National Tsunami Hazards Mitigation Program - Benchmarking Workshop

Ram Sampath
Centroid LAB
Steven Prescott
Idaho National Laboratories

Talk

- SPH and Neutrino SPH
- Benchmark Problems and Setups
- Discussion of our approach
- Conclusions

SPH

- SPH - designed for solving astrophysical problems (Gingold & Monaghan) - 1977
- Integral representation of field variables with smoothing kernels.
- Fluid equations become

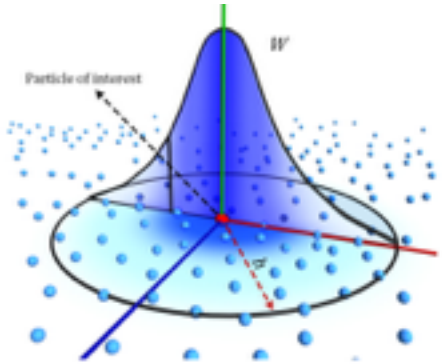
$$m\frac{d\mathbf{v}}{dt} = \overbrace{-V\nabla p}^{F_{pressure}} + \overbrace{V\mu\nabla^2\mathbf{v}}^{F_{viscosity}} + \overbrace{V\mathbf{f}}^{F_{external}},$$

- Volume conservation satisfied using pressure forces.
  - Pressures dependent on speed of sound.
- Needs neighborhood search
- Density computed by $\rho_i = \sum_j m_j W_{ij}.$

$$A(\mathbf{x}_i) = \int_\Omega A(\mathbf{x}_j) W(\mathbf{x}_i - \mathbf{x}_j, h)\, d\mathbf{x}_j,$$

$$A_i = \sum_i V_j A_j W_{ij} = \sum_i \frac{m_j}{\rho_j} A_j W_{ij}.$$

$$\nabla A_i = \sum_j \frac{m_j}{\rho_j} A_j \nabla W_{ij}.$$



$$W_{Poly6}(r,h) = \sigma^D_{Poly6} \begin{cases} (h^2 - r^2)^3 & 0 \le r \le h \\ 0 & \text{otherwise} \end{cases}$$

Neutrino - SPH

- Compact Hashing technique for nearest neighbor search.
- Uses Implicit Incompressible SPH (IISPH) - Details (http://www.naadir.tk/phd-thesis)
  - SPH approximation of the continuity equation to obtain discretized form of the poisson equation for pressure.
  - Relaxed Jacobi solver. (Parallel)

$$\frac{\rho_i(t+\Delta t) - \rho_i(t)}{\Delta t} = \sum_j m_j \left[\mathbf{v}_i(t+\Delta t) - \mathbf{v}_j(t+\Delta t)\right] \nabla W_{ij}(t) .$$

- Viscosity - Monaghan’s Method.
- Rigid Fluid coupling boundary particles

SPH

- Artificial Viscosity
  - Based on Von Neumann-Richmyer artificial viscosity (1950)

$$\mathbf{F}_i^v = -m_i \sum_j m_j \Pi_{ij} \nabla W_{ij},$$

$$\Pi_{ij} = -\nu \left(\frac{\min(\mathbf{v}_{ij} \cdot \mathbf{x}_{ij}, 0)}{|\mathbf{x}_{ij}|^2 + \epsilon h^2} \right),$$

$$\nu = \frac{2\alpha h c_s}{\rho_i + \rho_j}$$

- Solid Boundary Treatment
  - Pressure forces applied from boundary particles to fluid particles
  - Boundary viscosity

$$\mathbf{F}^v_{f_i \leftarrow b_j} = -m_{f_i} \Psi_{b_j}(\rho_{0_i}) \Pi_{ij} \nabla W_{ij},$$

$$\nu = \frac{\sigma h c_s}{2\rho_{f_i}},$$

- Adaptive Time step - Semi Implicit / Euler-Cromer Integration

Density/Pressure Computation

- Density.
  - Based on Monaghan 05 - SPH - Reports on Progress of Physics.

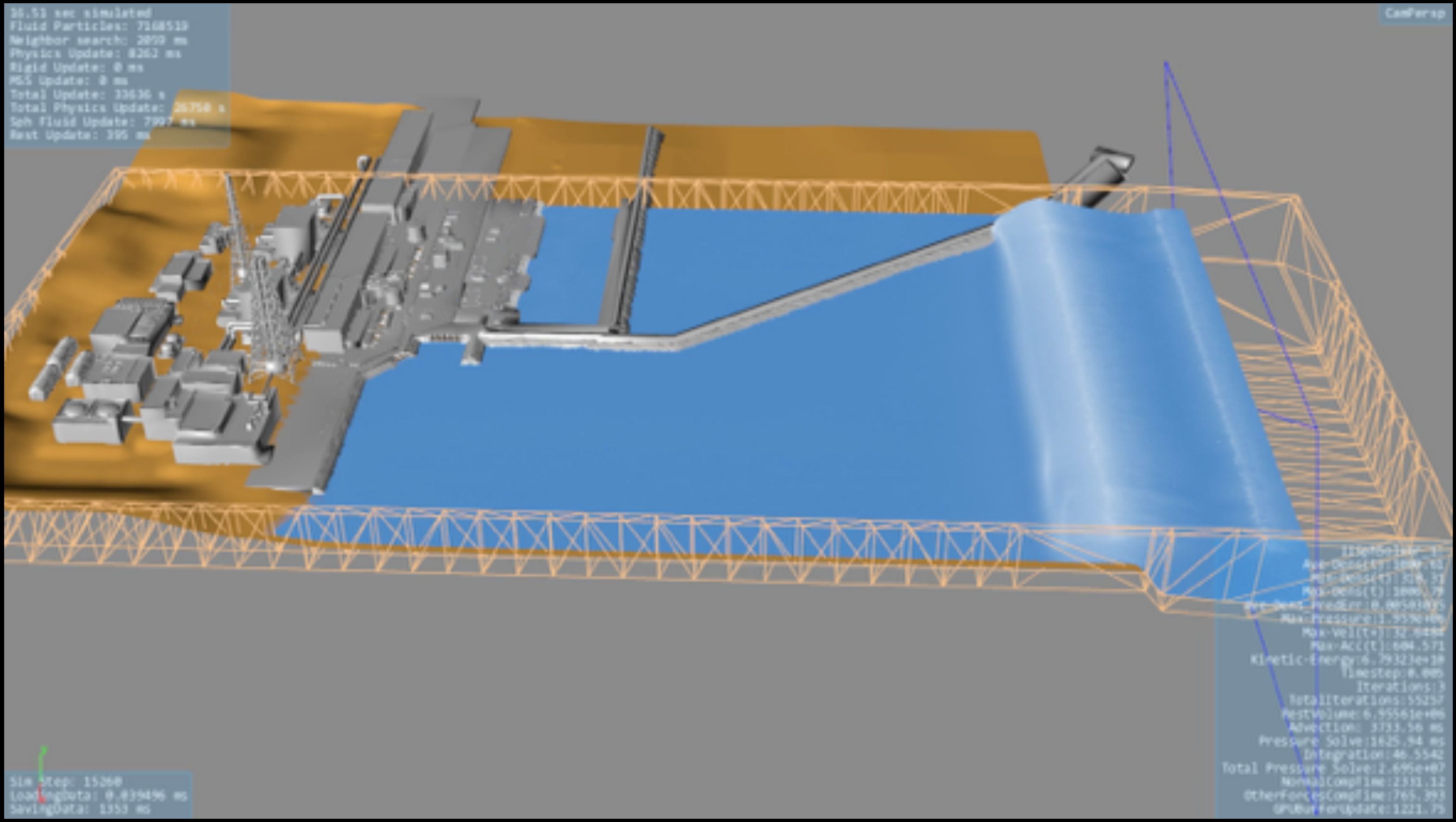
$$\frac{d\rho_i}{dt} = \sum_j m_j(\mathbf{v}_i - \mathbf{v}_j) \cdot \nabla W_{ij},$$

  - Conserves Mass
  - Underestimated densities at fluid interfaces are handled by special handling Rigid/Fluid/Air boundaries causing clumping of particles.
- Pressure Forces
  - State Equation based SPH (SESPH)

$$\mathbf{F}_i^p = -m_i \sum_j m_j \left(\frac{p_j}{\rho_j^2} + \frac{p_i}{\rho_i^2} \right) \nabla W_{ij}.$$

  - Particle Pressures are computed by Implicit Incompressible SPH method.
  - Jacobi method used for solution of this implicit method.

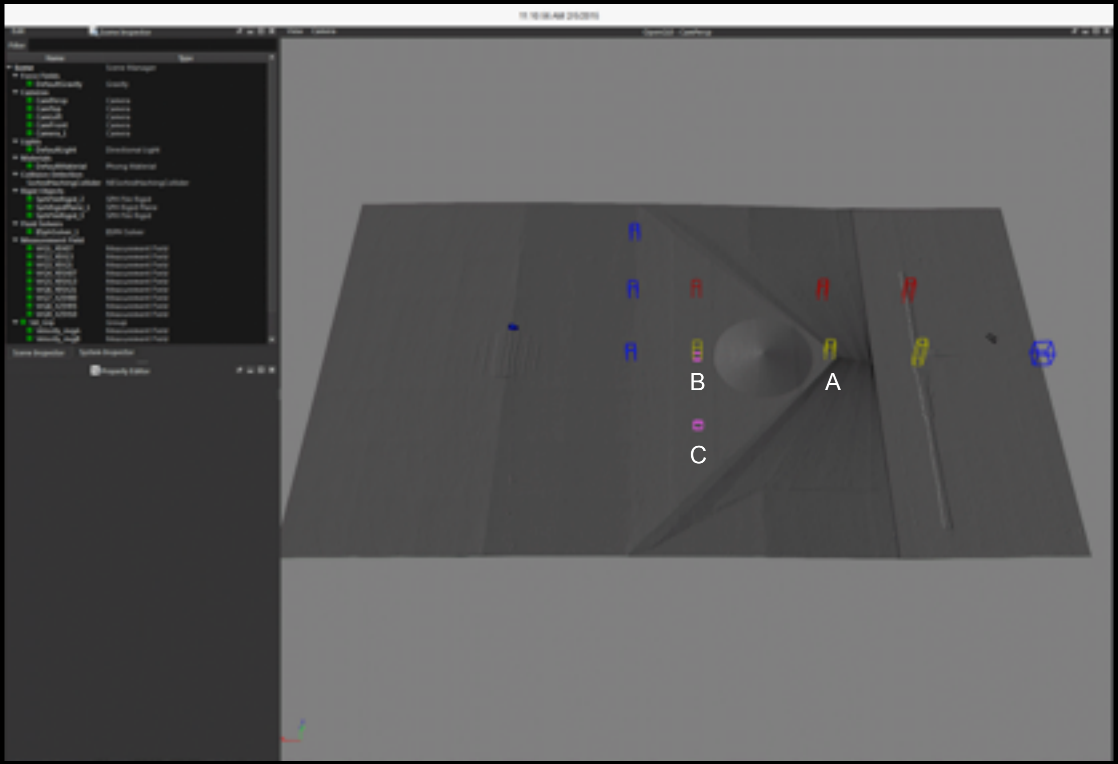
Geo scale



Benchmark Problem 5

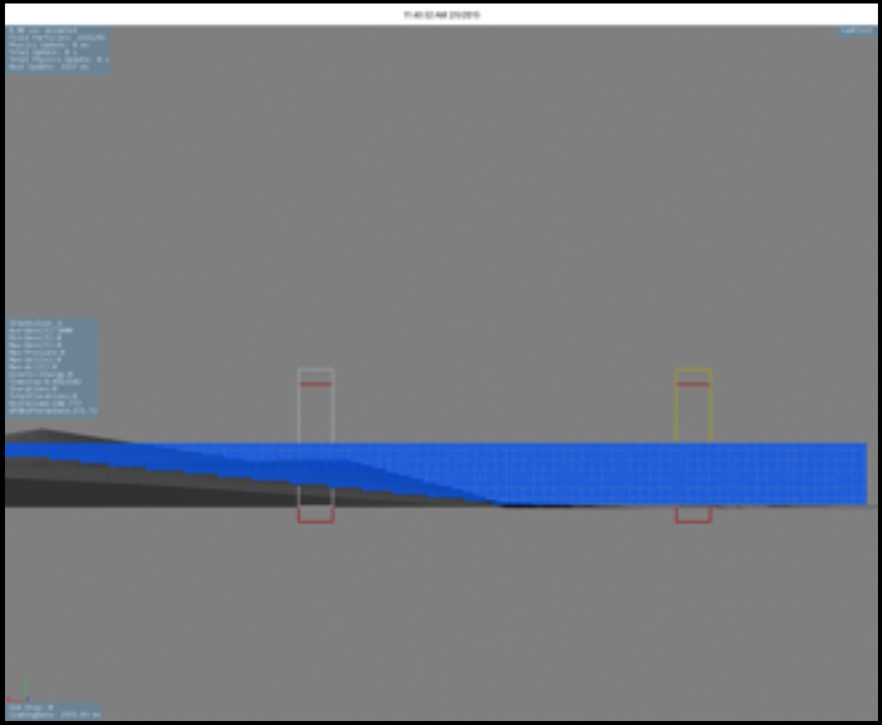
- Setup
    - Terrain geometry bathymetry data
    - Setup of Initial Conditions (Volume fill)
- Simulation
    - Time to settle
    - Paddle Movement
    - Measurement Fields
- Data and Video comparisons
- Discussion

Benchmark Problem 5 - Setup



Benchmark Problem 5 - Setup

- Volumetric representation of geometry of water
  - Boolean Operations to remove particles
- Particle overlap removal, settling (87% volume)



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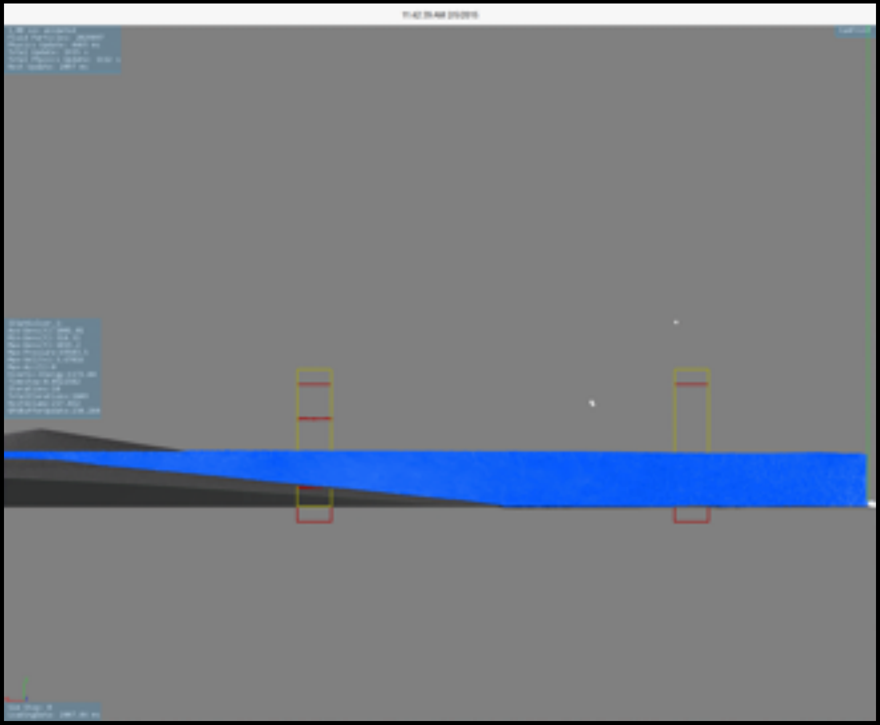


Wave Piston

- Goring 1978 Wave Model for a Piston wave maker.

Goring (1978) proposed a model for the purpose of laboratory solitary wave generation. The surface profile $\eta(x,t)$ of a solitary wave can be described using the following equation:

$$\eta(x,t) = H sech^2[\kappa(Ct - X_0)\ ] \qquad \text{(B-1)}$$

$$C = \sqrt{g(H+h)} \qquad \text{(B-2)}$$

$$\kappa = \sqrt{3H/4h^3} \qquad \text{(B-3)}$$

Where C is the wave celerity or phase velocity, X_0 is the wave displacement, H is the wave height and h is the depth of the ocean. Applying equation B-1 to the wave maker piston results in

$$X_0(t) = H/\kappa h\ (tanh(\kappa(Ct - X_0)) \qquad \text{(B-4)}$$

Using this equation one can solve for the wave piston displacement and wave piston duration using newton iterations resulting in

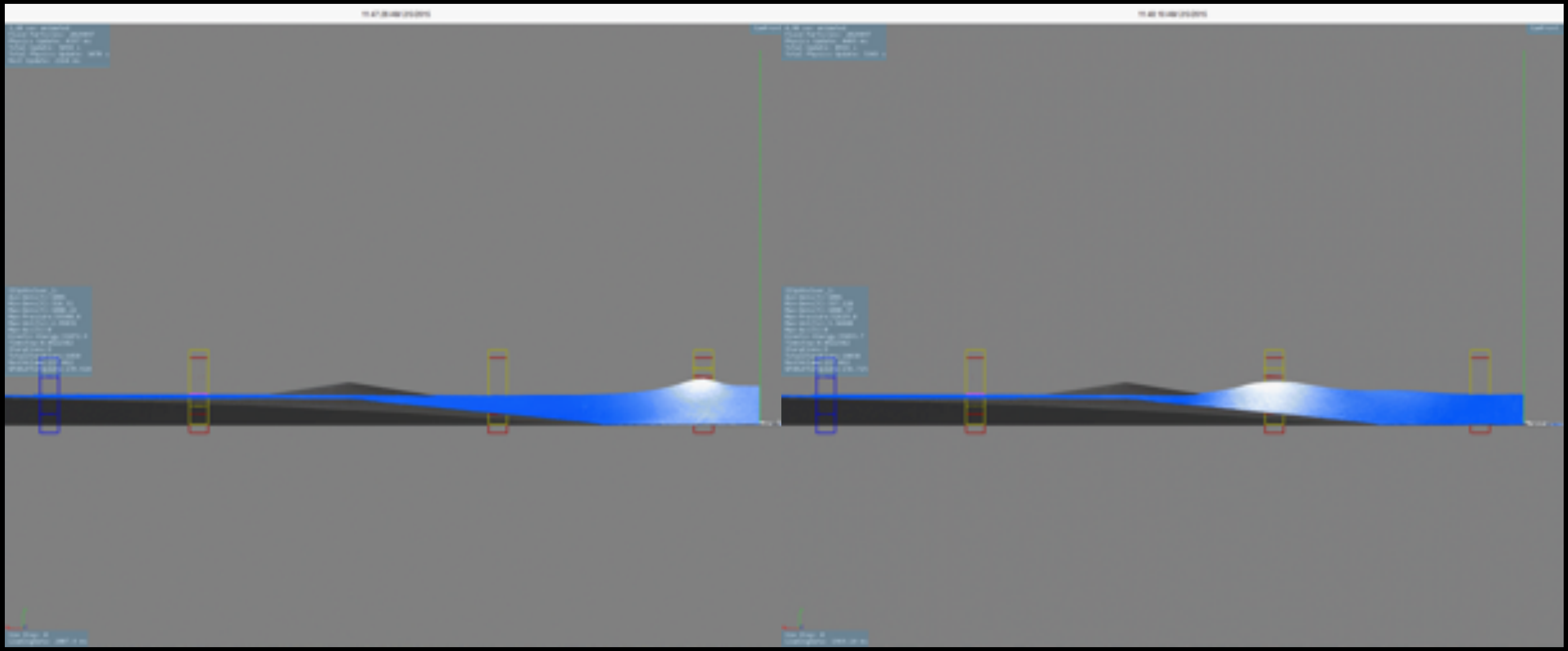
$$S = \sqrt{16Hh/3}$$

and

$$t_f = 2(3.80 + H/h)/\kappa C$$

where S is the displacement and t_f is the time taken for it.

Benchmark Problem 5 - Setup



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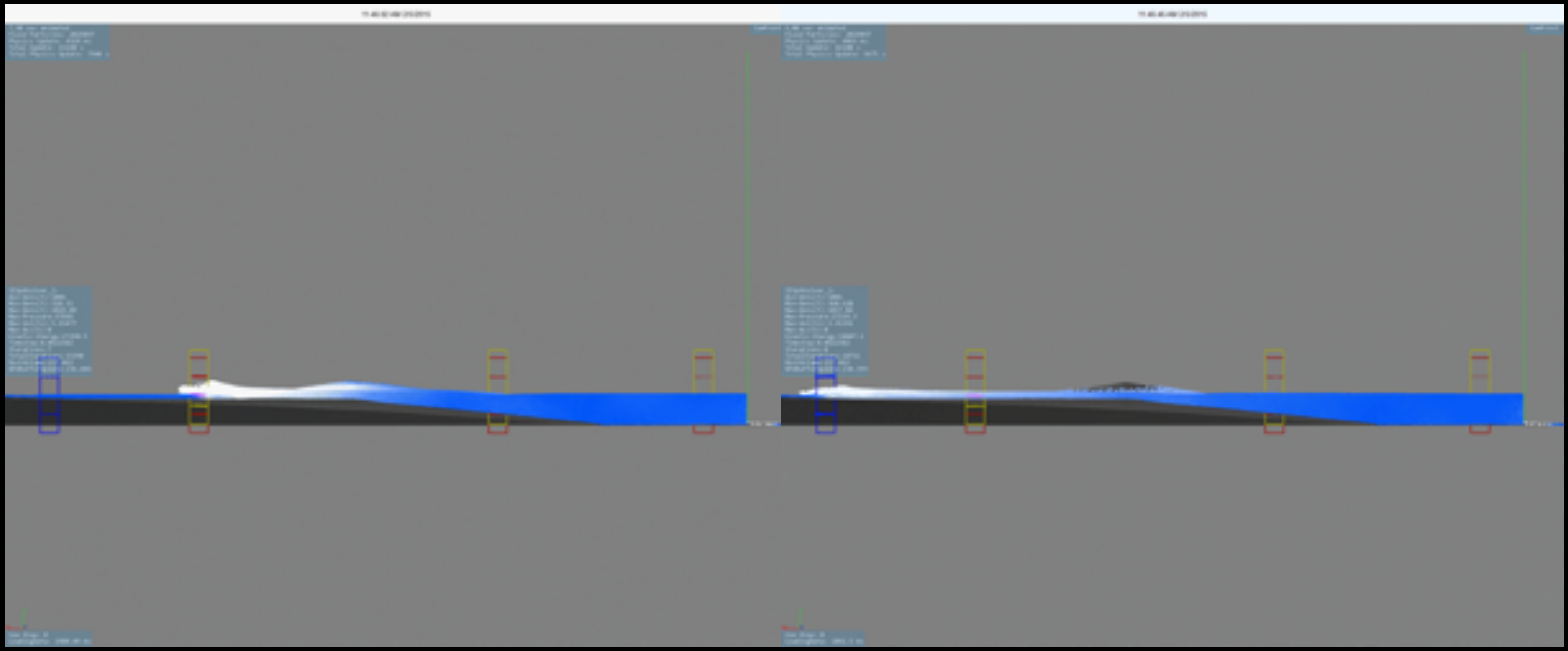
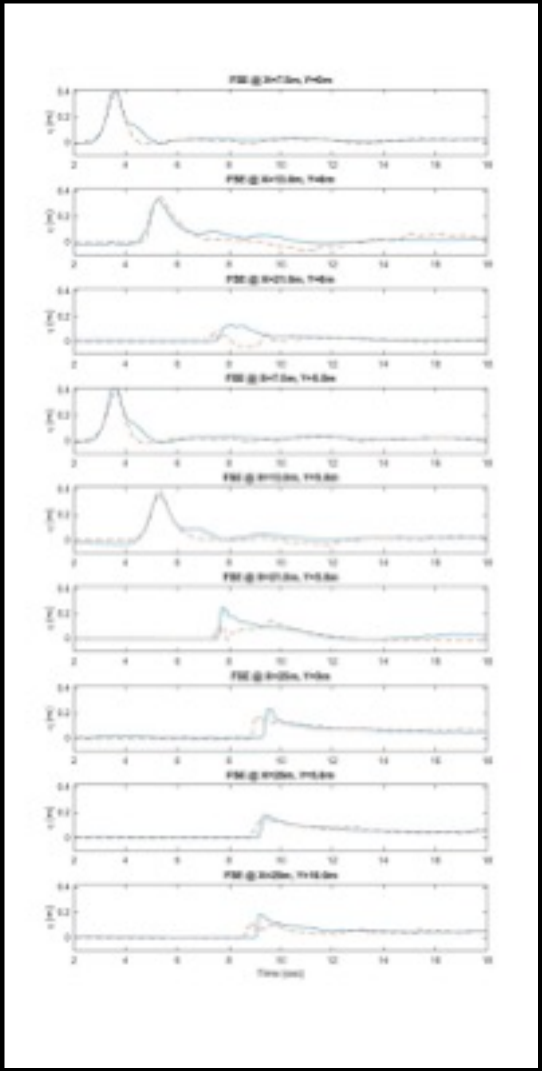


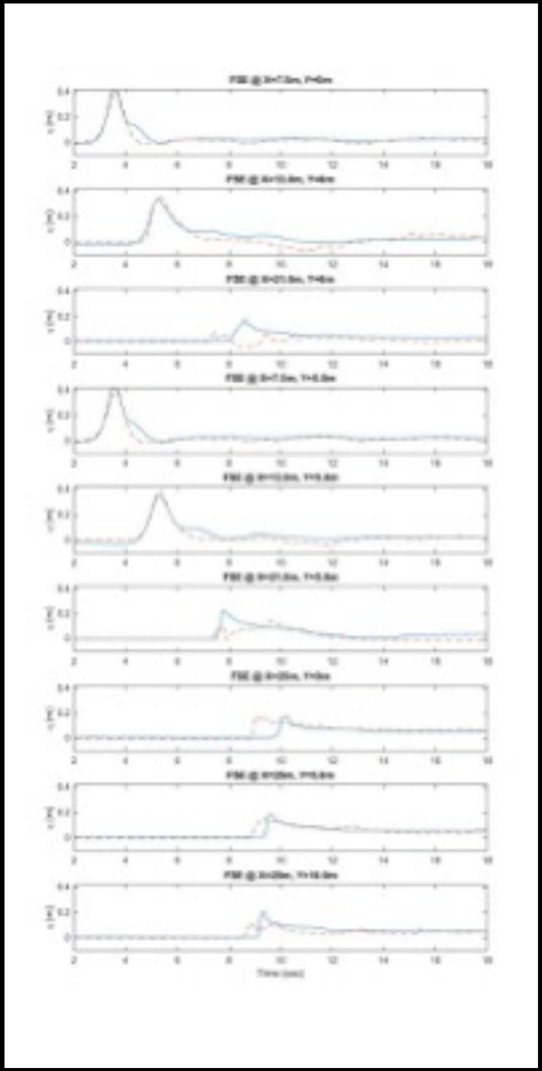
Benchmark Problem 5 - Data

- Roughness parameter 0.002



Benchmark Problem 5 - Data

- Roughness parameter 0.003



Benchmark Problem 5 - Data

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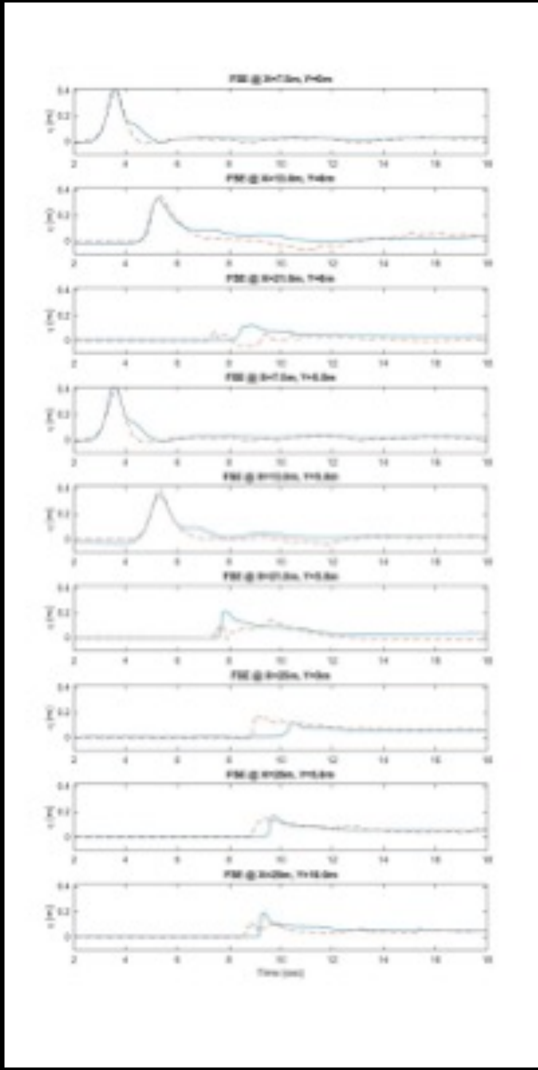

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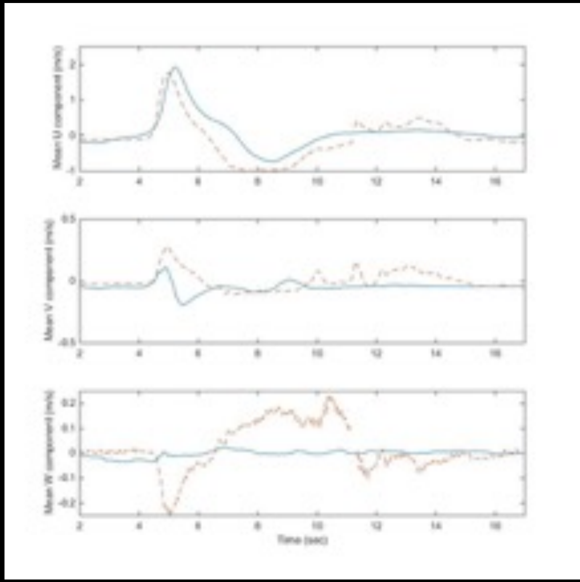
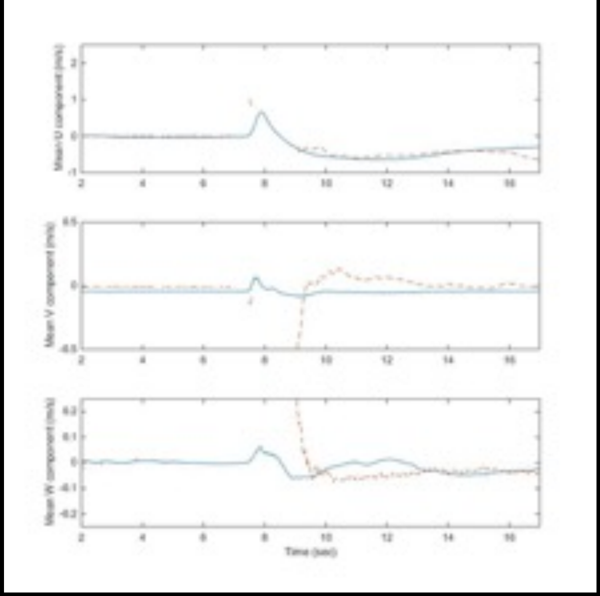
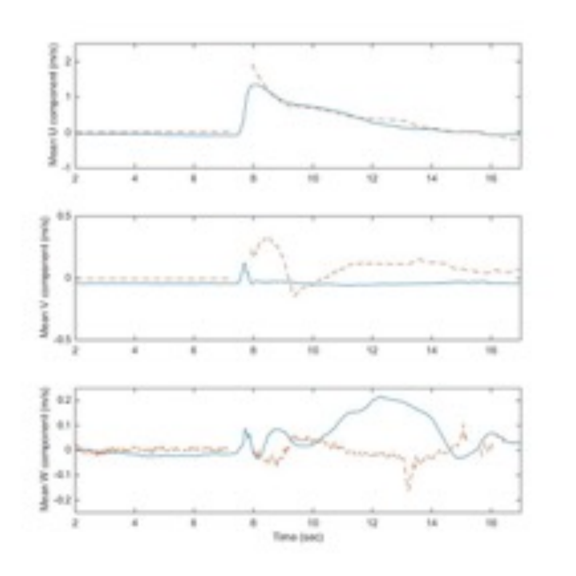
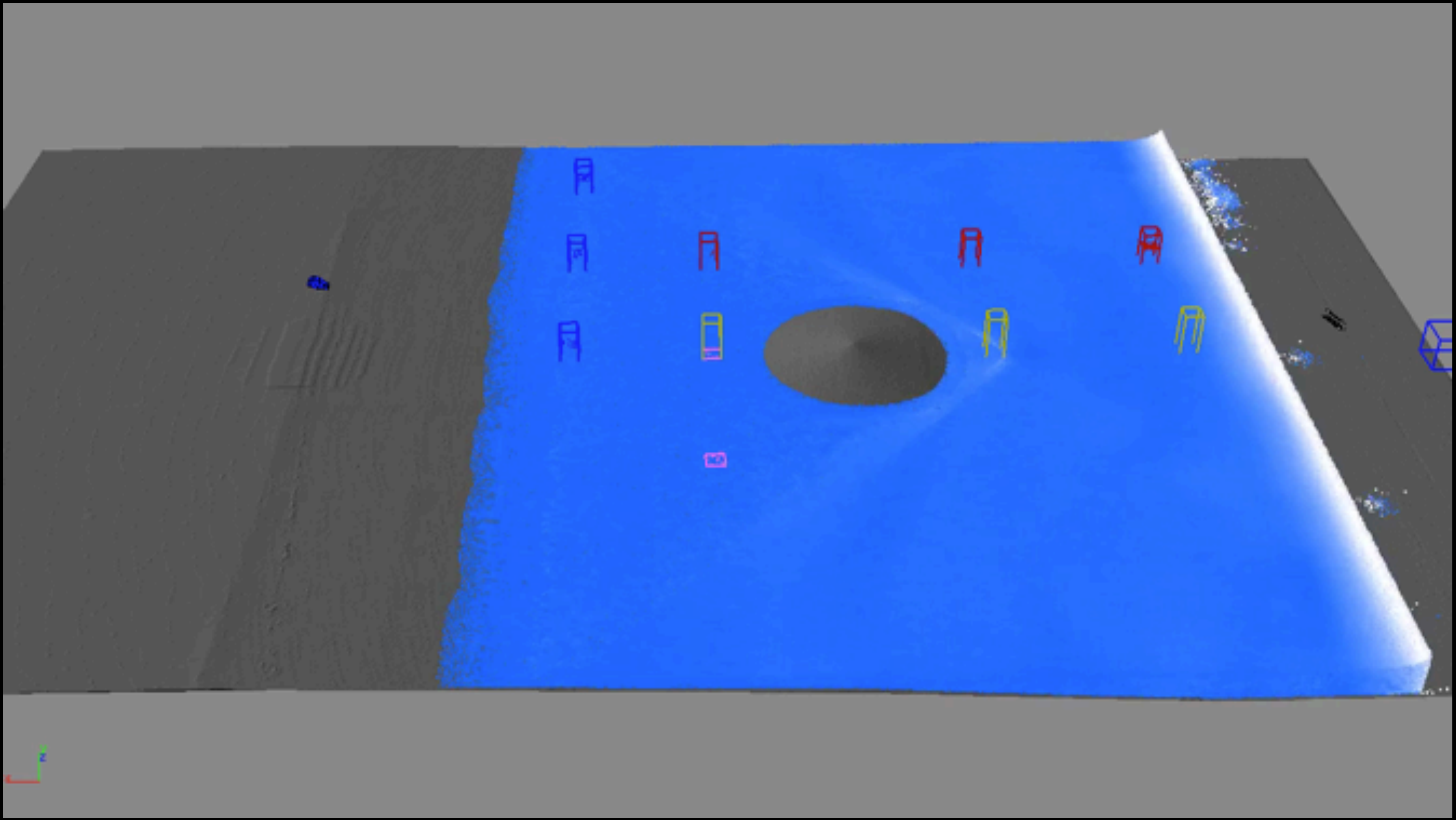
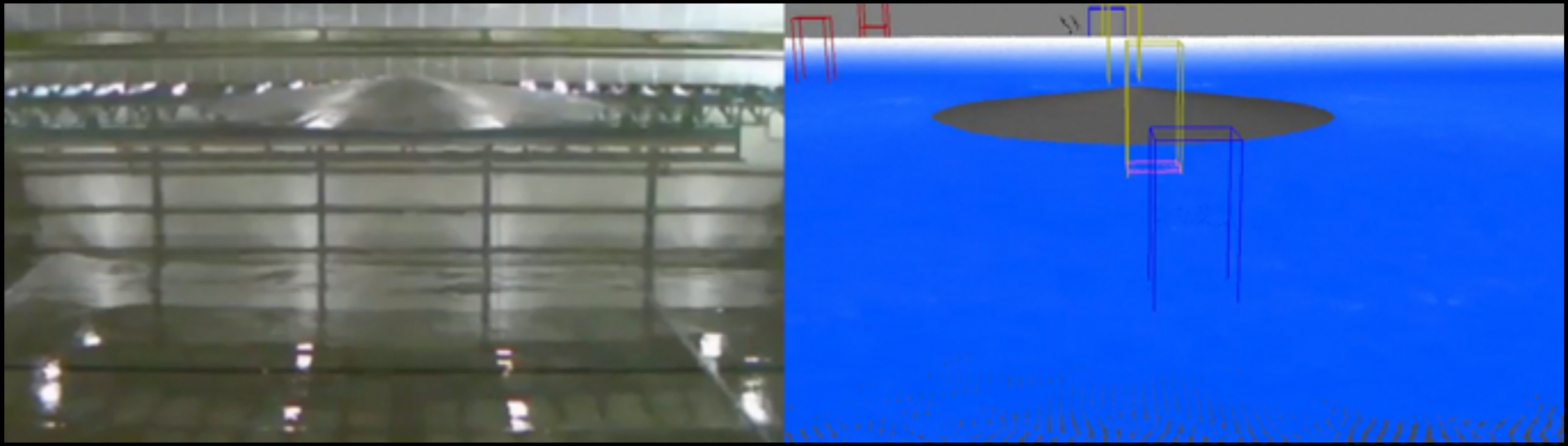




Benchmark 5 - Video



Benchmark 5 - Video



Benchmark Problem 5 - Discussion

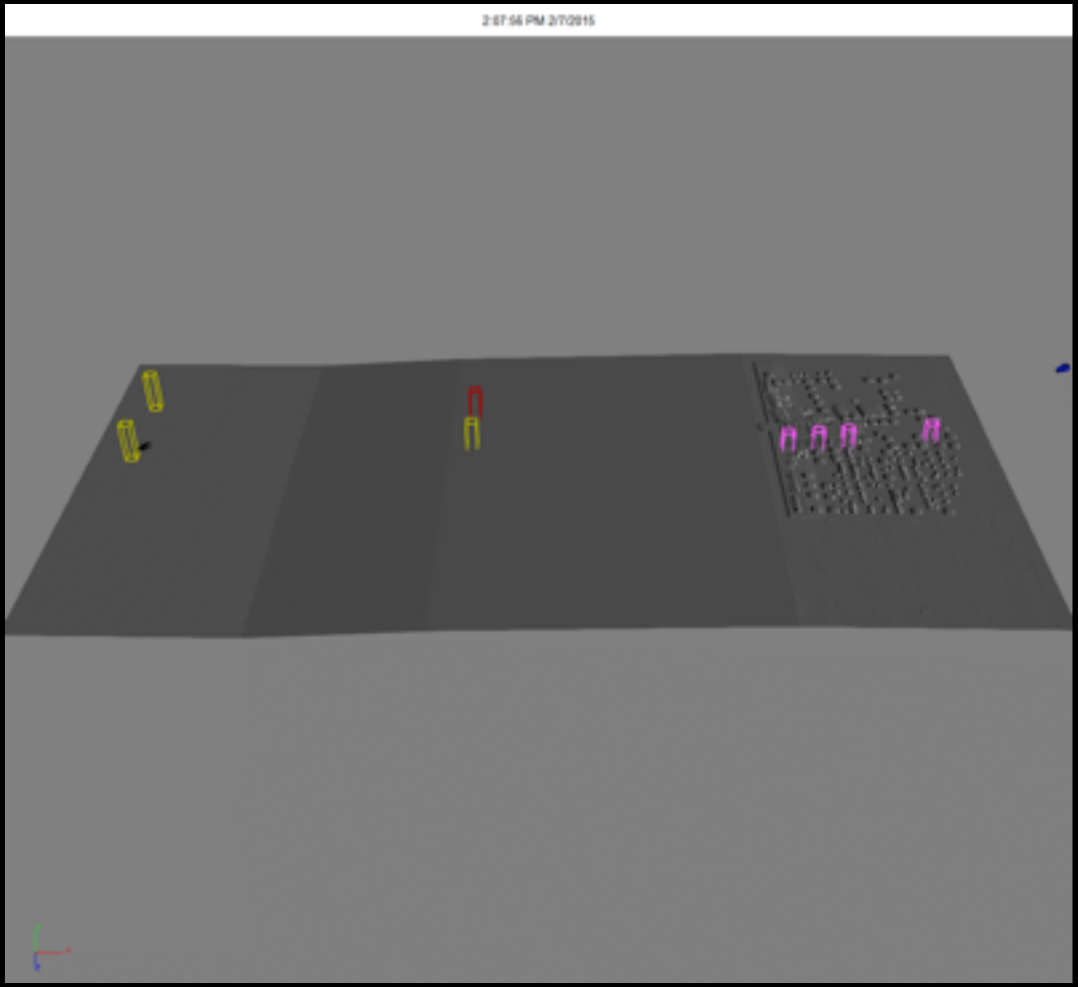
- No Turbulence Modeling
- Roughness based on Artificial Viscosity
  - Research on Manning Coefficient/Artificial Viscosity/Reynolds Number

Benchmark Problem 4

- Setup - Similar to Problem 5
- Simulation
    - Scripted Wave piston movement based on data
- Data and Video comparisons

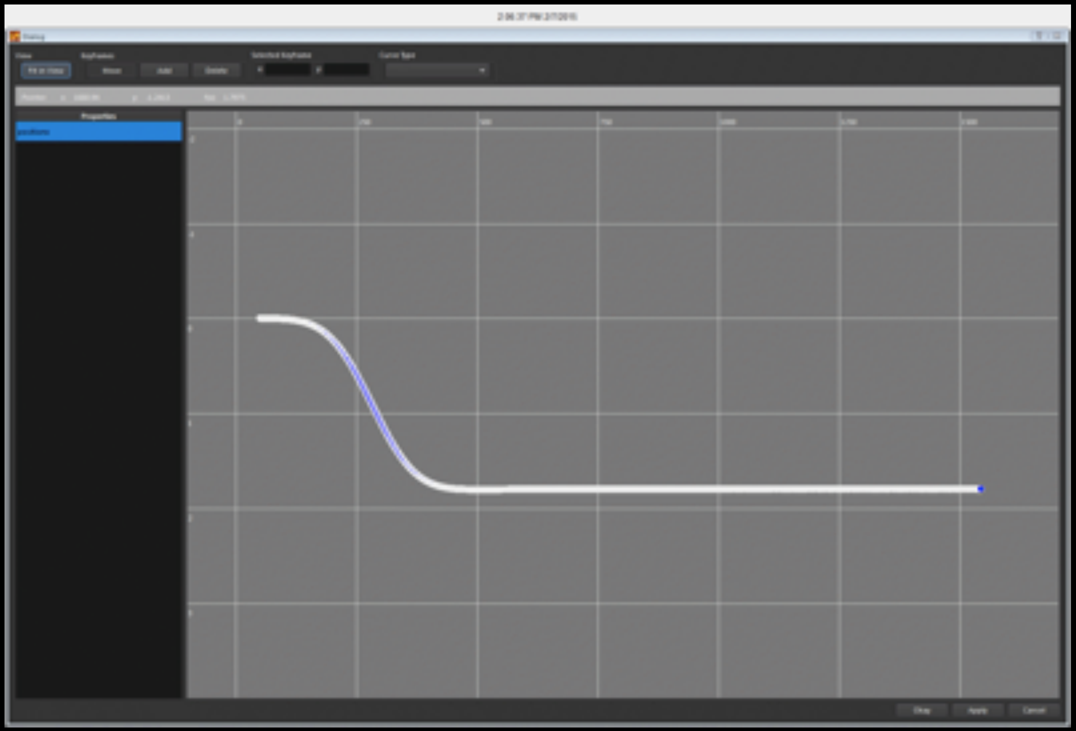
Benchmark Problem 4

- Setup - Terrain



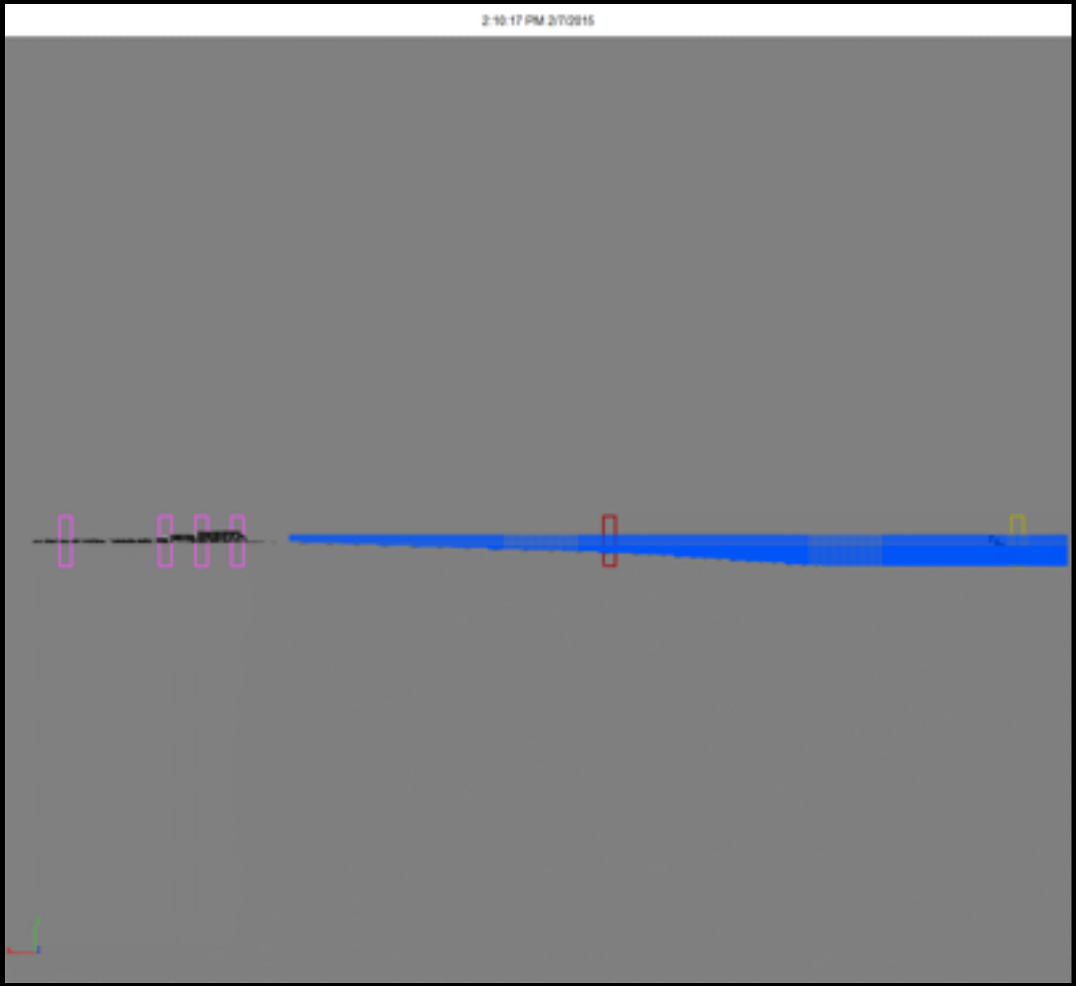
Benchmark Problem 4

- Wave piston movement



Benchmark Problem 4

- Simulation



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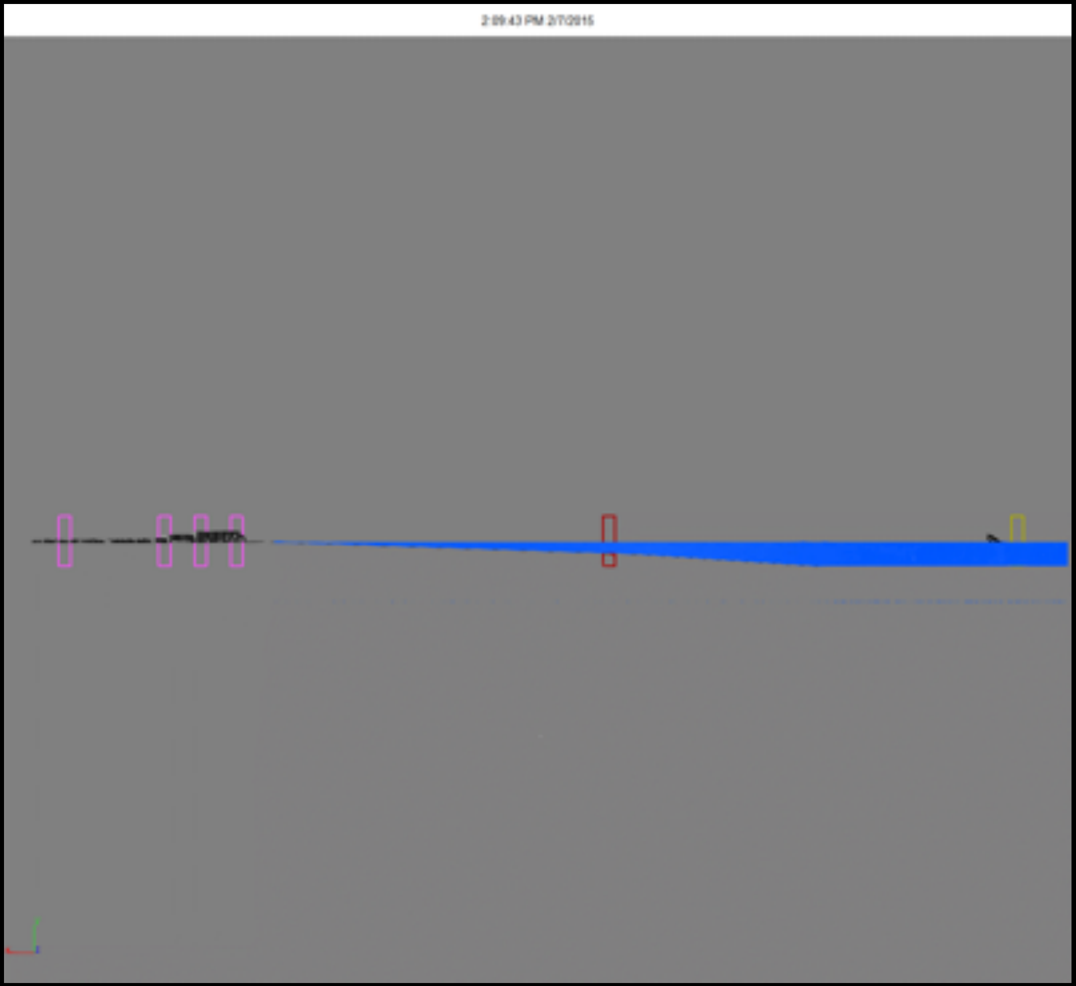

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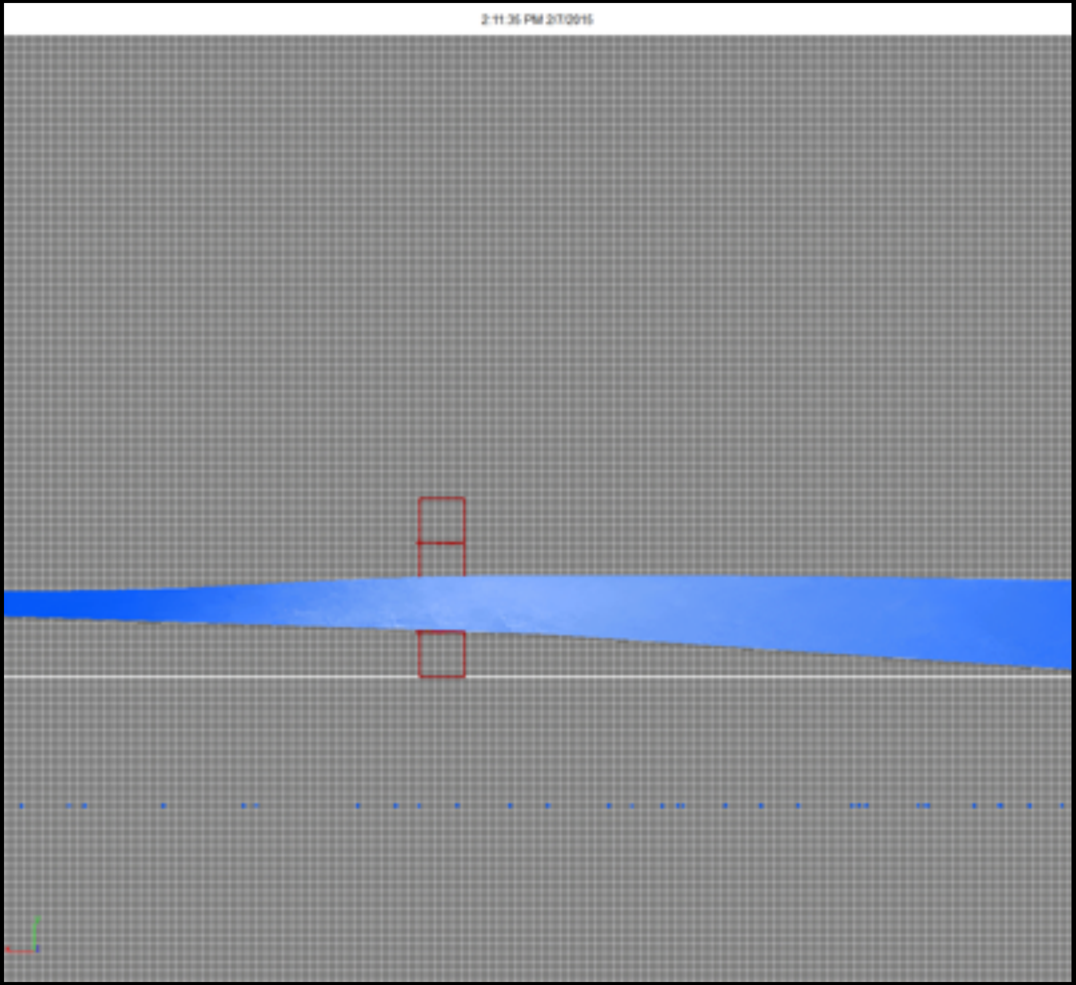

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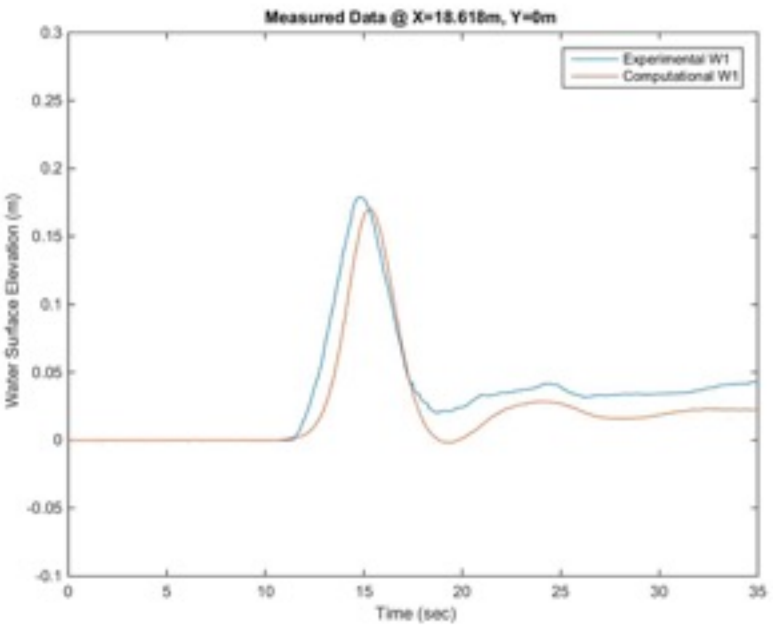

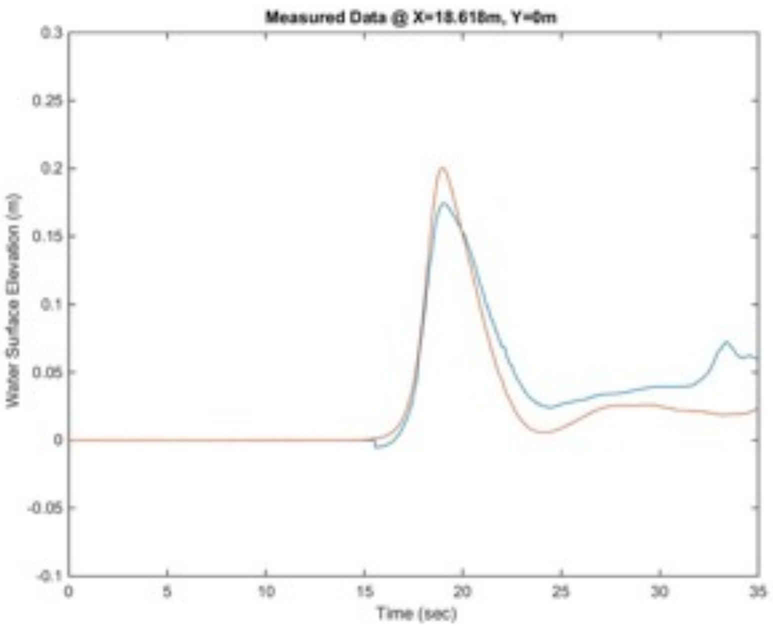

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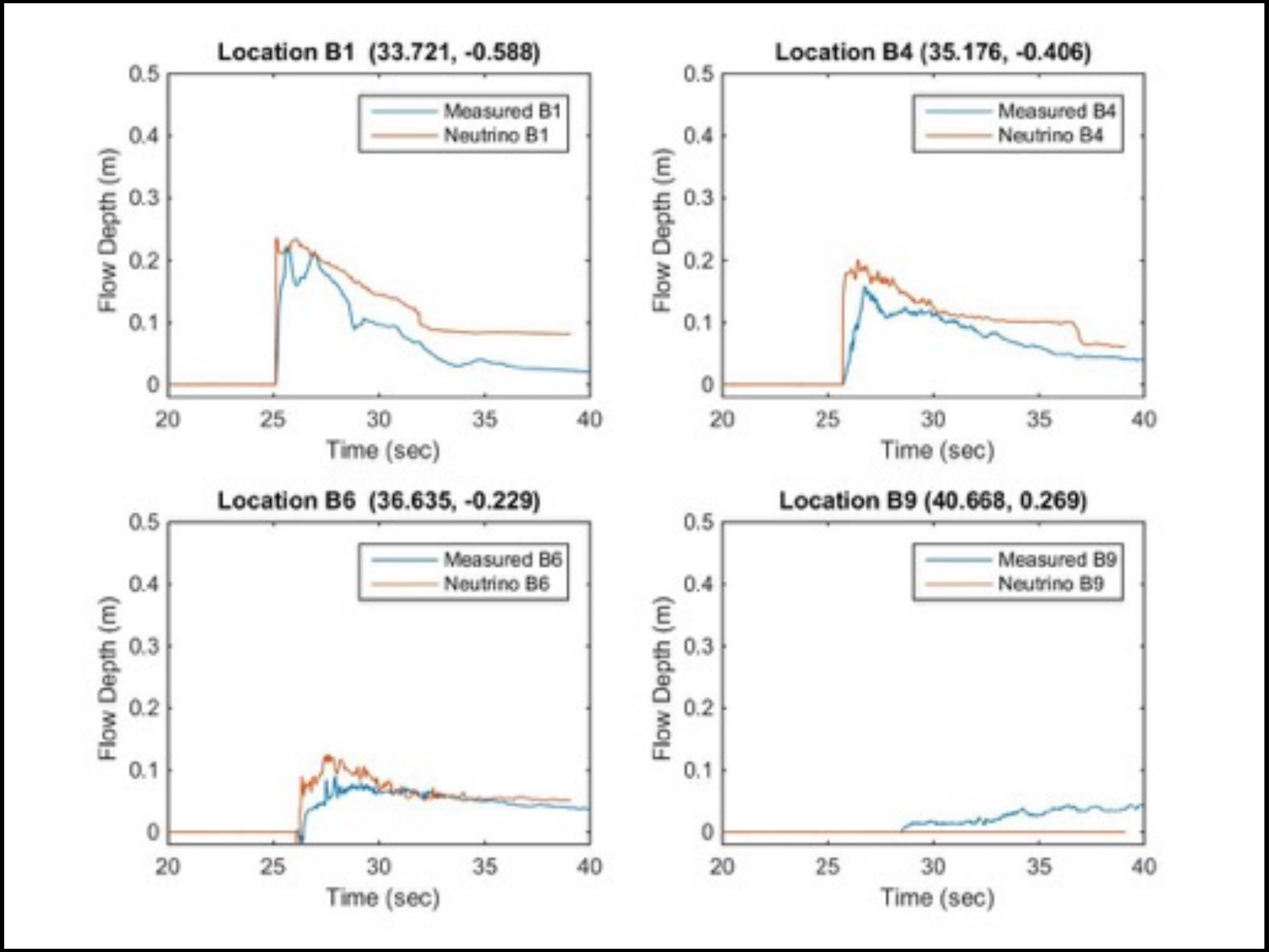

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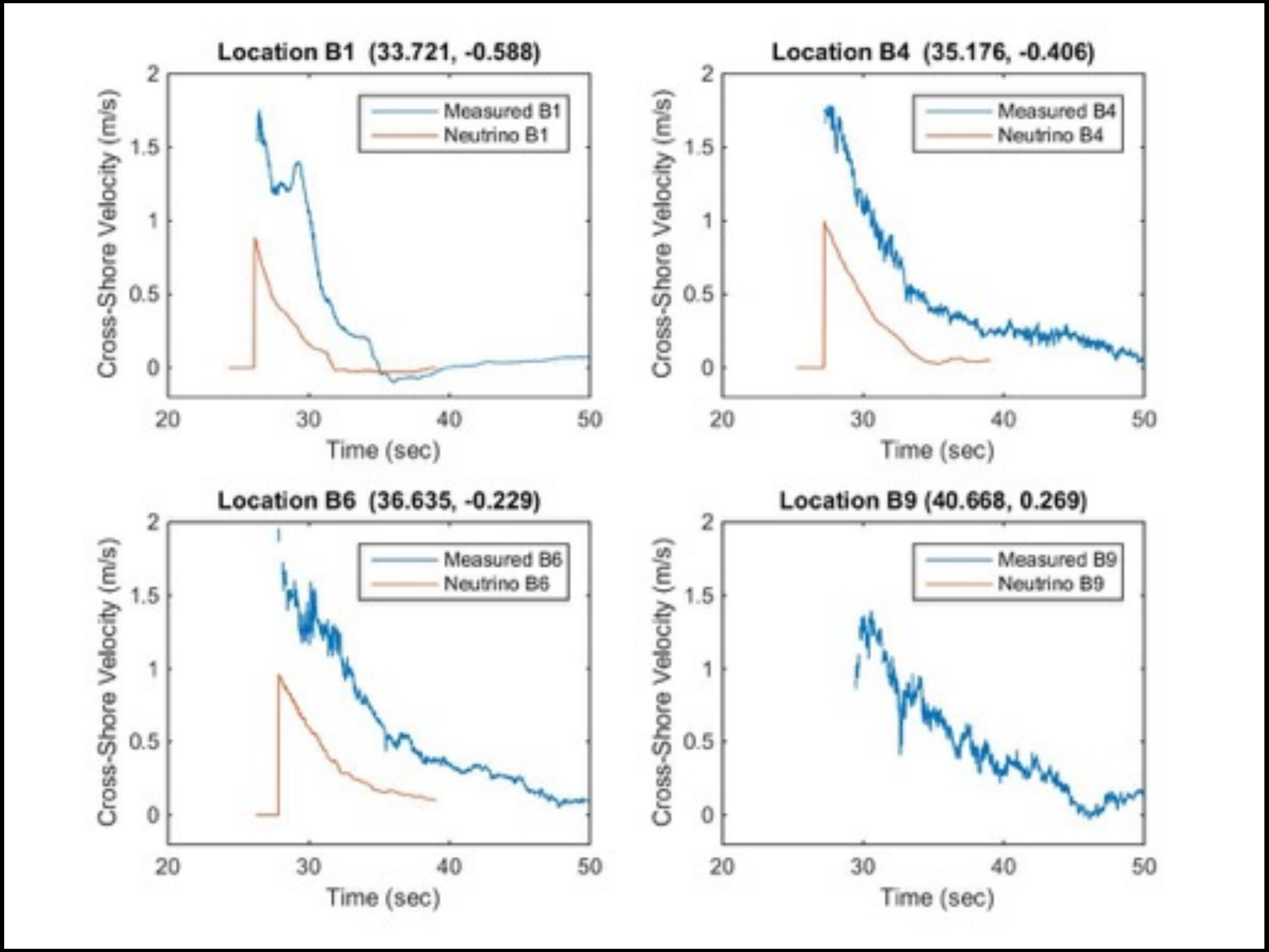


Benchmark Problem 4 - Video

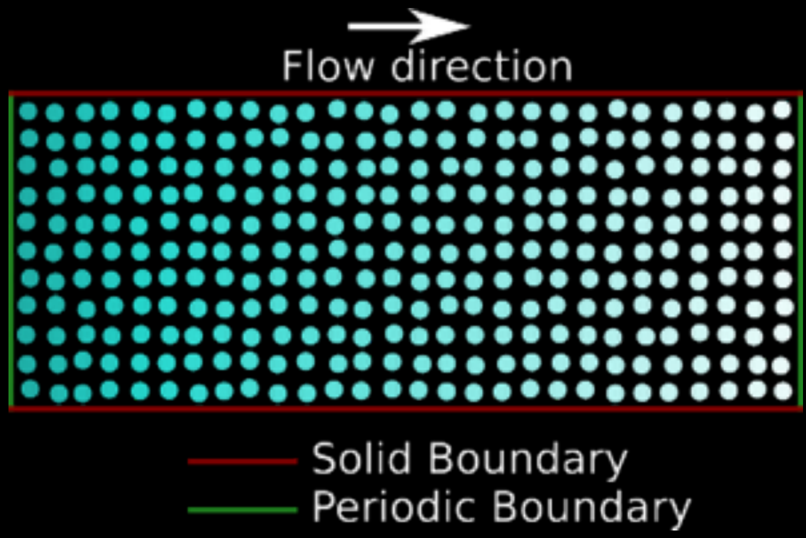
Benchmark Problem 4 - Discussion

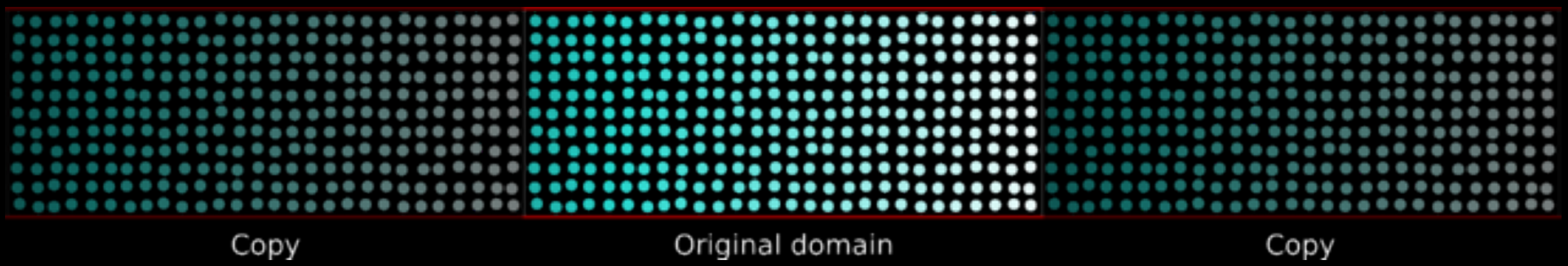
- Velocity Profiles
    - Base water height was 0.94m vs 0.97 (problem)
- Roughness coefficient was based on Problem 5
- Momentum flux not yet implemented on measurement

Benchmark Problem 1

- Setup
  - Periodic Boundary Conditions
  - Inflow Velocity set to U
  - Particle Interaction Radius based Passive Domain on either side of the flow boundary
  - Particles exiting the active domain are placed as copies in either side in the passive domain.
- Limitation
  - Roughness Modeling and model Resolution

Benchmark Problem 1





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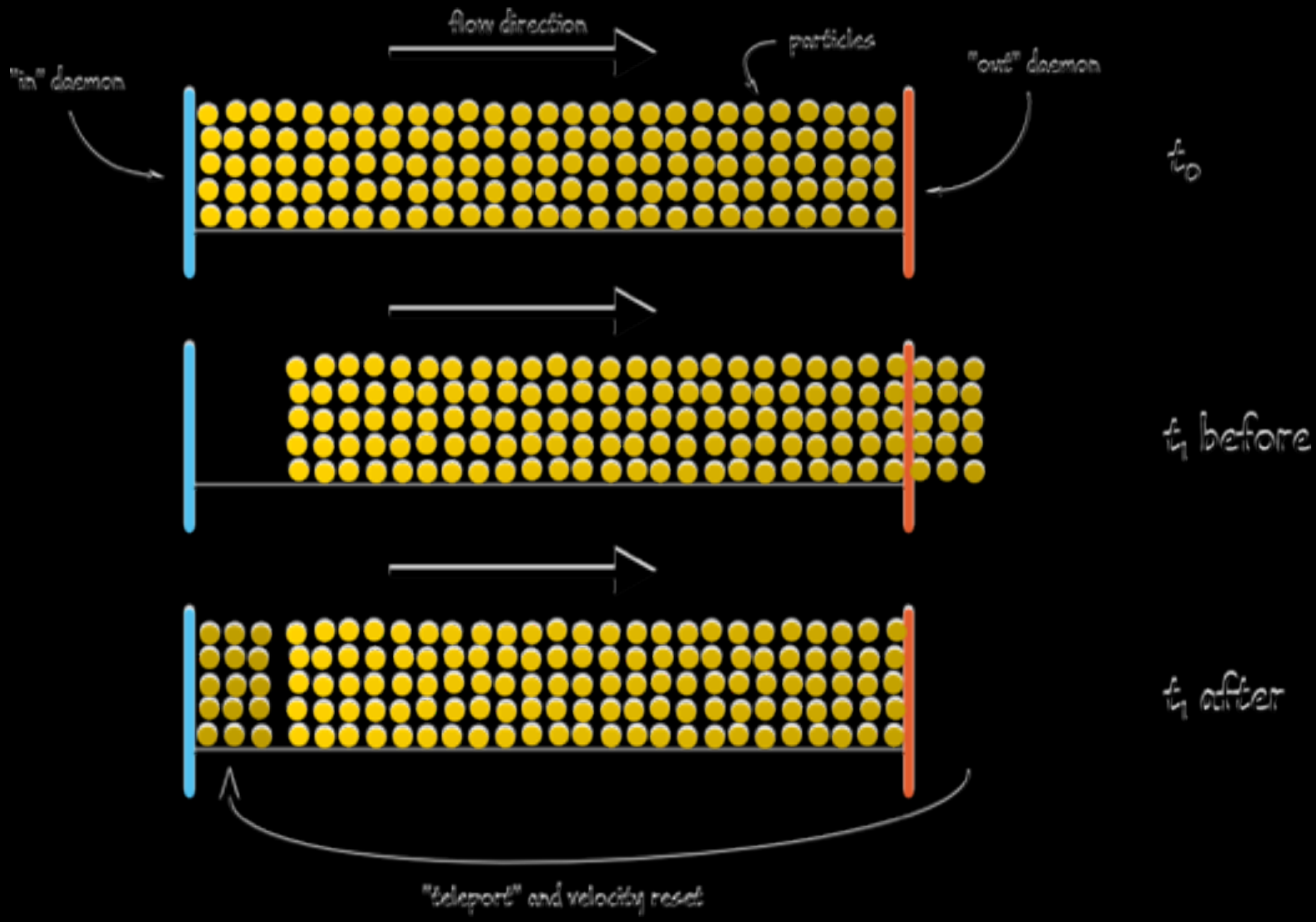

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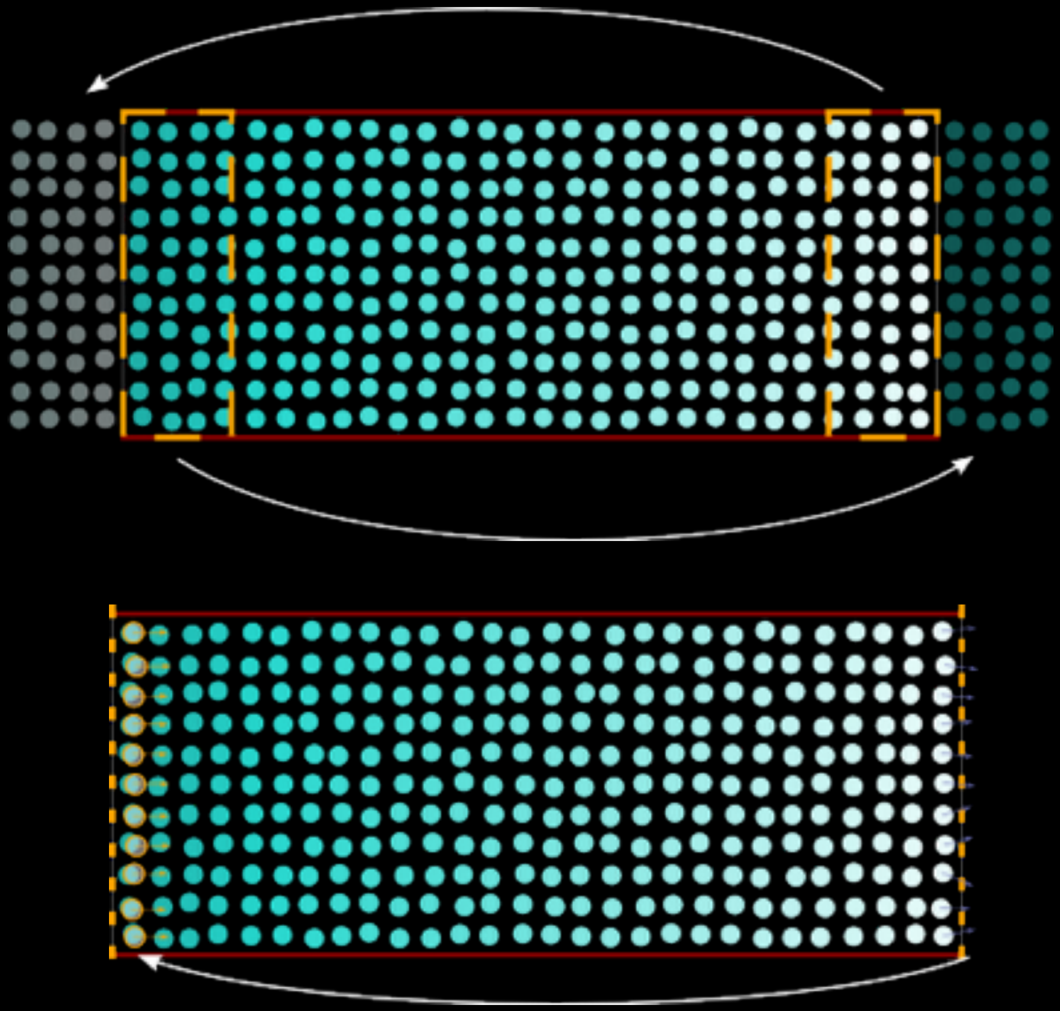

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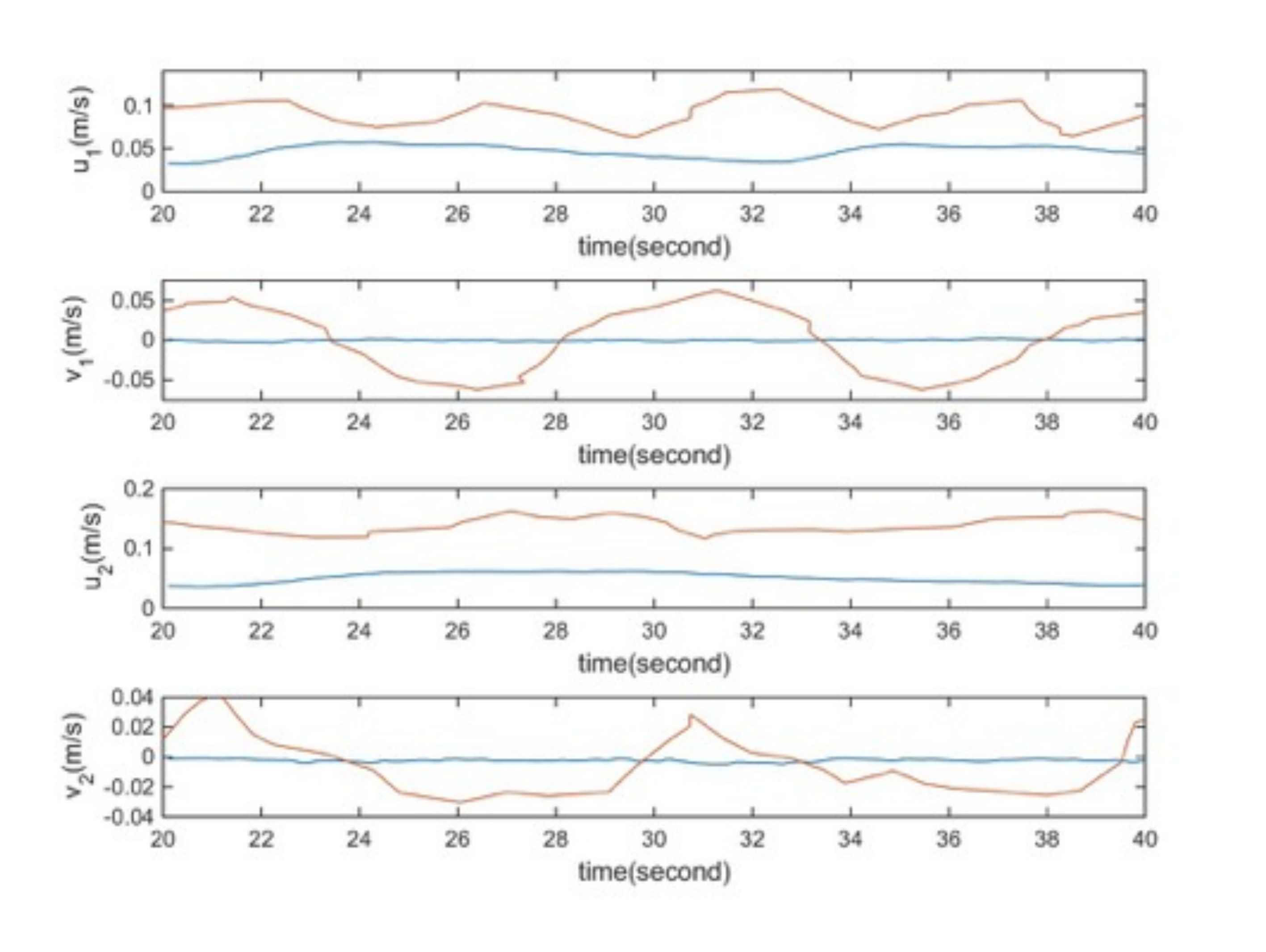

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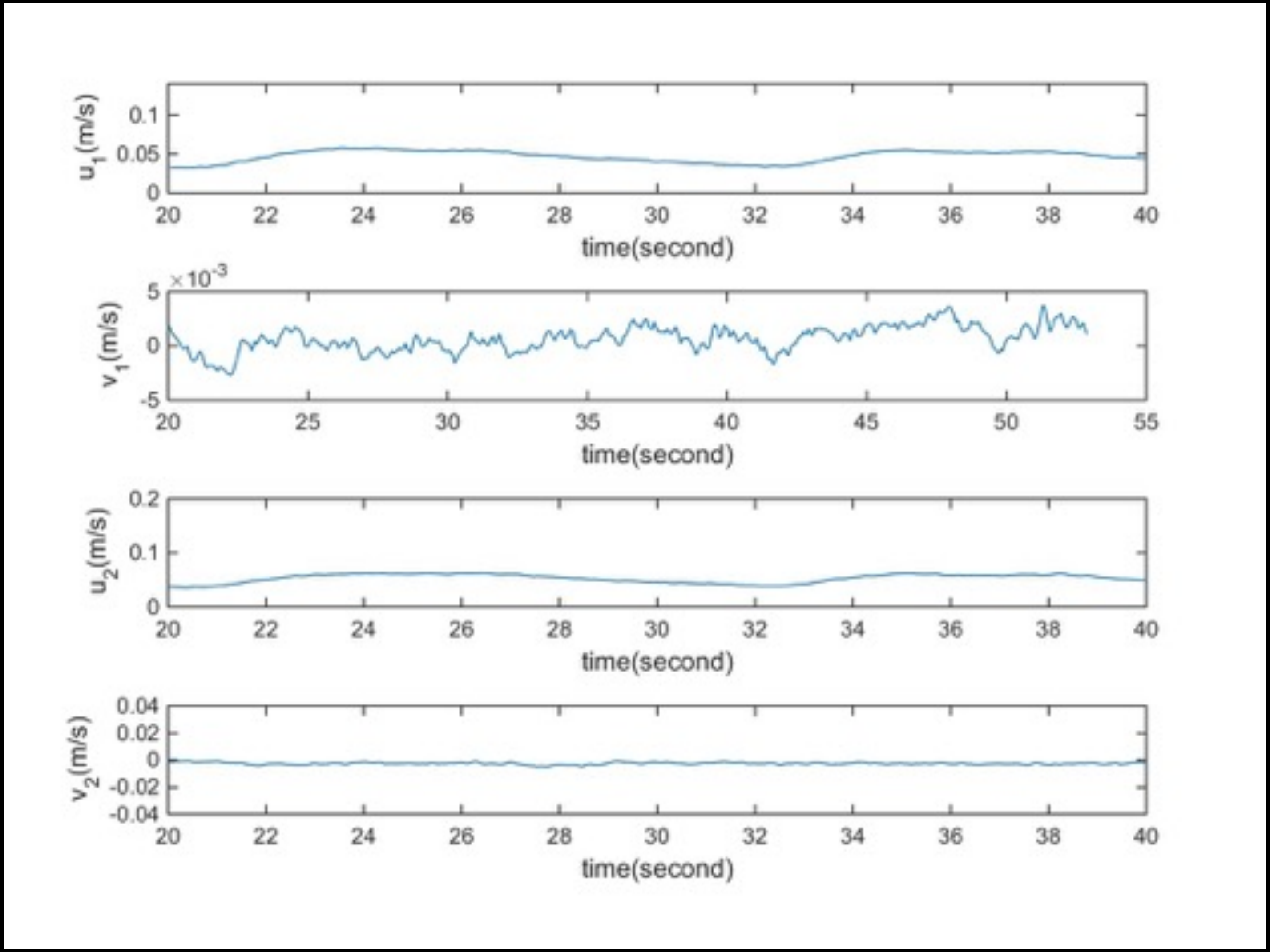
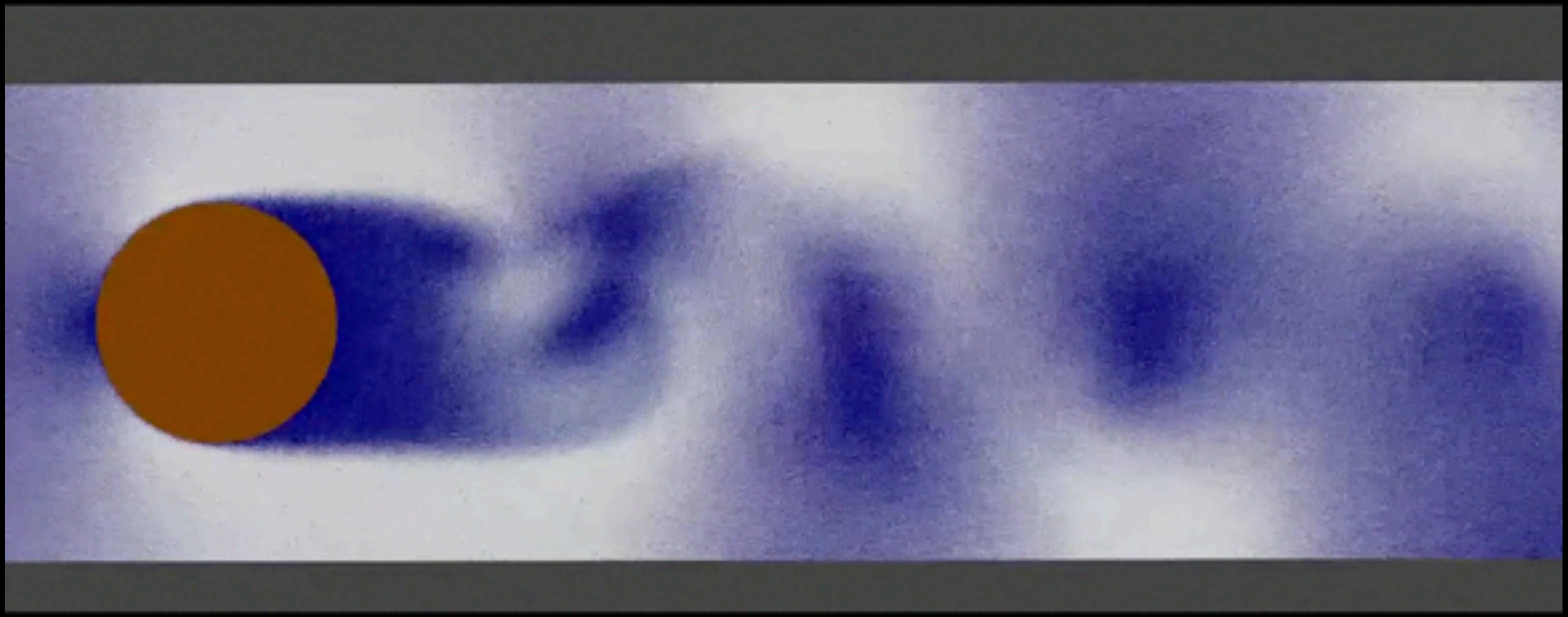


Benchmark Problem 1 - Alt Video

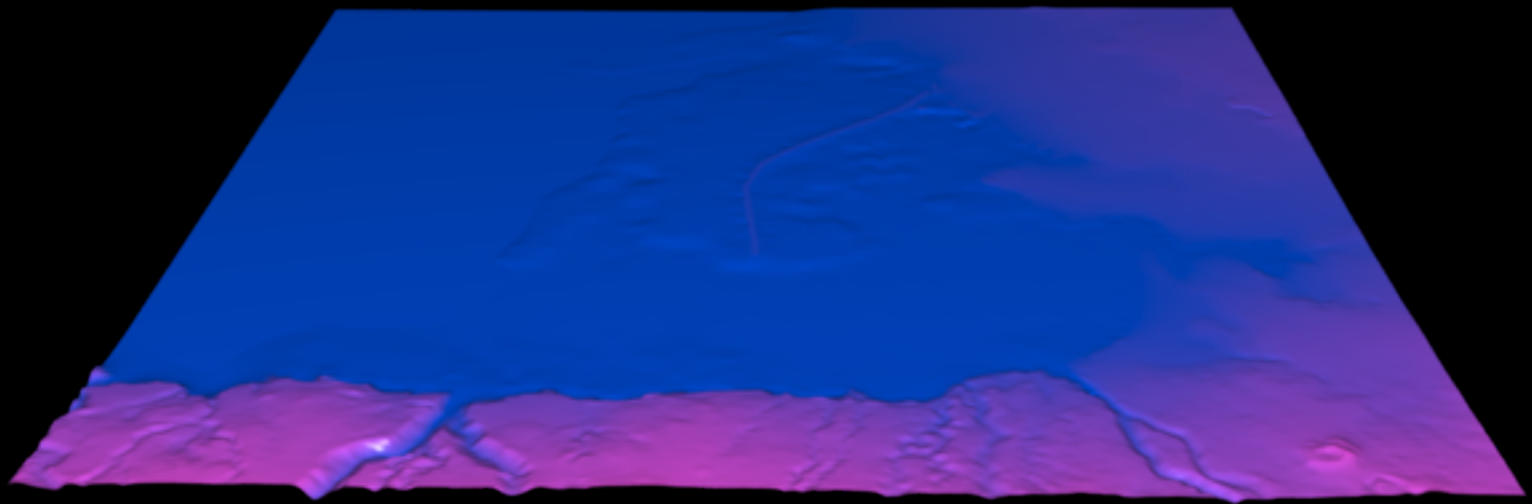


Benchmark Problem 1 - Discussion

- Vorticity not clearly prevalent with this problem domain
- Data didn’t match - work needed

Benchmark Problem 2

- Data
  - 7000x7000x2 m
  - 100 Million Particles with 0.5m Res
  - 800 Million Particles with 0.25m Res

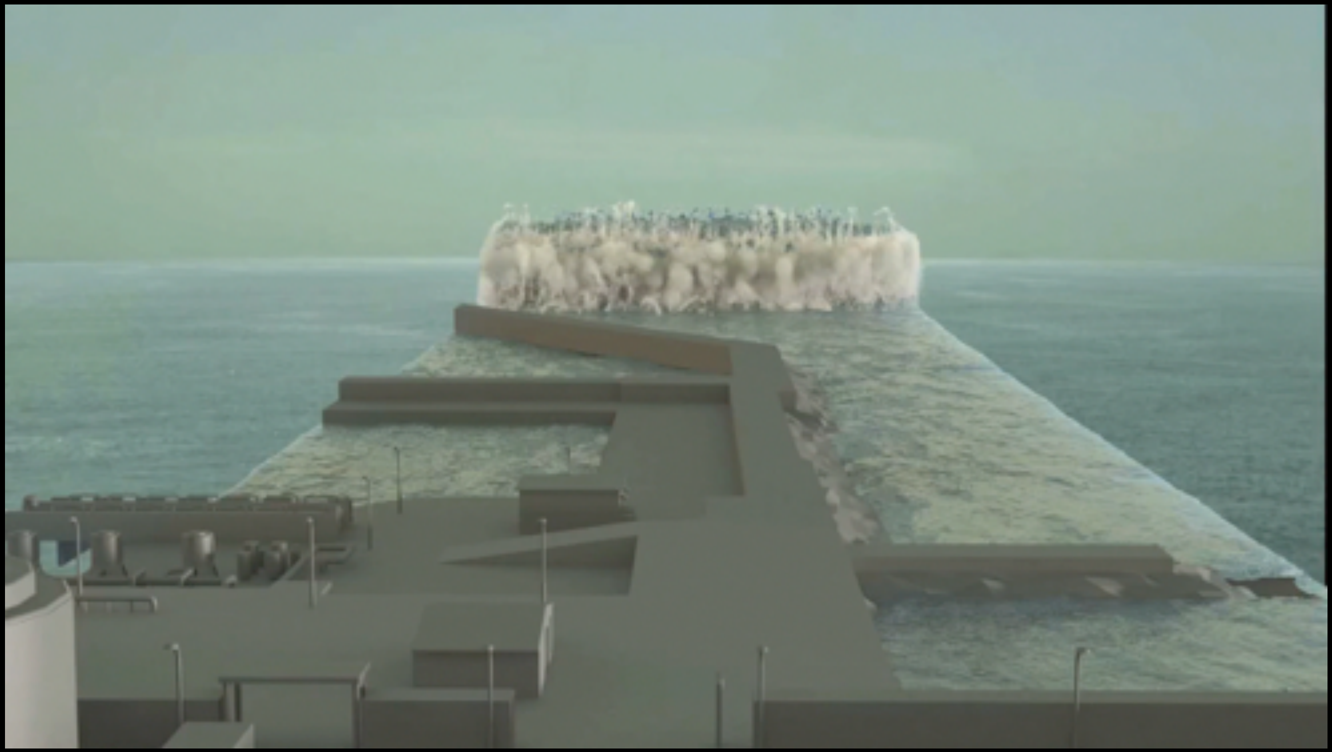


- Memory/Computing
  - 128 G Memory with 40 Threads - 1 Min Sim - 96 Hours

Conclusion and Future Work

- Better modeling of solid/fluid friction
- Coupling 2D shallow water simulations with 3D SPH
- Distributed computing to handle large particle count
- Validation in geophysical scale.

Monster Wave



Thanks

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