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The State of the Art and Science of Coastal Engineering

Experimental modeling of wave forces and hydrodynamics on elevated coastal structures subject to waves, surge or tsunamis: the effect of breaking, shielding and debris

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Introduction

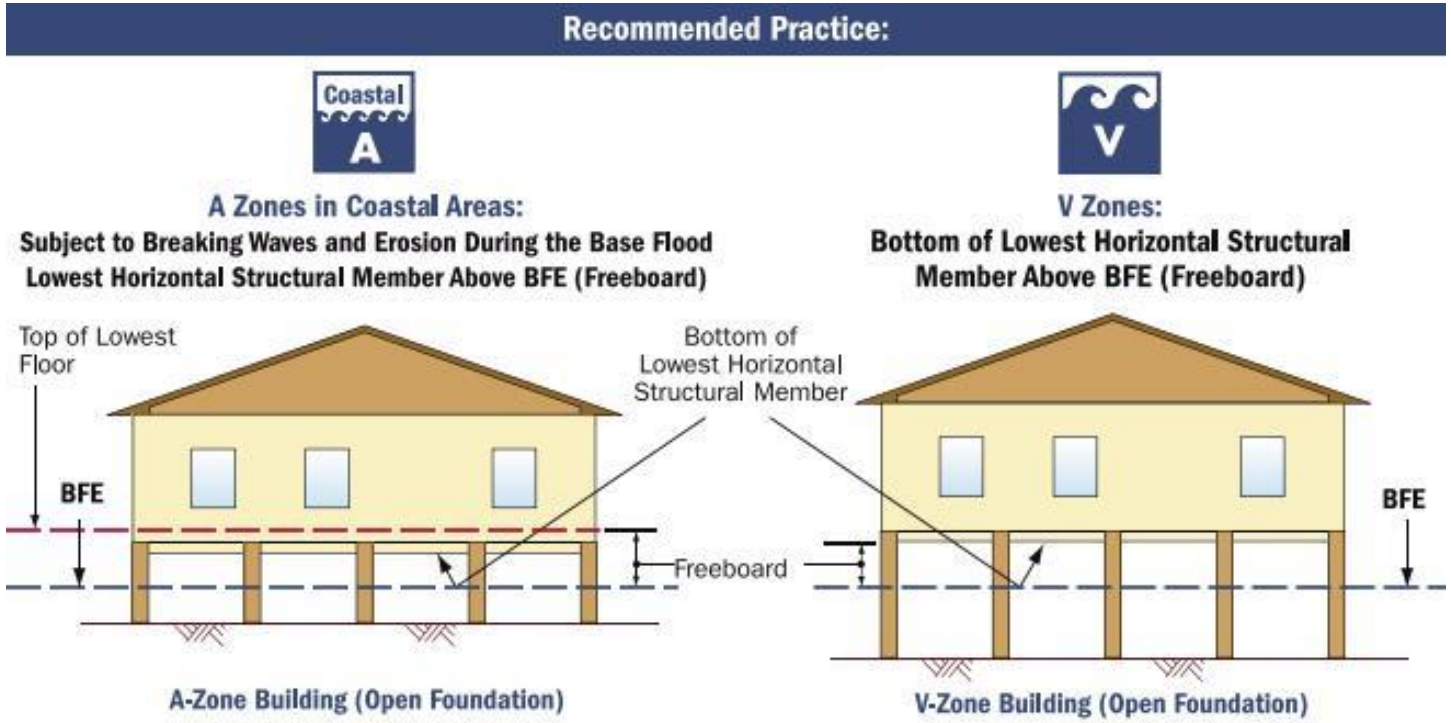
What is an elevated coastal structure?

Introduction

Why are they designed and build like this?

Introduction

Building codes and recommendations (FEMA, ASCE 7, Local codes, …)



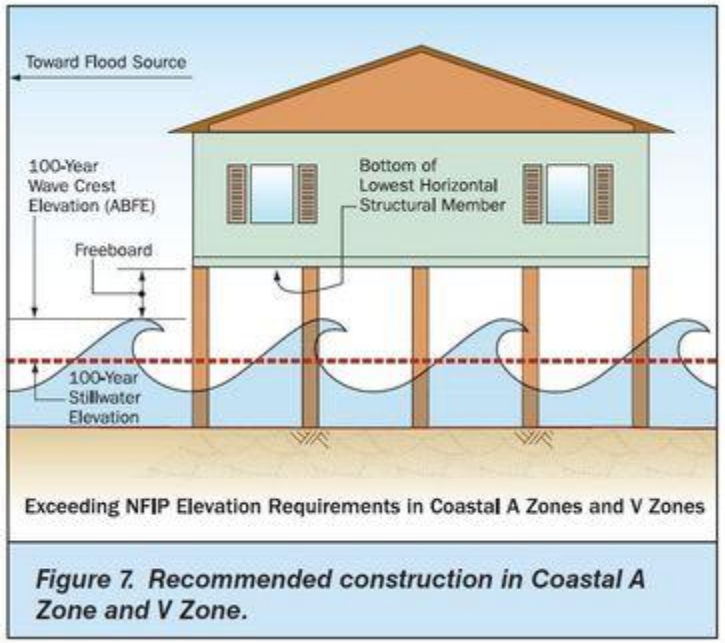


Figure 7. Recommended construction in Coastal A Zone and V Zone.

Introduction

Natural Hazards affecting Elevated Coastal Structures:

- Storm surge -> storm waves
- Earthquakes -> Tsunamis
- Wind
- Climate change
  - Sea level rise
  - Increase storm strength
  - Increased frequency

Photographs by Tori Tomiczek

Introduction

Scientific interest in understanding:

Actions

- Effect of storm surge: water level v.s. structure elevation (air gap)
- Effect of (short) waves at limited depth:
  - Broken waves
  - Breaking waves
  - Non-breaking waves
- Extreme events: Tsunamis
  - Broken bore
  - Breaking first impact
  - Non-breaking wave

Structural response

- Fragility and resilience
- Interaction with other structures (shielding)
- Debris impact
- Scour and liquefaction
- Etc.

The study

Modeling of wave forces and hydrodynamics on elevated coastal structures subject to waves, surge or tsunamis: the effect of breaking, shielding and debris

- Study on the impact forces of storm waves and tsunami-like waves on elevated coastal structures (Park et al., 2017; Tomiczek et al. 2018 – ICCE; Alam et al., in preparation)
- Effect of other structures on flow changes (shielding) – (Winter et al., in preparation)
- Impact forces on waterborne debris under Tsunami-like waves (Shekhar et al., in preparation)

Approach:

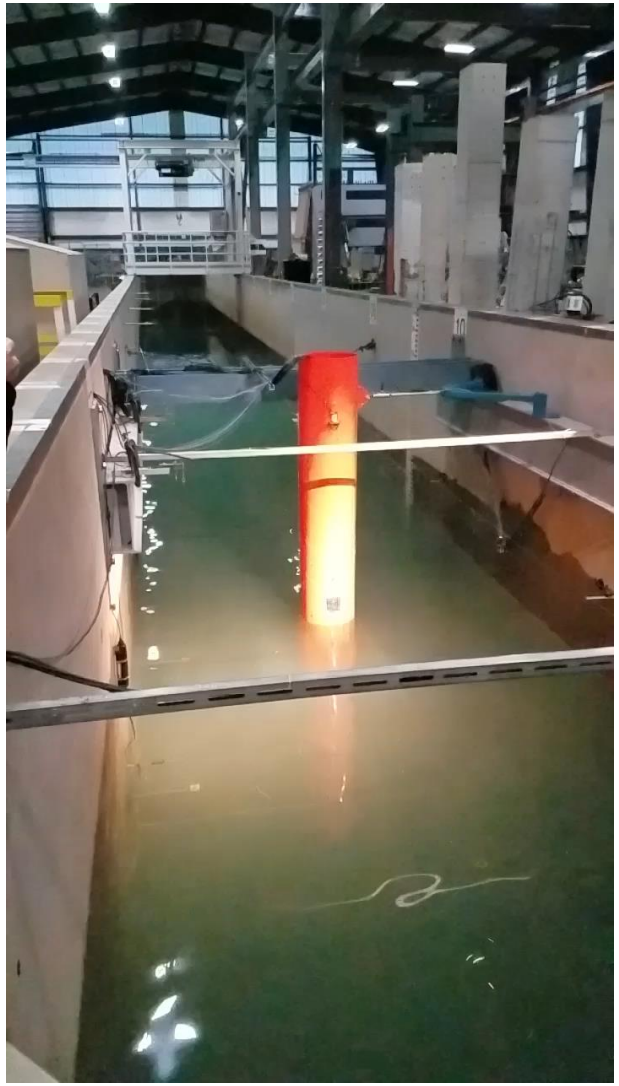
Physical modelling: extensive experimental campaign

Numerical modelling: detailed hydrodynamics (Park et al., 2017, 2018a, 2018b – ICCE)

Structural modelling: stress and deformation for design

Transport of large scale floating bodies: waterborne debris

Experiments conducted at the Large Wave Flume (LWF) at Hinsdale Wave Research Laboratory (HWRL), Oregon State University



Test Facility and Flume Bathymetry

HWRL Large Wave Flume, OSU

104 m long, 3.7 m wide, 4.6 m deep (max depth 2.7 m for wind waves)

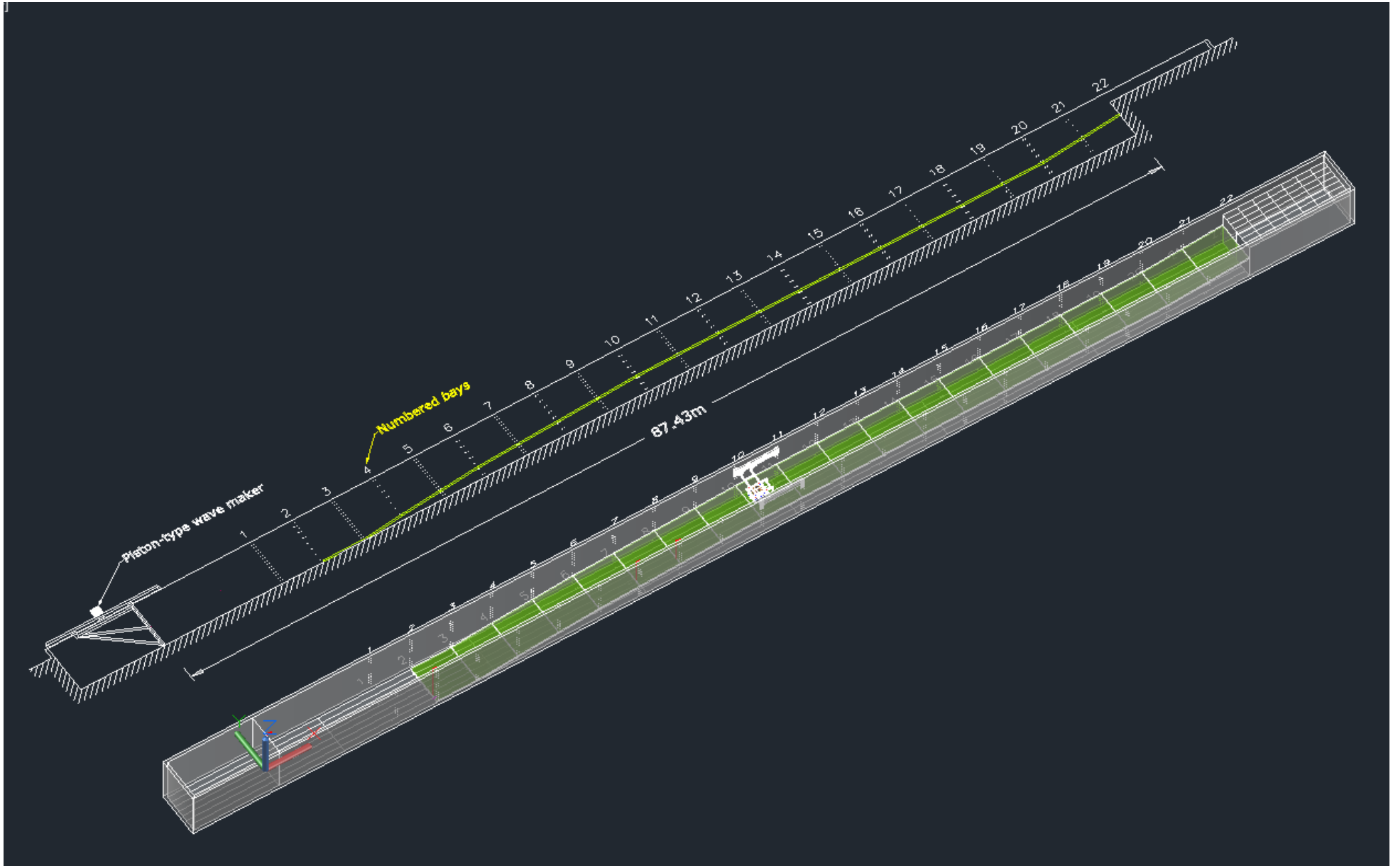
Piston-type, dry-back, 4.2 m stroke wave maker

One of the Experimental Facilities at OSU part of the NSF NHERI Program (prevent natural hazards from becoming societal disasters, i.e. earthquake, tsunami, hurricane, storm waves, wind, surge, overland flow, flooding,…).

Study sponsored by the National Science Foundation (NSF) and the U.S. Department of Homeland Security (USDHS).

Impact forces on offshore wind turbines by breaking waves
NSF NHERI – Dr. Andrew Myers, Northeastern University

Experimental design (concept)

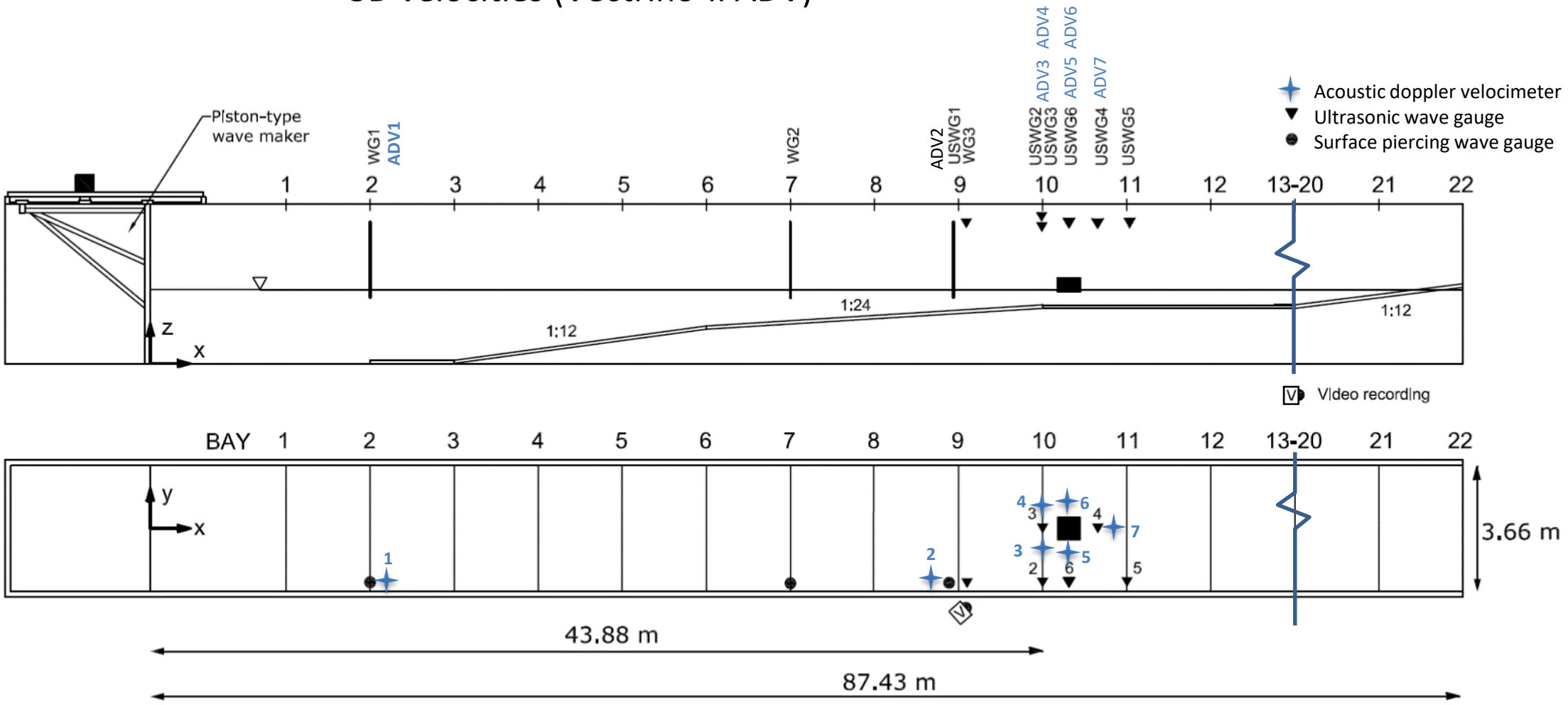


Measurements:

Hydrodynamics

Surface elevations (resistive wave gauges)

3D velocities (Vectrino-II ADV)



Measurements:

Wave induced-

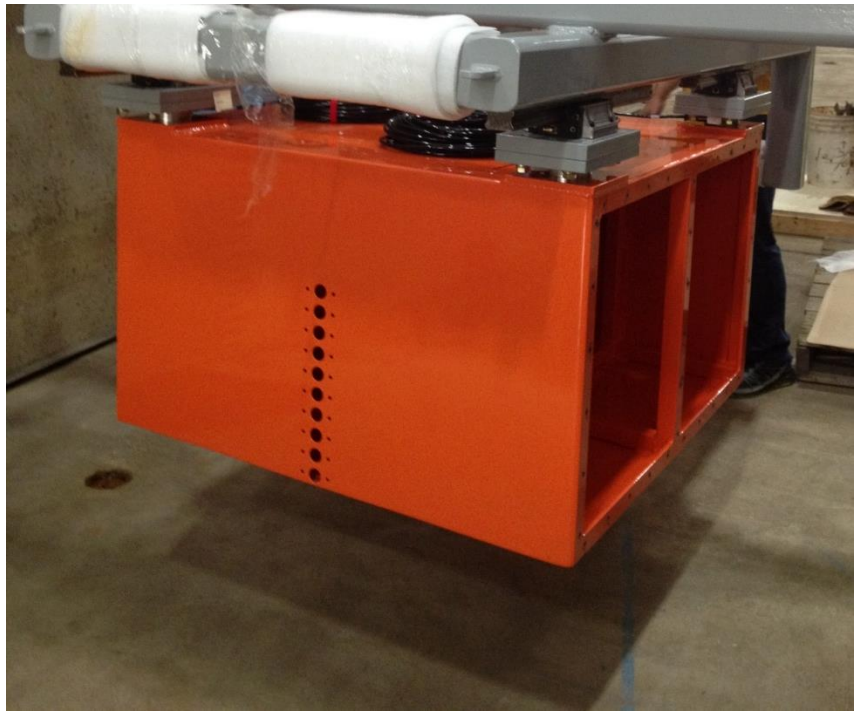
- Dynamic pressures at the structure's faces (DRUCK-PS800)
- Forces on the specimen (Pancake and in-line load cells)
- Accelerations at the structure (Multi-axial PCB-Piezotronics)

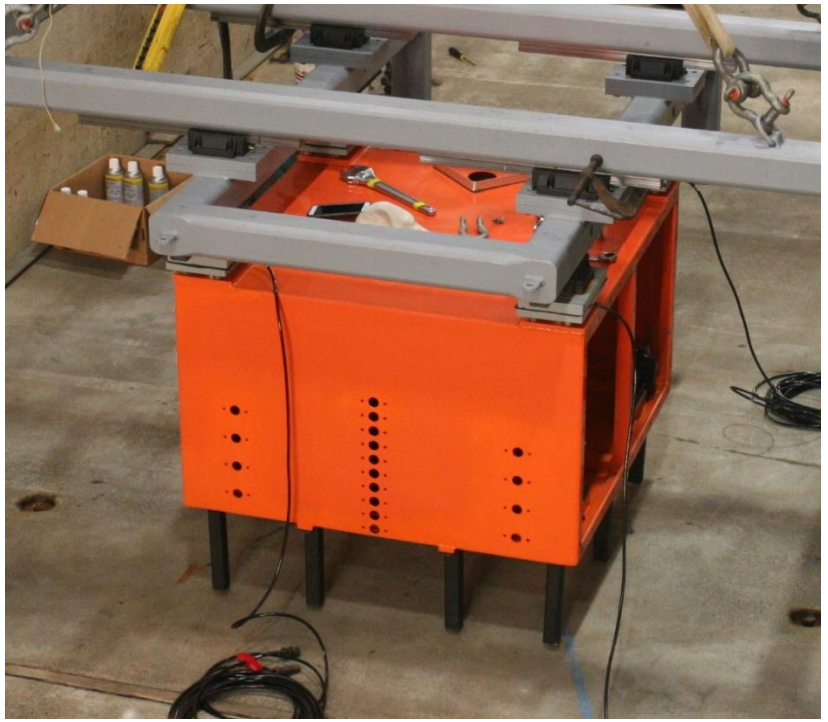
Mechanical properties of

- Specimen (elevated structure) – (Pluck, hammer, static load tests)
- Debris elements – (Swing tests)

Test specimen design and instrumentation

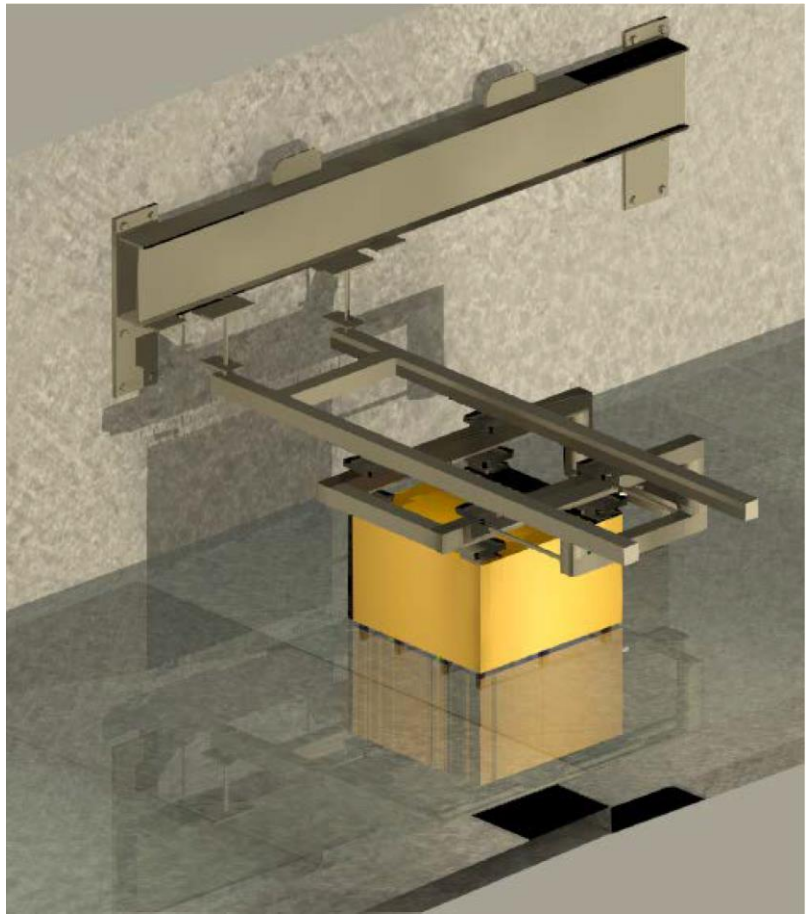
Elevated structure: Rigid steel box, 1 m x 1 m x 0.6 m
12 removable stilts, 4 designed for measuring longitudinal forces
28 pressure taps (18 at front, 2 on each side, 1 at the back, 8 at the bottom)
Connections at the top corners for force measurements
Connections at inside corners for 3-axis accelerometers





Test rig

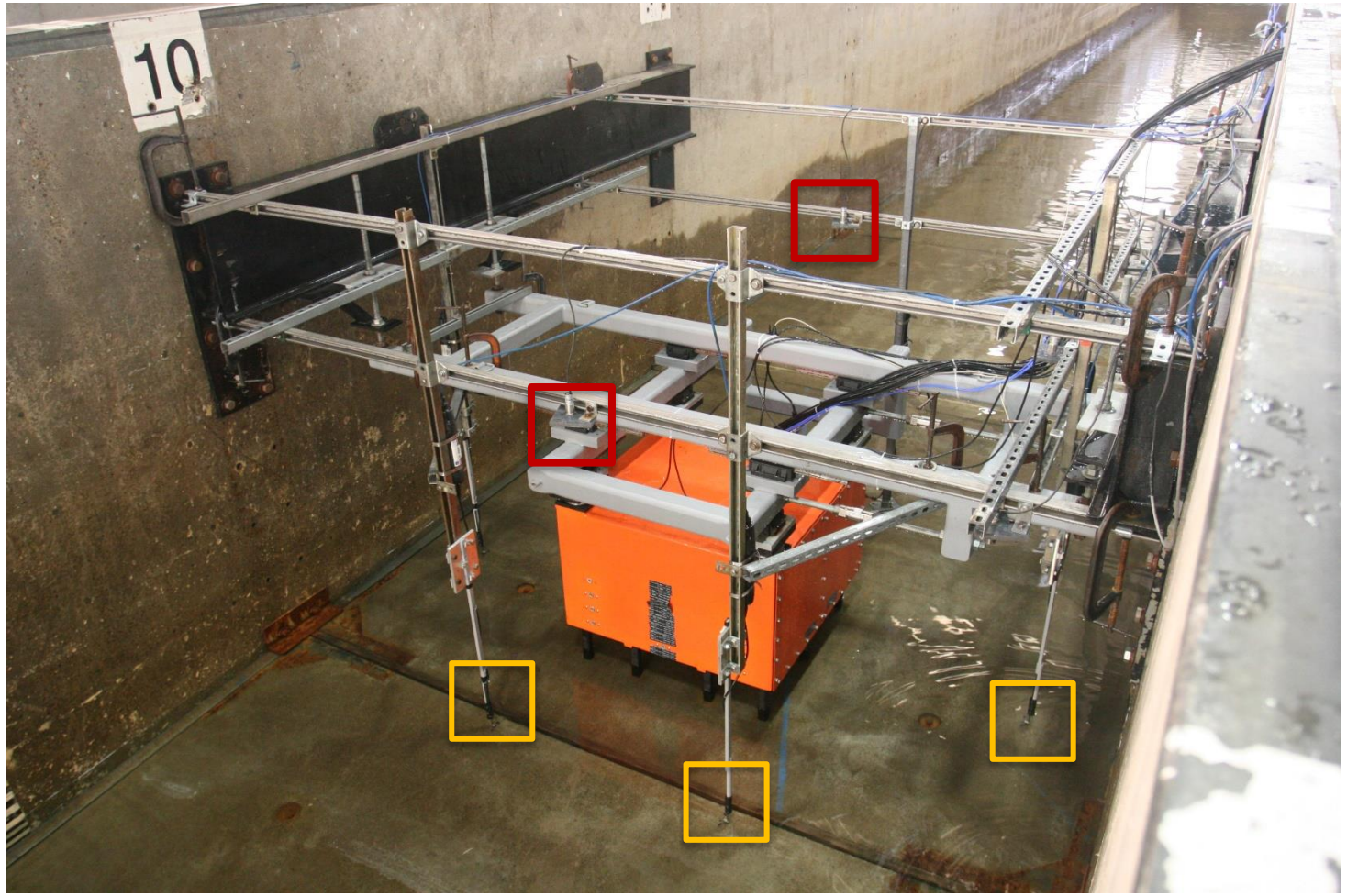
Allows the modification and fixing of the structure's elevation
Designed for measuring longitudinal and lateral forces
Control of stiffness
Low-friction linear rails and bearings



Test specimen design and instrumentation

ADV

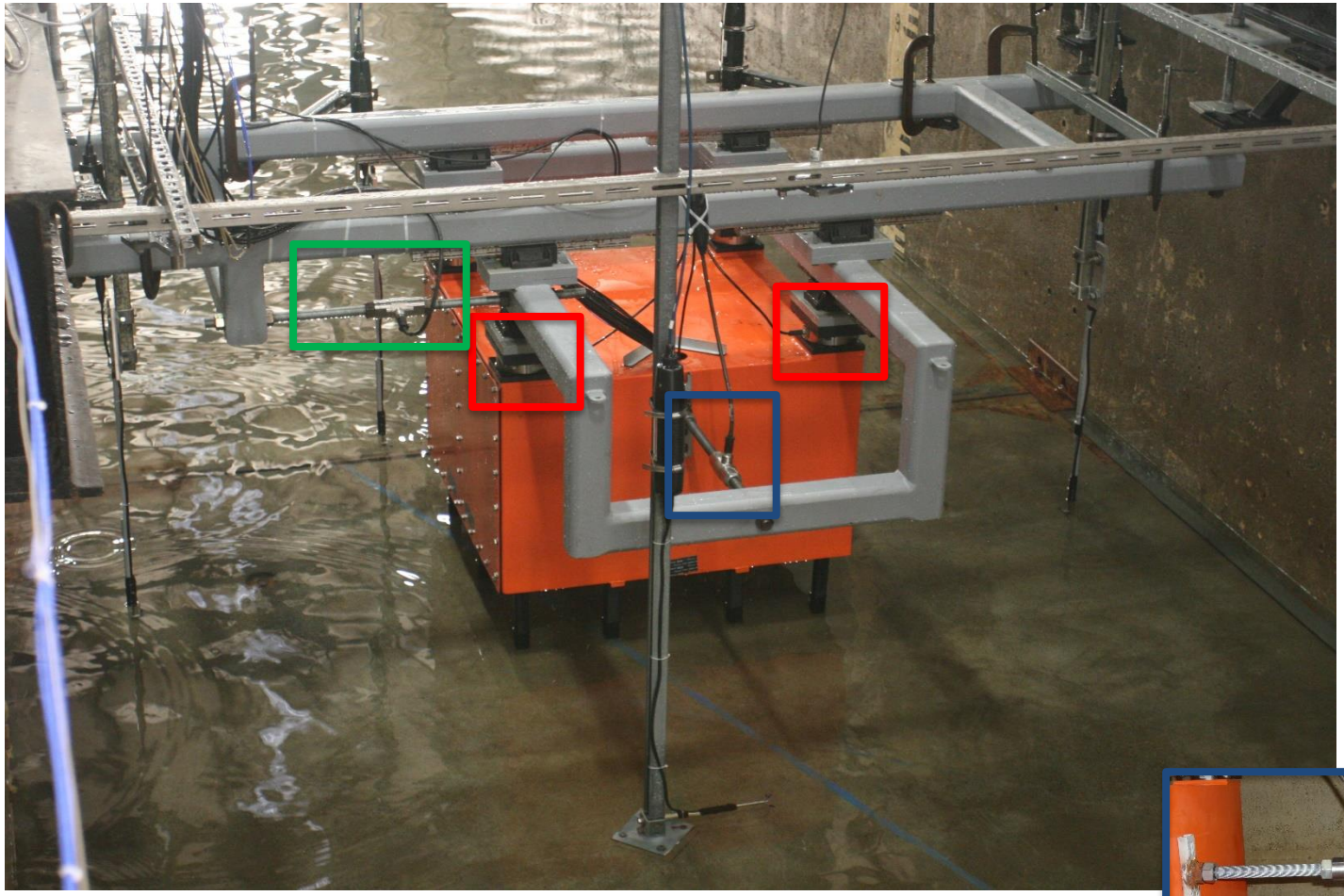
USWG



Front view

Test specimen design and instrumentation

In-line load cell
(for lateral loads)



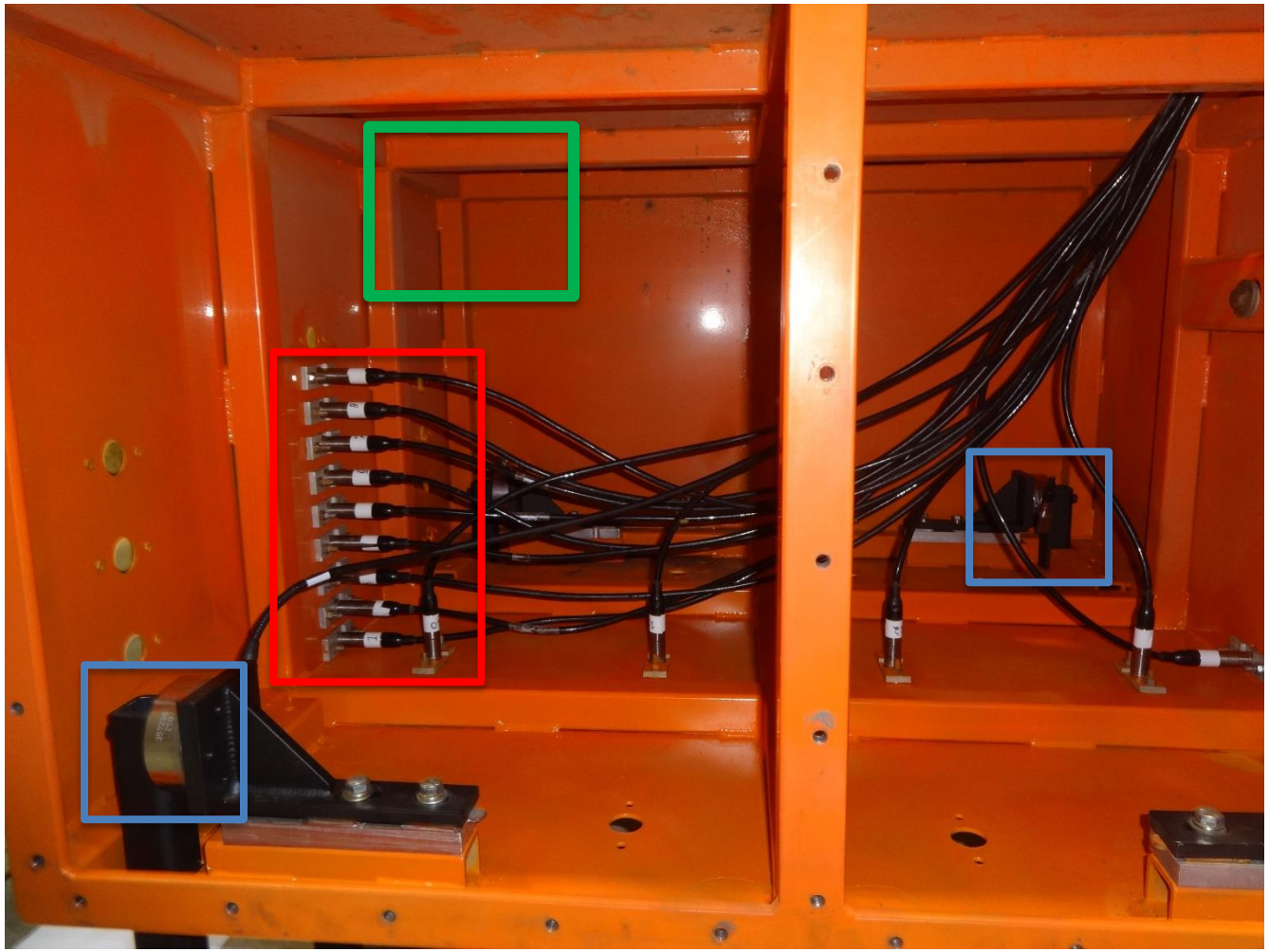
Rear view

Pancake
load cell

In-line load cell
(for longitudinal forces)

Test specimen design and instrumentation

Pressure gauges



Box inside

Accelerometers

Pancake load cell

Test program

- Different wave conditions: short waves and tsunamis
- Effect of wave breaking relative to the structure
- Variations in air-gap (freeboard)
- Relevance of stilts
- 3D Interaction with neighboring buildings (shielding)
- Debris impact forces: (variability of placing, density, damming effects)
- Uncertainty assessment
- Structural response (stiffness control)
- Structural characterization

Testing in **6 phases** (summer of 2016, winter/spring of 2017)
Overall, about 1100 individual tests
Comprehensive database

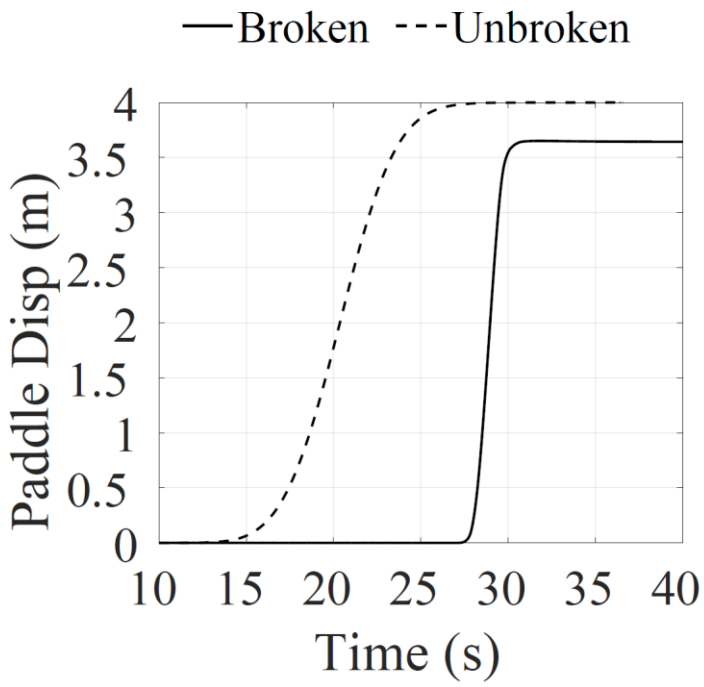
Test program

Phase 1: Wave calibration (undisturbed wave tests)

Measurement of wave conditions in absence of the structure

Identification of the breaking location for short (regular and irregular) and tsunami waves (solitary and transient)

Definition of the specimen location for the next phases

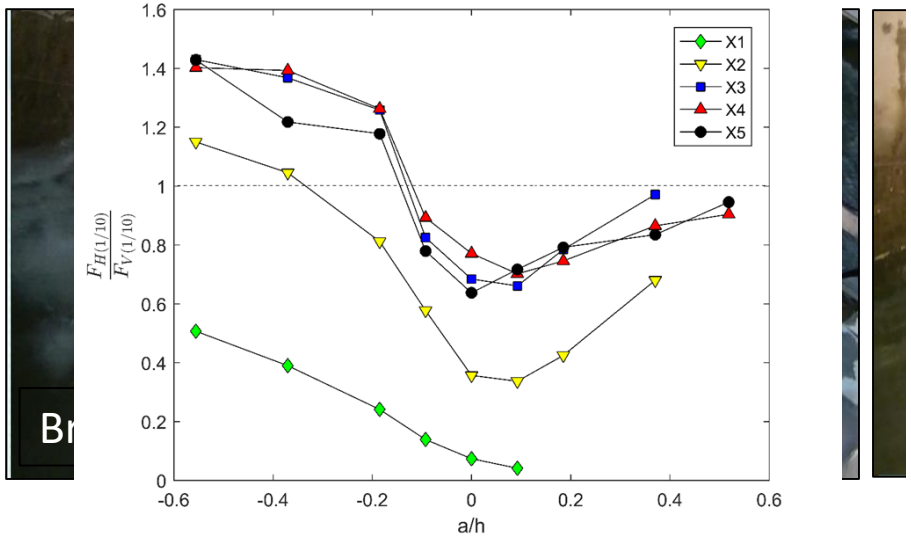


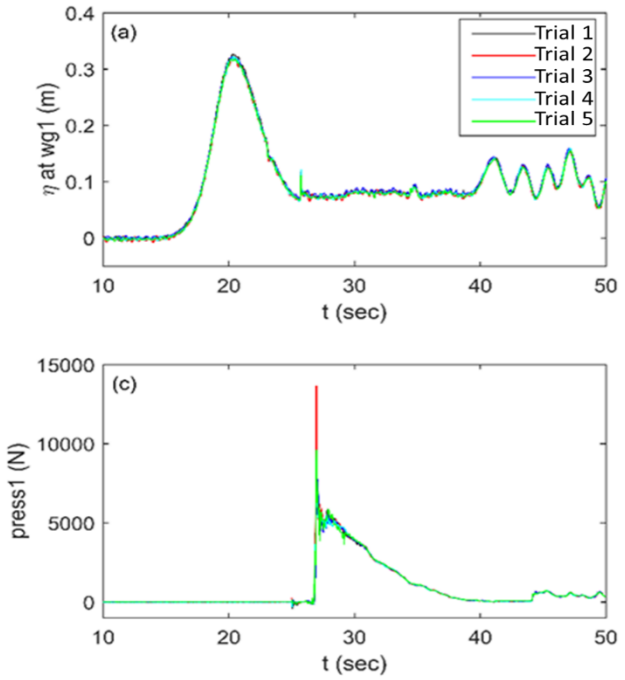
Wave Maker Displacement Time Histories

Test program

Phase 2: Air-gap (Park et al., 2017; Tomiczek et al., 2018)

- Basic specimen and rig
- Short waves and tsunamis
- Variation of relative elevation to the water level (air-gap)
- Surface elevation, pressure along the symmetry axis, vertical and longitudinal forces





Test program

Phase 3: Fixed air-gap (Alam et al., in preparation)

12 stilts, 2 instrumented

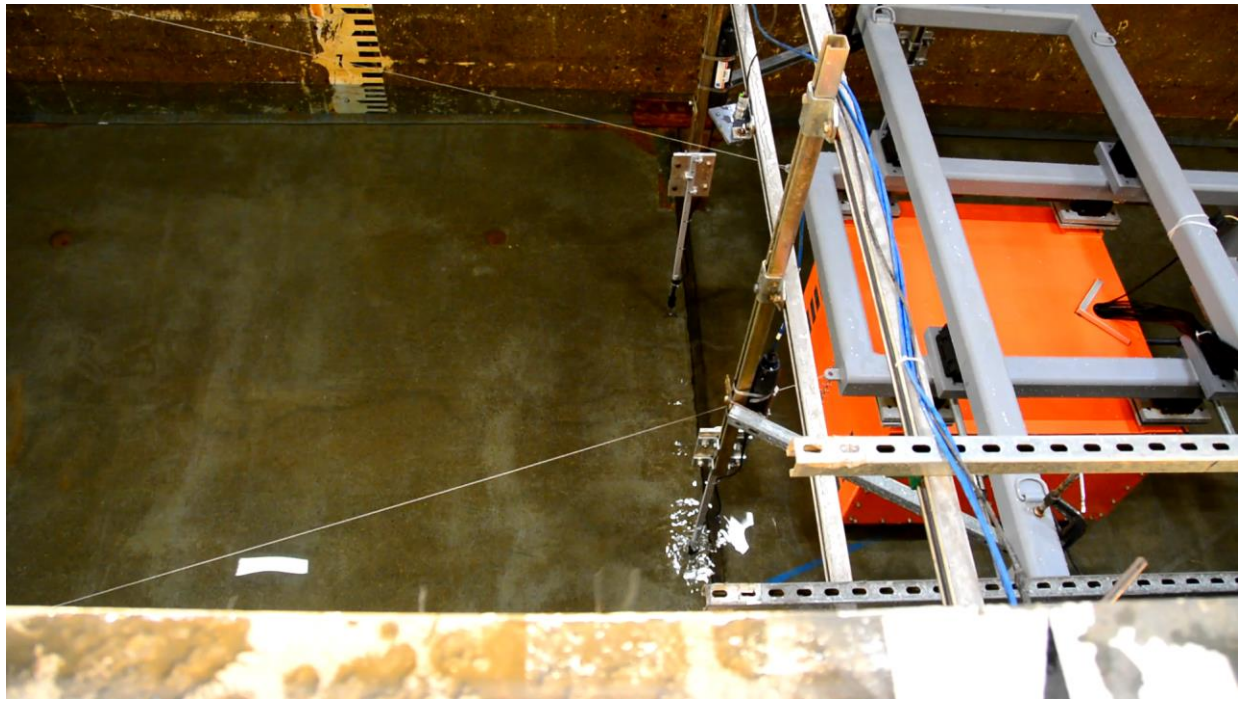
Improved rig and specimen for 3D measurements

Stiffness control

Broken, breaking and non-breaking tsunamis (solitary and transient waves)

Surface elevation, 3D velocities

Pressures on all faces, vertical, longitudinal and lateral forces, structural accelerations



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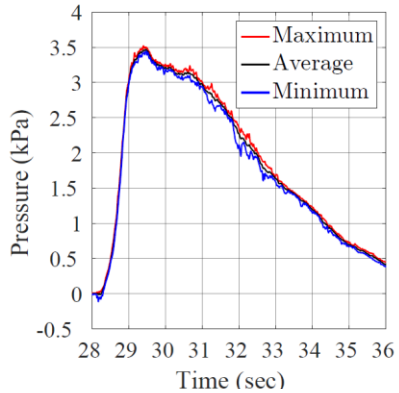
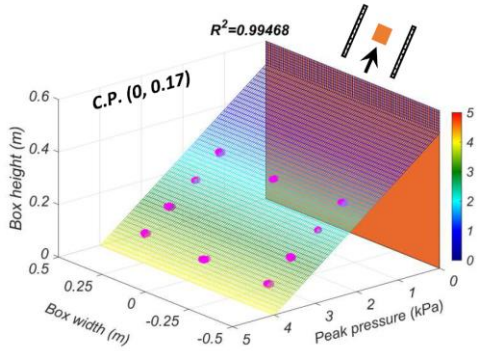
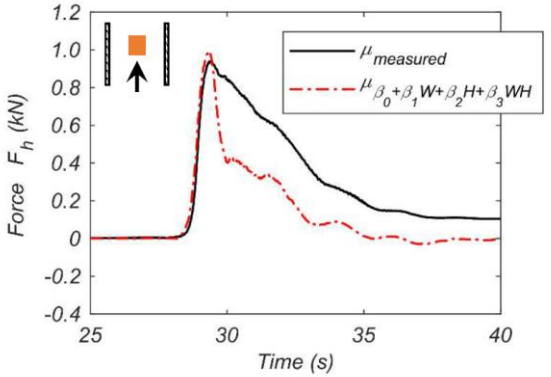
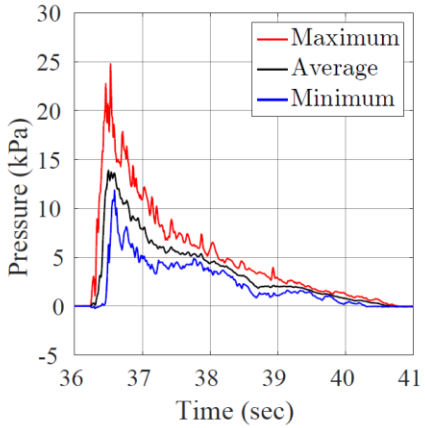
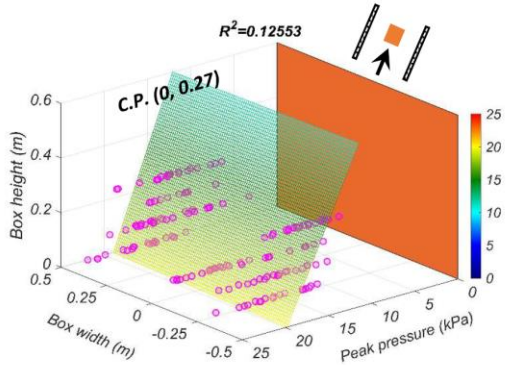
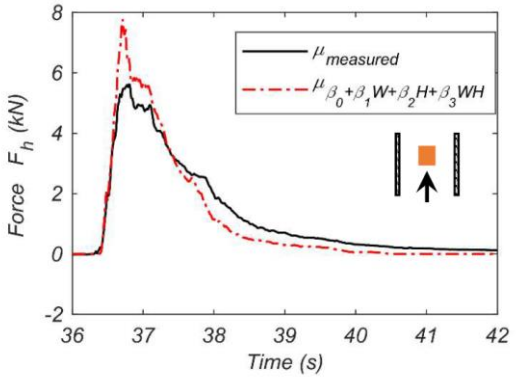












Test program

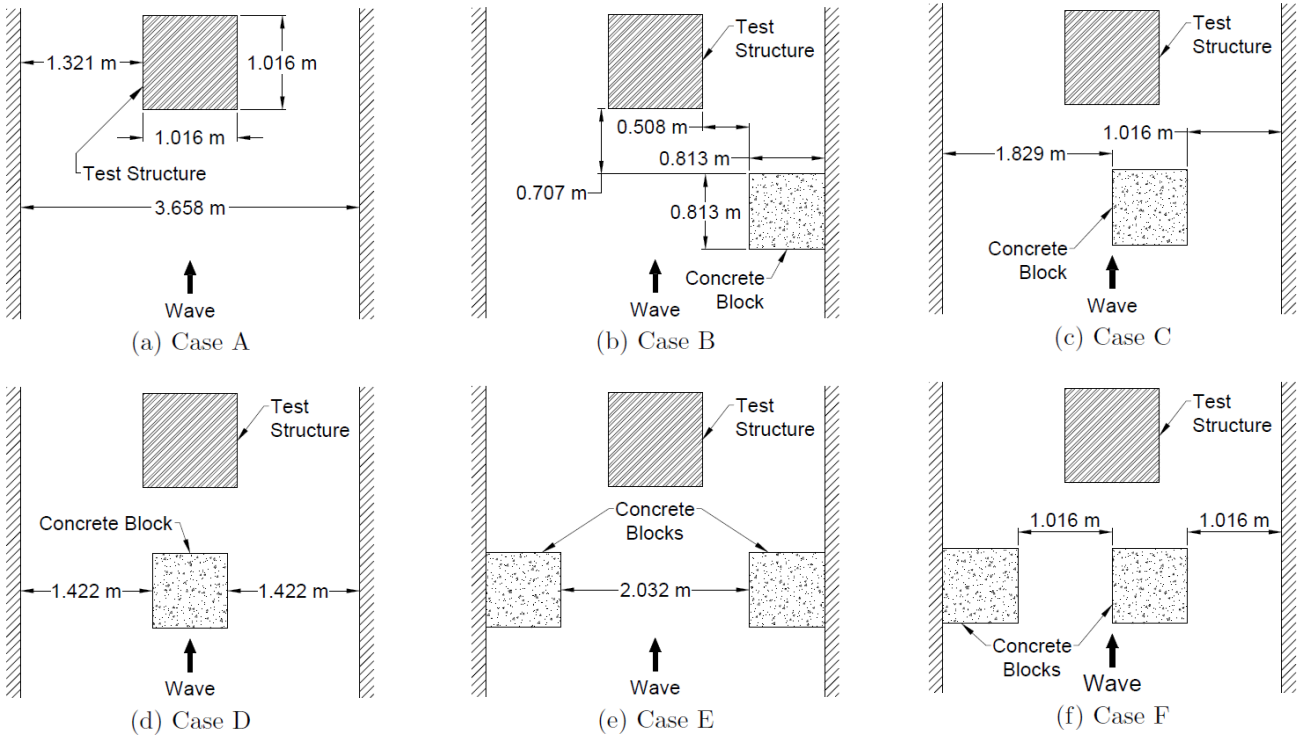
Phase 4: Interaction with neighboring structures (shielding), (Winter et al., in preparation)

3D effects: induced flow asymmetry

Broken, breaking and non-breaking tsunamis (solitary and transient waves)

Surface elevation, 3D velocities

Pressures on all faces, vertical, longitudinal and lateral forces, structural accelerations



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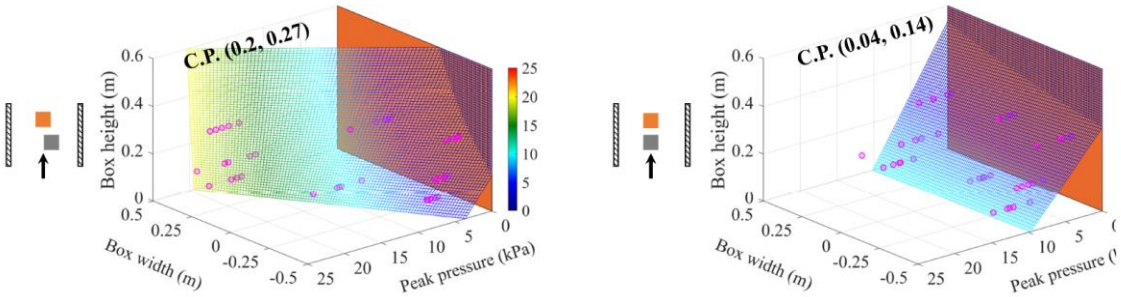
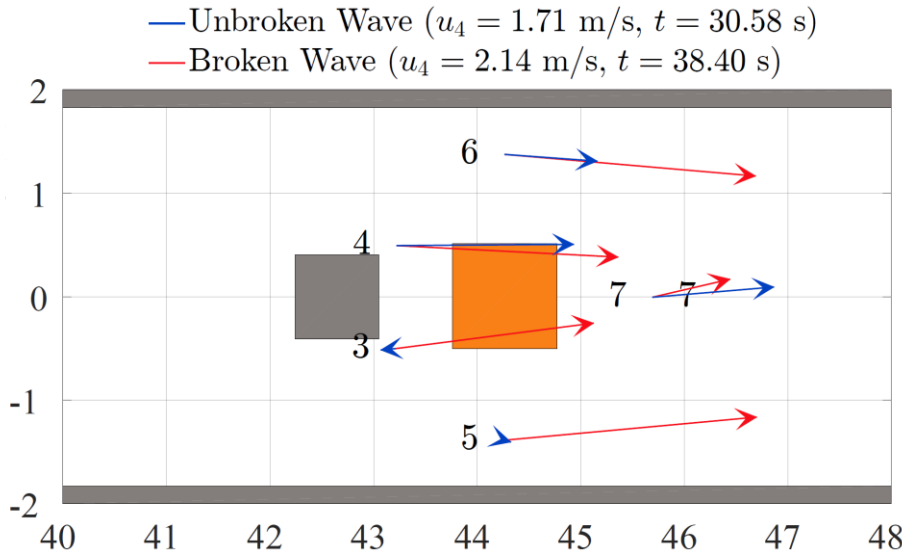
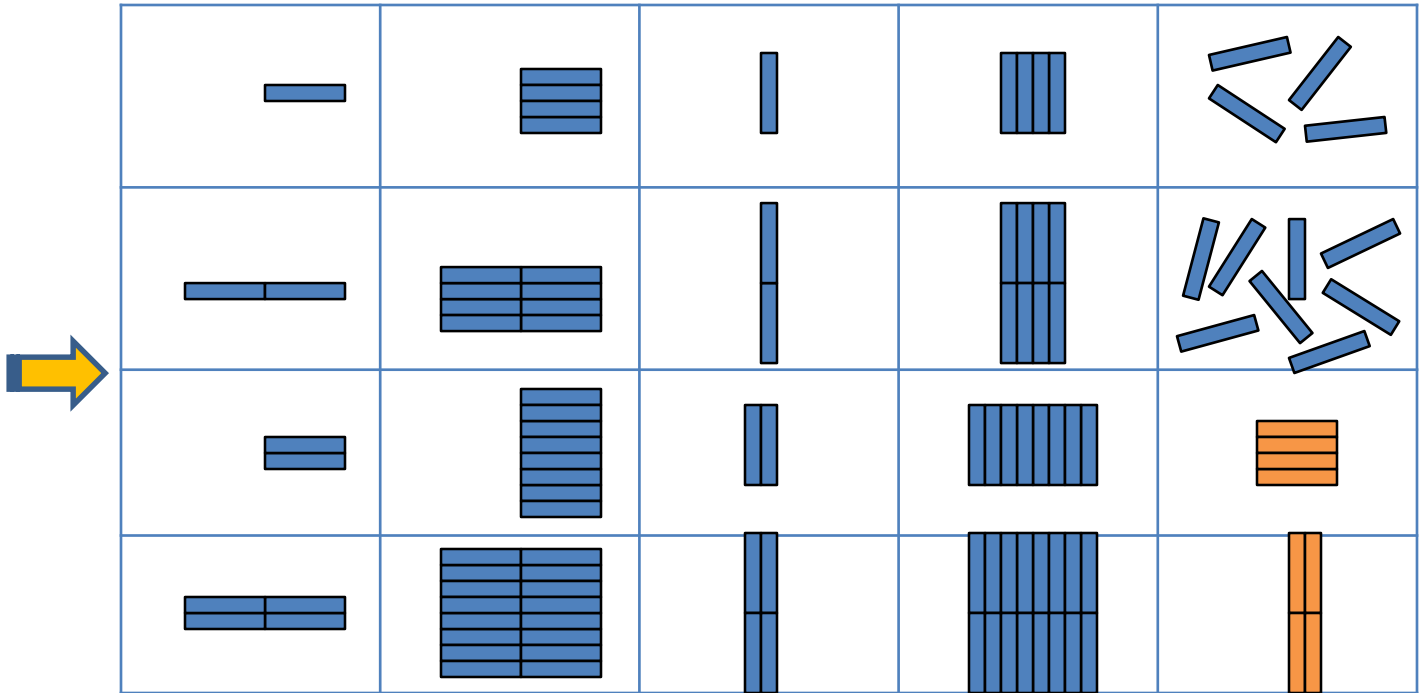




Test program

Phase 5: Debris impact (Shekhar et al., in preparation)

Waterborne debris (non-breaking wave)
Random v.s. regular placing
Probabilistic v.s. deterministic approach
2 types of materials (wood and HDPE) – effect of density and stiffness
Variable number of pieces, different orientations and sizes
Surface elevation, vertical, longitudinal and lateral forces, structural accelerations
Increased sampling rate



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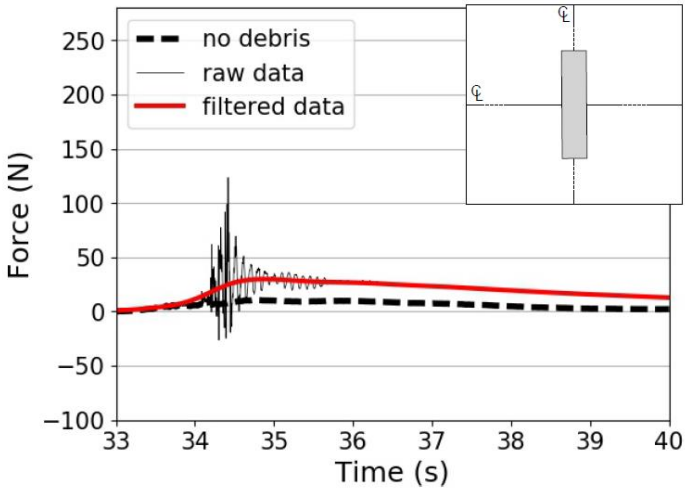
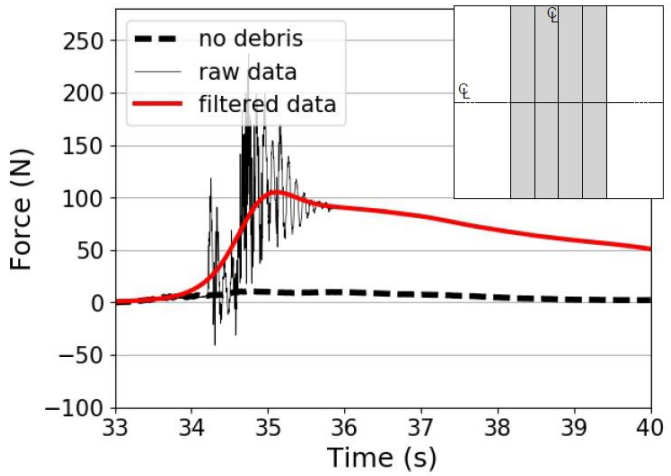
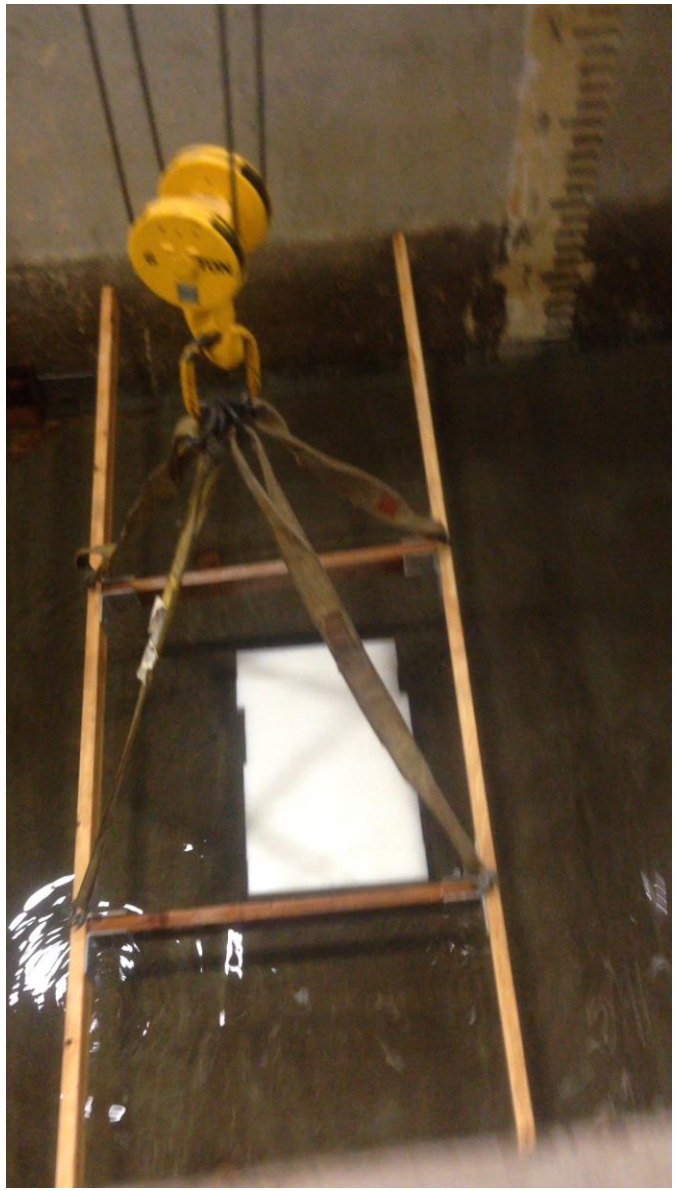




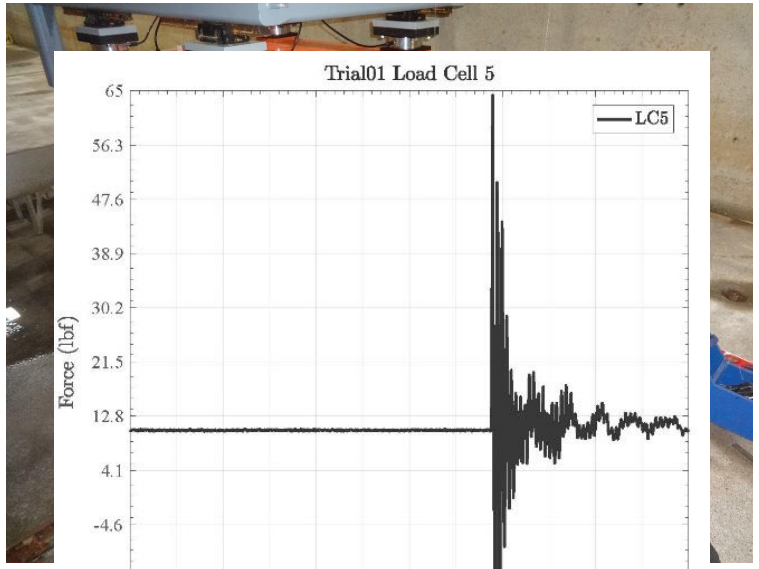


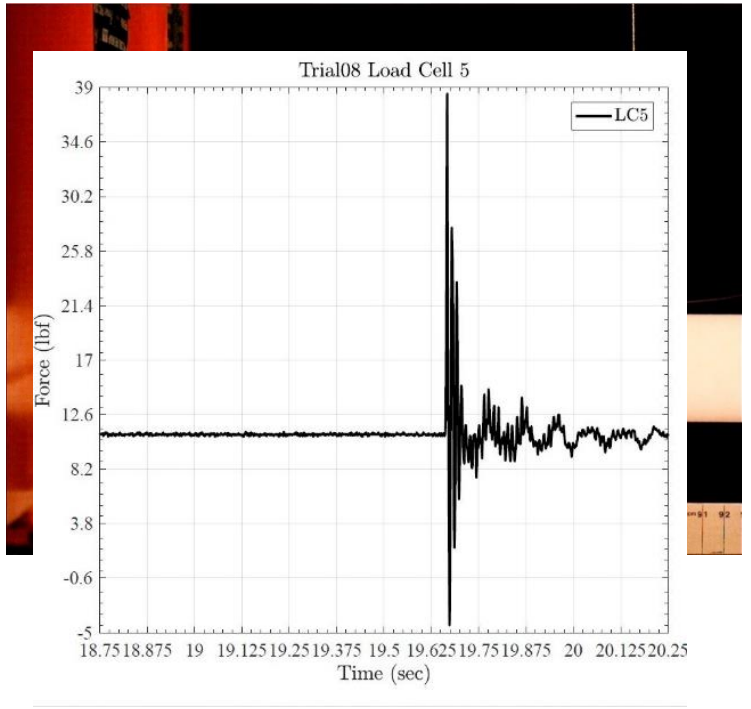
Test program

Phase 6: Structure and debris characterization

- Pluck tests
- Swing tests
- Hammer tests

$$F = v_i\sqrt{km}$$





Database

DESIGNSAFE-CI

NHERI: A NATURAL HAZARDS ENGINEERING RESEARCH INFRASTRUCTURE

NSF supported for collaborative research
Data repository for shared use
Creation of DOI for the dataset
Unlimited access

Concluding remarks

A comprehensive series of experiments have been conducted to study wave (-induced) forces and hydrodynamics on elevated coastal structures subject to waves, surge and tsunamis.

The effect of the elevation of the structure relative to the waterline, wave breaking conditions, flow shielding by adjacent structures, and waterborne debris, have been incorporated in the structural response of the specimen.

The experiments included detailed measurements of the free surface elevation, 3D velocities in the vicinity of the specimen, dynamic pressures on the exposed faces of the structure, forces and torques in all directions, 3D accelerations of the specimen, as well as the characterization of the mechanical properties of the specimen as well as the different debris blocks used.

Overall, close to 1100 tests have been executed and the data have been post-processed and uploaded in the NSF-NHERI Cyberinfrastructure: DesignSafe-CI.org

Acknowledgements

This project was conducted as part of the National Science Foundation funded NHERI program through Grants CMMI-1301016, CMMI-1536198 and CMMI-1519679

And by the U.S. Department of Homeland Security under Award Number 2015-ST-061-ND0001-01

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Thank you for your attention