Cascading Seismic and Tsunami Loads for the Design of Open Wharves

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OUTLINE

Background

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Hazards and Demands

Physical and numerical modeling

Validation

Application Example

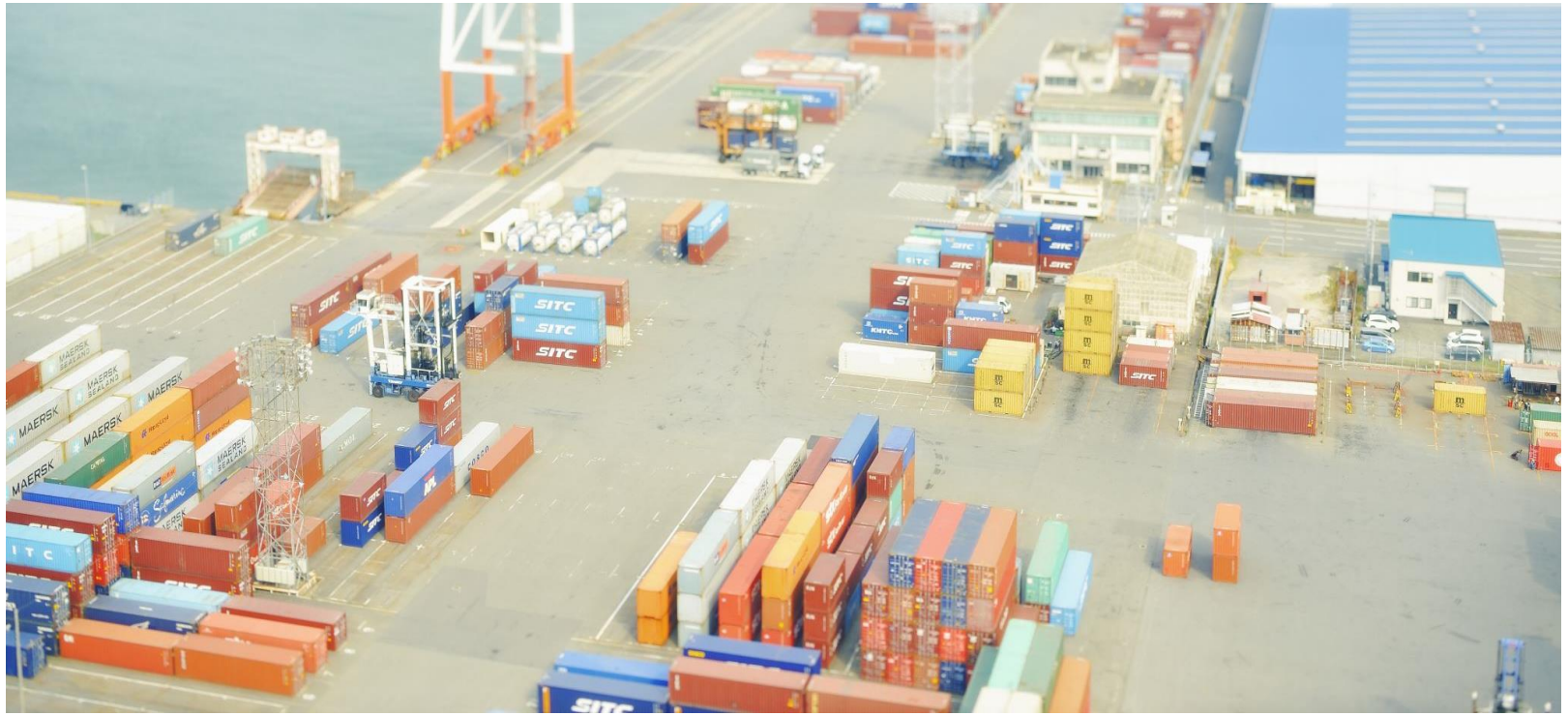
Preliminary Results

Conclusion

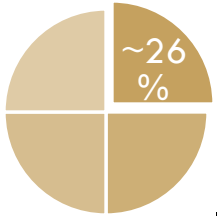
Summary

Future Work

PORTS IN THE UNITED STATES



926 ports in the US

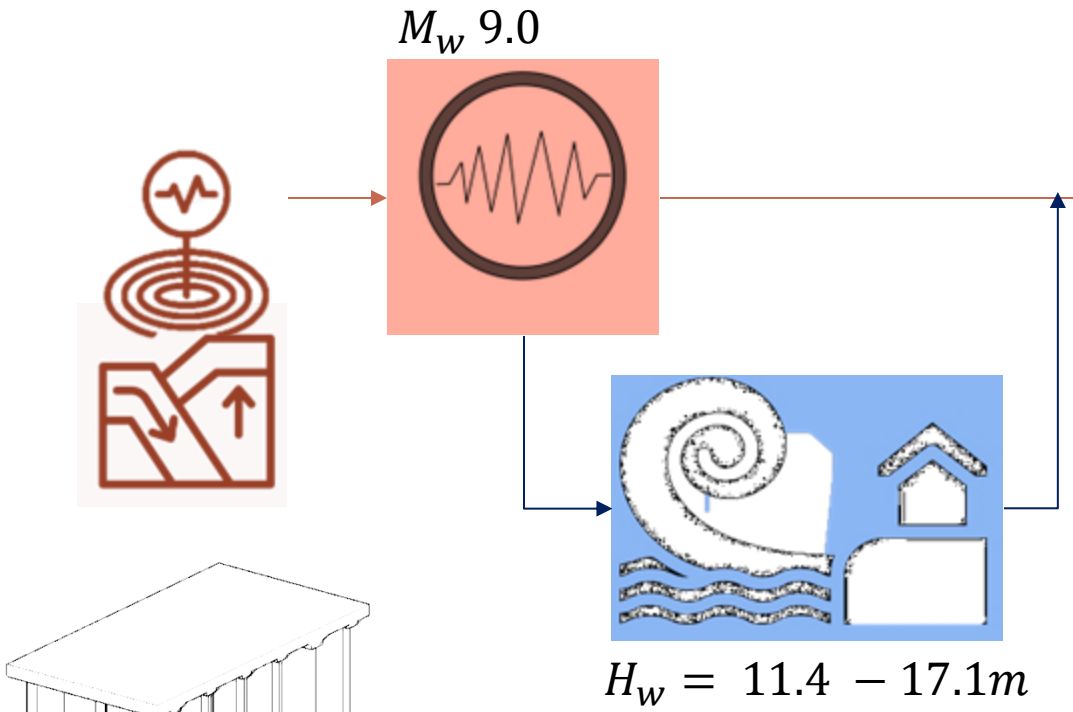


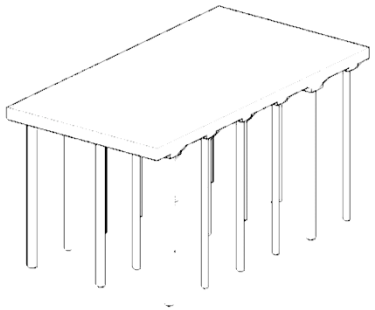
$4.6 trillion annual economic activity
~ ¼ of national economy

ASCE, 2017

RECENT EVENTS

2011 Japanese Earthquake and Tsunami

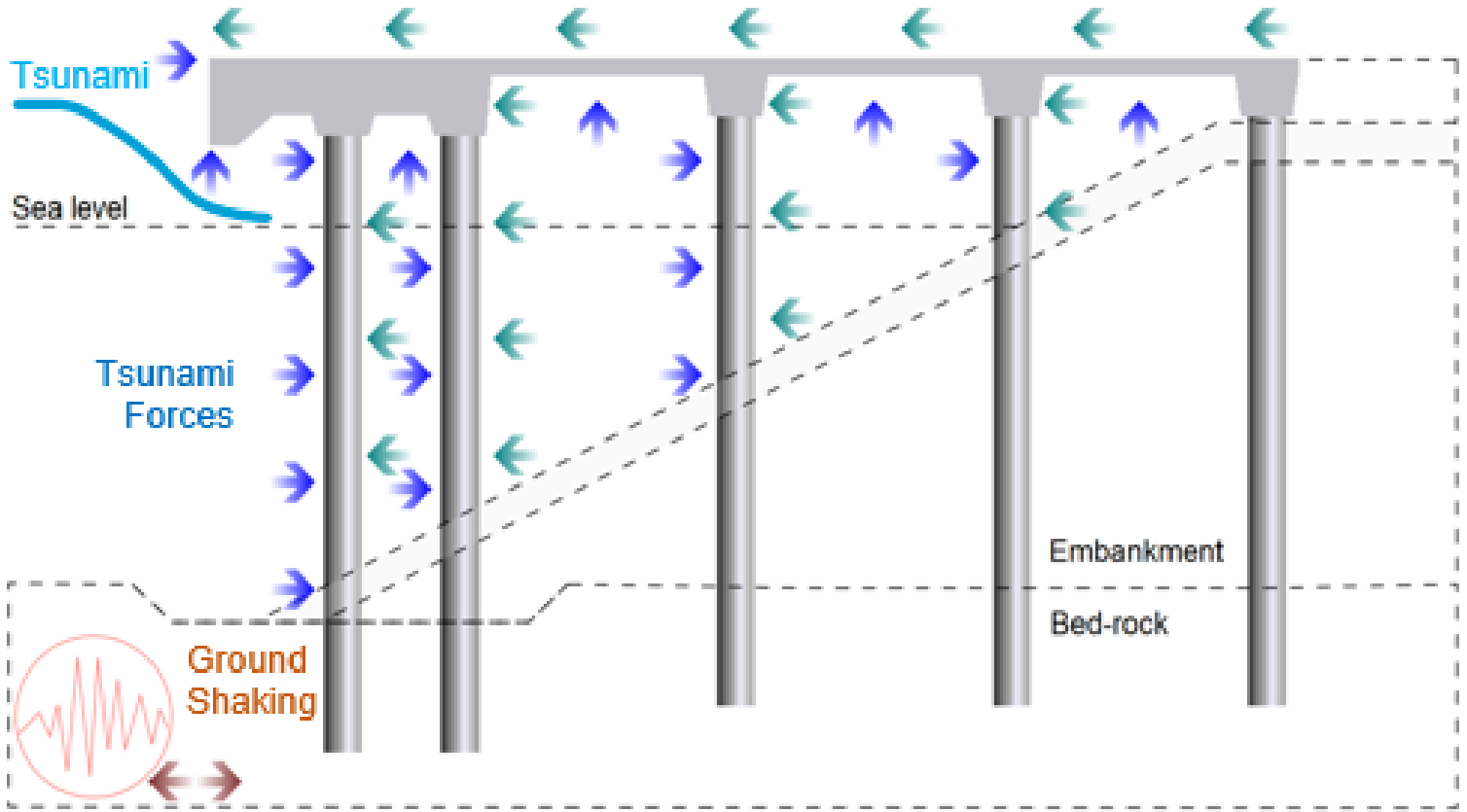




Damage to the 10 m deep Berth 3-2 in the Third Wharf Area of Onahama Port. Sugano et al (2014)

HAZARDS AND DEMANDS

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



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 and outflow stages
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.

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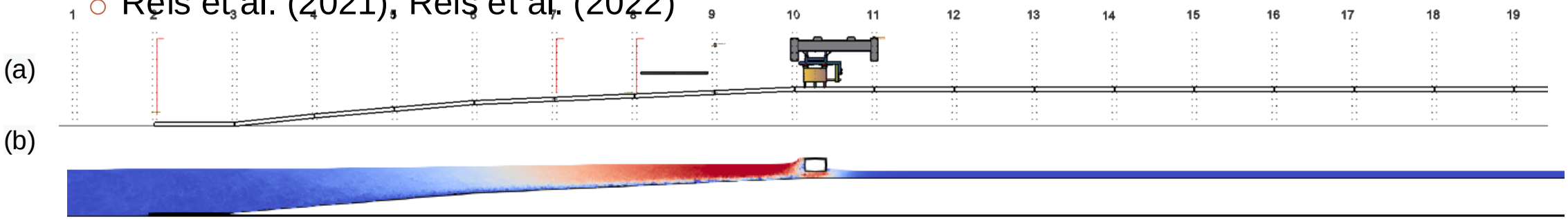
LITERATURE REVIEW

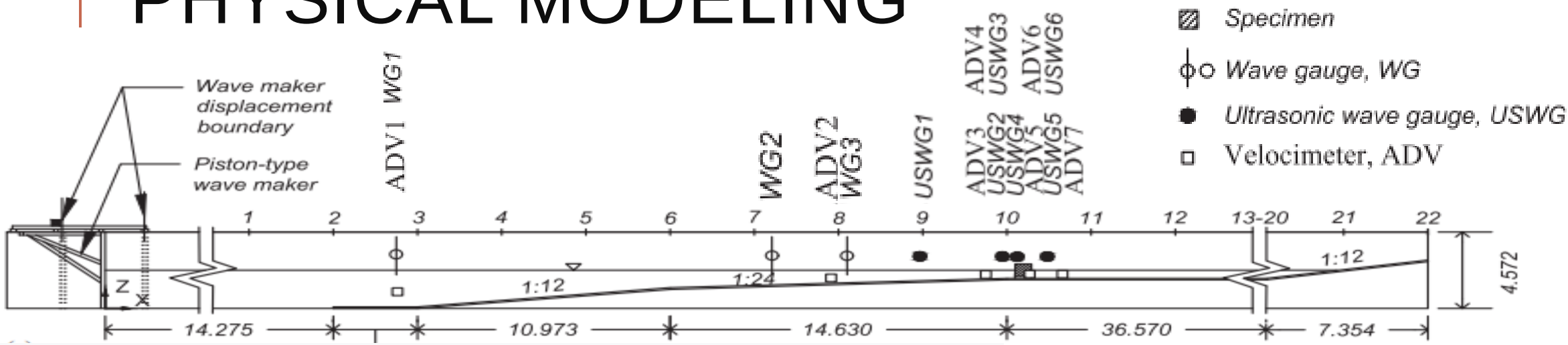
- Port structure earthquake analyses and needs
  - DesRoches et al. (2009, 2011); NIST GCR 12-917-19 (2012); Chiaramonte et al. (2013);
- No existing tsunami loading experiments for port structures
  - *Closest*.. Robertson et al. (2008) [Wall and Slab]
- Experimental tests of an elevated structure tested at OSU
  - Alam et al. (2020), Winter et al. (2020) [joint effort UW and OSU]
- Benchmarking of “DualSPHysics” with experimental results
  - Reis et al. (2021), Reis et al. (2022)

Elevated Structure instrumented at Hinsdale Wave Research Laboratory (HWRL) Oregon State University

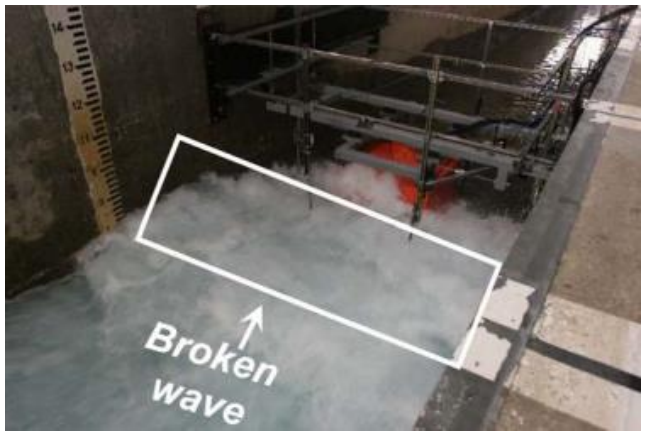


(a) Experimental setup for elevated structure in flume, (b) Numerical model developed in “DualSPHysics”

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)

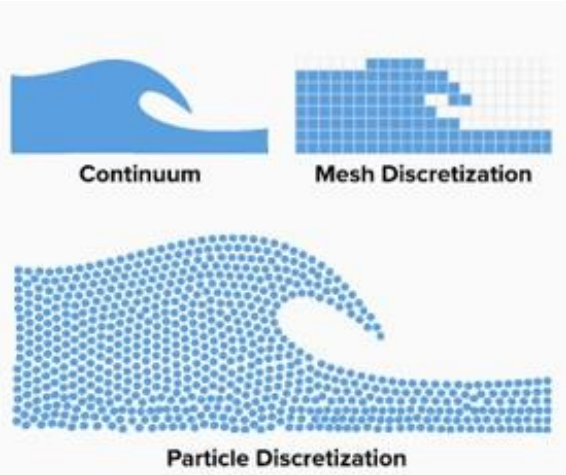
(c) Pressure gauge layout (Alam et al. 2020)

NUMERICAL MODELING

Fluids: Continuum system

Lagrangian NS-SPH scheme

Fluids: Discrete system



Dominguez et al. 2022

Smoothed Particle Hydrodynamics

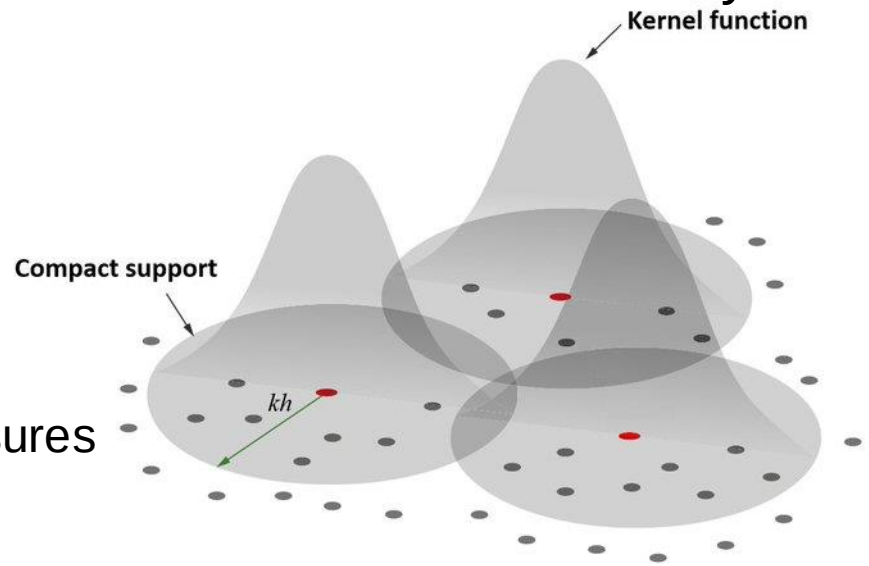
Conservation laws of continuum fluid dynamics apply to every particle

Navier-Stokes (NS) equations (PDE) are solved for each particle with the influence of the surrounding particles limited to a smoothing length to describe the motion of viscous fluids by solving

- Momentum conservation
- Mass conservation
- Energy conservation

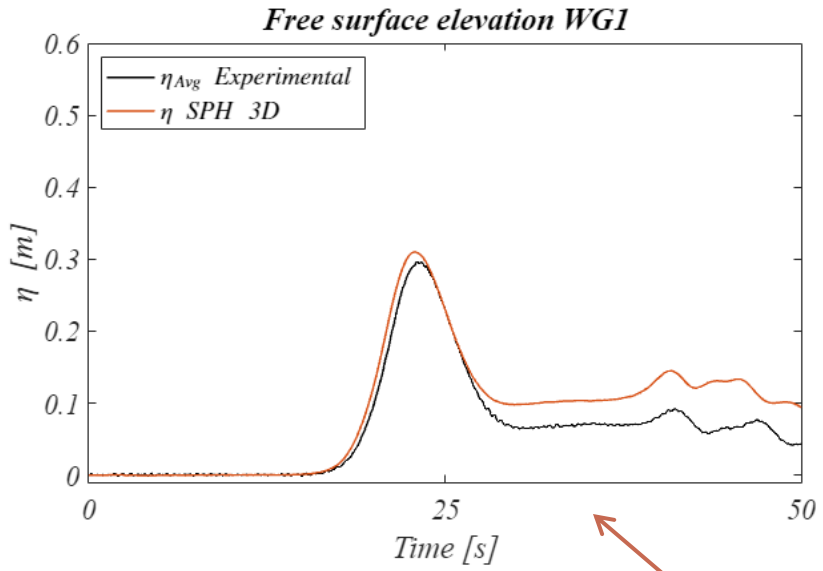
Weakly compressible fluids

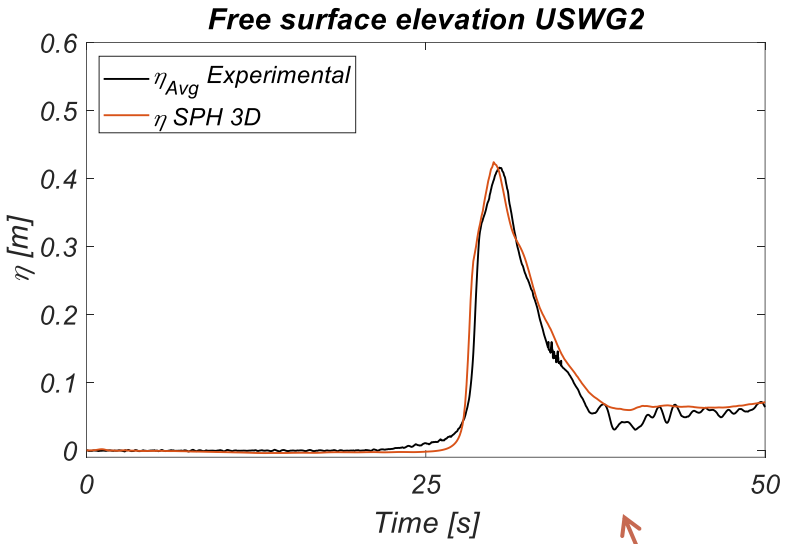
- Tait's Equation of State (EOS)
- Simplifies computation of pressures

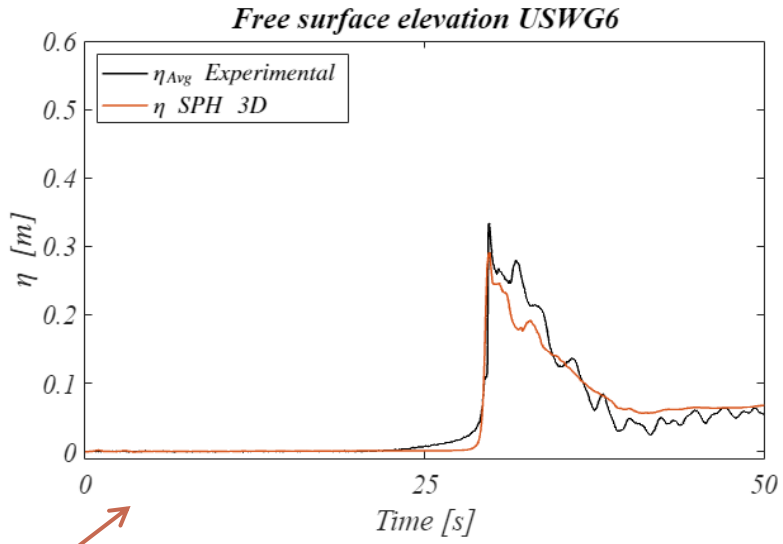


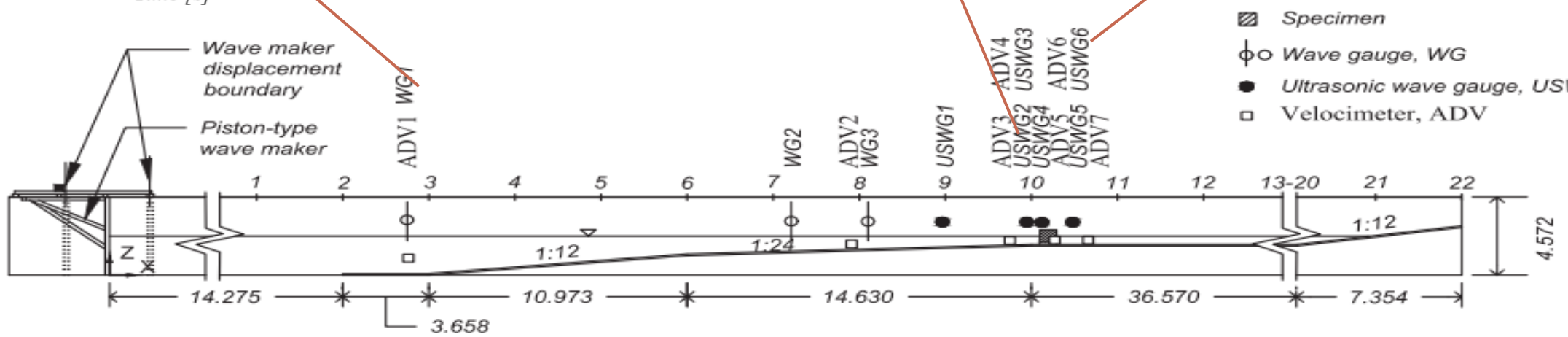
Dominguez et al. 2022

VALIDATION (Free Surface Elevation)

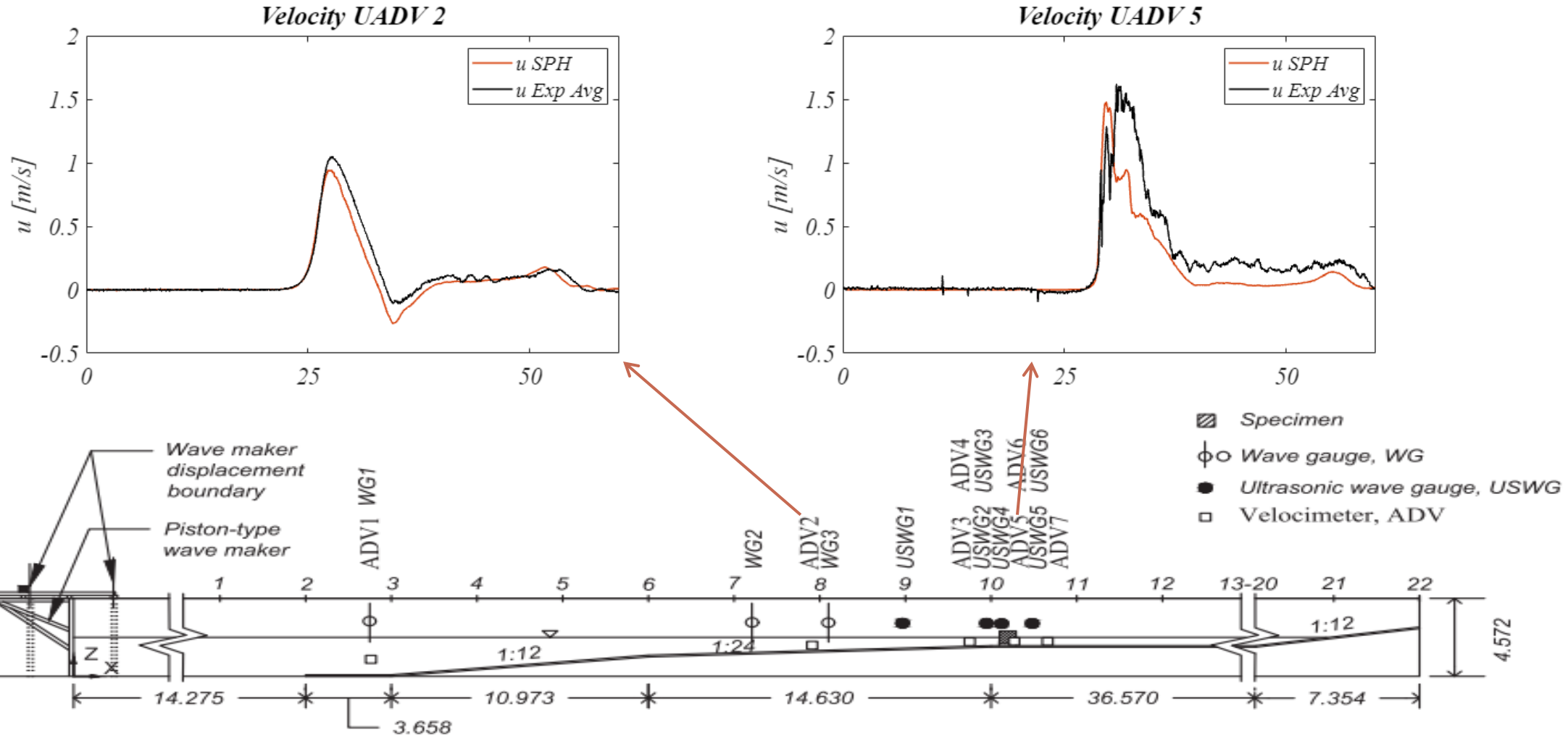




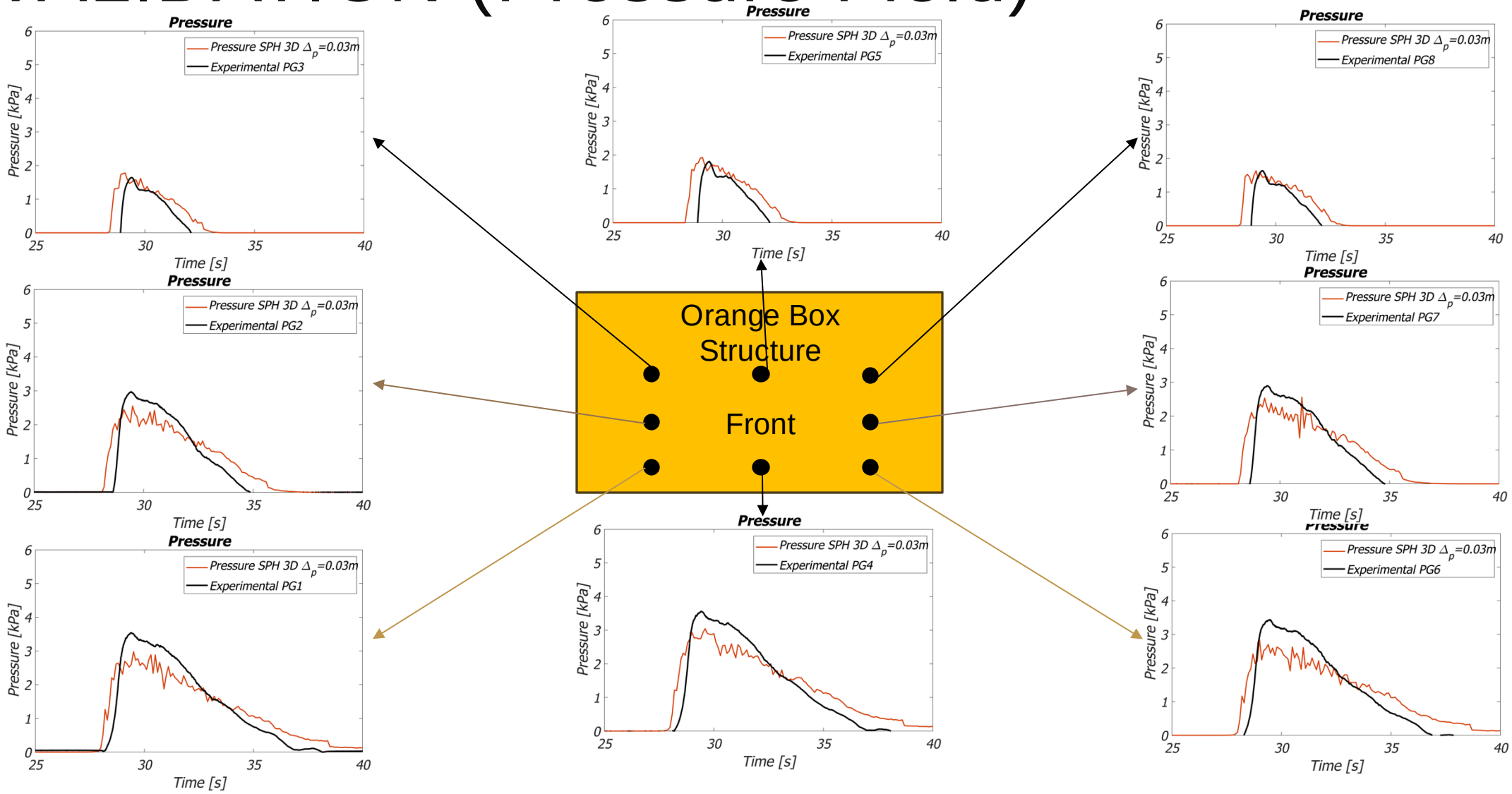




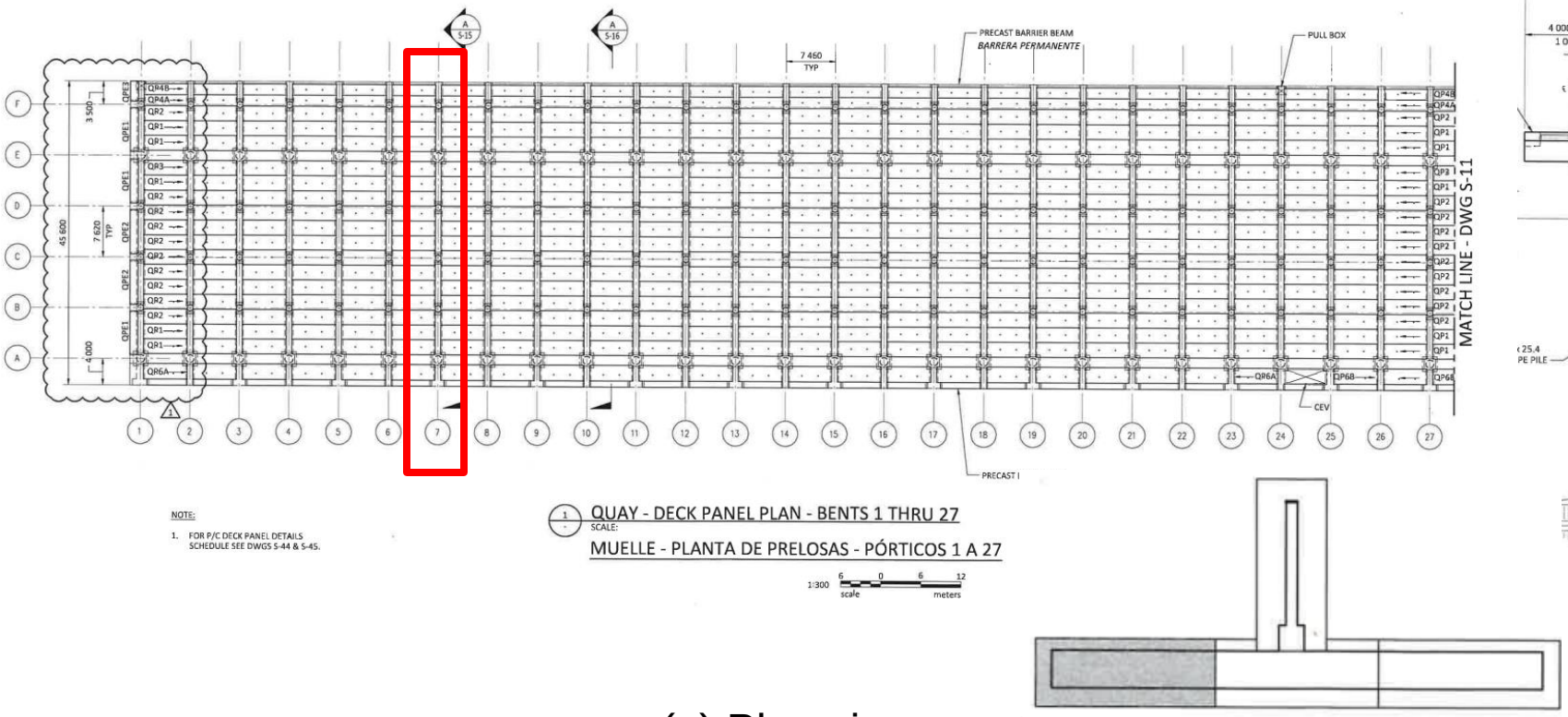
VALIDATION (Flow Velocity)



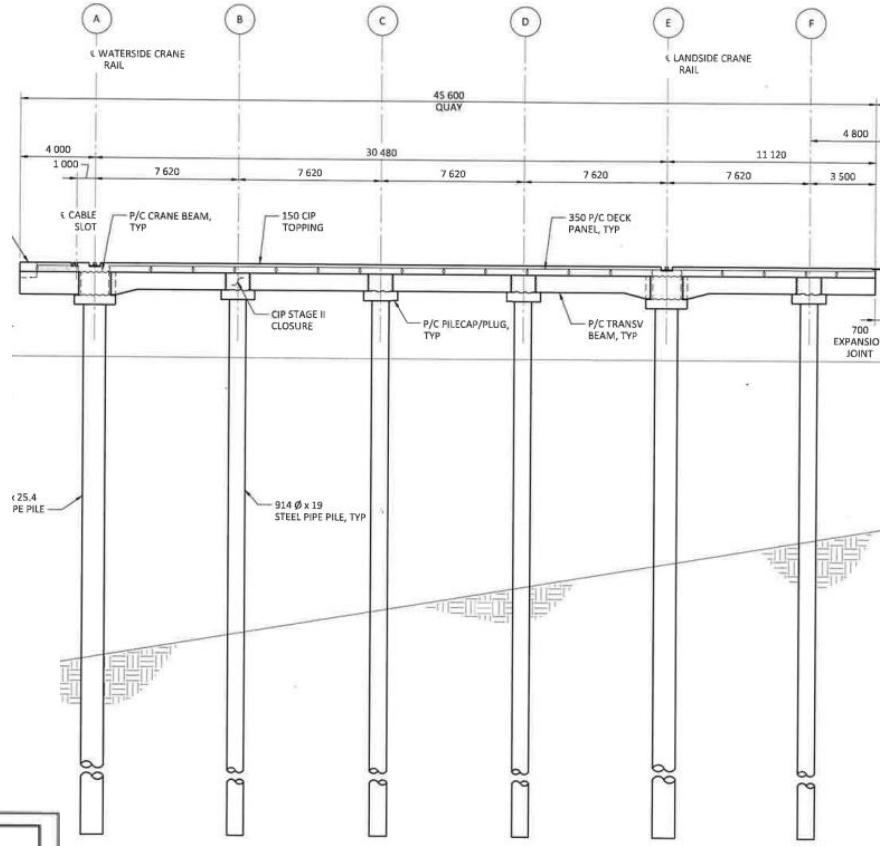
VALIDATION (Pressure Field)



APPLICATION EXAMPLE



(a) Plan view

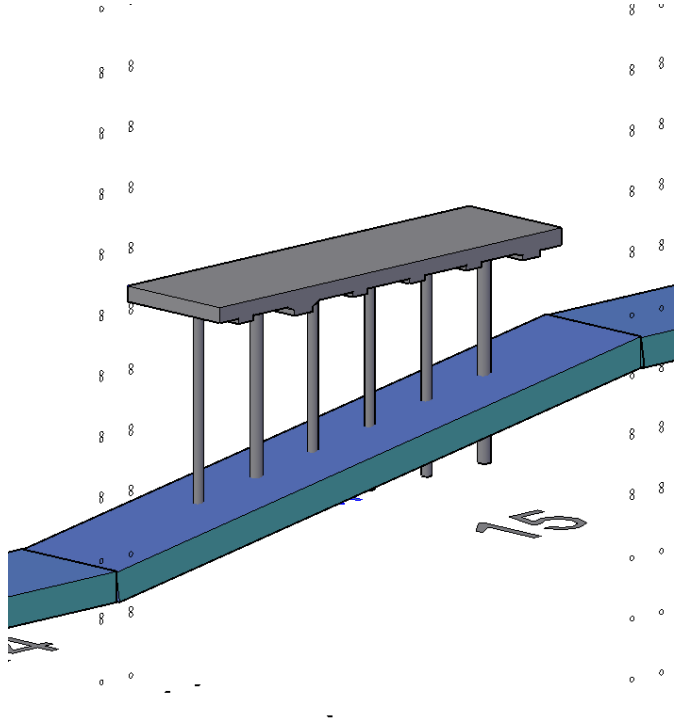


(b) Elevation view

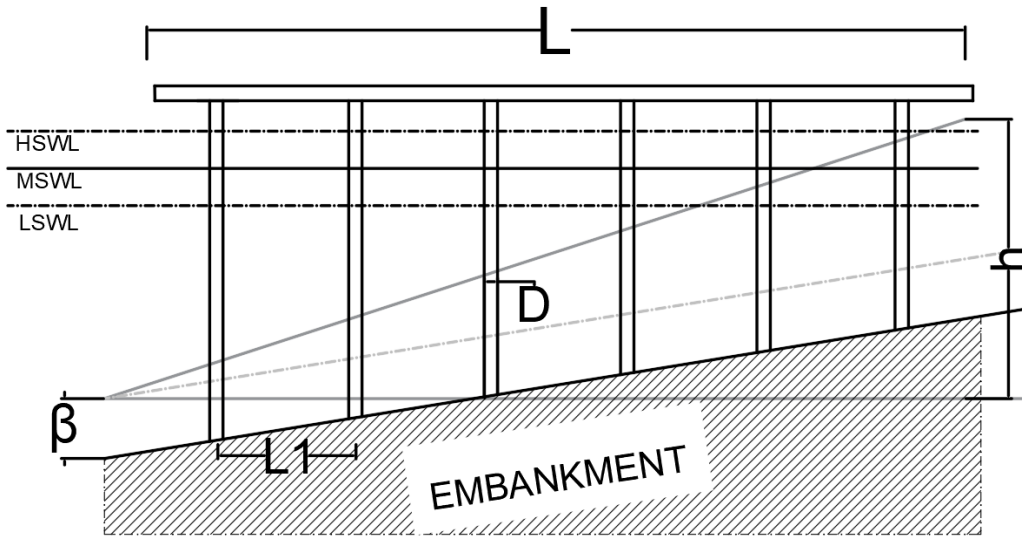
Baseline Model: Existing port in California. Courtesy of **W. (Bill) Bruin, SGH**.

MODELED GEOMETRIES

- Baseline geometry based on real example
- Sensitivity study performed to evaluate parameters affecting responses (horizontal and vertical pressures)
- Some assumptions:
  - Pseudo-3D strip model
  - Inlet flow conditions = Piston generated Tsunami wave
  - Total Number of particles = 3459128
  - Interparticle distance per wave height $\Delta p / h = 10$

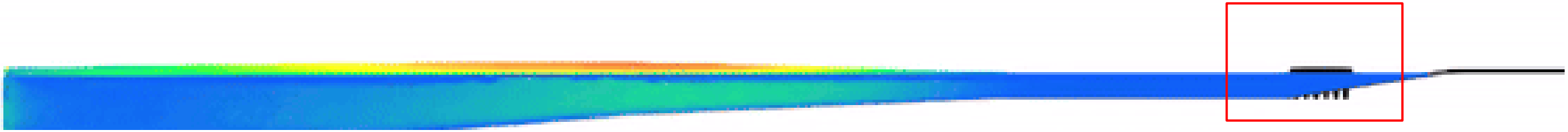


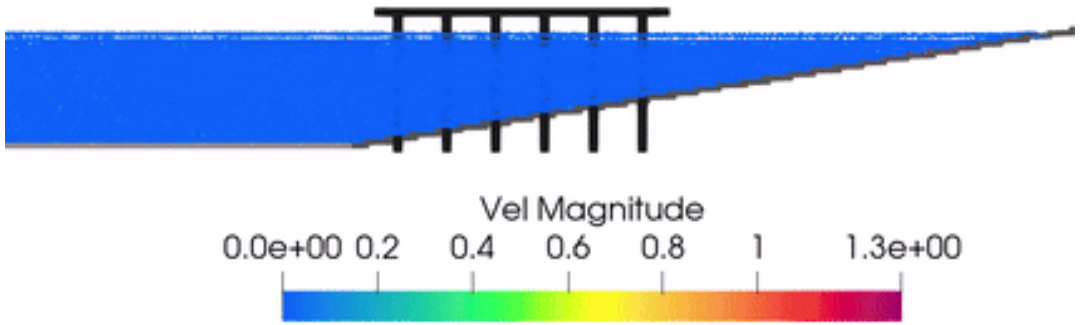
Parameter		Cases			
Comment	[-]	[-]	MIN	BL	MAX
Length (# Spans)	L	[ft]	100	**153**	200
Bottom Slope	l:h	[deg]	0	**1:6**	1:3
Dist between piles	L1	[ft]	20	**25**	30
Diameter of piles	D	[ft]	2	**2.5**	3
Height of piles \ Origin Shift	β	[ft]	55	**65**	75
Water Level	MWL	[ft]	-7	**0**	7
BL: Baseline Geometry					

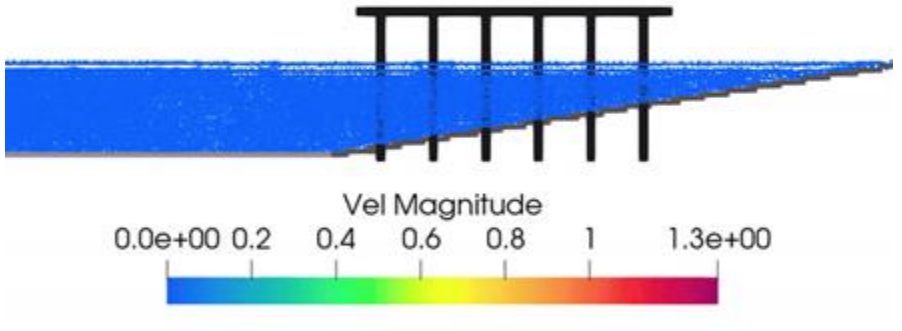


RESULTS

- Max Water Level
- Min Water Level

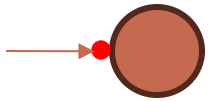




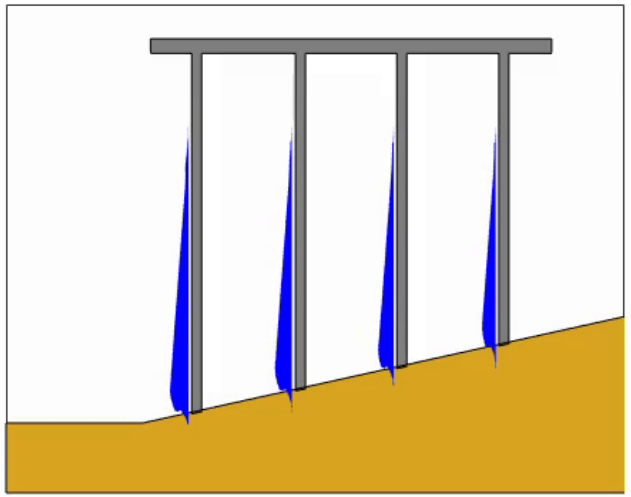


RESULTS (Horizontal Pressures)

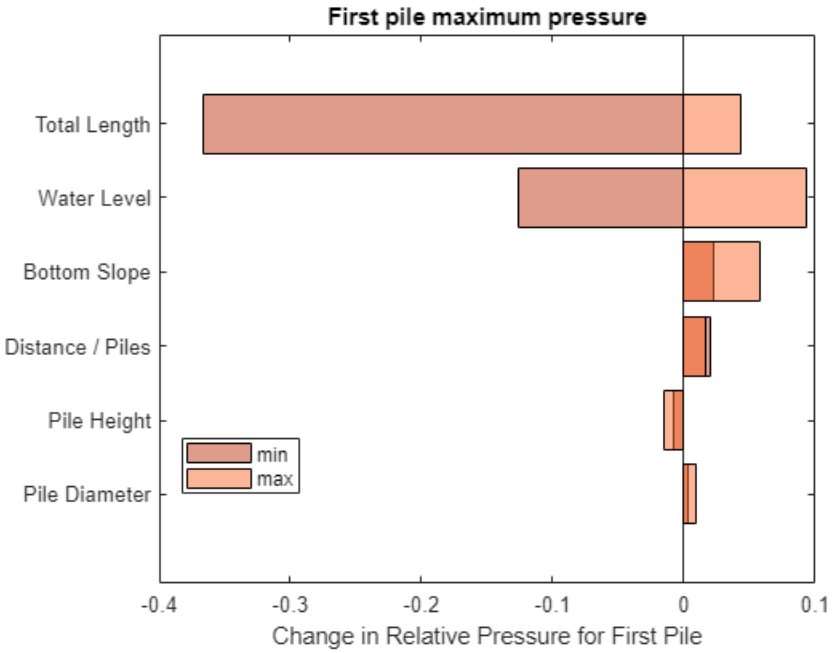
Pressure Measurement

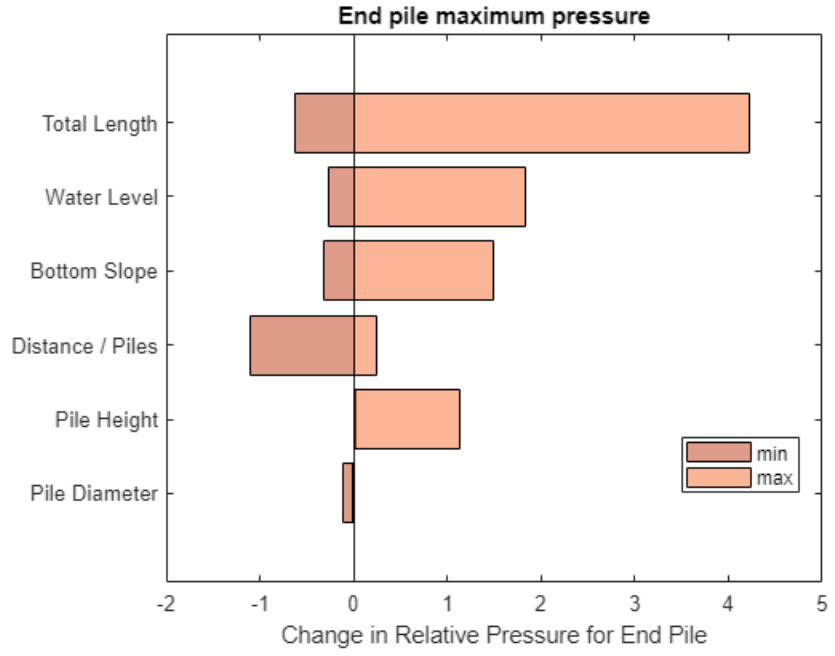


Pile Section

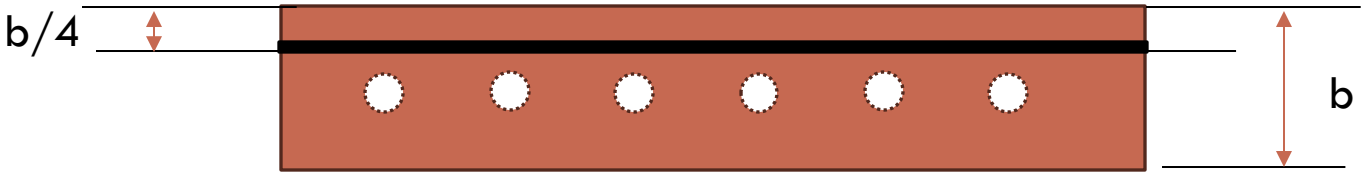


Pressure Series Along Pile Heights



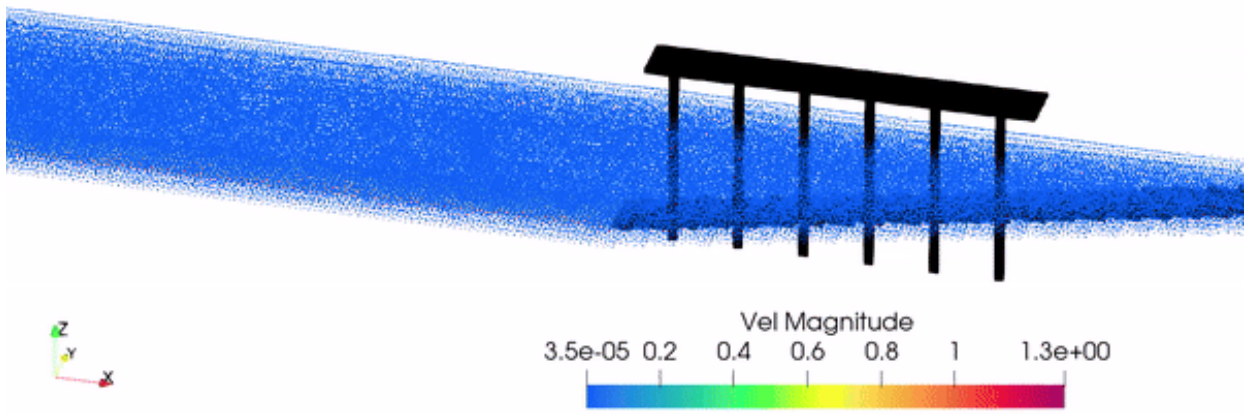


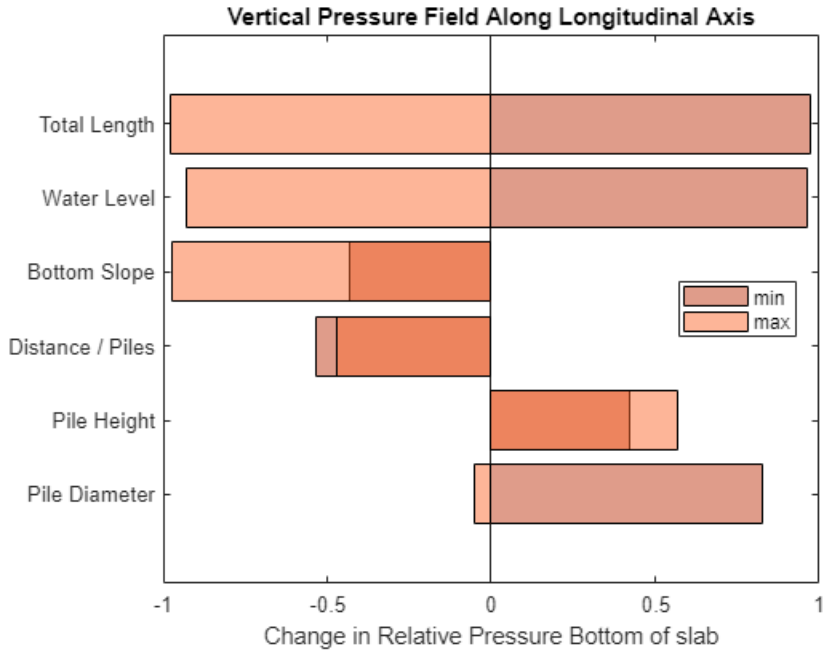
RESULTS (Vertical Pressure)



Pressure measurement location for vertical pressure

Strip model plan view





CONCLUSION (Summary)

- Numerical SPH models were validated for measuring:
  - Free surface elevation
  - Flow velocity
  - Pressure distributions
- Analysis of the Application Example
  - Pressure Field
    - Influence of parameters is similar between the pressure fields on the first pile and bottom of the slab
  - Future work is needed (see next slide)

CONCLUSION (Future Work)

- Tsunami modeling:
  - Evaluate the limitations of the pseudo-3D model
  - Estimate Forces
  - Assess direction wave loading (requires full 3D model)
- Cascading loading modeling:
  - Apply DualSPHysics pressure time-series on advanced nonlinear OpenSees soil-structure models
  - Perform cascading, sequential earthquake ground motion and tsunami loading analysis (SSI, nonlinear time history analyses)

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THANK YOU!

Questions?

EVALUATION OF PRESSURES

Measurements for pressures are executed @ 2dp distance from face of structure