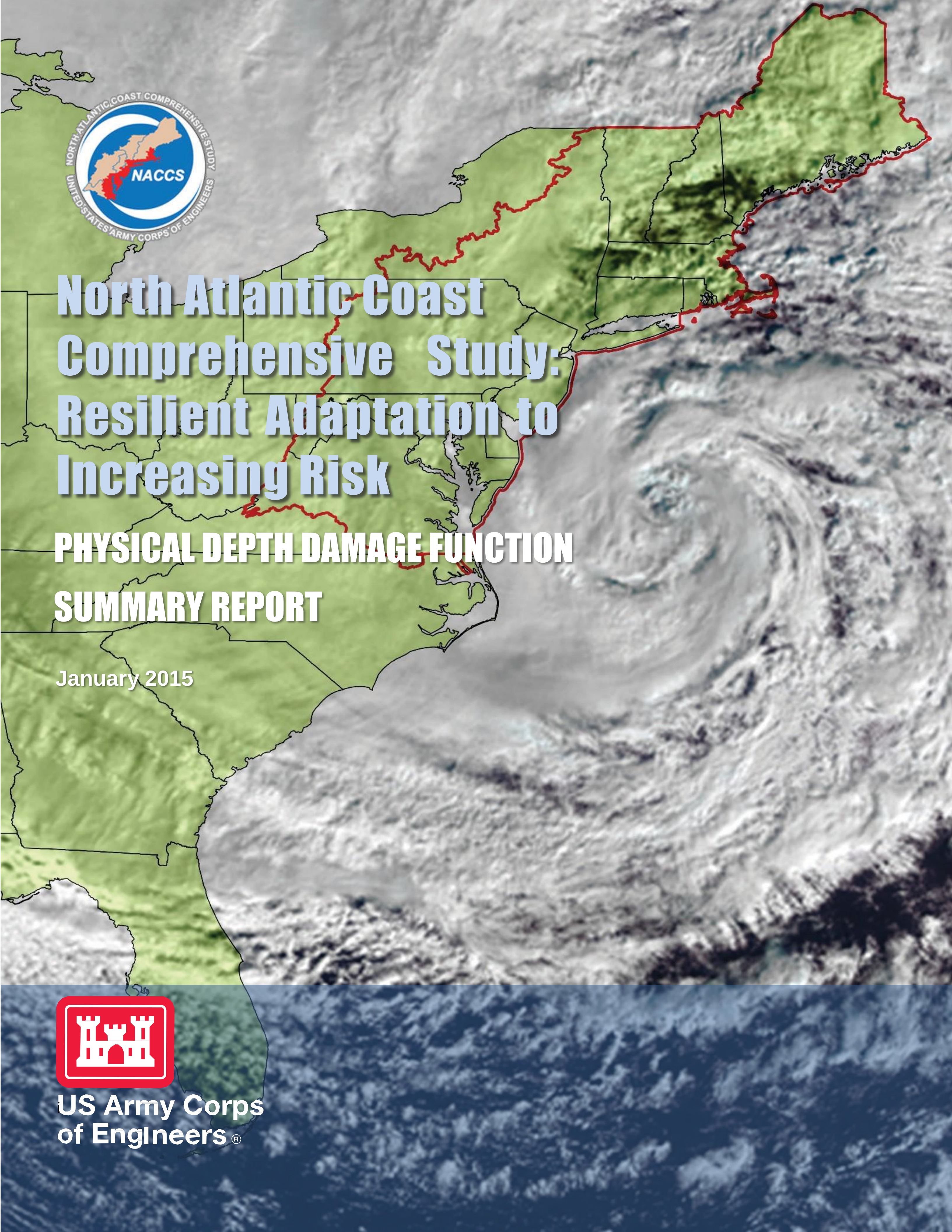

North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk

PHYSICAL DEPTH DAMAGE FUNCTION SUMMARY REPORT

January 2015

US Army Corps of Engineers®

PHYSICAL DEPTH-DAMAGE FUNCTION SUMMARY REPORT

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK

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1 Executive Summary

This report documents the results of a three-day workshop that took place on April 22-24, 2014, during which expert opinion was elicited to develop depth-damage relationships for coastal storm events. The expert panel consisted of a nine-person team, including coastal and structural engineers, appraisers, restorers, and catastrophe modelers from the insurance industry. Table 1 provides a list of the expert panelists and their respective occupations.

Table 1. Panel Members

Name	Occupation/Expertise
Bill Coulbourne, P.E.	Engineer/ Structural
Frank L. Headen	Restoration Specialist
Chris Jones, P.E.	Engineer/ Coastal Hazard Mitigation
Andrew Kennedy, P.E.	Engineer/ Coastal
Michael Pagano, P.E.	Engineer / Mechanical, Electrical, Plumbing (MEP)
Karthik Ramanathan, P.E.	Engineer/ Structural
Spencer Rogers	Engineer/ Coastal and Oceanographic
Jim Soucy	Flood Adjuster, Property Preservation
Jack Young	Pre-Disaster Assessor

Prior to the elicitation, a training session was conducted to familiarize panelists with important topics, key terms, and procedural information. For each generalized structure type, panelists were instructed to estimate most-likely, minimum, and maximum damage scenarios to capture 90% of the consequences that might result from a certain level of flooding. Thorough instruction on the identification and avoidance of numerous forms of bias was also provided. Key terms were defined for the panel in a manner consistent with the terminology used by current USACE-certified models to estimate coastal flood damages.

Each panelist was provided with a computer containing a panelist-specific electronic data worksheet for each prototype. Each worksheet was connected to a private network and designed so that the data could be entered and compiled in real time. The facilitator reviewed the spreadsheet with the panelists and explained how the measures were designed, and how to correctly fill out the worksheet.

The panel was asked to review an initial list of assumptions related to the general characteristics of the storm, flooding, and response characteristics, and to discuss and revise these as needed. The result of this dialog was an established list of assumptions relevant to the building prototypes and the flood event to be analyzed. This list ensured consistency in the methods used by the panel members when developing their individual damage functions.

Ten initial “strawman” prototypes were presented to the panel. Through discussion, these ten prototypes were further refined into fourteen prototypes, as shown in Table 2. Due to time constraints, two of the prototypes were not developed.

Table 2. Comparison of Initial and Final Prototypes

Initial Strawman Prototype	Final Prototype
Prototype 1: Apartments	Prototype 1A-1: One Story Apartment - No Basement Prototype 1A-3: Three Story Apartment - No Basement Prototype 1B-1: One Story Apartment - With Basement* Prototype 1B-3: Three Story Apartment - With Basement*
Prototype 2: Commercial - Engineered	Prototype 2: Commercial - Engineered
Prototype 3: Commercial - Non-Engineered	Prototype 3: Commercial - Pre/Non-Engineered
Prototype 4: High Rise Structures	Prototype 4A: Urban High Rise Prototype 4B: Beach High Rise
Prototype 5A: Single-Story Residence, No Basement	Prototype 5A: Single Story Residence, No Basement
Prototype 5B: Multistory Residence, No Basement	Prototype 5B: Two Story Residence, No Basement
Prototype 6A: Single-Story Residence, With Basement	Prototype 6A: Single Story Residence, With Basement
Prototype 6B: Multistory Residence, With Basement	Prototype 6B: Two Story Residence, With Basement
Prototype 7A: Building With Open Pile Foundation	Prototype 7A: Building With Open Pile Foundation
Prototype 7B: Building With Enclosed Pile Foundation	Prototype 7B: Building With Enclosed Pile Foundation

*Due to time constraints, damage functions were only developed for prototypes 1A-1 and 1A-3.

For each prototype, estimates were elicited for three separate damage mechanisms: inundation, waves, and erosion. The median values for each level of inundation (or percent compromise) were then compiled to produce damage functions for each structure category. Results were displayed on an overhead screen for review and quality check. During the post-elicitation discussion sessions, specific examples of storm-impacts on structures corresponding to the prototype categories were presented to the panel to illustrate the extent of the damage that occurred as a result of Hurricane Sandy. These examples included data collected through the post-hurricane damage survey conducted by IWR, observations and field data by some of the individual panel members, and photographs.

The elicitation effort produced 74 structure and content damage functions. These damage functions are anticipated to be predictive of the damages that would be incurred in future coastal events in the without-project condition, and will be used to improve analyses of economic justification of flood and storm risk management alternatives being considered for project planning areas. The new depth-damage functions are expected to be disseminated to the field through an Economic Guidance Memorandum (EGM) upon completion of the NACCS.

When applying the depth-damage functions the users are cautioned to consider whether the prototype descriptions are applicable to their specific study area. This includes a comparison of the prototype building descriptions to the buildings at the study area. Users should also consider if the study area building characteristics would allow damage to occur below the first finished floor or grade elevations. Some applications, such as the Beach-fx coastal damage model, require the user to adjust the depth-damage function to reflect the initial damage stage.

It is also important to note that the damage percentages in this document represent actual physical damages. Users should assess whether there are regulatory or safety considerations that would require actions such as building elevations/relocation or demolition and removal of the structure prior to reaching 100% physical damage.

This document presents separate depth-damage relationships for inundation, erosion and wave impacts. Analysts are cautioned that these functions should be evaluated independently for each structure. Typically only the damage function creating the greatest damage during any storm is incorporated into the annual damages. If the user is combining damage functions they must be careful to explicitly identify the methodology and basis for that decision. It is suggested that a damage matrix similar to the Beach-fx input template be included in the study documentation.

2 Introduction

The NACCS study team determined that an important element of the Coastal Storm Risk Management Framework to “address flood risks to vulnerable coastal populations impacted by Hurricane Sandy” would be to gather missing data and refine the analyses that USACE uses to estimate benefits for CSRM projects. The NACCS study team began a year-long effort to capture and document the actual economic damages that occurred in Hurricane Sandy to provide field teams with the data they need to properly assess the benefits in the future. Better quantifying the actual effects of the event will also help planners to adequately and cogently discuss and communicate risk and, when applicable, residual risk.

This data collection effort focused on four subcategories of NED benefits, namely:

- Assessment of damages to structures and their contents[1]
- Loss-of-life projection
- Emergency costs
- Secondary and tertiary effects

This report focuses on the physical damages incurred during Hurricane Sandy. To estimate the damages that would occur in different events, USACE studies are directed by planning guidance (Engineer Regulation [ER] 1105-2-100, [USACE 2000, Appendix E]) to apply depth-damage relationships to determine the amount of damage as a percentage of the structure or content value by depth of inundation.

Although in some cases those relationships might be readily available, in most cases, they are not, and USACE economists use generic depth-damage relationships produced by USACE’s

Institute for Water Resources (IWR). These generic relationships have been developed through the USACE Flood Damage Data Collection Program by post-flood surveys and expert elicitation. These generic damage functions are focused on fluvial flood events and limit damages to those caused by inundation. Coastal storms are different from riverine ones in that they have the added damage mechanisms of wave attack and erosion.[1] Using fluvial damage functions to measure the effectiveness of coastal interventions disregards the damages that occur from waves and erosion and may undercount the benefits to those interventions.

The PL 113-2 Jan 29, 2013 Disaster Relief Appropriations Act direction to “address flood risks to vulnerable coastal populations” and the resources provided by that legislation presented USACE with the opportunity to produce generic depth-damage relationships specific to coastal damage mechanisms. These depth-damage relationships are based on survey and physical data gathered by USACE, the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), local governments, and academic institutions in the aftermath of Hurricane Sandy for residential, non-residential, and public property, including structures, contents, and public infrastructure. The empirical data collected were presented to a panel of coastal storm damage experts, which included structural engineers, appraisers, restorers, and catastrophe modelers from the insurance industry, for a three-day elicitation to generate storm-damage functions. This working meeting produced several damage functions that captured the damages that occurred during Hurricane Sandy and that are anticipated to be predictive of the damages that would be incurred in future coastal events in the without-project condition. Some of the new damage functions also closed a data gap of being appropriate to densely populated metropolitan areas with significant portions of their populations living in high-rise apartment buildings. The new depth-damage functions are expected to be disseminated to the field through an Economic Guidance Memorandum (EGM) on completion of the NACCS.

The North Atlantic Coast Comprehensive Study (NACCS) is a collaborative effort to develop a risk reduction framework for the 31,000 miles of North Atlantic coastline affected by Hurricane Sandy. Part of this effort involves the development of coastal depth versus damage relationships to promote disaster resilient coastal communities. Following the collection of physical damage information through surveys performed in affected areas, a three-day expert opinion elicitation session was conducted in Clifton, New Jersey to develop damage functions for selected residential and nonresidential structure types. The information developed by the panel will be used specifically for the NACCS and more generally for coastal areas in other parts of the country.

2.1 Purpose

The objective of this effort was to produce coastal damage functions for residential, nonresidential, and public property. The Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies and USACE planning regulations require USACE district offices to estimate with- and without-project expected annual damages to estimate the benefits of flood risk management projects. A portion of these benefits accrues from reduction in damages to the residential and nonresidential structures in the floodplain and their contents. USACE district offices typically apply damage functions to

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[1] See Definitions section at the end of this report

estimate the amount of damage as a percentage of the structure or content value. USACE regulations further require district offices to make assessments of damage functions based on either area-specific surveys or surveys of comparable floodplains that reflect similar hydrologic and building characteristics. However, district offices are rarely equipped with the necessary financial resources or personnel for doing the expensive and time-consuming surveys required to document these damage functions. Additionally, Congress and the Assistant Secretary of Army (Civil Works) have expressed a desire to shorten the duration and cost of USACE implementation studies. Developing default content and structure damage functions for use by the districts was identified as a way of reducing the duration and cost of studies. In the past, default damage functions were developed through the Flood Damage Data Collection Program using post-flood surveys and expert elicitation. But these estimates are thought to be conservative and understated because they were developed for riverine flooding, and as a result, do not capture coastal storm damages caused by waves and erosion. In addition, current damage functions do not take into account certain characteristics that are particular to the North Atlantic region. These include building types and configurations, like high rise structures and buildings that have basements[2], as well as demographic characteristics like population density.

2.2 Approach

The approach to developing damage functions was to collect information regarding observed storm-related damage that impacted buildings. Hurricane Sandy provided an opportunity to collect empirical data and to ensure functions were suitable for use in evaluating coastal risk management options for NAD. Based on the information collected, ten structure-groups and functions were identified as typical of the North Atlantic region:

- Apartments
- Engineered Commercial Buildings
- Non-Engineered Commercial Buildings
- High Rise Structures
- Single-Story Residences without Basements
- Multistory Residences without Basements
- Single-Story Residence with Basements
- Multistory Residence with Basements
- Building With Open Pile Foundation
- Building With Enclosed Pile Foundation

Based on a review of prior studies and data from Sandy, a number of characteristics were identified as potentially important to the amount of damage incurred by a building during a coastal storm event. Table 3 shows initial prototype structure characteristics:

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[2] See Definitions section at the end of this report

Table 3. Initial Prototype Characteristics

Configuration	Quality and Condition	Basement and Foundation
Type of Structure	Age of Building	Foundation Type
Number of Stories	Condition of Building	Basement Use
Elevators/MEP	Construction Quality	Pile Diameter
Elevation of Lowest Finished Floor	Building Code in Use at Time of Construction	Foundation Embedment Depth
Finished Floor Use	Connection Condition	Pile Tip Elevation
Lobby Layout		Foundation Bracing
Interior Construction Type		Presence of Enclosure
Elevation of Utilities		Enclosure use

For storm damage estimation purposes, the following additional parameters were initially identified as being important:

- Rate of Rise and Velocity of Flood Waters
- Water depth above ground
- Wave Height
- Humidity
- Prior Warning
- Flood Duration
- Scour Depth
- Time Until Reentry

This information was combined to create ten initial strawman prototypes that were sent to panelists prior to the elicitation as part of a read-ahead packet. The read-ahead packet also included an overview of the purpose and objectives of the elicitation panel, a meeting agenda, and brief biographies of the panelists.

As part of the review and verification of this effort, additional empirical data were collected and analyzed to evaluate the reasonableness of the damage functions developed through the NACCS expert elicitation process. The verification process and results, detailed in Attachment G, used data collected by FEMA as part of the substantial damage estimates and the Mitigation Assessment Team (MAT) following Hurricane Sandy.

3 Post Hurricane Damage Survey

The development of the coastal damage functions for wave, inundation, and erosion damage included the collection and analysis of Hurricane Sandy damages using Office of Management and Budget (OMB) approved survey forms (OMB 0710-0001).

3.1 Questionnaire Development

Three survey instruments were prepared for use in the study area, one for each of the following structure categories:

- The residential survey instrument was developed to target single- and multi-family residential structures (up to 3 stories), townhouses, and row-houses
- The public survey instrument was developed to target schools, public offices, transport facilities, roads and bridges, water and wastewater treatment plants, electric power generation and distribution systems, subway and rail lines, and port terminal operators, etc.
- The nonresidential survey instrument was developed to target mixed use buildings, mid-rise structures (4 to 7 stories), hi-rises (8 stories and up), and commercial facilities.

Vehicle damage survey questions were incorporated into each of the survey forms (residential, nonresidential, and public), thereby ensuring that the geographic area where vehicle damage was surveyed corresponded to the overall survey area. These data are available for use, but generalized vehicle damage functions were not analyzed as a part of this task.

The survey instruments were developed in close coordination with IWR and Division staff members. Draft versions of each survey were reviewed and revised to incorporate IWR and Division comments. A copy of each survey instrument is provided in the attachments.

3.2 Community Communications

Notification of the survey purpose and procedures was provided to police departments and clerk’s offices in each municipality where interviews were conducted. Notification included a brief description of the project, the intent of the survey, and provided a USACE point of contact to verify the legitimacy of the survey and for additional questions about the study. The following measures were taken to ensure that the scope of work to be completed was communicated to the public:

Identification: All field personnel carried a picture ID and a letter stating that field personnel were performing the survey under USACE direction.

Fact Sheet: A one-page fact sheet was developed to supplement notification and online information. Municipal officials were encouraged to post copies of the fact sheet on local notice boards. The fact sheet was also carried in the field for distribution to interested parties.

3.3 Survey Process

Field surveys were conducted in the area affected by Hurricane Sandy to collect data on storm related damages. Staff conducted interviews with willing participants using the appropriate questionnaire.

In order to ensure that surveys were distributed to areas with the range of construction styles (including high rise and pile foundations), and to areas exposed to wave and erosion damage, a preliminary sample design was developed. Because of uncertainty regarding response rates the sample design targeted days of survey effort rather than an actual target number of surveys. Some areas, such as Long Beach, NY, Rockaway, and Manhattan were targeted to collect information on mid- and high-rise buildings. In New Jersey, areas of Monmouth and Ocean Counties were targeted to capture their exposure to erosion and wave damages, while Hoboken was targeted to capture flood impacts to older urban multi-family dwellings.

Following a review of available data, GIS was used to overlay the Sandy floodplain onto parcel mapping to identify survey candidates in each locality. These maps include topography and provide spatial data to evaluate the extent of wave exposure.

Buildings located on all landform types (mainland oceanfront, mainland sound or backbay, and barrier island) were included in the sample. To help identify conditions resulting in total structure failure, several communities provided lists of destroyed structures. Where possible, these data were merged GIS parcel data to identify the location and characteristics of buildings that were destroyed by waves or storm erosion. Surveys were conducted in the field between December 19, 2013 and February 28, 2014. Several additional surveys were returned by respondents in March 2014.

Interviews

To conduct the interviews, the survey team attempted to speak with owners of residential and nonresidential structures, whenever the owner was home and willing to participate. Surveys were distributed in person. Most surveys were also completed in person, but some potential respondents indicated that they preferred to complete the surveys at another time. When this happened, a survey was left with the potential respondent and the completed survey was returned via mail or email. Any follow-up questions were then resolved via email or phone.

Renters, co-residents, etc. were also interviewed and clearly noted as such. The survey team contacted property management companies for information about damage to high rises and large residential and commercial developments. Whenever possible, appointments were made with public officials best-suited to provide damages to public structures. Occasionally, local officials designated an appropriate representative to speak with the survey team based on the nature of the facility in question. Field personnel informed all interviewees of the purpose of the survey, that the survey was voluntary, and that their responses would be kept confidential.

Interviews were conducted within the mapped Sandy floodplain. The location of interviews is summarized below in Table 4, and shown in Figure 1. A summary of the survey results can be found in Attachment D. A summary of Lessons Learned is available in Attachment E.

Table 4. Location of Interviews

New York City	**33**	**Nassau County**	**12**
Rockaway Peninsula, NY	6	East Rockaway, NY	1
New York, NY	4	Freeport, NY	3
Rosedale, NY	3	Long Beach, NY	7
Staten Island, NY	20	Uniondale, NY	1
Ocean County	**58**	**Bergen County**	**24**
Barnegat Light, NJ	1	Little Ferry, NJ	12
Barnegat, NJ	5	Moonachie, NJ	12
Bayhead, NJ	1	**Hudson County**	**36**
Beach Haven,NJ	8	Hoboken, NJ	35
Brant Beach, NJ	3	Weehawkin, NJ	1
Ocean County (cont'd)		**Middlesex County**	**21**
Brick, NJ	1	Parlin, NJ	1
Harvey Cedars, NJ	3	Sayreville, NJ	8
Holgate, NJ	4	South River, NJ	12
Lavalette, NJ	1	**Monmouth County**	**60**
Long Beach Twp., NJ	4	Belford, NJ	5
Manahawkin, NJ	5	Highlands, NJ	22
Mantoloking, NJ	4	Leonardo, NJ	6
Normandy Beach, NJ	5	Port Monmouth, NJ	4
Pt. Pleasant, NJ	6	Union Beach, NJ	23
Ship Bottom, NJ	2		
Surf City, NJ	5		

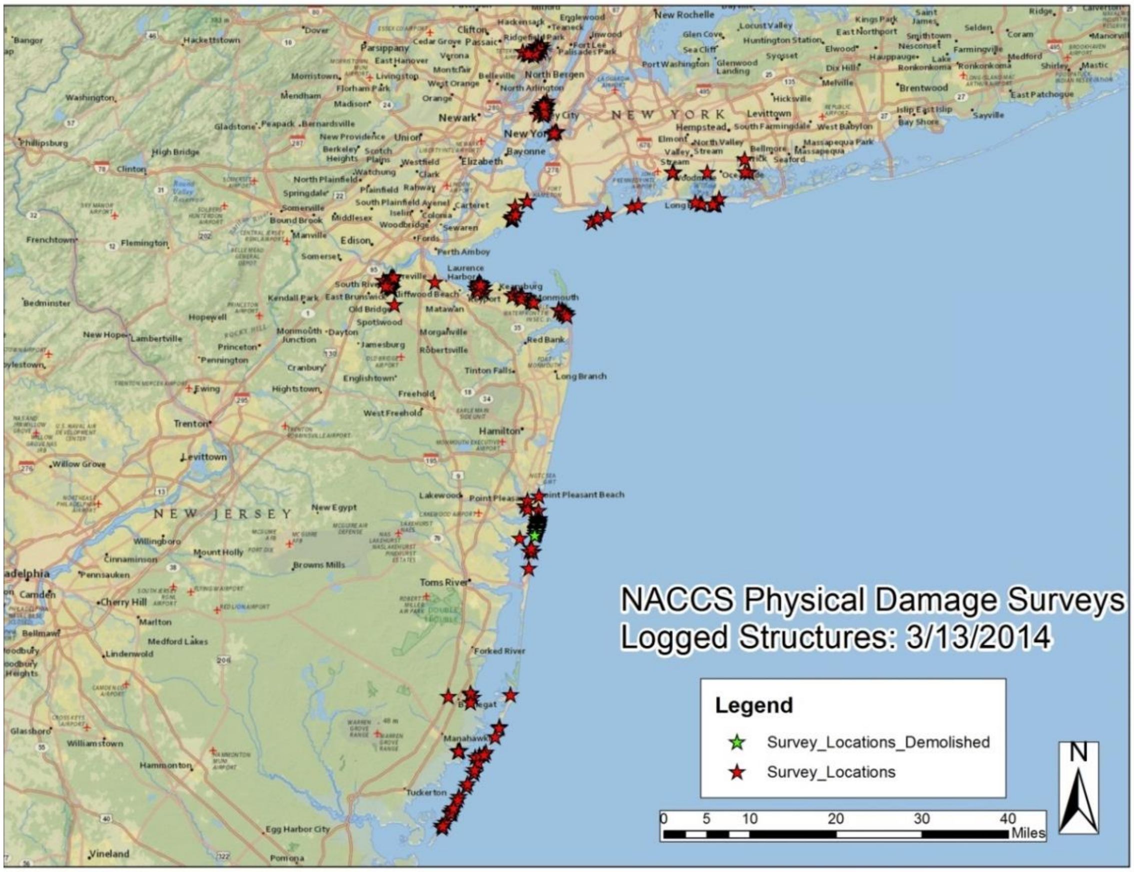


Figure 1. Location of Physical Damage interviews

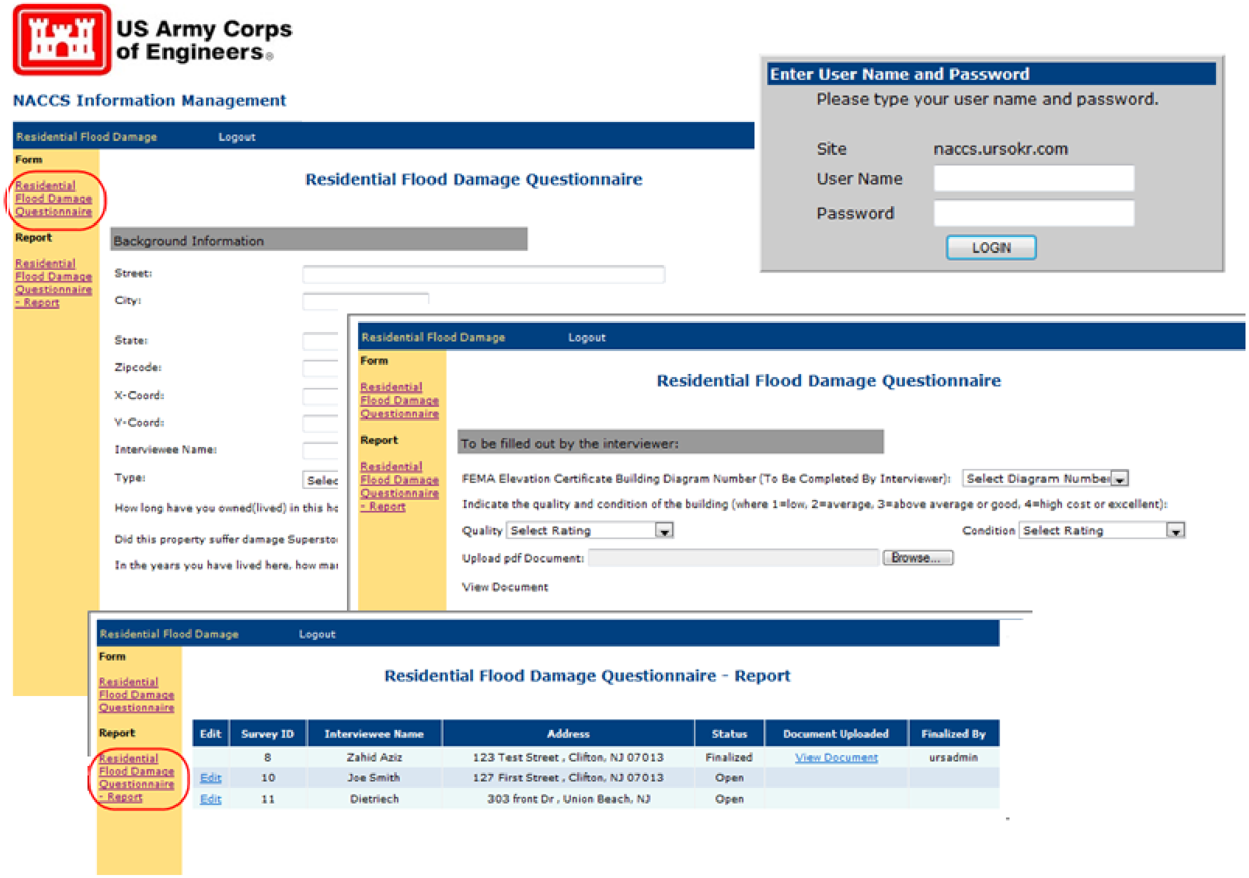
Follow Up

The survey team often followed up with survey respondents to fill in gaps in data. The team also contacted leads obtained through talking to available residents or business owners (including landlords, property management companies, and public officials) to gather additional data. Generally, the participation in the surveys was not as high as initially expected. In areas directly exposed to waves or deep flooding, many of the structures were completely destroyed or remained uninhabitable. Because many of the barrier island properties are seasonal use, interviews were conducted over the long President's Day weekend to improve participation.

Participation for high rise structures was also limited. All requests were referred to the central management companies, which were generally reluctant to release information. Frequently, the management companies indicated a willingness to participate, but even after numerous follow-up calls and visits, they ultimately were unable to quantify damage.

Data Management

A standardized SQL database was developed to capture the responses to the questionnaires. Each structure surveyed was registered in GIS and a map with grade and flood elevations was generated for each location. The information collected during the survey, including damages, rehabilitation costs, property location and ground elevation, and water height during the storm, was entered into the database on a real-time basis. A digital copy of each survey document was uploaded into the database. Hardcopies were stored in the project files. Information stored in the database was downloaded into an Excel spreadsheet for analysis and preparation of damage functions. Figure 2 presents screen captures form the SQL database.



NACCS Information Management

Please type your user name and password.

Site naccs.ursokr.com
User Name
Password

Residential Flood Damage Questionnaire

Background Information

Street:
City:
State:
Zipcode:
X-Coord:
Y-Coord:
Interviewee Name:
Type:
How long have you owned(lived) in this
Did this property suffer damage
In the years you have lived here, how

Residential Flood Damage Questionnaire

To be filled out by the interviewer:

FEMA Elevation Certificate Building Diagram Number (To Be Completed By Interviewer):
Indicate the quality and condition of the building (where 1=low, 2=average, 3=above average or good, 4=high cost or excellent):
Quality
Condition
Upload pdf Document:

Residential Flood Damage Questionnaire - Report

Edit	Survey ID	Interviewee Name	Address	Status	Document Uploaded	Finalized By
	8	Zahid Aziz	123 Test Street , Clifton, NJ 07013	Finalized	View Document	ursadmin
Edit	10	Joe Smith	127 First Street , Clifton, NJ 07013	Open		
Edit	11	Dietriech	303 front Dr , Union Beach, NJ	Open		

Figure 2. Screen Captures from the SQL Database

Quality Check

Information entered into the database was checked for correctness, accuracy, and completeness by persons with sufficient technical expertise and background knowledge of the project.

3.4 Analysis of Data

Once the surveys were completed and entered into the database, the structures where surveys were conducted were evaluated to determine the structure value. The replacement value of each structure was estimated using the RS Means Square Foot Costs (2014) cost estimating guide. Based on the information collected from the surveys, the building type and function was used to categorize the structure into one of the models in the RS Means guide. The other building characteristics, such as size and construction type, collected during the surveys were used to estimate the replacement value of the structure. The depreciated replacement value was then estimated based on the quality and condition of the structure and the depreciation ratios used by IWR.

As noted previously, many of the respondents did not report the amount of damage that occurred to their structures. For example, four feet of inundation was reported for several commercial office buildings; however respondents were not willing/able to provide a dollar figure for the damages to the structure.

The percent damage to each structure was estimated by dividing the total structure damage by the depreciated replacement value. In some cases, the amount of damage was greater than the estimated depreciated replacement value. This could be due to several reasons, including: underestimating of the replacement value of the structure, over-reporting the structure damages by the respondent, and respondent lumping damages from several categories (e.g., structure, content, outside equipment) into one figure. Therefore, any percent damage amount that was greater than 100 percent was capped at 100 percent.

As can be expected, the figures displaying the depth vs. damage did not present a distinct pattern. However, a general pattern can be seen showing an increase in damages as the depth of flooding increases.

4 Additional Data Sources

In addition to the post-Sandy damage surveys, the team also collected and reviewed additional data.

4.1 Village of Freeport, New York

The Freeport, NY Village Superintendent of Buildings, Floodplain Manager and Mitigation Coordinator provided a Master Disaster Assessment Spreadsheet with a listing of the buildings inspected after Hurricane Sandy. Each structure was inspected to determine if the storm caused any damage that would cause a violation of the Village building code and rendering the structure not suitable for occupation. Damage to the plumbing, electric, or other mechanical systems, would result in a status of “yellow.” Extensive damage to the foundation or structure in addition to other damage would result in a status of “red.” The home structure could not be occupied until an engineering inspection determined repairs has satisfactorily been completed. The Village also provided a map with all of the structures highlighted in the appropriate color designation.

The information provided by the Village of Freeport was reviewed for possible use to supplement the damage data obtained in the interviews. Because the damage data did not provide specific damage estimation, it was determined that the information would not be added to the damage database. Because Freeport is largely protected from ocean waves and erosion, it was also determined that the information would not contribute to our understanding of structural failure for these damage mechanisms. Accordingly, the information was not included in the data presented to the elicitation panel.

4.2 Structural Response of Low Rise New York City Buildings during Storm Sandy [3]

The New York City Department of buildings conducted or contracted inspections of every building damaged by Hurricane Sandy. The most buildings affected were located in Brooklyn, Queens, and Staten Island. As seen in Figure 3, however, the largest number of affected high-rise buildings was in Manhattan.

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[3] (Dan Eschenasy 2013)

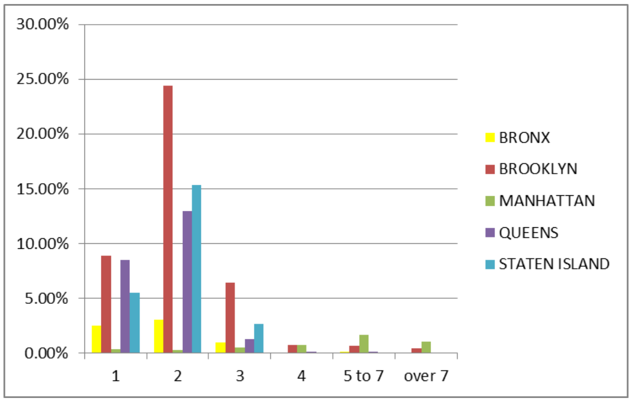

Figure 3. Distribution of building height (floors) in surge area (Dan Eschenasy 2013)

The Chief Structural Engineer of the Department conducted an analysis of the information collected and published his findings in the referenced paper. His analysis considered structural damage to be damage to the foundation, walls, and other structural systems. These assessments did not include damage to mechanical, electrical, and plumbing systems, or to permanently installed finishings normally included in structure damage assessments. Some of the findings of the assessments are that there was almost no structural damage to high- and mid-rise structures, residential 1- or 2-story structures are most likely to be damaged, and that building weight is a reliable predictor of structural response to surge (due to floatation or sliding off of the foundation).

The paper identified the following as common failure modes:

- Failure of foundation/basement wall
- Buildings moved off of foundations
- Failure of structure/bearing shear walls
- Soil-related failures
- Failure of wood decks, building enclosure, garages, and appurtenances

Twenty percent of the major building destruction (extensive damage to structure foundation, or complete collapse) in New York City was the result of fire. Approximately 159 buildings were affected by fire as a result of the storm. 145 of these buildings were located in Queens (primarily Breezy Point), 12 were located in Brooklyn, and two were located in Staten Island.[4]

This paper does not attempt to differentiate between buildings that suffered damage due to inundation, and those that suffered damage due to “additional dynamic effects,” as the physical proximity of the damaged buildings to the shore was not established.[5] The results of this analysis were summarized for the elicitation panel.

4.3 New York City Office of Emergency Management

The NYC OEM provided MapPLUTO[6] data detailing building characteristics. However, the information provided did not include information about damages. The MapPLUTO data were incorporated into the GIS/parcel data.

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[4] (Dan Eschenasy 2013)
[5] (Dan Eschenasy 2013)
[6] See Definitions section at the end of this report

4.4 Case Study: Building Destruction from Waves and Surge on the Bolivar Peninsula During Hurricane Ike, by Andrew Kennedy, A.M.ASCE; Spencer Rogers, M.ASCE; et al.

Two of the panel members were the authors of this case study of Hurricane Ike impacts. Following hurricane Sandy, Andrew Kennedy led a similar investigation of buildings in Ocean County, NJ. Analysis of the NJ data are currently in progress. The Hurricane Ike case study, published in the Journal of Waterway, Port, Coastal, and Ocean Engineering, discusses the results of a qualitative comparison of destruction levels across the entire Bolivar Peninsula, and the quantitative measurement of wave heights, surge levels, and building elevations in determining the point at which a building survived or failed in that area. Survival is defined as a large portion of the house remaining. Total failure is defined as only foundation or piles remaining. The aftermath of Hurricane Ike showed a distinct division between the two categories, with few examples of intermediate levels of damage.

The loss of the peninsula's fronting dune system one day prior to Ike's landfall "allowed waves to penetrate inland more easily at the height of the storm."[7] Wave and surge forces caused most of the catastrophic damage on the peninsula. Gauge measurements show that these forces were significantly larger on the Gulf side of the peninsula, where the highest percentages of destruction occurred. The bay side had extensive flooding, but little structural damage. In general, losses decreased from Gulf to Bay, indicating the reduction in wave forces across the land.

An evaluation of 128 wood-framed, single-family structures in a localized V-zone area with a BFE of 16- or 17-ft showed that all of the homes in a newer subdivision survived the storm with roof and walls largely remaining, while the majority of homes in the older subdivisions were destroyed. Most of these failures were determined to be the result of surge and waves destroying the superstructure above the pilings. The great majority of the homes that survived had a lowest horizontal structural member (LHM) elevation at or above the FEMA BFE. The extent of the damage decreased with proximity to the shoreline. Homes with LHMs below the BFE did not survive within 250 meters of the shoreline. Beyond 250 meters, several such homes did survive, but the vast majority failed (Figure 4).

> "A very clear divide can be seen between the surviving houses, which were invariably more highly elevated, and houses destroyed by the storm, which were generally lower." (Kennedy, A.M.ASCE, et al. 2011) See Figure 4.

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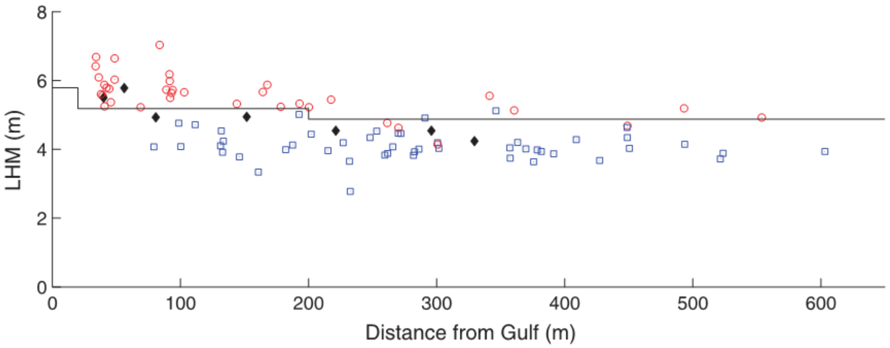
[7] (Kennedy, A.M.ASCE, et al. 2011)



(Color) Survival and destruction with increasing distance from the Gulf of Mexico shoreline in the Biscayne, Salt Cedar/Johnson Crawford areas; (○) surviving houses; (□) destroyed houses; (◊) houses surviving with noted wave damage; the elevation of wave damage for these houses was typically 0.25–0.3 m above the lowest horizontal structural member (LHM) elevation shown here; solid line gives the approximate 1993 FEMA BFE with distance inland

Figure 4. Survival and failure of structures in relationship to FEMA BFE

A second evaluation conducted in Crystal Beach utilized inundation, surge, and wave data measured by USGS Gauges GAL-1 and GAL-2. In the area of Gal-1, wave heights peaked at 1.8 – 1.9m, and the maximum surge plus wave elevation was over 6m. The survival of houses in this area was clearly shown to be dependent on some minimum elevation. In the area of Gal-2, maximum surge was approximately 4m. Waves in this area were estimated to be less than 0.9m. This area was shown to have a much less marked difference between survival and destruction in relation to elevation.

This information was presented informally to the panel members by the authors during discussions regarding wave damage. These discussions included qualitative comparisons to the observed Hurricane Sandy impacts.

4.5 White Paper: Large Building Flood Damage Functions, by Christopher P. Jones, P.E.[8]

This white paper, prepared for Taylor Engineering in Jacksonville, Florida, addresses the lack of publicly-available depth-damage functions (DDFs) for mid- and high-rise structures. It examines the problems inherent to the application of low-rise damage functions to mid- and high-rise structures, and illustrates how this usage could overestimate mid- and high-rise vulnerability to coastal storm events. Although this paper focuses on buildings in Palm Beach County, the author asserts that with some modification, the techniques introduced here can be applied to mid- and high-rise structures in other regions as well.

Several studies show that during coastal storm events, mid- and high-rise buildings generally perform much better than low-rise buildings. Reasons for this superior performance include the fact that mid- and high-rise structures typically have deep foundations, that their exterior walls are not integral to their structural systems, and that their structural systems are more robust in general than those of low-rise buildings. In the absence mid- and high-rise damage functions for structural damage, the paper evaluates and proposes the use of a combination of specific existing low-rise structure damage functions for use with selected building assemblies in mid- and high-rise structures, on a floor-by-floor basis.

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[8] (Christopher P. Jones 2011)

Assemblies are defined as aggregations of building components according to their principal location and function. The paper suggests that damage estimators use a component-based approach when estimating damages to mid- and high-rise structures. The assembly-damage approach requires knowledge of the susceptibility of individual components to flood damage, and of the relative value of each assembly to the total building value. The paper evaluates the sensitivity of the following assemblies (of typical oceanfront condominium and hotel construction in Palm Beach County, Florida) to erosion, wave, and inundation hazards: Foundation, Ground Floor Slab, Structural Frame, Exterior Walls, Interior, Utilities and Equipment, and Roof Covering, and approximates the value of each as a percent of total building value.

At the time that this paper was written, existing publicly available flood damage functions included HAZUS-MH, FEMA's Benefit Cost Analysis (BCA), and a USACE New Orleans District Study. An examination of these damage functions finds that they do not accurately capture the vertical distribution and magnitude of the damage that a typical mid- or high-rise structure would incur during a coastal storm event. The paper also examined four sources of erosion damage functions, and grouped them into Shallow Foundations and Deep Foundations. The shallow foundation erosion damage functions were found to be in reasonable agreement, and an average of these was considered suitable for use in the Palm Beach County Study. The deep foundation erosion damage functions showed considerable variation, and thus the average was not used. Instead, two of the deep-foundation erosion damage functions were modified for use in specific scenarios.

The findings and approaches from this study are generally compatible with the current analysis. As appropriate, Mr. Jones provided examples of this approach to the panel.

4.6 FEMA Mitigation Assessment Team

In December 2012, Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) composed of national and regional experts to assess the performance of buildings in New Jersey and New York during Hurricane Sandy. The MAT examined damages to buildings and related infrastructure, to determine damage patterns and to determine likely causes of structural failure or success. The MAT recommended actions that Federal, State, and local governments; the construction industry; and building code organizations can take to reduce future damage and protect lives and property in hazard-prone areas.

The MAT deployed to New Jersey and New York visited high-, mid-, and low-rise buildings; municipal buildings; historic buildings; transportation facilities; schools; coastal residential properties; data centers; and critical facilities such as hospitals, police, emergency medical service facilities, and fire stations.

Observations, conclusions, and recommendations related to the following topics are included in the Report:

- Low- and Mid-Rise Buildings
    - Foundation types – open, closed, deep, or shallow
    - Presence of basements or enclosures
    - Load path connection failures
    - Proximity to erosion control structures
    - Fire damage

- Mid- and High-Rise Buildings
    - Location in flood zone
    - Damage to mechanical, electrical, and plumbing systems
    - Presence of basements or subgrade tunnels
    - Erosion

The MAT found that most of the damage to low-rise buildings away from the shoreline resulted from inundation, while oceanfront low-rise buildings were damaged by wave action, erosion, and scour. Many low-rise one- and two-family dwellings in coastal areas were of older construction that pre-dates community adoption of floodplain regulations. Very few of these homes were elevated to the base flood elevation (BFE) in effect when Sandy struck. The MAT also found that most damage to mid- and high-rise buildings resulted from the inundation of mechanical, electrical, plumbing, and other critical systems. Many of these systems were not elevated to or above the Sandy flood level. In addition to building damage, utility outages were widespread.

A member of the MAT team was included in the elicitation panel. His experience imparted a valuable perspective on damage to one- and two-family residences, low-, mid-, and high-rise structures, and critical facilities affected by Hurricane Sandy.

4.7 FEMA Flood Insurance Data

Flood insurance claim data were obtained from FEMA. However, at the time that it was received, the dataset contained a large number of open claims. No conclusion could be drawn about the reason why those claims remained open, or whether the buildings in the open claims were damaged in the same way, or in a different way from the buildings in the closed claims. As a result, the dataset provided only a partial representation of the total damage. There were some concerns that using a partial data set would introduce bias as to the nature and the extent of the damage. In addition, FEMA legal counsel placed significant limitations on how the data could be used. With consideration of these two issues, analysis of the data was not included in this study.

4.8 Rockaway Beach Feasibility Study

An ongoing New York Division feasibility study in Rockaway Beach, NY, conducted an inventory of shorefront structures for the purpose of estimating damages caused by three mechanisms: inundation, erosion, and waves, using BeachFX.

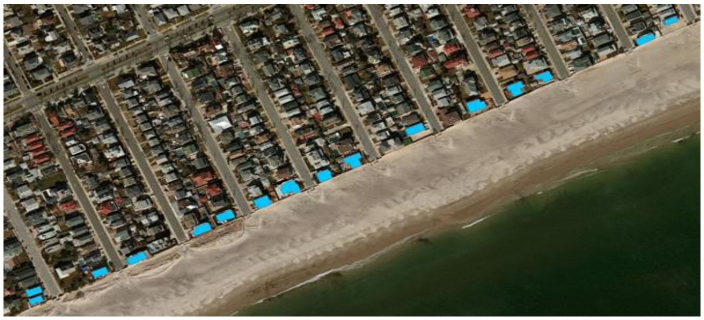

Figure 5. Locations of Rockaway structures destroyed during Hurricane Sandy are indicated in blue.

BeachFX is a Monte-Carlo simulation-based planning model designed to support decision-making in the coastal planning process. Using data derived from external sources, including detailed data on the physical and economic characteristics for all structures in a given area (an inventory), it evaluates the benefits and costs of coastal storm damage reduction projects for that area.

During Hurricane Sandy, 17 of the structures previously inventoried on the Rockaway Peninsula were destroyed. This provided a unique opportunity to verify the damage functions. These structures, highlighted in blue in Figure 5, were located between Beach 131st Street and Beach 143rd Street. The destroyed structures were mostly wood-frame colonial homes ranging in size from 1,000 – 2,700 sqft. A few of the buildings were 1-story ranch-style homes. Approximately 60% of the destroyed homes had basements. Ground elevation in this area was +9' to +11' NAVD, and main floor heights ranged from 1' – 7' above grade (3' on average).

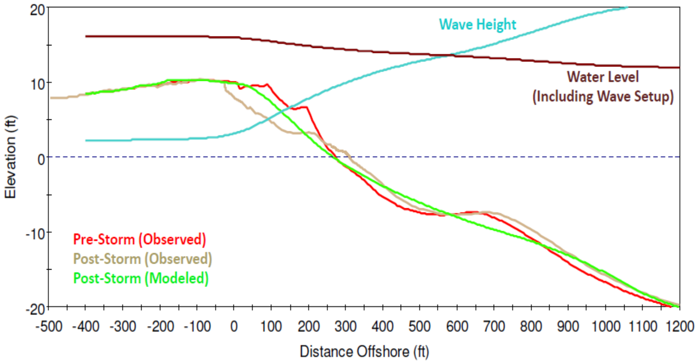

Figure 6. S-Beach Profile 27, modelled and observed at Beach 126th Street, Rockaway

Available S-Beach models show the storm surge, wave height, and pre- and post-storm shoreline in the same area as the destroyed structures (see Figure 6). The total water level, including wave set up,[9] was recorded at 16' NAVD, resulting in a water level upwards of 5' above grade at the structures, with wave heights at 3-4 ft. The majority of buildings, such as in Figure 7, appear to have been destroyed by wave action, which is not unexpected given the surge height and ground elevations. As seen in Figure 8, some structures were impacted by both waves and erosion.

Figure 7. Wave Damage, Rockaway Beach, NY.

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[9] See Definitions section at the end of this report

Figure 8. Wave and Erosion Damage, Rockaway Beach, NY.

5 Expert-Opinion Elicitation

Expert-opinion elicitation is a heuristic process of obtaining information in situations where empirical data are scarce or non-existent. It is heuristic in that it is an experience-based process of discovery, dependent on the knowledge and expertise of the participants. As such, expert-opinion elicitation is not a scientific tool, and cannot be expected to substitute for rigorous scientific research. However, it does supplement rigorous reliability and risk analytical methods by examining parameters and relationships that are difficult to characterize using traditional risk-analysis methods. Expert-opinion elicitation is a method well-suited to explore issues with significant uncertainty, complex issues, and issues that can have a significant effect on risk. The preferred setting for an expert-opinion elicitation panel is a face-to-face meeting of members assembled specifically to address issues defined by a team of analysts. [10]

5.1 Purpose and Objective

The purpose of the expert-opinion elicitation sessions conducted during the three-day period April 22 – 24, 2014, was to use a nationally-based expert panel to estimate the extent of damage resulting from coastal wave, erosion, and saltwater flooding for residential and nonresidential structures and their contents. Once trained, panelists were asked to render expert judgment on the issues that were communicated to them regarding coastal storm-related damage to selected categories of structures. Instead of estimating a total value for the prototypical structures or their contents, the panel was asked to estimate the damage percentages at various depths of flooding. The results of the elicitation were used to develop generic damage functions. These damage functions are used to estimate the percent loss from damages expected to result from a coastal storm event. The damage functions are applicable to homes and businesses located along the north Atlantic coast of the United States.

Note to users: Content-to-structure value ratios (CVSRs) are not available with these damage functions. CVSRs should be based on empirical valuation surveys.

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[10] Coastal Storm Damage Relationships Based on Expert Opinion Elicitation, 2002

5.2 Method

Beginning several months prior to the expert elicitation, the study team conducted weekly phone calls to develop the method and materials necessary for the sessions, and to select the appropriate panelists. The study team submitted its method through the vertical chain of review in the USACE and incorporated recommendations as necessary. Details regarding the scheduling of the panelists, the location, the equipment needed, and the agenda for the elicitation were finalized one month prior to the sessions.

5.3 Panelist Selection and Preparation

A list of potential panelists was developed based on known expertise in a particular field, professional reference, and previous participation in an expert-opinion elicitation panel. The panel was structured to ensure a broad range of expertise and experience in various engineering disciplines and insurance and risk management professions.

The panel was selected in part based on the desire to have experts with backgrounds in restoration, adjustments and appraisals, structural engineering, mechanical, electrical, and plumbing (MEP), and general risk management. Potential panelists were contacted to determine their interest and availability in participating in the panel.

The selected panelists included structural, mechanical/ electrical and coastal engineers (including individuals who worked on post Sandy inspection and recovery) and technical expertise from insurance adjustors, actuarial specialists and restoration specialists familiar with the costs of repairs and content replacement (see Table 1 on page 1). To ensure that the panelists arrived at the sessions with a common understanding of the issues and expectations, a packet of introductory materials was sent to each panel member prior to the beginning of the panel. The packet detailed the purpose and expectations of the expert-opinion elicitation panel. It also explained the elicitation process, the methods for collecting the data, and the proposed prototype structure and storm characteristics.

At the beginning of the panel session, the meeting facilitator and other members of the study team conducted an orientation for the panel. The orientation provided panelists with an overview of the NACCS study, the significance of the data to be developed, and an explanation of how the study would utilize the data. Panelists were also informed about the expert elicitation process, the expectations of each panelist, and the anticipated results of the study.[11] A summary of the data collected following Hurricane Sandy was presented. This included the types of structures that incurred damage, locations of the structures, the sources and depths of flooding, and damage amounts.

5.4 Training

Following the orientation, a training session was conducted to familiarize panelists with important topics, key terms, and procedural information. Panelists were instructed to focus on the total damage to the structures when making their estimates, and not to limit their estimate to their specific area of expertise. Rather than estimate a total value for the prototypical structures

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[11] Method and Approach, 2014

and contents, panelists were asked to estimate damage percentages for each at various depths of flooding.

The concept of uncertainty was discussed with the panel. Panelists were instructed not to presume that a certain level of flooding would produce an exact amount of damages. Factors such as construction characteristics, inventory value, quantity and placement of contents, local codes and regulations, floodwater contamination, and storm characteristics, would yield a range of possibilities. The purpose of the uncertainty exercise was to capture about 90% of the cases that might occur from a certain level of flooding. This 90% was to be based on the circumstances of an individual storm and the building characteristics, and not the probability of the storm event occurring. Damage functions were not expected to be an accurate representation of a specific structure. Rather, the average damage would be representative of the entire population of similar structures. The panel was instructed to eliminate extreme outcomes from its estimates.

Another topic discussed during the orientation session included definitions of the terminology used in coastal risk management evaluations. The study team was careful to define key terms in a manner consistent with the terminology used by the current USACE-certified models to estimate coastal flood damages. A glossary including key terms is presented at the end of this report.

Panelists received thorough instruction on the avoidance of inherent biases during the expert elicitation process. Panelists were encouraged to learn about the reasoning behind other panelists' estimates, but not to be swayed in their own estimate by the desire to conform. The main objective was not to develop a consensus, although estimates could be changed if necessary. The specific types of biases discussed were:

- **Observer bias**: Tendency to make measurement errors in the direction of one's wishes/expectations
- **Confirmation bias**: Tendency to emphasize information that confirms personal beliefs rather than information that might disprove them
- **Social desirability bias:** Tendency to describe beliefs in a socially desirable, but inaccurate, way
- **Overconfidence**: Tendency to assign high levels of confidence to issues that have large bands of uncertainty
- **Availability bias**: Tendency to overestimate the occurrence of rare, catastrophic events, which receive more publicity
- **Anchoring bias**: Tendency to remain relatively close to original starting value when making estimates
- **Inconsistency bias**: Occurs when experts are inconsistent in their reasoning as they work through a problem

A list of initial strawman prototype assumptions was distributed to the panelists for discussion. These assumptions included general characteristics related to the prototypical storm and structures. The panel was given the opportunity to discuss the assumptions and make changes as they deemed appropriate. A summary of this discussion and the resulting changes to the prototype storm and structures is available in the Expert Panel Meeting Minutes. Panelists were informed that their damage estimates were to be defined by storm parameters like flood duration, salt water, and wave type, and building parameters like construction characteristics, quantity and placement of contents, and local codes and regulations. It was emphasized that estimates needed to be applicable to a range of structures, and for that reason, panelists needed to avoid narrowing the prototypes into specific structures. Characteristics for the prototypical structures were varied for minimum, maximum, and most likely damage conditions. The panel was instructed to estimate the cost of repair according to current building codes, up to the replacement value of the structure.

5.5 Initial Panel Input

Each panelist was provided with a computer containing a panelist-specific electronic data worksheet for each prototype. Each worksheet was connected to a private network and designed so that the data could be entered and compiled in real time. The facilitator reviewed the spreadsheet with the panelists and explained how the measures were designed, and how to correctly fill out the worksheet.

Following the presentation, discussion, and refinement of each prototype’s assumptions, panelists independently entered their estimates for minimum, most likely, and maximum damage scenarios. For any given depth of flooding there was a range of estimates between the panelists. For the analysis, the median value of the individual panelists was used to represent the damage for each level of inundation or extent of erosion. Due to scheduling conflicts, all nine panelists were not available to provide input for every prototype. In cases where a panelist did not provide input, only the results of the panelists who provided feedback were used in the analysis (i.e., missing values were not counted as zero and included in the median value calculations).

5.6 Review of Panel Input and Data QC

After each elicitation, the median values for each level of inundation were compiled to produce damage functions for each structure category. The results were displayed on an overhead screen for discussion. If a considerable disparity was recorded among the individual panelist responses, the facilitator asked detailed questions to better understand the rationale for each assumption, and to give the panelists an opportunity to revise input errors.

5.7 Comparisons to Observed Sandy Impacts

During the post-elicitation discussion sessions, specific examples of storm-impacts on structures corresponding to the prototype categories were presented to the panel to illustrate the extent of the damage that occurred as a result of Hurricane Sandy. These examples included survey data, observations and field data by some of the individual panel members, and photographs.

The damage functions generated by the expert-opinion elicitation panel were compared on-screen to the results of the post-hurricane damage survey and the other data sources. The surveyed structures were grouped into categories that corresponded to the prototype categories. A scatterplot (Figure 9 through Figure 19) was created showing the percent damage and depth of flooding for each structure in the category.

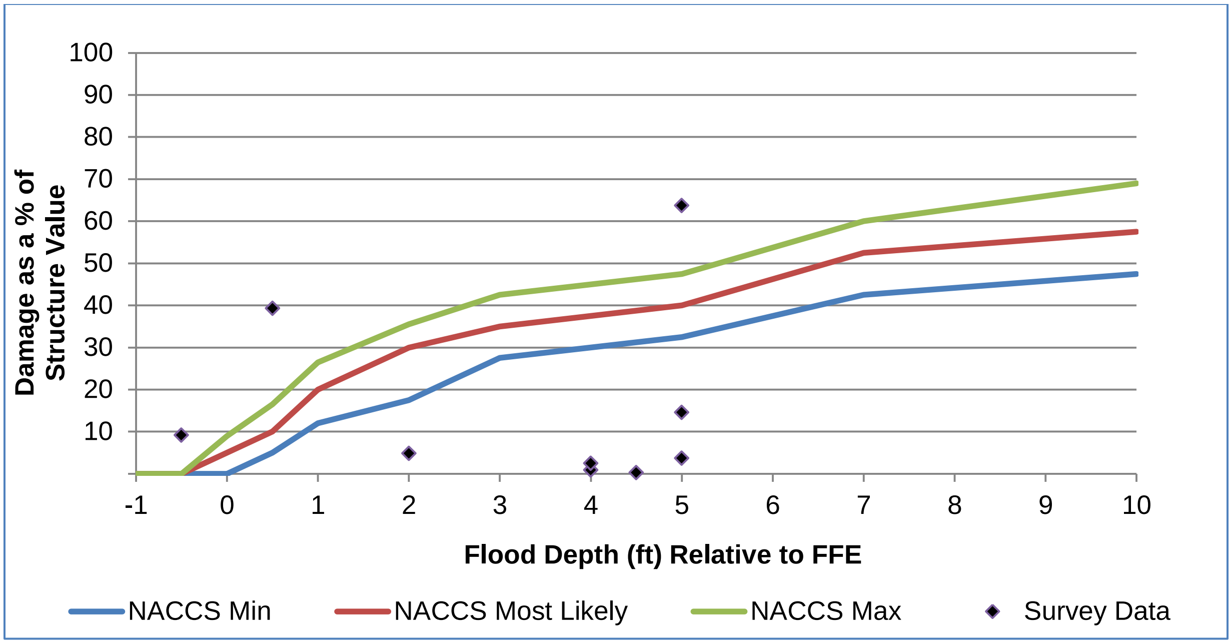

Figure 9. Comparison – Structural Damage from Inundation: NACCS Prototype 2 Engineered Commercial Structures vs. Survey Data for Engineered Commercial Structures

Figure 9 shows that the damage reported during the field surveys was based on a flood depth[12] of up to five feet above the first floor elevation. Structure damage was reported in most surveys to be less than 20% of the total structure value. The elicitation values appear higher than most of the reported survey data. This may be a reflection that the sample selection tended to exclude buildings with the highest levels of damage, since these structures were most likely to have been demolished or remain unoccupied. This concern is likely to apply to many of the comparisons, and be most noticeable for the erosion and wave damage functions.

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[12] See Definitions section at the end of this report

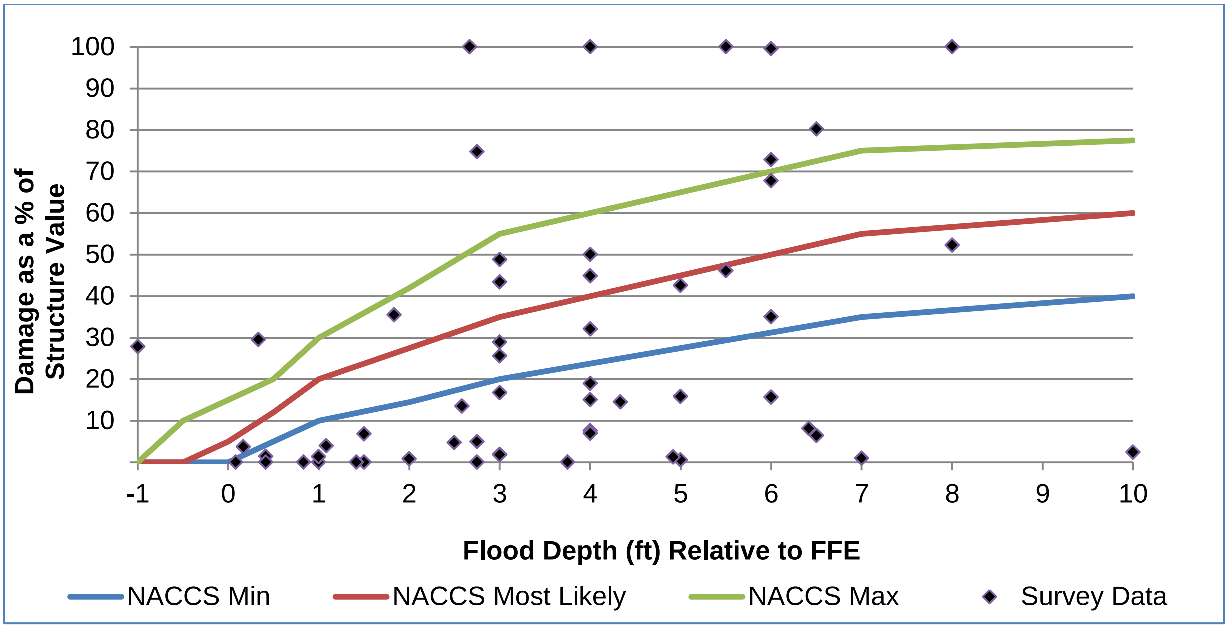

Figure 10. Comparison – Structural Damage from Inundation: NACCS Prototype 3 Non/Pre-Engineered Commercial Structures vs. Survey Data for Non/Pre-Engineered Commercial Structures

In Figure 10, damage reported during the field surveys was generally based on flood depths as high as six to eight feet above the first floor elevation with one respondent reporting a depth of ten feet above the first floor elevation. The elicitation values appear to reasonably represent the survey data reported for the structure damage as a percent of the total structure value although the elicitation estimates higher damage at a lower elevation.

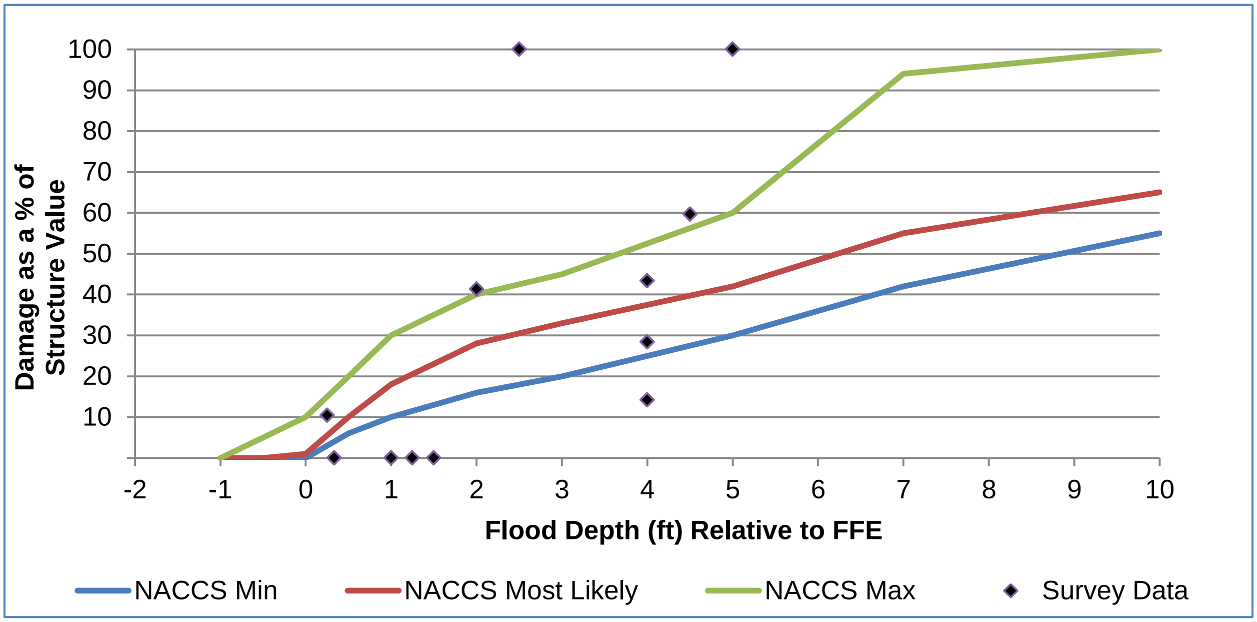

Figure 11. Comparison – Structural Damage from Inundation: NACCS Prototype 5A Single Story Residence, No Basement vs. Survey Data for Single-Story Residences without Basements

Figure 11 shows that the damage information collected during the field surveys for single – family residences without basements reported flooding depths up to five feet above the first floor elevation. At flood depths up to 1.5 feet several respondents indicated they suffered no structural damage to their homes, while the elicitation damage functions indicated damage would begin at depths from (-)1 feet.

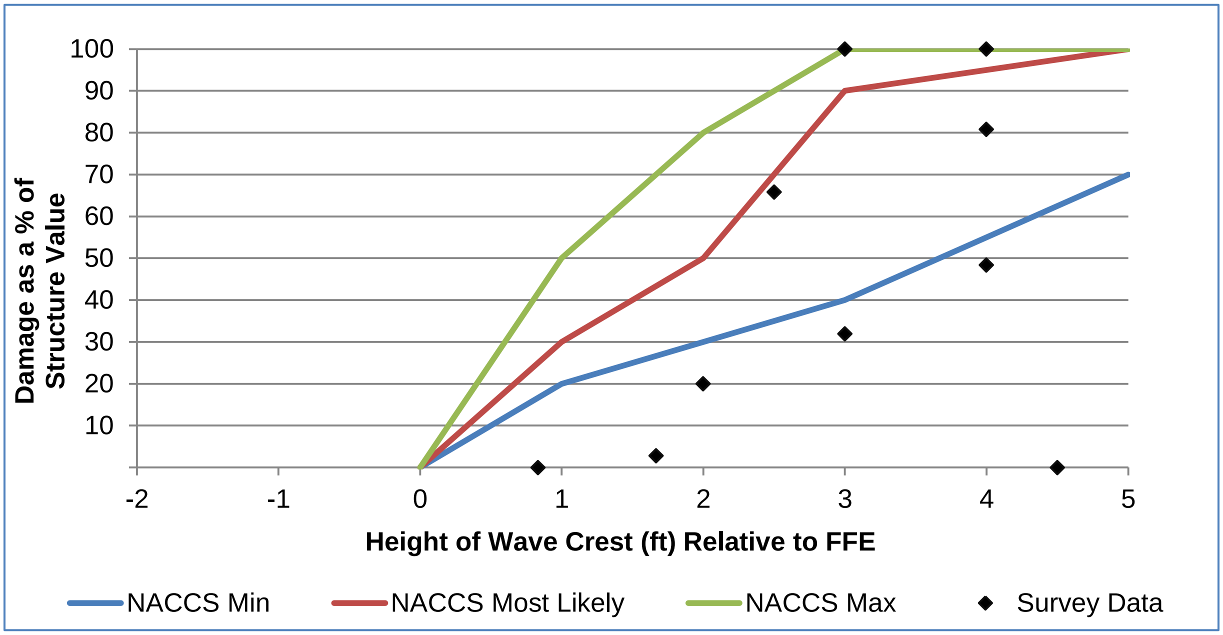

Figure 12. Comparison – Structural Damage from Waves, Slab Foundation: NACCS Prototype 5A Single Story Residence, No Basement vs. Survey Data for Single-Story Residences without Basements

The damage information collected during the field surveys generally follows the elicitation damage functions in Figure 12. However, the minimum damage functions assumed higher damage at each level. Several respondents reported minimal damage, below 20% of the structure value while reporting wave crests up to 2 feet above the first floor elevation. It is possible these structures were constructed with methods and materials more resistant to the reported storm wave action, or that the structure was exposed to non-breaking waves, which are not as destructive as breaking waves.[13] At wave crests more than 3 feet above the first floor the elicitation damage functions and the reported damages more closely follow. It is important to reiterate that structures destroyed by waves are likely to be under-represented in the field samples.

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[13] See Definitions section at the end of this report

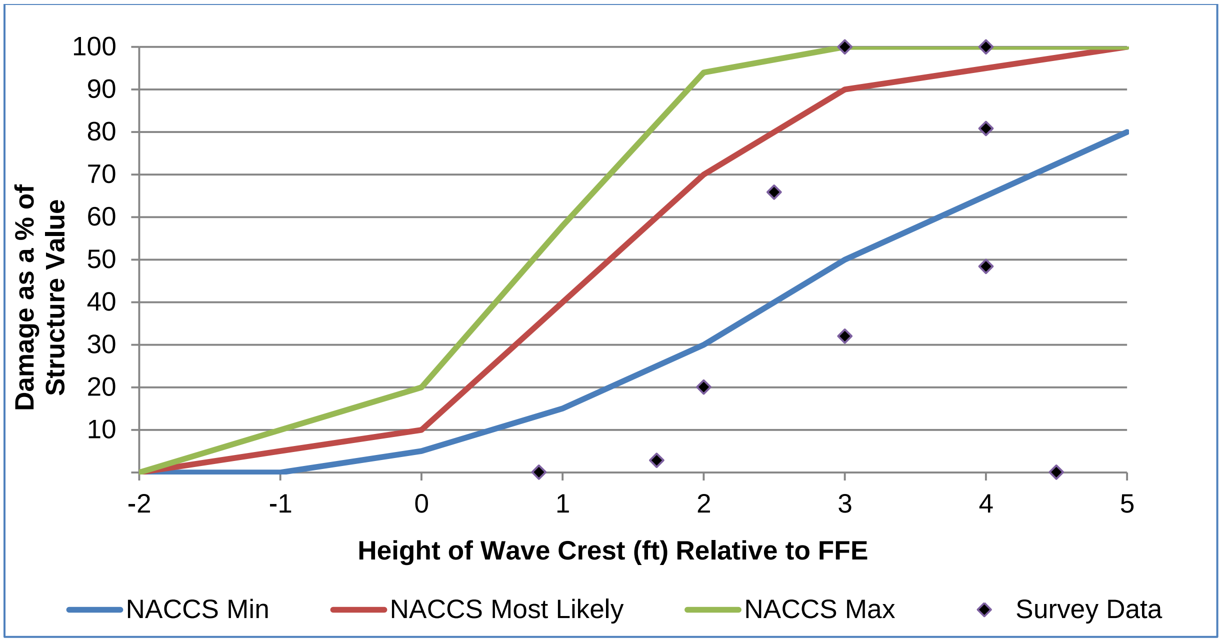

Figure 13. Comparison – Structural Damage from Waves, Extended Foundation Wall: NACCS Prototype 5A Single Story Residence, No Basement vs. Survey Data for Single-Story Residences without Basements

Figure 13 shows that the damage information collected during the field surveys generally follows the elicitation damage functions, however, the minimum damage functions from the elicitation estimate higher damage than reported at a number of structures. Several respondents reported limited damage, below 20% of the structure value, while reporting wave crests up to 2 feet above the first floor elevation

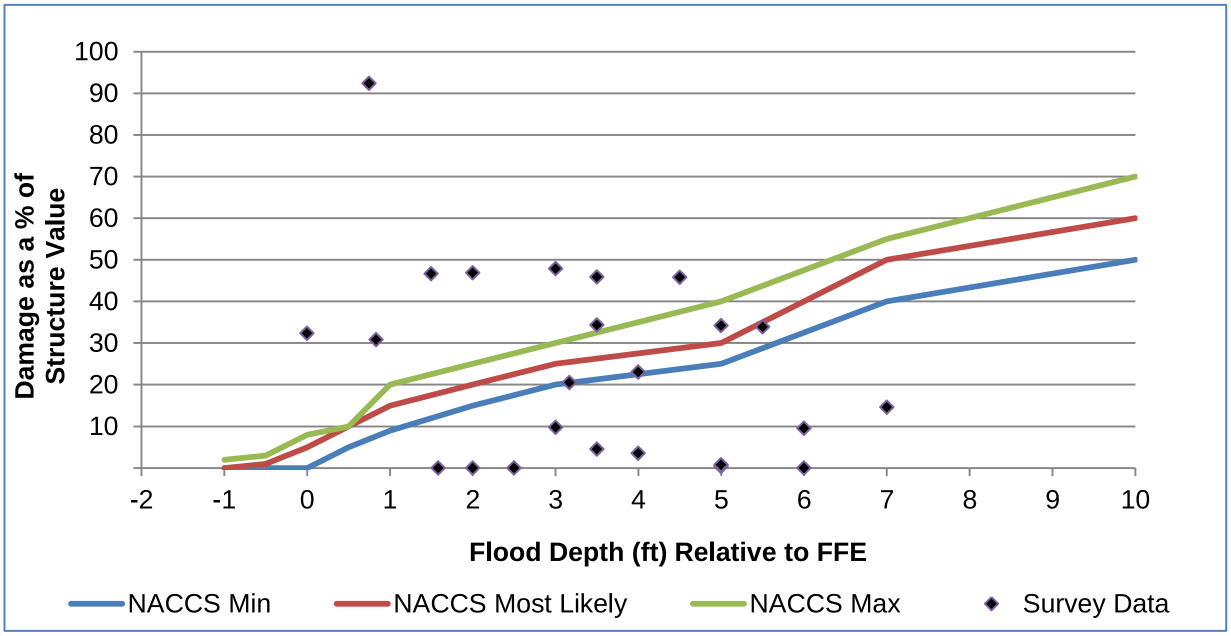

Figure 14. Comparison – Structural Damage from Inundation: NACCS Prototype 5B Two-Story Residence, No Basement vs. Survey Data for Multi-Story Residences without Basements

From Figure 14, it can be seen that the elicitation damage functions are relatively flat, which is also is reflected in the field survey data. The damages reported in the surveys generally range up to 50% of the structure value and were not highly sensitive to the flood depth.

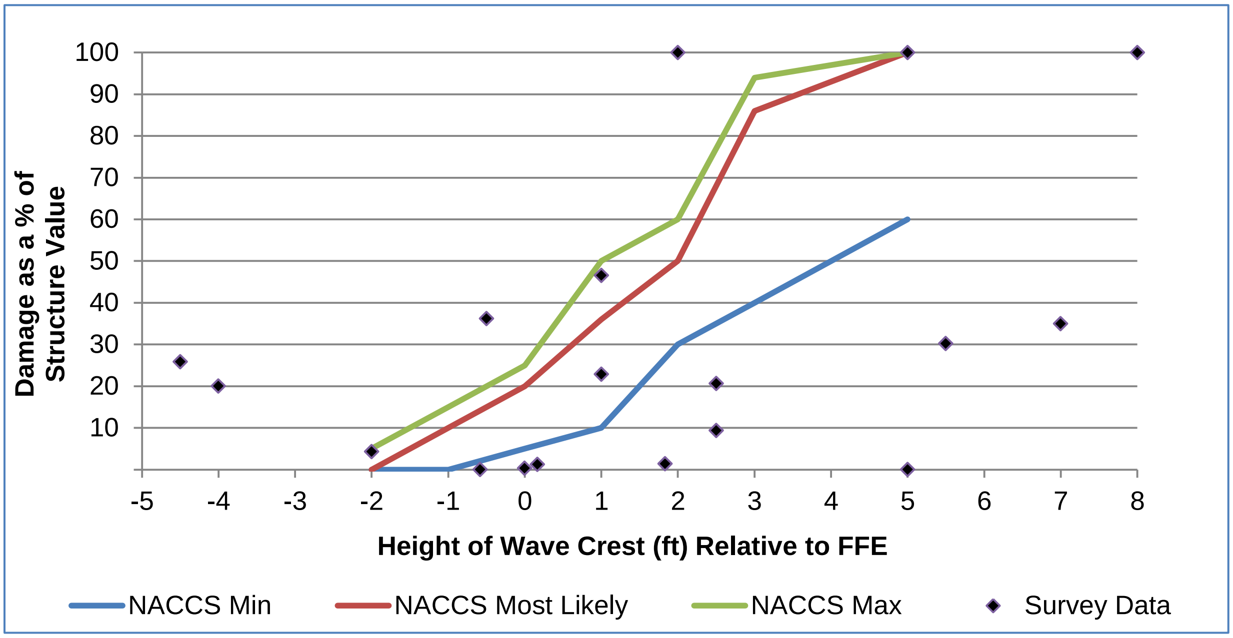

Figure 15. Comparison – Structural Damage from Waves: NACCS Prototype 5B Two-Story Residence, No Basement vs. Survey Data for Multi-Story Residences without Basements

The elicitation damage functions in Figure 15 only indicate damage for waves up to a depth of 5 feet above the first floor, as it was expected that the structure would most likely be completely destroyed at this point. However, several field survey reports indicated less than total damage up to a wave crest of 8 feet above the first floor. Based on the prototype foundation types, the elicitation damage functions indicate damage starting at elevation (-)2, however several residences had foundations/crawl spaces higher than 5 feet above grade and the owners reported structural damage with wave crests as much as (-)5 below the first floor. Depths up to 2.5 feet above the first floor caused damage that was reported as between 10% and 20% of the structural value, while the elicitation damage functions estimated damage would be higher. It is felt that the homeowners overstated exposure to waves.

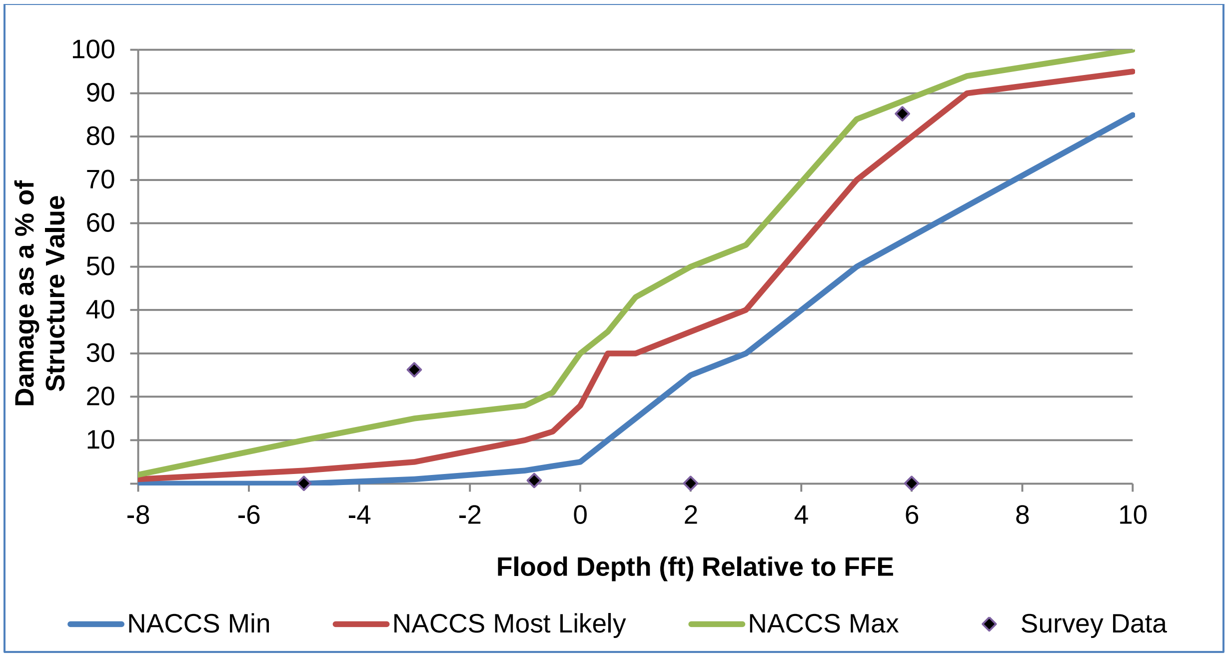

Figure 16. Comparison – Structural Damage from Inundation: NACCS Prototype 6A Single-Story Residence, with Basement vs. Survey Data for Single-Story Residences with Basements

The structural damages reported during the field surveys of the prototype do not follow typical damage relationships, such as the elicitation damage functions (Figure 16). Only one resident interviewed indicated damage below the first floor. In one extreme example, a respondent indicated there was no damage with 6 feet of water above the first floor.

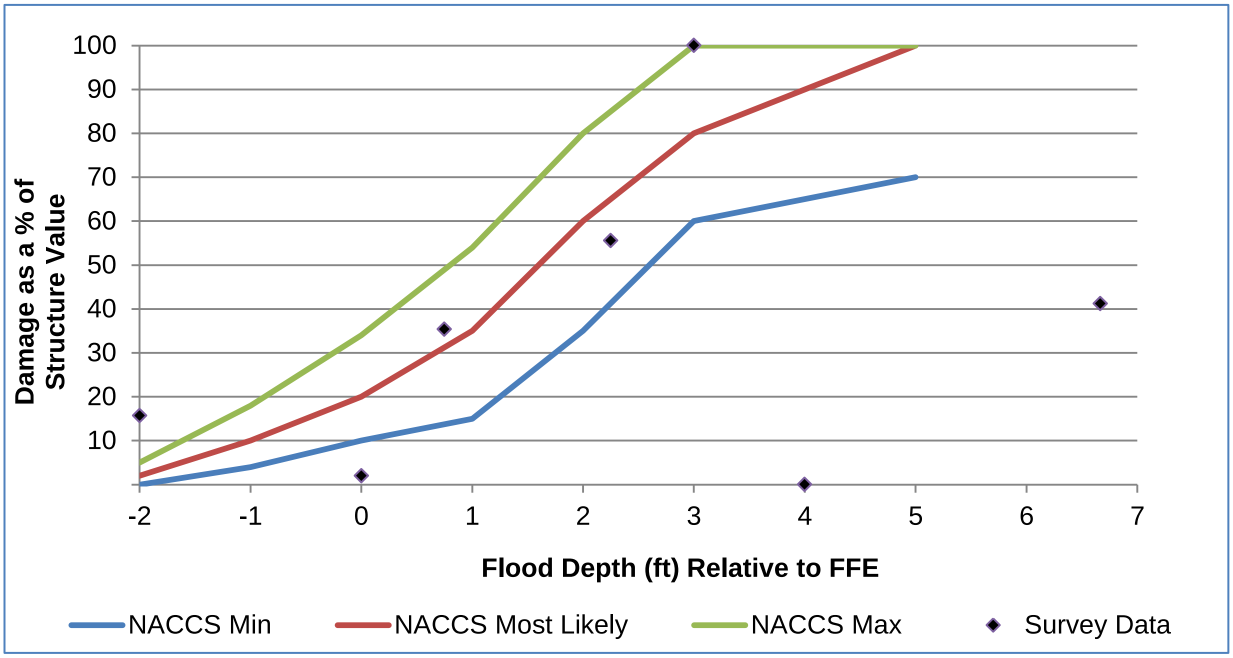

Figure 17. Comparison – Structural Damage from Waves: NACCS Prototype 6B Two-Story Residence, with Basement vs. Survey Data for Multi-Story Residences with Basements

The elicitation damage functions in Figure 17 generally follow the damages reported during the field surveys. One respondent confirmed damage at a wave crest elevation below FFE.

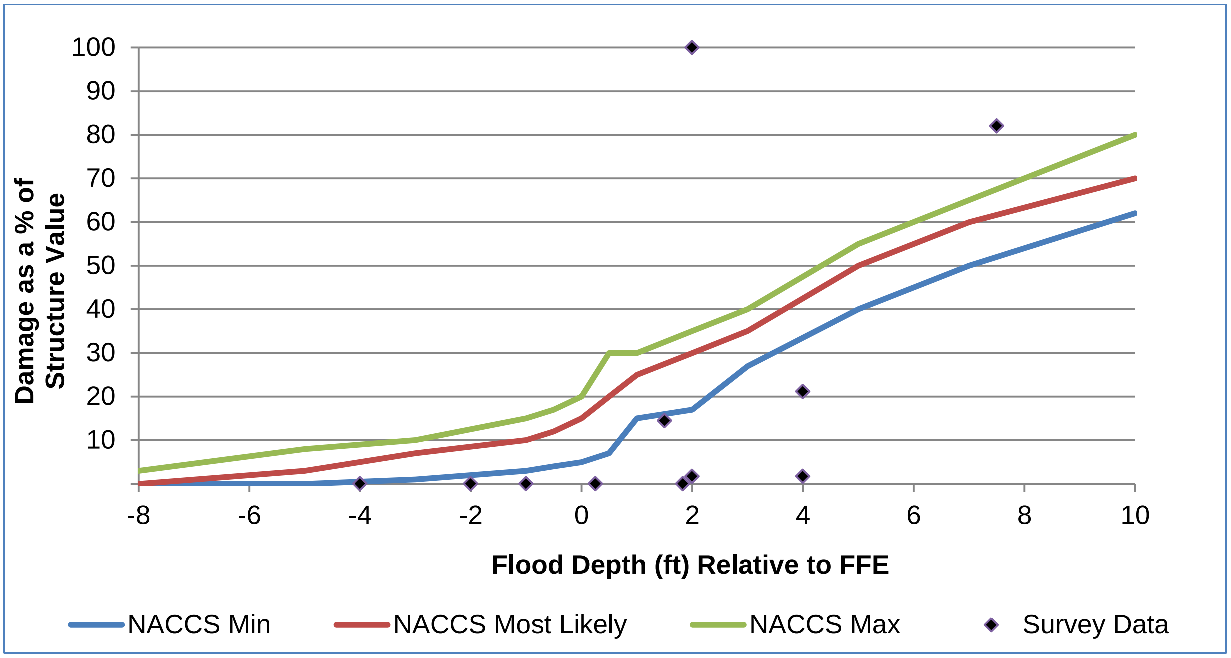

Figure 18. Comparison – Structural Damage from Inundation: NACCS Prototype 6B Two-Story Residence, with Basement vs. Survey Data for Multi-Story Residences with Basements

The elicitation damage functions in Figure 18 are generally higher than the damages reported during the field surveys. This appears to be from under reporting of damage by the homeowner. Several homeowners reported no damage with up to 4 feet of water above the first floor. Other respondents reported 100% damage with 2 feet of water and 82% damage with 8 feet of water above the first floor.

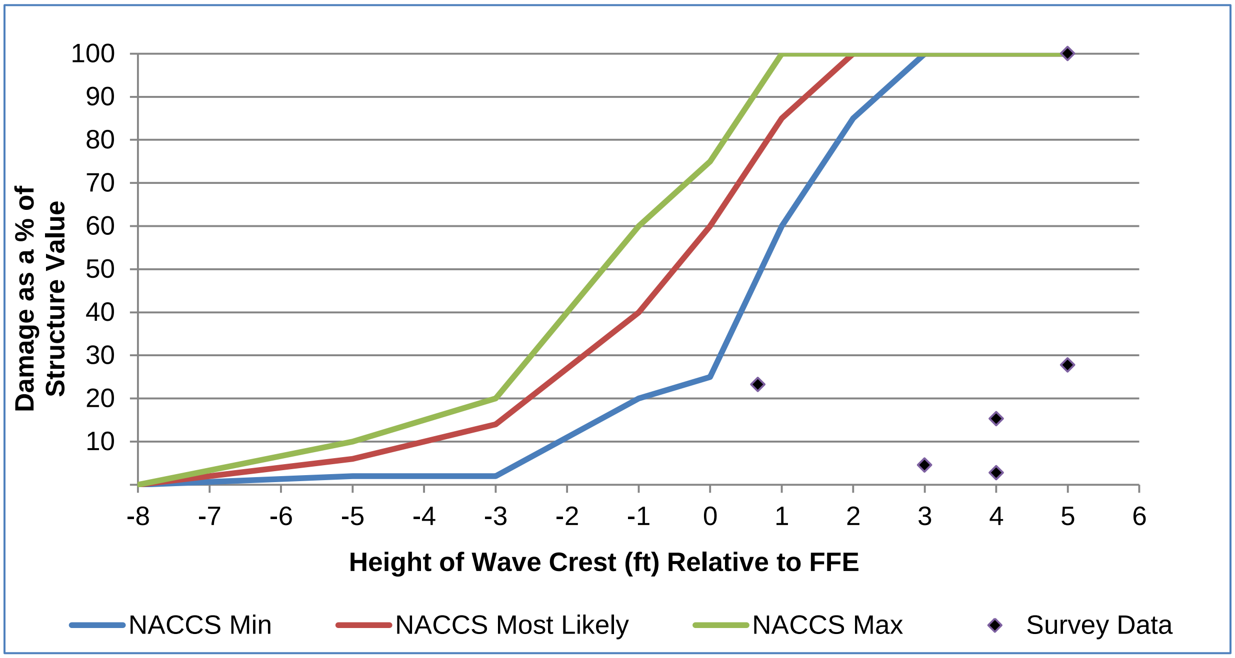

Figure 19. Comparison – Structural Damage from Waves: NACCS Prototype 7B Buildings on Pile Foundation with Enclosures vs. Survey Data for Buildings on Pile Foundations with Enclosures

Figure 19 shows the elicitation damage functions show a higher amount of damage at each elevation than the survey data indicated. It is suspected that the level of the enclosure was assigned as the first floor elevation during the field survey. A shift in the survey points to the left 8 or 9 feet would produce a better fit.

5.8 Data Comparisons to Other Functions

A number of damage functions were reviewed for the purpose of comparison, including damage functions from Economic Guidance Memorandums (EGMs) 01-03 and 04-01, the ACOE 2002 elicitation, the 2009 FEMA Non-Residential Depth-Damage Functions, and the 2011 FEMA Coastal Damage elicitation. The damage functions that were most comparable to the damage functions produced by the 2014 NACCS panel were EGM 01-03, EGM 04-01, and those generated by the ACOE 2002 elicitation. Figure 21 through Figure 35 provide these comparisons.

The EGM damage functions were derived from data collected from major flooding case studies across the United States. Post-flood surveys were conducted by the ACOE Flood Damage Collection Program using a standardized questionnaire. Data focused on the following residential categories: one-story, no basement; one-story, with basement; two or more stories, no basement; two or more stories with basement; split level, no basement; and split level, with basement.

To develop the model, a stepwise regression analysis of several possible independent variables was conducted, including flood depth, duration, warning lead time, and external building material. This analysis showed flood depth to be the only statistically significant variable for predicting flood damage. All other potential independent variables were therefore excluded from the final damage functions. Additional analysis of the depth-damage relationships within the data set indicated that a cubic form was the best statistical fit.

EGM damage functions are presented as mean percent damage, with accompanying standard deviations that provide a statistically valid measure of both the random error and the sampling error associated with the predicted percent damage at each depth. EGM damage functions are expressed as a percentage, rather than a dollar amount, because this makes them more easily applicable to different geographic regions. Expressing the damage functions as a percentage also insulates them from price level changes over time.

The EGM damage functions do not account for wave or erosion damage. Structure damage was modeled as a percentage of structure value. Content damage was modeled as a percentage of structure value using a Content-to-Structure Value Ratio. This step was taken to reduce the cost of determining content valuations for residential properties. The EGM damage functions do not include direct costs for clean-up expenses, unpaid hours for clean-up and repair, emergency damage prevention actions, and other flood-related costs. Comparisons were made between the EGM damage functions and the 2014 Inundation damage functions for the following residential categories: one-story, no basement; one-story, with basement; two or more stories, no basement; and two or more stories with basement.

Like 2014 damage functions, the 2002 damage functions were derived from an expert-opinion elicitation. The 2002 expert elicitation was conducted for the purpose of developing damage functions for use in Corps districts and for use by other local or national agencies. Although some of the participants in this panel brought expertise from the North Atlantic and California, the panel mainly focused on coastal storms in the hurricane-prone southeastern United States. In addition to inundation, the impacts of waves and erosion on structures were also considered.

The main curve in all of the 2002 damage functions represents the experts' median estimate of damage as a percent of total structure value, but the upper and lower curves were derived differently depending on the damage type. For inundation damage, the upper curve was set equal to the New Orleans District's estimate for structures on piers, and the lower curve was set equal to the A-Zone curves produced by the Federal Insurance and Mitigation Administration (FIMA). For wave and erosion damage, the upper and lower curves represent estimates of the range of damages.

Table 5 compares the EGM damage functions, 2002 damage functions, and 2014 damage functions in terms of derivation, damage mechanisms, and building characteristics. One important difference between the 2014 damage functions and the other two damage functions is that the 2014 damage functions varied building characteristics with the minimum, most-likely, and maximum damage scenarios.

All of the damage functions provide estimates for inundation damage. However, only the 2014 and 2002 damage functions estimate wave and erosion damage. Both the 2014 and EGM damage functions estimate content damage, but it is important to note that they do so in different ways. The EGM damage functions model content damage as a percent of structure value. The 2014 damage functions model content damage as a percent of content value. In the comparisons drawn in this report between the EGM and NACCS content damage functions, a CVSR was applied to the EGM damage functions to convert the EGM damage values to a percent of contents value. The 2002 damage functions do not address content damage.

EGM damage functions are limited to residential structures. The 2014 damage functions estimate damage to both commercial and residential usages. In the case of high rises, they can also address mixed-use occupancies. The 2002 elicitation agenda did not limit the topic to residential structures. Although residential structures were discussed in the workshop, the results can be extended to non-residential buildings of similar design and construction.

Different foundation characteristics were taken into account by the respective damage functions. The EGM damage functions focused on residential structures with and without basements. However, the foundation type (crawl space or slab) for the non-basement residences was not specified. The 2002 elicitation focused on buildings with crawl spaces and buildings with pile foundations, but did not address basements. The 2014 damage functions took a wider variety of foundation conditions into account than the 2002 and EGM damage functions.

All three damage functions estimate damage to single-story structures. The 2014 damage functions estimate damage to two-story structures, and the EGM damage functions estimate damage to two-or-more story structures. Some comparisons were drawn between 2014 two-story residential damage functions and EGM two-or-more story damage functions.

Table 5. Comparison of EGM, 2002, and 2014 Damage Function Characteristics

		2014 NACCS Elicitation	**2002 Elicitation**	**EGM 01-03 and EGM 04-01**
DERIVATION	Statistical Analysis			x
	Elicitation	x	x	
DAMAGE SOURCE	Wave Damage	x	x	
	Erosion Damage	x	x	
	Inundation Damage	x	x	x
DAMAGE POINT	Damage to Structure	x	x	x
	Damage to Contents	x		x
STORIES	One-Story	x	x	x
	Two-or-More Stories			x
	Two Story	x		
FOUNDATION	Shallow Foundation			x
	Basement	x		x
	Crawl Space	x	x	
	Slab	x		
	Pile Foundation		x	
	Open Pile Foundation	x	x	
	Closed Pile Foundation	x	x	
USAGE	Commercial	x		
	Mixed Use	x		
	Residential	x		x

Unlike the EGM damage functions and the 2002 damage functions, the 2014 damage functions vary the building characteristics with the minimum and maximum damage scenarios.

Wave Damage Estimates

Possible comparisons for wave damage were 2014 Prototype 5A with 2002 Structure Not on Piles; 2014 Prototype 7A with 2002 Structure on Piles (No Enclosures); and 2014 Prototype 7B with 2002 With Piles (Finished, Full Enclosure).

There are a few issues that complicate the comparison of the 2002 and 2014 wave damage functions. These issues render a comparison between 2014 Prototype 5A with 2002 Structure Not on Piles invalid, and require an adjustment to be made to the 2002 wave crest elevations for the 2014 Prototype 7A and 7B comparisons. Some of these issues relate to the assumptions that the each panel made regarding wave characteristics and measurement, and also to knowledge gained in the field following Hurricane Ike.

Both the 2002 and the 2014 elicitations used the height of the wave crest as the independent variable for their respective wave damage functions. However, this measurement was taken from different reference points. The 2002 panel measured the height of the wave crest relative to the bottom of the lowest horizontal member, whereas the 2014 panel measured the height of the wave crest relative to the top of the FFE.

The 2014 panel assumed depth-limited waves, where the height of a breaking wave is a function of still-water depth ($H_b = 0.78d$). The 2002 panel did not assume depth-limited waves. Wave height in the 2002 elicitation did not vary with still-water depth. Waves were either present, or they were not present; they were either damaging, or they were not damaging.

FEMA-sponsored tests at the time of the 2002 elicitation showed that a wave with a wave crest measuring 1.5 feet above the bottom of the LHM would cause a building to fail. This estimation is demonstrated in the three wave-damage functions produced by the 2002 elicitation. All of the median and upper damage estimates in these damage functions show 100% wave damage occurring at 1.5 feet above the bottom of the LHM. Lower wave crest heights were shown to produce lower damage.

A drawback of excluding depth-limitation as a wave characteristic is that the significance of the still water depth is lost. This can cause some disconnect between the damage functions and some real-world situations. For example, the failure point associated with the 2002 Structure Not on Piles damage function was a wave crest of 1.5 feet above the LHM. This parameter works well for a building on shallow footings consisting of piers or a crawlspace, but it is not well suited for estimating wave damage for a building with a slab-on-grade foundation, or any condition where the flood depth is less than 1.0 foot. The LHM in the slab case would be the slab itself, and with an on-grade condition—or any condition where flood depth is below 1.0 foot—there is not enough still water depth to propagate a wave crest of 1.5 feet above the LHM.

The relationship between wave height and still water depth was considered in each wave-damage scenario evaluated during the 2014 elicitation. The assumption of depth-limited waves required panel members to use the FFE to deduce the still water depth, and to then calculate the height of the wave accordingly. Panelists were then required to determine the point at which the still water depth would yield waves large enough to cause wave-type damage. Table 6 shows an example of wave crest elevation calculation results at different SWEs for a FFE of 9.0 feet above grade.

Table 6. Example of Wave Crest Elevation Calculation Results for a FFE of 9.0 Feet Above Grade

Still Water Elevation (d)	Adjusted Still Water Elevation (d-FFE)	Wave Height (H_b = 0.78d)	Wave Crest Elevation ($0.7H_b$+d)	Wave Crest Relative to Top of FFE (($0.7H_b$+d) - FFE)
1	-8	0.78	1.5	-7.5
2	-7	1.56	3.1	-5.9
3	-6	2.34	4.6	-4.4
4	-5	3.12	6.2	-2.8
5	-4	3.9	7.7	-1.3
6	-3	4.68	9.3	0.3
7	-2	5.46	10.8	1.8
8	-1	6.24	12.4	3.4
9	0	7.02	13.9	4.9
10	1	7.8	15.5	6.5
11	2	8.58	17.0	8.0

A rough comparison can be drawn between the 2002 and 2014 wave damage functions for pile-supported structures by setting the 2002 structure FFE equal to the corresponding 2014 structure FFE, estimating the height of the bottom of the LHM (by assuming floor and girder thicknesses), and using the appropriate height of the wave crest above the LHM to establish a still water elevation for each 2002 scenario. For example, in order to compare the respective points of failure for the 2002 Structure on Piles (No Enclosures) damage function and the 2014 Building on Open Pile Foundation (Prototype 7A) damage function, the following assumptions are made for the 2002 structure:

FFE = 9.0 feet above grade
Floor thickness = 1.0 foot
LHM thickness = 1.0 foot
Bottom of LHM = 7.0 feet above grade

Using the wave crest height associated with 100% damage for the 2002 Structure on Piles (No Enclosures) damage function, which is 1.5 feet from the bottom of the LHM, the wave crest elevation can be calculated and used to determine the still water level and the wave height for the 2002 damage function:

Wave crest elevation = 7.0 + 1.5 = 8.5 feet above grade
$0.7H_b+d = 8.5$
$1.55d = 8.5$
$d = 5.5$ feet
$H_b = 4.3$ feet

Table *7* shows the flood and wave characteristics derived from the wave crest height associated with 100% damage associated with the 2002 Structure on Piles (No Enclosures) damage function as compared to those estimated for the 2014 Building on Open Pile Foundation (Prototype 7A) damage function. The 2002 estimates are significantly lower than those produced in the 2014 elicitation. One reason for this difference is that the 2014 panel was able to draw from the results of field research conducted in Galveston, TX, following Hurricane Ike in 2008. Based on observations there, the panel determined that while a 1.5 foot wave can be expected to initiate structural damage, a larger wave would probably be required to cause a building to fail. For wave damage in general, the failure points estimated in the 2014 elicitation were higher than those estimated in the 2002 elicitation, and are consistent with field observations following Hurricane Ike.

Table 7. Comparison of Still Water Elevation and Wave Characteristics for 2002 Structure on Piles (No Enclosures) Damage Function with 2014 Building on Open Pile Foundation (Prototype 7A) Damage Function

Damage Function	**FFE Above Grade**	**Wave Crest Relative to Top of FFE**	**Still Water Elevation (d)**	**Wave Height (H_b = 0.78d)**	**Wave Crest Elevation ($0.7H_b$+d)**
2002 Structure on Piles (No Enclosures)	9.0	-0.5	5.5	4.3	8.5
2014 Building on Open Pile Foundation (Prototype 7A)	9.0	2.0	7.1	5.5	11.0

Another reason for the difference in estimates is the difference in the point of reference from which the height of the wave crest is measured. An adjustment of +1.5 feet can be made to the 2002 reference point, roughly transforming the LHM into the FFE, and increasing the flood depth and the wave height.

Wave crest elevation = 8.5 + 1.5 = 10.0 feet above grade
$0.7H_b+d = 10.0$
$1.55d = 10.0$
$d = 6.5$ feet
$H_b = 5.0$ feet

Table 8 provides a comparison of the adjusted flood and wave characteristics associated with the 2002 Structure on Piles (No Enclosures) damage function with those of the 2014 Building on Open Pile Foundation (Prototype 7A) damage function.

The basis for this adjustment is as follows: Following Hurricane Ike, research teams deployed in Galveston found that buildings with shore-perpendicular girders suffered less damage than those with shore-parallel girders. Investigators observed that when girders were perpendicular to the shore, the floor beams tended to act as the LHM, effectively raising the LHM height for these structures by one or two feet. At the time of observation, it was determined that girders were generally perpendicular to the shoreline for parking purposes, which ultimately depended on street- and garage-orientation. A similar rationale is assumed to be employed in other coastal areas. To accommodate for the variety of possible girder-orientation conditions, an adjustment of +1.5 feet was made to the 2002 reference point when the results of the 2002 elicitation were compared to the results of the 2014 elicitation, raising the height of wave crest to 3.0 feet from the bottom of the LHM at the 100% damage point. This adjustment assumes that both the girders and the floor beams in a pile-elevated structure are 1.0.

Table 8. Adjusted Comparison of Still Water Elevation and Wave Characteristics for 2002 Structure on Piles (No Enclosures) Damage Function with 2014 Building on Open Pile Foundation (Prototype 7A) Damage Function

Damage Function	**FFE Above Grade**	**Wave Crest Relative to Top of FFE**	**Still Water Elevation (d)**	**Wave Height (H_b = 0.78d)**	**Wave Crest Elevation ($0.7H_b$+d)**
Adjusted 2002 Structure on Piles (No Enclosures)	9.0	1.0	6.5	5.0	10.0
2014 Building on Open Pile Foundation (Prototype 7A)	9.0	2.0	7.1	5.5	11.0

A visual comparison of the original and the adjusted 2002 wave conditions on the 2014 Prototype 7A Building on Open Pile Foundation is illustrated in Figure 20. The original condition is shown in green, the adjusted in red.

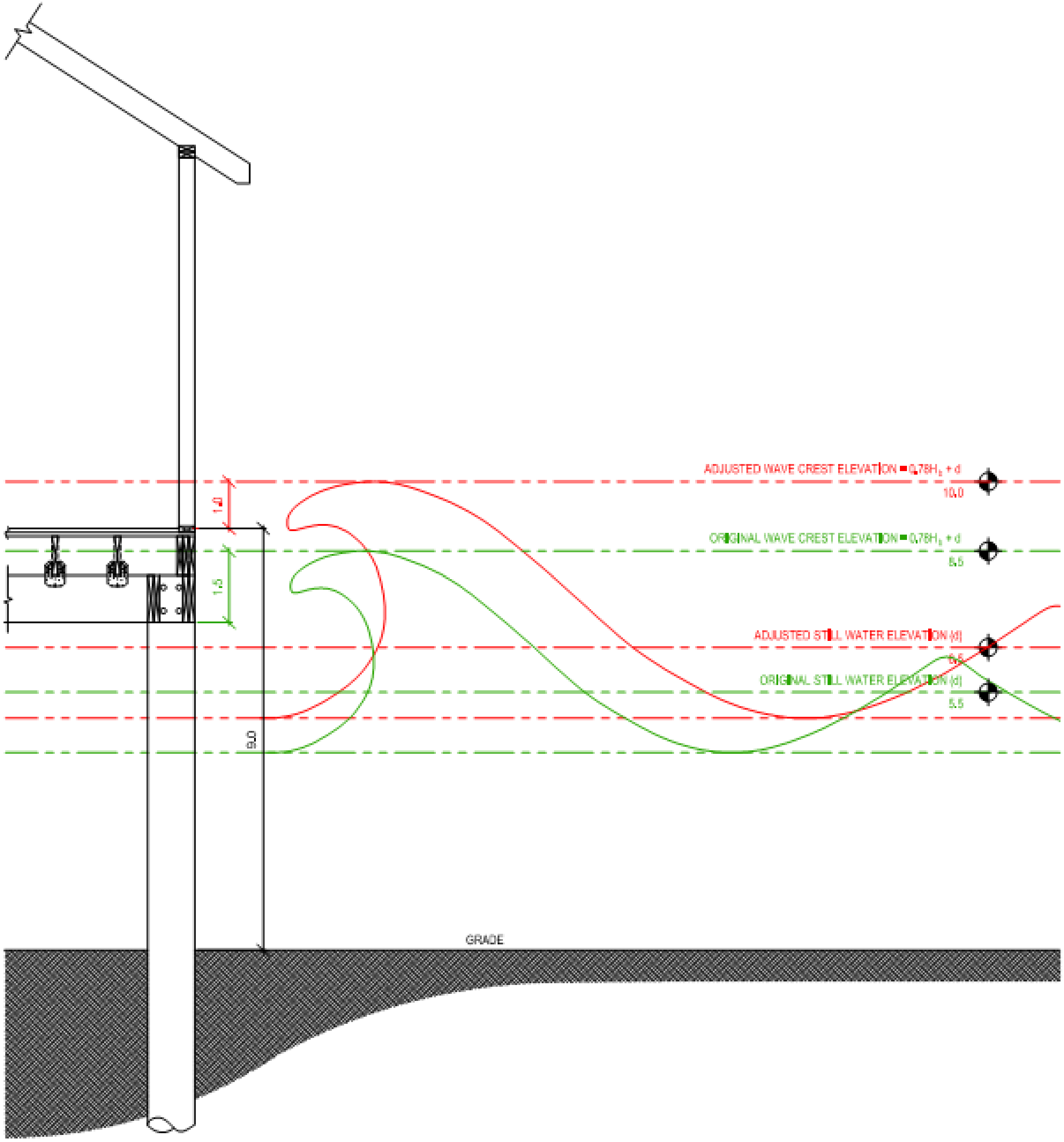

Figure 20. Visual Comparison of the Original and the Adjusted 2002 Wave Conditions

Figure 21 shows that the NACCS elicitation damage functions for structure damage as a percent of structure value are generally lower than the 2002 elicitation damage functions with a wider band of uncertainty than 2002. The current uncertainty reflects a greater understanding of the effects of mold on structures.

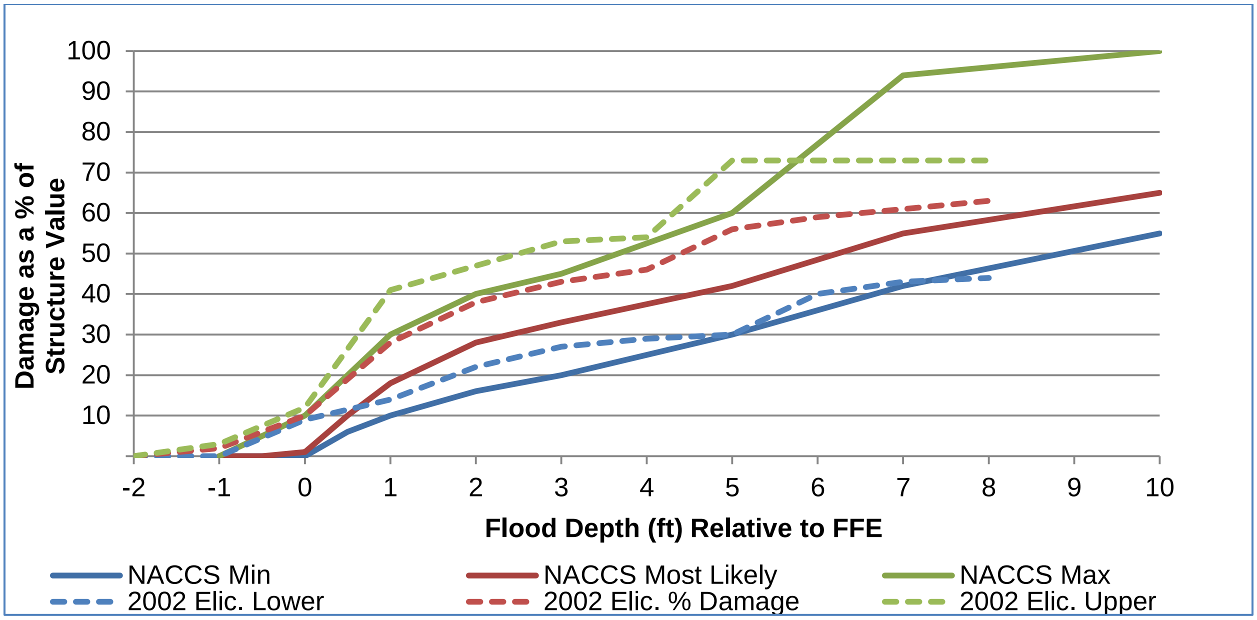

Figure 21. Comparison – Structural Damage from Inundation: NACCS Prototype 5A Single-Story, No Basement vs 2002 Elicitation Wood Frame without Piles

The elicitation damage functions in Figure 22 trend well with the damage functions presented in the Economic Guidance Memorandum (EGM) 01-03. Similar to the comparison to the 2002 elicitation damage functions presented in Figure 21, the expected damages are somewhat lower. As expected, the band of uncertainty for the elicitation damage functions is much wider. While somewhat lower, the damages from the most likely elicitation damage function compares well to the mean values from the EGM damage functions.

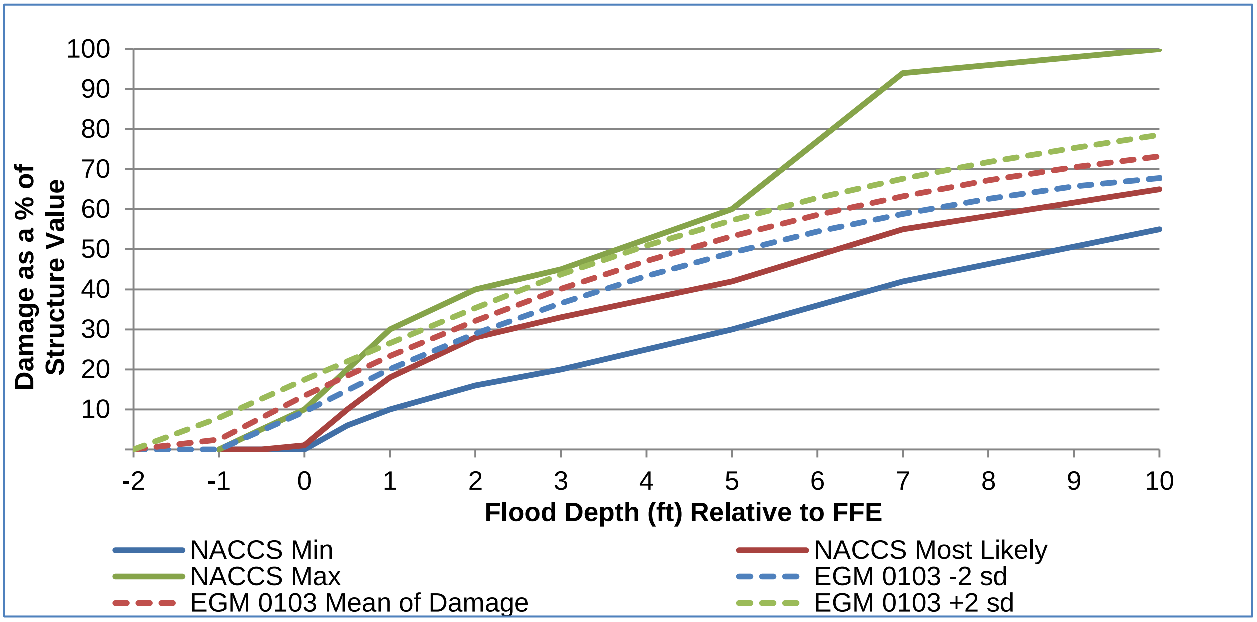

Figure 22. Comparison – Structural Damage from Inundation: NACCS Prototype 5A Single-Story, No Basement vs EGM 01-03 One Story, No Basement

Figure 23 presents a comparison of the NACCS Prototype 5A Single-Story, No Basement damage function with the EGM 01-03: One Story, No Basement damage function. A CVSR of 0.40 was applied to the EGM damage function to convert the EGM values from a percent of structure value to a percent of contents value. The NACCS damage function shows 100% contents damage occurring at a flood depth of 7 feet above the first floor elevation, and 75% of the contents damage occurs at approximately 3 feet. The EGM damage function shows the median content damage reaching 100% at 13 feet above the first floor elevation; 75% of the damage occurs at approximately 5 feet. One major reason for higher damage levels in the NACCS damage function is the damaging effect of mold, which was discussed by the panel at length.

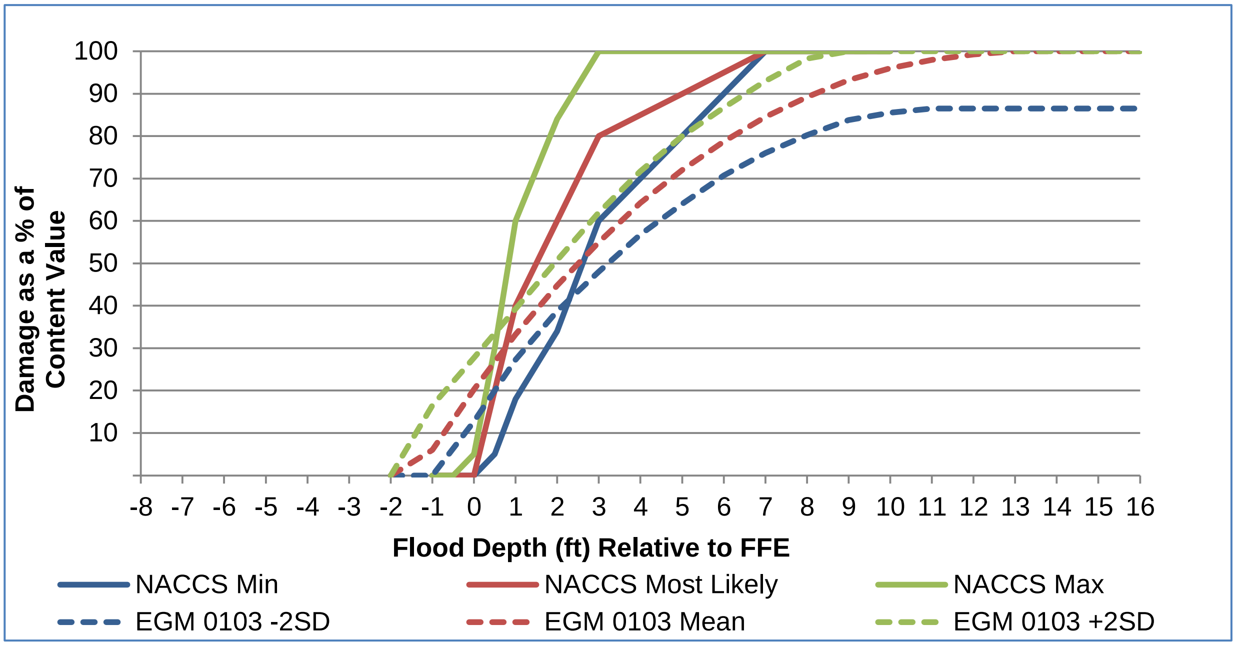

Figure 23. Comparison – Content Damage from Inundation: NACCS Prototype 5A Single-Story, No Basement vs. EGM 01-03: One Story, No Basement

Figure 24 presents the wave damage comparison for Prototype 5A, a single-story residence on a crawl space to the 2002 elicitation results for a structure not on piles. While the 2014 elicitation measured the height of the wave crest relative to the FFE, the 2002 elicitation measured the height of the wave crest relative to the bottom of the lowest horizontal member. To account for this difference, the x-axis for the 2002 elicitation has been shifted up 1.5 feet.

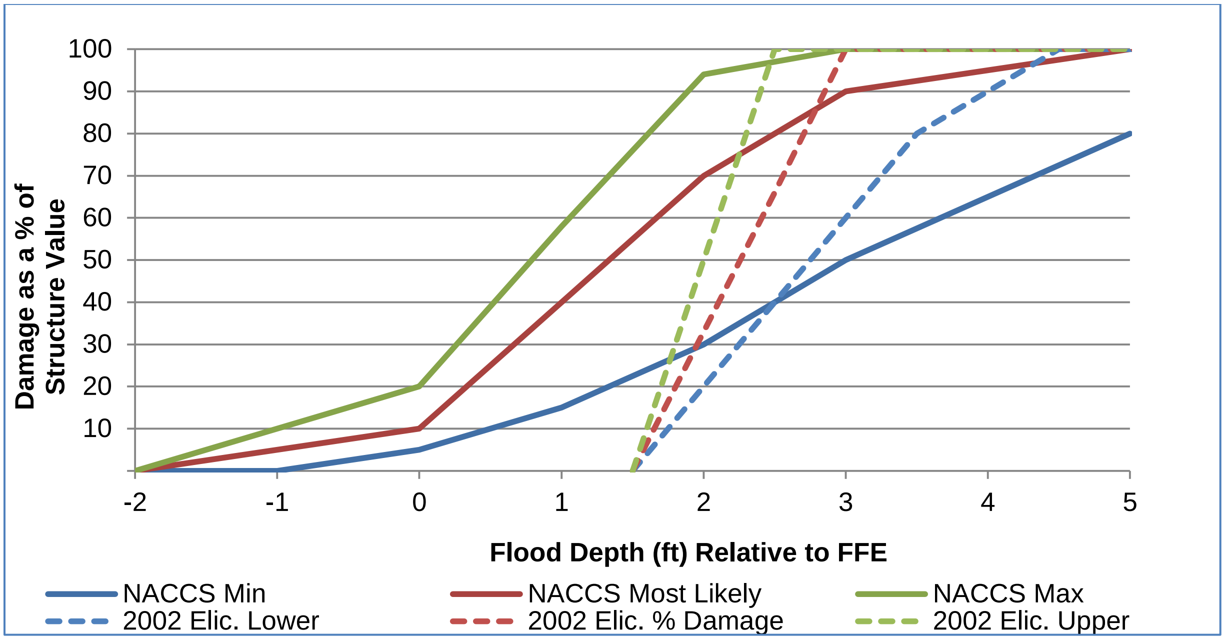

Figure 24. Comparison – Structural Damage from Waves, Extended Foundation Wall: NACCS Prototype 5A Single-Story, No Basement vs 2002 Elicitation Structure not on Piles

In Figure 25, both the NACCS and the 2002 damage functions depict structure damage as a percent of building footprint compromised by erosion. The damage functions are similar except for higher max damages for the 2002 maximum.

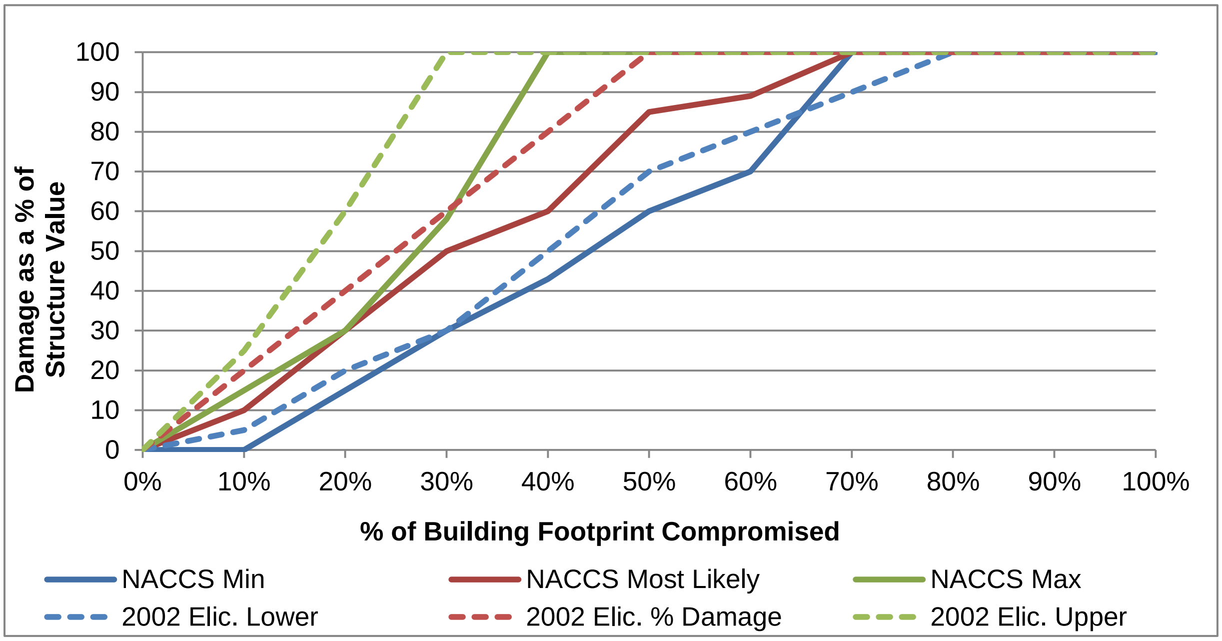

Figure 25. Comparison – Structural Damage from Erosion: NACCS Prototype 5A Single-Story, No Basement vs 2002 Elicitation Shallow Foundation

Both sets of damage functions in Figure 26 appear comparable.

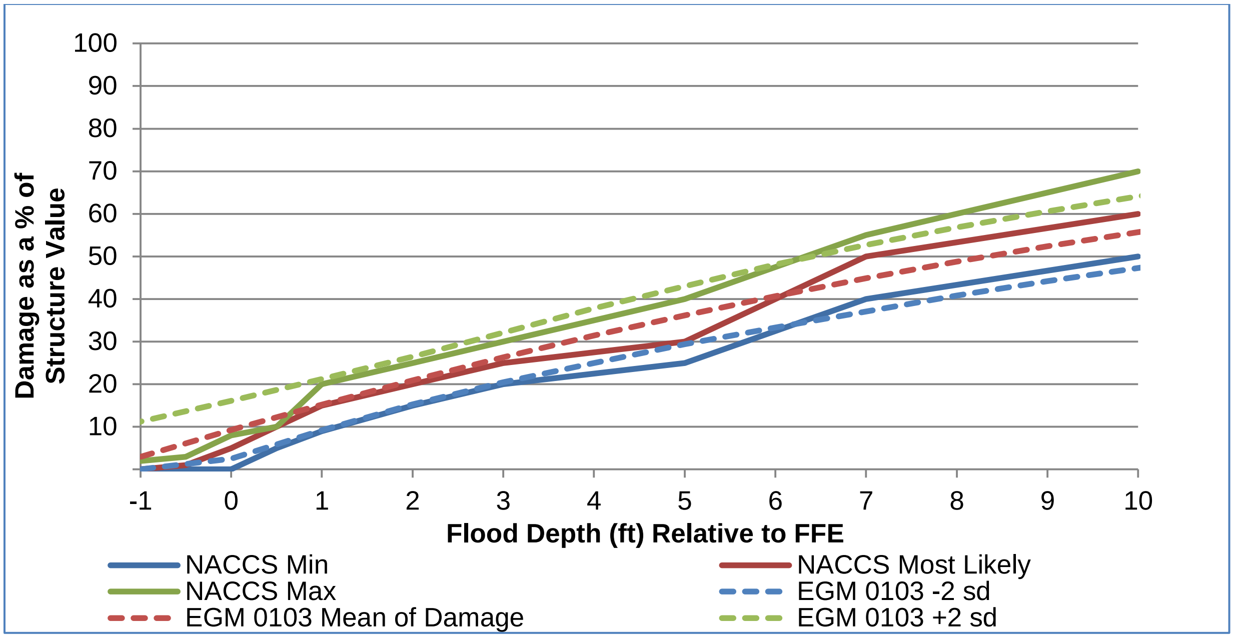

Figure 26. Comparison – Structural Damage from Inundation: NACCS Prototype 5B Two-Story, No Basement vs EGM 01-03 Two or More Stories, No Basement

In Figure 27, a CVSR of 0.40 was applied to the EGM damage function to convert the EGM values to a percent of contents value. The NACCS damage functions indicate that damage to contents as a percent of total contents value is greater than 50% at 5 feet of water above the first floor. At 10 feet of water damage equals 80% of the total contents value. The EGM damage functions show similar amounts of damage.

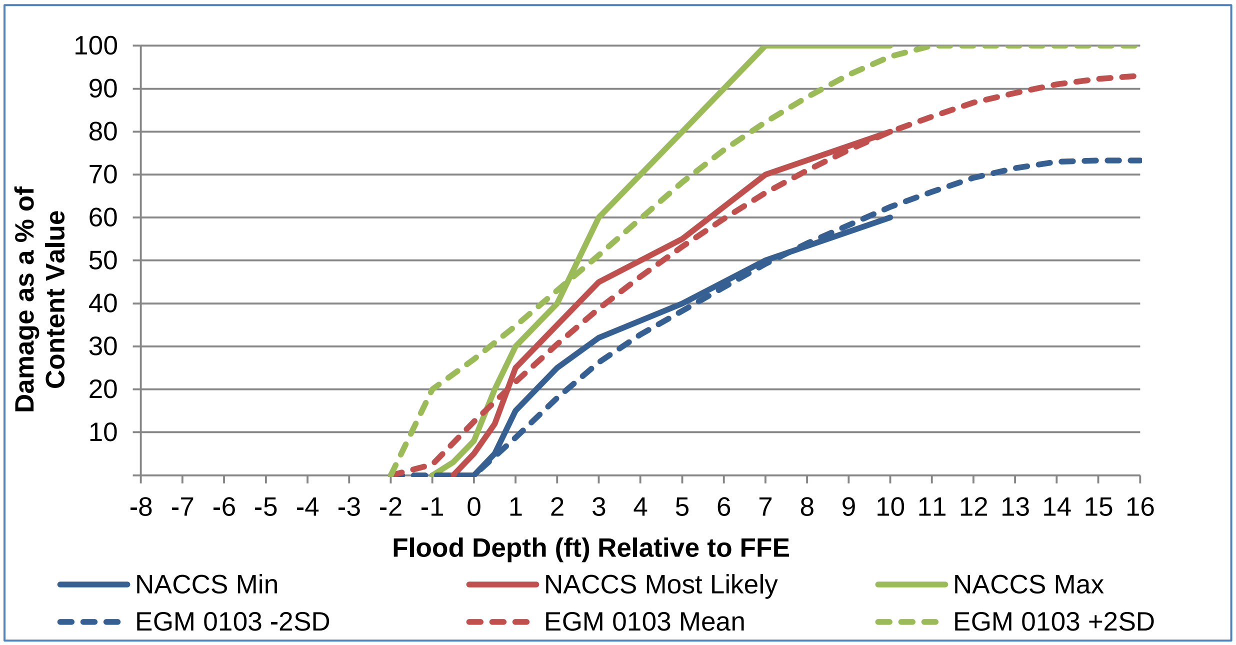

Figure 27. Comparison – Content Damage from Inundation: NACCS Prototype 5B Two-Story, No Basement vs EGM 01-03: Two or More Stories, No Basement

The inundation damage functions in Figure 28 are similar. The NACCS damage functions have much a wider band of uncertainty, which can expected when comparing minimum and maximum scenarios to +/- 1 standard deviation.

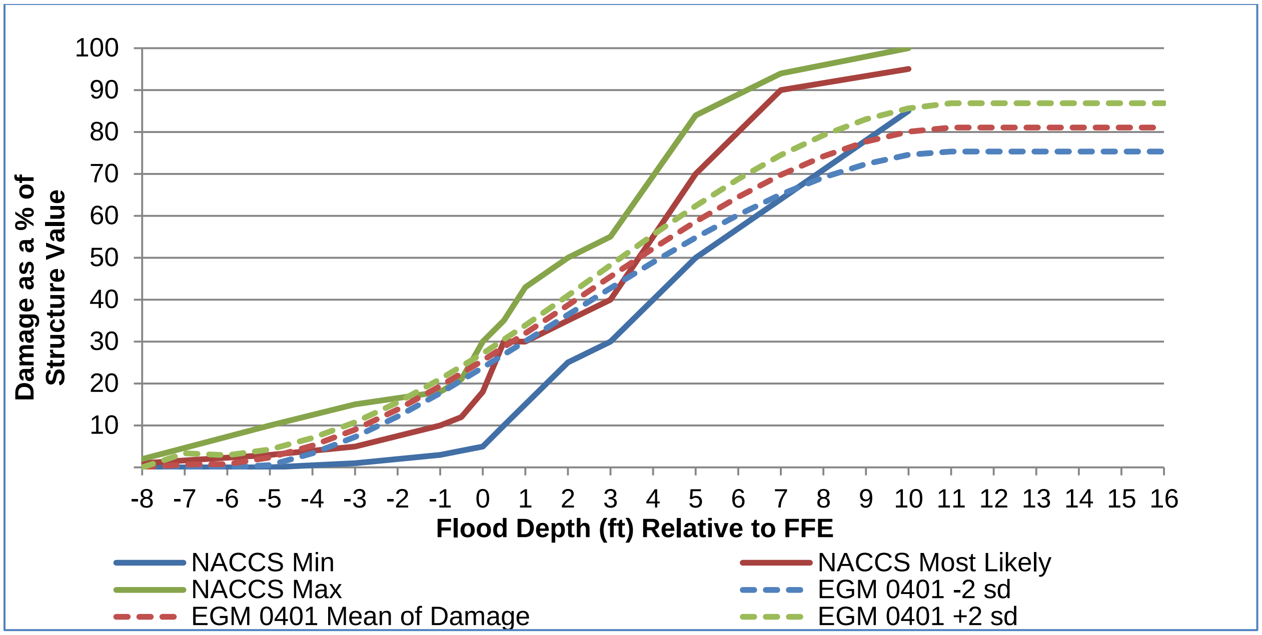

Figure 28. Comparison – Structural Damage from Inundation: NACCS Prototype 6A One Story, with Basement vs EGM 04-01 One Story, with Basement

The NACCS damage function in Figure 29 reflects the difference in basement configuration between homes in coastal areas and homes in riverine areas. Coastal homes tend to store a lower proportion of contents in the basement compared to contents on the first floor. At the first floor level, NACCS contents damage is only 15% of the total contents value. The EGM damage functions, which have been adjusted with a CVSR of 0.40, reflect a higher percent of contents in the basement. By the time the water reaches the first floor, damage to about 40% of the total content value has occurred. The lower proportion of contents in the basement is believed to be more representative of conditions in the NACCS study floodplains.

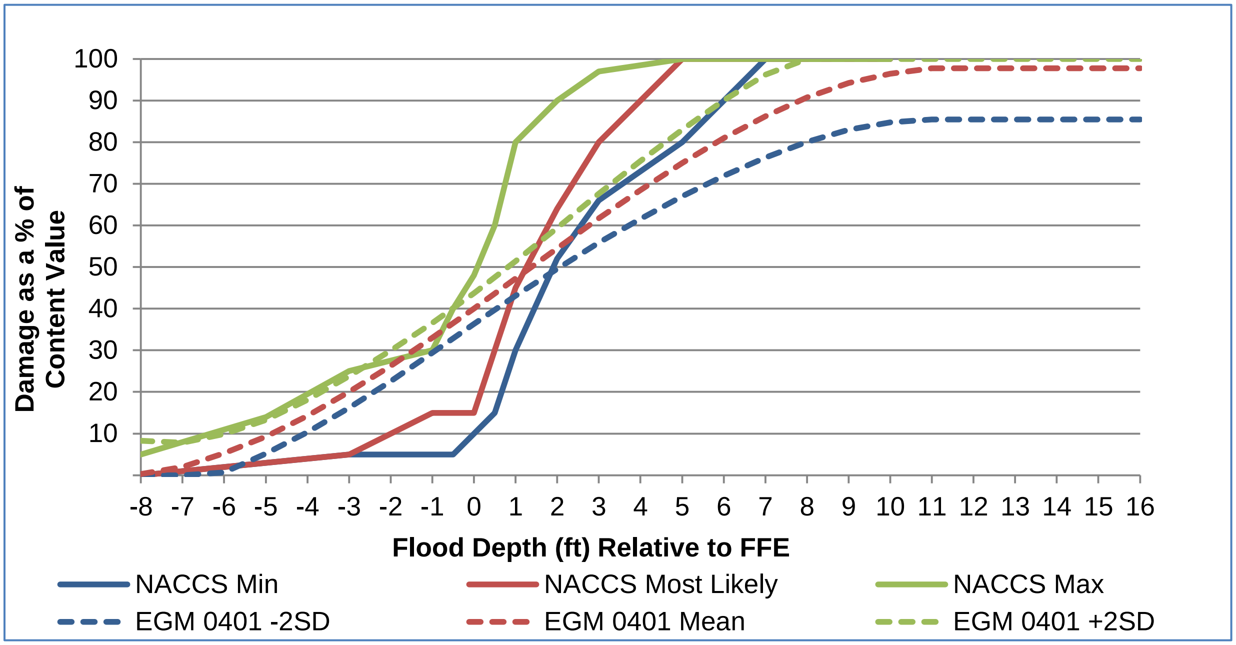

Figure 29. Comparison – Content Damage from Inundation: NACCS Prototype 6A One Story, with Basement vs EGM 04-01: One Story, with Basement

The trend on each of the damage functions in Figure 30 is similar, with the expected wider band of uncertainty for the NACCS damage functions.

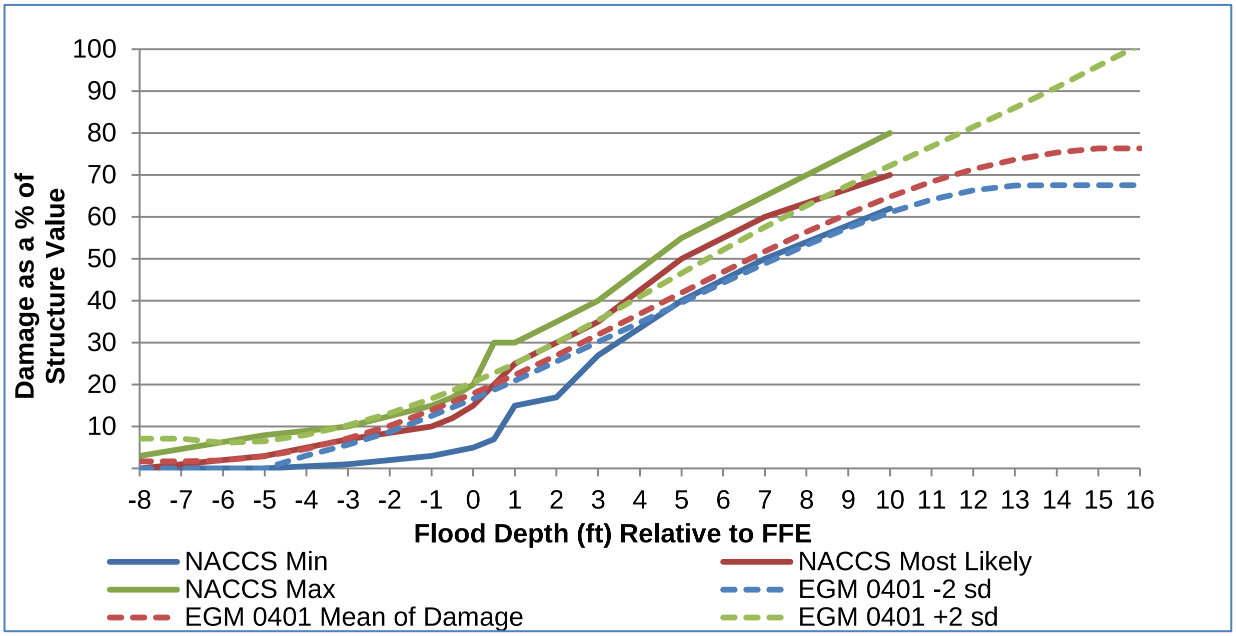

Figure 30. Comparison – Structural Damage from Inundation: NACCS Prototype 6B Two Story, with Basement vs EGM 04-01 Two or More Stories, with Basement

The NACCS most likely estimate and the EGM 04-01 Mean of Damage estimate in **Error! Reference source not found.**Table 31 are similar with regard to below-grade storage; however, the NACCS most likely damage curve reaches its maximum amount of damage at 10' above FFE, whereas the EGM 04-01 mean damage curve reaches its maximum at 16' above FFE. A major reason for higher damage levels in the NACCS damage function is the destructive effect of mold on contents, which was discussed by the panel at length.

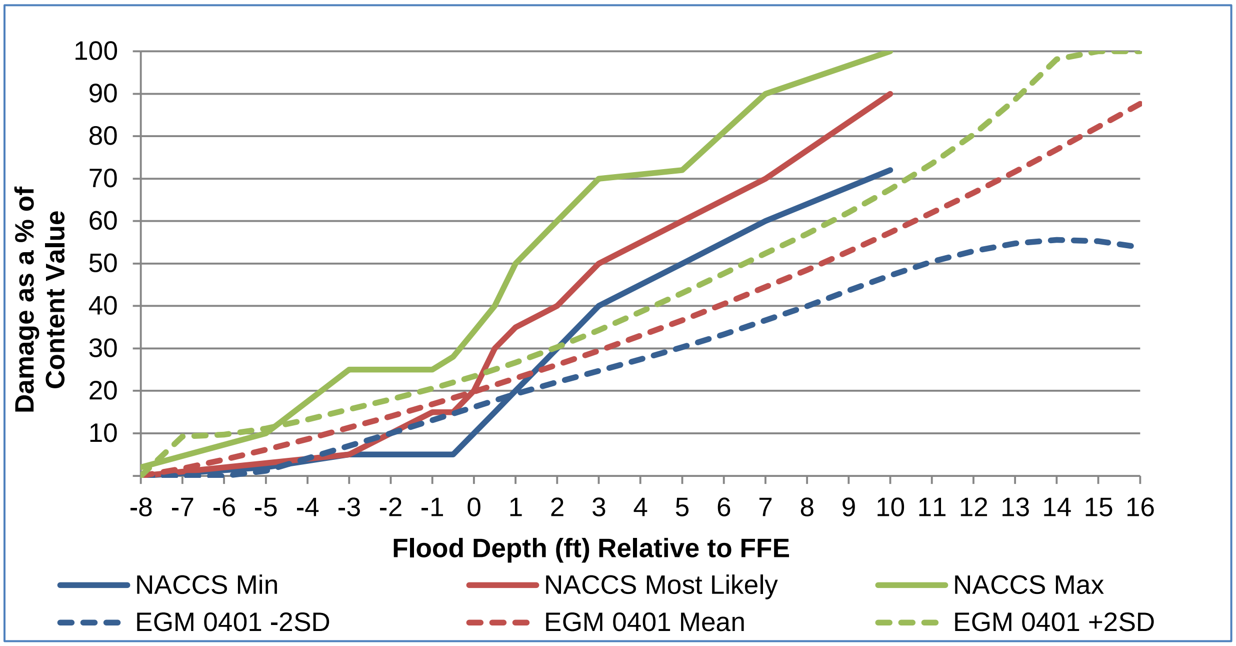

Figure 31. Comparison – Content Damage from Inundation: NACCS Prototype 6B Two Story, with Basement vs EGM 04-01: Two or More Stories, with Basement

Figure 32 shows the NACCS inundation damage function slightly higher than the 2002 inundation damage function. The upper bound of the NACCS damage function includes increased damage reflecting the lower level entrance structure, as well as some exposed utility connections.

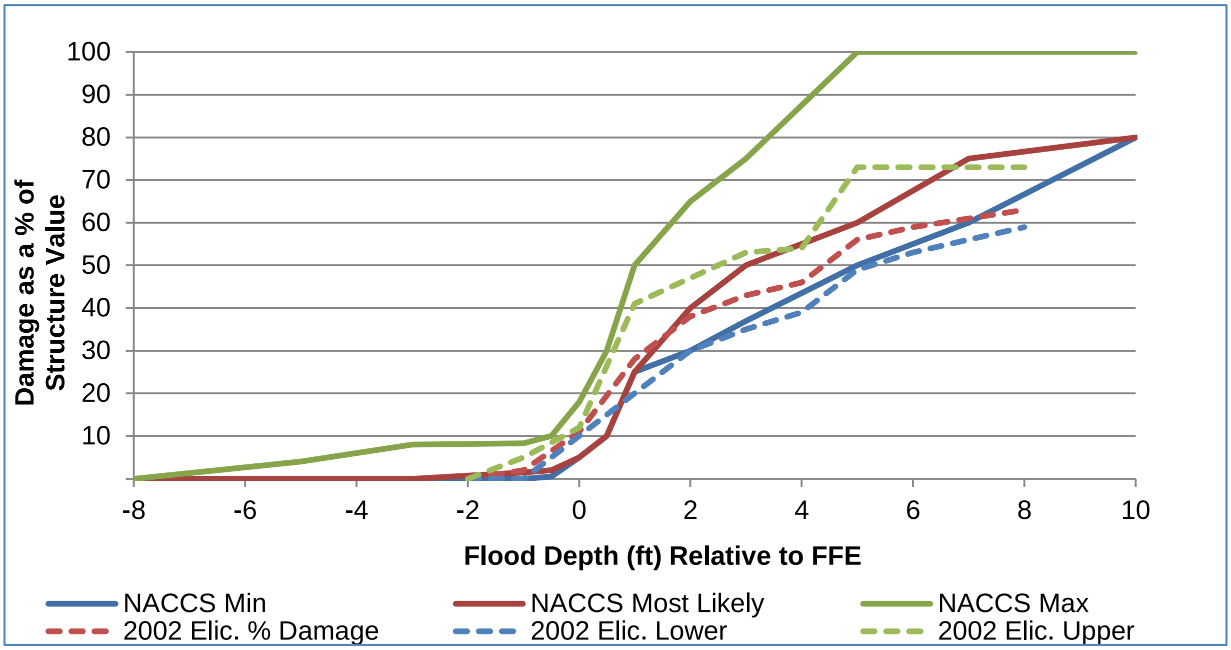

Figure 32. Comparison – Structural Damage from Inundation: NACCS Prototype 7A Building on Open Pile Foundation vs 2002 Elicitation Wood Frame with Piles, No Enclosure

The NACCS damage functions in Figure 33 have a significantly narrower uncertainty band than the 2002 elicitation damage functions, however, the expected 100% damage points are similar (within 10% of the footprint compromised) for the most-likely and maximum damage scenarios.

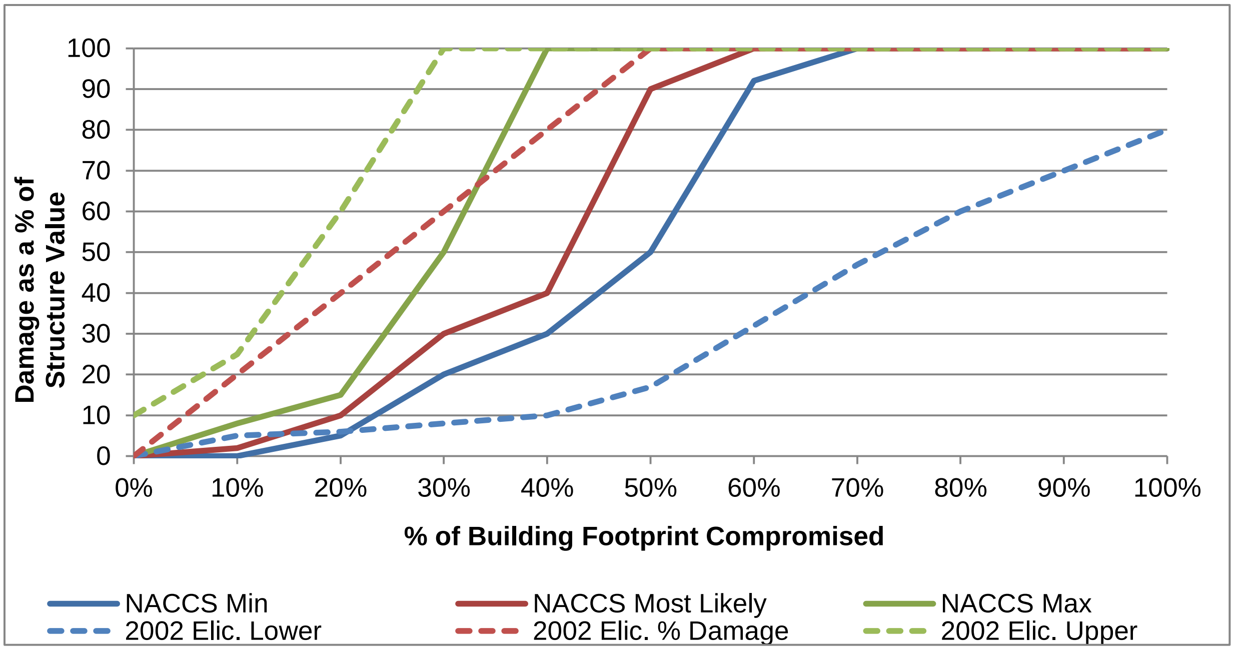

Figure 33. Comparison – Structural Damage from Erosion: NACCS Prototype 7A Building on Open Pile Foundation vs 2002 Elicitation Pile Foundation

In Figure 34, the NACCS elicitation damage function shows inundation causing a lower amount of damage below the finished floor elevation (FFE) than the 2002 elicitation damage function.

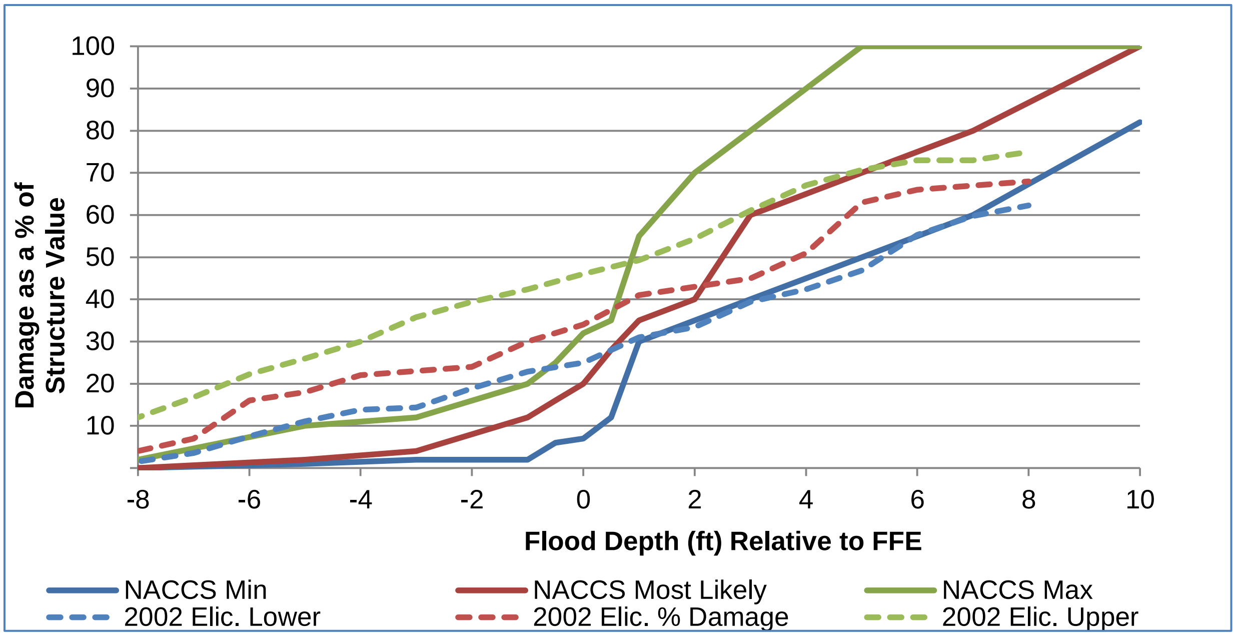

Figure 34. Comparison – Structural Damage from Inundation: NACCS Prototype 7B Building on Pile Foundation, with Enclosures vs 2002 Elicitation Wood Frame with Piles, Full Enclosures

Figure 35 shows that the NACCS and the 2002 Elicitation damage functions are quite consistent above the first floor elevation. However, there is an obvious disparity between the two damage functions below that level. The higher below-FFE damage values of the 2002 elicitation damage function are consistent with a finished and fully habitable enclosure area, which is not a common condition in the North Atlantic region.

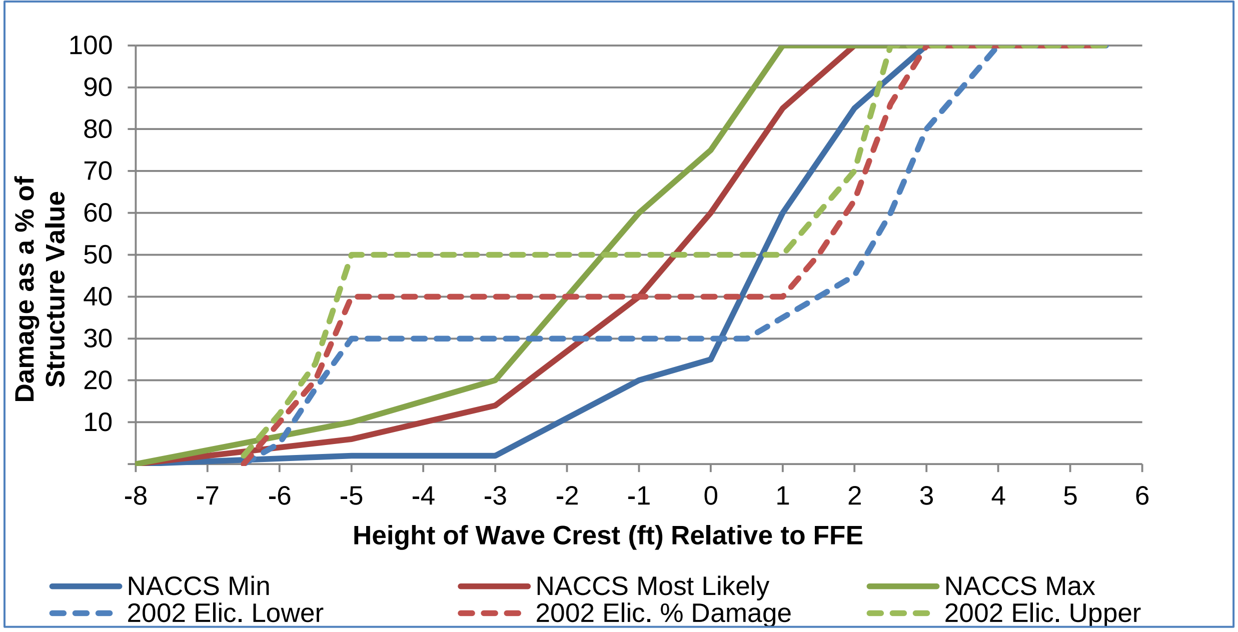

Figure 35. Comparison – Structural Damage from Waves: Comparison of NACCS Prototype 7B Building on Pile Foundation, with Enclosures vs 2002 Elicitation With Piles (Finished, Full Enclosure)

Figure 36 shows a visual comparison between the maximum-damage wave characteristics for the 2014 Prototype 7B wave damage function and the Adjusted 2002 Elicitation Pile Foundation, Finished Full Enclosures wave damage function.

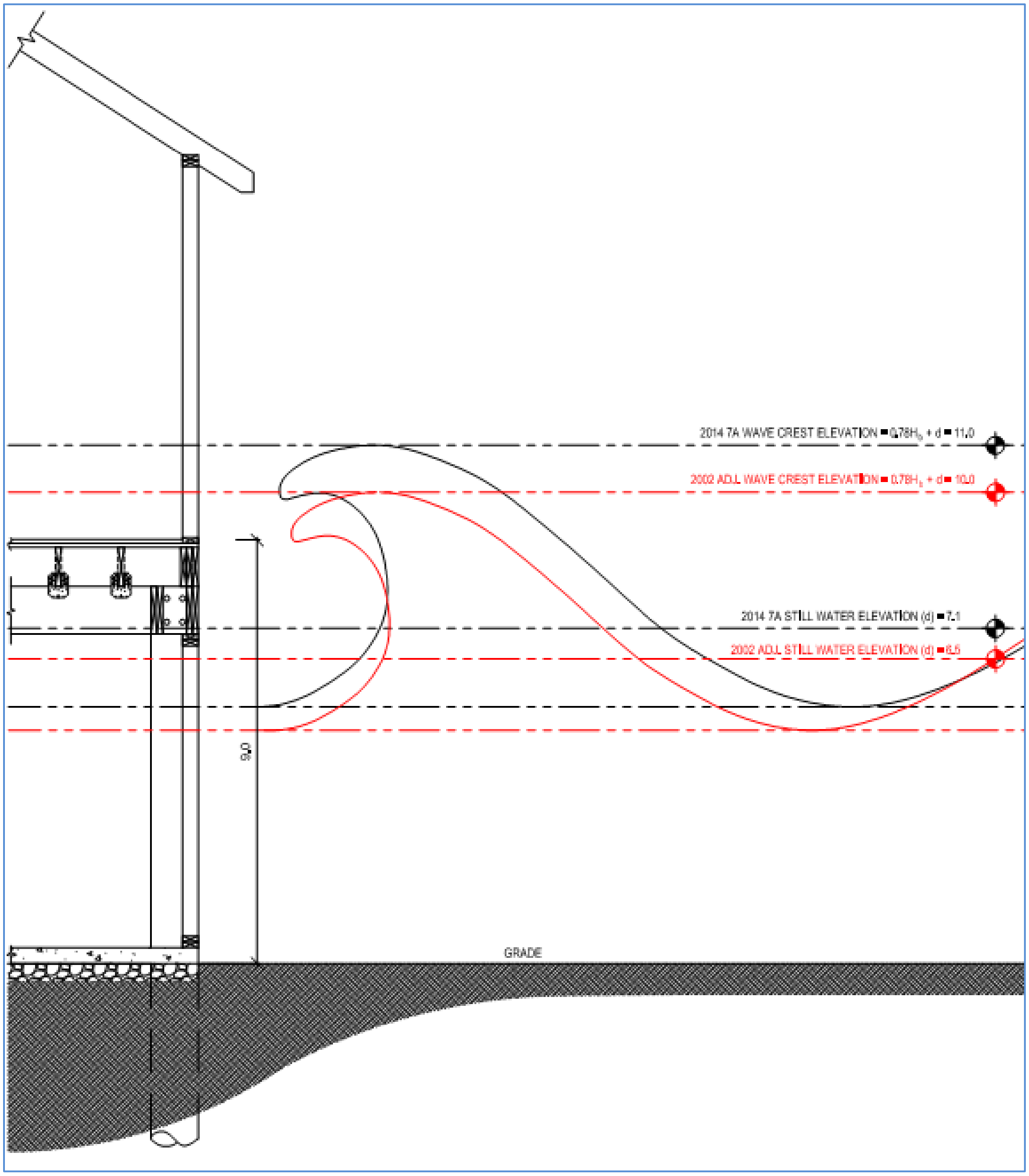

Figure 36. Illustration of 2014 Prototype 7B, 100% Wave Damage Conditions vs. Adjusted 2002 Elicitation Pile Foundation, Finished Full Enclosures, 100% Wave Damage Conditions

Figure 37 shows a similar shape between the NACCS and 2002 Elicitation damage functions, and a wider uncertainty in the NACCS damage functions above -3' FFE. The expected 100% damage levels are similar.

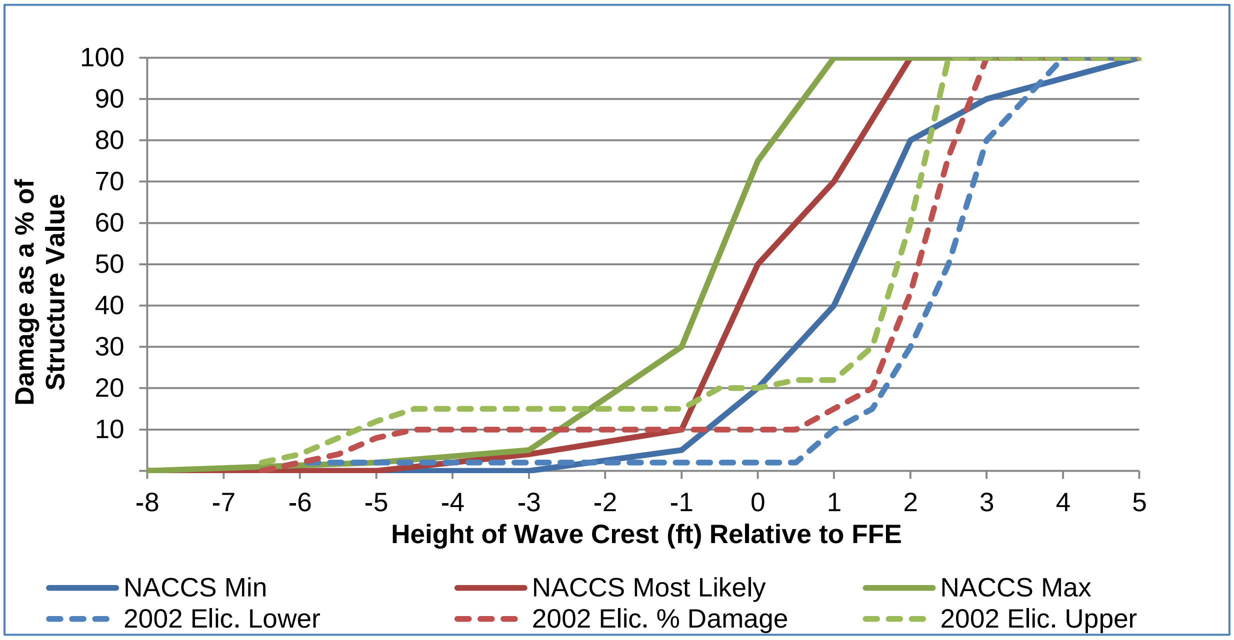

Figure 37. Comparison – Structural Damage from Waves: Comparison of NACCS Prototype 7A Building on Open Pile Foundation vs 2002 Elicitation Structure on Piles (No Enclosure)

A visual comparison between the wave characteristics for the 2014 Prototype 7A wave damage function and the 2002 Elicitation Pile Foundation, No Enclosures wave damage function can be seen in Figure 36. This illustration shows a slightly different building configuration, but the wave characteristics are the same.

5.9 Panel Input Revisions

Following each post-elicitation discussion, panelists were given the opportunity to make adjustments to their individual estimates, to discuss revisions to prototype characteristics, and to discuss their own input. These discussions broadened the knowledge base of the panelists and brought-up additional items to be considered in the damage analysis. For example, an in-depth discussion on the impacts of mold led many of the panelists to reconsider the potential damages from flooding. However, due to time constraints the panelists did not have the opportunity to review all of their estimates for individual prototypes during the elicitation, to take into consideration the various discussions that were held during the panel. However, after the panel session, panelists were given an opportunity to review their estimates and make any adjustments that they felt were appropriate.

6 Results

The results from the expert-opinion elicitation panel were compiled by building prototype and damage type. In addition to the damage estimates, the panelists provided guidance on the use of the damage functions. Table 2 (page 2) presents the prototype categories established by the expert-opinion elicitation panel. Additional information on the values provided by the panelists can be found in Attachment A, Meeting Minutes. During the panel, a peer review was conducted by Brian Maestri of the USACE, New Orleans District. The results of the peer review are provided in Attachment C at the end of this report. A subsequent verification of the NACCS damage functions is included as Attachment G.

6.1 General Prototype Characteristics

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts. Panelists were also instructed to exclude wind damage from the prototype storm characteristics.

6.2 Storm Characteristics

Storm characteristics were presented to the experts and refined as follows:

> After discussion, these characteristics were eliminated because they did not significantly affect the damage function results:
>
> - Warning time
> - Scour depth
>
> These characteristics were added because they had a significant effect on the damage function:
>
> - Wave characteristics (breaking/non-breaking)
> - Likelihood of Mold (a function of flood duration, humidity, time elapsed before reentry and access to resources like clean-up supplies, equipment, and electricity).
>
> These characteristics were modified:
>
> - Velocity
> - Wave height

The panel determined that the following characteristics described the Most Likely, Minimum, and Maximum prototype storm scenarios (Table 9):

Table 9. Prototype Storm Characteristics

	Most Likely	**Minimum Damage**	**Maximum Damage**
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Possible	Unlikely	Likely

For wave damage estimates, the panel calculated the height of the wave crest relative to the finished floor elevation of the building.

The panel determined that flood duration, humidity, and time to reentry and access to resources affected the likelihood of mold as follows (Table 10):

Table 10. Prototype Storm Characteristics - MOLD

	Mold Possible	Mold Unlikely	Mold Likely
Flood Duration	6 - 12 hours	Less than 6 Hours	More than 12 hours
Days Until Reentry	2 to 3	1	7 or more
Humidity Level	Moderate	Low	High

Erosion Damage Estimates

The 2014 panel calculated erosion as the percent of a building's footprint that is compromised, starting from its water-ward edge. "Percent compromised" was understood to represent the fraction of foundation capacity (ability to withstand lateral and vertical loads and support the building) lost. "Percent damage" was understood to mean the physical damage to the building resulting from a compromised foundation. The percent damage value does not consider the regulatory, safety-, or insurance-driven thresholds at which the building is to be condemned or removed.

6.3 Building Characteristics

- The panel discussed erosion and calculated it as a percent of a building's footprint compromised from its waterward edge.
- Due to the fact that BeachFX reports wave damage relative to the finished floor of a structure, the panel was instructed to calculate wave damage relative to the FFE
- The panel discussed the fact that a building's proximity to the shoreline was an important consideration when estimating wave damage and suggested that users be notified that wave damage functions were only to be used for buildings that would be exposed to waves.

6.4 Limitations and Recommendations for Use

Damages reflect actual physical damage. Users must assess whether there are regulatory or safety considerations that would require actions such as building elevation/relocation or demolition and removal of the building prior to reaching 100% physical damage. Each user should compare the building prototype description to their study area conditions.

Users should be aware that Beach-fx will not truncate damages below the ground elevation. The analyst may need to adjust/truncate the depth-damage curves to avoid overstating damage in Beach-fx.

The panel noted that the application of the erosion curves would be region and structure specific, and that users must inform themselves of the applicable building code and construction practices in a geographic area. Due to variations in factors such as soil types, topography, coastal flood conditions, wind speeds, typical building and foundation types, etc., a given percent of footprint compromised can result in different levels of damage in different geographic areas.

6.5 Prototype 1A-1: Apartments – 1 Story – No Basement

Most Likely Building Characteristics: The prototype building is of unreinforced masonry construction on a slab foundation. It is one story. Utilities are located on the first floor. Ceiling height is 8’-0”. Age range is between 15 and 30 years old. The FFE is 1’-0” above grade.

Minimum-Damage Building Characteristics: The prototype building is a newer building of steel or reinforced concrete construction on a slab foundation. It is one story. Utilities may be protected. The first floor elevation is 2’-0” above grade.

Higher-Damage Building Characteristics: The prototype building is an older building of wood frame or unreinforced masonry construction that is elevated above grade on a crawl space. See Table 11 below:

Table 11. Prototype 1A-1: Apartments – 1 Story – No Basement

	Most Likely	**Minimum Damage**	**Maximum Damage**
Stories	1	1	1
Foundation	Slab	Slab	Crawl Space
Utilities	1st floor	May be protected	
Age (years)	15 - 30	Newer	Older
Ceiling Height	8'-0"	8'-0"	8'-0"
Structure	Unreinforced masonry	Steel/ Reinforced concrete	Wood frame/ unreinforced masonry
Height of Finished Floor Above Grade	1'-0"	2'-0"	3'-0"

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

Table 12 through Table 20 provide the Prototype 1A-1: One-Story Apartments- No Basement; Inundation Damages, Erosion Damages, Wave-Slab Damages, and Wave-Wall Damages for structures and contents. Figure 38 through Figure 46 provide the corresponding damage functions.

Note regarding buildings with more than three stories and less than ten stories:

- For shallow foundations, use the Prototype 1 Damage Function
- For deep foundations, use the Prototype 4 Damage Function

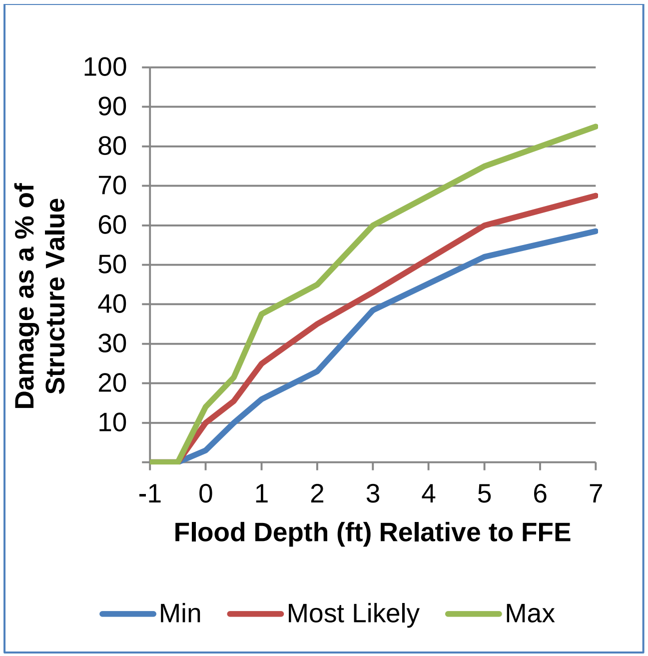

Figure 38. Prototype 1A1- Apartments – 1 Story – No Basement, Inundation Damage - Structure

Table 12. Prototype 1A-1: Apartments – 1 Story – No Basement, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	3	10	14
0.5	10	16	22
1.0	16	25	38
2.0	23	35	45
3.0	39	43	60
5.0	52	60	75
7.0	59	68	85

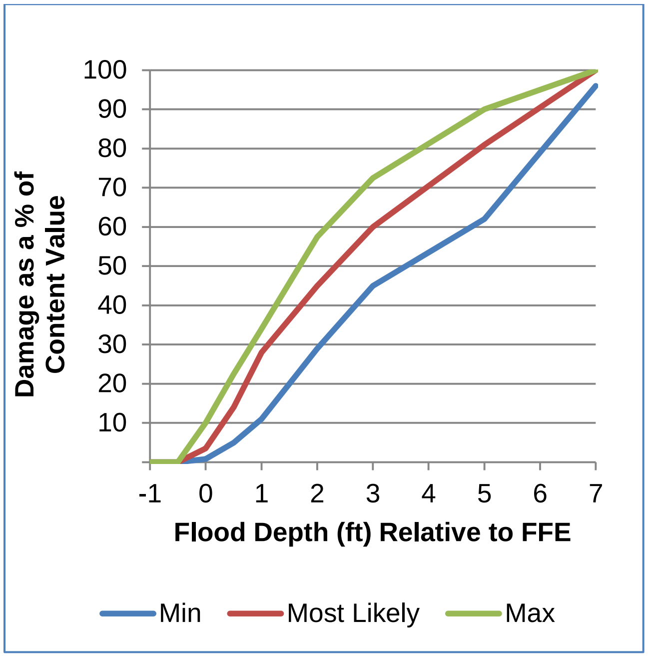

Figure 39. Prototype 1A-1: Apartments – 1 Story – No Basement, Inundation Damage – Content

Table 13. Prototype 1A-1: Apartments – 1 Story – No Basement, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	1	4	10
0.5	5	14	23
1.0	11	28	34
2.0	29	45	58
3.0	45	60	73
5.0	62	81	90
7.0	96	100	100

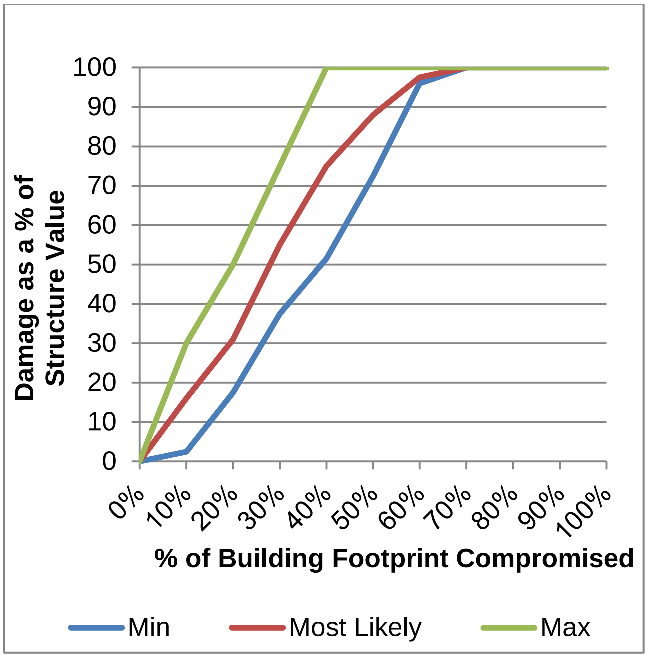

Figure 40. Prototype 1A-1: Apartments – 1 Story – No Basement, Erosion Damage – Structure

Table 14. Prototype 1A-1: Apartments – 1 Story – No Basement, Erosion Damage – Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	3	16	30
20%	18	31	50
30%	38	55	75
40%	52	75	100
50%	73	88	100
60%	96	98	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

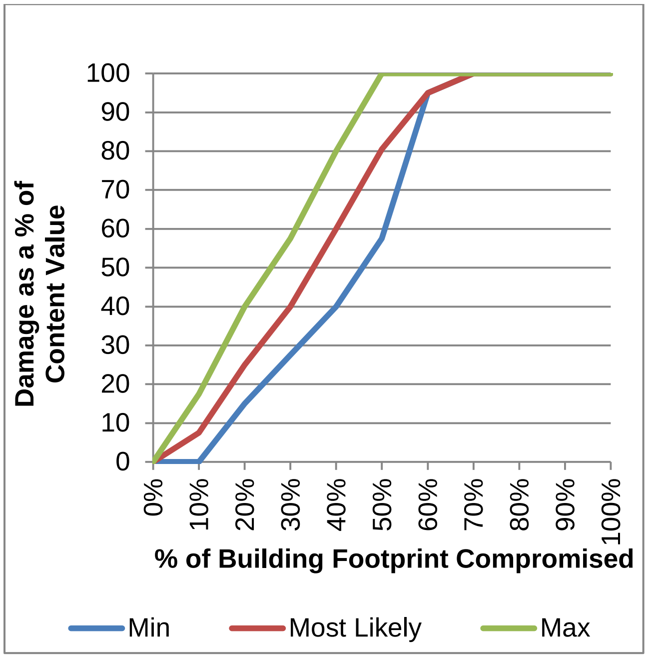

Figure 41. Prototype 1A-1: Apartments – 1 Story – No Basement, Erosion Damage - Content

Table 15. Prototype 1A-1: Apartments – 1 Story – No Basement, Erosion Damage - Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	8	18
20%	15	25	40
30%	28	40	58
40%	40	60	80
50%	58	81	100
60%	95	95	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

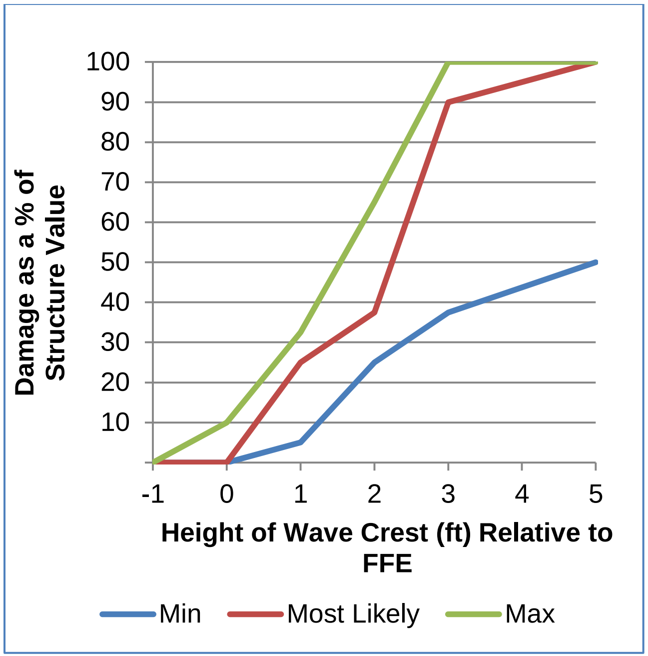

Figure 42. Prototype 1A-1: Apartments – 1 Story – No Basement, Wave Damage, Slab Foundation – Structure

Table 16. Prototype 1A-1: Apartments – 1 Story – No Basement, Wave Damage, Slab Foundation – Structure

Wave Crest	Min	Most Likely	Max
-1	0	0	0
0	0	0	10
1	5	25	32.5
2	25	37.5	65
3	37.5	90	100
5	50	100	100

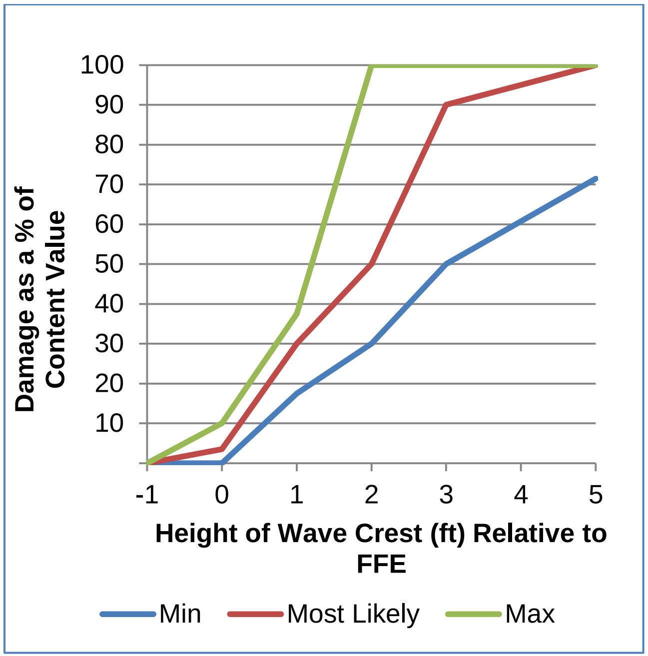

Figure 43. Prototype 1A-1: Apartments – 1 Story – No Basement, Wave Damage, Slab Foundation - Content

Table 17. Prototype 1A-1: Apartments – 1 Story – No Basement, Wave Damage, Slab Foundation - Content

Wave Crest	Min	Most Likely	Max
-1	0	0	0
0	0	3.5	10
1	17.5	30	37.5
2	30	50	100
3	50	90	100
5	71.5	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 18 and Figure 44 show wave, surge, and still water[14] characteristics associated with 100% wave damage for the most likely building characteristics of a single-story apartment building without a basement (Prototype 1A-1). This prototype has a slab foundation and a FFE of 1.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100% wave damage for this prototype is expected to occur with a still water depth (d) of 3.9 feet. This still water depth will typically allow a maximum wave height of 3.0 feet (H_b = .78d). The wave crest under this condition would be approximately 6.0 feet above grade ($0.7H_b$ + d).

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[14] See Definitions section at the end of this report

Table 18. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 1A-1 Apartments – 1 Story – No Basement, Most Likely Building Characteristics, Slab Foundation

Designation	Characteristic	Feet
A	FFE Above Grade	1.0
B	Wave Crest Height Above FFE	5.0
C	Breaking Wave Height (H_b = 0.78d)	3.0
D	0.7H_b	2.1
E	Still Water Elevation (d)	3.9
F	Wave Crest Elevation (0.7H_b + d)	6.0

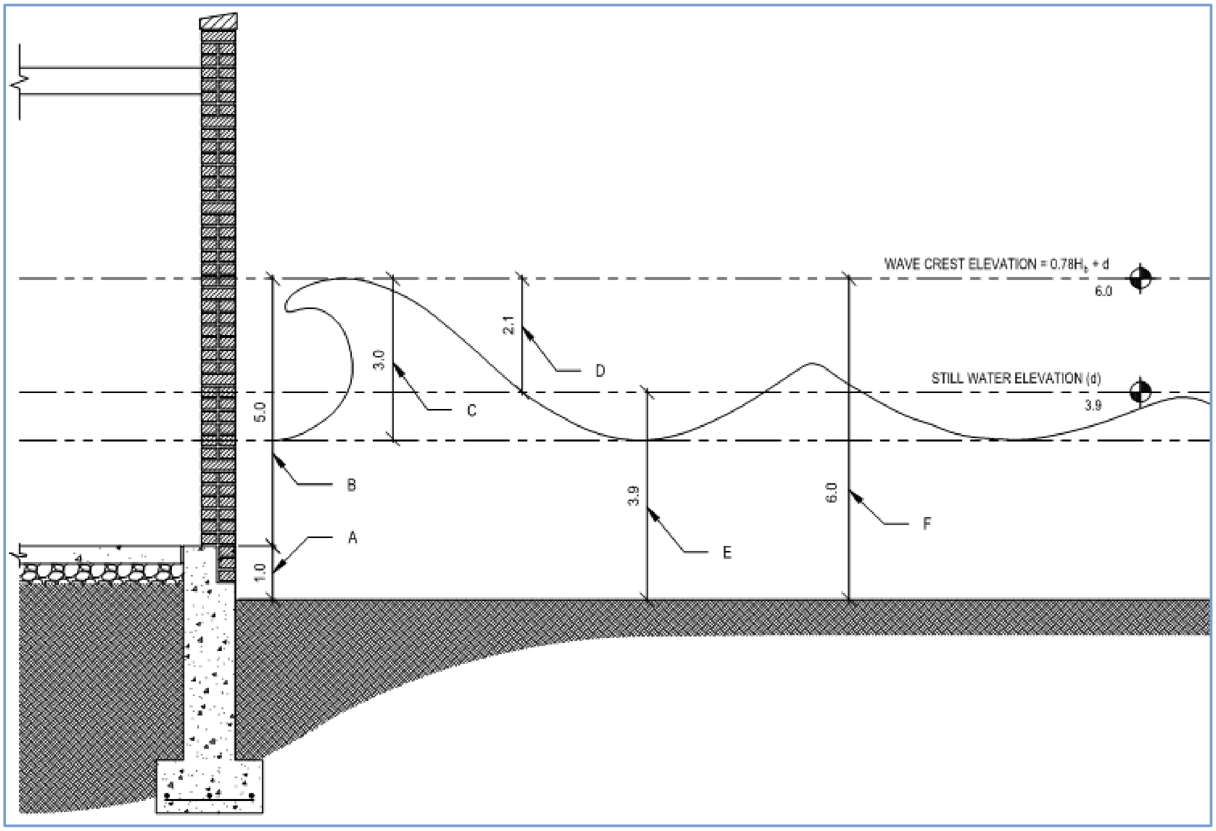

Figure 44. Illustration of Maximum Wave Damage Scenario, Prototype 1A-1 Most Likely Building Characteristics, Slab Foundation

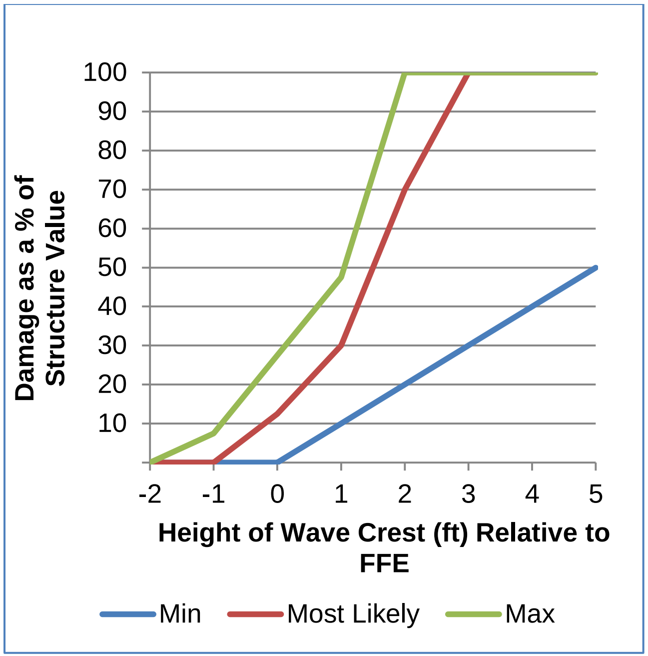

Figure 45. Prototype 1A-1: Apartments – 1 Story – No Basement, Wave Damage, Extended Foundation Wall - Structure

Table 19. Prototype 1A-1: Apartments – 1 Story – No Basement, Wave Damage, Extended Foundation Wall - Structure

Wave Crest	Min	Most Likely	Max
-2	0	0	0
-1	0	0	7.5
0	0	12.5	27.5
1	10	30	47.5
2	20	70	100
3	30	100	100
5	50	100	100

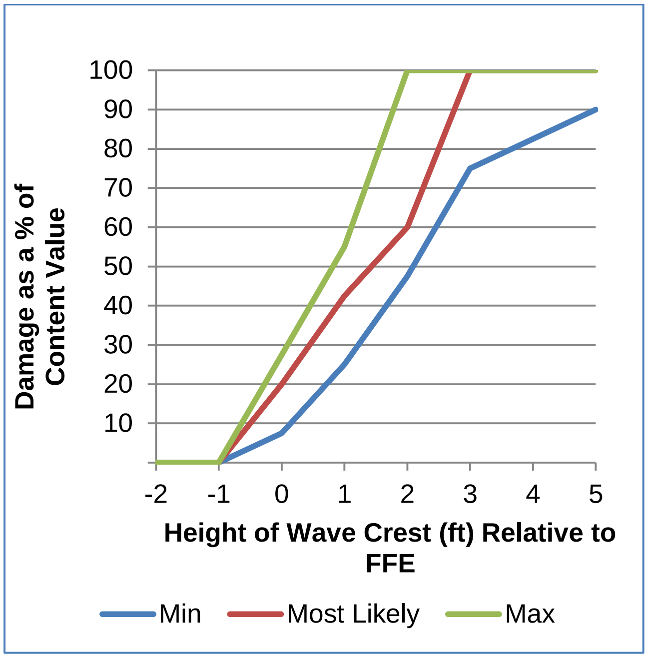

Figure 46. Prototype 1A-1: Apartments – 1 Story – No Basement, Wave Damage, Extended Foundation Wall- Content

Table 20. Prototype 1A-1: Apartments – 1 Story – No Basement, Wave Damage, Extended Foundation Wall- Content

Wave Crest	Min	Most Likely	Max
-2	0	0	0
-1	0	0	0
0	7.5	20	27.5
1	25	42.5	55
2	47.5	60	100
3	75	100	100
5	90	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

6.6 Prototype 1A-3: Apartments – 3 Stories – No Basement

Most Likely Building Characteristics: The prototype building is of unreinforced masonry construction on a slab foundation. It has three stories. Utilities are located on the first floor. Ceiling height is 8’-0”. Age range is between 15 and 30 years old. The finished floor is 1’-0” above grade.

Minimum-Damage Building Characteristics: The prototype building is a newer building of steel or reinforced concrete construction on a slab foundation. It has three stories. Utilities may be protected. The finished floor is 2’-0” above grade.

Higher-Damage Building Characteristics: The prototype building is an older building of wood frame or unreinforced masonry construction that is elevated above grade on a crawl space. It has three stories.

See Table 21 below:

Table 21. Prototype 1A-3: Apartments – 3 Stories – No Basement: Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	3	3	3
Foundation	Slab	Slab	Crawl Space
Utilities	1st floor	May be protected	
Age (years)	15 - 30	Newer	Older
Ceiling Height	8'-0"	8'-0"	8'-0"
Structure	Unreinforced masonry	Steel/ Reinforced concrete	Wood frame/ unreinforced masonry
Height of Finished Floor Above Grade	1'-0"	2'-0"	

Table 22 and Table 23 are presented below. Figure 47 and Figure 48, present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

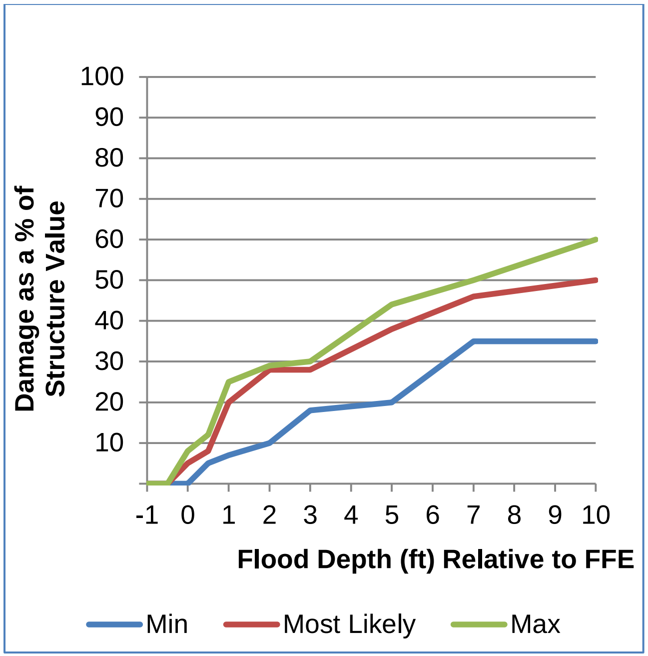

Figure 47. Prototype 1A-3: Apartments – 3 Stories – No Basement, Inundation Damage – Structure

Table 22. Prototype 1A-3: Apartments – 3 Stories – No Basement, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	0	5	8
0.5	5	8	12
1.0	7	20	25
2.0	10	28	29
3.0	18	28	30
5.0	20	38	44
7.0	35	46	50
10.0	35	50	60

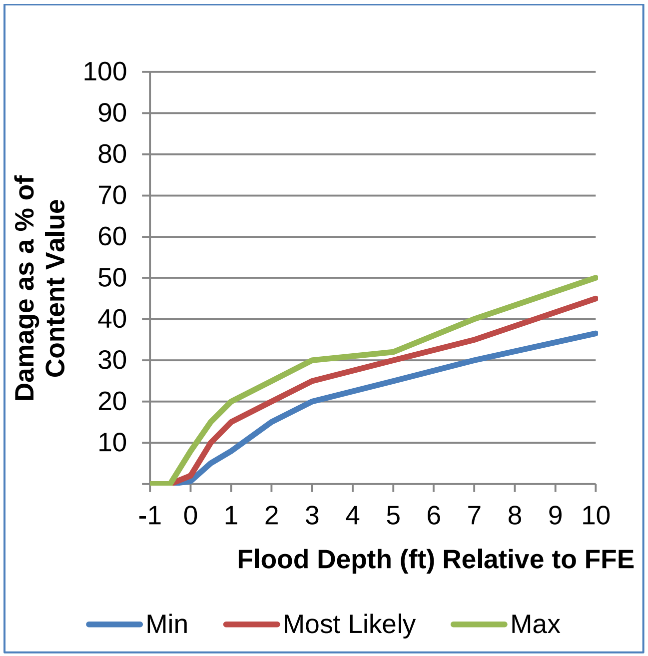

Figure 48. Prototype 1A-3: Apartments – 3 Stories – No Basement, Inundation Damage – Content

Table 23. Prototype 1A-3: Apartments – 3 Stories – No Basement, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	1	2	8
0.5	5	10	15
1.0	8	15	20
2.0	15	20	25
3.0	20	25	30
5.0	25	30	32
7.0	30	35	40
10.0	37	45	50

6.7 Prototype 2: Commercial – Engineered

Most Likely Building Characteristics: The building has a steel frame with precast infill.

Minimum-Damage Building Characteristics: The building has a reinforced concrete frame.

Higher-Damage Building Characteristics: The building has a steel frame with light cladding.

See Table 24 below:

Table 24. Prototype 2: Commercial Engineered: Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	2	2	2
Foundation	Slab	Slab	Slab
Structure	Steel frame; precast infill	Reinforced concrete	Steel frame with light cladding
Cladding		Concrete Panels	Light cladding
Height of Finished Floor Above Grade	0’-0”	0’-0”	0’-0”

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

Table 25 through Table 33 present Prototype 2 Inundation Damages to Structure, Perishable and Nonperishable Contents; Erosion Damages to Structure, Perishable Contents and Nonperishable Contents; and Wave Damages to Structure, Perishable Contents and Nonperishable Contents. Figure 49 through Figure 57 present the corresponding damage functions.

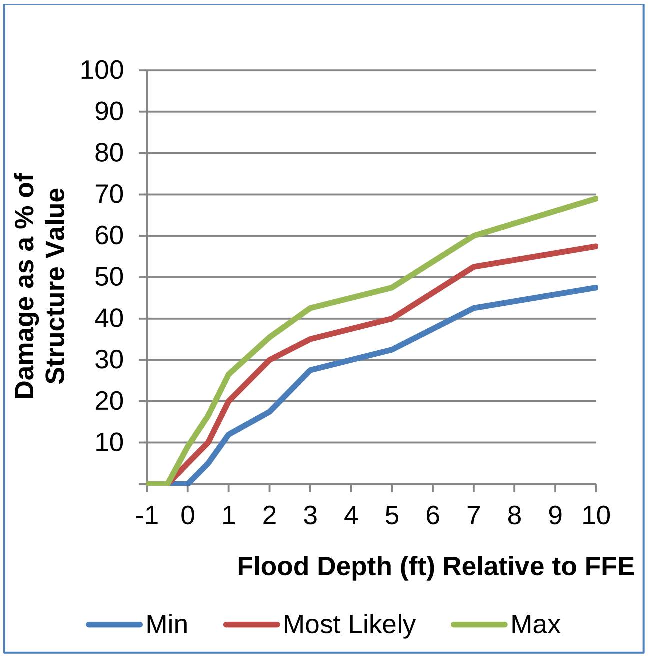

Figure 49. Prototype 2: Commercial Engineered, Inundation Damage – Structure

Table 25. Prototype 2: Commercial Engineered, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	0	5	9
0.5	5	10	17
1.0	12	20	27
2.0	18	30	36
3.0	28	35	43
5.0	33	40	48
7.0	43	53	60
10.0	48	58	69

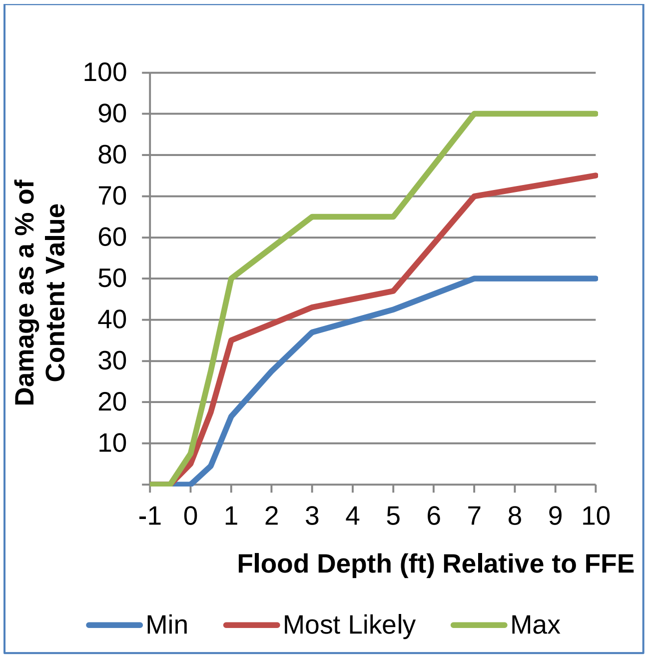

Figure 50. Prototype 2: Commercial Engineered, Inundation Damage – Perishable Content

Table 26. Prototype 2: Commercial Engineered, Inundation Damage – Perishable Content

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	0	5	8
0.5	5	18	28
1.0	17	35	50
2.0	28	39	58
3.0	37	43	65
5.0	43	47	65
7.0	50	70	90
10.0	50	75	90

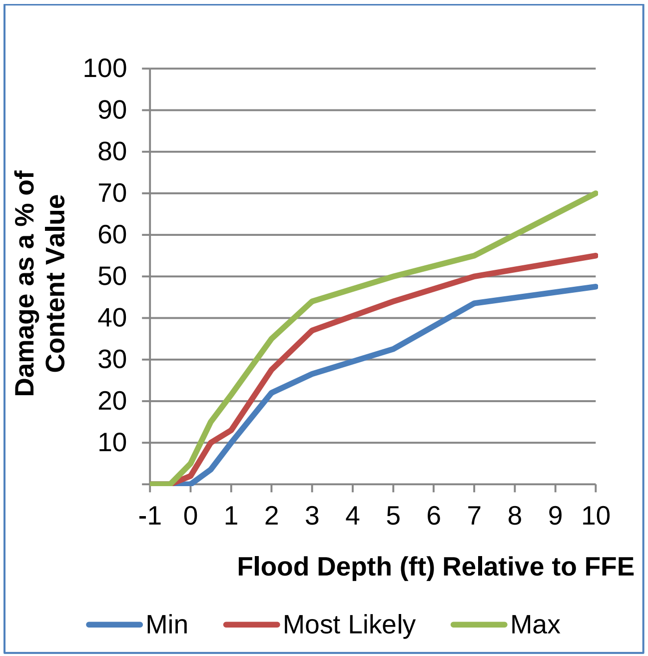

Figure 51. Prototype 2: Commercial Engineered, Inundation Damage – Nonperishable Content

Table 27. Prototype 2: Commercial Engineered, Inundation Damage – Nonperishable Content

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	0	2	5
0.5	4	10	15
1.0	10	13	22
2.0	22	28	35
3.0	27	37	44
5.0	33	44	50
7.0	44	50	55
10.0	48	55	70

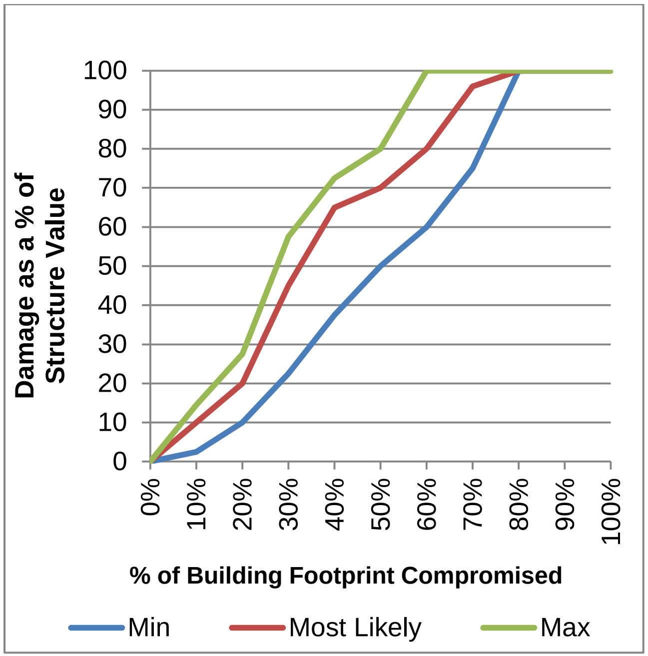

Figure 52. Prototype 2: Commercial Engineered, Erosion Damage - Structure

Table 28. Prototype 2: Commercial Engineered, Erosion Damage - Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	3	10	15
20%	10	20	28
30%	23	45	58
40%	38	65	73
50%	50	70	80
60%	60	80	100
70%	75	96	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

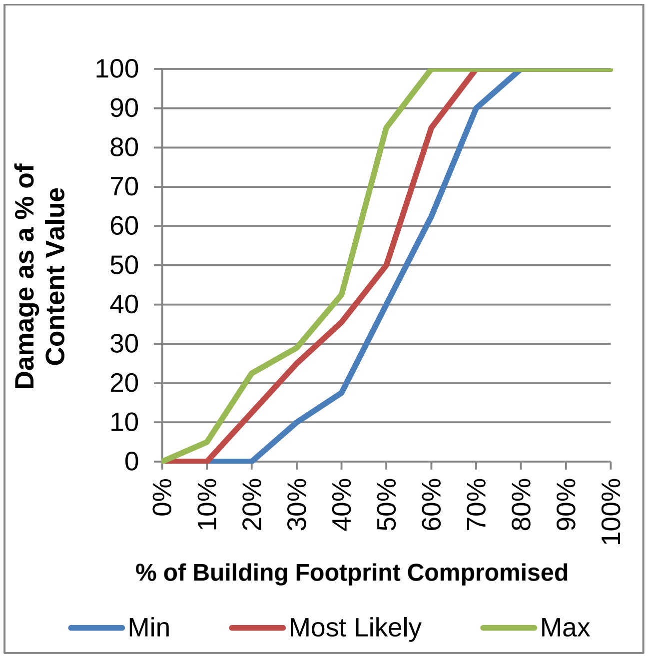

Figure 53. Prototype 2: Commercial Engineered, Erosion Damage - Perishable Content

Table 29. Prototype 2: Commercial Engineered, Erosion Damage - Perishable Content

Percent Compromised	Min	Most Likely	Max
0%	0	0	0
10%	0	0	5
20%	0	13	23
30%	10	25	29
40%	18	36	43
50%	40	50	85
60%	63	85	100
70%	90	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

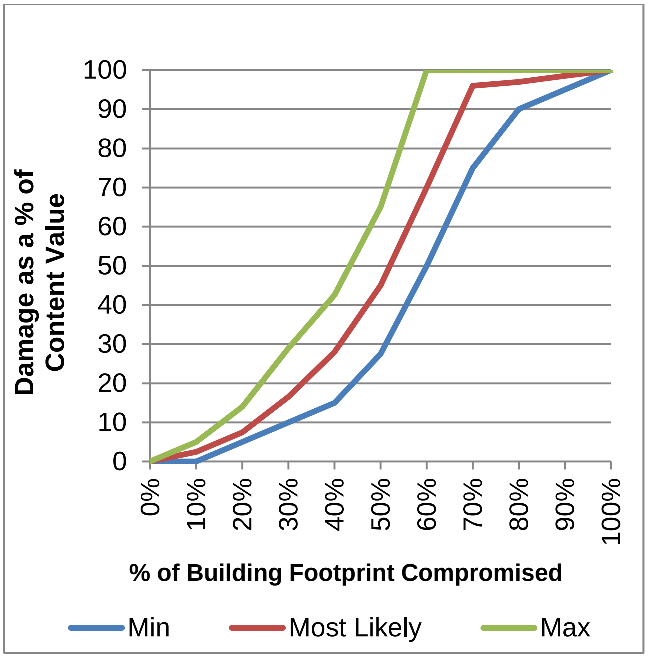

Figure 54. Prototype 2: Commercial Engineered, Erosion Damage - Nonperishable Content

Table 30. Prototype 2: Commercial Engineered, Erosion Damage - Nonperishable Content

Percent Compromised	Min	Most Likely	Max
0%	0	0	0
10%	0	3	5
20%	5	8	14
30%	10	17	29
40%	15	28	43
50%	28	45	65
60%	50	70	100
70%	75	96	100
80%	90	97	100
90%	95	99	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

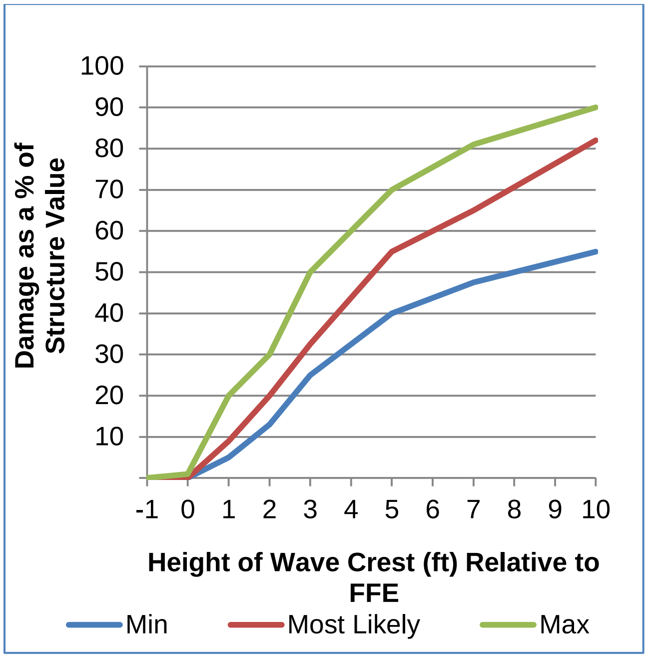

Figure 55. Prototype 2: Commercial Engineered, Wave Damage - Structure

Table 31. Prototype 2: Commercial Engineered, Wave Damage - Structure

Wave Crest	Min	Most Likely	Max
-1	0	0	0
0	0	0	1
1	5	9	20
2	13	20	30
3	25	33	50
5	40	55	70
7	48	65	81
10	55	82	90

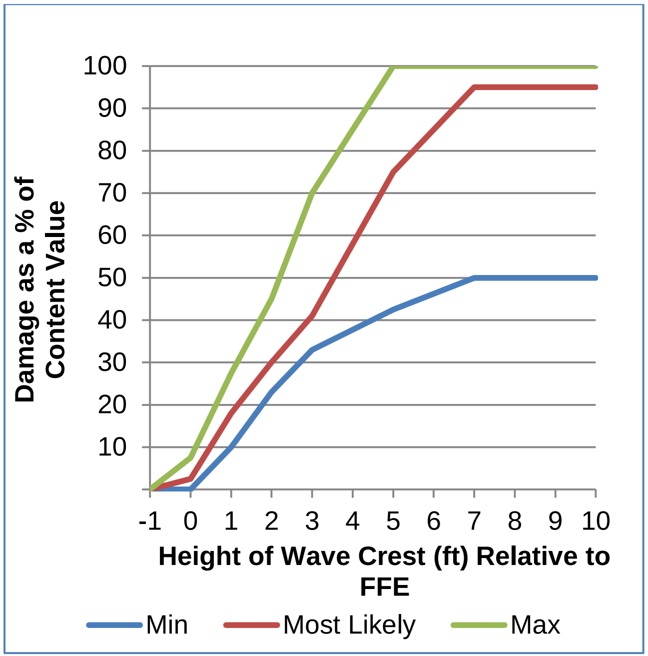

Figure 56. Prototype 2: Commercial Engineered, Wave Damage – Perishable Content

Table 32. Prototype 2: Commercial Engineered, Wave Damage – Perishable Content

Wave Crest	Min	Most Likely	Max
-1	0	0	0
0	0	3	8
1	10	18	28
2	23	30	45
3	33	41	70
5	43	75	100
7	50	95	100
10	50	95	100

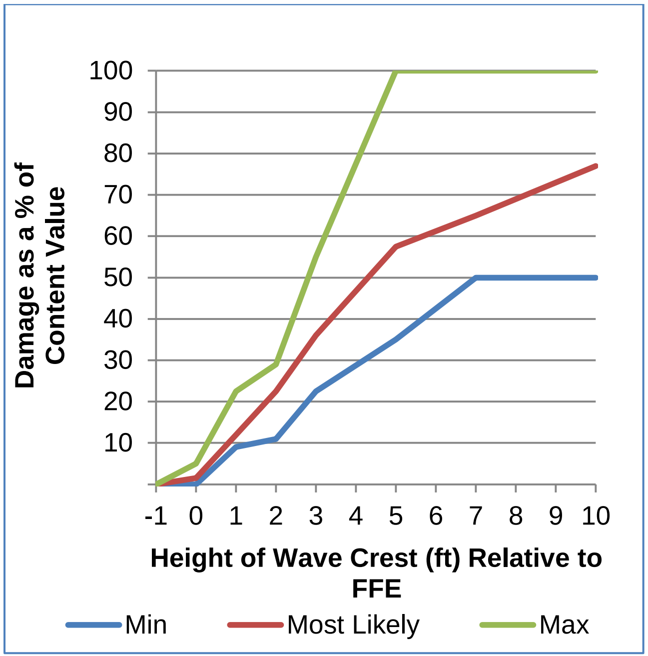

Figure 57. Prototype 2: Commercial Engineered, Wave Damage – Nonperishable Content

Table 33. Prototype 2: Commercial Engineered, Wave Damage – Nonperishable Content

Wave Crest	Min	Most Likely	Max
-1	0	0	0
0	0	2	5
1	9	12	23
2	11	23	29
3	23	36	55
5	35	58	100
7	50	65	100
10	50	77	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

A point of failure illustration for wave damage is not provided for this prototype because a building of this type was not expected to experience 100% damage as a result of wave impact.

6.8 Prototype 3: Commercial – Non/Pre Engineered

Most Likely Building Characteristics: The building has a steel or light metal frame and a slab foundation. The finished floor is 1'-0" above grade.

Minimum-Damage Building Characteristics: The building has a steel frame with masonry infill, and a slab foundation. The finished floor is 1'-0" above grade.

Higher-Damage Building Characteristics: The building has a wood or light metal frame and is elevated above grade on a crawl space. The finished floor is 3'-0" above grade.

See Table 34 below:

Table 34. Prototype 3: Commercial Non/Pre-Engineered: Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Foundation	Slab	Slab	Crawl space
Structure	Steel or light metal	Steel with masonry infill	Wood frame or light metal
Height of Finished Floor Above Grade	1'-0"	1'-0"	3'-0"

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

Table 34 through Table 43 presents Prototype 3 Commercial Non-Engineered Inundation, erosion and wave damages for structural, and perishable and nonperishable contents. Figure 58 through Figure 66 present the corresponding damage functions.

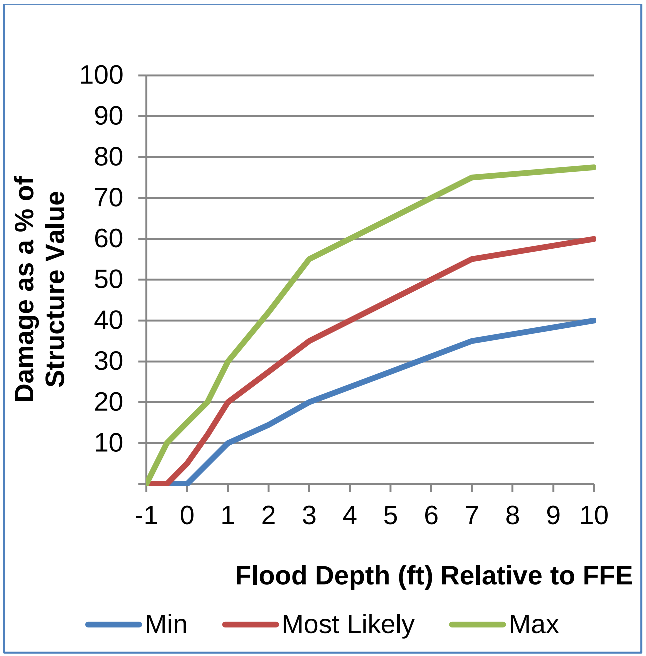

Figure 58. Prototype 3: Commercial Non/Pre-Engineered, Inundation Damage – Structure

Table 35. Prototype 3: Commercial Non/Pre-Engineered, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	10
0.0	0	5	15
0.5	5	12	20
1.0	10	20	30
2.0	15	28	42
3.0	20	35	55
5.0	28	45	65
7.0	35	55	75
10.0	40	60	78

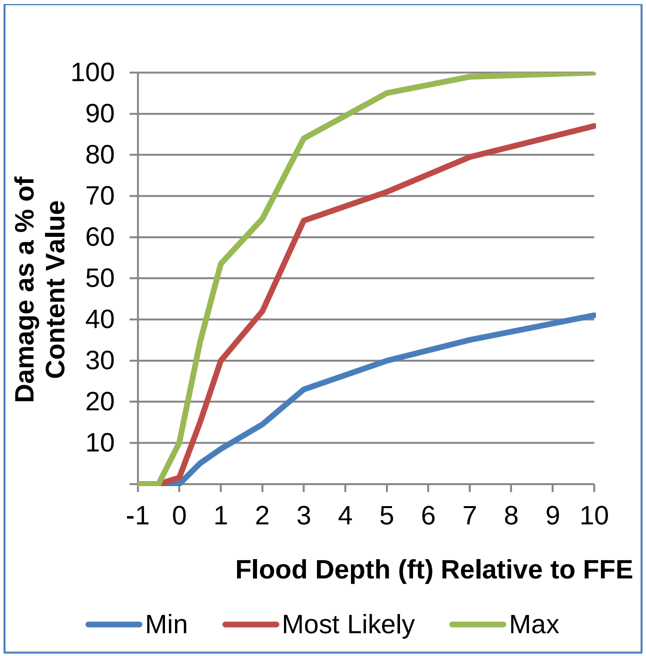

Figure 59. Prototype 3: Commercial Non/Pre-Engineered, Inundation Damage – Perishable Content

Table 36. Prototype 3: Commercial Non/Pre-Engineered, Inundation Damage – Perishable Content

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	0	2	10
0.5	5	15	35
1.0	9	30	54
2.0	15	42	65
3.0	23	64	84
5.0	30	71	95
7.0	35	80	99
10.0	41	87	100

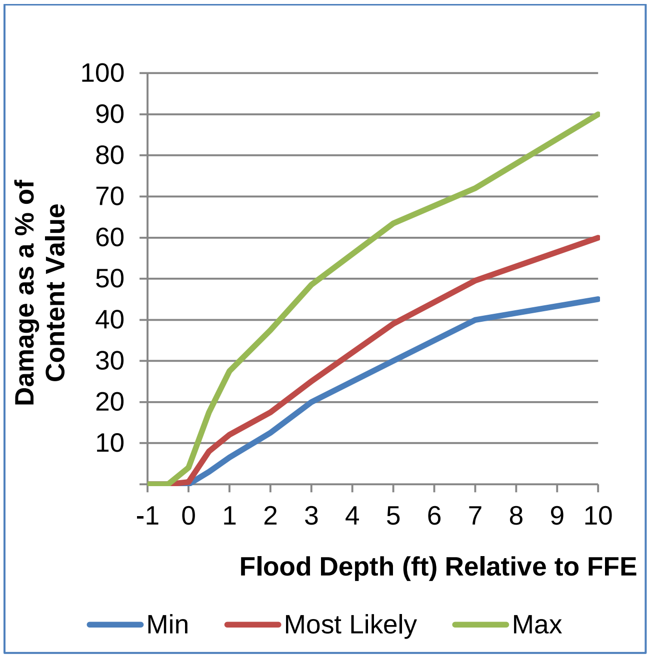

Figure 60. Prototype 3: Commercial Non/Pre-Engineered, Inundation Damage – Nonperishable Content

Table 37. Prototype 3: Commercial Non/Pre-Engineered, Inundation Damage – Nonperishable Content

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	0	1	4
0.5	3	8	18
1.0	7	12	28
2.0	13	18	38
3.0	20	25	49
5.0	30	39	64
7.0	40	50	72
10.0	45	60	90

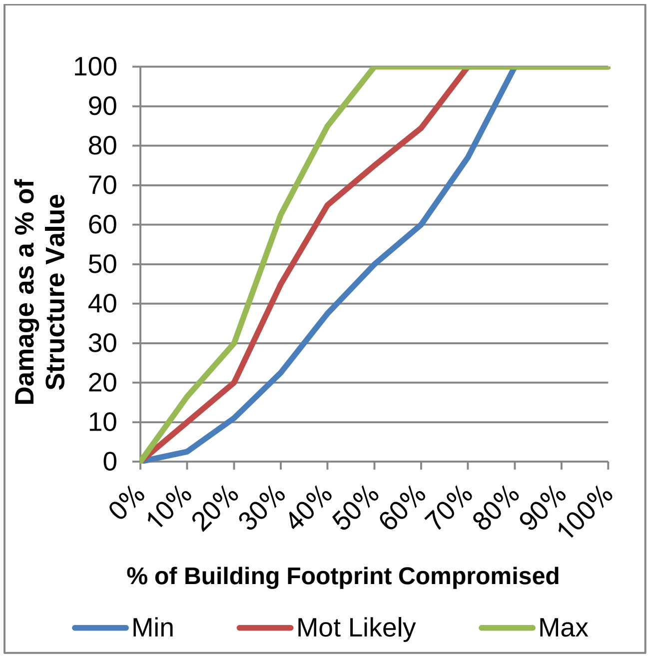

Figure 61. Prototype 3: Commercial Non/Pre-Engineered, Erosion Damage - Structure

Table 38. Prototype 3: Commercial Non/Pre-Engineered, Erosion Damage - Structure

Percent Compromised	Min	Most Likely	Max
0%	0	0	0
10%	3	10	17
20%	11	20	30
30%	23	45	63
40%	38	65	85
50%	50	75	100
60%	60	85	100
70%	77	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

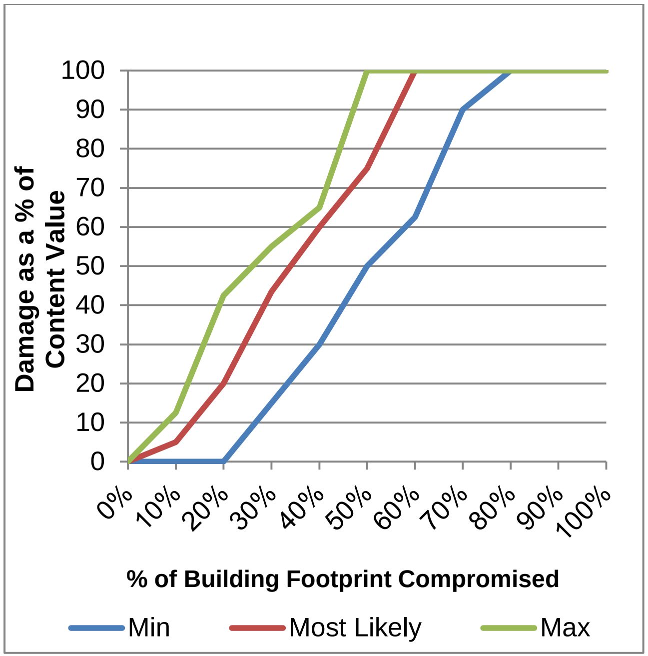

Figure 62. Prototype 3: Commercial Non/Pre-Engineered, Erosion Damage – Perishable Content

Table 39. Prototype 3: Commercial Non/Pre-Engineered, Erosion Damage – Perishable Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	5	13
20%	0	20	43
30%	15	44	55
40%	30	60	65
50%	50	75	100
60%	63	100	100
70%	90	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

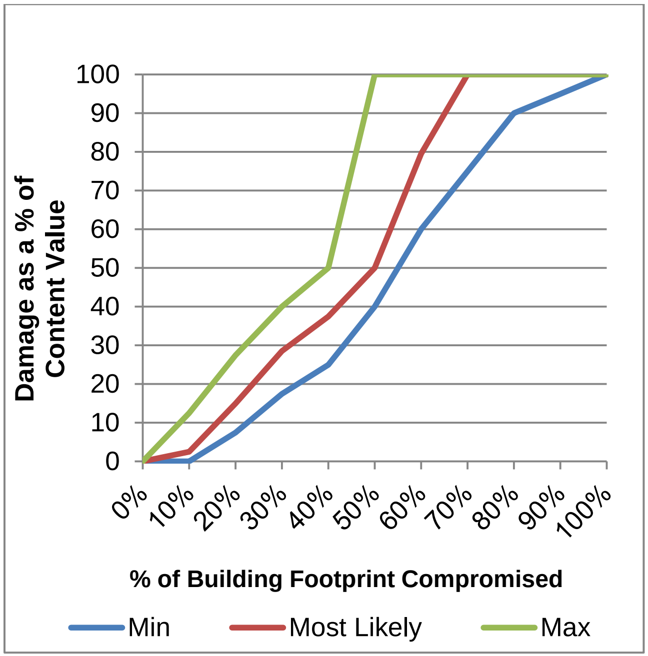

Figure 63. Prototype 3: Commercial Non/Pre-Engineered, Erosion Damage – Nonperishable Content

Table 40. Prototype 3: Commercial Non/Pre-Engineered, Erosion Damage – Nonperishable Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	3	13
20%	8	15	28
30%	18	29	40
40%	25	38	50
50%	40	50	100
60%	60	80	100
70%	75	100	100
80%	90	100	100
90%	95	100	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

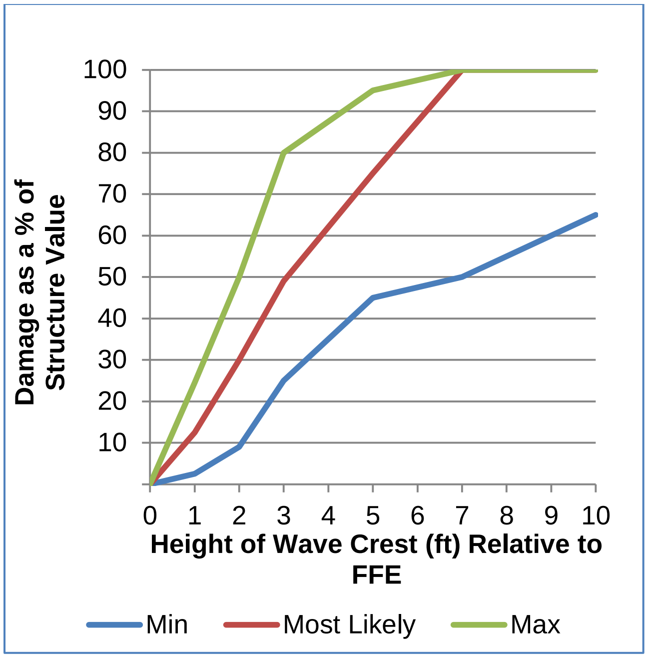

Figure 64. Prototype 3: Commercial Non/Pre-Engineered, Wave Damage - Structure

Table 41. Prototype 3: Commercial Non/Pre-Engineered, Wave Damage - Structure

Wave Crest	**Min**	**Most Likely**	**Max**
0	0	0	0
1	2.5	12.5	24.5
2	9	30	50
3	25	49	80
5	45	75	95
7	50	100	100
10	65	100	100

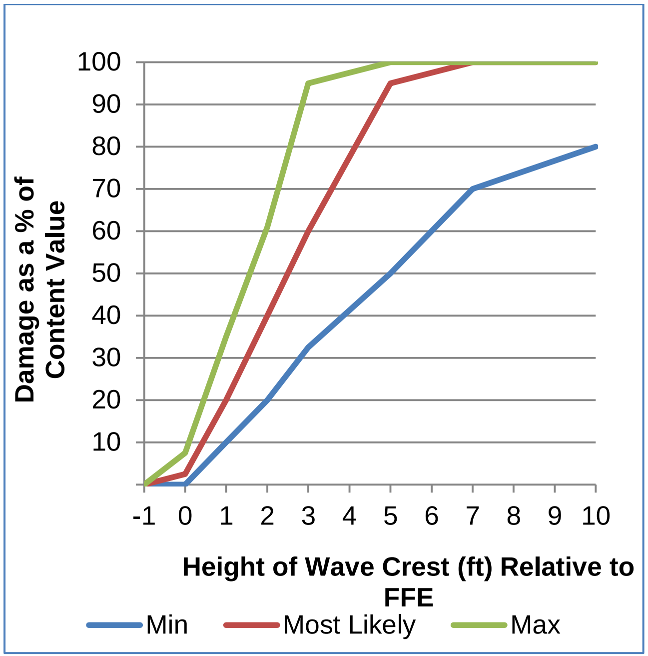

Figure 65. Prototype 3: Commercial Non/Pre-Engineered, Wave Damage – Perishable Content

Table 42. Prototype 3: Commercial Non/Pre-Engineered, Wave Damage – Perishable Content

Wave Crest	**Min**	**Most Likely**	**Max**
-1	0	0	0
0	0	2.5	7.5
1	10	20	35
2	20	40	61
3	32.5	60	95
5	50	95	100
7	70	100	100
10	80	100	100

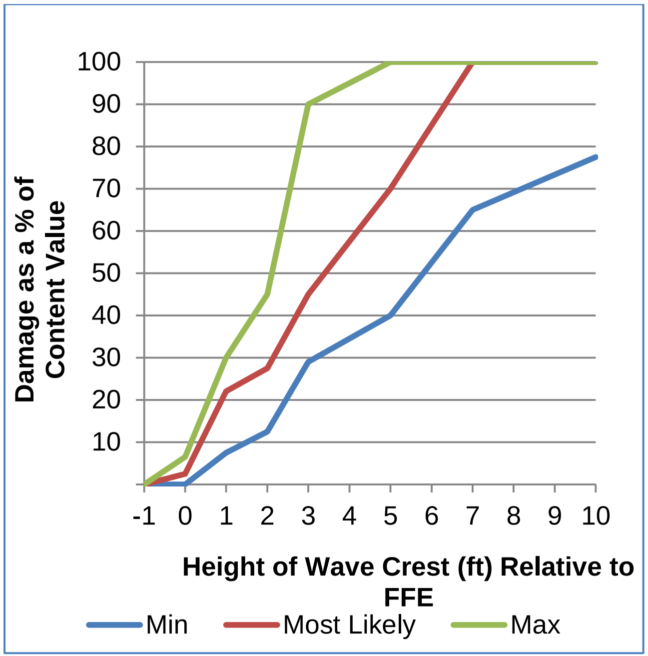

Figure 66. Prototype 3: Commercial Non/Pre-Engineered, Wave Damage – Nonperishable Content

Table 43. Prototype 3: Commercial Non/Pre-Engineered, Wave Damage – Nonperishable Content

Wave Crest	Min	Most Likely	Max
-1	0	0	0
0	0	2.5	6.5
1	7.5	22	30
2	12.5	27.5	45
3	29	45	90
5	40	70	100
7	65	100	100
10	77.5	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 44 and Figure 67 show wave, surge, and still water characteristics associated with 100% wave damage for the most likely building characteristics of a commercial non- or pre-engineered building (Prototype 3). This prototype has a slab foundation and a FFE of 1.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100% wave damage for this prototype is expected to occur with a still water depth (d) of 5.2 feet. This still water depth will typically allow a maximum wave height of 4.0 feet (H_b = .78d). The wave crest under this condition would be approximately 8.0 feet above grade ($0.7H_b + d$).

Table 44. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 3 Commercial Non/Pre-Engineered, Most Likely Building Characteristics

Designation	Characteristic	Feet
A	FFE Above Grade	1.0
B	Wave Crest Height Above FFE	7.0
C	Breaking Wave Height (H_b = 0.78d)	4.0
D	$0.7H_b$	2.9
E	Still Water Elevation (d)	5.2
F	Wave Crest Elevation ($0.7H_b$ + d)	8.0

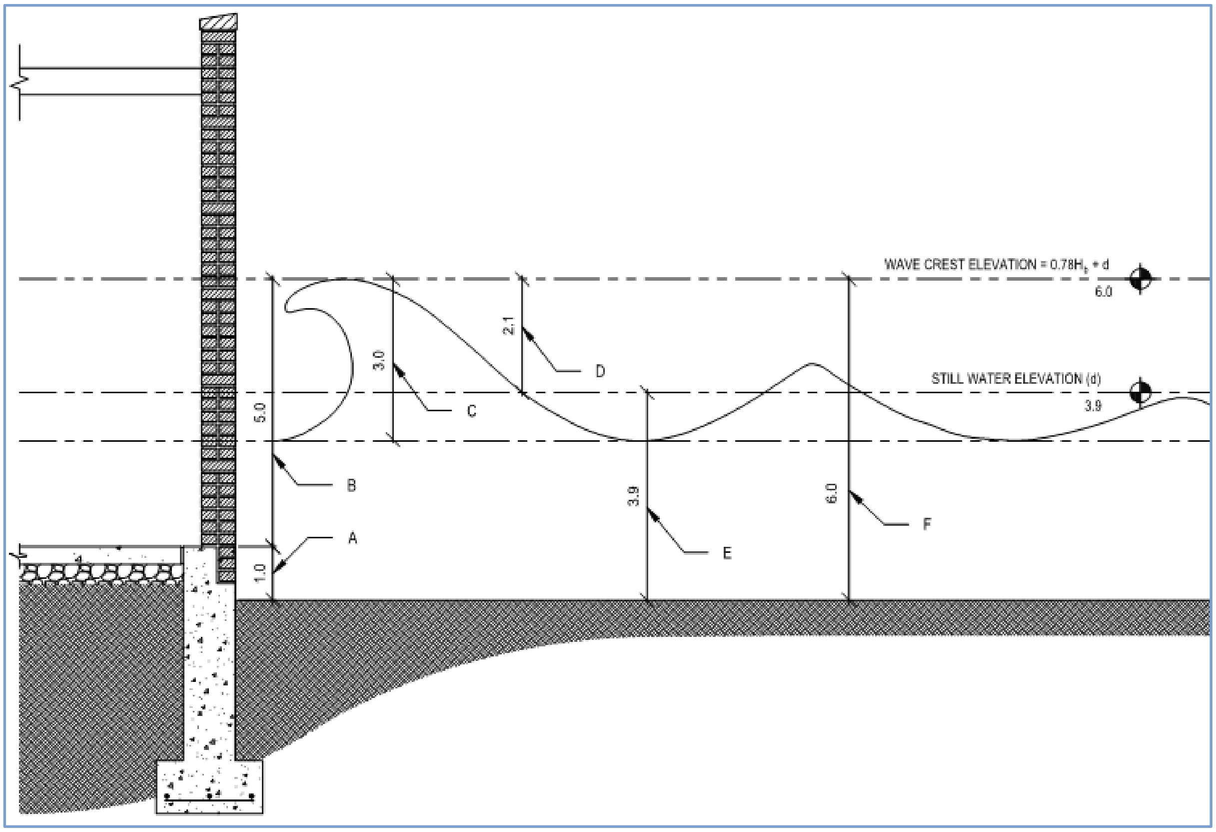

Figure 67. Illustration of Maximum Wave Damage Scenario, Prototype 3 Commercial Non/Pre-Engineered, Most Likely Building Characteristics

6.9 Prototype 4A: Urban High Rise

Most Likely Building Characteristics: The building is between 15 and 30 years old, and has a full basement with parking and Mechanical/Electrical/Plumbing (MEP) equipment. The first (ground) level has an open lobby layout with limited finishing. Upper levels are apartments. MEP equipment constitutes 40% of the building's total value.

Minimum-Damage Building Characteristics: The building is between 0 and 10 years old, with minimal MEP equipment in the basement. The first (ground) level has an open lobby layout with limited finishing. Upper levels are apartments. MEP equipment constitutes 35% of the building's total value.

Higher-Damage Building Characteristics: The building is older. It has multiple basements with extensive Mechanical/Electrical/Plumbing (MEP) equipment. The first (ground) level houses retail establishments. Upper levels are apartments. MEP equipment constitutes 50% of the building's total value.

See Table 45 below:

Table 45. Prototype 4A: Urban High Rise: Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	10	10	10
Foundation	Deep	Deep	Deep
Age	15 - 30	0 – 10	Old—unknown codes
Structure	Structural steel or reinforced concrete	Structural steel or reinforced concrete	Structural steel or reinforced concrete
Basement	Full basement with MEP and parking	Minimal MEP	Multiple basements, MEP+
1st Floor Use	Lobby	Open lobby	Retail
Upper Floor Use	Apartments	Apartments	Apartments
Elevators/MEP	40% of total value	35% of total value	50% of total value

Table 46 and Table 47 present the inundation damage for structure and contents for Prototype 4A, Urban High Rise. Figure 68 and Figure 69 present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

The damage to high rise buildings should be calculated as a percent of the first 10 stories.

Note regarding buildings with more than three stories and less than ten stories:

- For shallow foundations, use the Prototype 1 damage function
- For deep foundations, use the Prototype 4 damage function

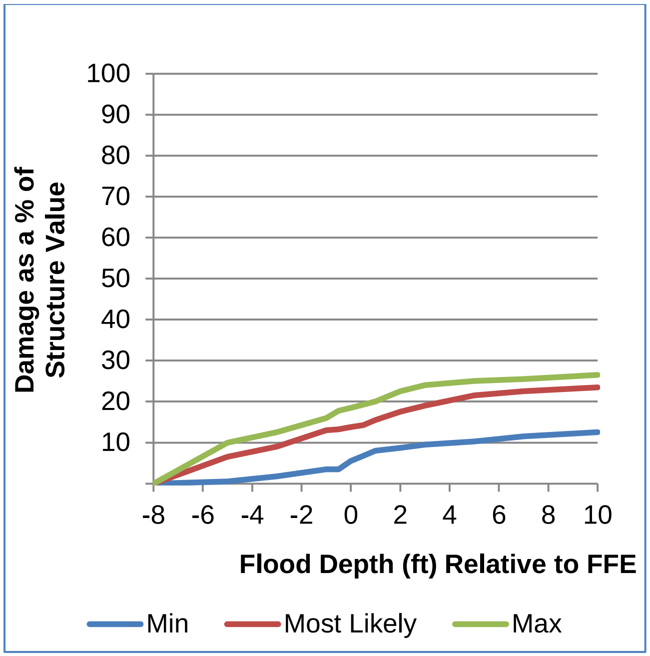

Figure 68. Prototype 4A: Urban High Rise, Inundation Damage – Structure

Table 46. Prototype 4A: Urban High Rise, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-8	0	0	0
-5	0.5	6.5	10
-3	1.75	9	12.5
-1	3.5	13	16
-0.5	3.5	13.25	17.75
0	5.5	13.75	18.5
0.5	6.75	14.25	19.25
1	8	15.5	20
2	8.75	17.5	22.5
3	9.5	19	24
5	10.25	21.5	25
7	11.5	22.5	25.5
10	12.5	23.5	26.5

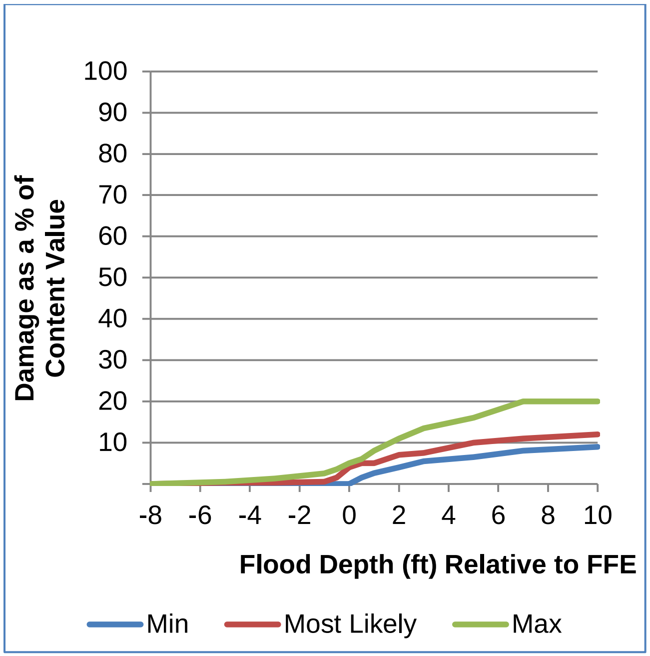

Figure 69. Prototype 4A: Urban High Rise, Inundation Damage – Content

Table 47. Prototype 4A: Urban High Rise, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-8	0	0	0
-5	0	0.25	0.5
-3	0	0.25	1.25
-1	0	0.5	2.5
-0.5	0	1.5	3.5
0	0	4	5
0.5	1.5	5	6
1	2.6	5	8
2	4	7	11
3	5.5	7.5	13.5
5	6.5	10	16
7	8	11	20
10	9	12	20

6.10 Prototype 4B: Beach High Rise

Most Likely Building Characteristics: The building is between 15 and 30 years old. The first (ground) level is a mix of apartments and parking space, and also houses some of the building's MEP equipment. Upper levels are apartments.

Minimum-Damage Building Characteristics: The building is between 0 and 10 years old. The first (ground) level is used for parking only. No MEP equipment is housed on the lower level. Upper levels are apartments.

Higher-Damage Building Characteristics: The building is older. The first (ground) level houses living space, and all of the building's MEP equipment. Upper levels are apartments.

See Table 48 below:

Table 48. Prototype 4B: Beach High Rise: Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	10	10	10
Foundation	Deep	Deep	Deep
Age	15 - 30	0 – 10	Old—unknown codes
Structure	Structural steel or reinforced concrete	Structural steel or reinforced concrete	Structural steel or reinforced concrete
1st Floor Use	Mix of parking and apartments	Parking	Living area
Upper Floor Use	Apartments	Apartments	Apartments
Elevators/MEP	Partial lower level	None on lower level	Lower level

Table 49 through Table 54 present Prototype 4B Beach High Rise Inundation Damages, Erosion Damages and Wave Damages for structure and contents. Figure 70 through Figure 75 present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

The damage to high rise buildings should be calculated as a percent of the first 10 stories

Note regarding buildings with more than three stories and less than ten stories:

- For shallow foundations, use the Prototype 1 damage function
- For deep foundations, use the Prototype 4 damage function

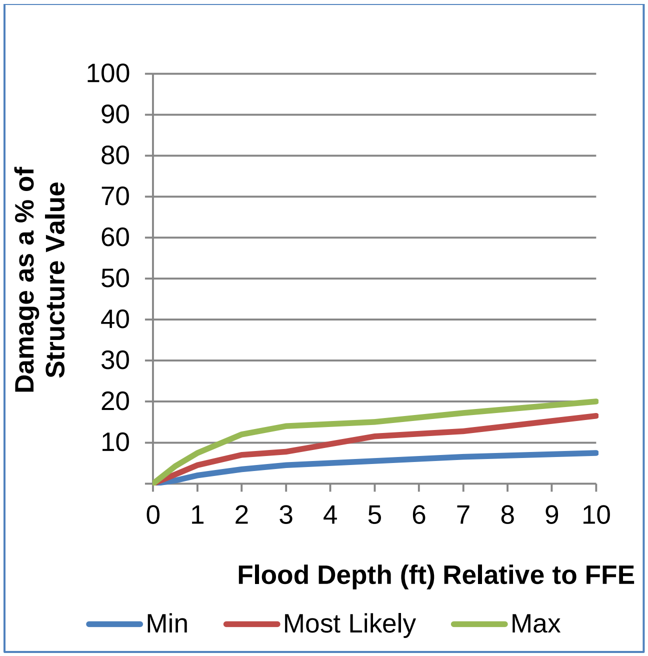

Figure 70. Prototype 4B: Beach High Rise, Inundation Damage – Structure

Table 49. Prototype 4B: Beach High Rise, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-8	0	0	0
-5	0	0	0
-3	0	0	0
-1	0	0	0
-0.5	0	0	0
0	0	0	0
0.5	0.75	2.25	4.25
1	2	4.5	7.5
2	3.5	7	12
3	4.5	7.75	14
5	5.5	11.5	15
7	6.5	12.75	17.25
10	7.5	16.5	20

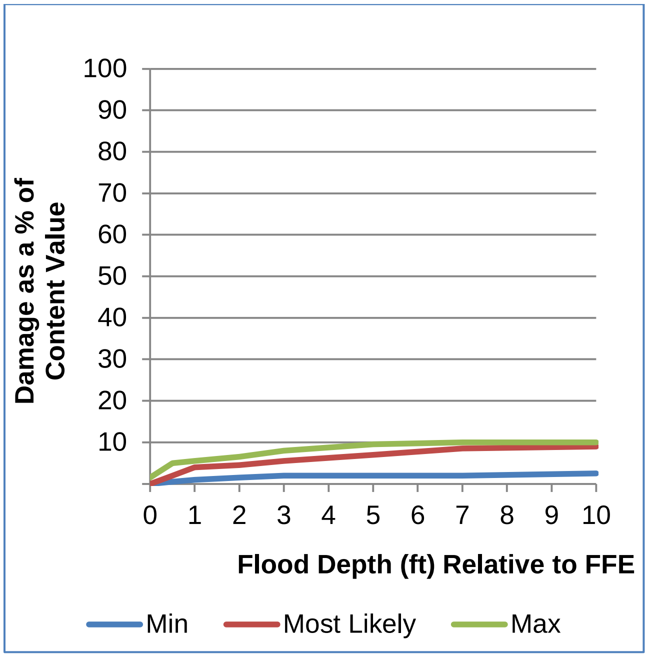

Figure 71. Prototype 4B: Beach High Rise, Inundation Damage – Content

Table 50. Prototype 4B: Beach High Rise, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-8	0	0	0
-5	0	0	0
-3	0	0	0
-1	0	0	0
-0.5	0	0	0
0	0	0	1.5
0.5	0.5	2	5
1	1	4	5.5
2	1.5	4.5	6.5
3	2	5.5	8
5	2	7	9.5
7	2	8.5	10
10	2.5	9	10

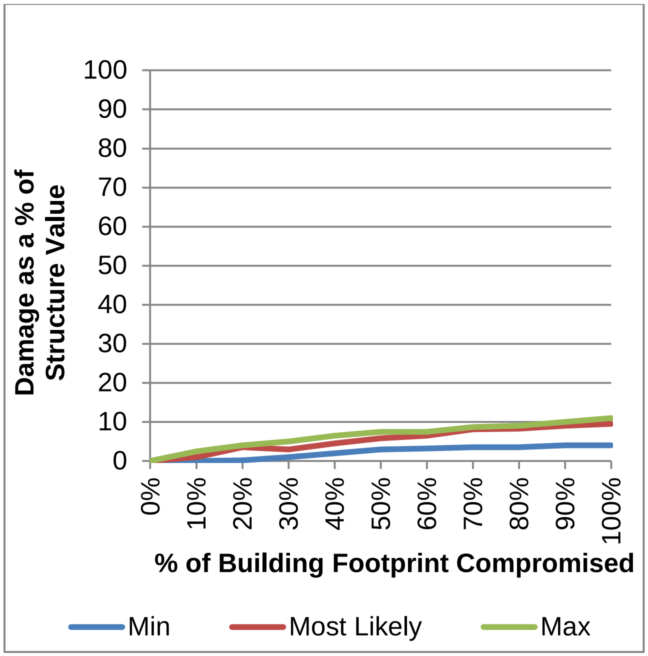

Figure 72. Prototype 4B: Beach High Rise, Erosion Damage - Structure

Table 51. Prototype 4B: Beach High Rise, Erosion Damage - Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0.05	1.025	2.5
20%	0.15	3.5	4
30%	1	3	5
40%	2	4.5	6.5
50%	3	5.8	7.5
60%	3.25	6.5	7.5
70%	3.5	8.1	8.7
80%	3.5	8.3	9
90%	4	9	10
100%	4	9.5	11

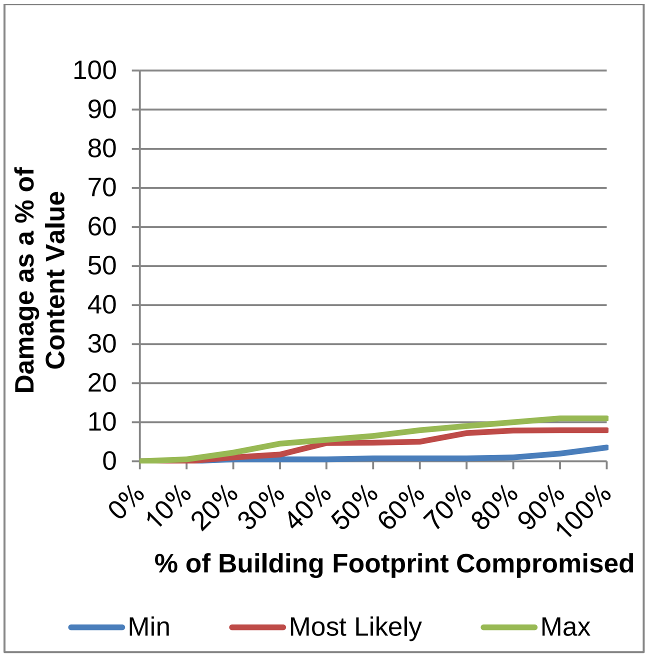

Figure 73. Prototype 4B: Beach High Rise, Erosion Damage - Content

Table 52. Prototype 4B: Beach High Rise, Erosion Damage - Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	0	0.5
20%	0.5	1	2.25
30%	0.5	1.75	4.5
40%	0.5	4.7	5.5
50%	0.75	4.8	6.5
60%	0.75	5	8
70%	0.75	7.25	9
80%	1	7.85	10
90%	2	8	11
100%	3.5	8	11

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

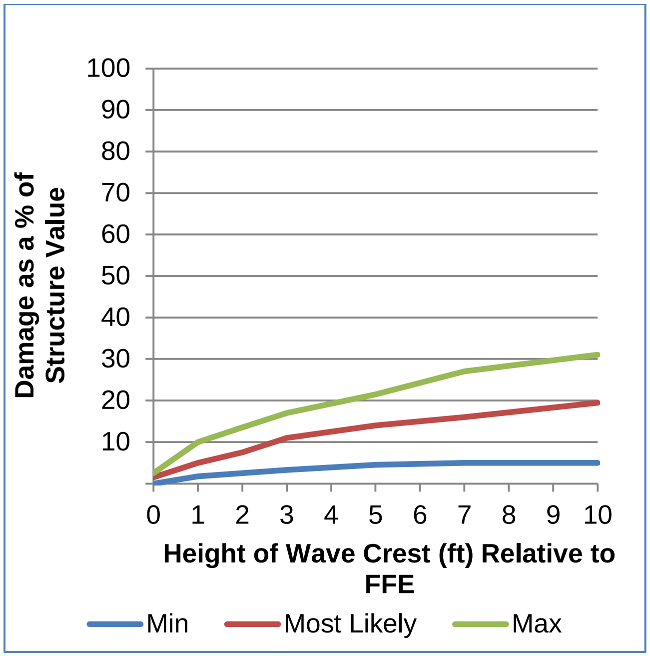

Figure 74. Prototype 4B: Beach High Rise, Wave Damage - Structure

Table 53. Prototype 4B: Beach High Rise, Wave Damage - Structure

Wave Crest	Min	Most Likely	Max
-2	0	0	0
-1	0	0	0
0	0	1.5	2.5
1	1.75	5	10
2	2.5	7.5	13.5
3	3.25	11	17
5	4.5	14	21.5
7	5	16	27
10	5	19.5	31

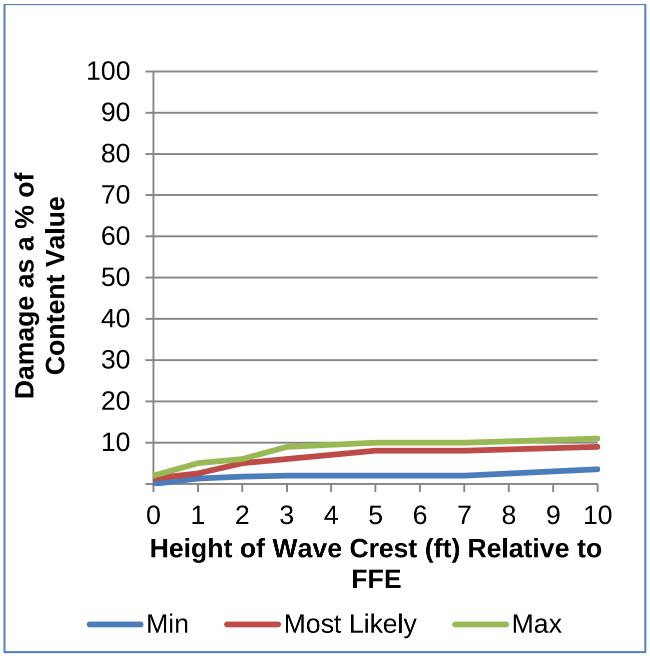

Figure 75. Prototype 4B: Beach High Rise, Wave Damage - Content

Table 54. Prototype 4B: Beach High Rise, Wave Damage - Content

Wave Crest	Min	Most Likely	Max
-2	0	0	0
-1	0	0	0
0	0	1.25	2
1	1.25	2.5	5
2	1.75	5	6
3	2	6	9
5	2	8	10
7	2	8	10
10	3.5	9	11

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

A point of failure illustration for wave damage is not provided for this prototype because a building of this type was not expected to experience 100% damage as a result of wave impact.

6.11 Prototype 5A: Single-Story Residence, No Basement

Most Likely Building Characteristics: The prototype building is of wood frame construction. It is 15 to 30 years old, and is in fair to good condition. The building is on a slab. The finished floor is 1’-0” above grade.

Minimum-Damage Building Characteristics: The prototype building is of masonry construction that is reinforced per code. It is 0 to 10 years old, and is in good condition. The building is on a slab. The finished floor is at grade level.

Higher-Damage Building Characteristics: The prototype building is of wood frame construction. It is older, and in poor condition. It is not known if the building was built to code. The building is elevated above grade on a crawl space. The finished floor is 3’-0” above grade.

See Table 55 below:

Table 55. Prototype 5A: Single Story Residence, No Basement: Building Characteristics

	Most Likely	**Minimum Damage**	**Maximum Damage**
Stories	1	1	1
Foundation	Slab	Slab	Crawl Space
Age	15 - 30	0 – 10	Old—unknown codes
Structure	Wood frame	Masonry, reinforced per code	Wood frame
Height of Finished Floor Above Grade	1’-0”	0’-0”	3’-0”
Condition	Fair/Good	Good	Poor

Table 55 through Table 64 provide Prototype 5A single-story residence, no basement; inundation damages, erosion damages, wave- slab damages and wave-wall damages for structure and contents. Figure 76 through Figure 84 present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

It is noted that as part of the damage function verification process described in Attachment G, the inundation damage functions for the no basement prototypes 5A and 5B are lower than the empirical damages collected from the FEMA substantial damage estimates. The verification report provides an assessment of possible causes for this result. Users are advised to review the verification results for this prototype and consider those findings in their selection of the appropriate depth-damage functions for their specific study area.

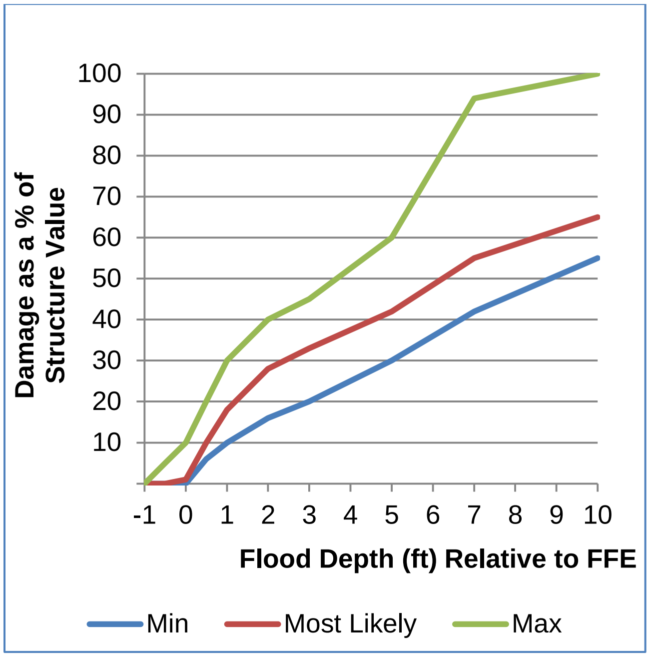

Figure 76. Prototype 5A: Single Story Residence, No Basement, Inundation Damage – Structure

Table 56. Prototype 5A: Single Story Residence, No Basement, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	5
0.0	0	1	10
0.5	6	10	20
1.0	10	18	30
2.0	16	28	40
3.0	20	33	45
5.0	30	42	60
7.0	42	55	94
10.0	55	65	100

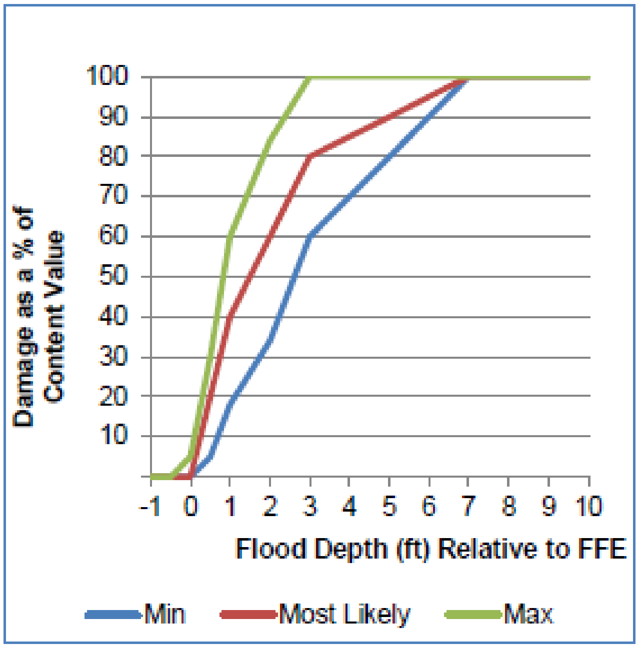

Figure 77. Prototype 5A: Single Story Residence, No Basement, Inundation Damage – Content

Table 57. Prototype 5A: Single Story Residence, No Basement, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	0	0	5
0.5	5	20	30
1.0	18	40	60
2.0	34	60	84
3.0	60	80	100
5.0	80	90	100
7.0	100	100	100
10.0	100	100	100

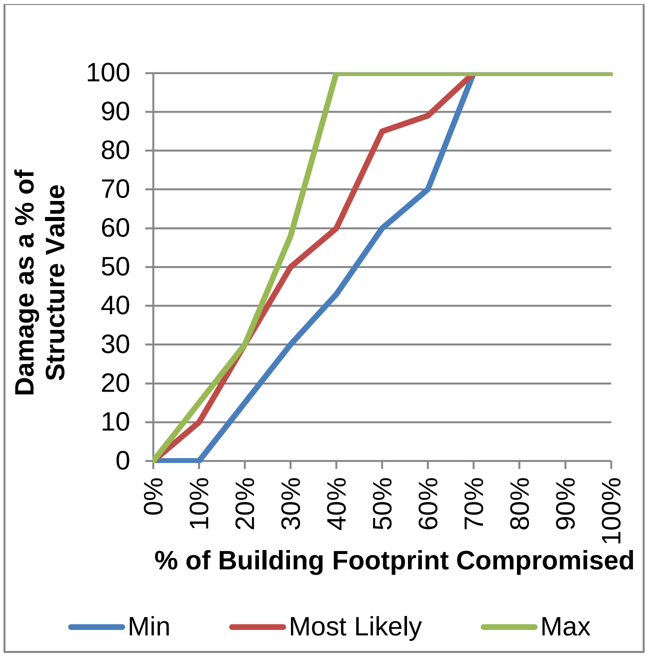

Figure 78. Prototype 5A: Single Story Residence, No Basement, Erosion Damage - Structure

Table 58. Prototype 5A: Single Story Residence, No Basement, Erosion Damage - Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	10	15
20%	15	30	30
30%	30	50	58
40%	43	60	100
50%	60	85	100
60%	70	89	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

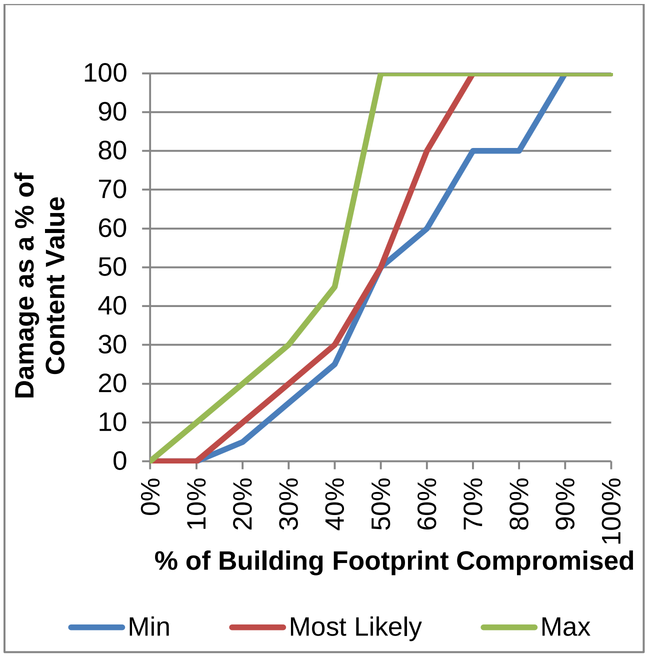

Figure 79. Prototype 5A: Single Story Residence, No Basement, Erosion Damage - Content

Table 59. Prototype 5A: Single Story Residence, No Basement, Erosion Damage - Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	0	10
20%	5	10	20
30%	15	20	30
40%	25	30	45
50%	50	50	100
60%	60	80	100
70%	80	100	100
80%	80	100	100
90%	100	100	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

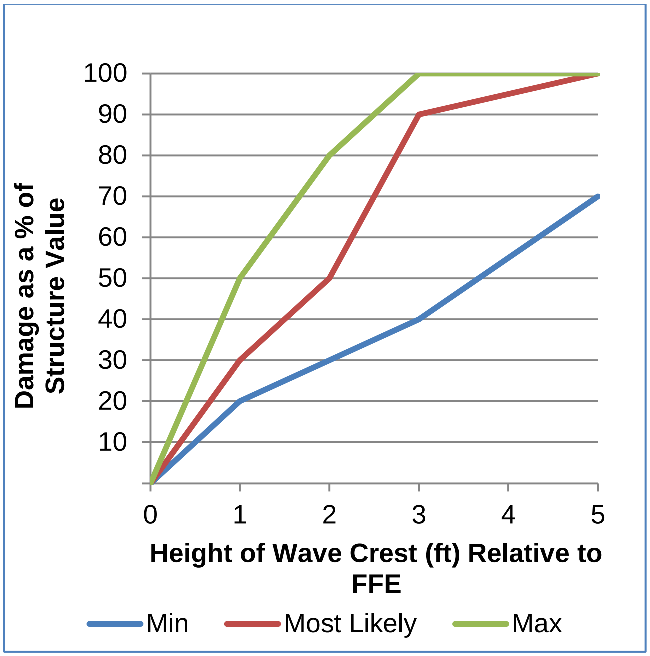

Figure 80. Prototype 5A: Single Story Residence, No Basement, Wave Damage, Slab Foundation - Structure

Table 60. Prototype 5A: Single Story Residence, No Basement, Wave Damage, Slab Foundation - Structure

Wave Crest	Min	Most Likely	Max
0	0	0	0
1	20	30	50
2	30	50	80
3	40	90	100
5	70	100	100

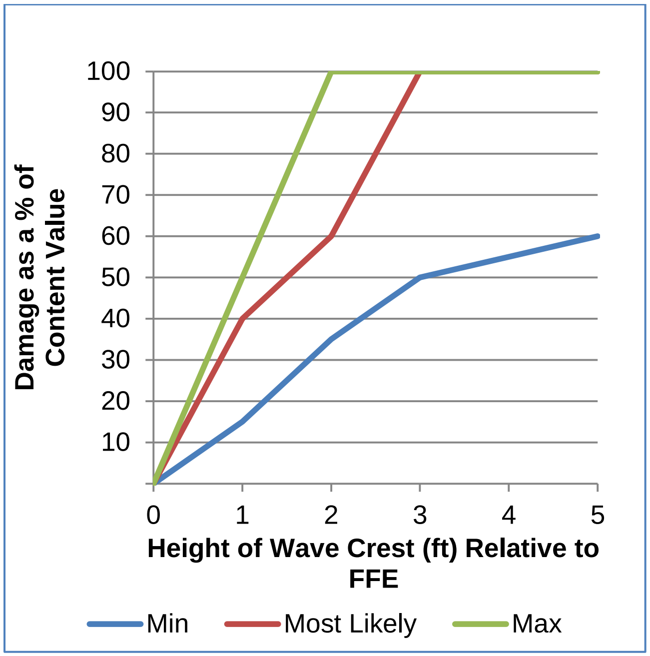

Figure 81. Prototype 5A: Single Story Residence, No Basement, Wave Damage, Slab Foundation - Content

Table 61. Prototype 5A: Single Story Residence, No Basement, Wave Damage, Slab Foundation - Content

Wave Crest	Min	Most Likely	Max
0	0	0	0
1	15	40	50
2	35	60	100
3	50	100	100
5	60	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 62 and Figure 82 show wave, surge, and still water characteristics associated with 100% wave damage for the most likely building characteristics of a single-story residence without a basement (Prototype 5A). This prototype has a slab foundation and a FFE of 1.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100% wave damage for this prototype is expected to occur with a still water depth (d) of 3.9 feet. This still water depth will typically allow a maximum wave height of 3.0 feet (H_b = .78d). The wave crest under this condition would be approximately 6.0 feet above grade ($0.7H_b + d$).

Table 62. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 5A Single Story Residence, No Basement, Most Likely Building Characteristics, Slab Foundation

Designation	Characteristic	Feet
A	FFE Above Grade	1.0
B	Wave Crest Height Above FFE	5.0
C	Breaking Wave Height (H_b = 0.78d)	3.0
D	$0.7H_b$	2.1
E	Still Water Elevation (d)	3.9
F	Wave Crest Elevation ($0.7H_b$ + d)	6.0

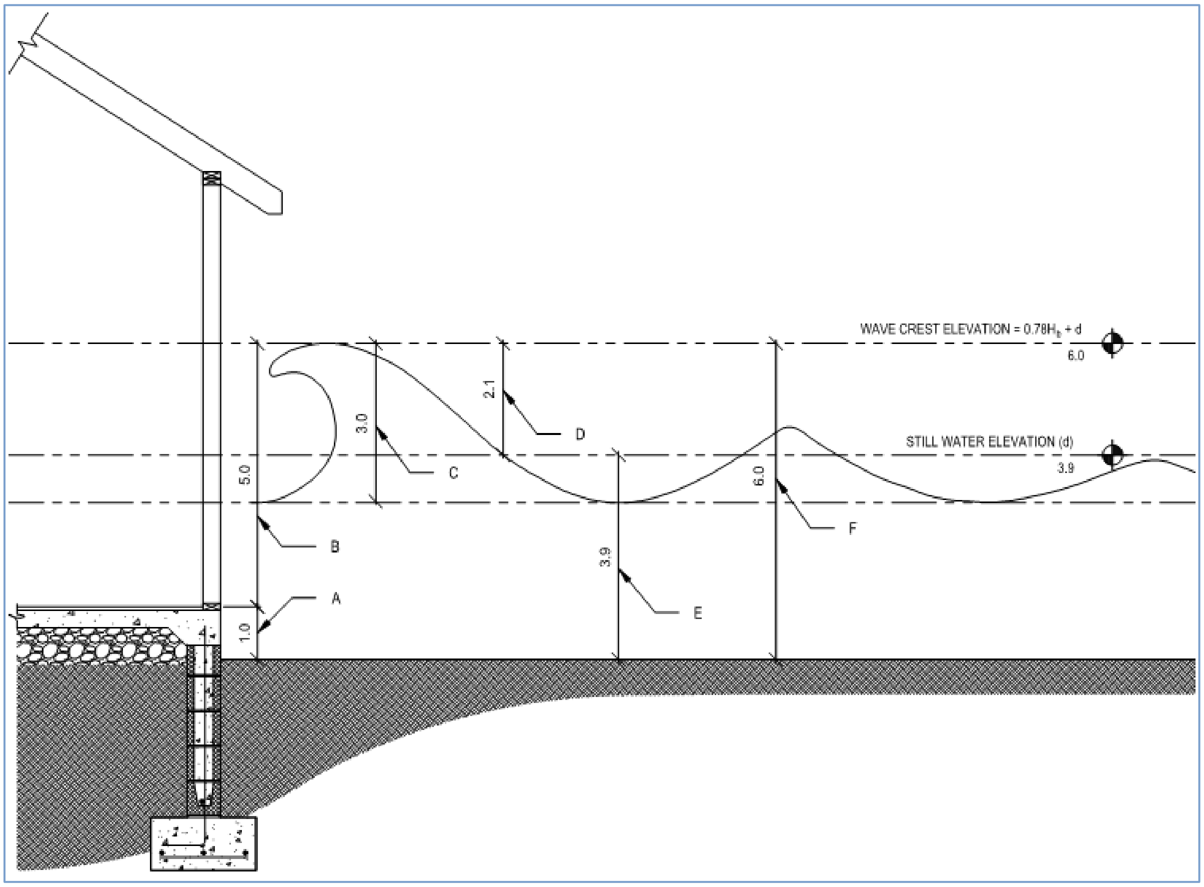

Figure 82. Illustration of Maximum Wave Damage Scenario, Prototype 5A Single Story Residence, No Basement, Most Likely Building Characteristics, Slab Foundation

The basis of the damage estimates in Table 63 and Table 65 is that there is some damage to the structure (including floor framing and utilities) when the wave/water elevation reaches within 1 foot below the finished floor. For the "most likely" conditions structure damages in Table 63 are estimated as 0% at -2 ft., 5% at -1 ft. and 10% at depth 0 ft. In the "maximum" condition presented in Table 65, the increase in foundation height from 1 ft. to 3 ft. above grade allows a larger breaking wave to reach the structure. The increase in wave crest elevations in the "Maximum" condition results in an increase in Table 63 damage to 10% at -1 ft. and 20% at depth 0 ft. The 100% damage level for the "maximum" condition is at a depth of 3 ft., 1 ft. lower than the 100% damage level for the "most likely" condition.

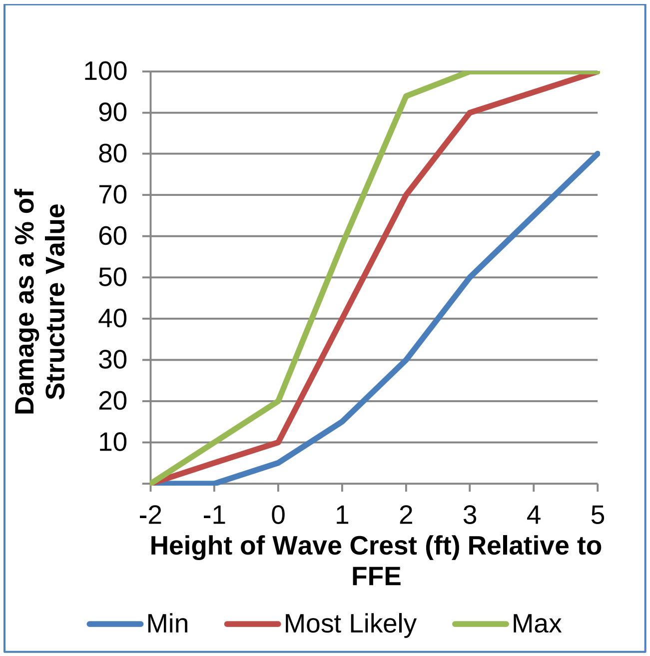

Figure 83. Prototype 5A: Single Story Residence, No Basement, Wave Damage, Extended Foundation Wall - Structure

Table 63. Prototype 5A: Single Story Residence, No Basement, Wave Damage, Extended Foundation Wall - Structure

Wave Crest	Min	Most Likely	Max
-2	0	0	0
-1	0	5	10
0	5	10	20
1	15	40	58
2	30	70	94
3	50	90	100
5	80	100	100

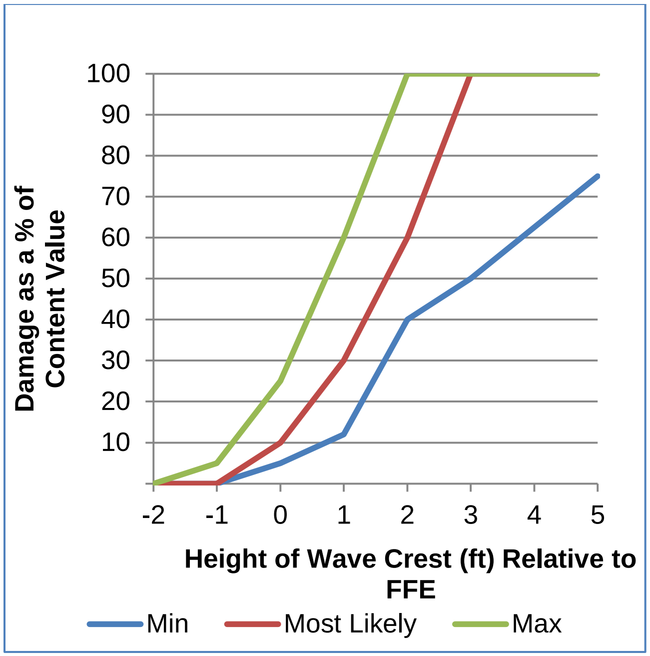

Figure 84. Prototype 5A: Single Story Residence, No Basement, Wave Damage, Extended Foundation Wall - Content

Table 64. Prototype 5A: Single Story Residence, No Basement, Wave Damage, Extended Foundation Wall - Content

Wave Crest	Min	Most Likely	Max
-2	0	0	0
-1	0	0	5
0	5	10	25
1	12	30	60
2	40	60	100
3	50	100	100
5	75	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 65 and Figure 85 show wave, surge, and still water characteristics associated with 100% wave damage for the maximum damage building characteristics of a single-story residence without a basement (Prototype 5A). This prototype has an extended wall foundation and a FFE of 3.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100% wave damage for this prototype is expected to occur with a still water depth (d) of 5.2 feet. This still water depth will typically allow a maximum wave height of 4.0 feet (H_b = .78d). The wave crest under this condition would be approximately 8.0 feet above grade ($0.7H_b$ + d).

A maximum damage scenario is presented here because it is recognized that analysts may encounter situations where the building stock for a given project is more like that considered in a prototype's maximum-damage scenario. It is important for analysts to understand where it may be appropriate to apply different damage functions due to the characteristics of the building stock.

Table 65. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 5A Single Story Residence, No Basement, Maximum Damage Building Characteristics, Extended Foundation Wall*

Designation	Characteristic	Feet
A	FFE Above Grade	3.0
B	Wave Crest Height Above FFE	5.0
C	Breaking Wave Height (H_b = 0.78d)	4.0
D	$0.7H_b$	2.8
E	Still Water Elevation (d)	5.2
F	Wave Crest Elevation ($0.7H_b$ + d)	8.0

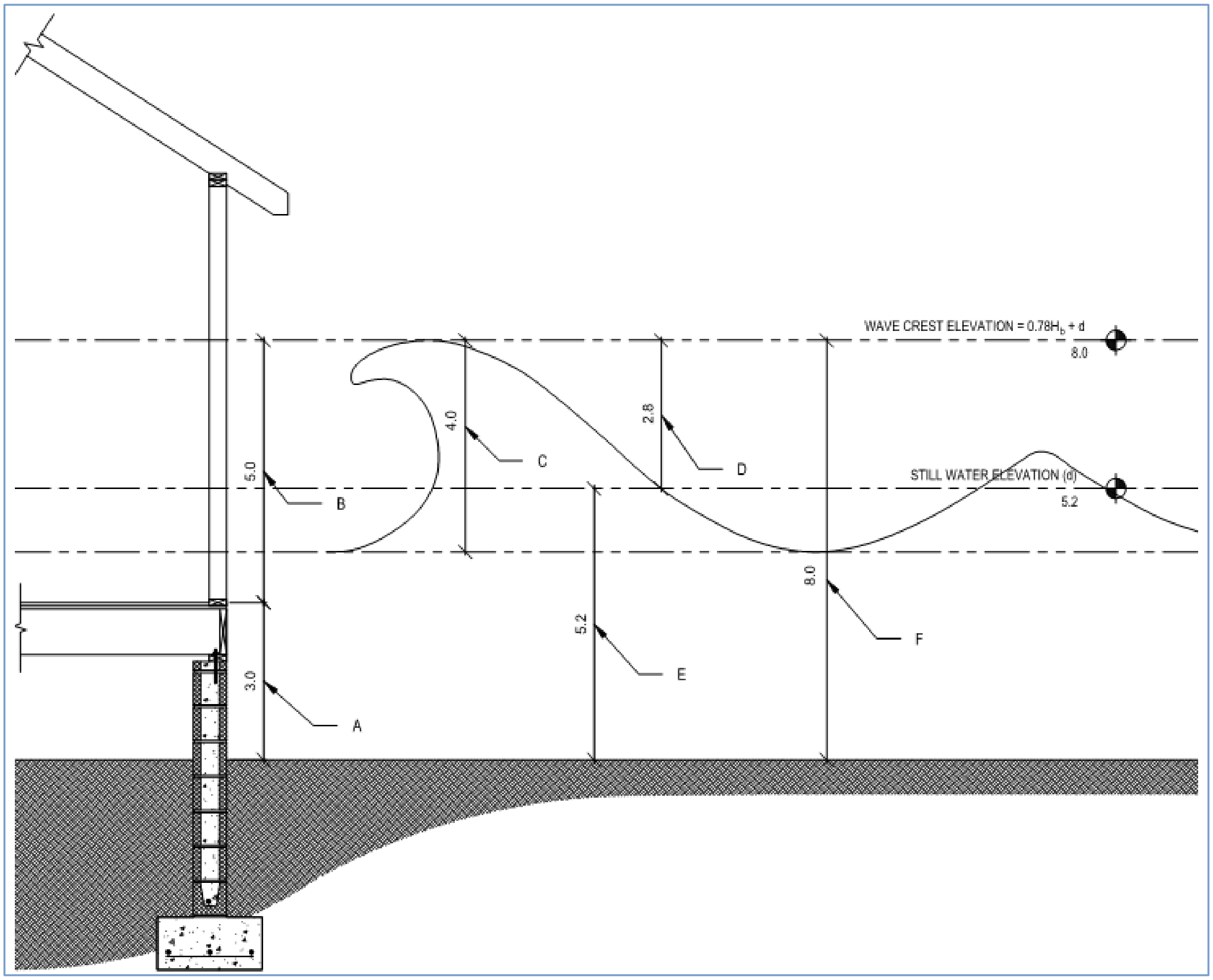

Figure 85. Illustration of Maximum Wave Damage Scenario, Prototype 5A Single Story Residence, No Basement, Most Likely Building Characteristics, Extended Foundation Wall

6.12 Prototype 5B: Two-Story Residence, No Basement

Most Likely Building Characteristics: The prototype building is of wood frame construction. It is 15 to 30 years old, and is in fair to good condition. The building is elevated above grade on a crawl space. The finished floor is 3’-0” above grade.

Minimum-Damage Building Characteristics: The prototype building is of masonry construction. It is 0 to 10 years old, and is in good condition. The building is on a slab. The finished floor is 1’-0” above grade.

Higher-Damage Building Characteristics: The prototype building is of wood frame construction. It is older, and in poor condition. It is not known if the building was built to code. The building is elevated above grade on a crawl space. The finished floor is 4’-0” above grade.

See Table 66 below:

Table 66. Prototype 5B: Two-Story Residence, No Basement: Building Characteristics

	Most Likely	**Minimum Damage**	**Maximum Damage**
Stories	2	2	2
Foundation	Crawl space	Slab	Crawl space
Age	15 – 30	0 – 10	Old—unknown codes
Structure	Wood frame	Masonry	Wood Frame
Height of Finished Floor Above Grade	3’-0”	1’-0”	4’-0”
Condition	Fair/Good	Good	Poor

Table 67 through Table 72 present Prototype 5B Two-Story Residence- No Basement, inundation damages, erosion damages, and wave damages for structure and contents. Figure 86 through Figure 91 present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

It is noted that as part of the damage function verification process described in Attachment G, the inundation damage functions for the no basement prototypes 5A and 5B are lower than the empirical damages collected from the FEMA substantial damage estimates. The verification report provides an assessment of possible causes for this result. Users are advised to review the verification results for this prototype and consider those findings in their selection of the appropriate depth-damage functions for their specific study area.

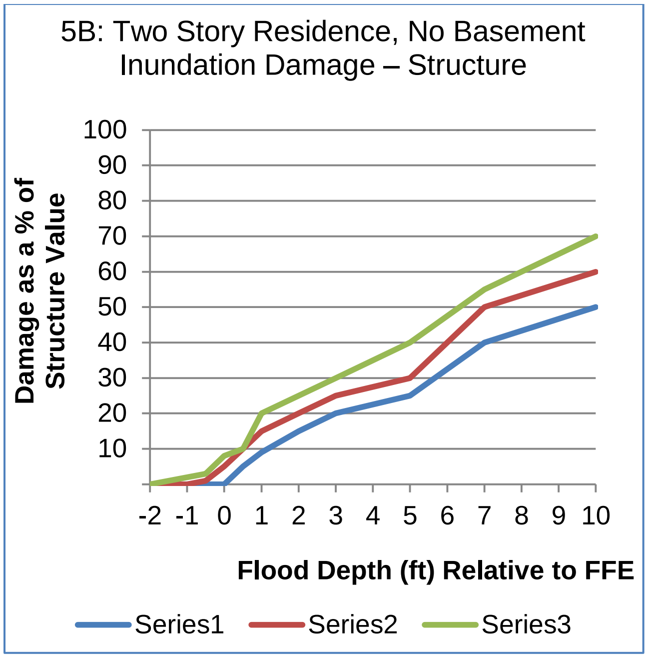

Figure 86. Prototype 5B: Two-Story Residence, No Basement, Inundation Damage – Structure

Table 67. Prototype 5B: Two-Story Residence, No Basement, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-2.0	0	0	0
-1.0	0	0	2
-0.5	0	1	3
0.0	0	5	8
0.5	5	10	10
1.0	9	15	20
2.0	15	20	25
3.0	20	25	30
5.0	25	30	40
7.0	40	50	55
10.0	50	60	70

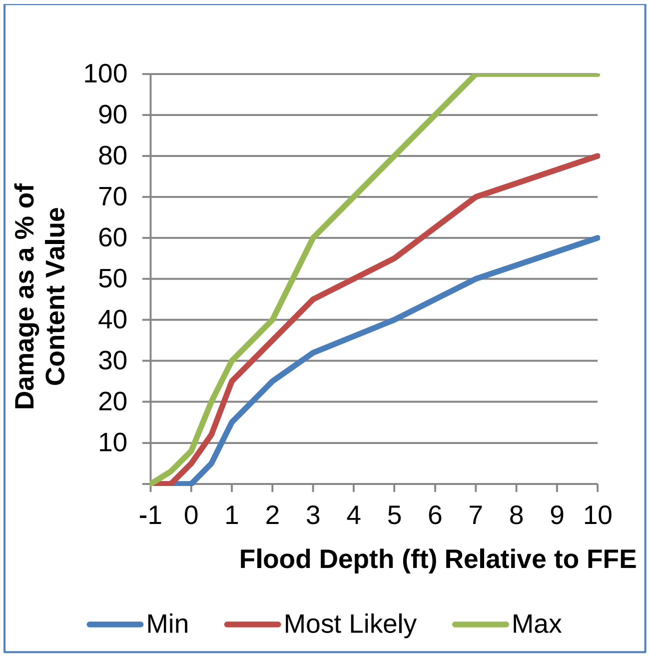

Figure 87. Prototype 5B: Two-Story Residence, No Basement, Inundation Damage – Content

Table 68. Prototype 5B: Two-Story Residence, No Basement, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	3
0.0	0	5	8
0.5	5	12	20
1.0	15	25	30
2.0	25	35	40
3.0	32	45	60
5.0	40	55	80
7.0	50	70	100
10.0	60	80	100

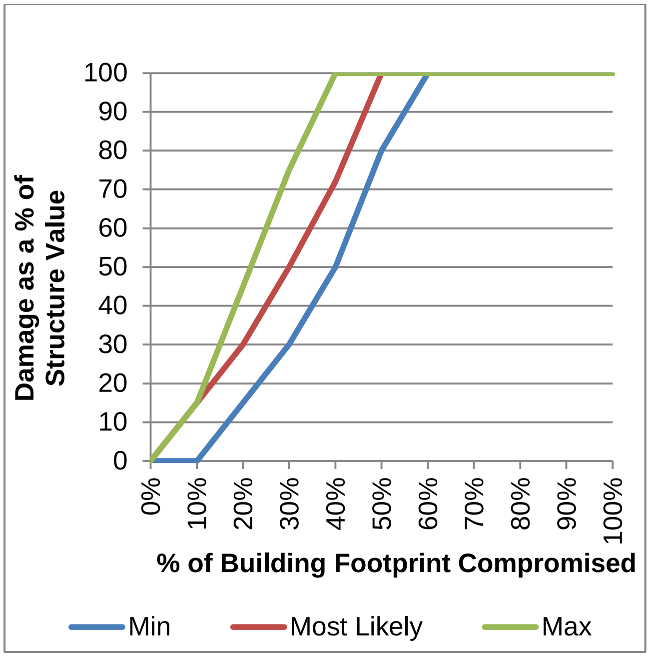

Figure 88. Prototype 5B: Two-Story Residence, No Basement, Erosion Damage - Structure

Table 69. Prototype 5B: Two-Story Residence, No Basement, Erosion Damage - Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	15	15
20%	15	30	45
30%	30	50	75
40%	50	72	100
50%	80	100	100
60%	100	100	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

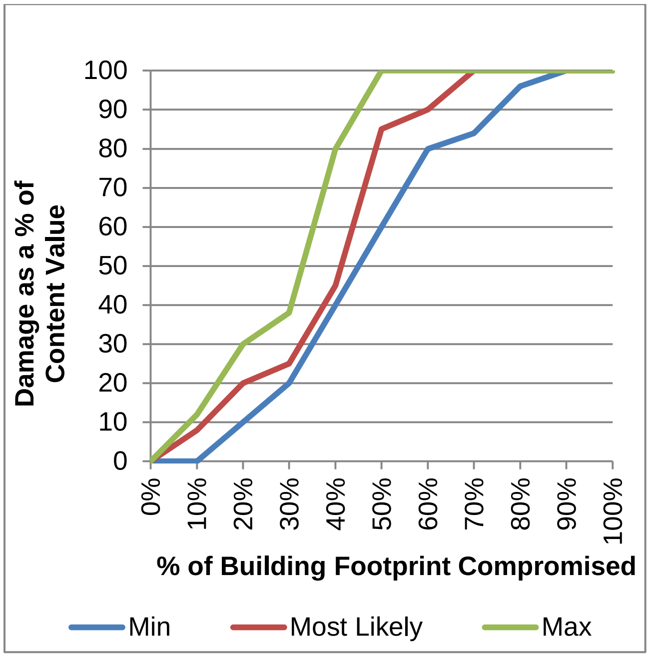

Figure 89. Prototype 5B: Two-Story Residence, No Basement, Erosion Damage - Content

Table 70. Prototype 5B: Two-Story Residence, No Basement, Erosion Damage - Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	8	12
20%	10	20	30
30%	20	25	38
40%	40	45	80
50%	60	85	100
60%	80	90	100
70%	84	100	100
80%	96	100	100
90%	100	100	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

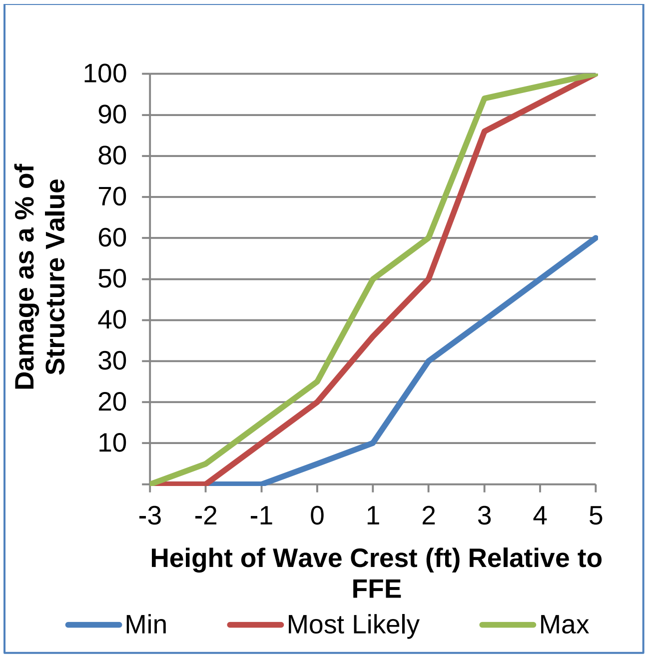

Figure 90. Prototype 5B: Two-Story Residence, No Basement, Wave Damage - Structure

Table 71. Prototype 5B: Two-Story Residence, No Basement, Wave Damage - Structure

Wave Crest	Min	Most Likely	Max
-3	0	0	0
-2	0	0	5
-1	0	10	15
0	5	20	25
1	10	36	50
2	30	50	60
3	40	86	94
5	60	100	100

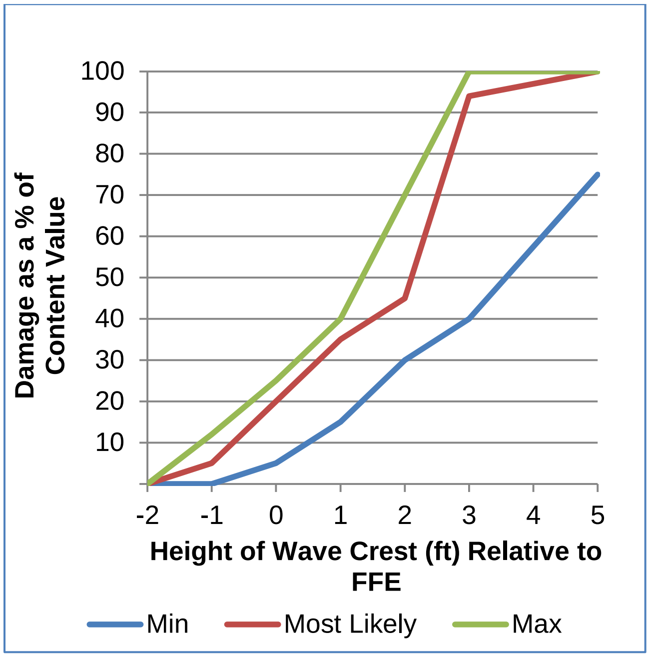

Figure 91. Prototype 5B: Two-Story Residence, No Basement, Wave Damage - Content

Table 72. Prototype 5B: Two-Story Residence, No Basement, Wave Damage - Content

Wave Crest	Min	Most Likely	Max
-2	0	0	0
-1	0	5	12
0	5	20	25
1	15	35	40
2	30	45	70
3	40	94	100
5	75	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 73 and Figure 92 show wave, surge, and still water characteristics associated with 100% wave damage for the most likely building characteristics of a two-story residence without a basement (Prototype 5B). This prototype has a crawl space foundation and a FFE of 3.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100% wave damage for this prototype is expected to occur with a still water depth (d) of 5.2 feet. This still water depth will typically allow a maximum wave height of 4.0 feet (H_b = .78d). The wave crest under this condition would be approximately 8.0 feet above grade ($0.7H_b$ + d).

Table 73. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 5B Two-Story Residence, No Basement, Most Likely Building Characteristics

Designation	Characteristic	Feet
A	FFE Above Grade	3.0
B	Wave Crest Height Above FFE	5.0
C	Breaking Wave Height (H_b = 0.78d)	4.0
D	0.7H_b	2.8
E	Still Water Elevation (d)	5.2
F	Wave Crest Elevation (0.7H_b + d)	8.0

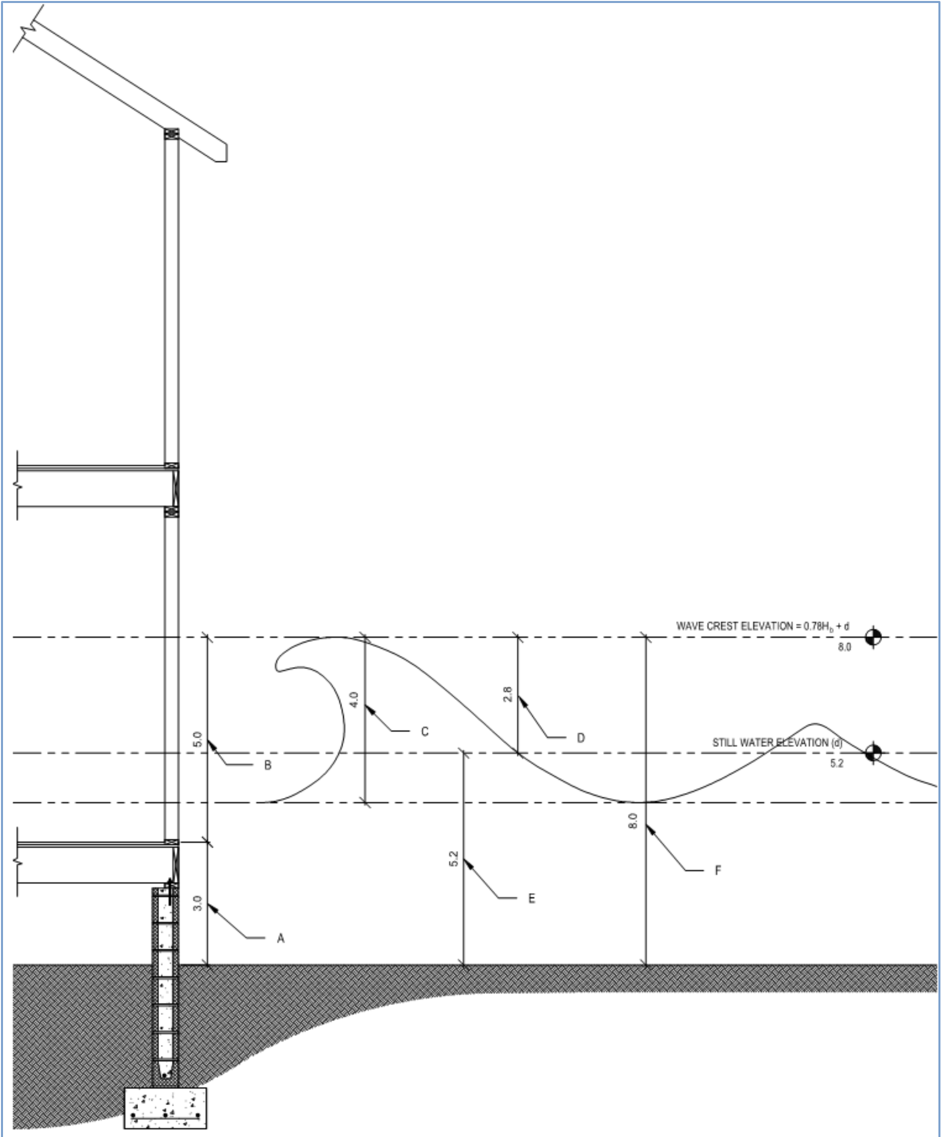

Figure 92. Illustration of Maximum Wave Damage Scenario, Prototype 5B Two-Story Residence, No Basement, Most Likely Building Characteristics

6.13 Prototype 6A: Single-Story Residence with Basement

Most Likely Building Characteristics: The prototype building is of wood frame construction. It is 15 to 30 years old, and in fair to good condition. The basement is unfinished, used for storage, and contains various utilities. The building has a block foundation and the finished floor is 3'-0" above grade.

Minimum-Damage Building Characteristics: The prototype building is of masonry construction. It is 0 to 10 years old, and in good condition. The basement is unfinished. Utilities are elevated. The building has a reinforced concrete foundation and the finished floor is 1'-0" above grade.

Higher-Damage Building Characteristics: The prototype building is of wood frame construction. It is older, and in poor condition. It is not known if the building was built to code. The basement is finished. The building has a block foundation and the finished floor is 4'-0" above grade.

See Table 74 below:

Table 74. Prototype 6A: Single-Story Residence with Basement: Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Foundation	Block	Reinforced concrete	Block
Age	15 – 30	0 – 10	Old—unknown codes
Structure	Wood frame	Masonry	Wood frame
Basement	Unfinished, storage	Unfinished	Finished
Utilities	Elevated, but washer & dryer may be in basement	Elevated	
Height of Finished Floor Above Grade	3'-0"	1'-0"	4'-0"
Condition	Fair/ Good	Good	Poor

Table 75 through Table 80 present Prototype 6A: Single -Story Residence with Basement, inundation damages, erosion damages, and wave damages for structure and contents. Figure 93 through Figure 98 present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

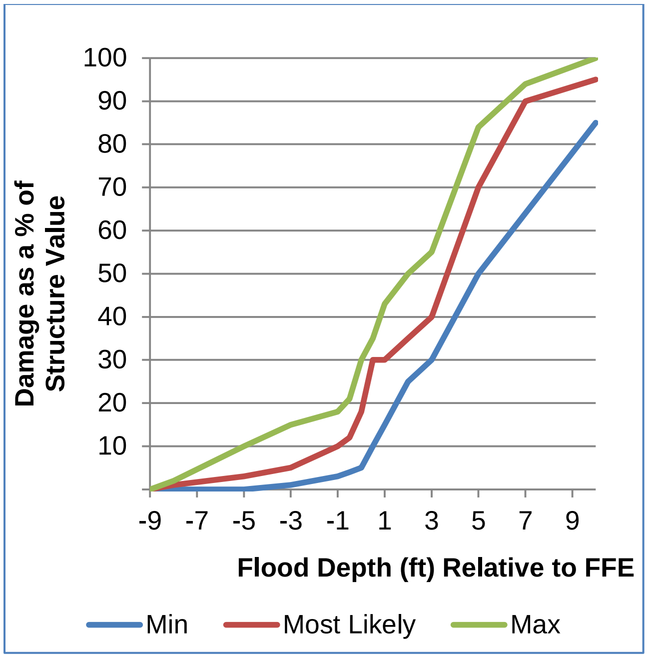

Figure 93. Prototype 6A: Single-Story Residence with Basement, Inundation Damage – Structure

Table 75. Prototype 6A: Single-Story Residence with Basement, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-9	0	0	0
-8	0	1	2
-5	0	3	10
-3	1	5	15
-1	3	10	18
-0.5	4	12	21
0	5	18	30
0.5	10	30	35
1	15	30	43
2	25	35	50
3	30	40	55
5	50	70	84
7	64	90	94
10	85	95	100

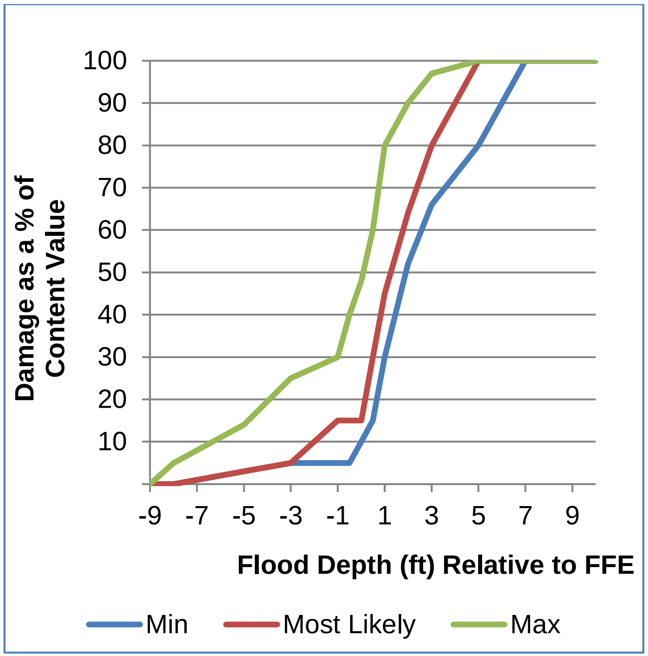

Figure 94. Prototype 6A: Single-Story Residence with Basement, Inundation Damage – Content

Table 76. Prototype 6A: Single-Story Residence with Basement, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-9	0	0	0
-8	0	0	5
-5	3	3	14
-3	5	5	25
-1	5	15	30
-0.5	5	15	40
0	10	15	48
0.5	15	30	60
1	30	45	80
2	52	64	90
3	66	80	97
5	80	100	100
7	100	100	100
10	100	100	100

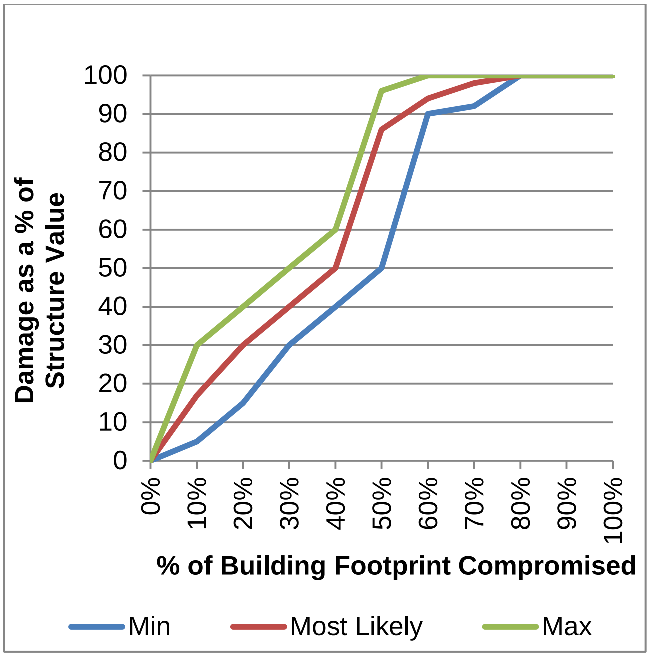

Figure 95. Prototype 6A: Single-Story Residence with Basement, Erosion Damage - Structure

Table 77. Prototype 6A: Single-Story Residence with Basement, Erosion Damage - Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	5	17	30
20%	15	30	40
30%	30	40	50
40%	40	50	60
50%	50	86	96
60%	90	94	100
70%	92	98	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

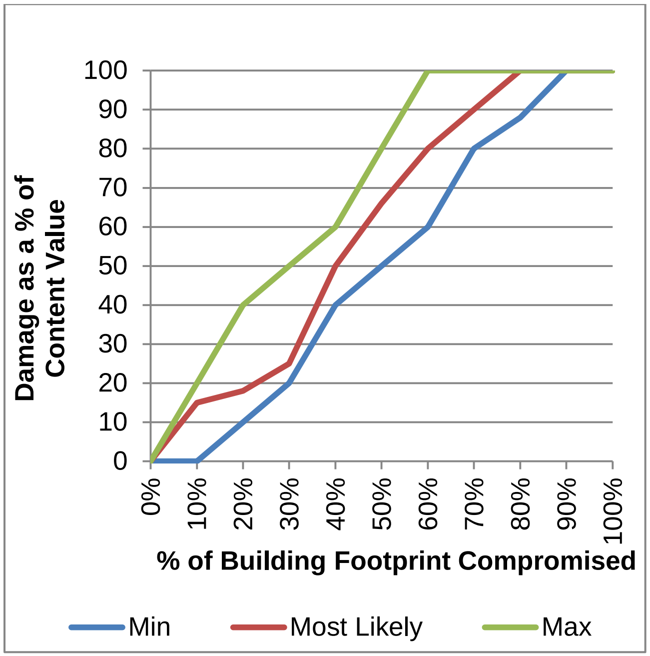

Figure 96. Prototype 6A: Single-Story Residence with Basement, Erosion Damage - Content

Table 78. Prototype 6A: Single-Story Residence with Basement, Erosion Damage - Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	15	20
20%	10	18	40
30%	20	25	50
40%	40	50	60
50%	50	66	80
60%	60	80	100
70%	80	90	100
80%	88	100	100
90%	100	100	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

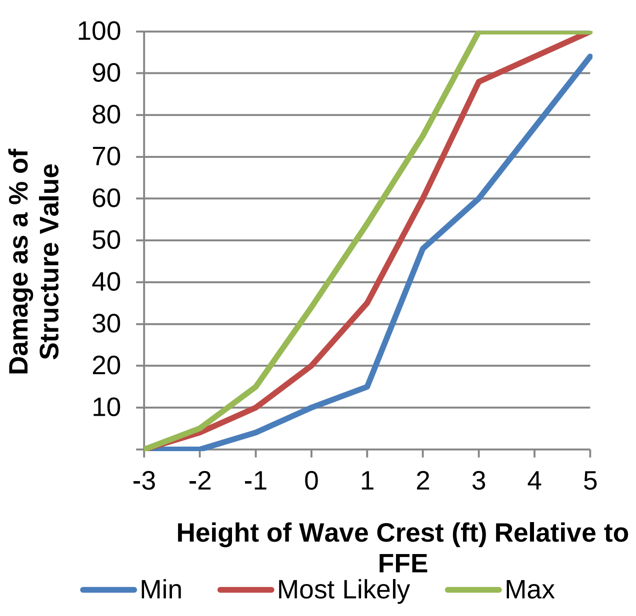

Figure 97. Prototype 6A: Single-Story Residence with Basement, Wave Damage - Structure

Table 79. Prototype 6A: Single-Story Residence with Basement, Wave Damage - Structure

Wave Crest	Min	Most Likely	Max
-3	0	0	0
-2	0	4	5
-1	4	10	15
0	10	20	34
1	15	35	54
2	48	60	75
3	60	88	100
5	94	100	100

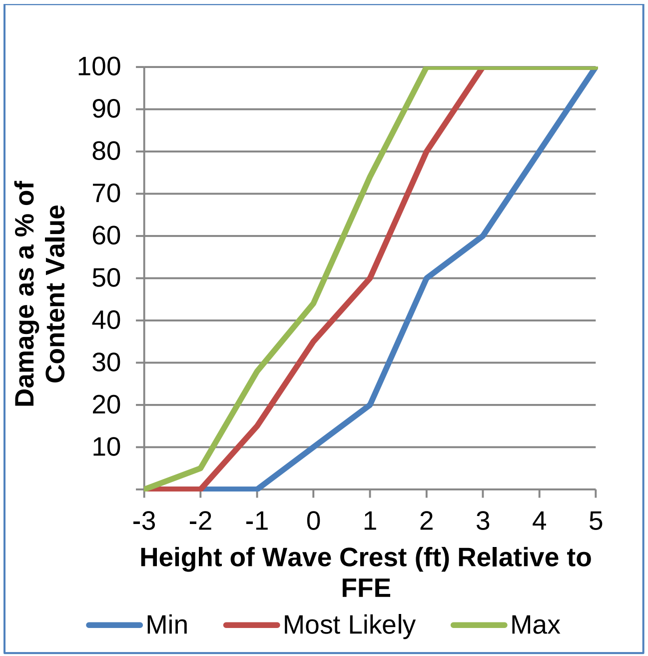

Figure 98. Prototype 6A: Single-Story Residence with Basement, Wave Damage - Content

Table 80. Prototype 6A: Single-Story Residence with Basement, Wave Damage - Content

Wave Crest	Min	Most Likely	Max
-3	0	0	0
-2	0	0	5
-1	0	15	28
0	10	35	44
1	20	50	74
2	50	80	100
3	60	100	100
5	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 81 and Figure 99 show wave, surge, and still water characteristics associated with 100% wave damage for the most likely building characteristics of a single-story residence with a basement (Prototype 6A). This prototype has a block foundation and a FFE of 3.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100%

wave damage for this prototype is expected to occur with a still water depth (d) of 5.2 feet. This still water depth will typically allow a maximum wave height of 4.0 feet (H_b = .78d). The wave crest under this condition would be approximately 8.0 feet above grade ($0.7H_b$ + d).

Table 81. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 6A Single-Story Residence with Basement, Most Likely Building Characteristics

Designation	Characteristic	Feet
A	FFE Above Grade	3.0
B	Wave Crest Height Above FFE	5.0
C	Breaking Wave Height (H_b = 0.78d)	4.0
D	$0.7H_b$	2.8
E	Still Water Elevation (d)	5.2
F	Wave Crest Elevation ($0.7H_b$ + d)	8.0

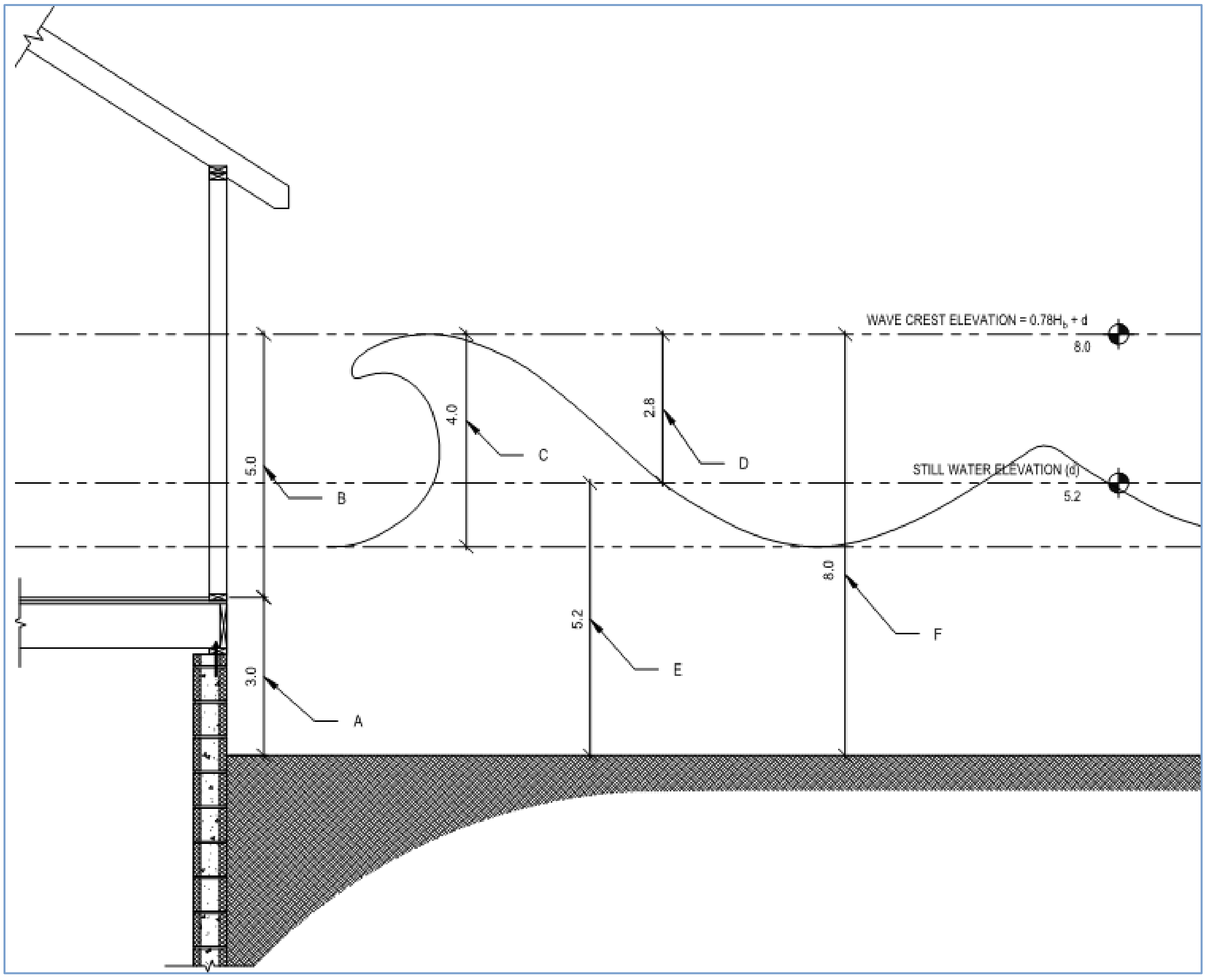

Figure 99. Illustration of Maximum Wave Damage Scenario, Prototype 6A Single-Story Residence with Basement, Most Likely Building Characteristics

6.14 Prototype 6B: Two-Story Residence with Basement

Most Likely Building Characteristics: The prototype building is of wood frame construction. It is 15 to 30 years old, and in fair to good condition. The basement is unfinished, used for storage, and contains various utilities. The building has a block foundation and the finished floor is 3’-0” above grade.

Minimum-Damage Building Characteristics: The prototype building is of masonry construction. It is 0 to 10 years old, and in good condition. The basement is unfinished. Utilities are elevated. The building has a reinforced concrete foundation and the finished floor is 1’-0” above grade.

Higher-Damage Building Characteristics: The prototype building is of wood frame construction. It is older, and in poor condition. It is not known if the building was built to code. The basement is finished. The building has a block foundation and the finished floor is 4’-0” above grade.

See Table 82 below:

Table 82. Prototype 6B: Two-Story Residence with Basement: Building Characteristics

	Most Likely	**Minimum Damage**	**Maximum Damage**
Stories	2	2	2
Foundation	Block	Reinforced concrete	Block
Age	15 – 30	0 – 10	Old—unknown codes
Structure	Wood frame	Masonry	Wood frame
Basement	Unfinished, storage	Unfinished	Finished
Utilities	Elevated, but washer & dryer may be in basement	Elevated	
Height of Finished Floor Above Grade	3’-0”	1’-0”	4’-0”
Condition	Fair/ Good	Good	Poor

Table 83 through Table 88 present Prototype 6B Two-Story with Basement, inundation damages, erosion damages and wave damages for structure and contents. Figure 100 through Figure 105 present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

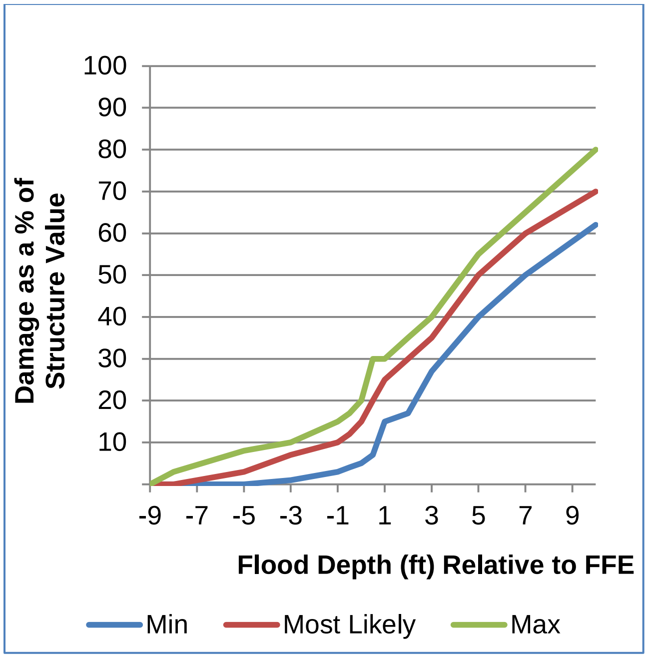

Figure 100. Prototype 6B: Two-Story Residence with Basement, Inundation Damage – Structure

Table 83. Prototype 6B: Two-Story Residence with Basement, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-9	0	0	0
-8	0	0	3
-5	0	3	8
-3	1	7	10
-1	3	10	15
-0.5	4	12	17
0	5	15	20
0.5	7	20	30
1	15	25	30
2	17	30	35
3	27	35	40
5	40	50	55
7	50	60	65
10	62	70	80

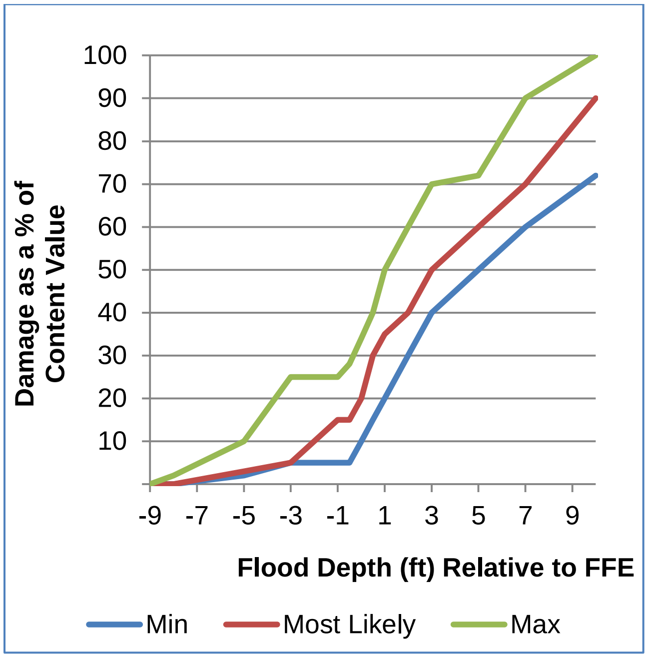

Figure 101. Prototype 6B: Two-Story Residence with Basement, Inundation Damage – Content

Table 84. Prototype 6B: Two-Story Residence with Basement, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-9	0	0	0
-8	0	0	2
-5	2	3	10
-3	5	5	25
-1	5	15	25
-0.5	5	15	28
0	10	20	34
0.5	15	30	40
1	20	35	50
2	30	40	60
3	40	50	70
5	50	60	72
7	60	70	90
10	72	90	100

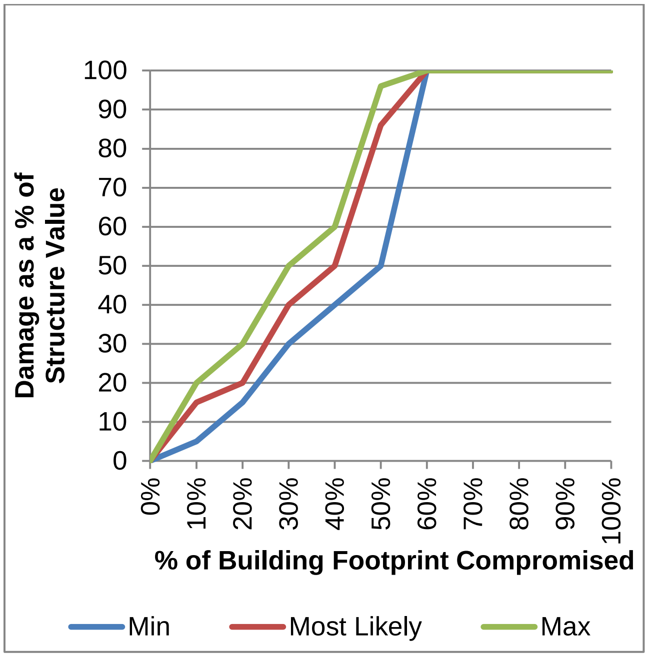

Figure 102. Prototype 6B: Two-Story Residence with Basement, Erosion Damage - Structure

Table 85. Prototype 6B: Two-Story Residence with Basement, Erosion Damage - Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	5	15	20
20%	15	20	30
30%	30	40	50
40%	40	50	60
50%	50	86	96
60%	100	100	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

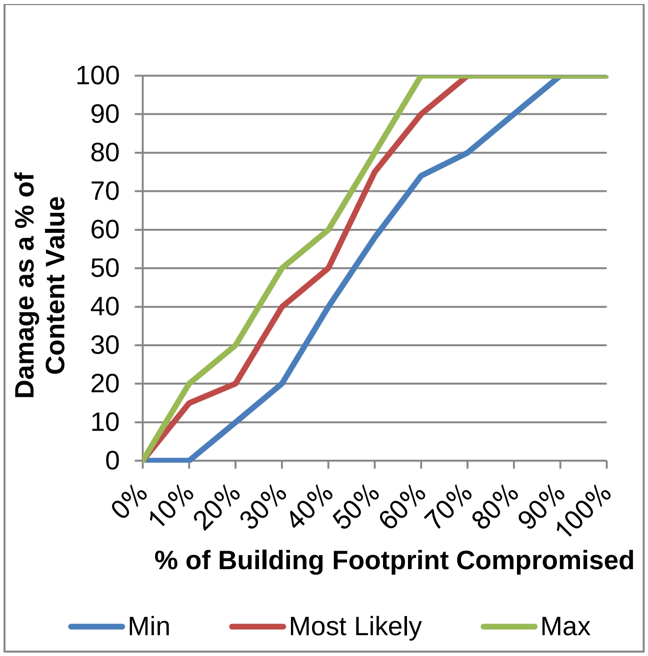

Figure 103. Prototype 6B: Two-Story Residence with Basement, Erosion Damage - Content

Table 86. Prototype 6B: Two-Story Residence with Basement, Erosion Damage - Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	15	20
20%	10	20	30
30%	20	40	50
40%	40	50	60
50%	58	75	80
60%	74	90	100
70%	80	100	100
80%	90	100	100
90%	100	100	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

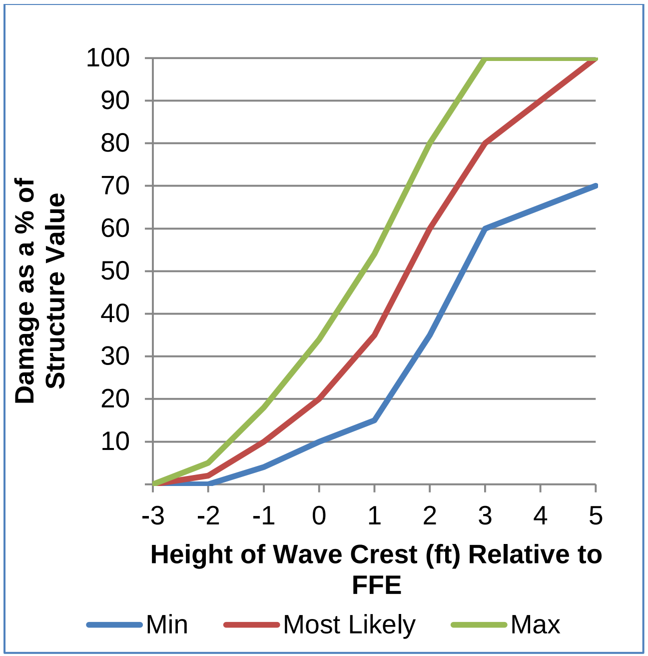

Figure 104. Prototype 6B: Two-Story Residence with Basement, Wave Damage – Structure

Table 87. Prototype 6B: Two-Story Residence with Basement, Wave Damage – Structure

Wave Crest	Min	Most Likely	Max
-3	0	0	0
-2	0	2	5
-1	4	10	18
0	10	20	34
1	15	35	54
2	35	60	80
3	60	80	100
5	70	100	100

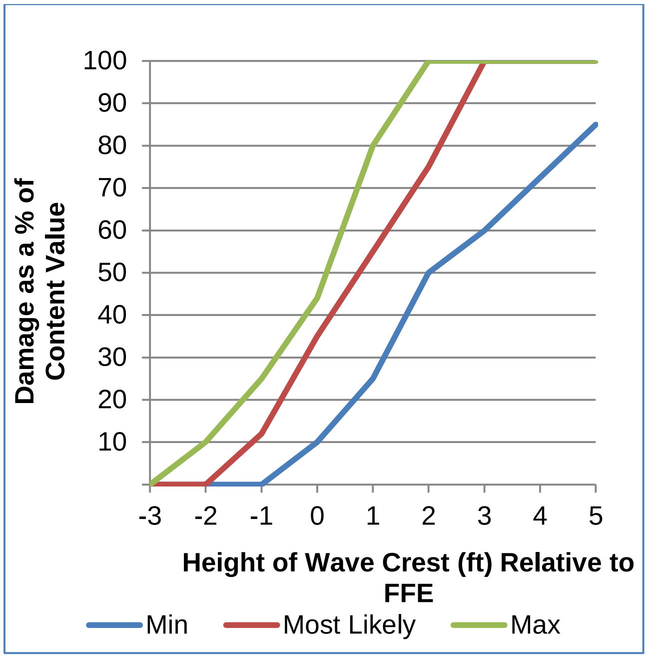

Figure 105. Prototype 6B: Two-Story Residence with Basement, Wave Damage - Content

Table 88. Prototype 6B: Two-Story Residence with Basement, Wave Damage - Content

Wave Crest	Min	Most Likely	Max
-3	0	0	0
-2	0	0	10
-1	0	12	25
0	10	35	44
1	25	55	80
2	50	75	100
3	60	100	100
5	85	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 89 and Figure 106 show wave, surge, and still water characteristics associated with 100% wave damage for the most likely building characteristics of a two-story residence with a basement (Prototype 6B). This prototype has a block foundation and a FFE of 3.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100% wave damage for this prototype is expected to occur with a still water depth (d) of 5.2 feet. This still water depth will typically allow a maximum wave height of 4.0 feet (H_b = .78d). The wave crest under this condition would be approximately 8.0 feet above grade ($0.7H_b$ + d).

Table 89. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 6B Two-Story Residence with Basement, Most Likely Building Characteristics

Designation	Characteristic	Feet
A	FFE Above Grade	3.0
B	Wave Crest Height Above FFE	5.0
C	Breaking Wave Height (H_b = 0.78d)	4.0
D	0.7H_b	2.8
E	Still Water Elevation (d)	5.2
F	Wave Crest Elevation (0.7H_b + d)	8.0

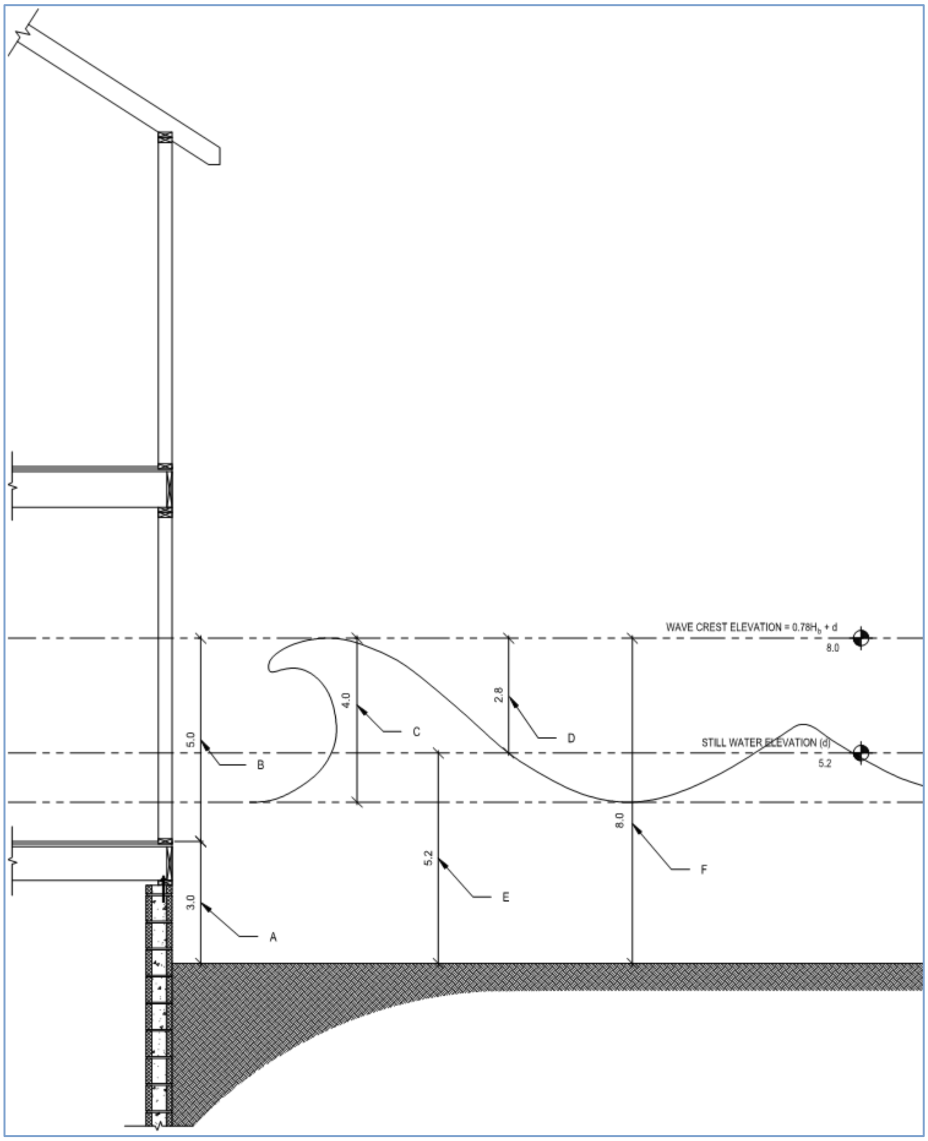

Figure 106. Illustration of Maximum Wave Damage Scenario, Prototype 6B Two-Story Residence with Basement, Most Likely Building Characteristics

6.15 Prototype 7A: Building on Open Pile Foundation

Most Likely Building Characteristics: The prototype building is 15 to 30 years old. Piles are 8” to 10” in diameter, and the connections are in fair condition. Utilities are elevated. Post-flood mold propagation is possible.

Minimum-Damage Building Characteristics: The prototype building is 0 to 10 years old. Piles are 10” to 12” in diameter, and the connections are in good condition. Utilities are elevated.

Higher-Damage Building Characteristics: The prototype building is older. It is not known if it was built to code. Piles are 6” in diameter or helical, and the connections are in poor condition. Utilities are located below the building.

See Table 90 below:

Table 90. Prototype 7A: Building on Open Pile Foundation: Building Characteristics

	Most Likely	**Minimum Damage**	**Maximum Damage**
Stories	1	1	1
Utilities	Elevated	Elevated	Below
Age	15 – 30	0 – 10	>30
Height of Finished Floor Above Grade	9’-0”	9’-0”	9’-0”
Building Use	Residential	Residential	Residential
Pile Diameter	8” – 10”	10” – 12”	6” or helical
Connection Condition	Fair	Good	Poor

Table 91 through Table 96 present Prototype 7A Building on Open Pile Foundation, inundation damages, erosion damages, and wave damages for structure and contents. Figure 107 through Figure 112 present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

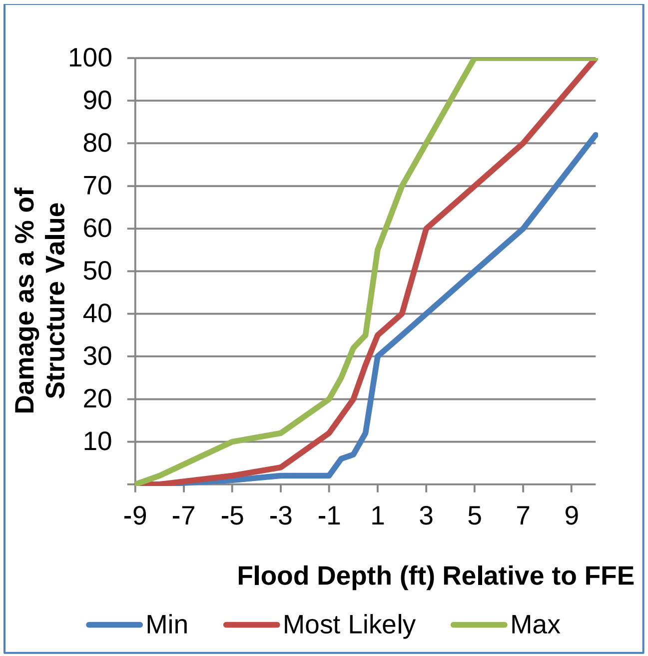

Figure 107. Prototype 7A: Building on Open Pile Foundation, Inundation Damage – Structure

Table 91. Prototype 7A: Building on Open Pile Foundation, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-9	0	0	0
-8	0	0	2
-5	1	2	10
-3	2	4	12
-1	2	12	20
-0.5	6	16	25
0	7	20	32
0.5	12	28	35
1	30	35	55
2	35	40	70
3	40	60	80
5	50	70	100
7	60	80	100
10	82	100	100

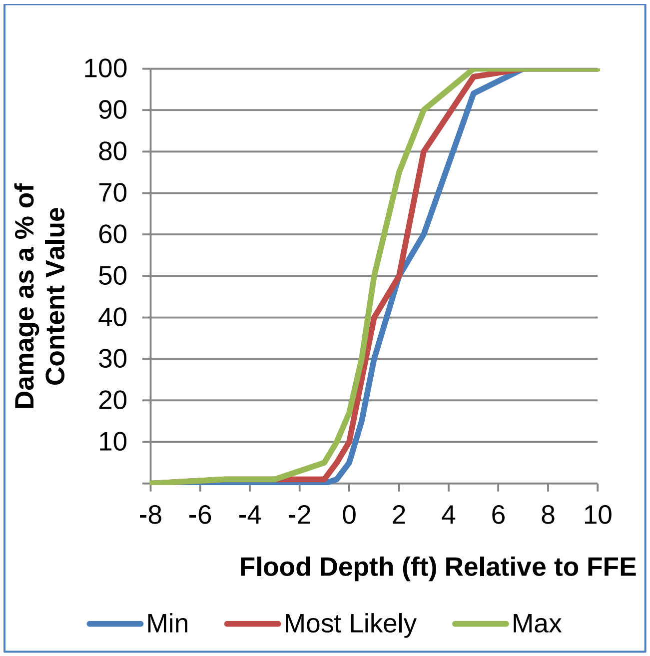

Figure 108. Prototype 7A: Building on Open Pile Foundation, Inundation Damage – Content

Table 92. Prototype 7A: Building on Open Pile Foundation, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-8	0	0	0
-5	0	1	1
-3	0	1	1
-1	0	1	5
-0.5	1	5	10
0	5	10	17
0.5	15	25	30
1	30	40	50
2	50	50	75
3	60	80	90
5	94	98	100
7	100	100	100
10	100	100	100

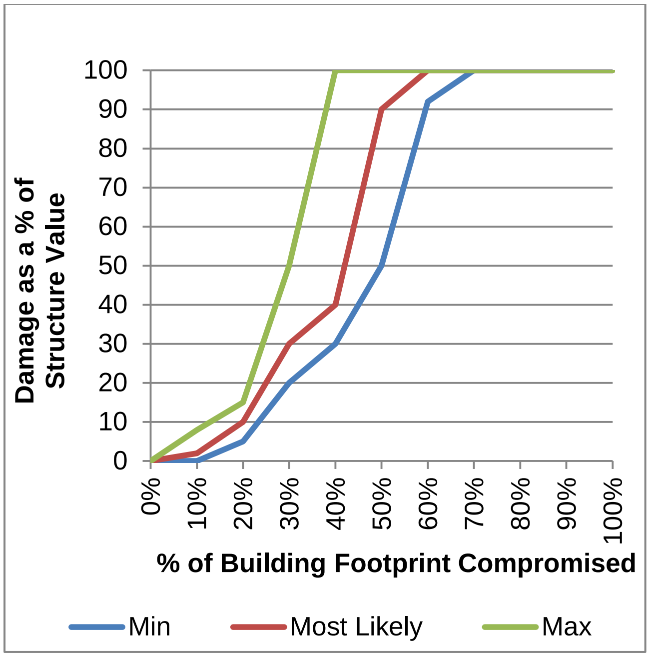

Figure 109. Prototype 7A: Building on Open Pile Foundation, Erosion Damage - Structure

Table 93. Prototype 7A: Building on Open Pile Foundation, Erosion Damage - Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	0	2	8
20%	5	10	15
30%	20	30	50
40%	30	40	100
50%	50	90	100
60%	92	100	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

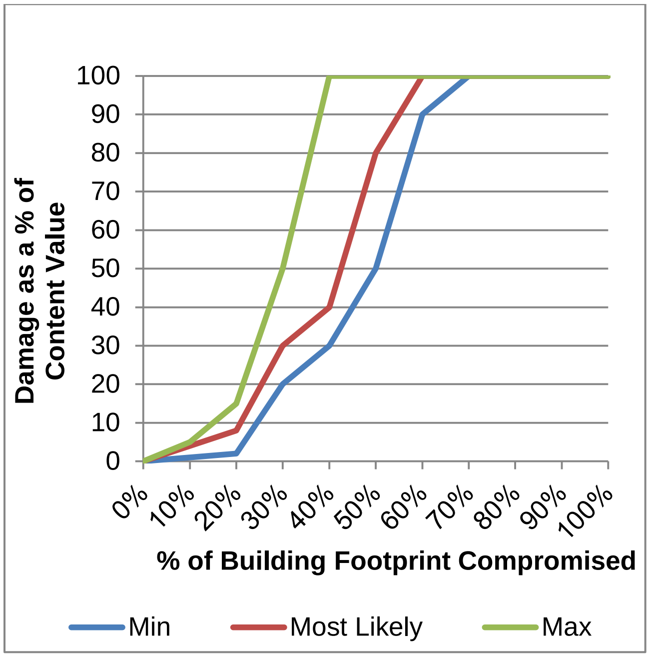

Figure 110. Prototype 7A: Building on Open Pile Foundation, Erosion Damage - Content

Table 94. Prototype 7A: Building on Open Pile Foundation, Erosion Damage - Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	1	4	5
20%	2	8	15
30%	20	30	50
40%	30	40	100
50%	50	80	100
60%	90	100	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

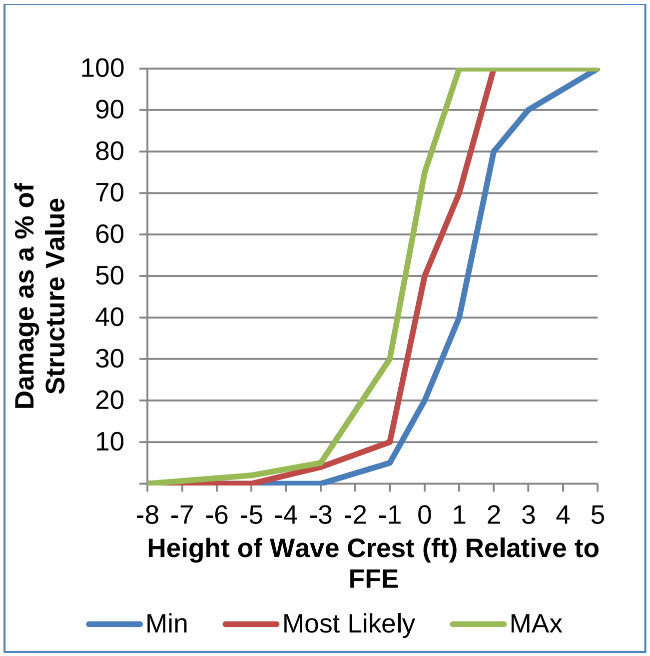

Figure 111. Prototype 7A: Building on Open Pile Foundation, Wave Damage - Structure

Table 95. Prototype 7A: Building on Open Pile Foundation, Wave Damage - Structure

Wave Crest	Min	Most Likely	Max
-8	0	0	0
-5	0	0	2
-3	0	4	5
-1	5	10	30
0	20	50	75
1	40	70	100
2	80	100	100
3	90	100	100
5	100	100	100

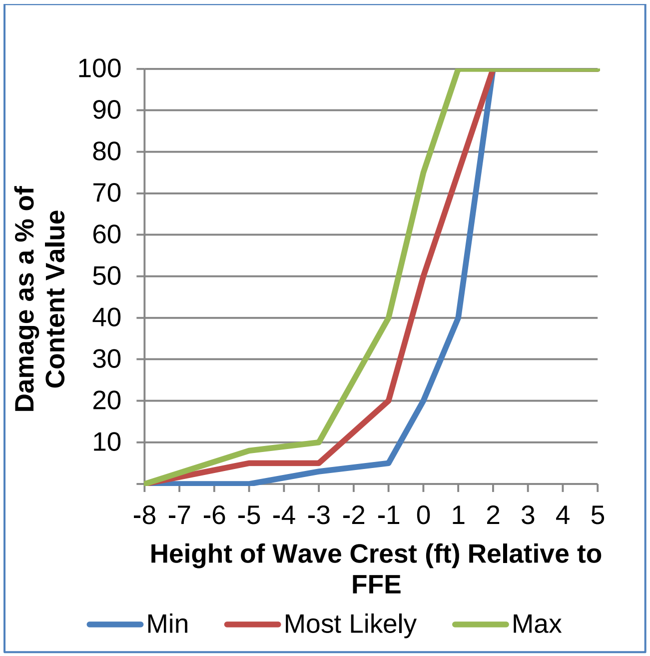

Figure 112. Prototype 7A: Building on Open Pile Foundation, Wave Damage - Content

Table 96. Prototype 7A: Building on Open Pile Foundation, Wave Damage - Content

Wave Crest	Min	Most Likely	Max
-8	0	0	0
-5	0	5	8
-3	3	5	10
-1	5	20	40
0	20	50	75
1	40	75	100
2	100	100	100
3	100	100	100
5	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 97 and Figure 113 show wave, surge, and still water characteristics associated with 100% wave damage for the most likely building characteristics of a building on an open pile foundation (Prototype 7A). This prototype has a FFE of 9.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100% wave damage for this prototype is expected to occur with a still water depth (d) of 7.1 feet. This still water depth will typically allow a maximum wave height of 5.5 feet (H_b = .78d). The wave crest under this condition would be approximately 11.0 feet above grade ($0.7H_b$ + d).

Table 97. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 7A Building on Open Pile Foundation, Most Likely Building Characteristics

Designation	Characteristic	Feet
A	FFE Above Grade	9.0
B	Wave Crest Height Above FFE	2.0
C	Breaking Wave Height (H_b = 0.78d)	5.5
D	$0.7H_b$	3.9
E	Still Water Elevation (d)	7.1
F	Wave Crest Elevation ($0.7H_b$ + d)	11.0

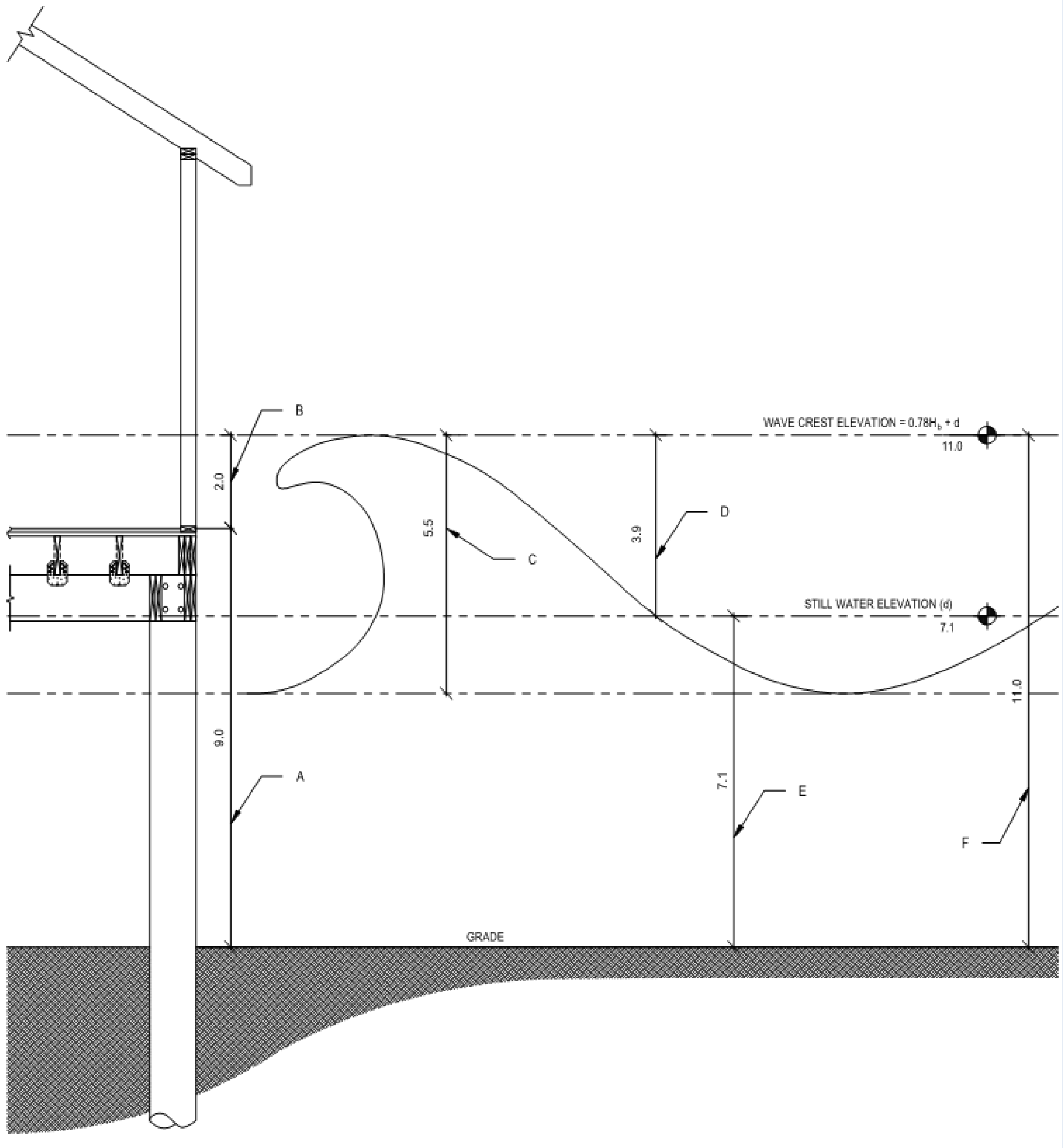

Figure 113. Illustration of Maximum Wave Damage Scenario, Prototype 7A Building on Open Pile Foundation, Most Likely Building Characteristics

6.16 Prototype 7B: Building on Pile Foundation with Enclosures

Most Likely Building Characteristics: The prototype building is 15 to 30 years old. The enclosure walls are not “break-away” walls, but they will break under some flooding circumstances. The enclosed space is used for parking, storage and access to utilities, which are located below the building. Piles are 8” to 10” in diameter, and the connections are in fair condition.

Minimum-Damage Building Characteristics: The prototype building is 0 to 10 years old. The enclosure walls are of “break-away” construction. The enclosed space is used for access to the building, and for parking. Piles are 10” to 12” in diameter, and the connections are in good condition. Utilities are elevated.

Higher-Damage Building Characteristics: The prototype building is older. It is not known if it was built to code. The enclosure walls are not “break-away” walls, and may not break at all under flooding circumstances. The enclosed space is used as living space. Piles are 6” in diameter or helical, and the connections are in poor condition. Utilities are located below the building.

See Table 98 below:

Table 98. Prototype 7B: Building on Pile Foundation with Enclosures: Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Utilities	Below	Elevated	Below
Age	15 – 30	0 – 10	>30
Height of Finished Floor Above Grade	9’-0”	9’-0”	9’-0”
Building Use	Residential	Residential	Residential
Pile Diameter	8” – 10”	10” – 12”	6” or helical
Connection Condition	Fair	Good	Poor
Enclosure Wall	Will break	Breakaway	Non-break
Enclosure Use	Parking, storage, utility access	Access and parking	Living space

Table 99 through Table 104, present Prototype 7B Building on Pile Foundation with Enclosures, inundation damages, erosion damages, and wave damages for structures and contents. Figure 114 through Figure 119 present the corresponding damage functions.

Damage function users are advised that the degree to which mold spreads throughout a building is a function of flood duration, humidity, and the amount of time it takes for people to reenter and remediate the building. The interrelationship of these last two factors is complex, and mold damages can vary widely as a result. If extensive mold is considered likely, the high damage function is considered more appropriate for use.

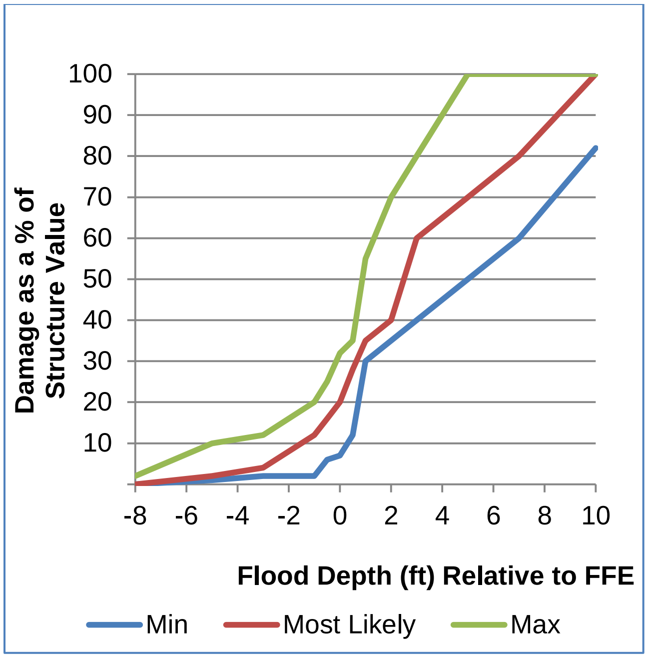

Figure 114. Prototype 7B: Building on Pile Foundation with Enclosures, Inundation Damage – Structure

Table 99. Prototype 7B: Building on Pile Foundation with Enclosures, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-8	0	0	2
-5	1	2	10
-3	2	4	12
-1	2	12	20
-0.5	6	16	25
0	7	20	32
0.5	12	28	35
1	30	35	55
2	35	40	70
3	40	60	80
5	50	70	100
7	60	80	100
10	82	100	100

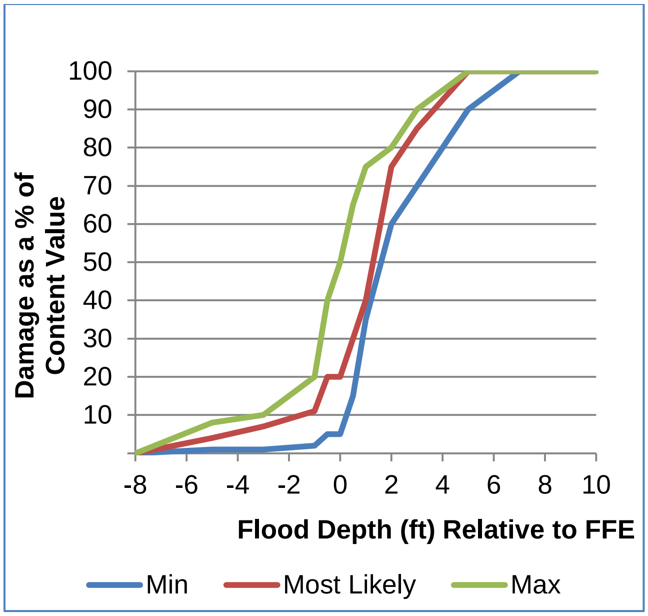

Figure 115. Prototype 7B: Building on Pile Foundation with Enclosures, Inundation Damage – Content

Table 100. Prototype 7B: Building on Pile Foundation with Enclosures, Inundation Damage – Content

Flood Depth	Min	Most Likely	Max
-8	0	0	0
-5	1	4	8
-3	1	7	10
-1	2	11	20
-0.5	5	20	40
0	5	20	50
0.5	15	30	65
1	35	40	75
2	60	75	80
3	70	85	90
5	90	100	100
7	100	100	100
10	100	100	100

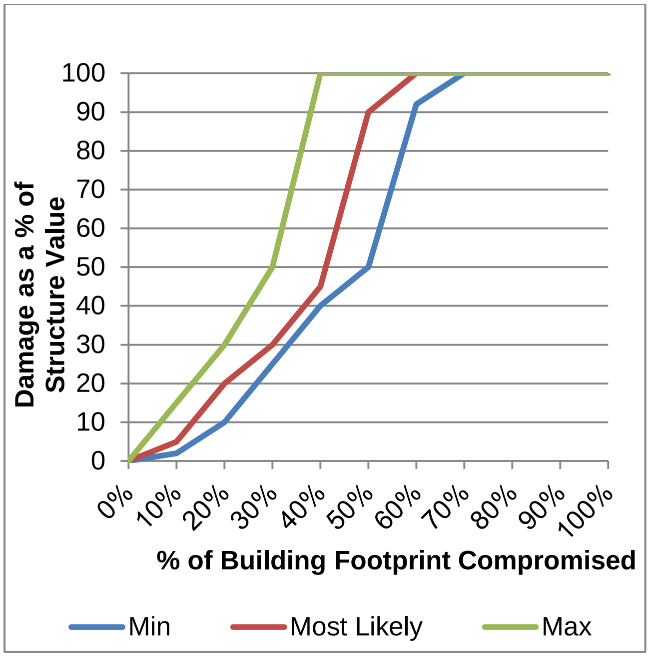

Figure 116. Prototype 7B: Building on Pile Foundation with Enclosures, Erosion Damage - Structure

Table 101. Prototype 7B: Building on Pile Foundation with Enclosures, Erosion Damage - Structure

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	2	5	15
20%	10	20	30
30%	25	30	50
40%	40	45	100
50%	50	90	100
60%	92	100	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

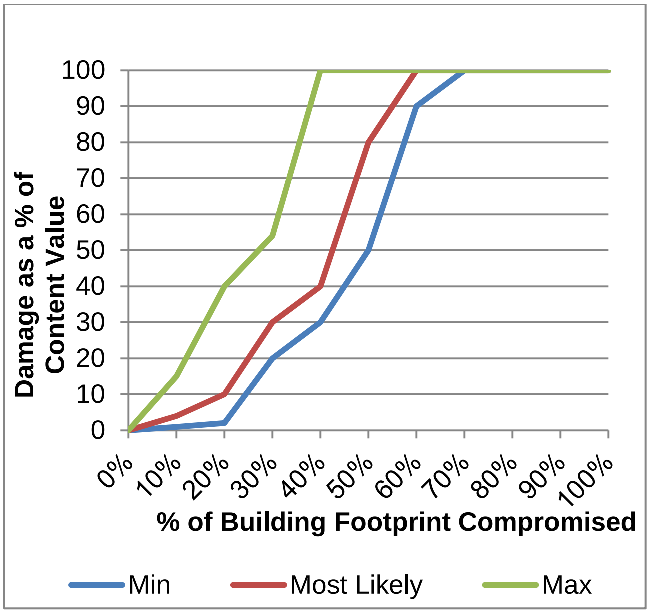

Figure 117. Prototype 7B: Building on Pile Foundation with Enclosures, Erosion Damage - Content

Table 102. Prototype 7B: Building on Pile Foundation with Enclosures, Erosion Damage - Content

Percent Comp-romised	Min	Most Likely	Max
0%	0	0	0
10%	1	4	15
20%	2	10	40
30%	20	30	54
40%	30	40	100
50%	50	80	100
60%	90	100	100
70%	100	100	100
80%	100	100	100
90%	100	100	100
100%	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

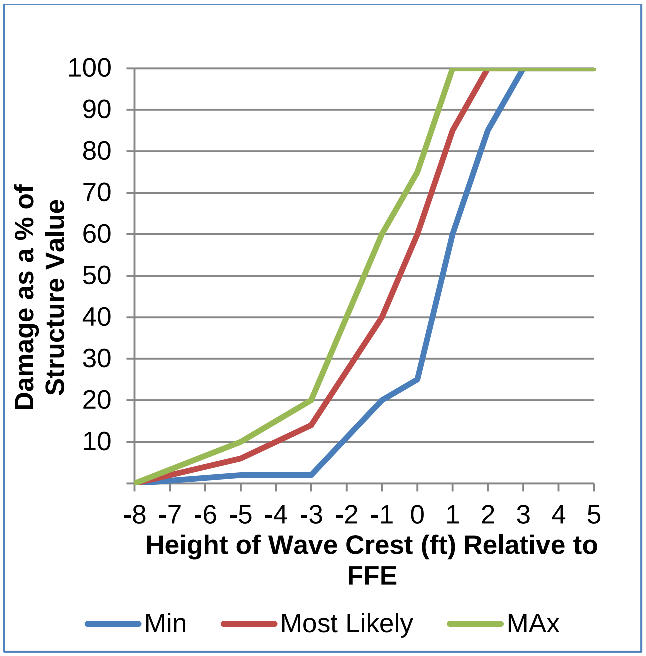

Figure 118. Prototype 7B: Building on Pile Foundation with Enclosures, Wave Damage – Structure

Table 103. Prototype 7B: Building on Pile Foundation with Enclosures, Wave Damage – Structure

Wave Crest	**Min**	**Most Likely**	**Max**
-8	0	0	0
-5	2	6	10
-3	2	14	20
-1	20	40	60
0	25	60	75
1	60	85	100
2	85	100	100
3	100	100	100
5	100	100	100

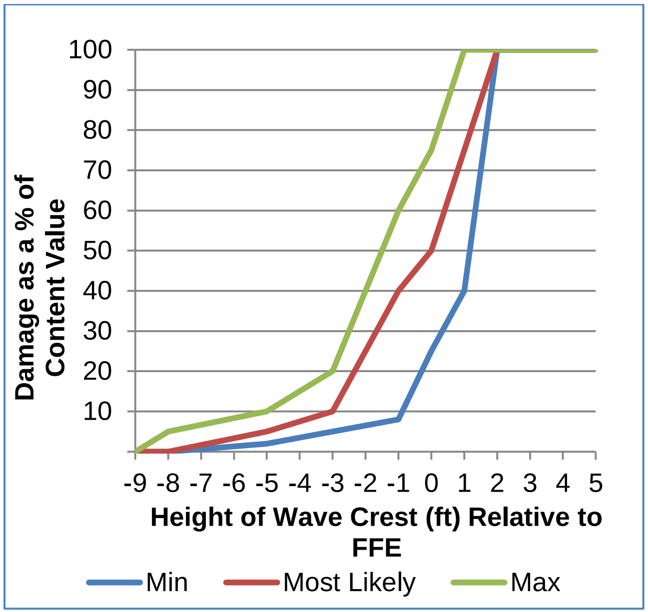

Figure 119. Prototype 7B: Building on Pile Foundation with Enclosures, Wave Damage - Content

Table 104. Prototype 7B: Building on Pile Foundation with Enclosures, Wave Damage - Content

Wave Crest	**Min**	**Most Likely**	**Max**
-9	0	0	0
-8	0	0	5
-5	2	5	10
-3	5	10	20
-1	8	40	60
0	25	50	75
1	40	75	100
2	100	100	100
3	100	100	100
5	100	100	100

Note: Wave and erosion damage functions are only to be used for structures that are close to the shoreline.

Table 105 and Figure 120 show wave, surge, and still water characteristics associated with 100% wave damage for the most likely building characteristics of a building on a pile foundation with enclosures (Prototype 7B). This prototype has a FFE of 9.0 feet above grade. With depth-limited breaking waves (typically the most damaging wave condition), 100% wave damage for this prototype is expected to occur with a still water depth (d) of 7.1 feet. This still water depth will typically allow a maximum wave height of 5.5 feet (H_b = .78d). The wave crest under this condition would be approximately 11.0 feet above grade (0.7H_b + d).

Table 105. Building, Flood, and Wave Characteristics, Maximum Wave Damage Scenario, Prototype 7B Building on Pile Foundation with Enclosures, Most Likely Building Characteristics

Designation	Characteristic	Feet
A	FFE Above Grade	9.0
B	Wave Crest Height Above FFE	2.0
C	Breaking Wave Height (H_b = 0.78d)	5.5
D	$0.7H_b$	3.9
E	Still Water Elevation (d)	7.1
F	Wave Crest Elevation ($0.7H_b$ + d)	11.0

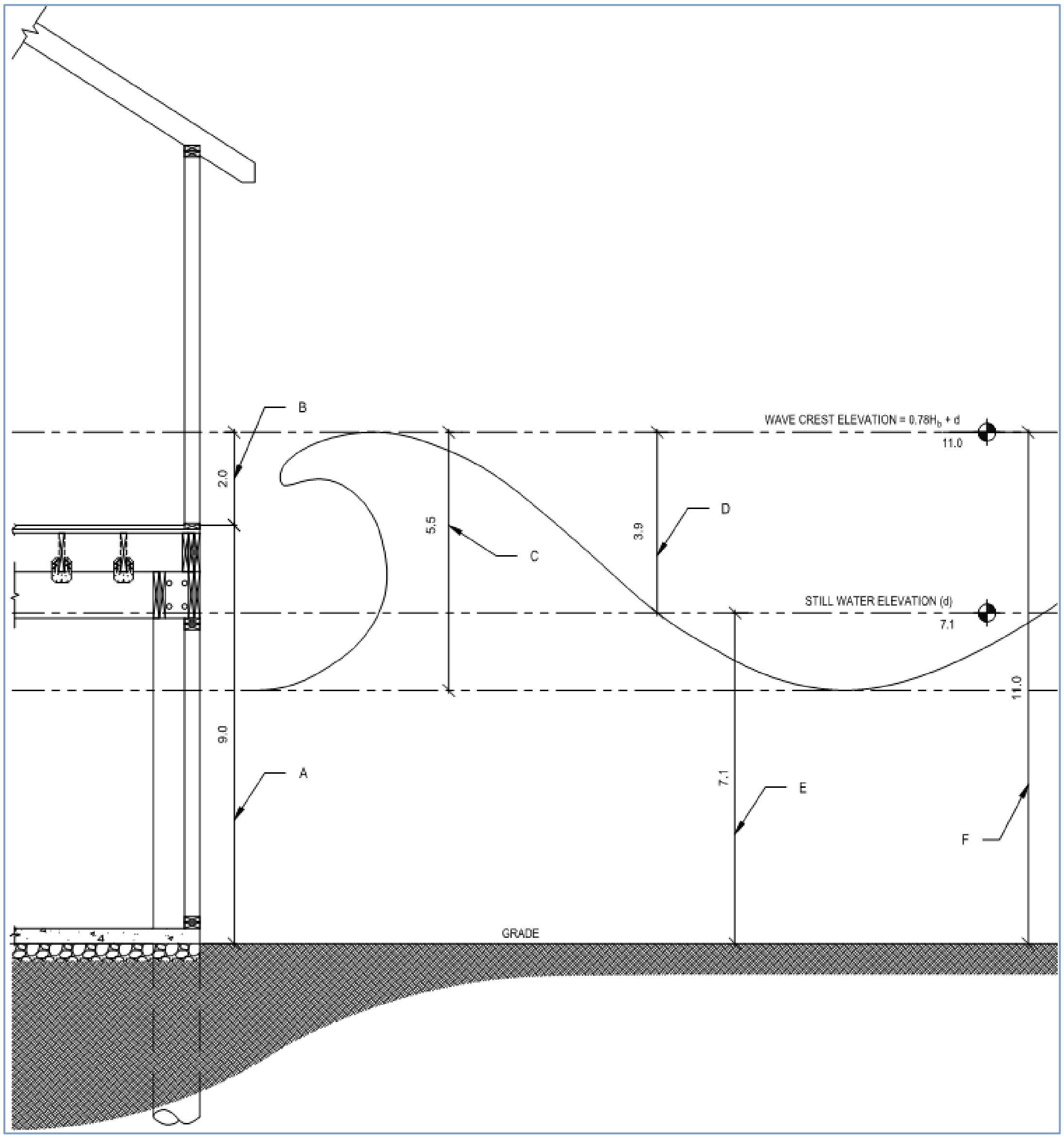

Figure 120. Illustration of Maximum Wave Damage Scenario, Prototype 7B Building on Pile Foundation with Enclosures, Most Likely Building Characteristics

7 Acronyms

CSVR: Content-to-structure value ratio

CSRM: Coastal Storm Risk Management

DDF: Depth-damage function

EGM: Economic Guidance Memo

FEMA: Federal Emergency Management Agency

FFE: First (Finished) Floor Elevation

IWR: Institute for Water Resources of the USACE

LHRM: Lowest Horizontal Structural Member

MEP: Mechanical, Electrical, and Plumbing

NACCS: North Atlantic Coast Comprehensive Study

NAD: North Atlantic Division of the USACE

NOD: New Orleans District of the USACE

NYD: New York District of the USACE

OEM: Office of Emergency Management

USACE: United States Army Corps of Engineers

8 Definitions

Basement: Subgrade on all four sides. May contain living space

Beach Erosion: The carrying away of beach materials by wave action, tidal currents, littoral currents, or wind [15]

Beach-FX: a software program developed by the Institute for Water Resources and the ERDC Coastal and Hydraulics Laboratory for evaluating the physical performance and economic benefits and costs of shore protection projects

Breaking Wave: a wave whose steepness has reached a limiting value, causing the wave to become unstable, break, and dissipate energy. Breaking waves cause impulsive (violent) conditions at structures

Contents: That which is not physically attached to a building

Corps: United States Army Corps of Engineers

Damage Valuation: based on cost of repair up to replacement value of the structure

Erosion: The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation

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[15] Morang, A., and Szuwalski, A. 2003. Glossary. In: Coastal Engineering Manual, Appendix A, Engineer Manual 1110-2-1100 (Change 1), U.S. Army Corps of Engineers, Washington, DC.

Flood Depth: Depth of inundation based on still water level. For the purposes of damage functions, the depth is measured relative to the finished floor elevation. A negative depth indicates a flood level that is below the FFE; a positive depth indicates a flood level above the FFE.

MapPLUTO: A municipal tax parcel database in GIS format, provided by New York City

Non-Breaking Wave: a wave whose steepness is less than the limiting value for breaking. Non-Breaking waves cause non-impulsive (non-violent) conditions at structures.

Runup: The upper level reached by a wave on a beach or coastal structure, relative to still-water level[16]

Scour: Removal of underwater material by waves and currents, especially at the base of a shore structure[17]

Wave Setup: Superelevation of the water surface over normal surge elevation due to onshore mass transport of the water by wave action alone [18]

Still Water Level (SWL): The surface of the water if all wave and wind action were to cease. In deep water, this level approximates the midpoint of the wave height. In shallow water it is nearer to the trough than the crest. Also called UNDISTURBED WATER LEVEL

Structure: A building and items that are physically attached to it

9 References

Christopher P. Jones, P.E. *Large Building Flood Damage Functions.* Durham, NC: DRAFT, 2011.

Dan Eschenasy, P.E., M.ASCE. *Structural Response of Low Rise New York City Buildings during Storm Sandy.* New York: DRAFT, 2013.

"Generic Depth-Damage Relationships." *Economic Guidance Memorandum (EGM) 01-03.* United States Army Corps of Engineers, December 01, 2000.

"Generic Depth-Damage Relationships for Residential Structures with Basements." *Economic Guidance Memorandum (EGM) 04-01.* 2003: United States Army Corps of Engineers, October 10, 2003.

Kennedy, A.M.ASCE, Andrew, et al. "Building Destruction from Waves and Surge on the Bolivar Peninsula during Hurricane Ike." *Journal of Waterway, Port, Coastal, and Ocean Engineering* (American Society of Civil Engineers) v137, no. n3 (2011): pp 132-141.

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[16] Morang, A., and Szuwalski, A. 2003. Glossary. In: Coastal Engineering Manual, Appendix A, Engineer Manual 1110-2-1100 (Change 1), U.S. Army Corps of Engineers, Washington, DC.

[17] Morang, A., and Szuwalski, A. 2003. Glossary. In: Coastal Engineering Manual, Appendix A, Engineer Manual 1110-2-1100 (Change 1), U.S. Army Corps of Engineers, Washington, DC.

[18] Morang, A., and Szuwalski, A. 2003. Glossary. In: Coastal Engineering Manual, Appendix A, Engineer Manual 1110-2-1100 (Change 1), U.S. Army Corps of Engineers, Washington, DC.

The Louis Berger Group, Inc. and URS Corporation . *Monte Carlo Simulation Model for the Engineering and Economic Analysis of Coastal Protection Projects: Beach-FX.* Certification Report, Alexandria: The Institute of Water Resources, 2007.

Morang, A., and Szuwalski, A. 2003. Glossary. In: Coastal Engineering Manual, Appendix A, Engineer Manual 1110-2-1100 (Change 1), U.S. Army Corps of Engineers, Washington, DC.

10 Attachments

A. OMB-Approved Survey Instruments for Residential, Nonresidential, and Public Facilities
B. NACCS Expert Panel Meeting Minutes
C. Development of Coastal Depth-Damage Relationships Using the Expert Elicitation Process, North Atlantic Coast Comprehensive Study, Concurrent Peer Review Summary Notes, 2014
D. Panelist Biographies
E. Summary of Survey Process and Results
F. Lessons Learned
G. Verification of North Atlantic Coast Comprehensive Study Damage Functions

ATTACHMENT A: OMB-APPROVED SURVEY INSTRUMENTS FOR RESIDENTIAL, NONRESIDENTIAL, AND PUBLIC FACILITIES

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK

RESIDENTIAL FLOOD DAMAGE SURVEY

(Personal Interview)
OMB- 0710-0001

The public report burden for this information collection is estimated to average 45 minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this data collection, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Executive Services Directorate, Information Management Division, and the Office of Information and Regulatory Affairs, Office of Management and Budget, Washington, D.C. 20503, Attn.: Desk Officer for U.S. Army Corps of Engineers. Respondents should be aware that notwithstanding any other provision of law, an agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. Please DO NOT RETURN your completed form to either of these offices.

Please return your completed survey directly to your interviewer, or send to:

U.S. Army Corps of Engineers
Institute for Water Resources
c/o URS
1255 Broad Street
Suite 201
Clifton, NJ 07013-3398
Attn: Don Rubin

US Army
Corps of Engineers

IWR INSTITUTE FOR WATER RESOURCES

OMB 0710-0001

RESIDENTIAL FLOOD DAMAGE QUESTIONNAIRE

1 to 4 Family

Your survey responses are important to help us improve the performance of Federal hurricane/storm damage reduction (Corps) projects. All of the questions in this survey pertain to Superstorm Sandy, which hit the coastline of New York and New Jersey in October 2012. The survey should be completed by the person who is best able to evaluate property damages incurred as a result of the hurricane. This survey is voluntary, and your responses will be kept strictly confidential. Thank you, in advance, for agreeing to participate in this important project.

Background Information

1 Address______________________________

2 Interviewee Name______________________________

Owner☐ Renter☐ Other ☐ ______________________________

3 May we contact you with further questions? .... Yes ☐ No ☐

Email: ☐ Phone: ☐

4 How long have you owned (lived in) this house? ☐

5 Is this your primary residence? .... Yes ☐ No ☐

5a If “No", is it a:

- ☐ Second Home
- ☐ Full-time rental (rented to the same tenant for a long-term basis)
- ☐ Seasonal rental (rented on a weekly or monthly basis)
- ☐ Other (please describe) ☐

6 Did you own/rent this property at the time of Superstorm Sandy? .... Yes ☐ No ☐

6a Did you purchase/lease the property after Superstorm Sandy? .... Yes ☐ No ☐

6b Did you own/rent a different property in the area hit by Sandy? .... Yes ☐ No ☐

7 Did this property suffer damage during Superstorm Sandy? .... Yes ☐ No ☐
If “No”, skip to Question 36.

8 Were you residing at this address during Superstorm Sandy? .... Yes ☐ No ☐

9 In the years you have lived here, how many times (including Superstorm Sandy) has this house had coastal storm damage? .... ☐

9a Please list the years of previous damage.

____

____

Structural Characteristics

10 How old is this house (years)? .... ……. ☐

11 Where is the main house situated? Please check one box from group A and one from group B.

11a **Group A – Source of Flooding**

☐ Ocean

☐ Sound or Bay

☐ River

11b **Group B – Distance From Flood Source**

☐ Waterfront parcel

☐ Waterfront Block

☐ First row behind waterfront

☐ Interior

12 Do you know the first floor elevation (defined as the top of the finished flooring of the lowest finished floor)? If so, insert here (with Datum)..

12a What is the source of the elevation? (i.e., survey, elevation certificate)

12b If your house is located in the V-zone, do you know the elevation of the bottom of the lowest horizontal structural member? If so, insert here (with Datum)

12c What is the source of the elevation for the Lowest Horizontal Member? (i.e., survey, elevation certificate)

12d What is the height (in feet) of the first floor in relation to the adjacent ground?

13 How many square feet of finished living area are in the house, not including the attic, garage, basement, or area underneath an elevated house?..................

(If you are unsure of the number of square feet, please give the dimensions.)................. X
(feet) (feet)

14 What type of foundation does the house have?

☐ Slab

☐ Piling - How many feet do they go below ground?...

☐ Concrete Block - How many feet does it go below ground? ....

☐ Basement – What is the percent (compared to footprint) of finished living area?

– What percent of the basement is finished? ....

☐ Other type of foundation: please describe ....

15 What category best describes the style of the house?

☐ 1-Story
☐ 1-1/2 Story Finished
☐ 1-1/2 Story Unfinished

☐ 2-Story
☐ 2-1/2 Story Finished
☐ 2-1/2 Story Unfinished

☐ 3-Story
☐ 3-1/2 Story Finished
☐ 3-1/2 Story Unfinished

☐ Bi-Level
☐ Split Level

16 Is there an under-the-house enclosure? .... Yes ☐ No ☐

16a If there is an under-the-house enclosure, please indicate the size of enclosed area devoted to each of the following uses:

Use	**Square Feet or**	**Dimensions (Feet X Feet)**
Finished Living Area		
Utility, Workshop, or Storage Area		
Garage		
Other (please describe)		

17 Is there a garage or outbuildings on the property?

Type	**Presence**	**Square Feet**	**Or Dimensions (Feet X Feet)**
Attached garage	Yes No		
Detached garage	Yes No		
Outbuilding (shed)	Yes No		
Other	Yes No		

18 What is the primary exterior wall covering on the house?

☐ Plywood
☐ Hardboard Sheets
☐ Stucco
☐ Siding
☐ Shingle
☐ Masonry Veneer
☐ Common Brick
☐ Face Brick
☐ Concrete Block
☐ Stone

19 What is the primary roof covering of the house?

☐ Composition Shingle
☐ Built-up Rock
☐ Wood Shingle (Embedded in Asphalt)
☐ Wood Shake
☐ Concrete Tile
☐ Clay Tile
☐ Galvanized Metal
☐ Slate
☐ Plastic Tile
☐ Composition Roll
☐ Other: ____________

20 What category best describes the heating and cooling system in the house?

Heating Only

☐ Forced Air
☐ Gravity Furnace
☐ Floor Furnace
☐ Wall Furnace (No Heat Ducts)
☐ Floor, Radiant Hot Water
☐ Ceiling, Radiant Electric
☐ Baseboard, Electric
☐ Baseboard, Hot Water
☐ Radiators, Hot Water
☐ Radiators, Steam

Heating and Cooling

☐ Warmed and Cooled Air
☐ Heat Pump System

Cooling Only

☐ Evaporative Water Cooler (Single or Short Ducts)
☐ Refrigerated, with Condenser and Ducts

21 How many fireplaces are in the house? .... ____________

22 Is there an elevator in the house? .... Yes ☐ No ☐

23 How many square feet of each of the following types of porches and decks are attached to the house? (If you are unsure of square feet, please give dimensions.)

Type of Porch or Deck	**Square Feet**	**or Dimensions (Feet X Feet)**
Slab		
Slab with Roof		
Wood Deck		
Enclosed Slab Porch		
Enclosed Wood Porch		

Long-Term Preparedness

24 Please indicate the location of the house utilities at the time of Superstorm Sandy. Indicate whether they had been previously elevated to prevent storm damage and, if so, whether elevating them was effective in reducing damages during Superstorm Sandy.

Utility	**Location** *(basement, first floor, second floor, etc.)*	**Elevated**	**Was elevation effective in reducing damages during Sandy?**	**Comments**
Central Air Conditioner		Yes No	Yes No	
Furnace		Yes No	Yes No	
Washer/Dryer		Yes No	Yes No	
Water Heater		Yes No	Yes No	
Other:		Yes No	Yes No	

Emergency Response

25 Just before Superstorm Sandy, how did you first become aware that flooding might reach your residence? (please check all that apply)

☐ TV

☐ Radio

☐ Telephone by a public or emergency worker

☐ Telephone by someone other than a public or emergency worker

☐ Face to face by public or emergency worker

☐ Face to face by someone other than a public or emergency worker

☐ Loudspeaker

☐ Siren

☐ Social Media (Facebook, etc.)

☐ C.B., ham radio or police scanner

☐ Newspaper

☐ Observing the water levels

☐ Other__________________

____

26 How many hours were there between the time you became aware that flooding would likely reach your residence until the water actually reached your property or you had to evacuate (whichever came first)? .... ☐

27 Did you evacuate your property as a result of Superstorm Sandy? ....Yes ☐ No ☐

28 What actions, if any, did you take to safeguard your property immediately prior to the storm and following Superstorm Sandy?

Property Safeguards	**Before Storm**		**After Storm**	
	Number of Unpaid Hours	**Dollars Spent**	**Number of Unpaid Hours**	**Dollars Spent**
Moved contents to higher ground				
Turned off electrical equipment				
Sandbagged the outside of the building				
Used another type of temporary barrier				
Moved vehicles to higher ground				
Boarded up windows/doors				
Moved outside furniture and belongings inside				
Other action ______________________________				

28a How much damage was prevented by these actions?

Inundation and Wave Damage

29 How high (in feet and inches) did the water get on the inside of the house relative to the first floor of the house? ……………………………………….. ☐

30 How long did the water remain in the house? .... ☐

31 Please indicate the sources of damage to your property. **(Check all that apply)**

☐ STORM SURGE (a sudden flow of water associated with a storm event)

☐ WAVE RUNUP (the rush of water up a structure, associated with the breaking of a wave)

☐ INUNDATION (the buildup of water overflow or ponding)

☐ EROSION

☐ WIND DAMAGE

☐ OTHER (please describe) ☐

32 After Superstorm Sandy, did you or other occupants of the house have to stay in temporary lodging due to damages to the house?..Yes ☐ No ☐
If "No", please skip to Question 33.

32a How many days did you or other occupants spend in temporary lodging? ☐

32b How much money in excess of normal expenses did you or the occupants spend on food, lodging and travel expenses until the house was reoccupied?

Food .... $☐
Lodging... $☐
Travel... $☐

32c How much of the expenses were reimbursed? $☐

32d Who was the payee (FEMA, other)?___________________________________

33 Please fill in the following table regarding inundation and wave damages to your structure and property as a result of Superstorm Sandy.

Inundation and Wave Damage[1]		**Dollars Spent (paid labor, supplies, etc.)**	**Number of Unpaid Hours**
Did the house and any attached garages incur structural damage? If so, what was the cost of repairing structural damage to the house and any attached garages?	Yes No		
Excluding motor vehicles, was there any damage to appliances, furniture, and other contents of the house and other buildings? (Only include content replacement and/or repairs; do not include repairs to the structure of the house or other buildings). If so, what was the cost of repair and/or replacement?	Yes No		
Did any detached garage incur structural damage? If so, what was the cost of repairing structural damage to any detached garages?	Yes No		
Did any other buildings incur structural damage? If so, what was the cost of repairing structure damage to other buildings on the property?	Yes No		
Was any landscaping damaged? If so, what was the cost of repairing/replacing damaged landscaping?	Yes No		
Did any automobiles, trucks or motorcycles at this property incur damage during Superstorm Sandy? If so, what was the total damage?	Yes No		
Did any boats or jet skis located at this property incur damages during Superstorm Sandy? If so, what was the total damage?	Yes No		
Was your property subject to vandalism, looting, or theft? If so, what was the additional cost of vandalism/looting/theft? *(Or check here if this was already included in repair costs reported above.)* ☐	Yes No		
Did you property suffer from damages due to mold? If so, what was the additional cost of treating any mold? *(Or check here if this was already included in repair costs reported above.)* ☐	Yes No		
Did you, or any other occupant, suffer from storm-related medical problems? If so, what was the cost of treatment?	Yes No		
After Superstorm Sandy, was clean up and debris removal necessary at your property? If so, what was the cost?	Yes No		
Is there a swimming pool on the property?	Yes No		
Is the swimming pool in-ground?	Yes No		
If the pool was damaged, what were your costs to repair or replace the pool?	Yes No		

[1] *Structural damage is defined as damage to any building components, including foundation, walls, floors, windows, roof, electrical systems, heating and cooling systems, plumbing, attached carpeting, attached shelves and cabinets, and built-in equipment and appliances.*

34 Which of the following is the primary source of your structural damage values? **(Please check one only)**

☐ Contractor estimate (before repairs)
☐ Contractor invoice (after repairs)
☐ Your own assessment
☐ Other (please describe) ☐

Erosion Damage

35 Was there erosion damage to your property? .... Yes ☐ No ☐

Erosion Damages		
What was the depth of the eroded area at the foundation of the house? (maximum depth that the ground was lowered)	_______feet	
What was the depth of the erosion relative to the bottom foundation footing or pile? Please insert the number of feet, and then check either 'above' or 'below'.	_______feet above ☐ below ☐	
Approximately what percent of the house footprint was undermined?	_______%	
If your house was destroyed or substantially damaged, did the amount of erosion make it infeasible to repair the damage or build another house on the same lot?	Yes No	
Did you repair the erosion damage?	Yes No	
What were the costs to repair the erosion damage?	Dollars Spent $__________	Number of Unpaid Hours ___________

36 After Superstorm Sandy, did you install any of the following measures to prevent ***future*** erosion damage?

Measures to Prevent Future Erosion	**Was Method Used?**	**Number of Unpaid Hours**	**Dollars Spent**
Armoring (e.g., rip rap, groins, sea walls, revetments, etc.)	Yes No		
Dune Construction	Yes No		
Sand Stabilization Measures (e.g., Sand Fencing, Vegetation, etc.)	Yes No		
Extended/Reinforced Pilings	Yes No		
Other action _________________	Yes No		

37 Additional Comments: In the space below, please share with us any feedback you may have regarding flooding impacts at this structure. For example, Sandy impacts not captured on the previous pages, or information regarding non-Sandy flood events that may have impacted your property.

Thank you for completing this survey!

Please return your completed survey directly to your interviewer, or send to:

U.S. Army Corps of Engineers
Institute for Water Resources
c/o URS
1255 Broad Street
Suite 201
Clifton, NJ 07013-3398
Attn: Don Rubin

To be filled out by the interviewer:

1. FEMA Elevation Certificate Building Diagram Number (To Be Completed By Interviewer): ☐

2. Indicate the quality and condition of the building (where 1=low, 2=average, 3=above average or good, 4=high cost or excellent): Quality ☐ Condition ☐

Definition of Condition Ratings

Condition Rating	**Definition**
0	No functional value remaining. Structure is missing valuable components such as walls or roofing, and is considered unusable.
1	In very poor condition. The structure is dilapidated and deteriorating. The structure is most likely abandoned.
2	Requires extensive repairs. The structure may have utility remaining, but is in need of extensive maintenance.
3	Requires some repairs and maintenance.
4	In average condition. There is normal wear on the structure, but no signs of major repairs or maintenance needed.
5	Little visible wear and tear on structure, but it is not considered "brand new." Most functional value is remaining.
6	Structure was recently built. There is no visible deterioration. This condition is rare in structure inventories and should be reserved for only "brand new" structures that have all functional value remaining.

Definition of Quality Ratings

Quality Rating	**Definition**
1	Low quality design, materials, and construction. Structure is most likely mass produced with plain exterior and little to no ornamentation.
2	Fair/average design, materials, and construction. Structure is most likely mass produced with a few upgrades in materials and ornamentation
3	Average materials, construction, standard design
4	High quality design, materials, and construction. Custom built structure with attention to detail and unique ornamentation.

NONRESIDENTIAL FLOOD DAMAGE SURVEY

(Personal Interview)

OMB- 0710-0001

The public report burden for this information collection is estimated to average 60 minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this data collection, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Executive Services Directorate, Information Management Division, and the Office of Information and Regulatory Affairs, Office of Management and Budget, Washington, D.C. 20503, Attn.: Desk Officer for U.S. Army Corps of Engineers. Respondents should be aware that notwithstanding any other provision of law, an agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. Please DO NOT RETURN your completed form to either of these offices.

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**US Army
Corps of Engineers**

**IWR
INSTITUTE FOR
WATER RESOURCES**

NONRESIDENTIAL FLOOD DAMAGE QUESTIONNAIRE

Your survey responses are important to help us improve the performance of Federal hurricane/storm damage reduction (Corps) projects. All of the questions in this survey pertain to Superstorm Sandy, which hit the coastline of New York and New Jersey in October 2012. The survey should be completed by the person who is best able to evaluate property damages incurred as a result of the hurricane. This survey is voluntary, and your responses will be kept strictly confidential. Thank you, in advance, for agreeing to participate in this important project.

PART ONE
FACILITY DATA AND INFORMATION

Background Information

1 Address ______________________________

2 Interviewee Name ______________________________

Owner ☐ Renter ☐ Other ☐ ______________________________

*If Renter, Building owner contact info ______________________________

____

3 May we contact you with further questions? .... Yes ☐ No ☐

Email: ________________ Phone: ________________

4 How long have you operated your business at this address? ________________

5 Did you own/rent this property at the time of the hurricane? .... Yes ☐ No ☐
If "Yes", skip to Question 6.

5a Did you purchase/lease the property after hurricane? .... Yes ☐ No ☐

5b Did you own/rent a different property in the area hit by the hurricane? ...... Yes ☐ No ☐

6 Did this property suffer damage during Superstorm Sandy? .... Yes ☐ No ☐

7 Briefly describe the major purpose of this business facility? ______________________________

____

8 Please indicate the number of full time, part time, and total employees.

__________ + __________ = ________________
Full Time Part Time Total Employees

9 How many shifts per day are there in your daily operation? .... ________

10 How many buildings are there at this facility? .... ________

Flooding Characteristics

11 While at this location, approximately how many times has this facility experienced flood damage, including the flooding from Superstorm Sandy? .... ☐

11a Please list the years of previous damage.

____

____

12 Just before Superstorm Sandy, how did you first become aware that flooding might reach your business? (please check all that apply)

☐ TV

☐ Radio

☐ Telephone by a public or emergency worker

☐ Telephone by someone other than a public or emergency worker

☐ Face to face by public or emergency worker

☐ Face to face by someone other than a public or emergency worker

☐ Loudspeaker

☐ Siren

☐ Social Media (Facebook, etc)

☐ C.B., ham radio or police scanner

☐ Newspaper

☐ Observing the water levels

☐ Other________________

____

13 How many hours were there between the time you became aware that flooding would likely reach your business or your business flooded or you had to evacuate (whichever is came first)? .... ☐

14 Did you take any actions to safeguard your business property immediately prior to Superstorm Sandy?......... Yes☐ No ☐ If "yes", please complete the table below.

Damage Prevention Action	Took Preventive Action	Dollars Spent on Action (paid labor, supplies, etc.)	Number of Unpaid Hours Spent	Was the Action Effective
1. Moved contents to higher ground	Yes No			Yes No
2. Elevated contents to a higher spot in the building	Yes No			Yes No
3. Shut off electrical equipment	Yes No			Yes No
4. Sandbagged the outside of the building	Yes No			Yes No
5. Used another type of temporary barrier	Yes No			Yes No
6. Moved vehicles to higher ground	Yes No			Yes No
7. Other action (describe):	Yes No			Yes No

14a How much damage was prevented by these actions?

15 How many days, if any, was this business closed due to Superstorm Sandy? ☐

15a Did your business set up temporary quarters at another location because of Superstorm Sandy? .... Yes ☐ No ☐

15b How much additional money did the flood cost your business in increased operational expenses, such as temporary quarters, additional transportation, communications, or storage expenses? .... ….. ☐

Facility-Level Damage Data

16 Please indicate the approximate dollar value of damage from Superstorm Sandy to the following categories in the table below.

Note that this form has been structured to accommodate those facilities with more than one building on a site. Please fill in only those columns that are applicable to your site. If you have more than three buildings on your site, please check here ☐ and submit extra copies of this particular page until feedback has been provided for each building.

Information regarding costs of repair/replacement of buildings/contents will be captured in Question #25 of this survey.

Type of Damage	Building 1 Dollars Spent	Building 1 Number of Unpaid Hours	Building 2 Dollars Spent	Building 2 Number of Unpaid Hours	Building 3 Dollars Spent	Building 3 Number of Unpaid Hours
Cleanup Costs[1]						
Landscaping and Outside Property Repair/Replacement Costs[2]						
Business Record Replacement Costs[3]						

[1] *Cleanup Costs = Costs of labor and materials to clean up interior and outside of building.*

[2] *Landscaping and Outside Property Repair/Replacement Costs = Costs to repair/replace damaged landscaping and other outside property (not inclusive of outbuildings or vehicles)*

[3] *Business Record Replacement Costs = The financial costs and unpaid hours for reconstructing business records that where damaged by the flood.*

This marks the end of Part One.

Please complete an individual Part Two response (pages 5 and 6) for each building at your facility.

PART TWO
INDIVIDUAL BUILDING CHARACTERISTICS

Please complete an individual Part Two response (pages 5 and 6)
for each building at your facility.

Building Characteristics

17 Building Number/Name: ____

18 What year was this building constructed? .... ____

19 What is the footprint of your building in square feet? .... ____

(If you are unsure of the number of square feet, please give the dimensions.)................. ____ (feet) X ____ (feet)

20 Does the building have a basement?..Yes ☐ No ☐

20a How many basement levels does the building have? .... ____

20b Please provide basement details in the following table:

Basement Level	Basement Level Area (in square feet, or dimensions in feet)	Percent of Basement Level Area that is Finished	What occupancies[1] are located in each basement level? (Are we interviewing business or building owners?)	What utility *(Mechanical, Electrical, and Plumbing)* equipment is located in each basement level?	Is this basement level connected to any basements for other buildings or other below-grade spaces[2]? *(Please indicate Yes/No; and if 'yes', please describe how they are connected.)*
B1					
B2					
B3					
B4					
B5					
B6					

[1] *Occupancies include, for example: parking, storage, retail, restaurant, office, etc.*

[2] *Below-grade spaces include, for example: utility vaults, tunnels, transit stations, etc.*

21 Indicate the number of the type of heating and cooling system that best describes the system that is used in your building…………………………….. ____

1. Electric
2. Electric Wall
3. Forced Air
4. Hot Water
5. Hot Water, Radiant
6. Space Heater
7. Steam
8. Steam, Without Boiler
9. Ventilation
10. Wall Furnace
11. Package Unit
12. Warmed and Cooled Air
13. Hot and Chilled Water
14. Heat Pump
15. Floor Furnace
16. Individual Thruwall Heat Pump
17. Complete HVAC
18. Evaporative Cooling
19. Refrigerated Cooling

22 How many passenger elevators are in each building?

Building 1 ____ Building 2 ____ Building 3 ____

23 How many freight elevators are in each building?
Building 1 Building 2 Building 3

Building-Specific Damage Data

24 During Superstorm Sandy, how high (in feet and inches) did the water get on the inside of the building relative to the first floor of the building?..

24a How long did the water remain in this building? ……………...

25 How much damage occurred to the structure (building and everything attached to it)?
Dollars $ …..Percent of structure value %
Unpaid hours spent on repair hrs

26 Please fill in the following table describing damage to this specific building during Superstorm Sandy. Note that value refers to depreciated value, not full replacement values. * *If your data are available only at the facility level (for all buildings on-site), then please check here and fill in the table below with your facility-level data.*

Level	**Pre-Sandy Value of Equipment Physically Attached or Anchored to Building (inside or outside)**	**What was the $ value of the loss?**	**Pre-Sandy Value of Other Equipment, Furniture, Supplies, Raw Materials, and Inventory Generally Stored on this Level**	**What was the $ value of the loss?**	**Pre-Sandy Value of all Vehicles Generally Stored on this Level**	**What was the $ value of the loss?**
2						
1 (Main)						
B1						
B2						
B3						
B4						
B5						
B6						

Pre-Sandy Value of all Vehicles Generally Stored Outside (but in the Immediate Vicinity) of this Building	**Percent Damaged During Sandy and Dollar Value of the Loss**
	% $
Pre-Sandy Value of all Other Equipment, Supplies, and Inventory Generally Stored Outside (but in the Immediate Vicinity) of this Building	**Percent Damaged During Sandy and Dollar Value of the Loss**
	% $

27 Additional Comments: In the space below, please share with us any feedback you may have regarding flooding impacts at this structure. For example, Sandy impacts not captured on the previous pages, or information regarding non-Sandy flood events that may have impacted your property.

Thank you for completing this survey!

Please return your completed survey directly to your interviewer, or send to:

U.S. Army Corps of Engineers
Institute for Water Resources
c/o URS
1255 Broad Street
Suite 201
Clifton, NJ 07013-3398
Attn: Don Rubin

To be filled out by the interviewer:

1. Indicate the class of each building.
Building 1 ______ Building 2 ______ Building 3 ______
   - A. Fireproof Structural Steel Frame
   - B. Reinforced Concrete Frame
   - C. Masonry Bearing Walls
   - D. Wood or Steel Stud Framed Exterior Walls
   - S. Metal Frame Walls
   - M. Mill Type Construction
   - P. Pole Frame Construction

2. Indicate the quality of each building on the property (where 1=low, 2=average, 3=above average or good, 4=high cost or excellent):
Building 1 ______ Building 2 ______ Building 3 ______

3. What is the condition of each building?
Building 1 ______ Building 2 ______ Building 3 ______

6. Excluding any basement or attic how many stories does each building have?
Building 1 ______ Building 2 ______ Building 3 ______

6a. What is the average story height of each building (in feet)
Building 1 ______ Building 2 ______ Building 3 ______

7. What is the shape of each building? Please select from: square, rectangular, L-shaped, U-shaped, or very irregular.
Building 1 ______ Building 2 ______ Building 3 ______

8. What FEMA Elevation Certificate Diagram Number best describes the building*? ______

**Ask your interviewer, or go to http://www.fema.gov/media-library-data/20130726-1437-20490-0725/f_053_elevcertif_30nov12_fillable.pdf pages 7, 8 and 9.*

Definition of Condition Ratings

Condition Rating	Definition
0	No functional value remaining. Structure is missing valuable components such as walls or roofing, and is considered unusable.
1	In very poor condition. The structure is dilapidated and deteriorating. The structure is most likely abandoned.
2	Requires extensive repairs. The structure may have utility remaining, but is in need of extensive maintenance.
3	Requires some repairs and maintenance.
4	In average condition. There is normal wear on the structure, but no signs of major repairs or maintenance needed.
5	Little visible wear and tear on structure, but it is not considered "brand new." Most functional value is remaining.
6	Structure was recently built. There is no visible deterioration. This condition is rare in structure inventories and should be reserved for only "brand new" structures that have all functional value remaining.

Definition of Quality Ratings

Quality Rating	Definition
1	Low quality design, materials, and construction. Structure is most likely mass produced with plain exterior and little to no ornamentation.
2	Fair/average design, materials, and construction. Structure is most likely mass produced with a few upgrades in materials and ornamentation
3	Average materials, construction, standard design
4	High quality design, materials, and construction. Custom built structure with attention to detail and unique ornamentation.

PUBLIC DAMAGE SURVEY

(Personal Interview)

OMB- 0710-0001

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Please return your completed survey directly to your interviewer, or send to:

U.S. Army Corps of Engineers
Institute for Water Resources
c/o URS
1255 Broad Street
Suite 201
Clifton, NJ 07013-3398
Attn: Don Rubin

US Army
Corps of Engineers

IWR
INSTITUTE FOR
WATER RESOURCES

PUBLIC DAMAGE SURVEY

Your survey responses are important to help us improve the performance of Federal hurricane/storm damage reduction (Corps) projects. All of the questions in this survey pertain to Superstorm Sandy, which hit the coastline of New York and New Jersey in October 2012. The survey should be completed by the person who is best able to evaluate property damages incurred as a result of the hurricane. This survey is voluntary, and your responses will be kept strictly confidential. Thank you, in advance, for agreeing to participate in this important project.

1 Name of Governmental Entity: ____

2 Agency: ____

3 Interviewee Name and Title: ____

4 Address: ____

5 Phone Number: ____

6 Email Address: ____

7 What specific facilities are covered by this survey?________________________________

8 Source(s) of flooding during Superstorm Sandy: ____________________________________

____

9 In the table below, list the damages that occurred to public property in your jurisdiction as a result of Superstorm Sandy.

Type of Property	**$ Damage**	**Flood Depth**	**Description of Property**	**Primary Cause of Damage (inundation, wave, erosion, etc.)**
Buildings - Structure				
Buildings - Contents				
Equipment - outside				
Vehicles- outside				
Supplies - outside				
Streets, highways, roads				
Drainage system				

Bridges				
Docks				
Marinas				
Boardwalks				
Parks				
Fuel Tanks				
Subway/Rail				
Tunnels				
Other				
Total				

10 Please list any other public cost that resulted from the flooding in your jurisdiction.

Type of Costs	$ Costs Incurred	Volunteer (unpaid hours)	Description
Pre-storm protective actions			
Emergency operations and flood fighting			
Police protection			
Additional costs of water supply			
Additional costs of sewage treatment			
Additional costs of flood cleanup			
Additional costs of trash collection and disposal			
Additional costs of debris removal			
Replacement of business records			
Repairs to levee, sand dunes, or other flood or coastal protection			
Cleanup of hazard waste			

Costs of emergency shelter operations			
Other costs			
Total			

11 Please describe any harmful public health and other environmental effects that flooding may have caused by inundation of landfills, sewage treatment plants, or other hazardous waste sites.

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12 If possible, can you identify key facilities or specific equipment that was damaged, the dollar damage, and associated flood depth?

____

____

____

____

____

____

Part 2 - Utilities

13 Please describe damages incurred by utility systems as a result of Superstorm Sandy.

Type of Costs	Functional Downtime (hours, days, etc.)	Repair/Replacement Costs ($)
Water Supply System		
Plant and equipment		
Distribution system		
Wastewater Treatment System		
Plant and equipment		
Distribution system		
Power Supply System		
Plant and equipment		
Distribution system		

14 What is the capacity of your plant?

Water Supply	
Wastewater Treatment	
Power Supply	

15 In the table below, list the damages that occurred to individual buildings, process or equipment as a result of Superstorm Sandy.

Specific Buildings, Process or Equipment	$ Damage	Flood Depth	Description of Item	Primary Cause of Damage (inundation, wave, erosion, etc.)

15 **Additional Comments**: In the space below, please share with us any feedback you may have regarding flooding impacts at this structure. For example, Sandy impacts not captured on the previous pages, or information regarding non-Sandy flood events that may have impacted your property.

____
____
____
____
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____

Thank you for completing this survey!

Please return your completed survey directly to your interviewer, or send to:

U.S. Army Corps of Engineers
Institute for Water Resources
c/o URS
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ATTACHMENT B: NACCS EXPERT PANEL MEETING MINUTES

NORTH ATLANTIC COAST COMPREHENSIVE STUDY:
RESILIENT ADAPTATION TO INCREASING RISK

TABLE OF CONTENTS

Introduction

As a component of the North Atlantic Coast Comprehensive Study (NACCS), an expert-opinion elicitation panel was conducted between April 23 and 25, 2014 to develop depth-damage function (DDFs) related to coastal storm events. This report contains a synopsis of the discussions that occurred during the panel session.

Purpose of Panel

The purpose of the three-day panel session was to use the collective experience of a nationally-based expert-opinion elicitation panel to develop generic DDFs that can be used to estimate the percent loss from damages that would be expected to occur from a coastal storm event. The results of the expert-opinion elicitation will be used to estimate the extent of damage resulting from coastal wave and saltwater flooding for residential and nonresidential structures and their contents. The DDFs will be applicable to homes and businesses located along the north Atlantic coast of the United States.

Attendees

The following panelists and supporting participants attended the panel session. The panelist and participants were provided the opportunity to introduce themselves near the beginning of the session.

ATTENDEES

Panelists:	
Name	**Occupation/Expertise**
Bill Coulbourne, P.E.	Engineer/ Structural
Frank L. Headen	Restoration Specialist
Chris Jones, P.E.	Engineer/ Coastal Hazard Mitigation
Andrew Kennedy, P.E.	Engineer/ General
Michael Pagano, P.E.	Engineer / Mechanical, Electrical, Plumbing (MEP)
Karthik Ramanathan, P.E.	Engineer/ Structural
Spencer Rogers, P.E.	Engineer/ Coastal and Oceanographic
Jim Soucy	Flood Adjuster, Property Preservation
Jack Young	Pre-Disaster Assessor
Supporting Participants:	
Name	**Position/ Organization**
Naomi Fraenkel	Division Economist/ Army Corps of Engineers (ACOE), North Atlantic Division
Brian Maestri	Economist, Principal Investigator, and Peer Reviewer/ ACOE, New Orleans District
Stuart Davis	Economist and Principal Investigator/ ACOE, Institute of Water Resources (IWR)
Kevin Knight	Economist/ ACOE, IWR
Robert Hampson	Coastal Engineer/ Moffatt & Nichol
Mike Cannon	Observer / URS

Jason Weiss	Observer / URS
Ann Terranova	Meeting Facilitator/ URS
Brian Beckenbaugh	Meeting Documentation / URS
Stacy Mulrain	Meeting Documentation / URS

Agenda

A detailed agenda was developed prior to the session (see attachment); however the agenda was revise-d during the session to reflect revisions to prototypes and time considerations. The following table provides the general order of when discussion took place.

April 22, morning:	Facilitators provided background materials and an overview of the status of the NACCS.
April 22, afternoon:	Discussion of individual prototypes began, starting with Prototype 1
April 23	Discussion of individual prototypes continued, focusing on Prototypes 1 – 5A
April 24	Discussion of individual prototypes was completed, Prototypes 5B – 7B.

Structure of Report

This report provides a synopsis of the panel proceedings. The first part of the report focuses on the training and background material provided to the panelists, as well as some of the most important conversations that took place during the meeting. The second part of the report focuses on the prototype development process.

NACCS Study Overview

- Naomi Fraenkel provided an overview of the NACCS study:
    - The ACOE evaluates projects based on benefit-cost analyses. Benefits are defined as bad things that do not happen if a ACOE project is in place; i.e., the difference between with-project damage and without-project damage.
    - The ACOE uses DDFs to estimate the potential damages from a given level of inundation. However, current DDFs do not take into account certain characteristics that are particular to the North Atlantic region. These include building types and configurations, like high rise structures and buildings that have basements, as well as demographic characteristics like population and density.
    - This expert-opinion elicitation panel is part of the ongoing NACCS study effort, which will incorporate wave and erosion impacts into the study process. The generic coastal DDFs to be developed by this panel will help to more accurately

evaluate coastal damage reduction alternatives, and move more coastal flood projects into fruition.

- A conversation ensued about existing coastal DDFs. While coastal DDFs were developed 12 years ago through another expert-opinion elicitation panel, the DDFs were more pertinent to residential structures than to apartments, commercial structures, or high rises. A focus area of this panel was on special engineered structures that were not captured during the prior panel, and also to update the residential analysis with damage data from recent events.
- A panelist asked whether the focus of this study was limited to residential structures, or if commercial and industrial structures were also included. It was explained that prototypes had been developed across a number of categories, not just residential. Panelists would have an opportunity to give input on the type of structures that would be evaluated during this elicitation.
- Stuart Davis explained that the ACOE uses DDFs to analyze all flood risk and coastal risk management projects. Although the data collected for the purpose of this panel were Sandy-specific, the investigators valued the experience that the panelists had gained in other areas of the United States. Panelists were asked to draw from this experience to lend their unique perspectives throughout the discussion, as these DDFs ultimately needed to be generalized for use throughout the whole country.
- Panelists were encouraged to learn about the reasoning behind other panelists' estimates, but not to be swayed in their own estimate by a desire to conform.
- Panelists were informed that post-storm damage interviews conducted for Sandy-impacted areas yielded little information on wave and erosion damage due to "all or nothing" nature of the damages. Structures impacted by waves generally suffered catastrophic failure, and owner interviews were difficult to obtain.

Panel Orientation

How the Meeting Would Be Conducted

- Jason Weiss explained the "strawman" prototype process and the spreadsheet system:
    - Each panel member was provided with a laptop to enter their results.
    - The laptop had access to spreadsheets that were developed for each prototype.
    - Facilitators would present "strawman" prototypes to the panel for discussion. Panelists were asked to draw from their own experience to verify whether each prototype was representative of a typical structure type within the study area. The idea was for each panelist to bring in an open point of view based on experience and expertise.
    - Panelists were walked through the laptop and spreadsheet set up, where panelists would enter damage values according to their expertise and experience.
    - As far as the mechanics of the spreadsheet were concerned, the main responsibilities of the panelists were to:
        - select the correct spreadsheet,
        - select the correct tab,
        - check their own answers for mistakes, and

        - Ensure that their “Most Likely” value was always equal to or higher than their “Minimum” value, and that their “Maximum value” was always equal to or higher than their “Most Likely” value.
    - A demonstration was given on how a summary of the elicitations would be displayed to the group after each elicitation was complete.
    - Following data entry, the panel would review results of all panel members and have another discussion. Panel members would be given the opportunity to explain the rationale behind their answers, especially in instances where there were outlying values.
    - Following the second discussion, panel members would be given the opportunity to change their answers if they were persuaded by information that others provided.
    - Ann clarified that only the final version of the spreadsheet would be saved.
- A panelist asked if all inundation would be salt water. It was confirmed that all inundation would be salt water.
- A panelist asked whether each expert was expected to focus on the total damage to the structures, or just the area that they specialized in. Panelists were instructed to focus on total damage, not just their area of expertise. Answers could be changed after the discussion, but there was no pressure to do so.
- Panelists were encouraged to share their information and data throughout the process.
- A panelist asked whether the DDFs were going to be structure-specific, or if they would be used to look at an average sense of damage over a wider area? It was explained that the DDFs would be applied on a structure by structure basis, averaged over a whole area. The DDFs were not expected to be an accurate representation of a specific structure. Rather, the average damage would be representative of what’s out there. There is a lot of uncertainty in the estimates, but the models that they would be applied to were built to accommodate that uncertainty.
- A panelist emphasized that it is critically important that everyone had the same mental image in mind when estimating damage; there was a consensus from the rest of the group.
- Naomi emphasized that the following impacts should not be included in the damage estimates, as they are part of a separate study:
    - Emergency costs (such as preparation and clean-up costs),
    - Loss of life,
    - Secondary and tertiary affects (such as downtime resulting from MEP (mechanical, electrical, and plumbing) failures, labor market costs, or delays in acquiring a new furnace when everybody in the neighborhood needs a new furnace at the same time).

  It is ok to take note of these affects during the panel, but they are not to be included.
- A clarification was made about the use of replacement cost and the calculation of benefits for existing structures. The panel was instructed to estimate the cost of repair to the current code, up to the replacement value of the structure.
- Panel discussed differences between structure and contents. One panelist introduced the “Shake Test” concept: if you pick up a building and shake it, anything that fell out would be categorized as contents. Anything that remained would be counted as structure. Mike Cannon concurred with the Shake Test and clarified that “Contents” are anything that could be taken with you when you moved.

- A discussion about MEP categorization took place. Some assumed it fell into the Content category; others felt that MEP should be categorized as Structure. At the end of this conversation, MEP was deemed to be part of the Structure category.
- A panelist asked if the spreadsheets were confidential, or if the panelists could have a copy of the spreadsheets at the end of the panel. Mike Cannon needed to defer to the ACOE about the individual spreadsheets, but they did plan to send the report to the panelists once it was compiled. Panelists were informed that the meeting was being recorded for the purpose of note-taking so that people could refer back in a couple of years if they need to clarify anything. Panelist names might be published, but would not be associated with any statements.
- A panelist asked if the most typical event would be represented by 1% chance storm event. The panel was informed that the flood would be scenario-specific; defined by parameters like velocity, salt water, and wave type, not probability of a storm event. This approach would help to eliminate availability bias.

Reducing Bias in Results

- Brian Maestri explained that the expert-opinion elicitation panel is a data gathering tool. Empirical data about DDFs are not readily available, so expert opinions are used in lieu of those data.
- Since opinions are vulnerable to bias, Brian discussed that the elicitation session was designed to reduce bias as much as possible. The panelists were instructed to remain vigilant in avoiding the following
    - Observer bias: Tendency to make measurement errors in the direction of one’s wishes/expectations
    - Confirmation bias: Tendency to emphasize information that confirms personal beliefs rather than information that might disprove them
    - Social desirability bias: Tendency to describe beliefs in a socially desirable, but inaccurate, way
    - Overconfidence: Tendency to assign high levels of confidence to issues that have large bands of uncertainty
    - Availability bias: Tendency to overestimate the occurrence of rare, catastrophic events, which receive more publicity
    - Anchoring bias: Tendency to remain relatively close to original starting value when making estimates
    - Inconsistency bias: Occurs when experts are inconsistent in their reasoning as they work through a problem
- The investigators emphasized that they are not looking for consensus, but to stick with what they think is right

Overview of Key Terms

- Mike Cannon defined key terms that would be used throughout the session, and emphasized the need for the panelists to understand the terms when estimating damages.
    - Basements were defined as subgrade on all four sides. There would be living levels below grade (NYC, Hoboken).
    - Damage was to be valued based on cost of repair up to replacement value of the structure. The panel was asked to come-up with a percentage that represented the amount of damage in relation to the undepreciated replacement value for each level of flooding.

  - Depth measurements required a reference point:
    - Most DDFs measured depth relative to the first finished floor elevation (FFE) above grade; negative depth was below the FFE, and positive depth was above it.
    - Where waves were concerned for non-pile supported structures, depth was generally measured relative to the grade elevation because that measurement expressed how much wave would be exerted against the wall of the structure.
    - For pile supported structures, the panel would probably measure depth relative to the first floor beam.
    - The panel was to be careful to focus on the appropriate point of reference
    - The panel would have the opportunity to change the point of reference if it deemed it appropriate.
    - A clarification was made that the flood depth for damage estimates would be based on the still-water level.
  - Storm induced erosion was defined as the general lowering of the grade, not to be confused with scour.
- A discussion took place about subgrade flooding. One panelist asked if an assumption should be made that above-grade flooding had to take place in order for water to be present at a subgrade elevation. In response to this question, other possible sources of subgrade flooding were discussed:
  - Hydrostatic pressure,
  - Tunnel connections between buildings,
  - Sewer back-ups, and
  - Downward sloping grade into a parking garage.

  It was clarified that subgrade flooding was not dependent on above-grade flooding.

Presentation on Coastal Definitions

- Rob Hampson of Moffatt Nichol gave a presentation on coastal definitions and processes, FEMA mapping standards, hydrostatic and breaking wave forces, local scour vs. beach erosion, and the wave measurement and erosion data that the USGS gathered during Sandy.
- Mike Cannon explained that for inundation functions, the still-water plus set-up was typically used because run-up was intermittent.
- Mike Cannon informed the panel that it might be necessary to differentiate between breaking waves and non-breaking waves when estimating damages.

  Breaking Wave:

  A wave whose steepness has reached a limiting value, causing the wave to become unstable, break, and dissipate energy. Breaking waves cause impulsive (violent) conditions at structures.

  Non-Breaking Wave:

  A wave whose steepness is less than the limiting value for breaking. Non-Breaking waves cause non-impulsive (non-violent) conditions at structures.

  In some areas, it was very common to have depths sufficient to carry non-breaking waves to buildings.

Presentation on Sandy Damages

A summary of work to date was provided:

- Mike Cannon discussed the ACOE's planning process and the various sources of data that the study gathered thus far.
- Mike gave a presentation on Sandy storm damage and interview results throughout NY and NJ. He discussed the difficulty in obtaining information on erosion due to the fact that many beach front structures were completely destroyed during the storm.
- Richard Franks presented examples of how DDFs are used to estimate coastal damages.

Application of Uncertainty

- Stuart Davis advised the panel that there was an impetus not to presume that damages would be exactly "x" amount from a certain level of flooding. Factors such as storm characteristics, water level, and building characteristics would yield a range of possibilities.
- The purpose of the uncertainty exercise was to capture about 90% of the cases that might occur from a certain level of flooding. This 90% should be based on the circumstances of an individual storm and the building characteristics, and not on the probability of the storm event occurring. The panel shouldn't focus on very extreme outcomes, like a break in the gas line that caused a fire, the destruction of a building with low levels of water, or a building's miraculous escape from damage under circumstances that should be damaging.
- Jason offered an "apple analogy" as an example: The most likely price that one might pay for a pound of apples could be $2.50. The minimum price might be $1.00/lb, and the maximum price could be $4.00. Other possible prices are $0.00 and $100.00, but these wouldn't be appropriate because they are not rational and based on expected values.
- Stuart spoke a little about the models that the ACOE used to estimate damages:
  - BeachFX is used to evaluate coastal storm damages, and to calculate erosion and wave damage. It uses a triangular probability distribution with minimum, most likely, and maximum characteristics.
  - HEC-FDA is used to assess inundation losses. It does not calculate erosion or wave damage. It can use either a normal or triangular distribution for the uncertainty analysis.
- A panelist asked for confirmation that the damage ratios are all conditioned on the flood level. Upon receiving it, the panelist then asked how the ACOE accounts for the uncertainty surrounding the flood level (x-axis). Mike Cannon explained that the uncertainty was built into the model. BeachFX does not apply an uncertainty to the water level, but HEC FDA does. Stuart believed that the ACOE might be working on a new coastal storm model that could account for that uncertainty. It was confirmed that the panel would only consider the uncertainty surrounding structure and storm, and not the uncertainty related to the water level in its calculations.

Summary of Discussions on Mold

- Since estimates on mold damage made by a previous panel prior to Hurricane Katrina were found to grossly underestimate the observed impact of mold on a building's structure and contents, the current panel was asked to carefully consider the issue of mold.
- Through discourse, the panel gained an understanding of the complicated nature of mold damage. The topic arose numerous times throughout the sessions, as panelists contended with the challenge of properly estimating the true impact of mold damage on

buildings.

- Mold was categorized under structural damage due to the fact that it cannot simply be cleaned off of a surface. Remediation involves the complete removal and replacement of all affected finishes, and the treatment of structural members, like studs and joists.
- In the prototypes, the experts were asked to consider mold for the “Most Likely”, “Minimum”, and “Maximum” scenarios as “Mold Possible”, “Mold Unlikely”, and “Mold Likely”, respectively.
- Mold damage was determined to be independent of water depth. Several panelists witnessed circumstances where contents and finishes on the second floor of a building were completely destroyed by mold, even though only the first floor received water. Similarly, contents and finishes on the first floor of a structure were observed to be destroyed by mold after water wicked up through the insulation in the crawl space to the finished floor.
- The panel established that the degree to which mold spread throughout a building was a function of flood duration, humidity, and the amount of time it took for people to reenter and remediate the building. The interrelationship of these three factors is complex, and some expressed an opinion that mold warranted its own DDF.
    - The impact of humidity is influenced by climate region and weather.
        - It was recognized that mold had some presence in all coastal buildings, but did usually not spread until humidity reached a critical point.
        - As humidity increases, the window of time available for remediation to be possible decreases.
        - The panel deliberated on how best to cope with the regional variation in climate. An expert panel in New Orleans determined that a foot of water coupled with 2 days no-access resulted in 90% contents damage due to mold and mildew. The same amount of water in Boston might yield a lower amount of damage.
        - Since the DDFs would be used in both the North Atlantic and the Gulf region, it was decided that a general disclaimer will be added to all prototypes to notify DDF users about the increased likelihood of mold propagation in the south.
    - Factors that affected access and remediation were identified as:
        - The level of humidity, as described above, decreases the amount of time available for remediation to be effective.
        - The ability to reach the building, which depends on the duration of the flood and the state of infrastructure (power loss, road conditions, etc.). In buildings that were elevated on piles, the loss of external staircases could lead to maximum mold, as access to the structure is limited without them. Even something as simple as opening windows was impossible if the building could not be accessed
        - The availability of supplies and equipment. For example, an air conditioning unit can help to pull moisture out of the air. But after a flooding disaster, the power grid may be down for days, making it impossible to run the unit without a generator. The demand on generators would then spike and a shortage would ensue. Those who did manage to acquire a generator would then need to contend with fuel shortages.
        - The above-described stress on resources would diminish the time available to successfully remediate mold in a building.
        - Even in low-humidity conditions, if circumstances prevent access and remediation for an extended period of time, mold damage can be severe.
- It was suggested that a general disclaimer about the impact of climate, access, and remediation on mold growth be added to all prototypes.

Prototype Categorization Approach

- Mike Cannon presented the rationale behind the "Strawman" prototype categories, explaining that the building characteristics had to be chosen based on "windshield survey" benchmarks. A windshield survey included any visual characteristics that a person could observe through the windshield of a car or from tax data, such as occupancy, construction type, height (stories), square footage, elevation, and building age.
- The panel was asked to ensure that the important physical building and storm criteria were captured in the prototypes' most likely, minimum and maximum scenarios. There was room in the agenda to add a prototype if the panel determined that the existing prototype categorization missed something important.
- Panel members discussed the variation within different building typologies and how best to handle it. Some variation could be built into minimum and maximum characteristics (for example, height above grade and MEP distribution). Other characteristics, like the presence or absence of a basement, were significant enough that the panel often felt a separate DDF was warranted. The building typology topic was revisited throughout the duration of the elicitation, as panelists considered each prototype.
- A lengthy discussion about usage type and its effect on prototype categorization took place. This conversation revolved primarily around the presence of certain SIC categories that occurred in both the Engineered and Non-engineered categories (Prototypes 2 and 3). New commercial categories were suggested for consideration:
    - Hotels - A question was posed as to whether hotels and apartments were similar, and it was determined that flood damages to hotels tended to be much higher.
    - Light Industrial/ Manufacturing
    - Health care/ Hospitals - the structure and content of hospitals could vary a lot
    - MEP complexity: A suggestion was made to categorize commercial by occupancy type and MEP. Depending on the occupancy, there could be a wide variation in the amount of MEP equipment used, and its proportion of total replacement value (10% – 40%). Prototypes could be categorized by MEP requirement and damage estimates could be approximated accordingly:
        - Low
        - Medium
        - High
        - Sophisticated
        - Sensitivity to water damage
- It was suggested that the actual location of the MEP equipment could be incorporated in the uncertainty analysis. Panelists agreed to add MEP percentages into the prototypes as needed.
- Occupancy could inform estimates about content, and can usually be determined through a windshield survey. Panelists agreed to build occupancy into the uncertainty analysis.

General Prototype Characteristics

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts. Panelists were also instructed to exclude wind damage from the prototype storm characteristics.

Storm Characteristics

Storm characteristics were presented to the experts and refined as follows:

After discussion, these characteristics were eliminated:

- Wave height
- Warning time
- Scour depth

These characteristics were added:

- Wave characteristics (breaking/non-breaking)
- Likelihood of Mold (a function of flood duration, humidity, time elapsed before reentry and access to resources).

This characteristic was modified:

- Velocity

The panel determined that the following characteristics described the Most Likely, Minimum, and Maximum prototype storm scenarios:

Prototype Storm Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Possible	Unlikely	Likely

The panel determined that flood duration, humidity, and time to reentry and access to resources affected the likelihood of mold as follows:

Flood Duration	Mold Possible 6 - 12 hours	Mold Unlikely Less than 6 Hours	Mold Likely More than 12 hours
Days Until Reentry	2 to 3	1	7 or more
Humidity Level	Moderate	Low	High

Building Characteristics

- The panel discussed erosion and calculated it as a percent of a building's footprint compromised from its waterward edge.
- Due to the fact that BeachFX reports wave damage relative to the finished floor of a structure, the panel was locked into calculating wave damage relative to the FFE
- The panel discussed the fact that a building's proximity to the shoreline was an important consideration when estimating wave damage and suggested that users be notified that wave DDFs were only to be used for buildings that would be exposed to waves.

Prototype Refinement and Discussions

Prototype 1: Apartments

Prototype 1: Apartments was presented and refined.

The prototype was initially subdivided into two categories:
- Prototype 1A: Apartments – No Basement
- Prototype 1B: Apartments – With Basement

During the discussion for this prototype, it was further subdivided:
- Prototype 1A-1: Apartments – 1-Story – No Basement
- Prototype 1A-3: Apartments – 3-Story – No Basement
- Prototype 1B-1: Apartments – 1-Story – With Basement
- Prototype 1B-3: Apartments – 3-Story – With Basement

Initial assumptions were revised as follows:

These characteristics were eliminated from the prototype definition because they aren't part of a normal building inventory:
- Basement Use
- Finished Floor Use
- Construction Quality
- Codes
- Dune or Seawall

These characteristics were added to the prototypes:
- Foundation
- Ceiling Height
- Height of Slab Above Grade

These characteristics were modified on the prototypes:
- Utilities
- Age (years)
- Structure

Discussion

- Due to time constraints, DDFs were only developed for:
    - 1-Story – No Basement
    - 3-Story – No Basement

  The rationale behind focusing on these two DDFs was that they could be compared to one another for the purpose of deriving the adjustment that would need to be made to a first-story estimate in order to apply it to a higher level.
- In order to keep the results comparable between the two subcategories, the panel limited the flood level to the first floor of each building. For this reason, estimates were not entered for flood heights above 8'-0", which was determined to be the typical floor-to-ceiling height for this type of structure.

- Erosion and wave damages were estimated for the 1-story prototype, to be subsequently inferred into the 3-story prototype at a later date. The wave and erosion DDF for the 3-story prototype will be developed by the study team and reviewed by a subset of the panel members.
- The panel discussed the similarity of this prototype to single-family residential structures.
- After the first round of elicitation for this prototype, the panel felt comfortable with the variation in estimates due to the fact that unknown reinforcement was a tremendous uncertainty.
- Discussion on Single-Story and Three-Story Apartments with Basements was deferred and a DDF was not completed.

Prototype 1A-1: Apartments – 1 Story – No Basement

Most Likely Building Characteristics
The prototype building is of unreinforced masonry construction on a slab foundation. It is one story. Utilities are located on the first floor. Ceiling height is 8’-0”. Age range is between 15 and 30 years old. The FFE is 1’-0” above grade.

Minimum-Damage Building Characteristics
The prototype building is a newer building of steel or reinforced concrete construction on a slab foundation. It is one story. Utilities may be protected. The first floor elevation is 2’-0” above grade.

Higher-Damage Building Characteristics
The prototype building is an older building of wood frame or unreinforced masonry construction that is elevated above grade on a crawl space.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Foundation	Slab	Slab	Crawl Space
Utilities	1st floor	May be protected	
Age (years)	15 - 30	Newer	Older
Ceiling Height	8'-0"	8'-0"	8'-0"
Structure	Unreinforced masonry	Steel/ Reinforced concrete	Wood frame/ unreinforced masonry
Height of Finished Floor Above Grade	1'-0"	2'-0"	0'-0"

Prototype 1A-3: Apartments – 3 Stories – No Basement

Most Likely Building Characteristics
The prototype building is of unreinforced masonry construction on a slab foundation. It has three stories. Utilities are located on the first floor. Ceiling height is 8’-0”. Age range is between 15 and 30 years old. The finished floor is 1’-0” above grade.

Minimum-Damage Building Characteristics
The prototype building is a newer building of steel or reinforced concrete construction on a slab foundation. It has three stories. Utilities may be protected. The finished floor is 2’-0” above grade.

Higher-Damage Building Characteristics
The prototype building is an older building of wood frame or unreinforced masonry construction that is elevated above grade on a crawl space. It has three stories.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	3	3	3
Foundation	Slab	Slab	Crawl Space
Utilities	1st floor	May be protected	
Age (years)	15 - 30	Newer	Older
Ceiling Height	8'-0"	8'-0"	8'-0"
Structure	Unreinforced masonry	Steel/ Reinforced concrete	Wood frame/ unreinforced masonry
Height of Finished Floor Above Grade	1'-0"	2'-0"	0'-0"

Prototype 2: Commercial – Engineered

Prototype 2 was presented and refined.

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:

- Age (years)
- Basement Use
- Construction Quality
- Codes
- Dune or Seawall
- Lobby Layout
- Backwater Valve
- MEP

This characteristic was added:

- Foundation

These characteristics were modified:

- Stories
- Utilities
- Structure

Discussion

- Large, high-acreage structures such as ports were to be excluded from the commercial category because these must be interviewed individually.
- The panelists considered the variation in content between different types of commercial enterprises and built it into the uncertainty of their estimates based on their own experience.
- Panelists decided to consider this prototype in two separate configurations: with basement and without basement. All of the “without basement” scenarios (minimum-damage, maximum-damage, and most likely) were determined to be built on slabs. Discussion of the “with basement” prototype was deferred and DDFs were not completed for it.

Prototype 2: Commercial – Engineered

Most Likely Building Characteristics
The building has a steel frame with precast infill.

Minimum-Damage Building Characteristics
The building has a reinforced concrete frame.

Higher-Damage Building Characteristics
The building has a steel frame with light cladding.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	2	2	2
Foundation	Slab	Slab	Slab
Structure	Steel frame; precast infill	Reinforced concrete	Steel frame with light cladding
Cladding		Concrete Panels	Light cladding
Height of Finished Floor Above Grade	0’-0”	0’-0”	0’-0”

Prototype 3: Commercial – Non/Pre-engineered

Prototype 3 was presented and refined. The name was modified for clarity.

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:
- Utilities
- Age (years)
- Construction Quality
- Codes
- Dune or Seawall

These characteristics were added:
- Stories
- Foundation
- Height of Slab Above Grade

This characteristic was modified:
- Structure

Discussion
- A question was raised as to the appropriateness of the term "Non-Engineered," as certain structures in this group were pre-engineered. The term "Marginally Engineered" came into play, but ultimately this prototype was referred to as Non/Pre-Engineered.
- A one-story, high bay structure was determined to be the most likely building type for this prototype, but it could also include wood- or steel-frame buildings, as well as masonry construction.

The panel provided damage estimates. Preliminary damage tables for Prototype 3 are attached.

Prototype 3: Commercial – Non-Pre-engineered

Most Likely Building Characteristics
The building has a steel or light metal frame and a slab foundation. The finished floor is 1’-0” above grade.

Minimum-Damage Building Characteristics
The building has a steel frame with masonry infill, and a slab foundation. The finished floor is 1’-0” above grade.

Higher-Damage Building Characteristics
The building has a wood or light metal frame and is elevated above grade on a crawl space. The finished floor is 3’-0” above grade.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Foundation	Slab	Slab	Crawl space
Structure	Steel or light metal	Steel with masonry infill	Wood frame or light metal
Height of Finished Floor Above Grade	1’-0”	1’-0”	3’-0”

Prototype 4: High Rise structures

Prototype 4 was presented and refined.

The prototype was divided into two categories:
- Prototype 4A: Urban High Rise
- Prototype 4B: Beach High Rise

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:
- Construction Quality
- Codes
- Dune or Seawall
- Backwater Valve
- Interior Construction

In addition, this characteristic was eliminated from 4B- Beach High Rise:
- Basement

These characteristics were modified on both new prototypes:
- Stories
- Age (years)
- 1st Floor Use
- Elevators/MEP

These characteristics were modified on 4A- Urban High Rise:
- Basement

Discussion
- High rise structures presented some unique challenges due to the comparatively high value of the buildings, the wide range of stories possible, and the various elevator/MEP configurations. Site also played a major role in the configuration and use of the lower level(s) of high rise structures, and the forces that they were exposed to.
- The panel encountered a quandary due to the fact that high rise buildings have numerous stories above the flood level.
  - Total damage was calculated as a percent of total building value and, in any structure, each story represented a percent of the total structure and total contents. As the number of stories in a building increased, each story represented a smaller proportion of the building’s total value. As a result, the impact of the damage to lower levels on the entire building would not translate effectively beyond a certain number of stories.
  - In order to keep the damage estimates meaningful across a variety of building heights, the panel opted to limit the prototype building to 10 stories. The stipulation would be that when users value a high rise, they

    will calculate the damage as a percent of the first 10 stories of that building.
  - Due to the high value of high rise buildings, panelists chose to increase the precision of their estimates to a single decimal point.
- Based on experience, panel members estimated that the total value of all MEP equipment in a high rise building ranged from 35% – 50% of the total value of the building. MEP included elevators, escalators, and conveyance. The panel agreed that total MEP equipment would represent 40% of total building value in the most likely scenario, 35% of total building value in the minimum damage scenario, and 50% of total building value in the maximum damage scenario. The distribution of the MEP equipment throughout the building, and which proportion of it is vulnerable to flooding, would be up to each individual panelist to decide based on their personal experience.
- A concern was raised that while the high rise prototype adequately addressed the high rise structures in urban settings, it neglected to capture important characteristics unique to beachfront settings. These characteristics included a lack of basement levels, an unsupported slab-on-grade condition at the lowest (grade) level, the presence of living areas at grade, and exposure to waves and erosion. In order to capture the site-specific characteristics of high rise structures, the panel decided to subdivide the prototype into two subcategories: Prototype 4A: Urban High Rise, and Prototype 4B: Beach High Rise. All three damage mechanisms (Inundation, Wave, and Erosion) would be applied to the Beach High Rise, but only Inundation would be applied to the Urban High Rise. For the Beach High Rise, the first floor was defined as the lowest level in the structure, typically at street level, and not the beach-access level (which is typically a level up).
- During the discussion after the tallies, the following concerns were raised:
  - Medians may = 0, even though some estimates indicated that there was damage to the 1st floor.
  - Situations where there is a small % of damage may be more significant than they appear, due to the overall value of the building
  - Some concern was expressed over establishing a default understanding about the specific level at which the carpet gets wet. Is it 0’-0”, or 0’-1”?
  - The panel recognized that buildings having more than 3 stories but less than 10 stories weren’t directly represented in the current prototypes. However, it was determined that Prototype 1 or Prototype 4 could be used to represent these buildings depending on foundation type. The panel determined that a caveat needed to be put in place to ensure that users of the damage functions chose the appropriate DDF.
    - For buildings with shallow foundations, users would be instructed to use the Prototype 1 DDF.
    - For buildings with deep foundations, users would be instructed to use the Prototype 4 DDF.
- Following the tallies, a presentation of damages incurred by beach high rises during Hurricane Ivan was presented to the panelists.

The panel provided damage estimates. Preliminary damage tables for Prototype 4A and 4B are attached.

Prototype 4A: Urban High Rise

Most Likely Building Characteristics

The building is between 15 and 30 years old, and has a full basement with parking and Mechanical/Electrical/Plumbing (MEP) equipment. The first (ground) level has an open lobby layout with limited finishing. Upper levels are apartments. MEP equipment constitutes 40% of the building's total value.

Minimum-Damage Building Characteristics

The building is between 0 and 10 years old, with minimal MEP equipment in the basement. The first (ground) level has an open lobby layout with limited finishing. Upper levels are apartments. MEP equipment constitutes 35% of the building's total value.

Higher-Damage Building Characteristics

The building is older. It has multiple basements with extensive Mechanical/Electrical/Plumbing (MEP) equipment. The first (ground) level houses retail establishments. Upper levels are apartments. MEP equipment constitutes 50% of the building's total value.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	10	10	10
Foundation	Deep	Deep	Deep
Age	15 - 30	0 – 10	Old—unknown codes
Structure	Structural steel or reinforced concrete	Structural steel or reinforced concrete	Structural steel or reinforced concrete
Basement	Full basement with MEP and parking	Minimal MEP	Multiple basements, MEP+
1st Floor Use	Lobby	Open lobby	Retail
Upper Floor Use	Apartments	Apartments	Apartments
Elevators/MEP	40% of total value	35% of total value	50% of total value

Prototype 4B: Beach High Rise

Most Likely Building Characteristics
The building is between 15 and 30 years old. The first (ground) level is a mix of apartments and parking space, and also houses some of the building's MEP equipment. Upper levels are apartments.

Minimum-Damage Building Characteristics
The building is between 0 and 10 years old. The first (ground) level is used for parking only. No MEP equipment is housed on the lower level. Upper levels are apartments.

Higher-Damage Building Characteristics
The building is older. The first (ground) level houses living space, and all of the building's MEP equipment. Upper levels are apartments.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	10	10	10
Foundation	Deep	Deep	Deep
Age	15 - 30	0 – 10	Old—unknown codes
Structure	Structural steel or reinforced concrete	Structural steel or reinforced concrete	Structural steel or reinforced concrete
1st Floor Use	Mix of parking and apartments	Parking	Living area
Upper Floor Use	Apartments	Apartments	Apartments
Elevators/MEP	Partial lower level	None on lower level	Lower level

Prototype 5: Residence without Basement

Prototype 5A: Single-Story Residence, No Basement

Prototype 5A was presented and refined.

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:

- Utilities
- Construction Quality
- Codes
- Dune or Seawall

These characteristics were added:

- Height of Floor Above Grade

These characteristics were modified:

- Foundation
- Age (years)
- Structure

Discussion

- The panel discussed whether Prototype 5A was actually the same as Prototype 1A- Apartment No Basement.
  - A number of the panelists agreed that the value of the structure, excluding MEP and interior finishes, was the same for both prototypes. Based on these similarities, some felt that the two prototypes should be merged.
  - Others felt that the distinction between the two prototypes needed to be preserved, as the contribution of structure and foundation to each prototype as a whole varied:
    - Apartments and condos tended to have more contents and interior partitions per square foot of exterior structure and foundation than single-family residences.
    - In addition, MEP constituted about 30% of the total value of a multi-unit apartment building, whereas it constituted approximately 19% of the total value of a single family home.
  - A point was raised that the differences in MEP value between apartments and single family residences could be offset by the value of the interior finishes in both, which tended to be more expensive in single family homes, and that the two prototypes could therefore still be considered analogous.
- The final decision was that the Prototype 5A DDFs were necessary, because they would be used the most. Panelists could use the same assumptions that they made for Prototype 1A if they felt the assumptions applied.
- Discussion about the prototype conditions ensued.

- Wood frame would be the most likely and maximum conditions, whereas reinforced masonry would be the low damage condition.
- Reinforced masonry was chosen over unreinforced masonry due to the fact that the age of the minimum damage building was less than 10 years.
- It was acknowledged that HAZUS did not make much distinction between wood and masonry where inundation damage was concerned, but there was some consensus that the two structural systems would behave differently when hit by waves or undermined by erosion.
- Although current codes prevented many new slab-homes (0 - 10 yrs. of age) from being built inside of the 400 year flood plain, panelists were instructed to consider the effects of rising sea level on these homes over the next 50 years.
- It was determined that the height of the max-damage crawlspace would be 3’-0” above grade.
- Proximity to shoreline was identified as an important circumstance for wave and erosion damage. Maximum damage occurred to buildings that were in close proximity to the shoreline, while those farther away suffered minimal damage. Rather than introduce these as maximum and minimum scenarios, the panel opted to specify that wave and erosion DDFs are only to be used for structures that are close to the shoreline.
- Some concern was expressed that the reach of waves varied by region. For example, in North Carolina waves penetrated to the 7th row of houses, because the homes were typically on piles. In New Jersey, heavy foundations prevented infiltration to that extent.

The panel provided damage estimates. Preliminary damage tables for Prototype 5A are attached.

Prototype 5A: Single-Story Residence, No Basement

Most Likely Building Characteristics
The prototype building is of wood frame construction. It is 15 to 30 years old, and is in fair to good condition. The building is on a slab. The finished floor is 1'-0" above grade.

Minimum-Damage Building Characteristics
The prototype building is of masonry construction that is reinforced per code. It is 0 to 10 years old, and is in good condition. The building is on a slab. The finished floor is at grade level.

Higher-Damage Building Characteristics
The prototype building is of wood frame construction. It is older, and in poor condition. It is not known if the building was built to code. The building is elevated above grade on a crawl space. The finished floor is 3'-0" above grade.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Foundation	Slab	Slab	Crawl Space
Age	15 - 30	0 – 10	Old—unknown codes
Structure	Wood frame	Masonry, reinforced per code	Wood frame
Height of Finished Floor Above Grade	1'-0"	0'-0"	3'-0"
Condition	Fair/Good	Good	Poor

Prototype 5B: Two-Story Residence, No Basement

Prototype 5B was presented and refined.

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:
- Utilities
- Construction Quality
- Codes
- Dune or Seawall

These characteristics were added:
- Height of Floor Above Grade

These characteristics were modified:
- Foundation
- Age (years)

Discussion

- Most of the assumptions used for Prototype 5A were also used for Prototype 5B. The major differences were that Prototype 5B was a two story structure and that, as such, it was more likely to be built on a crawl space than a slab.
    - The panel determined that the maximum-damage height of floor above grade would be 4’-0” based on the following rationale:
        - 4’0” of crawlspace will be fully inundated before flood depth reaches 0’-0” relative to the first floor, causing the waves to hit higher on the structure
        - More things may be stored in the crawl space
    - A 3’-0” height of floor above grade was determined to be the most likely scenario
    - A 1’-0” height of floor above grade was deemed to be the minimum-damage scenario
- Panel assumed that MEP equipment was located on the first floor and distributed up, but noted that furnaces in older houses were sometimes located in the crawlspace.
- Due to a limitation in the spreadsheets, panelists were instructed to add a note if they believed that there could be damages below -2’-0”

- During the discussion after the tallies:
    - For inundation damage, the panel deliberated on the impact of first floor structural damage on second floor structural damage. Some felt that 100% damage to the first floor would indicate 100% damage to the second floor; however, 100% structural damage did not necessarily mean that the building pancaked. The building could still be standing; it just might not be fit for living.
    - A question was raised about why some panelists estimated less than 100% contents damage when their estimates showed 100% structural

damage. The explanation was that the building might still be standing and the 2nd floor contents might be salvageable.

  - For wave damage, the panel again deliberated on the impact of first floor structural damage on second floor structural damage. In this case, it was determined that waves would destroy load bearing walls. Also, if an outside wall on the first floor was lost, the same wall was probably also lost on the second floor

The panel provided damage estimates. Preliminary damage tables for Prototype 5B are attached.

Prototype 5B: Two-Story Residence, No Basement

Most Likely Building Characteristics
The prototype building is of wood frame construction. It is 15 to 30 years old, and is in fair to good condition. The building is elevated above grade on a crawl space. The finished floor is 3’-0” above grade.

Minimum-Damage Building Characteristics
The prototype building is of masonry construction. It is 0 to 10 years old, and is in good condition. The building is on a slab. The finished floor is 1’-0” above grade.

Higher-Damage Building Characteristics
The prototype building is of wood frame construction. It is older, and in poor condition. It is not known if the building was built to code. The building is elevated above grade on a crawl space. The finished floor is 4’-0” above grade.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	2	2	2
Foundation	Crawl space	Slab	Crawl space
Age	15 – 30	0 – 10	Old—unknown codes
Structure	Wood frame	Masonry	Wood Frame
Height of Finished Floor Above Grade	3’-0”	1’-0”	4’-0”
Condition	Fair/Good	Good	Poor

Prototype 6: Residence with Basement

The one- and two-story prototypes were presented and discussed simultaneously.

Prototype 6A: Single-Story Residence with Basement

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:
- Dune or Seawall

These characteristics were added:
- Foundation
- Height of Floor Above Grade

These characteristics were modified:
- Age
- Basement Use

Prototype 6B: Two-Story Residence with Basement

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:
- Utilities
- Construction Quality
- Codes
- Dune or Seawall

These characteristics were added:
- Foundation
- Height of Floor Above Grade

These characteristics were modified:
- Age
- Basement Use

Discussion
- Panelists were instructed to use their best judgment in deciding how far the land below the basement must be eroded before the building is compromised.
- Most likely condition would have elevated utilities, but washer and dryer might be in the basement.
- The panel determined that mat-like foundations, which were defined as well-built, watertight basements with thick concrete and reinforced steel, would have catastrophic failure at an earlier undermining point than non-mat-like foundations. However, the presence of mat-like foundations on residential structures was deemed to be unlikely and was not included in the assessments.

The panel provided damage estimates. Preliminary damage tables for Prototype 6A and 6B are attached.

Prototype 6A: Single-Story Residence with Basement

Most Likely Building Characteristics
The prototype building is of wood frame construction. It is 15 to 30 years old, and in fair to good condition. The basement is unfinished, used for storage, and contains various utilities. The building has a block foundation and the finished floor is 3’-0” above grade.

Minimum-Damage Building Characteristics
The prototype building is of masonry construction. It is 0 to 10 years old, and in good condition. The basement is unfinished. Utilities are elevated. The building has a reinforced concrete foundation and the finished floor is 1’-0” above grade.

Higher-Damage Building Characteristics
The prototype building is of wood frame construction. It is older, and in poor condition. It is not known if the building was built to code. The basement is finished. The building has a block foundation and the finished floor is 4’-0” above grade.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Foundation	Block	Reinforced concrete	Block
Age	15 – 30	0 – 10	Old—unknown codes
Structure	Wood frame	Masonry	Wood frame
Basement	Unfinished, storage	Unfinished	Finished
Utilities	Elevated, but washer & dryer may be in basement	Elevated	
Height of Finished Floor Above Grade	3’-0”	1’-0”	4’-0”
Condition	Fair/ Good	Good	Poor

Prototype 6B: Two-Story Residence with Basement

Most Likely Building Characteristics

The prototype building is of wood frame construction. It is 15 to 30 years old, and in fair to good condition. The basement is unfinished, used for storage, and contains various utilities. The building has a block foundation and the finished floor is 3’-0” above grade.

Minimum-Damage Building Characteristics

The prototype building is of masonry construction. It is 0 to 10 years old, and in good condition. The basement is unfinished. Utilities are elevated. The building has a reinforced concrete foundation and the finished floor is 1’-0” above grade.

Higher-Damage Building Characteristics

The prototype building is of wood frame construction. It is older, and in poor condition. It is not known if the building was built to code. The basement is finished. The building has a block foundation and the finished floor is 4’-0” above grade.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	2	2	2
Foundation	Block	Reinforced concrete	Block
Age	15 – 30	0 – 10	Old—unknown codes
Structure	Wood frame	Masonry	Wood frame
Basement	Unfinished, storage	Unfinished	Finished
Utilities	Elevated, but washer & dryer may be in basement	Elevated	
Height of Finished Floor Above Grade	3’-0”	1’-0”	4’-0”
Condition	Fair/ Good	Good	Poor

Prototype 7: Building on Pile Foundation

Prototype 7A: Building on Open Pile Foundation

Prototype 7A was presented and refined.

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:

- Structure
- Construction Quality
- Codes
- Dune or Sea Wall
- Condition
- Bracing
- Embedment Depth
- Pile Tip Elevation

These characteristics were added:

- Stories
- Height of Floor Above Grade
- Building Use (specified as residential in all cases)

These characteristics were modified:

- Utilities
- Age
- Pile Diameter
- Connection Quality

Discussion

- Panel chose to use one elevation for both enclosed and unenclosed pile structures, because all of the waves that reached these buildings would be large and depth-limited. A 9’-0” height for walking surface above grade was settled upon so that a full story could be located in the enclosure.
- Erosion was handled as follows: Rather than estimate the minimum, maximum, and most-likely damage scenarios for pile embedment depth, the panel focused on the percent of the foundation that was compromised. Percent compromised was defined as a portion of the foundation that could no longer provide the support required to keep a structure upright and intact. Based on knowledge of local construction, the user of the function would need to estimate the depth at which erosion will compromise a structure. The user must be aware of pile depth, as well as the effects of scour and liquefaction.
- The panel discussed pile diameter, helical piles, and connection quality on the integrity of pile-supported buildings. It determined that piles with a diameter of 6” or helical piles would fall into the maximum-damage scenarios, and that poor connection quality and/or connection hardware over 8 years old would contribute towards maximum damage as well.
- The panel identified external stairs and decks to be among the most vulnerable parts of an elevated structure and captured those damages in their estimates.

- The panel also considered the fact that the destruction of staircases or decks could lead to increased levels of mold, as access to the structure would be limited without them.
- Panelists were advised that although the prototype conditions are is strictly residential, the DDF will be applied to nonresidential structures as well.
- Flood-borne debris was confirmed to be a secondary issue; noise in the DDF: In an oscillating wave field, velocity would occur in both directions. Debris would rarely align with crest of a wave; some would remain in the trough. Larger debris wouldn't get up to the speed of the flow and would drag at bottom. Smaller debris could get up to speed of wave crest velocity. In Katrina, small debris collected together and acted as a floating breakwater.

Prototype 7A: Building on Open Pile Foundation

Most Likely Building Characteristics
The prototype building is 15 to 30 years old. Piles are 8” to 10” in diameter, and the connections are in fair condition. Utilities are elevated. Post-flood mold propagation is possible.

Minimum-Damage Building Characteristics
The prototype building is 0 to 10 years old. Piles are 10” to 12” in diameter, and the connections are in good condition. Utilities are elevated.

Higher-Damage Building Characteristics
The prototype building is older. It is not known if it was built to code. Piles are 6” in diameter or helical, and the connections are in poor condition. Utilities are located below the building.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Utilities	Elevated	Elevated	Below
Age	15 – 30	0 – 10	>30
Height of Finished Floor Above Grade	9’-0”	9’-0”	9’-0”
Building Use	Residential	Residential	Residential
Pile Diameter	8” – 10”	10” – 12”	6” or helical
Connection Condition	Fair	Good	Poor

Prototype 7B: Building on Pile Foundation with Enclosures

Prototype 7B was presented and refined.

Initial assumptions were revised as follows:

These characteristics were not considered to be a factor in the damage analysis:

- Structure
- Construction Quality
- Codes
- Dune or Seawall
- Condition
- Bracing
- Embedment Depth
- Pile Tip Elevation

These characteristics were added:

- Stories
- Height of Floor Above Grade
- Building Use (specified as residential in all cases)

These characteristics were modified:

- Utilities
- Age
- Pile Diameter
- Connection Quality
- Enclosure Wall
- Enclosure Use

Discussion

- For enclosed structures, the panel adopted all of the same assumptions that were developed for the non-enclosed structures. The following assumptions were added:
    - Enclosure Use
    - Enclosure Wall Construction Type
- The panel assumed that the cost of the enclosure construction was generally cheap and that the contents would constitute most of the damage cost.
- The Most Likely Enclosure Wall Construction Type was defined as “Will Break,” meaning that, when hit by a wave, all of the normal nail and screw connections in a regularly-constructed wall will fail without transferring the failure load into the foundation. The difference is that non-breakaway walls may pull elements that they are bolted to from above along with them.

The panel provided damage estimates. Preliminary damage tables for Prototype 7A and 7B are attached.

Prototype 7B: Building on Pile Foundation with Enclosures

Most Likely Building Characteristics

The prototype building is 15 to 30 years old. The enclosure walls are not “break-away” walls, but they will break under some flooding circumstances. The enclosed space is used for parking, storage and access to utilities, which are located below the building. Piles are 8” to 10” in diameter, and the connections are in fair condition.

Minimum-Damage Building Characteristics

The prototype building is 0 to 10 years old. The enclosure walls are of “break- away” construction. The enclosed space is used for access to the building, and for parking. Piles are 10” to 12” in diameter, and the connections are in good condition. Utilities are elevated.

Higher-Damage Building Characteristics

The prototype building is older. It is not known if it was built to code. The enclosure walls are not “break-away” walls, and may not break at all under flooding circumstances. The enclosed space is used as living space. Piles are 6” in diameter or helical, and the connections are in poor condition. Utilities are located below the building.

Prototype Building Characteristics

	Most Likely	Minimum Damage	Maximum Damage
Stories	1	1	1
Utilities	Below	Elevated	Below
Age	15 – 30	0 – 10	>30
Height of Finished Floor Above Grade	9’-0”	9’-0”	9’-0”
Building Use	Residential	Residential	Residential
Pile Diameter	8” – 10”	10” – 12”	6” or helical
Connection Condition	Fair	Good	Poor
Enclosure Wall	Will break	Breakaway	Non-break
Enclosure Use	Parking, storage, utility access	Access and parking	Living space

Attachments

- Original Strawman Prototypes
- Table A – Prototype Revision Chart
- Detailed Agenda

BUILDING PROTOTYPE 1: APARTMENTS

The NACCS physical damage survey collected damage data and construction data for buildings impacted by Hurricane Sandy. For Prototype 1, these surveyed buildings included townhouses, condominiums and garden style apartments. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The prototype building is masonry construction, with apartments on each of its finished floors. The lower/basement level contains limited utilities, parking, and storage. Age range is between 15 and 30 years old. The building is built to older codes and has no major construction defects. Utilities are most likely elevated to prevent flood damage.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2’-0”.[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages.

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 1: APARTMENTS

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The building is structural steel or reinforced concrete construction, with apartments on each of its finished floors. There is no basement. Building is of newer construction, and is built better than or equal to current codes. Utilities are most likely elevated. The entire structure is located behind a dune or a seawall to prevent flood damage.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building is wood frame construction, with apartments on each of its three finished floors. The building has a full basement that is used for apartments. It is not built to code. Construction quality is poor and/or the building is poorly maintained. Utilities are not elevated.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 2:
COMMERCIAL STRUCTURES – ENGINEERED CONSTRUCTION

Commercial structures are split into engineered and non-engineered construction to reflect observed differences in vulnerability to storm damage.

The engineered commercial buildings are characterized by the following framing types: structural steel, reinforced concrete, masonry bearing walls, mill-type construction. The prototype structure is multiple stories and is used for office or retail. Content damages will be considered in two scenarios; one for occupancies containing non-perishable products, the second for occupancies containing perishable goods/ food products. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The building contains a partial basement/lower level which includes some utilities or parking. Age range is between 15 and 30 years old. The building is built to older codes and has no major construction defects.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2’-0”.[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages.

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 2:
COMMERCIAL STRUCTURES – ENGINEERED CONSTRUCTION

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The building has an open lobby layout with limited finishing. It does not have a basement. Utilities are elevated. Building is of newer construction, and is built better than or equal to current codes. Utilities are most likely elevated. Sewer backflow prevention devices have been installed. The entire structure may be located behind a dune or a seawall to prevent flood damage.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building is not built to code. Construction quality is poor and/or the building is poorly maintained. Utilities are not elevated. The building has a full basement with finished commercial space, such as offices, cafeteria, and/or gym. Electrical equipment and elevator machine room are located in the basement. Sewer backflow prevention devices have not been installed.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 3:
COMMERCIAL STRUCTURES – NON-ENGINEERED CONSTRUCTION

The non-engineered commercial buildings' lighter construction makes them more vulnerable to flood damage or wave impacts. These buildings are characterized by wood/steel stud-frame or metal frame and walls. The prototype building has no basement and contains retail and dining establishments. Content damages will consider two scenarios; one for occupancies containing non-perishable products, the second for occupancies containing perishable goods/ food products. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The prototype building has a steel frame and metal walls. Age range is between 15 and 30 years old. The building is built to older codes and has no major construction defects.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2'-0".[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages.

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 3:
COMMERCIAL STRUCTURES – NON-ENGINEERED CONSTRUCTION

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS
The building has a steel frame and metal walls. It is of newer construction, and is built better than or equal to current codes. Utilities are most likely elevated. The entire structure is located behind a dune or a seawall to prevent flood damage.

LOWER-DAMAGE STORM FACTORS
The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS
The building has a wood stud frame. It is not built to code. Construction quality is poor and/or the building is poorly maintained. Utilities are not elevated.

HIGHER-DAMAGE STORM FACTORS
The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 4: HIGH RISE STRUCTURES

The NACCS Survey collected data on a limited number of high rise buildings that suffered damage during Hurricane Sandy. These buildings are characterized by structural steel or reinforced concrete frames and have more than five stories. The structures are supported on deep foundations. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The basement/lower level of the prototype building contains parking and Mechanical/Electrical/Plumbing (MEP) equipment. The first (ground) level contains a lobby area with mixed commercial use. Upper levels are apartments. Age range is between 15 and 30 years old. The building is built to older codes and has no major construction defects.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2’-0”.[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages.

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 4: HIGH RISE STRUCTURES

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The building has limited basement usage. The first (ground) level has an open lobby layout with limited finishing. Upper levels are apartments. Elevator machine and control equipment are located at the top of the hoist way. Building is of newer construction, and is built better than or equal to current codes. The entire structure is located behind a dune or a seawall to prevent flood damage.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building may not be built to code. Construction quality is poor and/or the building is poorly maintained. The building may have a full basement with finished living and commercial space. All MEP equipment is located in the basement. Walls are constructed of load-bearing masonry instead structural framing. Sewer backflow prevention devices have not been installed.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 5A:
SINGLE-STORY RESIDENCES WITHOUT BASEMENTS

Residential prototypes have been divided to reflect the number of stories and the absence or presence of basements.

Prototype 5A is a one-story single-family home with no basement, approximately 1800 ft^2 in size. The vast majority of the residential structures included in the survey do not have a basement. This is typical of coastal areas that have high water tables. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The prototype building is of wood frame construction. It is 20 to 30 years old, and is in fair to good condition. It is built to older building codes and elevation requirements, and has no major construction defects. This building is at grade on a slab foundation. Utilities are most likely elevated to prevent flood damage.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2’-0”.[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 5A:
SINGLE-STORY RESIDENCES WITHOUT BASEMENTS

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The building is of masonry construction. It is of newer construction, and is built to current building codes. It is in good to excellent condition, and has no major construction defects. The building is elevated above grade on a crawl space. Utilities are most likely elevated. The entire structure may be located behind a dune or a seawall to limit wave or erosion impacts.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building is of wood frame construction. It is not built to code. Construction quality is poor and/or the building is poorly maintained. This building is at grade on a slab foundation. Utilities are not elevated.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 5B:
MULTISTORY RESIDENCES WITHOUT BASEMENTS

Prototype 5B is a two-story single-family home with a basement and a two-car garage, approximately 2400 ft^2 total. The vast majority of the residential structures included in the survey do not have a basement. This is typical of coastal areas that have high water tables. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The prototype building is of wood frame construction. It is 20 to 30 years old, and is in fair to good condition. It is built to older building codes and elevation requirements, and has no major construction defects. The building is elevated above grade on a crawl space. Utilities are most likely elevated to prevent flood damage.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2'-0".[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 5B:
MULTISTORY RESIDENCES WITHOUT BASEMENTS

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The building is of masonry construction. It is of newer construction, and is built to current building codes. It is in good to excellent condition, and has no major construction defects. The building is elevated above grade on a crawl space. Utilities are most likely elevated. The entire structure may be located behind a dune or a seawall to limit wave or erosion impacts.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building is of wood frame construction. It is not built to code. Construction quality is poor and/or the building is poorly maintained. This building is at grade on a slab foundation. Utilities are not elevated.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 6A:
SINGLE-STORY RESIDENCES WITH BASEMENTS

Residential prototypes have been divided to reflect the number of stories and the absence or presence of basements.

Prototype 5A is a one-story single-family home with no basement, approximately 1800 ft^2 in size. While the majority of the structures included in the survey do not have a basement, it is anticipated that some projects will need to evaluate the increased level of flood damage where a basement is present. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The prototype building is of wood frame construction. It is 20 to 30 years old, and is in fair to good condition. It is built to older building codes and elevation requirements, and has no major construction defects. The basement is unfinished, used for storage and contains various utilities.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2’-0”.[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 6A:
SINGLE-STORY RESIDENCES WITH BASEMENTS

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The prototype building is of masonry construction. It is of newer construction, and is built to current building codes and elevation requirements. It is in good to excellent condition, and has no major construction defects. The basement is unfinished and used only for storage. Utilities are most likely elevated. The entire structure may be located behind a dune or a seawall to limit wave or erosion impacts.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building is of wood frame construction. It is not built to code. Construction quality is poor and/or the building is poorly maintained. Utilities are not elevated. The basement is used as a living area.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 6B:
MULTISTORY RESIDENCES WITH BASEMENTS

Prototype 6B is a two-story single-family home with a basement and a two-car garage, approximately 2400 ft^2 total. While the majority of the structures included in the survey do not have a basement, it is anticipated that some projects will need to evaluate the increased level of flood damage where a basement is present. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The prototype building is of wood frame construction. It is 20 to 30 years old, and is in fair to good condition. It is built to older building codes and elevation requirements, and has no major construction defects. The basement is unfinished, used for storage and contains various utilities.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2’-0”.[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 6B:
MULTISTORY RESIDENCES WITH BASEMENTS

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The prototype building is of masonry construction. It is of newer construction, and is built to current building codes. It is in good to excellent condition, and has no major construction defects. The basement is unfinished and used only for storage. Utilities are most likely elevated. The entire structure may be located behind a dune or a seawall to limit wave or erosion impacts.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building is of wood frame construction. It is not built to code. Construction quality is poor and/or the building is poorly maintained. Utilities are not elevated. The basement is used as a living area.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 7A: PILE FOUNDATION – OPEN

These buildings are usually single-family homes elevated on 8” to 10” diameter wood piles. The prototype structures may be one level or more, with the main living area on uppermost floor. The buildings utilities are elevated and there is no enclosed space below the building. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The prototype building is of wood construction. It is 20 to 30 years old, and is in fair to good condition. It is built to older building codes and elevation requirements, and has no major construction defects. Piles are 8” to 10” in diameter with any bracing oriented perpendicular to shore. Pile embedment depth is 10’ – 15’ and pile tip elevation is -5’.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2’-0”.[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 7A: PILE FOUNDATION – OPEN

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The building is of wood frame construction. It is newer construction, and is built to current building codes and elevation requirements. It is in good to excellent condition, and has no major construction defects. Utilities are elevated. Piles are 10” to 12” in diameter with bracing oriented perpendicular to shore. The entire structure may be located behind a dune or a seawall to limit wave or erosion impacts.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building is of wood frame construction. It may not conform to code. Construction quality is poor and/or the building is poorly maintained. Utilities are not elevated. Piles are 6” to 8” in diameter with no bracing, or with bracing oriented parallel to shore. Poor beam-to-pile connections.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

BUILDING PROTOTYPE 7B: PILE FOUNDATION – WITH ENCLOSURE

These buildings are usually single-family homes elevated on 8” to 10” diameter wood piles. The prototype structures may be one level or more, with the main living area on uppermost floor. The space below the building is fully or partially enclosed. The base prototype includes what are considered to be the most likely storm and building conditions.

MOST LIKELY CONDITIONS[1]

BUILDING CHARACTERISTICS

The prototype building is of wood frame construction. It is 20 to 30 years old, and is in fair to good condition. It is built to older building codes and elevation requirements, and has no major construction defects. The space below the building partially enclosed with “breakaway” walls, but unfinished. The enclosed space is used for parking, storage and utilities. Construction is in accordance with older codes of 15 to 30 years ago. Piles are 8” to 10” in diameter with any bracing oriented perpendicular to shore. Pile embedment depth is 10’ – 15’ and pile tip elevation is -5’.

STORM CHARACTERISTICS

The prototype storm flood has a moderate rate of rise and velocity (1-3 fps),[2] with wave heights at approximately 78% of standing water depth.[3] Humidity is moderate. Residents have been warned (2 – 3 days) in advance of the storm. The flood duration is typically 6 – 12 hours. Scour depth is moderate: less than 2’-0”.[4] Residents are not able to reenter the buildings until 2 – 3 days after the storm.

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[1] It is recognized that damage estimates are subject to some variance due to differences between storm events and characteristics of individual buildings. This is a limitation of developing a limited number of damage curves to represent a multitude of possible conditions. The benefits of refining the estimates to reflect greater detail in the building or storm characteristics are limited by the lack of detailed knowledge available during typical feasibility studies to refine the application of the damages

[2] Moderate Velocity is in reference to flood characteristics, not to wave effects.

[3] Wave damages for this prototype are anticipated to be reported as % damage vs. wave height. Wave Conditions are for use in wave damage relationships only. Structures may be subject to various depths of flooding with different wave heights. Typically wave heights are limited to about 78% of the still water depth before breaking. In some cases high ground or obstructions seaward of the structure will reduce wave heights relative to the still water depth. In other cases the actual wave heights may be greater than 78% of the depth.

[4] The presence of high dunes (not overtopped excessively), bluffs or cohesive soils typically may limit local scour contributing to general erosion. Storm erosion of lower beach profiles results in both a general lowering of the grades and additional scour at the foundation.

BUILDING PROTOTYPE 7B: PILE FOUNDATION – WITH ENCLOSURE

UNCERTAINTY CONSIDERATIONS

In estimating the range of damages, reasonable variations in the prototype buildings and storm should be considered. Not all conditions will be present in every structure. Estimates should exclude special conditions such as flood-related fires, contaminated floodwater, or large debris impacts.

Some of the factors that may result in lower damages are:

LOWER-DAMAGE BUILDING FACTORS

The building is of wood frame construction. It is of new construction, and is built to current building codes and elevation requirements. It is in good to excellent condition, and has no major construction defects. The space below the building partially enclosed with “breakaway” walls, and is used for access only. Utilities are elevated. Piles are 10” to 12” in diameter with bracing oriented perpendicular to shore. The space below the building partially enclosed. The entire structure may be located behind a dune or a seawall to limit wave or erosion impacts.

LOWER-DAMAGE STORM FACTORS

The storm flood has a slow rate of rise and velocity (0-1 fps), with waves heights limited to less than 78% of standing water depth. Humidity is low. Residents received warning more than 3 days before the storm. The flood duration is less than 6 hours. There is no scour. Residents are able to reenter the buildings within a day after the storm.

Some of the factors that may result in higher damages are:

HIGHER-DAMAGE BUILDING FACTORS

The building is of wood frame construction. It may not conform to code. Construction quality is poor and/or the building is poorly maintained. A large portion of the space below the building is partially enclosed with permanent walls, and is inhabited space. Utilities are not elevated. Piles are 6” to 8” in diameter with no bracing, or with bracing oriented parallel to shore. Poor beam-to-pile connections.

HIGHER-DAMAGE STORM FACTORS

The storm flood has a rapid rate of rise and high velocity (>3 fps), with waves heights greater than 78% of standing water depth. Humidity is high. Residents received warning less than 2 days before the storm. The flood duration is more than 12 hours. Scour depth is greater than 2’-0”. Residents are unable to reenter the buildings for more than a week after the storm.

ORIGINAL

Prototype 1: Apartment

	Most Likely	Minimum	Maximum
Stories			3
Utilities	Elevated	Elevated	Not elevated
Age (years)	15-30	Newer construction	
Structure	Masonry	Structural steel or reinforced concrete	Wood Frame
Basement Use	Limited utilities, parking, storage	No basement	Apartments
Finished Floor Use	Apartments	Apartments	Apartments
Construction Quality	No major defects	Meets or exceeds code	Poor construction/ poor maintenance
Codes	Older	Current codes	Does not meet code standards
Dune or Seawall	No	Yes	No

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

NEW

Prototype 1A-1: Apartment - 1 Story - No Basement

	Most Likely	Minimum	Maximum
Stories	1	1	1
Foundation	Slab	Slab	Crawl Space
Utilities	1st floor	May be protected	
Age (years)	15 - 30	Newer	Older
Ceiling Height	8'-0"	8'-0"	8'-0"
Structure	Unreinforced masonry	Steel/ Reinforced concrete	Wood frame/ unreinforced masonry
Height of Slab Above Grade	1'-0"	2'-0"	0'-0"
Height of Wall Above Grade	2'-0"	3'-0"	1'-0"

Prototype 1A-3: Apartment - 3 Story - No Basement

	Most Likely	Minimum	Maximum
Stories	3	3	3
Foundation	Slab	Slab	Crawl Space
Utilities	1st floor	May be protected	
Age (years)	15 - 30	Newer	Older
Ceiling Height	8'-0"	8'-0"	8'-0"
Structure	Unreinforced masonry	Steel/ Reinforced concrete	Wood frame/ unreinforced masonry
Height of Slab Above Grade	1'-0"	2'-0"	0'-0"
Height of Wall Above Grade	2'-0"	3'-0"	1'-0"

Storm Characteristics

	Most Likely	Minimum	Maximum
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Possible	Unlikely	Likely

Storm Characteristics

	Most Likely	Minimum	Maximum
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Possible	Unlikely	Likely

ORIGINAL

Prototype 2: Commercial - Engineered

	Most Likely	Minimum	Maximum
Stories	Multiple	Multiple	Multiple
Utilities		Elevated	Not elevated
Age (years)	15-30	Newer construction	
Structure	Struct. steel/ reinf. concrete/ masonry	Struct. steel/ reinf. concrete/ masonry	Struct. steel/ reinf. concrete/ masonry
Basement Use	Partial basement with some utilities or parking	No basement	Finished commercial space, cafeteria, gym
Construction Quality	No major defects	Meets or exceeds code	Poor construction/ poor maintenance
Codes	Older	Current codes	Does not meet code standards
Dune or Seawall	No	Yes	No
Lobby Layout		Open, with limited finishing	
Backwater Valve	No	Yes	No
MEP			Basement (electric, elevator room)

NEW

Prototype 2: Commercial - Engineered

	Most Likely	Minimum	Maximum
Stories	2	2	2
Foundation	Slab	Slab	Slab
Utilities			basement
Structure	Steel frame precast infill	Reinforced concrete	steel frame with light cladding
Cladding		Concrete Panels	

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

Storm Characteristics

	Most Likely	Minimum	Maximum
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

ORIGINAL

Prototype 3: Commercial - Non-Engineered

	Most Likely	Minimum	Maximum
Utilities		Elevated	Not Elevated
Age (years)	15-30 years	Newer construction	
Structure	Steel frame with metal walls	Steel frame with metal walls	Wood stud frame
Construction Quality	No major defects	Meets or exceeds code	Poor construction/ poor maintenance
Codes	Older	Current codes	Does not meet code standards
Dune or Seawall	No	Yes	No

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

NEW

Prototype 3: Commercial - Pre/Non-Engineered

	Most Likely	Minimum	Maximum
Stories	1	1	1
Foundation	Slab	Slab	Crawl
Structure	Steel/ Light Metal	Steel - Masonry Infill	Wood Frame, light metal
Height of Slab Above Grade	1'-0"	1'-0"	3'-0"

Storm Characteristics

	Most Likely	Minimum	Maximum
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

ORIGINAL

Prototype 4: High Rise

	Most Likely	Minimum	Maximum
Stories	> 5	> 5	> 5
Foundation	Deep	Deep	Deep
Age (years)	15 - 30 years	Newer construction	
Structure	Structural steel or reinforced concrete	Structural steel or reinforced concrete	Structural steel or reinforced concrete
Basement Use	Parking and MEP	Limited usage	Finished living area/ commercial space
Construction Quality	No major defects	Meets or exceeds code	Poor construction/ poor maintenance
Codes	Older	Current codes	May not meet code standards
Dune or Seawall	No	Yes	No
Backwater Valve			No
Interior Construction			load-bearing masonry, not structural framing
1st Floor	Lobby with mixed commercial use	Open layout with limited finishing	
Upper Floors	Apartments	Apartments	
Elevators/MEP	Basement	Top of Hoistway	All in basement

NEW

Prototype 4A: Urban High Rise

	Most Likely	Minimum	Maximum
Stories	10	10	10
Foundation	Deep	Deep	Deep
Age (years)	15 - 30	0 - 10	Old--unknown codes
Structure	Structural steel or reinforced concrete	Structural steel or reinforced concrete	Structural steel or reinforced concrete
Basement	Full basement with MEP and Parking	Minimal MEP	Multiple, MEP+
1st Floor	Lobby	Open Lobby	Retail
Upper Floors	Apartment	Apartment	Apartment
Elevators/MEP	40%	35%	50%

Prototype 4B: Beach High Rise

	Most Likely	Minimum	Maximum
Stories	10	10	10
Foundation	Deep	Deep	Deep
Age (years)	15 - 30	0 - 10	Old--unknown codes
Structure	Structural steel or reinforced concrete	Structural steel or reinforced concrete	Structural steel or reinforced concrete
1st Floor	Mix of Parking and Apartments	Parking	Living
Upper Floors	Apartment	Apartment	Apartment
Elevators/MEP	Partial Lower Level	None	Lower Level

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

Storm Characteristics

	Most Likely	Minimum	Maximum
Mold	Mold Possible	Mold Unlikely	Mold Likely

Storm Characteristics

	Most Likely	Minimum	Maximum
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

ORIGINAL

Prototype 5A: Single Story Residence, No Basement

	Most Likely	Minimum	Maximum
Stories	1	1	1
Foundation	Slab	Crawl space	Slab on grade
Utilities	Elevated	Elevated	Not elevated
Age (years)	20-30	Newer construction	
Structure	Wood frame	Masonry	Wood frame
Construction Quality	No major defects	No major defects	Poor construction
Codes	Older	Current codes	Does not meet code standards
Dune or Seawall	No	Yes	No
Condition	Fair to good	Good to excellent	Poor maintenance

NEW

Prototype 5A: Single Story Residence, No Basement

	Most Likely	Minimum	Maximum
Stories	1	1	1
Foundation	Slab	Slab	Crawl Space
Age (years)	15 - 30	0 - 10	Old--unknown codes
Structure	Wood Frame	Masonry - Reinforced per code	Wood Frame
Height of Floor Above Grade	1	0	3
Condition	Fair/Good	Good	Poor

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

Storm Characteristics

	Most Likely	Minimum	Maximum
Velocity	Low	< 1	> 3
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

ORIGINAL

Prototype 5B: Two Story Residence, No Basement

	Most Likely	Minimum	Maximum
Stories	2	2	2
Foundation	Crawl space	Crawl space	Slab on grade
Utilities	Elevated	Elevated	Not elevated
Age (years)	20-30	Newer construction	
Structure	Wood frame	Masonry	Wood frame
Construction Quality	No major defects	No major defects	Poor construction
Codes	Older	Current codes	Does not meet code standards
Dune or Seawall	No	Yes	No
Condition	Fair to good	Good to excellent	Poor maintenance

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

NEW

Prototype 5B: Two Story Residence, No Basement

	Most Likely	Minimum	Maximum
Stories	2	2	2
Foundation	Crawl Space	Slab	Crawl Space
Age (years)	15 - 30	0 - 10	Old--unknown codes
Structure	Wood Frame	Masonry	Wood Frame
Height of Floor Above Grade	3	1	4
Condition	Fair/Good	Good	Poor

Storm Characteristics

	Most Likely	Minimum	Maximum
Velocity	Low	< 1	> 3
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

ORIGINAL

Prototype 6A: Single Story Residence, With Basement

	Most Likely	Minimum	Maximum
Stories	1	1	1
Utilities		Elevated	Not elevated
Age (years)	20-30	Newer Construction	
Structure	Wood Frame	Masonry	Wood frame
Basement Use	Unfinished, used for storage & utilities	Unfinished, used for storage only	Used as a living area
Dune or Seawall	No	Yes	No
Condition	Fair to good	Good to excellent	Poorly maintained

NEW

Prototype 6A: Single Story Residence, With Basement

	Most Likely	Minimum	Maximum
Stories	1	1	1
Foundation	Block	Reinforced Concrete	Block
Age (years)	15 - 30	0 - 10	Old--unknown codes
Structure	Wood Frame	Masonry	Wood Frame
Basement	Unfinished (storage & utilities)	Unfinished (elevated utilities)	Finished
Height of Floor Above Grade	3	1	4
Condition	Fair/ Good	Good	Poor

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

Storm Characteristics

	Most Likely	Minimum	Maximum
Velocity	Low	< 1	> 3
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

ORIGINAL

Prototype 6B: Two Story Residence, With Basement

	Most Likely	Minimum	Maximum
Stories	2	2	2
Utilities		Elevated	Not elevated
Age (years)	20 - 30	Newer construction	
Structure	Wood frame	Masonry	Wood frame
Basement Use	Unfinished, used for storage & utilities	Unfinished, used for storage only	Used as a living area
Construction Quality	No major defects	No major defects	Poor construction
Codes	Older	Current codes	Does not meet code standards
Dune or Seawall	No	Yes	No
Condition	Fair to good	Good to excellent	Poor construction

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

NEW

Prototype 6B: Two Story Residence, With Basement

	Most Likely	Minimum	Maximum
Stories	2	2	2
Foundation	Block	Reinforced Concrete	Block
Age (years)	15 - 30	0 - 10	Old--unknown codes
Structure	Wood Frame	Masonry	Wood Frame
Basement	Unfinished (storage & utilities)	Unfinished (elevated utilities)	Finished
Height of Floor Above Grade	3	1	4
Condition	Fair/ Good	Good	Poor

Storm Characteristics

	Most Likely	Minimum	Maximum
Velocity	Low	< 1	> 3
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

ORIGINAL

Prototype 7A: Building With Open Pile Foundation

	Most Likely	Minimum	Maximum
Utilities		Elevated	Not elevated
Age (years)	20-30	Newer construction	
Structure	Wood frame	Wood frame	Wood frame
Construction Quality	No major defects	No major defects	Poor construction
Codes	Older	Current codes	May not meet code standards
Dune or Seawall	No	Yes	No
Condition	Fair to good	Good to excellent	Poor
Pile Diameter	8" - 10"	10" - 12"	6" - 8"
Bracing	Perpendicular to shore	Perpendicular to shore	nonexistent or parallel to shore
Embedment Depth	10' - 15'		
Pile Tip Elevation	5'-0"		
Connection Condition			Poor

NEW

Prototype 7A: Building With Open Pile Foundation

	Most Likely	Minimum	Maximum
Stories	1	1	1
MEP	Elevated	Elevated	Below
Age (years)	15 - 30	0 - 10	Old--unknown codes
Height of Floor Above Grade	9'-0"	9'-0"	9'-0"
Building Use	Residential	Residential	Residential
Pile Diameter	8" - 10"	10" - 12"	6" or helical
Connection Condition	Fair	Good	Poor

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

Storm Characteristics

	Most Likely	Minimum	Maximum
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

ORIGINAL

Prototype 7B: Building With Enclosed Pile Foundation

	Most Likely	Minimum	Maximum
Utilities		Elevated	Not elevated
Age (years)	20-30	Newer construction	
Structure	Wood frame	Wood frame	Wood frame
Construction Quality	No major defects	No major defects	Poor construction
Codes	Older	Current codes	May not meet code standards
Dune or Seawall	No	Yes	No
Condition	Fair to good	Good to excellent	Poor
Pile Diameter	8" - 10"	10" - 12"	6" - 8"
Bracing	Perpendicular to shore	Perpendicular to shore	nonexistent or parallel to shore
Embedment Depth	10' - 15'		
Pile Tip Elevation	5'-0"		
Connection Condition			Poor
Enclosure	Partial, unfinished, with breakaway walls	Partial, unfinished, with breakaway walls	Large portion used for living space, permanent
Enclosure use	Parking, storage, utilities	Access only	

NEW

Prototype 7B: Building With Enclosed Pile Foundation

	Most Likely	Minimum	Maximum
Stories	1	1	1
MEP	Below	Elevated	Below
Age (years)	15 - 30	0 - 10	Old--unknown codes
Height of Floor Above Grade	9'-0"	9'-0"	9'-0"
Building Use	Residential	Residential	Residential
Pile Diameter	8" - 10"	10" - 12"	6" or helical
Connection Condition	Fair	Good	Poor
Enclosure Wall	Will break	Breakaway	Non Break
Enclosure Use	Parking, storage, utility access	Access and parking	Living space

Storm Characteristics

	Most Likely	Minimum	Maximum
Rate of Rise and Velocity	Moderate; 1-3 fps	Slow; 0-1 fps	Rapid/High; >3fps
Wave Heights	78% of standing water depth	< 78% of standing water depth	>78% of standing water depth
Humidity	Moderate	Low	High
Flood Duration	6 - 12 hours	< 6 hours	> 12 hours
Time Until Reentry	2 - 3 days	1 day	> 7 days
Warning	2 - 3 days in advance	> 3 days in advance	< 2 days in advance
Scour Depth	< 2'-0"	None	> 2'-0"

Storm Characteristics

	Most Likely	Minimum	Maximum
Wave Characteristics	Breaking	Non-Breaking	Breaking
Mold	Mold Possible	Mold Unlikely	Mold Likely

USACE North Atlantic Coast Comprehensive Study (NACCS)
Depth Damage Function Study
Expert Elicitation Panel
April 22-24, 2014

APRIL 22, 2014 (DAY 1) - MORNING SESSION (9:00 am - 12:00 pm)			
TOPIC	**DETAILS**	**TIME**	**LEAD**
Continental Breakfast	**(Coffee and light breakfast provided)**	**8:30 am - 9:00 am**	
Welcome and Introductions		**9:00 am - 9:30 am**	
- Welcome	Provide an overview of Panel expectations and outcomes		USACE - Naomi Fraenkel
- Office Orientation/Safety Briefing	Discuss office logistics, what to do in event of emergency		URS - Mike Cannon
- Introduction of NACCS Team	Round-Robin of key USACE and Contractor team members		URS - Ann/All Participants
- NACCS Study Overview	Provide an overview of NACCS Study, accomplishments to date, how results will be utilized in future efforts		USACE - Naomi Fraenkel
- Ongoing Efforts			USACE - Naomi Fraenkel
- Intended Outcomes and Use of Results			USACE - Stuart Davis
- Introduction of DDF Expert Panel Members	Round-robin of Panel member introductions		URS - Ann/All Participants
- Review Agenda	High level review of agenda; identify additional topics to meet Panel		URS - Ann Terranova
Panel Orientation		**9:30 am - 10:30 am**	
- How the Meeting will be Conducted	Review process, ensure Panel member understanding, respond to questions		URS - Jason Weiss
- Open discussion, voting, tabulate, repeat			URS - Jason Weiss
- Expert Elicitation Panel Member Expectations	Review Panel member expectations, what they hope to get out of the Panel; what USACE hopes to achieve		URS - Ann Terranova
- Bias and how it applies to Panel Member discussions			USACE - Brian Maestri
- Session Objectives/Outcomes/Assumptions	Identify what will characterize a successful Panel at its completion		URS - Ann Terranova
- Define Key Terms	Establish baseline understanding of key terms used by Panel Members for expert elicitation		URS - Mike Cannon
- USACE terminology			URS - Mike Cannon
- Coastal terminology			Moffatt Nichol
- Sandy storm characteristics, discussion			Moffatt Nichol
- Sandy storm characterize damages, discussion			URS - Mike Cannon
- Application of Uncertainty	Define/discuss how uncertainty will be factored into estimates by Panel member		IWR, USACE - Stuart Davis
Break		**10:30 am - 10:45 am**	
Categorization Approach		**10:45 am - 12:00 pm**	
- Initial groupings/prototype buildings (for content and structural elicitations)	Discuss rationale for how protoype categories have been established		URS - Mike Cannon
- Open discussion, appropriate categorization approaches, including groundrules for adding categories, maximum number allowable	Facilitated discussion to address Panel member concerns, issues regarding categories; what is a reasonable number of categories to consider for this Panel		URS - Ann Terranova
- Present final grouping revisions			URS - Ann Terranova
- Additional discussion (focused on outliers)			URS - Ann Terranova
- Close discussion and vote			URS - Ann Terranova
- Present category results	Concurrence by Panel members on protype categories to be discussed; adjust agenda as needed		URS - Ann Terranova
Lunch		**12:00 pm - 1:00 pm**	

APRIL 22, 2014 (DAY 1) - AFTERNOON SESSION (1:00 pm - 4:30 pm)

TOPIC	DETAILS	TIME	LEAD
Work to Date		**1:00 pm - 1:30 pm**	
- Summary and brief Q&A of work to date	Discuss the work conducted to-date and currently underway as it relates to the development of the depth damage functions leading up to the Expert Elicitation Panel		URS - Mike Cannon
- Introduction to USACE planning			URS - Mike Cannon
- How coastal damages are currently estimated			URS- Richard Franks
- Overview of survey and results			URS - Mike Cannon
- Other data sources and reports - overview results or focus on major differences; do after initial voting)	No previous DDFs will be discussed at this time; it will be shared after initial entry of responses by Panel members for each prototype		URS - Mike Cannon
- Mechanics of data entry			URS - Jason Weiss
Building Type 1 - Apartments		**1:30 pm - 2:45 pm**	
- Present Prototype, survey results, exterior photos, maps	Provide context, background, and baseline understanding of assumptions for prototype discussion		URS - Mike Cannon
- Facilitated group discussion			URS - Ann Terranova
- Gap analysis			URS - Ann Terranova
- Panelists enter initial estimates			URS - Ann Terranova
- Discuss consolidated results, rationale and assumptions, existing DDFs	Include bias in discussion, how this will impact Panel members changing their responses		URS - Ann Terranova
- Panelists revise estimates as needed			URS - Ann Terranova
- Present final results			URS - Ann Terranova
Break	**(Drinks and light snacks provided)**	**2:45 pm - 3:00 pm (15 minutes)**	
Building Type 2 - Commercial Engineered		**3:00 pm - 4:30 pm**	
- Present Prototype, survey results, exterior photos, maps	Provide context, background, and baseline understanding of assumptions for prototype discussion		URS - Mike Cannon
- Facilitated group discussion			URS - Ann Terranova
- Gap analysis			URS - Ann Terranova
- Panelists enter initial estimates			URS - Ann Terranova
- Discuss consolidated results, rationale and assumptions, existing DDFs	Include bias in discussion, how this will impact Panel members changing their responses		URS - Ann Terranova
- Panelists revise estimates as needed			URS - Ann Terranova
- Present final results			URS - Ann Terranova
Adjourn Day 1		***4:30 PM***	

END OF DAY 1 (APRIL 22, 2014)

APRIL 23, 2014 (DAY 2) - MORNING SESSION (8:30 am - 12:00 pm)

TOPIC	DETAILS	TIME	LEAD
Continental Breakfast	**(Coffee and light breakfast provided)**	**8:30 am - 9:00 am**	
Review Day One Accomplishments		**9:00 am - 9:15 am**	
Building Type 3 - Commercial Non-engineered		**9:15 am - 10:30 am**	
- Present Prototype, survey results, exterior photos, maps	Provide context, background, and baseline understanding of assumptions for prototype discussion		URS - Mike Cannon
- Facilitated group discussion			URS - Ann Terranova
- Gap analysis			URS - Ann Terranova
- Panelists enter initial estimates			URS - Ann Terranova
- Discuss consolidated results, rationale and assumptions, existing DDFs	Include bias in discussion, how this will impact Panel members changing their responses		URS - Ann Terranova
- Panelists revise estimates as needed			URS - Ann Terranova
- Present final results			URS - Ann Terranova
Break		**10:30 am - 10:45 am**	
Building Type 4 Prototype - Highrise		**10:45 am - 12:00 pm**	
- Present Prototype, survey results, exterior photos, maps	Provide context, background, and baseline understanding of assumptions for prototype discussion		URS - Mike Cannon
- Facilitated group discussion			URS - Ann Terranova
- Gap analysis			URS - Ann Terranova
- Panelists enter initial estimates			URS - Ann Terranova
- Discuss consolidated results, rationale and assumptions, existing DDFs	Include bias in discussion, how this will impact Panel members changing their responses		URS - Ann Terranova
- Panelists revise estimates as needed			URS - Ann Terranova
- Present final results			URS - Ann Terranova
Lunch		**12:00 pm - 1:00 pm**	

APRIL 23, 2014 (DAY 2) - AFTERNOON SESSION (1:00 pm- 4:30 pm)

TOPIC	DETAILS	TIME	LEAD
Building Type 5 Prototype - Residential (No Basement)		**1:00 pm - 2:45 pm**	
- Present Prototype, survey results, exterior photos, maps	Provide context, background, and baseline understanding of assumptions for prototype discussion		URS - Mike Cannon
- Facilitated group discussion			URS - Ann Terranova
- Gap analysis			URS - Ann Terranova
- Panelists enter initial estimates			URS - Ann Terranova
- Discuss consolidated results, rationale and assumptions, existing DDFs	Include bias in discussion, how this will impact Panel members changing their responses		URS - Ann Terranova
- Panelists revise estimates as needed			URS - Ann Terranova
- Present final results			URS - Ann Terranova
Break	**(Drinks and light snacks provided)**	**2:45 pm - 3:00 pm (15 minutes)**	
Building Type 6 Prototype - Residential (With Basement)		**3:00 pm - 4:30 pm**	
- Present Prototype, survey results, exterior photos, maps	Provide context, background, and baseline understanding of assumptions for prototype discussion		URS - Mike Cannon
- Facilitated group discussion			URS - Ann Terranova
- Gap analysis			URS - Ann Terranova
- Panelists enter initial estimates			URS - Ann Terranova
- Discuss consolidated results, rationale and assumptions, existing DDFs	Include bias in discussion, how this will impact Panel members changing their responses		URS - Ann Terranova
- Panelists revise estimates as needed			URS - Ann Terranova
- Present final results			URS - Ann Terranova
Adjourn Day 2		***4:30 PM***	

END OF DAY 2 (APRIL 23, 2014)

APRIL 24, 2014 (DAY 3) - M ORNING SESSION (8:30 am - 12:00 pm)

TOPIC	**DETAILS**	**TIME**	**LEAD**
Continental Breakfast	**(Coffee and light breakfast provided)**	**8:30 am - 9:00 am**	
Review Day Two Accomplishments		**9:00 am - 9:15 am**	
Building Type 7 Prototype - Pile Supported		**9:15 am - 10:30 am**	
- Present Prototype, survey results, exterior photos, maps	Provide context, background, and baseline understanding of assumptions for prototype discussion		URS - Mike Cannon
- Facilitated group discussion			URS - Ann Terranova
- Gap analysis			URS - Ann Terranova
- Panelists enter initial estimates			URS - Ann Terranova
- Discuss consolidated results, rationale and assumptions, existing DDFs	Include bias in discussion, how this will impact Panel members changing their responses		URS - Ann Terranova
- Panelists revise estimates as needed			URS - Ann Terranova
- Present final results			URS - Ann Terranova
Review and Compare Final Results		**10:30 am - 11:15 am (URS)**	
Review Expert Elicitation Panel Accomplishments		**11:15 am - 11:45 am (URS)**	
- Did we meet our expectations?			URS - Ann Terranova
- What worked, areas for improvement			URS - Ann Terranova
Next Steps - What to Look for on NACCS		**11:45 am - 11:55 am (USACE)**	
Thank you and Words of Appreciation		**11:55 am - 12:00 pm (USACE)**	
Adjourn Day 3		***12:00 PM***	
Lunch		**12:00 pm - 1:00 pm**	

APRIL 24, 2014 (DAY 3) - AFTERNOON SESSION (1:00 pm- 3:00 pm)

TOPIC	**DETAILS**	**TIME**	**LEAD**
Agenda to be expanded as needed to accommodate additional Prototypes identified by Panel members			

END OF DAY 3 (APRIL 24, 2014) - EXPERT ELICITATION PANEL ADJOURN

ATTACHMENT C: DEVELOPMENT OF COASTAL DEPTH-DAMAGE RELATIONSHIPS USING THE EXPERT ELICITATION PROCESS, NORTH ATLANTIC COAST COMPREHENSIVE STUDY, CONCURRENT PEER REVIEW SUMMARY NOTES, 2014

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK

Development of Coastal Depth-Damage Relationships
Using the Expert Elicitation Process
North Atlantic Coast Comprehensive Study (NACCS)

Clifton, New Jersey
April 22 – 24, 2014

Concurrent Peer Review Summary Notes

Introduction. The goal of the expert opinion elicitation sessions conducted in Clifton, New Jersey during the three-day period April 22 – 24, 2014, was to develop coastal depth-damage relationships for prototypical residential and nonresidential structures and their contents. Three damage mechanisms were considered: inundation, erosion, and wave damage. The panel of experts was also instructed to develop an uncertainty range for their damage percentages at various depths of flooding including a minimum, maximum, and most likely value. The information developed by the panel will be used specifically for the North Atlantic Coast Comprehensive Study and more generally for coastal areas in other parts of the country.

The research team included a moderator and a technical facilitator from URS, two economists from Institute of Water Resources (IWR), an economist from URS, an economist from New Orleans District serving as a peer reviewer, an economist from North Atlantic Division, technical integrators (recorder and equipment coordinator) from URS, and the panel of experts. The national panel consisted of two coastal engineers, a construction engineer, a post-disaster survey specialist, a FEMA claims adjustor, two restoration specialists, an electrical engineer, and a civil and environmental engineer.

Preparation for the Expert Elicitation Sessions. The research team conducted weekly phone calls several months in advance of the expert sessions to select and schedule the panel experts and develop the methodology and materials for the sessions. A month before the sessions, a meeting was held at New York District to finalize the scheduling of the experts, the location and the equipment needed, and to summarize the agenda for the sessions. A packet of introductory materials containing the purpose of the expert opinion elicitation sessions, the significance of the data to be developed by the panel, the methods for collecting the data, and the proposed prototype structure categories was sent to each of the panel members. A summary of the agenda, procedures, and methodology to be used in the sessions was presented to Dr. David Moser, lead economist of the Corps of Engineers, for his review and comment. His comments included the following: develop more specific assumptions regarding the force and duration of waves for storm damage conditions; incorporate building standards when collecting damage ranges from experts; use consistent methods of determining the depreciated value of structures and their contents; develop uncertainty ranges that would include 90 percent of the damage conditions for the development of a probability distribution; collect the median value, rather than the mean value, for the minimum, most-likely, and maximum values provided by the expert panel; and use the precise terminology that he provided when collecting expert opinions and presenting the results. His comments were incorporated into the procedures and methodology to be used during the sessions.

Orientation of the Experts. North Atlantic Division economist, Naomi Frankel, began her introductory remarks by thanking the panel members for attending the sessions. She explained the significance of the data to be developed by the panel and how the data will be used as part of the North Atlantic Coast Comprehensive Study. An updated meeting overview packet was given to each of the panel members. After the introduction, the experts were asked to introduce themselves to the other members of the panel. The moderator of the sessions then introduced the members of the research team and the office logistics.

The moderator and other members of the research team conducted an orientation for the panel. The technical facilitator explained how the sessions would be conducted and what will be expected of each panel member. It was stressed to the experts that their main objective was not to develop a consensus among the members; rather, the members should work independently of each other and then come together to discuss their results and to insure consistency in the estimation process. The results could then be modified to reflect the range of opinions or values. The IWR economist, Mr. Stuart Davis, explained how the data would be used for evaluations throughout the Corps and how uncertainty would be factored into the estimates provided by the experts.

A second topic discussed during the orientation included the identification of biases inherent in the presentation of opinions during the expert elicitation process. This discussion was led by the peer review economist from New Orleans District. Some of the biases include the tendency to describe beliefs in a socially desirable but inaccurate way (group think), the tendency for measurement errors in the direction of the wishes or expectations of the expert (observer bias), the tendency to factor in unrelated considerations in providing opinions (motivational bias), and the tendency to assign unduly high levels of confidence to uncertain conclusions (overconfidence). This discussion included strategies to help the experts minimize the impact of potential biases.

The third topic discussed during the orientation session included definitions of the terminology used in coastal risk management evaluations. As an example, the appropriate depth variable to use for damages resulting from breaking waves is considered to be the "difference between the top of wave (crest) and the bottom of the lowest horizontal structural member (walking floor elevation)." This definition was used in order maintain consistency with the Corps certified Beach-FX coastal computer model.

The final topic discussed by the technical facilitator as part of the orientation session was a summary of the data collected following Hurricane Sandy including the types of structures that incurred flood damage, the depths of flooding, source of flooding (inundation, erosion, or wave damage), amounts of damages, and locations of the structures.

Following the orientation, the experts were provided with an initial list of assumptions related to the general characteristics of the storm, flooding, and response characteristics. Assumptions were made regarding the general characteristics of the storm (content of salt in water, duration of the flood, and velocity of the water), the environmental conditions following the flood event (humidity levels, susceptibility to mold, and length of time before residents can return to structure), the structural characteristics of the prototypical structures (foundation height, average square footage, number of stories, and type of exterior walls), and the typical contents in the various residential and non-residential structure categories. These assumptions were varied for the minimum, maximum, and most likely scenarios. It should be noted the panel did not provide estimates of content-to-structure value ratios (CSVRs) or the average value of the structures. The panel was only asked to provide the damage percentages at each depth of flooding. As each of the structural categories was presented to the panel, the initial assumptions were displayed on an overhead screen. The panel members then had the option of either verifying or revising these assumptions.

Each member of the panel was assigned a seat at the table and provided with a laptop computer for data entry. The room contained two overhead screens, one at the front of the room and the other at back of the room, so that the experts could view and discuss their results throughout the sessions. The overview and training session lasted approximately four hours.

Expert Elicitation Proceedings. The moderator and technical facilitator began the proceedings by describing each of the seven prototypical residential and non-residential structure categories to the experts and displaying this information on the overhead screen. These categories included: single-story residential (with and without basements); residential structures constructed on piles (open and with enclosures); multi-story residential structures; apartment building (with and without basements); commercial structures with engineered construction (with and without basements); commercial structures with non-engineered construction (with and without basement); and high rise commercial structures. The experts were given the opportunity to discuss and/or make changes to the assumptions regarding the structural components, characteristics of the storm event, and the environmental conditions.

The panelists were then instructed to independently estimate the minimum, most likely, and maximum damage percentage of the total value of the structure and its contents at various depths of flooding and for each of the three damage mechanisms (inundation, erosion, and wave damage). The minimum, most likely, and maximum estimates represented 90 percent of all possible damage outcomes. The uncertainty surrounding the depth-damage relationships was captured by varying the structural characteristics of the prototypical structures (foundation height and exterior walls), by varying the characteristics of the flood event (content of salt in water, duration of the flood, and velocity of the water) and by varying the environmental conditions following the flood event (humidity levels, susceptibility to mold, and length of time before residents can return to structure).

After the panelists entered their estimates into their electronic data worksheets, the results were displayed on the overhead screens. The experts could then view and discuss the results as a group and provide the rationale for their individual estimates. The research team was available throughout the process to clarify issues and to answer questions. In cases where a wide range of responses was recorded, the facilitator would ask the panel more specific questions. Following the group discussion, the experts were given time to revise their original estimates as needed. The research team used the median values, rather than the mean values, to represent the damage percentages at various depths of flooding.

This process was repeated for each of the seven residential and non-residential structural prototypes and for each of the three damage mechanisms during the remaining two and one half days of the sessions.

Peer Review Comments. The following comments were made by Brian Maestri, economist from New Orleans District, as part of his peer review of the expert elicitation sessions.

The Contractor, URS, should be commended for their outstanding job in organizing these expert elicitation sessions and for providing a facility and equipment necessary to meet the objectives of the research team. The conference room had windows, comfortable chairs, a large table, overhead screens, and individual laptop computers for the experts. Name cards identified the positions of the experts at the table. Since breakfast and lunch were provided in the conference room, there was no need for the panel members to leave the room for an extended period of time. It is recommended that future expert elicitation sessions use similar facilities.

The nine-member expert panel assembled by the Contractor and the research team contained diversified coastal engineering expertise that adequately met the objectives of the research team. The panel of experts should be commended for being conscientious and helpful throughout the sessions. When the topic of mold was introduced into the discussion on the second day, the session lasted an hour and a half longer than scheduled. The experts were willing to fully discuss the issue and adjust their estimates accordingly. The expert elicitation process went slowly on the first day of the sessions. The experts initially provided damage percentages for specific structures rather than for prototypical structures that were varied for minimum, maximum, and most likely damages conditions. Their tendency was to achieve a level of accuracy that contained very narrow bands of uncertainty. It had to be emphasized to the panel that the depth-damage relationships would be applied to a structure inventory containing variations of the prototypical structures. Once this point was made, pace of the sessions increased and the results were more aligned with the expectations of the research team. It is recommended that the research team in future sessions emphasize to the panel how the Corps will use the data developed during the sessions.

Entry of the damage percentages into an electronic spreadsheet workbook during the session allowed the experts to view individual results on their own computer as well as for the group as a whole on the overhead screens. This saved time and helped the discussion regarding differences in estimates provided by the experts. However, several problems with networking and improperly displayed results were noted on the first day. First, when two or more experts tried to save their individual results simultaneously, they often lost their data and had to begin the process all over again. Second, if an expert accidentally entered his estimates into a spreadsheet designated for another expert, then the results of one of the experts could be lost. Finally, due to the large volume of data entries, the damage percentages could be entered inconsistently for various depths of flooding and/or for minimum, most likely and maximum values. The following recommendations regarding data entry are made for future sessions: the experts should verbally express when they are saving data so that other experts will not save their data at the same time; the name labels on the bottom of the Excel worksheets should be color coded so that it will be easier for the experts to save their data in the designated worksheet; and the spreadsheet cells should be formatted to prevent illogical or inconsistent damage percentages from being entered into the spreadsheet cells.

The panel was asked to develop depth-damage relationships for a large number of prototypical residential and non-residential structures and for three damage mechanisms in a relatively short period of time. Unlike as in previous expert elicitation sessions designed to develop depth-damage relationships, this expert panel was not asked to estimate a total value for the prototypical structures or their contents. The panel was only asked to estimate the damage percentages at various depths of flooding. This saved time and was more in line with their levels of expertise within their fields. Corps users of the depth-damage relationships developed during these sessions may expect CSVRs to also be available with these relationships. It is recommended that the research team emphasize in the final report that CSVRs are not available with these depth-damage relationships, and that CSVRs should be based on empirical valuation surveys.

The chief economist of the Corps, Dr. David Moser, made two recommendations regarding uncertainty prior to the start of the expert elicitation sessions. First, the damage percentages provided by the experts at each depth of flooding should be based on median values rather than mean values to help avoid the impact that extreme estimates could have on actual damage percentages. Second, the experts should develop an uncertainty range that would capture 90 percent of the damage possibilities instead of providing minimum, most likely and maximum percentages such that there is a 90 percent chance that the estimate range contains the most likely value. This method was selected because it is more consistent with the use of minimum, most likely and maximum values as inputs for a triangular probability distribution. It is recommended that future research teams employing expert methods share their methodology with the vertical review chain in the Corps prior to the start of the sessions. Having concurrence with the methods used to estimate uncertainty from the lead economist of the Corps will be advantageous to the research team during the Corps review process.

Due to the technical nature of developing depth-damage relationships for beachfront properties impacted by beach erosion and wave action, it was important for the experts to use the same reference elevations as the Corps certified Beach-FX model. The reference elevation for the damage percentages caused by erosion for structures with shallow and pile foundations was dependent on the “percent of the footprint” compromised. The reference elevation for the damage percentages caused by wave action for beachfront structures with pile foundations (open or with enclosures) is the difference between the wave crest and the bottom of the lowest horizontal member (in feet). It is recommended that future research teams provide the experts with terminology that is consistent with the terminology used by the current models to estimate coastal flood damages.

ATTACHMENT D: PANELIST BIOGRAPHIES

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK

NACCS Expert Panelist Biographies

Bill Coulbourne	Bill Coulbourne has over 40 years of engineering, construction, and consulting experience with Fortune 500 companies, mid-size consulting firms, non-profits and single person practices. Mr. Coulbourne has a BS degree in Civil Engineering from Virginia Tech and a Masters in Structural Engineering from the University of Virginia. Mr. Coulbourne's last 15 years have been spent in the business of finding solutions to structural engineering problems caused by natural hazards. As part of that practice, he has been to or managed teams that have been to every major hurricane and flood disaster since 1995 that has occurred in the united States and its territories. Mr. Coulbourne has co-authored FEMA's Coastal Construction Manual which has become the preeminent engineering tool for building in high wind and flood areas. He wrote FEMA 320, Building a Safe Room in Your Home, a document on how to build safe rooms in buildings to protect occupants from tornado threats. Mr. Coulbourne teaches as an off-campus faculty member at the University of Delaware, giving a course to Senior Civil Engineering students on Building Design and a course on Engineering for Disasters. He instructs for ASCE and for many of his clients. He participates in writing the national design standards for building design (ASCE 7 – Minimum Design Loads for Buildings and Other Structures) and for flooding (ASCE 24 – Flood Resistant Design and Construction).
Frank L. Headen	As CEO of First Restoration Services (Charlotte, NC), Frank Headen gained decades of experience in the industry, working on many high-profile projects such as the Pentagon (Washington, DC) and World Trade Center Tower 7 (New York, NY), following 9-11; the NASA facilities at the Kennedy Space Center (FL); the FBI Headquarters and Hyatt Regency Hotel (New Orleans, LA), following Hurricane Katrina; the Biltmore House (Asheville, NC), following a fire in its carpenter shop; and the EPA Headquarters and FBI Washington Field Office (Washington, DC) following severe flooding and heavy rains.

Christopher P. Jones	Christopher P. Jones is a registered professional engineer specializing in coastal hazard identification, hazard mitigation and coastal engineering. He has over 30 years’ experience as a practicing engineer, and has worked throughout the United States and abroad on studies and projects related to: - flood hazard mapping and map revisions - flood loss estimation modeling - post-disaster damage investigations - flood-resistant design and construction - building codes and standards - coastal setback studies - beach management plans - beach nourishment Mr. Jones uses his knowledge of coastal construction and forensic studies to improve coastal flood hazard mapping guidance, and uses his knowledge of flood hazards to inform post-disaster damage investigations. He has served as an expert witness on coastal management and flood hazard mitigation issues in over 20 hearings and trials at the local, state and federal levels.
Andrew Kennedy	Andrew Kennedy is an associate professor in the Department of Civil & Environmental Engineering & Earth Sciences and the College of Engineering at Notre Dame. He obtained his undergraduate degree in Civil Engineering from Queen's University, Canada, and his master's degree from the University of British Columbia. Professor Kennedy attended Monash University, Australia for his Ph.D., graduating in 1998. He was then a postdoctoral researcher at the Center for Applied Coastal Research at the University of Delaware before accepting a faculty position at the University of Florida. Professor Kennedy's research focuses on waves, surge, and currents in the coastal ocean and their effects on human activities. Parts of this work are observational, ranging from the rapid deployment of wave and surge gauges in advance of hurricane landfalls, to the analysis of very large-scale bathymetric LIDAR datasets to determine morphological changes during large storms. A recent focus correlates observed storm damage to observed and predicted hydrodynamics in coastal regions. Parts of Professor Kennedy's research are theoretical and computational, and deal with water wave theory in shallow and deep water, and in the generation of near-shore circulation by breaking waves. This work has direct application to the prediction of storm waves and water levels, damage, and erosion.

Michael Pagano, PE	Mr. Pagano has more than 25 years of experience in the design and construction of electrical systems for government and industrial clients. He has managed the design of many projects, including medium voltage substation and distribution networks, telecommunications facilities, water and wastewater treatment facilities, green energy facilities and roadway lighting. His specialty includes electric safety and electric system studies. Mr. Pagano's experience includes the operation and maintenance of electrical systems, and investigation of electrical failures of large campus developments. He managed project staff and oversaw coordination of repairs and remediation of deficient conditions.
Karthik Ramanathan	Dr. Karthik Ramanathan is an Engineer in AIR's Research and Modeling group, working primarily on the wind and storm surge vulnerability of civil engineering systems. He has been involved in the development of the storm surge component of the AIR U.S. hurricane model. He has participated in AIR's post-disaster damage surveys, including one in 2012 for Hurricane Sandy in New York and New Jersey. He holds a Master's degree in Structural Engineering from the University of Pittsburgh, a Master's degree in Structural Engineering, Mechanics and Materials from the Georgia Institute of Technology, and a Ph.D. in Civil Engineering from the Georgia Institute of Technology with a special focus in earthquake engineering. The central focus of his dissertation research was on the seismic vulnerability and risk assessment of highway bridge classes in California.
Spencer Rogers	For more than 30 years, Spencer Rogers has helped private property owners, builders, designers, and governmental agencies to develop hurricane-resistant construction methods, understand shoreline erosion alternatives and implement marine construction techniques. He serves on the faculty at the University of North Carolina at Wilmington's Center for Marine Science, and as adjunct faculty in the department of civil, construction, and environmental engineering at North Carolina State University. Mr. Rogers co-authored The Dune Book, a guidebook on dune species, planning, and best management practices along developed shorelines. He also has contributed to the FEMA Coastal Construction Manual. His research has been published in numerous scholarly journals, including the Journal of the American Shore and Beach Preservation Association, and the Journal of Marine Education. He also is a regular speaker at conferences about coastal engineering and hazards, including the annual Solutions to Coastal Disasters. In 2005, Rogers was part of a select group of engineers and scientists on the FEMA Hurricane Katrina Mitigation Assessment Team to conduct a coastal damage evaluation in Mississippi, Louisiana and Alabama. Mr. Rogers joined Sea Grant in 1978, having worked as a coastal

	engineer for the Bureau of Beaches and Shores in the Florida Department of Natural Resources during his early career. He holds a master's in coastal and oceanographic engineering from the University of Florida and a bachelor's in engineering from the University of Virginia.
Jim Soucy	During his 20 years as Operations Manager for Parsons Brinckerhoff, Jim Soucy conducted FEMA Preliminary Damage Assessments for floods, hurricanes, earthquakes, tornados, and fires, as well as the World Trade Center attack. As part of the FEMA Grant Housing program, Mr. Soucy worked with Federal, State, and Local officials immediately after a natural disaster hit. He determined how many inspectors needed to be deployed and positioned throughout the affected areas, and coordinated inspections with disaster victims in need of federal aid. Mr. Soucy has worked in all 50 states, and has also lead numerous assessments in Puerto Rico, the US Virgin Islands, Guam, Samoa, and the Truk Lagoon. He spent two weeks on a FEMA-rented sail boat as part of a 6-man inspection team in the Lower Mortlocks after they were hit by a Typhoon.
Jack Young	Mr. Young is a nonresidential appraiser and restoration specialist. He has extensive experience with FEMA specifications and procedures for post-flood inspection and has provided support in states such as California, Florida, Louisiana, Oregon, and various Gulf Coast region states. He is a certified assistant purchasing agent for hospitals and hotels. He is also a certified flood insurance adjuster.

ATTACHMENT E:SUMMARY OF SURVEY PROCESS AND RESULTS

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK

Analysis of Survey Data

Once the surveys were completed and entered into the database, the structures where surveys were conducted were evaluated to determine the structure value. The replacement value of each structure was estimated using the RS Means Square Foot Costs (2014) cost estimating guide. Based on the information collected from the surveys, the building type and function was used to categorize the structure into one of the models in the RS Means guide. The other building characteristics, such as size and construction type, collected during the surveys were used to estimate the replacement value of the structure. The depreciated replacement value was then estimated based on the quality and condition of the structure and the depreciation ratios used by IWR.

The data were reviewed to remove records that were not usable. Records that were missing key pieces of information or appeared to be incorrect were removed from the analysis. As noted previously, many of the respondents did not report the amount of damage that occurred to their structures. For example, four feet of inundation was reported for several commercial office buildings; however respondents were not willing/able to provide a dollar figure for the damages to the structure. These records were removed from the analysis. Records were also removed if enough information was not available about the structure to estimate the replacement value.

The percent damage to each structure was estimated by dividing the total structure damage by the depreciated replacement value. In some cases, the amount of damage was greater than the estimated depreciated replacement value. This could be due to several reasons, including: underestimating of the replacement value of the structure, over-reporting the structure damages by the respondent, and respondent lumping damages from several categories (e.g., structure, content, outside equipment) into one figure. Therefore, any percent damage amount that was greater than 100 percent was capped at 100 percent.

The records for residential structures were categorized into prototypes based on the foundation type and style of the building. The records were then grouped by damage mechanism. If a respondent indicated any sort of wave damage, the record was considered to having been from wave damage. Most of the structures where wave damage was prevalent were also located on waterfront parcel. The records for nonresidential structures were categorized into prototypes based on the business purpose.

Table 1 summarizes the data used for the residential analysis and Table 2 summarizes the data used for the nonresidential analysis.

Table 1. Residential Survey Data

ID	Foundation Type	House Style	Flood Depth (ft)	Structure Damage	Content Damage	Structure Value	Percent Damage
5A - 1-Story, No Basement (inundation)							
199	Concrete Block	1-1/2 Story Finished	1.25	$0	$9,000	$324,121	0%
7	Concrete Block	1-1/2 Story Finished	4.00	$31,000	$71,000	$217,692	14%
27	Concrete Block	1-1/2 Story Finished	5.00	$169,172	NULL	$111,987	100%
90	Concrete Block	1-Story	1.00	$0	NULL	$114,706	0%
91	Concrete Block	1-Story	4.00	$20,000	$15,000	$70,391	28%
3	Concrete Block	1-Story	4.50	$80,000	$5,000	$134,163	60%
16	Concrete Block	1-1/2 Story Finished	1.50	$0	$15,000	$173,078	0%
2	Concrete Block	1-1/2 Story Finished	4.00	$70,000	$50,000	$161,502	43%
108	Concrete Block	1-Story	0.25	$11,000	$4,300	$105,451	10%
50	Concrete Block	1-Story	0.33	$0	$2,800	$113,119	0%
170	Concrete Block	1-Story	0.33	$0	$58,000	$60,779	0%
47	Concrete Block	1-Story	2.00	$40,000	$10,000	$96,839	41%
33	Concrete Block	1-Story	2.50	$110,000	$20,000	$97,554	100%
32	Concrete Block	1-Story	5.00	$190,000	$50,000	$85,206	100%
5A - 1-Story, No Basement (wave)							
75	Concrete Block	1-1/2 Story Finished	1.67	$6,000	$4,000	$213,157	3%
38	Concrete Block	1-1/2 Story Finished	2.50	$120,000	NULL	$182,286	66%
73	Concrete Block	1-1/2 Story Finished	3.00	$60,000	$120,000	$187,703	32%
72	Concrete Block	1-1/2 Story Finished	4.00	$120,000	NULL	$79,768	100%
146	Concrete Block	1-1/2 Story Finished	4.50	$0	$80,000	$161,632	0%
202	Slab	1-1/2 Story Finished	4.00	$65,000	$25,000	$134,443	48%
70	Concrete Block	1-Story	2.00	$6,000	NULL	$29,950	20%
162	Concrete Block	1-Story	3.00	$100,000	$40,000	$92,556	100%
240	Concrete Block	1-Story	4.00	$80,000	NULL	$99,002	81%
186	Concrete Block	1-Story	7.00	$120,000	$90,000	$130,570	92%
45	Other	1-Story	6.00	$120,000	$10,000	$112,212	100%
68	Slab	1-Story	0.83	$0	NULL	$72,257	0%

ID	Foundation Type	House Style	Flood Depth (ft)	Structure Damage	Content Damage	Structure Value	Percent Damage
5B – 2-Story, No Basement (inundation)							
148	Concrete Block	2-Story	0.83	$52,000	$10,000	$168,592	31%
62	Concrete Block	2-Story	3.00	$164,116	NULL	$1,676,453	10%
94	Concrete Block	2-Story	4.00	$35,000	$35,000	$151,580	23%
244	Slab	2-Story	0.00	$80,000	NULL	$247,059	32%
127	Concrete Block	3-Story	2.00	$0	NULL	$22,165,567	0%
123	Slab	3-Story	4.00	$500,000	$500,000	$14,170,343	4%
122	Slab	3-Story	5.00	$250,000	$250,000	$62,766,480	0%
121	Slab	3-Story	5.00	$426,000	$400,000	$54,290,995	1%
167	Slab	3-Story	6.00	$22,000	$15,000	$230,679	10%
106	Concrete Block	2-Story	1.50	$100,000	$43,000	$214,317	47%
49	Concrete Block	2-Story	2.00	$83,000	$50,000	$176,892	47%
153	Concrete Block	2-Story	2.50	$0	$3,000	$273,699	0%
235	Concrete Block	2-Story	3.17	$40,000	NULL	$194,755	21%
1	Concrete Block	2-Story	3.50	$106,000	$17,000	$231,047	46%
43	Concrete Block	2-Story	4.50	$35,000	$20,000	$76,444	46%
154	Concrete Block	2-Story	5.00	$85,000	$22,500	$248,528	34%
6	Other	2-Story	3.00	$65,000	$30,000	$135,673	48%
176	Slab	2-Story	1.58	$0	$10,000	$128,878	0%
194	Slab	2-Story	3.50	$40,400	$15,000	$117,439	34%
193	Slab	2-Story	5.50	$45,000	$2,000	$132,593	34%
184	Slab	2-Story	6.00	$0	$1,200	$211,667	0%
109	Concrete Block	3-Story	3.50	$12,000	$6,000	$262,467	5%
168	Slab	3-Story	7.00	$25,000	$7,000	$170,764	15%
187	Concrete Block	2-Story	0.75	$79,400	NULL	$85,908	92%
5B – 2-Story, No Basement (wave)							
147	Slab	2-1/2 Story Finished	5.50	$80,000	$35,000	$264,577	30%
39	Slab	2-1/2 Story Finished	7.00	$195,000	$80,000	$557,477	35%
166	Concrete Block	2-Story	0.00	$1,000	$2,400	$355,588	0%

ID	Foundation Type	House Style	Flood Depth (ft)	Structure Damage	Content Damage	Structure Value	Percent Damage
30	Concrete Block	2-Story	0.17	$2,000	NULL	$157,527	1%
8	Concrete Block	2-Story	1.00	$82,000	$5,600	$358,949	23%
77	Concrete Block	2-Story	1.83	$4,000	NULL	$282,293	1%
172	Concrete Block	2-Story	2.00	$242,000	$70,000	$174,653	100%
71	Concrete Block	2-Story	2.50	$18,000	NULL	$192,998	9%
11	Concrete Block	2-Story	2.50	$50,000	$10,000	$242,423	21%
175	Concrete Block	2-Story	8.00	$325,000	$40,000	$207,257	100%
46	Other	2-Story	6.00	$90,000	$5,000	$89,582	100%
169	Slab	2-Story	-0.58	$0	$300	$156,628	0%
163	Slab	2-Story	-0.50	$90,000	NULL	$248,528	36%
40	Slab	2-Story	1.00	$100,000	$60,000	$214,953	47%
185	Slab	2-Story	5.00	$0	$26,000	$124,308	0%
37	Slab	3-Story	-4.50	$46,500	$15,000	$180,065	26%
36	Slab	3-Story	-4.00	$40,000	$17,000	$199,867	20%
35	Slab	3-Story	-2.00	$10,000	$45,500	$230,969	4%
239	Slab	2-1/2 Story Finished	5.00	$75,000	NULL	$70,582	100%
6A - 1-Story, With Basement (inundation)							
89	Basement	1-1/2 Story Finished	-5.00	$0	$21,000	$288,354	0%
105	Basement	1-Story	-3.00	$68,000	$1,200	$259,912	26%
51	Basement	1-Story	-0.83	$2,000	$5,000	$292,076	1%
142	Concrete Block	Bi-Level	2.00	$0	NULL	$39,342,586	0%
152	Slab	Bi-Level	5.83	$126,796	$1,370	$148,753	85%
85	Slab	Bi-Level	6.00	$0	$15,600	$159,851	0%
6B – 2-Story, With Basement (inundation)							
52	Basement	2-Story	-2.00	$0	$12,300	$156,580	0%
88	Basement	2-Story	-1.00	$0	$10,100	$323,975	0%
86	Basement	2-Story	0.25	$0	$65,000	$305,028	0%
191	Basement	2-Story	1.50	$50,000	$30,000	$345,375	14%
190	Basement	2-Story	2.00	$300,000	$125,000	$275,400	100%

ID	Foundation Type	House Style	Flood Depth (ft)	Structure Damage	Content Damage	Structure Value	Percent Damage
182	Basement	2-Story	7.50	$136,000	$11,000	$165,791	82%
192	Basement	3-Story	4.00	$35,000	$0	$165,688	21%
234	Basement	2-Story	1.83	$0	$60,000	$191,943	0%
135	Basement	3-Story	2.00	$100,000	$15,000	$5,911,376	2%
134	Basement	3-Story	4.00	$100,000	$20,000	$5,911,376	2%
20	Basement	2-Story	-4.00	$0	$10,000	$207,178	0%
6B – 2-Story, With Basement (wave)							
164	Basement	Bi-Level	0.75	$50,000	$25,000	$141,487	35%
183	Basement	3-Story	6.67	$93,000	$5,000	$226,003	41%
155	Basement	2-Story	-2.00	$40,000	$15,000	$255,315	16%
165	Basement	2-Story	0.00	$6,000	NULL	$299,680	2%
44	Basement	2-Story	2.25	$120,000	$20,000	$216,124	56%
188	Basement	2-Story	3.00	$220,000	NULL	$213,382	100%
156	Basement	2-Story	4.00	$0	$85,000	$826,075	0%
7A – Open Pile Foundation (wave)							
65	Piling	2-Story	3.00	$10,000	$15,500	$219,444	5%
64	Piling	2-Story	5.00	$50,000	$30,000	$180,221	28%
78	Piling	2-Story	4.00	$7,000	$10,000	$254,775	3%
69	Piling	2-Story	4.00	$40,000	NULL	$261,646	15%
74	Piling	1-Story	0.67	$50,000	$50,000	$215,145	23%
28	Piling	1-Story	5.00	$37,759	NULL	$23,475	100%

Table 2. Nonresidential Survey Data

ID	Business Purpose	Flood Depth (ft)	Structure Damage	Content Damage	Structure Value	Percent Damage
2 – Commercial, Engineered Construction						
173	realty office	2.0	$70,000	$30,000	$1,453,632	5%
133	business center, offices	4.5	$100,000	$0	$38,763,520	0%
125	dry cleaners	4.0	$20,000	$0	$2,326,896	1%
241	Day Program Building of a Not for Profit Organization that provides programs and services for individuals with developmental disabilities.	-5.0	$35,239	$85,817	$3,084,900	1%
242	Executive Office of a Not for Profit Organization that provides programs and services for individuals with developmental disabilities.	-0.5	$189,690	$114,728	$2,064,510	9%
82	restaurant and hotel	0.5	$2,000,000	0	$5,089,500	39%
111		5.0	$50,000	$500,200	$343,746	15%
112		5.0	$10,000	$10,150	$272,556	4%
126	coffee shop	5.0	$200,000	$0	$313,814	64%
144	senior care facility	4.0	$750,000	$0	$30,143,880	2%
3 – Commercial, Non/Pre-Engineered						
54	Marina, Boat Yard, Storage	1.5	$0	$0	$27,323	0%
159	Marine Towing (Tugboat Operator)	10.0	$300	$0	$12,475	2%
54	Marina, Boat Yard, Storage	2.7	$30,000	$0	$30,000	100%
54	Marina, Boat Yard, Storage	4.0	$1,000	$10,000	$2,000	50%
53	Masonry Building Supplies	2.8	$0	$0	$410,380	0%
53	Masonry Building Supplies	3.8	$0	$0	$225,621	0%
53	Masonry Building Supplies	3.8	$0	$0	$125,414	0%
53	Masonry Building Supplies	3.8	$0	$0	$73,521	0%
160	Test Drilling	0.8	$0	$0	$581,453	0%
225	police dept. (shares office with municipal)	3.0	$143,586	$0	$330,728	43%

ID	Business Purpose	Flood Depth (ft)	Structure Damage	Content Damage	Structure Value	Percent Damage
224	borough offices shared w/ police	3.0	$42,624	$0	$254,361.60	17%
34	Restaurant Bar	8.0	$2,600,000	$500,000	$645,456	100%
10	Marina, marine supplies	6.5	$200,000	$1,877,000	$249,165	80%
93	Pre-school	0.3	$200,000	$130,000	$676,192	30%
233	yacht club, marina	1.0	$0	$0	$61,200	0%
99	Private Boat Club	1.8	$150,000	$40,000	$423,072	35%
79	gift shop for body and home decor	5.5	$626,000	$400,500	$412,224	100%
203	clothing, gift shop	4.0	$100,000	$0	$222,994	45%
208		3.0	$150,000	$0	$585,792	26%
61	Italian restaurant	6.0	$250,000	$200	$343,068	73%
243	Café that is a full service restaurant that also is a certified training site	-5.0	$18,343	$14,827	$1,039,600	2%
31	Restaurant	-4.0	$0	$140,000	$3,616,000	0%
23	fire house	4.0	$50,000	$159,022	$660,796	8%
87	HVAC - specialty duct design & fabrication	5.0	$70,000	$0	$164,528	43%
22	civic and senior center building	2.6	$80,694	$0	$596,471	14%
53	Masonry Building Supplies	1.4	$0	$0	$125,181	0%
157	Fishing Cooperative & Restaurant	6.0	$400,000	$0	$590,538	68%
55	Hunting Equipment Store	2.8	$368,000	$0	$492,115	75%
84	Stamp sales via eBay, also sells high-tech educational products for indstrial arts	0.4	$4,210	$0	$296,150	1%
97	Rebar Fabricator	6.5	$20,000	$0	$311,428	6%
100	Manufacturer - Mortar and Grout	3.0	$500,000	$0	$1,727,544	29%
157	Fishing Cooperative & Restaurant	4.3	$100,000	$0	$689,255	15%
189	Church	8.0	$750,000	$0	$1,434,919	52%
14	music retail and repair	3.0	$3,200	$70,000	$167,692	2%
19	custom metal work	2.5	$50,000	$168,000	$1,059,940	5%
21	barber shop	1.0	$1,000	$500	$72,871	1%

ID	Business Purpose	Flood Depth (ft)	Structure Damage	Content Damage	Structure Value	Percent Damage
59	American Legion www.bcnjal.org	3.0	$26,500	$26,500	$1,480,000	2%
60	church	3.0	1500000	0	$3,073,960	49%
83	Italian restaurant	5.0	7000	24500	$1,224,960	1%
110	restaurant	4.0	$15,000	$20,000	$214,400	7%
115	market/cafe	4.0	$300,000	$20,200	$1,989,659	15%
116	elementary school	5.0	2000000	0	$12,623,520	16%
139		0.1	$0	$5,030	$835,635	0%
174	realty office	0.2	10000	0	$267,330	4%
216	municipal bldg and police offices	-1.0	$200,000	$0	$719,245	28%
226	fire house	2.8	$50,885	$0	$1,028,065	5%
227	municipal bldg and police offices	6.0	$502,000	$0	$504,000	100%
228	fishing club	2.0	5000	0	$649,230	1%
229	municipal bldg	4.0	$483,843	$0	$357,000	100%
232	restaurant	1.1	$200,000	$225,000	$5,023,980	4%
236	restaurant	0.4	$0	$11,000	$2,725,560	0%
237	restaurant and bar	4.0	$150,000	$50,000	$790,616	19%
4	Bar, Restaurant, Strip Mall	4.0	$375,000	$200,000	$1,167,679	32%
5	convenience store, sandwiches	6.0	$125,000	$100,000	$356,967	35%
9	Fire Dept	1.5	$49,347	$4,025	$722,669	7%
12	Restaurant bar	4.9	$5,000	$125,000	$395,274	1%
41	Restaurant	7.0	$5,000	$16,000	$528,840	1%
42	Auto Repair	6.4	$17,500	$0	$215,767	8%
48	restaurant/ bar	6.0	$140,000	$222,000	$891,977	16%
151	Restaurant, Marine Fueling & Landing	5.5	$1,300,000	$695,000	$2,820,480	46%

ATTACHMENT F: LESSONS LEARNED

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK

Lessons Learned

1. **Issue**: Survey organization, vital questions determining rest of survey not asked first. Due to the organization of the questions on the survey, quite a lot of time was spent on interviews for properties in which there was either no damage, or the damage was caused by a non-flood event (such as an uprooted tree or a general loss of power).
   Suggestion: Question 7 should be the very first question asked, immediately following the introduction. If the potential participant is willing to be interviewed, the next question to be asked should be Question 6, and then Question 31. If the property suffered no damage, if the interviewee did not occupy the property during the storm, or if the property only received wind damage, the interviewer can abandon the interview at an early point and move on to the next property.
   Example:

   > Question 7: Did this property suffer damage during Hurricane Sandy?
   > Questions 6: Did you own or rent this property during Hurricane Sandy?
   > Question 31: Please indicate the source of damage to your property (Storm surge, Wave run up, Inundation, Erosion, Wind Damage, Other)

   Suggest similar alteration be made in the Non-Residential form.

2. **Issue**: Survey organization, vital cost information not asked upfront. In a case similar to #1 Issue above, interviews progressed to questions 28 and 33, only for the interviewer to find out that the interviewee did not have information about actual costs.
   Suggestion: The most important questions should be asked first. This will allow the interviewer to establish early on whether the subject is able to answer the questions, and thus whether a complete interview is worthwhile.

3. **Issue**: Survey organization non-structured. The organization of the current survey instrument is confusing to both interviewers and interviewees. Instrument jumps from flood characteristics, to building characteristics, to damage prevention, back to flood characteristics, and *then* asks if the property was damaged by flooding, or by wind. Then it asks about costs associated with temporary lodging (Question 32), and then it returns to physical damage and related costs (Question 33).
   Suggestion: The survey instrument should be restructured so that questions are grouped by categories: Damages and Damage Costs, Preventative Measures and Temporary Lodging Costs, and finally, ancillary information about the property location and building characteristics. A more organized survey instrument will help people to organize their thoughts. Suggest doing several test rounds in the field to improve overall "flow."
   Example: Questions about physical damage should be grouped together and asked in the following order:

   > Question 11A: What was the source of the flooding?

Question 29: How high did the water get on the inside of the house, relative to the first floor?
Question 30: How long did the water remain in the house?
Question 33: Dollars and unpaid hours spent to repair or replace damaged contents and structure.
Question 34: What is the primary source of your structural damage values?
Question 35: Was there erosion damage to your property?

4. **Issue:** In some cases, interviewees were simply unable to itemize their damage costs. Many people could not separate them into Contents or Structure.
   Suggestion: Provide a field for "lump sum" estimates, and an area to expand upon the specific items that were damaged for later analysis.

5. **Issue:** Questions 13 – 24 tend to overlap and be redundant. Also, some of the questions are unclear.
   Suggestion: Reorganize this section to eliminate redundancies.
   Example: Question 14 asks what percent of the structure's basement is finished. But the next question (Question 15) asks if the 1.5-, 2.5-, or 3.5-story structure is finished or unfinished. Not clear if "finished/unfinished" pertains to the upper level or the basement (for example, some Cape Cod residences have a "0.5" level that is often converted to living space, but is occasionally left as an attic). Also, Question 15 can probably be eliminated altogether, as the FEMA diagram number will provide this information.

6. **Issue:** A number of questions consistently confused both interviewers and interviewees due to their placement in the survey, due to their sentence structure, and/or due to the sequence of storm-related events.
   Suggestion: Reviewing these questions and moving rearranging or rewording them as necessary: 25, 26, 28, 30, 32b, 33, and 35 on the residential form, and similar questions on the nonresidential form.

7. **Issue:** Interviewees were consistently unable to provide depreciated value for their property. Usually this was due to a due to general lack of knowledge about the concept of depreciation, but occasionally the interviewee was stumped as to which depreciation method the interviewer was asking for.
   Suggestion: Collect criteria that would enable the interviewer to calculate depreciated value.

8. **Issue:** The survey looked intimidating to interviewees because of the amount of pages. In many cases, the interviewee was put off by this immediately, i.e. "I don't have time for this".
   Suggestion: Decrease the size of the survey and make the layout more concise.

9. Survey was not effective for structures that were completely destroyed, as owners were generally not available for interview.

10. The following terms should be clearly defined on the survey instrument:
    - First Floor
    - Under the House Enclosure – specific to pile-supported structures, or do crawlspaces count as well? This is an example of a question that does not actually need to be asked, as the answer can be observed by the interviewer.
    - Waterfront Block – how does this apply to roads that are not parallel to the water?
    - Interior – how does this apply to roads that are not parallel to the water?
    - Elevated Utility- An elevated AC unit is easy to identify, but what does an elevated washer and dryer look like? If a furnace is on the first floor, and the first floor is a foot or two above grade, is that considered elevated?

ATTACHMENT G: VERIFICATION OF NORTH ATLANTIC COAST COMPREHENSIVE STUDY DAMAGE FUNCTIONS

NORTH ATLANTIC COAST COMPREHENSIVE STUDY:
RESILIENT ADAPTATION TO INCREASING RISK

Verification of North Atlantic Coast Comprehensive Study Damage Functions

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1 Introduction

As part of the North Atlantic Coast Comprehensive Study (NACCS), the U.S. Army Corps of Engineers (USACE), North Atlantic Division was tasked with using data from Hurricane Sandy and other coastal storms to develop inundation, erosion, and wave impact damage functions for specific types of buildings. The damage functions were developed by a panel of experts during an expert opinion elicitation session. During the session, the expert panel developed damage functions for 12 building prototypes of the most likely, minimum, and maximum percent structure and content damage for various storm magnitudes for each damage mechanism (wave, inundation, and erosion). Findings from the session are documented in the NACCS *Physical Damage Function Summary Report* (which is the main body of this appendix).

After the USACE Agency Technical Review of the results of the NACCS expert elicitation, USACE requested that additional empirical evidence be analyzed and presented for verification of the damage functions. This verification study was conducted by the NACCS team in response to that request.

1.1 Purpose of Study

The purpose of this verification study is to analyze additional empirical evidence to evaluate the reasonableness of the damage functions developed through the NACCS expert elicitation process. To accomplish this, data collected by the Federal Emergency Management Agency (FEMA) related to Substantial Damage estimate efforts and the Mitigation Assessment Team (MAT) following Hurricane Sandy were reviewed and analyzed.

1.2 Expert Elicitation Results

The NACCS expert elicitation conducted in April 2014 yielded 12 building prototypes and 74 damage functions for inundation, erosion, and wave damage mechanisms. Table 1 lists the prototypes and damage functions developed during the NACCS expert elicitation. Details of the expert elicitation and damage functions can be found in the NACCS *Physical Damage Function Summary Report*.

Table 1. NACCS Expert Elicitation Prototypes and Damage Functions

Prototype	Description	Structure				Content			
		Inundation	Erosion	Wave	Wave-Wall	Inundation	Erosion	Wave	Wave-Wall
1A	1-Story Apartment, No Basement	X	X	X	X	X	X	X	X
1A-3	3-Story Apartment, No Basement	X				X			
2	Commercial, Engineered Construction	X	X	X		2	2	2	
3	Commercial, Non/Pre-Engineered Construction	X	X	X		2	2	2	
4A	Urban High Rise	X				X			
4B	Beach High Rise	X	X	X		X	X	X	
5A	1-Story Residence, No Basement	X	X	X	X	X	X	X	X
5B	2-Story Residence, No Basement	X	X	X		X	X	X	
6A	1-Story Residence, With Basement	X	X	X		X	X	X	
6B	2-Story Residence, With Basement	X	X	X		X	X	X	
7A	Building on Open Pile Foundation	X	X	X		X	X	X	
7B	Building on Pile Foundation, With Enclosures	X	X	X		X	X	X	

Notes:
A “2” in the content cells means the content damage functions were developed for both nonperishable and perishable items.
An “X” in both the Wave and Wave-Wall columns means the damage functions were developed for waves with a slab foundation and waves with a wall foundation.

1.3 Comparison of Expert Elicitation Results to Other Damage Functions

The coastal damage functions developed through the NACCS expert elicitation were compared to generic damage functions for residential structures provided in USACE Economic Guidance Memoranda (EGM) 01-03 and 04-01 and to the results of an expert elicitation conducted in 2002.

All of the damage functions yield estimates for inundation damage. However, only the NACCS and 2002 damage functions estimate wave and erosion damage. Both the NACCS and EGM damage functions estimate content damage, but it is important to note that they do so in different ways. The EGM damage functions model content damage as a percent of structure value. The NACCS damage functions model content damage as a percent of content value. In the comparisons drawn in this report between the EGM and NACCS content damage functions, a content-to-structure value ratio (CSVR) was applied to the EGM damage functions to convert the EGM damage values to a percent of content value. The 2002 damage functions do not include content damage.

EGM damage functions are limited to residential structures. The NACCS damage functions estimate damage to both residential and nonresidential structures. The 2002 elicitation did not specifically discuss nonresidential structures; however, the results can be extended to nonresidential structures of similar design and construction.

Different foundation characteristics were taken into account by each damage function. The EGM damage functions focused on residential structures with and without basements. However, the foundation type (crawl space or slab) for residential structures without basements was not specified. The 2002 elicitation focused on structures with crawl spaces and pile foundations, but not those with basements. The NACCS damage functions took a wider variety of foundation conditions into account than the 2002 and EGM damage functions.

Table 2 shows a comparison of damage mechanisms and structure characteristics for the three estimation methods.

Table 2. Comparison of NACCS, 2002 Elicitation, and EGM Damage Function Characteristics

Characteristic		NACCS Elicitation	2002 Elicitation	EGM 01-03 and EGM 04-01
Damage Mechanism	Wave Damage	X	X	
	Erosion Damage	X	X	
	Inundation Damage	X	X	X
Damage Category	Damage to Structure	X	X	X
	Damage to Contents	X		X
Number of Stories	One-Story	X	X	X
	Two or More Stories			X
	Two-Story	X		

Characteristic		NACCS Elicitation	2002 Elicitation	EGM 01-03 and EGM 04-01
Foundation Type	Shallow Foundation			X
	Basement	X		X
	Crawl Space	X	X	
	Slab	X		
	Pile Foundation		X	
	Open Pile Foundation	X	X	
	Closed Pile Foundation	X	X	
Usage	Nonresidential	X		
	Mixed Use	X		
	Residential	X		X

Note: "X" indicates that structure characteristic is discussed in listed report.

Table 3 shows comparisons between the NACCS damage functions and the data collected in the post-Hurricane Sandy damage survey conducted between December 2013 and February 2014. Unfortunately, content damage comparisons could be drawn only for inundation damage in prototypes 5A, Residential, 1-Story, No Basement; 5B, Residential, 2-Story, No Basement; 6A, Residential, 1-Story, With Basement; and 6B, Residential, 2-Story, With Basement. Comparisons of structural damage were more abundant, but these were typically limited to inundation damage. In addition, comparisons for erosion were also limited. A more detailed analysis of the comparison can be found in the NACCS *Physical Damage Function Summary Report*.

Table 3. Comparison of NACCS Prototypes and Damage Mechanisms with 2002 Elicitation, Survey Data, and EGM Damage Functions

NACCS Building Prototype	Damage Mechanism	CONTENTS			STRUCTURE		
		2002 Elicitation	Survey Data	EGM	2002 Elicitation	Survey Data	EGM
1A-1:, 1-Story Apartment, No Basement	Erosion						
	Inundation						
	Wave						
1A-3: 3-Story Apartment, No Basement	Inundation						
2: Commercial , Engineered Construction	Erosion						
	Inundation					X	
	Wave						

NACCS Building Prototype	Damage Mechanism	CONTENTS			STRUCTURE		
		2002 Elicitation	Survey Data	EGM	2002 Elicitation	Survey Data	EGM
3: Commercial, Pre/Non-Engineered Construction	Erosion						
	Inundation					X	
	Wave						
4A: Urban High Rise	Inundation						
4B: Beach High Rise	Erosion						
	Inundation						
	Wave						
5A: 1-Story Residence, No Basement	Erosion				X		
	Inundation			X	X	X	X
	Wave				X	X	
5B: 2-Story Residence, No Basement	Erosion						
	Inundation			X		X	X
	Wave					X	
6A: 1-Story Residence, With Basement	Erosion						
	Inundation			X		X	X
	Wave						
6B: 2-Story Residence, With Basement	Erosion						
	Inundation			X		X	X
	Wave					X	
7A: Building on Open Pile Foundation	Erosion				X		
	Inundation				X		
	Wave				X		
7B: Building on Pile Foundation, With Enclosures	Erosion						
	Inundation				X		
	Wave				X	X	

Note: “X” indicates that a similar prototype and damage mechanism are discussed in listed report.

The NACCS damage functions were compared to the results of the post-Hurricane Sandy damage survey. The surveyed structures were grouped into categories that corresponded to the prototype categories. A scatterplot showing the percent damage and depth of flooding for each structure in the category was plotted on the same graph as the NACCS damage functions. An assessment of the comparisons with survey damage is provided in Table 4.

Table 4. Assessment of Survey Data

Damage Mechanism	NACCS Building Prototype	Assessment of Comparison	Notes
Inundation	2: Commercial, Engineered Construction	Poor Comparison, but data are limited	Limited data; surveys show less damage than NACCS damage functions.
	3: Commercial, Pre/Non-Engineered Construction	Good Comparison	Data are extensive and prototype comparison seemed reasonable.
	5A: 1-Story Residence, No Basement	Poor Comparison	Data are extensive and show more damage per level than the elicitation damage functions.
	5B: 2-Story Residence, No Basement	Poor to Fair Comparison	Data points do pass though the NACCS damage functions, but the trend of the data is inconclusive. Damage functions and data points overlap, but the trend of the data is hard to read.
	6A: 1-Story Residence, With Basement	Poor to Fair Comparison, but data are limited	Data are limited, and there are a few outliers.
	6B: 2-Story Residence, With Basement	Fair to Good Comparison	Fit could be improved by eliminating some outlier points.
Wave	5A: 1-Story Residence, No Basement	Fair to Good Comparison	Data tend to follow NACCS damage function quite well for the minimum level, but not for the most likely.
	5B: 2-Story Residence, No Basement	Poor to Fair Comparison	Data are extensive and show more damage per foot below the first floor, and less damage per foot above the first floor, than the elicitation damage functions.
	6B: 2-Story Residence, With Basement	Fair to Good Comparison	Data are limited, but fit could be improved by eliminating two outlier points.
	7B: Building on Pile Foundation, With Enclosures	Poor Comparison.	There are differences between the enclosure assumptions made during the elicitation and those made during the survey, as a leftward shift of the survey data by 8.0 feet would produce a better fit. Otherwise, damage functions do not intersect data at all: data show relatively little damage, whereas damage functions show complete destruction. The structures that match the prototype characteristics better may have been completely destroyed, making it impossible to collect data for them through the survey.

The relatively limited data and some poor comparisons led to the decision to seek additional sources and data for the comparative analysis.

2 Substantial Damage Estimates

Following disaster events, FEMA supports communities by conducting Substantial Damage estimate evaluations. The evaluations are conducted on individual structures to estimate the percent damage from the event. The percent damage estimate is then used to determine whether certain rebuilding requirements will need to be met.

Substantial Damage estimates completed following Hurricane Sandy were evaluated and compared to the results of the NACCS expert elicitation.

2.1 Base Data

The NACCS team gathered FEMA Substantial Damage information, evaluated the survey areas compared to the area covered by the Substantial Damage information, and adjusted the data accordingly. More details are provided below.

2.1.1 Substantial Damage Estimates

During a Substantial Damage evaluation, a field team inspects certain elements of a damaged structure and estimates the percent damage to each element. The information is incorporated into the Substantial Damage Estimator (SDE) tool developed by FEMA. The tool uses algorithms to estimate the total percent damage to the structure based on the estimated damage to the individual elements and the characteristics of the structure. The tool and associated documentation are available at https://www.fema.gov/media-library/assets/documents/18692.

The Substantial Damage estimates for residential structures are calculated based on the estimated damage to 12 elements:

- Foundation
- Superstructure
- Roof Covering
- Exterior Finish
- Interior Finish
- Doors and Windows
- Cabinets and Countertops
- Floor Finish
- Plumbing
- Electrical
- Appliances
- Heating, Ventilation, and Air Conditioning (HVAC)

The Substantial Damage estimates for nonresidential structures are calculated based on the estimated damage to seven elements:

- Foundation
- Superstructure
- Roof Covering
- Interior
- Plumbing
- HVAC
- Electrical

2.1.2 Survey Areas

The NACCS team obtained and evaluated the results of Substantial Damage estimate evaluations conducted in New Jersey and New York after Hurricane Sandy. Figure 1 shows the locations of the Substantial Damage estimates used for this analysis. With the exception of Long Beach Island in New Jersey, there is very little overlap with the location of the damage surveys conducted before the expert elicitation session.

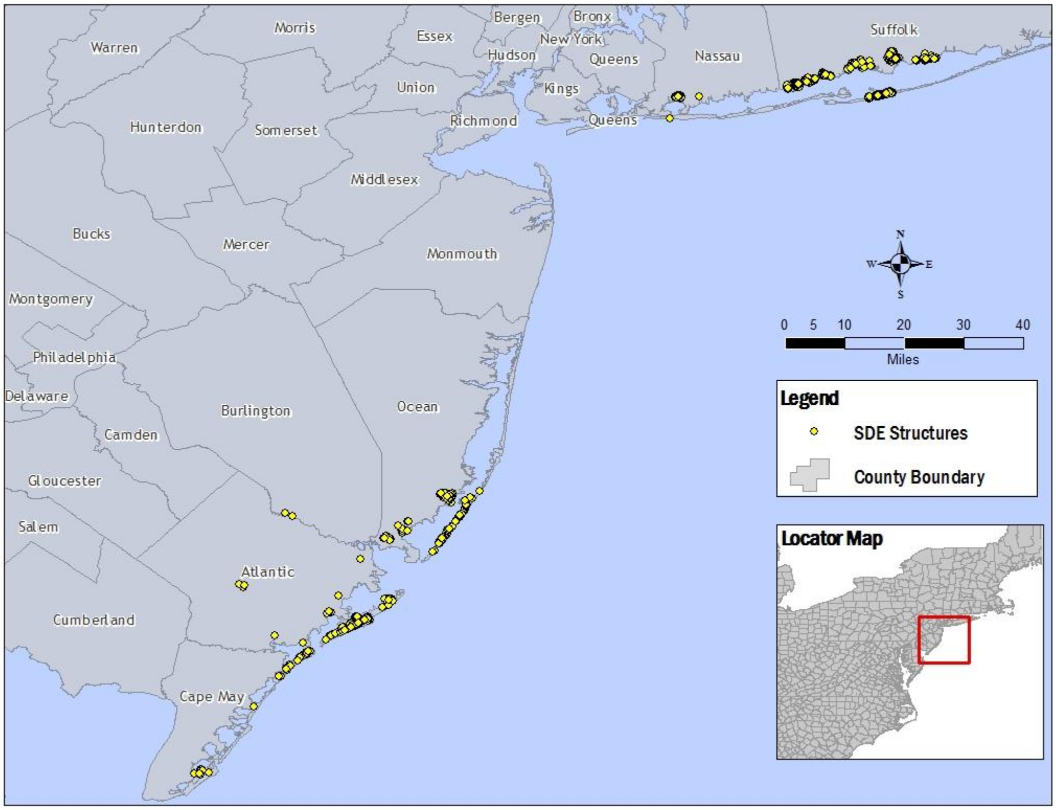

Figure 1. Areas Covered by the Substantial Damage Estimates

Because Substantial Damage estimates are confidential, individual records cannot be provided, and all findings are aggregated.

2.1.3 Adjustments to Data

The NACCS team obtained 4,154 records. The data were reviewed to remove unusable data, such as records that were missing key pieces of information (e.g., foundation type, number of stories). Based on that review, 562 records were removed from the data set.

The Substantial Damage data incorporated damage from wind into the total structure damage estimate. The following actions were taken to review the impacts of wind and adjust the data to account for only flood:

- The records were reviewed to identify structures that received only wind-related damage. However, none of the structures were identified as having sustained only wind-related damage.
- The records were reviewed to identify structures that had a high percentage of damage to the roof element but relatively little damage to the other elements, which would indicate the damage was primarily wind related. Based on this review, 14 structures were removed from the analysis.
- The impact of the roof element was reviewed in the SDE tool to estimate its significance on the total percent damage of a structure. The review indicated that damage to roofs only contributes a small percentage to the total percent damage estimate. The percent of the roof damage was typically less than 2 percent of the total damages, with almost all less than 4 percent. Because roof damage only contributed a small percent to the total percent damage, no adjustments were made to the results.

The finding of relatively little wind-related damage in the Substantial Damage estimates is consistent with the nature of Hurricane Sandy. Because Hurricane Sandy was a tropical storm at landfall, it was not considered a major wind event.

After removing unsuitable data, 3,578 records remained in the data set and were evaluated. Table 5 summarizes the numbers of records that were removed and evaluated.

Table 5. Records Removed and Evaluated

State	Original Number of Records	Records Removed from Analysis	Records Evaluated
New Jersey	355	8	347
New York	3,799	568	3,231
Total	**4,154**	**576**	**3,578**

2.2 Method of Analysis

To evaluate the NACCS expert elicitation results in relation to the Substantial Damage estimates, the data were disaggregated by prototype and damage mechanism, and inferences were made regarding content damage.

2.2.1 Prototypes

Substantial Damage estimate data for the structures were grouped according to the 12 building prototypes. The prototypes were assigned based on the “StructureType,” “FoundationType,” and “StoryType” fields in the Substantial Damage estimate records. Because Substantial Damage estimates are primarily conducted for residential structures, almost all of the records were for residential structures. Records were matched to prototype 5A, Residential, 1-Story, No Basement; 5B, Residential, 2-Story, No Basement; 6A, Residential, 1-Story, With Basement; 6B, Residential, 2-Story, With Basement: 7A, Building on Open Pile Foundation; and 7B, Building on Pile Foundation, with Enclosures.

2.2.2 Damage Mechanism

The records were further disaggregated for the inundation, erosion, and wave damage mechanisms. Because Substantial Damage estimate data only specify the damage by flood, wind, or both, the following criteria were used to assign damage mechanisms.

Wave Damage

Because the Substantial Damage estimates do not separately record wave-related damage, FEMA data were used to identify where waves could have contributed to the total damage estimate. A geographic information system (GIS) was used to identify where the structures are located in relation the modeled 1-percent chance event (100-year) Limit of Moderate Wave Action[1] (LiMWA) for the 1.5-foot wave height cutoff. Structures located on the ocean side of the LiMWA were assumed to have wave damage. In addition, a coastal engineer manually reviewed where the structures were located in relation to the LiMWA. Because Hurricane Sandy exceeded the 1-percent chance event storm in many areas, structures landward of the LiMWA were individually reviewed. Fetch size, seaward obstructions, 1-percent chance event and 0.2 percent chance event (500-year) wave heights were evaluated in deciding which structures had potential wave damage.   Figure 2 provides an example of structures that were assumed to have wave damage.

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[1] LiMWA is a line modeled by FEMA to show the inland limit of the area expected to receive 1.5-foot or greater breaking waves during the 1-percent chance event. Additional information can be found at http://www.fema.gov/media-library-data/1403553277396-e137edb5f4736e5ab59f144d8a3159ad/FPM_1_Pager_LiMWA_Final_061914.pdf

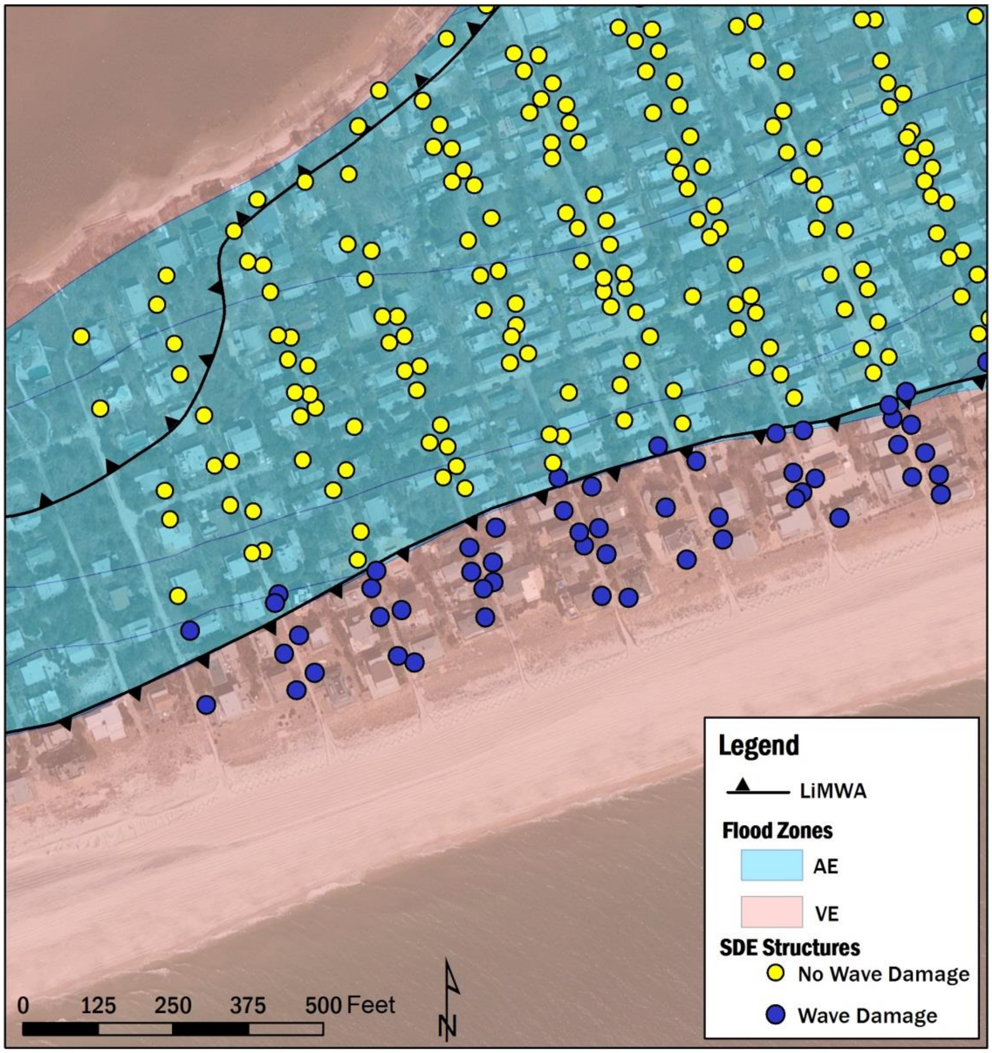

Figure 2. Example of Structures Assumed to Have Wave Damage

The wave height at the identified structures was initially estimated by calculating the Depth-Limited Wave (DLW), which provided a proxy for estimating overland wave effects at each structure. This approach was used in Hurricane Katrina Recovery maps and has been successfully applied in many other areas of coastal engineering practice. It relies solely on the depth-limiting relationships for breaking waves. In cases where the ground slopes away from the shoreline, the DLW may overestimate the actual wave height. Smaller waves at the structure would, therefore, not be in a breaking condition. Non-breaking waves would typically have a lower wave crest and exert much less force on the structure. Because the DLW calculated using the modeled 1-percent chance event stillwater elevation (SWEL) overstates the actual wave crest at many structures, the wave height was adjusted to represent approximately 70 percent of the wave being above the SWEL:

$$DLW = H_c * 0.70$$

Controlling wave height (H_c) = 0.78*$depth$ (depth was calculated by subtracting 3-meter resolution topography data from 1-percent-chance event modeled SWEL data.

An alternative approach to identifying the total water level would have been to use the flood depths collected with the SDE tool. However, the SDE tool does not specify whether the reported flood depths are the SWEL or the total water level (including wave effects). The individuals conducting the Substantial Damage estimates would not likely separate wave effects from the SWEL, so the reported depths likely include the wave height.

Erosion

Erosion damage is not captured by the SDE tool. Other available data, such as foundation damage and the location of the structure in relation to the coast, were investigated as ways to infer whether the damage to a structure was caused by erosion. However, these ways did not provide an adequate level of certainty of where erosion damage could have occurred. Therefore, the erosion damage mechanism was not assigned to any of the structures.

Inundation

The structures that were not assigned as having wave or erosion damage were considered to have received damage primarily from inundation.

Table 6 summarizes the structures assigned to each prototype and damage mechanism.

Table 6. Substantial Damage Estimate Records Assigned to Each Prototype and Damage Mechanism

Prototype	Total	Damage Mechanism	
		Inundation	Wave
5A: 1-Story Residence, No Basement	1,122	954	168
5B: 2-Story Residence, No Basement	1,745	1,544	201
6A: 1-Story Residence, With Basement	87	84	3
6B: 2-Story Residence, With Basement	493	483	10
7A & 7B: Building With Pile Foundation	131	44	87
Total	**3,578**	**3,109**	**469**

2.2.3 Content Damage

The SDE tool does not provide estimates for content damage, so direct comparison to the NACCS expert elicitation results were not possible. However, using the Substantial Damage estimate data, inferences were made about the amount of damage to the contents. The content damage for structures was based on the percent damage to selected elements listed in Section 2.1.1, as described below.

Although considered part of the structure, the Appliances, Cabinet and Countertops, and Interior Finish elements were selected to represent content damage. Because these elements are impacted by interior flooding, they indicate the extent of damage to the interior of the structure and are being used as a proxy for content damage. Although the Floor Finish element is also an indicator of interior flooding, it was not selected because it could be 100 percent damaged from an inch of water, which would not be representative of overall interior damage. The Appliances and Cabinets and Countertops elements can also be damaged with relatively low flooding depths, but they provide a better indication of overall interior damage for various depths of flooding. Because damage related to the Interior Finish element is associated with flood depth and duration, it was considered to be a fairly good indicator of overall interior damage.

To derive the overall content damage, the percent damage recorded for the Appliances, Cabinet and Countertops, and Interior Finish elements were added together, with double weighting given to the Interior Finish element. The total was divided by 4 to estimate the percent content damage. This is represented by the following formula:

% Content Damage = (% damage to Appliances + % damage to Cabinets and Countertops + (2 x % damage to Interior Finish)) / 4

The formula was reviewed by the NACCS team and thought to be a reasonable representation of content damage given the available data.

2.3 Comparison to Expert Elicitation Results

The results of the Substantial Damage estimates for each prototype and damage mechanism are displayed on Figures 3 through 28, which also show the comparison to the NACCS expert elicitation results. The results were reviewed to identify how well the physical damage function for each prototype and damage mechanism conform to the Substantial Damage estimates.

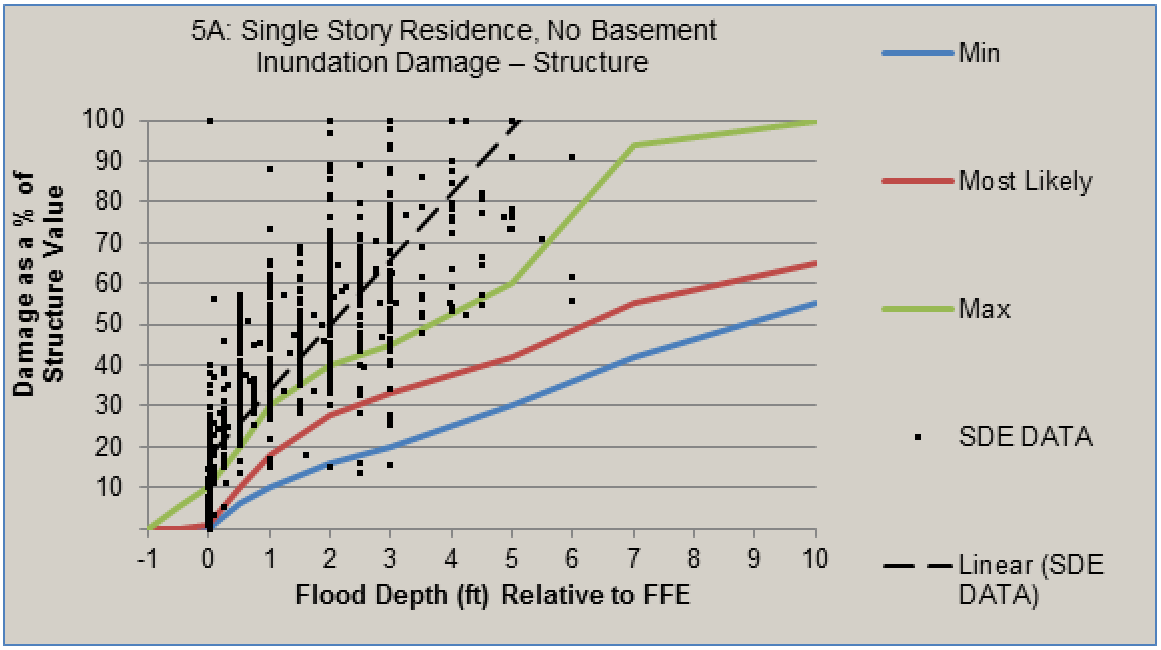

Figure 3. 5A: 1-Story Residence, No Basement Structure Comparison - Inundation

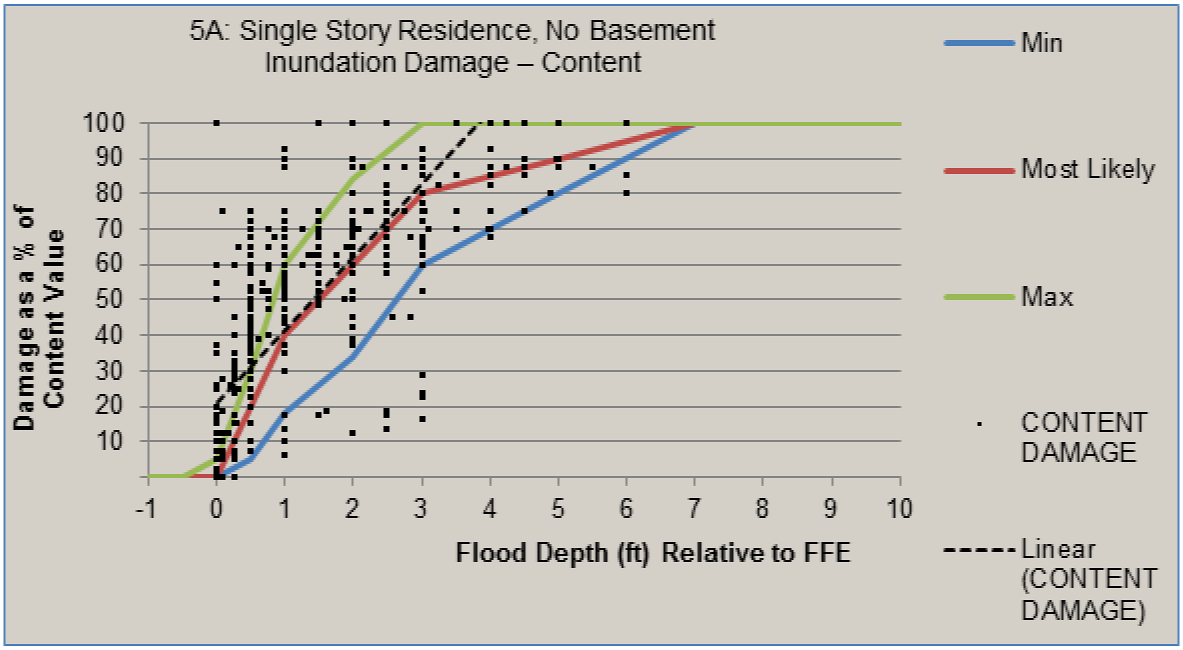

Figure 4. 5A: 1-Story Residence, No Basement Content Comparison – Inundation

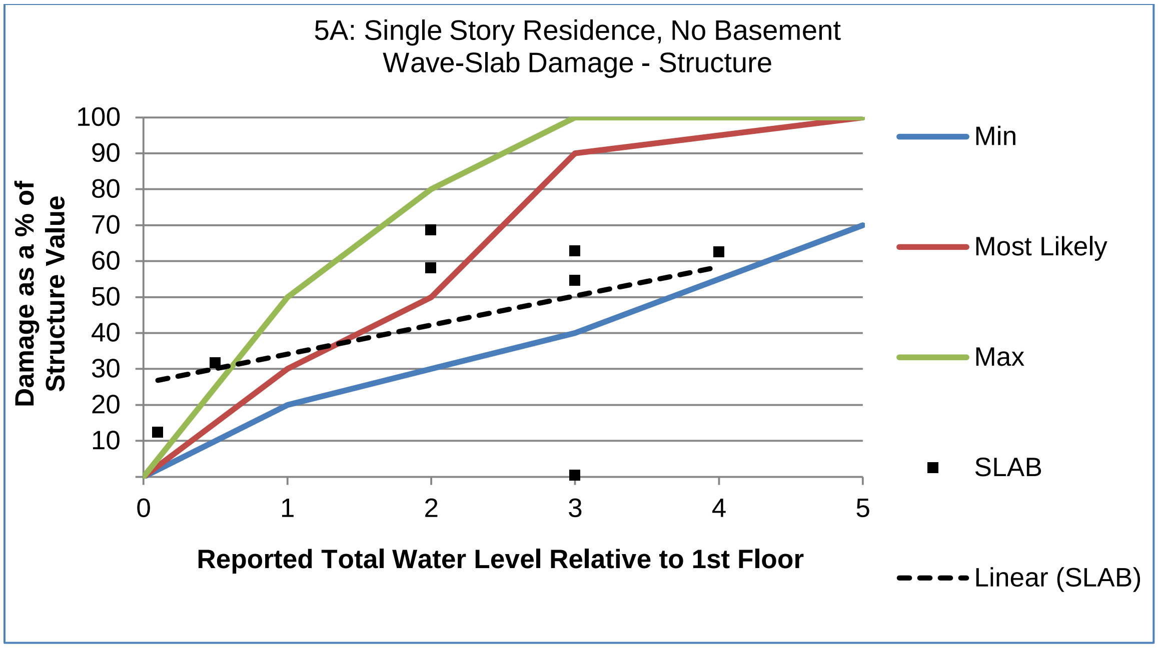

Figure 5. 5A: 1-Story Residence, No Basement Structure Comparison – Wave (Slab)

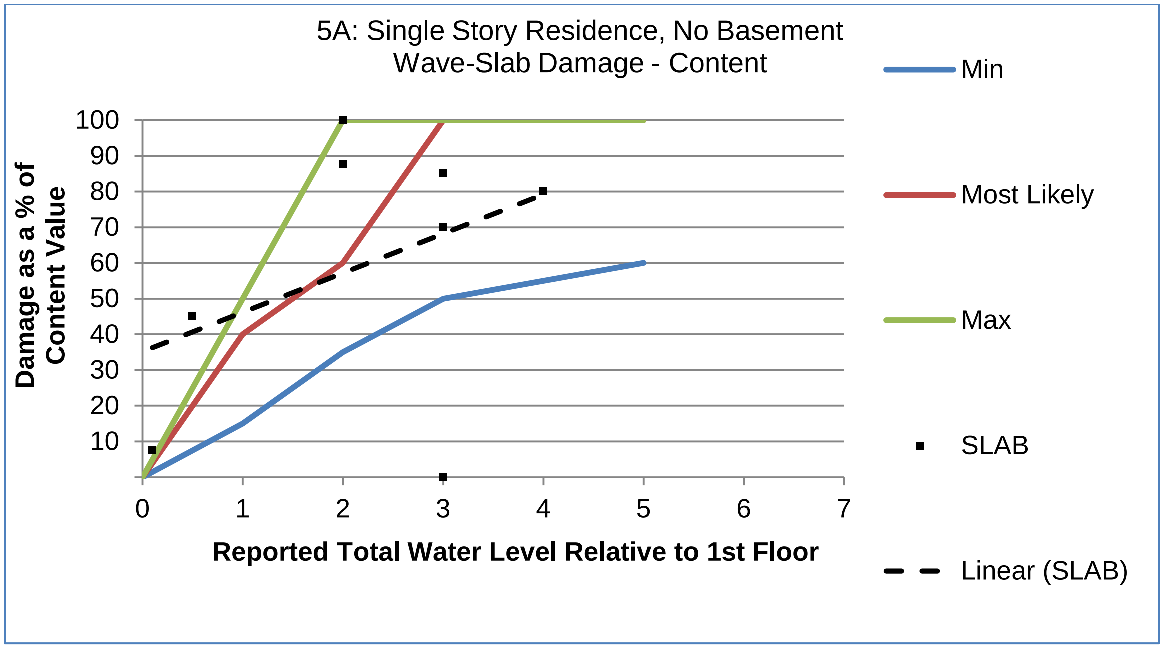

Figure 6. 5A: 1-Story Residence, No Basement Content Comparison – Wave (Slab)

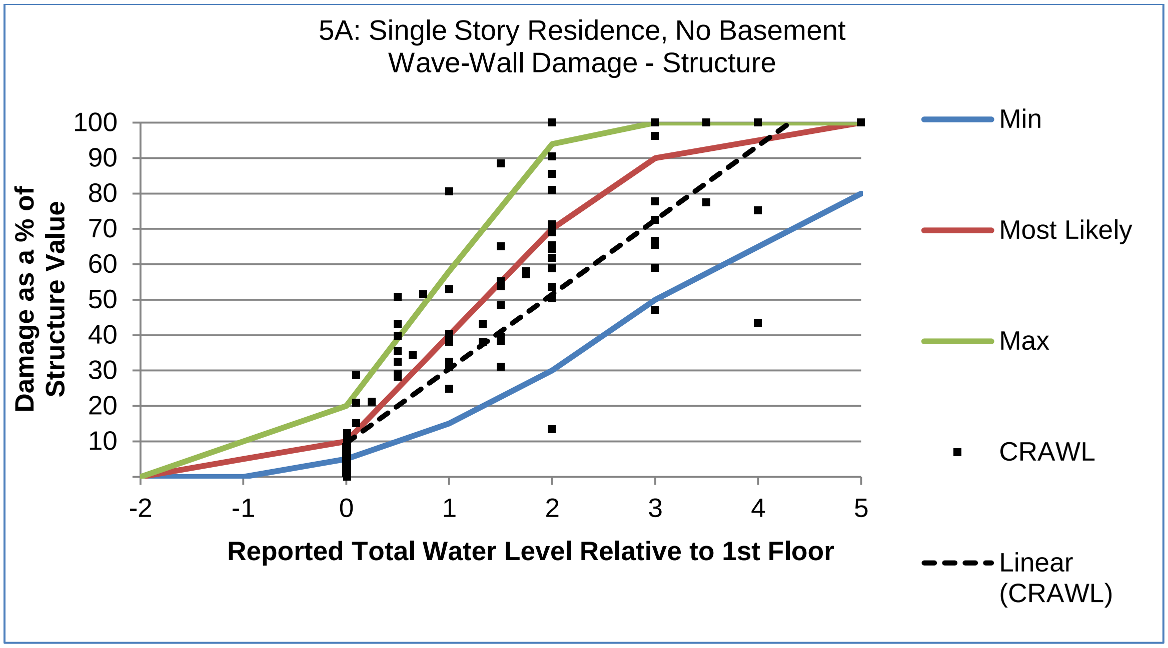

Figure 7. 5A: 1-Story Residence, No Basement Structure Comparison – Wave (Wall)

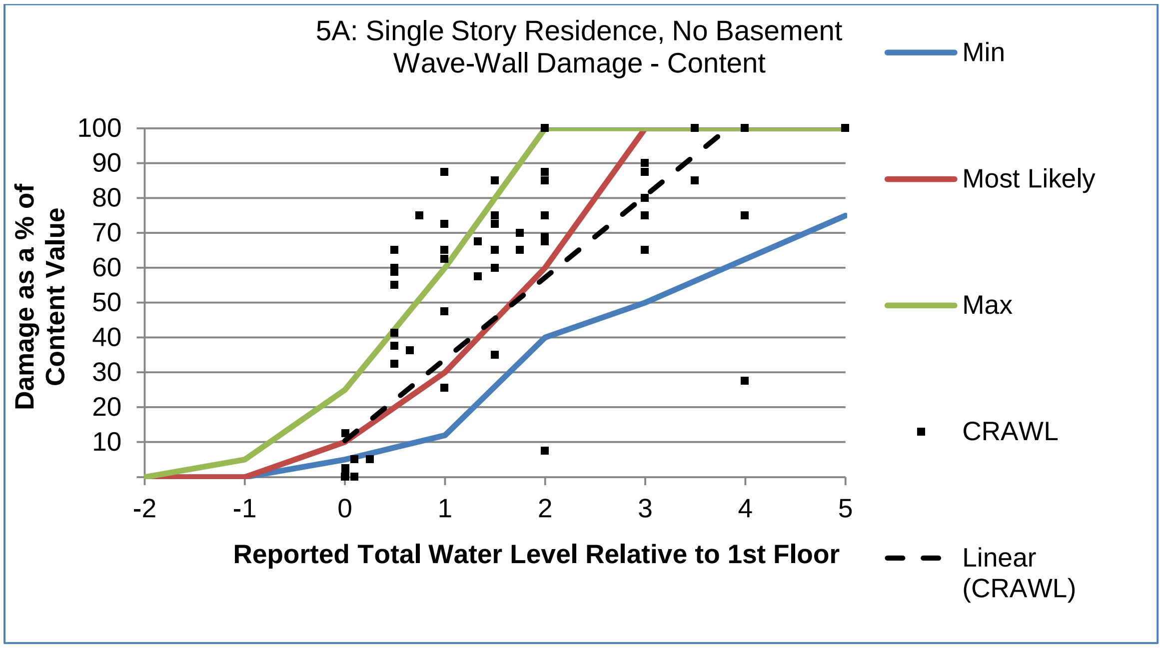

Figure 8. 5A: 1-Story Residence, No Basement Content Comparison – Wave (Wall)

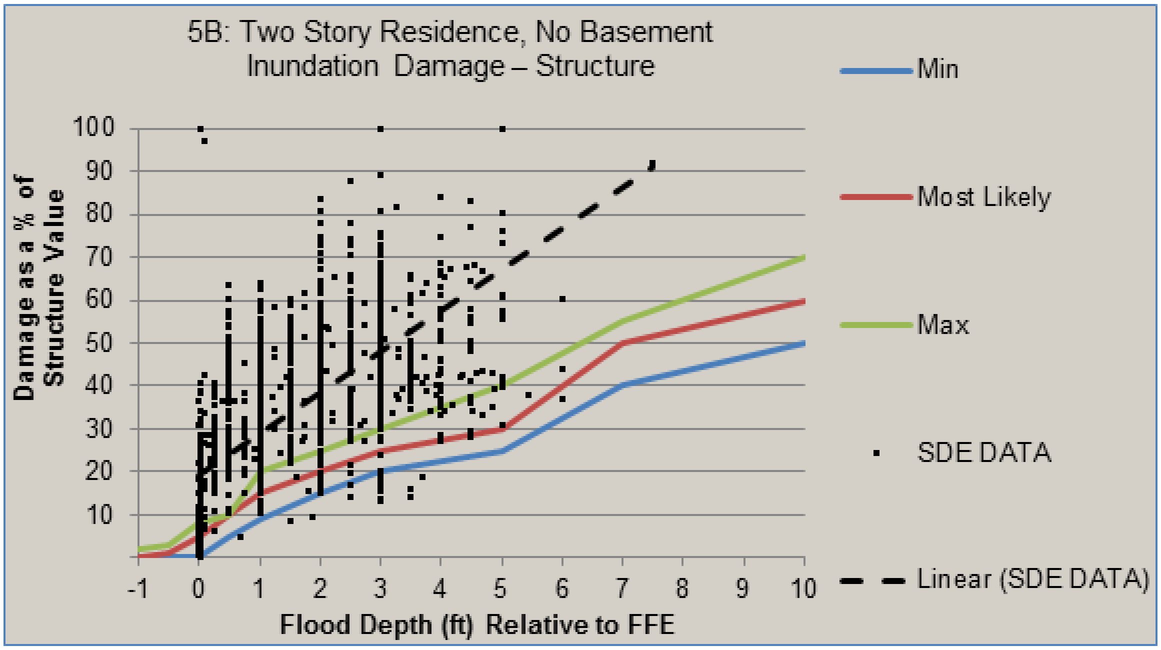

Figure 9. 5B: 2-Story Residence, No Basement Structure Comparison – Inundation

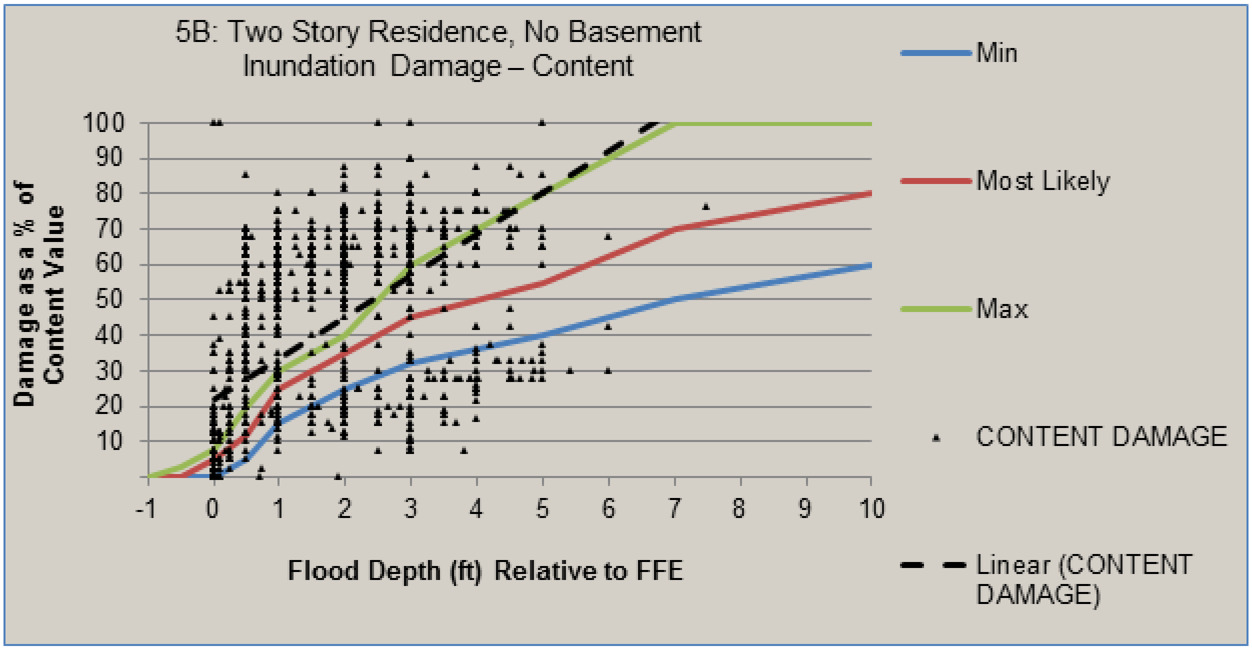

Figure 10. 5B: 2-Story Residence, No Basement Content Comparison – Inundation

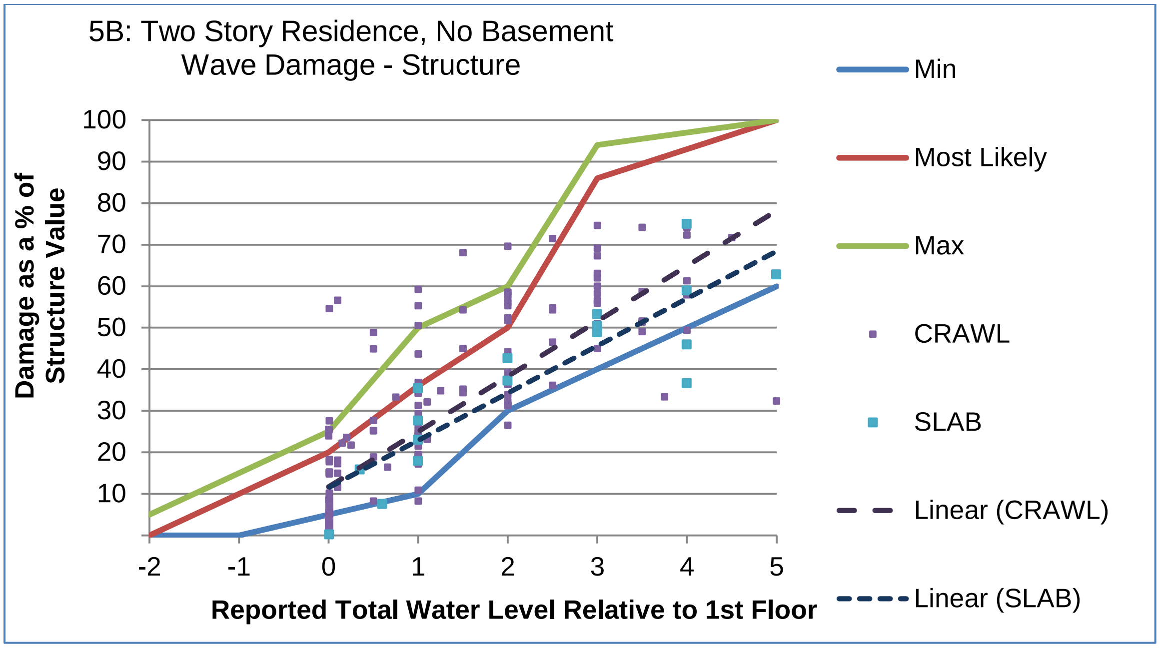

Figure 11. 5B: 2-Story Residence, No Basement Structure Comparison – Wave

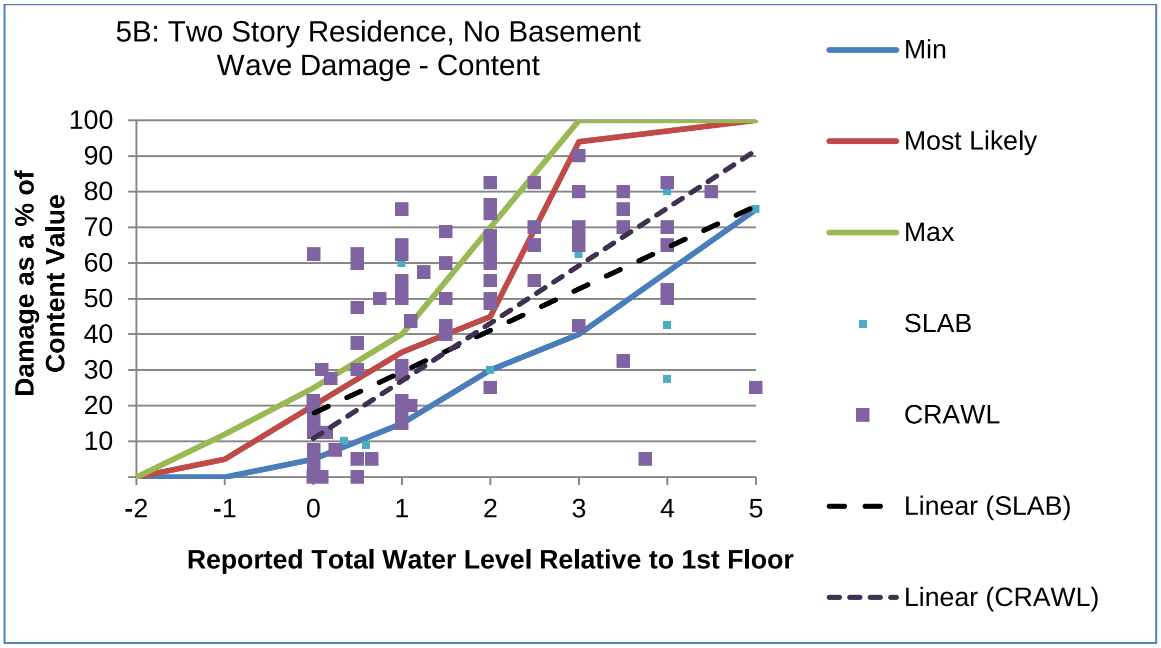

Figure 12. 5B: 2-Story Residence, No Basement Content Comparison – Wave

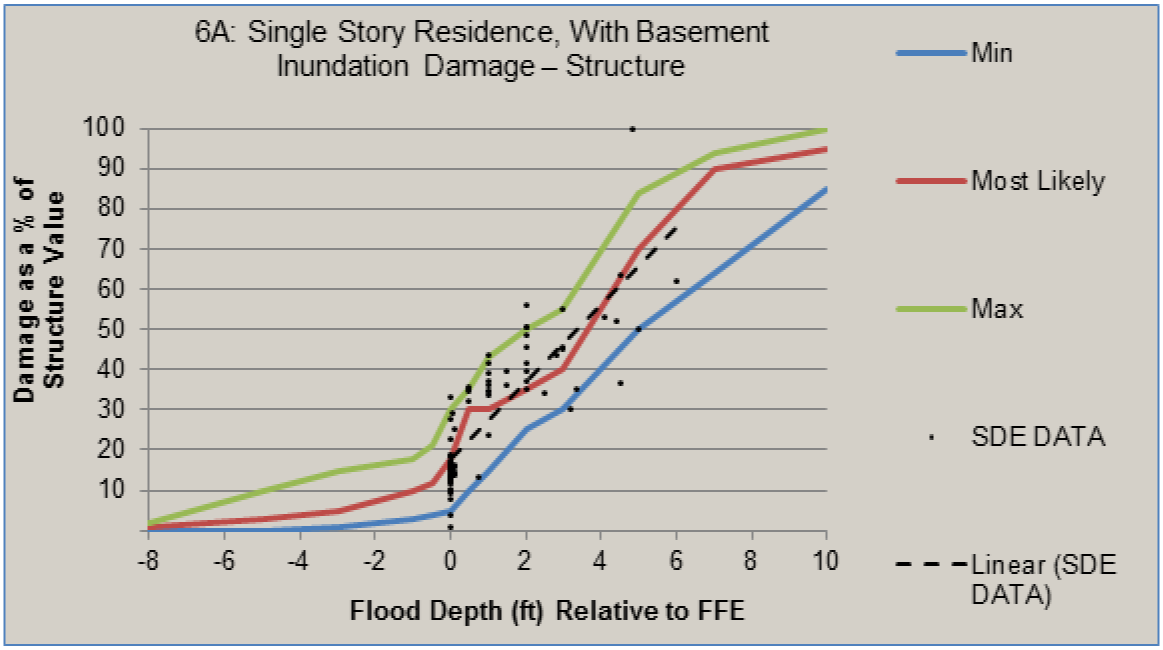

Figure 13. 6A: 1-Story Residence, With Basement Structure Comparison – Inundation

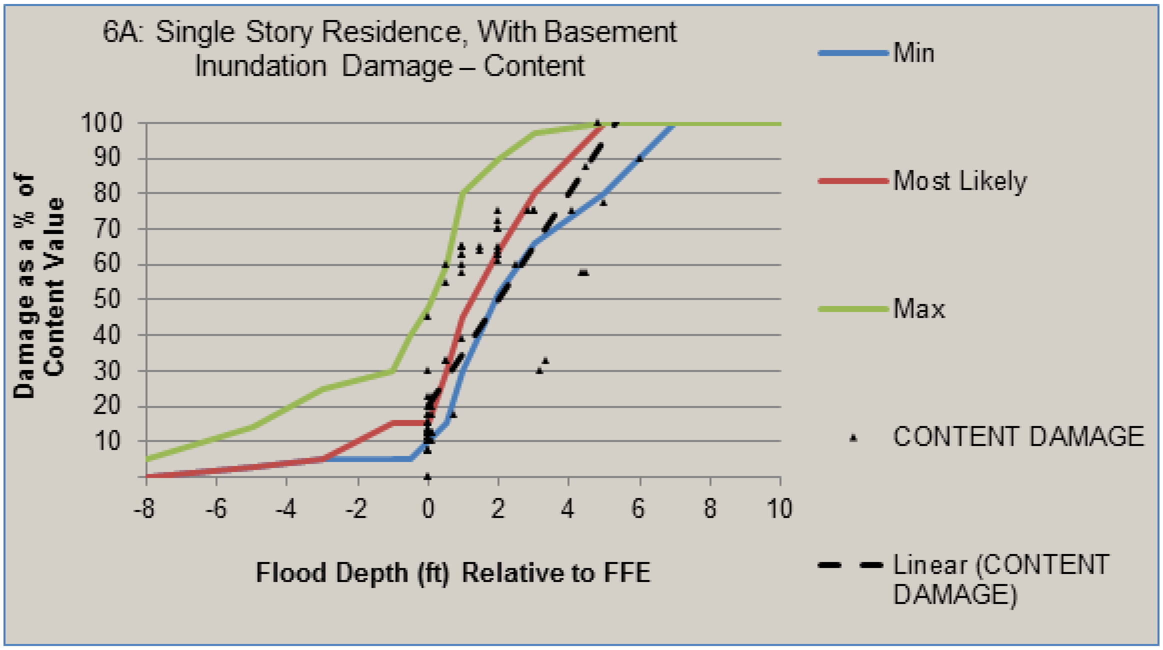

Figure 14. 6A: 1-Story Residence, With Basement Content Comparison – Inundation

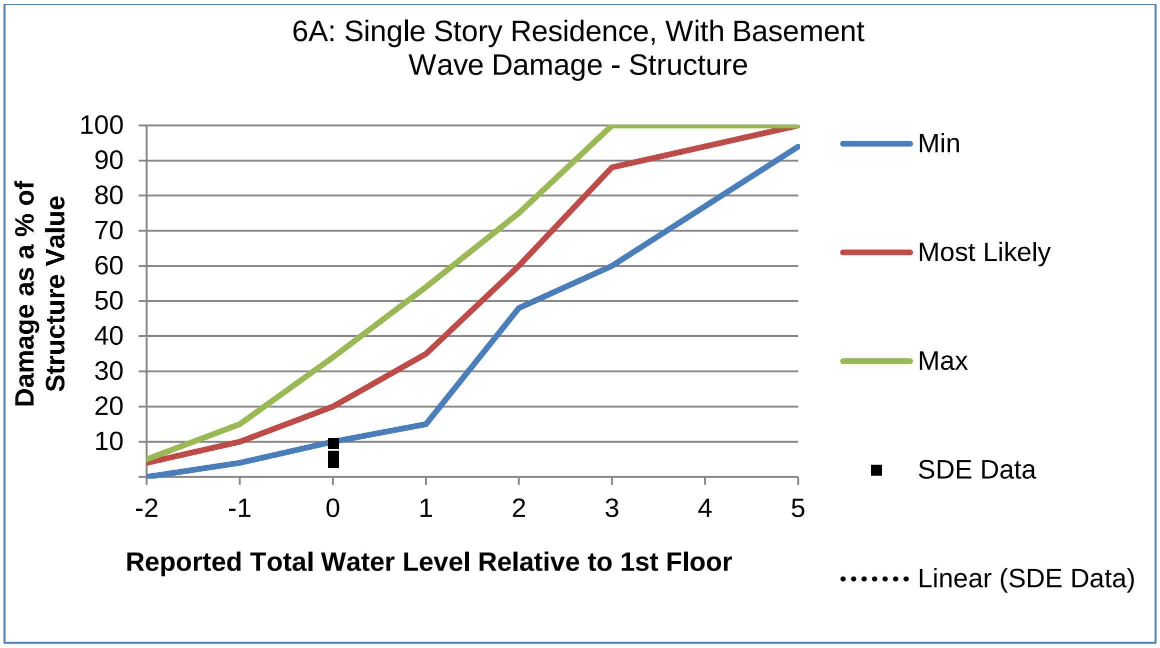

Figure 15. 6A: 1-Story Residence, With Basement Structure Comparison – Wave

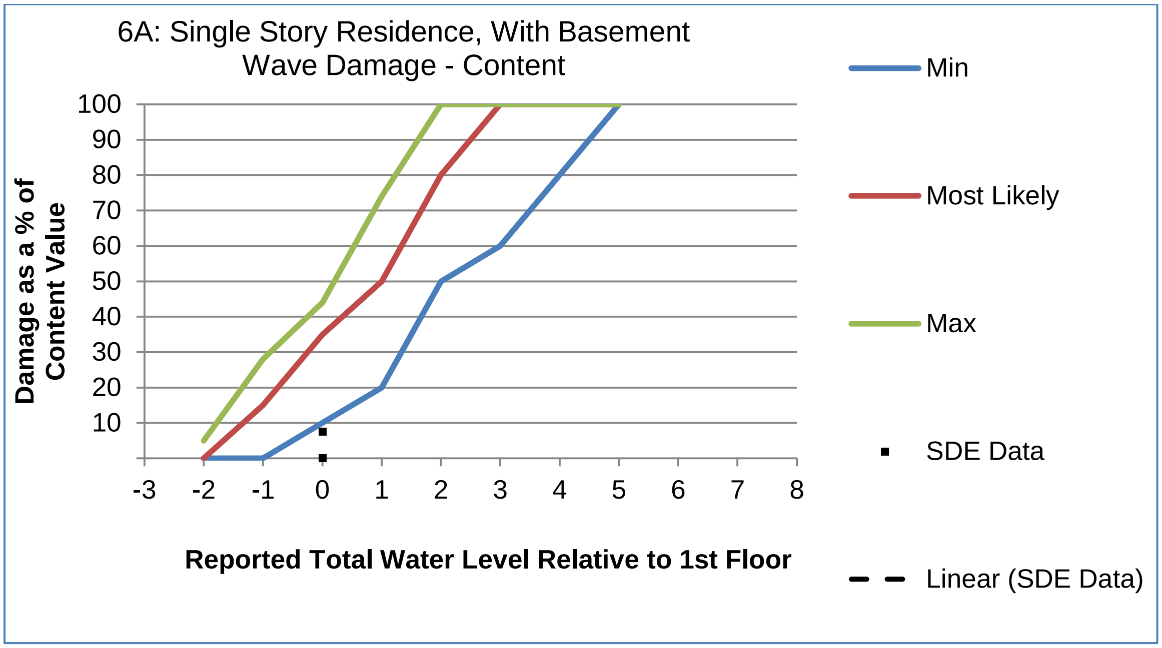

Figure 16. 6A: 1-Story Residence, With Basement Content Comparison – Wave

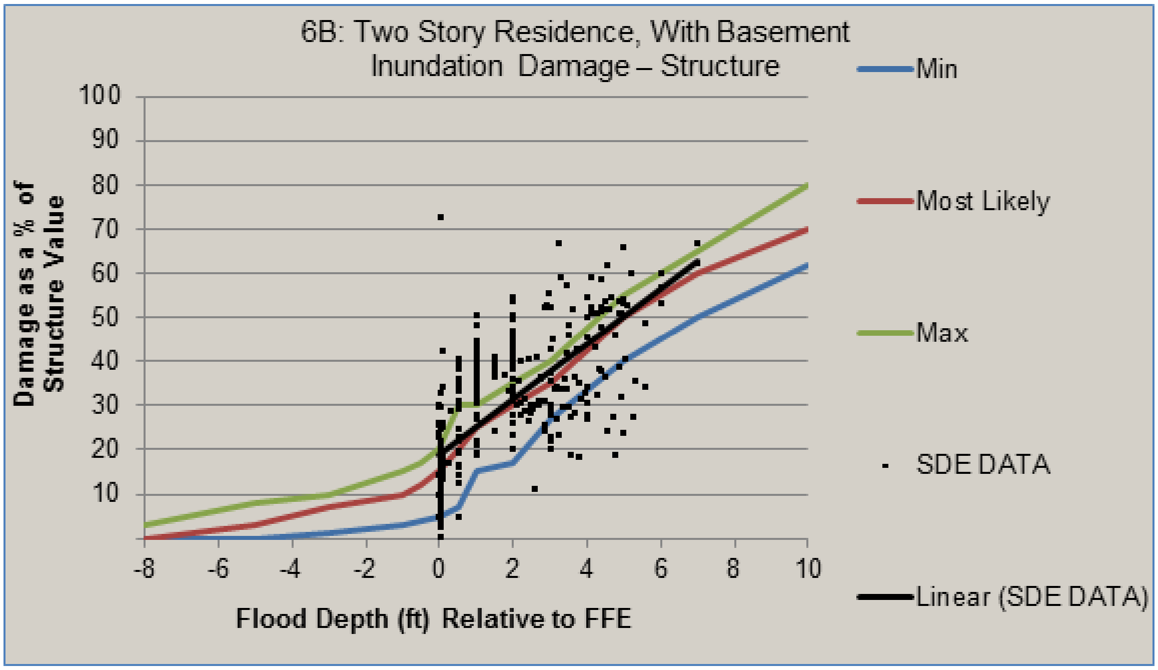

Figure 17. 6B: 2-Story Residence, With Basement Structure Comparison – Inundation

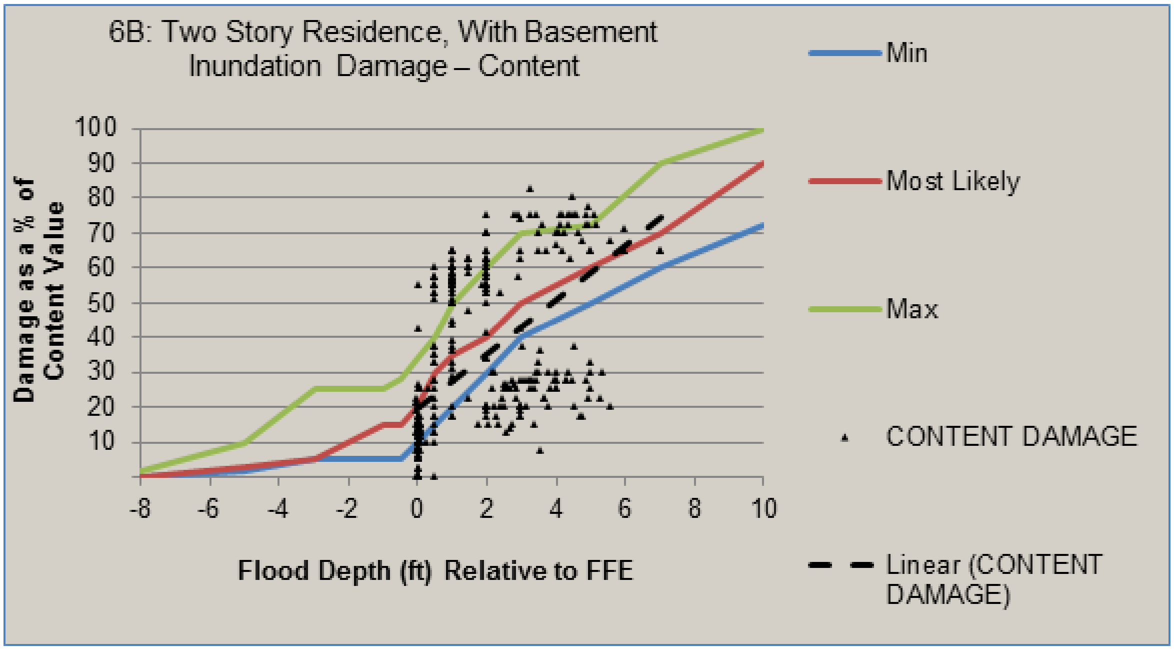

Figure 18. 6B: 2-Story Residence, With Basement Content Comparison – Inundation

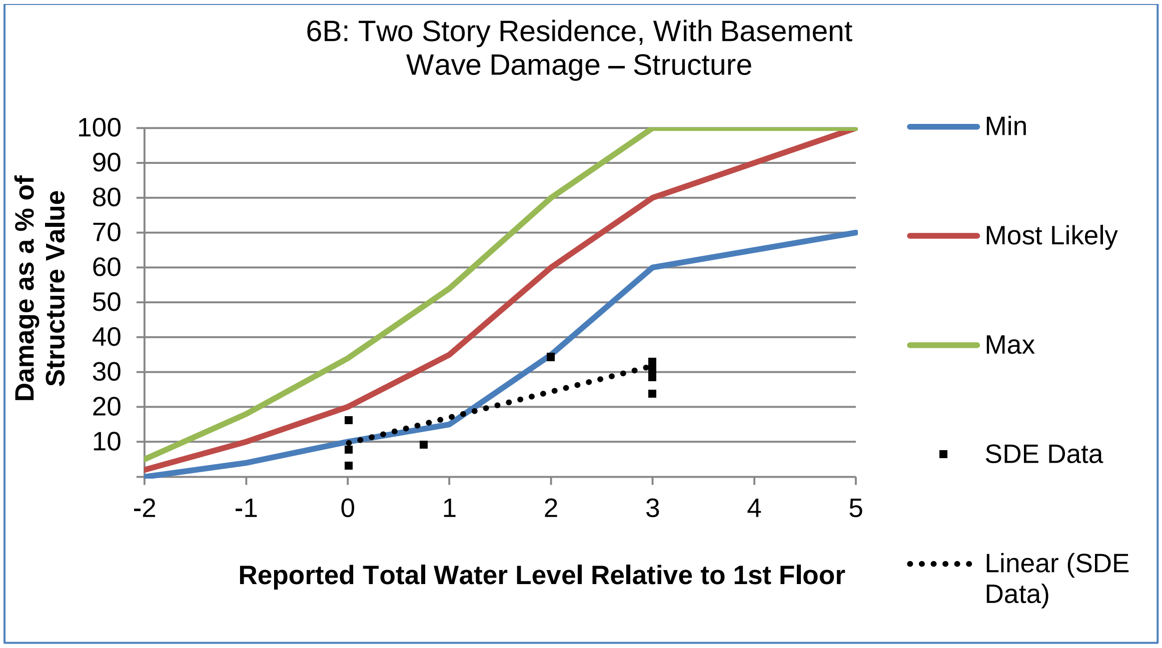

Figure 19. 6B: 2-Story Residence, With Basement Structure Comparison – Wave

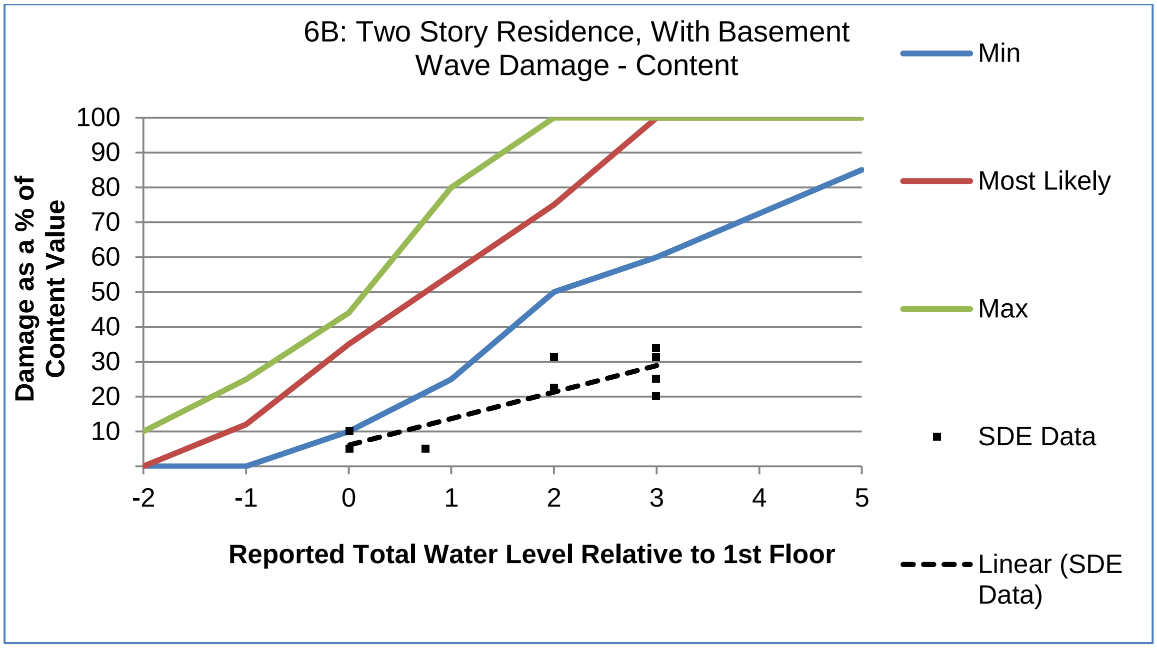

Figure 20. 6B: 2-Story Residence, With Basement Content Comparison – Wave

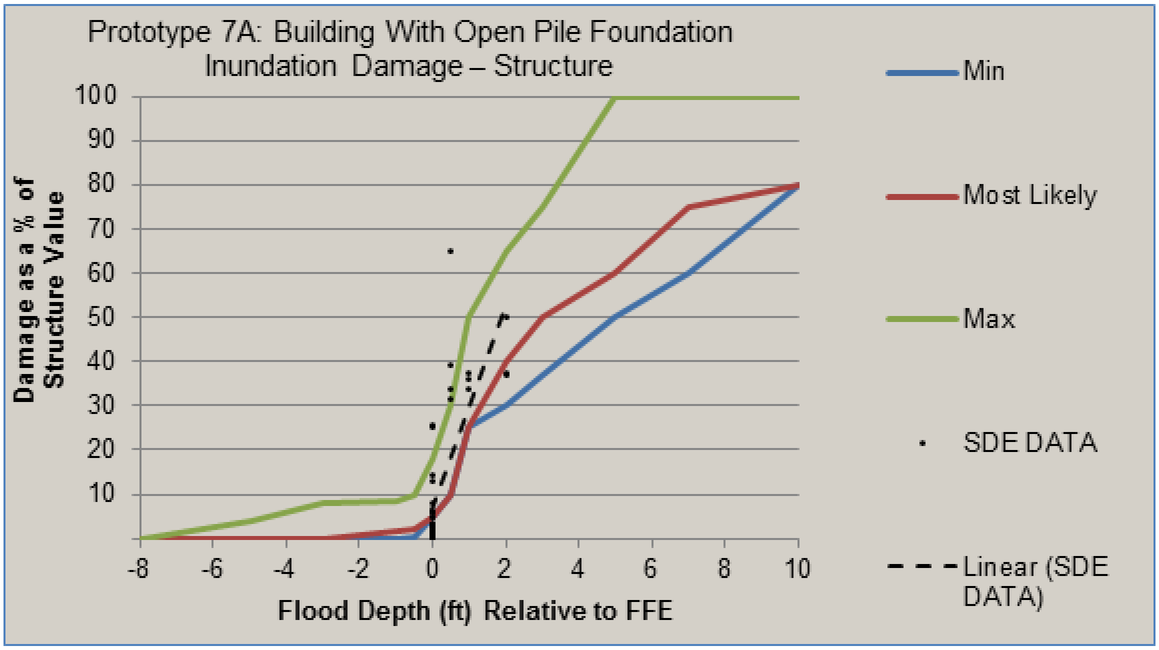

Figure 21. 7A: Building On Open Pile Foundation Structure Comparison – Inundation

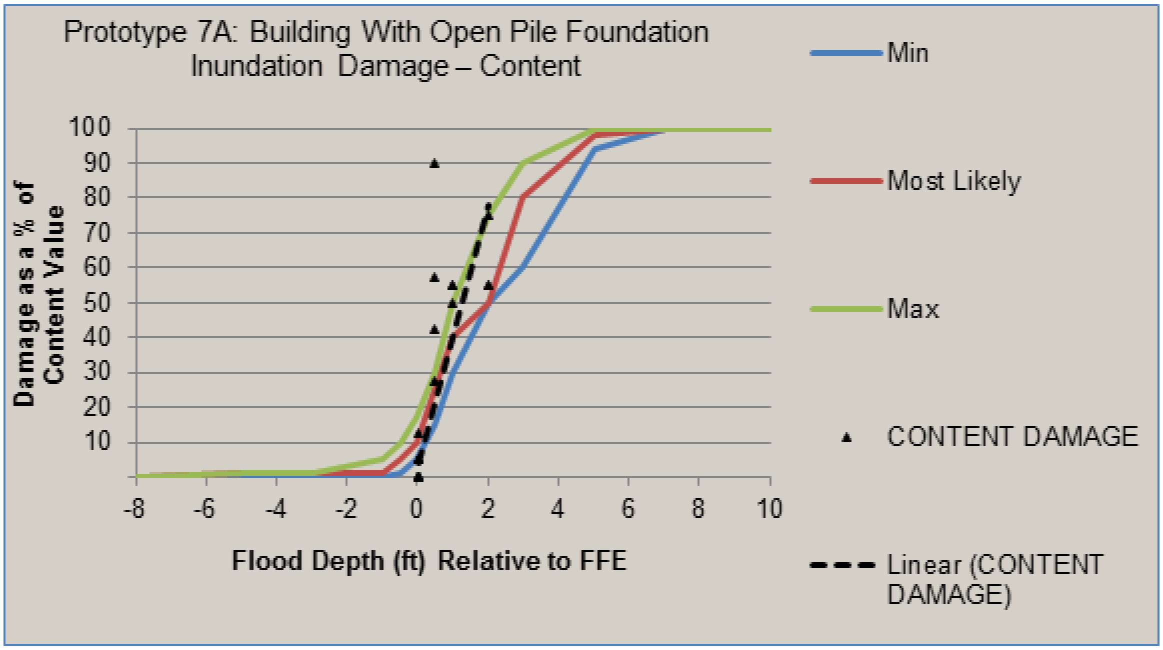

Figure 22. 7A: Building On Open Pile Foundation Content Comparison – Inundation

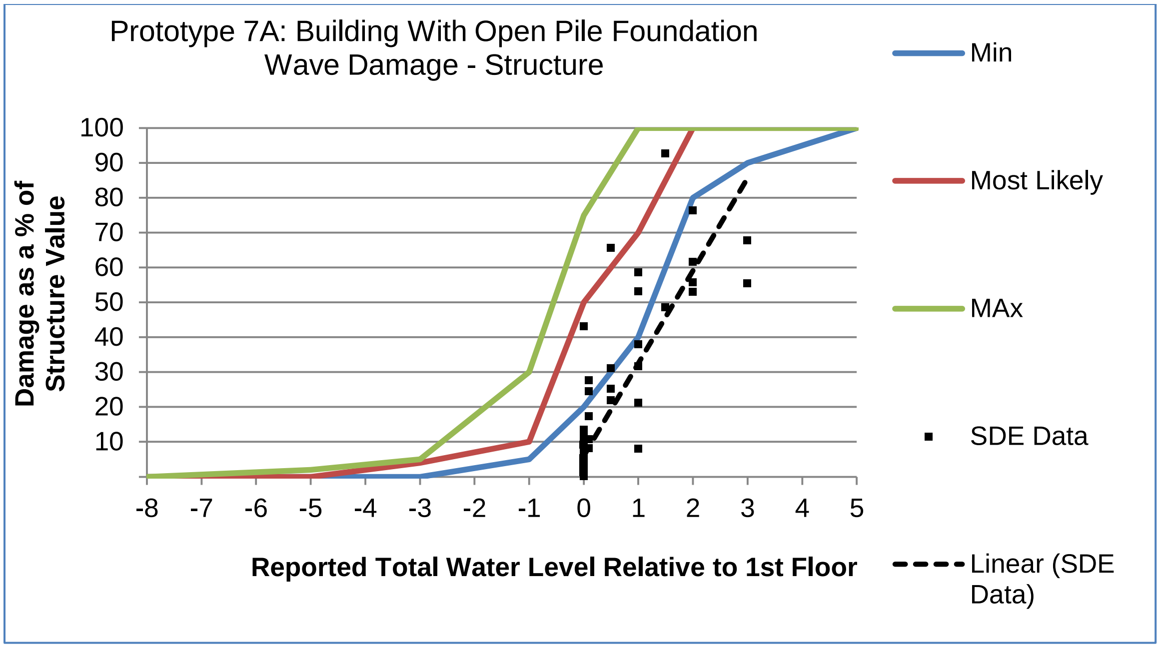

Figure 23. 7A: Building On Open Pile Foundation Structure Comparison – Wave

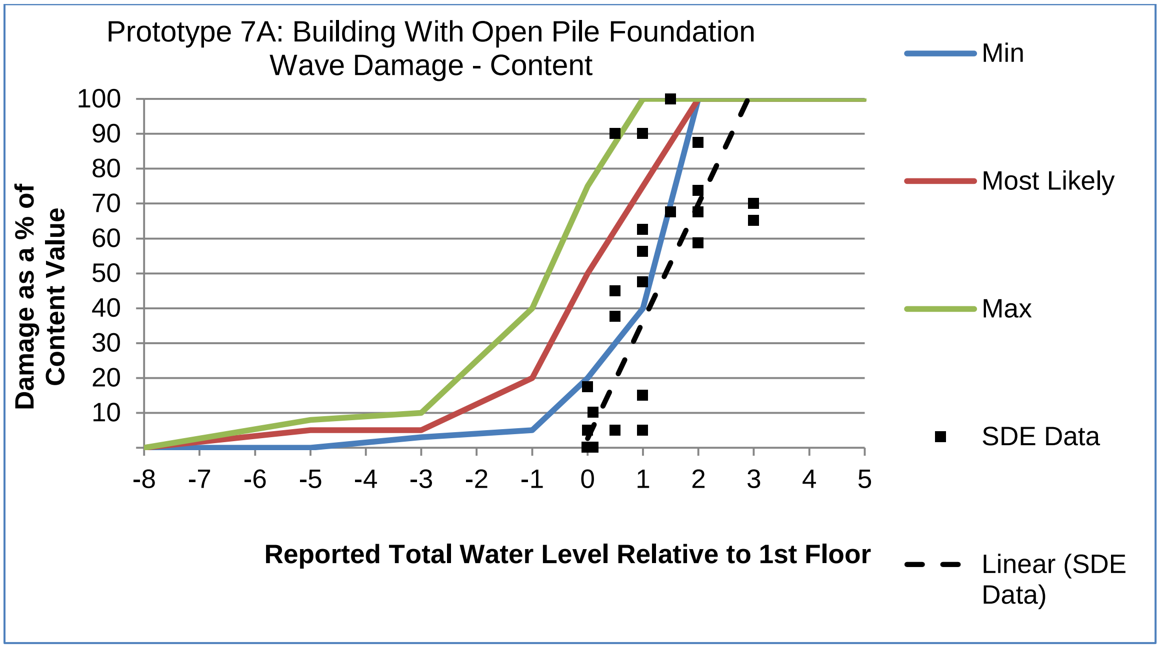

Figure 24. 7A: Building On Open Pile Foundation Content Comparison – Wave

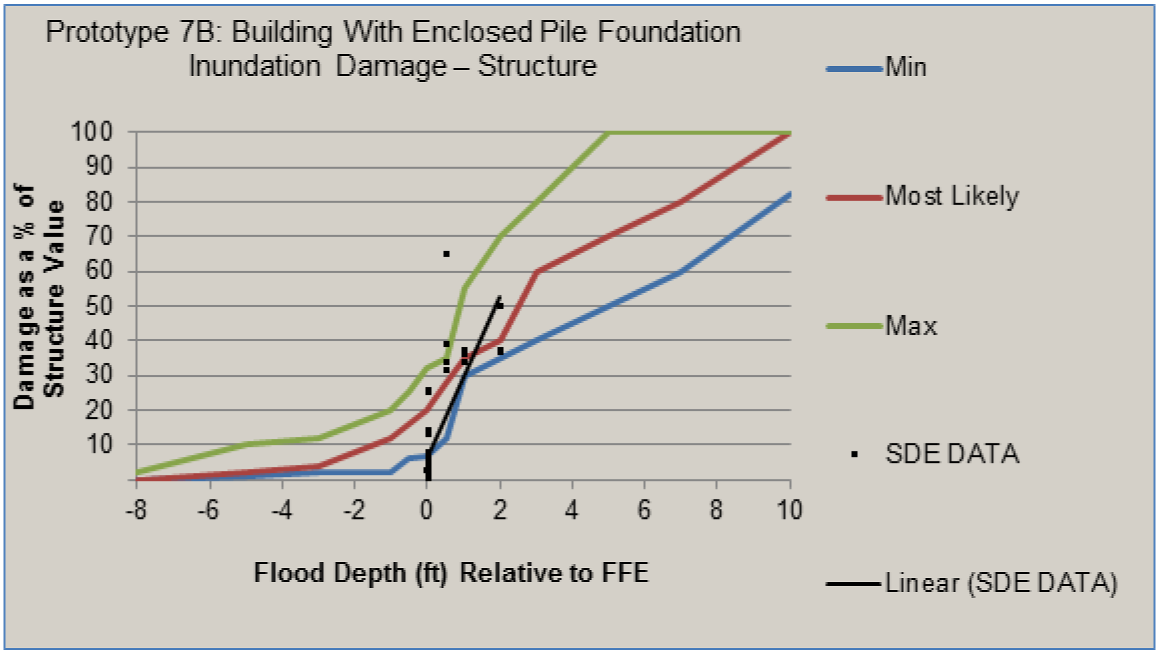

Figure 25. 7B: Building On Pile Foundation, With Enclosures Structure Comparison – Inundation

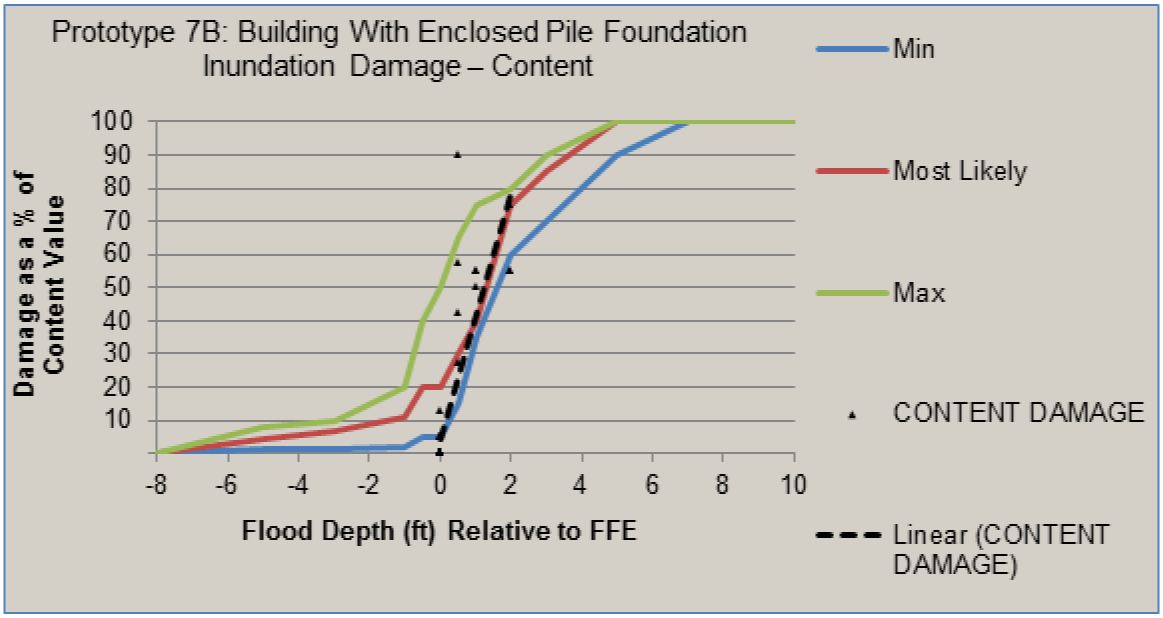

Figure 26. 7B: Building On Pile Foundation, With Enclosures Content Comparison – Inundation

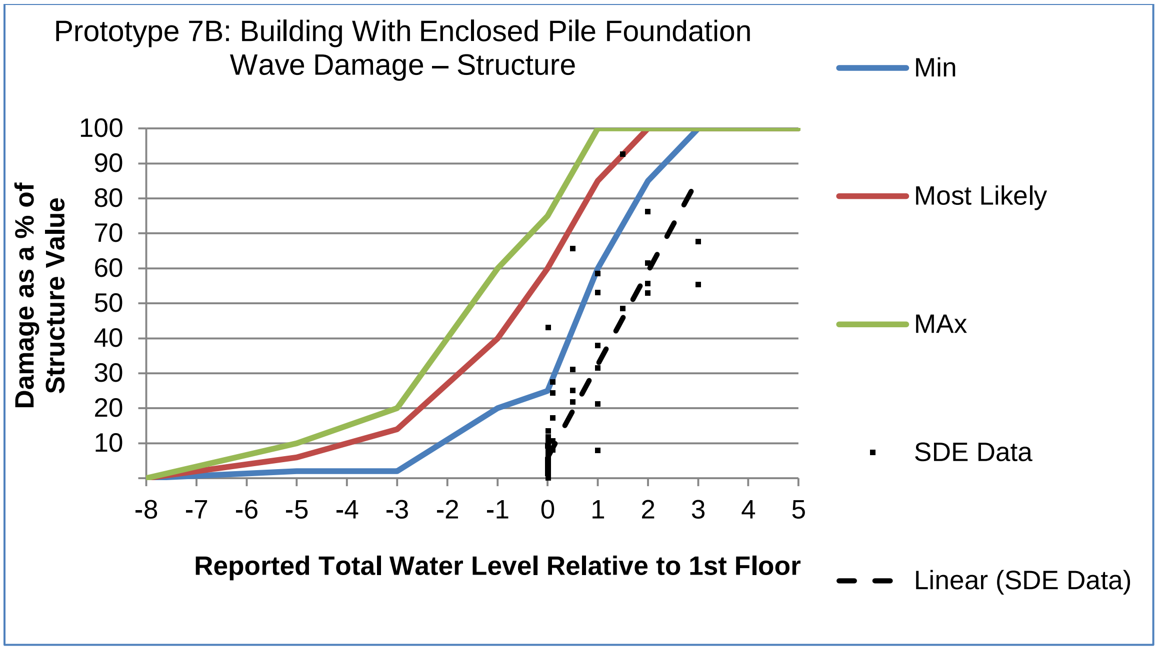

Figure 27. 7B: Building On Pile Foundation, With Enclosures Structure Comparison – Wave

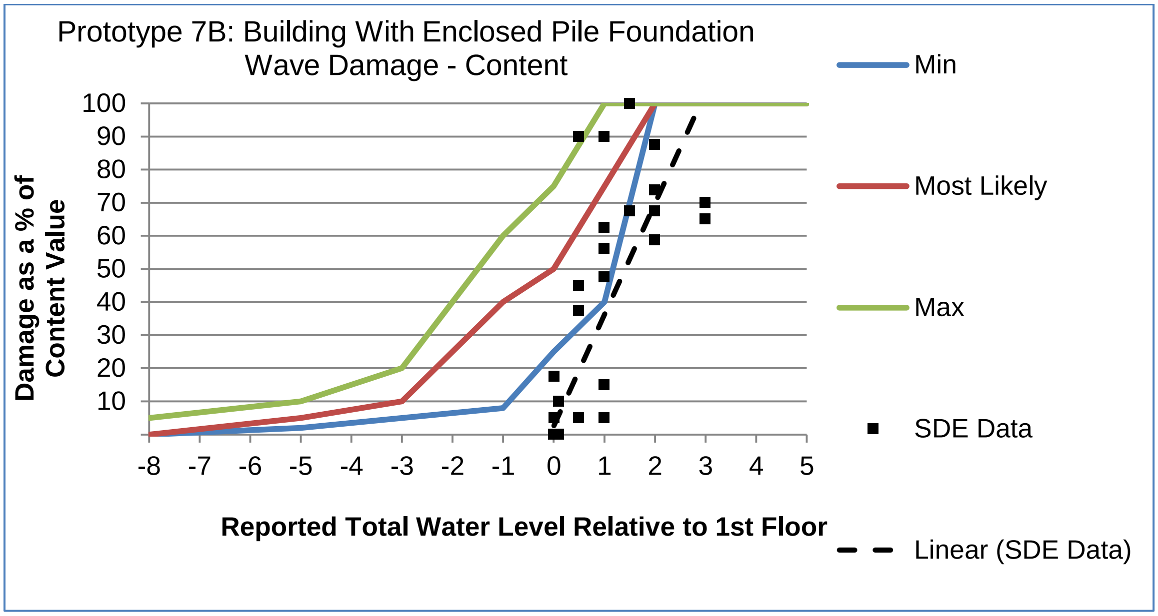

Figure 28. 7B: Building On Pile Foundation, With Enclosures Content Comparison – Wave

Table 7 shows the results of the comparison between the NACCS expert elicitation and the Substantial Damage estimates. The following criteria were used to evaluate how well the Substantial Damage estimate data points matched the NACCS damage functions: “Good” indicates that the trend line falls within the uncertainty bands, “Fair” indicates that the trend line falls partially within the bands, and “Poor” indicates that the trend line falls outside of the bands.

Table 7. Comparison of NACCS Expert Elicitation and Substantial Damage Estimates

Prototype	Damage Mechanism	Structure	Content	Notes
5A: 1-Story Residence, No Basement	Inundation	Poor	Fair to Good	
	Wave (Slab)	Fair	Fair	Few data points
	Wave (Wall)	Good	Good	
5B: 2-Story Residence, No Basement	Inundation	Poor	Fair	Substantial Damage estimate data trends around the maximum damage function
	Wave	Good	Good	
6A: 1-Story Residence, With Basement	Inundation	Good	Fair	Substantial Damage estimate data trends around the minimum damage function
	Wave	Poor	Poor	Very few data points
6B: 2-Story Residence, With Basement	Inundation	Good	Good	Substantial Damage estimate data indicated a wider uncertainty band
	Wave	Poor to Fair	Poor	Very few data points
7A: Building on Open Pile Foundation	Inundation	Good	Fair to Good	Substantial Damage estimate data trend is steeper, probably due to the lack of negative floor depths in the Substantial Damage estimate data
	Wave	Poor	Poor	
7B: Building on Pile Foundation, with Enclosures	Inundation	Fair to Good	Fair to Good	Substantial Damage estimate data trend is steeper, probably due to the lack of negative floor depths in the Substantial Damage estimate data
	Wave	Poor	Poor	

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3 Mitigation Assessment Team

The mission of the MAT program is to conduct forensic engineering analyses of structures and related infrastructure to determine the causes of structural failure, identify successes, and to recommend actions that Federal, State, and local governments; the construction industry; and building code organizations can take to reduce future damage and protect lives and property in hazard-prone areas.

Findings from the Hurricane Sandy MAT[2] were evaluated and compared to the results of the NACCS expert elicitation.

3.1 Base Data

The MAT for Hurricane Sandy consisted of four field teams, each focused on a structure type: coastal structures; high rise, police and fire stations, and schools; historic structures; and hospitals. Each field team included several subject matter experts with experience in the focus structure type. For the analyses, the MAT also used flood information from the FEMA Modeling Task Force (MOTF), which included flood depths and SWELs for the New York and New Jersey areas affected by Hurricane Sandy.

The MAT report prepared by FEMA following Hurricane Sandy (FEMA P-942) discusses why some structures failed and the level of damage. The report includes photographs, flood depth, and base flood elevation at each structure, and the flood zone each structure is located in.

The MAT damage assessments were conducted for residential and nonresidential structures. For some observations from the MAT report, there is specific information provided in the report regarding the erosion, inundation, or wave damage that occurred to a structure. In other cases, the extent of the damage caused by erosion, inundation, or waves was not specifically noted in the report and had to be inferred from the photographs. The MAT data do not contain specific information about structure contents except what can be inferred from the photographs.

3.2 Method of Analysis

The NACCS team[3] reviewed the Hurricane Sandy MAT report and other MAT data in project files (such as photographs not selected for use in the report) to identify structures that were observed in the field and could be assigned to one of the building prototypes. The team attempted to identify structures for all 12 of the building prototypes and damage mechanisms, but given the nature of MAT investigations, not all prototypes and damage mechanisms were covered.

The estimated damage to the structures was based on analysis of the structure photographs and information provided in the reports. Characteristics of the hazard (e.g., inundation levels, extent

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[2] Information regarding the MAT program is available at https://www.fema.gov/what-mitigation-assessment-team-program. The Hurricane Sandy MAT report is available at https://www.fema.gov/media-library/assets/documents/85922.

[3] Members of the NACCS team (Bill Coulbourne and Omar Kapur) participated in the Hurricane Sandy MAT (as well as other MATs), analyzed the MAT data, and compared it to the NACCS expert elicitation results.

of erosion, wave height) were based on the photographs and/or information in the report, such as flood depths, base flood elevations at the structures, and the flood zones.

Content damage was inferred from the photographs and based on the extent of structure damage. Where the information provided in the MAT report was not complete in terms of content damage estimates or whether more than one mechanism contributed to the damage, other file photographs not included in the MAT report or data provided in the MOTF files were searched to determine whether the damage mechanisms could be clarified.

3.3 Comparison to Expert Elicitation Results

The NACCS team identified 47 structures from the MAT data that matched the prototypes developed during the NACCS expert elicitation. Only structures that had a reasonably close fit to a prototype were used; using structures that did not meet the prototype characteristics would make a comparison to the expert elicitation results less relevant. The 47 estimates covered nearly all of the prototypes, with the exception of prototypes 1B, Apartment with Basement and 3, Commercial Pre/Non-Engineered, though some prototypes had more estimates than others. Figure 29 shows the distribution of prototypes that were evaluated.

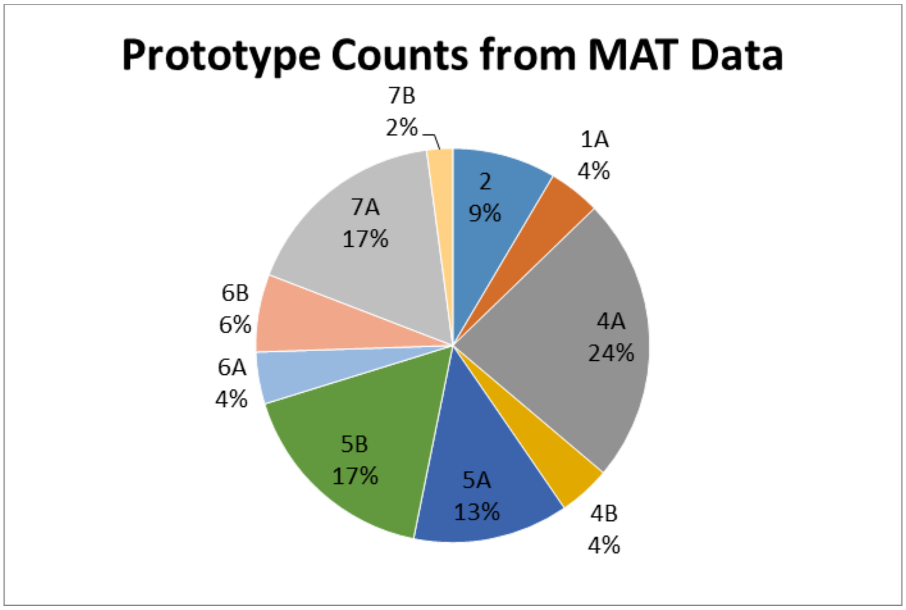

Figure 29. Distribution of Evaluated Prototypes

The observations were primarily for inundation damage (63 percent); wave damage (24 percent) and erosion (13 percent) were less prevalent. Additionally, the observations were heavily based on structure damage (91 percent of observations), with only a few observations of content damage (9 percent). This was because, in many cases, the MAT could not gain access to buildings. However, where the entire building was severely structurally damaged, the level of damage to the contents was estimated to be at or near the structural damage level.

Table 8 shows the results of the comparison between the MAT report and the NACCS expert elicitation results.

Table 8. Comparison between MAT Report and NACCS Expert Elicitation

Prototype	Category	Damage Mechanism	MAT Reference[1]	Flood Level[2] (feet) or Erosion (% area)	Percent Damage Estimate[3]	Expert Elicitation Results on Percent Damage (min, most likely, max)	Comments
1A: Apartment, No Basement	Structure	Inundation	Fig H-30	4	25	19, 33, 37	
	Structure	Inundation	Fig 4-7	0	0	0, 5, 8	Multi-level apartment
2: Commercial, Engineered Construction	Structure	Inundation	Fig 3-7	2	20	18, 30, 36	Motel, probably wood frame
	Contents	Inundation	Fig 3-7	2	50	28, 39, 58	
	Structure	Inundation	Fig 5-5	0.5	10	5, 10, 17	
	Structure	Inundation	Fig H-11	0.5	10	5, 10, 17	
4A: Urban High Rise	Structure	Inundation	Fig H-16	-1	20	3, 13, 16	
	Structure	Inundation	Fig 5-10	-6	20	0.5, 6, 10	School w/ basement, does not fit prototype
	Contents	Inundation	Fig 4-27	1	5	9, 17, 22	Mech. equip. on upper floors
	Structure	Inundation	Fig 4-30	4	30	10, 20, 24	Equip. in basement
	Structure	Inundation	Fig 4-27	1	5	8, 15, 20	
	Structure	Inundation	Fig 5-5	4	15–20	10, 19, 24	Hospital
	Structure	Inundation	Fig H-16	4	20–25	10, 19, 24	Med. center with basement
	Structure	Inundation	Fig 4-2-4-6	-1	20	3, 13, 16	
	Structure	Inundation	Fig 4-7	0	5	5, 14, 18	
	Structure	Inundation	Fig 4-8	2	20	8, 17, 22	
	Structure	Inundation	Fig 4-14	3	15	9, 19, 24	
4B: Beach High Rise	Structure	Inundation	Fig 3-51	-2	10	0, 0, 0	
	Structure	Inundation	Fig 4-19	4	20	5, 10, 14	

Prototype	Category	Damage Mechanism	MAT Reference[1]	Flood Level[2] (feet) or Erosion (% area)	Percent Damage Estimate[3]	Expert Elicitation Results on Percent Damage (min, most likely, max)	Comments
5A: 1-Story Residence, No Basement	Structure	Inundation	Fig 3-17	4	60	33, 44, 62	House floated
	Structure	Inundation	Fig 3-23	4	100	33, 44, 62	House floated
	Structure	Inundation	Fig 3-24	1.5	20	13, 23, 35	
	Structure	Wave	Fig 3-30	7	100	100, 100, 100	House collapsed
	Structure	Wave	Fig 3-1	3–5	90	40, 90, 100	
	Contents	Wave	Fig 3-1	3–5	100	50, 100, 100	
5B: 2-Story Residence, No Basement	Structure	Inundation	Fig 3-11	3	100	20, 25, 30	Long duration inundation
	Structure	Inundation	Fig 3-18	4	30	22, 27, 35	
	Structure	Erosion	Fig 3-12	50%	70	80, 100, 100	
	Structure	Erosion	Fig 3-13	60%	70	100, 100, 100	
	Structure	Erosion	Fig 3-26	50%	70	80, 100,100	
	Structure	Wave	Fig 3-16	-7	15	0, 0, 0	
	Structure	Wave	Fig 3-28	-2	100	0, 0, 5	
	Structure	Wave	Fig 3-65	2	50	30, 50, 60	
6A: 1-Story Residence, With Basement	Structure	Inundation	Fig 3-2	-2	5	3, 10, 18	
	Contents	Inundation	Fig 3-2	-2	60	5, 15, 30	
6B: 2-Story Residence, With Basement	Structure	Inundation	Fig 3-31	0	20	5, 15, 20	
	Structure	Inundation	Fig 3-49	-1	15	3, 10, 15	
	Structure	Inundation	Fig 3-50	-2	10	2, 8, 12	
7A: Building on Open Pile Foundation	Structure	Inundation	Fig 3-33	-1	10	0, 2 , 8	
	Structure	Erosion	Fig 3-27	15%	10	3, 6, 12	Deck collapsed
	Structure	Erosion	Fig 3-29	60%	10	71, 77, 88	

Prototype	Category	Damage Mechanism	MAT Reference[1]	Flood Level[2] (feet) or Erosion (% area)	Percent Damage Estimate[3]	Expert Elicitation Results on Percent Damage (min, most likely, max)	Comments
	Structure	Erosion	Fig 3-22	50%	30	50 ,90, 100	"Percent compromised" was understood to represent the fraction of foundation capacity (ability to withstand lateral and vertical loads and support the building) lost.
	Structure	Wave	Fig 3-35	0	50	20, 50, 75	
	Structure	Wave	Fig 3-37	-1	30	5, 10, 30	Parking area washed through
	Structure	Wave	Fig 3-41	3	100	90, 100, 100	
	Structure	Wave	Fig 3-42	3	30	90, 100, 100	
7B: Building on Pile Foundation, with Enclosures	Structure	Wave	Fig 3-44	1	100	60, 85, 100	Townhouses

[1] Figure numbers are those provided in the FEMA MAT report P-942.
[2] Flood level is compared to the reference point of the expert elicitation results for the equivalent prototype.
[3] Fixed equipment in basement is considered part of the structure.

Of the 47 damage estimates that were developed from the MAT data, 26 fell within the range of the minimum and maximum estimates of the NACCS expert elicitation, 12 estimates were above the maximum estimated damage, and 9 estimates were below the minimum estimated damage.

A scatter plot comparing the findings from the MAT review to the NACCS expert elicitation for prototype 4A**,** Urban High Rise is shown in Figure 30. Prototype 4A, Urban High Rise was selected because it was the most prevalent type observed by the MAT and documented in the report. Approximately 50 percent of the actual damage estimate percentage inundation data points fall within the minimum–maximum range; the same is true for the entire damage set as a whole.

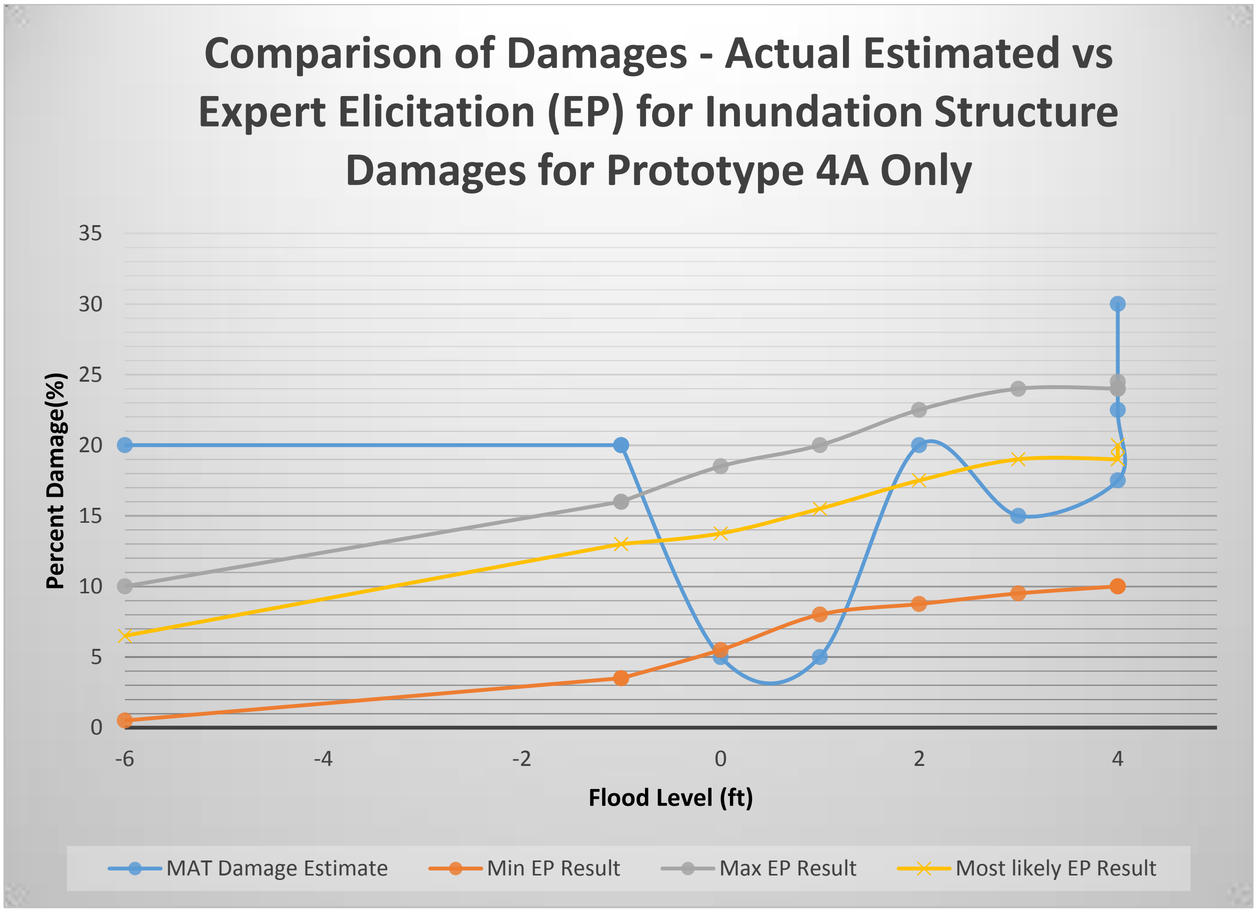

Figure 30. Comparison of Damage for Prototype 4A, Urban High Rise

For the structures that received inundation damage (including all prototypes), the median damage estimate from the MAT data is 5.5 percent greater than the most likely damage estimated through the expert elicitation. The standard deviation between the actual damage estimate and most likely estimate from the expert elicitation is 18.8 percent (for structure damage from inundation only), which suggests a wider uncertainty band of the actual damage estimate compared to the expert elicitation results. The MAT damage estimate is as much as 12.5 percent less than the most likely damage percent from the expert elicitation to as much as 75 percent greater than the most likely damage percent from the expert elicitation (Figure 31).

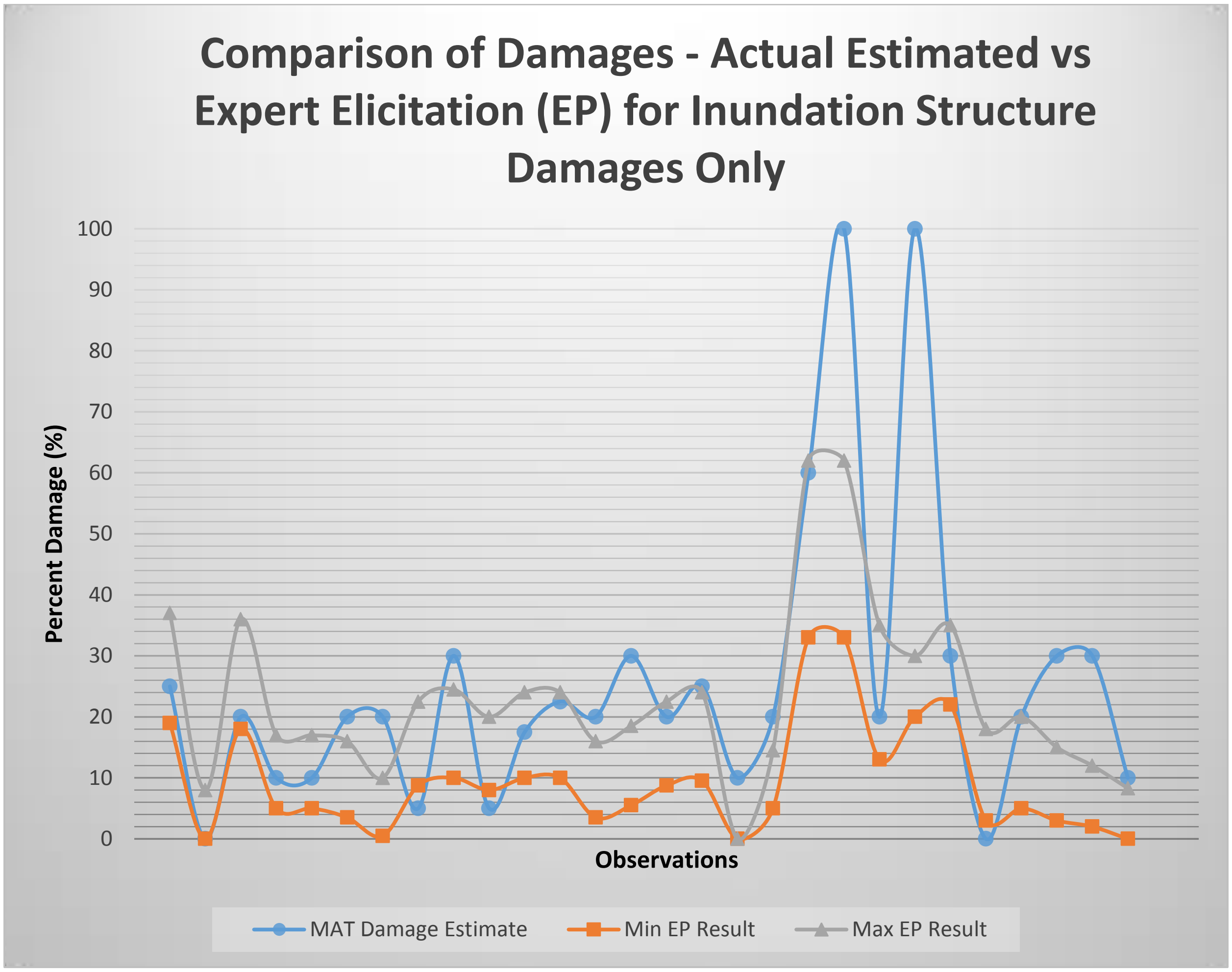

Figure 31. Comparison of MAT Damage Estimates to NACCS Expert Elicitation

Several key issues should be noted about these comparisons. The buildings inspected by the MAT and used in this analysis do not always align perfectly with the prototypes developed by the NACCS experts. For instance, Fig. 5-10 in the MAT report is a school building with a basement, which is not a prototype. The building was compared to the damage functions for prototype 4A**,** Urban High Rise, which is a larger multi-level building with a basement. The school was chosen to provide a damage comparison for a building with a basement. When mechanical equipment in lower levels is significantly damaged, the percent damage could be different from the expert elicitation results because the equipment is included as part of the structure. While the expert panel also included equipment with the structure, actual percent damage observed could vary significantly because of building size and the amount and location of the mechanical equipment.

The MAT damage estimates were developed by observing the photographs in the MAT report and using the written description of the damage as a gauge for the extent of damage. No additional information was collected for the structure. This method introduces some level of error. Though the extent of the error is unknown, the observations were made by experienced structural engineers who are also skilled damage investigators, which should reduce the level of error in the damage estimates.

4 Summary and Recommendations

The Substantial Damage estimates and MAT report were reviewed and compared to the damage functions develop through the NACCS post-Hurricane Sandy damage surveys and expert elicitation. The findings were that the NACCS damage function methods are reasonable, though they may understate inundation damages for residential structures without basements. The verification process found that the variation in reported damages was frequently greater than the uncertainty bands developed through the expert elicitation.

The NACCS expert elicitation for residential structures with basements matched fairly well with the Substantial Damage estimates, but the comparisons with the residential structures without basements were quite different. The Substantial Damage data revealed that there was very little damage to foundations during Hurricane Sandy, at least for structures that had inundation damage. This indicates that foundation damage may not be a significant factor in coastal storm events. If that is the case, most of the damage to structures occurs above the foundation. Therefore, the damage functions should be slightly higher for structures without basements compared to structures that have basements. This is because more value of a structure is associated with basement foundations, and given similar amounts of damage, the total percent damage would be lower for structures with basements because of the higher replacement value. This finding not only conflicts with the NACCS expert elicitation, but also conflicts with most existing damage functions.

Additional analysis was conducted to compare prototypes 5A, 1-Story Residence, No Basement and 6A, 1-Story Residence With Basement Substantial Damage estimates and prototypes 5B, 2-Story Residence, No Basement and 6B, 2-Story Residence With Basement Substantial Damage estimates (Figures 32 and 33). The Substantial Damage estimates show little difference between structures with basements and those without basements. However, the large number of 6A, 1-Story Residence With Basement structures showing damage at 0 feet of flooding is most likely a result of the SDE tool not allowing field staff to enter negative values for flood height in relation to the first floor.

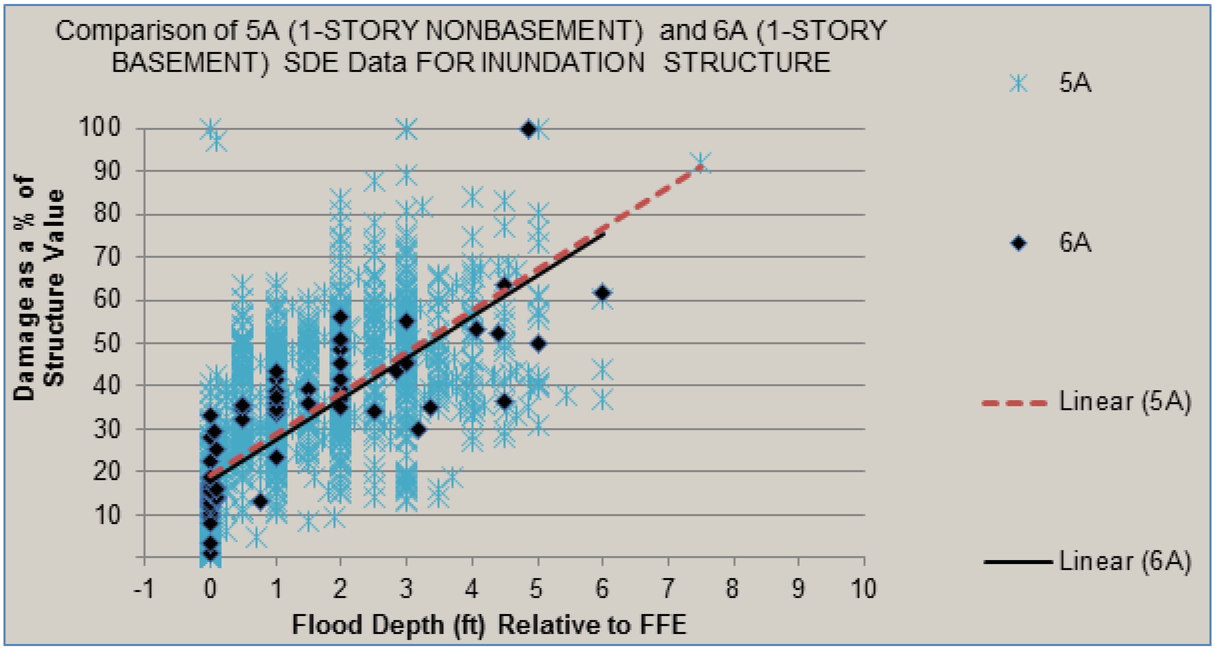

Figure 32. Comparison of Substantial Damage Estimates for 1-Story Residential Structures

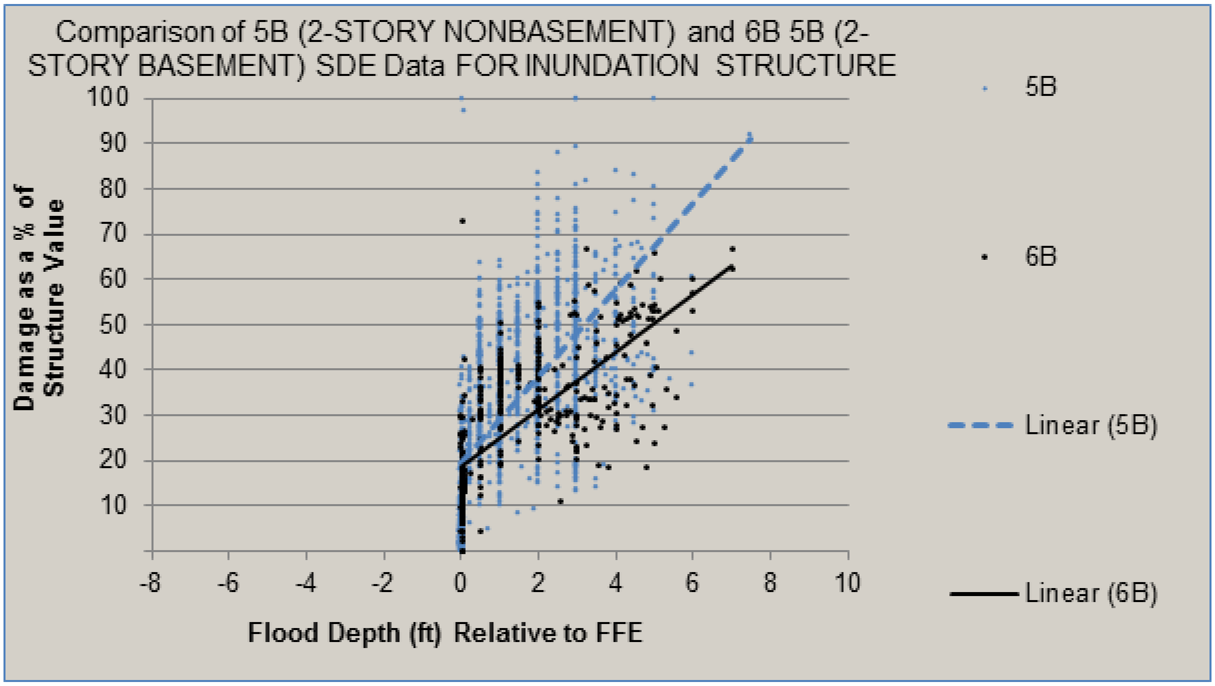

Figure 33. Comparison of Substantial Damage Estimates for 2-Story Residential Structures

The MAT review also indicated that the NACCS damage functions were low for prototypes 5A, 1-Story Residence, No Basement and 5B, 2-Story Residence, No Basement. Based on this result, the NACCS team recommends that the NACCS *Physical Damage Function Summary Report* include a discussion of these findings when presenting the depth-damage relationships for prototypes 5A, 1-Story Residence, No Basement and 5B, 2-Story Residence, No Basement. The Substantial Damage estimate data did not match well with the NACCS damage functions for wave damage. This is thought to be related to the Substantial Damage estimates not being a good representation of actual wave heights. Review of the MAT data matched fairly well with the NACCS damage functions for waves, so the NACCS team recommends that the NACCS damage functions be used.

Overall, while many of NACCS damage functions for the most likely case were appropriate, the uncertainty bands appear too tight. The NACCS team recommends that future investigations evaluate how the uncertainty bands could be widened to capture the considerable uncertainty for any given structure type.