Superstorm Sandy Storm Surge and Residential Damage Correlation – A case study of Long Beach, NY

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ABSTRACT

The New York City region is currently recovering from the damage caused on October 29, 2012 from Superstorm Sandy, the largest low pressure storm ever to make landfall on the US east coast north of North Carolina. This storm tested all aspects to the infrastructure of the communities living close to the Atlantic Coast. Research was performed to review and process data that were collected before, during, and after the storm. The research focused on the city of Long Beach, NY. The scope of the research included three tasks: (1) reviewing and processing hydraulic data collected from USGS tide gages before and during the storm; (2) collecting and processing structural data collected after the storm focused on extent of damage to residential buildings and type of building construction; and (3) correlating, analyzing, and mapping flood data and residential damage utilizing GIS software.

The results of this research points to a strong recovery theme– residences designed with heavier and sturdier materials (i.e. brick and stucco facades) are more likely to resist damage during a storm than those constructed with lighter materials (i.e. lightweight siding on wood frames). The damage can be resultant of hydrostatic and buoyant forces due to rising floodwaters, hydrodynamic forces due to flowing water, impact forces due to water waves, as well as hurricane force winds. The extent of damage can also be correlated to the applicable zoning laws. Homes built in accordance with stricter coastal zoning practices are better designed to resist hurricane forces.

With Long Beach acting as a snapshot of the Northeastern coast, the research conducted with this city may be applied to many other coastal communities providing invaluable guidance to rebuilding during storm recovery and preparation for future events.

INTRODUCTION

In late October of 2012, meteorologists began tracking the late season tropical storm as it approached the Atlantic coast in New Jersey and New York. On the 29th of October, the storm approached land as a Category 2 hurricane. The storm had a barometric pressure of 943 millibars, the lowest pressure storm system ever tracked that made landfall north of Cape Hatteras, North Carolina. The named storm made landfall near Atlantic City, NJ. The wind speeds at landfall placed the storm system in the “post tropical cyclone” category, but wind gusts reached 94 mph in New York, and the wind span of the storm was over 1,100 miles wide. The enormous reach and destructiveness of it prompted the storm to be renamed, “Superstorm

Sandy". The barometric pressure caused storm surges to reach 13.8 ft. at Battery Park, New York City. The highest peak wave height recorded was 39.7 ft. 500 miles south of Atlantic City. The waves at the entrance to New York Harbor were 32.5 ft. high.

The storm caused $36.8 billion of damage to the Jersey Shore, $19 billion to New York City and $41.9 billion to the entirety of New York State, including Long Island. The direct fatalities from the storm in United States reached 72, and indirect fatalities from storm cleanup efforts exceeded 87. Over 8.2 million people were left without power, including 29 hospitals, and 650,000 houses were damaged or destroyed in NY and NJ. Months of grief, safety hazards and inconvenience for the residents of those areas followed. The cities affected were anxious to rebuild and recover as quickly as possible, given the information that a storm of the same magnitude may be in the forecast in the near future. However, research into the storm and its affects needs to be compiled, and the recovery efforts, though well intentioned, may not always be the best route for long-term sustainability. This research project focuses on the structural damage caused by Superstorm Sandy. The information gathered includes what types of buildings were most affected. This information was correlated to the extent and height of the storm surge from the storm.

RESEARCH OBJECTIVES

The goal of this research project was to gather data from organizations such as FEMA (Federal Emergency Management Agency), NOAA (National Oceanic and Atmospheric Administration) and the United States Geological Survey (USGS), and use information gathered about the status of structures in areas affected by the storm, and determine if correlations exist between structural failure, building materials and hydrodynamic impacts. The project categorizes information on building materials from residential buildings that were damaged, with the overall objective being industry suggestions of the most resilient structure type, the most non-resilient structure type, or other alternatives that may prevent storm and flooding damage. There was a focus on hydraulic forces that structures experience during a flood and appropriate analyses of these forces can be considered. Ongoing work involves creating an interactive map using ArcGIS to plot on a community map the types of buildings that were damaged, where those buildings were located, the extent of storm surge inundation, and applicable wave forces measured. The information that was gathered could be used to help residents rebuild their houses or businesses to improve overall safety of the dwelling and to lower future insurance premiums. Residents may also decide to move away from the area, if risks outweigh the cost of rebuilding.

The compiling of this type of data was initially narrowed down to one coastal city – the City of Long Beach in Nassau County, Long Island, as pictured in Figure 1. Long Beach is just 18 miles southeast of Battery Park, Manhattan, New York City, and borders the communities of Atlantic Beach on the west, Lido Beach on the east, the Atlantic Ocean on the south, and the Reynolds Channel portion of the intercoastal waterway to the north. It has a 30,000 year-round population, which increases in the summer months. Figure 2 is an aerial map of Long Beach, illustrating that it is a densely populated beach community on the barrier island. Figure 2 also shows the extent of the storm surge from Superstorm Sandy. Almost all of Long Beach was flooded (shown in gray). The dark shaded areas near the bridge going over the intercoastal channel, and small spots in the south-west part of the city were the only locations that were spared water inundation.

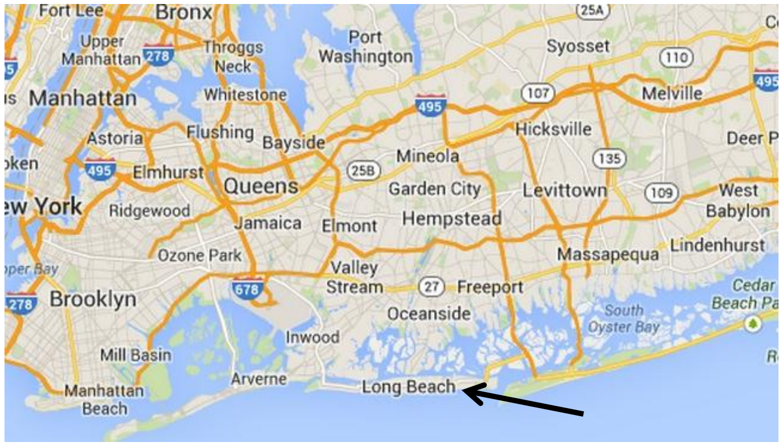


Figure 1 – Long Beach location in comparison to New York City

SUMMARY OF APPROACH

The work described here is part of a larger research program in the area of water-structure interaction as influenced by natural disasters such as hurricanes. This paper focuses specifically on the collection, correlating, and mapping of both hydraulic and structural damage data from the city of Long Beach, NY following Superstorm Sandy in 2012.

Phase 1 of the project included a field visit to Long Beach to verify and comprehend hydraulic data provided by the USGS throughout the town. The visit also provided a snapshot of the town a few months after Sandy hit. During the initial field visit, a contact was established with an organization named Sustainable Long Island. This organization focuses on economic and residential growth throughout the island. After the storm hit the group was particularly interested in the recovery of Long Beach with respect to rebuilding of both residential and commercial structures. The organization has its own division of citizens who are currently conducting research focused on economic recovery. They had already acquired a significant amount of residential data with respect to the status of homes in the town – i.e. under construction, demolished, vacant, or for sale – and shared said data with the Manhattan College research team (Sustainable Long Island, 2013).

Phase II of the work included expanding upon the previously gathered data. The damaged homes were further categorized by the type of external cladding with respect to common building materials – i.e. lightweight siding, brick, or stucco. This information was gathered by a "virtual" visual inspection of the homes.

Phase III of the work focused on the correlation and mapping of the hydraulic and structural damage data gathered in Phase I and Phase II. This information combined to make a powerful statement about structural damage due to natural disasters.

RESULTS AND DISCUSSION

Regional Flood Marks and Water Level Data

The barrier island that comprises the city of Long Beach has the potential to be flooded both from the south (via the Atlantic Ocean) or from the north (via the intercoastal channel). Table 1 lists locations near Long Beach house stations where predicted tides for the day the Storm hit,

Figure 2 – Aerial Map of Long Beach showing the Population Density and extent of Superstorm Sandy Water Inundation

October 29th, 2012. The predicted high tide water levels are calculated in advance using numerical models created by NOAA (NOAA, 2013).

Table 1 – Predicted high tide levels for October 29th, 2012 with respect to NAVD88 (North Atlantic Vertical Datum of 1988)

Station and Location	**Time of High Tide**	**Predicted Water Level in NAVD88 datum**
Long Beach Bay Side	8:19 AM	6.432 ft
Jones Inlet (Point Lookout), Atlantic Ocean East of Long Beach	7:41 AM	5.972 ft
East Rockaway Inlet, Atlantic Ocean West of Long Beach	7:54 AM	6.692 ft

The Long Beach Bay Side gage and the East Rockaway Atlantic Ocean gage were selected to be used for a data comparison to the actual water levels recorded by USGS gages temporarily deployed for the storm considering their locations are closest to the ocean and bay sides of Long Beach.

Figure 3 shows how the water heights varied throughout the city. The figure includes the predicted heights from NOAA (Table 1), and the zone's base flood elevation, or BFE. The BFE is the elevation set by the Federal Emergency Management Agency (FEMA) at which a structure must be built in order to comply with building code standards. BFE's are determined by examining water level data records. It is based off of the 100-year water levels, or the water level that has a 1% chance of occurring for a given year.

Figure 3 also compares the highest water surface elevations (high water mark, or HWM) reached at 6 different locations in Long Beach during Superstorm Sandy as recorded by temporarily deployed USGS gages, as well as the NOAA predicted water heights for that day (Table 1) and the FEMA BFE's at the same locations. Places where the HWM exceeds the BFE experienced the most damage on the island. Since structures were built using FEMA BFE levels to avoid floods, these structures were not prepared for such high flood waters. The water caused damage to electrical systems or structural supports. At every storm gage's location, the HWM exceeded the predicted water height significantly, as the predicted water height does not take into account wind forces or storm surges.

Figure 4 displays the depth of the flooding – which subtracts the water surfaces reached from the storm from the ground elevations throughout the region. The greater the depth of water, the greater the hydrostatic forces experienced by the structure, and thus potential damages to structures. The areas that experienced the greatest depth of flooding inundation were the areas that bordered the intercoastal channel, or the north side of the city. The northeast and north-central sections of the city had many blocks with over 6 ft of water. Thus, the storm surge from Superstorm Sandy flooded the city via the bay side. The southeast section of the city which is closer to the Atlantic Ocean had many blocks that had less than 2 ft of water inundation.

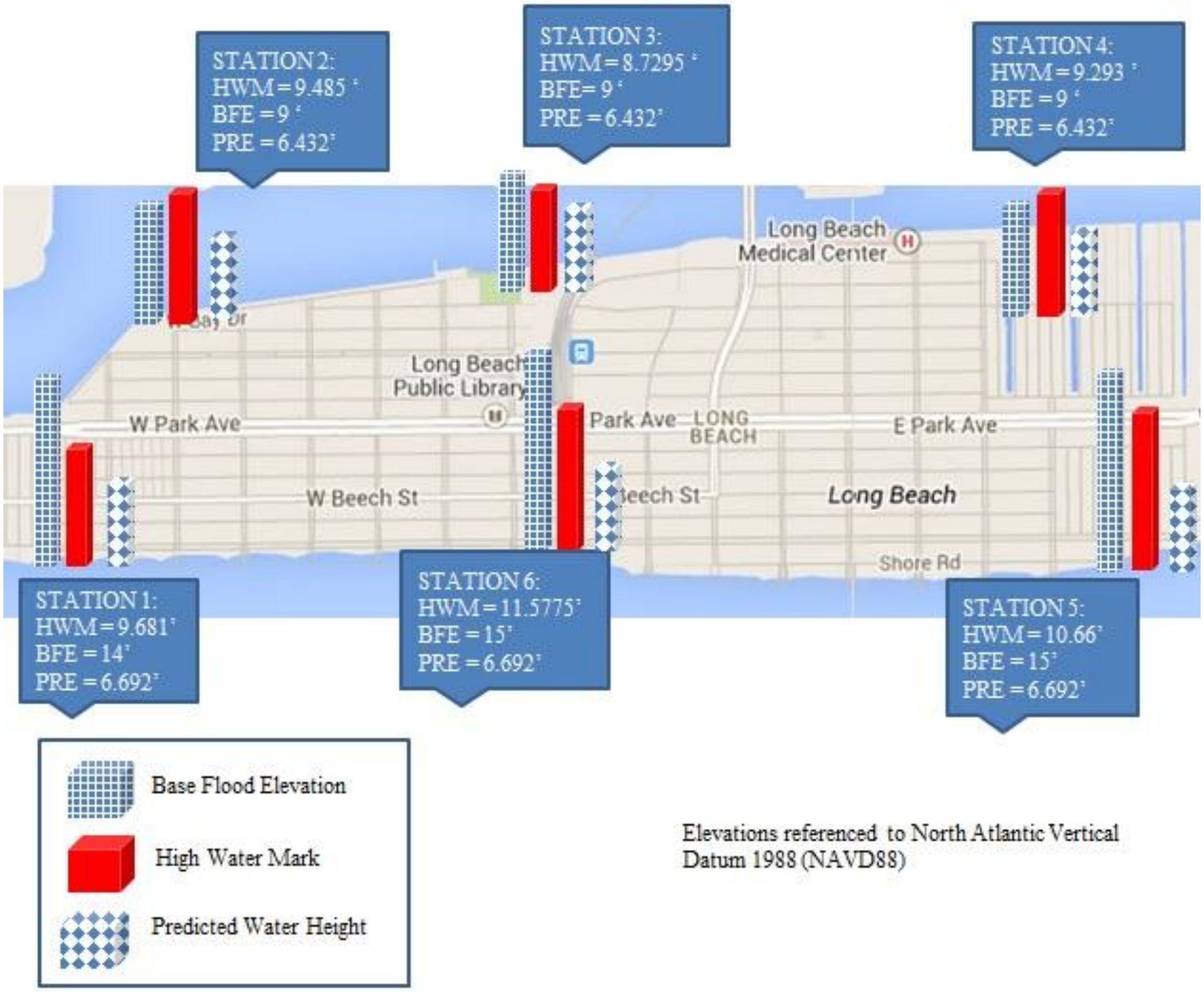


Figure 3 – Water height comparison for Long Beach during Superstorm Sandy

Survey of Structural Damage

Figure 5 shows the division of Long Beach into 3 districts (West End, Central District, and East End) and 5 zones (numbered sequentially starting in the south going north) and indicates the number of homes damaged in each of the districts. Each zone and district was analyzed by Sustainable Long Island with respect to the economic status of the homes. The Manhattan College research team analyzed homes in the same domains. They further classified the homes as damaged during Superstorm Sandy such that homes that Sustainable Long Island categorized as either affected by the storm were now considered damaged. Houses that were classified as having a refuse container ("pod") on site were assumed to be under construction to repair damages incurred during Superstorm Sandy. Houses that were originally classified as demolished were very few, and grouped together with the houses under construction for the structural assessment portion of the research. Houses that were classified as "for sale" or "vacant" were assumed to be so due to either real or perceived damage from the storm. It is recognized that the "For Sale" and "Vacant" categories may actually include some houses that were not physically damaged by the storm, but are simply for sale for other reasons, which may

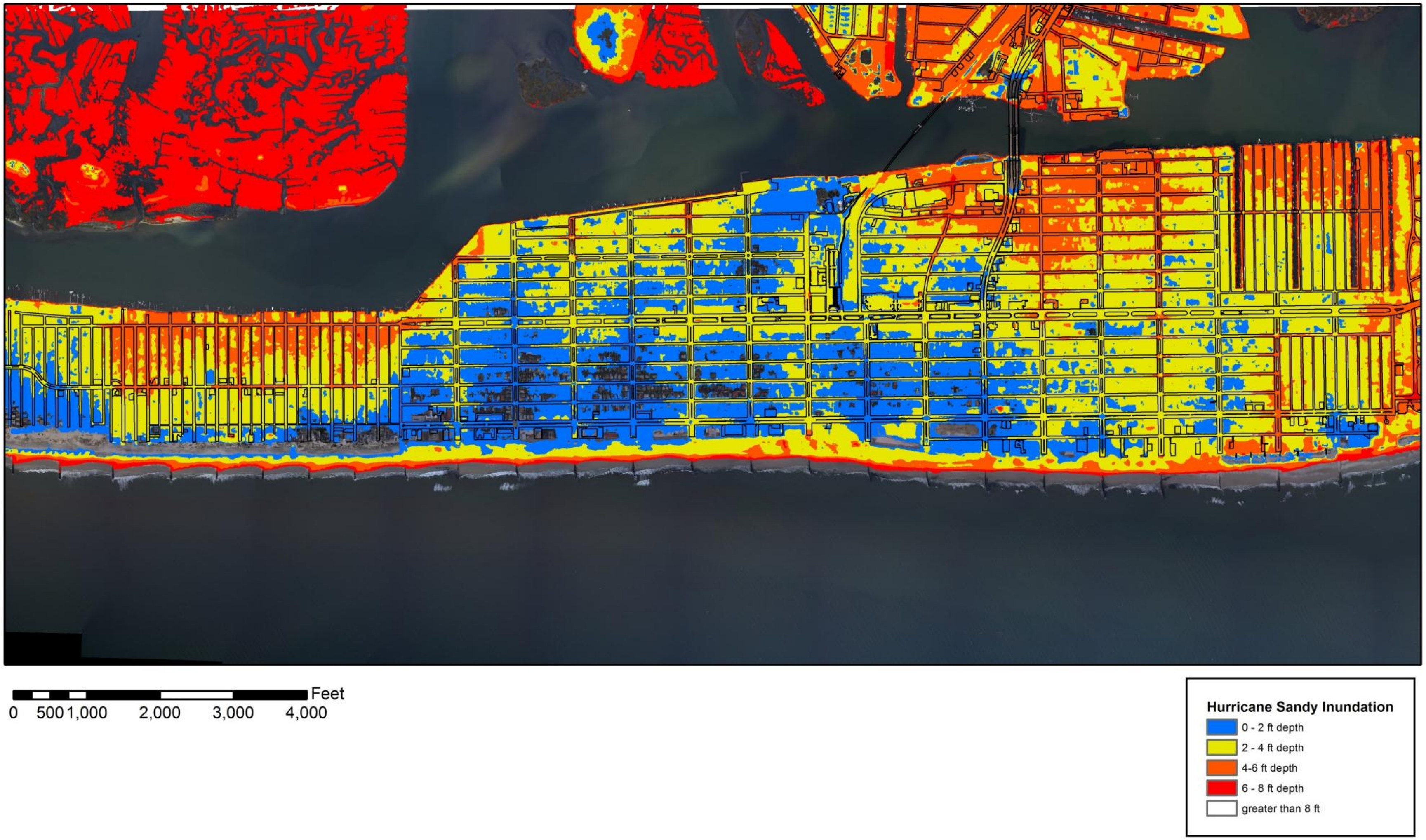


Figure 4 – Depth of Inundation during Superstorm Sandy.

or may not include fear of potential future damage. Data will be shown which distinguishes houses under construction from those for sale.

Structural assessment data focuses on the Central and East End districts of Long Beach. Similar data exists for the West End as well, but the structural assessment has as not yet been complete.

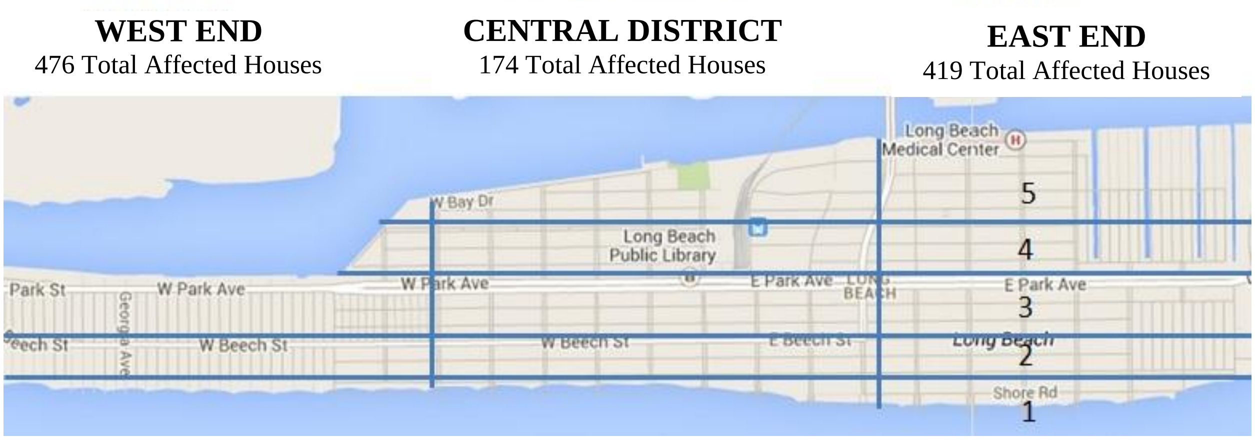
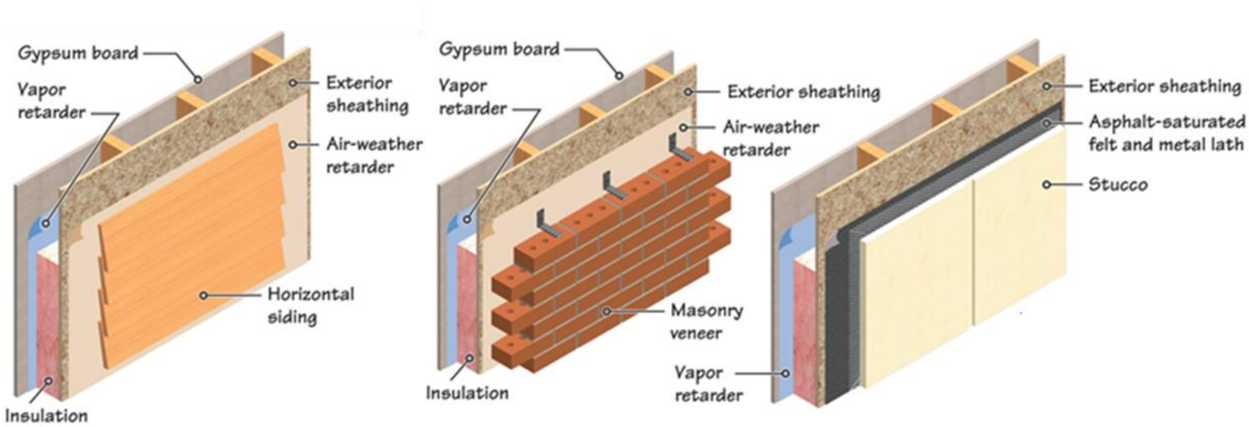


Figure 5 – Long Beach, New York when divided up into three sections (West End, Central District and East End) and zones 1-5

The Central District had less than half the number of houses affected than both the West End and East End. When again referring to Figure 4, it can be seen that inundation levels were indeed the lowest in the Central District. Lower inundation levels lead to lower hydrostatic and buoyant forces on the structures, and thus fewer total houses damaged.

The Manhattan College team virtually assessed each of the damaged homes visually to identify the building materials used for external cladding. The research team acknowledges that visual assessment does not fully define the extent of damage to a structure, but it does serve as a preliminary assessment of the houses. Homes were historically assessed through photos and images available on Google Earth.

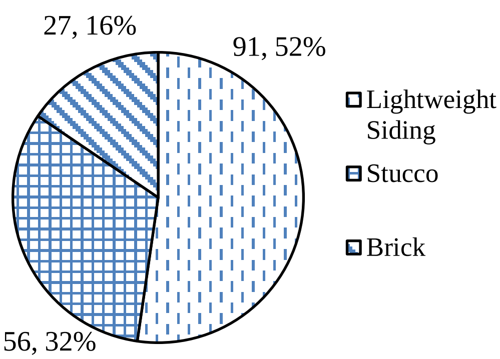
Houses were classified as lightweight siding, stucco, or brick (masonry) facades. Lightweight siding includes all houses with vinyl siding, aluminum siding, or shingles visible from the outside of the house. Stucco houses consist of those that have an adobe-type exterior, with more of a flat, textured surface acting as one slab rather than strips of siding. Brick houses have a masonry façade. Figure 6 shows examples of the external wall systems of typical houses with siding, brick, and stucco. Each of these types of houses was assumed to be internally constructed as a typical wood light frame structure.



(a) Lightweight Siding (b) Masonry Veneer (c) Stucco

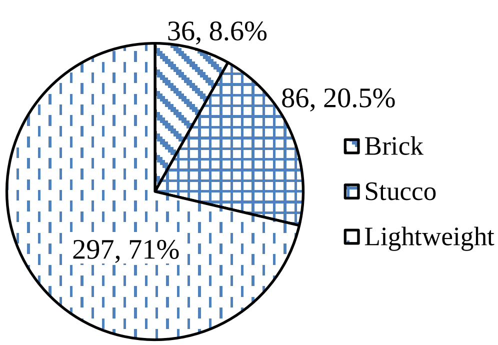
Figure 6 – Typical composition of residential buildings (Mehta et al., 2013)

A comparison of the damage to these types of houses can be seen in Figure 7 – Central District details in part (a) and East End district details in part (b). Brick, stucco and lightweight siding houses have been divided up into houses that are for sale, vacant and in construction in the central district of Long Beach. The percentages of houses with lightweight siding that were affected far surpass the percentages of both stucco and brick houses, as they are the lightest and thus least resilient type of external cladding used in house construction studied here. The conclusion can be made that houses with lightweight siding suffered the most damage from Superstorm Sandy, whereas brick houses suffered the least.



Material Type	Vacant	Under Construction	For Sale	Total Affected
Lightweight Siding	20	53	18	91
Stucco	16	31	9	56
Brick	3	21	3	27
Total	**39**	**105**	**30**	**174**

a.) Central District



Material Type	Vacant	Under Construction	For Sale	Total Affected
Lightweight Siding	76	192	29	297
Stucco	24	53	9	86
Brick	9	24	3	36
Total	**109**	**269**	**41**	**419**

b.) East District

Figure 7 – A breakdown of total affected houses in the (a) Central District and (b) the East District

Heavier building materials better resist uplift due to buoyant forces. Damage to a house can occur during storm inundation as buoyant forces cause uplift on a house, creating added stresses on the anchorage systems connecting houses to foundations. Heavier building materials also better resist overturning moment felt as hydrodynamic and hydrostatic forces push laterally on a structure. Overturning moment can also create stresses on the foundation anchorage systems. Heavier and stronger building materials (brick and stucco) will also resist damage to the external cladding systems, i.e. tearing of lightweight siding.

Houses classified as "lightweight siding" experienced the most damage in the Central and East Districts of Long Beach, NY. These houses are made with the most lightweight materials, and are more susceptible to buoyant, hydrodynamic, and hydrostatic forces. Typical lightweight siding may weigh less than 1 psf.

The classification of "stucco" denotes houses that are built with a clay or similar material as the outermost layer of the house. These materials tend to be heavier and stronger than houses that have a "lightweight siding" classification. They are more rigid and offer greater resistance to damage to the external cladding systems during storms than the thin, lightweight vinyl or aluminum siding and offer more resistance to uplift and overturning moment. A typical stucco façade of approximately 1" thickness may weigh approximately 10 psf.

"Brick" houses are more dense (30-50 lb/ft^3) and thicker (4 in nominal) than lightweight siding. A typical brick veneer may weigh approximate 10 to 17 psf. This heavier building material also provides increased resistance to uplift and overturning moment caused by the aforementioned forces.

Table 2 lists each zone and the total number of houses in the East End and Central Districts combined that were damaged categorized by external cladding material. There are 593 houses total. Recall that zone 1 is on the oceanfront and the zones are numbered sequentially to the north with zone 5 on the bay side of the Central and East End districts. It is important to note that Zone 1 falls into the FEMA designated Zone VE: Coastal flood zone with velocity hazard (i.e. wave action) and zones 2 through 5 are all in Zone AE: Special flood hazard area with BFE defined (without velocity hazard) (FEMA, 2009).

Table 2 – Total houses affected by zone and external cladding material for East and Central districts

	Total brick houses affected	Total stucco houses affected	Total lightweight siding affected	Total houses affected – all materials
Zone 1	0	0	0	0
Zone 2	4	5	6 (40% of zone 2)	15
Zone 3	14	29	35 (45% of zone 3)	78
Zone 4	13	38	76 (60% of zone 4)	127
Zone 5	32	70	271 (73% of zone 5)	373

First consider total houses damaged per zone. Zone 1 had no houses damaged in the East or Central Zones. While surprising, it is important to recall the BFEs in this zone were actually several feet higher than the HWMs were here (recall Figure 3). These houses were designed with the expectation that water levels could indeed reach and exceed that which were experienced during Superstorm Sandy. These houses are also in the FEMA defined VE zone which may experience wave impact as well as storm inundation. These houses, if properly designed to code, were designed under additional wave impact loads requiring more robust construction.

Zone 5 on the bayside had the most number of total houses damaged. Again, recalling Figure 3, the HWMs exceeded the BFEs in this zone and as such the houses experienced hydrostatic and buoyant forces during Superstorm Sandy that were greater than anticipated and provided for in the codes. From this data, it can also be seen that as each zone approached closer to the bay side, a greater number of houses were damaged.

Inundation levels should also be considered, recalling Figure 4. Inundation heights on the bayside were higher and reached further extents than the inundation on the Oceanside. Thus houses in the bayside zones were exposed to larger hydrostatic and buoyant forces than houses on the Oceanside which had lower indundation levels.

When considering number of damaged houses in each zone, the damage can be attributed to two factors: (1) HWMs exceeded expected BFEs on the bayside but HWMs were less than BFEs on the oceanside and (2) houses on the oceanside were in FEMA zone VE and designed more robustly than houses on the bayside, as houses in Zone VE are designed considering wave impact.

When considering type of external cladding material, houses with lightweight siding accounted for a greater number of damaged houses in each zone. In zones 4 and 5 there were more houses with lightweight siding damaged than houses with brick and stucco combined where in zone 5, the lightweight siding houses accounted for 72% of the total houses damaged. Again, heavier, stronger external cladding materials were able to better resist the hydrostatic, buoyant, and hydrodynamic forces felt during Superstorm Sandy.

CONCLUSIONS

This paper focuses on the preliminary studies of water-structure interaction under the influence of hurricane forces, namely hydrostatic forces and buoyant forces from water inundation and hydrodynamic forces from wave impact. Several conclusions can be made based on this work.

Results show that houses constructed using heavier building materials (i.e. brick and stucco) for external cladding were damaged to a lesser extent than houses constructed using typical lightweight siding (vinyl or aluminum) for external cladding. Heavier building materials better resist uplift due to buoyant forces. Damage to a house can occur during storm inundation as buoyant forces cause uplift on a house, creating added stresses on the anchorage systems connecting houses to foundations. Heavier building materials also better resist overturning moment felt as hydrodynamic and hydrostatic forces push laterally on a structure. Overturning moment can also create stresses on the foundation anchorage systems. Heavier and stronger building materials (brick and stucco) will also resist damage to the external cladding systems, i.e. tearing of lightweight siding.

Results also show that houses situated on the bayside of Long Beach experienced more damage than those on the Oceanside. Houses on the bayside had higher inundation levels than the

Oceanside and thus experienced larger hydrostatic and buoyant forces. High water marks also exceeded BFEs on the bayside, inferring that the hydrostatic and buoyant forces that the houses were subjected to were higher than anticipated.

Houses on the Oceanside are situated in FEMA's Coastal VE zone which assumes that the houses may experience impact from waves in addition to slowly rising waters. As such, houses in this zone were more robustly designed and better resisted the impact of Hurricane Sandy.

ACKNOWLEDGEMENTS

Funding for this research was generously made available by Dr. John Mahony, Professor of Civil and Environmental Engineering of the Civil and Environmental Engineering Department at Manhattan College. Manhattan College would also like to thank our partners at Sustainable Long Island – specifically The Director of Programs for Sustainable Long Island, Fernando Tirado – who graciously shared their data with the research team in an effort to facilitate our work.

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