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Tsunami inundation and forces on coastal communities

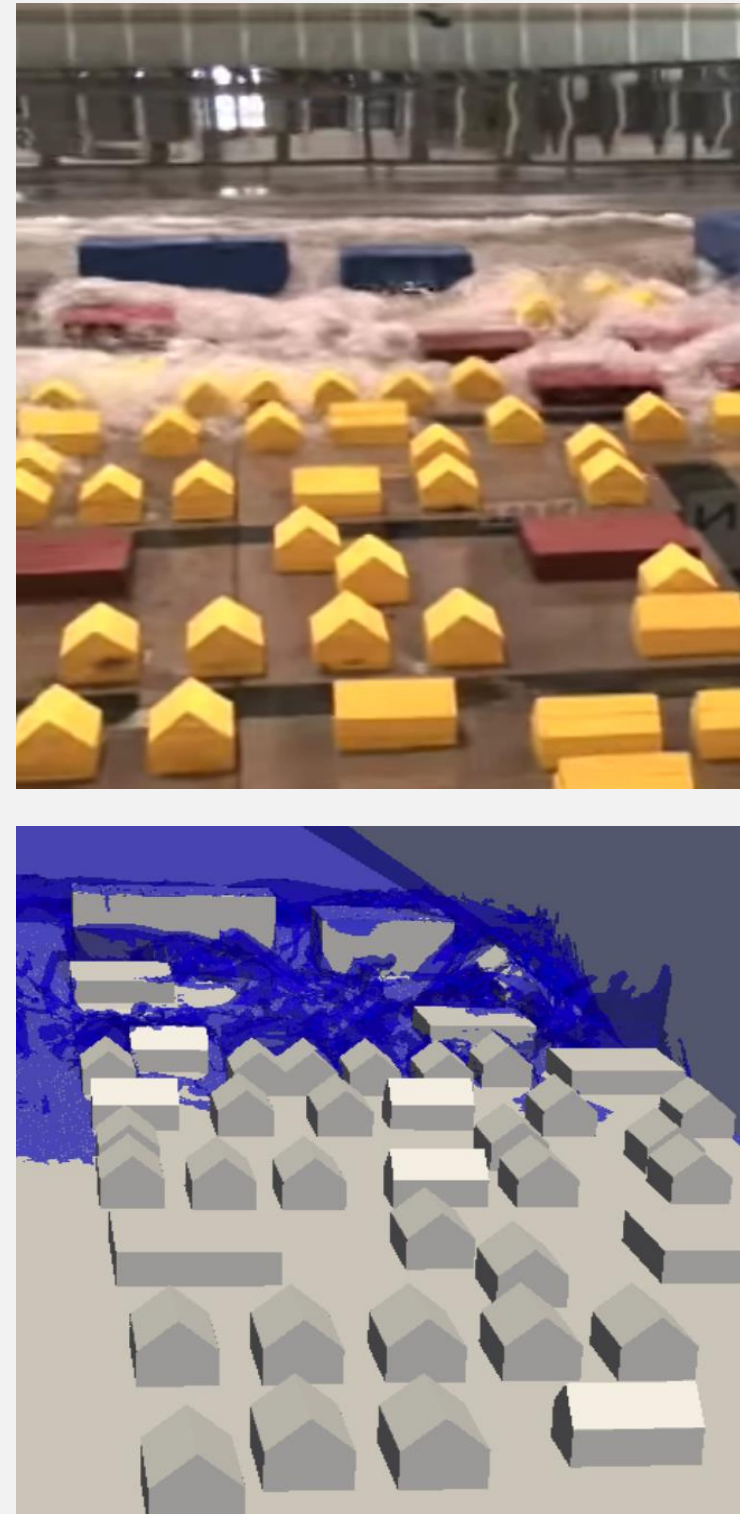
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INTRODUCTION

For the past decade, research on modeling of tsunami inundation has mostly focused on modeling tsunami run up on 2D slope or 3D topography with complex shoreline. But few of them simulate **flows overland** especially flows around the **macro-roughness** onshore like groups of buildings near shoreline. In this study, two different numerical approaches were used to model community-scale tsunami inundation: a high-fidelity 3D **Computational Fluid Dynamics (CFD)** approach and a 2D approach based on **depth-averaged shallow water equations**. The numerical models were first validated against existing experimental data of a 1:50 idealized model of the town Seaside, Oregon. For the 3D approach, the experimental basin was modeled using 4 separate subsections due to limited computational resources. The 2D approach was able to model the entire basin in a single simulation with much more efficiency.



SIMULATION METHODOLOGY

In this study, two different numerical approaches were used to model the inundation.

2D Simulations:

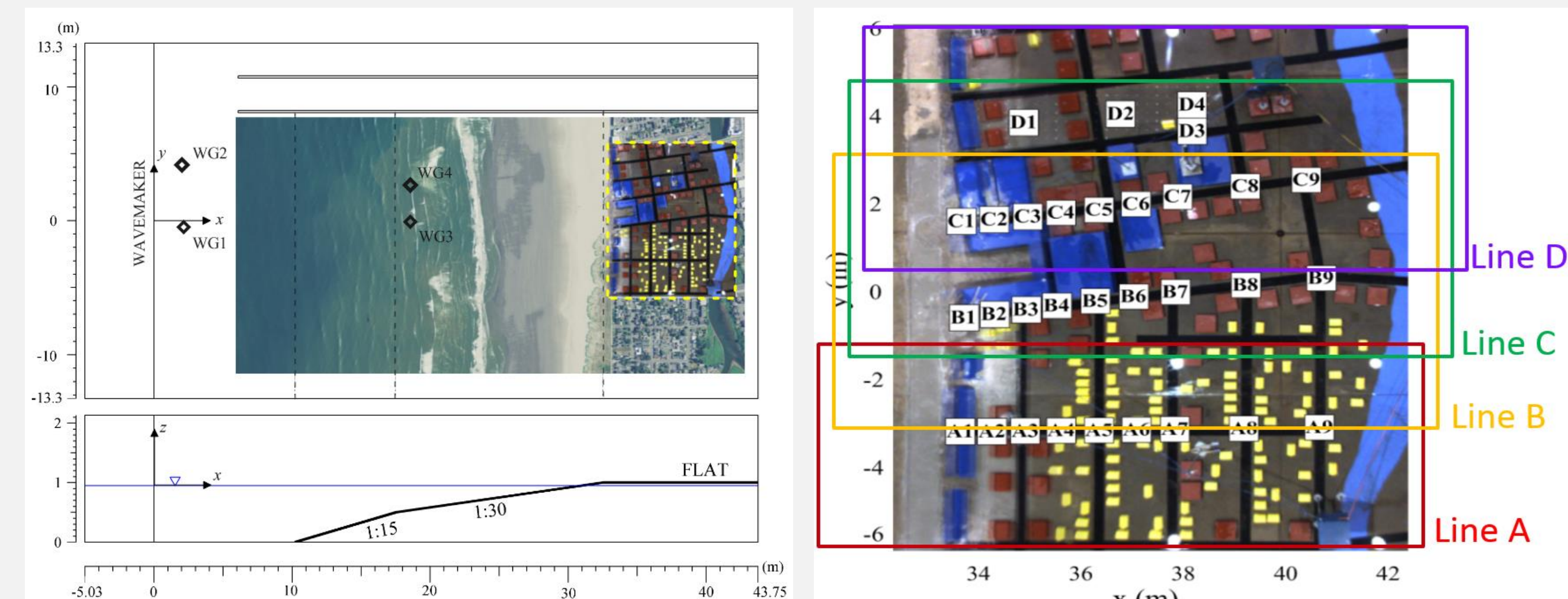
- Depth-averaged shallow water equations solved using open-source package **GeoClaw** with high-resolution finite volume methods and Adaptive Mesh Refinement (AMR) techniques.
- Typical computation time: 5-6 hours with 1 computer core

3D Simulations:

- CFD models developed using open-source CFD package **OpenFOAM**
- Typical computation time: 8-10 days with 128 computer cores in parallel
- Domain subdivided into four sections to improve computational efficient
- Allows for direct computation of forces and moments on structures

FLOW THROUGH A COMMUNITY

An experiment on tsunami inundation through an urban waterfront was conducted at Oregon State University. A 1:50 scale model of part of the town of Seaside, Oregon, located on the U.S. Pacific Northwest coastline and adjacent to the Cascadia Subduction Zone (CSZ), was constructed and a series of experiments were conducted to measure flow velocities and water levels at 31 locations within the model-scale community (Park et al., 2013). The rectangular basin is equipped with a segmented, piston-type wave maker to simulate tsunami inundation. The figure below on the left shows top view and side view of the basin superimposed with the experimental setup and an image of the town of Seaside. In the front of the town, there was seawall with a height of 0.04 m (model scale). The figure below on the right shows the locations of the 31 gauges where **water level and flow velocity were measured** in the experiment, numbered A1-A9 (Line A), B1-B9 (Line B), C1-C9 (Line C), and D1-D4 (Line D), and 4 different subsections modeled in 3D simulation.



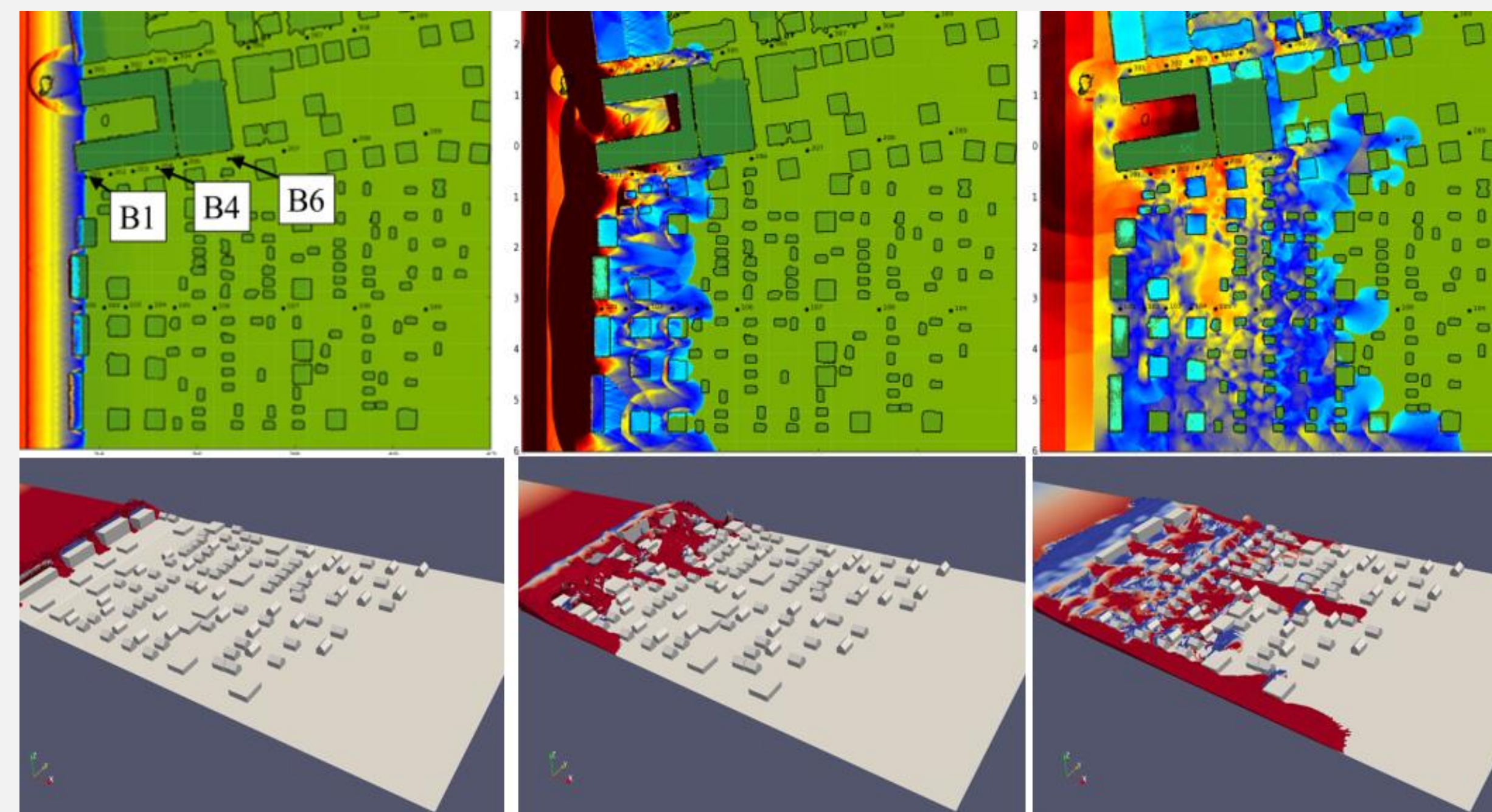
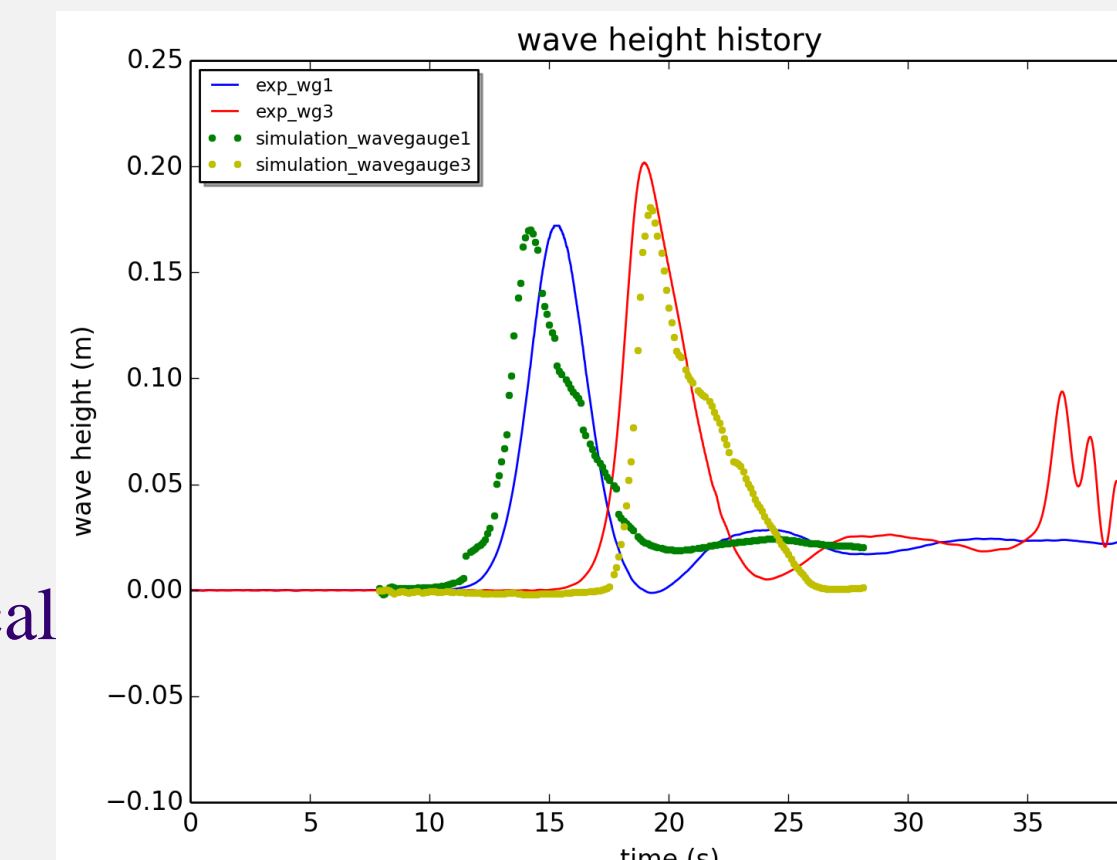
Figures adapted and modified from Park et al., 2013

FREE SURFACE ELEVATION, VELOCITY AND MOMENTUM FLUX

Wave generation

The figure at right shows time history of wave height at two wave gauges offshore.

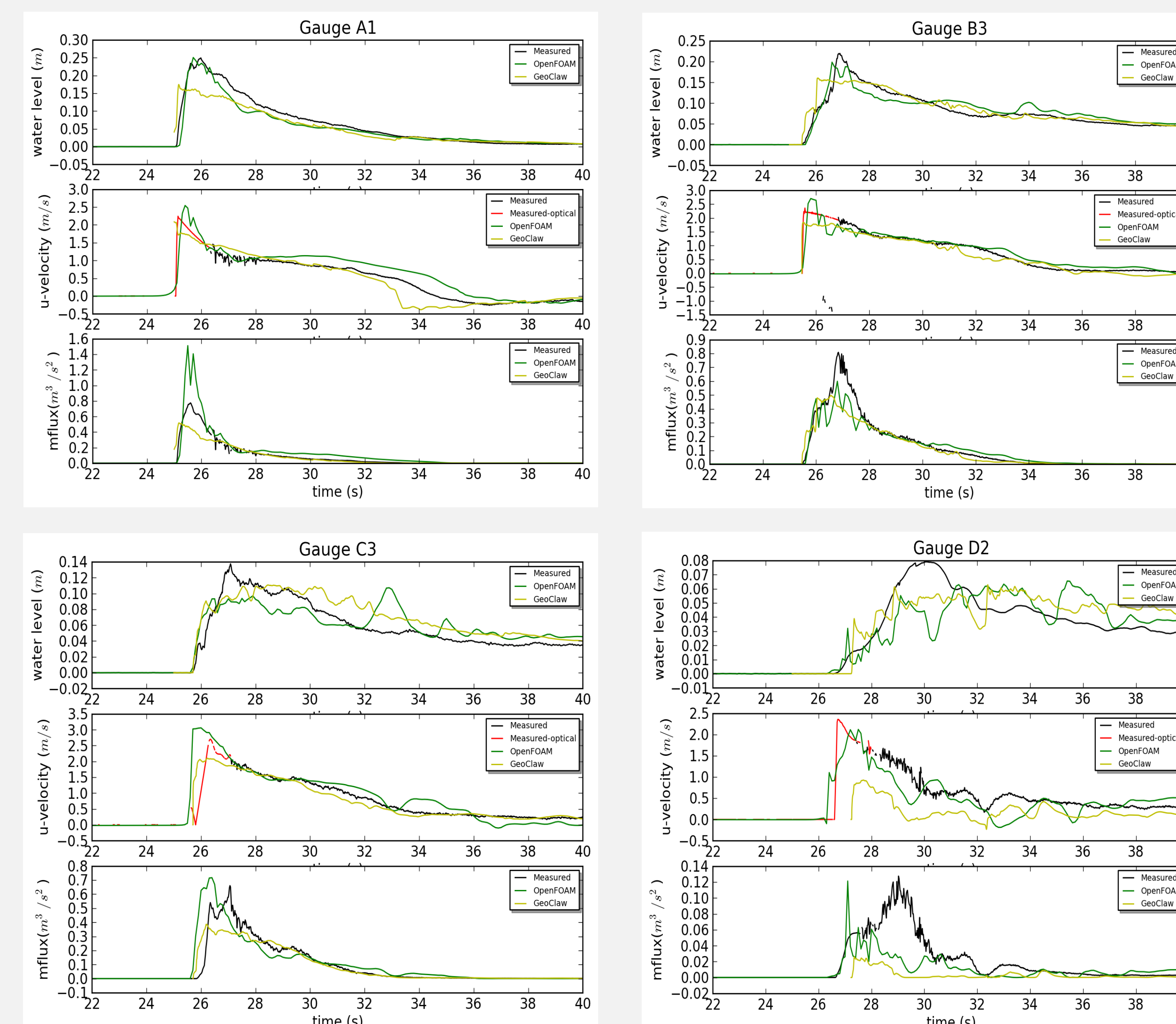
- Good correlation between the measured and predicted results
- the tsunami waves generated in the numerical underestimated and had slightly slower propagating speed.



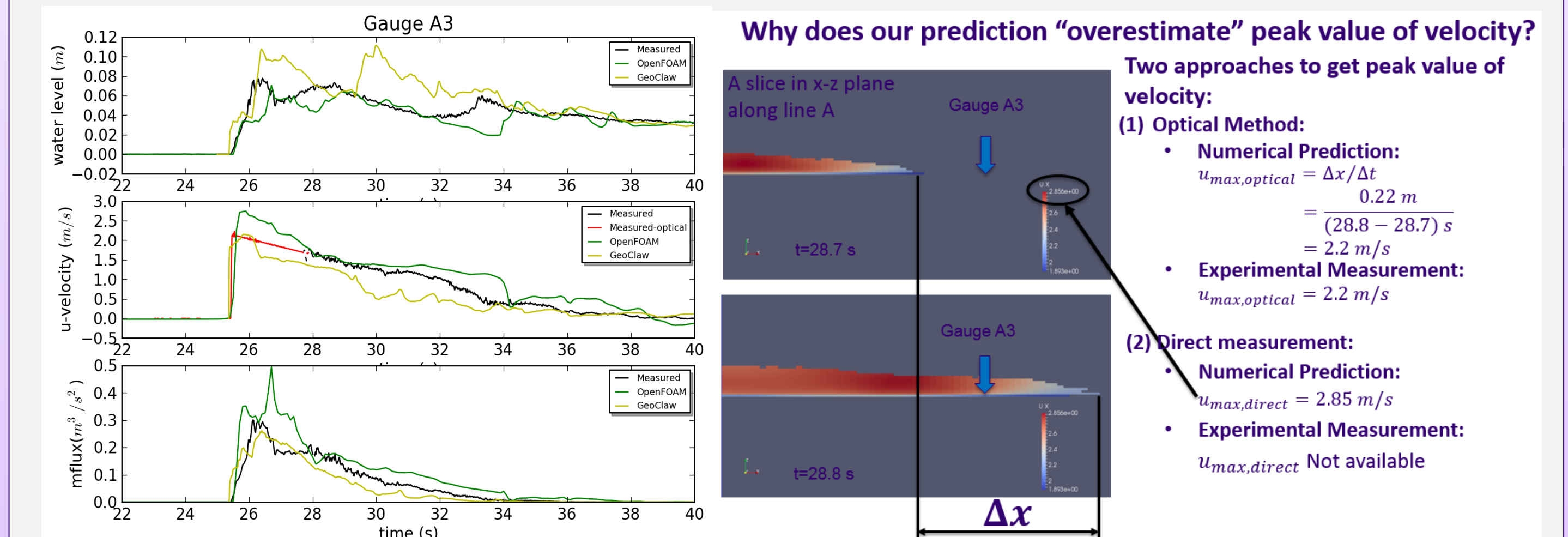
The figure above shows snapshots of the inundation process at 3 different moments (Top: GeoClaw. Bottom: OpenFoam, subsection A).

Free surface elevation, velocity and momentum flux

Free surface elevation, h , cross-shore component of velocity, u , and momentum, hu^2 , at selected gauges onshore are shown below (Black and red: measurement. Green: OpenFOAM. Gold: GeoClaw). Prediction and measurement agreed well, except for that velocities and momentum flux showed large discrepancies around the peak.



Overestimation of peak value in velocity



Experiment:

- Direct measurement failed, as acoustic doppler velocimeters failed to record velocity
- Optical methods were used to estimate velocity, for example 2.2 m/s (gauge A3)
 - Peak value of velocity history was computed by analyzing trajectory of leading edge of the bore from image data (Rueben et al., 2011).
 - Then the red solid line in velocity history was obtained by fitting a second order polynomial curve from peak value to later time histories.

OpenFOAM:

- Direct measurement showed 2.85 m/s at gauge A3, shown with green solid line
- As shown in the contours above, maximum velocity does not occur at the front edge of the incoming bore
- Simulating the optimal method, the fluid velocity is approximately 2.2 m/s at gauge A3, matching experimental results

Conclusion: Using optical methods to obtain peak and/or missing data in velocity may be problematic and can underestimate velocity peaks. This becomes critical for force prediction, as forces are proportional to the square of the velocity.

SAMPLE FORCES ON BUILDINGS

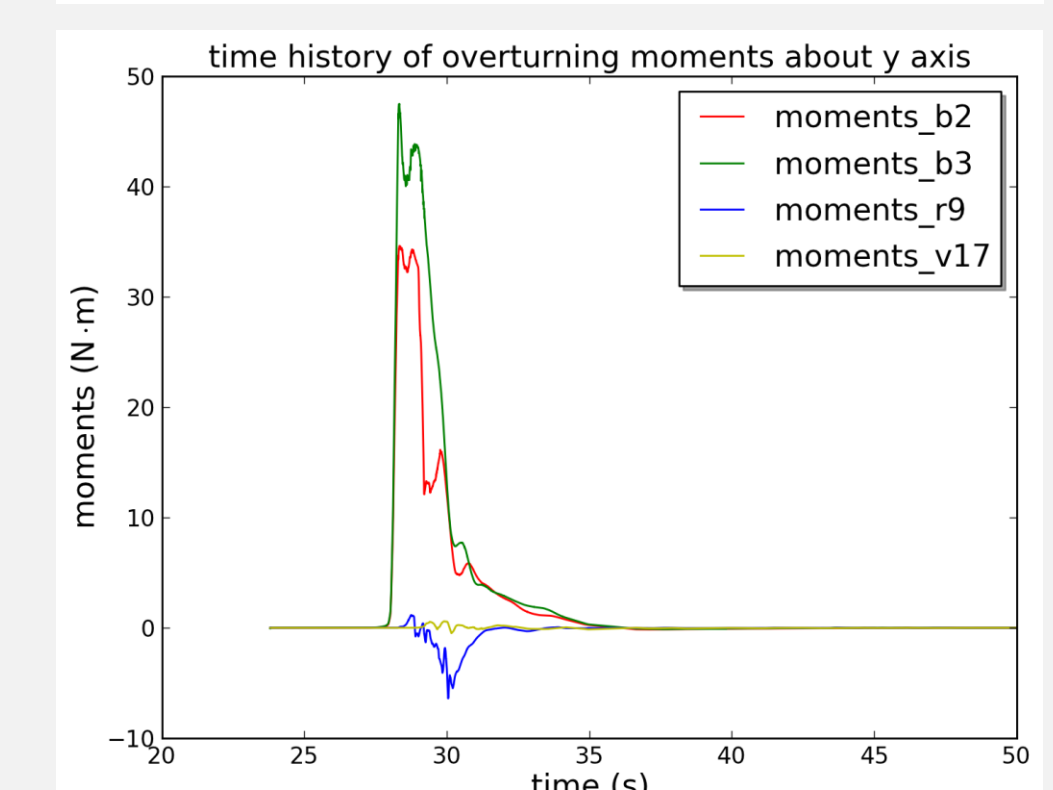
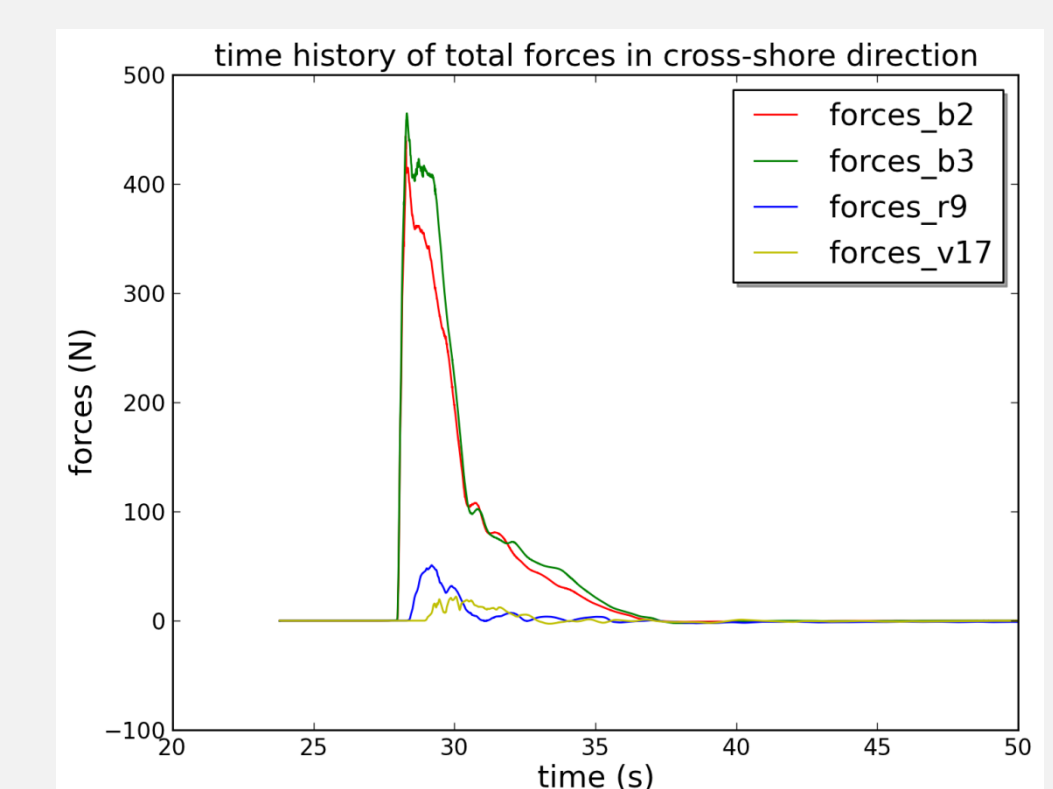
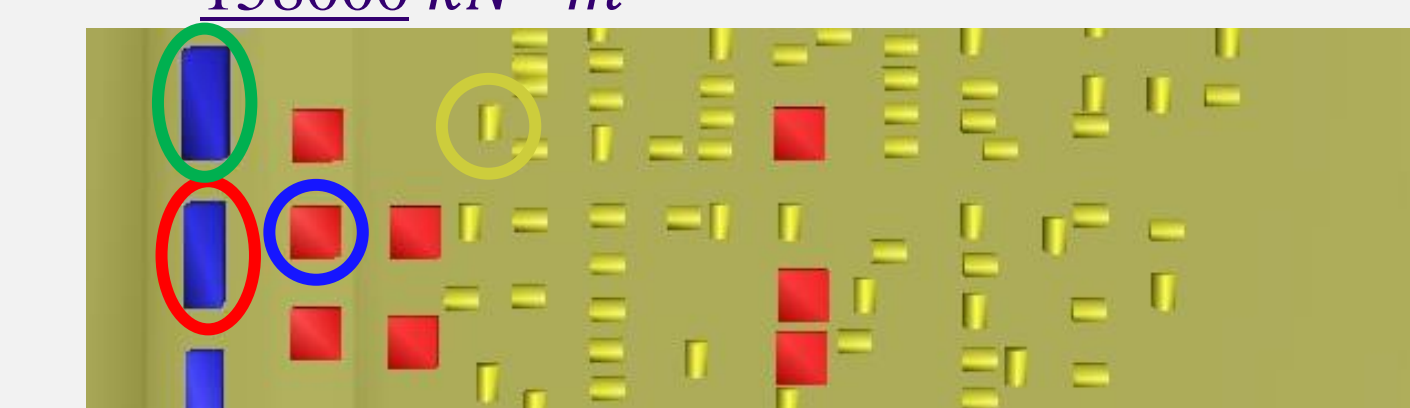
With the 3D approach, tsunami forces and overturning moment on buildings can also be predicted

Forces (on building in green circle)

- Peak = 450 N (model scale) = 12500 kips (prototype)
- Seismic design load for this building = 6500 kips

Overturning moments (on building in red circle)

- Peak = 35 N · m (model scale) = 218000 kN · m (prototype)
- Minimum moment required to overturn the building (estimated based on its weight) = 158000 kN · m



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