CRC 4th Annual Meeting 2019, UNC Chapel Hill, NC

Experimental and Numerical Study to Improve Damage and Loss Estimation due to Overland Wave and Surge Hazards on Near-Coast Structures

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Oregon State University

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Colorado State University

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Project Overview

Objective 1: Quantify surge/wave forces on near-coast structures and develop new predictive equations.

Objective 2: Develop the conditional probabilities (fragilities) for building damage.

Objective 3: Illustrate next-generation risk-informed design.

Technical Approach

Task 1: Hydraulic model test program at OSU and data analysis.

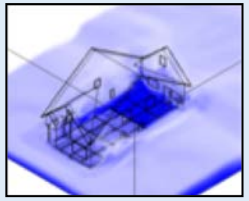
Task 2: Numerical model program at CSU. Verification and fragility development.

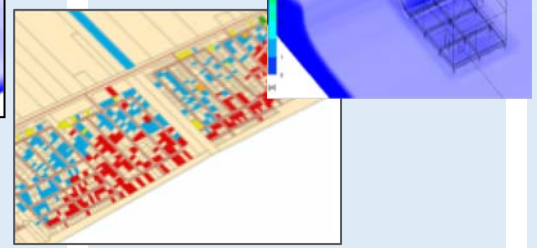
Task 3: Develop performance based design examples to illustrate methodology for engineering practice.

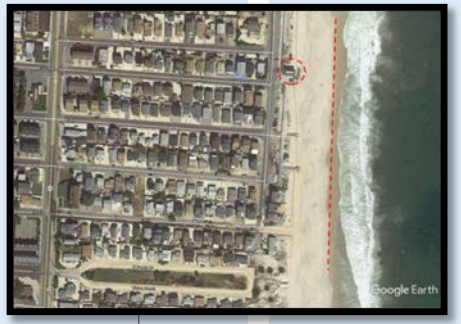
Task

2016 | 2017 | 2018 | 2019

1. Physical model testing
2. Numerical modeling program
3. Applications to risk-based decision-making
4. Education/Workforce
5. Stakeholder Engagement







C1 V

SUMEX

C2

Sy1

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C3

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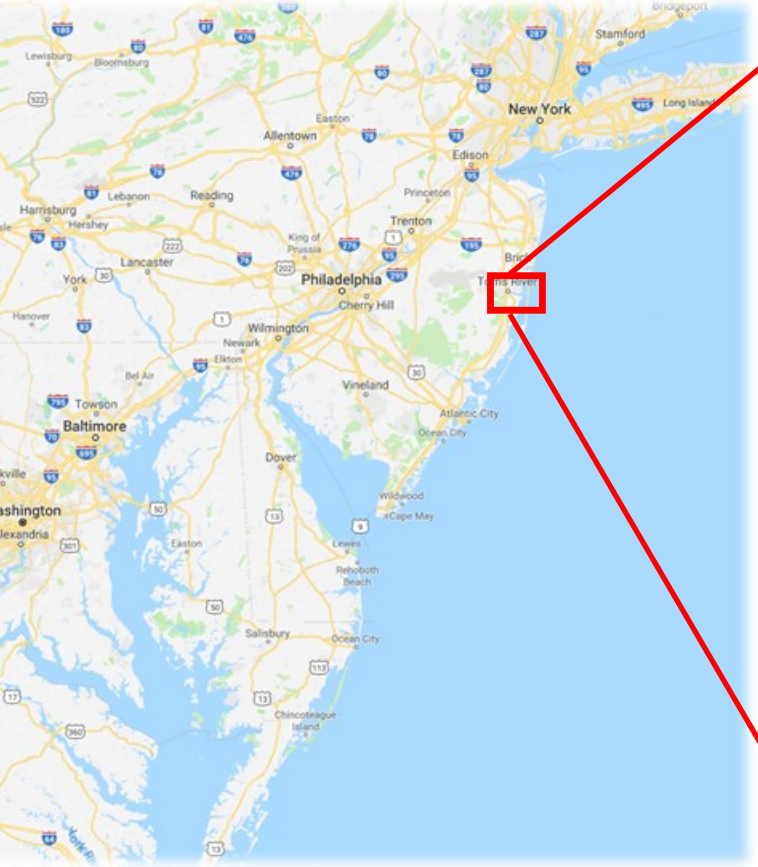
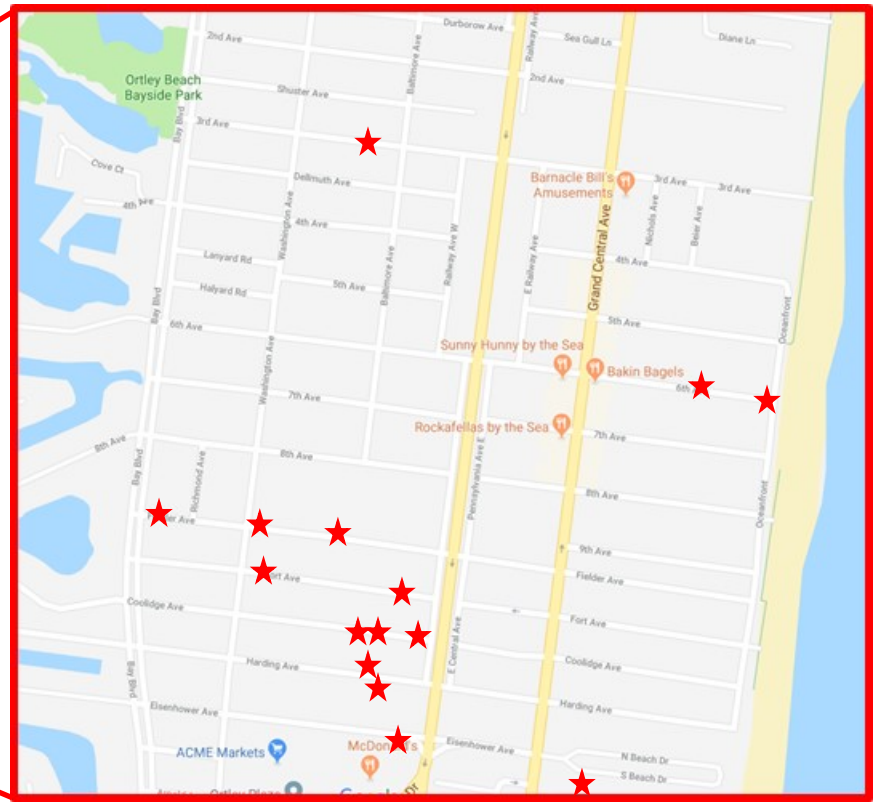
EU4

SUMEX

= End User meeting
FEMA HAZUS stakeholders
Wash DC, (TBD)

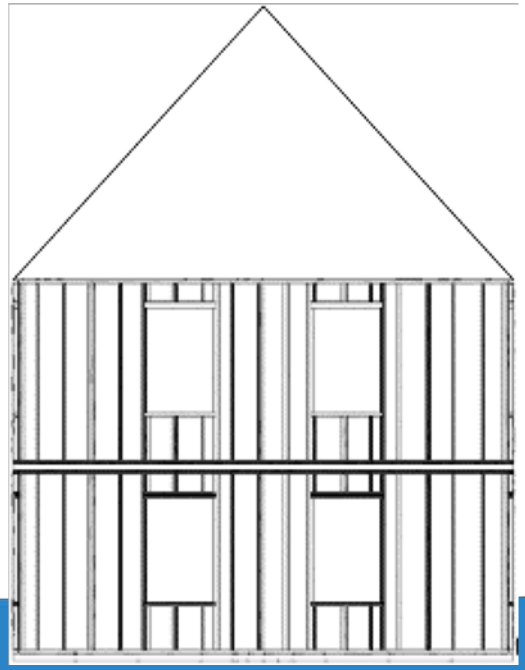

New York
Philadelphia
Baltimore
Wilmington
Atlantic City
Trenton
Edison
Allentown
Reading
Lancaster
Harrisburg
Dover
Salisbury
Ocean City
Cape May
Lewes
Rehoboth Beach
Towson
Vineland


West Point Island
Ortley Cove
Mikes Island
ORTLEY BEACH
Grand Central Ave
Inward Thoroughfare
ACME Markets
Harbor Island
W Central Ave
Shore Store


Ortley Beach Bayside Park
Barnacle Bill's Amusements
Sunny Hunny by the Sea
Bakin Bagels
Rockafellas by the Sea
Grand Central Ave
ACME Markets

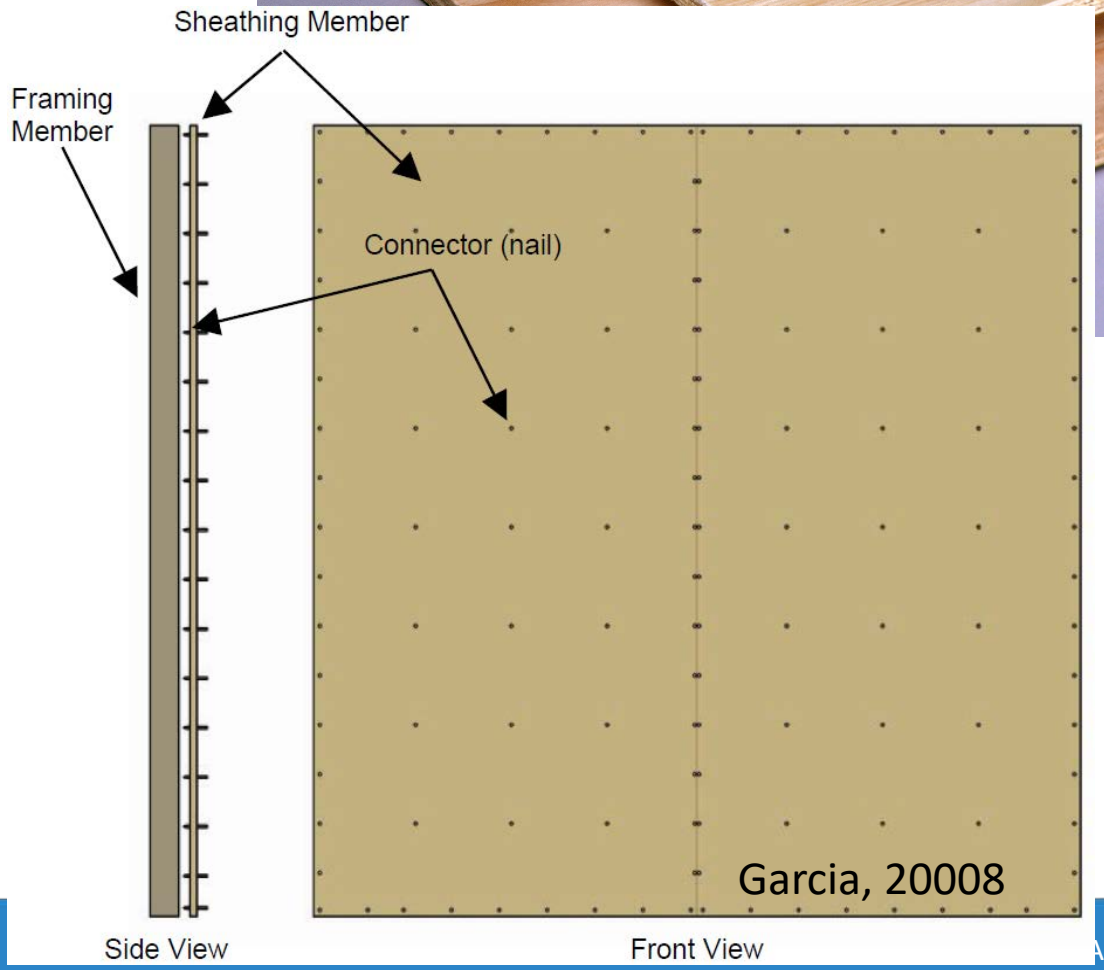
Specimen Design

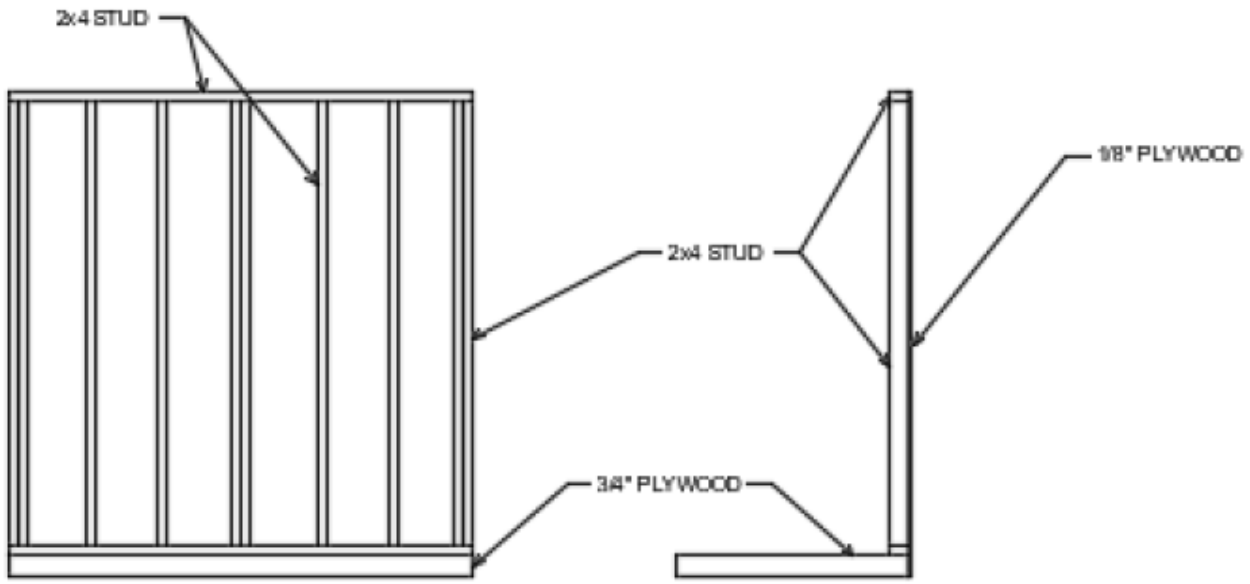
- Scaling Factor, width of flume
- Sandy vs. Katrina
  - Ortley Beach, NJ
- Composite structure archetype
  - Front to side ratio – 3:2
  - Roof Pitch – 1:1
  - Stories – 2
  - Windows
  - Slab-on-grade (S1-3)
  - Elevated on piles (S4)



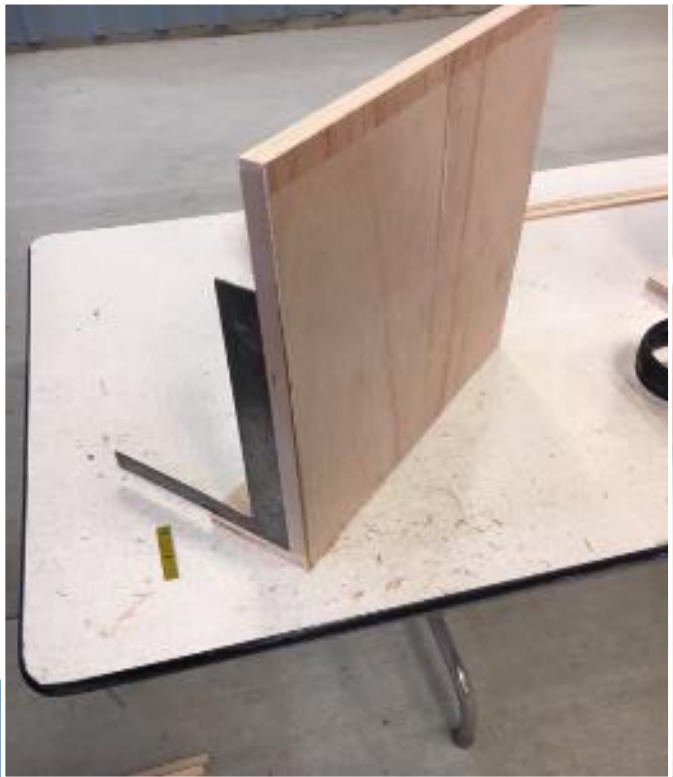
Scaling the Construction

- Scaled to actual dimensions
  - 2x4 → 1.5” x 3.5”
- Discrepancies
  - Sheathing plywood
    - OSB vs. Luan
  - Nails
    - 8d vs. 23 gauge
    - Spacing pattern
  - Floor Simplification
  - Truss/Roof Simplification
  - 2x4 vs. 2x6 walls



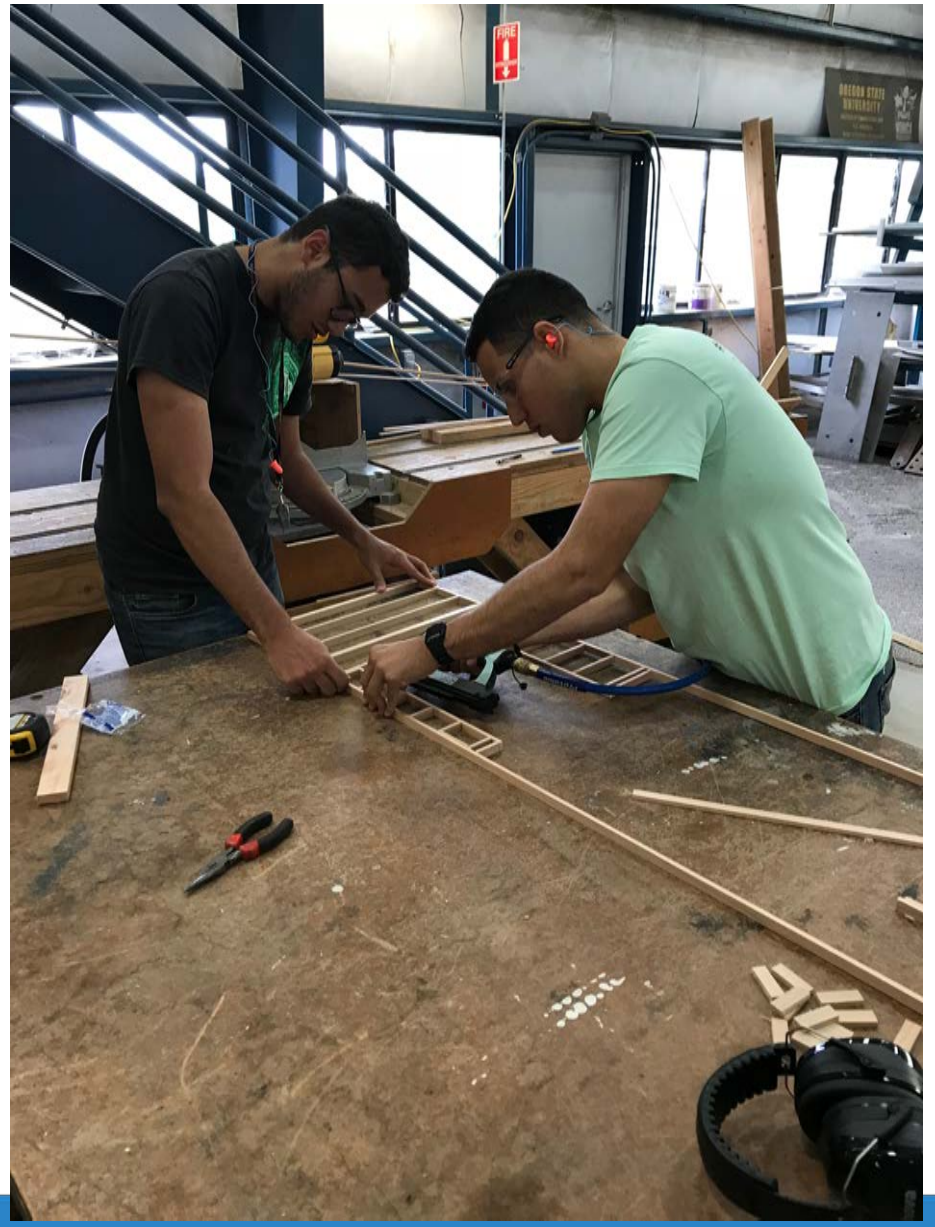


- 13 Final Test Walls
- Baseline stiffness
- Mirrored Specimen Construction
- 16in x 16in Wall
  - Mounted to ¾” plywood
  - 2-inch nail spacing
  - Double-stud end/center



Specimen Construction

- Full-length wall assembly-line construction
  - Template Walls
  - Multiple nailers at one time
- Specimen assembled wall-by-wall
- Pre-drill LC/steel plate mounting holes
- Avg. 60 man-hrs/specimen



Elevated Structure Construction

- FEMA CCM
- Assumed rigid at soil
- 12-in square piles
- Floor diaphragm
  - Joists: 2x10s
  - Girders: (2) 2x12s

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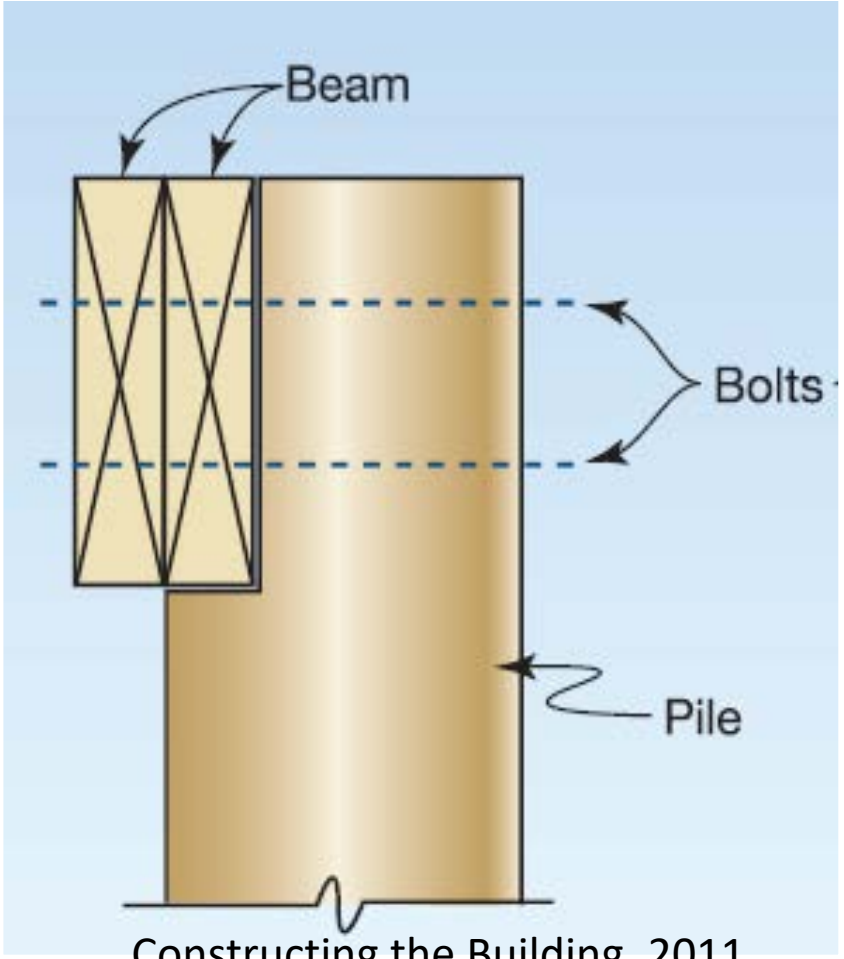
  - Girder-to-pile



Constructing the Building, 2011

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- Assumed rigid at soil
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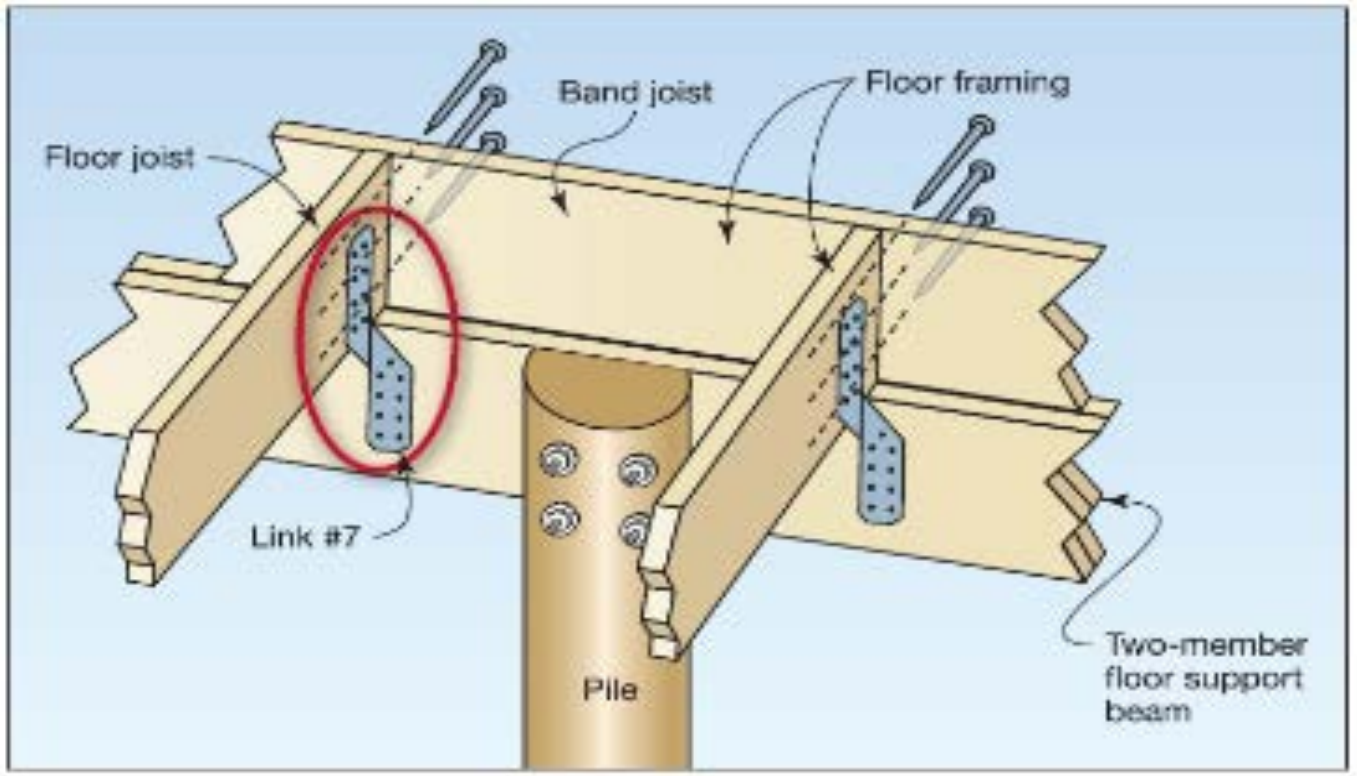
  - Girder-to-pile
  - Joist-to-girder



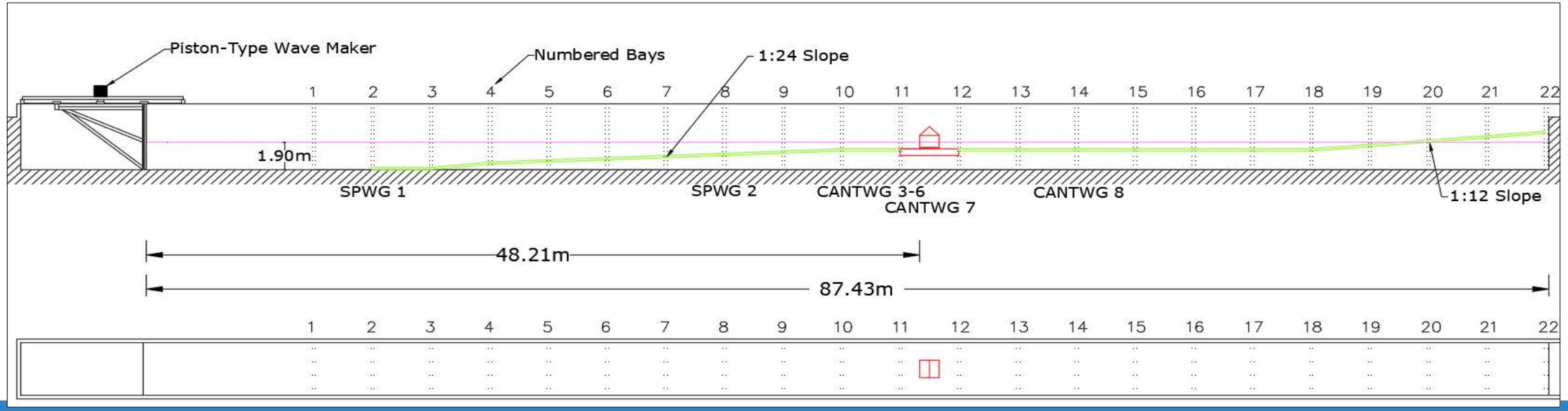
Constructing the Building, 2011

COA
A U.S.

th Annual Meeting 2019

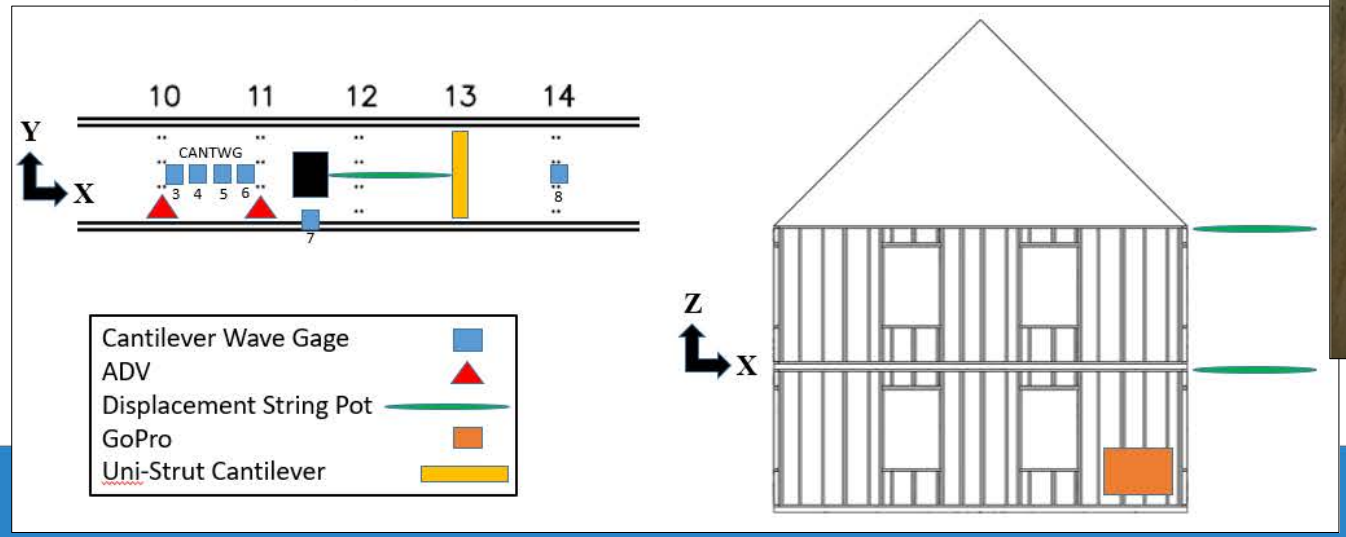
Methodology: Instrumentation, Layout, and Descriptions

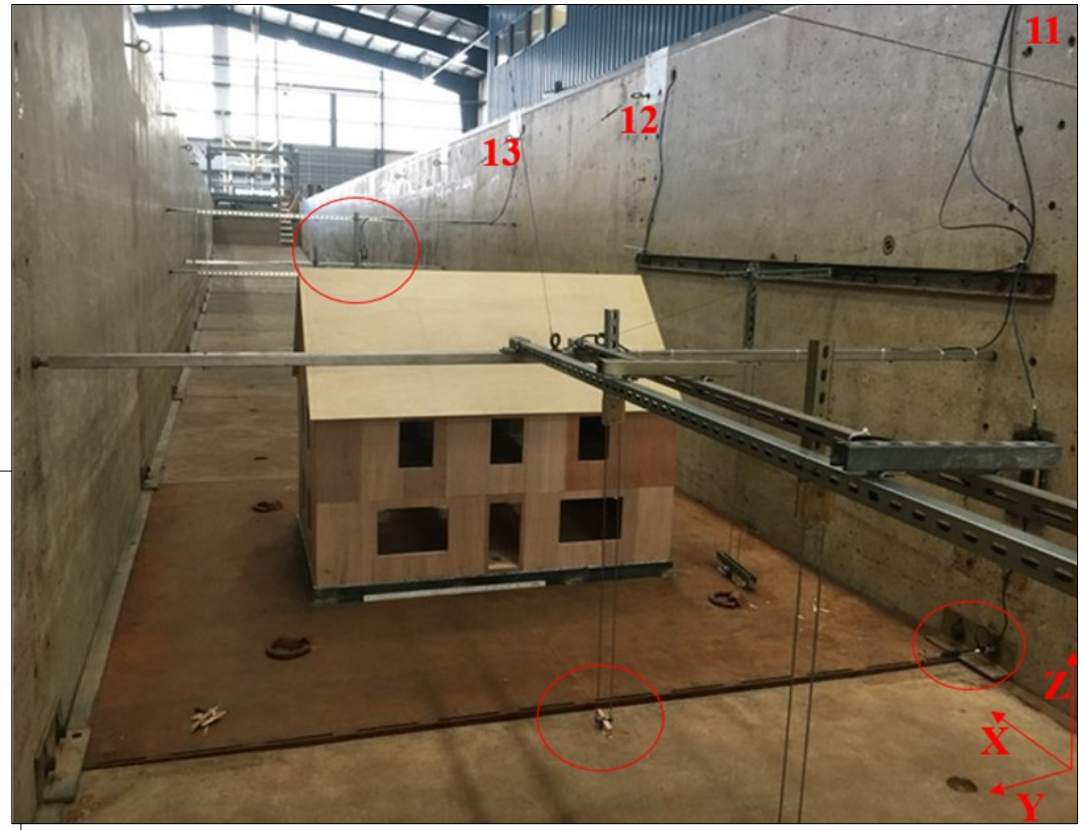
- Bathymetry simulates the low-angled, sandy coastal approach of the shore in the northeastern U.S. in areas such as Ortley Beach.
- At specimen: a bathymetric slope of zero used to simulate flat peninsulas or barrier islands.
- 1:12 slope was used beyond Bay 17 in order to facilitate wave dissipation and minimize downtime between experimental trials.



Methodology: Instrumentation, Layout, and Descriptions

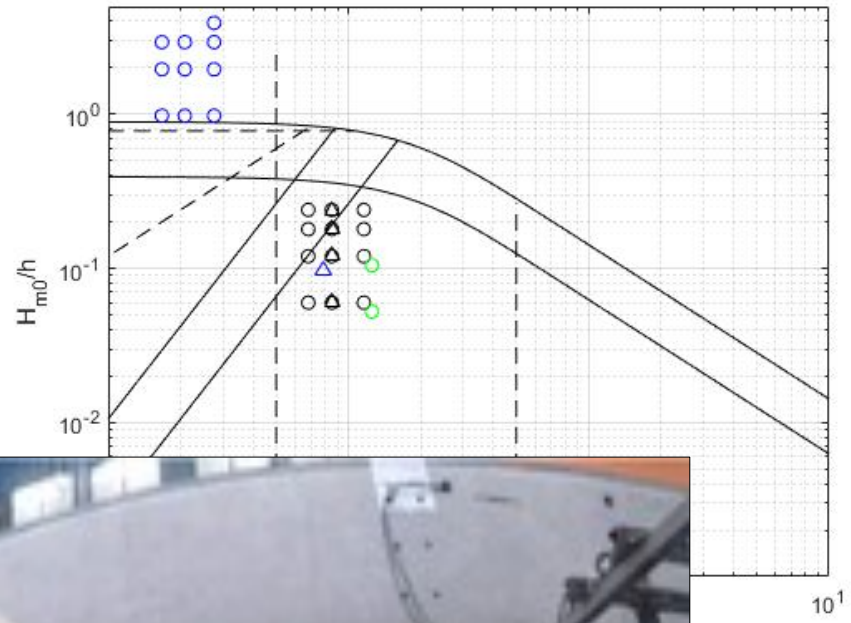
- Two accelerometers both mounted on the second floor of the specimen, one in the front right quadrant of the specimen, and one in the back right quadrant.
- Sampling rate of 100 or 1000 Hz.





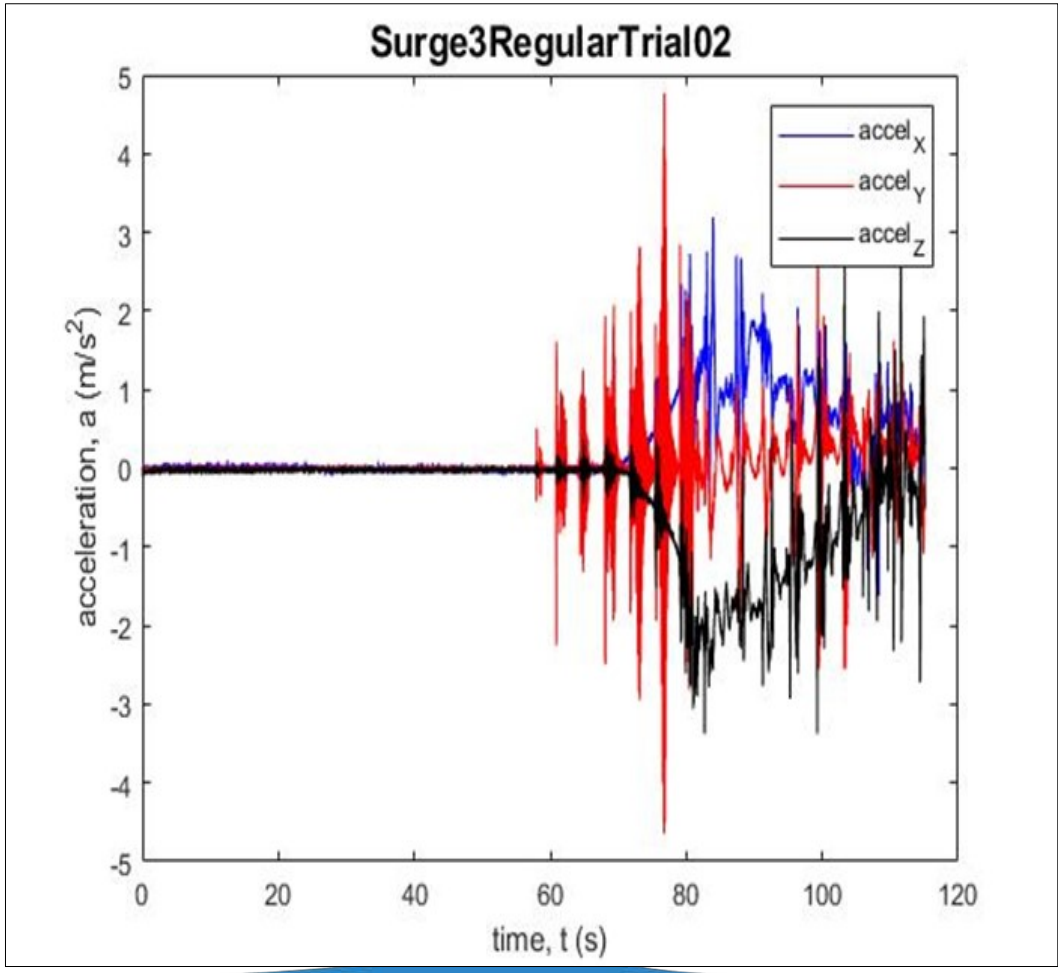
Conditions

- Three surge levels
  - h = 1.55 m; bottom of first floor door frames
  - h = 1.66 m; bottom of first floor window frames
  - h = 1.90 m; top of first floor window/door frames
- Four wave heights
  - H_s = 0.1 m, 0.2 m, 0.3 m, 0.4 m
- Three periods
  - Tp = 3.7 s, 4.9 s, 6.1 s
- Three types of waves
  - Regular, Solitary, TMA (random)
- Trial duration
  - Three minutes for regular waves
  - (Exception was failure trial, about 2 minutes)
  - 35 minutes for TMA



Examples of Observed Data

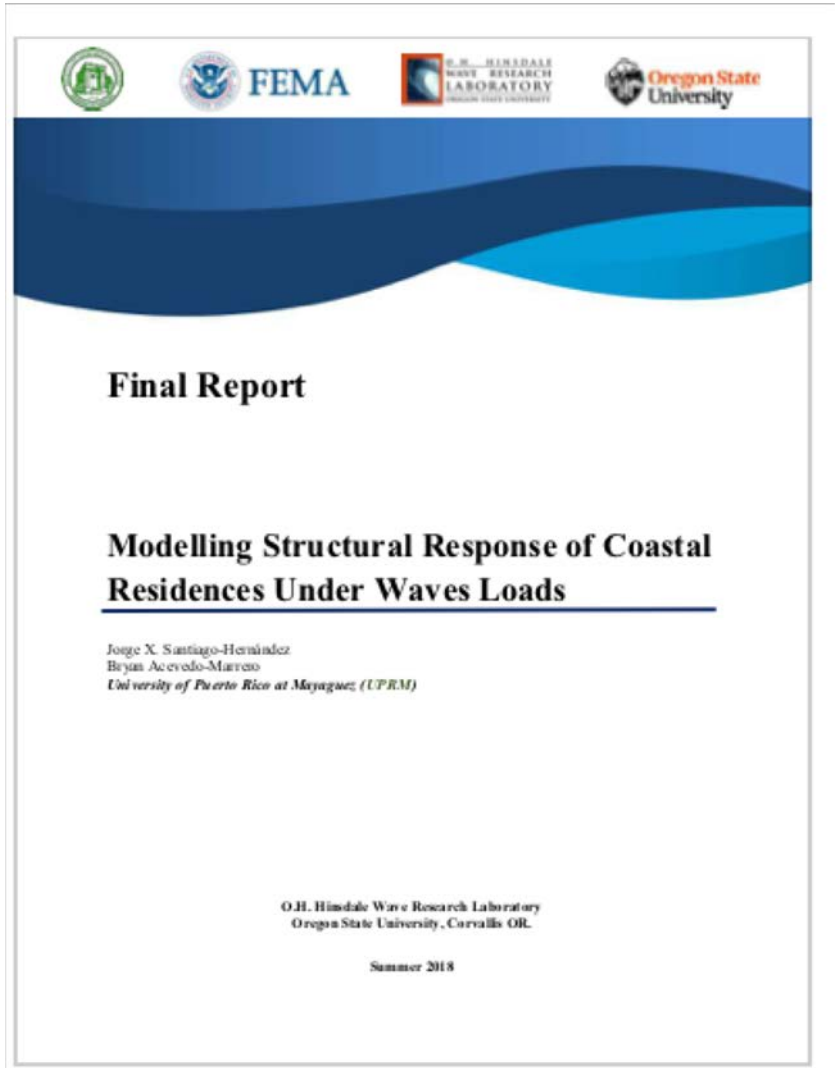
- Final trial 02 at surge level 3: data is less noisy compared to other trials.
- Acceleration is steadily increasing to failure.
- In the time domain, acceleration reaches almost 5 m/s^2 in the y-direction compared to about 3 m/s^2 and in both the x and z-directions.
- Frequency domain, accelerations reach a peak of 0.65 m/s^2 in the y-direction at frequencies between 0 and 1 Hz.
- These values are significantly higher when compared to those of trial 01 in the frequency domain by about 1 order of magnitude.



Progressive Damage Observations

- Screen capture of trial 02 at surge level 3, Hs = 0.2 m and Tp = 3.7 s.
- Testing video showing stages of specimen destruction
  - Frame 3: panel displacement on rear of specimen.
  - Frames 4-6: displacement.


MITRE
Disaster Dynamics



FEMA

O.H. Hinsdale Wave Research Laboratory

Oregon State University

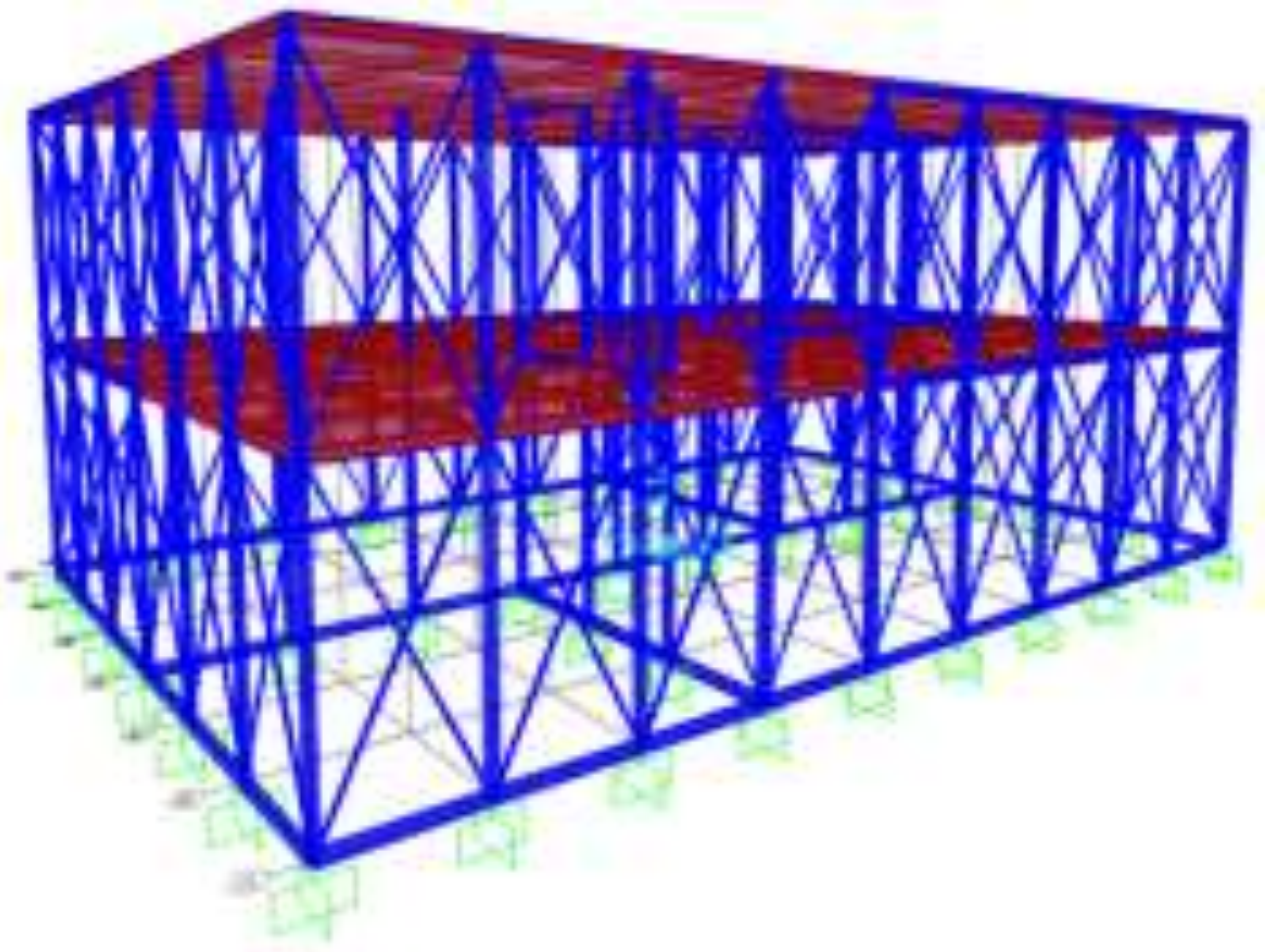
Final Report

Modelling Structural Response of Coastal Residences Under Waves Loads

Jorge X. Santiago-Hernández
Bryan Acevedo-Marrero
University of Puerto Rico at Mayaguez (UPRM)

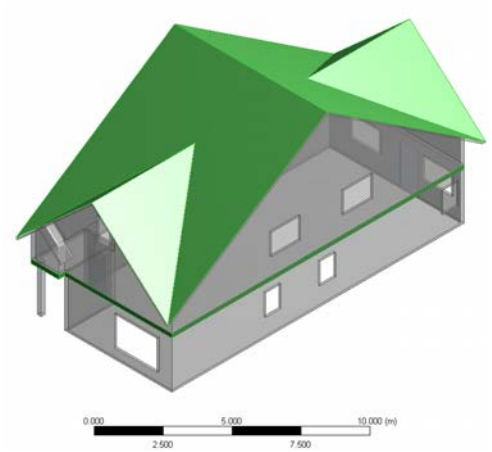
O.H. Hinsdale Wave Research Laboratory
Oregon State University, Corvallis OR.

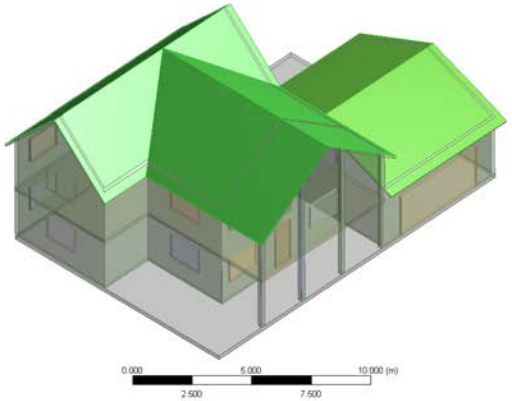
Summer 2018

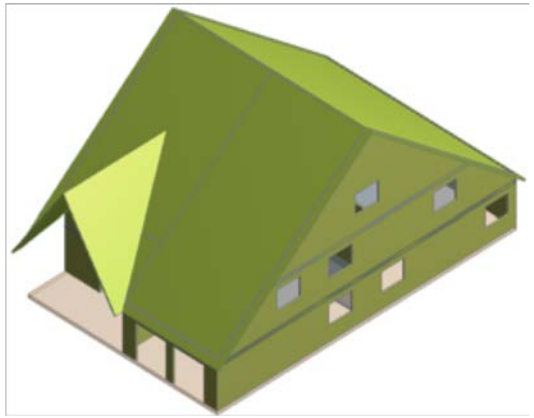


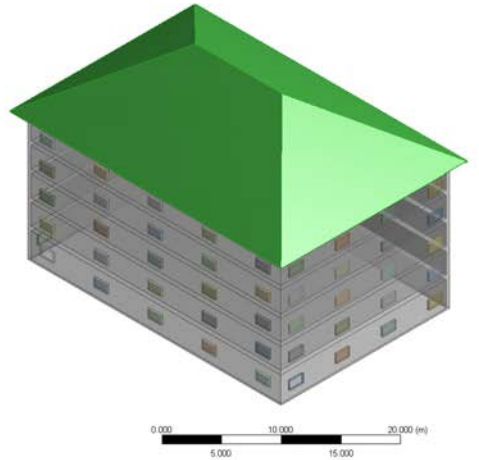
- OSU
- University of Puerto Rico
- California Polytechnic State Univ.
- Hanyang University (Korea)
- Tokyo University of Marine Science and Technology (Japan)

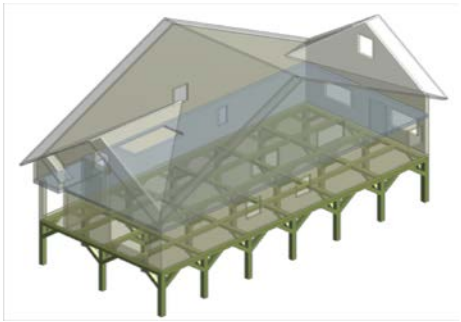
Fragility development for four building archetypes

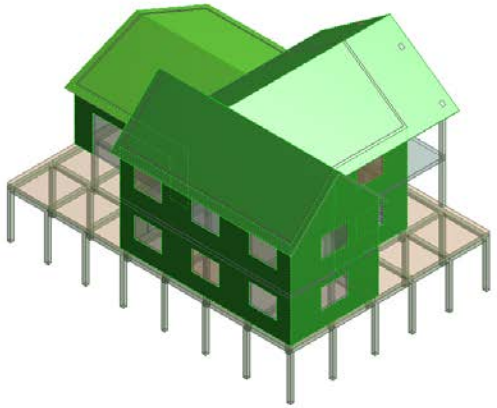


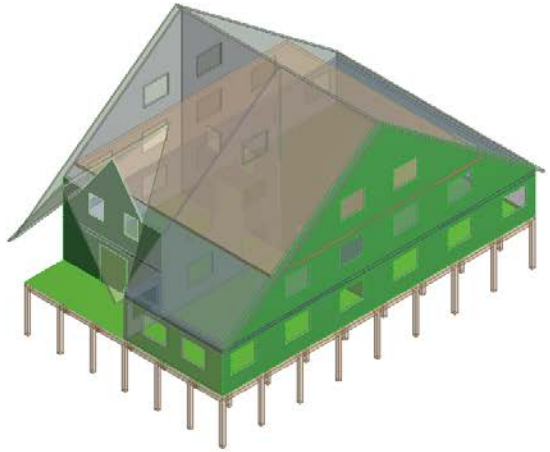


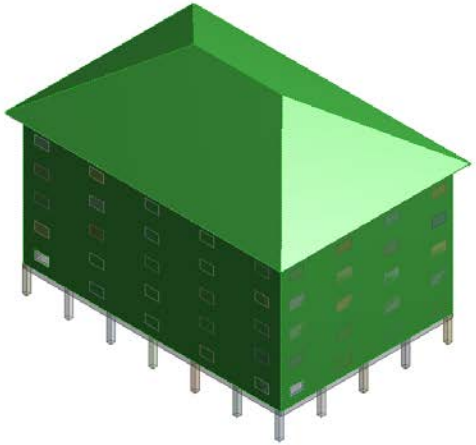










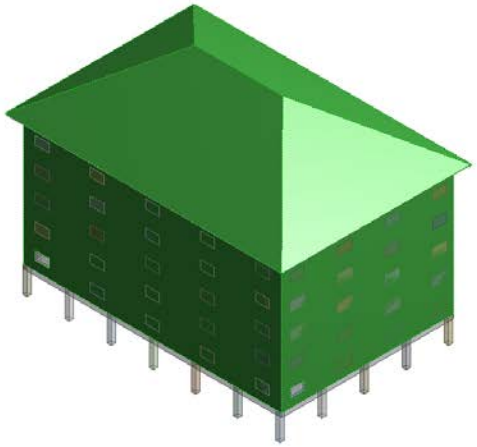


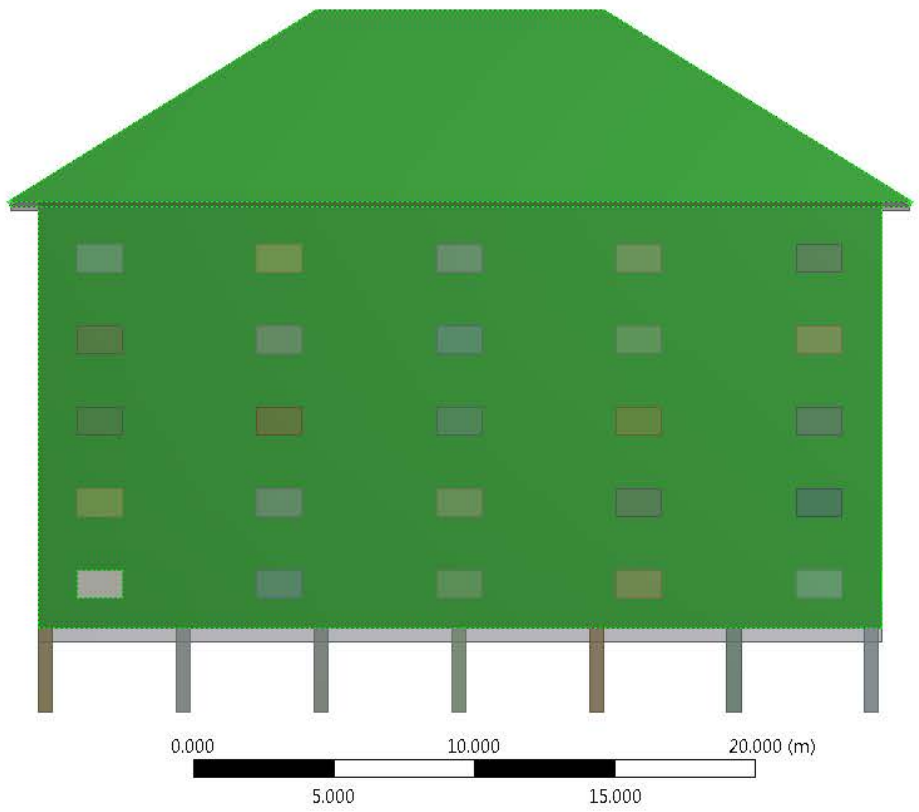
Achetype 1
1-story small house
1200 sqft

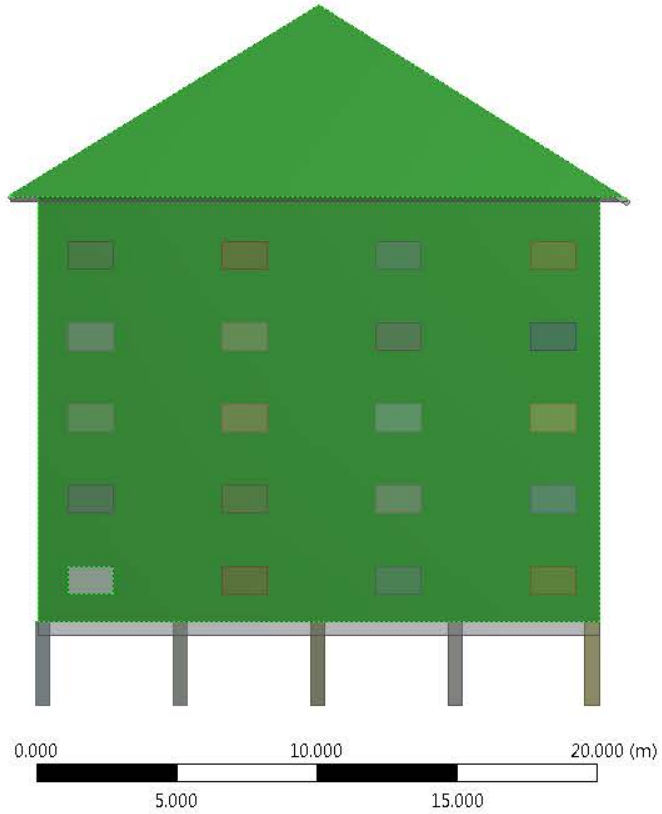
Achetype 2
2-story regular house
2000 sqft

Achetype 3
2-story large house
2800 sqft

Achetype 4
5-story apartment complex

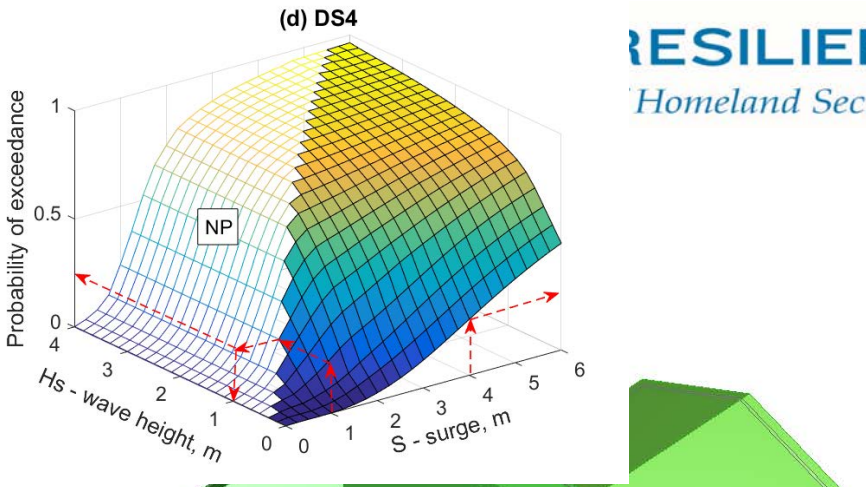


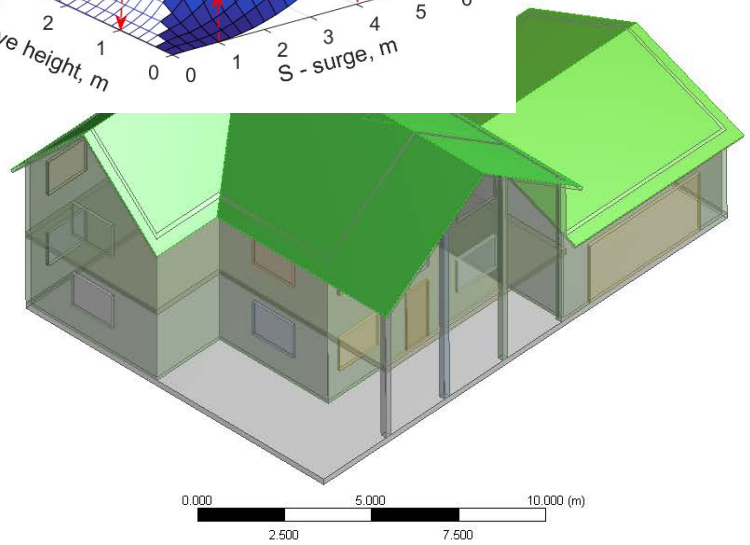




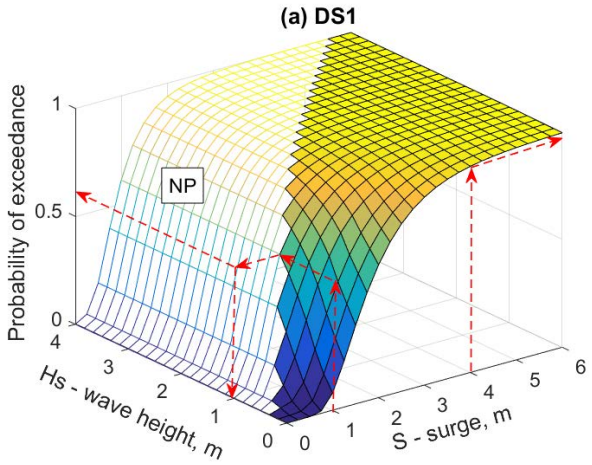
Achetype 4
5-story apartment complex

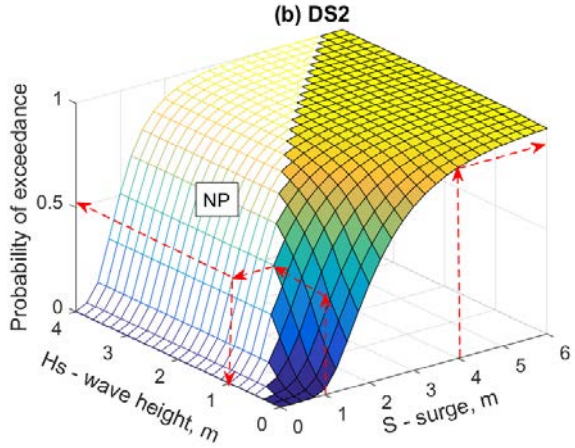
Fragility surfaces for components damage

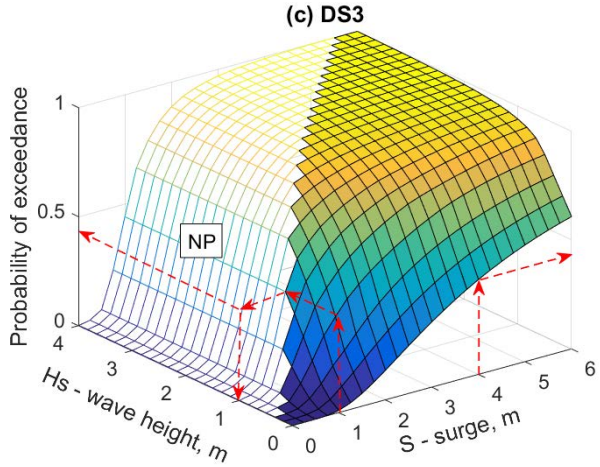


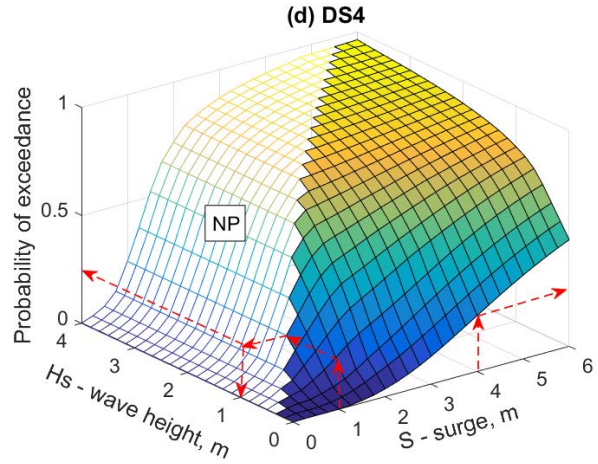


Achetype 2
2-story regular house
2000 sqft



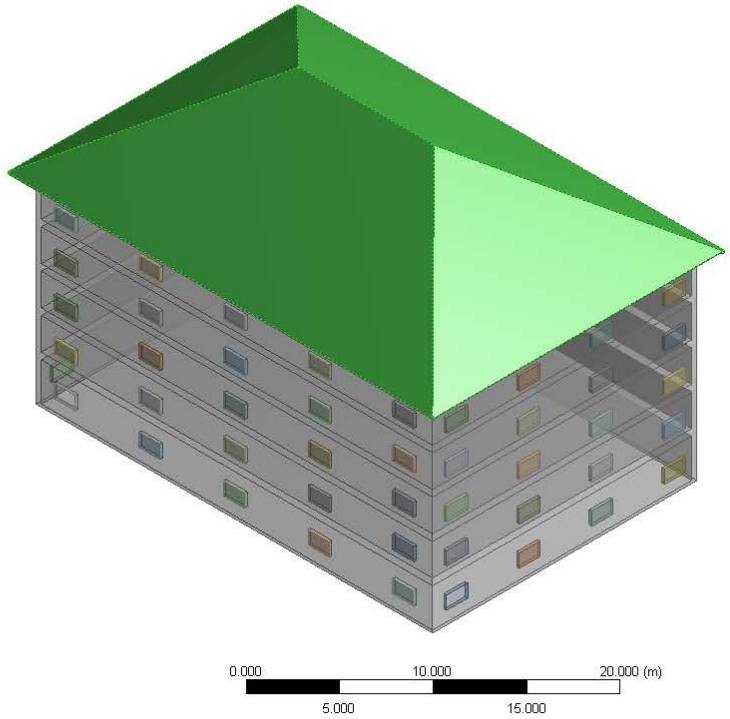




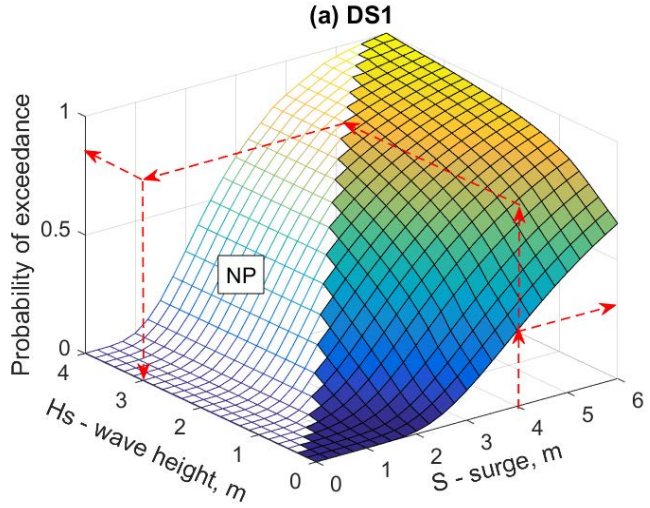


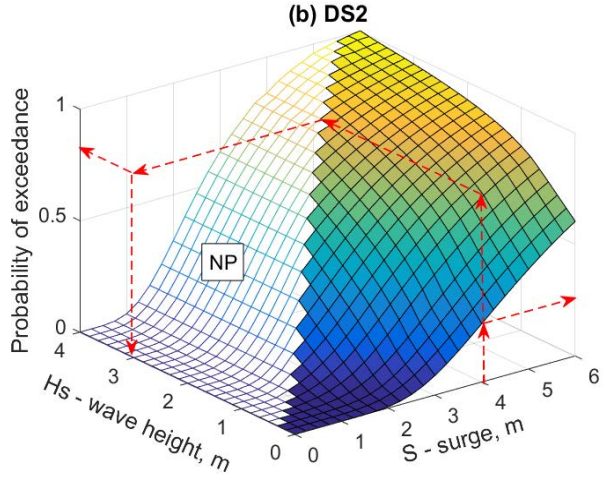
NP = Not Possible combination of $\boldsymbol{H_s - S}$

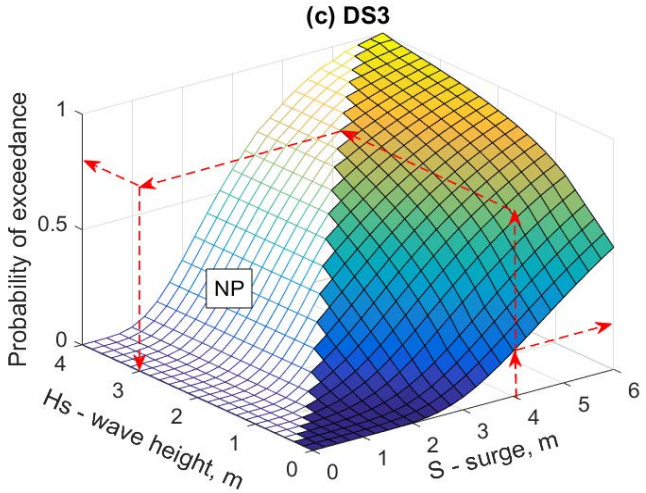
Fragility surfaces for components damage

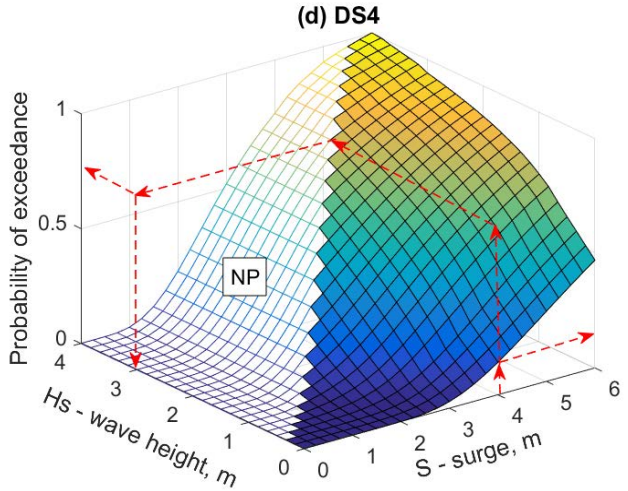


Achetype 4
5-story apartment complex









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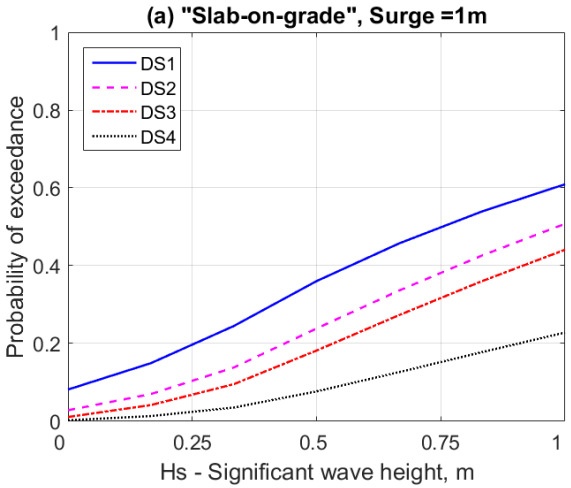
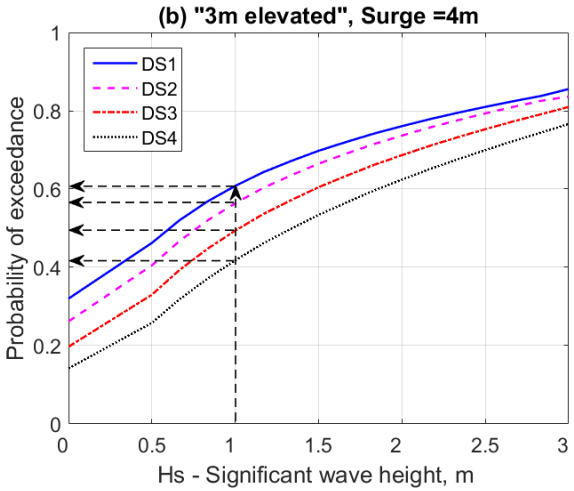
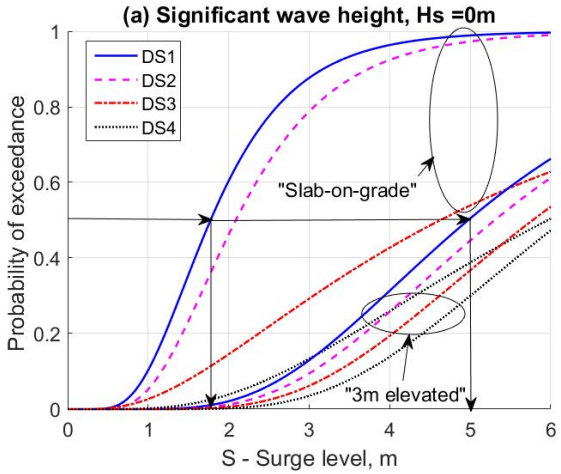
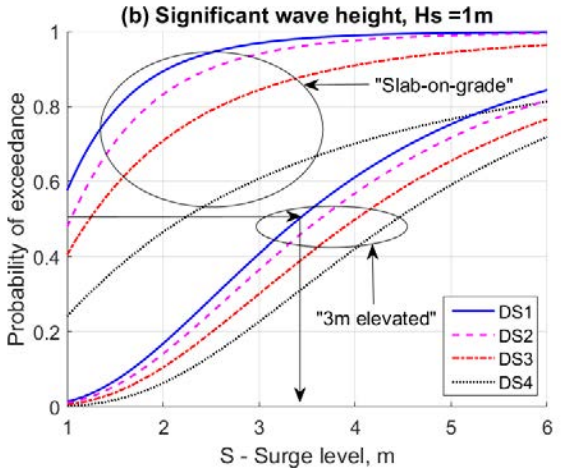


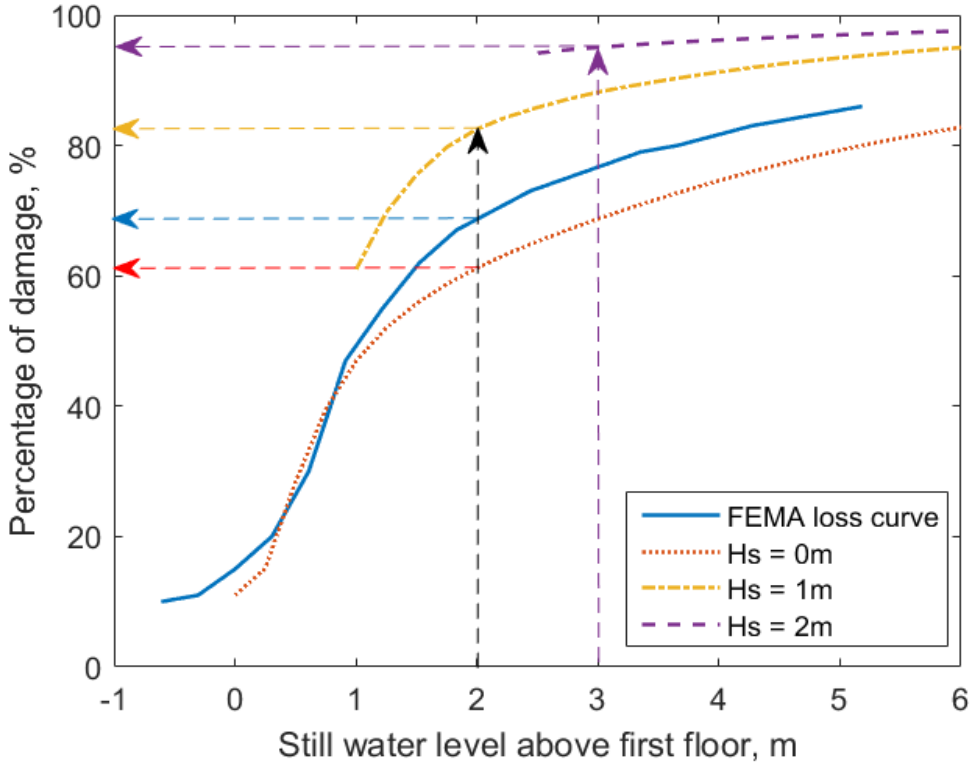


Fragility curve for some specific surge levels



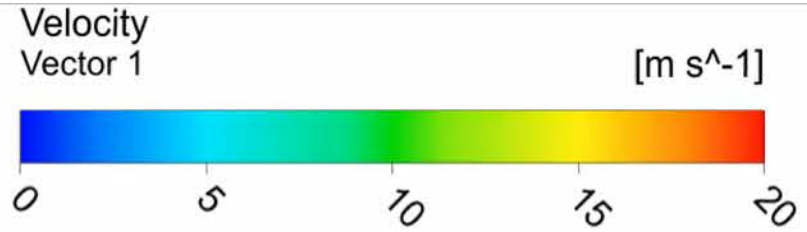


Fragility curve for some specific significant wave heights

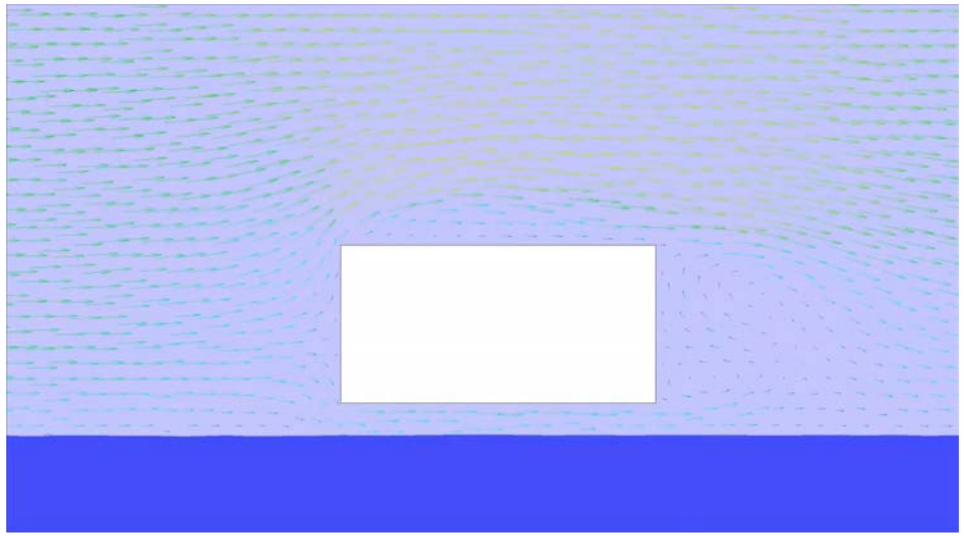


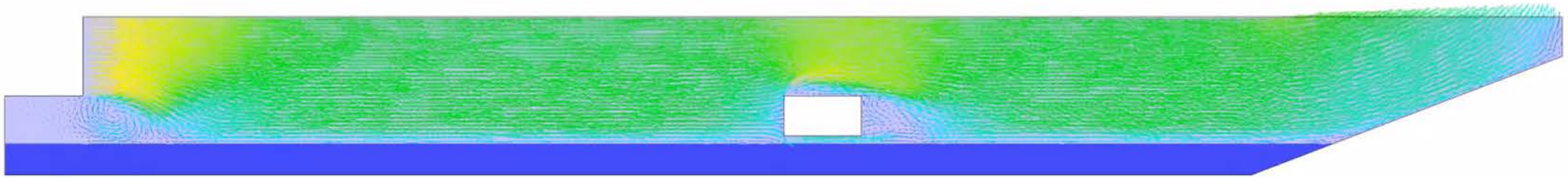
Comparison of total loss to FEMA cost damage estimator for a single-family dwelling at coastal V-zone, no obstruction

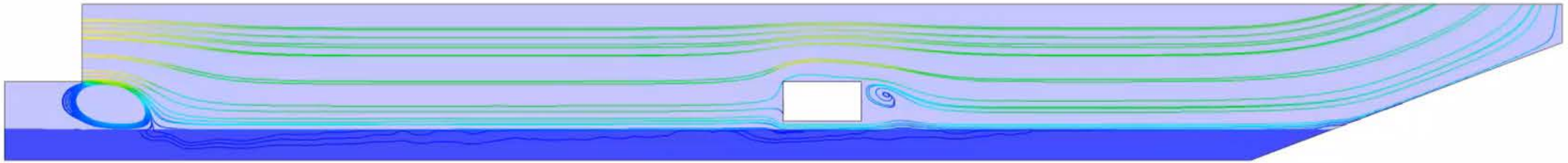
Propose for a combine wind, wave, and surge in a wind-wave flume



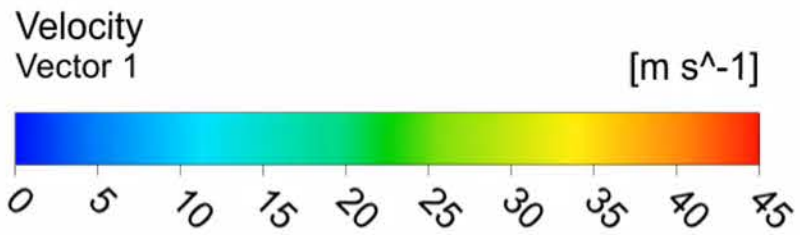
Wind speed = 15 m/s,
Wave=0.2m, Surge= 0.4m



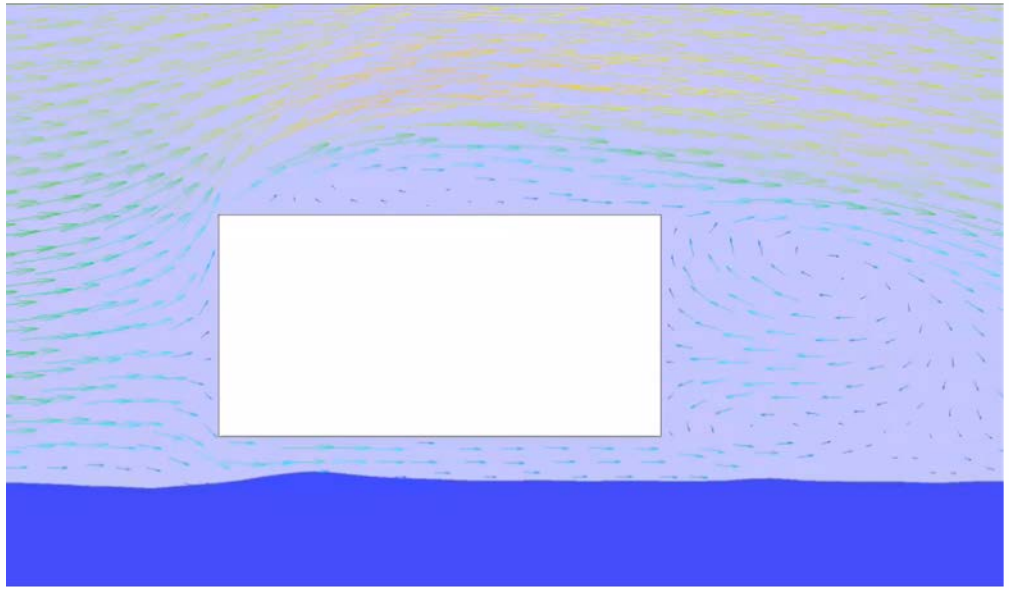


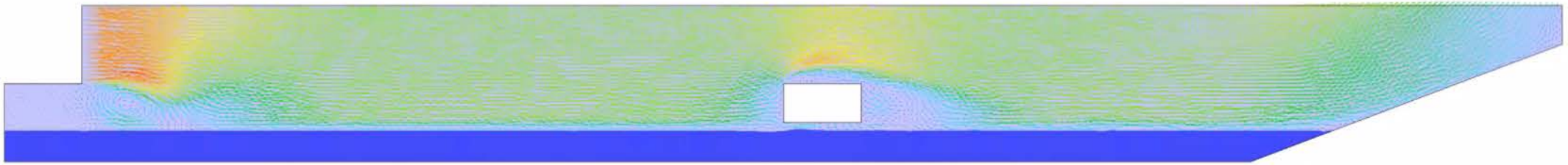


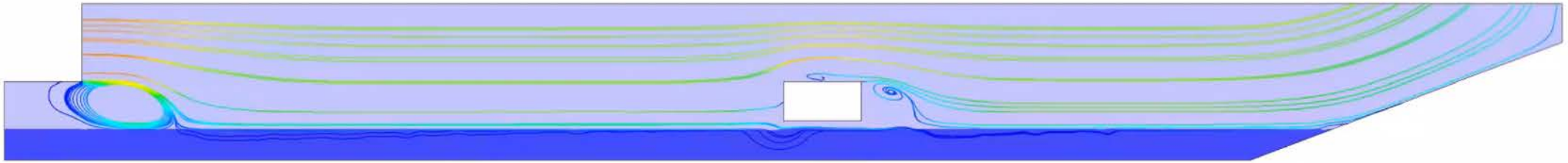
Propose for a combine wind, wave, and surge in a wind-wave flume



Wind speed = 40 m/s,
Wave=0.2m, Surge= 0.4m







Some reviewer comments from "Hurricane Surge-Wave Building Fragility Methodology for Use in Damage, Loss, and Resilience Analysis"
by T. Do, J.W. van de Lindt, and D.T. Cox

ASCE Journal of Structural Engineering

- Addition of hydrodynamic forces is a welcome advance for fragilities
- Should not be limited to just HAZUS
- How can fragility surfaces be incorporated into HAZUS ?

References

Peer reviewed papers

1. Do, T., van de Lindt, J.W., Cox, D.T. "Hurricane Surge-Wave Building Fragility Methodology for Use with HAZUS-MH," *J Structural Engineering* **(submitted 2/2018)**
2. Park, H., Do, T., Tomiczek, T., Cox, D.T., van de Lindt, J.W. "Numerical Modeling of Non-breaking, Impulsive Breaking, and Broken Wave Interaction with Elevated Coastal Structures: Laboratory Validation and Inter-Model Comparisons," *Ocean Engineering* (***submitted 1/2018***)
3. Tomiczek, T., Wyman, A., Park, H., Cox, D.T. "Application and Modification of Goda's Formulae to Estimate Horizontal and Vertical Forces on Elevated Coastal Structures. Part 1: Nonbreaking Waves," *Coastal Engineering* (***submitted 8/2017***)
4. Tomiczek, T., Park, H., Cox, D.T., van de Lindt, J.W., Lomonaco, P. (2017) "Experimental Modeling of Horizontal and Vertical Wave Forces on an Elevated Coastal Structure," *Coastal Engineering*, 128, 58-74.
5. Do, Trung, van de Lindt, J., Cox, D.T. (2016) "Performance-Based Design Methodology for Inundated Elevated Coastal Structures Subjected to Wave Load Engineering Structures," *Engineering Structures*, 117, 250 – 262.

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6. Do, T., van de Lindt, J.W., Cox, D.T. (2018) "Physic-Based Component Fragility Model for Near-Coast Residential Wood Building Subjected to Hurricane Wave and Surge" Engineering Mechanics Institute Conference 2018, Cambridge MA (abstract submitted).
7. Park, H., Do, T., Tomiczek, T., Cox, D., van de Lindt, J.W. (2018) "Laboratory Validation and Inter-Model Comparisons of Non-breaking, Impulsive Breaking, and Broken Wave Interaction with Elevated Coastal Structures using IHFOAM and FLUENT," *International Conference on Coastal Engineering*, ASCE. (abstract accepted).
8. Tomiczek, T., Wyman, A., Park, H., Cox, D.T. (2018) "Application and modification of Goda Formulae for Non-impulsive Wave Forces on Elevated Coastal Structures," *International Conference on Coastal Engineering*, ASCE. (abstract accepted).