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

Daniel Stapleton, PE
GZA Coastal Engineering Study
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)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Extreme waves, wind, water levels - two characteristic coastal storm types

Extratropical Nor'easters

Tropical Cyclones (Hurricanes)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean 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>
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

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.
Study Results (Metocean Data Analysis): Tidal Datums

Prevailing Water Levels:

- NOAA Nantucket Tide Station 8449130

<table>
<thead>
<tr>
<th>Tidal Datum</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>0.2</td>
<td>-1.84</td>
</tr>
<tr>
<td>MLLW</td>
<td>0</td>
<td>-2.04</td>
</tr>
</tbody>
</table>
GZA Coastal Engineering Study
Meteocean Data Analysis and Numerical Wave Modeling

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)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Extreme Water Levels

![Graph showing extreme water levels and recurrence intervals](image-url)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Extreme Water Levels

Figure 11: Combined Stillwater Flood-Frequency Data from Multiple Data Sources
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

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)
GZA Coastal Engineering Study
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><strong>USACE NACCS 7380</strong></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
GZA Coastal Engineering Study
Meteocean Data Analysis and Numerical Wave Modeling

Study Results (Meteocean 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
GZA Coastal Engineering Study
Metoocean Data Analysis and Numerical Wave Modeling

(Bathytopo Data)
GZA Coastal Engineering Study
Meteocean Data Analysis and Numerical Wave Modeling

(Bathytopo Data)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

(Bathytopo Data)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

(Modeling Mesh)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

(Modeling Mesh)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

(Modeling Mesh)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

(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/
GZA Coastal Engineering Study

Metocean Data Analysis and Numerical Wave Modeling

(Scenario Simulation Circulation Model: ADCIRC)

ADCIRC-simulated Storm Surge and Wind during Hurricane Bob (1991)
GZA Coastal Engineering Study
Meteocean Data Analysis and Numerical Wave Modeling

(Wave Model: SWAN)
GZA Coastal Engineering Study
Metoocean Data Analysis and Numerical Wave Modeling

Study Results (+/- 50 to 100-year; 70 mph 1-minute, 10-meter wind)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

Study Results (+/- 50 to 100-year; 70 mph 1-minute, 10-meter wind)
GZA Coastal Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

Study Results (+/- 50 to 100-year; 70 mph 1-minute, 10-meter wind)
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)
## GZA Coastal Engineering Study

**Metocean Data Analysis and Numerical Wave Modeling**

<table>
<thead>
<tr>
<th>Recurrence Interval (years)</th>
<th>Significant Wave Heights (Hs) at SWAN Model Output Save Points at Town Pier (in feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td><strong>Prevailing Monthly Wind Speed</strong></td>
<td><strong>0.7</strong></td>
</tr>
<tr>
<td>1</td>
<td><strong>1.1</strong></td>
</tr>
<tr>
<td>2</td>
<td><strong>1.6</strong></td>
</tr>
<tr>
<td>5</td>
<td><strong>1.8</strong></td>
</tr>
<tr>
<td>10</td>
<td><strong>1.9 to 2.0</strong></td>
</tr>
<tr>
<td>25</td>
<td><strong>2.1 to 2.4</strong></td>
</tr>
<tr>
<td>50</td>
<td><strong>2.2 to 2.6</strong></td>
</tr>
<tr>
<td>100</td>
<td><strong>2.2 to 2.7</strong></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 $H_{max}$: 4 to 5 feet
- Predicted peak wave crest elevation ($H_s$): 7 feet NAVD88
- Predicted peak wave crest elevation ($H_{max}$): 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
GZA Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

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).
GZA Engineering Study
Metocean Data Analysis and Numerical Wave Modeling

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)
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
Envision Nantucket is a collaboration between the University of Florida Preservation Institute Nantucket, Nantucket Preservation Trust, and the Town of Nantucket.