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MEMORANDUM

TO:	**Michael Mocciae** **City Of Norwalk** **Recreation and Parks Department** **PO Box 5125** **125 East Avenue** **Norwalk, CT 06856-5125**	**DATE:**	**February 6, 2013**
		BCE#	**31866**
		RE:	**Calf Pasture Beach**
FROM:	**Russell Titmuss**	**SUBJ.:**	**Wave Analysis and Pier Deck Elevation**

As discussed, we have performed a wave analysis for the Calf Pasture site in order to determine the desirable pier deck elevation to reduce the risk of future storm damage.

The existing timber pier at Calf Pasture Beach in Norwalk, CT, having been damaged by Hurricane Irene, was further damaged by Hurricane Sandy. The tide and wave conditions at the site during these two storms were investigated to determine likely wave crest elevations. If the pier can be constructed above the wave crest elevation, it will be much less susceptible to future storm damage.

The existing pier deck elevation, based on survey prior to Sandy, is +13.4 feet above Mean Low Water (MLW).

No recorded wind data and water elevations have been found for Norwalk, but data is available for Bridgeport, CT from NOAA tide station 8467150. This tide station is located as shown on the attached NOAA Tidal Benchmark sheet. (Exhibit 1). The wind was blowing from east to west in both storms and, as a result, water elevations recorded at this location may be lower than those actually experienced at the Calf Pasture shoreline.

Maximum recorded water elevations were as follows:

Sandy	+13 feet MLW
Irene	+11 feet MLW

Maximum sustained wind speeds and direction were as follows:

Sandy	59 mph	East direction
Irene	46 mph	East to East south east direction

Wave heights were estimated using ACES software for the Limited Fetch conditions shown on the attached sheet (Exhibit 2). The estimated wave heights are equivalent to significant wave heights H_s. H_s is defined as the average height of the one third highest waves. Some waves will be larger than this height and the often accepted wave height distribution is a Rayleigh distribution.

90% exceedance wave height (10% of waves are higher) $H_{10} = 1.27\ H_s$
99% exceedance height (1% of waves are higher) $H_1 = 1.67\ H_s$

Summary of estimated wave heights is as follows:

Wave Heights in feet		
	Sandy	Irene
H_s	6.05	3.89
H_{10}	7.68	4.94
H_1	10.10	6.49
T_p (wave period)	4.75 secs	3.87 secs

Recorded wave heights during Sandy are available for NOAA Data Buoy 44039 in Central Long Island Sound and these show fairly good agreement with estimated heights. Maximum H_s was 2.2 meters or 7.2 feet. The slightly larger wave heights would be expected at the more exposed open water location.

Waves in deep water are an even shape with the total wave height split equally above and below the tide elevation. As they move into shallow water, waves become distorted with a greater proportion of the height above the tide elevation (Still Water Line, SWL). In addition, there is a phenomenon known as wave setup which locally raises the water height near a shoreline with breaking waves. Combining this data, an estimate of the top of wave crest elevation can be made. This is presented in the Table below:

	Sandy			**Irene**		
	H_s	H_{10}	H_1	H_s	H_{10}	H_1
Total wave height	6.1	7.7	10.1	3.9	4.9	6.5
Wave height above SWL	4.0	5.3	7.7	2.4	3.2	4.6
SWL El. (MLW)	+13.0	+13.0	+13.0	+11.0	+11.0	+11.0
Wave Setup	1.0	1.0	1.0	1.0	1.0	1.0
Top of Wave Crest El. (MLW)	**+18.0**	**+19.3**	**+21.7**	**+14.4**	**+15.2**	**+16.6**

The Still Water Elevations can be compared to FEMA Still Water Elevations to estimate approximate return period or probability. FEMA Still Water Elevations should include wave setup effects and are as follows:

10% annual chance +11.9 MLW (1 in 10 year)
2% annual chance +13.4 MLW (1 in 50 year)
1% annual chance +13.9 MLW (1 in 100 year)

This would mean the SWL for Sandy is close to a 1 in 50 year event and the SWL for Irene is close to a 1 in 10 year event. The combined probability for water level and wave heights would be expected to be somewhat lower than these numbers but is much more difficult to determine. The FEMA Flood Zone elevation is Zone VE Elevation +19.8 MLW.

Pier Deck Elevation

The existing pier deck elevation, based on survey prior to Sandy, is +13.6 feet above Mean Low Water (MLW). The existing jetty is approximately 230 feet long and the maximum ramp for ADA compliance would be 1:20. The inshore elevation is +12.2 which limits the maximum outshore elevation to +23.7 for ADA compliance.

In order to minimize future damage for a 100 year event, the pier deck would need to be raised above Elevation +21.7 MLW. This would require raising the pier by approximately 9 feet which will be impractical at this location without major changes to the existing jetty. The base width of the jetty would need to increase by approximately 36 feet with a significant area of new impacts of approximately 5,000 square feet. Expanding the jetty would require approximately 8,000 tons at a cost of $800,000.

If no changes are made to the jetty footprint, the walkway could be built up using vertical concrete walls on each side. The practical limit for this approach would be an increase of 3 to 4 feet giving a pier deck elevation in the range +16.6 to +17.6 feet above MLW.

Summary and Recommendations

Hurricane Sandy water levels were close to FEMA 1% annual probability water levels. Adding estimated inshore wave height to the water levels results in an estimated elevation for top of wave crest of +21.7 MLW. Raising Pier Deck to this elevation seems to be impractical due to excessive cost and impacts of jetty modifications.

Storm Irene represented at least a 10 year return period event and provides a more practical design limit for minimal damage. Our recommended approach is to design the replacement structures for minimal damage in an equivalent event to Strom Irene. Recommendations are as follows:

- Raise pier deck and stringers above elevation +15.2 MLW with a top of deck elevation +16.6 MLW or higher.
- Modify jetty by raising concrete walkway surface above riprap stone. Construct reinforced concrete sidewalls each side to support ramp.
- Detail pier structure to improve connections and survivability for an event worse than Irene.
- Decking should be fixed down with screws and the stringers should be fixed down with angles in an effort to further prevent damage as seen during these storm events.
- Consider use of larger (wider stringers)
- Estimated costs of reconstruction
  - Pier - $558,100
  - Seawall - $439,900
  - Jetty & Revetment – $113,900
  - Total Cost with Contingency - $1,402,500