Coastal Engineering 80 (2013) 79–82

Contents lists available at SciVerse ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Short communication

Buried relic seawall mitigates Hurricane Sandy's impacts

Jennifer L. Irish [a,*], Patrick J. Lynett [b], Robert Weiss [c], Stephanie M. Smallegan [a], Wei Cheng [c]

[a] 221 D Patton Hall, Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA 24061, USA
[b] KAP 224D, Department of Civil and Environmental Engineering, University of Southern California, Los Angeles, CA, USA
[c] 1051A Derring Hall, Department of Geosciences, Virginia Tech, Blacksburg, VA, USA

ARTICLE INFO

Article history:
Received 15 April 2013
Received in revised form 3 June 2013
Accepted 6 June 2013
Available online xxxx

Keywords:
Hurricanes
Storm surge
Waves
Storm damage
Seawalls

ABSTRACT

Field observations to quantify damage, overwash, sediment deposition, and breaching in the aftermath of Hurricane Sandy revealed clear differences in patterns of the impact between two neighboring boroughs along the New Jersey shore: Bay Head and Mantoloking. Field data and observations gathered immediately after the storm indicate that a relic seawall in Bay Head appeared to lessen the wave-driven effects of Hurricane Sandy as compared to its southern neighbor Mantoloking. Complimentary detailed numerical simulations demonstrate that this relic seawall reduced the wave-induced forces on ocean front structures, indicated by wave-averaged momentum flux, by a factor of two. The difference in impact of Hurricane Sandy between Bay Head and Mantoloking underscores the urgent need for sustainable multi-level protection against natural hazards, in order to create resilient coastal communities.

1. Introduction

As Hurricane Sandy transited the western North Atlantic Ocean in October 2012, the storm caused widespread flooding, wind, and wave damage, first across the Caribbean Islands then across the entire United States eastern seaboard, with impacts extending as far inland as Chicago, Illinois. Among the hardest hit states were New York and New Jersey. Making landfall in New Jersey on 29 October 2012, Hurricane Sandy became just the second significant hurricane to strike this state since 1851 (Landsea et al., 2004). Hurricane Sandy started as a tropical depression in the Caribbean Sea on 22 October 2012 and was upgraded to a hurricane on 24 October, shortly before passing over Jamaica and Cuba on its way north. As Hurricane Sandy traveled up the east coast of the United States, it interacted with a non-tropical weather system, also referred to as Nor'easter, and transformed from a hurricane to a hybrid system that is publicly referred to as Superstorm Sandy. Hurricane Sandy was a historically large storm (National Oceanic and Atmospheric Administration [NOAA], 2012a) that featured record storm surges (NOAA, 2012b; US Geological Survey [USGS], 2012) and large waves (National Data Buoy Center [NDBC], 2012) over multiple high tides. Hurricane Sandy devastated the region, wreaking havoc in coastal communities, caused widespread erosion of the dunes as well as barrier island breaching in some locations. Situated along the hardest-hit stretch of the New Jersey shore are what were previously two idyllic coastal communities: the Boroughs of Bay Head and Mantoloking. Before Hurricane Sandy, these adjacent boroughs featured similar topography and residential development. Yet, while similar surges and large waves arrived at their shores, the observed impacts of Hurricane Sandy, manifested in structural damage and beach erosion, were vastly different between the two locales. The cause of this difference lies in a forgotten historical relic. The core of the Bay Head dune was in fact a century-old, unyielding stone seawall, which had been covered over with fine to very fine dune sand by aeolian transport and beach nourishment during the twentieth century. The discovery of the relic seawall came as a surprise to many of the transient residents, and it constitutes the difficulties these transient communities have in maintaining and planning for future disasters arriving at their shores. Recently, coastal engineers have used combinations of hard and soft structures in storm damage reduction design (e.g., Basco, 1998; US Army Corps of Engineers, 2008; Yang et al., 2010; Yang et al., 2012) — for example, a rock seawall buried within a dune was constructed in 2000 in Virginia Beach, Virginia to protect critical naval infrastructure (Basco, 2000). Such approaches have recently been adopted because they proved to be both cost-effective and environmentally friendly alternatives to more classical coastal structure design. Yet, because of the rarity of extreme flood and wave events, the benefits of such multi-level designs are not often demonstrated as clearly as they were at Bay Head during Hurricane Sandy.

2. Setting and hurricane characteristics

The Boroughs of Bay Head and Mantoloking were settled in the mid- to late-1800s (Bay Head Historical Society, 2012; Borough of

* Corresponding author. Tel.: +1 540 231 2298; fax: +1 540 231 7532.
E-mail addresses: jirish@vt.edu (J.L. Irish), plynett@usc.edu (P.J. Lynett), weiszr@vt.edu (R. Weiss), ssmalls@vt.edu (S.M. Smallegan), chengwei@vt.edu (W. Cheng).

0378-3839/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.coastaleng.2013.06.001

Mantoloking, 2012) on the narrow barrier spit separating Barnegat Bay from the Atlantic Ocean (Fig. 1a). Both boroughs have grown into affluent vacation communities. Private beach homes situated behind a recreational beach and coastal dune seamlessly dotted the coastline, with one borough running into the next with no visual distinction between the two. Pre-storm lidar topography from September 2010 (US Army Corps of Engineers, 2012) and beach profiles from September 2012 (The Richard Stockdon Coastal Research Center [RSCRC], 2012a) show that the beaches and dunes in both boroughs were similar, with dune-crest elevations between 5.8 and 6.1 m above mean sea level (MSL). What distinguishes the shoreline in these two boroughs, however, lies beneath the surface: in Bay Head, a 1260-m long stone seawall initially constructed in 1882 (NOAA, 2012c; Psuty and Ofiara, 2002; Salter, 2007; State of New Jersey, 1962) (Fig. 1a, d) has for decades been covered over by a sandy dune. A series of 10 groins, only visible during low tide, were also constructed in Bay Head over the last century (Psuty and Ofiara, 2002). Other than emergency sand placement following major non-tropical storms in 1962 and 1992, neither Bay Head nor Mantoloking have received major beach nourishment in recent decades (Department of Environmental Protection — State of New Jersey, 1981; RSCRC, 2012b).

Hurricane Sandy, classified as a post-tropical cyclone when it made landfall near Atlantic City, New Jersey at 8 pm local time on 29 October 2012, was characterized by maximum sustained winds of 130 km/h with hurricane-force winds extending an unusually large radial distance of 280 km from the hurricane eye (National Hurricane Center, 2012). Tide gages to the north and south of the two boroughs show that water levels were more than 1 m above normal levels for a full day (NOAA, 2012b; USGS, 2012), with maximum water levels reaching 3.5 and 2.0 m, MSL at The Battery in New York City and at Atlantic City, respectively (NOAA, 2012b). Just offshore of New Jersey, significant wave heights in excess of 3 m persisted for two days, where the maximum observed significant wave height, of 9.9 m, nearly coincided with hurricane landfall (NDBC, 2012).

3. Field survey and observations

On November 14, 2012, we surveyed high water marks and assessed damage, overwash, and breaching in both Bay Head and Mantoloking. We found that flood elevations were very similar, with oceanfront flood elevations, as measured from water lines on the interior of homes, of 4.6 and 4.2 m above MSL in Bay Head and Mantoloking, respectively (Fig. 1b, Table 1). High water marks on the exterior of homes, thereby including the effect of individual ocean waves, are between 4.0 and 6.5 m. Erosion and damage to oceanfront homes, however, were drastically different in the two locales. In Mantoloking, widespread significant overwash led to breaching of the barrier spit in several locations. In contrast, while some areas in Bay Head overwashed, no breaching occurred. Our survey revealed that all oceanfront homes in the two boroughs received some degree of damage, ranging from flooding of the ground floor to complete destruction of the structure (Fig. 1e, f).

In Montoloking the entire dune almost vanished, and three major barrier spit breaches were formed, with widths of 165 m, 59 m, and 35 m. In Bay Head, only the portion of the dune located seaward of the seawall was eroded. The section of dune behind the seawall only experienced minor local scouring. It should be noted that it was impossible to estimate the sediment volumes moved by the storm with accuracy, since recovery operations by home-owners and government agencies commenced shortly after storm passage. However, judging from the size of sand piles created by bulldozing sand from the beach road, the sand volume in Bay Head was smaller than in Mantoloking, but not significantly smaller. We suspect,

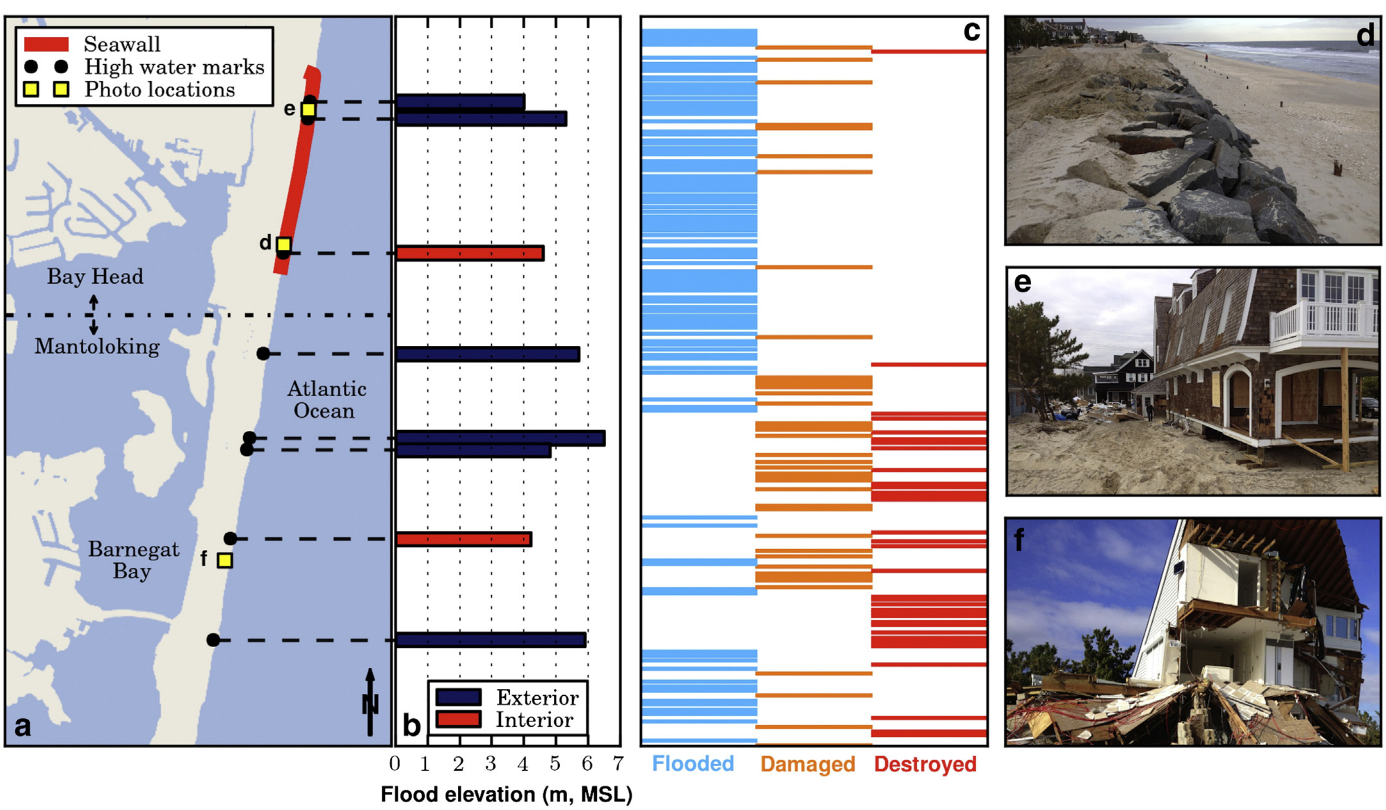

Fig. 1. Observations in Bay Head and Mantoloking, New Jersey following Hurricane Sandy. (a) Study area map showing locations of the relic seawall; high water marks; and photographs shown in panes d, e, and f. (b) Flood elevations measured from high water marks. (c) Degree of damage to oceanfront homes. (d) Exposed relic seawall in Bay Head. (e) Damage to oceanfront home in Bay Head. (f) Damage to oceanfront home in Mantoloking.

Table 1
Hurricane Sandy high water marks as measured on 14 November 2012.[a]

Latitude	Longitude	Elevation (m, MSL)	Description
40.051	74.047	6.5	Exterior floodmark on house
40.051	74.047	4.8	Wrack line in tree stand
40.039	74.050	5.9	Exterior floodmark on house
40.045	74.049	4.2	Interior floodmark inside house
40.071	74.042	4.0	Exterior floodmark on house
40.070	74.042	5.3	Exterior floodmark on house
40.062	74.044	4.6	Interior floodmark inside house
40.056	74.046	5.7	Wrack line in bushes

[a] Latitude–longitude positions are approximate.

however, that this difference in sand volumes moved by the storm can be explained by the volume of sediment protected by the seawall in Bay Head. Whereas in Mantoloking, the dune sands were fully exposed to erosional forces.

The damage assessment of the houses located in Mantoloking and Bay Head was performed using Google Earth to evaluate aerial imagery collected before, 20 September 2010 (Google Inc., 2011), and immediately after, 31 October 2012, Hurricane Sandy made landfall in New Jersey (NOAA, 2012c). The integrity of each house was determined by comparing its pre-storm structure, such as the location of rooflines, to its post-storm structure. A house that no longer sits on its foundation is labeled destroyed, whereas a house that has a different roofline is considered damaged. Otherwise, the house is assumed to be flooded (Fig. 1c). Our hypothesis regarding this stark contrast in Hurricane Sandy's impact in these communities is that the relic seawall dampened wave forces and held the shoreline. As Fig. 1c shows, the vast majority of oceanfront homes in Bay Head are classified as flooded, 88%, where just one oceanfront home is classified as destroyed. In contrast, more than half of the oceanfront homes in Mantoloking were classified as damaged (28%) or destroyed (28%).

4. Numerical model setup

Numerical simulations use the depth-integrated Boussinesq-type wave model discussed in Lynett et al. (2012). Surge and wave conditions at the peak of the storm are simulated to gage the impact of the seawall during the time of most severe surge and wave conditions. Offshore wave conditions are taken from the National Data Buoy Center buoy #44065 (NDBC, 2012) during the peak of the storm, which gives a significant wave height of 9.9 m and a peak period of 13.8 s in a water depth of 50 m. These conditions are used to drive the offshore wave condition in the simulation. Note however, that as these huge waves propagate close to the shoreline, depth-limited breaking over the mild coastal slopes caps the wave heights to roughly 40% of the local water depth. Peak still-water elevation, which includes both the contributions from storm surge and tide, is specified as +4.1 m MSL, based on an oceanfront interior flood mark measured during our survey.

The crest elevation of the stone seawall is found from engineering drawings dating back to 1962 (State of New Jersey, 1962), and is +4.8 m MSL. These drawings also show the base of this structure extending down to MSL with side slopes of 1:1. Characteristic beach profiles from both Mantoloking and Bay Head are generated from pre-storm information (RSCRC, 2012a, 2012b) and our post-storm survey data. Simulations use a horizontal resolution of 2 m.

5. Discussion and conclusions

Using simulations with the Boussinesq-type model, we attempt to quantitatively assess the protective effect of the hidden seawall. With our focus on structural damage, the most appropriate hydrodynamic proxy is momentum flux; for shallow water waves, depth-averaged momentum flux per unit length normal to the direction of wave propagation is given as ρHU^2, where ρ is the water density, H is the total water depth, and U is the depth-averaged velocity. The simulation results, shown and summarized in Fig. 2, are presented as wave-averaged

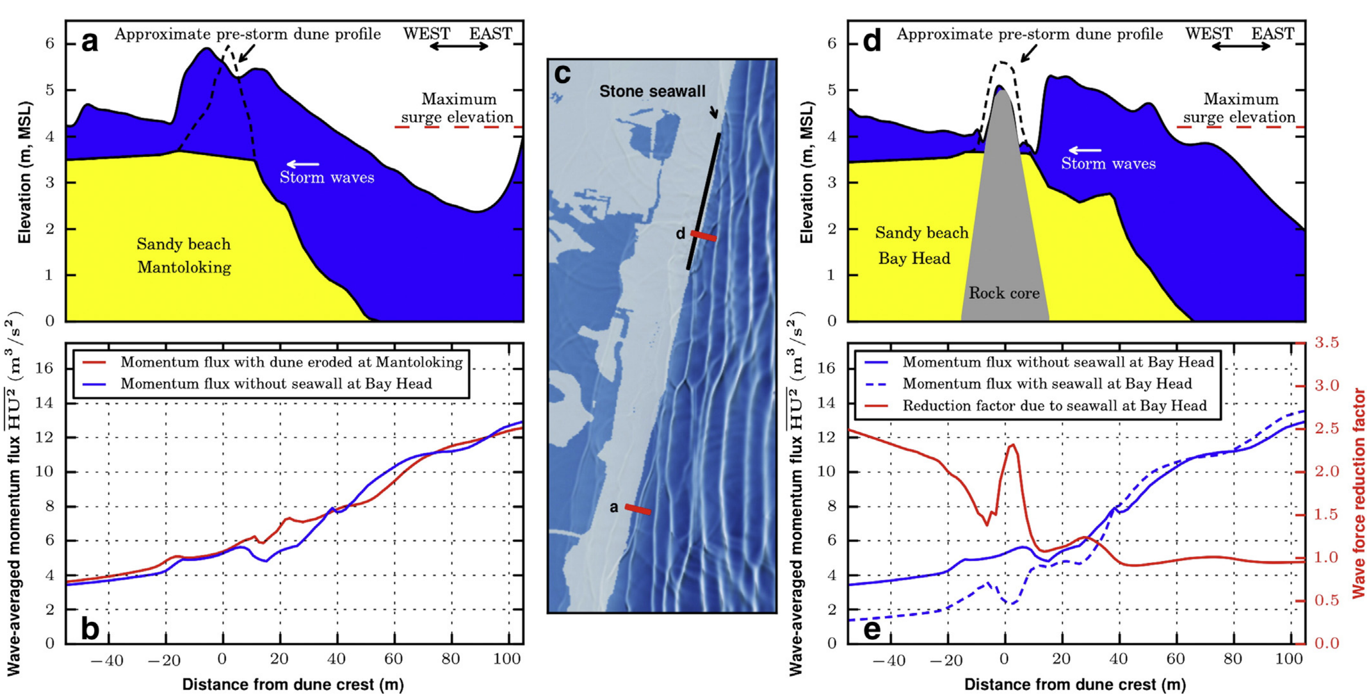

Fig. 2. Summary of the numerical simulation results for Mantoloking and Bay Head. (a and d) Snapshots of the ocean surface elevation, where broken wave bores are over-running the original locations of the dunes. (b and e) Wave-averaged momentum flux divided by the fluid density as a function of location along the beach profile. (c) Larger spatial picture of the simulation, showing the locations of the two examined beach profiles.

values taken over 30 min of simulation time. Examining the Bay Head simulations, it is clear that behind the seawall, the wave force potential is reduced by greater than a factor of two (Fig. 2e) — if the seawall did not exist, wave-averaged forces on these oceanfront homes would have been twice as large as experienced. Similarly, erosive flow velocities over the dunes in Bay Head were reduced, with respect to those in Mantoloking. Additionally, as pre-storm beach profiles and hydrodynamic conditions during the storm were very similar from Mantoloking to Bay Head, had the seawall not existed, forces on the oceanfront homes would have been equally similar, and the damage observed in Mantoloking would have likely been found in Bay Head as well. Despite the immense magnitude and duration of the storm, conditions were such that a relatively small coastal obstacle that reduced potential wave loads by a factor of two made the difference between widespread destruction and minor structural impacts. With compassion but with little solace for the devastated Borough of Mantoloking, we are left with a clear, compelling, and unintentional example of the need for multiple levels of protection against natural hazards, in order to ensure the resiliency of coastal communities for the decades to come.

Acknowledgments

This research was supported by the National Science Foundation via Grant # EAR-1312813. The authors wish to thank the Boroughs of Bay Head and Mantoloking for granting access during the field visit on 14 November 2012, specifically we wish to thank Mayor William Curtis, Ms. D'Arcy Green, Mr. Christopher Nelson, and Mr. Courtney Bixby. The authors are especially grateful to Mr. Thomas Buck and Mr. Christopher Wojcik for coordination of our visit and for facilitating access to difficult to reach locations.

References

Basco, D.R., 1998. The economic analysis of 'soft' versus 'hard' solutions for shore protection: an example. Proc. 26th International Conference on Coastal Engineering. ASCE, New York, pp. 1449–1460.

Basco, D.R., 2000. Beach Monitoring Results and Management Plan FCTCLANT, Dam Neck, Virginia Beach, VA, Final Report. Beach Consultants, Inc., Norfolk, VA.

Bay Head Historical Society, 2012. About Bay Head Historical Society. Bay Head Historical Society, Bay Head, NJ (http://www.bayheadhistoricalsociety.com/about.php, accessed December 13, 2012).

Borough of Mantoloking, 2012. Borough of Mantoloking History, Borough of Mantoloking, Mantoloking, NJ. (http://www.mantoloking.org/?page_id=37, accessed December 13, 2012).

Department of Environmental Protection — State of New Jersey, 1981. New Jersey Shore Protection Master Plan, State of New Jersey, Trenton, NJ. (http://www.gpo.gov/fdsys/pkg/CZIC-tc224-n5-n47-1981-v-2/html/CZIC-tc224-n5-n47-1981-v-2.htm, accessed December 13, 2012).

Google Inc., 2011. Google Earth version 6.1. Google Inc., Mountain View, CA (http://www.google.com/earth/index.html, accessed November 26, 2012).

Landsea, C.W., Anderson, C., Charles, N., Clark, G., Dunion, J., Fernandez-Partagas, J., Hungerford, P., Neumann, C., Zimmer, M., 2004. The Atlantic hurricane database re-analysis project: documentation for the 1851–1910 alterations and additions to the HURDAT database. In: Murnane, R.J., Liu, K.-B. (Eds.), Hurricanes and Typhoons Past, Present, and Future. Columbia University Press, New York, NY, pp. 178–221.

Lynett, P.J., Borrero, J.C., Weiss, R., Son, S., Greer, D., Renteria, W., 2012. Observations and modeling of tsunami-induced currents in ports and harbors. Earth and Planetary Science Letters 327/328, 68–74.

National Data Buoy Center, 2012. Station 44065 (LLNR 725) — New York Harbor Entrance — 15 NM SE of Breezy Point, NY, National Data Buoy Center, Stennis Space Center, MS. (http://www.ndbc.noaa.gov/station_page.php?station=44065, accessed November 26, 2012).

National Hurricane Center, 2012. Hurricane Sandy Advisory Archive. National Hurricane Center, Miami, FL (http://www.nhc.noaa.gov/archive/2012/refresh/SANDY+shtml/121028.shtml?, accessed December 13, 2012).

National Oceanic and Atmospheric Administration, 2012a. NOAA's National Weather Service Newport/Morehead City, NC: Event summaries/case studies — October 29, 2012 — Hurricane Sandy. National Oceanic and Atmospheric Administration, Washington, DC (http://www.erh.noaa.gov/mhx/EventReviews/20121029/20121029.php, accessed December 13, 2012).

National Oceanic and Atmospheric Administration, 2012b. NOAA Tides and Currents. National Oceanic and Atmospheric Administration, Washington, DC (http://tidesandcurrents.noaa.gov/, accessed November 26, 2012).

National Oceanic and Atmospheric Administration, 2012c. Aerial photos of Hurricane Sandy Damage from NOAA's National Geodetic Survey, Washington, DC. (http://oceanservice.noaa.gov/news/weeklynews/nov12/ngs-sandy-imagery.html, accessed November 26, 2012).

Psuty, N.P., Ofiara, D.D., 2002. Coastal Hazard Management: Lessons and Future Directions from New Jersey. Rugters University Press, New Brunswick, NJ.

Salter, E., 2007. Salter's History of Monmouth and Ocean Counties New Jersey: Embracing A Geneological Record of Earliest Settlers in Monmouth and Ocean Counties and their Descendents. (originally published in 1890) Heritage Books Inc., Westminster, MD.

State of New Jersey, 1962. Construction Plans: Stone Seawall and Groins, Borough of Bay Head, Ocean County, New Jersey, State of New Jersey, Trenton, NJ.

The Richard Stockdon Coastal Research Center, 2012a. Beach–dune Performance Assessment of New Jersey Beach Profile Network (NJBPN) Sites at Northern Ocean County, New Jersey after Hurricane Sandy Related to FEMA Disaster DR-NJ 4086. Stockdon College, Galloway, NJ.

The Richard Stockdon Coastal Research Center, 2012b. New Jersey Beach Profile Network 2011 Annual Report on Shoreline Changes in New Jersey Coastal Reaches One Through Fifteen, Raritan Bay to Delaware Bay — Covering 25 years of Research. Stockdon College, Galloway, NJ.

US Army Corps of Engineers, 2008. Coastal Engineering Manual, Part V, Chapter 3 Shore Protection Projects, EM 1110-2-110 (Part V). US Army Corps of Engineers, Washington, DC.

US Army Corps of Engineers, 2012. 2010 USACE Lidar: New Jersey, Washington, DC. (http://www.csc.noaa.gov/digitalcoast/data/coastallidar/download, accessed November 26, 2012).

US Geological Survey, 2012. USGS Flood Information — Current flood events–Hurricane Sandy — Streamgages. US Geological Survey, Reston, VA (http://water.usgs.gov/floods/events/2012/sandy/StormTideAndRDG.html, accessed November 26, 2012).

Yang, R., Wu, Y., Hwung, H., Liou, J., Shugan, I., 2010. Current countermeasure of beach erosion control and its application in Taiwan. Ocean and Coastal Management 53 (9), 552–561.

Yang, B., Hwang, C., Cordell, H.K., 2012. Use of lidar shoreline extraction for analyzing revetment rock beach protection: a case study of Jekyll Island State Park, USA. Ocean and Coastal Management 69, 1–15.