ICCE 2018

36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

Baltimore, Maryland | July 30 – August 3, 2018

The State of the Art and Science of Coastal Engineering

Development of Fragility Curves for Reinforced Dunes

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Acknowledgements

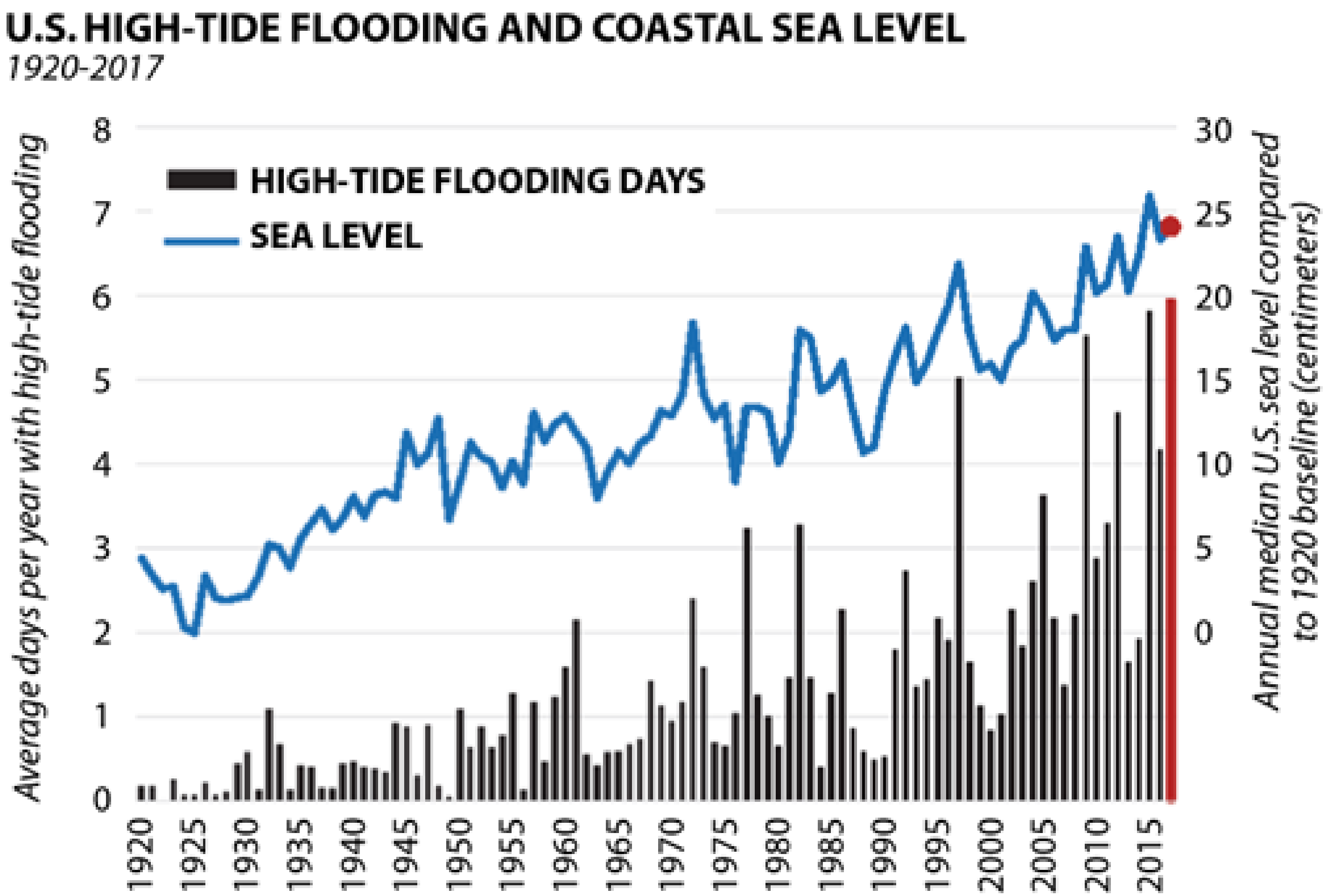
- National Science Foundation, CMMI #1719671
  (Program Manager – Rick Fragaszy)
- Lynn Bocamazo, U.S. Army Corps of Engineers – New York District
- Kimberly Shaw, Town of East Hampton
- Aram Terchunian & Benjamin Spratford, First Coastal Corporation
- Sue Genthner, Siasconset Beach Preservation Fund

Outline

- Background
- Objective and Approach
- Identification of Damage States
- Field monitoring of Geotextile Sand-filled Container (GSC) reinforced dunes
- 2-D XBeach Site Calibration
- Next Steps

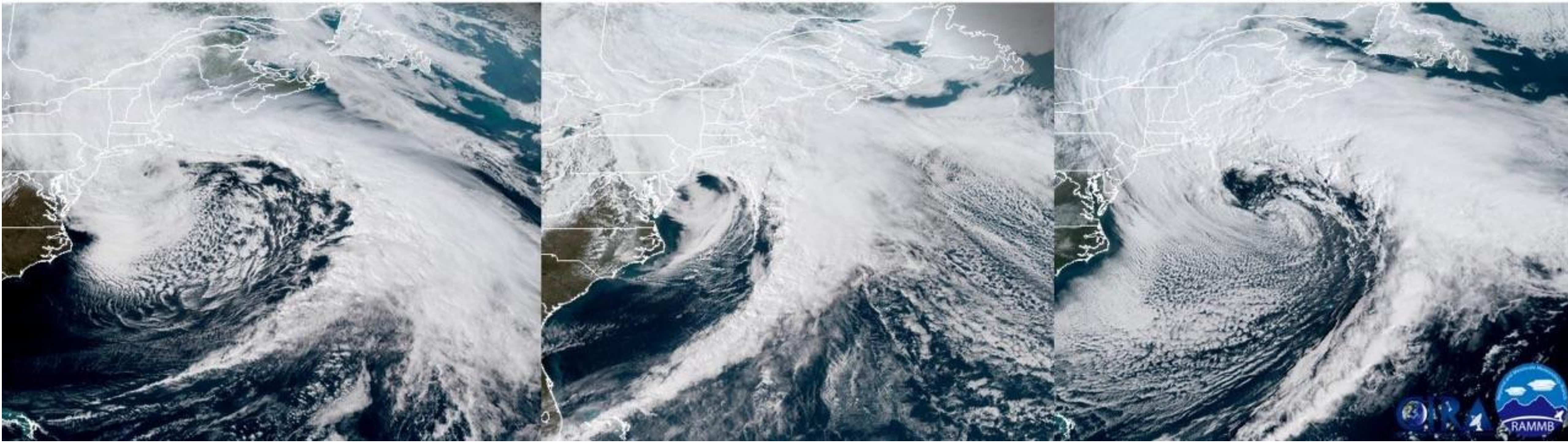
Background

- 2017 State of U.S. High Tide Flooding (Sweet et al. 2018)
- 27 of the 98 tide gauge locations along U.S. coastlines reported a record number of high tide flooding events in 2017



Background

MARCH 2 | MARCH 7 | MARCH 13



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Background

STA Brant Point (Nantucket, MA) – Winter Storm Juno (2014)

Background

- Vulnerabilities are exposed during recovery periods following significant weather events:
  - Natural recovery of the nearshore, beach, & dune system = **Years to Decades** (Lee et al. 1998)
  - Assess-Scope-Fund-Construct Recovery Project = **Years to Decades**
- States issue emergency permits that sometimes contradict good science and engineering to reduce imminent threats
- Lessons learned have resulted in numerous revisions of emergency permits
  - I.e. Permits for Geotextile Sand-filled Containers (GSCs) to protect imminently threatened structures

Background

- North Carolina Permit History (Lopanski 2016)
  - Mid ‘90s: Size, location, time limit (2-5 yrs), provision for beach nourishment projects & one time use per property
  - Early 2000s: Provision for Inlet Hazard Areas extends time limit to 8 yrs
  - 2015: 8 yr time limit for all structures if GSCs exposed above grade

Various emergency GSC applications in North Carolina (Lopanski 2016)

Problem Statement

- Recurring flooding and storm events increase the strain on natural and constructed coastal defense systems so impacts from subsequent, less severe storm events become more significant.
- GSC applications are typically an emergency or temporary erosion response where the level of design, monitoring, and maintenance seems to have a direct correlation to the in-situ performance.
- Numerous lab experiments have been developed to predict the hydraulic stability of GSC revetments, but there has been limited in situ validation of these systems, especially when they are used to reinforce the core of a natural system (Dassanayake and Oumeraci 2012).

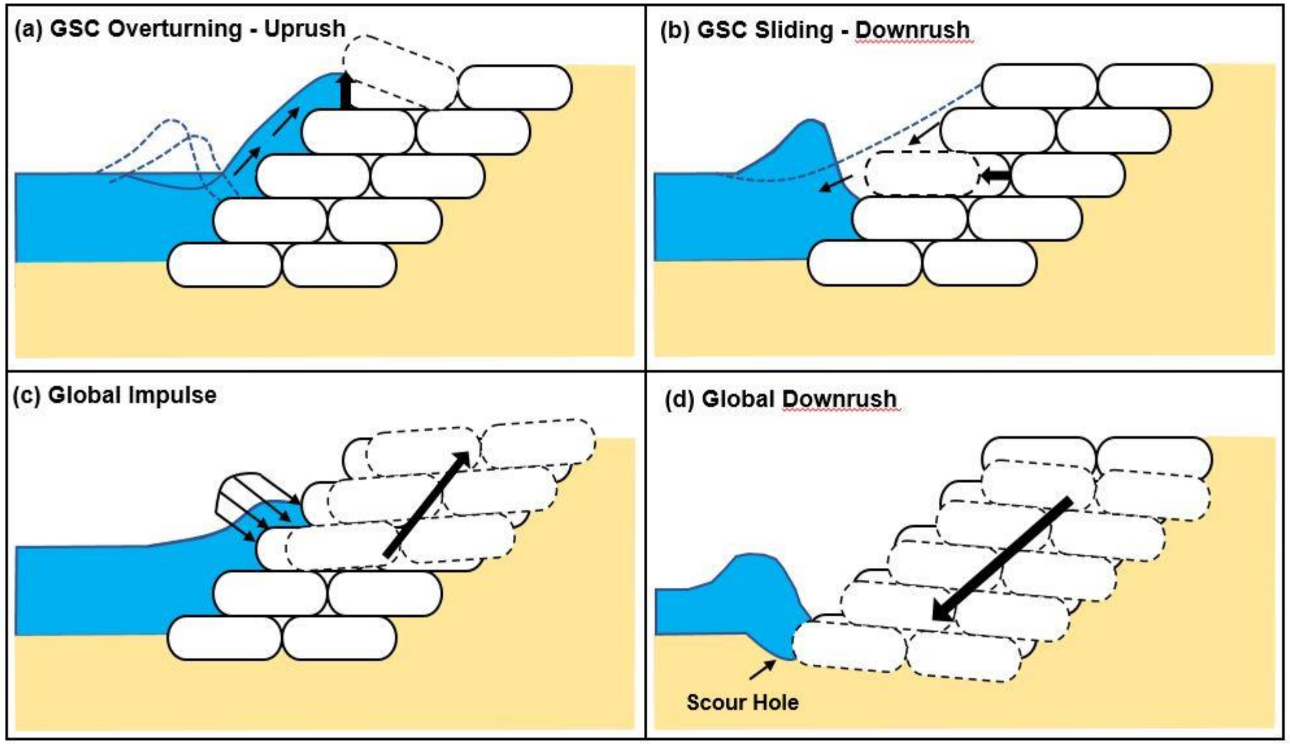
Objective and Approach

- Develop probabilistic fragility curves for a range of damage states to these reinforced natural systems to provide a solution to assess the performance and understand the tradeoffs of these systems when considering stabilization alternatives for coastal protection systems.
- Approach:
  - Identification of Damage States
  - Field Monitoring of GSC-reinforced dunes
  - Numerical modeling using XBeach, GSC stability criteria, and slope stability analyses

Identification of Damage States

- Definition of “damage” depends on the perspectives of the stakeholders:
  - I.e. Coastal protection of infrastructure, recreation and tourism, habitat, etc.

Damage State	Description of Damage
0	As-built profile with vegetation intact
1	Dune volume modified (will be quantified)
2	First exposure of GSCs
3	10% normalized movement of GSCs (defined as the movement of the GSC/length of GSC)
4	Instability of GSC system for the following failure modes:
4a	Overturning stability of individual GSCs
4b	Sliding stability of individual GSCs
4c	Global stability under impulse wave loading
4d	Global stability under downrush forces
4e	Rupture of geotextile



Field Monitoring of GSC-reinforced Dunes

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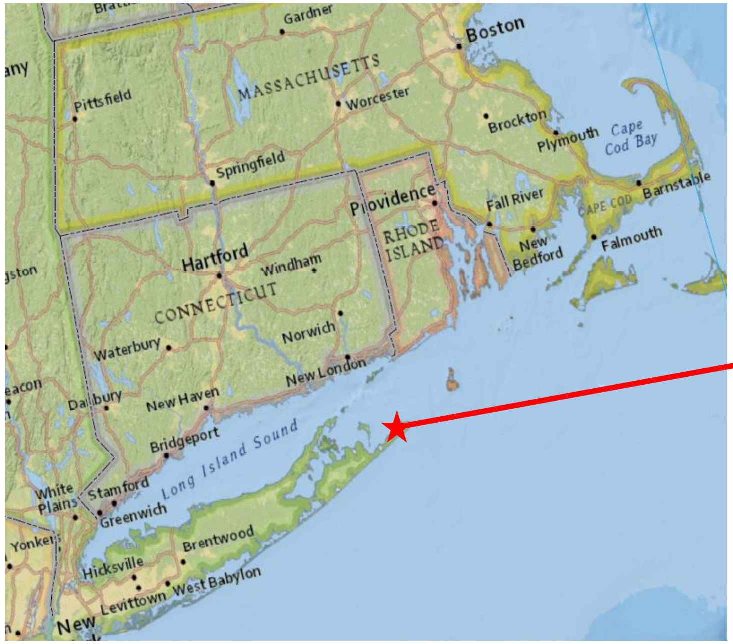
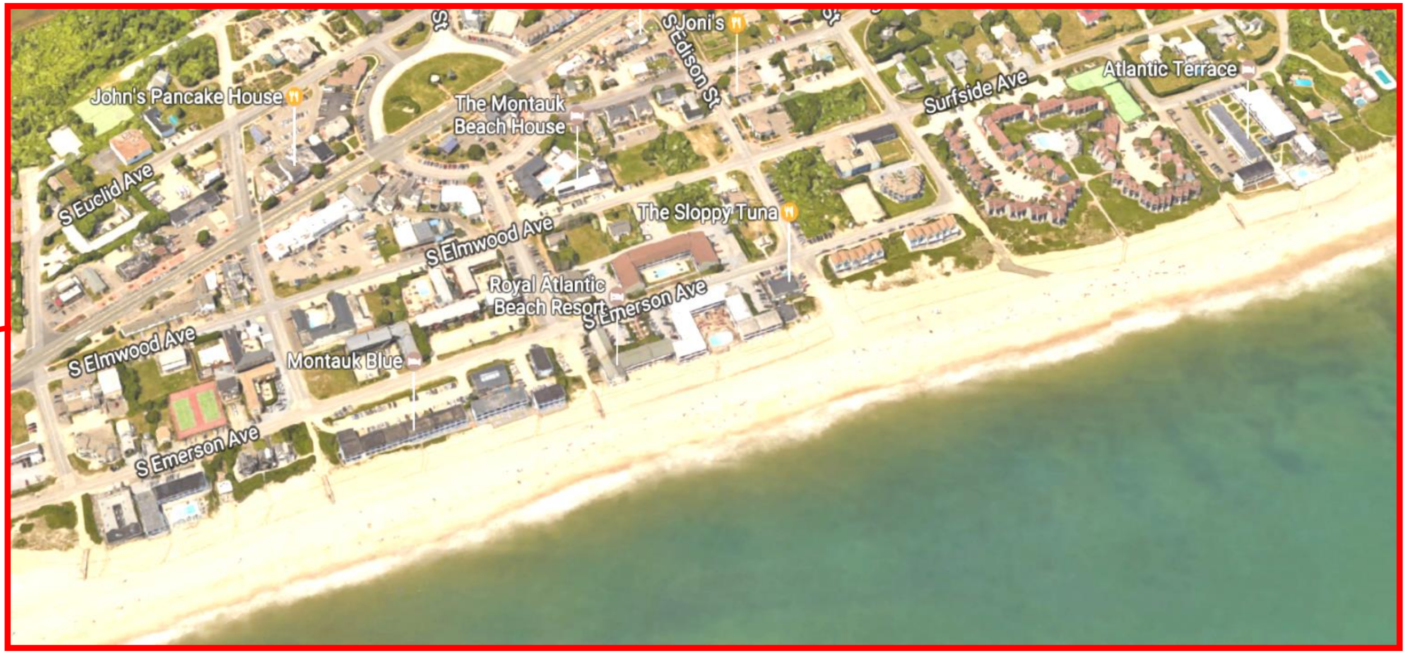
UNIVERSITY OF RHODE ISLAND · HOPE · 1892

- Downtown Montauk, NY
  - Development encroachment on natural foredunes has resulted in an erosion "hot spot"
  - Historical record of erosion data & corresponding wave/tidal data for significant weather events



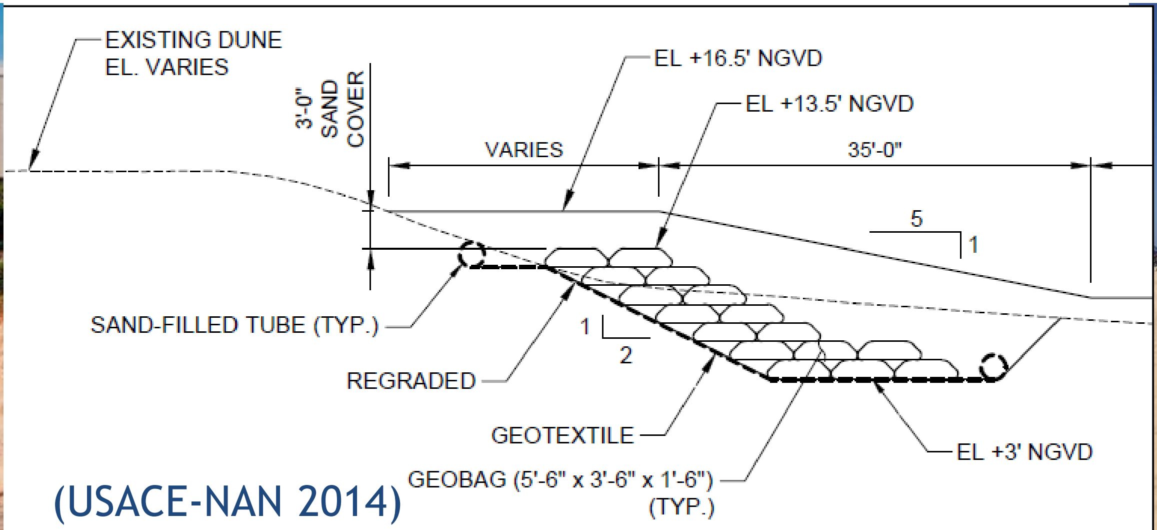


(Google Maps 2017)

Field Monitoring of GSC-reinforced Dunes

- U.S. Army Corps of Engineers New York District – Downtown Montauk Stabilization Project
  - Completed in March 2016
  - 109,000 cubic yards of sand to fill 11,000 Geosynthetic Sand-Filled Containers (GSCs) & reconstruct the dune/berm cross section

Hurricane Sandy (Newsday, Oct 2012)



(USACE-NAN 2014)

Post Construction (July 2016)

Field Monitoring of GSC-reinforced Dunes

- Cross shore profiles – Critical Royal Atlantic Section (Transect #13)

Field Monitoring of GSC-reinforced Dunes

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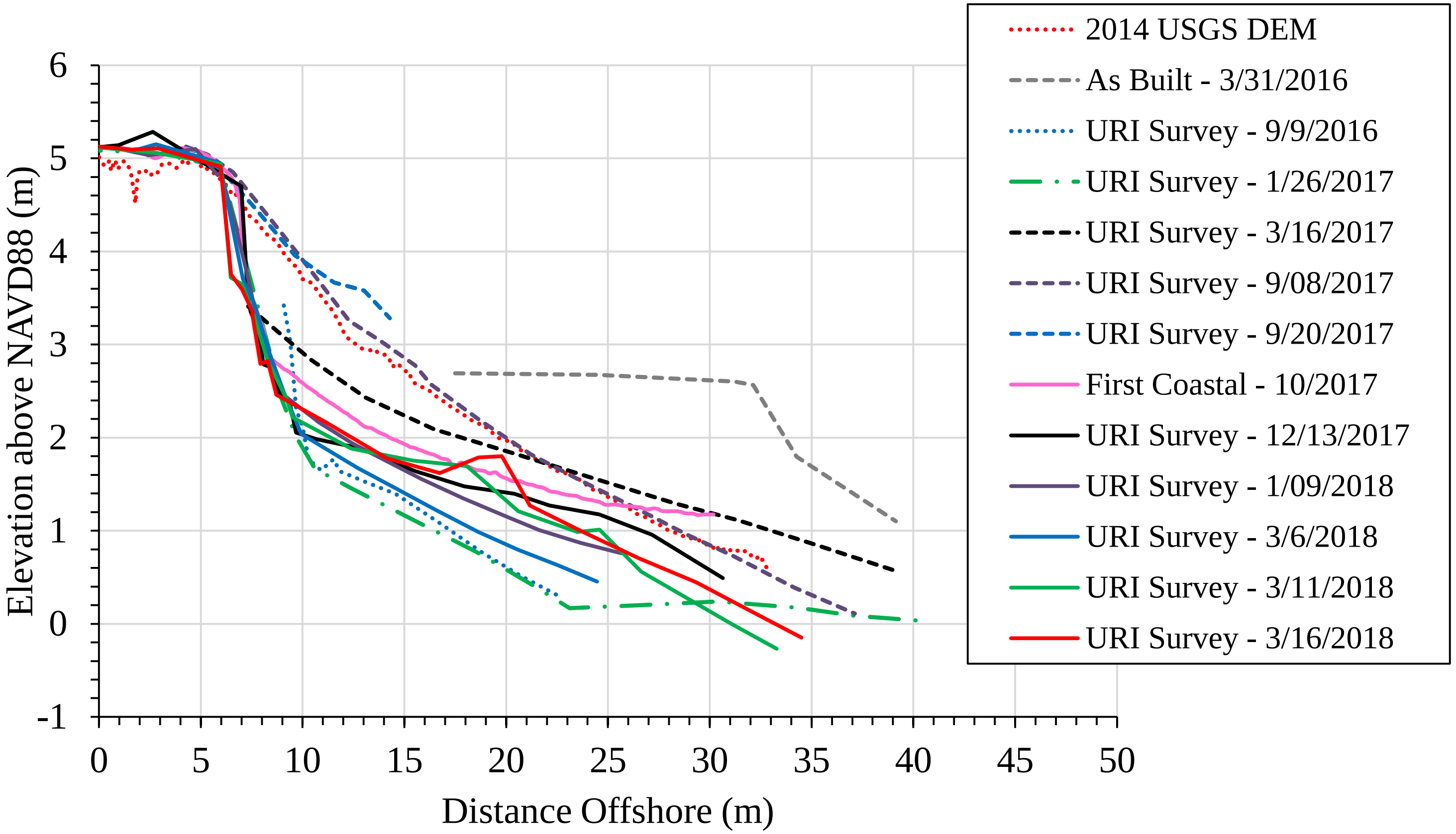
- Cross shore profiles – Transect #13



Peak Storm Wave Parameters & Water Levels

Events	H_s (m)	T_p (s)	MWD (deg)	SWFL Above MHHW (m)
09/06/2016	3.7	11	095	0.47
01/23/2017	6.0	11	097	0.78
09/19/2017	4.2	13	106	0.47
10/30/2017	5.0	13	142	0.77
01/04/2018	5.5	8	323	0.81
03/03/2018	4.2	10	073	0.81
03/07/2018	4.6	15	085	0.61
03/13/2018	3.9	12	094	0.47

25-yr Event: H_s = 4 m, T_p = 14 s, SWFL = 1.43 m (MHHW) (USACE-NAN 2014)

H-Sandy: H_s = 9.65 m, T_p = 15 s, SWFL = 1.41 m (MHHW)

Field Monitoring of GSC-reinforced Dunes

2-D XBeach Site Calibration (TS Hermine)

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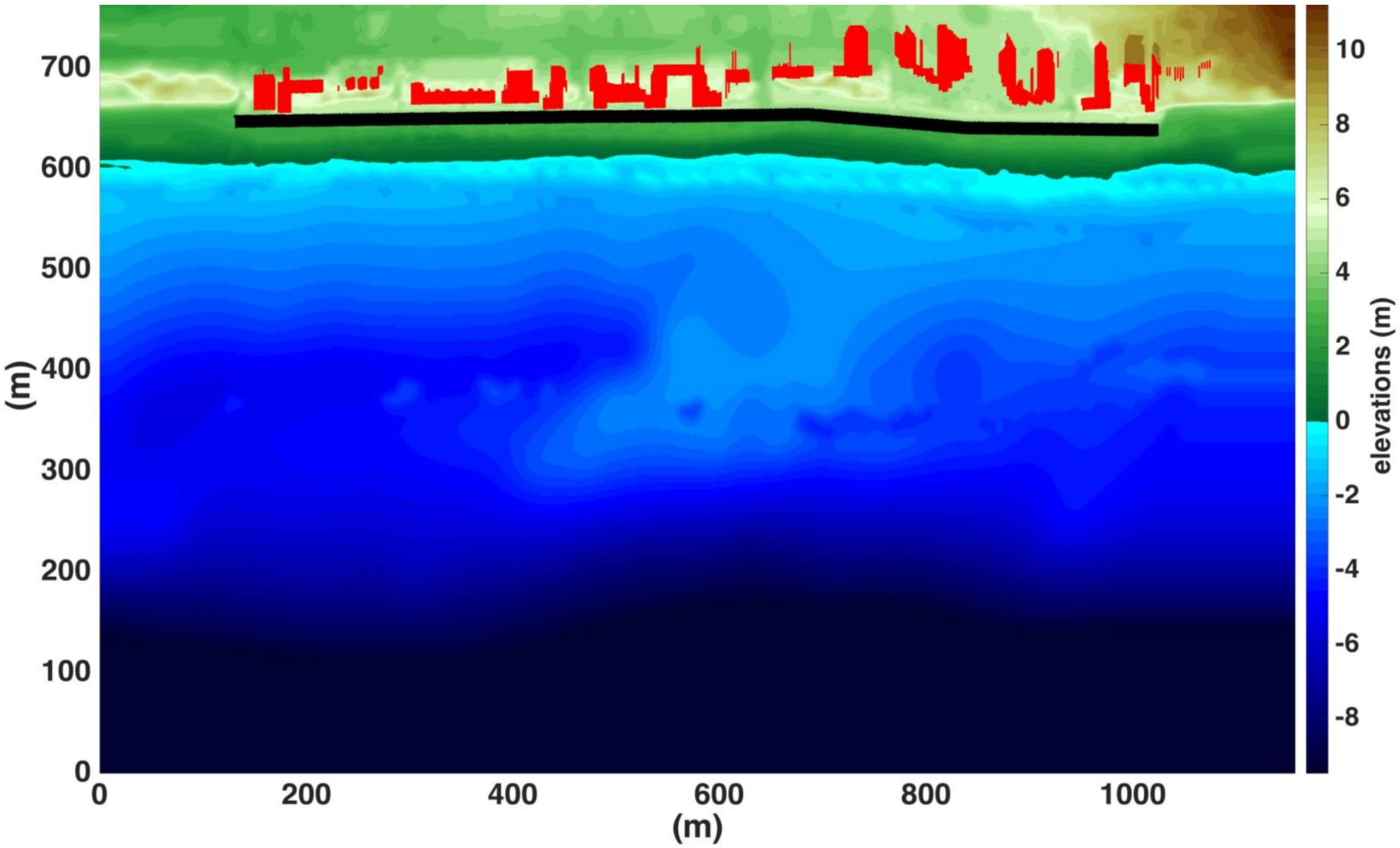

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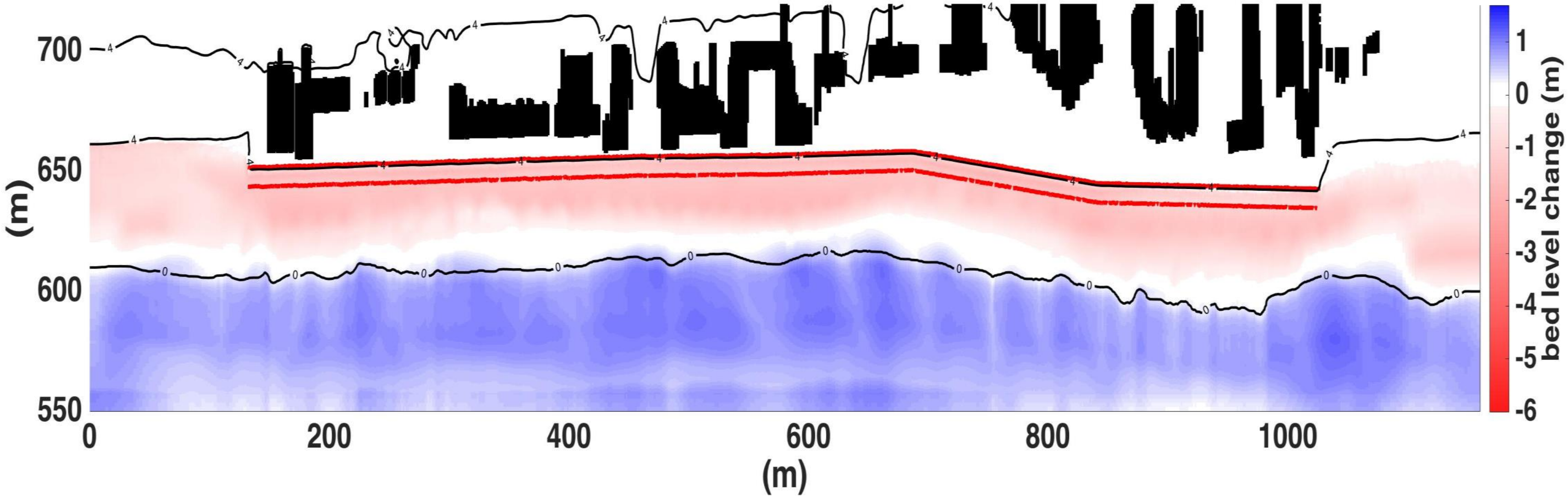

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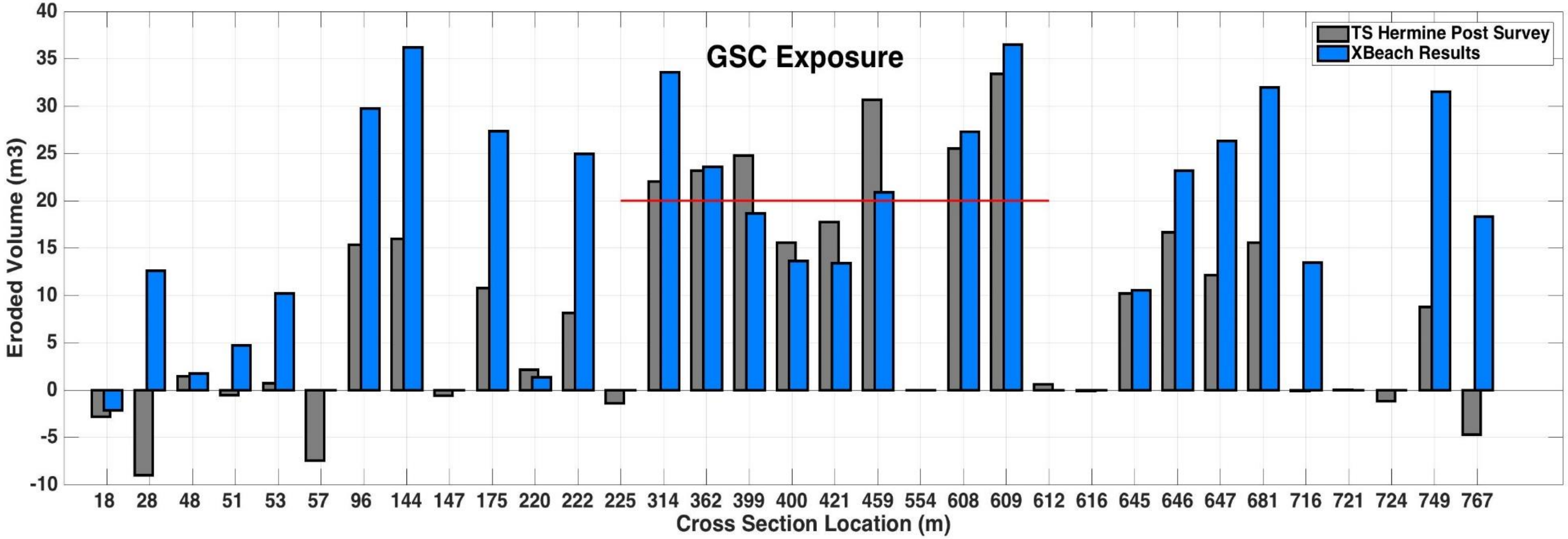
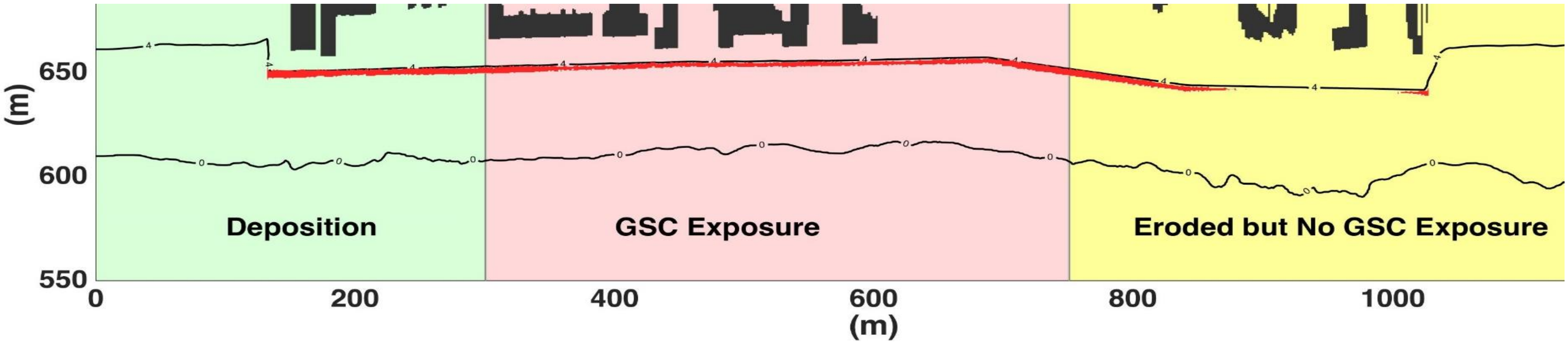


TS Hermine Post Survey

2-D XBeach Results



2-D XBeach Results (TS Hermine)

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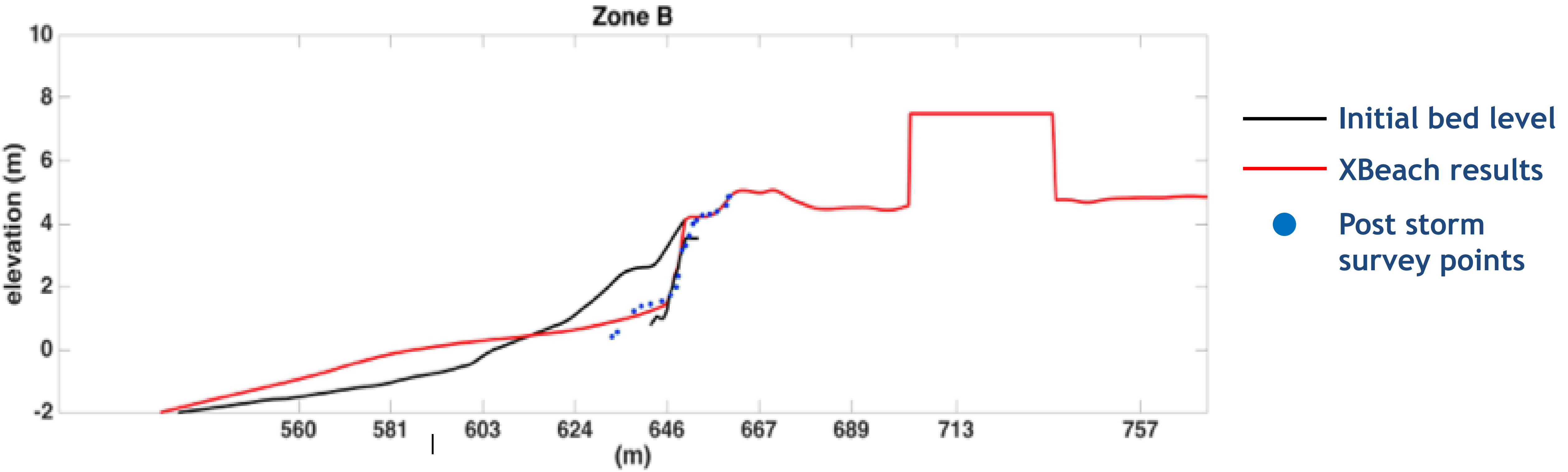


Typical cross section profile of the bed level change in front of the Royal Atlantic Hotel resulting from Tropical Storm Hermine.

(Dassanayake and Oumeraci 2012)

Next Steps

- 1-D XBeach analyses of other recorded storm events for further calibration.
- Monte Carlo simulations using 1-D XBeach to evaluate Damage States 2 (GSC exposure) and 3 (GSC slope or crest instability using Dassanyake and Oumeraci 2012).
- Geotechnical stability analyses to evaluate Damage State 4.

(Dassanayake and Oumeraci 2012)

Thank you

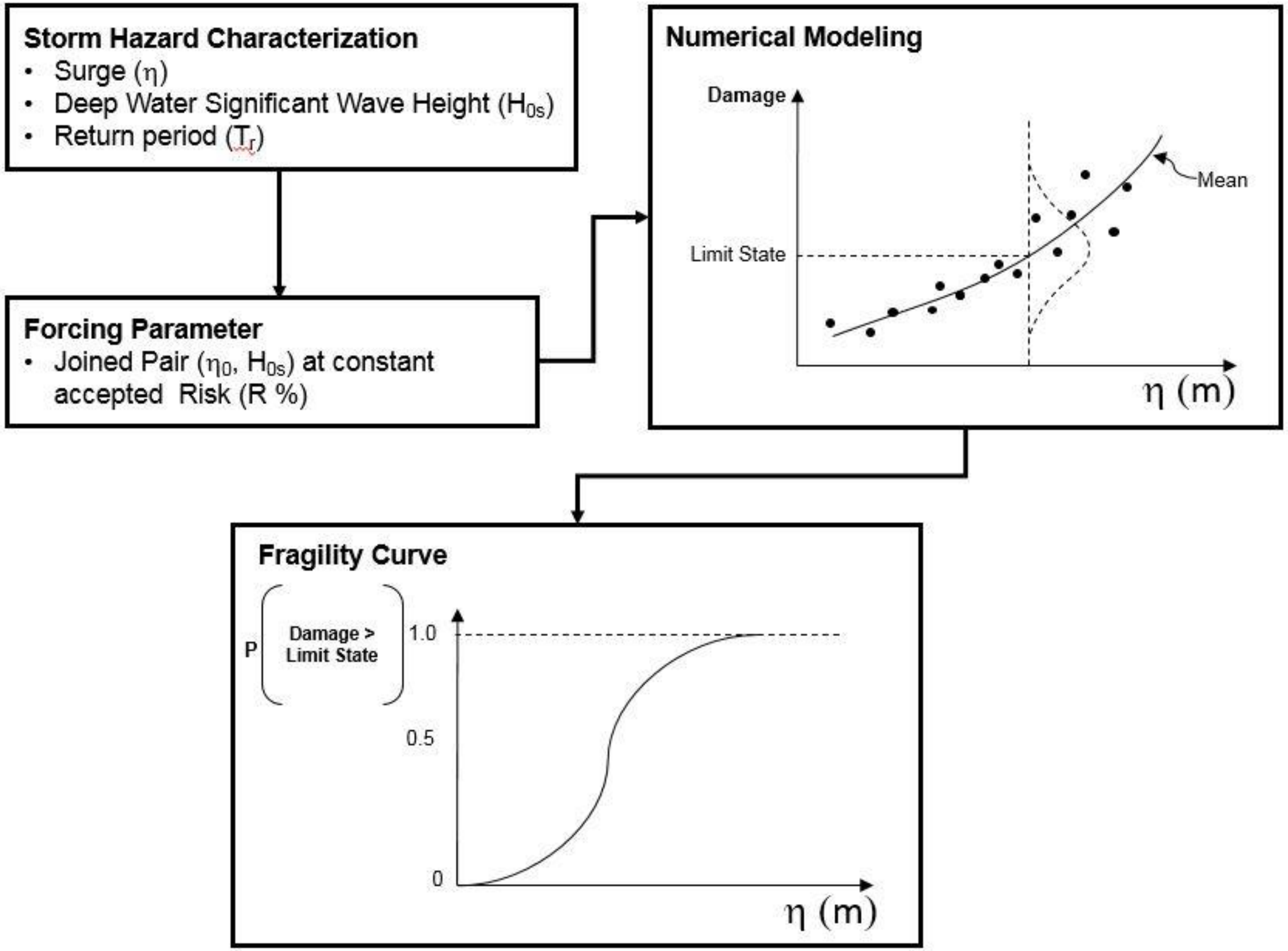
Downtown Montauk Beach, New York

July 21st, 2016

March 16th, 2018

(Dassanayake and Oumeraci 2012)

Development of Fragility Curves



Development of Fragility Curves

Table 1: Available hydraulic stability formulae for GSC-structures		
Authors/Structures	**Formulae / Nomograms**	**Remarks**
Hudson (1956) / Initially for rubble mount structures	$N_s = \frac{H}{\Delta D_n} = (K_D \cot\alpha)^{1/3}$ $W_{50} = \frac{\rho_S g H^3}{K_D(\rho_S/\rho_W - 1)^3 \cot\alpha}$	Formula based on geometrical considerations of the balance of wave generated flow forces acting on an armour stone in a slope of a breakwater. Later new K_D values were found for different types of armour units and structures
Wouters (1998) / GSC-revetments	$N_s = \frac{H_s}{(\rho_E/\rho_w - 1)\cdot D} = \frac{C_w}{\sqrt{\xi_0}}$ $D = l \cdot \sin\alpha$ $lc = \frac{H_s\sqrt{\xi_0}}{(\rho_E/\rho_w - 1)\cdot \sin\alpha\, C_w}$	a formula for describing the stability number with the surf similarity parameter based on previous experimental data. Instead of the required weight of the armour unit, the thickness D of the cover layer defined by the relationship $D = lc \sin\alpha$
Oumeraci et al. (2002b, 2002c, 2003) / GSC-revetments and low crested structures	$N_{s,slope} = \frac{H_s}{(\rho_E/\rho_w - 1)\cdot D} < \frac{C_w}{\sqrt{\xi_0}}$ $lc = \frac{H_s^{3/4}\sqrt{T}}{C_w\left(\frac{2\pi}{g}\right)\left(\frac{\rho_{GSC}}{\rho_w} - 1\right)\sqrt{\frac{\sin(2\alpha)}{2}}}$ $N_{s,crest} = \frac{H_s}{(\rho_{GSC}/\rho_w - 1)\cdot D} < 0.79 + 0.09\frac{R_c}{H_s}$ $lc = \frac{H_s}{\left(\frac{\rho_{GSC}}{\rho_w} - 1\right)\left(0.79 + 0.09\frac{R_c}{H_s}\right)\sin(\alpha)}$	Based on the Hudson (1956) formula for the hydraulic stability of rock armour units (non-deformable) and similarly to Wouters (1998), a stability number N_s is formulated and postulated to be a function of the surf similarity. Two different formulae for slope and crest GSCs for high overtopping revetments and low-crested structures based on small and large scale experiments Here $D = lc \sin\alpha$

C_D, C_L C_M = drag, lift and inertia coefficients
C_w = empirical parameter derived from N_S [-]
D_{50} = thickness of armour layer [m]
g = acceleration due to gravity
H_s = incident significant wave height [m]
K_D = stability coefficient (obtained experimentally)
KO = coef. account for deformation during overturning
KS = coef. account for deformation during sliding
$L_0 = g\,T^2/(2\pi)$ = deep water wave length using T_p [m]
l_c = length of the container [m]
N_s = stability number [-]
Rc = crest freeboard [m]

Re= $\left(\frac{uD}{\nu}\right)$ = Reynolds number
Tp= peak wave period
u=horizontal velocity
W_{50} = average weigh of element [kg]
α = slope angle of structure slope [°]
$\xi_0 = \tan\alpha/(H_s/L_0)^{1/2}$ = Iribarren number [-]
$\Delta = (\rho s/\rho w - 1)$
$\frac{\partial u}{\partial t}$ = horizontal acceleration [m/s²]
μ = friction factor between geotextiles [-]
ρ_s = density of armour unit [kg/m³]
ρ_W = density of water [kg/m³]
ρ_E = density of GSC [kg/m³]

(Dassanayake and Oumeraci 2012)

Development of Fragility Curves

$$N_{s,slope} = \frac{H_s}{(\rho_E/\rho_w - 1)\cdot D} < \frac{C_w}{\sqrt{\xi_0}}$$

$$lc = \frac{H_s^{3/4}\sqrt{T}}{C_w\left(\frac{2\pi}{g}\right)\left(\frac{\rho_{GSC}}{\rho_w} - 1\right)\sqrt{\frac{\sin(2\alpha)}{2}}}$$

$$N_{s,crest} = \frac{H_s}{(\rho_{GSC}/\rho_w - 1)\cdot D} < 0.79 + 0.09\frac{R_c}{H_s}$$

$$lc = \frac{H_s}{\left(\frac{\rho_{GSC}}{\rho_w} - 1\right)\left(0.79 + 0.09\frac{R_c}{H_s}\right)\sin(\alpha)}$$

C_D, C_L C_M = drag, lift and inertia coefficients
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(Dassanayake and Oumeraci 2012)