Pre-Test Planning for Experimental Studies on Tsunami-Borne Debris Loads on Bridges

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Outline

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  - Fundamental questions
- Progress-to-date
  - Experiment test matrix
  - Debris tracking
- Acknowledgements

Objectives

- Gain insight into debris impact loads on bridges during tsunami overtopping using both numerical and experimental simulation tools.
  - **Numerical tools** include mesh-based (FEM), particle-based (SPH), and hybrid particle-mesh based (PFEM) methods for simulating debris transport, debris impact and debris damming.
  - **Experimental tool** uses the Large-Wave Flume at OSU for testing a large-scale bridge model subject to range of tsunami-like waves and bores with and without single and multi-object debris in the water.

Objectives continued

- Explore countermeasures to minimize impact loads.
- Develop prescriptive load equations that include the effect of debris for inclusion in the *Design Guideline for Coastal Bridges* under development by PEER for the AASHTO Committee on Bridges and Structures.

Prescriptive equations for debris forces

a) Impulse-momentum approach:

$$F = \frac{\pi m_p v_I}{2\Delta t}$$

F = maximum impact force

m_p = total mass of the debris

v_I = impact velocity of the debris

Δt= time to reduce the debris velocity to zero

b) Work-energy approach:

$$F = \frac{mu^2}{S}$$

S = stopping distance of the debris

Prescriptive equations for debris forces continued

The problem with impulse-momentum and work-energy approaches is that Δt and S are difficult to calculate.

ASCE/SEI 7-10 recommends a value of 0.03 s for Δt.

Coastal Construction Manual recommends values from 0.1 to 1.0 s.

c) Flexible impact approach:

$$F_i = 1.3u_{max}\sqrt{km_d(1+c)}$$

k = effective stiffness of the debris

m_d = total mass of the debris

u_{max} = flow velocity

c= hydrodynamic mass coefficient

Participants

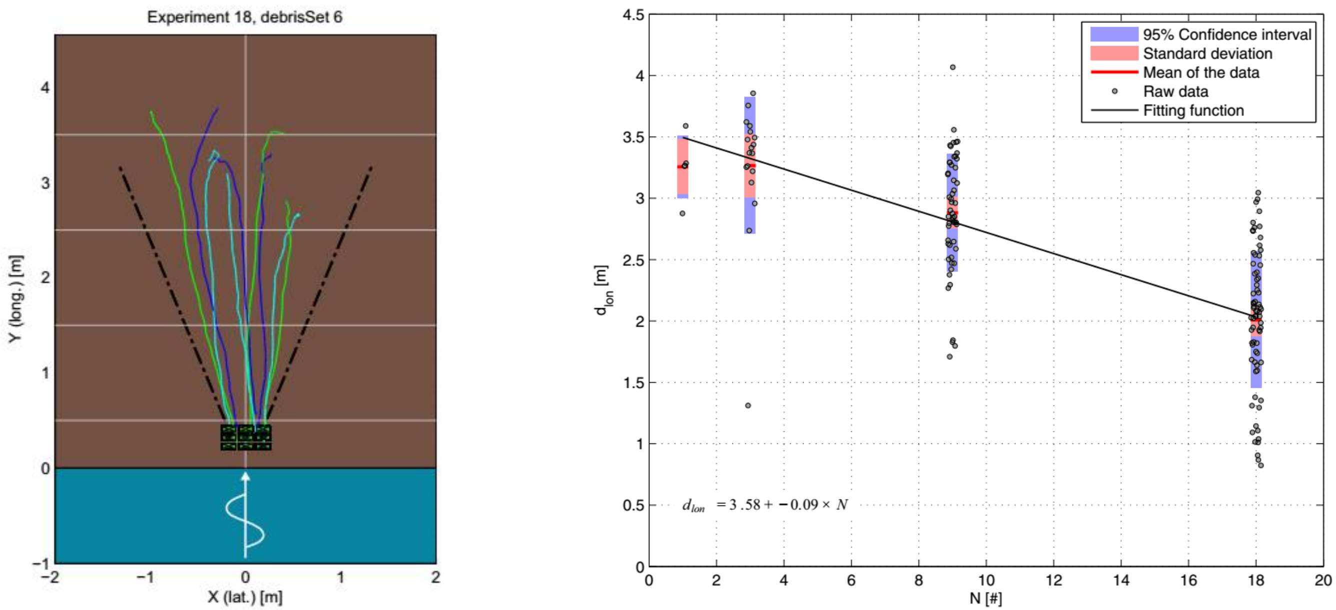
- Ian Buckle, Principal Investigator, UNR
- Denis Istrati, Co-Principal Investigator, UNR
- Seddigheh (Anis) Hasanpour, Graduate Assistant, UNR
- Michael Scott, Co-Principal Investigator, OSU

Background: challenging issues

1. Multi-disciplinary topic involving coastal engineers, hydraulic and structural engineers. Multi-physics simulations are necessary.
2. Field of fluid-structure interaction is in its infancy. Realistic numerical modelling of tsunami overtopping a bridge requires a multi-phase flow in combination with FSI. Only a few software packages have these capabilities. Only limited validation has been done with experiments at reasonable scale.
3. Past work on debris impact has focused on simple building-like structures. Nothing currently available for tsunami debris impact on bridges. Is the debris impact, damming and inundation process the same in the two types of structures?

Background: challenging Issues (continued)

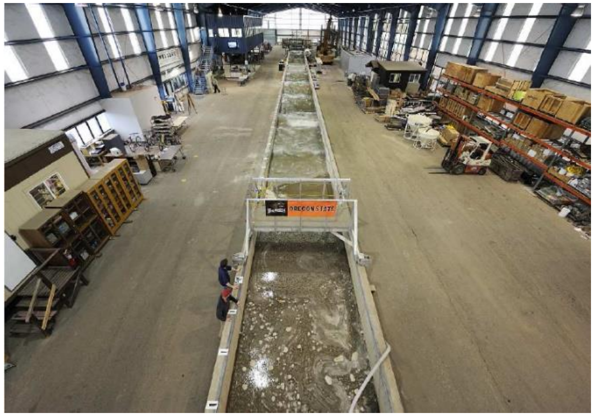
5. Debris transport involves significant uncertainties, which can affect the trajectory, as well as the velocity and orientation of the debris when it impacts a structure. Predictive equations may need to be probabilistically-based.

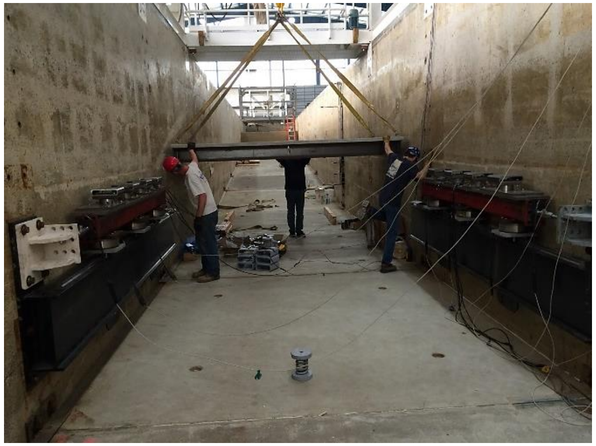


Debris trajectories of 9 containers (left), maximum longitudinal displacement of debris units versus total number of debris (right), (Nistor et. al., 2017)

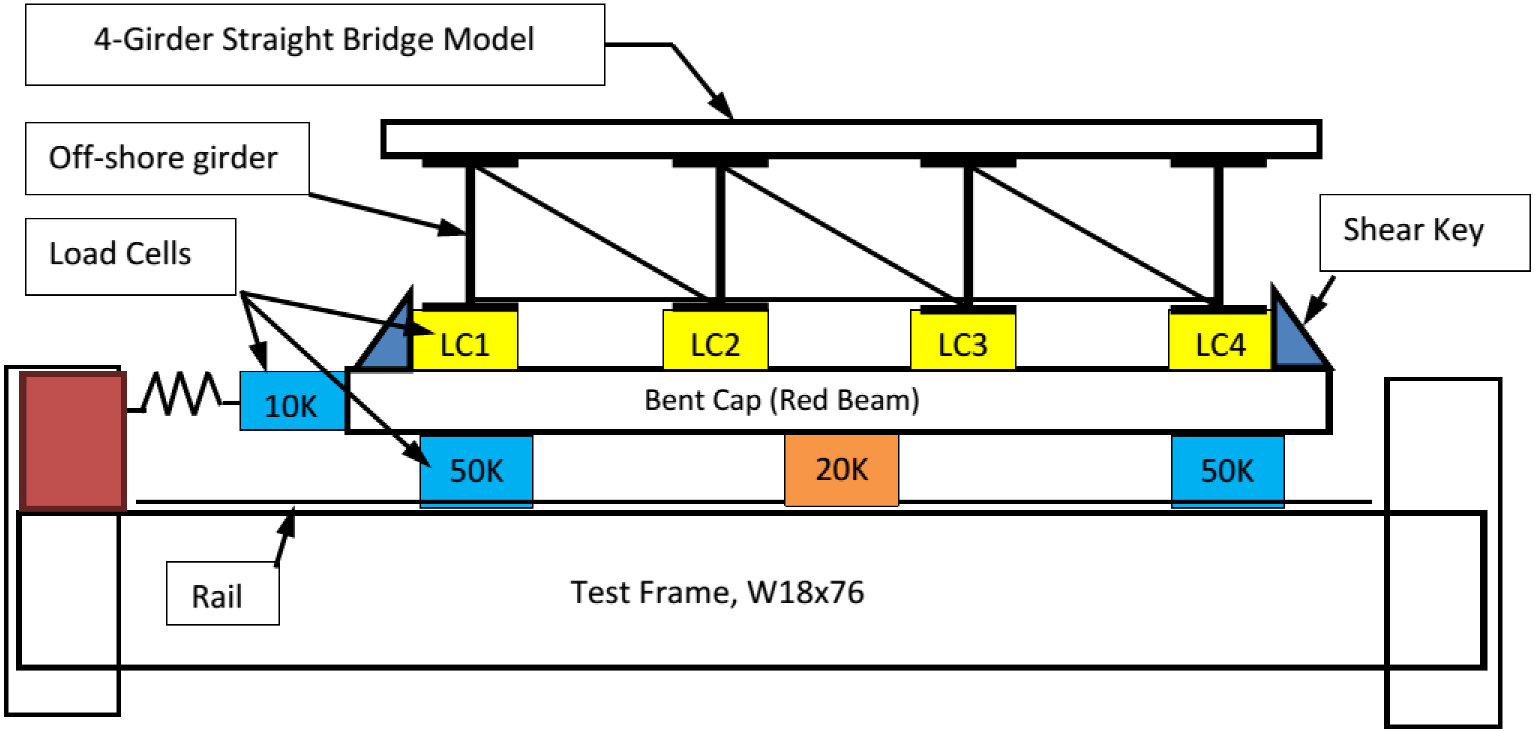
Background: previous UNR Experiments at OSU

- Installed 'large-scale', single-span, bridge in 100 m wave flume at OSU, and ran family of solitary waves and bores.
- Explored the role of structure flexibility, air entrapment, air venting, and skew.
- Clear water experiments only.
- Extensive instrumentation allowed measurement of total horizontal and vertical forces on bridge, and the distribution of these forces to connections and substructures.



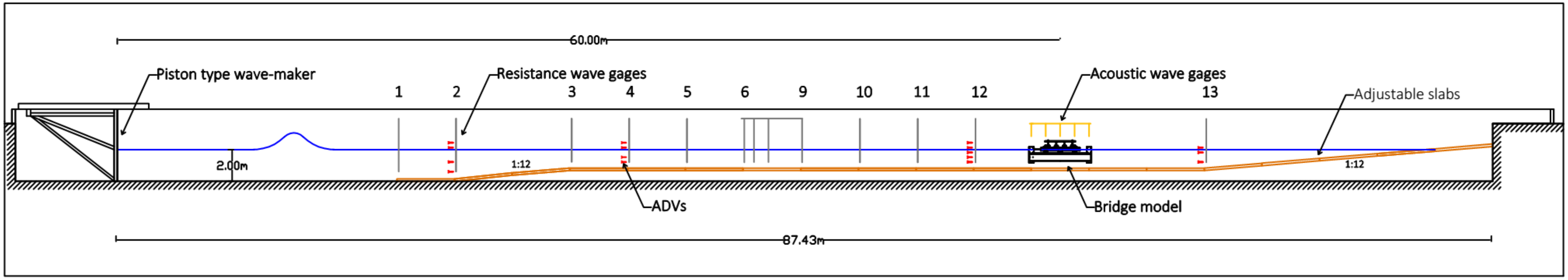


Background: bridge setup and load cell configuration

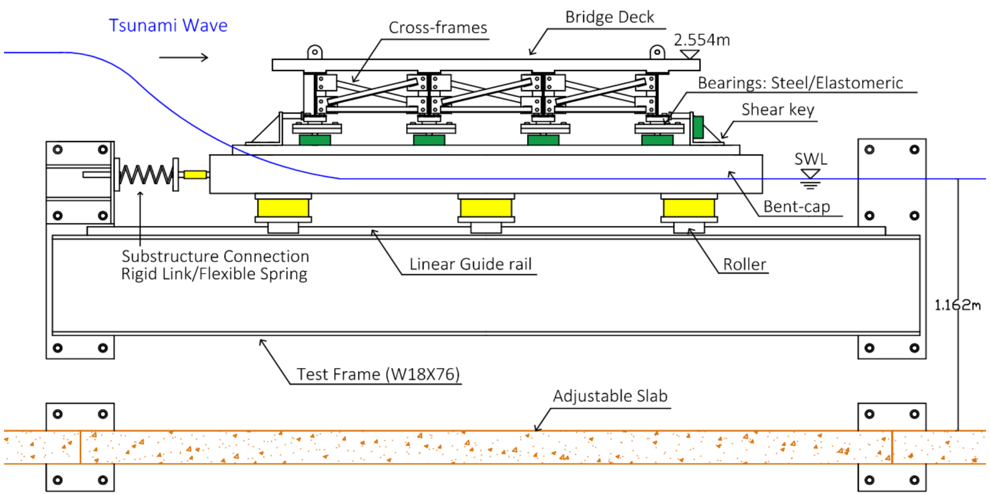


Load Cell Configuration Straight Bridge:

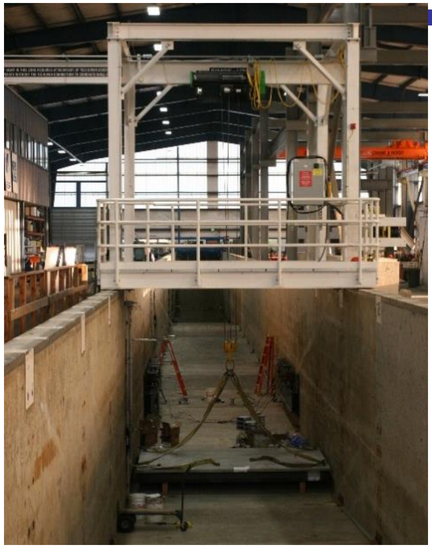
Background: flume bathymetry and instrumentation



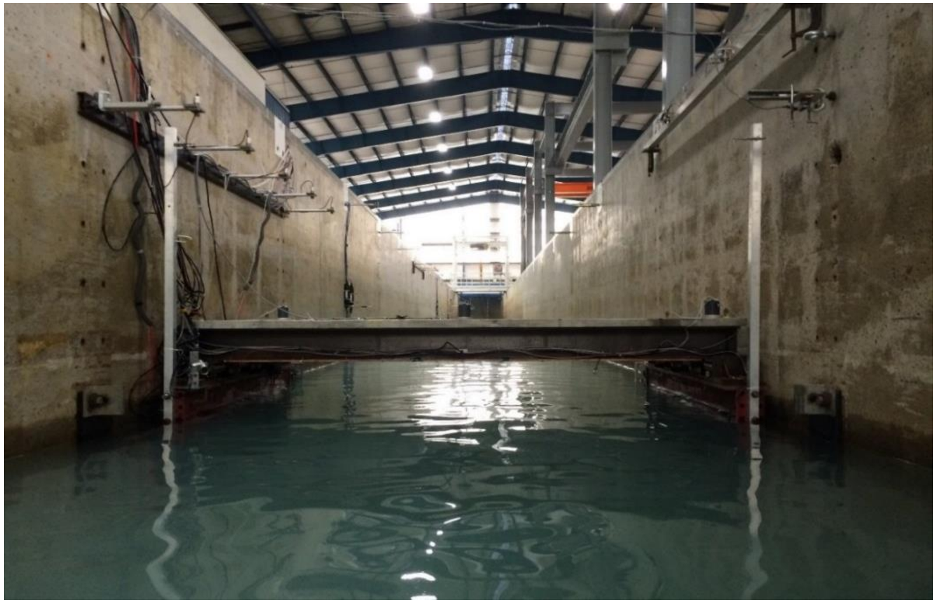
- 13 resistive-type wave gages to measure wave height and capture the evolution of the tsunami wave
- 5 ultrasound gages to track overtopping of the bridge
- 16 Vectrino-II ADVs to measure wave velocities at certain locations
- 2 pressure gages co-located with two velocity profiles



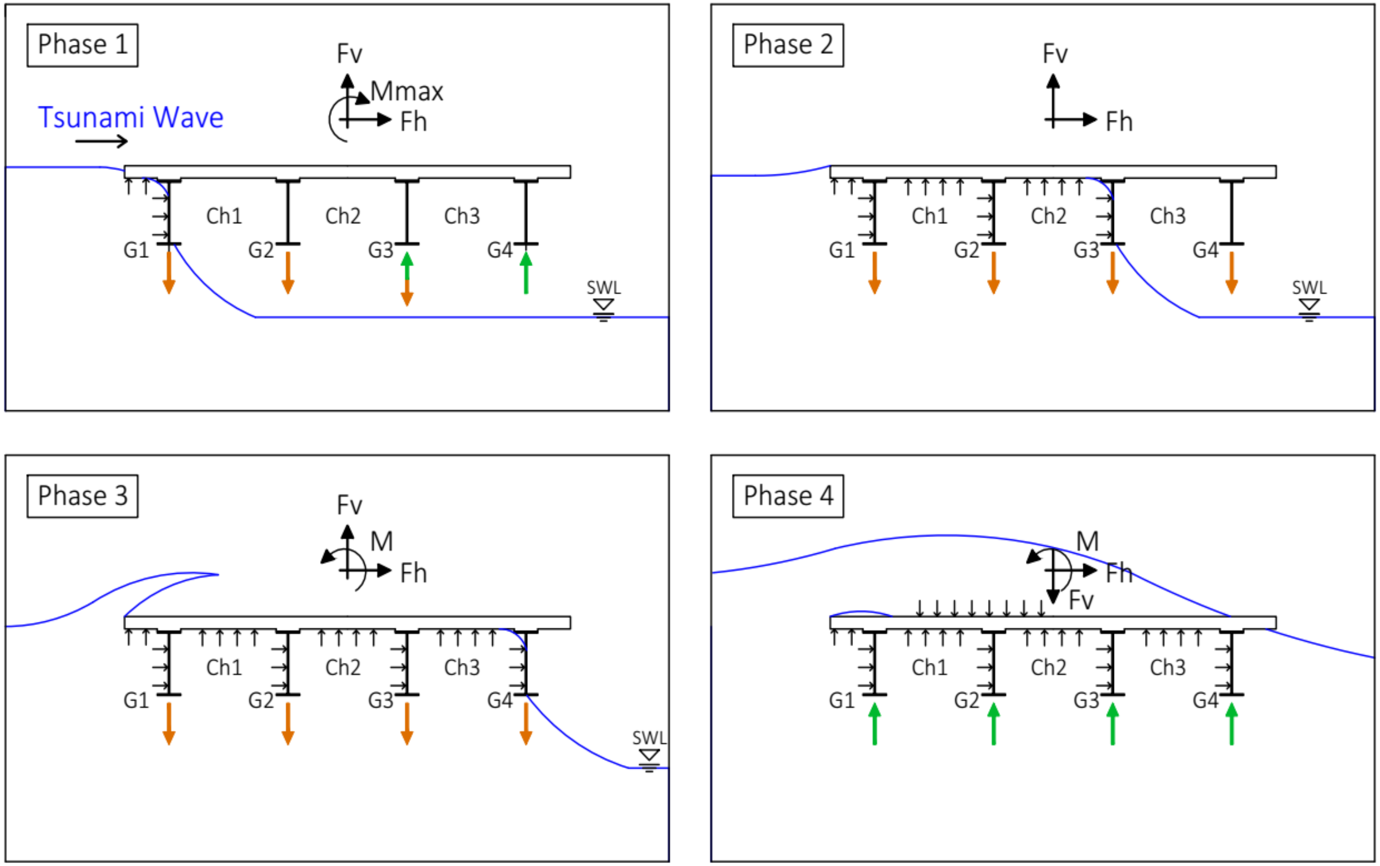
Background: installation of bridge model in the flume







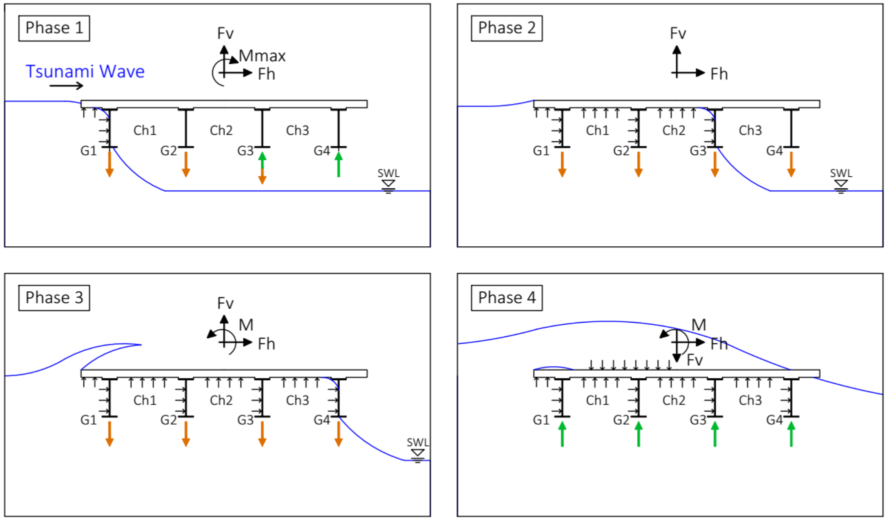
Background: inundation phases of an open-girder bridge



How are these phases influenced by debris impact and damming?

Fundamental questions:

- Will the existence of waterborne debris modify the bridge inundation mechanism?
- How will the debris affect the applied forces and overturning moments?



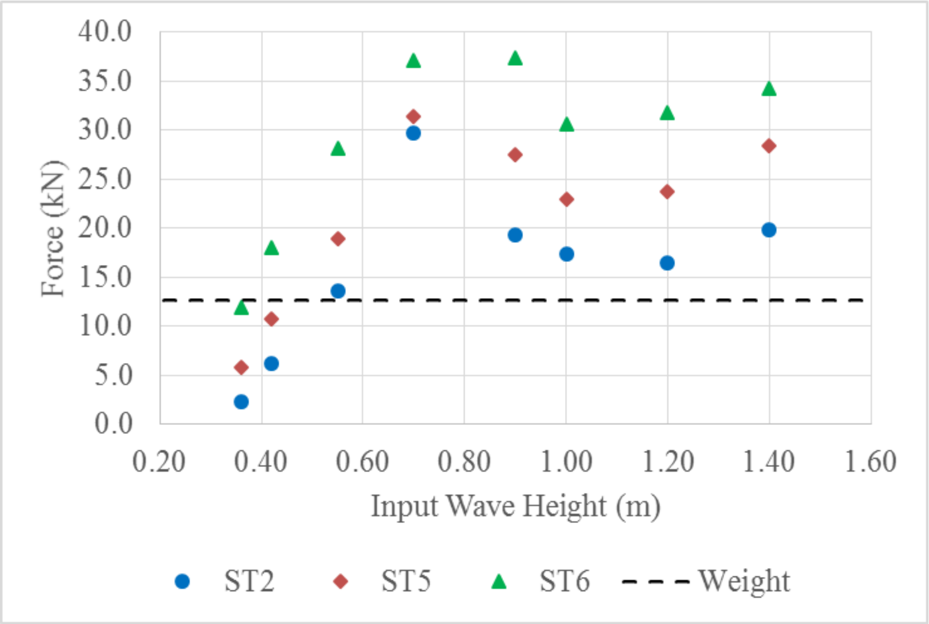
- What will be the distribution of this loading to the structural components? Will it be a local effect on the offshore girder or will the effect be transferred to other girders and connections as the inundation progresses?

- Will the debris get trapped inside the chambers and generate additional quasi-steady/damming loads?

Fundamental questions, continued:

Major differences in uplift forces observed for different bridge types:

- Open-girder bridges with cross-frames
- Open-girder bridges with diaphragms, and
- Box-girder bridges



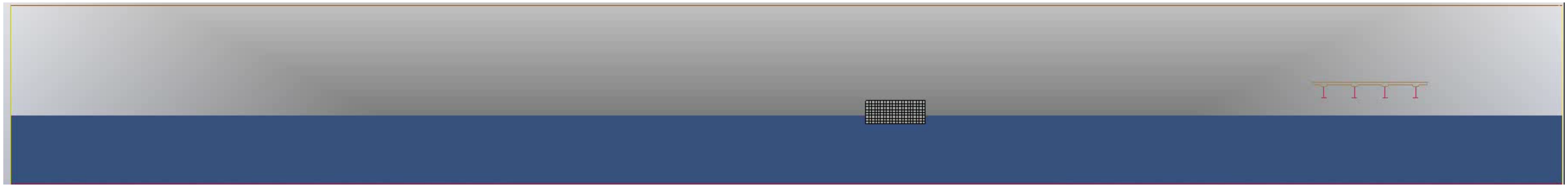
Box-girder bridges are subject to significantly larger uplift forces than open-girder bridges. On the other hand, open-girder bridges could potentially trap debris within the chambers? So…

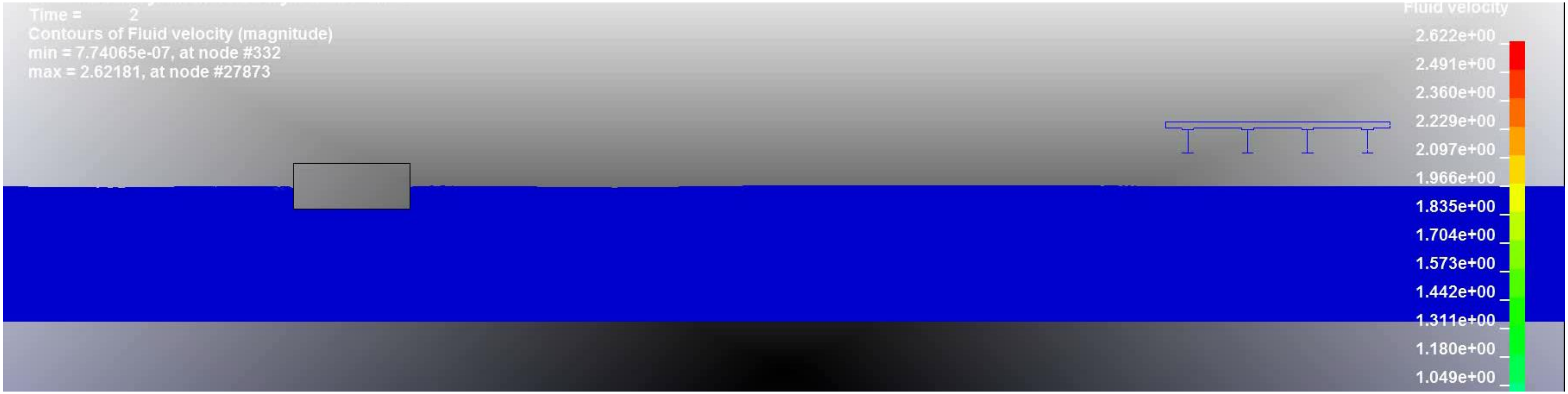
- Which bridge type is more advantageous for tsunami-prone areas?
- How would the debris impact and damming loads change for the different bridge types?

Fundamental questions continued:

Wave type expected to play significant role in response.

1) Experiments with tsunami-like solitary waves have good repeatability and easier to simulate numerically. But their ability to transport debris is limited



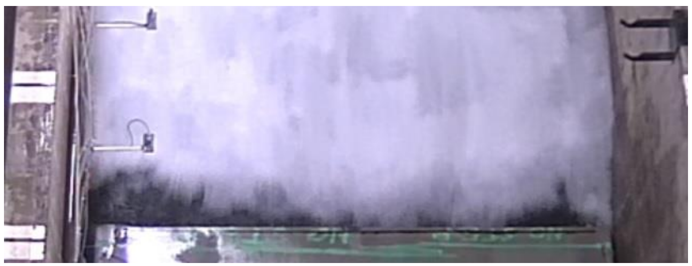


Fundamental questions continued:

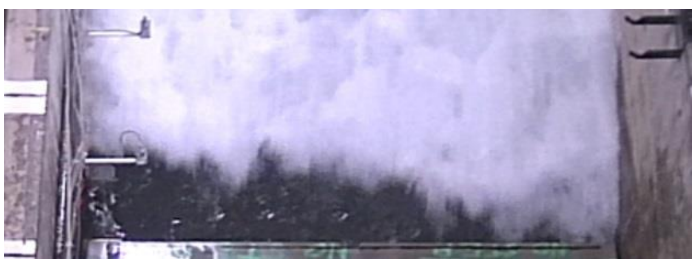
2) Bores are more realistic but have very high variability (poor repeatability) due to the chaotic (plunging type) wave-breaking process.

Bore 1.40m (Instant before impact)

Run 1



Run 2



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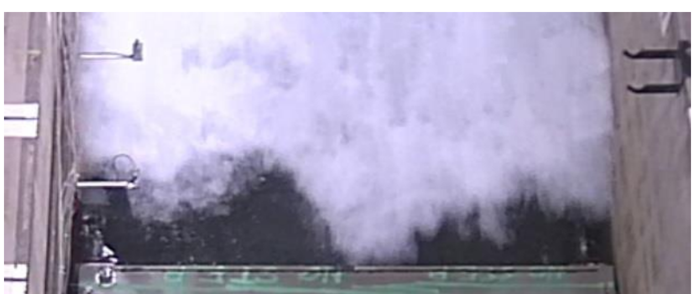
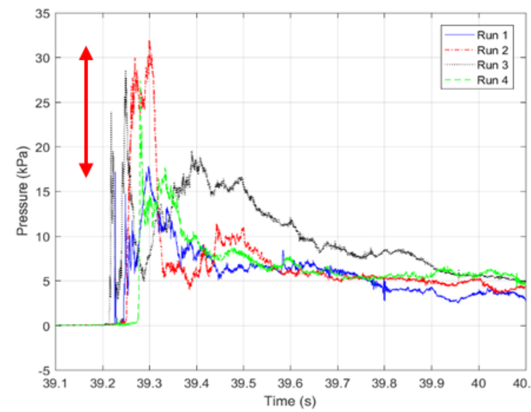
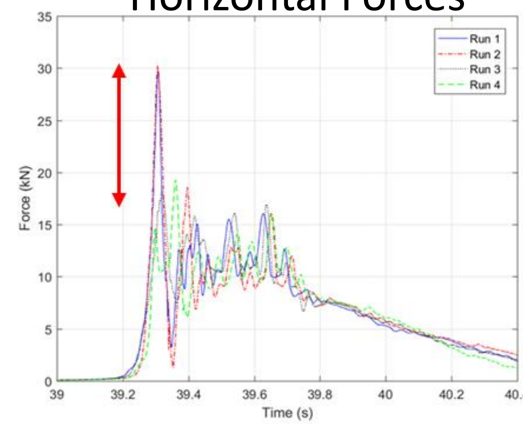


Pressures on Offshore Girder



Horizontal Forces



Fundamental questions continued:

This can lead to variability in the recorded wave height histories, spatial distribution of fluid particles across the width of the flume and in the hydrodynamic forces.

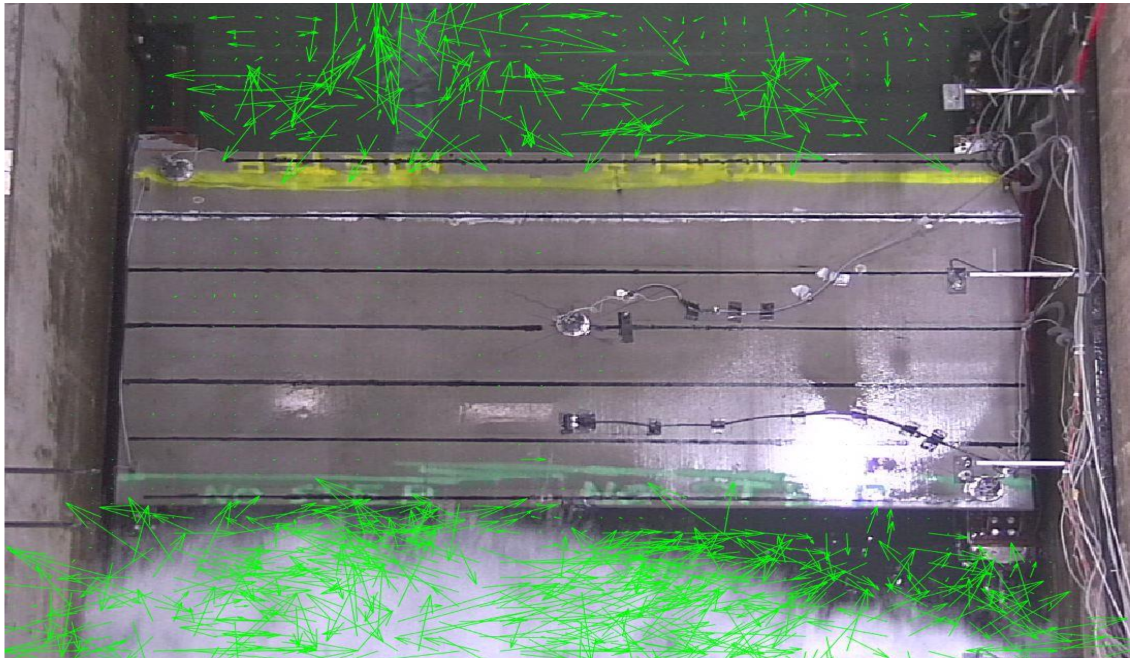
How is the spatial variability going to affect debris transport and impact on the bridge?

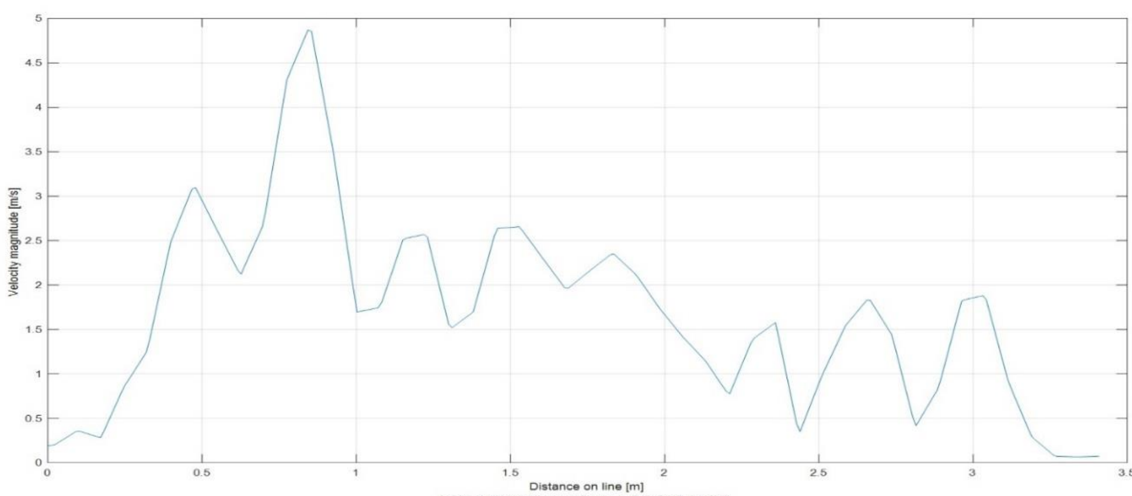
Fundamental questions continued:

How to monitor wave and bridge response and track debris?

- Wave and bridge response
  - Wave gages, ultrasound gages, Vectrino-II ADVs pressure gages, accelerometers and displacement transducers, and load cells in shear keys, substructure springs, bearings and bent caps
- Debris tracking
  - High-speed cameras and computer vision methods to track fluid velocities and debris motion
  - Debris mounted sensors (GPS or equivalent)
  - Both of above

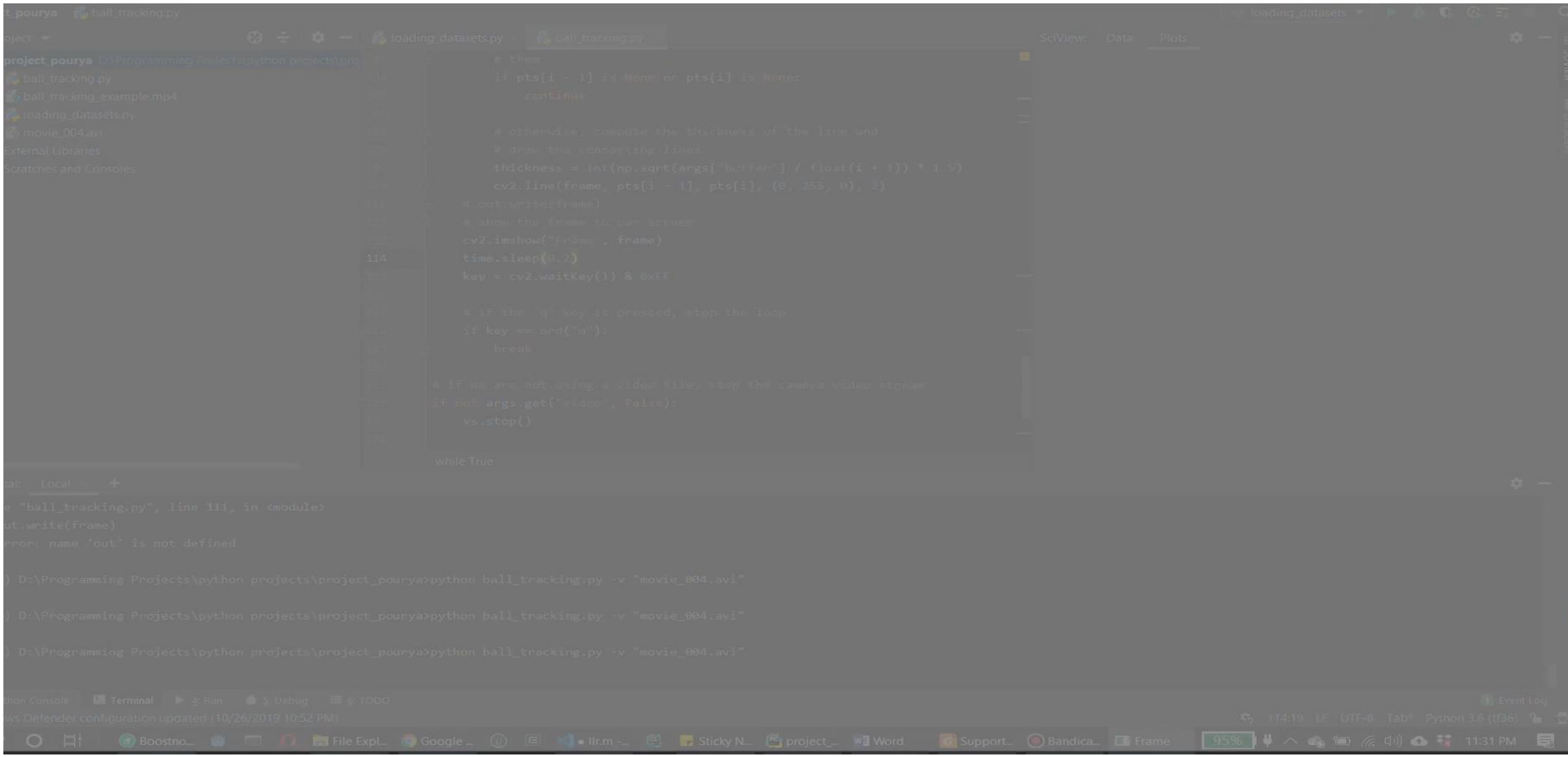
Particle image velocimetry (PIV) for tracking debris





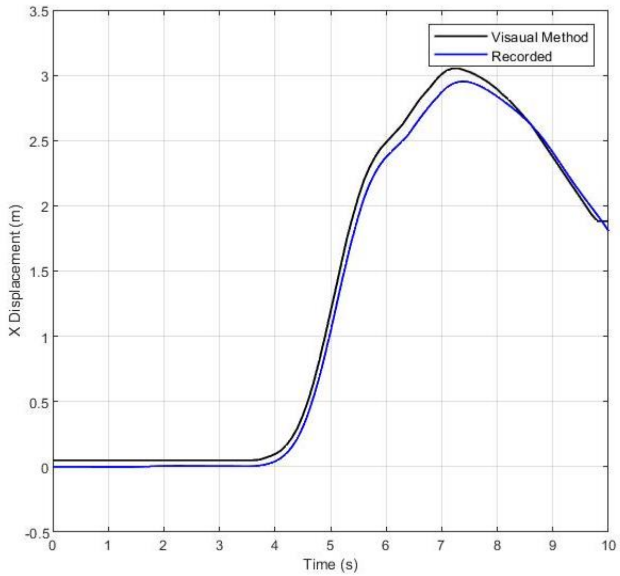
Color imaging for tracking debris

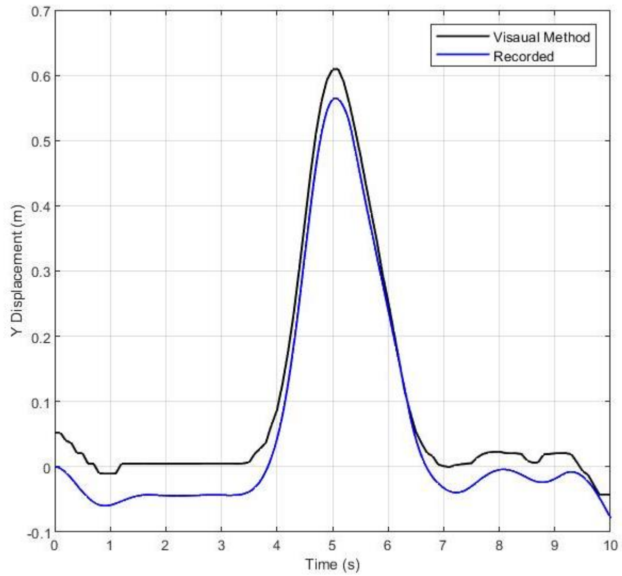
Color Tracking



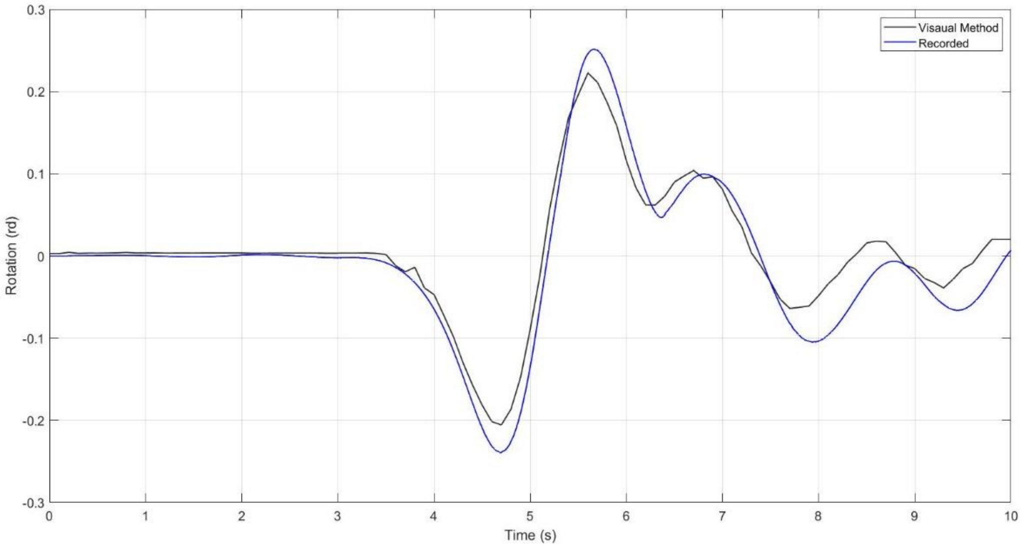
Color tracking of debris

Automated Color Tracking





Avoids time-consuming manual post-processing of videos for PIV



Pre-test planning of debris experiments

1) Determine type and scale of debris objects:

- Large objects representing containers, vessels, tree trunks…
- Small objects representing, say, building materials
- Single object vs multi-object tests

2) Develop test matrix based on matrix used for clear-water experiments e.g. wave heights, wave types (solitary waves and bores), substructure stiffness, and debris testing sequence. Review matrix with Director and staff, Hinsdale Wave Research Laboratory at OSU.

Pre-test planning of debris experiments

3) Conduct experiments in flume at UNR to evaluate debris tracking options and make final selection (computer vision vs color tracking vs GPS or equivalent).

4) Plan mobilization to Corvallis: transportation of bridge model, test fixtures, supplementary instrumentation, and personnel; arrange accommodation and safety training.

5) Conduct experiments in Spring 2020…

Acknowledgements

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  - Pacific Earthquake Engineering Research Center
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  - Director and staff, Earthquake Engineering Laboratory, University of Nevada Reno


Thank you!