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Floodproofing New York: The City's Response to Superstorm Sandy

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Abstract

This presentation will provide consultants, engineers, and architects with an overview of newly in-place floodproofing building code requirements for New York City, as well as various floodproofing strategies that satisfy both code requirements and (often more stringent) project-specific needs. Various systems and assemblies for wet and dry floodproofing will be discussed, together with the advantages and disadvantages of the designs' approaches. Case studies will be presented that illustrate the implementation of several different floodproofing strategies and the presenters' lessons learned during the projects' design and construction.

Speakers

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KENRICK J. HARTMAN specializes in the evaluation and repair of building envelope systems. He has experience with a variety of materials, including terra cotta, brick, concrete, steel, glass, and various roofing and waterproofing products. Hartman performs field-testing, moisture infiltration investigations, façade evaluations, and repair design for modern and historical structures.

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DOUGLAS STIEVE specializes in diagnosis and repair design for building envelope failures in contemporary and historical buildings. Since joining WJE in 1991, Stieve has provided professional services for over 600 buildings throughout the northeast United States. He has experience with many types of materials, including brick, concrete masonry, natural stone, and exterior insulation and finish systems (EIFS). Stieve has managed design and construction services for several multimillion-dollar repair and rehabilitation projects, and provided consulting services for new buildings.

Floodproofing New York: The City's Response to Superstorm Sandy

SANDY HITS NEW YORK CITY

In the fall of 2012, New York City experienced one of the most damaging weather events in the city's history. Superstorm Sandy struck New York City on the evening of October 29, 2012, as a post-tropical cyclone with winds in excess of 80 miles per hour and accompanied by heavy rains. While the storm declined from its height as a Category 3 hurricane by landfall, the storm's wind and rain, combined with a massive storm surge, brought flooding to many of the city's coastal regions. During Sandy's arrival, New York City's waters were experiencing a spring tide, which is a peak high tide during a full moon. Water levels during spring tides are approximately 6 inches (152 millimeters) higher than the average high tide and are believed to have contributed to the flooding. Furthermore, the severity of a storm surge is closely linked to the diameter of a storm's area, and given that Sandy was over 1,000 miles (1,609 kilometers) wide—over three times larger than Hurricane Katrina—the associated storm surge produced record flood levels, particularly when combined with the already high waters under the spring tide. The measured peak flood height was 14 ft. (4.3 m) above the mean lower low water in downtown Manhattan, smashing the previous record of 10 ft. (3.0 m) during 1960's Hurricane Donna. While the rains and winds contributed to the total damage, the storm surge caused the most destruction in the area.

In total, 51 square miles (132 square kilometers) of New York City were flooded. See *Figure 1* for the approximate areas of flooding. Note that only 33 square miles (85 square kilometers) were included in the 100-year floodplain at the time. The flooded areas included 88,700 buildings as well as critical infrastructure such as hospitals and other care facilities, key power facilities, and transportation networks. All of the city's wastewater treatment plants were within the flood zone. In New York City alone, the storm caused approximately $19 billion in damages and, tragically, 43 deaths.[1]

NEW YORK CITY REGROUPS AND PROMOTES BUILDING RESILIENCY

As part of initial hazard control efforts, New York City contracted with private engineering firms to perform evaluations of buildings affected by the storm in accordance with ATC-45, *Safety Evaluation of Buildings After Wind Storms and Floods*. The inspections were usually completed in teams of three, consisting of one inspector for the New York City Department of Buildings, one licensed professional engineer (of any state), and one junior engineer (not required to be professionally licensed).

The first phase of the evaluation was a "rapid assessment" of approximately 82,000 buildings and consisted of a five- to ten-minute exterior evaluation. Based on the initial inspection, a given building was assigned a rating of "Unsafe," "Restricted Use," or "Inspected" and labelled with the appropriate color-coded tag, which was placed conspicuously on the building. About 73,000 of the buildings were labelled with the green-colored "Inspected" tags, 7,800 with yellow-colored "Restricted Use" tags, and 930 with the red-colored "Unsafe" tags (*Figure 2*).

A follow-up detailed inspection was later performed in December 2012 that focused on the approximately 8,700 buildings with yellow and red tags. After this survey, 1,300 yellow tags and 780 tags remained. Approximately 230 buildings were considered destroyed. Upon completion, this evaluation effort became the largest building inspection initiative in the city's history.[2]

Prior to Sandy, New York City had several flood-related building standards in place, namely those adopted in 1983 when FEMA released the first Flood Insurance

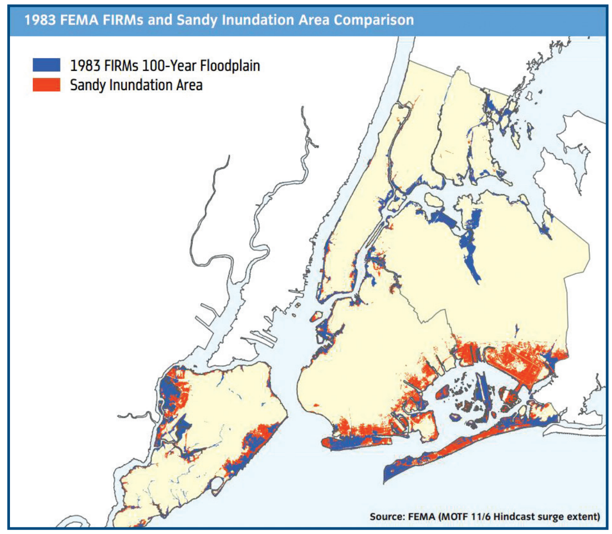

Figure 1 – Comparison of 100-year floodplain and area inundated by Sandy ("A Stronger, More Resilient New York," www.nyc.gov).

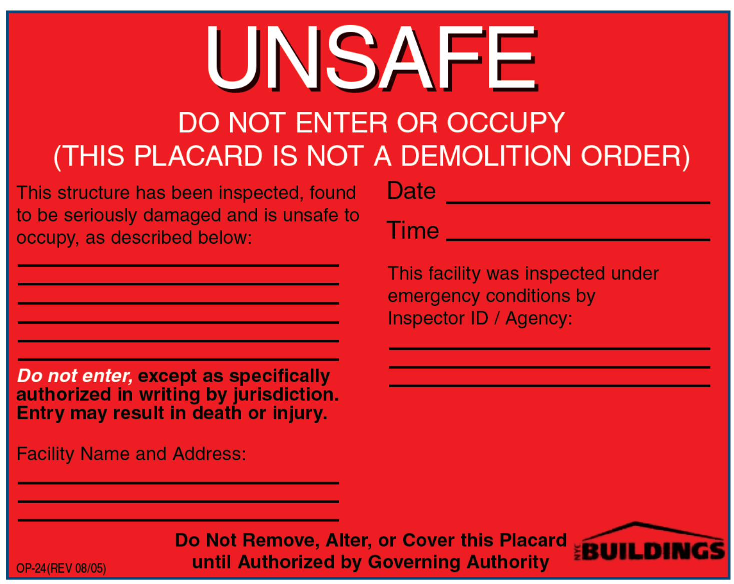

Figure 2 – Red-colored "Unsafe" tag used during rapid evaluation.[7]

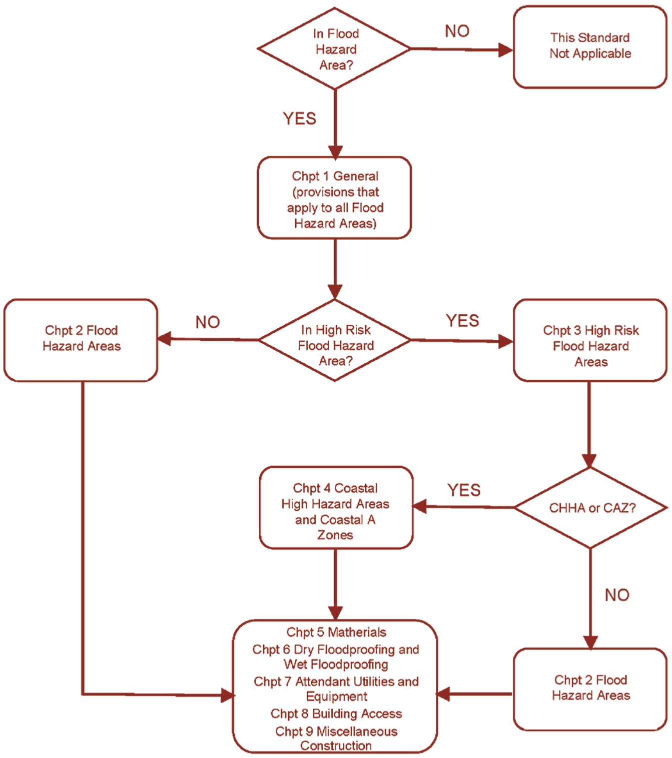

Figure 3 – Flowchart (Figure 1-2, Application of Chapters).

Rate Maps (FIRMs) for New York City. These maps showed the base flood elevations (BFEs) and the floodplains based on a 100-year flood. These floodplains were further delineated into subregions based on their level of risk (e.g., V-Zones are for areas in which wave impacts are expected to be greatest). Buildings within the 100-year floodplain are required by the federal government to carry flood insurance. In 2010, New York State implemented a more stringent provision that requires new and substantially improved buildings to include "freeboard" when determining the design flood elevation (DFE). Freeboard was put in place to account for uncertainties during determination of the BFEs, as well as to account for the potential future rise of sea levels. Freeboard is considered a pseudo safety factor for the BFE and is usually 1 to 2 ft. (0.3 to 0.6 m), depending on the structural occupancy category of the building. The freeboard is added to the BFE to establish the DFE (i.e., the DFE is 1 to 2 ft. [0.3 to 0.6 m] above the BFE). Because New York City is to meet the minimum code requirements of New York State, the city adopted the (freeboard) increase in the design flood elevation in an Emergency Rule in January 2013, and later in "Appendix G: Flood-Resistant Construction" of the 2014 New York City Building Code (among other newly adopted requirements).

Appendix G of the New York City Building Code is focused on provisions related to flood-resistant construction and, in 2014, was updated from its 2008 version to reinforce New York City's push toward building resiliency based on lessons learned from Superstorm Sandy. In addition to the prescribed design flood elevations, the appendix provides requirements for various methods of protecting buildings from flood events—namely the strategies of dry floodproofing and wet floodproofing. Dry floodproofing requires that a building or structure be watertight to the DFE and "substantially impermeable" to the passage of water. The structural components that comprise the watertight barrier must resist all induced flood loads as prescribed by ASCE 7. Comparatively, wet floodproofing allows floodwaters to pass directly through the building or structure, allowing the portions of the building below the DFE to be intentionally flooded (and drained as the floodwaters recede) during flood events. This method allows the hydrostatic pressure caused by incoming/outgoing floodwaters on the structure to equalize, minimizing the hydrostatic loading on the structure. It should be noted that residential buildings, as classified by the New York City Building Code for flood zone purposes, are not allowed to be dry floodproofed; and that occupancy restrictions on residential and commercial structures exist on spaces below the DFE, depending on which floodproofing method is used (wet versus dry) and the classified zone per the applicable FIRM.[3]

Appendix G frequently references ASCE 24, *Flood-Resistant Design and Construction*, which further prescribes and details floodproofing requirements.

ASCE 24-14, FLOOD-RESISTANT DESIGN AND CONSTRUCTION

All new construction, structural repairs, and substantial improvements to existing buildings and structures proposed to be constructed in flood hazard areas are to comply with the American Society of Civil Engineers (ASCE) 24-14. Historic structures are usually exempt from complying with the standard.

The 2014 edition is a referenced standard in the 2015 International Building Code (IBC) and the 2015 International Residential Code (IRC). The IRC requires dwellings in floodways to be designed in accordance with ASCE 24-14 and includes an alternative that allows communities to require homes in any flood zone to be designed in accordance with ASCE 24-15.[4] However, many states and municipalities are still working off the earlier version of ASCE 24. The 2006 IBC referenced ASCE 24-05. The Federal Emergency Management Agency (FEMA) deems ASCE 24 to meet or exceed the minimum requirements of the National Flood Insurance requirements for buildings and structures.[5]

Design and construction in flood hazard areas must account for the elevation of the structure, foundations, resistance to damage both during and after a flood event, obstructions, structural members, obstructions and enclosures below elevated structures, materials, floodproofing, utilities, means of egress, and adverse impacts to other structures and property.

ASCE 24-14 includes a flow diagram to assist the designer in determining the provisions of the standard that apply to a particular building or structure. *Figure 3* is a diagram of the flowchart.

The process to compliance is to initially determine if the site is located within a flood hazard area. Most jurisdictions have adopted maps prepared by FEMA. Only buildings or other structures located within a flood hazard area have to comply with the standard. The consensus is to use a 1% annual chance (a.k.a. 100-year flood) as the benchmark to determine whether the standard applies. In most cases, this becomes the DFE.

If the building or structure is located within the DFE, then it must comply with the requirements of Chapter 1—"General" of the standard. Chapter 1 includes information on the identification of flood hazard areas and the assignment of a flood design class, which is based on the threat to human life and welfare as well as the structure's occupancy and use. This information is used, if needed, in later chapters. Chapter 1 includes provisions to resist flotation, collapse, or permanent lateral movement. However, the most prominent requirement is that the lowest floors (with the exception of nonresidential uses) must be elevated to or above the DFE.

The next step is to determine if the project is located within a High-Risk Flood Area. These are areas that include but are not limited to coastal zones as will be discussed below: areas subject to flash floods, mudslides, ice jams, high-velocity flow areas, and erosion (*Figure 4*). If the building or structure is located within the High-Risk Flood Area, then it must also comply with the requirements of Chapter 2—"Basic Requirements for Flood Hazard Areas That Are Not Identified as Coastal High Hazard Areas and Coastal A Zones." Chapter 2 provides specific requirements to resist damage for each of these areas.

If the project is located within a Coastal High-Hazard Area or Coastal A Zone (these are areas that include but are not limited to areas with breaking wave heights greater than 1.5 ft.), then it must also comply with the requirements of Chapter 4—"Coastal High Hazard Areas and Coastal A Zones," Chapter 5—"Materials," Chapter 6—"Dry Floodproofing and Wet Floodproofing," Chapter 7—"Attendant Utilities and Equipment," Chapter 8—"Building Access," and Chapter 9—"Miscellaneous Construction."

Coastal High-Hazard Areas and Coastal A Zones defined in Chapter 4 are areas where wave forces can be significant and must be considered. The minimum elevation of the structure will be raised 1, 2, 3, or more feet above the DFE, depending on the flood design class. The chapter also includes several foundation enhancements and limitations on enclosed areas below the DFE.

Specific damage-resistant materials are included within Chapter 5—"Materials" for areas of the structure below the minimum elevation of the structure as defined by the flood design class.

Chapter 6 establishes the criteria for dry and wet floodproofing that were presented above. Dry floodproofing is not permitted for residential use groups or within High-Risk Flood Hazard Areas, Coastal High-Hazard Areas, or Coastal A Zones. Specific requirements for dry floodproofing include minimum warning times and approval of the dry floodproofing technique by the local jurisdiction. Wet floodproofing is only permitted for Flood Design Class 1 structures, parking, and structures that are functionally dependent on close proximity to water.

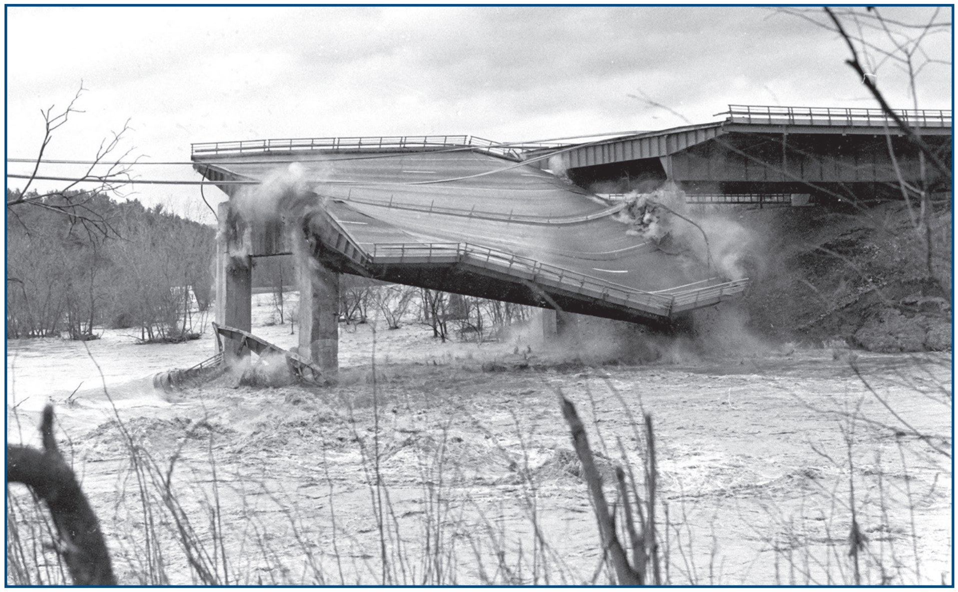

Figure 4 – Schoharie Creek Bridge collapsed suddenly in 1987 after scouring severely undermined a footing under one of the bridge's piers.

Chapters 7 and 8 include provisions for attendant utilities and equipment and building access.

RETROFITTING BUILDINGS FOR FLOOD RISK IN NEW YORK CITY

In 2014, the Department of City Planning in New York City published a report entitled "Retrofitting Buildings for Flood Risk." The document provides a step-by-step guide specific to the unique dense building fabric and the 520 miles (837 kilometers) of shoreline located within the city. There are nearly 71,500 buildings, 532 million sq. ft. (49.4 m^2) of interior space, and 400,000 residents located within the DFE and 520 miles (837 kilometers) of shoreline.[6] The city also has structures with shared party walls and relatively tight building sites.

It would take centuries for new construction to replace existing buildings, as it would be an economic burden and extremely disruptive to mandate wholesale replacement. Planned coastal improvements also take a very long time to implement.

The process is to identify the flood risk, identify the flood elevation, review relevant regulations, and identify an adaption strategy and design of strategies for individual projects.

As with ASCE 24, FEMA maps are used to determine in which zone the property is located.

CONSIDERATIONS DURING FLOODPROOFING DESIGN

The first step in the design of a floodproofing system is to determine the project goals. In which parts of the building are floodwaters acceptable? Which zones of the building is it critical that floodwaters not reach? What code prescriptions are required, and how can those prescriptions be accommodated while meeting project needs? Is it advantageous to clearly delineate the areas that are allowed to be exposed to floodwaters from those that are not, and design accordingly?

The design of a successful floodproofing system is often a complicated process involving an interdisciplinary team of design professionals working in tandem to meet project goals. While inherently the design must meet all applicable code requirements, project-specific needs are commonly more difficult to satisfy.

Structural building elements included in the floodproofing system should be designed to perform as intended, whether a given structural element is intended to fail in order to relieve flood loads (e.g., break-away walls) or designed to resist flood loads (e.g., flood retention walls). Flood retention systems often involve stout structural elements that (especially during retrofitting) are complicated and costly to construct.

Figure 5 – Flood balloons installed as part of a training drill.

Figure 6 – Floodgates in the closed position (as seen from the "dry" side).

Mechanical and electrical systems—particularly those that are critical to building operations—are to be located above the designed flood level and out of harm's way. Consistent with structural design considerations, retrofitting an existing building to relocate key equipment has been proven to be a costly effort and is best considered during initial design if or when possible.

The waterproofing portion of an effective floodproofing system depends on the integration of the mechanical, electrical, plumbing, (MEP), structural, and waterproofing design disciplines. The "pencil test," in which a designer is able to continuously outline the flood elevation and then the flood-resistant barrier, if utilized, is an effective way to troubleshoot potential design issues. Any penetration within the floodproofing region should be relatively watertight so that floodwaters do not have free access into the structure. Related considerations include the need for backflow preventers at drainage pipes that link "wet zones" to "dry zones." The most common instance of this is floor drains within mechanical spaces, although others exist.

Because a flood will induce substantial hydrostatic pressure onto the waterproofing membrane, the product chosen for use as the floodproofing membrane should perform under those design conditions. This will include the material's ability to withstand sustained hydrostatic pressure as well as the orientation of this pressure relative to the substrate. Note that most waterproofing membranes are able to perform under positive pressure conditions; however, some floodproofing designs may require waterproofing membranes to perform under negative pressure (i.e., hydrostatic pressure is acting through the substrate, not against it). The selection of a waterproofing membrane should include the membrane's ability to resist negative, positive, or both negative and positive loading, given project requirements. With all floodproofing designs, the membrane should be able to withstand project-specific hydrostatic conditions. It is also critical that any substrate to which the floodproofing membrane is applied meet the structural requirements needed to resist the hydrostatic (structural) loads.

As inferred, floodproofing systems are often complicated and involve integrated designs to be effective. Occasionally, a given design requires human interaction to be effective. In a dry floodproofing scenario, this could include installation of flood balloons (*Figure 5*), sandbags, and closing of floodgates (*Figure 6*) at the floodproofing barrier. Wet floodproofing systems may require similar "active" participation as access doors between wet and dry zones may need to be sealed and emergency systems activated.

Note that the initial cost of a floodproofing system that acts passively—the structural, mechanical, waterproofing, or other elements of a building that are intended to withstand a designed flood—can be much higher than a floodproofing system that is active—in other words, a system that is dependent on human interaction such as installation of sand bags and flood balloons. However, the continued cost associated with training of staff to implement the active floodproofing protocols and the practice/training drills required to perform them successfully under duress may be equally as costly. Given that a more active system is cost-effective (and desirable/chosen), the designer should carefully consider the inadvertent errors associated with installation of the floodproofing barrier. Lower costs do not necessarily balance performance.

SUMMARY

The floodwaters created during Superstorm Sandy and the associated damages spurred New York City to upgrade its floodproofing measures. While still in recovery, New York City has reacted to the damages from Sandy, including implementation of new floodproofing protocols that better protect affected buildings from future flood events. Design professionals are required to meet the new floodproofing standards, mainly those outlined in the New York City Building Code and ASCE 24. Implementation of these requirements can be a complicated endeavor that includes consideration of the structural, mechanical, electrical, plumbing, and waterproofing aspects of a building. These considerations impact the costs associated with a successful floodproofing system, as well as the active labor implication of its components.

REFERENCES

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6. "Retrofitting Buildings for Flood Risk," Department of City Planning, City of New York.
7. ATC-45, *Safety Evaluation of Buildings after Wind Storms and Floods*.