SIMULATING EARTHQUKE AND TSUNAMI IMPACTS ON OPEN TYPE WHARVES

Presenter: **Jorge Romero**

PIs: Andre R. Barbosa, Claudia Reis

2025 PEER ANNUAL MEETING
MARCH 25, 26 2025
UC BERKELEY, CALIFORNIA

Oregon State University

PEER

Cascadia CoPes Hub
THE CASCADIA COASTLINES AND PEOPLES HAZARDS RESEARCH HUB

OUTLINE

Background

Objectives

Hazards and Demands

Workflow

Physical and numerical modeling

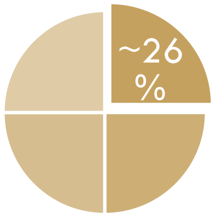
Validation

Application Example

Summary

Future Work

PORTS IN THE UNITED STATES



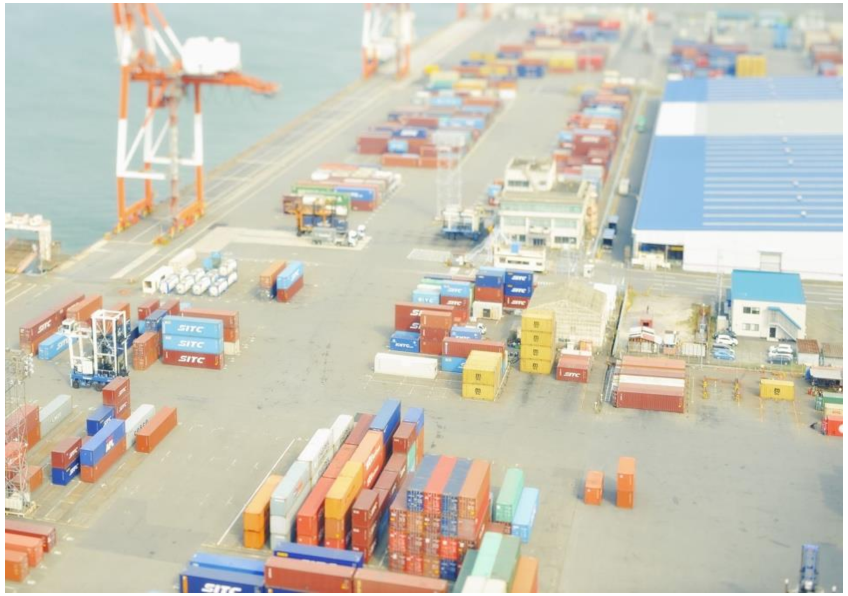
$4.6 trillion annual economic activity ~ ¼ of national economy

ASCE, 2017

26* Ports

23 Ports

12 Ports



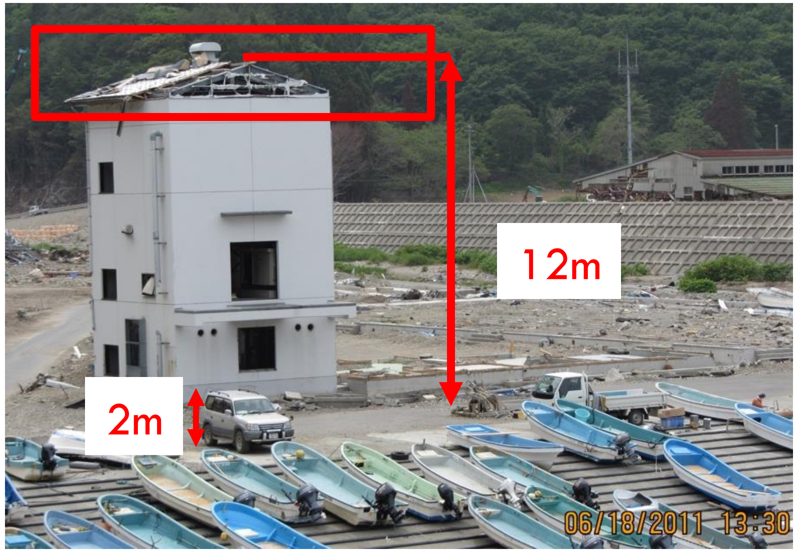
*Northwest Seaport Alliance Along Columbia River and Astoria

CASCADING SEISMIC TSUNAMI EVENTS

2011 Japanese Earthquake and Tsunami

Damage to the 10 m deep Berth 3-2 in the Third Wharf Area of Onahama Port. Sugano et al (2014)

Damage to the Omoe Fishing Port, Omoe. Credits: H. Yeh



Water Level at Fishing Port, Omoe. Credits: H. Yeh

OBJECTIVES

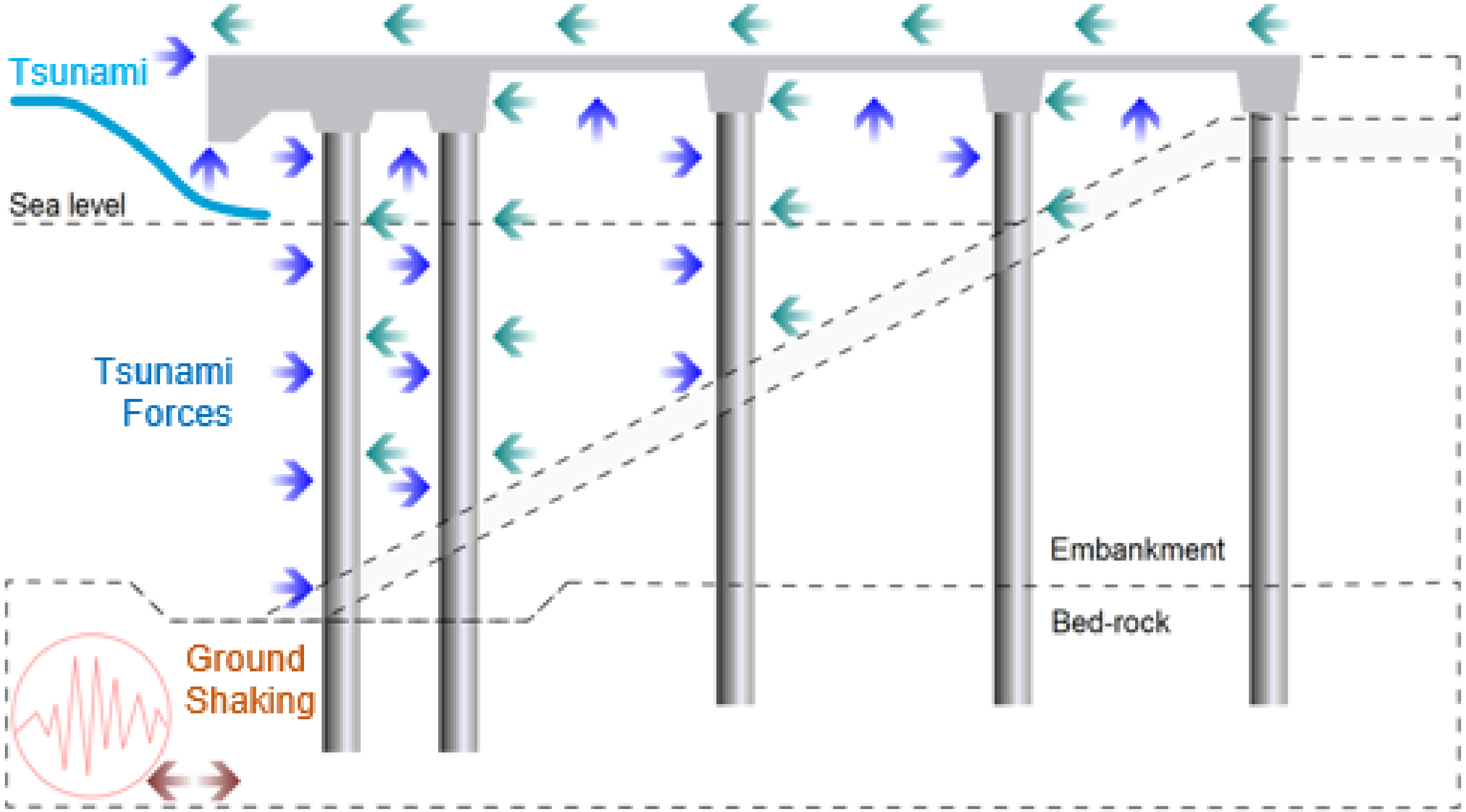
1. Develop deterministic and probabilistic seismic and tsunami multi-hazard analyses of open type wharves (*NSF-funded Cascadia CoPes Hub Project*)
2. Develop models of tsunami-structure interaction for open type wharves during tsunami inflow stage
3. Characterize structural response to cascading seismic and tsunami loads
4. Provide recommendations for the design of open type wharves that are in tsunami prone regions.

OBJECTIVES

1. Develop deterministic and probabilistic seismic and tsunami multi-hazard analyses of open type wharves (*NSF-funded Cascadia CoPes Hub Project*)
2. **Develop models of tsunami-structure interaction for open type wharves during tsunami inflow stage**
3. **Characterize structural response to cascading seismic and tsunami loads**
4. Provide recommendations for the design of open type wharves that are in tsunami prone regions.

HAZARDS AND DEMANDS

1. Seismic forces and drifts
2. Tsunami pressures / forces and drifts
3. Scouring effects on foundations

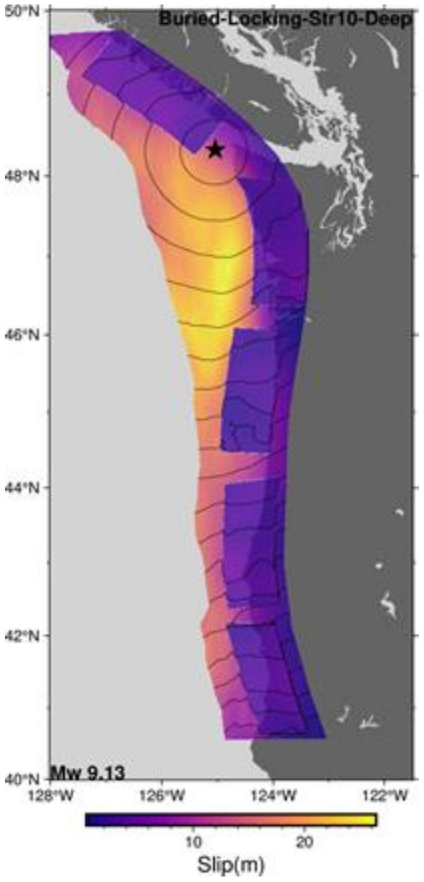


The cascading impacts of megathrust earthquakes

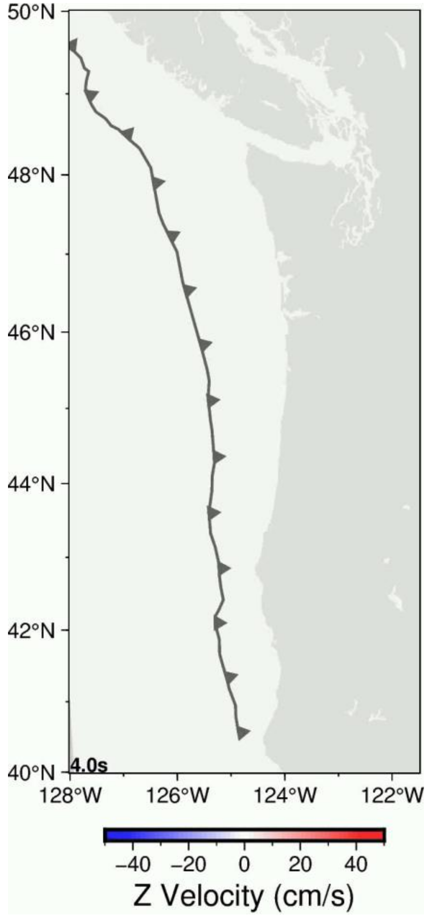
Connecting ground shaking and tsunamis in the Cascadia Subduction Zone

Coupled time-dependent 3D earthquake & tsunami simulations

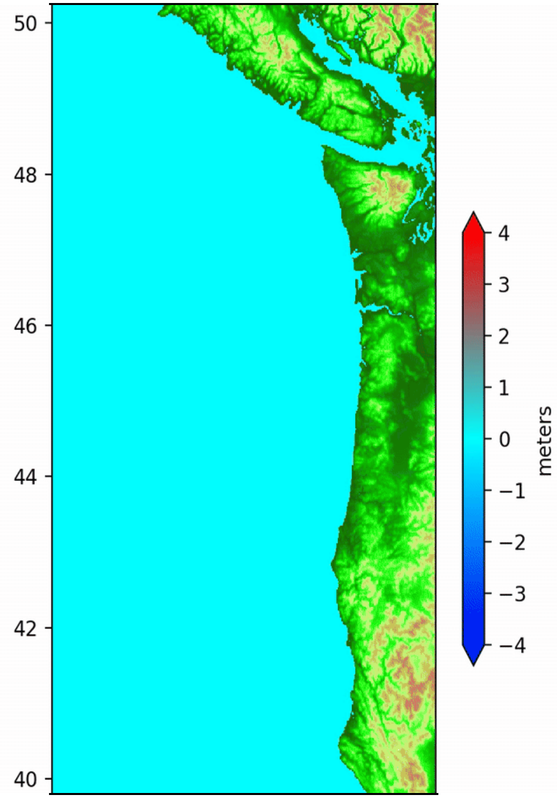
Earthquake Scenario



Output Ground Shaking



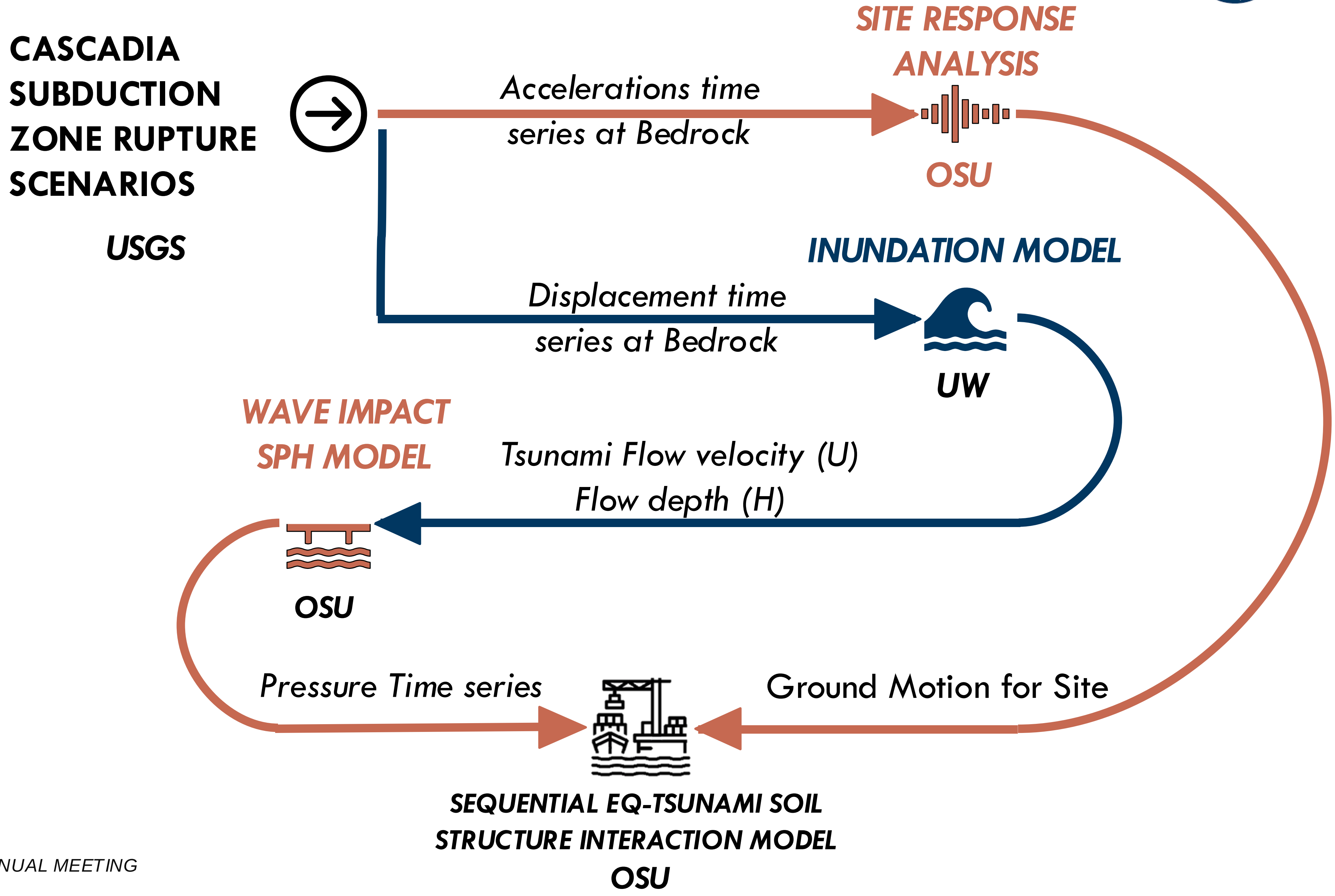
Tsunami Simulation



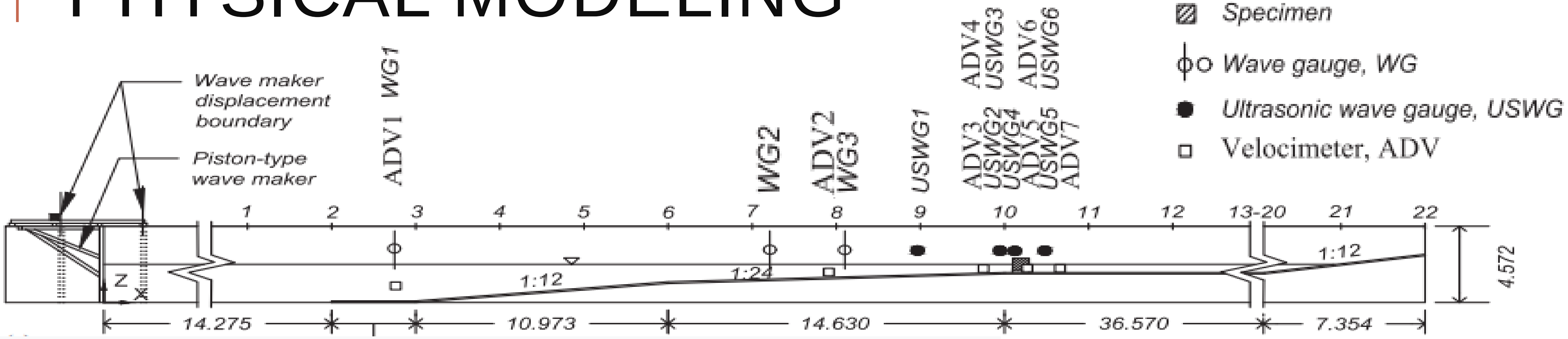
52 scenarios in a logic tree being computed for the earthquake

Using the same earthquake source in both the shaking and tsunami simulations, gives better understanding of the time dependent cascading hazards associated with megathrust earthquakes

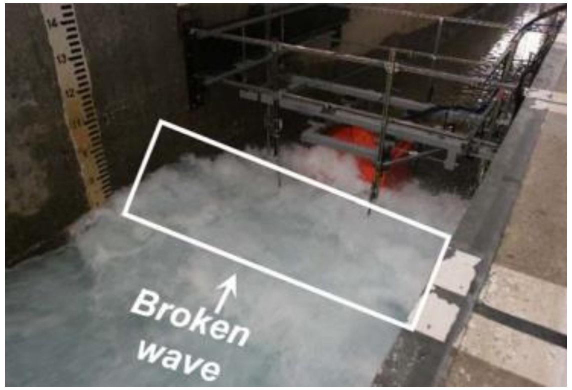
Harold Tobin, Madeleine Lucas, Anna Ledeczi, Erin Wirth, Audrey Dunham, Randall LeVeque , Yong Wei and other collaborators


CASCADIA SUBDUCTION ZONE RUPTURE SCENARIOS
USGS
Accelerations time series at Bedrock
SITE RESPONSE ANALYSIS
OSU
Displacement time series at Bedrock
INUNDATION MODEL
UW
Tsunami Flow velocity (U)
Flow depth (H)
WAVE IMPACT SPH MODEL
OSU
Pressure Time series
Ground Motion for Site
SEQUENTIAL EQ-TSUNAMI SOIL STRUCTURE INTERACTION MODEL
OSU

PHYSICAL MODELING



(a) Experimental setup for elevated structure in Flume HWRL (Alam et al. 2020)



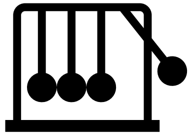
(b) Structure subjected to different wave loading (Alam et al. 2020)

(c) Pressure gauge layout (Alam et al. 2020)

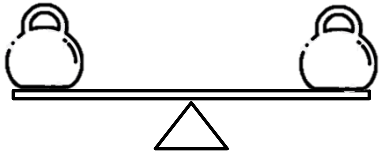
NUMERICAL MODELING

Smoothed Particle Hydrodynamics

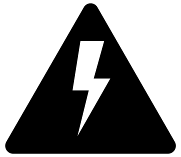
- Momentum conservation



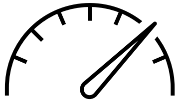
- Mass conservation



- Energy conservation



- Tait's Equation of State
  - Weakly Compressible condition

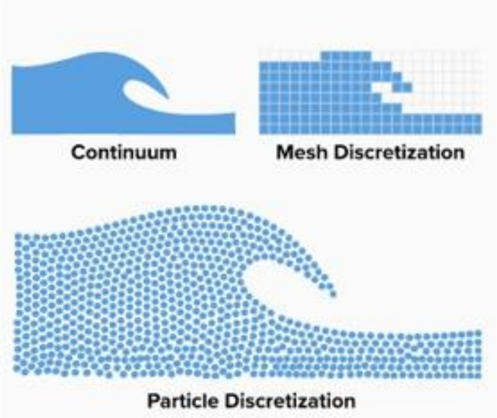


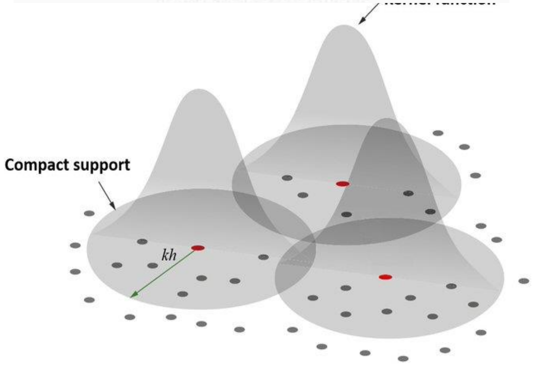
Fluids: Continuum system

Lagrangian NS-SPH scheme

Kernel Based Solution

Fluids: Discrete system

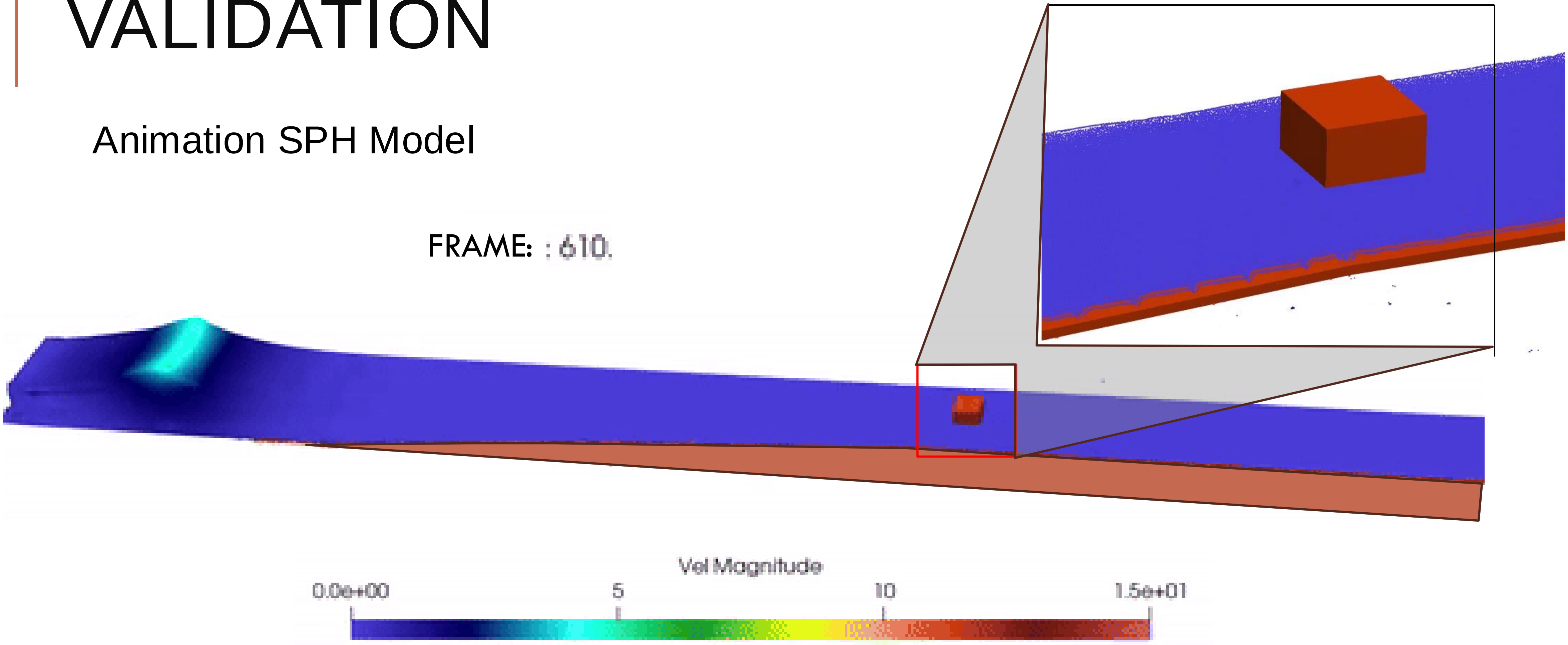




Dominguez et al. 2022

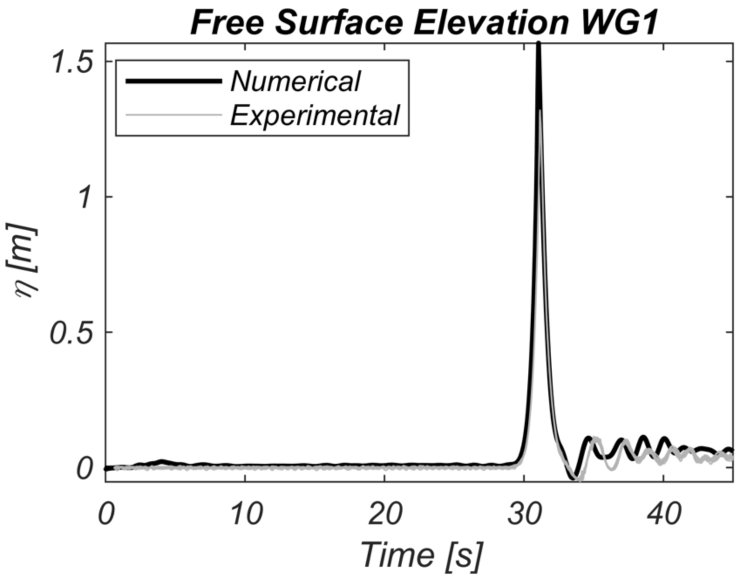
VALIDATION

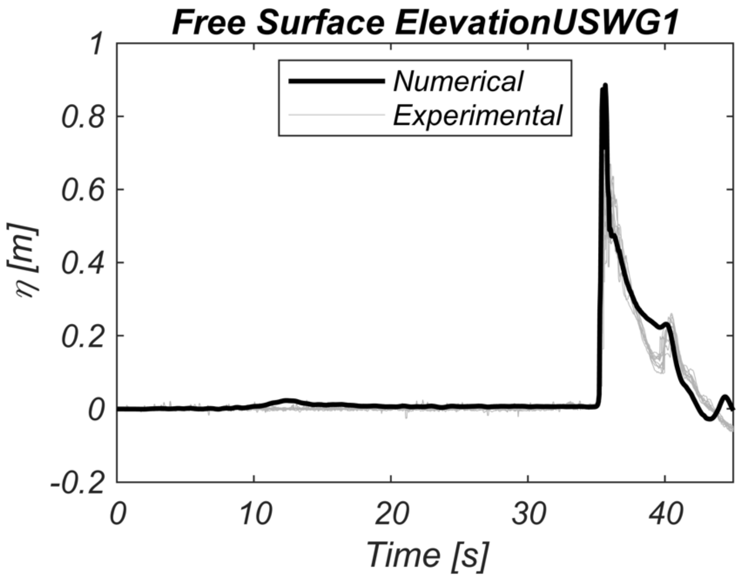
Animation SPH Model

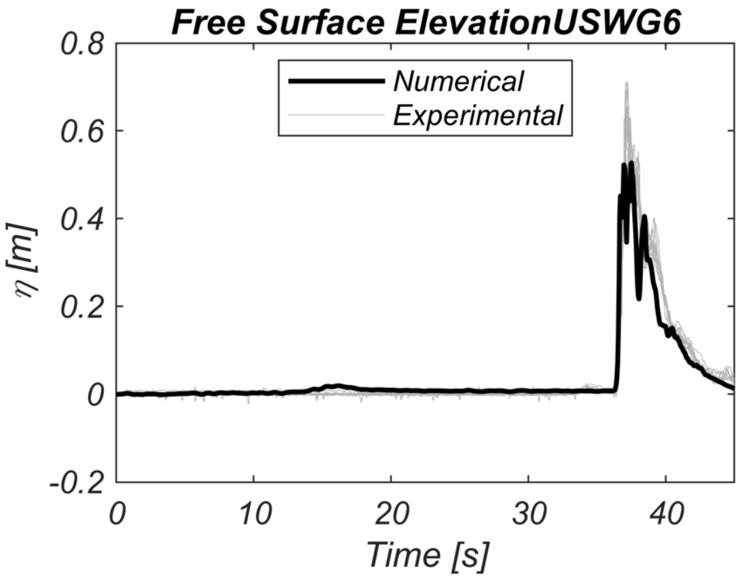


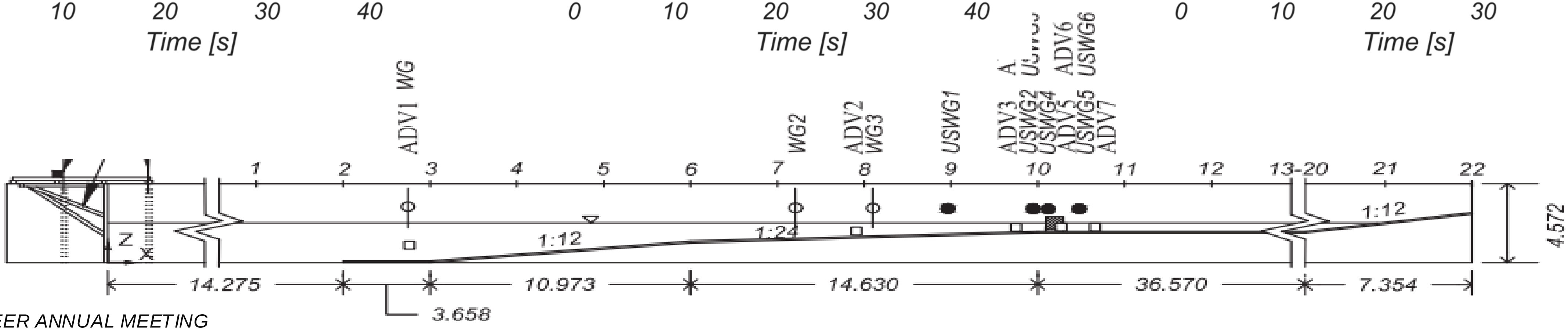
VALIDATION

Free Surface Elevation (Broken Wave)



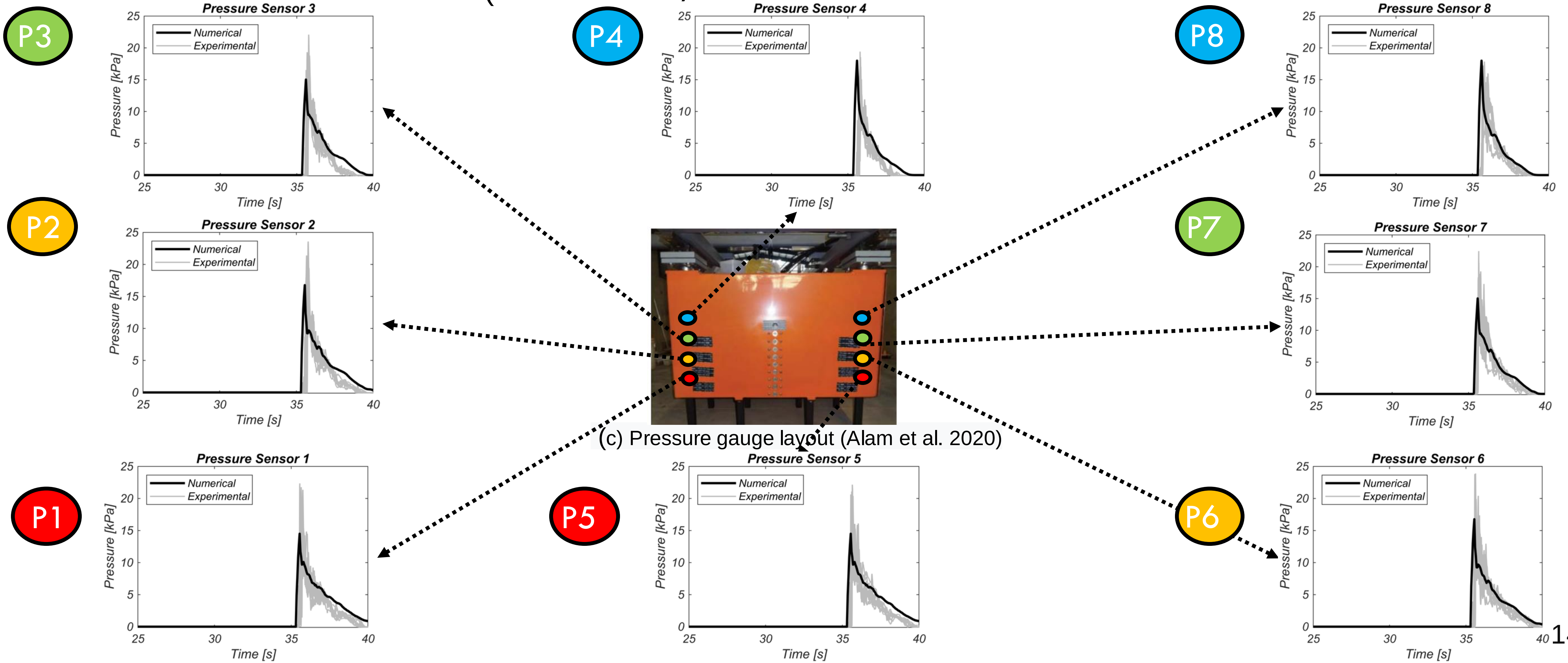






VALIDATION

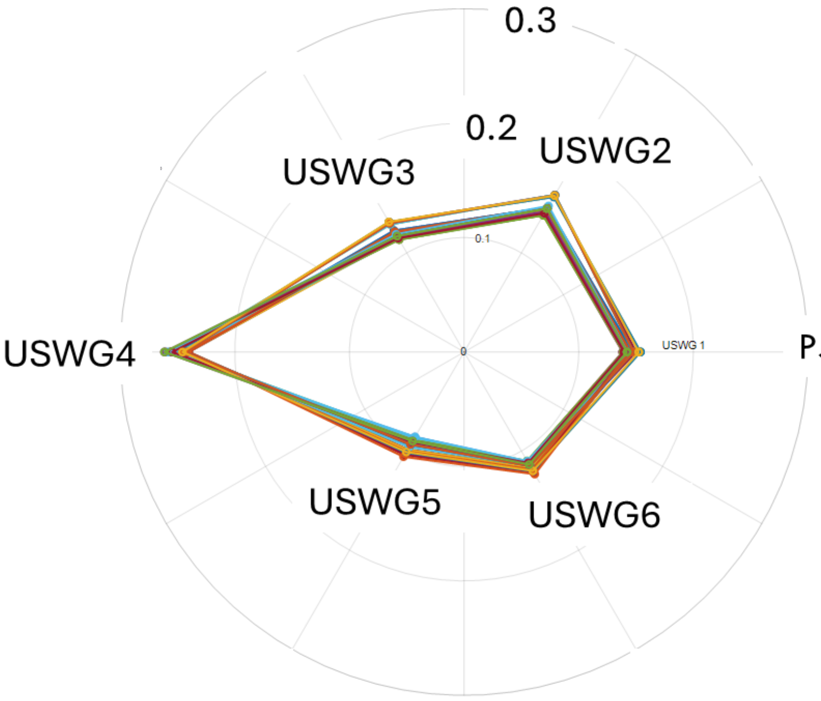
Pressure Field - Front Face (Broken Wave)



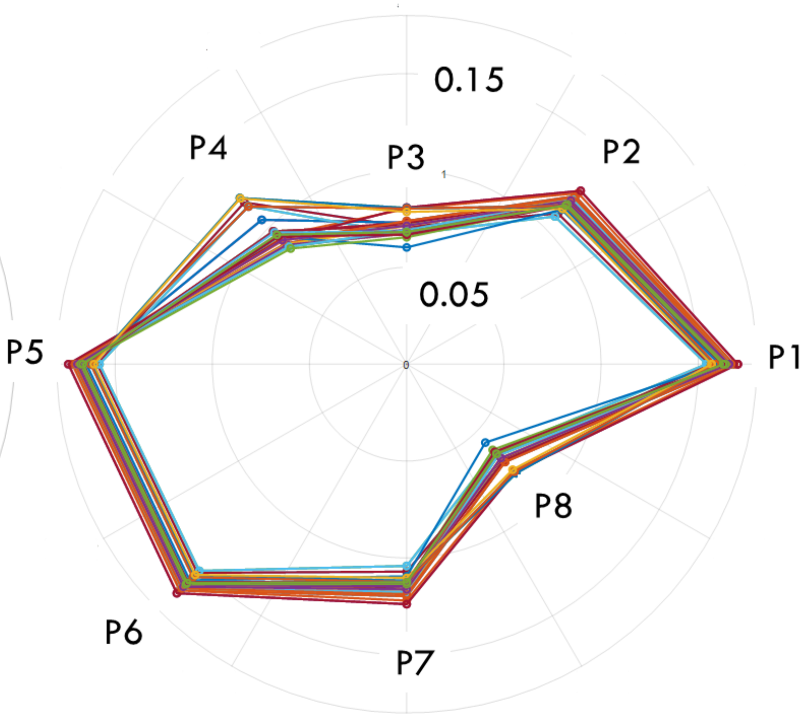
(c) Pressure gauge layout (Alam et al. 2020)

VALIDATION – SENSITIVITY ANALYSIS

Parameter	Min	Max
Viscosity	0.005	0.05
DDT	0.01	0.25
Hsph/dp	1.5	2.3



RRMSE – FREE SURFACE ELEVATION TIME SERIES

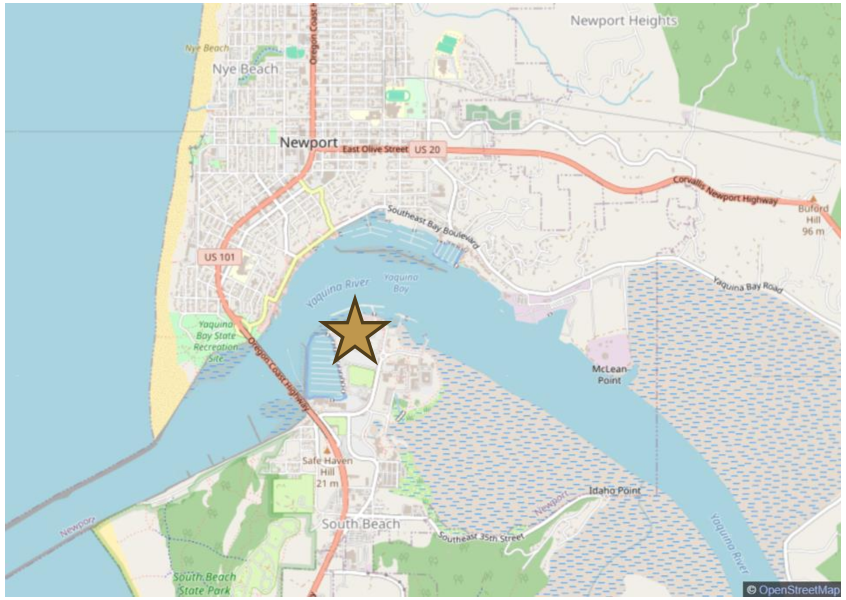


RRMSE - PRESSURE TIME SERIES

APPLICATION EXAMPLE

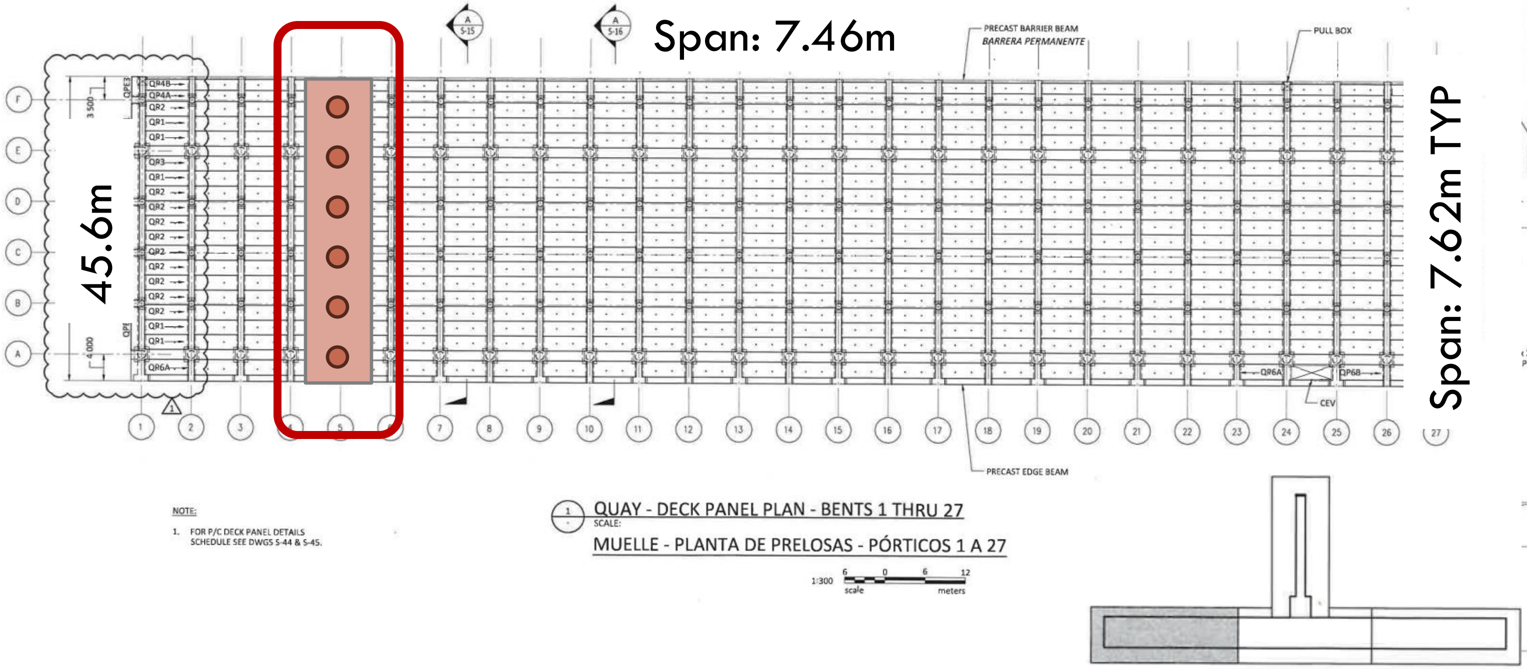
- Location:
  - Hatfield Marine Science Building, OSU, Newport, OR (Yaquina Bay)

- Available Site Data:
  (Courtesy of GRI)
  - VS Borehole logging
  - CPT
  - SPT

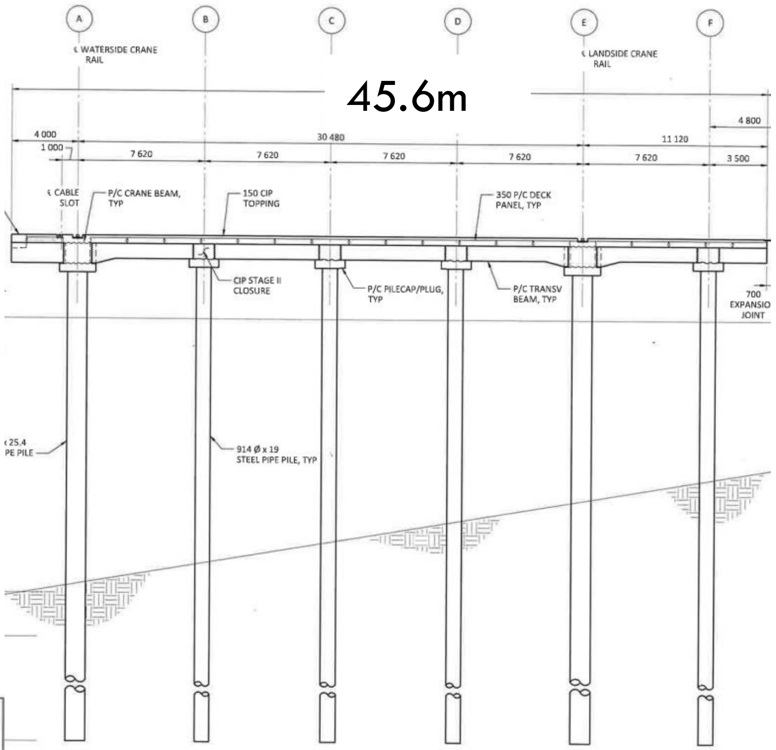


Newport, OR

APPLICATION EXAMPLE- STRUCTURE



(a) Plan view

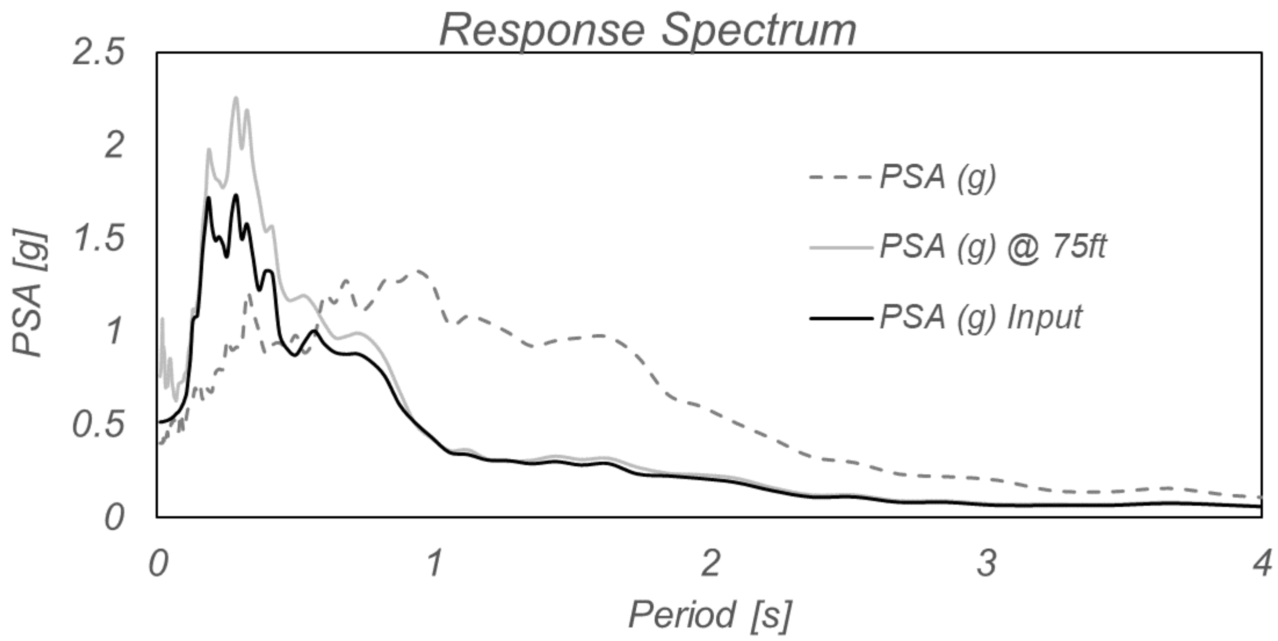


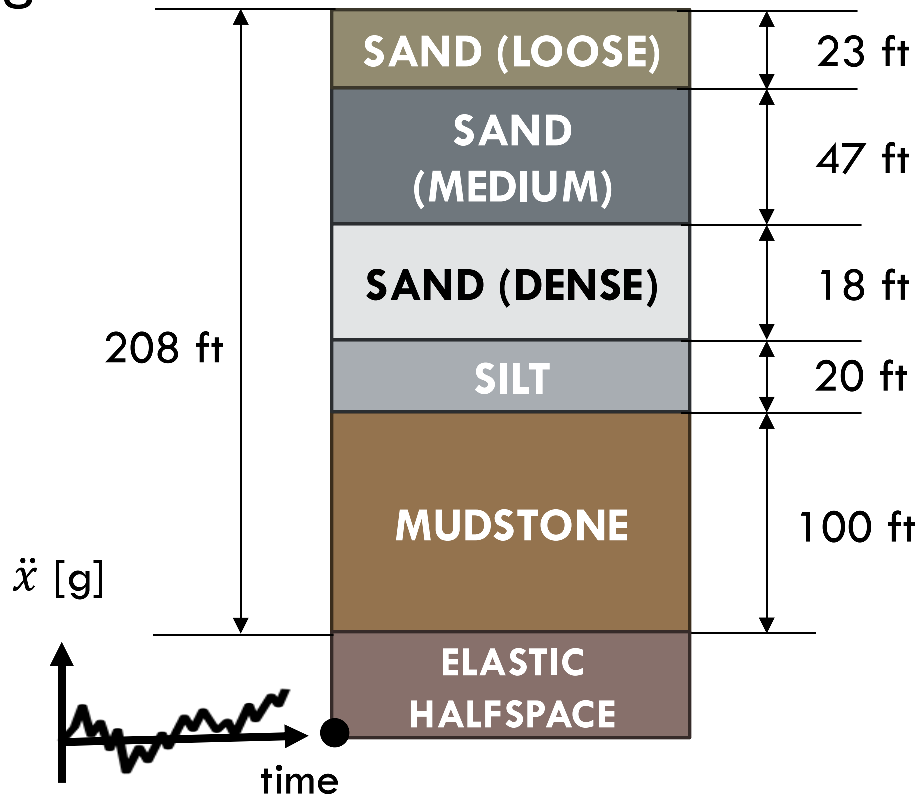
(b) Elevation view

Structure Model: Courtesy of **W. (Bill) Bruin, SGH**.

SEISMIC MODEL

- DEEPSOIL Model:
  - Ground Motion – Site Response Analysis
    - Buried Locking – Str 10 – Deep

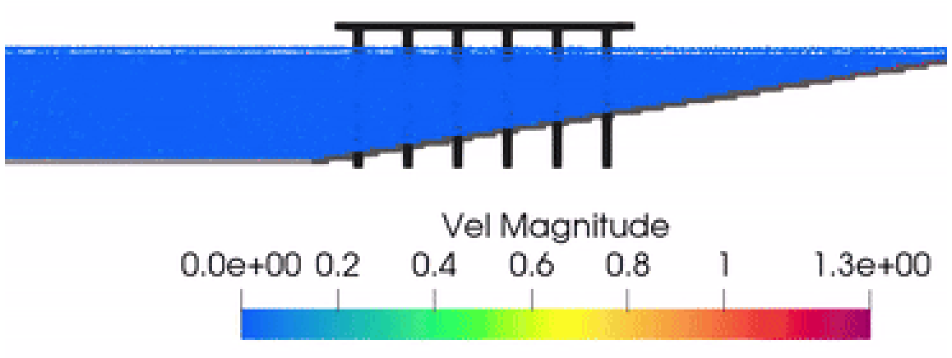


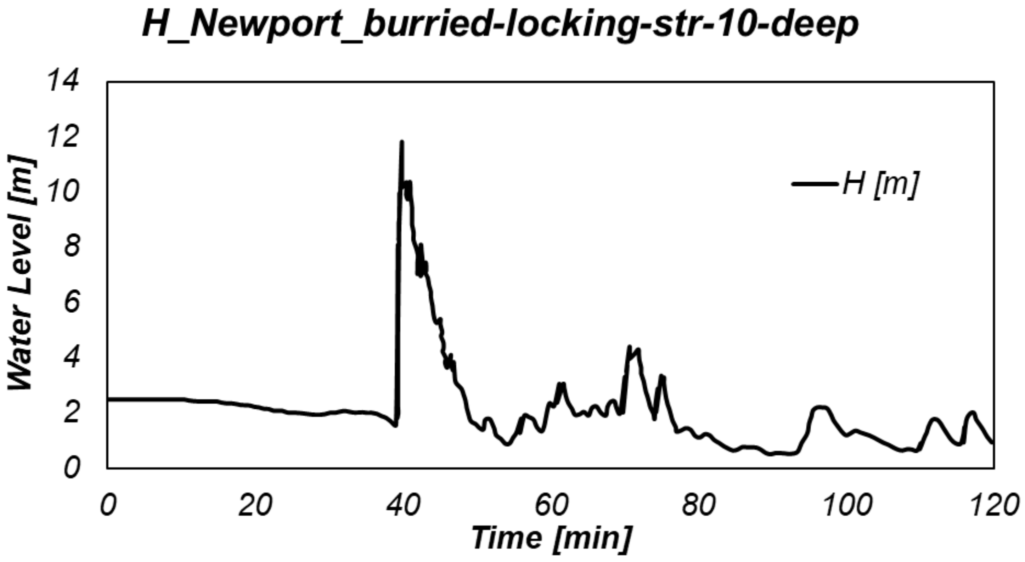


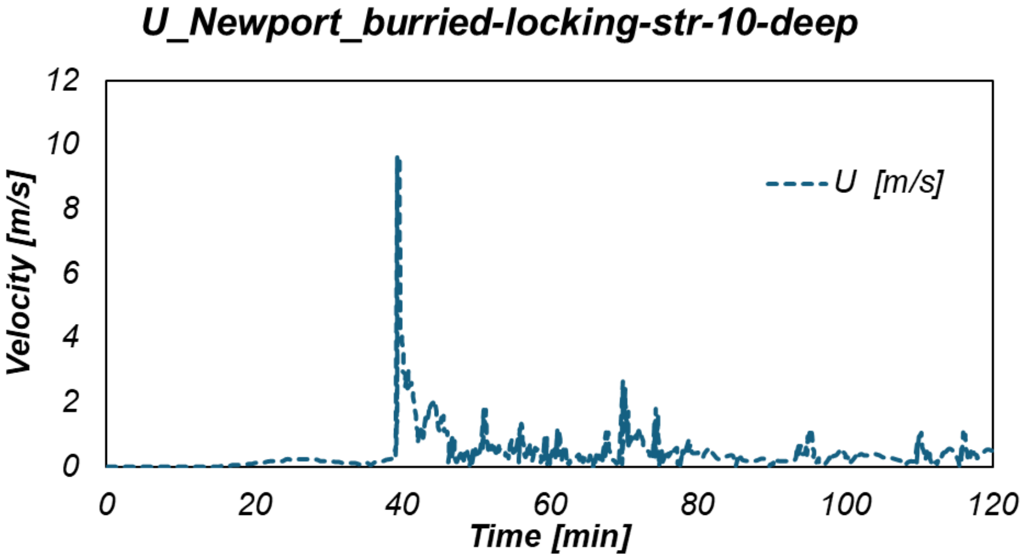
SOIL PROFILE
Courtesy of: GRI

WAVE IMPACT MODEL

- Input for SPH Model:
  - Tsunami inundation models (GeoCLAW) (52 Scenarios)
  - Example Scenario: Buried Locking – Str 10 – Deep

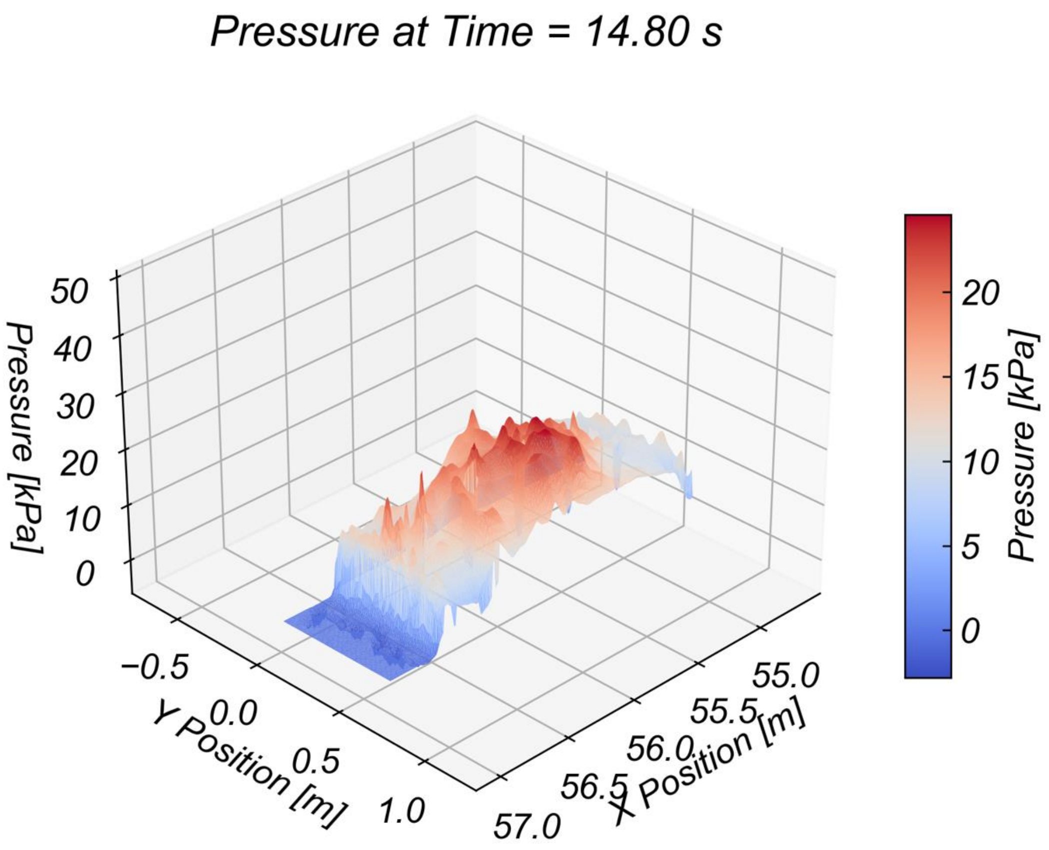


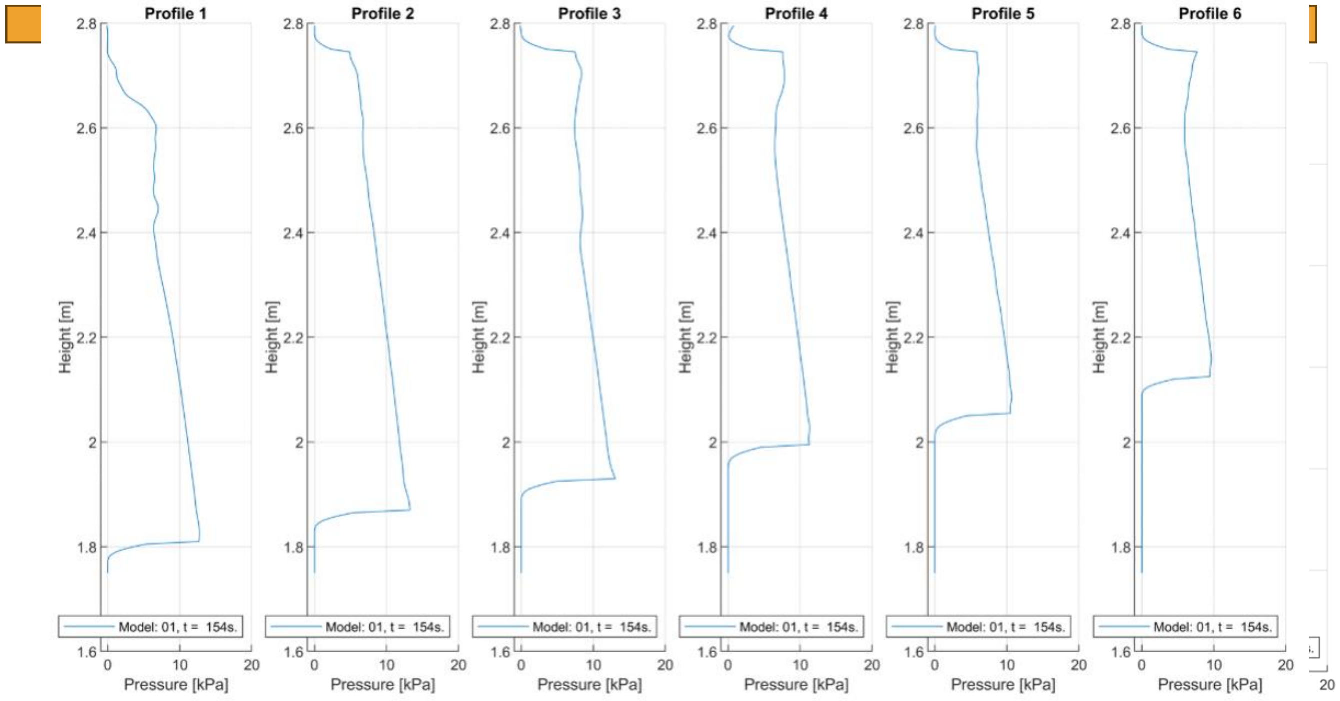




WAVE IMPACT MODEL

- Input for OpenSees Model:





Piles - Horizontal Pressures

OPENSEES MODEL

- Soil
  - Material: Elastic, pressure independent multi-yield, pressure dependent multi-yield
- Piles and girders
  - 2D, 3D - (Elastic Beam-Column -Fiber)

- Include tsunami pressure

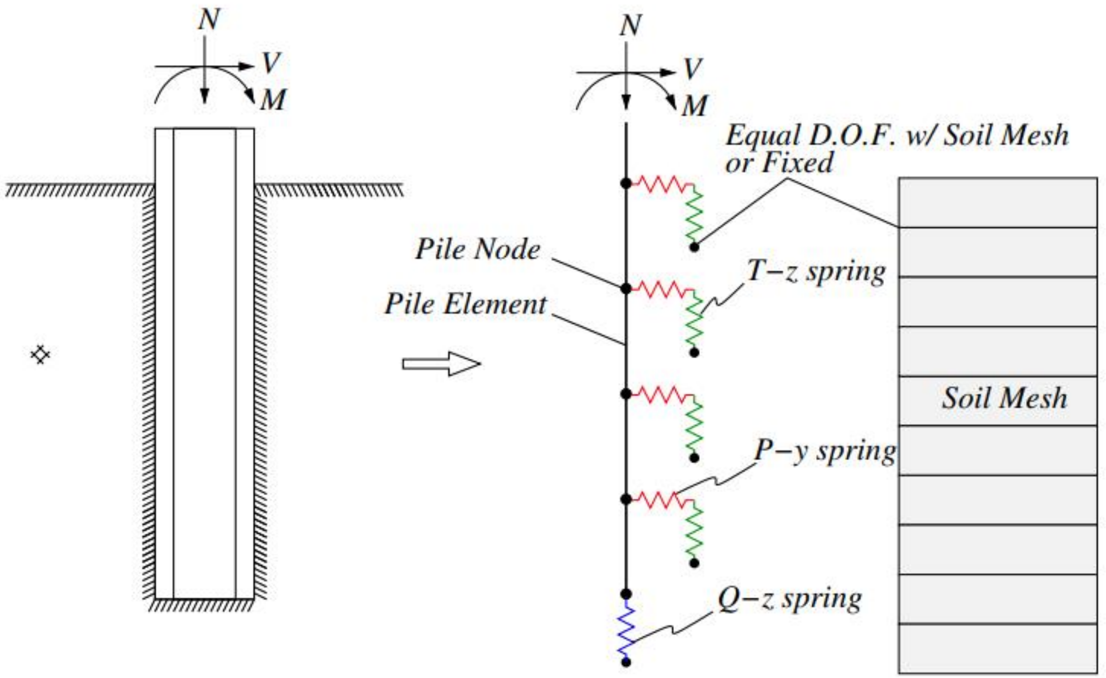


Figure 8. Soil–structure interaction springs (p–y, t–z, and Q–z).

CHIARAMONTE, (2013)

SUMMARY

- SPH models were validated
  - Broken Wave
  - Unbroken Wave
  - Sensitivity Analysis
- Application Example
  - Pressure Fields demands are obtained from a **full-scale** rigid structure model (SPH).

FUTURE WORK

- Tsunami modeling (Define set of cases to run)
- Cascading loading modeling:
    - Apply DualSPHysics pressure time-series on nonlinear OpenSees soil-structure interaction models
    - Perform cascading, sequential earthquake and tsunami loading analysis (SSI, nonlinear time history analyses) to assess damage states of the structure.

REFERENCES

- Shafieezaedeh, Abdollah, Reginald DesRoches, and Karthik Ramanathan 2011. **"Developing fragility curves for a typical pile- supported wharf structure."**
- Wittkop, R. , Jarradat, O. , Johnson, G. , Martin, G. , Rix, G. and Robertson, I. 2012, **Program Plan for the Development of Seismic Design Guidelines for Port Container, Wharf, and Cargo Systems**, Grant/Contract Reports (NISTGCR), National Institute of Standards and Technology, Gaithersburg, MD
- Sugano, Takahiro, Atsushi Nozu, Eiji Kohama, Ken-ichiro Shimosako, and Yoshiaki Kikuchi. 2014. "**Damage to Coastal Structures**." *Soils and Foundations*
- ASCE. "**Infrastructure Report Card**" *2017*.
- Alam, Mohammad S., Andrew O. Winter, Glen Galant, Krishnendu Shekhar, Andre R. Barbosa, Michael R. Motley, Marc O. Eberhard, et al. 2020. "**Tsunami-Like Wave-Induced Lateral and Uplift Pressures and Forces on an Elevated Coastal Structure**." *Journal of Waterway, Port, Coastal, and Ocean Engineering*
- Winter, Andrew O., Mohammad S. Alam, Krishnendu Shekhar, Michael R. Motley, Marc O. Eberhard, Andre R. Barbosa, Pedro Lomonaco, Pedro Arduino, and Daniel T. Cox. 2020. "**Tsunami-Like Wave Forces on an Elevated Coastal Structure: Effects of Flow Shielding and Channeling.** " *Journal of Waterway, Port, Coastal, and Ocean Engineering*
- Reis, Cláudia, Stéphane Clain, Jorge Figueiredo, André R. Barbosa, Maria Ana Baptista, and Mário Lopes. 2021. "**Experimentally Validated Numerical Models to Assess Tsunami Hydrodynamic Force on an Elevated Structure**."
- Domínguez, J. M., G. Fourtakas, C. Altomare, R. B. Canelas, A. Tafuni, O. García-Feal, I. Martínez-Estévez, et al. 2022. "**DualSPHysics: From Fluid Dynamics to Multiphysics Problems**." *Computational Particle Mechanics*
- Reis, Cláudia, André R. Barbosa, Jorge Figueiredo, Stéphane Clain, Mário Lopes, and Maria Ana Baptista. 2022. "**Smoothed Particle Hydrodynamics Modeling of Elevated Structures Impacted by Tsunami-like Waves**."
- **"Overview of California's Ports Report"** 2025. https://lao.ca.gov/Publications/Report/4618
- P. Brenan. "**Oregon Ports Report",** 2025. https://www.oregonlegislature.gov/lpro/Publications/2004JE_Oregon_Ports.pdf

THANK YOU!

Questions?