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Evaluation of the National Flood Insurance Program's Building Standards

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Jamie Marshall, and Spencer M. Rogers, Jr.

Christopher Jones and Associates

October 2006

Prepared under subcontract to the American Institutes for Research
as part of the 2001–2006 Evaluation of the National Flood Insurance Program

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REPORTS IN THE EVALUATION OF THE NATIONAL FLOOD INSURANCE PROGRAM

This Evaluation consists of a series of reports assessing questions identified and prioritized by a steering committee about the National Flood Insurance Program. The reports of the Evaluation will be posted on the FEMA website as they are finalized. The website URL is http://www.fema.gov/business/nfip/nfipeval.shtm. The reports in the Evaluation are:

The Evaluation of the National Flood Insurance Program – Final Report
American Institutes for Research and NFIP Evaluation Working Group

Assessing the Adequacy of the National Flood Insurance Program's 1 Percent Flood Standard. Galloway, Baecher, Plasencia, Coulton, Louthain, Bagha, and Levy, Water Policy Collaborative, University of Maryland.

Assessing the National Flood Insurance Program's Actuarial Soundness. Bingham, Charron, Kirschner, Messick and Sabade, Deloitte Consulting.

Costs and Consequences of Flooding and the Impact of the National Flood Insurance Program. Sarmiento and Miller, Pacific Institute of Research and Evaluation.

Developmental and Environmental Impacts of the National Flood Insurance Program: A Review of Literature. Rosenbaum, University of Florida.

The Developmental and Environmental Impact of the National Flood Insurance Program: A Summary Research Report. Rosenbaum and Bouleware, University of Florida.

An Evaluation of Compliance with the National Flood Insurance Program Part A: Achieving Community Compliance. Monday, Grill, Esformes, Eng, Kinney and Shapiro, American Institutes for Research.

An Evaluation of Compliance with the National Flood Insurance Program Part B: Are Minimum Building Requirements Being Met? Mathis and Nicholson, Dewberry.

Evaluation of the National Flood Insurance Program's Building Standards. Jones, Coulbourne, Marshall, and Rogers, Christopher Jones and Associates.

Managing Future Development Conditions in the National Flood Insurance Program. Blais, Nguyen, Tate, Dogan, ABSG Consulting; and Mifflin and Jones.

The National Flood Insurance Program's Environmental Reviews: An Assessment of FEMA's Implementation of NEPA and Executive Order 11988. Rosenbaum, University of Florida.

The National Flood Insurance Program's Mandatory Purchase Requirement: Policies, Processes and Stakeholders. Tobin and Calfee, American Institutes for Research.

The National Flood Insurance Program's Market Penetration Rate: Estimates and Policy Implications. Dixon, Clancy, Seabury, and Overton, RAND Corporation.

Performance Assessment and Evaluation Measures for Periodic Use by the National Flood Insurance Program. Miller, Langston, and Nelkin, Pacific Institute of Research and Evaluation.

State Roles and Responsibilities in the National Flood Insurance Program. Mittler, Morgan, Shapiro, and Grill, American Institutes for Research.

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EXECUTIVE SUMMARY

Background and Purpose of this Study

Floodplain management regulations adopted by communities and states contain provisions that affect new construction in floodplain areas. These regulations must equal or exceed National Flood Insurance Program (NFIP) minimum design and construction requirements for buildings in the Special Flood Hazard Area (SFHA), and are intended to minimize flood damage to buildings during the base flood (also known as the 100-year flood, and as the 1-percent annual chance flood).

The purpose of this study was to evaluate those design and construction requirements, with particular emphasis on: 1) damages prevented or induced by strict adherence to those minimum requirements, and 2) the costs and benefits of modifying the minimum requirements to reduce building damages during flooding.

Specifically, this study was designed and conducted to address three sets of questions regarding NFIP building standards for typical single family homes in the SFHA:

- What impacts have the NFIP's building standards for new construction in Special Flood Hazard Areas had on risk exposure and property loss? Which standards are the most and least effective in reducing exposure and property losses due to floods? Is the cost of implementing the major standards commensurate with their benefits?

- Are the NFIP's standards for construction and building design adequate and sufficiently stringent so that losses are minimized at a reasonable cost to communities and property owners when flood damage occurs? Are the standards and incentives sufficient to protect against flood risks that may be increasing in the future?

- Do the NFIP's building standards effectively protect buildings from damages during the 100-year flood? If current standards are not effective, how should FEMA change them? Are higher levels of protection achievable and more important, are the benefits achieved by these standards commensurate with the costs associated with meeting them?

These issues were addressed through a study that included the following:

- Review of building flood damage and foundation performance in coastal and non-coastal floodplains.

- Review of the literature and calculation of construction costs for one-and two-story houses with several foundation types under a variety of flood conditions.

- Calculation of the costs of adding freeboard and changing foundations. FEMA's benefit-cost analysis (BCA) model was modified in this study to allow generalized benefit/cost calculations to be made with all cost inputs expressed as a percentage of the initial (at-BFE) building cost. The model was run with variable discount rates (ranging from 3% to 9%), flood damage functions (V and Coastal A, and A), BFEs (in coastal areas, ranging from 12 ft to 20 ft mean sea level [msl]) and Flood Hazard Factors (FHF) in riverine areas, ranging from 25 to 150.

- The B/C models run in this study account for building and contents damages, and do not account for other economic costs to the building owner or community (e.g., clean-up and demolition costs, uninsured losses, displacement and relocation costs, loss of jobs and tax base, etc.). The resulting benefit-cost ratios (B/C) are conservative, and will understate the true benefits associated with exceeding minimum NFIP building standards.

- Calculation of the maximum justified cost of mitigation, i.e., freeboard and/or foundation changes at the time of initial construction -- expressed as a percentage of initial construction cost -- that would yield a B/C greater than or equal to 1.0. All cost inputs were expressed as a percentage of the initial (at-BFE) construction cost to generalize the results.

- Examination of the sensitivity of the B/C results to inclusion of displacement costs when building occupants must move out of flood damaged homes.

- Examination of flood insurance premium discounts for adding freeboard, and development of a general method to determine the time to recover the costs of freeboard through future flood insurance premium savings.

General Findings

On an individual building level, NFIP building standards have reduced flood damage relative to nearby pre-FIRM type structures. Flood losses for new construction are reduced through elevation and proper selection of the building foundation. Post-storm observations and calculations made during this study demonstrate that incorporation of freeboard is one of the most effective means of reducing property losses.

Generally speaking, NFIP building standards do reduce flood losses to new construction under present day base flood events. However, building standards are implemented in conjunction with the Flood Insurance Rate Map (FIRM), which does not account for increasing flood hazards in the future. Thus, while NFIP building standards may be generally effective today, their future effectiveness will be reduced as the FIRM becomes obsolete due to changing flood conditions. Revising building standards may be one way to compensate for changing flood conditions in the future.

This study found, for the residential buildings analyzed, the cost of adding freeboard or installing a more flood-resistant foundation at the time of construction is modest but the benefit of doing so can be great, particularly in coastal areas subject to wave effects and riverine floodplains with small flood hazard factors. Incorporating freeboard and/or changing the foundation type would also help to reduce future flood damage resulting from sea level rise and erosion in coastal areas, and from development impacts in riverine areas.

Under the current flood premium rate structure, flood premium discounts will be sufficient to recover the incremental costs borne by property owners to incorporate freeboard at the time of initial construction -- in just a few years time for many buildings.

However, floods more severe than the 100-year flood do occur, and incorporation of freeboard and modified foundations can help reduce losses from such floods. This study indicates that higher levels of protection are achievable for single family structures, and that the benefits of doing so will exceed the costs, particularly in high hazard areas. Additional B/C analyses could help to define a flood return period for which additional elevation is justified for other classes of structures.

With a few exceptions, NFIP building standards evaluated by this study generally protect against the 100-year flood. NFIP flood insurance premium rates generally promote sound construction practices and reduce potential flood damages. However, some changes to building standards and insurance premium rates are warranted, as a way of further reducing flood damages, providing additional incentives for flood loss reduction, and eliminating disincentives.

While this study did not investigate building practice effects on flood loss reduction *at a community level*, extension of the individual building findings to a broader scale seems reasonable. Reduced flood damage to individual buildings aggregates to reduced flood losses and disruption to the community. Study authors have observed this first-hand as part of post flood investigations -- where flood damage was widespread and great, individuals and communities often struggle to recover, while other nearby communities with less flood damage recover quickly.

This study did not investigate the effects of potential changes in NFIP building standards on the flood insurance fund, disaster assistance payments and other financial aspects of the NFIP and FEMA. However, since modified building standards could reduce flood damage at the individual building level, it seems reasonable to expect flood claims, disaster assistance and other post-disaster payments might also be reduced. The exact impact on the NFIP would depend on flood premiums received and payments made. The study authors believe that the cost of implementing building standards changes would be small, since the NFIP and the participating communities already enforce standards which are similar to the changed standards this study recommends.

Detailed Findings

At the time of initial construction, the incremental costs of replacing minimally compliant A zone foundations (such as slab-on-fill and crawlspace foundations) with pier foundations or pile foundations are relatively small, generally less than 5% to 10% of the cost of the building. In Coastal A zones, post-storm field studies have shown that minimally compliant A zone foundations often fail, and this replacement is warranted. In A zones outside coastal areas, NFIP compliant slab-on-fill and crawlspace foundations are generally adequate, and the incremental cost of changing to a pile foundation is not likely justified (but owners may wish to do so to create under-house parking). However, changing to a pier foundation is probably justified, especially for flood depths more than a few feet above grade.

At the time of initial construction, the cost of incorporating freeboard in a pile or masonry pier foundation averages approximately 1% to 2% of the at-BFE building cost for 4 ft of added freeboard (approximately 0.25% to 0.5% per foot of freeboard).

At the time of initial construction, the cost of incorporating freeboard in a masonry wall with interior pier (crawlspace) foundation averages approximately 3% to 6% of the at-BFE building cost for 4 ft of added freeboard (approximately 0.8% to 1.5% per foot of freeboard).

At the time of initial construction, the cost of incorporating freeboard in a fill foundation averages approximately 3% to 11% of the at-BFE building cost for 4 ft of added freeboard. Although the fill quantity and fill cost do not increase linearly with freeboard, they add an average of 0.8% to 3.0 % per foot of freeboard to the at-BFE building cost.

As expected, the B/C ratios calculated in this study decrease with increasing discount rate, with all other factors held constant. B/C ratios also decrease with increasing BFE and FHF, indicating that a foot of freeboard is worth less (in terms of damage reduction) in areas where there is a greater vertical spread in flood elevations associated with different return periods.

B/C calculations were tabulated and the B/Cs were determined for various combinations of freeboard, additional construction cost and discount rate. The data were then examined to identify the percent of additional construction cost that an owner would be justified in spending at the time of construction (B/C = 1.0) for each freeboard-BFE-discount rate or freeboard-FHF-discount rate combination.

In the V zone and Coastal A zone cases studied, calculations show that it is worth spending from 103% to 106% of the at-BFE building cost to add one to four feet of freeboard, and in some cases it may be worth spending up to 107% to 114% of the at-BFE building cost.

In the A zone cases studied, calculations show that it is worth spending less than in V zones and Coastal A zones to add freeboard – this is due to the fact that A zone flood depth-damage functions predict less damage for a given flood depth than do the V zone/Coastal A zone functions. The A zone calculations show it is worth spending from 100.5% to 102% of the at-BFE building cost to add one to four feet of freeboard, and in some cases it may be worth spending up to 103% to 106% of the at-BFE building cost.

A sensitivity analysis was undertaken to investigate the effect of including displacement costs in the B/C calculations. Using BCA default displacement times, the effect varies slightly between flood hazard zones and with number of stories in an A zone. However, the effect can be generalized as follows: adding monthly displacement costs equal to 1% of the initial (at-BFE) building cost increases the computed B/C by approximately 10%, and so forth.

The relationship between initial freeboard costs and flood premium discounts was also considered in a separate analysis. Even if future building and contents damages prevented are not considered the annual flood premium savings are generally sufficient to pay for the costs of adding freeboard in several years time for many buildings. In the case of V zone buildings, the time required to recover freeboard costs through flood premium savings is short – a year or two. In the case of A zone buildings, the recovery time can extend to more than 15 years, due to the lower A zone premiums and premium discounts, which are used to offset the initial freeboard cost.

Recommendations

B-1. The NFIP should not allow new A zone construction to be built with the top of the lowest floor at the BFE. Instead, the NFIP should require the top of the lowest floor of A zone structures to be built above the BFE such that the floor system is not in contact with flood waters during the base flood. This could be accomplished by either: 1) requiring sufficient freeboard, or 2) by changing the lowest floor reference elevation in A zones to be consistent with V zones (i.e., the bottom of the lowest horizontal structural member supporting the lowest floor must be at or above the BFE).

B-2. The NFIP should require at least 1 foot of freeboard for all new construction in the special flood hazard area. The exact freeboard amount should be guided by several factors:

- Freeboard requirements contained in consensus standards such as the American Society of Civil Engineer's (ASCE) standard *ASCE 24*. *ASCE 24* contains freeboard provisions which vary by building importance (the standard requires critical facilities to be elevated higher above the BFE than typical residential structures, for example). The *ASCE 24* freeboard provisions apply to the lowest floor, the use of flood resistant materials and utilities.

- Future flood conditions. *ASCE 24* does not account explicitly for future increases in flood hazards, thus, freeboard in excess of *ASCE 24* requirements may be appropriate in some flood hazard areas. The NFIP should consider flood loss reduction under present day base flood conditions and under future flood conditions when it establishes freeboard requirements.

- Flood elevation frequency. The NFIP should attempt to establish freeboard requirements that are flood-risk consistent. For example, 1 foot of freeboard at a site with a flood hazard factor of 20 may yield protection against a certain flood return period event. Equivalent protection at a different site with a flood hazard factor of 75 would require more than 1 foot of freeboard.

B-3. The NFIP should mandate V zone design and construction practices in Coastal A zones (e.g., requiring open foundations and the area below the BFE to be free of obstructions, making the lowest floor reference elevation the bottom of the lowest horizontal structural member supporting the lowest floor, designing for simultaneous action of flood and wind). Some communities have mandated V zone standards in A zones for years, but implementation of this recommendation on a larger scale would require changes to the flood hazard mapping process and the FIRM. Note that the 2005 edition of *ASCE 24* requires new construction in Coastal A zones to meet V zone standards, and the FEMA has published supporting post-Katrina Coastal A zone construction guidance.

B-4. The B/C results of this study are sensitive to the flood depth-damage function used in the analysis. The NFIP should, on an ongoing basis, review and update depth-damage functions based on flood claims data, results of Mitigation Assessment Team (MAT) investigations and other data. This may require collection of some additional data now deemed optional during the flood claims adjustment process.

B-5. Flood insurance premium rates should reflect anticipated flood damages and provide incentives to property owners and communities to exceed minimum NFIP building standards. The Community Rating System (CRS) does this on a community scale, but additional effort is needed to provide incentives to individuals. For example:

- The NFIP should re-evaluate flood insurance premium discounts for buildings in A zones. Current A zone discounts effectively cease at one to two feet above the BFE (unlike V zones where substantial discounts are awarded for up to four feet of freeboard). Additional discounts for increased freeboard in A zones may be one of the most powerful arguments for better construction that can be made to property owners.

- The NFIP should revise flood premium rates and coverage for NFIP-compliant pile-elevated buildings outside the V zone. Present rates and coverage penalize property owners who might otherwise adopt the superior pole-type construction, with pilings extending above the lowest floor to a higher floor or the roof.

B-6. The NFIP should consider development of an A Zone Risk Factor Rating Form and process, similar to that in place for V zones. This action could provide another way to reward A zone building owners to adopt design and construction practices that exceed NFIP minimum standards.

1. BACKGROUND

The National Flood Insurance Program (NFIP) is a Federal program enabling property owners in participating communities to purchase insurance protection against losses from flooding. This insurance is designed to provide an insurance alternative to disaster assistance to meet the escalating costs of repairing damage to buildings and their contents caused by floods. The NFIP was created in 1968 to reduce flood risk and losses associated with flooding. Since its inception, the Program as been revised by Congress four times: 1973, 1997, 1994 and 2004. The NFIP is administered by the Mitigation Division of the Federal Emergency Management Agency (FEMA), which is part of the U.S. Department of Homeland Security.

The NFIP has four primary goals:

- To reduce the costs of flooding to individuals through the purchase of flood insurance.
- To reduce future flood damages through the adoption of floodplain management regulations by communities and states.
- To reduce federal expenditures associated with flood control and flood disaster assistance payments.
- To restore and preserve the natural and beneficial values of floodplains.

1.1. Purpose of the Study

This study is part of the larger NFIP Evaluation, a series of studies assessing questions identified and prioritized by a steering committee about the National Flood Insurance Program. A list of all of the NFIP Evaluation studies is at the front of this report. This study focuses on NFIP design and construction standards for new buildings in the Special Flood Hazard Area (SFHA)[1].

Floodplain management regulations adopted by communities and states contain provisions that affect new construction in floodplain areas. These regulations must equal or exceed NFIP minimum design and construction requirements for buildings in the SFHA, which are contained in the Code of Federal Regulations (CFR), Title 44, Part 60 – Criteria for Land Management and Use (U.S. Government Printing Office 2005). These requirements are intended to minimize flood damage to buildings during the base flood (also known as the 100-year flood, and as the 1-percent annual chance flood).

The purpose of this study is to evaluate those design and construction requirements[2], with particular emphasis on: 1) damages prevented or induced by strict adherence to those minimum requirements, and 2) the costs and benefits of modifying the minimum requirements to reduce building damages during flooding.

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[1] The SFHA is the land within a community with a 1 percent, or greater, chance of flooding in any given year. This area is referred to by many as the 100-year floodplain.
[2] The term "building standards" will be used to refer to the NFIP's minimum design and construction requirements for new and substantially improved buildings in the SFHA.

1.1.1. Basic Questions to be Addressed

The study was designed with the following questions (developed by FEMA and the American Institutes for Research [AIR]) in mind:

- What impacts have the NFIP's building standards for new construction in Special Flood Hazard Areas (SFHA) had on risk exposure and property loss? Which standards are the most and least effective in reducing exposure and property losses due to floods? Is the cost of implementing the major standards commensurate with their benefits?

- Are the NFIP's standards for construction and building design adequate and sufficiently stringent so that losses are minimized at a reasonable cost to communities and property owners when flood damage occurs? Are the standards and incentives sufficient to protect against flood risks that may be increasing in the future?

- Do the NFIP's building standards effectively protect buildings from damages during the 100-year flood? If current standards are not effective, how should FEMA change them? Are higher levels of protection achievable and more important, are the benefits achieved by these standards commensurate with the costs associated with meeting them?

1.2. NFIP Flood Hazard Zones and Building Standards

In an attempt to address the basic questions listed above, this study divides the SFHA into three flood hazard zones (V zone, A zone, and Coastal A zone), and deals with building standards for each zone. However, there are certain building standards that apply to all new buildings in all parts of the SFHA. These are listed first, followed by the additional building standards pertinent to each flood hazard zone.

1.2.1. All Zones within the SFHA

Most of the NFIP building standards are performance standards, where general requirements are stipulated, but where prescriptive details are not (usually) provided. By and large, these general requirements address: 1) the elevation of the lowest floor, 2) the means by which a building is elevated to or above the base flood elevation (BFE), i.e., the foundation, and 3) the materials used below the BFE. It is up to the building designer or contractor, or the community floodplain management official, to determine which specific design and construction practices meet the general requirements.

The following NFIP building standards apply to new buildings in any part of the SFHA:

- The structure must be designed and anchored to prevent flotation, collapse or lateral movement of the structure resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy.

- The structure must be constructed with materials below the BFE that are flood-damage resistant.

- The structure must be constructed with methods and practices that minimize flood damage.

- Unless located at or above the BFE, utilities and equipment below the BFE must be designed and/or located to prevent floodwaters from entering or accumulating within the components.

- Any enclosed spaces below the BFE can only be used for building access, parking and storage.

Manufactured homes must have their lowest floor elevated to or above the BFE if they are: 1) placed outside a manufactured home park, 2) placed in a new manufactured home park or in an expansion to an existing manufactured home park, and 3) a replacement for a substantially damaged home in an existing park.[3] Substantially improved manufactured homes must meet the same requirements as those homes described above.

1.2.2. V Zones

The V zone is known also as the Coastal High Hazard Area (CHHA), and extends from offshore to an inland limit based on one or more mapping criteria. The mapping criteria relate to high velocity wave action effects (e.g., the 3-foot breaking wave height, the 3-foot wave runup depth, or a wave overtopping rate exceeding a threshold rate), and to the physical presence of a primary frontal dune (PFD) (FEMA 2003, see Appendix D).[4] Although the first generation of coastal Flood Insurance Rate Maps (FIRMs) established base flood elevations (BFEs) at the still water level and did not account for wave action, wave effects have been incorporated into coastal FIRMs since about 1980 (FEMA 2000, see section 7.8.1.3). As used in this study, the term “V zone” includes those zones designated on the FIRM as V, V1-30, VE and VO.

In addition to the NFIP building standards that apply to all parts of the SFHA, there are five additional requirements for new construction in V zones:

- The elevation of the bottom of the lowest horizontal structural member (supporting the lowest floor) must be at or above the BFE.

[3] Manufactured homes in parks predating floodplain management regulations may be exempt from the lowest floor elevation requirement. Specifically, manufactured homes placed or substantially improved on sites in an existing manufactured home park must have the lowest floor elevated to or above the BFE, or must have the lowest floor elevated on reinforced piers no less than 36 inches in height above grade.

[4] All but the last criteria are based on explicit wave effects during the base flood, while the PFD criterion is tied to the shoreline morphology rather than a specific flood hazard. See 44 CFR Section 65.11 for a discussion of the PFD.

- Pile, pier, post or column foundations (i.e., “open” foundations that allow flood waters and waves to pass beneath elevated buildings) must be used.[5] The space below the lowest floor must be free of obstructions, or constructed with wood latticework, insect screening or non-supporting breakaway walls. No fill may be used to elevate or provide structural support to a new building in a V zone.

- When used, any enclosures below the BFE can only be constructed with screening, lattice or breakaway walls. Breakaway walls cannot provide vertical support to the building. Breakaway walls must satisfy the lateral loading requirements in 44 CFR 60.3(e)(5), i.e., they must either break free when exposed to lateral wind and water loads between 10 and 20 pounds per square foot (psf), or if they are designed to break free at loads greater than 20 psf, must be certified by a designer to break free during the base flood.

- The building and its foundation must resist flotation, collapse and lateral displacement due to wind and water loads acting simultaneously. A registered architect or engineer must develop or review the structural plans, specifications and construction plans, and must certify that the design and methods of construction to be used are in accordance with accepted standards of practice for meeting the performance requirements.

In addition to the above design and construction requirements there are two requirements related to siting and site alterations in V zones:

- New construction must be located “landward of the reach of mean high tide.”

- Man-made alterations of sand dunes or mangrove stands which would increase potential flood damage are prohibited.

1.2.3. A Zones

The A zone is that portion of the SFHA that is not subject to high velocity wave action during the base flood and is not designated as zone V due to primary frontal dune considerations. The source of flooding in an A zone can be a stream or river that overflows its banks; a lake; or coastal storm surge accompanied by wave heights and wave runup depths less than 3 feet. As used in this study, the term “A zone” includes those zones designated on the FIRM as A, A1-30, A-99, AE, AH, AO and AR.

In addition to the NFIP building standards that apply to all parts of the SFHA, there are several additional requirements for new construction in A zones:

- The top of the lowest floor, including basement, must be at or above the BFE, unless: 1) the community has been granted a basement exception, or 2) the structure is a non-residential structure that is watertight below the BFE with walls that are substantially impermeable to the passage of water.

[5] Some solid walls have been allowed below the BFE in V zones. Most commonly, these are shore-perpendicular walls required to transmit wind or seismic loads from upper building stories to the soil, fire separation walls required by the building code, and walls surrounding stairwells and building egress features. These walls typically are associated with large buildings.

- No restriction on the foundation type is made as long as the building is anchored to the foundation and the foundation supports the elevated structure during the base flood event. Fill may be used to elevate and provide structural support to a building.

- Enclosures below the BFE must contain flood openings that allow the automatic entry and exit of flood waters.

- In an AO zone, the top of the lowest floor must be elevated above the highest adjacent grade, at least as high as the depth number specified in feet on the FIRM.

1.2.4. Coastal A Zones

NFIP regulations treat building standards for A zones in riverine and coastal areas the same, and coastal FIRMs do not designate a Coastal A zone. In fact, coastal FIRMs depict A zones the same way as inland FIRMs do. The “Coastal A zone” is a non-regulatory term that has been used in recent years to draw a distinction between coastal and inland A zones, and to highlight similarities between V zones and A zones in coastal areas. The rationale for these efforts is based on a growing body of evidence that flood hazards in coastal A zones are more like those in V zones than those in riverine A zones, and that building damages in coastal A zones are consistent with those observed in V zones, not riverine A zones (Jones, Coulbourne and Tertell 2001; FEMA 2005a).

Pending formal designation of a Coastal A zone, the following working definition has been developed (American Society of Civil Engineers [ASCE], 2005; FEMA, 2005a) and is used by this study: area landward of a V zone, or landward of an open coast without mapped V zones. In a coastal A zone, the principal source of flooding will be astronomical tides, storm surges, seiches or tsunamis, not riverine flooding. During base flood conditions the potential for breaking wave heights between 1.5 feet and 3.0 ft will exist.

NFIP building standards in Coastal A zones are identical to those in A zones -- a coastal building in an area subject to a 2.9 ft breaking wave height during the base flood would be mapped today as an A zone, and conformance with A zone building standards only would be required – despite the fact that breaking waves of that size are capable of destroying or heavily damaging typical residential wood-frame walls which could be used as foundation walls in an A zone (U.S. Army Corps of Engineers [USACE] 1975; FEMA 2000, see Chapter 11).

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2. STUDY METHODOLOGY

This study employed several methods to evaluate NFIP building standards, including:

- Conducting a literature review documenting: 1) the performance of NFIP compliant buildings during flood events, and 2) the costs of elevating those buildings on NFIP compliant foundations (see Chapter 3).

- Meeting with NFIP staff and other experts to discuss building standards in floodplain areas.

- Surveying floodplain professionals regarding NFIP building standards (see Appendix A).

- Conducting a benefit-cost (B/C) analysis of NFIP building standards:
    - Defining a set of typical coastal residential buildings and flood conditions for detailed analyses (see Chapter 4).
    - "Designing" several types of building foundations for the typical buildings, under a wide range of flood conditions and freeboard.[6] (see Chapter 5)
    - Estimating foundation and construction costs for the typical buildings (see Chapter 6).
    - Performing benefit-cost analyses to evaluate the use of freeboard and the replacement of minimally compliant foundations with improved foundations (see Chapter 7).

- Using an expert panel to guide the study and review its findings.

FEMA, AIR and the project's expert panel all reviewed the typical buildings and flood conditions to be analyzed, and a member of the expert panel performed an independent design of selected V zone foundations to verify the study's foundation designs were reasonable. An outline of the major components of this study is shown in Figure 1.

[6] As used in this study, "freeboard" is the height above the BFE to which the lowest floor of a building is raised.

FIGURE 1. Outline of Benefit-Cost Evaluation Component of NFIP Building Standards

Define Buildings to be Analyzed

- 1- and 2-story residences, average to very good quality
- 1,500 to 4,800 sf
- Slab, wall, pier, pile foundations (per NFIP allowances)
- Lowest floor elevations (BFE and higher)
- Hip roofs, 7/12 slope

Define Flood Conditions

- Stillwater flood depths
- Flood Velocities
- Wave heights and wave crest elevations
- Local scour at foundations
- Wind speeds associated with A zone, Coastal A zone, V zone

Identify Building/Flood Combinations for Analyses

- V zone: 420 combinations
- Coastal A Zone: 480 combinations
- A zone: 600 combinations

"Design" Individual Foundations

- Calculate flood, wind and other loads per FEMA (2000) and ASCE (2002)
- Calculate required foundation dimensions to resist loads with appropriate safety factors and given material properties

Calculate Construction Costs

- Adjusted and refined Base Cost of building with standard (crawlspace) foundation per Marshall & Swift (2003)
- Base Cost minus standard foundation cost = *Building Only Cost*
- Calculate *Individual Foundation Costs* for slab, pier, wall and pile foundations per Marshall & Swift (2003)
- Add Individual Foundation Costs to Building Only Cost to get *Final Building Cost* for each Combination Analyzed

Freeboard Costs

- Calculate incremental costs to raise lowest floor by 1 ft, 2 ft, 3 ft, and 4 ft

Foundation Change Costs

- Calculate cost differential to substitute one foundation type for another

Benefit-Cost Analyses

- Use FEMA (2005e) BCA Model
- Select Discount Rate (7.0%, with sensitivity analysis for 3.0%, 5.0%, 9.0%)
- Select Useful Life = 30 years
- Assume Building Contents Value = 30% of Building Value
- Normalize all cost and saving inputs as a percent of Final Building Cost
- Define flood depth-frequency relationships for each flood zone
- Define typical ranges of BFEs for coastal floods and Flood Hazard Factors (FHFs) for non-coastal floods
- Define depth-damage curves for each flood zone and building type
- Calculate B/C ratios for adding freeboard or changing foundation types, by flood zone
- Generalize results

3. LITERATURE REVIEW

3.1. Building Performance

Many publications document building successes and failures during coastal and riverine flood events, but the two most useful sources are FEMA and the U.S. Army Corps of Engineers, National Floodproofing Committee (USACE, NFPC).

- FEMA has mobilized its Mitigation Assessment Team (MAT), previously known as its Building Performance Assessment Team (BPAT), following severe hurricanes and riverine floods. Findings of many of the reports from coastal flood events are summarized in chapter 2 of FEMA (2000). MAT reports are available at http://www.fema.gov/rebuild/mat/mat_reprts.shtm.

- FEMA has developed a series of *fact sheets* and *recovery advisories* dealing with building performance and best practices for construction in floodplains (e.g., FEMA, 2005a; FEMA, 2005b; FEMA, 2006a).

- Many of the NFPC reports are available at http://www.usace.army.mil/civilworks/cecwp/NFPC/nfpc.htm . USACE (1998) provides an excellent summary of building performance during both riverine and coastal flood events.

The MAT and NFPC documents repeatedly stress the importance of elevating buildings above the flood level on adequate foundations, and the importance of using flood-resistant materials. Failure to do so results in building damage or loss. This is true especially in riverine floods of high velocity, and in coastal areas subject to wave effects.

The inclusion of wave heights into coastal flood hazard mapping was driven by post-hurricane Frederic (1979) observations that revealed the frequency and intensity of damage inflicted by waves striking coastal buildings that were elevated only to the 100-year storm surge stillwater level, in compliance with NFIP requirements at that time (FEMA 2000, see Chapter 2).[7] This is also the reason that the present study devotes much of its attention to building standards that mitigate the effect of wave heights.

3.1.1. Flood Insurance Incentives for Sound Building Practices

NFIP insurance provisions and premium rates generally encourage sound building practices through incentives (e.g., reduced premium rates when the lowest floor is elevated above the BFE) and disincentives (e.g., higher premium rates for enclosures below the BFE in V zones). The NFIP has also developed some procedures by which policyholders are rewarded (through reduced premiums) for adopting design and construction practices which exceed NFIP minimum requirements. The V Zone Risk Factor Rating Form (FEMA 2005c) is a good example – this form and rating procedure can be used to obtain V zone premium discounts of up to 60%

[7] Wave heights have been included in new coastal flood insurance studies (FISs) and restudies since1980.

for exceeding NFIP minimum requirements.[8] Discounts can be obtained for such things as: siting V zone buildings away from the shoreline and out of areas subject to long-term erosion; protecting buildings via sand dunes, beach nourishment or erosion control structures; adding freeboard; accounting for future conditions in foundation design; increasing foundation embedment and pile diameter; designing foundations that require minimal bracing; eliminating breakaway enclosures below the BFE, etc.

Not all NFIP insurance provisions and premium rates promote better construction, however. Rogers (2005) has documented one scenario where the NFIP premium rate structure discourages a building practice which reduces storm damage to structures. Many reports promote the use of pole-type construction, where the pilings extend from in the ground, past the lowest floor and to a higher floor or to the roofline. In situation where pole-type construction is used, the buildings sometimes are penalized by the NFIP through increased flood premiums and/or reduced flood policy coverage for the structure and contents between the lowest floor and the floor at the top of the pilings. The effect of this “piling penalty” has been to encourage builders and owners to terminate piling foundations at the BFE, even though continuing the pilings upward to a higher floor results in buildings which better resist flood and wind damage. In cases where flood levels have exceeded the BFE, buildings with the pilings terminating at the BFE have experienced far greater damage than buildings with pilings extending to a higher floor (Rogers, 2005; FEMA 2006b).

3.2. Building Foundations and Construction Costs

Many publications were found that contain information on the costs of raising existing homes on retrofit or replacement foundations. However, relatively few publications contained information on foundation costs and freeboard costs for new construction. Information on foundation retrofit/building elevation costs, and on new foundations is contained in Table 1 (note that the costs included in the table have not been adjusted for inflation).

These documents suggest that the costs of flood-resistant foundations typically range from approximately 5% to 15% of the total building cost for 1- and 2-story residences, and that the additional cost of raising homes a few feet at the time of initial construction (adding freeboard) is small, usually less than approximately 0.5% to 1% additional for each foot the building is raised.

[8] Many of the practices for which premium discounts can be obtained are recommended by the Coastal Construction Manual (FEMA 2000)

TABLE 1. Literature Review of Costs to Elevate or Change Foundations, Existing Homes and New Construction

Publication, Author, Date	Building Modification	Location	Date	Cost	Comments
		Elevating/Retrofitting Existing Homes			
A Floodproofing Success Story, USACE (1993)	Elevate 19 existing homes (1-story, brick veneer, crawlspace foundations) in A zone, between 2 and 6 ft	Dry Creek, Goodlettesville, TN	1989 - 1990	$568,000 for 19 homes ($30,000 per home)	Homes range from 1,000 to 1,475 sf in size.
Technical Information, Elevating Substantially Damaged Buildings in Dade County, FEMA (1993)	Raising existing slab-on-grade masonry homes	Miami-Dade County, FL	1992	$30,000 - $37,000 to raise each home up to 3 ft	Estimated costs to elevate a 2,000 sf home. Add $1,000 - $1,800 for each additional ft of elevation above 3 ft
Mitigation Success Stories III, Assoc. of State Floodplain Managers [ASFPM] (2000), p. 17	Elevate 7 existing homes	Westport, CT	1994 - 1995	$336,000 for 7 homes ($48,000 per home)	Foundation type, flood zones and elevation raised unknown
Mitigation Success Stories III, ASFPM (2000), p. 18	Elevate 15 existing homes	Westport, CT	1996 - 1999	$991,000 for 15 homes ($66,000 per home)	Foundation type, flood zones and elevation raised unknown
Mitigation Success Stories IV, ASFPM (2002), p. 11	Elevate 41 existing A zone homes	Sacramento County, CA	Post-1997 flood	$2.7 million for 44 homes ($61,000 per home)	Foundation type and elevation raised unknown
Homeowner's Guide to Retrofitting, FEMA (1998), p. 44	Elevate existing *wood-frame* house (on basement or crawlspace) by extending existing walls 2 feet or building an open foundation	Generic location	1998	$17/sf of building footprint	Includes extending utilities and adding or extending staircases. Add 10% for house with brick veneer on walls Add $0.75 per sf of building footprint for each additional foot of elevation up to 8 ft; add $1.00 per sf of footprint for each foot of elevation over 8 ft

TABLE 1. Literature Review of Costs to Elevate or Change Foundations, Existing Homes and New Construction

Publication, Author, Date	Building Modification	Location	Date	Cost	Comments
Homeowner's Guide to Retrofitting, FEMA (1998), p. 44	Elevate existing *masonry* house (on basement or crawlspace) by extending existing walls 2 feet or building an open foundation	Generic location	1998	$35/sf of building footprint	Includes extending utilities and adding or extending staircases. Add $0.75 per sf of building footprint for each additional foot of elevation up to 8 ft; add $1.00 per sf of footprint for each foot of elevation over 8 ft
Homeowner's Guide to Retrofitting, FEMA (1998), p. 44	Elevate existing wood-frame or masonry house (on *slab foundation*) 2 ft, by raising slab and constructing foundation walls or open foundation	Generic location	1998	$47/sf of building footprint	Includes extending utilities and adding or extending staircases. Add 10% for wood-frame house with brick veneer on walls Add $0.75 per sf of building footprint for each additional foot of elevation up to 8 ft; add $1.00 per sf of footprint for each foot of elevation over 8 ft
Mitigation Success Stories IV, ASFPM (2002), p. 15	Elevate 15 existing homes in V zone onto pile foundations	Delaware	Post-1998 flood	$35,000 per home	Elevation raised unknown
Mitigation Success Stories IV, ASFPM (2002), p. 17	Elevate one existing A zone home by 4 ft	Collier County, FL	Post-1998 flood	$54,000	Foundation type unknown
Mitigation Success Stories IV, ASFPM (2002), p. 40	Elevate four existing A zone homes between 4.2 and 8.2 ft on foundation walls	Vassar, MI	Post-1998 mitigation plan adoption	$200,000 for four homes ($50,000 per home)	Subgrade basements were filled during the project
Non-Structural Flood Damage Reduction, USACE (2001), p. 25	Estimated cost to raise a 1,200 sf home 10 ft	Vermilion River Basin, Lafayette Parish, LA	1999	$49/sf of bldg footprint	$49/sf cost includes $37/sf construction cost, + 30% to cover design, profit and contingencies
Mitigation Success Stories IV, ASFPM (2002), p. 57	Elevate one existing A zone home by approximately 5-6 ft	Glasgow, MT	2000	$88,000	Subgrade basement was filled, house was elevated (foundation type not stated)
Mitigation Success Stories IV, ASFPM (2002), p. 89	Elevate 10 existing A zone homes	King County, WA	2000 - 2001	$568,000 for 10 homes ($57,000 per home)	Foundation types and elevations raised unknown

TABLE 1. Literature Review of Costs to Elevate or Change Foundations, Existing Homes and New Construction

Publication, Author, Date	Building Modification	Location	Date	Cost	Comments
		New Construction			
Elevating to the Wave Crest Level: A Benefit-Cost Analysis, FEMA (1980)	Study examined the costs and benefits of elevating a 1,500 sf residential structure from the stillwater level to the wave crest level, over a range of BFEs and coastal erosion conditions	V zone and A zone	1979	B/C of elevating to the wave crest level ranged from 1.0 to 8.2 based on flood damage reduction alone, and from 1.4 to 9.5 based on flood premium savings alone	Hurricane Frederic (1979) destroyed many pile-elevated, NFIP compliant homes in Gulf Shore, AL (at that time the NFIP only mandated elevation to the stillwater level).
Coastal Construction Manual, FEMA (1986), Appendix F	Timber piles, installed (8 in square, 10 in square and 8 in round)	Generic	1985	\$5/lf to \$13/lf	Coastal home construction cost estimates
Coastal Construction Manual, FEMA (1986), Appendix F	Precast concrete piles, installed (8 in square to 10 in square)	Generic	1985	\$7/lf to \$16/lf	Coastal home construction cost estimates
Coastal Construction Manual, FEMA (1986), Appendix F	Reinforced concrete masonry piers (12 x 12 in or 16 x 16 in)	Generic	1985	\$20/lf to \$50/lf	Coastal home construction cost estimates
Homebuilder's Guide to Coastal Construction, Fact Sheet 6, FEMA (2005b)	Cost differential between a slab or crawlspace foundation and a pile or column foundation – A zone 3,000 sf home, homes elevated to the same height above grade	Generic	2005	Adds > 2% to building cost	Consensus estimate by a group of designers and industry experts
A Comparative Cost Evaluation of Foundation Types Permitted by NFIP Regulations in Coastal A Zones and V Zones, FEMA (2005d) – see Appendix 2	Cost differential to add freeboard or change foundation types	Coastal A zones and V zones	2005	The additional cost of constructing a V zone foundation instead of an A zone foundation varies from approx. 2% to 10%+ of the base building cost	A zone foundations include slab, masonry piers and 8" masonry wall/piers. V zone foundations include 10" and 12" timber piles, 8" and 10" steel H piles, 10" and 12" precast concrete piles. Each foot of freeboard above the BFE adds from 0.3% to 0.5% of the base building cost.

NOTE: Retrofitting and new construction costs cited in the table are not adjusted for inflation.

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4. DEFINING TYPICAL BUILDINGS AND FLOOD CONDITIONS FOR THIS STUDY

The major effort of this study – the benefit-cost analysis of NFIP building standards – was designed to be representative of a wide range of residential homes sited in floodplain areas. Representative building characteristics and flood conditions to which the buildings would be subject, were defined at the beginning of the project by the study team, the expert panel and FEMA staff.

4.1. Buildings Evaluated in this Study

Buildings used in this study include can be characterized as 1- and 2-story residences, rectangular in shape, between 1,500 and 4,800 square feet (sf) in size, and situated in V zones, Coastal A zones and A zones.[9] All homes were given hip roofs with a 7/12 roof pitch. Most of the effort in this study was devoted to evaluating the costs and benefits of adding freeboard and changing foundation types to these buildings. Figure 2 and Table 2 illustrate pertinent dimensions for the buildings evaluated in this study.

FIGURE 2. Building Footprint (source: FEMA 1998, p.44)

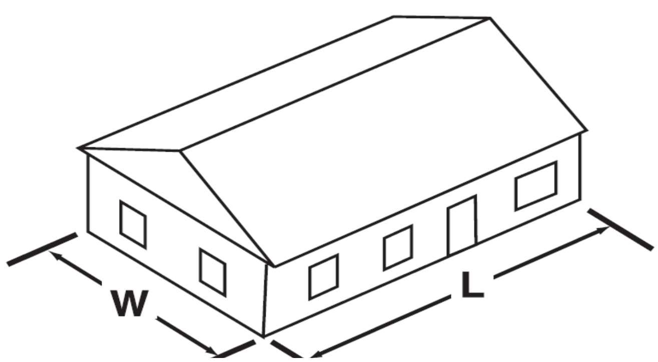

TABLE 2. Dimensions of Buildings Used in this Study

Building Case	Length (ft)	Width (ft)	Number of Stories	Footprint Size (sf)	Building Size (sf)
1	50	30	1	1,500	1,500
2	50	30	2	1,500	3,000
3	60	40	1	2,400	2,400
4	60	40	2	2,400	4,800

[9] This study did not consider repairs, retrofits, improvements or additions to existing buildings.

These four building types were placed on between three and six foundation types in each of the three flood hazard zones investigated. Lowest floor elevations for each building/foundation/zone combination were varied from the BFE to four feet above the BFE, in 1-ft increments (see Table 3).[10] Four to seven flood conditions (see Section 5.2) were applied to each building/foundation/zone/floor combination. A total of 1,500 combinations of buildings and flood conditions were evaluated fully, not counting the sensitivity analyses run during the benefit cost portion of the study.

TABLE 3. Building/Foundation/Flood Zone/Floor Elevation/Flood Condition Combinations Analyzed in this Study

Flood Hazard Zone	Building Sizes	Foundation Types	Lowest Floor Elevations	Flood Conditions	Building Combinations Analyzed
V	4 (see Table 2)	Timber Pile Concrete Pile Masonry Pier	BFE BFE + 1 ft BFE + 2 ft BFE + 3 ft BFE + 4 ft	7 (see Table 4)	420
Coastal A	4 (see Table 2)	Timber Pile Concrete Pile Masonry Pier 8” Masonry Wall 12” Masonry Wall Fill and Concrete Slab-on-Grade	BFE BFE + 1 ft BFE + 2 ft BFE + 3 ft BFE + 4 ft	4 (see Table 4)	480
A	4 (see Table 2)	Timber Pile Concrete Pile Masonry Pier 8” Masonry Wall 12” Masonry Wall Fill and Concrete Slab-on-Grade	BFE BFE + 1 ft BFE + 2 ft BFE + 3 ft BFE + 4 ft	5 (see Table 4)	600

[10] Foundation and cost calculations were run on two floor elevations below the BFE (BFE – 1 ft, BFE – 2 ft) for A zones and Coastal A zones, but these floor elevations were not used in subsequent analyses. Buildings like this would not be permitted in the SFHA.

4.2. Flood and Wind Conditions Evaluated in this Study

Sixteen different flood conditions and two different wind conditions were used to "design" the foundations listed in Table 3.[11] Key terms for these flood and wind conditions are defined below, are illustrated in Figure 3 and are listed in Table 4.

> *Flood Hazard Zone*: V zone, Coastal A zone and A zone (see descriptions in Sections 1.2.2, 1.2.3 and 1.2.4).
>
> *Associated Wind Speed*: the 3-second gust wind speed used in the foundation design calculations for each flood hazard zone (110 mph in the A zone, and 130 mph in the V zone and Coastal A zone).
>
> *Flood Condition*: a set of flood depth, flood velocity, wave height and scour conditions used in the foundation design analyses. There are 16 flood conditions used in this study, seven in V zones, four in Coastal A zones and 5 in A zones. Flood conditions within each zone are numbered, with the lower numbers corresponding to the least severe conditions, and the highest numbers corresponding to the most severe conditions.
>
> *Stillwater Depth*: the vertical distance (ft) between the ground elevation and the stillwater elevation. The stillwater elevation is the elevation of the flood water surface, with wave effects damped out.
>
> *BFE Depth*: the vertical distance (ft) between the ground elevation and the wave crest elevation.
>
> *Wave Height*: the vertical distance (ft) between the wave crest and the wave trough.
>
> *Flood Velocity*: the velocity (ft/sec or fps) at which flood waters flow across the ground. This study assumed the velocity was constant throughout the water column.
>
> *Scour*: localized erosion depth (ft) caused by flood flow and/or waves interacting with the building foundation.
>
> *Floodborne Debris*: each foundation was also subject to impact from a 1,000 lb object floating at the stillwater level, traveling at the specified flood velocity.
>
> *Windborne Debris*: the study did not consider windborne debris effects on the buildings analyzed, and assumed all building envelopes above the lowest floor would remain intact.

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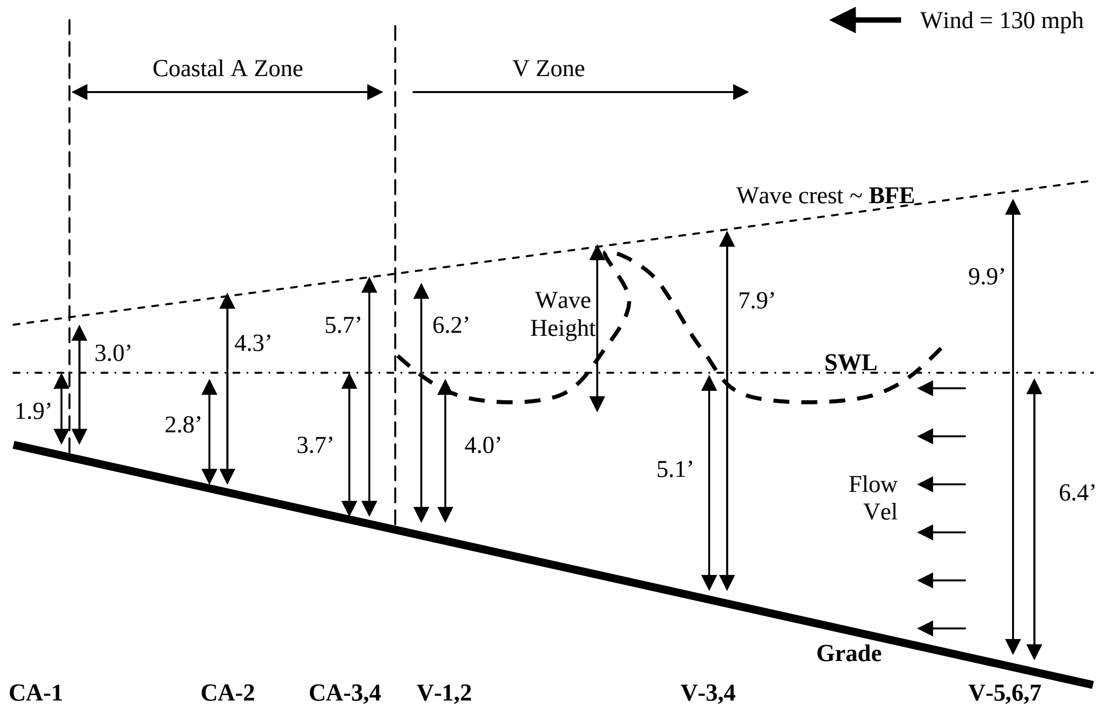
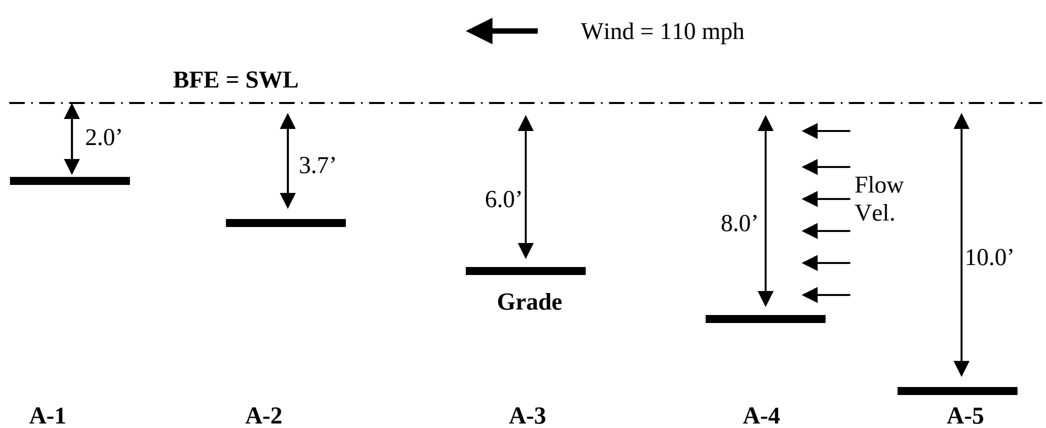
[11] As used in this report, "design" includes the calculation of foundation characteristics and dimensions (e.g., pile diameter; pile embedment; pier and wall footing sizes and embedment; slab thickness; fill quantities, slopes and protection). Detailed designs with construction drawings and specifications were not developed.

FIGURE 3a. V Zone and Coastal A Zone Flood Conditions Modeled During this Study



Flood Conditions (see Table 4 for complete list of conditions)

FIGURE 3b. A Zone Flood Conditions Modeled During this Study



Flood Conditions (see Table 4 for complete list of conditions)

TABLE 4. Flood and Associated Wind Conditions Used by this Study to Develop and Cost Building Foundations

Flood Hazard Zone and Associated Wind Speed	Flood Condition	Stillwater Depth (ft)	BFE Depth (ft)	Wave Height (ft)	Flood Velocity (fps)	Scour (ft)
V Zone (130 mph)	V-1	4.0	6.2	3.0	3.0	3.0
	V-2	4.0	6.2	3.0	6.0	4.0
	V-3	5.1	7.9	4.0	4.0	3.0
	V-4	5.1	7.9	4.0	6.0	4.0
	V-5	6.4	9.9	5.0	4.0	4.0
	V-6	6.4	9.9	5.0	6.0	5.0
	V-7	6.4	9.9	5.0	8.0	6.0
Coastal A Zone (130 mph)	CA-1	1.9	3.0	1.5	2.0	1.0
	CA-2	2.8	4.3	2.2	3.0	2.0
	CA-3	3.7	5.7	2.9	3.0	3.0
	CA-4	3.7	5.7	2.9	6.0	4.0
A Zone (110 mph)	A-1	2.0	2.0	0.0	2.0	0.0
	A-2	3.7	3.7	0.0	3.0	0.0
	A-3	6.0	6.0	0.0	3.0	0.0
	A-4	8.0	8.0	0.0	4.0	0.0
	A-5	10.0	10.0	0.0	4.0	0.0

4.2.1. V Zone

There are seven V zone flood conditions used in this study, with the intensity of the flood effects increasing from the landward side of the V zone (conditions V-1 and V-2) toward the seaward direction. All V zone conditions were developed with depth-limited breaking waves.

The first two conditions, V-1 and V-2, represent minimal V zone conditions; the stillwater depth is 4.0 ft, enough to support a 3.0 ft breaking wave height (the minimum wave height necessary for an area to be mapped as a V zone)[12]. The BFE Depth (vertical distance between the wave crest elevation and the ground) is 6.2 ft for these conditions, and a building here would have to have the bottom of the floor beam supporting the elevated floor 6.2 ft above the ground. Condition V-1 assumes a flood flow velocity of 3.0 fps and local scour of 3.0 ft around a foundation element. Condition V-2 assumes a flood flow velocity of 6.0 fps and 4.0 ft of local scour.

The V-3 and V-4 conditions account for another 1.1 ft of stillwater depth, which is accompanied by 4.0 ft breaking waves and a BFE depth 7.9 ft above the ground. Condition V-3 assumes a flood flow velocity of 4.0 fps and local scour of 3.0 ft, while condition V-4 assumes a flood flow velocity of 6.0 fps and 4.0 ft of local scour.

The V-5, V-6 and V-7 conditions are the most extreme ones evaluated, and represent the case where the bottom of the floor beam supporting the elevated floor would have to be above the crest of a 5.0 ft breaking wave, with its crest 9.9 ft above grade. Flood velocities and local scour range from 4.0 fps to 8.0 fps and 4.0 ft to 6.0 ft, respectively. This situation is representative of the most severe V zone conditions likely to be seen by buildings in most coastal areas.[13]

4.2.2. Coastal A Zone

There are four Coastal A zone flood conditions used in this study, with the intensity of the flood effects decreasing in the inland direction from the seaward boundary of the Coastal A zone (coincident with the landward side of the V zone). Conditions CA-3 and CA-4 are incrementally less severe than, but roughly equivalent to, conditions V-1 and V-2.

Stillwater depths, wave heights, wave crest elevations, flow velocities and local scour all decrease through the Coastal A zone to the location where condition CA-1 occurs. Condition CA-1 represents the landward limit of the Coastal A zone, where the wave height is 1.5 ft (ASCE 2005). Inland of this point the energy in the waves diminishes rapidly and A zone foundations typically are adequate (FEMA 2005a). Like V zone conditions, Coastal A zone conditions were developed with depth-limited breaking waves.

[12] A shallower stillwater depth and the corresponding smaller wave height would cause this site to be classified as a Coastal A zone.
[13] Granted, some buildings may see more severe V zone conditions during the base flood, but condition V-7 likely captures the vast majority of extreme V zone situations experienced by buildings constructed on land.

4.2.3. A Zone

There are five A zone flood conditions used in this study. All are specified based on stillwater depth and flow velocity only, there are no breaking waves or scour effects included. Stillwater flood depths range from 2.0 ft above grade (condition A-1) to 10.0 ft above grade (condition A-5). This range of conditions likely includes those base flood conditions experienced by the majority of structures placed in non-coastal (riverine and lake) A zones. Comparison of conditions A-1 and CA-1, and A-2 and CA-3 and CA-4, will reveal the influence of waves and scour on foundation design and costs.

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5. FOUNDATION DESIGNS

Individual foundations were "designed"[14] for each building type, in each flood zone, for each flood condition, and for each floor elevation. Designs were based on:

- Flood, wind and other loads were calculated according to *ASCE 7-02, Minimum Design Loads on Buildings and Other Structures* (ASCE 2002) and the *Coastal Construction Manual* (FEMA 2000). Breaking wave, hydrodynamic and debris impact loads were included. Calculation of hydrostatic loads was not required since pile and pier foundations are not subject to hydrostatic loads, and since wall foundations were assumed to have flood openings, as required by the NFIP.

- Wind speeds used in the analyses were 3-second gust speeds at a 30-ft elevation in exposure category C. The wind speed used in V zone and Coastal A zone designs was 130 mph; the wind speed used in A zone designs was 110 mph.

- Buildings were assumed to be "enclosed" and wind loads were calculated using a 7/12 roof pitch.

- Typical soil conditions were assumed and soil properties were taken from the Naval Facilities Engineering Command reference *Foundations and Earth Structures* (NAVFAC 1982).

- All loads and conditions were used to calculate stable foundation dimensions, or if stability was not possible under the specified flood and scour conditions, this was noted during the analysis.[15]

5.1. Pile Foundations

This study evaluated both treated timber and precast concrete piles in all flood hazard zones. All piles were spaced 10 feet apart. Piles at least 12 inches in diameter were used in this study, and for ease of computations, uniform piles were assumed (tapered piles were not used). In some cases, lateral loads (wind and flood) were high enough to lead to pile failure via bending stresses in excess of the allowable value – in these cases, pile diameters were increased to the point where the stress was within the allowable limits (in the real world, a designer might reduce the pile spacing instead). Calculations showed consistently that the wind load on the building controlled the pile foundation design.

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[14] Each "design" was based on the combination of factors mentioned previously and was not intended to be a precise design. Instead, the method used here is intended to provide a reasonable and consistent approximation of what an actual design would be.

[15] Foundation stability was problematic when typical pier and wall foundations were used outside of A zones. Typical 16 x 16 masonry piers were found to be inadequate against larger wave heights, and would be undermined by most Coastal A Zone and V zone conditions specified herein. Typical wall foundations would be undermined and/or fail due to lateral loads under the more energetic Coastal A zone conditions. Unlike pile foundations (where a design was always determined in this study) adequate wall and pier designs were not determined by this study since the pier size, wall thickness and embedment requirements far exceeded what most designers and contractors would use.

In V zones, timber and concrete pile embedment requirements (below the specified scour depth) were approximately linear with increasing freeboard, for all building sizes and flood conditions (see Figure 4 for typical results). In Coastal A zones (see Figure 5 for typical results), calculated pile embedments (below specified scour depths) for conditions CA-3 and CA-4 tended to resemble the embedments required for V zone conditions V-1 and V-2. This is consistent with the fact that these locations were close to each other, on opposite sides of the V zone - Coastal A zone boundary (see Figure 3). Pile embedment at the landward boundary of the Coastal A zone (condition CA-1) was similar to the calculated pile embedment in A zones, with only a shallow, uniform embedment requirement across all freeboard values. Pile embedment for condition CA-2 typically fell between CA-1 and CA-3.

It should be noted that even though 12 inch pile diameters were used for all flood zones in this study, 12 inch diameter piles were not required to resist the loads in A zones[16]. Thus, the costs of the A zone pile foundations (see Chapter 6) may be greater than the costs using adequate designs with smaller diameter piles. Looking toward to the benefit-cost discussion, if an A zone pile foundation using 12-inch piles is justified economically, a less expensive pile foundation will also be justified.

5.1.1. Pile Design Review

Upon completion of the initial pile foundation designs, one member of the project's Expert Panel (a structural engineer) reviewed the design methodology in detail. As part of the review, 14 timber pile designs were selected (10% of the V zone timber pile cases) and an independent pile design -- determination of pile diameter and pile embedment depth -- was completed for each. The selected cases spanned the range of building size, floor elevation and flood condition parameters being considered by this study. The independent review for the 14 cases used a more rigorous design methodology than that employed in this study, as a check on the design assumptions and approximations used in this study.[17] A comparison of the results of the two designs for the 14 selected case shows:

- Pile embedments determined by this study were greater than the independent embedment calculation in ten cases (by an average of 8.1 ft) and less in four cases (by an average of 5.3 ft).
- Pile diameters determined by this study were greater than the independent diameter calculation in seven cases (by an average of 0.9 in), equal in six cases, and less than the independent calculation in one case (by 1.2 in).

[16] Lower wind speeds and the absence of waves and scour in A zones resulted in loads that could be resisted by smaller diameter piles. Twelve-inch piles were typically required for the foundations in V zones and Coastal A zones due to higher wind speeds, coupled with wave and scour effects.

[17] The foundation design methodology employed in this study used some approximations and assumptions to simplify and expedite the design of hundreds of foundations. While this methodology was slightly different than a detailed foundation design for an actual structure, the results appeared reasonable and were verified by the independent review.

FIGURE 4. Pile Embedment Depth (ft) vs. Floor Elevation,
V Zone, 50'x30', 1 Story - Timber Piles

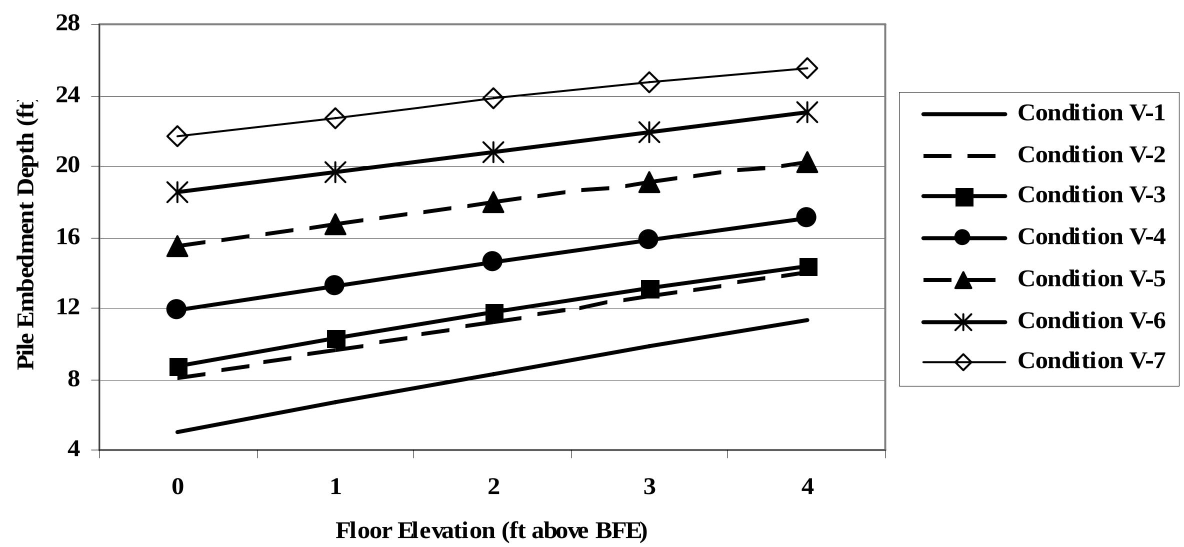
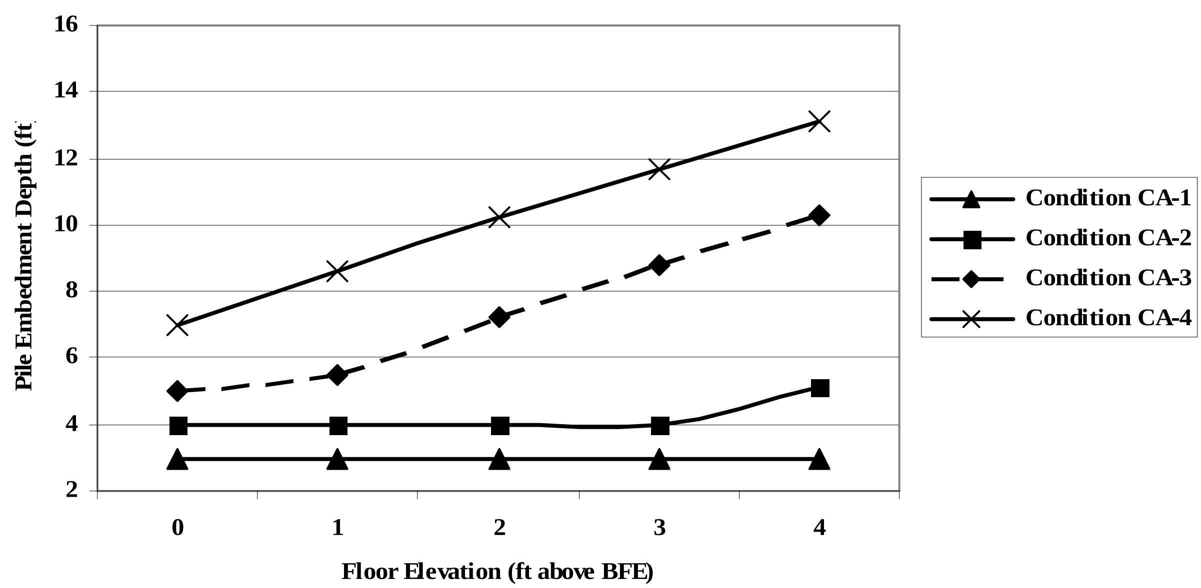


FIGURE 5. Pile Embedment Depth (ft) vs. Floor Elevation
Coastal A Zone, 50'x30', 1-Story, Timber Piles



- The independent reviewer also recalculated the 14 cases while allowing the minimum pile diameter to vary (as a check on the study constraint that timber pile diameters must be greater than or equal to 12 inches). Recalculated pile diameters still equaled or exceeded 12 inches in nine of the 14 cases; in the remaining five cases, pile diameters varied between 9.9 and 10.8 inches.

Based on the independent check, the study's pile design methodology was judged by the study leader to be appropriate for this study. On the whole, this study's pile design methodology was slightly more conservative (i.e., resulting in greater pile embedment and or diameter) than the more detailed independent design, and where study embedment depths or pile diameters were less than the corresponding independent results, those differences usually were small.

5.2. Masonry Pier Foundations

This study evaluated reinforced concrete masonry piers in all flood hazard zones. Masonry piers were assumed to be consistent with standard practice in many V zones -- 16 inches square in cross-section, and spaced at 10 feet on center. Loads were applied to pier-supported buildings in a fashion similar to the pile-supported buildings. Calculations showed pier cross sections larger than 16 inches square would be required for scenarios with high freeboard at the more energetic V zone conditions V-5, V-6 and V-7. Larger piers typically are not observed in coastal construction, indicating that standard practice may not be adequate to resist flood and wind loads in V zones, where the BFE is one story or higher above the ground.

Pier foundations in V zones and Coastal A zones can be deficient in another way, also. The pier footings used in this study were similar to those commonly constructed in the field (3-ft square footings, 8-in thick and 30 inches below grade). Calculations in this study showed that these footings were not adequate to resist V zone and Coastal A zone scour and overturning forces on the building. Post-storm investigations reveal that these footings are not capable of resisting the scour specified for the V zone and Coastal A zone flood conditions in this study (see the *Homebuilder's Guide to Coastal Construction, Fact Sheets 11 and 14* [FEMA 2005b]). Thus, use of the typical pier foundations and footings is not recommended under those conditions specified herein for V zones and Coastal A zones.[18] Pile foundations, or modified pier foundations such as those contained in FEMA (2006b), are recommended in these situations. This study found typical pier foundations designed in accordance with sound engineering practice to be adequate in A zone conditions not subject to waves and scour.

5.3. Wall Foundations

This study evaluated the use of 8-inch and 12-inch thick concrete masonry perimeter wall foundations (with masonry piers supporting the interior of the buildings) in A zones and Coastal A zones. The walls were supported on conventional spread footings. Wall foundations modeled in this study for A zone conditions were found to be adequate, but like the masonry pier foundations, typical perimeter wall foundations in Coastal A zone conditions could not resist the scour and wave loads and thus are not recommended in Coastal A zones (they are prohibited by the NFIP in V zones). Cost calculations in this study will understate the actual costs for wall foundations required to resist Coastal A Zone flood and scour conditions.

5.4. Elevation on Fill (Concrete Slabs)

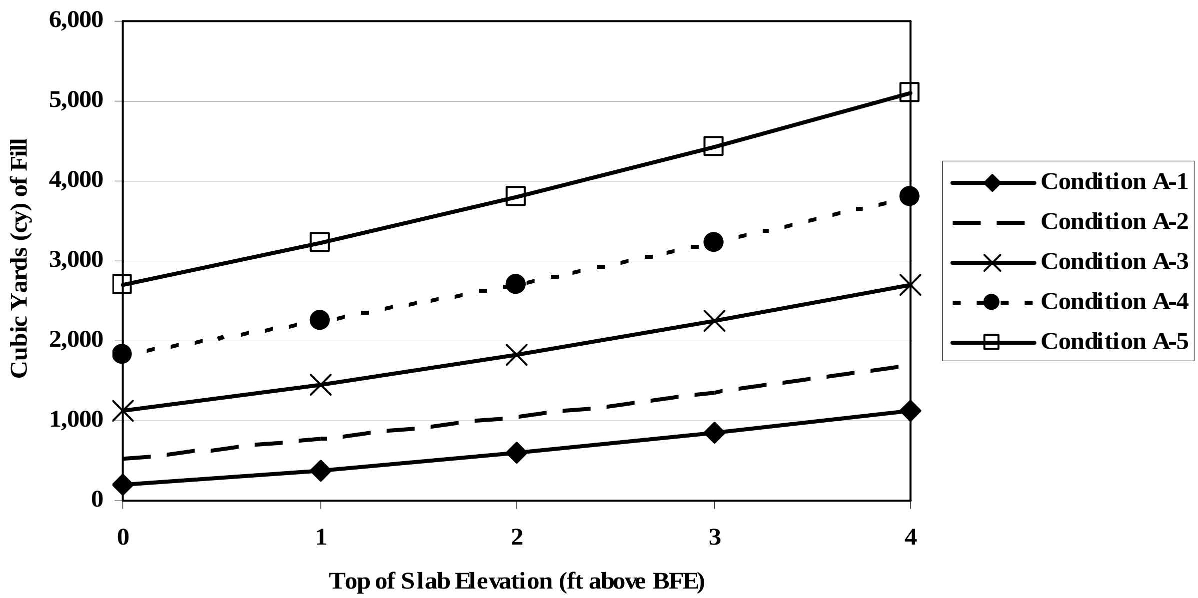
Elevation of concrete slabs (4-inch thick) on fill were evaluated during this study for A zones and Coastal A zones. The slabs were elevated to the BFE and above using compacted fill, with the top of the fill pad extending beyond the building footprint 10 ft in all directions, and with side slopes of 1:3 (vertical:horizontal). Fill stabilization (with vegetation) was assumed in

[18] Nevertheless, typical (i.e., often inadequate) masonry pier foundations were carried through the foundation cost analysis portion of this study. Given the calculated and observed failures of these foundations in V zones and some Coastal A zones, the foundation cost results understate the required dimensions and costs for these foundations.

the Coastal A zone. Elevation of slabs by fill was not evaluated for V zones because they are prohibited by the NFIP.

This study found that relatively large quantities of fill are required to elevate homes more than a few feet above existing grade (see Figure 6). Thus, if the BFE is as shown in conditions A-3, A-4 or A-5 (six to 10 feet above grade), use of a slab foundation elevated on fill is not practical, even before freeboard considerations are included. Foundation cost estimates (see Chapter 7) verify this.

FIGURE 6. Fill (cy) Required to Elevate Slab Foundation, 50'x30' Building Footprint, Top of Fill Pad Extends 10 ft Beyond Footprint in All Directions, 1:3 Side Slopes



NOTE: See Table 4 and Figure 3 in Section 4.2 for a description of flood conditions.

6. BUILDING COSTS

6.1. A Note about Building Costs[19] and This Study

The benefit-cost calculations made during this study were structured so that all dollar inputs are expressed as a percentage of the initial building cost, not in absolute dollar terms. This approach helps to generalize the results of the study, and extends the applicability of its results beyond the year upon which the study's building cost data were obtained.

Since this study began in 2003, all building costs, including foundation costs, were calculated using data and procedures from Marshall & Swift (2003), supplemented where necessary, with other data. This approach provides a consistent building valuation procedure, which is useful for making *relative* cost comparisons when freeboard and alternate foundations are considered. The presumption that today's (or future) foundation and freeboard costs remain relatively constant (in percentage terms) when compared with the entire building cost is a reasonable assumption.

Finally, although the 2003 per-square-foot building costs cited in this chapter may appear low (especially given today's residential construction costs and massive reconstruction looming on the horizon following back-to-back severe hurricane seasons in 2004 and 2005) the study methodology produces generic benefit-cost results that are not tied to 2003 building cost data or to any specific point in time.

6.2. Building Cost Calculation Procedure

Building costs were developed in this study for the typical buildings shown in Table 2 on a variety of foundation types. This involved a process where final or total building costs were "built-up" using Marshall & Swift (2003) costs calculation procedures. The process is illustrated in the "Calculate Construction Cost" box in Figure 1[20].

6.2.1. Key Cost Definitions

Base Cost

June 2003 building cost (see Table 5, upper) for each of the building sizes (see Table 2) calculated using Marshall & Swift's (2003) *Residential Cost Handbook*. Each building is placed upon the standard Marshall & Swift foundation -- a crawlspace with interior piers (see Figure 7). A "quality of construction" adjustment was included in the base building cost as a proxy for differences between typical buildings constructed in various flood hazard zones. Other cost

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[19] All building costs in this study exclude the costs of the land upon which the buildings are placed.

[20] A fundamental assumption of this study is that the building (and its costs) can be separated into its foundation, and everything else above the foundation (floor system, walls, roof, interior components and systems, etc.). This assumption is consistent with the "segregated cost method" contained in Marshall & Swift (2003), where the foundation cost for the base building can be computed separately from the cost of other building elements. Thus, if the base foundation cost is computed separately and deducted from the base building cost, this leaves the cost of the building without a foundation. Other foundations can be placed beneath the building, costs can be calculated for the building plus the other foundation, and cost comparisons can be made.

adjustments were made to the base building cost for floor coverings, floor insulation, hurricane connectors and heat pumps, all using Marshall & Swift data and procedures.

Refined Cost

The base building cost, refined to include numbers of appliances and plumbing fixtures that deviate from the Marshall & Swift default numbers. Table 5 (lower) shows the June 2003 refined building costs developed using the Marshall & Swift data and procedures. Note that although these refinements were made in an attempt to characterize typical homes in each flood hazard zone, the net effect of the refinements was small, adding approximately $2/sf to $3/sf to the Marshall & Swift base costs.

Standard Foundation Cost

The June 2003 cost for the standard foundation was determined using Marshall & Swift (2003) procedures and is shown in Table 6 (upper). Its cost was modest, estimated at $2.09/sf to $2.65/sf for the typical buildings evaluated in this study.

Building Only (without Foundation) Cost

The cost of the building without the standard foundation (see Table 6, lower).

Individual Foundation Cost

The cost of an individual slab, pier, wall or pile foundation, estimated using Marshall & Swift (2003) data and procedures. Individual foundations and their costs are discussed in Section 6.3.

Final Building Cost

The "built-up" cost of the building only cost, plus the individual foundation cost. Final costs are discussed in Section 6.3.

6.2.2. Construction Quality

Descriptions of each of the construction qualities used in this study have been extracted from Marshall & Swift (2003) and are included below. This study assumed the following qualities of construction: V zone = very good quality; Coastal A zone = good quality; A zone = average quality[21].

Average Quality

Usually mass produced and will meet or exceed the minimum construction requirements of lending institutions, mortgage-insuring agencies and building codes; by most standards, the

[21] Prior to the development of the generalized benefit-cost calculation procedure, discussions with project reviewers indicated their desire to see additional calculations made using good and very good quality homes in A zones. However, the benefit-cost procedure developed in this study does not depend on actual construction costs – all incremental costs and savings have been normalized with respect to the total construction cost for a home – and these additional quality calculations were not required.

quality of materials and workmanship is acceptable but does not reflect custom craftsmanship; cabinets, doors, hardware and plumbing are usually stock items; residences of average quality will be encountered more frequently than residences of other qualities.

Good Quality

May be mass produced in above-average residential developments or built for an individual owner; good quality standard materials are used throughout; they will exceed the minimum construction requirements of lending institutions, mortgage-insuring agencies and building codes; some attention is given to architectural design in both refinements and details; interiors are well finished; exteriors have good fenestration with ornamental materials or other refinements.

Very Good Quality

Typical of those built in high-quality tracts or developments and are frequently individually designed; attention has been given to interior refinements and details; exteriors have good fenestration with some custom ornamentation.

FIGURE 7. Marshall & Swift (2003) base foundation elements

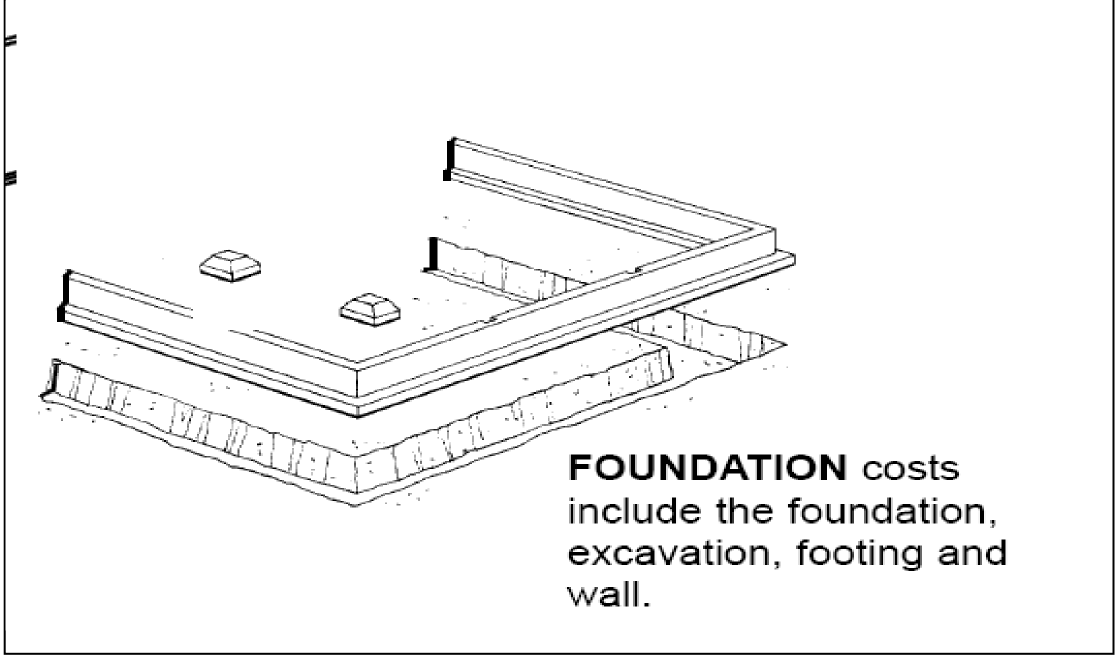


TABLE 5. Construction Costs* of Buildings Used in this Study (2003)

Building Case	Description	A Zone (Average Quality)		Coastal A Zone (Good Quality)		V Zone (Very Good Quality)	
		M&S cost ($/sf)[1]	Cost ($)	M&S cost ($/sf)[1]	Cost ($)	M&S cost ($/sf)[1]	Cost ($)
Base Cost							
1	30x50, 1-story, 1,500 sf	63.99	95,980	87.91	131,859	106.92	160,382
2	30x50, 2-story, 3,000 sf	54.41	163,233	75.54	226,611	97.15	291,438
3	40x60, 1-story, 2,400 sf	58.81	141,145	81.23	194,947	98.52	236,452
4	40x60, 2-story, 4,800 sf	50.17	240,825	69.86	335,334	89.82	431,124
Refined Cost							
1	30x50, 1-story, 1,500 sf	66.76	100,128	90.06	135,088	107.94	161,906
2	30x50, 2-story, 3,000 sf	56.66	169,979	77.96	233,856	100.08	300,229
3	40x60, 1-story, 2,400 sf	61.26	147,025	83.69	200,853	100.71	241,717
4	40x60, 2-story, 4,800 sf	52.48	251,903	72.77	349,283	93.57	449,134

* Base costs reported here include Marshall & Swift (2003) base costs, plus adjustments for floor coverings, floor insulation, hurricane connectors and heat pumps. Refined costs include adjustments for appliances and plumbing fixtures deemed typical for the residences used in this study.

TABLE 6. Construction Costs without Marshall and Swift (2003) Foundation

Building Case	Description	A Zone (Average Quality)		Coastal A Zone (Good Quality)		V Zone (Very Good Quality)	
		M&S cost ($/sf)[1]	Cost ($)	M&S cost ($/sf)[1]	Cost ($)	M&S cost ($/sf)[1]	Cost ($)
Foundation Cost							
1	30x50, 1-story, 1,500 sf	2.65	3,975	2.65	3,975	2.65	3,975
2	30x50, 2-story, 3,000 sf	2.09	6,270	2.09	6,270	2.09	6,270
3	40x60, 1-story, 2,400 sf	2.65	6,360	2.65	6,360	2.65	6,360
4	40x60, 2-story, 4,800 sf	2.09	10,032	2.09	10,032	2.09	10,032
"Building Only" Cost (without Foundation)							
1	30x50, 1-story, 1,500 sf	64.10	96,153	87.41	131,113	105.29	157,931
2	30x50, 2-story, 3,000 sf	54.47	163,709	75.86	227,586	97.99	293,959
3	40x60, 1-story, 2,400 sf	58.61	140,665	81.04	194,493	98.07	235,357
4	40x60, 2-story, 4,800 sf	50.39	241,871	70.68	339,251	91.48	439,102

6.3. Foundation Costs and Final Building Costs

The next step in the study was to take the individual foundations designed (for the various combinations of building size, flood zone, flood conditions and floor elevation), to estimate their costs, and to combine building only costs with foundation costs. Basic assumptions, a few examples and summary tables are given below.

6.3.1. Pile Foundations

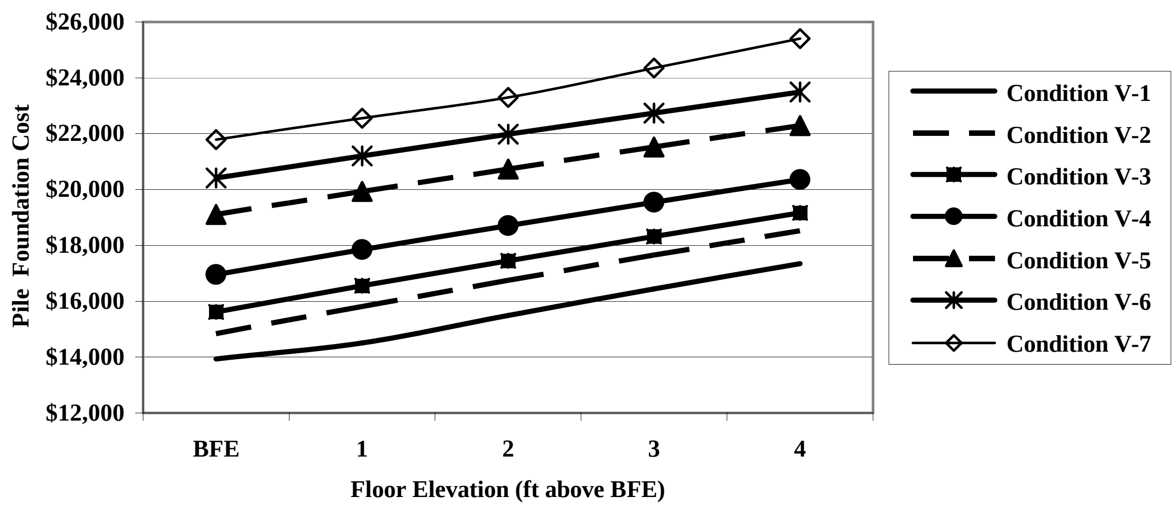
Unit costs for 12-in timber and concrete piles are given in Table 7. These values were used in conjunction with the required pile length (embedment depth + length out of the ground) and the number of piles to calculate individual pile foundation costs. Pile foundation cost calculations assumed that a minimum embedment depth would be 6.0 ft into the ground, even if individual pile design embedment calculations showed less embedment was adequate to resist the applied loads. Pile foundation costs were based on 24 piles beneath the 1,500 sf and 3,000 sf buildings, and 35 piles beneath the 2,400 sf and 4,800 sf buildings. In instances where calculated pile diameter requirement exceeded the 12-inch initial estimate, the unit costs were multiplied by the ratio of the required pile cross-sectional area to the cross-sectional area of the 12-inch pile.

TABLE 7. 2003 Unit Costs for Pile Foundations

Pile	Setup Cost ($)	Material Cost ($/lf)	Driving Cost ($/lf)
Timber	10,150	11.48	6.73
Concrete	11,310	13.63	8.47

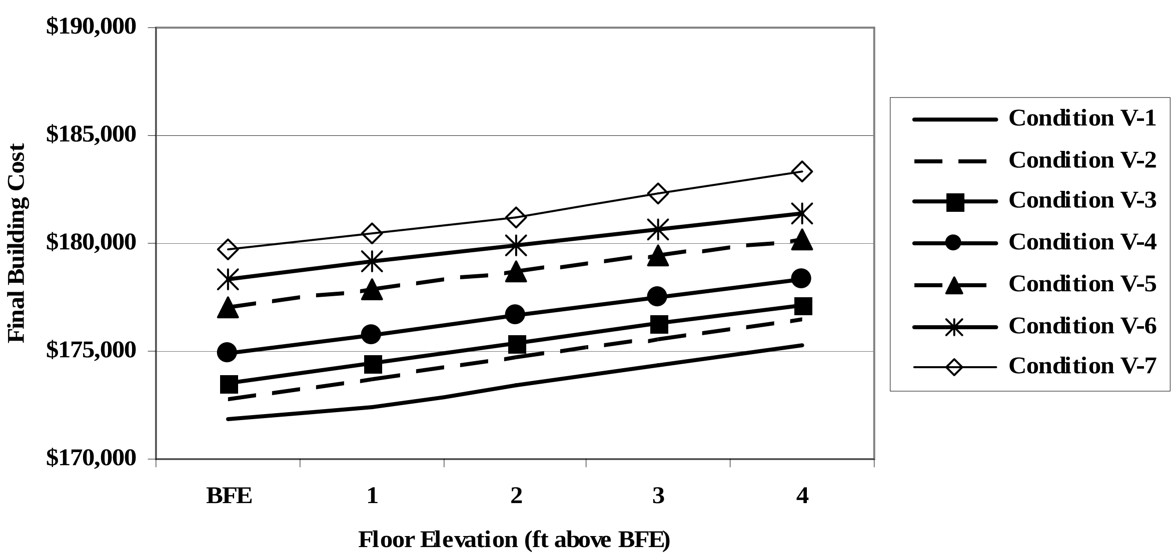
Calculated timber pile foundation costs for the 1,500 sf, 1-story V zone building are shown in Figure 8. These costs translate into a range of approximately $9/sf to $17/sf for the building. Note the similar shapes of the curves to the pile embedment curves in Figure 4. By adding the foundation costs to the base-building-minus-foundation cost ($157,931 from Table 6), the final building costs can be obtained. These results are shown in Figure 9.

FIGURE 8. Timber Pile Foundation Cost vs. Floor Elevation, V Zone, 50'x30', 1 Story (Bldg. cost without foundation = $157,931)



NOTE: See Table 4 and Figure 3 in Section 4.2 for a description of flood conditions.

FIGURE 9. Final Building Cost vs. Floor Elevation, V Zone, 50'x30', 1 Story, Timber Pile Foundation



NOTE: See Table 4 and Figure 3 in Section 4.2 for a description of flood conditions.

Similar analyses were performed for pile foundations across all flood hazard zones and building sizes. The foundation cost trends for the 1,500 sf, 1-story building cases are typical, and are shown in Table 8.

TABLE 8. Timber Pile Foundation Costs, 50'x30', 1-Story Building

Flood Hazard Zone	Floor Elevation	Flood Condition						
		1	2	3	4	5	6	7
A Zone	BFE	$12,979	$13,448	$14,082	$14,633	$15,184	†	†
	BFE + 1 ft	$13,255	$13,723	$14,357	$14,909	$15,460	†	†
	BFE + 2 ft	$13,530	$13,999	$14,633	$15,184	$15,735	†	†
	BFE + 3 ft	$13,806	$14,275	$14,909	$15,460	$16,011	†	†
	BFE + 4 ft	$14,082	$14,550	$15,184	$15,735	$16,287	†	†
Coastal A Zone	BFE	$13,048	$13,406	$13,792	$14,213	†	†	†
	BFE + 1 ft	$13,324	$13,682	$14,068	$15,221	†	†	†
	BFE + 2 ft	$13,599	$13,957	$14,868	$16,183	†	†	†
	BFE + 3 ft	$13,875	$14,233	$15,841	$17,107	†	†	†
	BFE + 4 ft	$14,150	$14,509	$16,775	$18,000	†	†	†
V Zone	BFE	$13,930	$14,839	$15,617	$16,955	$19,110	$20,413	$21,788
	BFE + 1 ft	$14,507	$15,816	$16,552	$17,845	$19,933	$21,205	$22,551
	BFE + 2 ft	$15,494	$16,753	$17,453	$18,707	$20,736	$21,981	$23,300
	BFE + 3 ft	$16,439	$17,656	$18,325	$19,545	$21,521	$22,742	$24,349
	BFE + 4 ft	$17,350	$18,530	$19,171	$20,362	$22,291	$23,488	$25,405

† Not Applicable, as only five A zone conditions and four Coastal A zone conditions are defined in this study (see Table 4 and Figure 3 in Section 4.2).

The V zone pile foundation cost data in Table 8 show that the foundation cost increases as the V zone conditions get more severe, i.e., from the landward V zone condition (V-1) to the most seaward condition (V-7). Foundation cost also increases with freeboard (from the BFE to BFE + 4 ft). These same trends are apparent for all other V zone pile foundation combinations (4 building sizes, timber and concrete piles).

The Coastal A zone pile foundation cost data in Table 8 show that the foundation cost also increases from the landward Coastal A zone condition (CA-1) to the most seaward condition (CA-4), and with increasing freeboard (from BFE to BFE + 4 ft). The trends are not as uniform as in the V zone, however. The Coastal A zone pile foundation cost trends reflect the pile embedment trends shown in Figure 5: embedments and costs in the more severe Coastal A zone conditions tend to behave similar to V zone trends, while embedments and costs in the landward part of the Coastal A zone are similar to A zone trends (uniform embedment across conditions, and increasing foundation costs due to freeboard).

The A zone pile foundation cost data in Table 8 show that the foundation cost also increases from the shallowest A zone condition (A-1) to the deepest condition (A-5), and with increasing freeboard (from BFE to BFE + 4 ft). The trends are more consistent for A zones than other flood hazard zones, since the lateral loads are less and the embedment requirements tend to be uniform across different flood conditions.

6.3.2. Masonry Pier Foundations

Unit costs for the masonry piers are given in Table 9. Pier foundation cost calculations assumed all piers would be spaced 10 feet apart and constructed in a typical fashion – i.e., 16-inch square masonry block piers, reinforced and filled with concrete, extending 30 inches into the ground and supported on 8 inch thick, 3-foot square reinforced concrete footings – even though calculations showed most of these designs were not sufficient to resist the anticipated lateral loads and expected scour under V zone and Coastal A zone conditions described in Table 4.[22] The pier foundations described in this report (and commonly constructed) are adequate only for A zones not subject to waves and scour.

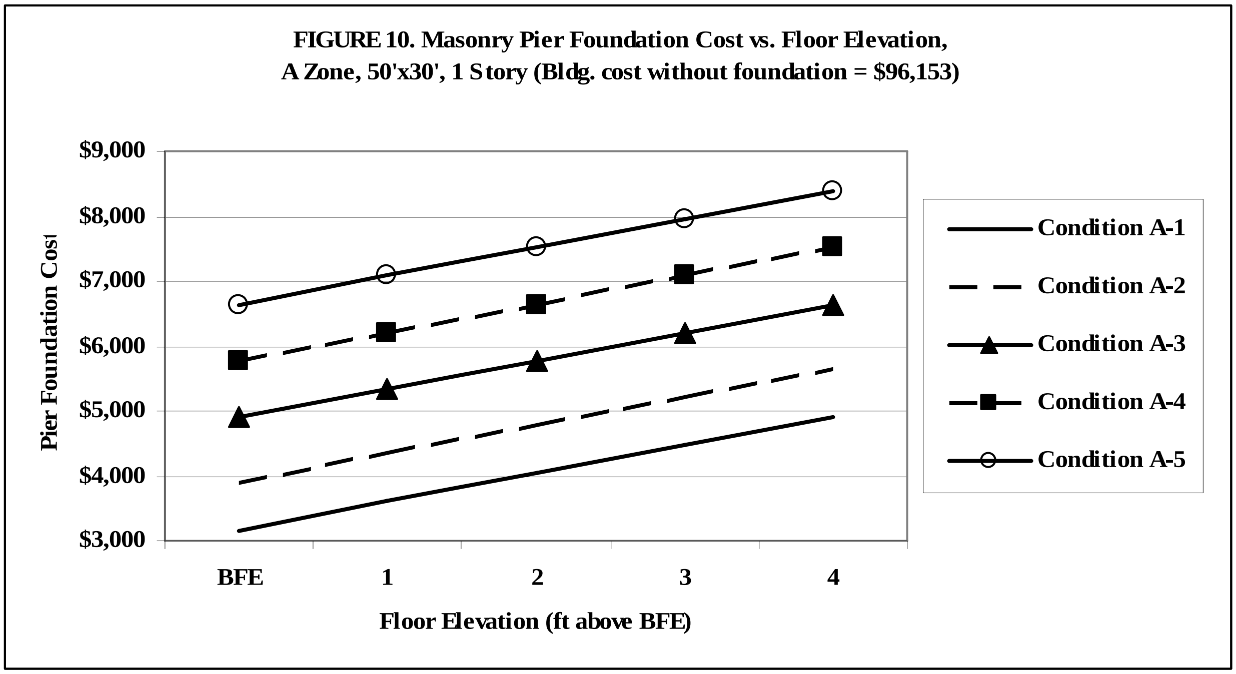
TABLE 9. 2003 Unit Costs for Masonry Pier Foundations

	Cost ($/lf)	Footing Cost ($ each)
16” square masonry pier, reinforced and filled, set 30” into ground and atop 8” thick reinforced concrete footing	$18.12	$64.00

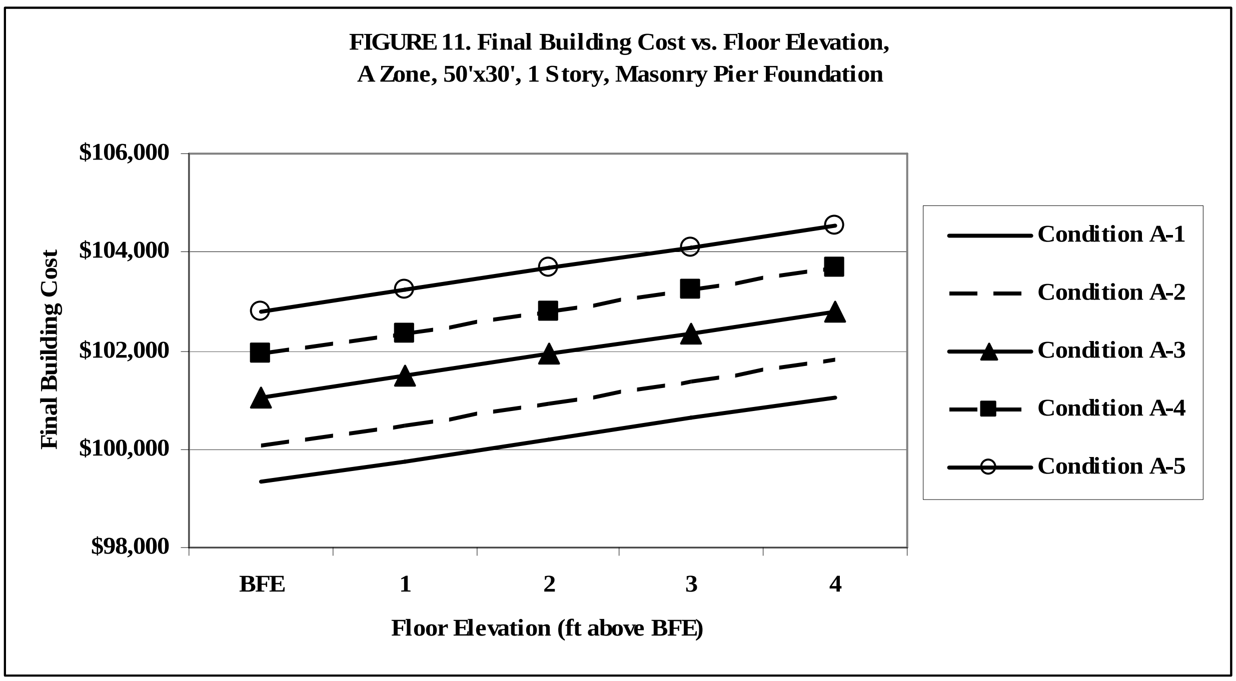
Calculated masonry pier foundation costs for the 1,500 sf, 1-story A zone building are shown in Figure 10. These costs translate into a range of approximately $2/sf to $6/sf for the

[22] This assumption was used to preserve a typical pier foundation alternative (consistent with typical construction practice), and calculated costs represent a lower bound for actual pier foundation costs. In the case of an actual building design, footing sizes and embedment depths would have to be increased considerably, and column cross-sections would have to be increased for conditions V-5, V-6 and V-7, making the actual costs comparable to (or even in excess of) pile foundation costs.

building. By adding the foundation costs to the base-building-minus-foundation cost ($96,153 from Table 6), the final building costs can be obtained. These results are shown in Figure 11. Similar analyses were performed for masonry pier foundations across all flood hazard zones and building sizes. The foundation cost trends for the 1,500 sf, 1-story building cases are typical, and are shown in Table 10. Note that since the pier embedment depth was fixed at 30 inches for all cases, pier foundation costs for condition CA-4 are identical to condition CA-3, costs for condition V-2 are identical to condition V-1, costs for condition V-4 are identical to V-3, and costs for conditions V-6 and V-7 are identical to V-5 (pier costs vary only with pier height above grade). Also, given the similar stillwater flood depth (e.g., CA-1 vs. A-1, CA-3 vs. A-2, V-5 vs. A-3), Coastal A zone and V zone pier foundation costs are higher than A zones costs due to the fact that taller piers are required to elevate above the wave crest.



NOTE: See Table 4 and Figure 3 in Section 4.2 for a description of flood conditions.



NOTE: See Table 4 and Figure 3 in Section 4.2 for a description of flood conditions.

TABLE 10. Masonry Pier Foundation Costs, 50'x30', 1-Story Building

Flood Hazard Zone	Floor Elevation	Flood Condition						
		1	2	3	4	5	6	7
A Zone	BFE	$3,167	$3,906	$4,906	$5,776	$6,646	†	†
	BFE + 1 ft	$3,602	$4,341	$5,341	$6,211	$7,081	†	†
	BFE + 2 ft	$4,037	$4,776	$5,776	$6,646	$7,516	†	†
	BFE + 3 ft	$4,471	$5,211	$6,211	$7,081	$7,950	†	†
	BFE + 4 ft	$4,906	$5,646	$6,646	$7,516	$8,385	†	†
Coastal A Zone*	BFE	$3,928	$4,493	$5,102	$5,102	†	†	†
	BFE + 1 ft	$4,362	$4,928	$5,537	$5,537	†	†	†
	BFE + 2 ft	$4,797	$5,363	$5,972	$5,972	†	†	†
	BFE + 3 ft	$5,232	$5,798	$6,406	$6,406	†	†	†
	BFE + 4 ft	$5,667	$6,232	$6,841	$6,841	†	†	†
V Zone*	BFE	$5,320	$5,320	$6,059	$6,059	$6,929	$6,929	$6,929
	BFE + 1 ft	$5,755	$5,755	$6,494	$6,494	$7,364	$7,364	$7,364
	BFE + 2 ft	$6,189	$6,189	$6,929	$6,929	$7,799	$7,799	$7,799
	BFE + 3 ft	$6,624	$6,624	$7,364	$7,364	$8,233	$8,233	$8,233
	BFE + 4 ft	$7,059	$7,059	$7,799	$7,799	$8,668	$8,668	$8,668

† Not Applicable, as only five A zone conditions and four Coastal A zone conditions are defined in this study (see Section 4.2).
* Masonry pier foundation costs for Coastal A zone and V zone are based on typical construction practices, not based on designs required to resist the loads and conditions stipulated in Table 4. Properly designed pier foundations under those scenarios would be larger, deeper and more expensive. The Coastal A zone and V zone pier foundation costs shown above -- while reflective of common construction practice -- are lower than the cost of an adequately designed pier foundation.

As was the case with pile foundations, the A zone pier foundation cost data in Table 10 show that the foundation cost increases as the A zone conditions get more severe, i.e., from the landward A zone condition (A-1) to the most seaward condition (A-5). Foundation costs also increase with freeboard (from the BFE to BFE + 4 ft).

The Coastal A zone pier foundation costs and V zone pier foundation costs also increase from the landward Coastal A zone condition (CA-1) to the most seaward condition (CA-4), from the most landward V zone condition (V-1) to the most seaward condition (V-7), and with increasing freeboard (from BFE to BFE + 4 ft).

6.3.3. Wall Foundations

Unit costs for the masonry wall (crawlspace) foundations are based on the Marshall & Swift (2003) standard foundation and are given in Table 11. Wall foundation cost calculations assumed walls would be 8-inch or 12-inch concrete masonry block, supported by reinforced concrete footings, and reflective of typical construction practice. The foundations would also include masonry piers to support the interiors of the buildings (i.e., the perimeter wall would replace the exterior piers). Even though design calculations showed these designs were not sufficient to resist the anticipated lateral loads and expected scour under Coastal A zone conditions described in Table 4, the Coastal A zone cost calculations were made[23]. The wall foundations described in this report (and commonly constructed) are adequate only for those for A zones not subject to waves and scour.

TABLE 11. 2003 Unit Costs for Masonry Wall (Crawlspace) Foundations with Interior Piers

Wall Construction		Unit Cost ($/sf)			
		1-story, 1,500 sf	2-story, 3,000 sf	1-story, 2,400 sf	2-story, 4,800 sf
8-in concrete masonry wall on reinforced concrete footing (extends from footing to 24-in above grade).	Cost for initial construction	$2.65	$2.09	$2.65	$2.09
	Cost to raise foundation 1 ft	$1.05	$0.53	$0.86	$0.43
12-in concrete masonry wall on reinforced concrete footing (extends from footing to 24-in above grade).	Cost for initial construction	$3.98	$3.14	$3.98	$3.14
	Cost to raise foundation 1 ft	$1.16	$0.58	$0.94	$0.47

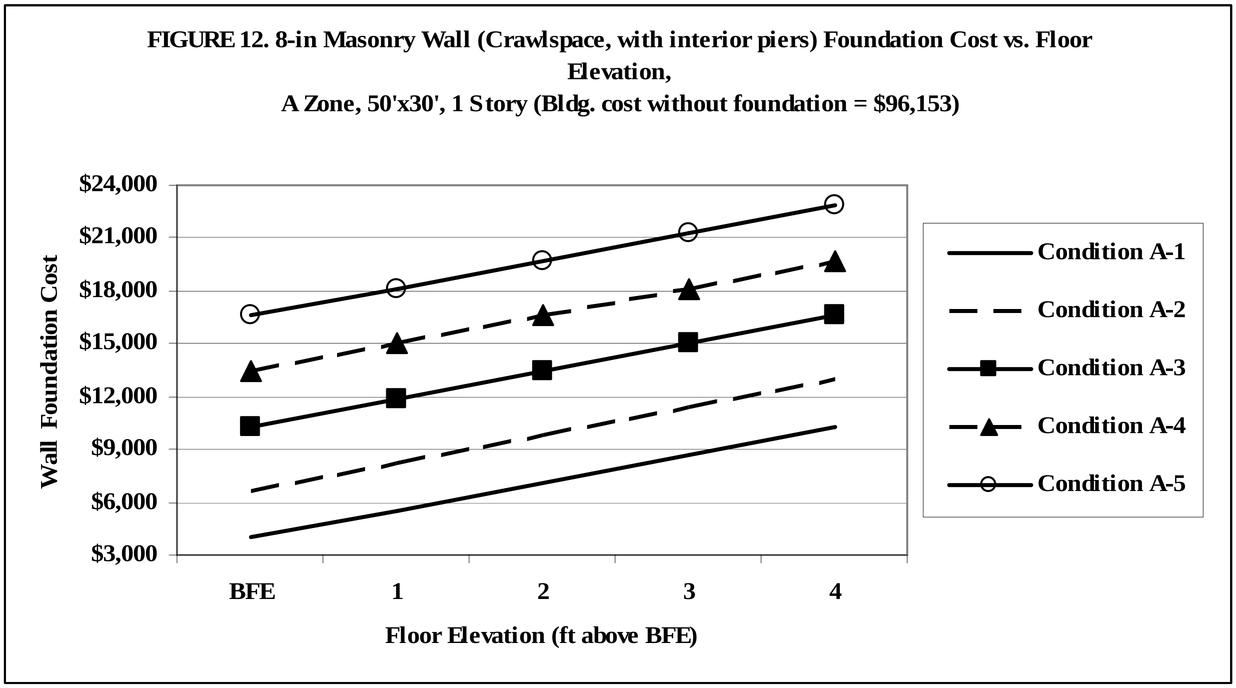
Calculated masonry wall foundation costs for the 1,500 sf, 1-story A zone building are shown in Figure 12. These costs translate into a range of approximately $3/sf to $15/sf for the building. By adding the foundation costs to the base-building-minus-foundation cost ($96,153

[23] This assumption was used to preserve a typical crawlspace foundation alternative (consistent with typical construction practice). In the case of an actual building design, footing sizes and embedment depths would have to be increased considerably, and column cross-sections would have to be increased for Coastal A zone conditions, making the actual costs comparable to (or even in excess of) pile foundation costs.

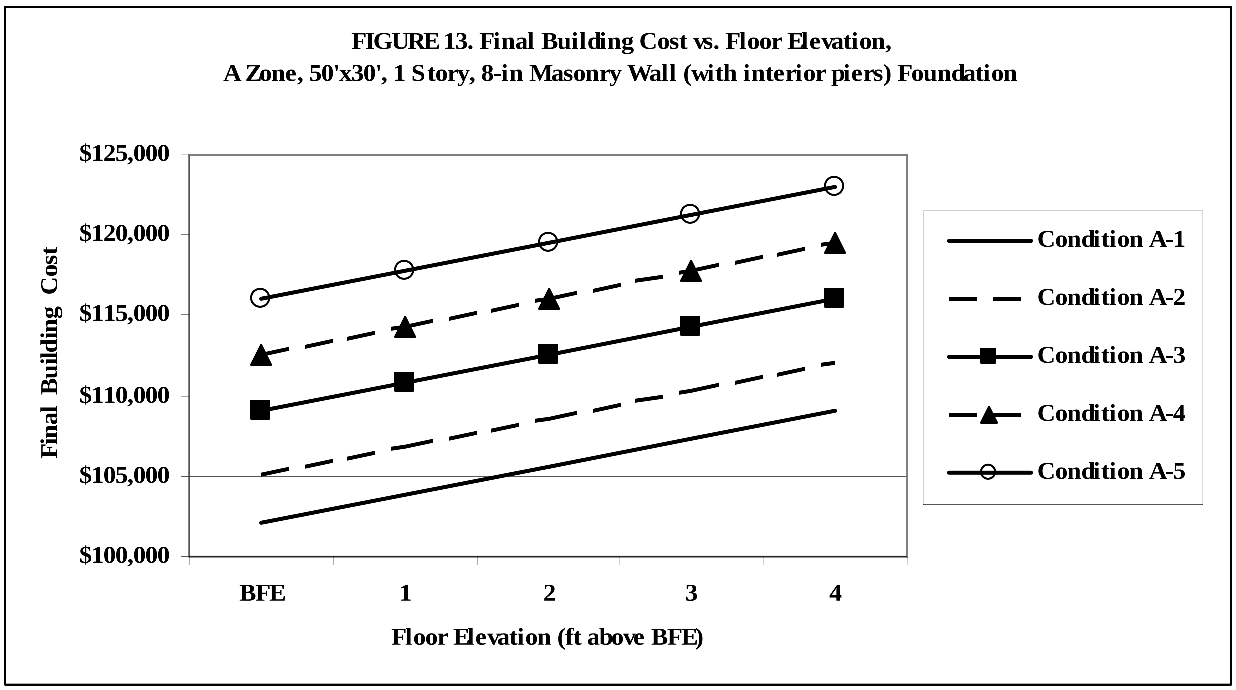
from Table 6), the final building costs can be obtained. These results are shown in Figure 13. Similar analyses were performed for masonry wall foundations in Coastal A zones. The foundation cost trends for the 1,500 sf, 1-story building cases are typical, and are shown in Table 12. Note that since the wall embedment depth was constant for all cases, wall foundation costs for condition CA-4 are identical to condition CA-3 (wall costs vary only with pier height above grade).

6.3.4. Elevation on Fill (Concrete Slab)

The fill foundation costs (see Table 13) were calculated using the assumptions described in Section 5.4, with a June 2003 unit fill cost of $11.31/cy installed. Building costs for buildings elevated on fill were predicated on the assumption that the cost of a concrete slab would be approximately equal to the cost of a wood floor system (which is used in conjunction with all other foundations). Thus, the final building cost is the sum of the without-foundation cost shown in Table 6 and the fill costs in Table 13.



NOTE: See Table 4 and Figure 3 in Section 4.2 for a description of flood conditions.



NOTE: See Table 4 and Figure 3 in Section 4.2 for a description of flood conditions.

TABLE 12. 8-in Masonry Wall Foundation Costs, 50'x30', 1-Story Building

Flood Hazard Zone	Floor Elevation	Flood Condition						
		1	2	3	4	5	6	7
A Zone	BFE	$3,972	$6,649	$10,272	$13,422	$16,572	†	†
	BFE + 1 ft	$5,547	$8,224	$11,847	$14,997	$18,147	†	†
	BFE + 2 ft	$7,122	$9,799	$13,422	$16,572	$19,722	†	†
	BFE + 3 ft	$8,697	$11,375	$14,997	$18,147	$21,297	†	†
	BFE + 4 ft	$10,272	$12,950	$16,572	$19,722	$22,872	†	†
Coastal A Zone*	BFE	$6,731	$8,779	$10,984	$10,984	†	†	†
	BFE + 1 ft	$8,306	$10,354	$12,559	$12,559	†	†	†
	BFE + 2 ft	$9,881	$11,929	$14,134	$14,134	†	†	†
	BFE + 3 ft	$11,456	$13,504	$15,709	$15,709	†	†	†
	BFE + 4 ft	$13,031	$15,079	$17,284	$17,284	†	†	†
V Zone	BFE	**	**	**	**	**	**	**
	BFE + 1 ft	**	**	**	**	**	**	**
	BFE + 2 ft	**	**	**	**	**	**	**
	BFE + 3 ft	**	**	**	**	**	**	**
	BFE + 4 ft	**	**	**	**	**	**	**

† Not Applicable, as only five A zone conditions and four Coastal A zone conditions are defined in this study (see Section 4.2).
* Masonry wall foundation costs for Coastal A zones are based on typical construction practices, not based on designs required to resist the loads and conditions stipulated in Table 4. Wall foundations under those scenarios would be larger, deeper and more expensive. The Coastal A zone wall foundation costs shown above -- while reflective of common construction practice -- are lower than the cost of an adequately designed wall foundation.
** Wall foundations are not permitted in V zones

TABLE 13. Fill Foundation Costs, 50'x30' Building

Flood Hazard Zone	Floor Elevation	Flood Condition						
		1	2	3	4	5	6	7
A Zone	BFE	$2,287	$5,974	$12,784	$20,665	$30,623	†	†
	BFE + 1 ft	$4,328	$8,660	$16,480	$25,369	$36,456	†	†
	BFE + 2 ft	$6,738	$11,766	$20,665	$30,623	$42,898	†	†
	BFE + 3 ft	$9,546	$15,321	$25,369	$36,456	$49,981	†	†
	BFE + 4 ft	$12,784	$19,356	$30,623	$42,898	$57,732	†	†
Coastal A Zone*	BFE	$3,574	$5,606	$7,950	$7,950	†	†	†
	BFE + 1 ft	$5,851	$8,231	$10,948	$10,948	†	†	†
	BFE + 2 ft	$8,516	$11,272	$14,388	$14,388	†	†	†
	BFE + 3 ft	$11,600	$14,758	$18,301	$18,301	†	†	†
	BFE + 4 ft	$15,132	$18,719	$22,716	$22,716	†	†	†
V Zone	BFE	**	**	**	**	**	**	**
	BFE + 1 ft	**	**	**	**	**	**	**
	BFE + 2 ft	**	**	**	**	**	**	**
	BFE + 3 ft	**	**	**	**	**	**	**
	BFE + 4 ft	**	**	**	**	**	**	**

† Not Applicable, as only five A zone conditions and four Coastal A zone conditions are defined in this study (see Section 4.2).
* Fill foundation in Coastal A zones will be subject to scour and erosion, and are not recommended.
** Elevation on fill is not permitted in V zones

6.4. Freeboard and Foundation Cost Comparisons

6.4.1. Pile Foundation Cost

review of all of the pile foundation cost calculations (all flood zones, flood conditions, building types and pile materials) shows that the effects of increasing flood hazards and increasing freeboard are most pronounced in V zones, followed by Coastal A zones, then A zones. The approximate percent foundation cost increases are summarized in Table 14, broken down into hazard effects (i.e., flood depth, wave height, flow velocity and scour) and freeboard effects.

TABLE 14: Approximate Percent Increase in Pile Foundation Cost Due to Increasing Flood Severity and Freeboard

Scenario		Flood Hazard Zone		
		V Zone	Coastal A Zone	A Zone
Hazard Effect on Pile Foundation Cost	Hold Floor Elevation Constant, Move from Least Hazardous Condition to Most Hazardous Condition	50% - 80% (V-1 to V-7)	10% to 80% (CA-1 to CA-4)	10% - 20% (A-1 to A-5)
Freeboard Effect on Pile Foundation Cost	Hold Flood Condition Constant, Add Freeboard	20% to 50% (BFE to BFE + 4 ft)	10% to 50% (BFE to BFE + 4 ft)	5% to 15% (BFE to BFE + 4 ft)

It should be noted that although some of the percentage increases in Table 14 are large, the costs of the pile foundations are small by comparison to the total building costs. Since the pile foundations represent approximately 5% to 15% of the total building cost, the cost impacts of increasing flood hazards on pile foundations are relatively modest (from less than 2% of the building cost to approximately 12% of the building cost). The cost impacts of freeboard for pile foundations are even less, averaging approximately 1% to 2% of the at-BFE building cost for 4 ft of added freeboard (approximately 0.25% to 0.5% per foot of freeboard). Based on this analysis, it is clear that hazard intensity has a greater impact on the foundation and building costs than does adding freeboard.

For example, Table 6 shows the without-foundation cost for a 1,500 sf building is $157,931. Table 8 shows the timber pile foundation cost for this building elevated to the BFE on a pile foundation and subject to flood condition V-1 is $13,930, yielding a final building cost of $171,861 (also shown on Figure 9). The cost of adding four feet of freeboard is the difference between the foundation cost at the BFE and the foundation cost at the BFE + 4 ft (see Table 8: $17,350 - $13,930 = $3,420). The added foundation cost divided by the at-BFE building cost yields $3,420/$171,861 = 2.0% cost increase for four feet of freeboard. This result is typical for V zone pile foundations analyzed in this study, and higher than the typical A zone and Coastal A zone freeboard costs, which are approximately 1% for four feet of freeboard.

6.4.2. Pier Foundation Cost

Given the pier construction assumption stated previously, a review of all of the pier foundation cost calculations (all flood zones, flood conditions, building sizes) shows that the collective effects of increasing flood hazards (i.e., flood depths) and increasing freeboard are to add between approximately 2% to 5% to the building cost[24], based on the least severe flood condition for a building at the BFE. Approximately one-third of the increase is due to freeboard effects, and approximately two-thirds of the increase is due to flood hazard effects. The cost impact of freeboard for masonry pier foundations averages approximately 1% to 2% of the at-BFE building cost for 4 ft of added freeboard (approximately 0.25% to 0.5% per foot of freeboard).

6.4.3. Wall Foundation Cost

Given the wall construction assumption stated previously, a review of all of the wall foundation cost calculations (A and Coastal A flood zone conditions, all building sizes, 8-in and 12-in walls) shows that the effects of increasing flood hazards (i.e., flood depths) and increasing freeboard are to add between approximately 10% to 20% to the building cost[25], based on the least severe flood condition for a building at the BFE. Approximately one-third of the increase is due to freeboard effects, and approximately two-thirds of the increase is due to flood hazard effects. The cost impact of freeboard for masonry wall (with interior pier) foundations averages approximately 3% to 6% of the at-BFE building cost for 4 ft of added freeboard (approximately 0.8% to 1.5% per foot of freeboard).

6.4.4. Slab on Fill Foundation Cost

Given the slab on fill construction assumption stated previously, a review of all of the foundation cost calculations (A and Coastal A flood zone conditions, all building sizes) shows that the effects of increasing flood hazards (i.e., flood depths) and increasing freeboard are to add between approximately 10% to 60% to the building cost, based on the least severe flood condition for a building at the BFE. Approximately one-tenth to one-fifth of the increase is due to freeboard effects, and approximately the remaining three- to four-fifths of the increase is due to flood hazard effects. The cost impact of freeboard for fill foundations averages approximately 3% to 11% of the at-BFE building cost for 4 ft of added freeboard[26].

6.4.5. Foundation Cost Comparison

A comparison of Tables 8, 10, 12 and 14 shows that, for A and Coastal A zones, pier foundations are generally the most cost effective, with the exception of slab-on-fill foundations where the height of the fill pad is low (less than two feet). The advantage of fill quickly disappears as the fill pad height increases. Figure 14 and Table 15 summarize the foundation cost trends for the 1-story, 1,500 sq ft A zone house, which are representative of other houses modeled in this study as well.

For V zones, pier foundations are less expensive than pile foundations – but that may be due in part to the comparison of typical shallow pier embedment foundations versus pile foundations with the required embedment to resist all lateral forces and scour. As was stated

[24] The higher percentage, 5%, is associated with the 1-story, 1,500 sq ft house; the lower percentage, 2%, is associated with the 2-story, 4,800 sq ft house.

[25] The higher percentage, 20%, is associated with the 1-story, 1,500 sq ft house; the lower percentage, 10%, is associated with the 2-story, 4,800 sq ft house.

[26] The fill quantity and fill cost do not increase linearly with freeboard (the cost increase in percentage terms is lowest for one foot of freeboard, and increases for each additional foot of freeboard), but on average, add 0.8% to 3.0 % per foot of freeboard to the at-BFE building cost.

previously, typical pier foundations are not recommended in V zones and Coastal A zones where scour and large lateral loads will be present during the base flood.

Data in Table 15 and other data in Chapter 7 demonstrate that the incremental costs of replacing minimally compliant A zone foundations (such as slab-on-fill and crawlspace foundations) with pier foundations or pile foundations are relatively small, generally less than 5% to 10% of the cost of the building. In Coastal A zones, post-storm field studies have shown that minimally compliant A zone foundations often fail, and this replacement is warranted. In A zones outside coastal areas, NFIP compliant slab-on-fill and crawlspace foundations are generally adequate, and the incremental cost of changing to a pile foundation is not likely justified. However, changing to a pier foundation is probably justified, especially for flood depths more than a few feet above grade. Analyses in Chapter 7 will examine this topic further.

Figure 14. Foundation Cost Summary, A Zone, 50' x 30', 1-story, Floor at BFE

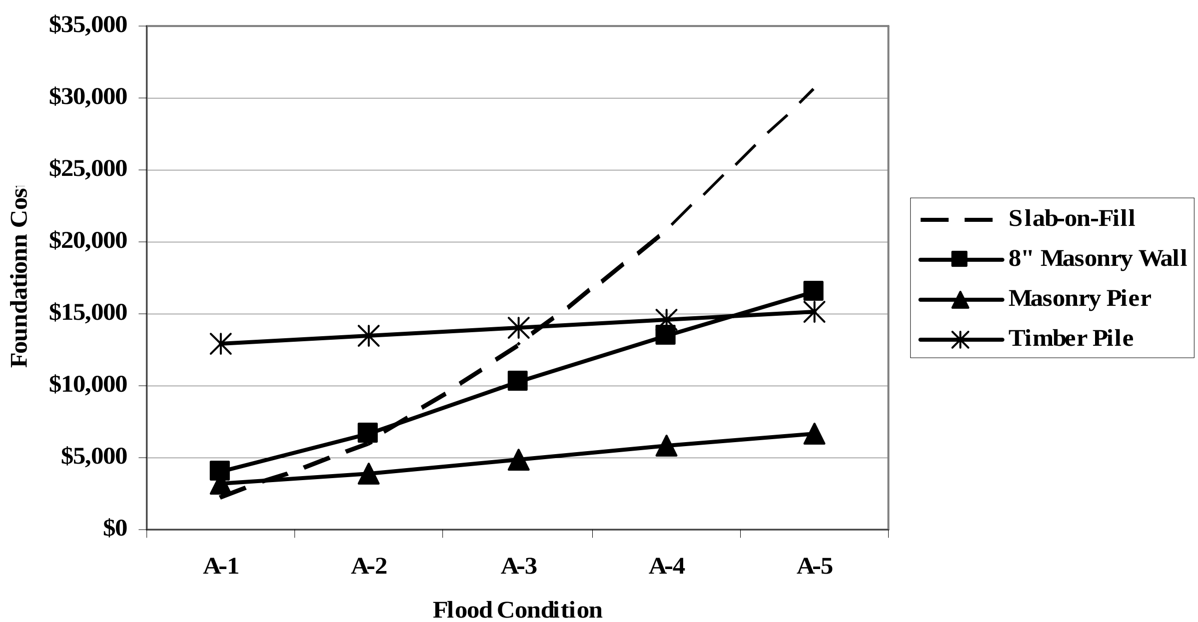


Table 15. Foundation Cost Comparison, A Zone, 1,500 sq ft, 1-Story House

	Foundation Cost ($/sq ft)		
Foundation Type	**Floor at BFE, 2 ft above Grade**	**Floor at BFE, 6 ft above Grade**	**Floor at BFE, 10 ft above Grade**
Slab-on-Fill	1.52	8.52	20.42
Masonry Pier	2.11	3.27	4.43
8” Masonry Wall	2.65	6.85	11.05
Timber Pile	8.65	9.39	10.12

7. BENEFIT-COST ANALYSES

Benefit-cost models in FEMA's BCA Toolkit CD-ROM Version 2.0 (FEMA 2005e) were investigated for use by this study. The models are employed by many for the analysis of publicly funded hazard mitigation projects, and consistency with those analysis procedures is desirable for the 1-and 2-story residential buildings considered by this study.

After a preliminary review of each of the four flood models available in the BCA Toolkit (Riverine A zone, Limited Data; Riverine A zone, Full Data; Coastal A zone; V zone), it was determined that:

- The Riverine A zone Limited Data model was not appropriate for this study since the model relies on observed historical damages and does not allow detailed user inputs for flood hazard and building parameters.

- Even though the Riverine A zone Full Data model allows detailed user inputs, it requires specification of the 10-yr, 50-yr, 100-yr and 500-yr flood discharges and water levels of the same return periods. The model could not be used in this study since building damage under various flood elevations is being investigated, without regard to flood discharge.

- The Coastal A zone and V zone models allow detailed user inputs, specify the flood hazard only in terms of flood elevation, and could potentially be used in this study.

The V zone model and the Riverine A zone full data model were not used in this study.[27] Instead, the Coastal A zone model, or a modification to it, was used for all of the benefit-cost analyses (V zone, Coastal A zone, A zone) in this study.

Using the Coastal A zone model(s), *this study determined the maximum justified cost of mitigation, i.e., freeboard and/or foundation changes at the time of initial construction* -- *expressed as a percentage of initial construction cost* -- *that would yield a B/C greater than or equal to 1.0. This approach generalizes the results and avoids problems associated with specific buildings and their costs at specific points in time.*

[27] A review of the BCA Toolkit (version 2.0) V zone model and Coastal A zone model determined that the Coastal A zone model could be modified for use in all three flood hazard zones (V zone, Coastal A zone, Riverine A zone), and provided intermediate results that were consistent with independent calculations of flood frequency. Modifying the V zone model for use in all three zones proved problematic, so this model was not used in this study. Modifying the Riverine A zone full data model for use in all three zones was not feasible due to its reliance on flood discharge values. Since the benefit-cost calculations were completed for this study, FEMA has released version 3.0 of the BCA Toolkit. Version 3.0 models were not investigated in detail or modified for use by this study.

7.1. Benefit-Cost Model Description

The Coastal A zone model used in this study is documented in FEMA (2005f). The model inputs (which may be model-default values or user-defined) can be broken down into the following categories:

- Project Description
- Discount Rate
- Building Data (e.g., building type and number of stories; footprint area and total floor area; elevation of the lowest floor; replacement value; level of damage that will result in building demolition, etc.)
- Contents Data (e.g., value of contents)
- Displacement Costs (e.g., one-time costs; temporary rental costs; other ongoing displacement costs)
- Value of Public/Non-Profit Services Housed in the Building
- Lost Rent and Business Income
- Mitigation Project Information (e.g., type of mitigation; cost of mitigation; useful life of mitigation project; relocation time and costs during mitigation project)
- Flood Elevation Data (e.g., 1-yr, 10-yr, 50-yr, 100-yr and 500-yr flood elevations; expected annual number of floods at 1-ft increments from 2-ft below the lowest floor to 8-ft above the lowest floor)
- Depth-Damage Functions (building damage % versus depth of flooding relative to the lowest floor; separate building and contents damage curves, which vary by building type and number of stories)
- Displacement Time and Costs (period of time out of the building versus flood depth above the floor, and associated costs)

The model calculates expected annual damages and costs, with and without the mitigation project, calculates the annual benefits of the mitigation project, converts those benefits to a present value, compares the present value of the project benefits to the initial project cost, and computes a B/C ratio. This ratio serves as the basis for comparing foundation and freeboard changes in this study.

7.2. Model Inputs Used in this Study

Inputs used in this study are described below and in Table 16.

TABLE 16: Input Parameters Used in this Study

Input Parameter		Values Used in this Study		
Parameter	**Coastal A Zone Model Default**	**V Zone**	**Coastal A Zone**	**A Zone**
Discount Rate	FEMA Guidance (2004 and other) mandates 7.0%[1] per OMB Circular A-94, Appendix C.	3.0%, 5.0%, 7.0%, 9.0%	3.0%, 5.0%, 7.0%, 9.0%	3.0%, 5.0%, 7.0%, 9.0%
Project Useful Life	30 years[2]	30 years	30 years	30 years
Building Data				
Building Type	†	residence	residence	residence
Number of Stories	†	1 and 2	1 and 2	1 and 2
Building Size	†	1,500 to 4,800 sf	1,500 to 4,800 sf	1,500 to 4,800 sf
Building Cost	†	*	*	*
Lowest Floor Elevation	†	BFE, BFE+1, BFE+2, BFE+3, BFE+4	BFE, BFE+1, BFE+2, BFE+3, BFE+4	BFE, BFE+1, BFE+2, BFE+3, BFE+4
Building Damage that Results in Demolition	50%[3]	50%	50%	50%
Value of Contents	30%[4]	30%	30%	30%
Public/Non-Profit Services Housed in Building	†	none	none	none
Lost Rent and Business Income	†	none	none	none
Mitigation Project				
Project Type	†	Freeboard[5]	Freeboard[5]	Freeboard[5]
Initial Project Cost	†	% of Building Cost[6]	% of Building Cost[6]	% of Building Cost[6]
Annual Costs to Maintain Project	†	none[7]	none[7]	none[7]
Relocation Time	†	none	none	none
Relocation Costs	†	none	none	none
Flood Elevation Data	From Flood Insurance Study (FIS)	Range of BFEs (12 ft to 20 ft msl), with n-yr wave crest elevations calculated using HAZUS flood elevation ratios[9]	Range of BFEs (12 ft to 20 ft msl), with n-yr wave crest elevations calculated using HAZUS flood elevation ratios[9]	Range of FHFs (25 to 150), with n-yr flood elevations calculated using method by Wilbert Thomas[8]
Depth-Damage Functions	Default functions (buildings and contents) from FIA for different flood zones and building types	FIA V zone function, no obstructions[10]	FIA V zone function, no obstructions[10]	FIA A zone functions for 1- and 2-story, no basement
Displacement Time and Costs	Default time based on flood depth above lowest floor, costs associated with displacement	none[11]	none[11]	none[11]

(Table Notes †, *, and 1 - 11 are on next page)

Notes for Table 16

† User defined

* Building costs were calculated in this study (see Chapter 7) using Marshall & Swift (2003) and the foundations designed for various flood conditions (see Section 7). The building cost input into model here is the cost for a new building, elevated to the BFE on a minimally compliant NFIP foundation.

1. January 2006 Appendix C to OMB Circular A-94 gives nominal rate = 5.2%, real rate = 3.0%.
2. FEMA (2004), section 4.14 uses 30 years as the useful life of a residential elevation project.
3. FEMA (2004), section 2.4.5 uses 50% damage as the threshold for demolition.
4. FEMA (2004), section 2.4.6 uses 30% as the ratio of contents to structure value.
5. Mitigation Project in this study means the addition of freeboard or the use of a different foundation at the time of initial construction.
6. As used in this study, “initial project cost” is the additional cost to provide freeboard and/or a different foundation at the time of initial construction. The reference from which additional costs are calculated is the cost to elevate the home to the BFE on a minimally compliant NFIP foundation.
7. There are assumed to be no annual costs to maintain the initial freeboard or foundation change. However, in a study of this type, this field could be used to insert other annual costs or savings, such as reductions in flood insurance premiums.
8. Thomas (2003) developed a procedure to calculate n-year flood depths in streams, given only the 100-yr flood depth. The following FHFs were used in the analysis: 25, 50, 75, 100 and 150. Thomas (personal communication, July 17, 2006) confirmed that the range was reasonable -- a review of 100 streams in one state showed FHFs between 10 and 100. Since B/C decreases as FHF increases, using the range 25 to 150 will result in conservative B/C values.
9. 10-yr, 50-yr and 500-yr flood Elevation Ratios were developed for the HAZUS Flood Model (EQE 2000, Section 5.2.2.2). The relationship was extended to the 1-yr level in this study.
10. EQE (2000, Section 8.2.3) determined that the V zone depth-damage functions provide a better fit to actual damage in Coastal A zones.
11. Sensitivity tests were run to examine the effects of including monthly displacement costs (as a percentage of initial construction cost) and using BCA model default displacement times.

7.2.1. Discount Rate

FEMA’s Benefit-Cost guidance (FEMA 2004, pages 3, 7, 14; FEMA 2005f, page 6-5) states clearly that a discount rate of 7.0% should be used for FEMA-funded hazard mitigation projects, and states that this rate is mandated by the Office of Management and Budget (OMB).[28] Inasmuch as different users of this study may look at the results from different perspectives, and may require analyses at rates other than the OMB discount rate, the cost-benefit analyses in this study were made using a baseline rate of 7.0%, and sensitivity analyses were run for 3.0%, 5.0% and 9.0%. The 5.0% rate corresponds roughly to the current OMB nominal discount rate (the rate paid by 30-year Treasury bonds), the 3.0% rate corresponds to the current OMB real discount rate, and the 9.0% rate corresponds to higher rates that consumers may see at present.

However, extension of this study’s results to other rates is not difficult – the B/C ratio for a project with a 7.0% discount rate can be converted to a B/C ratio at another rate, by multiplying the 7.0% B/C by the ratio of the present value coefficient for the new rate to the present value coefficient for 7.0%[29].. For example, if a project has a B/C = 2.00 at a discount rate of 7.0% and useful life of 30 years, the same project would have a B/C = 2.48 at a discount rate of 5.0% and a useful life of 30 years and (2.48 = 2.00 x [15.37/12.41]).

[28] OMB publishes, on an annual basis, nominal and real discount rates to be used in the evaluation of federal programs and expenditures. The 2006 values are 5.2% and 3.0%, respectively (OMB 2006).
[29] Values of these present value coefficients have been tabulated and are contained in numerous documents, and are included in Table 17

TABLE 17. Present Value Coefficients vs. Discount Rate and Project Useful Life* (Source: FEMA 2005f, page 9-10)

Useful Life (years)	Discount Rate									
	1%	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
1	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.93	0.92	0.91
2	1.97	1.94	1.91	1.89	1.86	18.3	1.81	1.78	1.76	1.74
3	2.94	2.88	2.83	2.78	2.72	2.67	2.62	2.58	2.53	2.49
4	3.90	3.81	3.72	3.63	3.55	3.47	3.39	3.31	3.24	3.17
5	4.85	4.71	4.58	4.45	4.33	4.21	4.10	3.99	3.89	3.79
6	5.80	5.60	5.42	5.24	5.08	4.92	4.77	4.62	4.49	4.36
7	6.73	6.47	6.23	6.00	5.79	5.58	5.39	5.21	5.03	4.87
8	7.65	7.33	7.02	6.73	6.46	6.21	5.97	5.75	5.53	5.33
9	8.57	8.16	7.79	7.44	7.11	6.80	6.52	6.25	6.00	5.76
10	9.47	8.98	8.53	8.11	7.72	7.36	7.02	6.71	6.42	6.14
15	13.87	12.85	11.94	11.12	10.38	9.71	9.11	8.56	8.06	7.61
20	18.05	16.35	14.88	13.59	12.46	11.47	10.59	9.82	9.13	8.51
25	22.02	19.52	17.41	15.62	14.09	12.78	11.65	10.67	9.82	9.08
30	25.81	22.40	19.60	17.29	15.37	13.76	**12.41**	11.26	10.27	9.43
40	32.83	27.36	23.11	19.79	17.16	15.05	13.33	11.92	10.76	9.78
50	39.20	31.42	25.73	21.48	18.26	15.76	13.80	12.23	10.96	9.91
60	44.96	34.76	27.68	22.62	18.93	16.16	14.04	12.38	11.05	9.97
70	50.17	37.50	29.12	23.39	19.34	16.38	14.16	12.44	11.08	9.99
80	54.89	39.74	30.20	23.92	19.60	16.51	14.22	12.47	11.10	10.00
90	59.16	41.59	31.00	24.27	19.75	16.58	14.25	12.49	11.11	10.00
100	63.03	43.10	31.60	24.50	19.85	16.62	14.27	12.49	11.11	10.00
1000	100.00	50.00	33.33	25.00	20.00	16.67	14.29	12.50	11.11	10.00

* Shaded cells indicate the Discount Rates and Useful Life used by this study. The present value coefficient corresponding to a discount rate of 7.0%, and a useful life of 30 years (12.41) was used for this study's baseline B/C calculations.

7.2.2. Mitigation Project Description

As used in this study, "mitigation project" refers to the addition of freeboard or the use of a different foundation at the time of initial construction. The study considered the affects of adding between one and four feet of freeboard at the time of initial construction. The study considered the affects of replacing of A zone type foundations with V zone type foundations, and replacing pier foundations with pile foundations.

7.2.3. Useful Life

The useful life of the mitigation project used in this study is 30 years, as suggested by FEMA (2004) guidance. This study's results can be extended to other useful lives – the B/C ratio for a project with a 30-year life can be converted to a B/C ratio for another useful life by multiplying the 30-year life B/C by the ratio of the present value coefficient for the new useful life to the present value coefficient for the 30-year life (see Table 17). For example, if a project has a B/C = 2.00 at a discount rate of 7.0% and useful life of 30 years, the same project would have a B/C = 2.22 with a useful life of 50 years and a discount rate of 7.0% (2.22 = 2.00 x [13.80/12.41]).

7.2.4. Building Damage that Results in Demolition

This study used 50% damage[30] as the threshold for building demolition, as called for by FEMA (2004). This value is also consistent with the percent damage which triggers substantial damage for a building in the SFHA.

7.2.5. Contents Value

This study used a contents-to-structure-value ratio of 30%, as suggested by FEMA (2004) guidance. In other words, this study assumed that the value of contents within a building would equal 30% of the construction cost of the building.

7.2.6. Public/Non-Profit Use of the Buildings

This study assumed the buildings being evaluated are private, residential structures, and that there would be no loss of public/non-profit services associated with damage to the buildings.

7.2.7. Lost Rent and Business Income

This study assumed the buildings were owner-occupied residential buildings, and no loss of rent or business income would result from damage to the buildings.

7.2.8. Displacement Time and Costs

Although FEMA's Coastal A zone model (and other models) include default estimates for the length of time that building occupants will be forced to leave the building in the event of

[30] Damage is expressed as a percentage of building value.

flood damage (where the displacement time increases with increasing flood depth above the floor), *this study assumed no displacement would occur. Thus, the results of this study are conservative – B/C values determined by this study will be low, when compared to B/C values which incorporate the displacement effects of flooding; higher mitigation costs at the time of initial construction will be justified than those determined by this study.* However, sensitivity tests reported later in this chapter summarize the effect of displacement costs on B/C values.

7.2.9. Flood Elevation Data

This study is generic – it does not evaluate the benefits and costs of a particular mitigation project at a particular location, for which a Flood Insurance Study can be consulted to determine the 100-yr flood elevation and other return period flood elevations. Instead, the study was designed so its results would be applicable over a wide range of coastal and riverine base flood conditions (see Table 4 and Figure 3). The study design is contingent on two things being known:[31]

- A relationship between the 100-yr flood (base flood) level and flood levels for other return periods, at any location within the SFHA (FEMA's model requires the user to input the 100-yr and other return period flood levels).

- Some measure of the actual base flood level, or an additional relationship between the 100 year flood level and another return period flood level.

Satisfying the first condition was accomplished using flood elevation frequency relationships developed previously, or developed during this study. The second condition was addressed by specification of a reasonable range of BFEs (for V zones and Coastal A zones), and Flood Hazard Factors (FHFs) for A zones. Note that as the coastal BFE or riverine FHF increases, the severity of the local flooding increases – high coastal BFEs and high riverine FHFs are associated with more hazardous flooding.

V Zones and Coastal A Zones

Generic relationships between the 100-yr flood elevations and other flood elevations were determined during development of the HAZUS Coastal Flood Model (EQE 2000). The relationships were determined through a selective review of coastal Flood Insurance Studies for the Atlantic, Gulf of Mexico and Pacific coasts. Although not exhaustive, the review examined coastal flood data from 46 coastal communities (27 Atlantic, 11 Gulf of Mexico, eight Pacific) on different shoreline exposures (31 open coast, 15 bay) with different flood conditions determining BFEs (38 wave height dominant, 8 wave runup dominant). The relationships -- called "Flood Elevation Ratios," or the ratio between the n-yr flood elevation and the 100-yr flood elevation *at the shoreline*, were determined to be approximately constant on a nationwide basis, with small standard deviations. The coastal flood elevation ratios are shown in Table 18.

[31] The B/C ratio for a mitigation project depends on two factors related to the flood hazard: the base flood level at the site, and either the flood elevation frequency distribution (V zones and Coastal A zones) or Flood Hazard Factor (A zones).

Given the 100-year flood elevation, other flood elevations can be calculated. For example, if the 100-year flood elevation is 20.0 ft NGVD, the 1-year flood elevation will be 5.8 ft (20.0 x 0.29), the 10-year flood elevation will be 12.8 ft (20.0 x 0.64), the 50-year flood elevation will be 17.6 ft (20.0 x 0.88), and the 500-year flood elevation will be 24.6 ft (20.0 x 1.23).

TABLE 18. Coastal Flood Elevation Ratios at the Shoreline

Flood Return Period (years)	**Flood Elevation Ratio*** (n-yr flood elevation / 100-yr flood elevation)
1	0.29
10	0.64
50	0.88
100	1.00
500	1.23

* The 10-yr, 50-yr and 500-yr ratios were taken from EQE (2000). The 1-yr ratio was determined by extrapolation during this study.

For the purposes of this study, it is assumed that the same ratios will hold for depth-limited waves throughout the V zone and Coastal A zone. Sensitivity tests show the actual ratios throughout the V zone and Coastal A zone are within approximately 2% to 8% of the ratios at the shoreline, for typical ranges of BFEs in coastal areas (e.g., 12 ft to 20 ft) and for flood elevations that will enter into damage calculations (i.e., for flood levels 2 feet below the BFE and higher).

The Coastal A zone model (as used for V zones and Coastal A zones) employed the ratios in Table 18 in the following manner. The 100-year flood elevation (BFE) was input as the elevation of the “first” (i.e., lowest) floor on the model’s Building Data input screen. This elevation was then transferred to the 100-year flood elevation cell on the Flood Hazard input screen, and the 1-yr, 10-yr, 50-yr and 500-yr flood elevations were calculated automatically using the ratios in Table 18.[32] This flood elevation frequency data was then used by the model to determine the expected annual number of floods at 1-ft increments from two ft below the BFE to eight ft above the BFE. Freeboard was added later in 1-ft increments on the model’s Mitigation Project input screen, and the model was rerun each time freeboard was added.

A Zones

A simple determination of flood elevation ratios in non-coastal areas through a review of Flood Insurance Studies is not practical. Moreover, unlike coastal areas where all flood elevations at the shoreline are referenced to the same “zero depth” elevation (+/- mean sea level, msl), zero flood depth in riverine areas occurs at an infinite number of elevations above msl.

[32] The ratios will apply approximately at a site distant from the shoreline, since all wave heights considered in this study are depth-limited, both at the shoreline and away from the shoreline.

A procedure was developed by Thomas (2003) for this study, to estimate n-year flood depths in a stream, given the 100-year flood depth (see Appendix 3). The method is based on general relationships between the slope of the discharge-frequency curve and the relation between depth and discharge contained in the well-known *Bulletin 17B* (USGS 1982) and other sources. Application of this procedure shows that nationwide-average "Flood Depth Ratios" can be determined, and that those ratios are as given in Table 19.

TABLE 19. Flood Depth Ratios for a Stream

Flood Return Period (years)	**Flood Depth Ratio*** (n-yr flood depth /100-yr flood depth, where depth is measured in the channel)
1	0.18
10	0.69
50	0.91
100	1.00
500	1.21

* Using the procedure developed by Thomas (2003). The 1-yr ratio is calculated at the 1.01-yr return period.

The ratios in Table 19 must be used in conjunction with some estimate of the actual flood level or flood depth. However, unlike coastal floodplains where a reasonable range of stillwater elevations/BFEs can be estimated, BFEs in riverine floodplains vary too widely to identify a narrow range for use in this study. Instead of using the BFE to provide additional flood hazard specification in A zones, the "Flood Hazard Factor" will be used.[33]

Using Equation 8 from Thomas (2003) in conjunction with the FHF definition, unique values of the 100-yr flood depth in the channel (d_{100}) were determined for a range of typical FHFs for riverine A zones (see Figure 15 and Table 20). The 10-yr flood depth (d_{10}) is equal to d_{100} – FHF/10, or 0.69 d_{100}. Channel flood depths at other return periods (d_n) were calculated using the flood depth ratios in Table 19. All flood elevations E_n were referenced to the channel bottom elevation E_C, and apply throughout the local floodplain. Since this study is generic in nature, E_C was set equal to zero, and the flood depth ratios in Table 19 became flood elevation ratios, which were then used in the A zone B/C analyses (using the Coastal A zone model modified for A zones).

7.2.10. Flood Depth-Damage Functions

Flood depth-damage functions used in this analysis were those contained in the BCA Toolkit (FEMA 2005e). A zone damage functions were used for A zone buildings and their contents. V zone damage functions were used for V zone buildings and contents, as well as for

[33] The FHF for a stream reach is the difference between the 100-year and 10-year flood surface elevations rounded to the nearest one-half foot and multiplied by 10. For example, if the difference between the 100-year and the 10-year water-surface elevations is 0.7 foot, the FHF is 5; if the difference is 1.4 feet, the FHF is 15; if the difference is 5.0 feet, the FHF is 50, etc. The FHF is a parameter that was computed and published in early FISs, but is no longer included in today's studies. However, the FHF calculation can still be made with available information.

Coastal A zone buildings and contents. The use of V zone damage functions for Coastal A zones was based on a study at Pensacola Beach (EQE, 2000, section 8.2.3) and on observed Coastal A zone building damages after recent hurricanes (FEMA 2005a). The damage functions used in this study are listed in Tables 21 and 22.

FIGURE 15. Sketch of Generic Riverine Floodplain and A Zone Flood Elevations Used in this Study

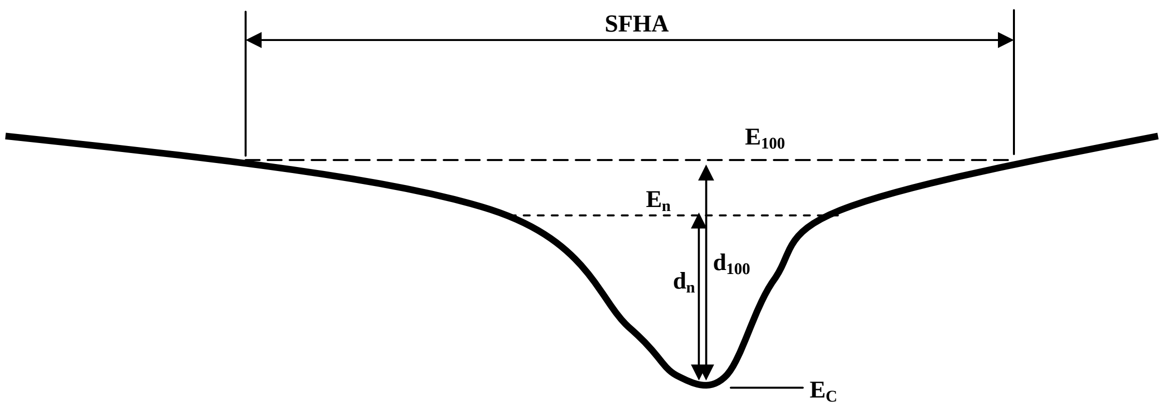


TABLE 20. A Zone Flood Hazard Factors and Associated Flood Depths Used in this Study*

Flood Hazard Factor (FHF)	Difference Between 100-yr and 10-yr Flood Depths in Channel (ft) [$d_{100} - d_{10}$]	d_{100} (ft) Satisfying Thomas (2003) Equation 8	Corresponding d_{10} (ft)
25	2.5	8.0	5.5
50	5.0	16.0	11.0
75	7.5	24.0	16.5
100	10.0	32.0	22.0
150	15.0	48.0	33.0

* d_{100} is measured relative to channel bottom E_C and rounded to the nearest whole foot (see Figure 15).

TABLE 21: V Zone and Coastal A Zone Depth-Damage Functions Used in this Study

Flood Depth (ft)*	One or More Stories, No Obstructions	
	Building Damage (%)	Contents Damage (%)
< -2	0	0
-2	10	0
-1	12	6
0	15	15
1	23	23
2	35	35
3	50	50
4	58	58
5	63	63
6	67	67
7	70	70
8	72	72
> 8	78	78

* Depth is measured from the bottom of the lowest horizontal structural member supporting the lowest floor.

TABLE 22: A Zone Depth-Damage Functions Used in this Study

Flood Depth (ft)*	One-Story, No Basement		Two-Story, No Basement	
	Building Damage (%)	Contents Damage (%)	Building Damage (%)	Contents Damage (%)
< -2	0	0	0	0
-2	0	0	0	0
-1	0	0	0	0
0	9	14	5	8
1	14	21	9	14
2	22	33	13	20
3	27	41	18	27
4	29	44	20	30
5	30	45	22	33
6	40	60	24	36
7	43	65	26	39
8	44	66	29	44
> 8	45	68	33	50

* Depth is measured from the top (walking surface) of the lowest floor.

7.3. B/C Results

7.3.1. V Zones and Coastal A Zones

B/C values were calculated for new homes using the inputs shown in Table 16. Sample results are shown in Figures 16-19, where B/C ratios are plotted against the cost to elevate above the BFE (equal to 12.0 ft msl in this case), for different freeboard levels and different discount rates. To use the figures, select the BFE-Discount Rate combination desired, go to the appropriate figure and read across along the B/C = 1.0 line to see the additional cost justified for various freeboard levels. For example, if the BFE is 12 and the Discount Rate is 5.0%, use Figure 17 – reading across one sees that it is worth spending another 5% at the time of initial construction to add 1 ft of freeboard, or another 9% to add 2 ft of freeboard, etc. The figures clearly show that the B/C ratio decreases as the discount rate increases, with all other inputs held constant. The B/C ratio also decreases as the BFE increases, with other inputs constant.

All the V zone and Coastal A zone B/C calculations were tabulated and the B/Cs were determined for various combinations of freeboard, additional construction cost and discount rate. The data were then examined to identify the *percentage of additional construction cost* -- rounded to the nearest 1%[34] – that an owner would be justified in spending at the time of construction (B/C = 1.0) for each freeboard-BFE-discount rate combination. These results are shown in Table 23 and Figures 20-23 and are summarized below:

- 1 foot of freeboard above the BFE: spending 103% of the at-BFE building cost is justified, and in some cases it may be worth spending up to 107% of the at-BFE building cost[35].

- 2 feet of freeboard above the BFE: spending 104% of the at-BFE building cost is justified, and in some cases it may be worth spending up to 111% of the at-BFE building cost.

- 3 feet of freeboard above the BFE: spending 105% of the at-BFE building cost is justified, and in some cases it may be worth spending up to 113% of the at-BFE building cost.

- 4 feet of freeboard above the BFE: spending 106% of the at-BFE building cost is justified, and in some cases it may be worth spending up to 114% of the at-BFE building cost.

Note that the results cited above account only for damage to the buildings and their contents. Any additional costs resulting from the flooding (e.g., displacement costs such as temporary housing) and any cost savings as a result of adding freeboard (e.g., flood insurance premium reductions) justify spending even more money at the time of initial construction to reduce future flood damages.

[34] If the justified cost was less than 1.0% of the initial construction cost, it was rounded to the nearest 0.5%

[35] That is, for one foot of freeboard, spending an additional 3% above the at-BFE building cost at the time of construction is always justified for the scenarios studied herein. Spending up to 7% more than the at-BFE building cost for one foot of freeboard is justified for some BFE-discount rate combinations.

Figure 16. B/C Ratio versus Cost to Elevate with Freeboard (V Zone and Coastal A Zone, Piles or Piers, No Obstructions, BFE = 12 ft, DR = 3.0%, UL = 30 years, Contents @ 30%)

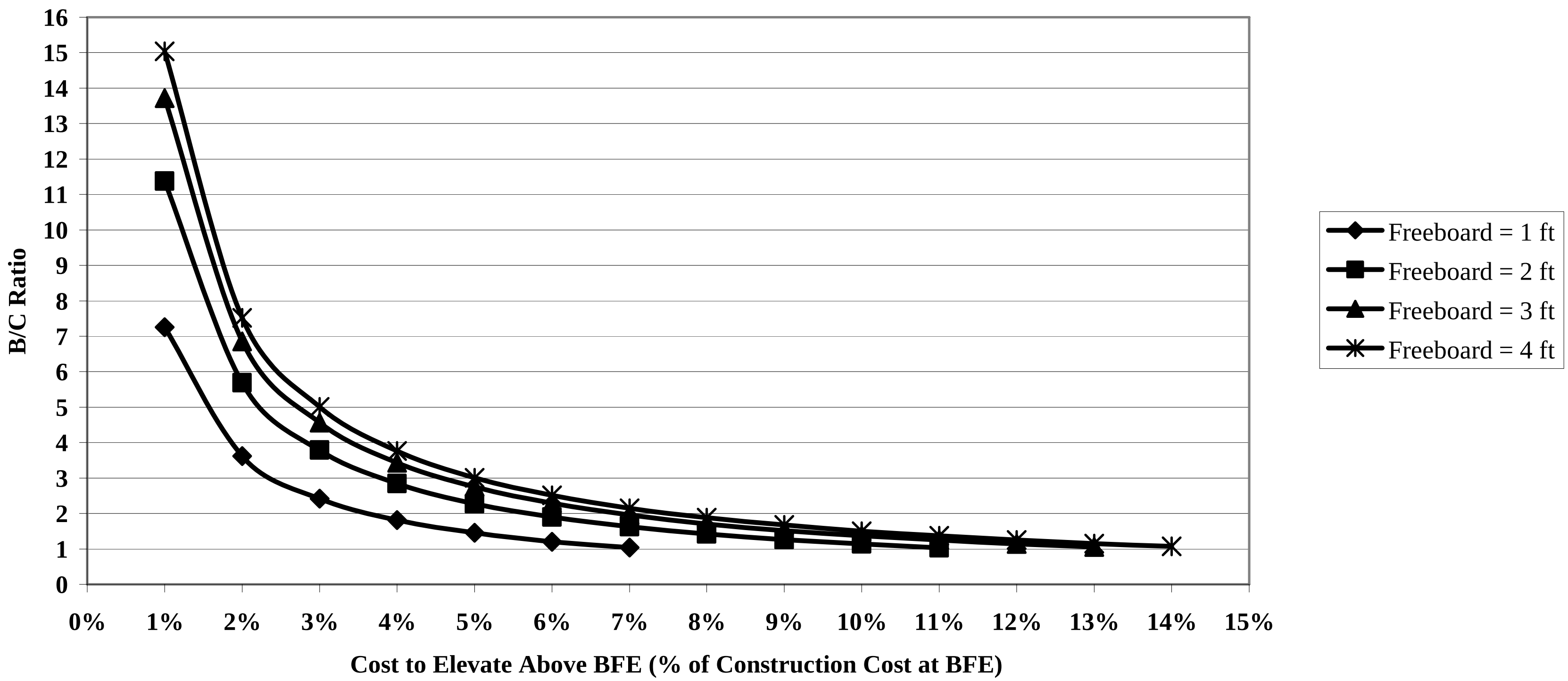


Figure 17. B/C Ratio versus Cost to Elevate with Freeboard (V Zone and Coastal A Zone, Piles or Piers, No Obstructions, BFE = 12 ft, DR = 5.0%, UL = 30 years, Contents @ 30%)

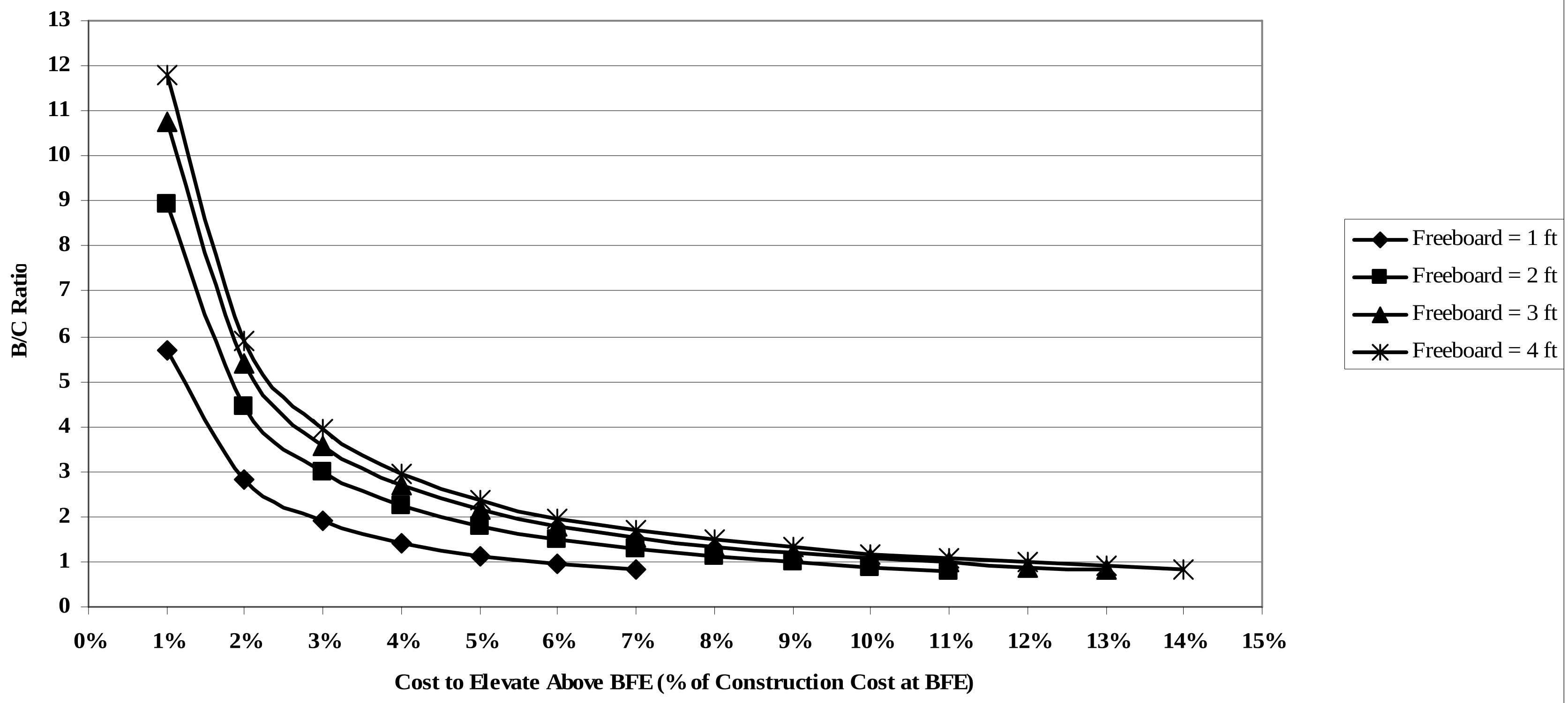


Figure 18. B/C Ratio versus Cost to Elevate with Freeboard (V Zone and Coastal A Zone, Piles or Piers, No Obstructions, BFE = 12 ft, DR = 7.0%, UL = 30 years, Contents @ 30%)

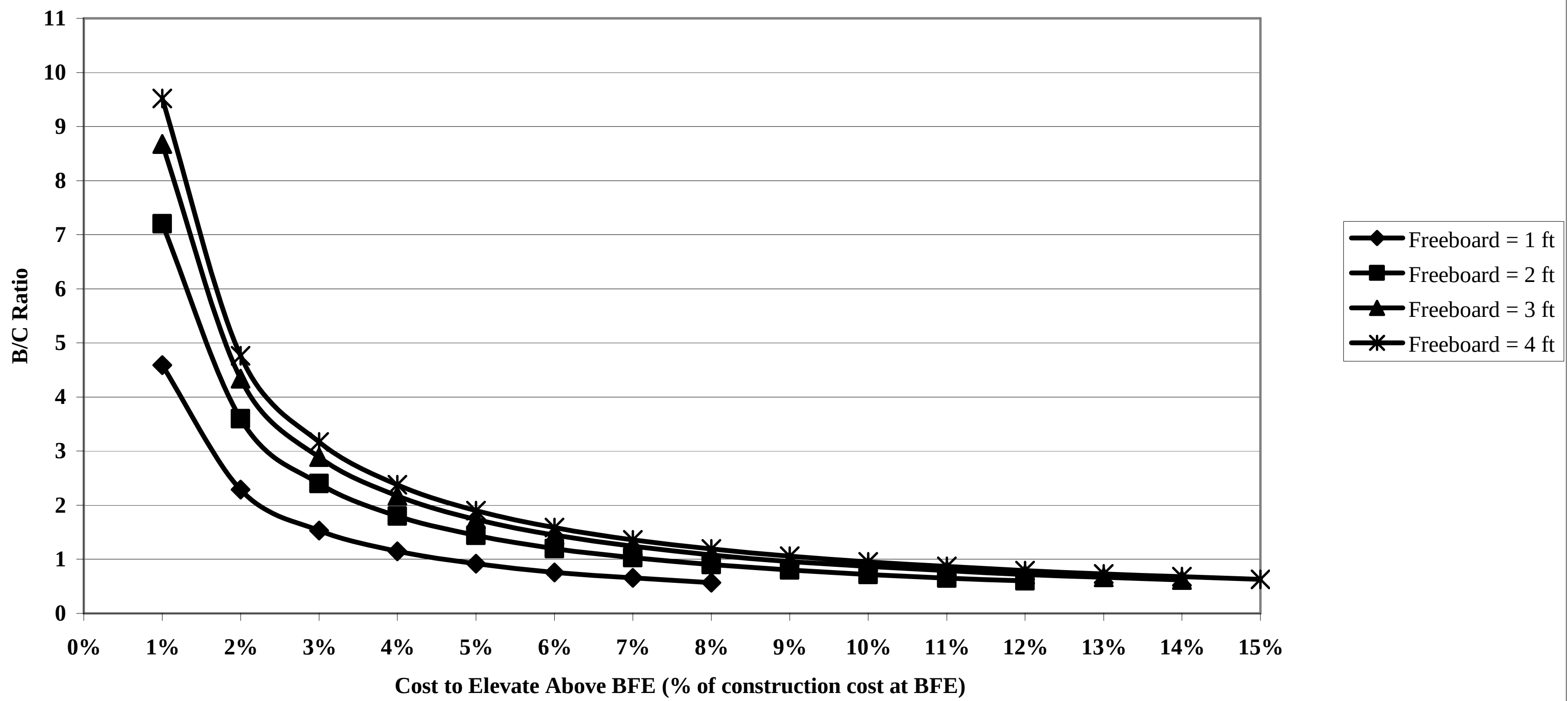


Figure 19. B/C Ratio versus Cost to Elevate with Freeboard (V Zone and Coastal A Zone, Piles or Piers, No Obstructions, BFE = 12 ft, DR = 9.0%, UL = 30 years, Contents @ 30%)

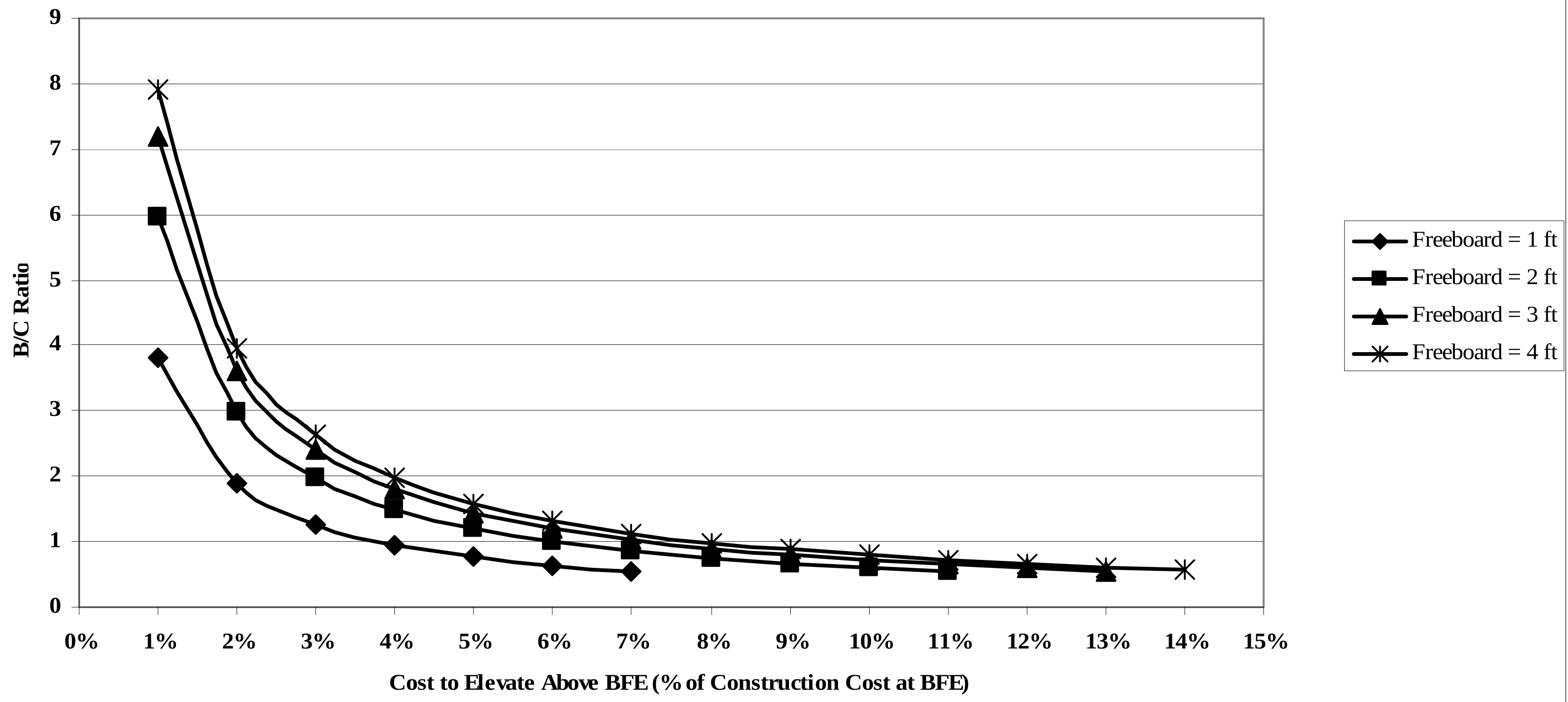


Table 23. Percent* of Additional Construction Cost-Justified (B/C ≥ 1.0) for Various Combinations of Freeboard, BFE and Discount Rate (V zone and Coastal A Zone, Pile and Pier Foundations, useful life =30 Years, Contents Value = 30% of Structure Value)

Discount Rate = 3.0%

Freeboard (ft)	**BFE (ft msl)**				
	12	14	16	18	20
1	7	6	6	5	5
2	11	10	9	8	8
3	13	12	11	11	10
4	14	14	13	12	12

Discount Rate = 5.0%

Freeboard (ft)	**BFE (ft msl)**				
	12	14	16	18	20
1	6	5	4	4	4
2	9	8	7	7	6
3	11	10	9	8	8
4	12	11	10	10	9

Discount Rate = 7.0%

Freeboard (ft)	**BFE (ft msl)**				
	12	14	16	18	20
1	5	4	4	3	3
2	7	6	6	5	5
3	9	8	7	7	7
4	10	9	8	8	8

Discount Rate = 9.0%

Freeboard (ft)	**BFE (ft msl)**				
	12	14	16	18	20
1	4	3	3	3	3
2	6	5	5	4	4
3	7	7	6	6	5
4	8	7	7	7	6

* Percentages rounded to the nearest 1%. If the justified cost was less than 1.0% of the initial construction cost, it was rounded to the nearest 0.5%. Percentages account for flood damage to structure and contents only, and would be higher if displacement costs and flood insurance premium savings were included.

**Figure 20. V Zone and Coastal A Zone, DR = 3.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding
B/C = 1.0**

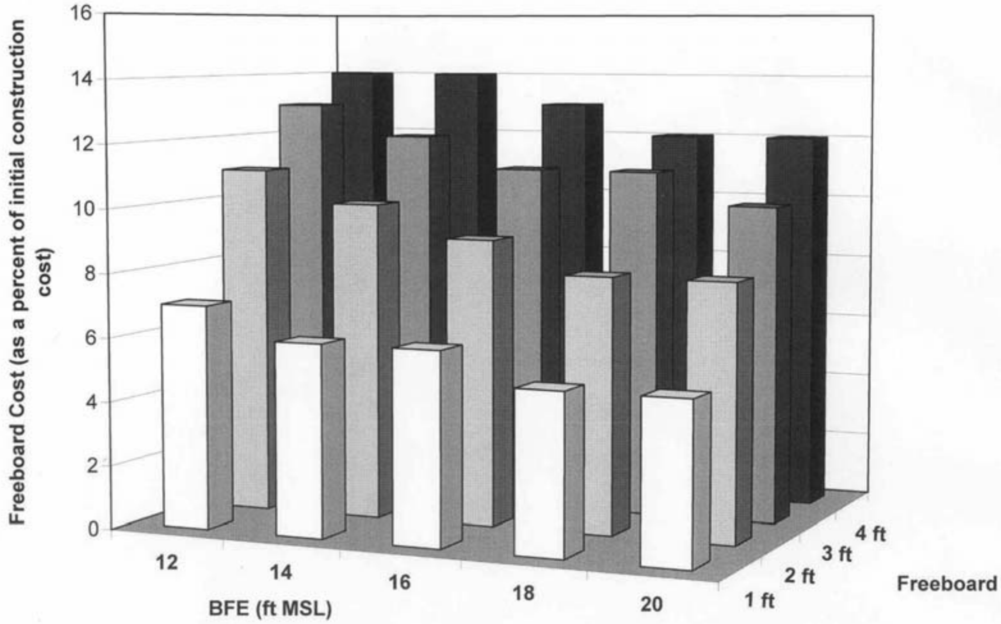


**Figure 21. V Zone and Coastal A Zone, DR = 5.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding
B/C = 1.0**

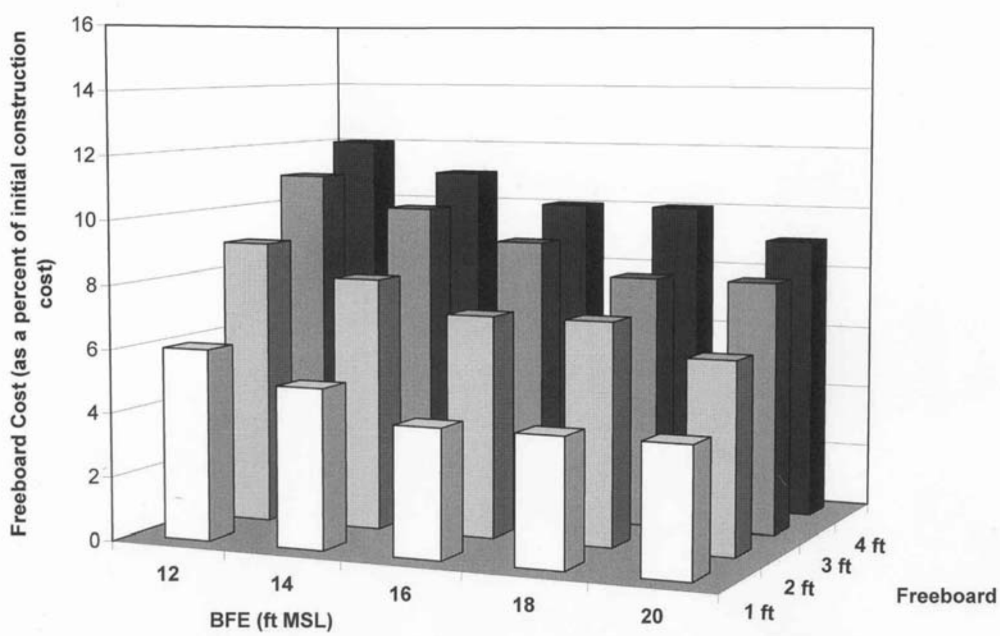


Figure 22. V Zone and Coastal A Zone, DR = 7.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding B/C = 1.0

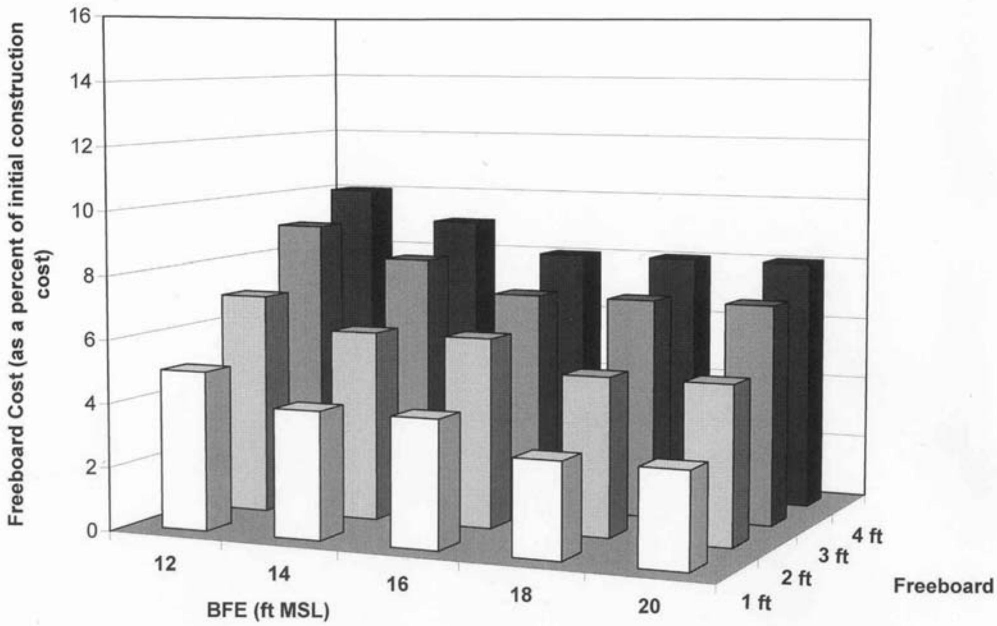
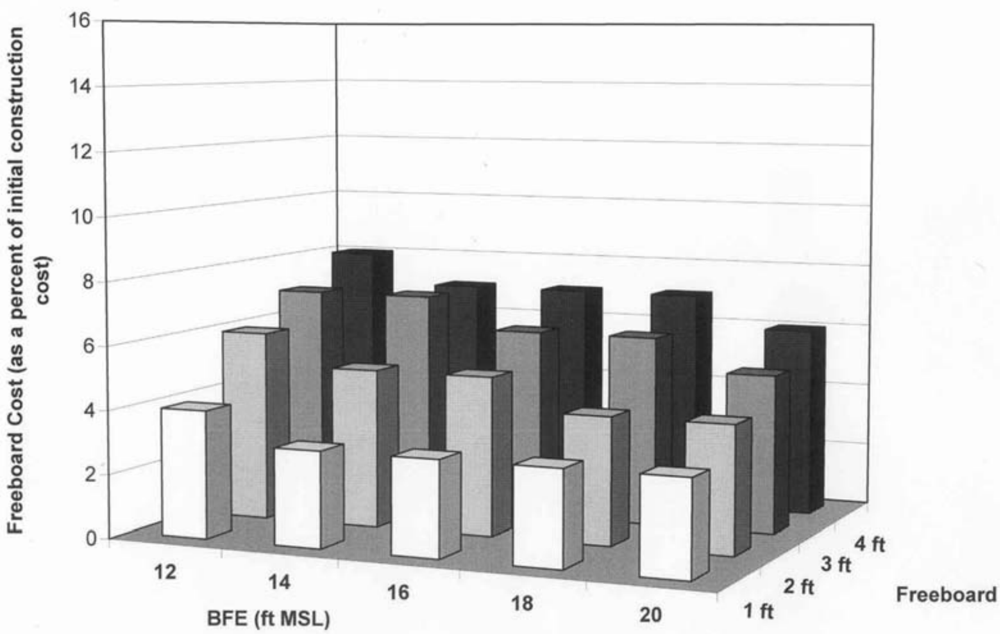


Figure 23. V Zone and Coastal A Zone, DR = 9.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding B/C = 1.0



7.3.2. A Zones

Similar calculations were made for A zones, except Flood Hazard Factors[36] were used in lieu of BFEs, and two sets of calculations were made (for one story buildings and two-story buildings)[37]. B/C values were calculated for new homes using the inputs shown in Table 16. Sample results are shown in Figures 24-31, where B/C ratios are plotted against the cost to elevate above the BFE, for different flood hazard factors, different freeboard levels and different discount rates. The figures clearly show that the B/C ratio decreases as the discount rate increases, with all other inputs held constant. The B/C ratio decreases as the FHF increases, with all other inputs held constant. B/C ratios for two-story buildings are less than for corresponding one-story buildings due to lower depth-damage values (see Table 22).

All the A zone B/C calculations were tabulated and the B/Cs were determined for various combinations of freeboard, additional construction cost and discount rate. The data were then examined to identify the percent of additional construction cost -- rounded to the nearest 1%[38] – that an owner would be justified in spending at the time of construction (B/C = 1.0) for each freeboard-FHF-discount rate combination. These results are shown in Tables 24 and 25, and in Figures 32-39.

In the *one-story* A zone cases studied, the calculations show:

- 1 foot of freeboard above the BFE: spending 100.5% of the base building (at BFE) cost is justified, and it may be worth spending up to 104% of the base building cost. If the FHF = 150, DR = 9.0% results are excluded, spending 101% of the base building cost is justified.

- 2 foot of freeboard above the BFE: spending 101% of the base building cost is justified, and it may be worth spending up to 105% of the base building cost. If the FHF = 150, DR = 9.0% results are excluded, spending 102% of the base building cost is justified.

- 3 feet of freeboard above the BFE: spending 102% of the base building cost is justified, and it may be worth spending 106% of the base building cost.

- 4 feet of freeboard above the BFE: spending 102% of the base building cost is justified, and it may be worth spending 106% of the base building cost. If the FHF = 150, DR = 9.0% results are excluded, spending 103% of the base building cost is justified.

In the *two-story* A zone cases studied, the calculations show:

- 1 foot of freeboard above the BFE: spending 100.5% of the base building (at BFE) cost is justified, and it may be worth spending 102% of the base building cost.

[36] The FHF is the difference between the 100-year and 10-year flood surface elevations rounded to the nearest one-half foot and multiplied by 10
[37] A zone depth-damage functions differ by number of building stories, V zone depth-damage functions do not.
[38] If the justified cost was less than 1.0% of the initial construction cost, it was rounded to the nearest 0.5%

- 2 feet of freeboard above the BFE: spending 101% of the base building cost is justified, and it may be worth spending 103% of the base building cost.

- 3 feet of freeboard above the BFE: spending 101% of the base building cost is justified, and it may be worth spending 103% of the base building cost. If the FHF = 150, DR = 9.0% results are excluded, spending 102% of the base building cost is justified.

- 4 feet of freeboard above the BFE: spending 102% of the base building cost is justified, and it may be worth spending 103% of the base building cost.

The lower justified costs for two-story buildings are a result of the different A zone damage functions for one-story and two-story buildings. The same depth of flooding above the lowest floor leads to less damage (as a percent of the building and contents value) in a two-story building than a one story building.

As in the case of the V zone and Coastal A zone, the results cited above account only for damage to the buildings and their contents. Any additional costs resulting from the flooding (e.g., displacement costs such as temporary housing) and any cost savings as a result of adding freeboard (e.g., flood insurance premium reductions) will make spending additional money at the time of initial construction justified.

Figure 24. B/C Ratio versus Cost to Elevate with Freeboard (A Zone, 1-story, No Basement, FHF = 25, DR = 3.0%, UL = 30 Years, Contents @ 30%)

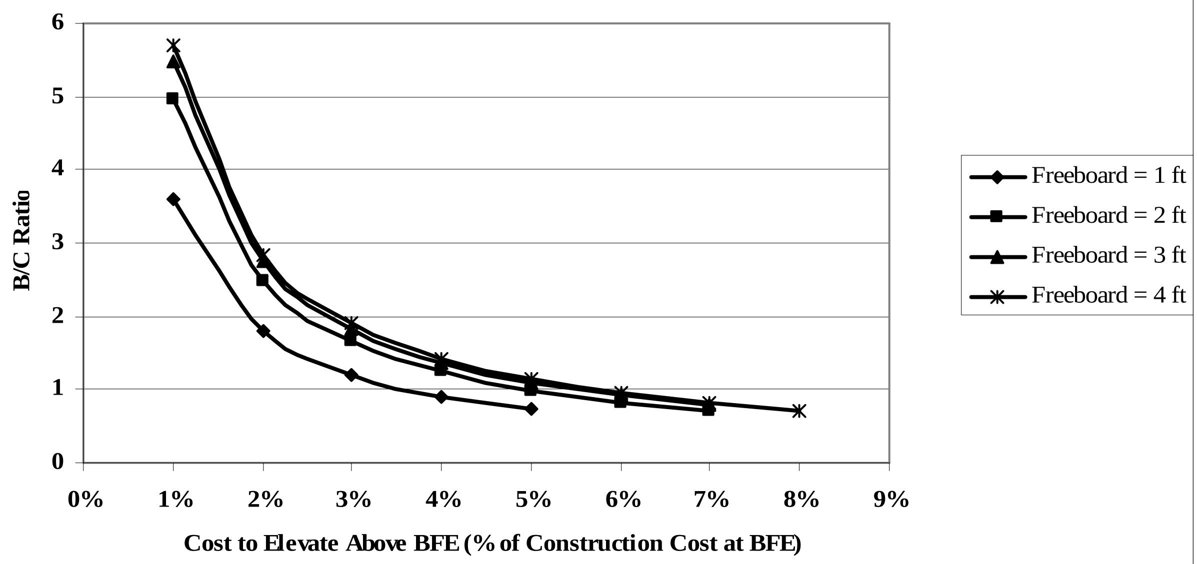


Figure 25. B/C Ratio versus Cost to Elevate with Freeboard (A Zone, 1-story, No Basement, FHF = 25, DR = 7.0%, UL = 30 Years, Contents @ 30%)

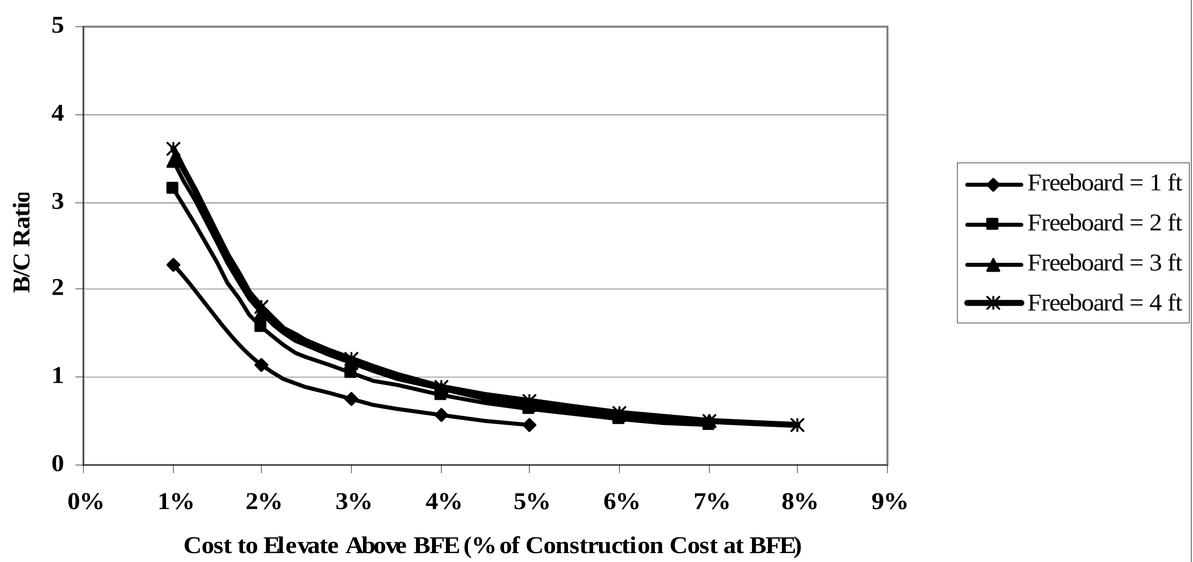


Figure 26. B/C Ratio versus Cost to Elevate with Freeboard (A Zone, 1-story, No Basement, FHF = 50, DR = 3.0%, UL = 30 Years, Contents @ 30%)

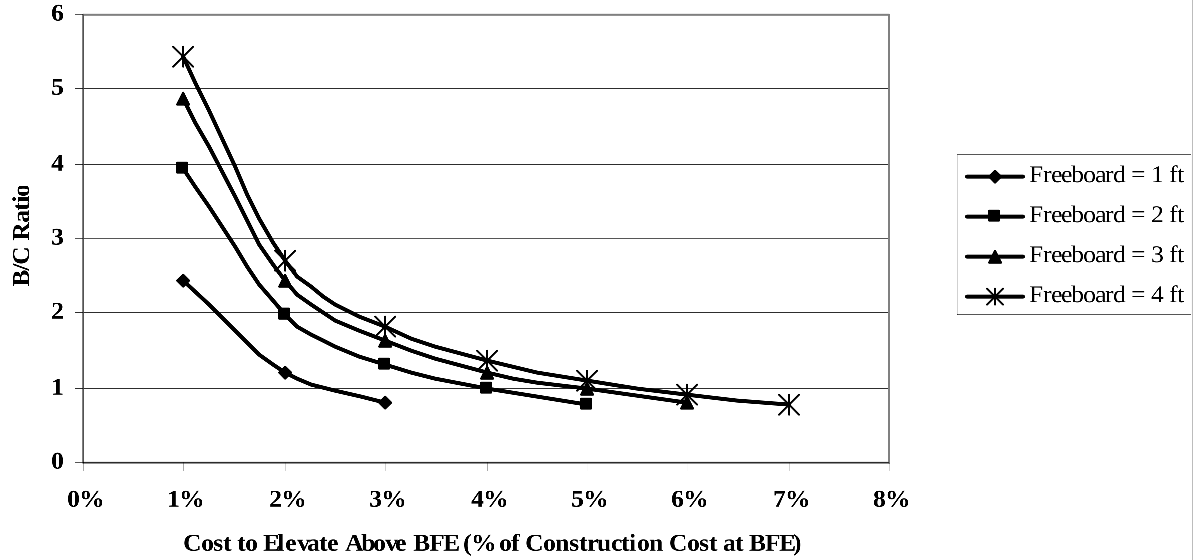


Figure 27. B/C Ratio versus Cost to Elevate with Freeboard (A Zone, 1-story, No Basement, FHF = 50, DR = 7.0%, UL = 30 Years, Contents @ 30%)

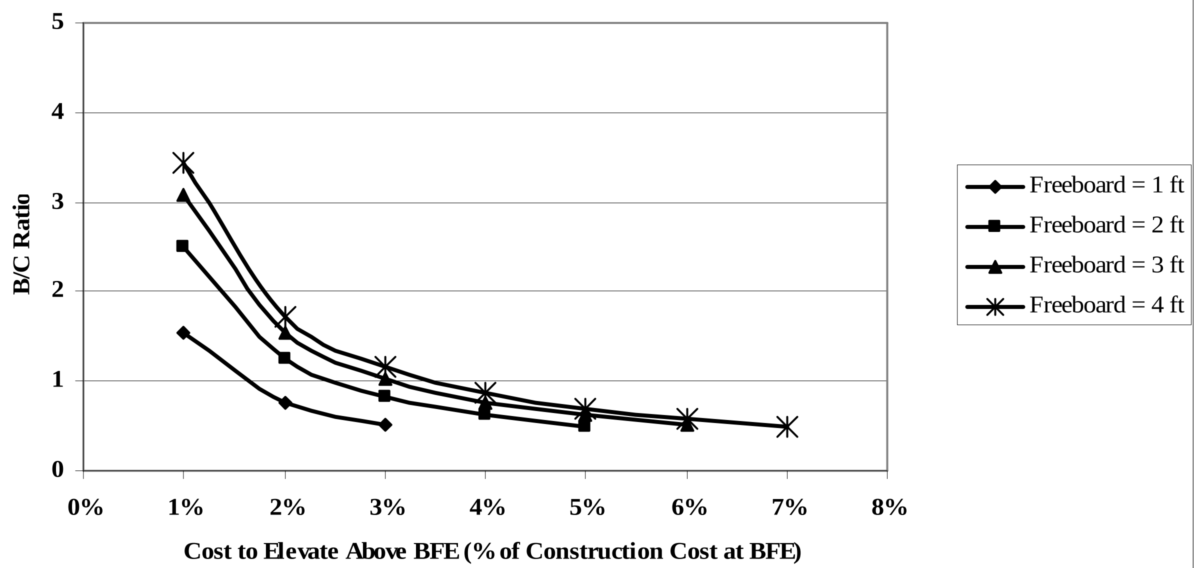


Figure 28. B/C Ratio versus Cost to Elevate with Freeboard (A Zone, 2-story, No Basement, FHF = 25, DR = 3.0%, UL = 30 Years, Contents @ 30%)

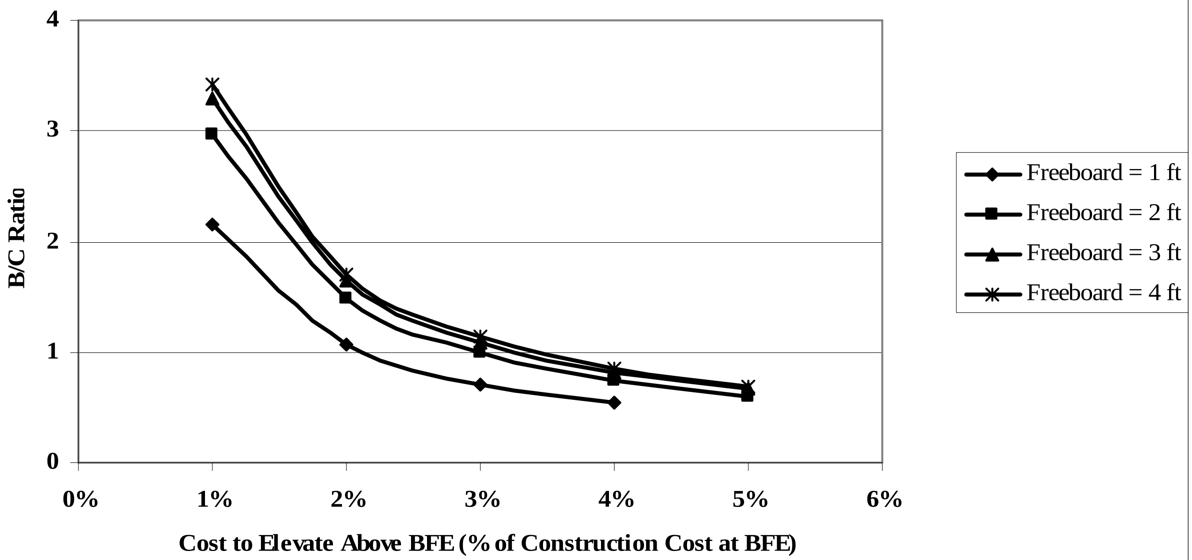


Figure 29. B/C Ratio versus Cost to Elevate with Freeboard (A Zone, 2-story, No Basement, FHF = 25, DR = 7.0%, UL = 30 Years, Contents @ 30%)

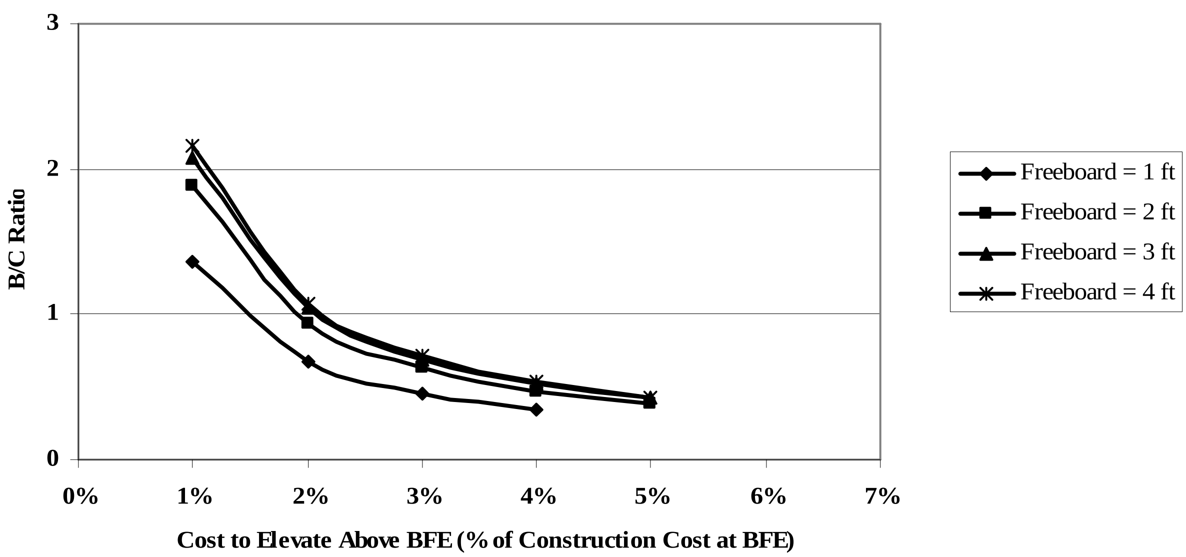


Figure 30. B/C Ratio versus Cost to Elevate with Freeboard (A Zone, 2-story, No Basement, FHF = 50, DR = 3.0%, UL = 30 Years, Contents @ 30%)

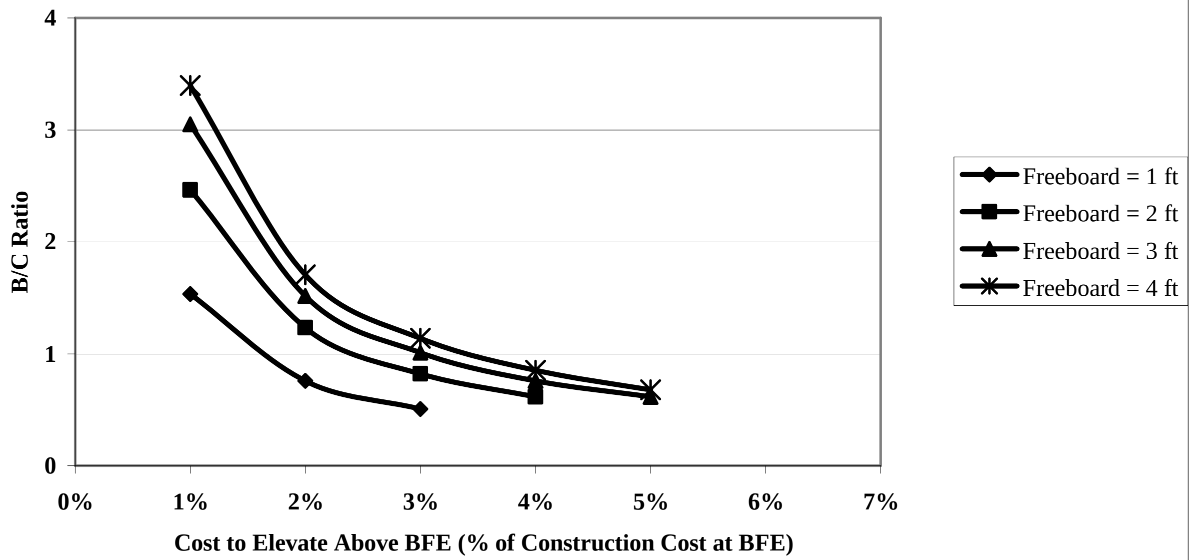


Figure 31. B/C Ratio versus Cost to Elevate with Freeboard (A Zone, 2-story, No Basement, FHF = 50, DR = 7.0%, UL = 30 Years, Contents @ 30%)

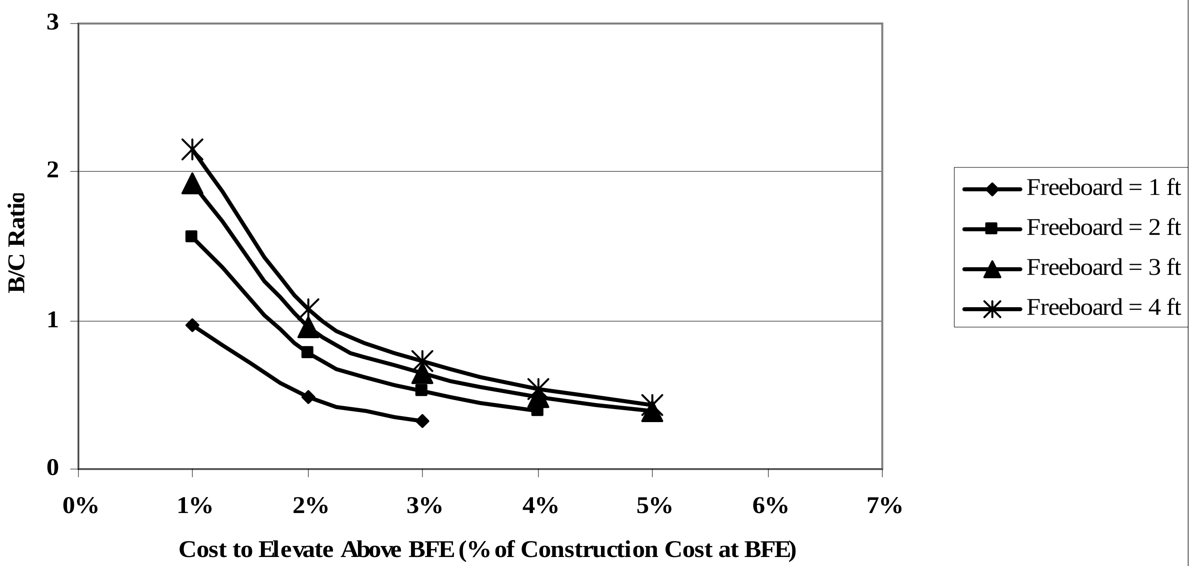


Table 24. Percent* of Additional Construction Cost Justified (B/C ≥ 1.0) for Various Combinations of Freeboard, Flood Hazard Factor and Discount Rate (A Zone, 1-story, useful life =30 Years, Contents Value = 30% of structure value)

Discount Rate = 3.0%

Freeboard (ft)	FHF				
	25	50	75	100	150
1	4	3	2	2	1
2	5	4	3	3	3
3	6	5	5	4	4
4	6	5	5	5	4

Discount Rate = 5.0%

Freeboard (ft)	FHF				
	25	50	75	100	150
1	3	2	2	1	1
2	4	3	3	2	2
3	4	4	4	3	3
4	5	4	4	4	3

Discount Rate = 7.0%

Freeboard (ft)	FHF				
	25	50	75	100	150
1	2	2	1	1	1
2	3	3	2	2	2
3	4	3	3	3	3
4	4	4	3	3	3

Discount Rate = 9.0%

Freeboard (ft)	FHF				
	25	50	75	100	150
1	2	1	1	1	0.5
2	3	2	2	2	1
3	3	3	2	2	2
4	3	3	3	3	2

* Percentages rounded to the nearest 1%. If the justified cost was less than 1.0% of the initial construction cost, it was rounded to the nearest 0.5%. Percentages account for flood damage to structure and contents only, and would be higher if displacement costs and flood insurance premium savings were included.

Table 25. Percent* of Additional Construction Cost Justified (B/C ≥ 1.0) for Various Combinations of Freeboard, Flood Hazard Factor and Discount Rate (A Zone, 2-story, useful life =30 years, contents value = 30% of structure value)

Discount Rate = 3.0%

Freeboard (ft)	**FHF**				
	25	50	75	100	150
1	2	2	2	1	1
2	3	3	2	2	2
3	3	3	3	3	2
4	3	3	3	3	3

Discount Rate = 5.0%

Freeboard (ft)	**FHF**				
	25	50	75	100	150
1	2	1	1	1	0.5
2	2	2	2	2	1
3	3	2	2	2	2
4	3	3	3	3	2

Discount Rate = 7.0%

Freeboard (ft)	**FHF**				
	25	50	75	100	150
1	2	1	1	0.5	0.5
2	2	2	1	1	1
3	2	2	2	2	2
4	2	2	2	2	2

Discount Rate = 9.0%

Freeboard (ft)	**FHF**				
	25	50	75	100	150
1	1	1	0.5	0.5	0.5
2	2	1	1	1	1
3	2	2	2	2	1
4	2	2	2	2	2

* Percentages rounded to the nearest 1%. If the justified cost was less than 1.0% of the initial construction cost, it was rounded to the nearest 0.5%. Percentages account for flood damage to structure and contents only, and would be higher if displacement costs and flood insurance premium savings were included.

Figure 32. A Zone, 1-Story, No-Basement, DR = 3.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding B/C = 1.0

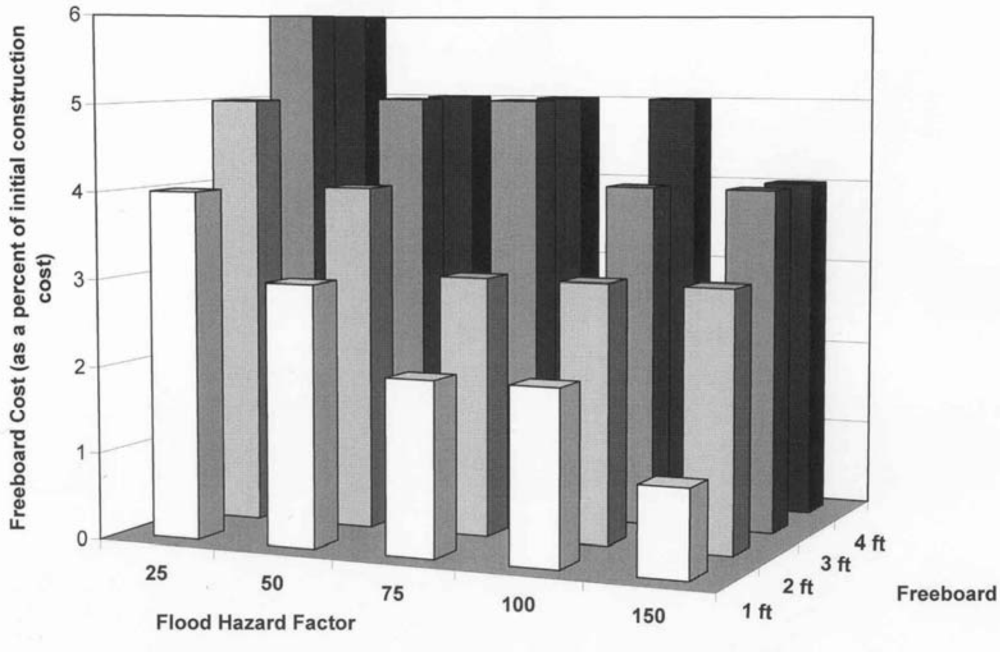


Figure 33. A Zone, 1-Story, No-Basement, DR = 5.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding B/C = 1.0

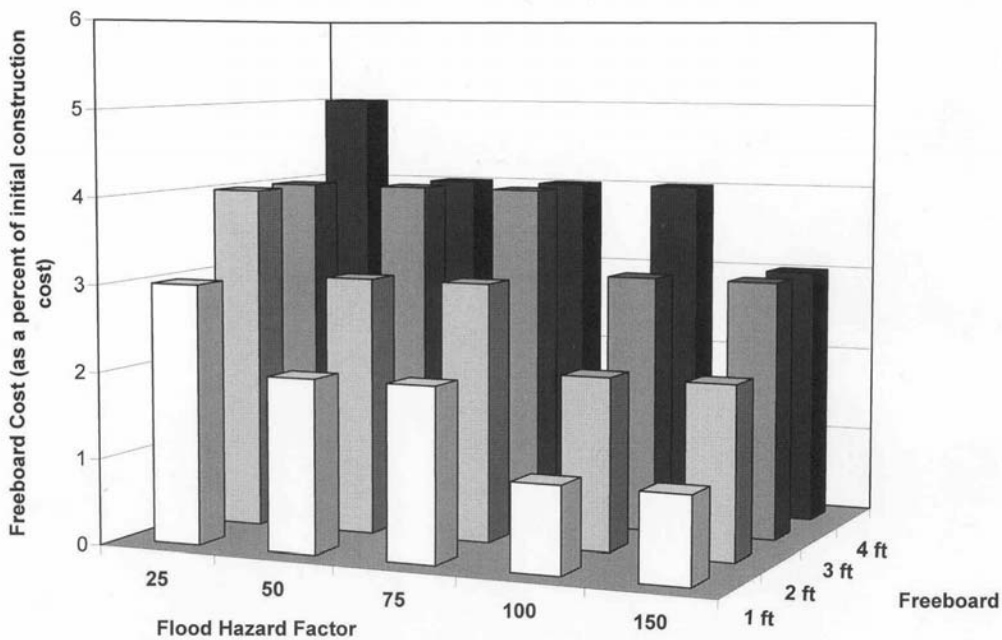


Figure 34. A Zone, 1-Story, No-Basement, DR = 7.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding
B/C = 1.0

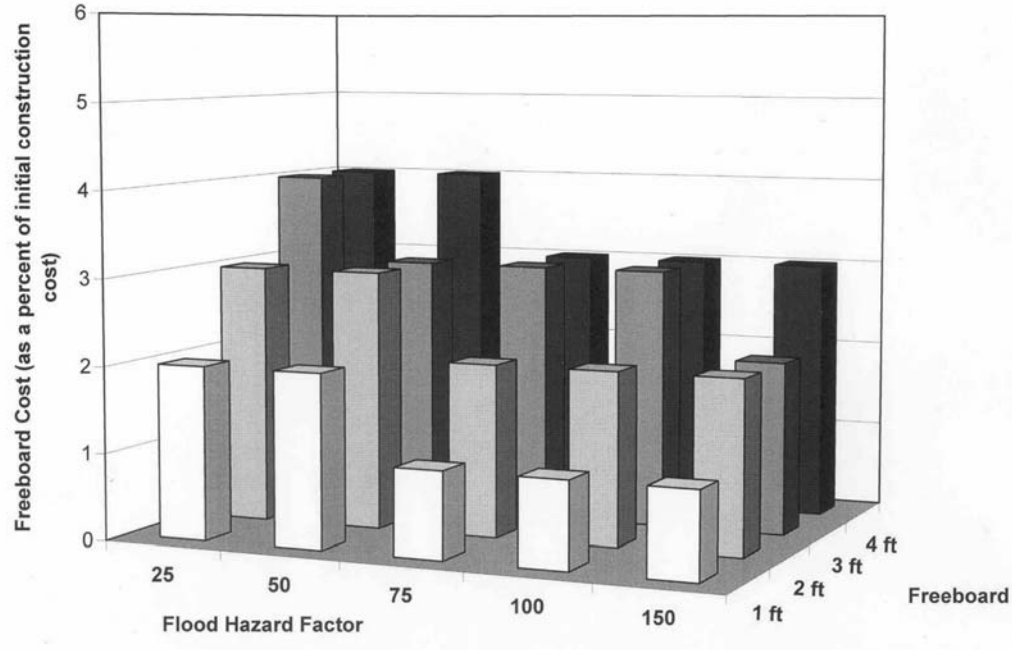


Figure 35. A Zone, 1-Story, No-Basement, DR = 9.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding
B/C = 1.0

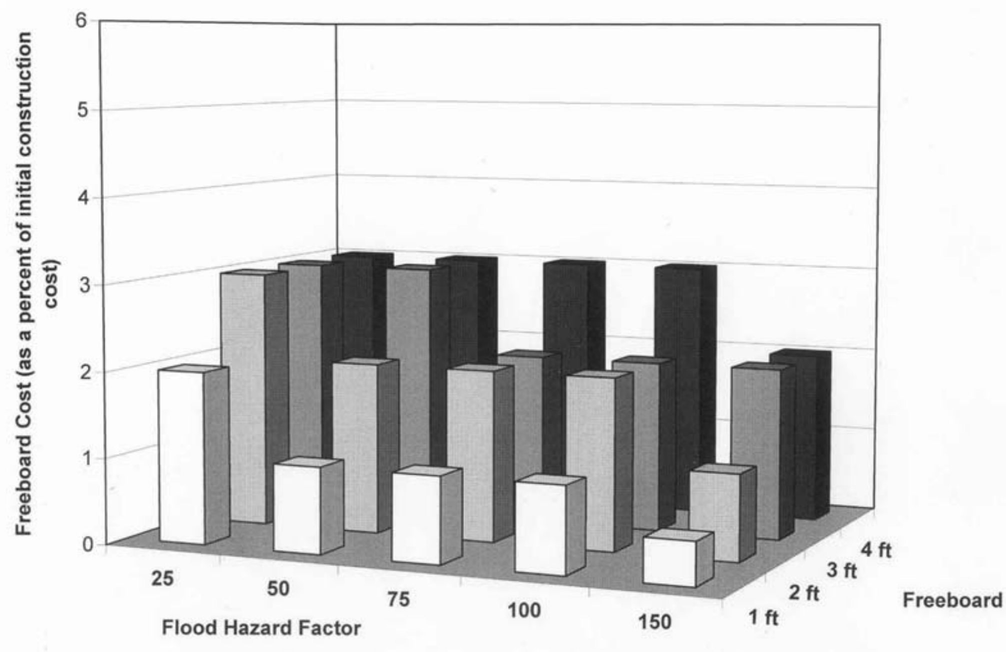


**Figure 36. A Zone, 2-Story, No-Basement, DR = 3.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding
B/C = 1.0**

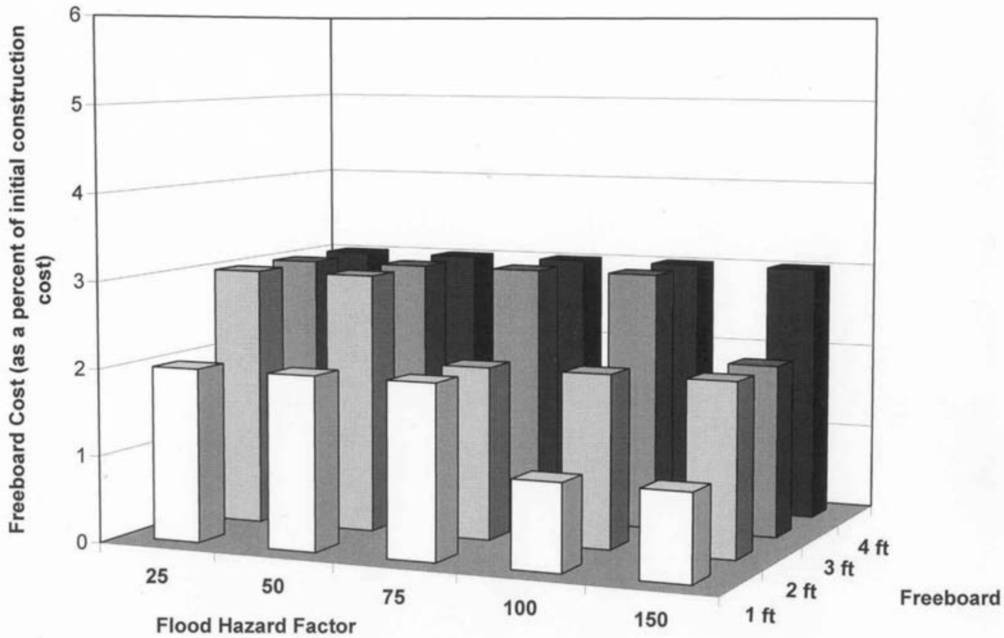


**Figure 37. A Zone, 2-Story, No-Basement, DR = 5.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding
B/C = 1.0**

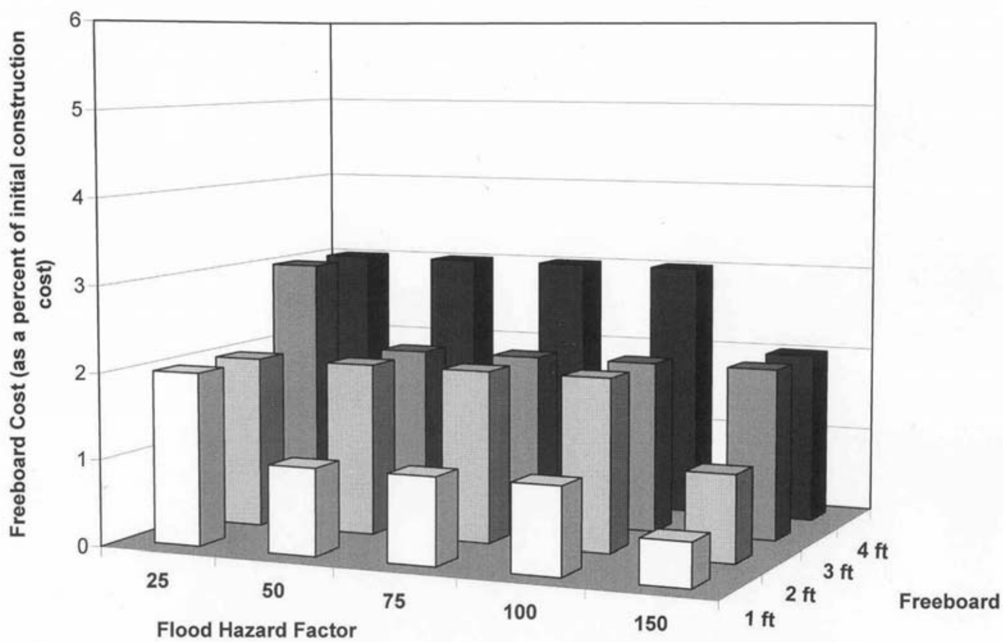


Figure 38. A Zone, 2-Story, No-Basement, DR = 7.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding
B/C = 1.0

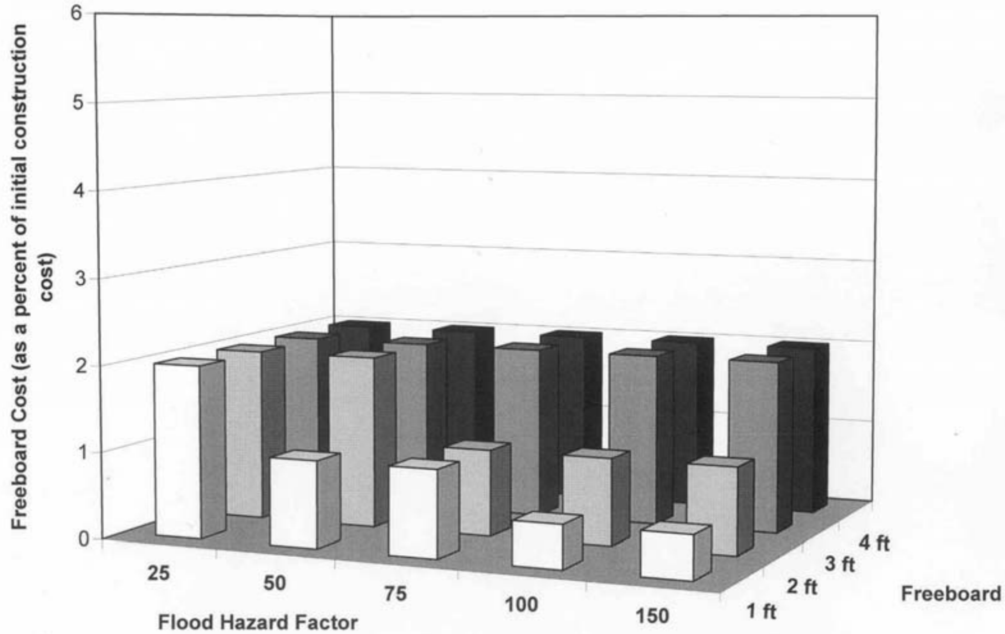
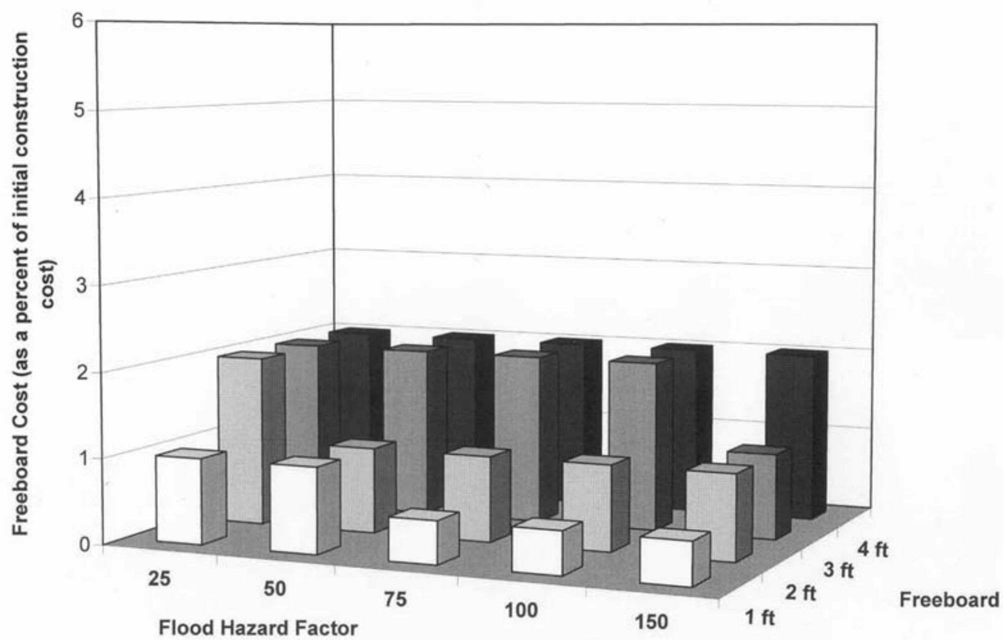


Figure 39. A Zone, 2-Story, No-Basement, DR = 9.0%, UL = 30 yrs
Approximate Maximum Freeboard Cost (additional construction cost) Yielding
B/C = 1.0



7.3.3. Sensitivity of B/C Results to Displacement Costs

The sensitivity of the B/C results to the inclusion of displacement costs was investigated for V zones, Coastal A zones and A zones (both, one- and two-story buildings). Monthly displacement costs were expressed as a percentage of the initial building cost, and BCA model default displacement times were used. The results show that inclusion of displacement costs acts to increase the B/C for a given scenario (i.e., shifting the B/C curves in Figures 16-19 and 24-31 upward), although the increase is not dramatic (see Table 26).

TABLE 26. B/C Change Due to Inclusion of Displacement Costs = 1.0% of Initial Building Cost

Flood Hazard Zone, Building	Average Ratio# of B/Cs	Range of B/C Ratios#
A Zone, 1-story*	1.11	1.07 to 1.14
A Zone, 2-story*	1.08	1.03 to 1.12
Coastal A Zone and V Zone, 1- and 2-story^	1.11	1.11 to 1.12

* averaged across FHF = 25, 50, 75, 100 and 150
^ averaged across BFE = 12, 14, 16, 18 and 20 ft
# Ratio of B/Cs = B/C with Displacement Cost divided by B/C without displacement cost

While the effect of including displacement costs varies slightly between flood hazard zones and with number of stories in an A zone, the effect can be generalized as follows: adding monthly displacement costs equal to 1% of the initial building cost (i.e., $2,000/month for a $200,000 building) increases the computed B/C by approximately 10%. If an initial B/C was 2.0, inclusion of a monthly displacement cost of 1% results in a B/C of approximately 2.2.

The effect scales linearly with the relative displacement cost. For example, if the monthly displacement cost is equal to 0.5% of the initial building cost ($1,000/month for the $200,000 house), the computed B/C increases by approximately 5%. If the monthly displacement cost is equal to 0.3% of the initial building cost ($700/month for the $200,000 house), the computed B/C increases by approximately 3%, etc.

The inclusion of reasonable displacement costs in the B/C calculations should not have a significant effect on the additional justified costs shown in Tables 23-25 (since the values contained in the tables have been rounded to the nearest 1%), and those tables will be applicable for the generalized analyses, without or with displacement costs. If a user is interested in a particular building, it is suggested that the BCA model be used with inputs specific to the scenario, including any projected displacement costs.

7.3.4. Effects of Flood Insurance Premium Savings Due to Freeboard

The value of flood premium discounts for adding freeboard was also investigated. The StandardFlood® program was used to calculate 2006-2007 flood insurance premiums for V zone and A zone buildings[39] with the maximum coverage available through the NFIP ($250,000 structure value, $100,000 contents value). Premiums were first calculated for each flood hazard

[39] Flood insurance premiums for Coastal A zone buildings are included in the A zone buildings – the NFIP does not have separate premium rates for Coastal A zone buildings.

zone with buildings at the BFE, and then calculated for the same buildings with 1 ft, 2 ft, 3 ft and 4 ft of freeboard. Annual savings were calculated by subtracting the with-freeboard premium from the at-BFE premium, and dividing by the at-BFE premium. Results are shown in Table 27.

TABLE 27. Annual Savings (expressed as a percentage of initial building cost, rounded to the nearest 0.1%) Due to Flood Insurance Premium Discounts for Freeboard (assumptions: maximum NFIP coverage, $250,000 building, $100,000 contents; $500 deductible; V zone, no obstructions; A zone, no basement; no CRS discount)

Freeboard	V Zone	A Zone, 1-story	A Zone, 2-story
1 ft	0.5%	0.1%	0.1%
2 ft	1.0%	0.2%	0.1%
3 ft	1.2%	0.3%	0.1%
4 ft	1.4%	0.3%	0.1%

The average at-BFE A zone premium was approximately $1,000/year, while the at-BFE V zone premium was approximately $5,000/year. Thus, a 0.2% annual savings for a $250,000 A zone building is equivalent to approximately $500/year, or a 50% annual flood insurance premium discount. A 1.3% annual savings for a $250,000 V zone building is equivalent to approximately $3,300/year, or a 66% annual flood insurance premium discount.

Even if future building and contents damages prevented are not considered, the annual flood premium savings are generally sufficient to pay for the costs of adding freeboard in a few years time for many buildings. For example, consider the $250,000 V zone house mentioned above. Calculations in Section 7.4 showed that the per-foot cost of freeboard added at the time of initial construction is approximately 0.25% to 0.5% of the cost of the house constructed to the BFE. Table 27 shows that the flood premium savings for this house would be approximately 0.4% to 0.5% per foot of freeboard added. The ratio of the annual flood premium savings to the freeboard cost varies from 0.8 to 2.0, and calculations show the time required to recover the freeboard cost through flood premium savings varies from approximately 6 months to 16 months. Adding freeboard in this case will pay for itself rapidly. Even if the freeboard costs calculated in Section 7.4 are low, the time required to recover the freeboard cost is still short – if the cost to add freeboard is double that calculated in Section 7.4, the time required to recover the freeboard cost is approximately one to three years.

For a $250,000 A zone house on a 8-in wall foundation with interior piers[40], Section 7.4 showed the per-foot cost of adding freeboard would be approximately to 0.8% of the at-BFE construction cost. Table 27 shows that the flood premium savings for this house would be approximately 0.1% per foot for the first foot of freeboard added (there is no meaningful flood insurance premium discount in zone A for more than one foot of freeboard for a 2-story house, or two feet of freeboard for a 1-story house). The ratio of the annual flood premium savings to the freeboard cost is approximately 0.1, and calculations show the time required to recover the freeboard cost through flood premium savings would be over 15 years. The difference between the V zone and the A zone results is due to the lower flood insurance premiums (and lower

[40] This cost A zone house would be 2-story, 4,800 sq ft in this study.

discounts) for A zone houses, and higher relative costs for adding height to the wall and interior pier foundation.

This analysis was generalized to allow building owners and designers to determine the time required to recover the costs of including freeboard through future flood premium savings – for buildings in any flood hazard zone. The results of the analysis are shown in Figure 40 and Table 28. Both the table and the figure require an estimate of the ratio of the annual flood premium savings to the freeboard cost. For ratios greater than approximately 0.2, the results are not sensitive to the discount rate chosen.

Figure 40. Years to Recover Cost of Freeboard Through Annual Flood Insurance Premium Savings

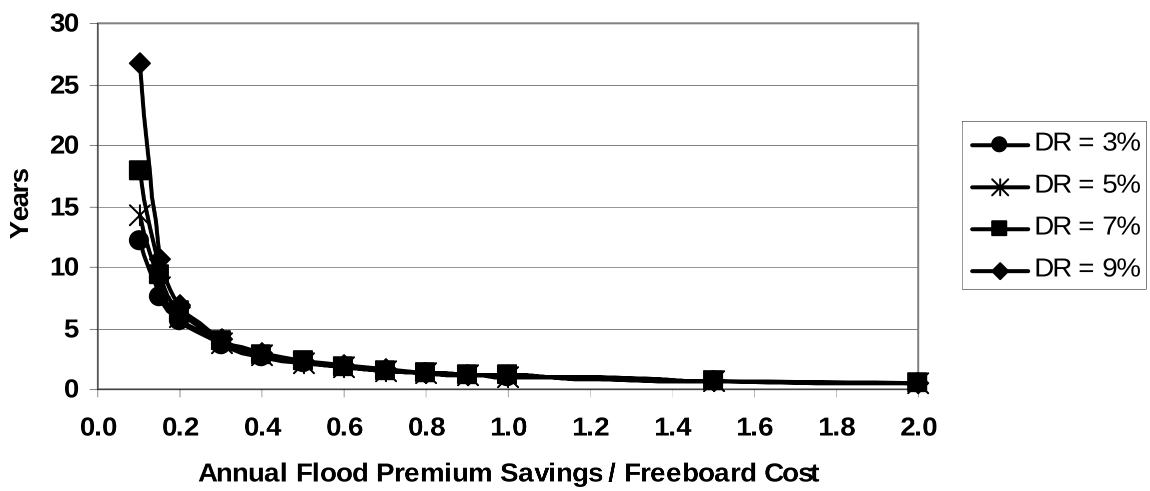


Table 28. Time to Recover Cost of Adding Freeboard at Time of Construction, through Annual Flood Premium Savings*.

Ratio of Annual Flood Premium Savings to Freeboard Cost	Average time (years) to recover freeboard cost (DR = 3% to 9%)	Time to recover freeboard cost (years) with DR = 3%	Time to recover freeboard cost (years) with DR = 5%	Time to recover freeboard cost (years) with DR = 7%	Time to recover freeboard cost (years) with DR = 9%
0.1	17.7	12.1	14.2	17.8	26.7
0.2	6.2	5.5	5.9	6.4	6.9
0.3	3.8	3.6	3.7	3.9	4.1
0.4	2.8	2.6	2.7	2.8	3.0
0.5	2.2	2.1	2.2	2.2	2.3
0.6	1.8	1.7	1.8	1.8	1.9
0.7	1.5	1.5	1.5	1.6	1.6
0.8	1.3	1.3	1.3	1.4	1.4
0.9	1.2	1.1	1.2	1.2	1.2
1.0	1.1	1.0	1.1	1.1	1.1
1.5	0.7	0.7	0.7	0.7	0.7
2.0	0.5	0.5	0.5	0.5	0.5

* This analysis does not consider damages avoided due to freeboard; it only considers 2006-07 flood insurance premium savings.

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8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1. Study Intent and Overview

NFIP minimum building standards relate principally to elevating a building to the BFE, use of flood-resistant materials below the BFE, and prohibiting certain types of foundations in V zones. The purpose of this study was to evaluate NFIP design and construction requirements, with particular emphasis on: 1) damages prevented or induced by strict adherence to those minimum requirements, and 2) the costs and benefits of modifying the minimum requirements to reduce building damages during flooding.

This study was designed and conducted to address three sets of questions regarding NFIP building standards for typical single family homes in the SFHA:

- What impacts have the NFIP's building standards for new construction in Special Flood Hazard Areas had on risk exposure and property loss? Which standards are the most and least effective in reducing exposure and property losses due to floods? Is the cost of implementing the major standards commensurate with their benefits?

- Are the NFIP's standards for construction and building design adequate and sufficiently stringent so that losses are minimized at a reasonable cost to communities and property owners when flood damage occurs? Are the standards and incentives sufficient to protect against flood risks that may be increasing in the future?

- Do the NFIP's building standards effectively protect buildings from damages during the 100-year flood? If current standards are not effective, how should FEMA change them? Are higher levels of protection achievable and more important, are the benefits achieved by these standards commensurate with the costs associated with meeting them?

These issues were addressed through a study that included the following:

- review of building flood damage and foundation performance in coastal and non-coastal floodplains.

- review of the literature and calculation of construction costs for typical houses with several foundation types under a variety of flood conditions.

- calculation of the costs of adding freeboard and changing foundations.

- calculation of the maximum justified cost of mitigation, i.e., freeboard and/or foundation changes at the time of initial construction -- expressed as a percentage of initial construction cost -- that would yield a B/C greater than or equal to 1.0. All cost inputs were expressed as a percentage of the initial (at-BFE) construction cost to generalize the results. The B/C results depend on damages avoided, and do not include other economic losses to the building owner or community (such as clean-up and demolition costs, uninsured losses, displacement and relocation costs, loss of jobs and tax base, etc.), thus, the results reported here understate the benefits associated with exceeding NFIP minimum building standards.

- examination of the sensitivity of the B/C results to inclusion of displacement costs when building occupants must move out of flood damaged homes.

- examination of flood insurance premium discounts for adding freeboard, and development of a general method to determine the time to recover the costs of freeboard through future flood insurance premium savings.

8.2. Study Findings

The general findings of this study are: 1) for the buildings analyzed, the cost of adding freeboard or installing a more flood-resistant foundation at the time of construction is modest but the benefit of doing so can be great, particularly in coastal areas subject to wave effects and riverine floodplains with small flood hazard factors; and 2) NFIP floodplain management regulations and flood insurance premium rates generally promote sound construction practices and reduce potential flood damages, but some changes are warranted to provide additional incentives for flood loss reduction and to eliminate disincentives.

Detailed findings are listed below:

1. Calculations show pier foundations are generally the most cost effective for A zones and some Coastal A zones (where scour is not expected), with the exception of slab-on-fill foundations in A zones where the height of the fill pad is low (less than two feet). The advantage of fill quickly disappears as the fill pad height increases.

2. Pile foundations cost more than traditional masonry pier foundations, but are recommended in situations where scour is likely during the base flood.

3. At the time of initial construction, the incremental costs of replacing minimally compliant A zone foundations (such as slab-on-fill and crawlspace foundations) with pier foundations or pile foundations are relatively small, generally less than 5% to 10% of the cost of the building. In Coastal A zones, post-storm field studies have shown that minimally compliant A zone foundations often fail, and this replacement is warranted. In A zones outside coastal areas, NFIP compliant slab-on-fill and crawlspace foundations are generally adequate, and the incremental cost of changing to a pile foundation is not likely justified (but owners may wish to do so to create under-house parking). However, changing to a pier foundation is probably justified, especially for flood depths more than a few feet above grade.

4. At the time of initial construction, the cost of incorporating freeboard in a pile foundation averages approximately 1% to 2% of the at-BFE building cost for 4 ft of added freeboard (approximately 0.25% to 0.5% per foot of freeboard).

5. At the time of initial construction, the cost of incorporating freeboard in a masonry pier foundation averages approximately 1% to 2% of the at-BFE building cost for 4 ft of added freeboard (approximately 0.25% to 0.5% per foot of freeboard).

6. At the time of initial construction, the cost of incorporating freeboard in a masonry wall with interior pier (crawlspace) foundation averages approximately 3% to 6% of the at-BFE building cost for 4 ft of added freeboard (approximately 0.8% to 1.5% per foot of freeboard).

7. At the time of initial construction, the cost of incorporating freeboard in a fill foundation averages approximately 3% to 11% of the at-BFE building cost for 4 ft of added freeboard. Although the fill quantity and fill cost do not increase linearly with freeboard, they add an average of 0.8% to 3.0 % per foot of freeboard to the at-BFE building cost.

8. FEMA's BCA model was modified in this study to allow generalized benefit/cost calculations to be made with all cost inputs expressed as a percentage of the initial (at BFE) building cost. The model was run with variable discount rates (ranging from 3% to 9%), flood damage functions (V and Coastal A, and A), BFEs (in coastal areas, ranging from 12 ft to 20 ft msl) and Flood Hazard Factors (in riverine areas, ranging from 25 to 150). The model was run only with building and contents damages, and other costs (e.g., clean-up and demolition costs, uninsured losses, displacement and relocation costs, loss of jobs and tax base, etc.) were ignored. The resulting B/C values are conservative, and will understate the true B/C of the actions studied.

9. As expected, the B/C ratios decrease with increasing discount rate, with all other factors held constant. B/C ratios also decrease with increasing BFE and FHF, indicating that a foot of freeboard is worth less (in terms of damage reduction) in areas where there is a greater vertical spread in flood elevations associated with different return periods.

10. V zone and Coastal A zone B/C calculations were tabulated and the B/Cs were determined for various combinations of freeboard, additional construction cost and discount rate. The data were then examined to identify the percent of additional construction cost that an owner would be justified in spending at the time of construction (B/C = 1.0) for each freeboard-BFE-discount rate combination. In the V zone and Coastal A zone cases studied, the calculations show[41]:

    - For 1 foot of freeboard above the BFE: spending 103% of the at-BFE building cost is justified, and in some cases it may be worth spending up to 107% of the at-BFE building cost.

    - For 2 feet of freeboard above the BFE: spending 104% of the at-BFE building cost is justified, and in some cases it may be worth spending up to 111% of the at-BFE building cost.

[41] Note that the results cited below account only for damage to the buildings and their contents. Any additional costs resulting from the and any cost savings as a result of adding freeboard (e.g., flood insurance premium reductions) will make spending even more money at the time of initial construction justified.

- For 3 feet of freeboard above the BFE: spending 105% of the at-BFE building cost is justified, and in some cases it may be worth spending up to 113% of the at-BFE building cost.

- For 4 feet of freeboard above the BFE: spending 106% of the at-BFE building cost is justified, and in some cases it may be worth spending up to 114% of the at-BFE building cost.

11. A zone B/C calculations were tabulated and the B/Cs were determined for various combinations of freeboard, additional construction cost and discount rate. The data were then examined to identify the percent of additional construction cost that an owner would be justified in spending at the time of construction (B/C = 1.0) for each freeboard-BFE-discount rate combination. A zone calculations show[42]:

- Over the ranges of BFEs and FHFs considered, the A zone, 1-story B/C ratios are approximately one-third of the V zone B/C ratios, with other factors held constant. The A zone, 2-story B/C ratios are approximately one-fourth of the corresponding V zone B/C ratios. The reductions in the B/C are attributable to different depth-damage functions.

- B/C ratios for two-story buildings are less than for corresponding one-story buildings due to lower depth-damage functions.

In the *one-story* A zone cases studied, the calculations show:

- For 1 foot of freeboard above the BFE: spending 100.5% of the base building (at BFE) cost is justified, and it may be worth spending up to 104% of the base building cost. If the FHF = 150, DR = 9.0% results are excluded, spending 101% of the base building cost is justified.

- For 2 foot of freeboard above the BFE: spending 101% of the base building cost is justified, and it may be worth spending up to 105% of the base building cost. If the FHF = 150, DR = 9.0% results are excluded, spending 102% of the base building cost is justified.

- For 3 feet of freeboard above the BFE: spending 102% of the base building cost is justified, and it may be worth spending 106% of the base building cost.

- For 4 feet of freeboard above the BFE: spending 102% of the base building cost is justified, and it may be worth spending 106% of the base building cost. If the FHF = 150, DR = 9.0% results are excluded, spending 103% of the base building cost is justified.

In the *two-story* A zone cases studied, the calculations show:

[42] Note that the results cited below account only for damage to the buildings and their contents. Any additional costs resulting from the flooding and any cost savings as a result of adding freeboard (e.g., flood insurance premium reductions) will make spending even more money at the time of initial construction justified.

- For 1 foot of freeboard above the BFE: spending 100.5% of the base building (at BFE) cost is justified, and it may be worth spending 102% of the base building cost.

- For 2 feet of freeboard above the BFE: spending 101% of the base building cost is justified, and it may be worth spending 103% of the base building cost.

- For 3 feet of freeboard above the BFE: spending 101% of the base building cost is justified, and it may be worth spending 103% of the base building cost. If the FHF = 150, DR = 9.0% results are excluded, spending 102% of the base building cost is justified.

- For 4 feet of freeboard above the BFE: spending 102% of the base building cost is justified, and it may be worth spending 103% of the base building cost.

12. A comparison of the costs of adding freeboard and the results of the B/C analyses (i.e., items 4 through 7 compared with item 11 above) show that freeboard in V zones is almost always justified; that freeboard in A zones is usually justified for pier foundations, sometimes justified for wall foundations, but rarely justified for slab-on-fill foundations. In the latter case, a switch to another foundation type would usually be justified, however.

13. A sensitivity analysis was undertaken to investigate the effect of including displacement costs in the B/C calculations. Using BCA default displacement times, the effect varies slightly between flood hazard zones and with number of stories in an A zone. However, the effect can be generalized as follows: adding monthly displacement costs equal to 1% of the initial building cost increases the computed B/C by approximately 10%, and so forth.

14. The relationship between initial freeboard costs and flood premium discounts was also considered in a separate analysis. Even if future building and contents damages prevented are not considered[43], the annual flood premium savings are generally sufficient to pay for the costs of adding freeboard in several years time for many buildings. In the case of V zone buildings, the time required to recover freeboard costs through flood premium savings is short – a year or two. In the case of A zone buildings, the recovery time can extend to more than 15 years, due to the lower A zone premiums and premium discounts, which are used to offset the initial freeboard cost.

8.3. NFIP Building Standards: Effectiveness and Costs

On an individual building level, NFIP building standards have reduced flood damage relative to nearby pre-FIRM type structures. Flood losses for new construction are reduced through elevation and proper selection of the building foundation. Post-storm observations and calculations made during this study demonstrate that incorporation of freeboard is one of the most effective means of reducing property losses. In coastal areas subject to waves and erosion, post-storm observations have demonstrated the importance of FEMA's free-of-obstruction rule and use of pile or pier foundations with sufficient embedment to resist scour and lateral loads.

[43] If the damage reduction and flood premium savings are considered jointly, higher B/Cs and reduced freeboard cost recovery times result.

Calculations performed during this study and obtained from the literature show that the additional costs of adding freeboard at the time of construction are small, and would generally return benefits in excess of the costs, particularly in V zones and Coastal A zones, and in non-coastal A zones with low Flood Hazard Factors[44]. The additional costs of modifying foundation types would also return benefits in excess of costs, particularly in coastal flood hazard areas.

While this study did not investigate building practice effects on flood loss reduction *at a community level*, extension of the individual building findings to a broader scale seems reasonable. Reduced flood damage to individual buildings aggregates to reduced flood losses and disruption to the community. Study authors have observed this first-hand as part of post flood investigations -- where flood damage was widespread and great, individuals and communities often struggle to recover, while other nearby communities with less flood damage recover quickly.

This study did not investigate the effects of potential changes in NFIP building standards on the flood insurance fund, disaster assistance payments and other financial aspects of the NFIP and FEMA. However, since modified building standards could reduce flood damage at the individual building level, it seems reasonable to expect flood claims, disaster assistance and other post-disaster payments might also be reduced. The exact impact on the NFIP would depend on flood premiums received and payments made. The study authors believe that the cost of implementing building standards changes would be small, since the NFIP and the participating communities already enforce standards which are similar to the changed standards this study recommends.

Moreover, under the current flood premium rate structure, flood premium discounts will be sufficient to recover the incremental costs borne by property owners due to building standard changes -- in just a few years time for many buildings. These results suggest that, for the types of buildings analyzed here, flood losses can be reduced now and in the future through small expenditures at the time of new construction.

8.4. Do NFIP Building Standards Minimize Losses, Now and in the Future?

Generally speaking, NFIP building standards do reduce flood losses to new construction under present day base flood events. However, building standards are implemented in conjunction with the FIRM, which does not account for increasing flood hazards in the future. Thus, while NFIP building standards may be generally effective today, their future effectiveness will be reduced as the FIRM becomes obsolete due to changing flood conditions. Revising building standards may be one way to compensate for changing flood conditions in the future. This study showed that building damages under base flood conditions could be reduced, at modest cost, by incorporating freeboard and/or changing the foundation type. These actions would also help to reduce future flood damage resulting from sea level rise and erosion in coastal areas, and from development impacts in riverine areas. .

[44] A floodplain area with a low Flood Hazard Factor is characterized by a 100-year flood level that is no more than a few feet above the 10-year flood level.

8.5. NFIP Building Standards and Protection During the 100-Year Flood

With three exceptions, noted below, NFIP building standards evaluated by this study generally protect against the 100-year flood. However, floods more severe than the 100-year flood do occur, and incorporation of freeboard and modified foundations can help reduce losses from such floods. The B/C analyses indicate that there is a damage reduction benefit by taking such actions, and additional analyses might help to define a flood return period to which additional elevation is justified. This study indicates that higher levels of protection are achievable, and that the benefits of doing so will exceed the costs, particularly in high hazard areas.

Constructing a minimally compliant A zone building with the top of the lowest floor at the BFE is not an effective way to reduce flood damage – it actually guarantees flood damage will occur to the typical residential building during the base flood (i.e., flood damage to the floor system, floor and floor covering [through direct contact with floodwaters] and flood damage to walls [through wicking action]. Although NFIP regulations require the use of flood damage resistant materials below the BFE, many floor systems, floors and floor coverings are prone to flood damage. Given the modest costs of adding freeboard at the time of construction, it seems prudent to change the lowest floor reference elevation in A zones to be consistent with that in V zones –the bottom of the lowest horizontal supporting structural member supporting the lowest floor.

Another ineffective NFIP building standard allows buildings in Coastal A zones to be supported on fill and/or shallow foundations. Many of these foundations cannot withstand scour and lateral flood loads that will be experienced just landward of the V/A boundary during the base flood. Flood loads and conditions in Coastal A zones, which can include damaging waves and erosion, are different that those in riverine or lacustrine A zones which are usually subject to inundation and slowly moving water. By using the same minimum building standards for all A zones, regardless of the source and severity of the flood forces, it appears the NFIP unintentionally reduces the degree of flood resistance built into minimally compliant A zone structures in coastal areas.

Finally, studies of flood damage in coastal areas by Rogers (2005) have found that the NFIP penalizes some non-V zone pile-supported buildings through increased flood premiums and/or reduced flood policy coverage. Owners and builders, apparently sensitive to these disincentives, have adopted NFIP-compliant but inferior construction practices which render buildings more vulnerable to flood damage in the event that flood levels rise above the lowest floor. This piling penalty is contrary to flood damage reduction promoted by the NFIP.

8.6. Recommendations

B-1. The NFIP should not allow new A zone construction to be built with the top of the lowest floor at the BFE. Instead, the NFIP should require the top of the lowest floor of A zone structures to be built above the BFE such that the floor system is not in contact with flood waters during the base flood. This could be accomplished by either: 1) requiring sufficient freeboard, or 2) by changing the lowest floor reference elevation in A zones to be consistent with V zones (i.e., the bottom of the lowest horizontal structural member supporting the lowest floor must be at or above the BFE).

B-2. The NFIP should require at least 1 foot of freeboard for all new construction in the special flood hazard area. The exact freeboard amount should be guided by several factors:

- Freeboard requirements contained in consensus standards such as *ASCE 24* (ASCE 2005). *ASCE 24*[45] contains freeboard provisions which vary by building importance (the standard requires critical facilities to be elevated higher above the BFE than typical residential structures, for example). The *ASCE 24* freeboard provisions apply to the lowest floor, the use of flood resistant materials and utilities.

- Future flood conditions. *ASCE 24* does not account explicitly for future increases in flood hazards, thus, freeboard in excess of *ASCE 24* requirements may be appropriate in some flood hazard areas. The NFIP should consider flood loss reduction under present day base flood conditions and under future flood conditions when it establishes freeboard requirements.

- Flood elevation frequency. The NFIP should attempt to establish freeboard requirements that are consistent with the flood risk. For example, 1 foot of freeboard at a site with a flood hazard factor of 20 may yield protection against a certain flood return period event. Equivalent protection at a site with a flood hazard factor of 75 would require more than 1 foot of freeboard.

B-3. The NFIP should mandate V zone design and construction practices in Coastal A zones (e.g., requiring open foundations and the area below the BFE to be free of obstructions, making the lowest floor reference elevation the bottom of the lowest horizontal structural member supporting the lowest floor, designing for simultaneous action of flood and wind). Some communities have mandated V zone standards in A zones for years, but implementation of this recommendation on a larger scale would require changes to the flood hazard mapping process and the FIRM[46]. Note that the 2005 edition of *ASCE 24* requires new construction in Coastal A zones to meet V zone standards, and the FEMA has published supporting post-Katrina guidance.

B-4. The B/C results of this study are sensitive to the flood depth-damage function used in the analysis. The NFIP should, on an ongoing basis, review and update depth-damage functions based on flood claims data, results of MAT investigations and other data. This may require collection of some data now deemed optional during the flood claims adjustment process.

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[45] At present, ASCE 24 is adopted by reference by the *International Building Code* (International Code Council [ICC] 2006a) and by the National Fire Protection Association's (NFPA) *Building Construction and Safety Code* (NFPA 2006), but not by the *International Residential Code* (ICC 2006b)

[46] Post-Katrina flood hazard maps in Mississippi will show the landward limit of the 1.5 ft breaking wave height, which can serve as the landward boundary of the Coastal A Zone. This is the first time that such a designation will be shown on a FIRM.

B-5. Flood insurance premium rates should reflect anticipated flood damages and provide incentives to property owners and communities to exceed minimum NFIP building standards. The Community Rating System (CRS) does this on a community scale, but additional effort is needed to provide incentives to individuals. For example:

- The NFIP should re-evaluate flood insurance premium discounts for buildings in A zones. Current A zone discounts effectively cease at one to two feet above the BFE (unlike V zones where substantial discounts are awarded for up to four feet of freeboard). Additional discounts for increased freeboard in A zones may be one of the most powerful arguments that can be made to property owners.

- The NFIP should revise flood premium rates and coverage for NFIP-compliant pile-elevated buildings outside the V zone. Present rates and coverage penalize property owners who might otherwise adopt the superior pole-type construction, with pilings extending above the lowest floor to a higher floor or the roof.

B-6. The NFIP should consider development of an A Zone Risk Factor Rating Form and process, similar to that in place for V zones. This action could provide another way to reward A zone building owners to adopt design and construction practices that exceed NFIP minimum standards.

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9. ACRONYMS

AIR	American Institutes for Research
ASCE	American Society of Civil Engineers
ASFPM	Association of State Floodplain Managers
B/C	benefit-cost ratio
BCA	benefit-cost analysis
BFE	base flood elevation
BPAT	(FEMA) Building Performance Assessment Team
CHHA	coastal high hazard area
CFR	Code of Federal Regulations
CRS	Community Rating System
DR	discount rate
FEMA	Federal Emergency Management Agency
FHF	flood hazard factor
FIA	Federal Insurance Administration
FIRM	Flood Insurance Rate Map
ft	foot or feet
ICC	International Code Council
in	inch or inches
lf	linear foot
MAT	(FEMA) Mitigation Assessment Team
msl	mean sea level
NAVFAC	Naval Facilities Engineering Command
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NFPC	(USACE) National Flood Proofing Committee
OMB	United States Office of Management and Budget
PFD	primary frontal dune
psf	pounds per square foot
sf	square foot or square feet
SFHA	Special Flood Hazard Area
SWL	stillwater level or stillwater elevation
UL	useful life
USACE	United States Army, Corps of Engineers
USGS	United States Geological Survey

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Appendix 1: NFIP Building Standards Survey

A seven-question survey was developed near the inception of this study to solicit opinions of floodplain professionals on the NFIP's minimum building standards. The survey was posted on Christopher Jones' web site between May 20, 2003 and July 11, 2003, and its availability was announced to the floodplain management community. Individuals were free to respond voluntarily, or not to respond. In addition, Jones contacted nine individuals and solicited their opinions directly. A total of 58 people participated, either by email, telephone or face-to-face interview.[47] The survey questions are listed below:

1. Are NFIP minimum standards for building design and construction rigorous enough to minimize losses at a reasonable cost to communities and property owners when flood damage occurs?

2. Are the NFIP minimum standards sufficient to protect existing development against flood risks that may increase in the future (e.g., as a result of new construction causing increased runoff and higher BFEs, or as a result of other factors such as subsidence, sea level rise, coastal erosion)?

3. Are the NFIP minimum elevation requirements (i.e., top of lowest floor in A zones, bottom of lowest horizontal member in V zones) justified and adequate? Should freeboard be mandated for certain flood hazard zones or certain types of structures? If so, how much freeboard is appropriate?

4. The NFIP requires pile or column foundations and allows breakaway walls in V zones, and allows any type of foundation in A zones (e.g., fill, slab, foundation wall, pier, pile, column). Should the NFIP foundation requirements be changed for certain flood hazard zones or certain types of structures?

5. What about structures built on fill in or near the SFHA – should elevation or foundation requirements be modified for structures in the SFHA, or mandated for structures near or removed from the SFHA?

6. In your community or state, what building practices have been found effective against the forces and conditions associated with local flood hazards? What building practices have been found ineffective? Please include a description of the local flood hazards.

7. If you were free to change anything about the NFIP's minimum design and construction requirements, what changes would you make?

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[47] Note that this survey used non-random sampling, thus, the results may be biased toward those with strong opinions in favor of changing the NFIP requirements rather than maintaining the status quo. On the other hand, most of the responses were obtained from professionals who are involved in some aspect of floodplain management and coastal construction, hence, the respondents are likely to be well-informed on the subject. While the results of this survey are not statistically valid due to sample size and sampling methodology, the responses can still inform discussions of NFIP building standards.

The 58 survey respondents can be broken down as follows:

- 23 NFIP State Coordinators or floodplain management staff (representing 19 states)
- nine local floodplain managers and/or building officials (representing eight communities)
- eight insurance agents or insurance industry employees
- seven floodplain management consultants
- seven federal employees
- two building contractors
- two unknown respondents

Approximately one-half of the survey respondents represented areas with or dealt with riverine flooding only, while about one-half of the respondents represented areas with or dealt with coastal flooding (and to some extent, riverine flooding).

Survey responses were aggregated to avoid potential identification of respondents. Further, since responses to some questions were quite lengthy, they were paraphrased and grouped with other responses to the same question. Aggregate survey responses and the most common responses for each question are listed below (the question is repeated, followed by a summary of the responses *in italics*).

Note that there are always fewer than 58 responses to each question, and this is attributable to several factors: 1) some surveys were completed by groups rather than individuals, 2) some respondents did not respond to every question, and 3) some responses focused on other aspects of the NFIP (e.g., insurance issues, hazard mapping, consistency between insurance and regulatory aspects of the program, etc.), and 4) the meaning of some responses was not clear. Thus, not all responses were counted in the tally below. Approximately 40 usable responses were received for most questions.

1. Are NFIP minimum standards for building design and construction rigorous enough to minimize losses at a reasonable cost to communities and property owners when flood damage occurs?

   Yes: 17 *No: 23*

2. Are the NFIP minimum standards sufficient to protect existing development against flood risks that may increase in the future (e.g., as a result of new construction causing increased runoff and higher BFEs, or as a result of other factors such as subsidence, sea level rise, coastal erosion)?

   Yes: 5 *No: 36*

Of those replying no, riverine respondents tended to say that future conditions hydrology should be considered in mapping, coastal respondents tended to say that erosion and sea level rise should be considered.

3. Are the NFIP minimum elevation requirements (i.e., top of lowest floor in A zones, bottom of lowest horizontal member in V zones) justified and adequate? Should freeboard be mandated for certain flood hazard zones or certain types of structures? If so, how much freeboard is appropriate?

Yes: 6 *No: 34*

Responses varied, but those who responded no tended to say that a minimum of 1 ft of freeboard should be required, that freeboard should be sufficient to elevate the entire floor system above the BFE in A zones, or that freeboard should be variable (and be based on Benefit-Cost analysis), etc.

4. The NFIP requires pile or column foundations and allows breakaway walls in V zones, and allows any type of foundation in A zones (e.g., fill, slab, foundation wall, pier, pile, column). Should the NFIP foundation requirements be changed for certain flood hazard zones or certain types of structures?

Yes: 25 *No: 11*

Of those responding yes, several thought breakaway walls should be eliminated (due to use of enclosed space, not due to building standards issues), several said the use of fill to remove a structure from the SFHA should be eliminated (even though the question did not address the effect of fill on mapping), and several called for V zone foundations in (at least part of) A zones in coastal areas.

5. What about structures built on fill in or near the SFHA – should elevation or foundation requirements be modified for structures in the SFHA, or mandated for structures near or removed from the SFHA?

Yes: 22 *No: 7*

Of those responding yes, approximately ¾ said one or more of the following: do not allow fill to be used to elevate buildings, do not allow basements to be constructed in areas where fill has been placed, do not allow parcels to be removed from the SFHA by fill placement. Approximately ¼ of those responding yes said that fill placement was acceptable, but the better guidance is needed on fill compaction and protection (against velocity and erosion).

6. In your community or state, what building practices have been found effective against the forces and conditions associated with local flood hazards? What building practices have been found ineffective? Please include a description of the local flood hazards.

The most effective practices listed can be grouped into three categories, in decreasing order of their mention: 1) elevation and freeboard, 2) adoption and enforcement of *building codes and 3) avoidance of flood hazards and preservation of open space. Ineffective practices listed by respondents included elevation on fill and manufactured home installations.*

7. If you were free to change anything about the NFIP's minimum design and construction requirements, what changes would you make?

   Responses were varied, but can be grouped under the following categories (in no particular order): 1) require freeboard, including for manufactured housing, 2) eliminate/restrict/modify the use of fill in the SFHA, 3) restrict the use of breakaway walls, 4) modify substantial damage regulations to incorporate repetitive losses, 5) restrict siting in floodways and V zones, 6) modify the mapping of flood hazards (e.g., eliminate unnumbered A zones, map future conditions, map Coastal A zones, map VO zones and velocity in other zones, include mapping of small watersheds, improve mapping of debris flow, ice jams and sedimentation), 7) establish minimum floor elevations in recognition of the allowable rise in floodways, 8) revise flood insurance (e.g., increase flood insurance and Increased Cost of Compliance limits, make insurance and regulations consistent), 9) clarify NFIP regulations and definitions, and 10) move toward a no adverse impact model for hazard delineation and building regulation.

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Appendix 2: A Comparative Cost Evaluation of Foundation Types Permitted by NFIP Regulations in Coastal A and V Zones

FEMA-1604-DR-MS
515 East Amite Street
Jackson, MS 39201-2709

MEMORANDUM

TO: Shabbar Saifee, HPA Group Supervisor

FROM: Dan Powell, Acting HPA Group Deputy Supervisor

Cc: Jim McCulloch, HM Architect

DATE: December 4, 2005

RE: A comparative cost evaluation of foundation types permitted by NFIP regulations in coastal A and V zones.

Background: NFIP requirements for coastal A and V Zone foundations

The NFIP minimum requirements for foundation design in A zones make no distinction between inland and coastal areas. Technical Fact Sheet No. 11, "Home Builder's Guide to Coastal Construction", acknowledges that foundation construction permitted under NFIP for inland A zones is generally not suitable for coastal construction. Buildings located in both inland and coastal A zones must be elevated so that the top of the lowest floor is at or above the BFE. Coastal A zones are based on a wave crest (equaling the BFE) between one and a half and three feet. The problem is that some foundation types, while suitable for inland construction and technically permitted in coastal A zones under NFIP regulations, are not capable of withstanding the combined forces of high winds, velocity flooding, scour, erosion and floating debris. Post event damage assessments have concluded that structures in coastal A zones are subject to the same combination of forces more typically associated with the high hazard coastal V zones.

Coastal A zone foundation construction that has been prone to failure include slabs-on-grade elevated over structural fill, various types of enclosed perimeter foundations, and masonry pier foundations. In contrast, open foundations free of obstruction and consisting of piles or columns with adequate embedment to resist scour, have proven to be less prone to failure. In recognition of the problem, NFIP has recommended that foundation design in coastal A zones comply with the more stringent requirements applied to V zones.

SFHA's designated as V zones have a crest equal to or greater than three feet. Buildings located in V zones must be elevated on pilings or columns so that the bottom of the lowest horizontal structural member of the lowest floor is at or above the BFE. Enclosures below the BFE are prohibited. The building design must be certified by a licensed engineer or architect that it will resist flotation, collapse, and lateral movement resulting from combined wind and hydrostatic loads. The recommendation that more stringent V zone requirements be applied to coastal zone A buildings has raised the question of how much the design and construction upgrades will cost the end user.

Costs: Coastal versus inland construction costs

The issue of coastal versus inland home costs has already been partly addressed in Technical Fact Sheet No.6. The fact sheet notes that coastal homes will always cost more to design, construct, maintain, and insure than inland homes. They are subject to higher risks and the possibility of more frequent and severe damage, as well as more rigorous code and regulatory requirements. The argument is made that the high initial cost must be balanced with long-term life cycle costs. Rather than building to the minimum standard, a marginally larger initial investment in design and material upgrades could save a significant amount of money in reduced maintenance, repair, and insurance premiums over the long haul. The discussion concludes with a table breaking down the added initial costs for different design items that are required by codes or NFIP for coastal home construction in A and V zones. Based on the analysis, coastal homes cost 15% - 30% more than homes in inland areas. Also included is a list of costs for design items that exceed minimum code/NFIP requirements but further reduce various life cycle cost. These additional items added 5% to the base building cost. The total construction cost for required design features and optional upgrades above code is in the 20% - 35% range for coastal construction in A and V zones.

Because both A and V zones are lumped together in the analysis, what is not so clear is the expected cost for applying the more stringent and expensive V zone requirements to coastal A zones. In the preceding analysis referred to, the additional cost of pile/column foundations for both A and V zones is noted only as greater than 2% of the base building cost. How much greater? Code mandated wind zone requirements would be similar for both A and V zones, therefore the cost should remain relatively constant for a given structure regardless of the zone in which it's located. As far as building codes are concerned, what will govern a structure supported on an open foundation design and located in a high wind zone will be the tendency of the building to overturn. Building codes currently have no provisions for structural design guidelines addressing the impact of storm surge on buildings located in coastal regions. Open foundation designs consisting of unobstructed piles or columns offer less resistance to hydrostatic and hydrodynamic loads due to storm surge and will transfer to grade the dead load and applied live loads, including wind loads that are imposed on the superstructure. The importance of foundation design to the survivability of a structure subject to extreme loading conditions cannot be overstated. Failure of an inadequately designed foundation will result in failure of the entire structure. Viewed in this light, proposed upgrades to the foundation design become critical and deserve a more thorough consideration of the cost implications.

Cost comparison methodology: A Zone and V Zone foundation types (See Table 1 attached)

Costs were developed from the 2005 Marshall & Swift cost estimating guide. To insure continuity with the cost analysis presented in Technical Fact Sheet No. 6, costs are based on the same prototype: a 3,000 square foot home of average construction quality, compliant with all codes, with an average perimeter/floor area ratio, and featuring a moderate number of windows.

All costs are based on calculated base building costs and exclude site acquisition and site improvements. Calculated costs are relative and are presented as percentages to account for variations in square footage. Foundation type, design, depth of footing and corresponding cost will vary depending on site location, site context, soil bearing capacity, susceptibility to erosion, etc. In the examples given, pile footings have been embedded 10' below grade because deep embedment to protect against erosion and sour effects is recommended in coastal areas. The cost comparison table developed provides a percentage cost factor for reductions or extensions of pile footings. A cost estimate for reinforced concrete frame and steel moment frame have not been included in Table 1 as the estimating software was unavailable at the time of this analysis.

Conclusions based on the following table of cost comparisons

- The additional cost for upgrading an A zone foundation to comply with V zone requirements will vary from 1.9 % - 10.4%++ of base building cost. The higher the foundation elevation needed to meet the required BFE, the higher the percentage of foundation cost to base building cost.

- The net additional cost to upgrade an A zone foundation to V zone requirements is arrived at by deducting the A zone foundation Types 1, 2, 3, or 4 from Type 5/ Piles/Columns.

- Each additional foot of vertical elevation varies from 0.3% - 0.5% of base building cost. Adding additional freeboard will have a negligible impact on total project cost while providing a significant reduction in hazard.

Table I

Approximate Costs - Coastal A Zone Foundation Types **Types 1, 2, 3, & 4 are permitted by NFIP in all A zones but are not recommended for coastal A zones. Type 5, open foundation, is both permitted and recommended for coastal A zones and required in coastal V zones.**		% of Base Building Cost	Add'l cost for upgrade from A zone, foundation Types 1 thru 4, to V zone foundation requirements
Type I: Concrete	8" perimeter concrete foundation w/ interior concrete piers, bottom of footing 3' below grade, top of foundation 2' above grade	6.5%	Not permitted in V zones
	Each additional vertical foot of foundation wall	1.0%	
Type 2: CMU	8" perimeter CMU foundation w/ interior CMU piers, bottom of footing 3' below grade, top of foundation 2' above grade	5.5%	Not permitted in V zones
	Each additional vertical foot of foundation wall	Add 0.7%	
Type 3: Slab	Concrete slab-on-grade over 1' compacted structural fill, bottom of perimeter footing 8" below slab	4.4%	Not permitted in V zones
	Each additional vertical foot of fill	Add 1.2%	
Type 4: Piers, CMU	Open foundation, 1'-4" square CMU piers 10' on center, bottom of footing 3' below grade, top of pier 2' above grade	3.6%	Not permitted in V zones
	Each additional vertical foot of foundation piers	Add 0.2%	
Approximate Costs - Coastal V Zone Foundation Types			
Type 5: Piles, wood	Open foundation, **10" diameter treated wood piles** set 10' below grade, top of pile 3' above grade, piles at 10' on center	8.4%	1.9% to 4.8%+
	Each vertical foot, either addition to elevation or reduction in embedment	+/- 0.3%	
Type 5: Piles, wood	Open foundation, **12" diameter treated wood piles** set 10' below grade, top of pile 3' above grade, piles at 10' on center	11.3%	4.8% to 7.7%+
	Each vertical foot, either addition to elevation or reduction in embedment	+/- 0.3%	
Type 5: Piles, steel	Open foundation, **8 x 8 steel "H" piles** set 10' below grade, top of pile 3' above grade, piles at 10' on center	11.3%	4.7% to 7.6%+
	Each vertical foot, either addition to elevation or reduction in embedment	+/- 0.4%	
Type 5: Piles, steel	Open foundation, **10 x 10 steel "H" piles** set 10' below grade, top of pile 2' above grade, piles at 10' on center	14.0%	7.5% to 10.4%+
	Each vertical foot, either addition to elevation or reduction in embedment	+/- 0.5%	
Type 5: Piles, precast concrete	Open foundation, **10" diameter precast concrete piles** set 10' below grade, top of pile 3' above grade, piles at 10' on center	12.1%	5.6% to 8.5%+
	Each vertical foot, either addition to elevation or reduction in embedment	+/- 0.4%	
Type 5: Piles, precast concrete	Open foundation, **12" diameter precast concrete piles** set 10' below grade, top of pile 3' above grade, piles at 10' on center	13.5%	7.0% to 9.9%+
	Each vertical foot, either addition to elevation or reduction in embedment	+/- 0.5%	

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Appendix 3: An Approximate Method for Estimating Flood Depths for Various Recurrence Intervals

An Approximate Method for Estimating Flood Depths for Various Recurrence Intervals

December 15, 2003

Wilbert Thomas

An approximate method for estimating flood depths for various recurrence intervals was developed that utilizes the **known** flood depth for the 100-year flood. The flood depth for the 100-year flood is often available from Flood Insurance Studies published by the Federal Emergency Management Agency. The following method is based on the slope of discharge-frequency curve and the relation between depth and discharge.

Considerable research and literature are available for discharge frequency analyses based on the annual maximum peak discharge. Bulletin 17B, Guidelines For Determining Flood Flow Frequency (Interagency Advisory Committee on Water Data), documents procedures for estimating flood discharges for various recurrence intervals (such as the 100-year or 1-percent annual chance flood). The Bulletin 17B procedure is to fit a Pearson Type III frequency distribution to the logarithms of the annual maximum peak discharges at a given gaging station. The slope of the discharge-frequency curve is based on the standard deviation and coefficient of skewness of the logarithms of the annual maximum peak discharges.

The equation for the discharge-frequency curve based a Pearson Type III distribution is

$$\log Q_T = \log Qbar + K_T * S_{logQ} \qquad (1)$$

where $\log Q_T$ is the logarithm of the T-year flood discharge, log Qbar is the mean of the logarithms of the annual peak discharges, S_{logQ} is the standard deviation of the logarithms of the annual peak discharges, and K_T is a Pearson Type III frequency factor that is a function of recurrence interval (T) and skewness and is given in Appendix 3 of Bulletin 17B. The relation between the depth of the T-year flood and the T-year discharge can be estimated based on the work of several investigators and basic hydraulic theory.

For several streams in the mid-western USA, Leopold and Maddock (1953) showed that for less than bankfull discharge there was a relation between channel depth (d) and discharge (Q) of the form $d = c\,Q^f$, where c and f are constants indicative of a given channel shape. Thomas (1964) found this type of relation applicable for greater than bankfull discharges in New Jersey, and for simplicity modified the equation to $d_T = c\,(Q_{2.33})^f$, where d_T is the flood depth above the 50-percent duration flow for a given return period T, $Q_{2.33}$ is the mean annual flood discharge (return period of 2.33 years), and c and f are constants for a given return period.

Leopold and Maddock (1953) found that the exponent f in their equation $d = c\,Q^f$ averaged about 0.40 for streams in the mid-western USA when discharges were less than bankfull. Dunne and Leopold (1978) found the exponent f averaged 0.38 for discharges less than bankfull for the upper Green River watershed in Wyoming. Leopold and others (1964) found that the exponent f averaged 0.52 for discharges less than bankfull for several locations in the Seneca Creek watershed in Maryland. Burkham (1978) used stage-discharge relations for 539 gaging stations in seven states from Table 1 to define an average value of 0.42 for the exponent f for discharges greater than bankfull.

Manning's open-channel flow equation can be used to illustrate that the average depth in a rectangular channel is proportional to the 3/5 (0.60) power of discharge and to the 3/8 (0.375) power of discharge in triangular channels. All these studies indicate that flood depth is proportional to discharge raised to a power between about 0.4 and 0.6. Since there is uncertainty in any relation between depth and discharge, an exponent of 0.6 is recommended for the relation between T-year flood depth (d_T)and discharge (Q_T) as follows:

$$d_T = c\ (Q_T)^{0.6}. \qquad (2)$$

In Equation 2, the coefficient c is a function of Manning's n value, the top width of the channel and the friction slope, data that are all site specific. Taking the logarithm of Equation 2 results in the following equation :

$$\log d_T = \log c + 0.6\ (\log Q_T). \qquad (3)$$

For example, the 100-flood depth would be

$$\log d_{100} = \log c + 0.6\ (\log Q_{100}). \qquad (4)$$

The equation for other recurrence interval floods would be similar to Equation 4. The difference in depth between the 100- and 2-year floods, for example, can be written as (where log c cancels out in the subtraction):

$$\log d_{100} - \log d_2 = 0.6[\log Q_{100} - \log Q_2]. \qquad (5)$$

Using Equation 1 to define [$\log Q_{100} - \log Q_2$], Equation 5 can be rewritten as (note that log Qbar cancels out in the subtraction):

$$\log d_{100} - \log d_2 = 0.6\ [(K_{100} - K_2)\ S_{\log Q}\ ]. \qquad (6)$$

Equation 6 can be rewritten in the more generic form

$$\log d_T = \log d_{100} - 0.6\ [(K_{100} - K_T)\ S_{\log Q}\ ]. \qquad (7)$$

The K_T values in Equation 7 can be obtained from Appendix 3 in Bulletin 17B for various values of skewness (G) or approximated from the following equation given in Appendix 3 of Bulletin 17B:

$$K_T = 2/G\ \{[(K_{n,T} - G/6)\ G/6 + 1]^3 - 1\} \qquad (8)$$

where G is the coefficient of skewness of the logarithms of the annual maximum peak discharges and $K_{n,T}$ is the standard normal deviate for recurrence interval T or the K value for zero skew. The above equation is not defined for G=0, use $K_{n,T}$ for zero skew.
A simple alternative to using Equation 8 would be to always use zero skew and assume the logarithms of the annual maximum peak discharges are approximately normally distributed. This is a reasonable assumption since the average of the skew values for the Bulletin 17B skew map is approximately zero.

Hardison (1974) developed a national map of skewness coefficients (G) for the USA. In so doing, he developed regional averages of the standard deviation (S_{logQ}) and the skewness of the logarithms of annual peak discharges (G), variables needed in the right-hand side of Equation 7. Hardison (1974) used the major watershed boundaries shown in Figure 1 but in some cases his subdivision of the major regions did not agree with Figure 1. Hardison did not provide a figure with his report so Figure 1 is used as the best representation of Hardison's regions.

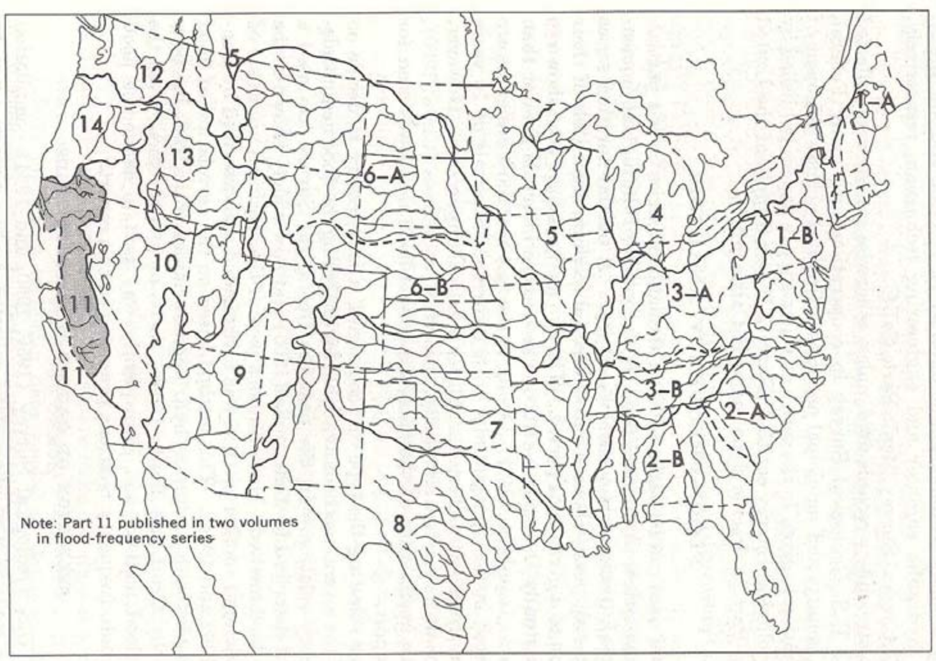

FIGURE 1.—Map of conterminous United States. The area covered by this report is shaded.

The boundaries given in Figure 1 are more subdivided than those given in Table 1 that follows. For example, only one value of regional standard deviation and skewness is given in Table 1 for Regions 2, 3, 5 and 6 although Hardison subdivided these regions. Hardison's values for the subregions of Regions 2, 3, 5, and 6 were simply averaged to give the single value in Table 1. The values in Table 1 illustrate regional differences across the USA. Note the average skewness of the 15 regions in Table 1 is about -.08 or very close to zero.

The following table summarizes the regional average standard deviation (S_{logQ}) and skewness (G) of the logarithms of annual peak discharges for major watersheds in the USA.

Table 1. Summary of regional values of standard deviation and skewness.

Region (see Figure 1)	**Average standard deviation (S_{logQ}) (log units)**	**Average skewness (G)**
1A	0.222	0.382
1B	0.247	0.517
2	0.278	0.004
3	0.241	-0.173
4	0.199	-0.184
5	0.326	-0.413
6	0.326	-0.024
7	0.338	-0.296
8	0.418	-0.179
9	0.224	-0.224
10	0.278	-0.369
11	0.426	-0.001
12	0.183	-0.053
13	0.200	-0.154
14	0.211	0.134

The values shown in Table 1 can be used to determine the K_T values in Equation 7 that are needed to estimate log d_T. The K_T values are given in Appendix 3 of Bulletin 17B and are determined by entering this appendix with a recurrence interval (exceedance probability) and skewness or can be approximated from Equation 8.

If zero skew (normal distribution) is assumed for the entire USA, then the K_T values become, for example, $K_{n,2} = 0.0$, $K_{n,5} = 0.84162$, $K_{n,10} = 1.28155$, $K_{n,25} = 1.75059$, $K_{n,50} = 2.05375$, $K_{n,100} = 2.32635$, and $K_{n,500} = 2.87816$. (These are the $K_{n,T}$ values in Equation 8.) Other values can be obtained from Appendix 3 using the column with skew = 0.0. The use of zero skew eliminates the need to use Appendix 3 of Bulletin 17B or Equation 8.

The logarithm of the T-year depth (log d_T) can be estimated from Equation 7 assuming the 100-year depth (d_{100}) is known. Equation 8 can be used to estimate the K_T values in Equation 7 or the

K_T values for zero skew given above can be used as a simple alternative. The use of Equation 8 with the average skewness (G) values in Table 1 is not much more difficult than using zero skew.

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