Smoothed-Particle Hydrodynamics (SPH)

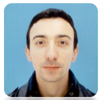
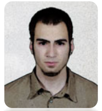
Intro
Challenges And Validation

Topics

- **Introduction**
  - Team
  - SPH
- **SPH Challenges**
  - Topics
  - Industry Requirements
- **Neutrino-SPH**
  - Validation
    - Dam Break Problem
    - Lid Driven Cavity Flow
    - NTHMP Solitary Waves
    - NTHMP Channel Flow Problem

Introduction: Team

- Neutrino-SPH Developers
  - **Ram Sampath**

    - R&D Engineer: Disney Feature Animation, Digital Domain etc.
    - M.S: Computer Science – University of South Carolina.
  - **Niels Montanari**

    - M.S: Applied Mathematics - University of Grenoble.
    - Diplôme d'ingénieur: Computer Science – University of Bordeaux.
  - **Nadir Akinci**

    - Post Doctoral – MIT.
    - Ph.D – University of Frieberg.

Introduction: SPH

- Particles
  - A particle is a minute fragment or quantity of matter'
- Usual meanings in science
  - Smallest constituents of matter (Standard Model)
  - Nanoparticles, colloidal particles
  - Dust, powder, ashes
  - Sediment grains, water droplets

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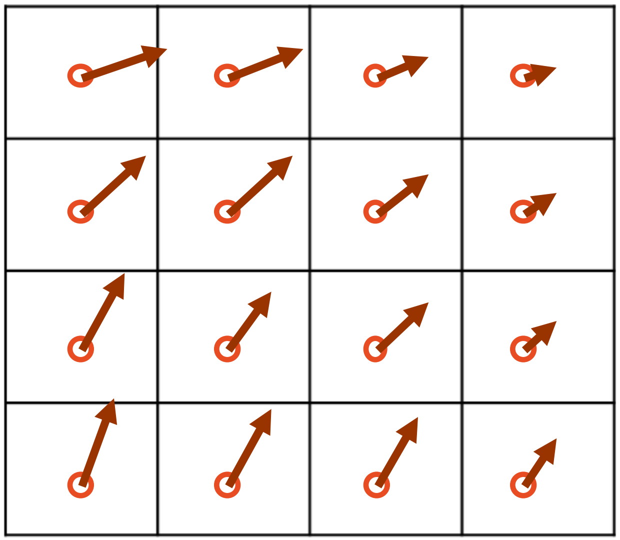
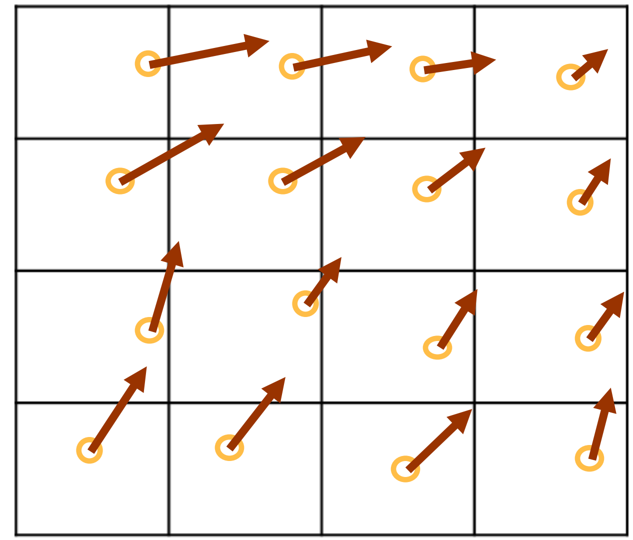
- The duality of ’particles’ in SPH
  - They are material points
  - They have volume, mass, pressure, density, etc.

Introduction: Eulerian Vs Lagrangian





$\mathbf{v}(x, y, z, t)$

$\mathbf{v}(x + \Delta t \cdot u, y + \Delta t \cdot v, z + \Delta t \cdot w, t + \Delta t)$

- Eulerian: Flow quantities sampled at grid positions advected with flow.

$$\frac{\partial A}{\partial t} + (\boldsymbol{v}.\boldsymbol{\nabla})A = 0$$

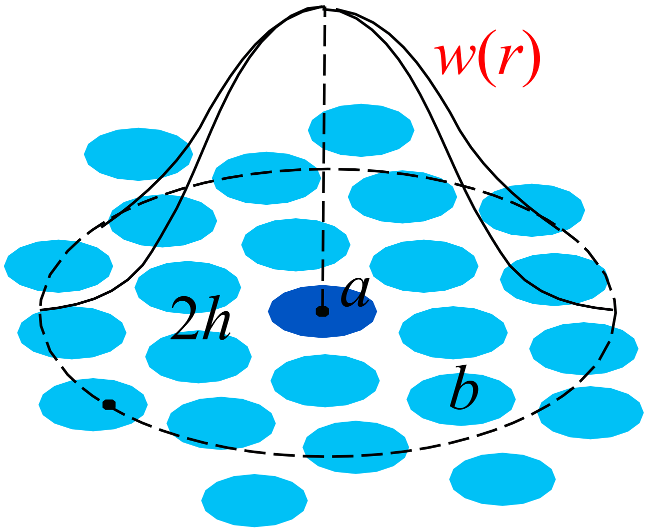
- Lagrangian: Flow quantities sampled at positions moving with the flow.

$$\frac{dA}{dt} = 0$$

Introduction: SPH Interpolation

- Particle a has position $\mathbf{r}_a$, mass m_a, volume V_a, etc.
- Particle Interactions are computed using the '**kernel**' $w(r)$
- The support of w has size $2h$, h = **smoothing length**, w is normalized

$$ {}_{\Omega}\; w(r)\,d\mathbf{r} = 1 $$



Lucy, L.B. (1977), Astron. J. **82**:1013–1024

Gingold, R.A., Monaghan, J.J. (1977), Mon. Not. R. Astron. Soc. **181**:375–389

Introduction: SPH Advantages

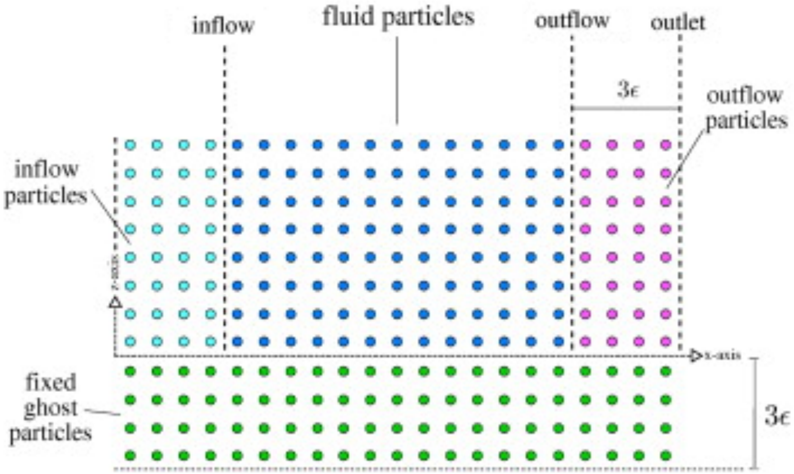
- Deal with Complex Geometry
- Robust
- Tracking Interfaces
  - Free Surface
  - Multi-Phase
  - Fluid-Structure.
- No need for methods like Level-Set or VOF
- Lagrangian method – Conservation

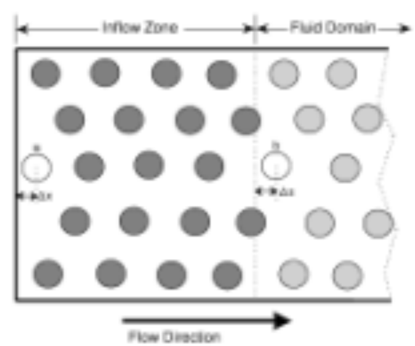
SPH Challenges

- Boundary Handling
- Computational Time
- Coupling
- Multi-Phase Solutions
- Variable Resolution
- Turbulence Modeling
- Non Iso-Thermal Flows
- Aerodynamic/Wind Driven Flows
  - High Reynolds Number Flows
- User Interface and Problem Setup

SPH Challenges: Boundary Handling

- Rigid Boundaries
- Open Boundaries
  - Flow Emitter
  - Flow Killer





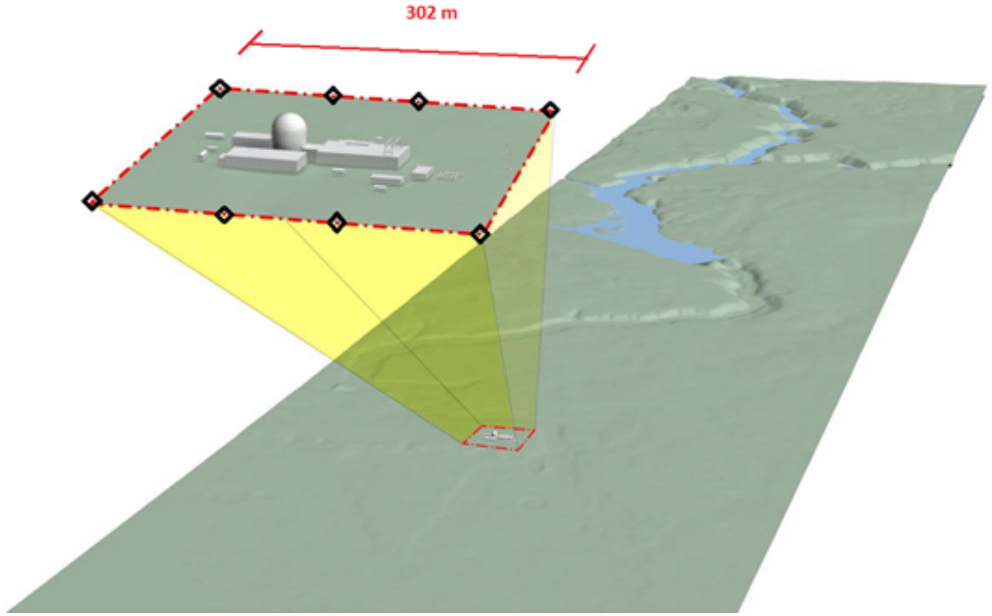
SPH Challenges: Computational Time

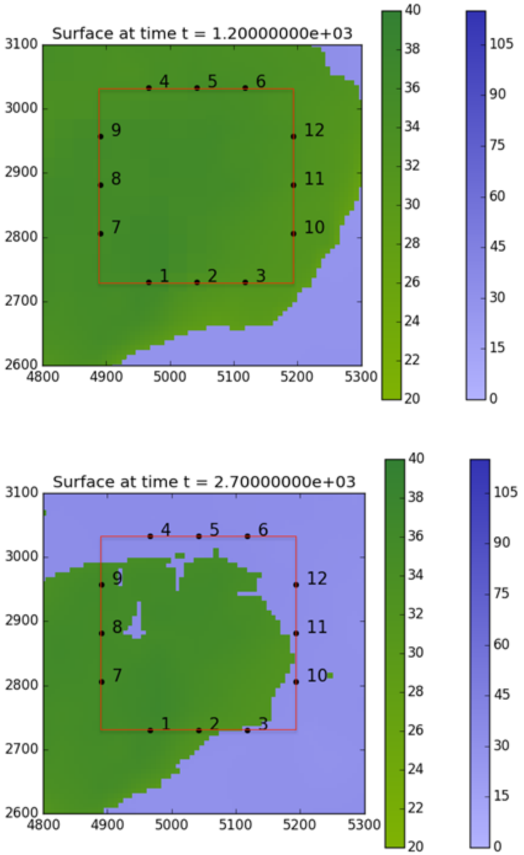
- Neighborhood Search
- Pressure Solve
- High Performance Computing
  - Multi Core
  - GPU
  - Distributed

Industry Requirements: Coupling

- Case study: Dam Breach induced Flooding.
  - Shallow Water model for dam break until region of interest
  - Solve the Navier-Stokes equations with SPH – Flow Structure
  - Couple Domains - Inflow boundary
    - Horizontal velocity components + Height.

Industry Requirements: Coupling

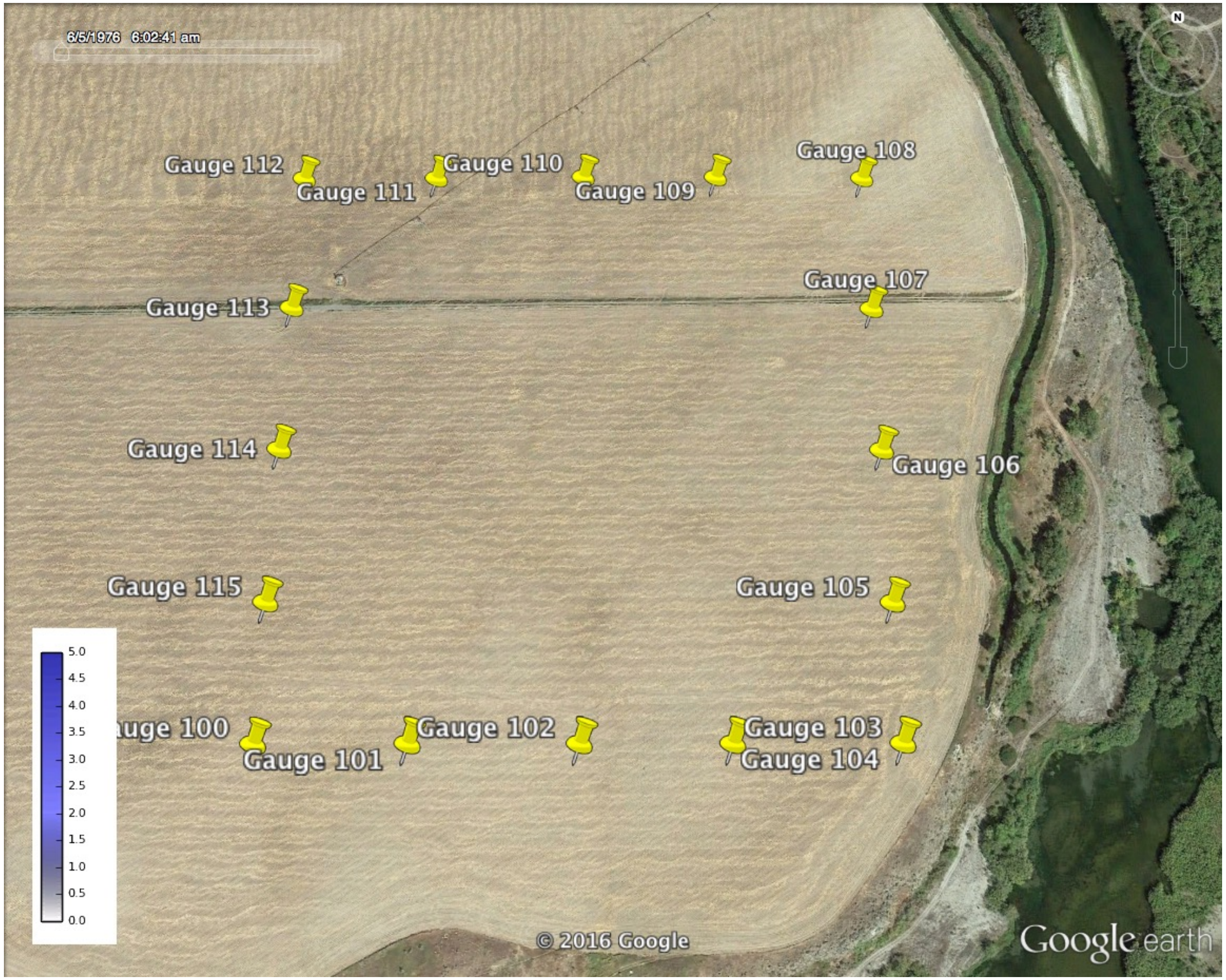




Neutrino-SPH: Coupling

- Shallow Water Coupling
  - GeoClaw
    - Riemann Solver
    - Adaptive Mesh Refinement
    - Parallel
    - Setup by python script
    - Measurement Gauges
  - Domain is coupled to SPH along gauges

Neutrino-SPH: Coupling



Industry Requirements: Coupling

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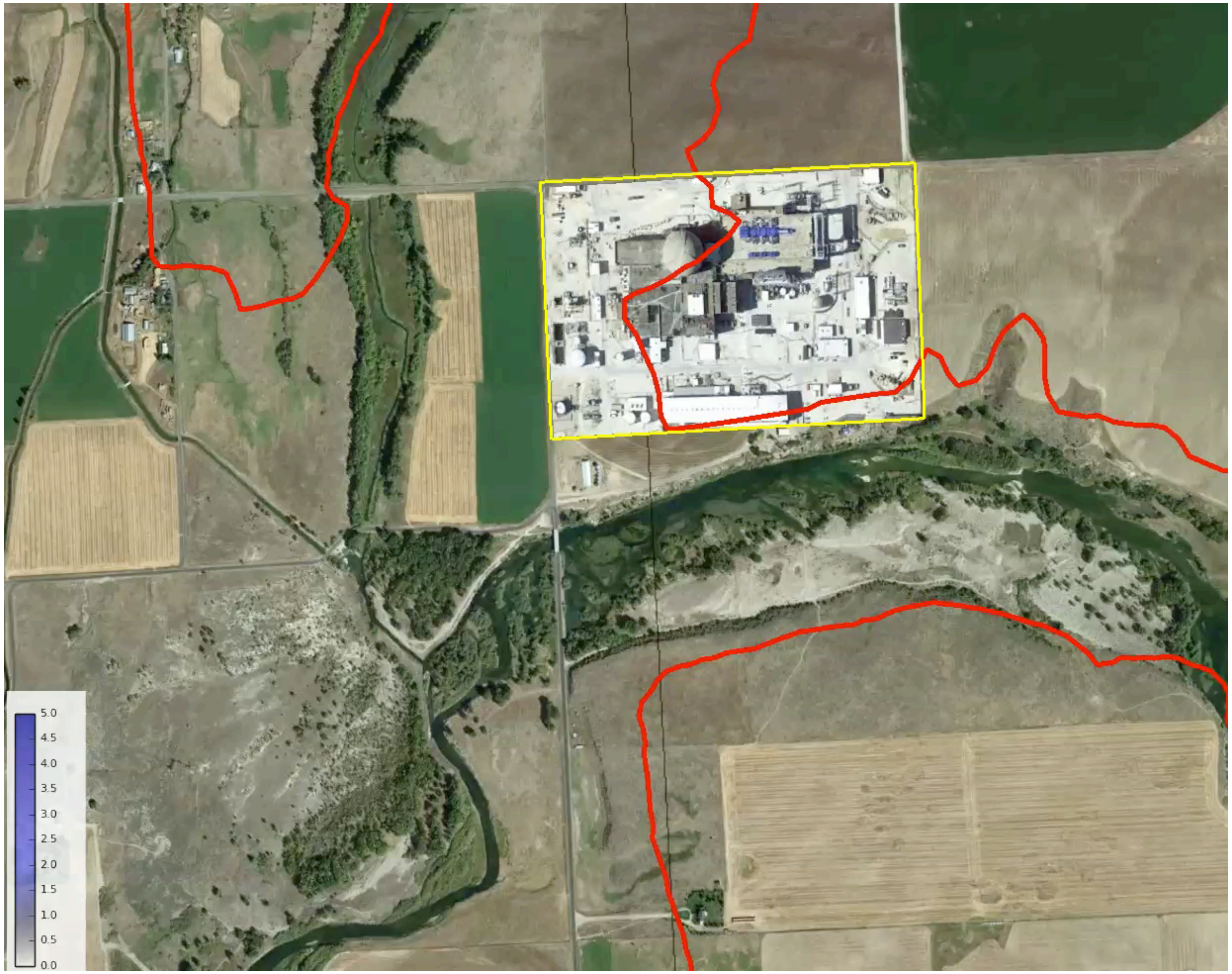
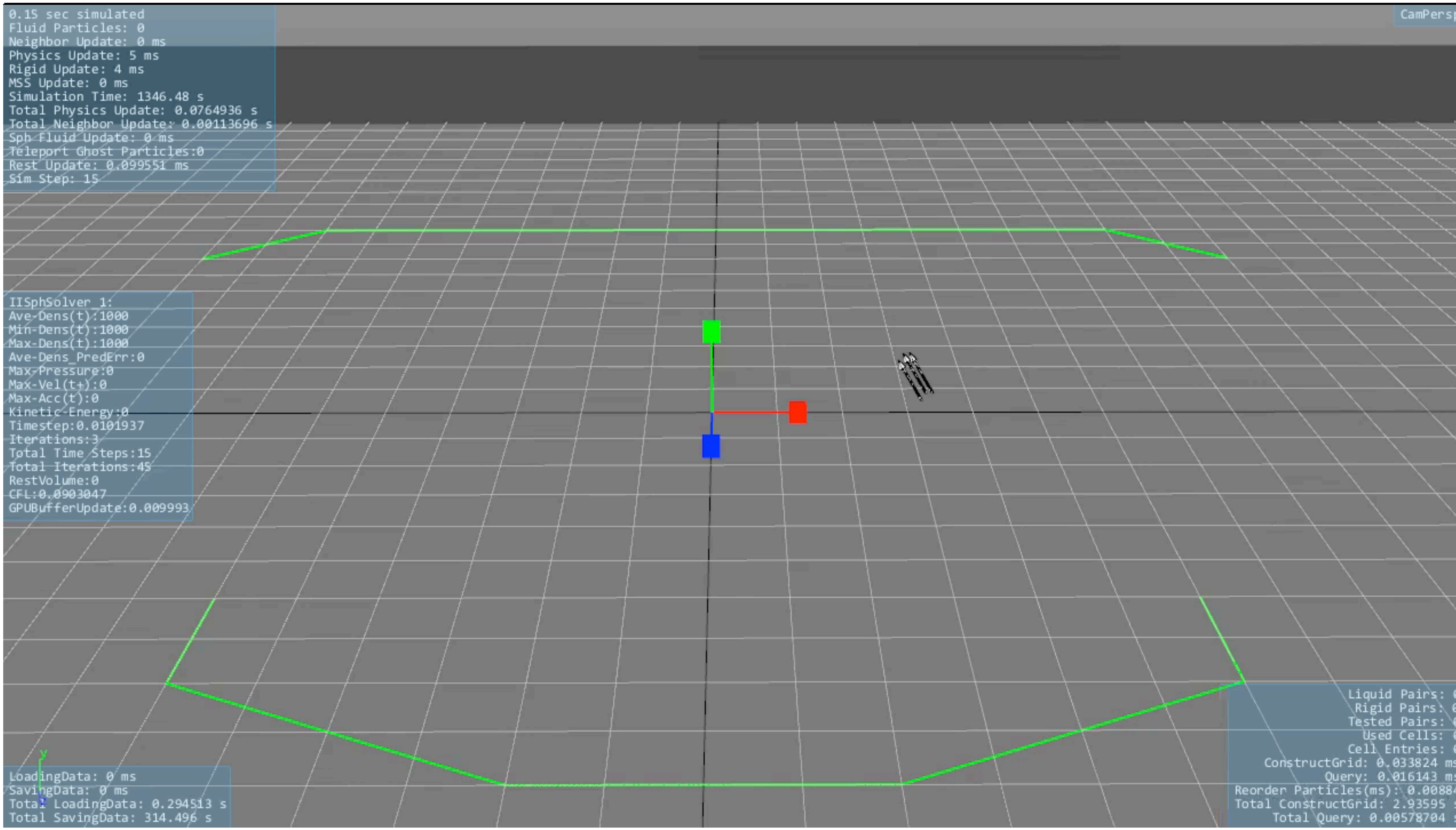


Neutrino-SPH: Coupling

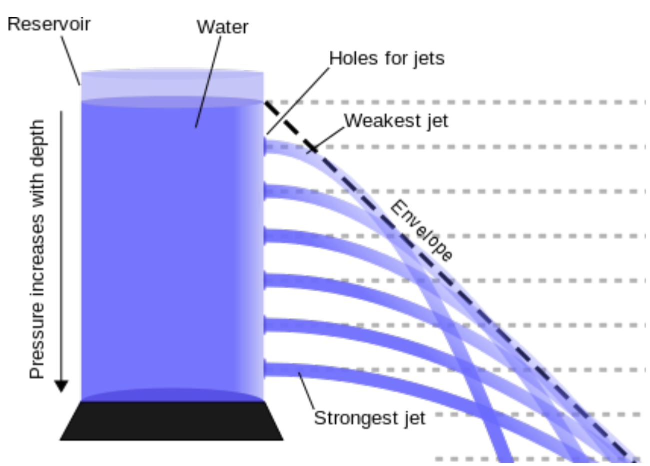
- Define the topology of the boundary by the set of gauge positions and connections.
- Prescribe the inflow velocity, direction and height using the shallow water data.
- Interpolate in time to synchronize the shallow water data with the SPH simulation.

Neutrino-SPH: Coupling



Industry Requirements: Coupling

- Case study: rainfall-induced flooding.
  - Rainfall with the Navier-Stokes equations is overkill.
  - Use a simple fluid model based on Bernoulli's principle.
  - Solve the Navier-Stokes equations with SPH afterwards.
  - Couple the domains with an inflow boundary.



Neutrino-SPH: Coupling

- From the mass conservation, the variation of fluid height follows:

$$\frac{dh}{dt} = \frac{Fr_{in}(t) - Frout(t)}{A}$$

- For a rectangular hole, the outflow rate is:

$$Fr_{out}(t) = WemitHo_{ut}(t)|\boldsymbol{v}_{out}(t)|$$

- From Bernoulli's principle - free jet
  - Outflow velocity :- Torricelli's law:

$$|\boldsymbol{v}_{out}(t)| = \begin{cases} 0, & \text{if non submerged} \\ \sqrt{|\boldsymbol{g}|H_{out(t)}}, & \text{if partially submerged} \\ \sqrt{2|\boldsymbol{g}|(z_{floor} + h(t) - zemit)}, & \text{if fully submerged} \end{cases}$$

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Neutrino-SPH: Coupling

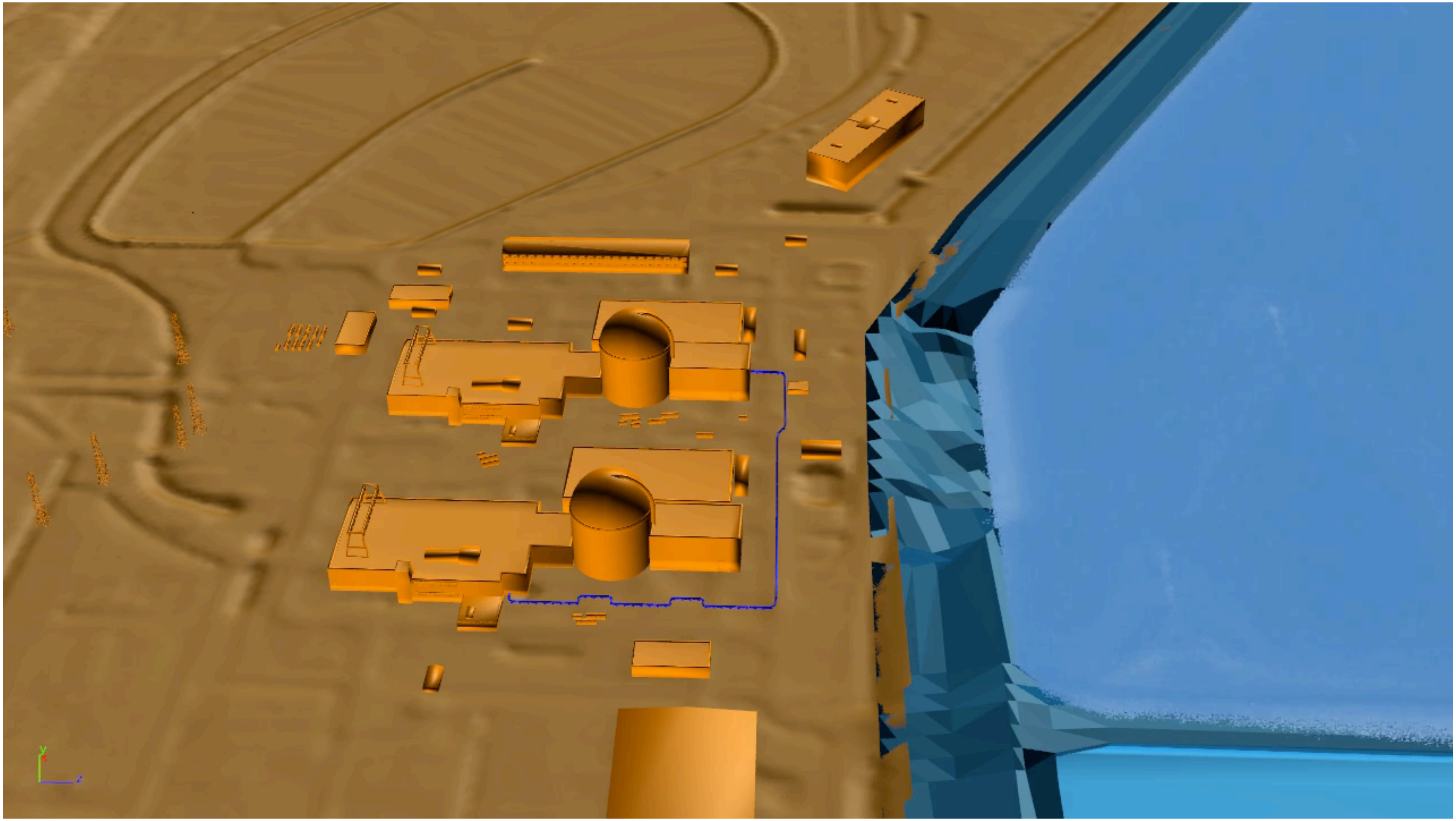
- Extensions possible to take into account:
  - Discharge coefficient;
  - Hole Shapes (e.g., circular);
  - Submerged Jet.

- In the case of an inflow rate constant over time, or more generally converging to a given value, a steady state is eventually reached, at which $Fr_{out}^{lim} = Fr_{in}^{lim}$.
- Value of fluid height and outflow velocity at the steady state can be computed analytically or numerically.

Neutrino-SPH: Coupling

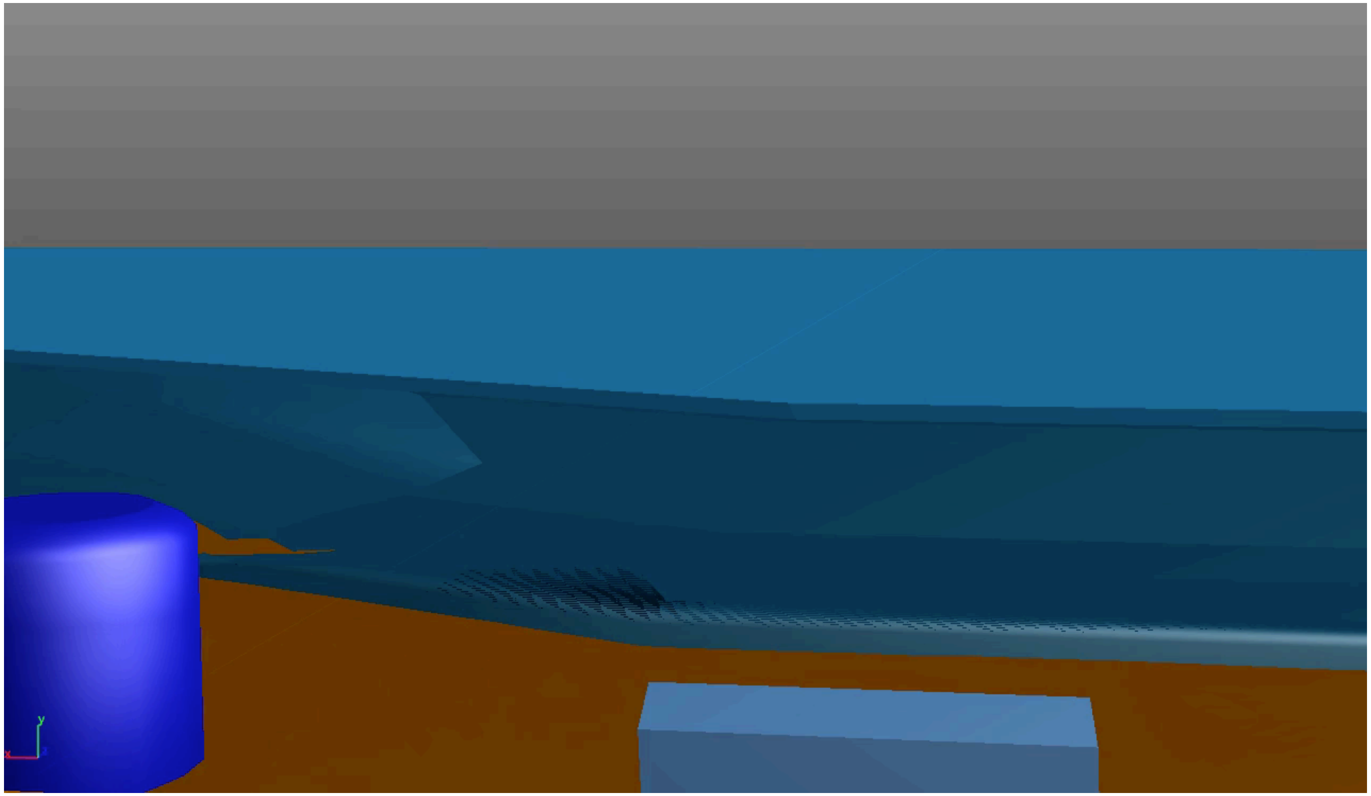
- Neutrino-SPH Emission Systems
  - Torricelli Emitter
    - Arbitrary Shape for Container
    - Inflow
      - Rainfall etc
  - Calculated Accumulation
    - Emitters can be Coupled
      - Outflow => Inflow
  - Flow Emitter
    - Rectangular Shape
    - Controlled by time varying flow rate
    - Mass Conserving

Case Study 2: NPP Flooding Breach



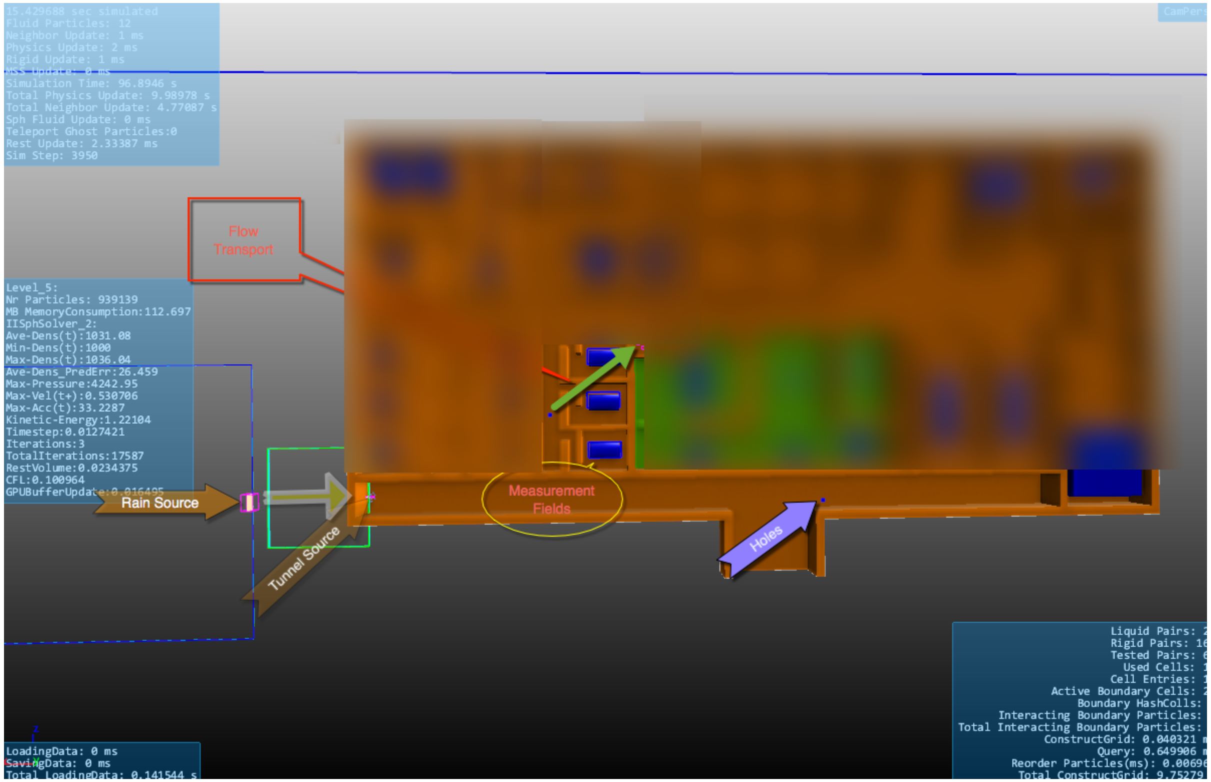
Case Study 2: NPP Flooding Breach

SWMM Provided Input Erosion Model



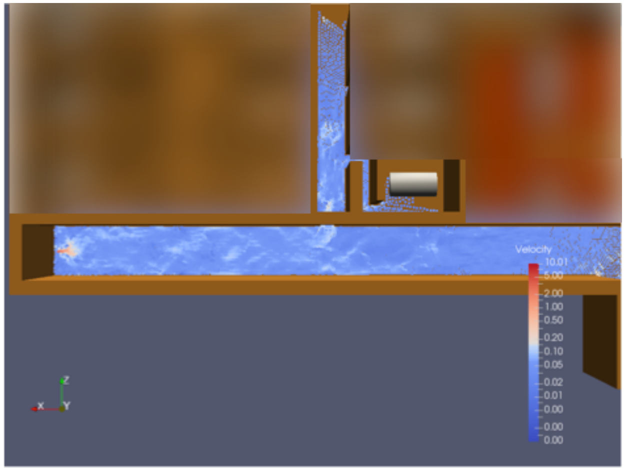
Case Study 3: Rain Induced Flooding at NPP

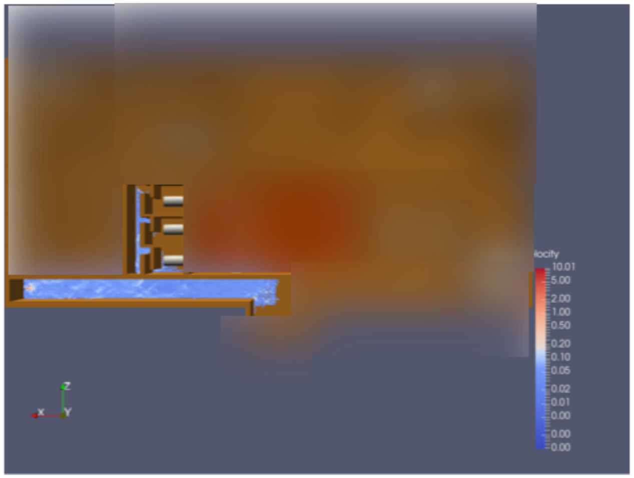
- Setup
  - Buildings
  - Levels
    - Components
    - Emitters
    - Transporters
    - Killers



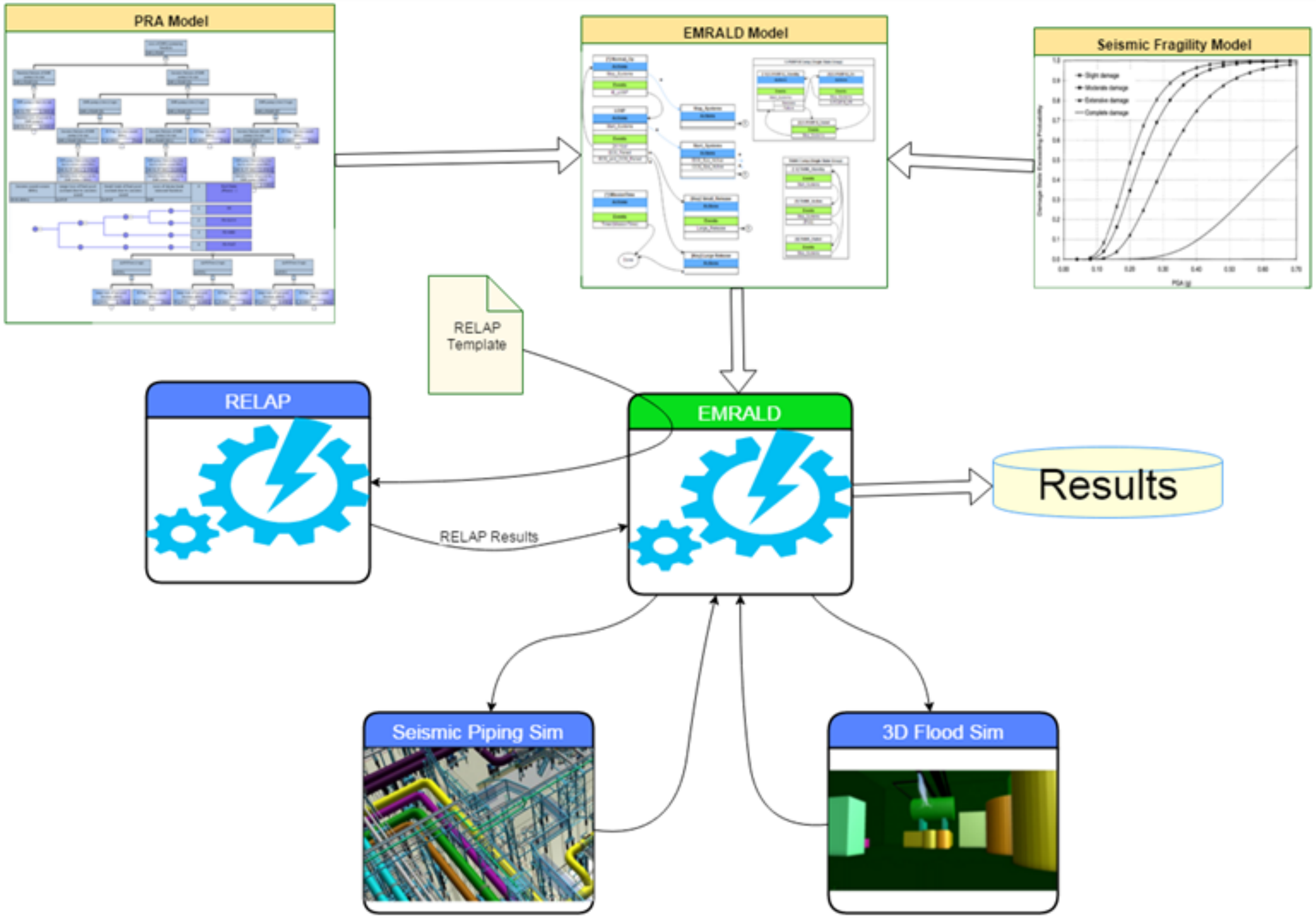
Case Study 3: Rain Induced Flooding at NPP

- Flooding Setup
  - Building
    - Open Section (Rain)
  - Tunnel
    - Connecting Room
    - Opening in Tunnel
      - Inflow to Room
  - 1 Room
    - Components
  - 2 Room
    - Components
  - Coupled Torricelli Emiiter
    - Rain Emitter => Tunnel Emitter
    - Rain Emitter Info = 0.03 $\frac{m^s}{s}$
  - Simulations: 2 Hours

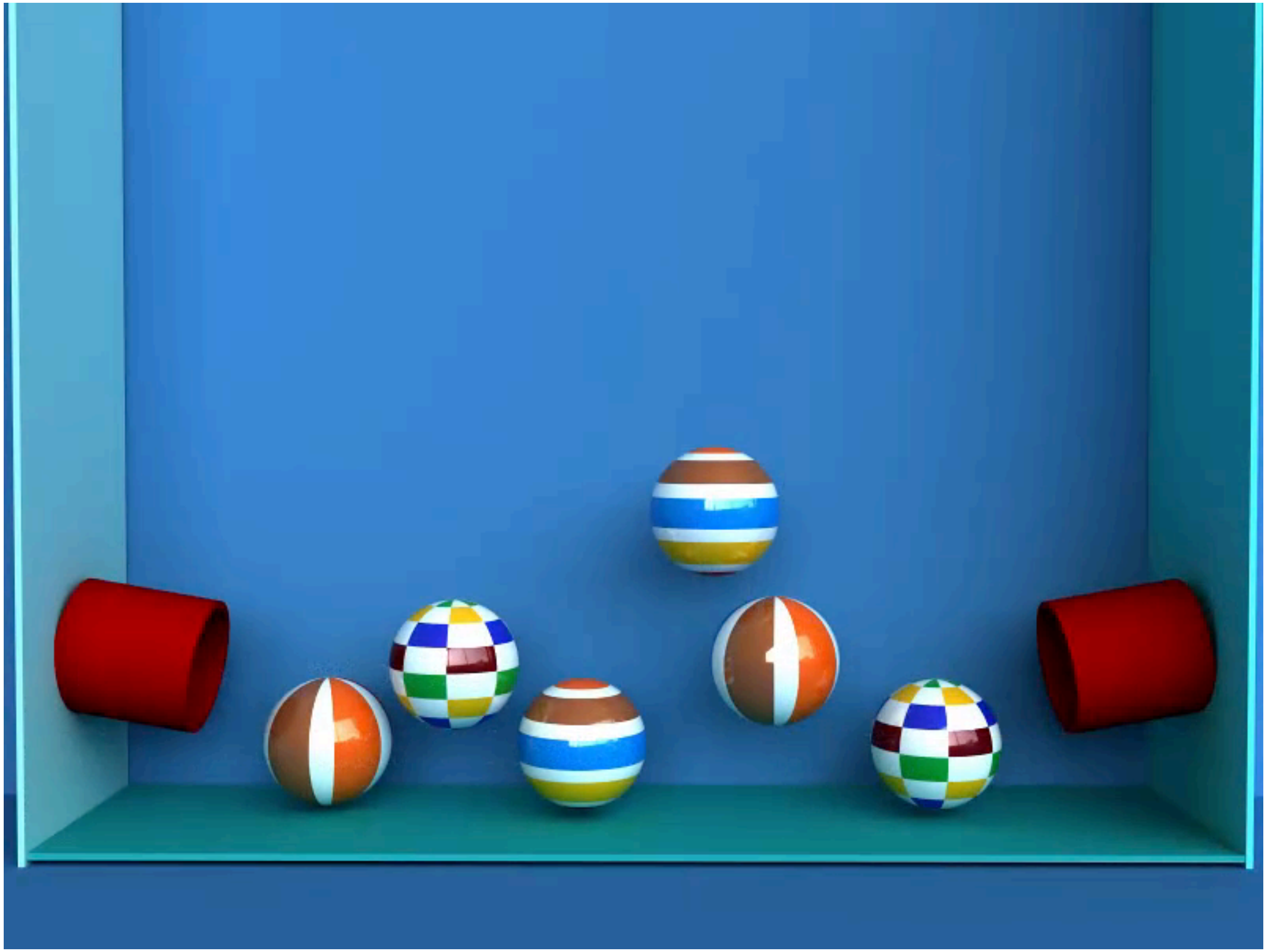




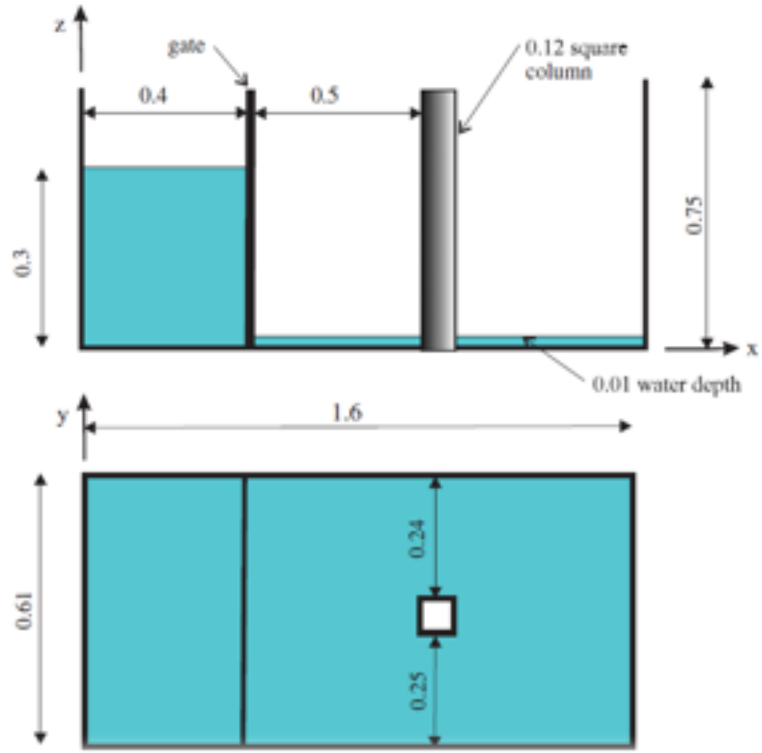
Neutrino-SPH: Communications



Neutrino-SPH: Multi Phase Flows



Neutrino-SPH: Dam Break Problem



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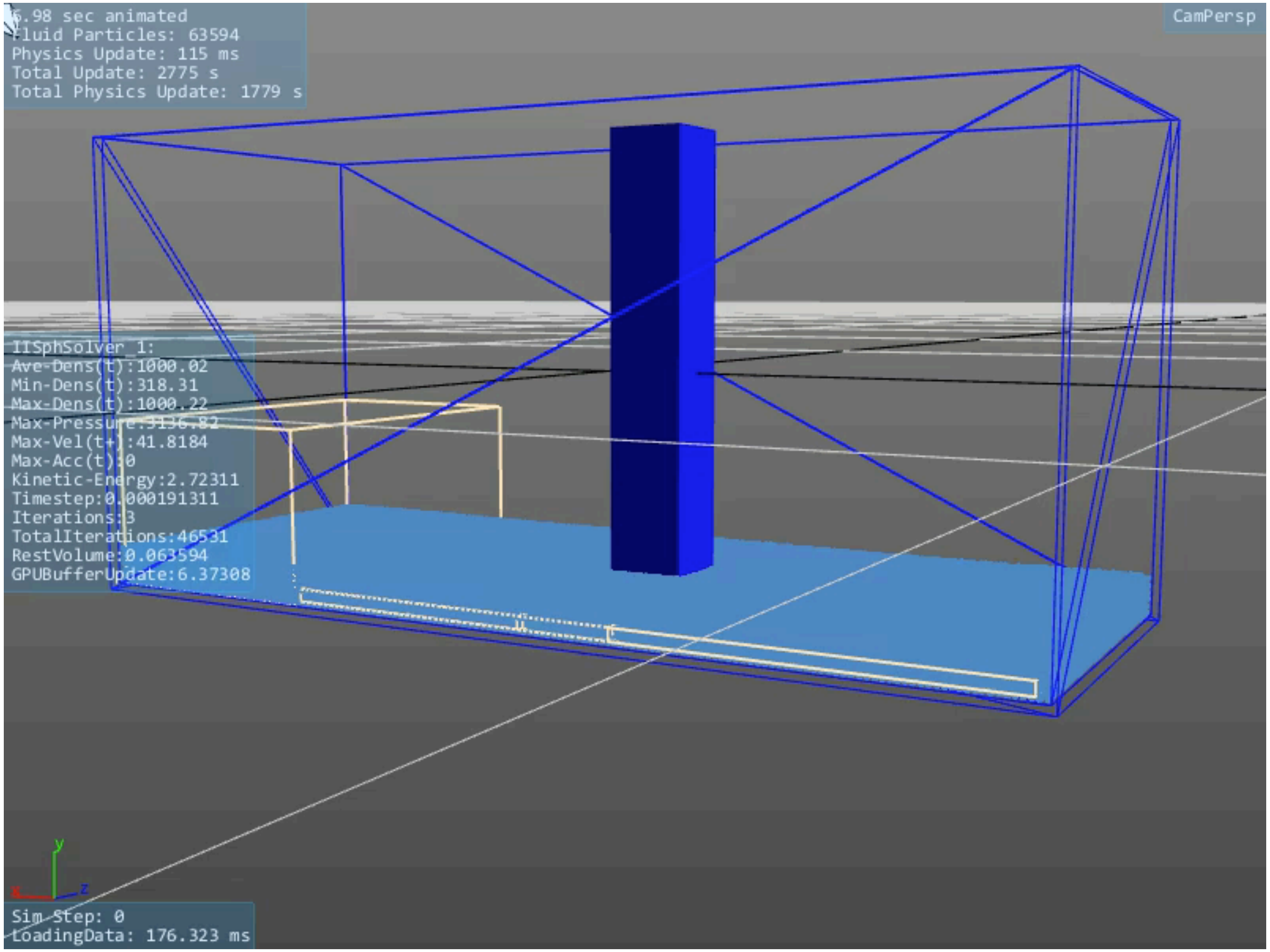

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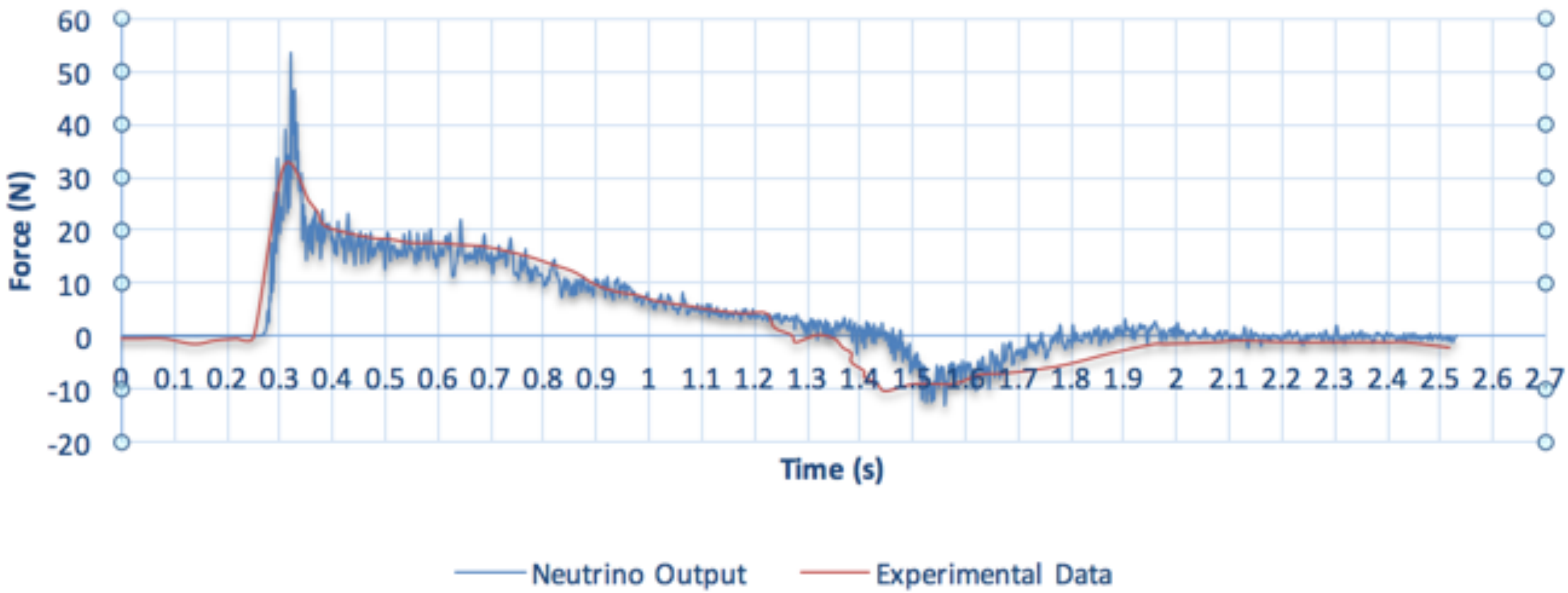
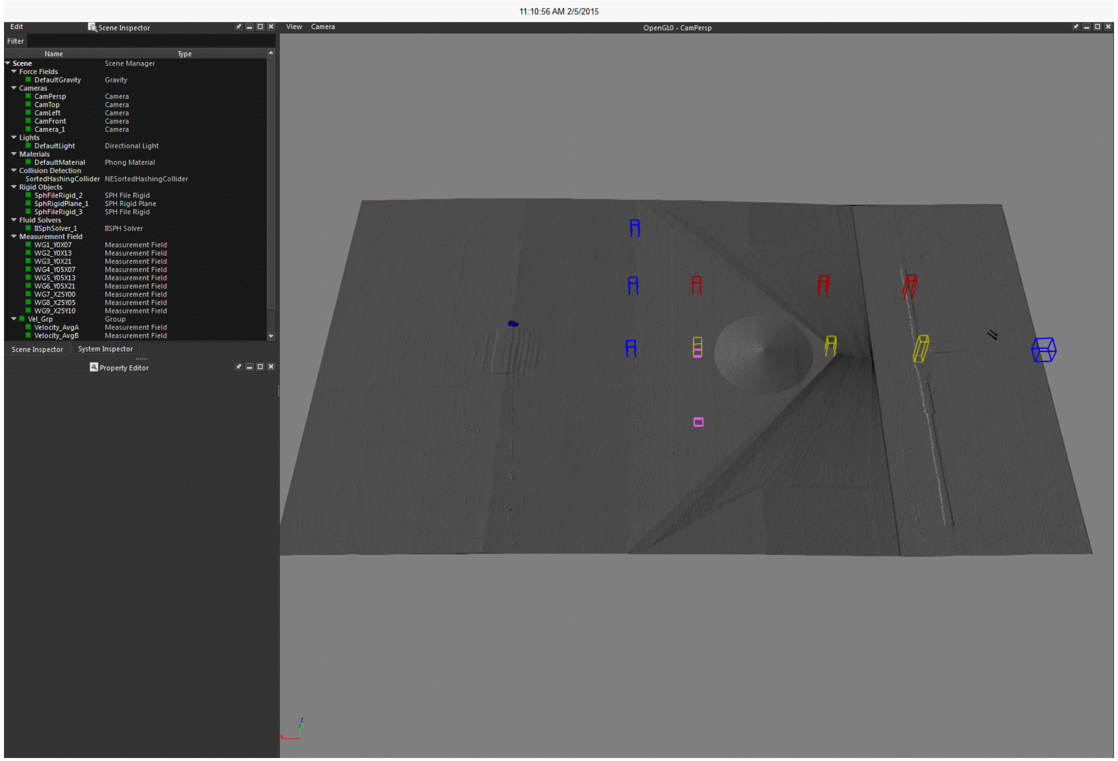


Neutrino-SPH: NTHMP Solitary Waves

- Benchmark 1: Wave Tank – Solitary Waves



Neutrino-SPH: NTHMP Solitary Waves

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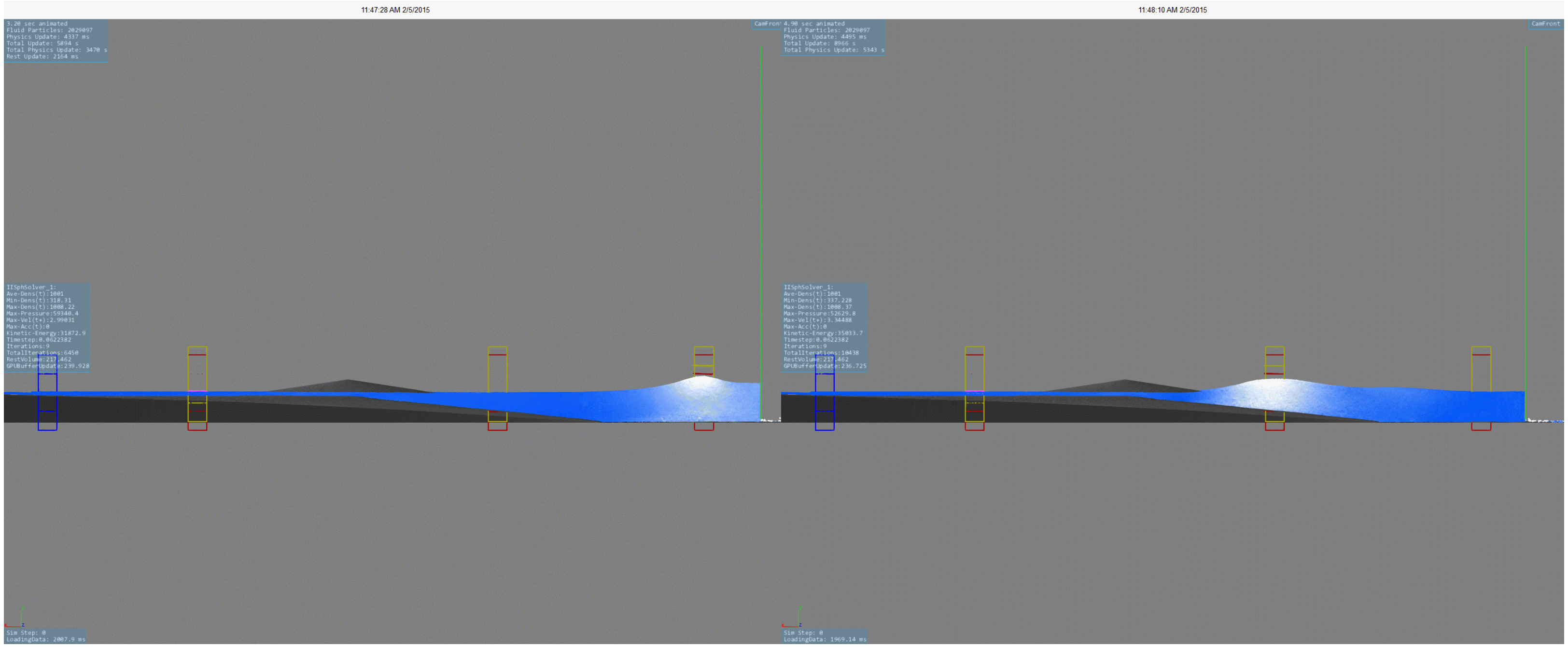

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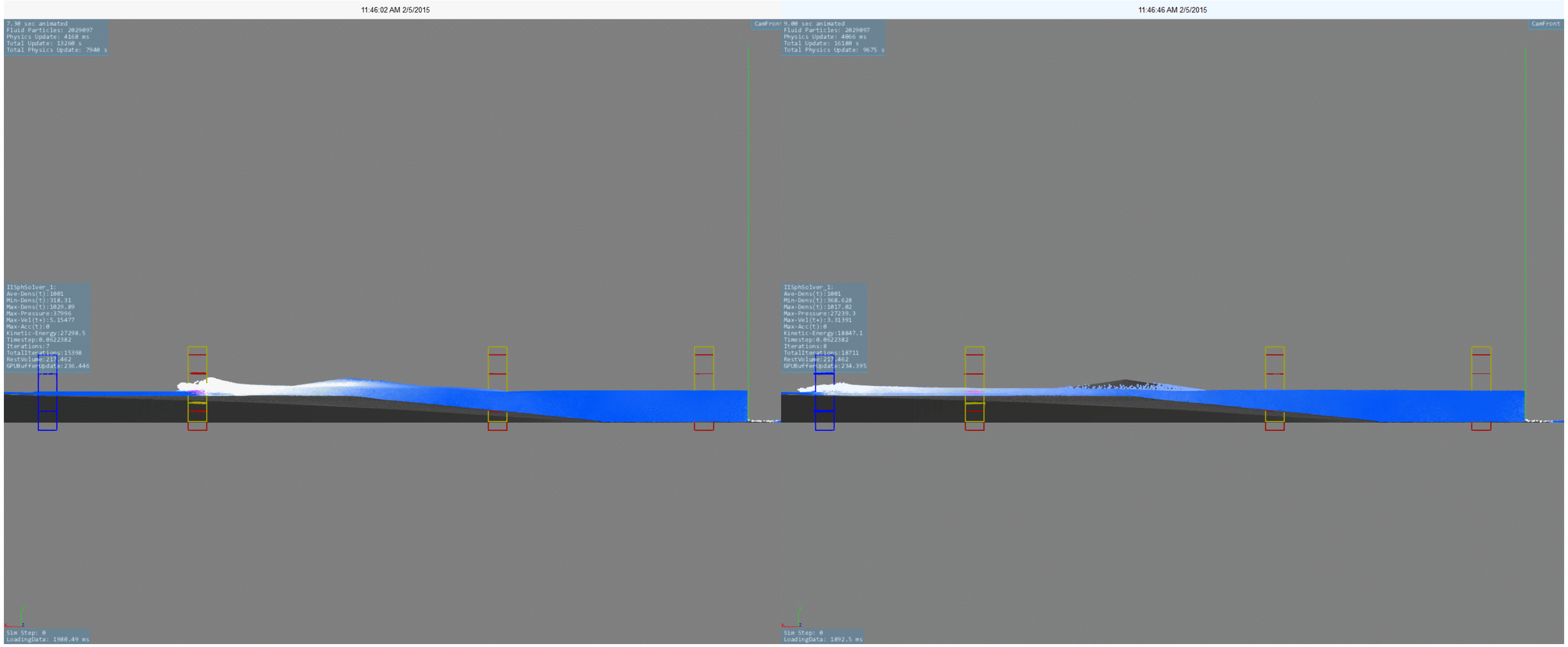

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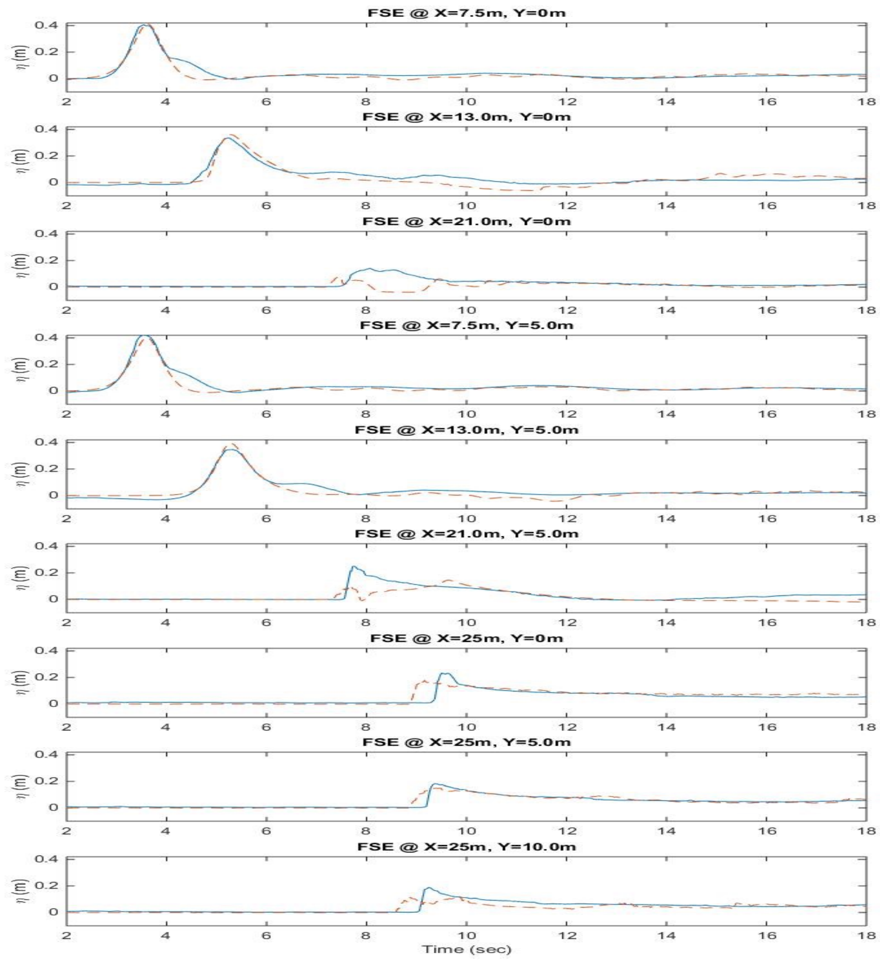

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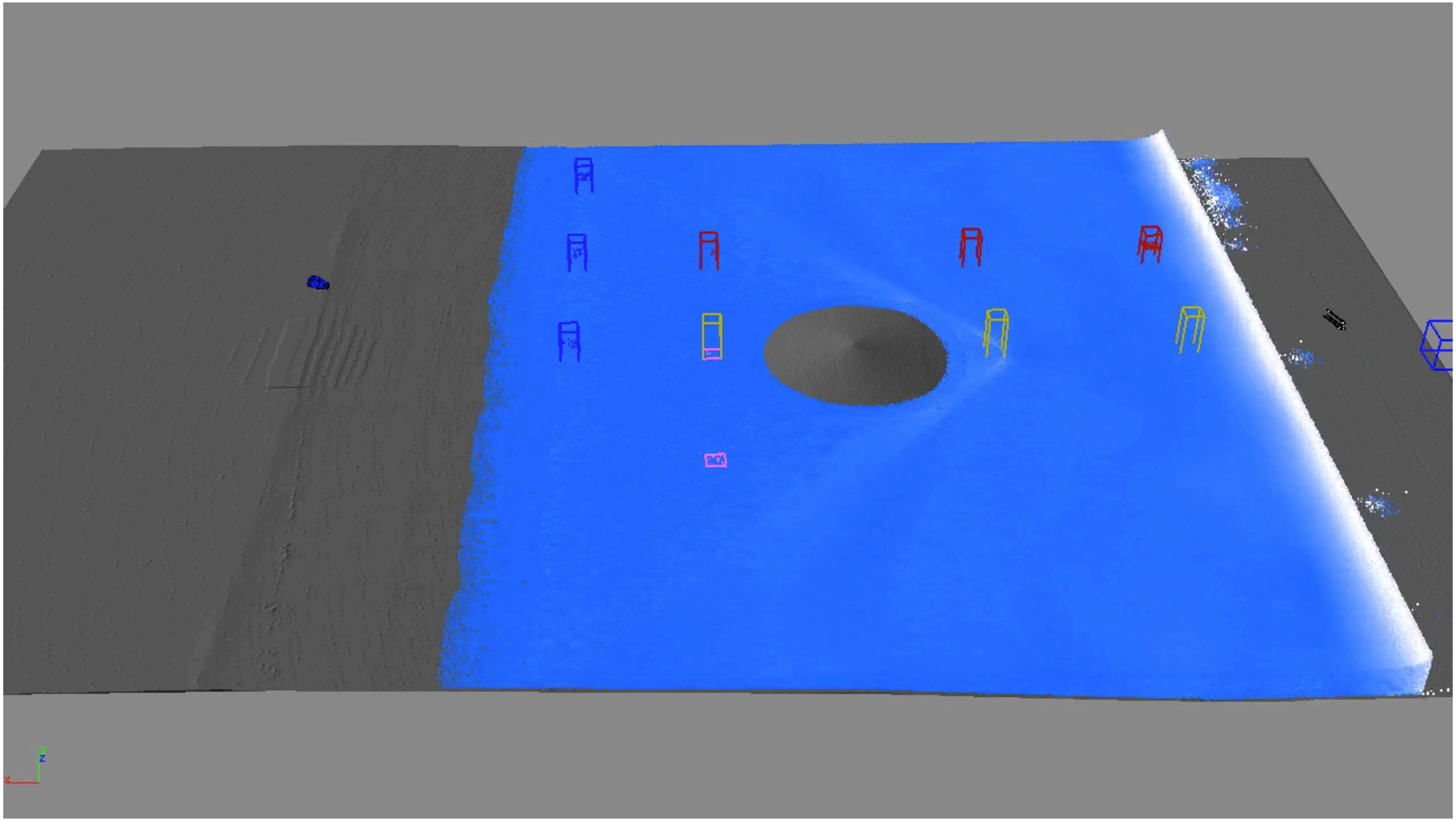

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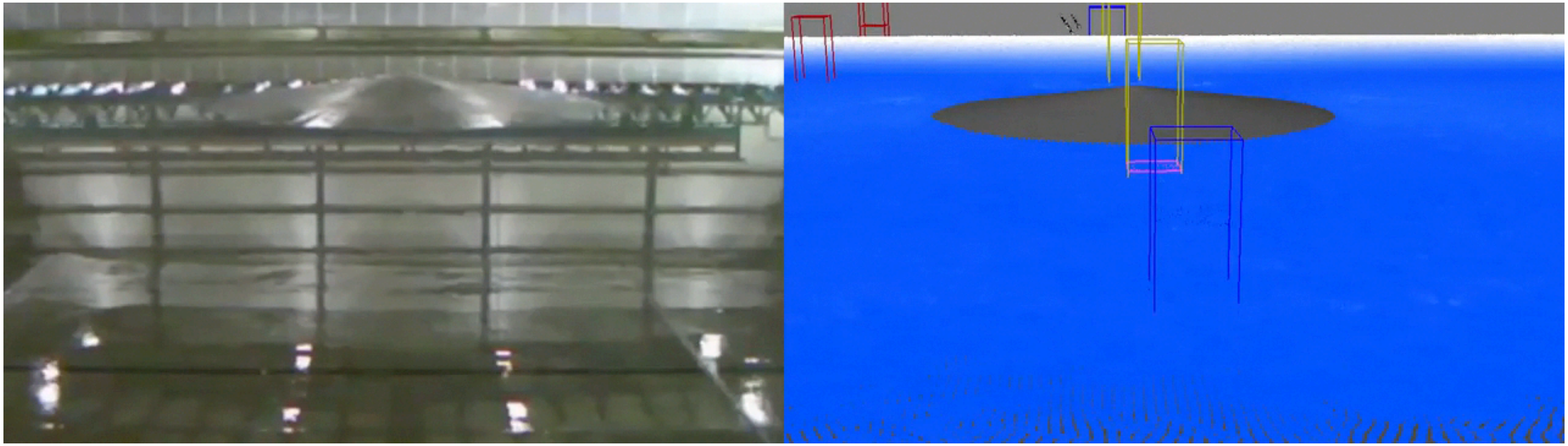
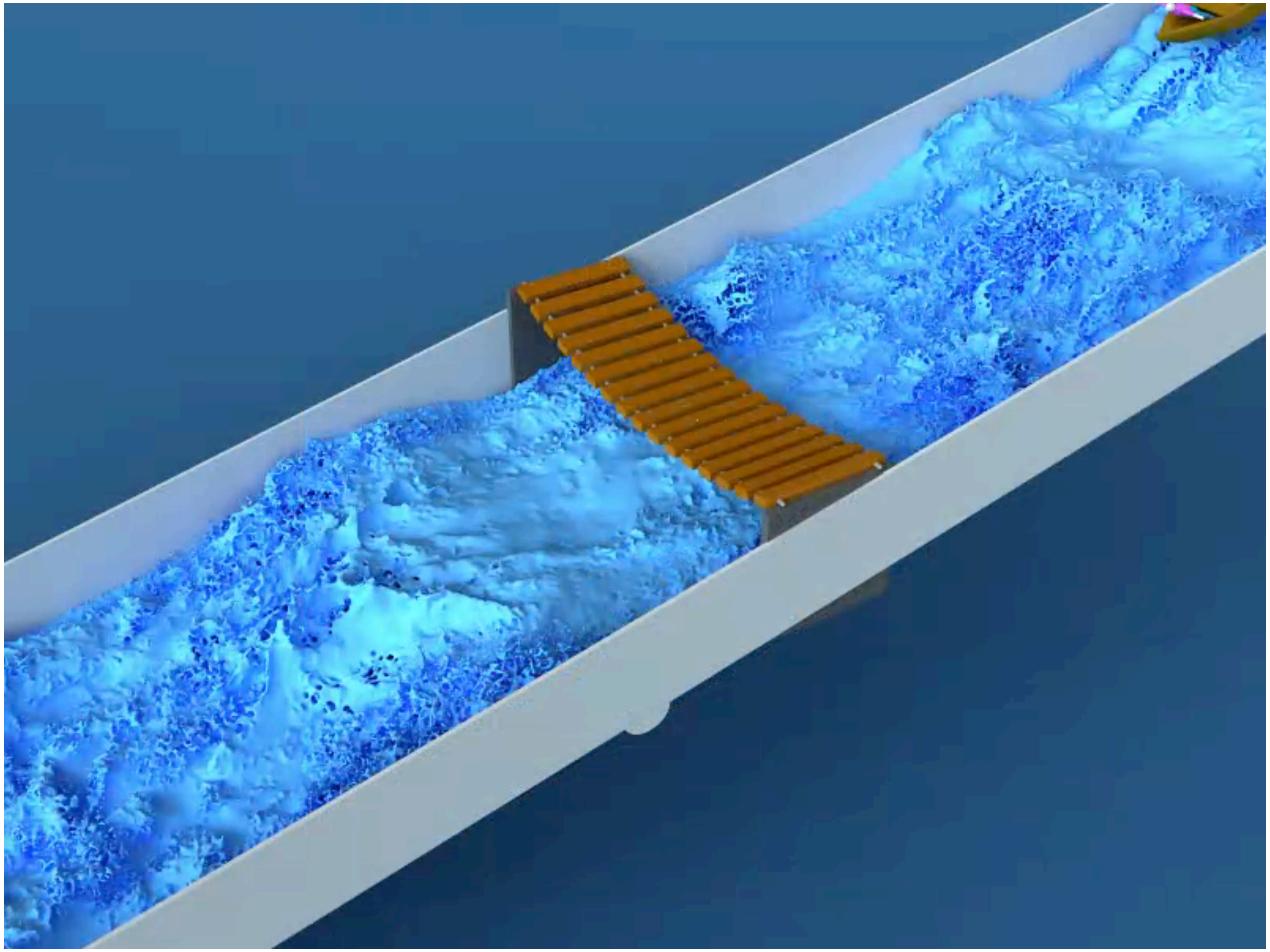
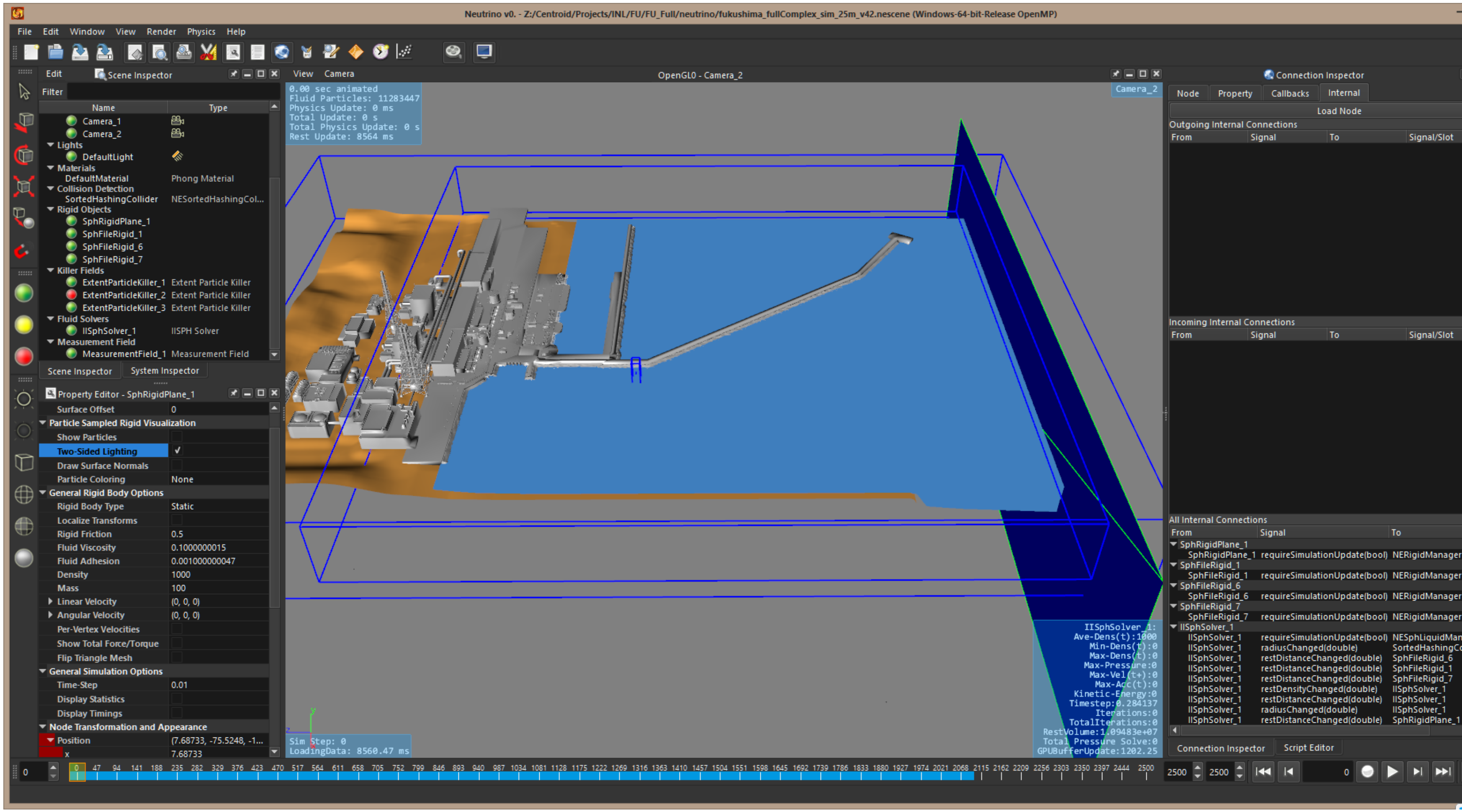
Neutrino-SPH: NTHMP Solitary Waves



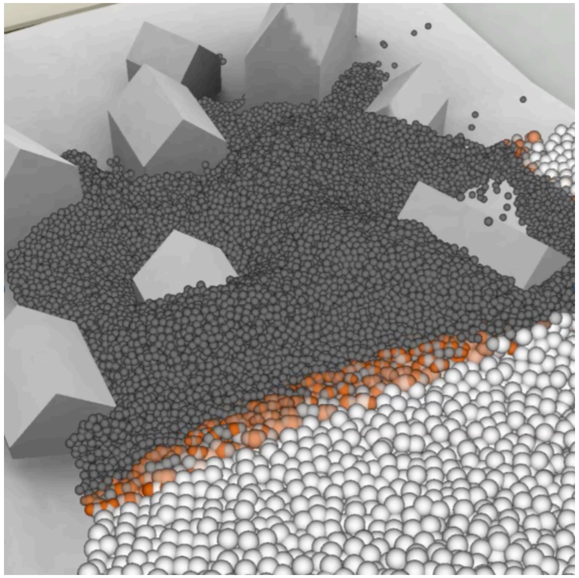
Neutrino-SPH: Videos

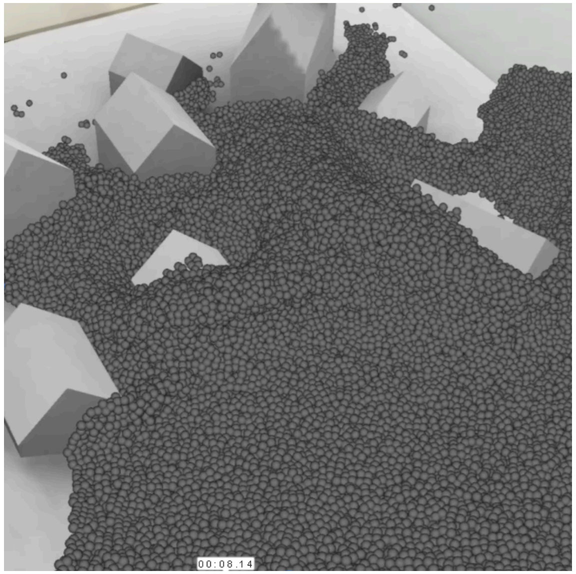


Neutrino-SPH: UI/Problem Setup



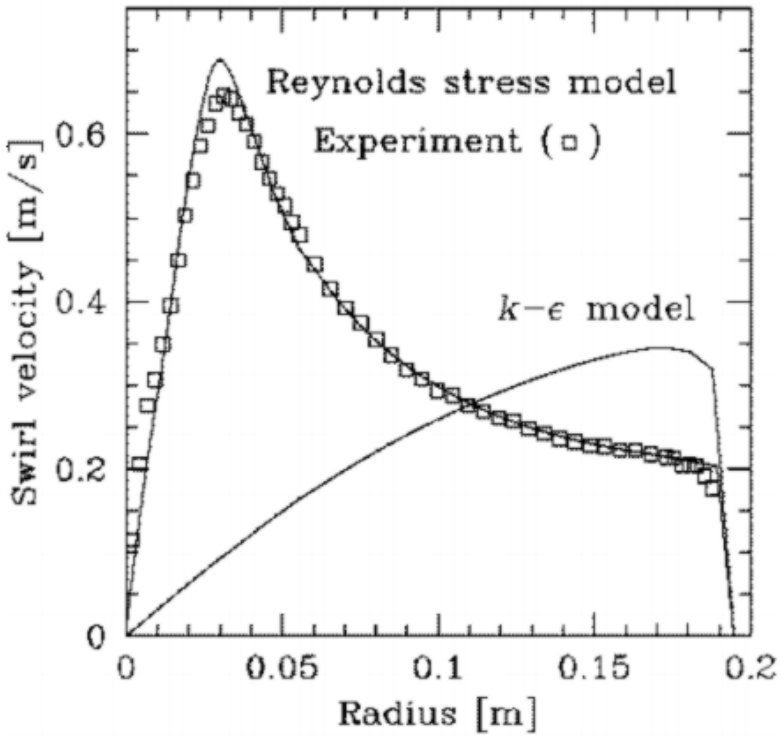
SPH Challenges: Variable Resolution





SPH Challenges: Turbulence Modeling

- Turbulence in strongly swirling flow cant seem to be captured by k-e model

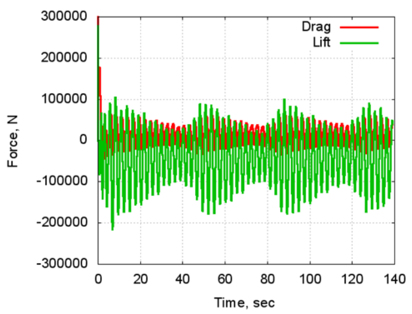


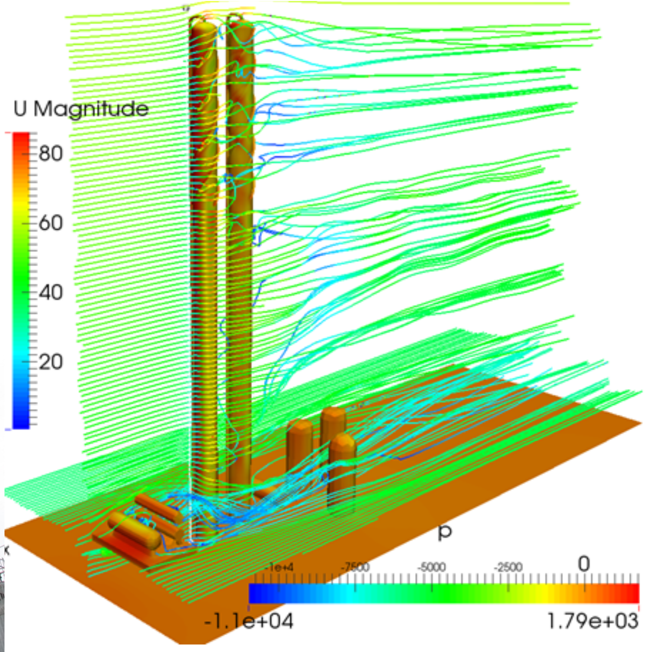
SPH Challenges: Non-Isothermal Flows

- Use Energy Conservation Equation
- Use Boussinesq Approximation
- Boundary Conditions
  - Handle Temperature
  - Model Free Surface Heat Transfer/Multiphase fluid/air etc

SPH Challenges: Wind Driven Flows

- Traditional CFD Modeling
- Correct Modeling of Turbulence
- Coupling of SPH and Grid CFD
  - (OpenFOAM)





Neutrino-SPH: In Development

- SPH For Free Surface Flows
  - Validity for Risk Analysis & Estimation
- Coupling
  - Two way coupling
- High Wind
  - Coupling with Mesh CFD
- Extensions to Non Isothermal Flows
  - Thermal Flow through pipes
- Explosions
  - SPH or Coupling with Mesh CFD
- Fracture

Thank you

- Dr Curtis Smith (INL)
- Steve Prescott
- Dr Nam Dinh (NSCU)
- Niels Monanari (Centroid LAB)
- Nadir Akinci (Centroid LAB)