GZA
WATERFRONT/COASTAL ENGINEERING AND DESIGN

GZA Metocean Data Analysis and Numerical Model Simulations – Nantucket, MA
June 26, 2019

Daniel Stapleton, PE
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Metocean Data Analysis and Numerical Wave Modeling  

Study Results (Metocean Data Analysis): Wind Intensity and Direction

Prevailing Winds:

- **NOAA National Data Buoy Center Station NTKM3 - 8449130 - Nantucket Island, MA** (a land station), available for the period of November 2008 through December 2012. The data includes: a) 2-minute average wind speed by month; b) 5-second gust speed by month; c) peak gust speed; and d) 2-minute average wind speed by direction.

- Mean monthly wind speed: between 5 and 10 knots (+/− 6 to 12 mph)

- One standard deviation: upper bound 8 to 15 knots (+/− 1 to 17 mph)
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Study Results (Metocean Data Analysis): Extreme waves, wind, water levels - two characteristic coastal storm types

Extratropical Nor’easters

Tropical Cyclones (Hurricanes)
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Study Results (Meteocean Data Analysis): Wind Intensity and Direction

Extreme Winds:

- **Nantucket Airport - Nantucket Island, MA** (a land station), available for the 71 year record. The data includes:
  a) 1/2-minute average wind speed by month;
  b) 3-second gust speed by month;
  c) peak gust speed; and
  d) ½ -minute average wind speed by direction.

- **Directional Wind speeds:**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Maximum Wind Speed (mph)¹</th>
<th>Occurrence Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Wind (315° to 45°)</td>
<td>64</td>
<td>11/13/2014</td>
</tr>
<tr>
<td>East Wind (45° - 135°)</td>
<td>60</td>
<td>6/20/1974</td>
</tr>
<tr>
<td>South Wind Freq (135° - 225°)</td>
<td>72</td>
<td>9/2/1984</td>
</tr>
<tr>
<td>West Wind Freq (225° - 315°)</td>
<td>61</td>
<td>2/17/1982</td>
</tr>
<tr>
<td>All Direction Wind</td>
<td>72</td>
<td>9/2/1984</td>
</tr>
</tbody>
</table>
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Study Results (Metocean Data Analysis): Wind Intensity and Direction

Figure 3 – GZA GEV analysis of Nantucket Airport Wind Speeds (1-minute, 10-meter); ASCE/SEI 7-10 converted wind speeds shown for comparison
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Study Results (Metocean Data Analysis): Tidal Datums

<table>
<thead>
<tr>
<th></th>
<th>ft-MLLW</th>
<th>ft-NAVD88</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHHW</td>
<td>3.57</td>
<td>1.53</td>
</tr>
<tr>
<td>MHW</td>
<td>3.23</td>
<td>1.19</td>
</tr>
<tr>
<td>NAVD88</td>
<td>2.04</td>
<td>0</td>
</tr>
<tr>
<td>MSL</td>
<td>1.77</td>
<td>-0.27</td>
</tr>
<tr>
<td>MTL</td>
<td>1.72</td>
<td>-0.32</td>
</tr>
<tr>
<td>MLW</td>
<td>0</td>
<td>-1.84</td>
</tr>
<tr>
<td>MLLW</td>
<td>0</td>
<td>-2.04</td>
</tr>
</tbody>
</table>

Prevailing Water Levels:
- NOAA Nantucket Tide Station 8449130
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Study Results (Meteocean Data Analysis): Extreme Water Levels

**Extreme Water Levels:**

- **Data Sources:**
  - NOAA Nantucket Tide Station
  - FEMA FIS and FIRMs
  - USACE North Atlantic Coast Comprehensive Study (NACCS)

- **Coastal Flooding Components:**
  - Stillwater elevations
  - Wind-generated waves
  - Wave set-up
  - Wave crest elevation
  - Wave condition (breaking or non-breaking)
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Study Results (Metocean Data Analysis): Extreme Water Levels

[Graph showing observed annual maximum water levels and adjusted data with recurrence intervals]
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Study Results (Meteocean Data Analysis): Extreme Water Levels

Figure 11: Combined Stillwater Flood-Frequency Data from Multiple Data Sources
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Study Results (Metocean Data Analysis): Sea Level Rise

Predicted Sea Level Rise (NOAA 2017)

<table>
<thead>
<tr>
<th>Year</th>
<th>Low</th>
<th>Int-Low</th>
<th>Int</th>
<th>Int-High</th>
<th>High</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2030</td>
<td>0.16</td>
<td>0.26</td>
<td>0.56</td>
<td>0.85</td>
<td>1.12</td>
<td>1.28</td>
</tr>
<tr>
<td>2050</td>
<td>0.53</td>
<td>0.69</td>
<td>1.35</td>
<td>2.0</td>
<td>2.76</td>
<td>3.18</td>
</tr>
<tr>
<td>2070</td>
<td>0.85</td>
<td>1.15</td>
<td>2.30</td>
<td>3.45</td>
<td>4.79</td>
<td>5.81</td>
</tr>
</tbody>
</table>

Observed Sea Level Rise (avg. 0.14 in/yr; 0.12 ft/10 years; 1.2 feet/100-years)
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**Metocean Data Analysis and Numerical Wave Modeling**

Study Results (Metocean Data Analysis): Effect of Sea Level Rise on Extreme Water Levels

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Mean Stillwater Elevation (SWEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 yr</td>
</tr>
<tr>
<td>USACE NACCS 7380</td>
<td></td>
</tr>
<tr>
<td>Year 2020</td>
<td>3.3</td>
</tr>
<tr>
<td>Year 2030</td>
<td>3.9</td>
</tr>
<tr>
<td>Year 2050</td>
<td>4.7</td>
</tr>
<tr>
<td>Year 2070</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Table 6: Predicted Water Levels for different Recurrence Intervals at Nantucket assuming NOAA 2017 Intermediate SLR Projection
Study Results (Metoocean Data Analysis): Wave Simulation Nantucket Harbor

- Wave refraction at Point
- Wave heights in harbor controlled by local wind windfield (northeast fetch) over harbor, not deepwater ocean swells/waves
- Wave attenuation at inlet
- During extreme coastal flood conditions, overtopping and breach of barrier beaches is possible
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(Bathytopo Data)
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Metocean Data Analysis and Numerical Wave Modeling (Bathytopo Data)
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(Bathytopo Data)
GZA Coastal Engineering Study
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(Modeling Mesh)
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(Modeling Mesh)
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(Modeling Mesh)
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(Tidal Circulation Model: ADCIRC)

ADCIRC-simulated Peak Flood Tide Currents at: 04:00 Aug. 8, 1991
UMASS Dartmouth
FVCOM Tidal Simulation

Finite-Volume Coastal Ocean Model (FVCOM) developed by Chen et al. (2006a-b)
University of Massachusetts, Dartmouth, MA

Reference:
http://fvcom.smast.umassd.edu/research_projects/Nsound/
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(Scenario Simulation Circulation Model: ADCIRC)

ADCIRC-simulated Storm Surge and Wind during Hurricane Bob (1991)

Water Surface Elevation (ft)
-8.0
-6.0
-5.8
-4.7
-3.6
-2.4
-1.3
-0.9
-0.2
-2.0

Wind Speed
44.29 m/s
0.00 m/s

Day 18 06:00:00
after 1991-08-01
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(Wave Model: SWAN)
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Study Results (+/- 50 to 100-year; 70 mph 1-minute, 10-meter wind)
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Study Results (+/- 50 to 100-year; 70 mph 1-minute, 10-meter wind)
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Study Results (+/- 50 to 100-year; 70 mph 1-minute, 10-meter wind)
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Study Results: wave modeling consistent with observed effects of wave fences on wave transformation at Town Pier

Existing Wave Fence during 100-year recurrence interval event with 98mph 1-minute sustained northeast wind and Elevation 6 feet NAVD88 Stillwater Elevation (White lines indicate the zone of increased wave height due to structure effects "Storm Damage Cone" observed by Town)
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**Meteocean Data Analysis and Numerical Wave Modeling**

<table>
<thead>
<tr>
<th>Recurrence Interval (years)</th>
<th>Significant Wave Heights ((H_s)) at SWAN Model Output Save Points at Town Pier (in feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>2</td>
<td>1.6</td>
</tr>
<tr>
<td>5</td>
<td>1.8</td>
</tr>
<tr>
<td>10</td>
<td>1.9 to 2.0</td>
</tr>
<tr>
<td>25</td>
<td>2.1 to 2.4</td>
</tr>
<tr>
<td>50</td>
<td>2.2 to 2.6</td>
</tr>
<tr>
<td>100</td>
<td>2.2 to 2.7</td>
</tr>
</tbody>
</table>
Perspective based on observed conditions: January 27, 2015 Nor’easter Town Pier Damage
January 27, 2015 Nor’easter Water Level, Wind and Wave Conditions

- Peak water Level: 4.9 feet NAVD88
- Maximum Sustained 1-minute 10 meter Wind: +/- 35 to 40 mph
- Wind Direction: North to Northeast
- Predicted Peak $H_s$ Wave Heights @ Pier: 2 to 2.5 feet
- Predicted Peak $H_{\text{max}}$: 4 to 5 feet
- Predicted peak wave crest elevation ($H_s$): 7 feet NAVD88
- Predicted peak wave crest elevation ($H_{\text{max}}$): 8 to 9 feet NAVD88
- Annual Exceedance Probability: +/- 10-year recurrence interval
- 2030 Annual Exceedance Probability: +/- 1 to 5-year recurrence interval
- 2050 Annual Exceedance Probability: +/- <1-year recurrence interval
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Street Scale – GZA Coupled Coastal, Surface Flow, Stormwater Infrastructure, Groundwater Model

Interconnected Channel and Pond Routing Model v4.0 (ICPR4)

GZA Project Example: Queens, New York City

Model terrain (green) with building extrusions (orange) and stormwater network (red).
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Project Example: Queens, New York City
Interconnected Channel and Pond Routing Model v4.0 (ICPR4)

Model terrain (left) with building extrusions, topographic breaklines, and stormwater catch basin locations (right)
Project Example: Queens, New York City

Model results show reduced ponding through implementing flood mitigation measures (shoreline berms, tide gates, additional stormwater infrastructure)
GZA Data Visualization: Coastal Flood Simulation, Long Wharf, New Haven, Ct
GZA Data Visualization: Coastal Flood Simulation, Long Wharf, New Haven, Ct
Envision Nantucket is a collaboration between the University of Florida Preservation Institute Nantucket, Nantucket Preservation Trust, and the Town of Nantucket.
GZA Data Visualization: Coastal Flood Losses, East Hampton, New York