FLUID STRUCTURE INTERACTIONS
RESEARCH GROUP

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Numerical Investigations on Fluid-Structure Interactions Using Particle Based Methods for Marine Applications

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Introduction & Motivation

• Many fluid-structure interaction problems often involve violent fluid motions in marine engineering field, such as slamming and green water when a ship travels in rough seas which can produce overall momentum change and deformation of the hull. Hence, it is important to consider the fluid-structure interactions, breaking waves and flow separations in order to avoid damages caused by dynamic loads on the structures.

• As it is difficult to obtain analytical solutions for such complicated problems, numerical methods and experiments are adopted in investigations. Traditional grid-based numerical methods like finite element method have been developed but they are not efficient for large deformation problems. Particle based methods like Smoothed Particle Hydrodynamics (SPH) are an alternative to simulate fluid flows due to their Lagrangian and meshless properties.

Figure 1: Rough sea slamming on offshore structure (3.bp.blogspot.com/…/s200/freakwave.jpg)

Figure 2: slamming on ship

Objective

To apply and improve the smoothed particle hydrodynamics method or combine SPH and other numerical method, FEM for example, for structures to simulate violent fluid-structure interactions.

Theory

- The formulation of SPH is often divided into two steps: integral representation and then particle approximation.

  Integral representation: $< f(x) >= \int_{\Omega} f(x')W(x-x',h)dx'$

  Particle approximation: $< f(x_i) >= \sum_{j=1}^{N} \frac{m_j}{\rho_j} f(x_j) \cdot W_{ij}$ and $\rho_i = \sum_{j=1}^{N} m_j W_{ij}$

  here h is the smoothing length defining the influence area

- Governing equations normally include (1) continuity equation and (2) momentum equation

  1). $\frac{D\rho}{Dt} = -\rho \frac{\partial v^{\beta}}{\partial x^{\beta}}$ 2). $\frac{Dv^{\alpha}}{Dt} = \frac{1}{\rho}\frac{\partial \sigma^{\beta}}{\partial x^{\beta}}$

  SPH form of these equations can be easily derived

  a). $\frac{D\rho_i}{Dt} = -\rho_i \sum_{j=1}^{N} \frac{m_j}{\rho_j} v_i^{\beta} \cdot \frac{\partial W_{ij}}{\partial x_i^{\beta}}$ and b). $\frac{Dv_i^{\alpha}}{Dt} = \frac{1}{\rho_i}\sum_{j=1}^{N} m_j \frac{\sigma_j^{\alpha\beta}}{\rho_j}\frac{\partial W_{ij}}{\partial x_i^{\beta}}$

Simulation of dam breaking with SPH

Two ways of simulation with SPH:
- weakly compressible SPH

By using the equation of state the pressure can be calculated based on density. It is computationally simple but only small time step size is allowed, and the pressure values fluctuate with a slight change of the density.

- truly incompressible SPH

Pressure is calculated through Poisson's equation, results are more accurate than weakly compressible method but it is computationally more complicated although large time step size is allowed.

Results obtained from weakly compressible SPH

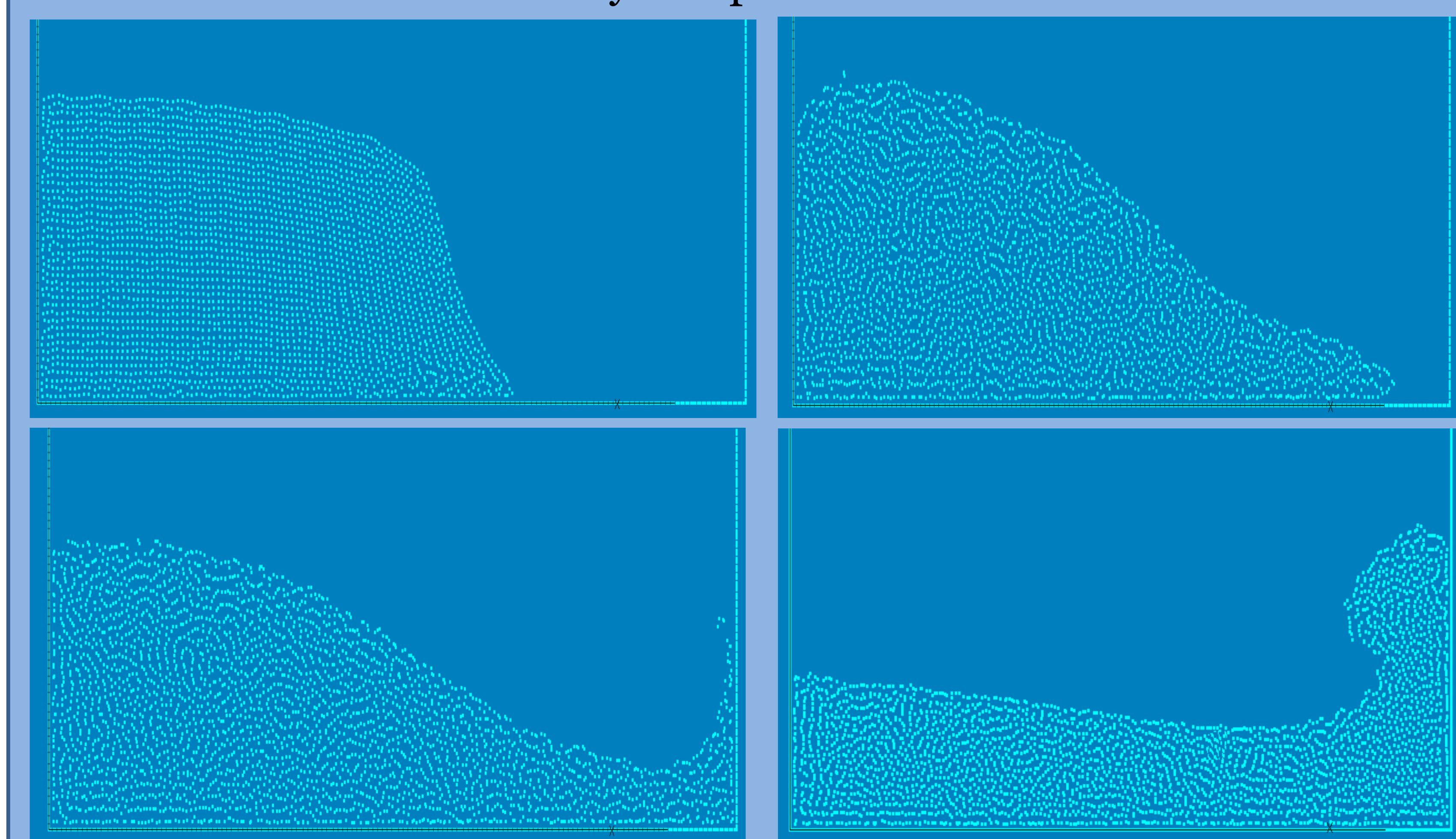

Figure 3. simulation of free surface flow with weakly compressible SPH

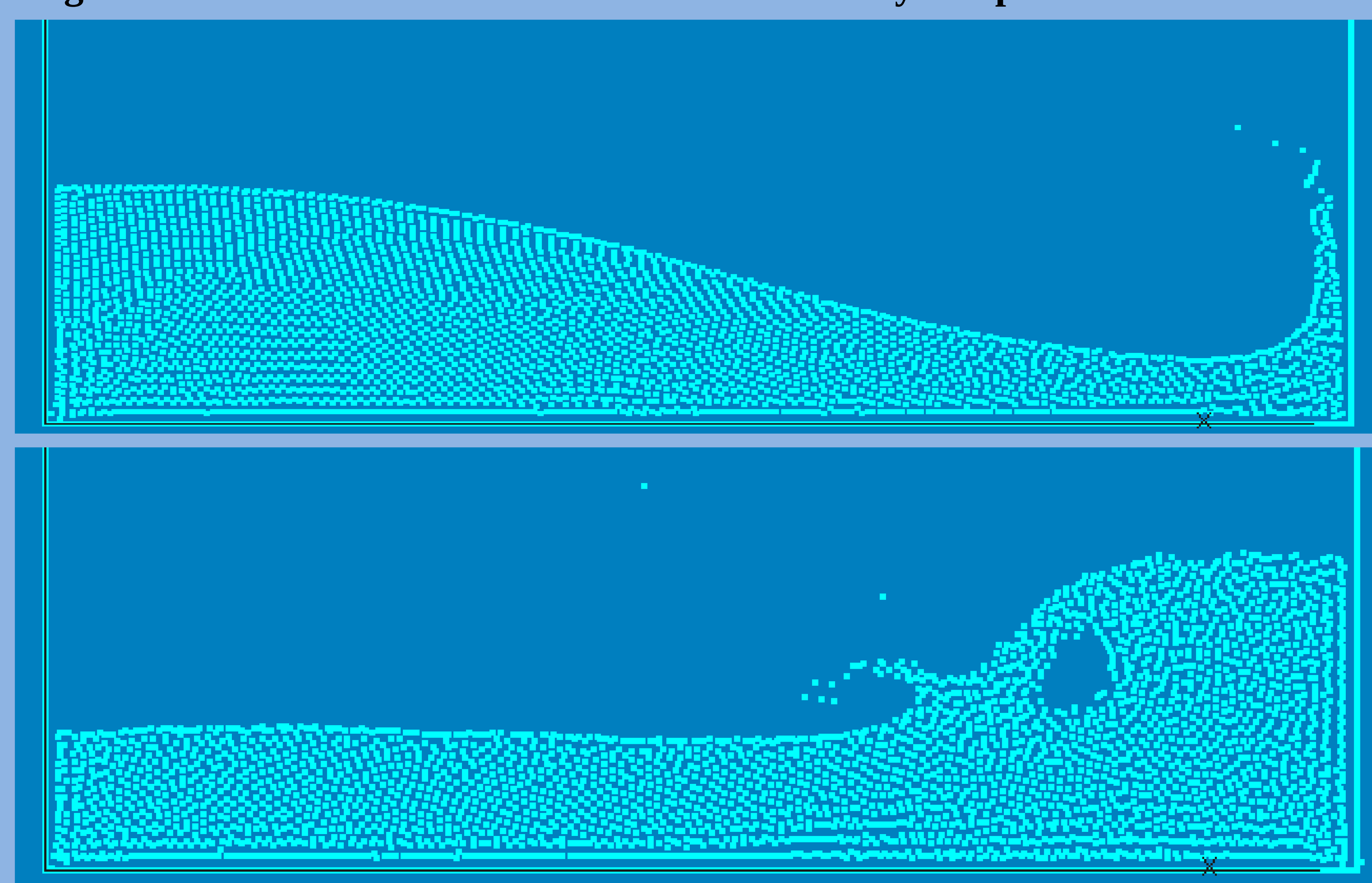

Figure 4.simulation of flow impact with solid wall in incompressible SPH

Conclusions

- SPH is a pure meshfree, particle based method which is widely used for fluid simulations especially rough sea motion simulations
- SPH approximations is simple to use for fluid simulations
- Incompressible SPH gives more smooth and reliable values especial for force calculations
- More work will be done to improve pressure accuracy to make SPH method more practical for fluid structural interaction problems

FSI Away Day 2011