COMPARISION OF HURRICANE SANDY IMPACTS IN THREE NEW JERSEY COASTAL COMMUNITES

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Hurricane Sandy made landfall in Brigantine, NJ, USA on October 29, 2012 and left many coastal communities in New York and New Jersey devastated. In New Jersey, the damage levels varied significantly between Sandy Hook in the north and Cape May to the south. This study reports on data collected under a National Science Foundation (NSF) RAPID grant focusing on Sandy related damage in three of New Jersey's coastal communities: Sea Girt, Bay Head and Mantoloking. These communities were specifically chosen due to their close proximity to one another and the vast difference in damage each experienced. Sea Girt and Mantoloking bracket the study area, and are located less than 12 km apart, with Bay Head located in between. In comparison to one another, Sea Girt experienced the least amount of damage, Bay Head experienced a moderate amount, while Mantoloking was severely damaged. Under the NSF funding, field data including watermarks, structure damage assessments, and scour information were collected. This data is currently being used to evaluate several different factors in an attempt to determine why Sea Girt fared so well, compared to Bay Head and Mantoloking, and why some portions of Mantoloking were nearly completely destroyed, while others were minimally impacted. Several conclusions arising from this study are that: (1) structural damage to houses in Bay Head and Mantoloking was a direct result of wave impact, overland surge propagation, and/or severe scour; (2) both Bay Head and Mantoloking experienced flooding from the bayside, although the intensity varied tremendously between the two boroughs, (3) the presence of an existing rock seawall along Bay Head's dune line significantly mitigated storm surge propagation though the Borough and direct wave attack on the oceanfront structures; and (4) Sea Girt experienced the least amount of flooding and structural damage due to its natural high elevation, as well as its protective wide beach and high dune system. The data from this study has been utilized to validate and evaluate several storm models currently being applied to investigate the damaging effects of Sandy along the coasts of New York and New Jersey. Ultimately, the objective is to utilize the modeling techniques and assessments derived from these measurements to help coastal communities recover and rebuild from future natural disasters.

Keywords: Hurricane Sandy; watermarks; storm surge

PROJECT MOTIVATION

Background

Hurricane Sandy made landfall along the New Jersey coast at 8pm EDT on October 29th, 2012. At landfall, wind gusts of between 129 and 145 km/hr were recorded in New York and New Jersey. The large wind field associated with the storm generated an extreme storm surge north of the eye at landfall. Measured water levels ranged from +1.9 m above NAVD88 (North American Vertical Datum of 1988) at Atlantic City to +3.4 m NAVD88 at The Battery in lower Manhattan. Subsequently, the return period associated with the observed water levels was determined to be anywhere from approximately 30 years at Atlantic City to upwards of 500 years at the Battery (USACE, 2013). Hurricane Sandy's large diameter winds also resulted in long fetches over the Mid-Atlantic and subsequent generation of extreme wave heights. Significant wave heights in excess of 9.75 m were measured 22.5 km east of Sea Bright by the National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center (NDBC) buoy 44065 (located at the entrance to NY Harbor). Along the ocean shoreline these large waves contributed significantly to the storm surge through wave set-up. A wave gauge deployed in the surf zone at Sea Bright, NJ by the United States Geological Survey (McCallum, 2013) measured peak water levels of +5 m and a maximum wave crest elevation of +5.9 m NAVD88 during Sandy. The data suggest that wave set-up added approximately 1.5 m to the storm surge along the open ocean coast.

The storm surge generated by Sandy was particularly devastating because it coincided with a spring tide. This combination of the existing spring tide and additional storm surge allowed for the propagation of larger waves farther inland, subjecting a larger area of coastline to flooding and wave impact. Along the New Jersey coast, an estimated 40,500 primary residences and over 15,600 rental units sustained severe or major damage, and in many areas, there was complete loss of the beach and dune system (NJDCA, 2013). However, from Sandy Hook to Cape May, these damage levels varied significantly. Some coastal communities, such as Atlantic City, survived with minor damage, while others, such as Ortley Beach, were almost completely destroyed.

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Objective and Area of Study

This study examines the effects of Hurricane Sandy in three New Jersey communities located within a 12 km length of coast, with the focus of specifically capturing the spatial variability of both the surge and the resulting damage to structural systems. The study area encompasses the communities of Mantoloking, Bay Head, and Sea Girt, located along the central Atlantic Ocean coast of New Jersey (Figure 1). Each of these communities had differing coastal protection levels in place prior to Sandy, and each experienced significantly varying storm damage.

The southern-most community in the study area is the Borough of Mantoloking, which endured the most significant damage of the three sites. Prior to Sandy, Mantoloking's primary coastal defense consisted of tall and narrow dunes fronted by a minimal beach. As Sandy made landfall, these dunes were quickly eroded and overtopped, and the barrier spit that Mantoloking resides on was breached in several locations. A representative pre-storm cross shore beach profile at Mantoloking is shown in Figure 2 below.

Figure 1: Study Location Map

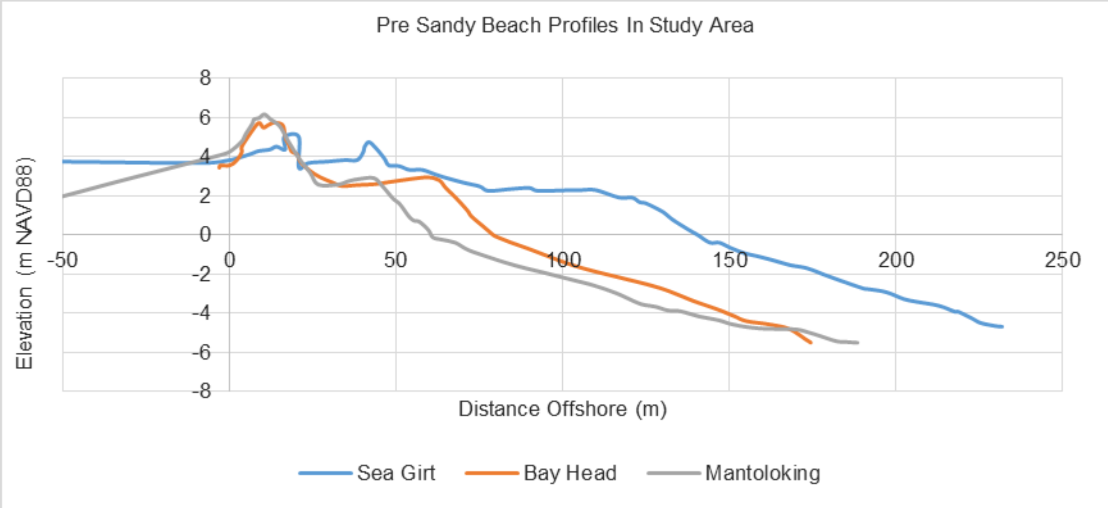


Figure 2: Pre Sandy beach profiles of Sea Girt (blue), Bay Head (orange), and Mantoloking (grey), (Richard Stockton, 2012).

The second site in the study area, the Borough of Bay Head, is located immediately north of Mantoloking. Several parts of Bay Head experienced damage similar to that of its neighboring town, Mantoloking; however, overall, Bay Head fared significantly better. The community's primary coastal defense was similar to Mantoloking's, in that it consisted of a narrow beach and dune system (see Figure 2 for a pre Sandy beach profile). However, unlike Mantoloking, the existing dune in Bay Head covered a seawall that was originally constructed as a bulkhead in the late 1800s and later reinforced with rock in response to a devastating synoptic cyclone (nor'easter) that occurred in March of 1962 (*Map of Bay Head 1883*; State of New Jersey, 1962). In addition, many individual homeowners have built upon the seawall, thus altering its original design size, and resulting in inconstant heights along its length. This seawall spans approximately 75% of the ocean frontage of the borough. Upon initial inspection, it was evident that this seawall provided a secondary level of protection; the structures located behind the seawall fared much better than those located within the 25% of the Borough without the seawall. Notably, even with 25% of the community exposed to surge and direct wave attack, Bay Head's section of the barrier spit did not experience any breaching.

The Borough of Sea Girt, the third community evaluated in this study, is located 5 km north of Bay Head. This town experienced the least damage of the three towns. Prior to Sandy, Sea Girt received a large-scale beach nourishment project constructed by the state of New Jersey in partnership with the US Army Corps of Engineers. This project resulted in a wide beach and augmented an already large dune that successfully protected the community during Sandy. Figure 2 shows a pre-Sandy beach profile in Sea Girt (displayed in blue); note the significant difference in beach width between the three communities. The expansive beach and dune system in Sea Girt was able to actively absorb the surge and wave energy and minimized wave overtopping during Sandy.

The remarkable variability of the damage in each of these towns emphasized the need to better understand the surge propagation and resulting damage, as well as to investigate why and how specific structures failed in certain areas. In an effort to preserve the data required to help answer these questions, it was necessary to collect as much information from the study area as quickly as possible. Relevant data that can be used to quantify surge heights, individual structure damage, scour dimensions, and locations is quickly lost during post-storm recovery and restoration. The objective of the intensive data collection effort undertaken in this study was to capture detailed measurements of the surge elevation, landform changes, and resulting structural damage across this 12 km reach of the New Jersey coast before they were lost.

Research Questions

The two primary questions that the data collected under this grant will help to address are: (1) how does storm surge propagate over a beach/dune/seawall system and through a coastal community, and (2) how do the details of this surge propagation influence structural stability? In particular, why were certain structures compromised, while others remained virtually untouched? What siting/building strategies made some structures significantly more resilient to the extreme forces during Sandy?

METHODOLOGY

Field Surveys

From December, 2012 through February, 2013, a total of 12 field surveys were conducted to catalog the damage and collect data in each of the three communities. In the months following Sandy, access to the most severely impacted communities was limited to residents and government officials. Through February, 2013, daily access for the survey team had to be granted by the local officials and National Guard. Based on ease of access, Sea Girt was surveyed first, followed later by Bay Head and Mantoloking.

For each survey, members of the field crews were provided with a very basic set of identical tools and guidelines to ensure consistency in documentation (Table 1). A 'Hurricane Damage Assessment' form was created to record damage of individual structures as quickly, accurately, and consistently as possible. This form was modified from a previously existing document developed by Massara (2012). The form was used to record structure and damage information such as the age of the structure, foundation type, condition, and percentage of the structure damaged. Factual information such as structure age, was originally estimated while in the field, and later confirmed in the post-data collection analysis with the use of public documents. In addition to the data recorded on the damage assessment form, each structure was documented with photos and either an address or Global Positioning System (GPS) coordinates obtained using a standard handheld GPS device. During the initial survey, scour depressions were documented with photos, descriptions, measurements, and GPS coordinates. Watermarks were documented by measured heights above a reference point, photos, and GPS coordinates using the handheld GPS device (Figure 3). A second survey was later conducted to more accurately pinpoint locations using a Real Time Kinematic (RTK) survey grade GPS system (Figure 4). The RTK GPS provided the northing and easting coordinates and the ground elevation at each watermark and more accurate dimensions of the scour depressions. This information was later used to calculate the surge depth and water level elevations at each watermark site.

Table 1: Field survey tool list

Number	Tool
1 Version	Hurricane Damage Assessment form
2 EA	Garmin Oregon 550 handheld GPS system
1 EA	Real Time Kinematics GPS system
2 EA	Panasonic DMC-ZS20 camera
2 EA	Measuring Tape

Figure 3: Field crew measuring a watermark

Figure 4: Field crew documenting severe scour found around a

Quality Assurance

Field crew members were trained to properly document structural damage, scour, and watermarks before entering the field. This was done in an effort to ensure that all field observations were documented in a manner that was as consistent as possible. As a second measure to ensure consistency, at the end of the data collection, all documentation was reviewed by a single crew member. This individual reviewed the structure damage descriptions by thoroughly re-inspecting the photos and fixing any inconsistencies.

After each field survey, the information collected on the various devices (GPS, cameras, Hurricane Damage Assessment forms) was consolidated into one electronic database via the use of a Microsoft Access data entry form that was developed specifically for this study. The Microsoft Access form consisted of an interface that allowed the user to enter all of the information from the Hurricane Damage Assessment forms, coordinates from the GPS, and photos from the cameras. Information was entered into the program on a structure by structure basis. Each entry consisted of an individual structure's Hurricane Damage Assessment form information, along with the associated GPS coordinates, pictures, watermark and scour information. The program assigned a specific 'ID' number to each entry; therefore, each structure and its associated information was identified by the same ID number.

COLLECTED DATA

Summary of Data Collected

Upon completion of the field surveys, a total of 653 structure damage assessments were performed in the study area. Table 2 lists the number of structures assessed, watermarks measured, and photographs taken during each field survey. On February 5, 2013, the crews surveyed severe scour depressions at 19 individual locations previously identified in Mantoloking. The position and depth of each scour hole was located with the RTK GPS. Other scour depressions that were found around structures were only documented on the Hurricane Damage Assessment form for each structure. Table 3 lists the cumulative number of structures assessed and data points collected in each of the three towns.

Table 2: Number of structure damage assessments, watermarks, and photographs recorded during each field day.

Date	Town	No. of Structure Damage Assessments	No. of Watermarks – Initial Surveys	No. of Watermarks – Revisited with RTK GPS	No. of Photos Taken
12/14/2012	Sea Girt	55	13	8	122
12/22/2012	Mantoloking	89	25	14	137
12/28/2012	Mantoloking	81	24	14	216
12/28/2012	Bay Head	20	10	4	26
12/30/2012	Mantoloking	66	42	35	218
12/31/2012	Mantoloking	94	23	20	403
1/15/2013	Mantoloking	61	23	22	108
1/15/2013	Bay Head	14	2	2	41
1/25/2013	Mantoloking	21	11	10	60
1/25/2013	Bay Head	21	3	1	60
2/5/2013	Mantoloking	-	-	-	67
2/5/2013	Bay Head	68	34	31	167
2/18/2013	Bay Head	63	63	32	64

Table 3: Total number of structure damage assessments, watermarks, and photographs recorded in each town.

Town	Total No. of Structure Damage Assessments	Total No. of Existing Structures	Total No. of Watermarks – Initial Surveys	Total No. of Watermarks – Revisited with RTK GPS	Total No. of Photos Taken

Sea Girt	55	1258	13	8	122
Bay Head	186	959	112	71	358
Mantoloking	412	524	148	119	1209
Total	653	2741	273	198	1689

Results

Upon completion of the field surveys, the collected information was categorized into three different data sets - (1) structure damage, (2) watermarks, and (3) scour. The following three sections describe, in detail, the data collected and the direct results found within each set. Furthermore, this study analyses the data sets together, as a whole, to determine any correlation and dependences between the data sets.

Structure Damage Assessments. In the Borough of Mantoloking, field crews were able to access and survey 412 of the 524 residential houses and in the Borough of Bay Head, 186 of the 959 structures. The structures surveyed in Bay Head were all located in the portion of the town that resides on the barrier peninsula. Although the field crews did not survey all of the houses in Bay Head, the structures that were surveyed are located in the area geographically most similar to Mantoloking. In the Borough of Sea Girt, damage was limited to only the oceanfront properties making it unnecessary to perform structure damage assessments on all of the 1,258 houses within the town. A total of 55 structure damage assessments were obtained in Sea Girt.

A comprehensive ‘Structure Condition’ rating was included on the Hurricane Damage Assessment form, where ratings of ‘excellent, good, fair, poor, about to collapse, or collapsed’ were applied to each of the structures during the evaluations. After the first survey in Mantoloking, an additional category ‘removed’ was added to denote structures that were completely demolished by Sandy and were no longer present on the property. A description of each damage rating, along with photographs, is presented in the appendix.

After organizing the data from the Hurricane Damage Assessment forms, an analysis of the ‘Structure Condition’ ratings was made and a comparison among the three communities was conducted. Of the 55 structures surveyed in Sea Girt, none received a damage rating worse than ‘fair’. The 186 structures surveyed in Bay Head received ratings between ‘excellent’ and ‘about to collapse’; however, none received a ‘collapsed’ or ‘removed’ rating. The 412 structures surveyed in Mantoloking received damage ratings ranging from ‘excellent’ to ‘removed’. Figures 5 and 6 graphically present the quantification of ‘Structure Condition’ ratings for each surveyed structure (recall only damaged portions of Bay Head and Sea Girt were surveyed) in each town, where the distribution of structure condition ratings and the cumulative distribution is shown, respectively. In Sea Girt, 78% percent of the surveyed structures showed no visible damage and the remaining 22% were determined to be in ‘good’ to ‘fair’ condition. In Bay Head, 63% of the surveyed structures showed no visible damage, 27% were determined to be in ‘good’ to ‘fair’ condition, and 9% of the surveyed structures were significantly damaged. In Mantoloking, only 30% of the surveyed structures showed no visible damage and 47% were in ‘good’ to ‘fair’ condition. The remaining 23% of structures surveyed were significantly damaged.

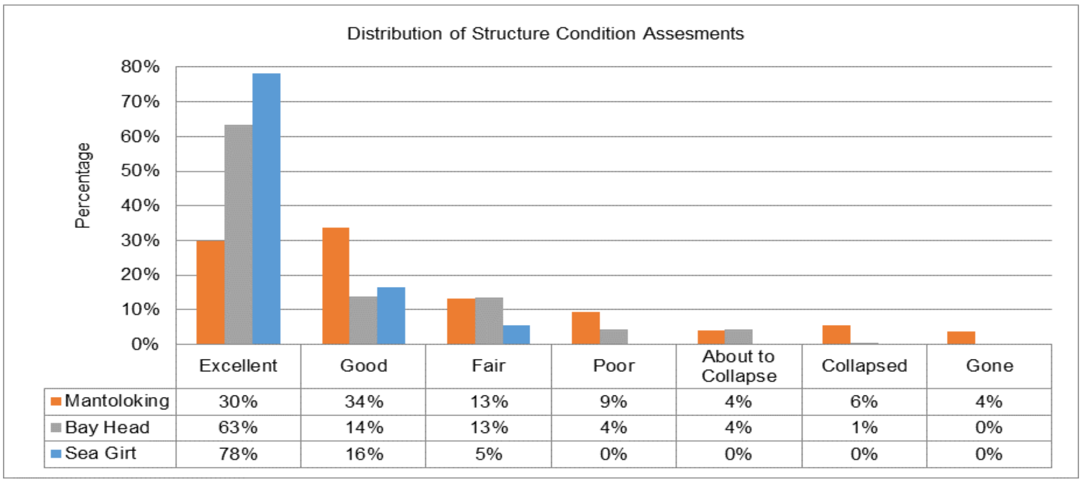


Figure 5: 'Structure Condition' percentages for each of the three communities displayed as a histogram.

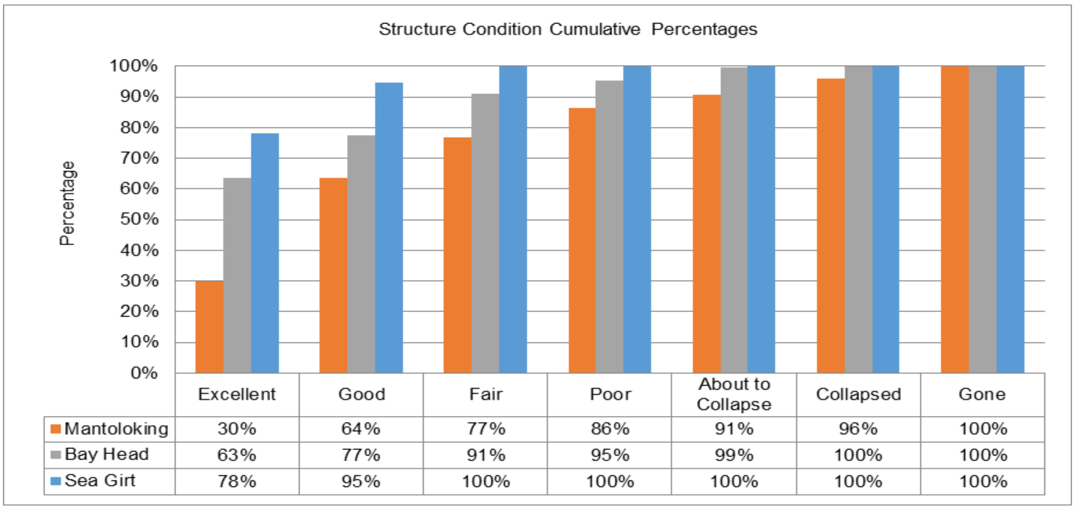


Figure 6: 'Structure Condition' percentages for each of the three communities displayed as a cumulative histogram.

Watermarks. Throughout the 12 km study area, a total of 273 watermarks were identified during initial surveys. Of these, 198 were surveyed at a later date with a more accurate survey grade RTK GPS system. The watermarks that were not resurveyed were either not found, had been removed, or were in areas inaccessible to the GPS equipment. Data from the second survey provided more accurate horizontal coordinates and ground elevations for each watermark location. The ground elevation values were then used in conjunction with the measured watermark heights to calculate the watermark elevations and the inundation depths. The maximum inundation depths and the averaged inundation depths, by town, are shown in Table 4 and Table 5 respectively. As evident from Table 4, the total maximum inundation depth within the study area was found to be 1.68 m, with a corresponding watermark elevation of 2.16 m NAVD88. While this watermark was found on a structure located on the bayside of Mantoloking, and was consistent with subsequent model results (Blumberg, 2014; Nederhoff, 2014), a separate study found several watermarks on oceanfront structures in Mantoloking, of which the maximum was 6.5 m MSL (Irish, 2013). The oceanfront watermark measurements found by Irish include the effect of individual waves, thus offering an explanation for the apparent discrepancy between the results of both studies.

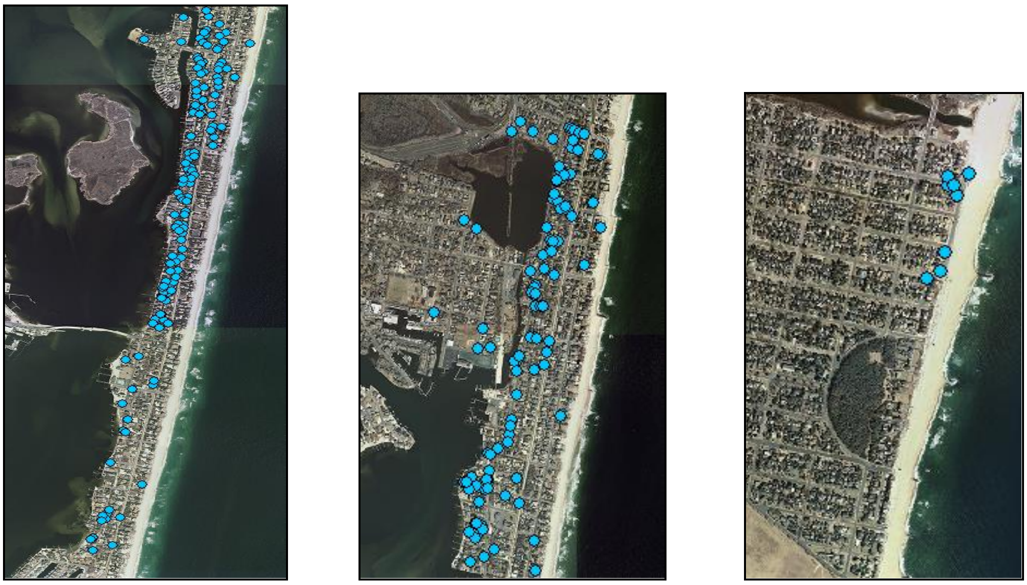
Table 4: Greatest calculated surge depths at identified watermarks in each town.

Town	Greatest Inundation Depth at Watermark (m)*	Associated Watermark Elevation (m NAVD88)	Associated Ground Elevation (m NAVD88)	Location
Sea Girt	0.62	4.99*	4.37	Corner of Ocean Ave and New York Blvd
Bay Head	1.55	2.01	0.46	Bayside end of Johnson Street
Mantoloking	1.68	2.16	0.48	North end of Lagoon Lane (on bayside)
*The watermark found at this extreme elevation was most likely not from surge, but instead from overwash that splashed into the streets and collected in a low spot.				

Table 5: Averaged values for surge depth, watermark elevation, and ground elevation in each town.

Town	Average Inundation Depth (m)	Average Watermark Elevation (m)	Average Ground Elevation (m)
Sea Girt	0.38	4.42	4.04
Bay Head	0.99	2.01	1.07
Mantoloking	0.89	2.17	1.27

The spatial distribution of the measured watermarks in (a) Mantoloking, (b) Bay Head, and (c) Sea Girt is shown in Figure 7. The data are displayed in an ArcGIS format that was generated from the Microsoft Access database. Note that most of the watermarks were found on the bayside of Mantoloking and Bay Head. This is primarily because the water was mostly 'calm' in this area; it slowly rose and fell, leaving obvious marks. On the ocean side, however, the rough wave action and high velocity surge flow was rarely steady enough to leave clear marks. In the three communities, the watermarks were most commonly found on garage doors, glass doors, windows, fence posts, columns, light-colored siding, and flag poles.



(a) Mantoloking **(b) Bay Head** **(c) Sea Girt**

Figure 7: ArcGIS map displaying watermarks revisited with the RTK GPS in (a) Mantoloking, (b) Bay Head, and (c) Sea Girt. Each light blue dot represents an individual watermark.

Scour. A total of 19 severe scour depressions were documented with RTK GPS surveyed coordinates and elevations; however, the scour found at every structure was documented with photos, dimensions, and sketches on the Hurricane Damage Assessment forms. The majority of the scour depressions were found in Mantoloking. Scour throughout Bay Head was very sparse, and none was recorded in Sea Girt.

Of the total structures located along the bayside in Mantoloking, 13% received 'Structure Condition' ratings of 'poor' or worse. Of these, 100% of the structures had documented scour in the immediate vicinity. Through the course of the surveys, it became evident that severe scour was the primary cause of foundation failure, and often, near collapse for houses located directly adjacent to the bay in Mantoloking. In Bay Head, all of the bayside structures received 'Structure Condition' ratings of 'excellent'; only one of these structures had evidence of scour nearby. The Borough of Sea Girt, which is only located along the oceanfront and is not adjacent to a bay, did not have any failed structures associated with the presence of scour. Scour depressions are caused by concentrated, fast moving fluid flow, thus indicating that high velocity flow was present more throughout the Borough of Mantoloking than in either of the other communities. The data collected in these three communities is being used in several ongoing studies focused on understanding storm surge propagation through developed areas including the development of scour.

Figure 8: Foundation failure of a house on the bayside of Mantoloking due to severe scour.

DISCUSSION OF OBSERVATIONS AND MEASUREMENTS

Validation of Data Collected

The Borough of Mantoloking conducted a survey of damaged structures in the community. They categorized each house as either 'livable' or 'unlivable', and found that approximately 25% of the structures were unlivable. This percentage is very similar to the findings from this study, which found that 23% of the surveyed structures in Mantoloking received ratings of either 'poor' or lower (see Figure 5). A typical house rated as 'poor' had significant structural and foundation damage, and would most likely be considered as 'unlivable'. Both studies found that about a quarter of the structures in Mantoloking experienced extreme to total damage, lending some validation to the somewhat subjective evaluations conducted by the survey team.

Patterns and Observations

Figure 9 presents the spatial distribution of watermarks, scour, and heavily damaged structures in Mantoloking and Bay Head. As initially suspected, the data reflects that most of the damage in the study area occurred in Mantoloking, a moderate amount occurred in Bay Head, and the least amount of damage occurred in Sea Girt. From observing the type and location of damage, several early conclusions can be made and research questions posed.

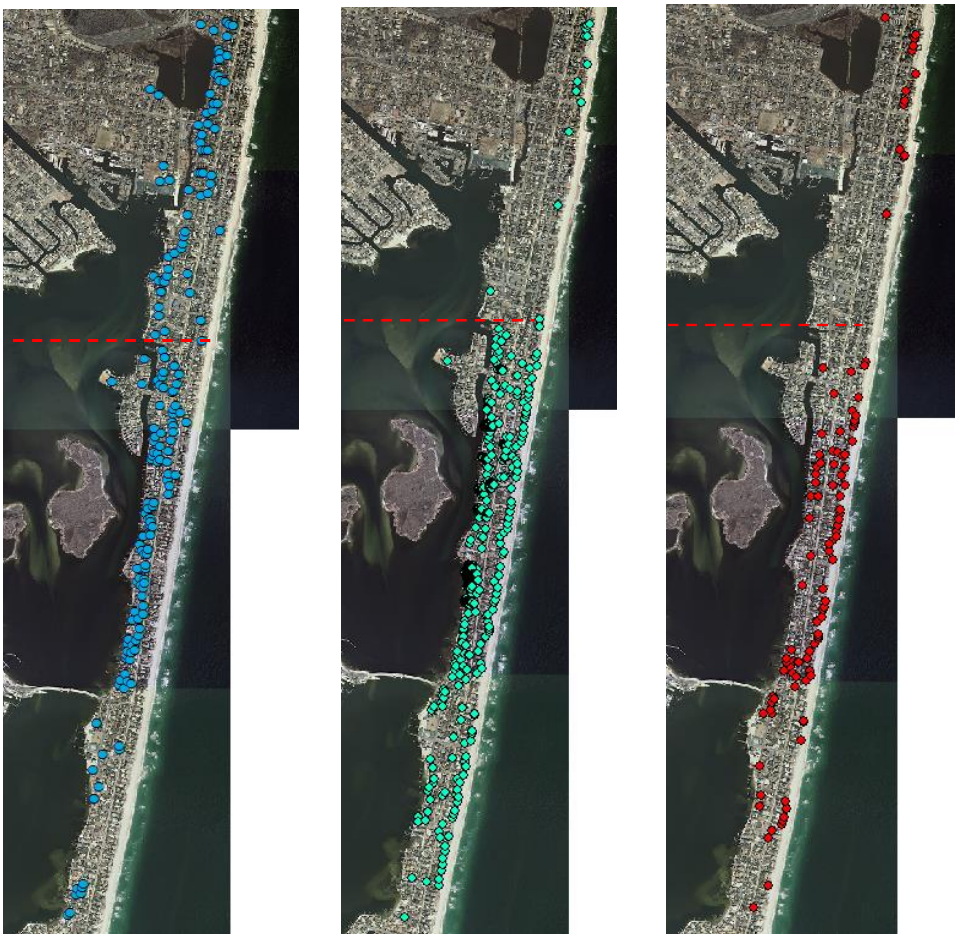


Figure 9: ArcGIS map of the Boroughs of Mantoloking and Bay Head (red dashed line indicates the boundary between Boroughs) displaying documented (a) watermarks, (b) property with scour, and (c) structures in a condition of 'poor' or worse. There were no recorded scour marks or heavily damage structures in Sea Girt; for a map of watermarks found in Sea Girt, see Figure 7c.

Of the houses that received 'Structure Condition' ratings of 'poor' or worse, the majority, 63% were located along the oceanfront in Bay Head and Mantoloking (see Figure 9c). This is primarily because once the dunes had eroded, these houses became exposed to strong wave action and channelized flow; they remained in this vulnerable state throughout the duration of the storm, resulting in severe structural damage. The oceanfront structures and property experienced damage from not only the wave action, but also from the inundation flow. From modeling the area in XBeach, Nederhoff (2014) concluded that most of the erosion occurred during Sandy's 10 hour storm peak. During the following 20 hour period, the barrier spit was exposed to a strong water level gradient flowing from the bay to the ocean. Therefore, any initial weak spots created during the peak hours, were then subjected to continual strong fluid flow, resulting in more erosion and greater damage.

From Figure 8c, it is evident that the oceanfront houses in Mantoloking were more heavily exposed to strong wave impact than the oceanfront homes in Bay Head. This is the result of wave energy dissipation provided by the existing rock seawall in Bay Head which was buried under the dune line and provided a secondary level of protection from direct wave attack and storm surge propagation. Irish (2013) examined the seawall's performance during Hurricane Sandy, and concluded that without the seawall's presence, the oceanfront homes in Bay Head would have experienced wave-averaged forces twice as large, and as a result, would have experienced significantly more damage. In contrast, the Borough of Mantoloking did not have a secondary layer of protection landward of the beach and dune to prevent direct wave attack and the formation of channelized flow.

Although most of the heavily damaged structures were located along the oceanfront, there were houses in Mantoloking rated as 'poor' or worse that were located in the middle of the barrier spit and along the bayside. In comparing panels b and c in Figure 9, it is evident that these structures are concentrated in areas where intense scour was also observed. It was hypothesized that scour caused by high velocity flow was the primary cause of foundation failure in the mid spit and bayside houses.

While watermarks were found throughout Bay Head and Mantoloking, they do not correlate well with the locations of heavily damaged structures. The majority of structures on which watermarks were noted received 'Structure Condition' ratings of 'fair' or better; this holds true in Sea Girt as well. This observation, in combination with the fact that watermarks were mostly located in areas close to the bay, offers evidence to conclude that flooding from the bayside was more 'gentle' and resulted in water levels which remained stationary for an extended period of time.

Barnegat Bay Surge Analysis

Water level observations collected by the US Geological Survey (USGS) along the bayside of Mantoloking and offshore water levels from Hurricane Sandy Storm Surge hindcast models (Blumberg, et. al., 2014) indicate that the peak bayside water level occurred approximately 7 hours after landfall, while peak oceanfront water levels occurred at landfall (Figure 10). This indicates that two separate flood events occurred in Bay Head and Mantoloking during Hurricane Sandy. The initial flooding occurred at landfall during which a high-velocity overland storm surge, reaching 8 feet (2.44 m) above NAVD88, propagated across the barrier spit. This overland surge and associated large wave attack along the oceanfront generated significant scour and structural damage along its path. The surge event was followed 7 hours later by a rapid rise in water level along the bay that peaked at 7 feet (2.13 m) above NAVD88 and slowly subsided over the following 24 hours. This second flood event generated prolonged, wide-spread flooding in Bay Head and Mantoloking and was responsible for the many watermarks observed during the study (note the correlation in watermark elevations in Table 5). These modeling results are preliminary and additional work needs to be performed to generate a more detailed understanding of how the flow propagation and scour developed and interacted with structures during the storm; however, they illustrate the potential usefulness of the data collected.

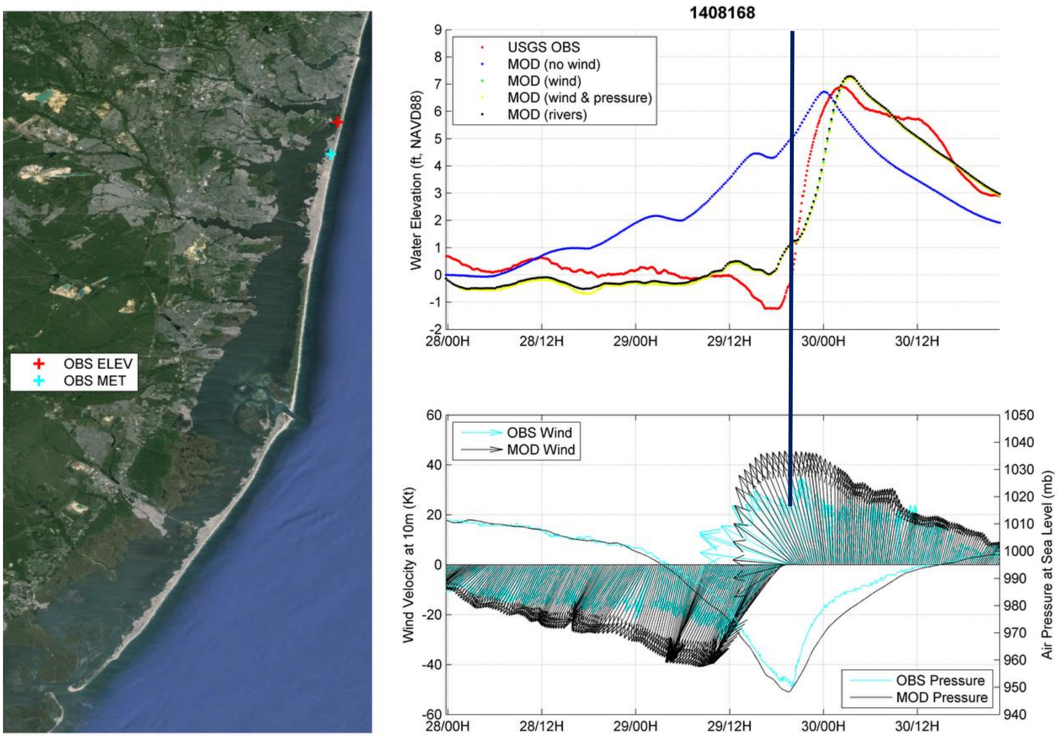


Figure 10: Left panel is a map indicating the location of water level observations (red) and atmospheric observations (blue). Upper right panel are the peak water elevations measured in Barnegat Bay at Mantoloking (red line) and the modeled storm surge (black line) at Mantoloking. Lower right panel is the measured and modeled wind and air pressure in Brick Township, NJ. Vertical line indicates the time of landfall.

Summary, Conclusions and Future Work

Hurricane Sandy's impact on the coasts of New York and New Jersey was an unfortunate disaster. Documenting the aftermath; however, provided an extremely unique opportunity to apply existing high-resolution coastal surveying capabilities to collect ephemeral data present after Sandy to: (1) improve our fundamental understanding of surge propagation over a developed coast, and (2) develop effective coastal hazard mitigation strategies that address structural stability during extreme surges. The measurements and observations obtained four months after Sandy in the Boroughs of Mantoloking, Bay Head, and Sea Girt provide significant evidence that: (1) structural damage to houses in Bay Head and Mantoloking was a direct result of wave impacts, overland surge propagation, and/or severe scour; (2) Bay Head and Mantoloking experienced significant flooding from the bayside; (3) Mantoloking experienced significantly greater storm surge propagation across its section of the barrier peninsula, and significant wave impacts along the oceanfront; (4) The presence of an existing seawall along the Bay Head oceanfront significantly mitigated storm surge propagation through the Borough and direct wave attack on oceanfront structures; and (5) Sea Girt, located along a coastal headland and protected by a wide beach and high dune along the oceanfront, experienced the least amount of flooding and damage during Hurricane Sandy. These results are consistent with the results found by several others in the wake of Sandy (USACE, 2013; Richard Stockton, 2012), which indicate that communities protected by significant natural coastal features and/or coastal protection structures were less prone to significant surge generated damage, while all barrier island/spit communities are vulnerable to significant inundation from bay waters.

ACKNOWLEDGMENTS

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APPENDIX

Table 6: Examples of surveyed houses for each of the different 'Structure Condition' ratings.

Photo	Structure Condition	Description
	Excellent	Structure is in excellent condition. Possible flood damage inside, but no structural damage.
	Good	Minor damage to garage door. Overall condition of structure is good.
	Fair	Localized damage to porch and siding. Foundation is exposed but has no visible damage.
	Poor	Obvious damage to siding and windows. Visible significant damage to structure's foundation.
	About to Collapse	Entire structure has suffered major damage and is being held up with temporary supports. House is unstable.
	Collapsed	Entire structure has undergone extreme damage, resulting in collapse. Demolition unavoidable.
	Removed	Structure has been completely destroyed or removed off of the foundation. There is no evidence of any surviving portion; all that remains is debris.

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