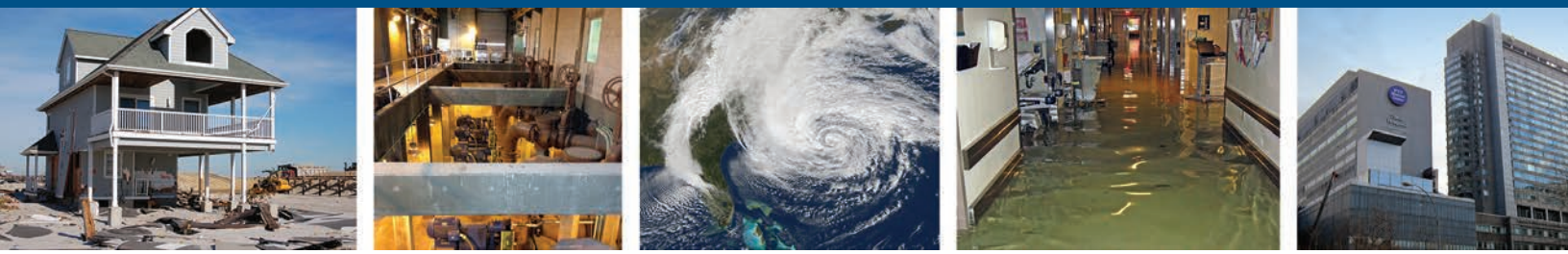

HURRICANE
SANDY
IN NEW JERSEY
AND NEW YORK

4 Performance of Mid- and High-Rise Buildings

The MAT observed commercial and residential mid- and high-rise buildings in the New Jersey and New York metropolitan areas affected by Hurricane Sandy.

Mid-rise buildings are defined in this MAT as having four to seven stories, and high-rise are defined as having eight or more stories.[1] Mid- and high-rise buildings are commonly used for residential and commercial use in densely populated urban areas. These buildings typically are designed to have robust structural systems; however, good structural performance alone does not ensure adequate protection from flood damage. Hurricane Sandy demonstrated that mid- and high-rise buildings do not have to be severely damaged or collapse to be rendered inoperable.

Observed damage to mid- and high-rise buildings was similar for the sites visited and caused by inundation from the high surge levels. Flood damage was predominantly to the critical building

1 The MAT definition for high-rise is adapted from the definition in the IBC: *"A building with an occupied floor located more than 75 feet above the lowest level of fire department vehicle access."* There is no definition in the IBC or other standards for mid-rise buildings; therefore, the MAT defined mid-rise as a building between four and seven stories.

systems of these structures, the failure of which crippled building operations and affected thousands of occupants. Residential units in most mid- and high-rise buildings are located above flood elevations and were not inundated inside the dwelling units. However, damage to building systems delayed recovery after the flooding and prevented people from reoccupying their homes and reopening their businesses quickly after the storm. Interruptions of businesses and temporary relocation of the residents of these highly occupied buildings increased the total financial loss to these facilities. The cost of returning building functions back to normal included both the direct costs of repairing the damaged equipment and contents as well as the cost of lost rent and business income.

TERMINOLOGY

Critical building systems: Includes any building system essential to the functioning of a building. May include MEP, emergency power, gas installations, communications, conveyance, and fire suppression.

4.1 Mid-Rise Buildings

The MAT visited seven mid-rise buildings that are part of public housing developments operated by the New York City Housing Authority (NYCHA). The housing developments visited are located throughout the Boroughs of Brooklyn and Queens and in various flood zones. All but one of the mid-rise residential buildings sustained significant damage to their mechanical and electrical systems as a result of water inundation from the storm surge. The MAT visited mid-rise buildings at the following developments:

- Carleton Manor
- Hammel Houses
- O'Dwyer Gardens
- Ocean Bay Apartments – Bayside
- Ocean Bay Apartments – Oceanside
- Red Hook West Houses
- Surfside Gardens

The mid-rise buildings highlighted in this chapter are a mix of buildings located inside and outside the SFHA. The buildings were all built in the 1950s and 1960s. Occupancy types were exclusively multi-family residential. All structures visited had subgrade spaces, almost all of which housed the building systems except for one development. The following observations are representative of the damage to mid-rises in the New York area that were inundated by storm surge.

4.1.1 Siting Effects on Building Performance

The location of each of the mid-rise developments was an important factor in the amount of flood damage they received. Table 4-1 lists each of the mid-rise developments visited along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations, and the level of storm surge experienced during Hurricane Sandy. The flood zones in Table 4-1 include those

shown on FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

Three of the developments visited in Queens, NY, are in Zone X yet experienced flood inundation. The other four sites visited in Queens and Brooklyn are in the SFHA. All seven of the mid-rise developments were subject to storm surge and inundation inside the building as a result of Hurricane Sandy. In the case of the properties on the Rockaway Peninsula and Coney Island, the flooding was a result of storm surge from the Atlantic or Jamaica Bay (to the north of the Rockaway Peninsula). The Red Hook development reportedly received flooding from a canal off Gowanus Bay that runs to the north of the property.

Table 4-1: BFEs, ABFEs, and Sandy Floodwater Elevations for Mid-Rise Buildings

Facility Name	Location (New York)	Relevant FEMA Flood Maps	Flood Zone on Map[a]	1-Percent-Annual-Chance Elevation (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[c]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Carleton Manor	Rockaway (Queens)	Effective FIRM	Unshaded X	n/a	n/a	11
		ABFE	A	11	15	
Hammel Houses	Rockaway (Queens)	Effective FIRM	Unshaded X	n/a	n/a	10
		ABFE	V	11	15	
O'Dwyer Gardens	Coney Island (Brooklyn)	Effective FIRM	AE	9	n/a	12
		ABFE	A	13	18	
Ocean Bay Apartments, Bayside	Rockaway (Queens)	Effective FIRM	Shaded X and AE	n/a and 8	n/a	10
		ABFE	A	10	13	
Ocean Bay Apartments, Oceanside	Rockaway (Queens)	Effective FIRM	Shaded X and AE	n/a and 7	10	10
		ABFE	A	11	15	
Red Hook West Houses	Red Hook (Brooklyn)	Effective FIRM	AE	9	n/a	11
		ABFE	A	11 and 12	17	
Surfside Gardens	Coney Island, (Brooklyn)	Effective FIRM	AE	9	n/a	12
		ABFE	A	13	18	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the Tropical Cyclone Report, Hurricane Sandy (AL182012) (NHC 2013b).

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

4.1.2 Structural Performance

The mid-rise residential developments are large and are constructed of heavy building materials and suffered no structural damage from inundation of floodwater or high winds.

Hammel Houses. The development opened in 1955, consists of 14 buildings with 708 total units, and houses a population of approximately 1,900 people. The buildings are six- and seven-story concrete-frame structures with brick façades.

The MAT observed consolidation of saturated soils at the Hammel Houses development (Queens, NY) as a result of Hurricane Sandy (Figure 4-1). The consolidation appeared to be caused by the saturation of under-compacted soils and did not affect the structural performance of the buildings.

Figure 4-1: Consolidated soils at Hammel Houses (Queens, NY)

4.1.3 Critical Building Systems

All but one of the mid-rise residential developments the MAT visited housed equipment for MEP systems in below-grade spaces. Where floodwater entered the structure and inundated the basement, these building systems were severely damaged or destroyed. Boilers, controls, electrical panels, switchgear assemblies, fuel tanks, and other mechanical systems were damaged. The MAT did not observe damage to utility company equipment, but all the sites visited lost municipal power from the service provider for a short duration. Outages extended past the restoration of the electrical grid (approximately less than 10 days) because of floodwater damage to electrical systems at the developments. Residents in buildings with damage to MEP equipment were without power, heat, and hot water until temporary equipment was obtained and installed (Bres 2012). Buildings were repaired later. According to reports from NYCHA, approximately 80,000 residents in 423 buildings were affected by lost power, heat, and/or hot water as a result of the storm. By November 18, heat, power, and hot water were completely restored (by either repair or replacement or the installation of temporary equipment) to all NYCHA buildings affected by the storm (New York City 2013a). The Ocean Bay developments and Red Hook West Houses are representative case studies of damage to critical building systems in mid-rise residential buildings.

Ocean Bay Apartments. Ocean Bay Apartments consists of two developments—the Bayside and Oceanside developments—separated by Beach Channel Drive on the Rockaway Peninsula in Queens (Figure 4-2). The Bayside development, constructed in 1961, consists of 24 buildings with a total of 1,378 units and houses a population of approximately 3,600 people. The Oceanside development was constructed in 1951 and consists of seven buildings with a total of 417 units that house a population of approximately 850 people. The buildings in both developments are mainly six- to nine-story concrete-frame structures with brick façades.

Figure 4-2: Aerial view of Ocean Bay Apartments, comprising Oceanside (yellow) and Bayside (red dashed), shows the location of Building 4 and Building 22, which house the central boiler plants (Queens, NY)

Damage to the two Ocean Bay Apartments developments differed based on the elevation of the central boiler plant and other mechanical and electrical equipment. The MAT observed significant damage to boilers, control systems, and electrical equipment in the basement of Building 22 of the ***Bayside development*** (Figures 4-3 to 4-5). Floodwater surrounding the building was approximately 2 feet deep; the floodwater entered the basement through several at-grade vented louvers and through exterior doors that opened to staircases leading to the basement (Figure 4-6). The basement was inundated with approximately 18 feet of floodwater. Residents at the Bayside development were without electricity and heat for several days after the storm until temporary electrical equipment was installed. Large portable generators were installed outside the buildings to provide electrical service while equipment was replaced and the electrical grid was repaired. In addition, temporary boilers were installed and expected to be used for an extended period because of the time required for repair or replacement of the damaged boilers.

The adjacent ***Oceanside development*** performed much better than the Bayside development because the boiler room was located on the ground level in Building 4. Less than 1 foot of water entered the building, and none of the mechanical or electrical equipment was damaged (Figure 4-7). The boilers at the Oceanside development were brought online as soon as utility service was restored to the facilities. According to NYCHA representatives, the Oceanside development, which is older than the Bayside development, was likely built without basements because of site design criteria or construction costs.

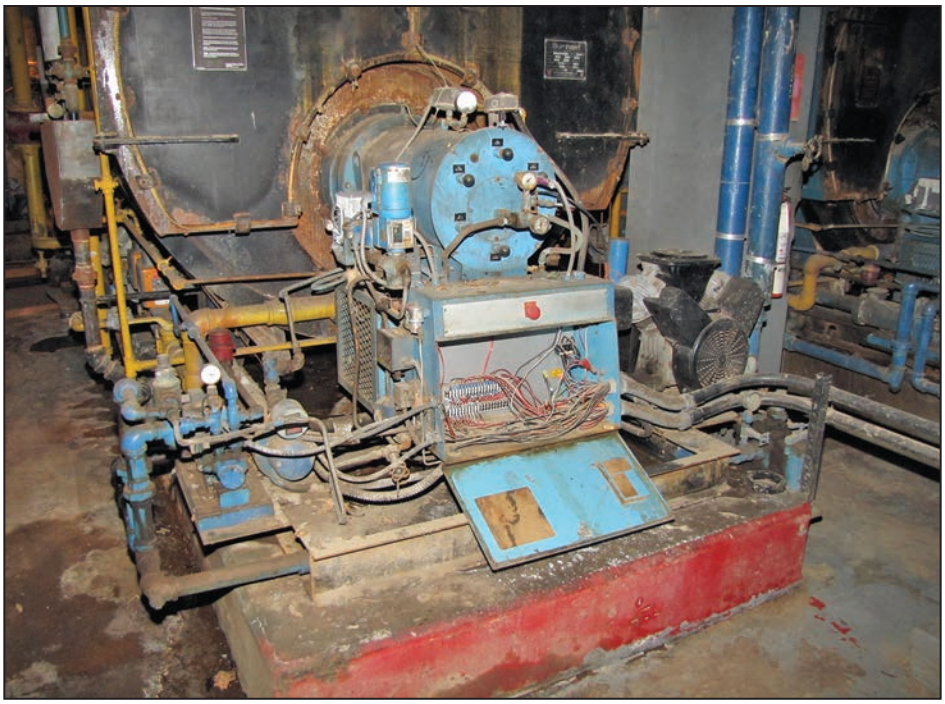

Figure 4-3:
A damaged boiler burner at the Bayside development (Ocean Bay Apartments; Queens, NY)

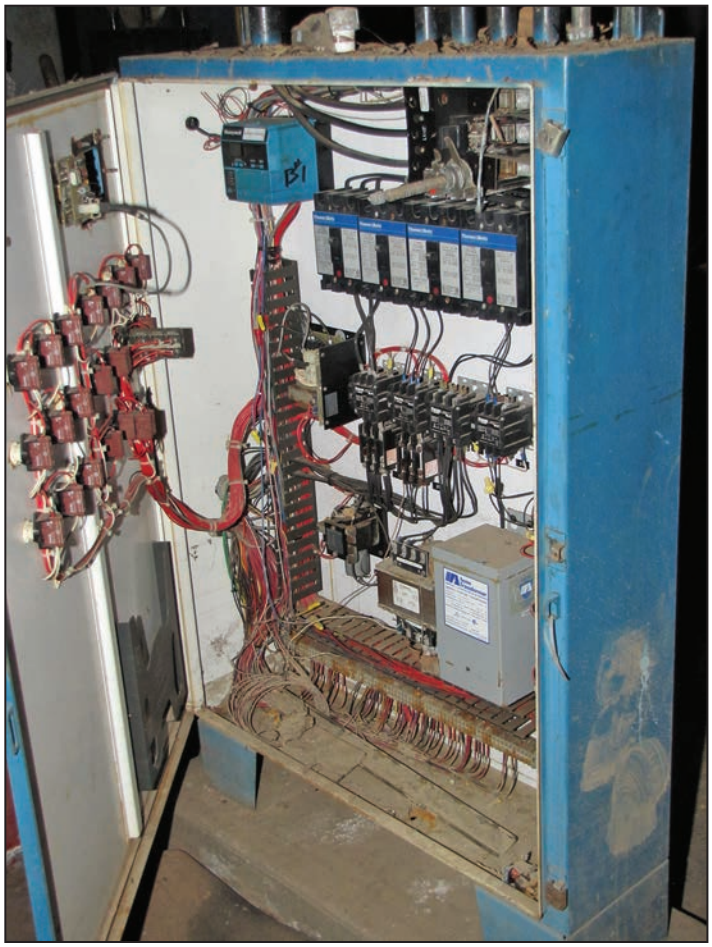

Figure 4-4:
Control equipment for a boiler that was inundated at the Bayside development (Ocean Bay Apartments; Queens, NY)

Figure 4-5: Electrical panels and switchgear system all had to be replaced after the basement was inundated at the Bayside development (Ocean Bay Apartments; Queens, NY)

Figure 4-6: Floodwater entered the basement of the Bayside development through exterior doors with staircases leading into the basement and several at-grade louvers (inset) (Ocean Bay Apartments; Queens, NY)

Figure 4-7: Boiler room at the Oceanside development, located slightly above ground level with a street level entrance (left), was not damaged by shallow floodwater (approximate flood depth indicated by dashed yellow line on right photograph) (Ocean Bay Apartments; Queens, NY)

Red Hook West Houses. The Red Hook West Houses is the largest NYCHA-owned property in Brooklyn. The development opened in 1955, consists of 14 buildings with a total of 1,470 units, and houses a population of approximately 3,330 people. The buildings are 3- to 14-story concrete-frame structures with brick façades.

Four boiler rooms in the basements of Buildings 1, 17, 19, and 25 provide heat and hot water to all buildings in the development (Figure 4-8). Furthermore, these spaces include electrical systems. The Hurricane Sandy storm surge flooded the basements (approximately 12 feet below grade) to the ceiling, causing extensive damage to boilers, control systems, electrical service and distribution equipment, and other mechanical equipment (Figures 4-9 and 4-10). Floodwater entered primarily through exterior ramps that provided access to the boiler rooms (Figure 4-11). The exterior doors at the base of the ramps failed because of floodwater forces that allowed floodwater to enter freely. Several interior partitions and doors also collapsed as a result of inundation (Figure 4-12). The heavy damage to electrical equipment resulted in the housing units being without power even after the electrical grid was restored. Residents were without electricity, heat, and hot water for several weeks after the storm until temporary equipment (generators and boilers) was installed.

4.1.4 Conveyance/Elevators

The MAT assessed only the elevators that NYCHA reported as having been damaged. Most of the elevator cabs observed by the MAT were not flooded, as they had been raised well above street level during the storm. The elevator systems included a hoisting system and motors that were located on the building roofs, so the elevator systems were largely protected from flooding. Mechanical and electrical equipment in the elevator pits, however, was damaged in the buildings that flooded. This damage, combined with the loss of utility service power, resulted in lengthy and costly repairs. Residents were therefore unable to use the elevators, which was a substantial hardship for many elderly and mobility impaired residents.

Figure 4-8: Aerial view of Red Hook West Houses; arrows indicate Buildings 1, 17, 19, and 25; boiler rooms in the basements of these buildings were inundated during Sandy (Brooklyn, NY)

Figure 4-9: Extensive flood damage to boilers, pumps, and control systems in the basement of Building 19 (Red Hook West Houses; Brooklyn, NY)

Figure 4-10: Floodwater damaged this electrical service and distribution equipment in the basement of Building 19 (Red Hook West Houses; Brooklyn, NY)

Figure 4-11: Floodwater entered the Building 25 basement through a ramp entrance to the boiler room; the approximate floodwater depth of 2 to 3 feet above grade is shown by the red line (Red Hook West Houses; Brooklyn, NY)

Figure 4-12:
Interior door of Building 19 collapsed when basement was inundated (Red Hook West Houses; Brooklyn, NY)

4.2 High-Rise Buildings

High-rise buildings suffered widespread damage and service losses from Hurricane Sandy storm surge inundation. The damage and service losses affected buildings throughout the New Jersey and New York metropolitan areas. The MAT visited nine high-rise buildings in New Jersey and New York, including one residential building in New Jersey (Jersey City condominium high-rise) and four commercial and four residential high-rise buildings in New York (includes Coney Island residential high-rise in Brooklyn).

All of the high-rise buildings highlighted in this chapter are located in SFHAs. The buildings range in age from 10 years to close to 100 years old. Occupancy types include residential, commercial, and mixed-use. All structures visited have subgrade spaces, with most of the subgrade spaces housing the building systems. The following observations are representative of the damage to high-rises in the New Jersey and New York area that were inundated by storm surge. The flood damage observed by the MAT was similar to the damage observed at the mid-rise buildings.

4.2.1 Siting Effects on Building Performance

The location of the high-rise buildings in an urban environment near the river and bay subjected all of the buildings to the Hurricane Sandy storm surge. All of the sites visited are located inside the SFHA in Zone AE, based on the Effective FIRM.

Table 4-2 lists each of the high-rise buildings visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites located in Zone A, and the level of storm

surge during Hurricane Sandy. The flood zones in Table 4-2 include those shown on FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

Table 4-2: BFEs, ABFEs, and Sandy Floodwater Elevations for High-Rise Buildings

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone on Map[a]	1-Percent-Annual-Chance Elevation (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[b]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Jersey City condominium high-rise	Jersey City, NJ	Effective FIRM	AE	9	n/a	10-11
		ABFE	A	12	18	
Coney Island residential high-rise	Coney Island (Brooklyn), NY	Effective FIRM	AE	9	n/a	12
		ABFE	A	12	17	
Manhattan commercial high-rise (1)	Manhattan, NY	Effective FIRM	AE	9	n/a	11-12
		ABFE	AE and V	13 and 14	16	
Manhattan commercial high-rise (2)	Manhattan, NY	Effective FIRM	Shaded X and AE	n/a and 9	n/a	10-11
		ABFE	A	11 and 12	15	
Manhattan commercial high-rise (3)*	Manhattan, NY	Effective FIRM	AE	9 and 10	n/a	11-12
		ABFE	A and V	13 and 14	16	
Manhattan residential high-rise (4 and 5)	Manhattan, NY	Effective FIRM	AE	10	n/a	11-12
		ABFE	A	11	15	
Manhattan residential high-rise (6)*	Manhattan, NY	Effective FIRM	AE	10	n/a	11-12
		ABFE	A	11	15	
Manhattan commercial high-rise (7)*	Manhattan, NY	Effective FIRM	AE	9	n/a	11-12
		ABFE	A and V	13 and 14	16-17	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the Tropical Cyclone Report, Hurricane Sandy (AL182012) (NHC 2013b).

* Not described further in this report.

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

All of the properties visited by the MAT had storm surge flooding and some amount of inundation as a result of Hurricane Sandy. In addition to being flooded because of their proximity to a flood source, the complexity and interconnectivity of typical buildings in the New York City urban environment influenced building performance. Shared subgrade areas allowed floodwater to travel between buildings, contributing to the flooding throughout a complex. This effect was observed in two high-rise residential buildings that shared a below-ground parking garage and basement where no measures were in place to prevent floodwater from entering the shared subgrade spaces.

4.2.2 Structural Performance

Most of the high-rise buildings visited by the MAT had no structural damage from either floodwater inundation or wind. Physical damage observed was limited to the collapse of nonstructural concrete block partition walls in basements. However, the parking garage slab in a Jersey City condominium the MAT visited was damaged by floodwater inundation.

Jersey City Condominium. Constructed in 2006, the condominium is a 12-story, rigid concrete-frame structure with 500 residential units and an interconnected two-level parking garage (Figures 4-13 and 4-14). The parking garage for the Jersey City Condominium is shared with an adjacent residential high-rise building, and is partially underneath the footprint of both condominium buildings.

Figure 4-13:
A Jersey City condominium and adjacent interconnected building (Jersey City, NJ)

Figure 4-14:
Aerial view of a Jersey City condominium and adjacent building where the highlighted region shows the approximate location of the two-level parking garage located partially beneath both buildings (Jersey City, NJ)
SOURCE: GOOGLE EARTH

The Hurricane Sandy storm surge flooded the first floor of the garage and building lobby with approximately 3 feet of water and submerged the basement of the garage. Water entered the first floor through the main lobby entrance sliding doors, damaging interior finishes. Water then moved through the lobby doors into the garage. In the garage basement, elevator equipment and a trash compactor were damaged. However, the mechanical equipment was housed on the twelfth floor and electrical equipment was elevated between the first and second floor; because the equipment was all elevated above the floodwater depth it was not damaged. One of the elevator bays was temporarily out of service due to flooding in the elevator pit (see Section 4.2.4).

The building would have been able to continue functioning immediately following the storm, except the storm surge inundation caused structural damage in the interconnected garage, requiring residents of both buildings to be evacuated. According to interviews, rapidly rising floodwater flooded the first floor of the garage before the basement level of the garage was fully inundated, so the floor slab had to support water that accumulated on the upper floor. This created a loading condition that may have exceeded the design loads (Figure 4-15) and caused the slab to spall and crack at the column hinges (Figure 4-16).

City engineers ordered the evacuation of the Jersey City condominium and the adjacent high-rise building sharing the garage because of concerns that the slab might collapse and compromise one or more of the columns, potentially causing progressive collapse of the buildings. During repair, tension cables were installed to provide additional support to the damaged slab from above while floodwater was pumped out of the basement (Figure 4-17). After the floodwater was pumped out, temporary shoring was installed in the basement (Figure 4-18). Subsequent inspections established that the structure was stable, and residents of the buildings were allowed to return. The adjacent high-rise building that shared the garage was still closed during the MAT visit (approximately 45 days after the storm) because of extensive damage to the electrical and fire systems in the basement.

Figure 4-15:
Ramp leading from the first floor of the Jersey City condominium garage to the basement level; the garage suffered structural damage when storm surge flooded the first floor of garage (Jersey City, NJ)

Figure 4-16:
First floor slab of the Jersey City condominium garage cracked and spalled at column hinges due to unbalanced flood loading (Jersey City, NJ)

Figure 4-17:
Tension cables provided additional support from above when floodwater was pumped out of garage basement (Jersey City, NJ)

Figure 4-18: Temporary shoring installed in the Jersey City condominium parking garage basement to support damaged slab above (Jersey City, NJ)

4.2.3 Critical Building Systems

Critical building systems (MEP, telecommunications, and emergency power) were located in the subgrade spaces of all but one of the high-rise buildings the MAT visited. Where the building systems were located in the subgrade spaces and unprotected, inundation badly damaged the equipment. Where the equipment was located on the upper floors of the building, no damage occurred. Building functionality varied depending on the extent of damage to critical building systems. Some buildings were able to continue operations after the storm with limited or full functionality after repairs or installing temporary equipment. However, the MAT observed two buildings with extensive damage that caused residents to be evacuated for several months. Manhattan commercial high-rise (1), Manhattan commercial high-rise (2), Manhattan residential high-rises (4 and 5), and Coney Island residential high-rise described in this section are representative case studies of damage to critical building systems in high-rise buildings.

Coney Island Residential High-Rise. The Coney Island residential high-rise is a multi-family residential development owned and operated by the NYCHA. The development opened in 1957, consists of five 14-story high-rise buildings with a total of 534 units, and houses a population of approximately 1,300 people. The buildings are concrete-frame structures with brick façades. The development has a central boiler plant in the basement of Building 3 (Figure 4-19). The site is less than 400 feet from the Atlantic Ocean waterfront.

Floodwater surrounding the properties was approximately 3 feet deep during Hurricane Sandy (Figure 4-20). The basement of Building 3, where the central boiler plant was located, was inundated. According to interviews with the building engineer, floodwater entered the basement through vented louvers and an emergency exit stairwell. Boilers, control systems, electrical panels, switchgear, and other mechanical equipment in the basement were damaged (Figures 4-21 and 4-22) and in some cases displaced (Figure 4-23). Temporary utilities were installed immediately after the storm to restore electricity and heat to residents while the equipment was repaired or replaced.

Figure 4-19: Aerial view of the five 14-story Coney Island residential high-rise (Brooklyn, NY)

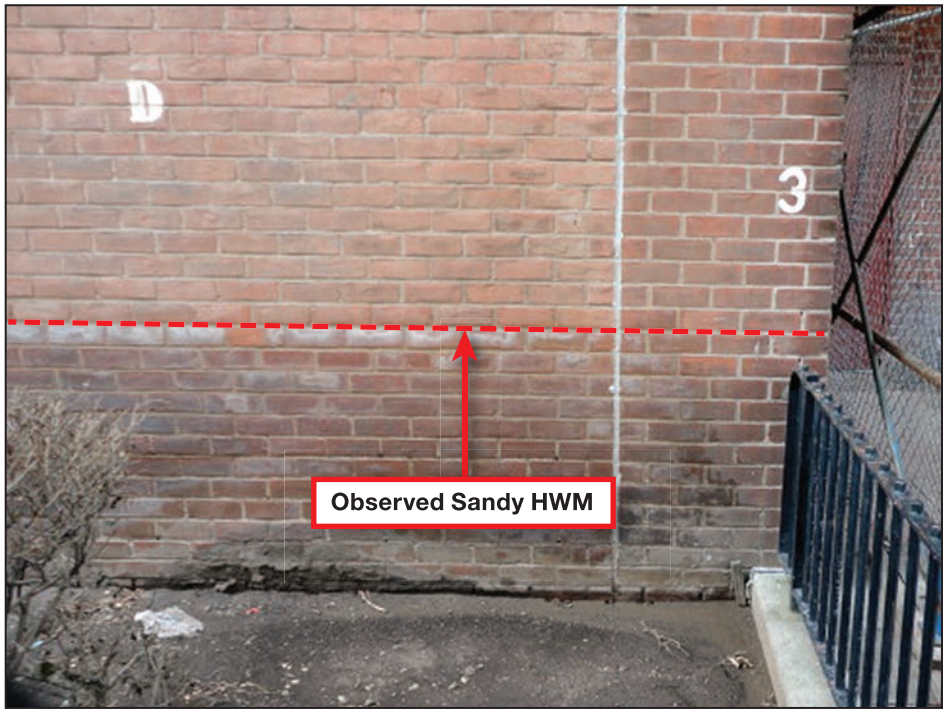

Figure 4-20:
HWM (red dashed line) 3 feet above grade on one of the Coney Island residential high-rise Houses buildings (Brooklyn, NY)

Figure 4-21:
Central boiler plant room in basement of Building 3 was inundated (Brooklyn, NY)

Figure 4-22:
Electrical distribution panel in the Building 3 basement was destroyed by corrosion due to seawater inundation (Brooklyn, NY)

Figure 4-23:
Some equipment in the central boiler plant room in the Building 3 basement was displaced by the floodwater entering the basement from an emergency exit stairwell (Brooklyn, NY)

Manhattan Commercial High-Rise (1). Manhattan commercial high-rise (1) is a 24-story building in Lower Manhattan. The high-rise, built in 1971, is two blocks from the East River near the South Street Seaport. The high-rise is a steel frame structure with masonry infill walls. Based on an interview with the building's chief engineer, water entered through the lobby doors as well as the loading dock, and the first floor of the building was inundated with more than 4 feet of water (Figure 4-24). Floodwater spread throughout the first floor and inundated the basement, primarily through the elevator shaft (Figure 4-25).

Figure 4-24:
HWM (red dashed line) along first floor electrical room wall (New York, NY)

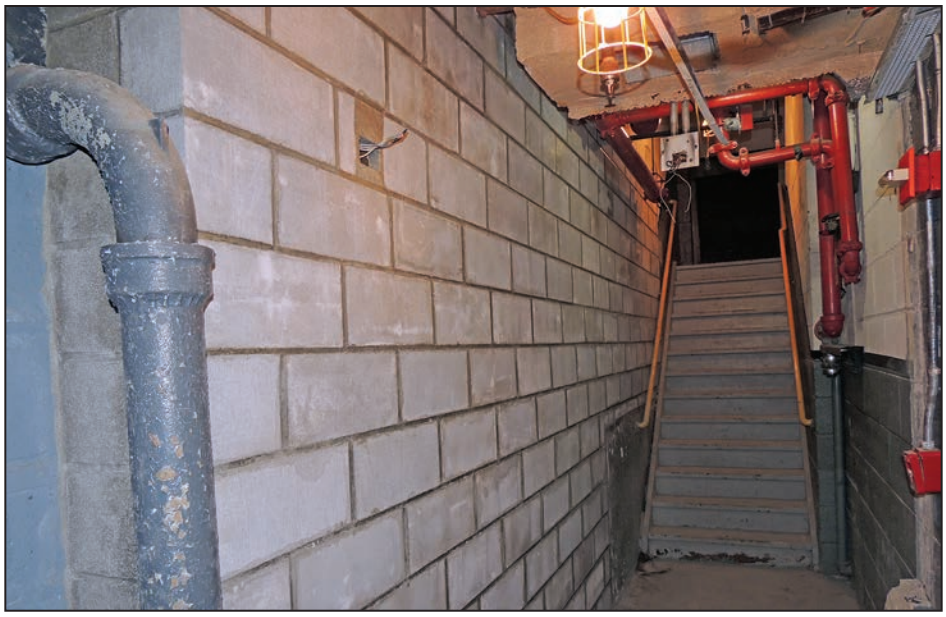

Figure 4-25:
Floodwater from the first floor lobby entered the basement through the elevator shaft; the elevator shaft walls had to be replaced after Hurricane Sandy (New York, NY)

The electrical service equipment, transfer switch, generator, and other equipment located in the first floor electrical room were all damaged. In the basement, the steam distribution system, water booster pumps, and other equipment in the mechanical room were damaged, leading to the building's loss of functionality.

The heating system for the building was repaired relatively quickly once steam service was back online from the utility provider. Telecommunications for the building were also repaired relatively quickly because telephones for the building were primarily supplied through a fiber optics network. Restoring electrical power to the building took considerably longer; approximately 45 days after Hurricane Sandy, the building was still operating on generator power (Figure 4-26). The building remained closed to tenants until repairs were made and re-opened in February 2013.

Figure 4-26:
Generator providing temporary power to Manhattan commercial high-rise (1) (New York, NY)

Manhattan Commercial High-Rise (2). An 11-story commercial and office building built in 1914, Manhattan commercial high-rise (2) is on the banks of the Hudson River near the southwest corner of the Chelsea District. The building suffered minor flood damage during Hurricane Sandy. Flood inundation was approximately 1 to 2 feet above street level. The HWM at a nearby pier was 12.3 feet.[2]

The electrical room (electrical service equipment, transfer switch, etc.) and chillers are located on the first floor, and the furnace and most other mechanical equipment are on the top floor. Flood depths on the first floor were minor and did not cause much damage.

More than 40,000 gallons of fuel was stored in four tanks in the basement that service more than 10 generators spread throughout the facility for various tenants. The fuel tanks and pumps distributing fuel to the generators are inside a floodproofed enclosure (Figures 4-27 and 4-28). In addition, the basement has six pumps (minimum capacity of 100 gallons per minute) to drain the basement in case of flooding. Prior to Hurricane Sandy, only two of the six pumps were connected to the emergency generator, but as an emergency protective measure, the other four were added to an emergency power circuit just before the storm.

Based on an interview with the building's chief engineer, water initially entered the basement through a telecommunications utility point of entry on the Hudson River side of the building. The six pumps successfully controlled flood levels in the basement, keeping the water below 3 inches throughout the basement. Generators throughout the building remained operational during the storm and after, until power service was restored by the utility provider.

Figure 4-27: Successful floodproofed fuel pump enclosure in basement of Manhattan commercial high-rise (2) (New York, NY)

2 USGS HWM-NY-NEW-003 from USGS Sandy Storm Tide Mapper http://water.usgs.gov/floods/events/2012/sandy/sandymapper.html.

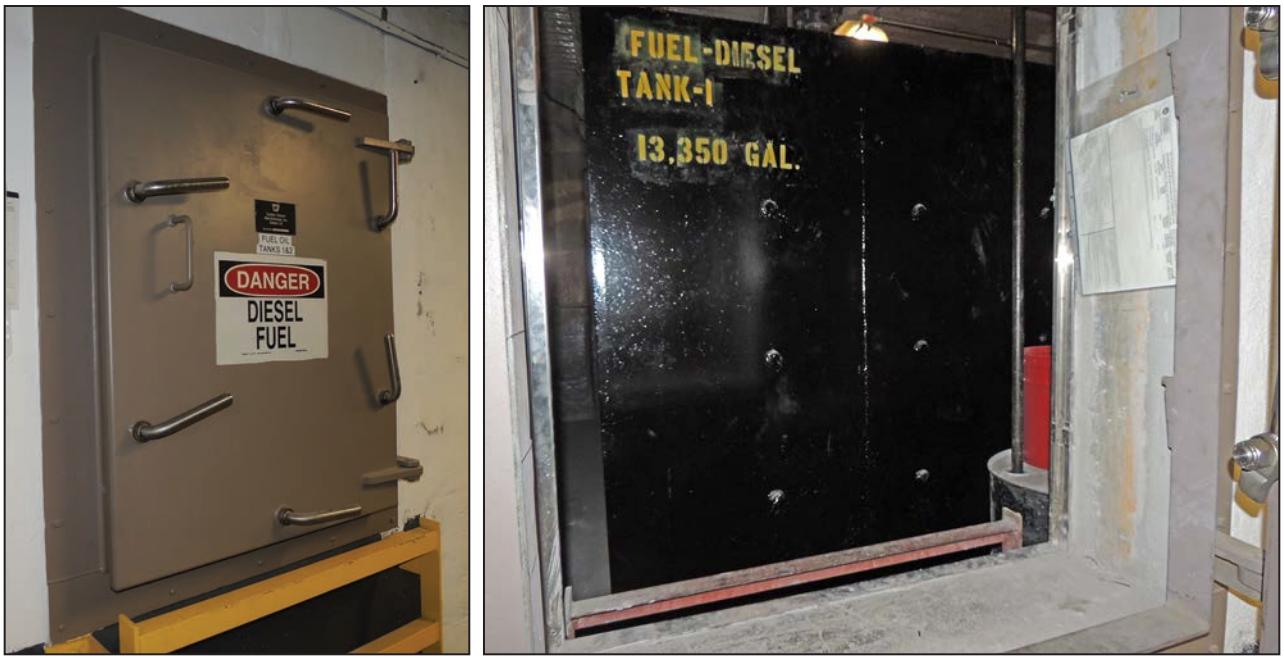

Figure 4-28: Successful floodproofed fuel tank enclosure in basement of Manhattan commercial high-rise (2) (New York, NY)

In contrast, the adjacent building had MEP equipment in the basement; it received over 1 foot of flooding in the basement and was closed for 2 weeks after Hurricane Sandy.

Manhattan Residential High-Rises (4 and 5). Manhattan residential high-rises (4 and 5) are a 28-story luxury apartment building built in 2009 and an adjacent 51-story residential building built in 2005. The buildings are mixed-use and have retail spaces on the first floors. The buildings are 3 blocks from the East River in Manhattan's Financial District and suffered significant flood damage during Hurricane Sandy. The residential buildings are interconnected through a shared basement, parking garage, and utility rooms. The 51-story building had floodgates that were 42 inches high above the ground surface, which was the BFE. The floodgates were installed at the ground-level parking garage entrance and the storefronts on the first floor (Figure 4-29). Flood depths along the first floor were minimal and did not cause much damage. However, a HWM at the loading docks indicates that the floodgates were overtopped, allowing water to enter the subgrade levels. Flood inundation levels from Hurricane Sandy were at approximately the same height as the top of the floodgate, but there was an additional 1 to 2 feet of wave action. Consequently, the subgrade areas of the buildings were inundated with approximately 30 feet of water.

The electrical room (electrical service equipment, transfer switch, etc.), chillers, mechanical equipment, and fuel storage were located in the subgrade space that is shared by the two buildings (Figure 4-30). Over 20,000 gallons of fuel is stored in tanks in the basement. A building engineer reported to the MAT that the fuel tanks were crushed by the high volume of water in the subgrade areas. The tanks released fuel into the basement areas, which mixed with the seawater and produced fumes that permeated the residential units. The building was not equipped with an emergency generator and remained closed until mid-February 2013.

Figure 4-29: Installed 42-inch-high floodgates (red arrow) were overtopped by storm surge, allowing inundation of subgrade levels (New York, NY)

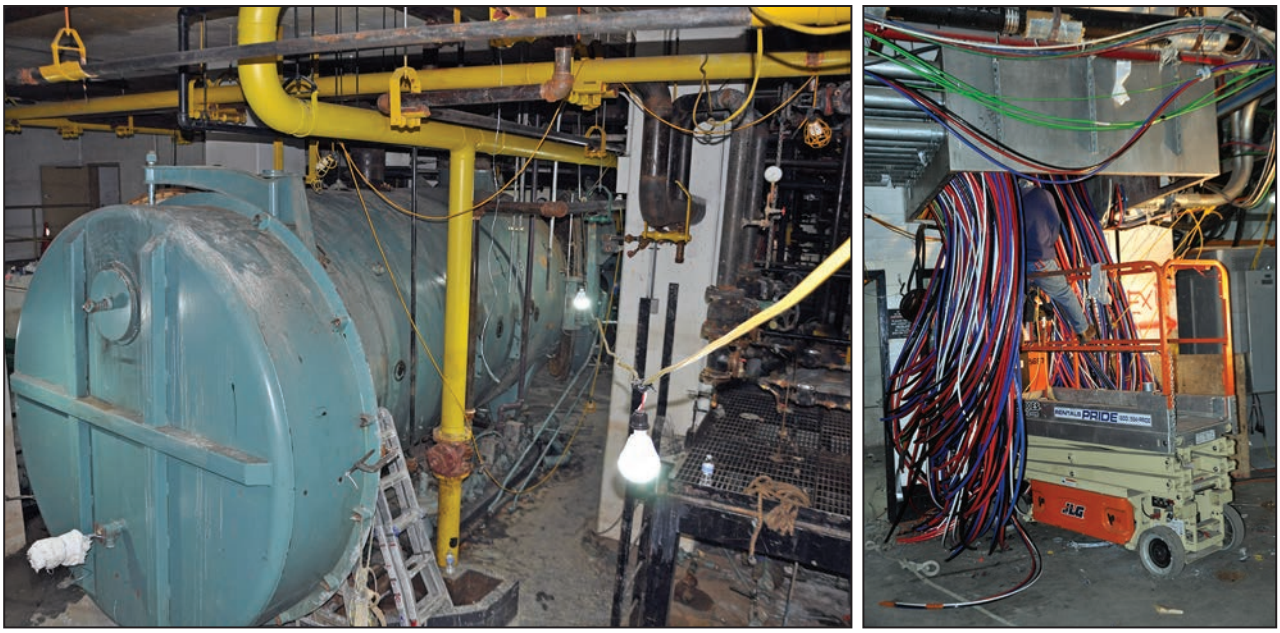

Figure 4-30: Mechanical room (left) was inundated when the 42-inch-high floodgate was overtopped by floodwater; electrical conduit throughout subgrade level (right) was replaced after being submerged in saltwater (New York, NY)

4.2.4 Conveyance/Elevators

Elevator systems in three of the high-rise residential buildings the MAT visited were damaged by Hurricane Sandy. The elevator pits and shafts extending below grade were inundated by floodwater, which damaged shaft walls, controls, and equipment. Loss of elevator service in the high-rises hindered vertical building access and adversely affected building service and operations.

- + One of the elevator bays of the Jersey City condominium building (see also Section 4.2.2) that connected the parking garage to the residential tower was temporarily out of service after equipment and controls in the elevator pit were inundated.

- + The CMU walls of the elevator shafts at both Manhattan commercial high-rise (1) and Manhattan residential high-rise (4) collapsed because of the hydrostatic pressure of floodwater in the basement (Figure 4-31).

Figure 4-31: Hydrostatic flood forces destroyed CMU walls around elevator shaft (red dashed lines) when elevator pit was inundated (Manhattan residential high-rise (4); Manhattan, NY)