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TRIP-MATRIX-COMPOSITE

imfd

Fluid-Solid-Interaction Simulations with the WCSPH Method in the Software Package YADE

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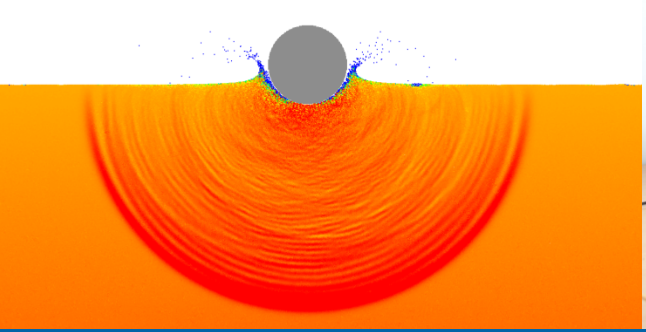
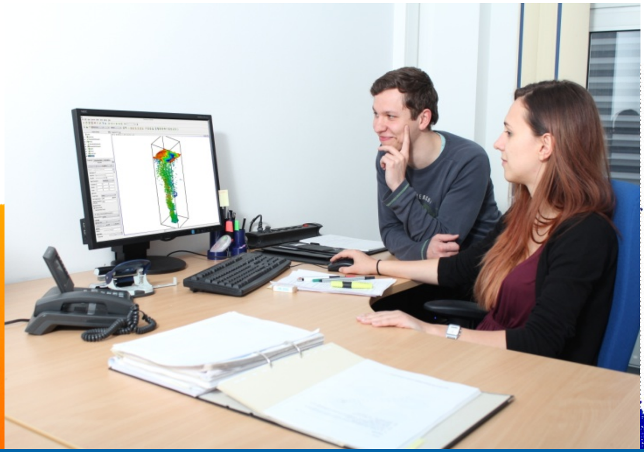
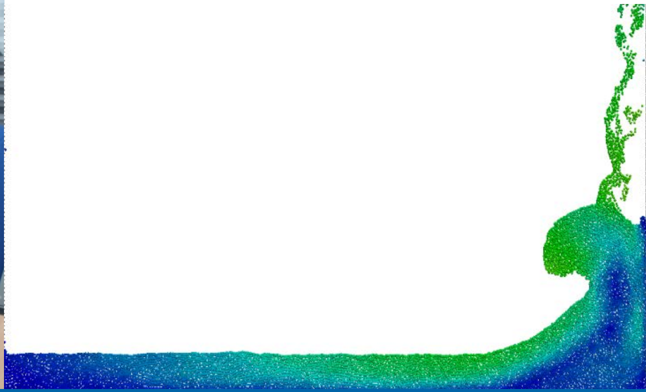
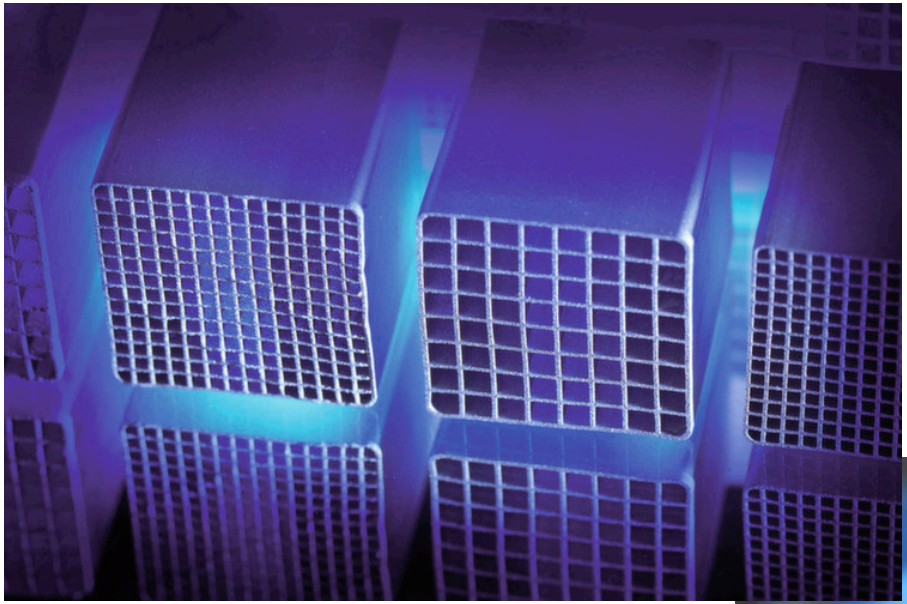




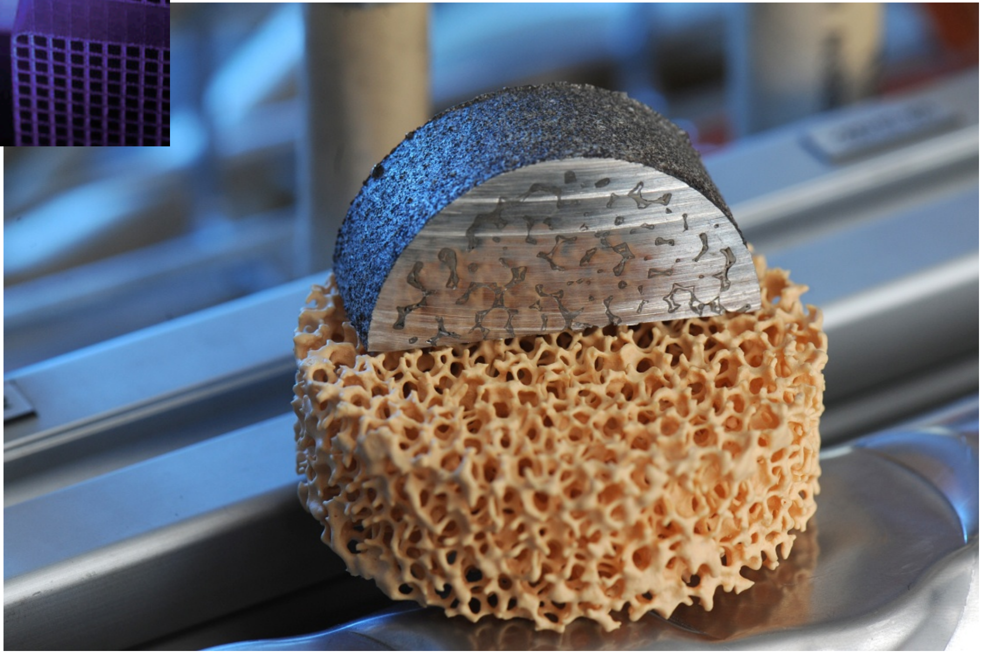


14th Workshop on Two-Phase Flow Predictions Halle (Saale)

Motivation



- Collaborative Research Center 799 TRIP-Matrix-Composites
- Design of tough and transformation toughened composite materials and structures based on $Fe\text{-}ZrO_2$



- Several manufacturing branches, i.e. infiltration and powder metallurgy
- Flamecasting as application route
- Interaction of steel-droplets with ceramic particles expected

Introduction Flamecasting

- Process divided in 4 Phases
  - ➢ Melting of composite
  - ➢ Particle, droplet flight
  - ➢ Wall impact
  - ➢ Solidification

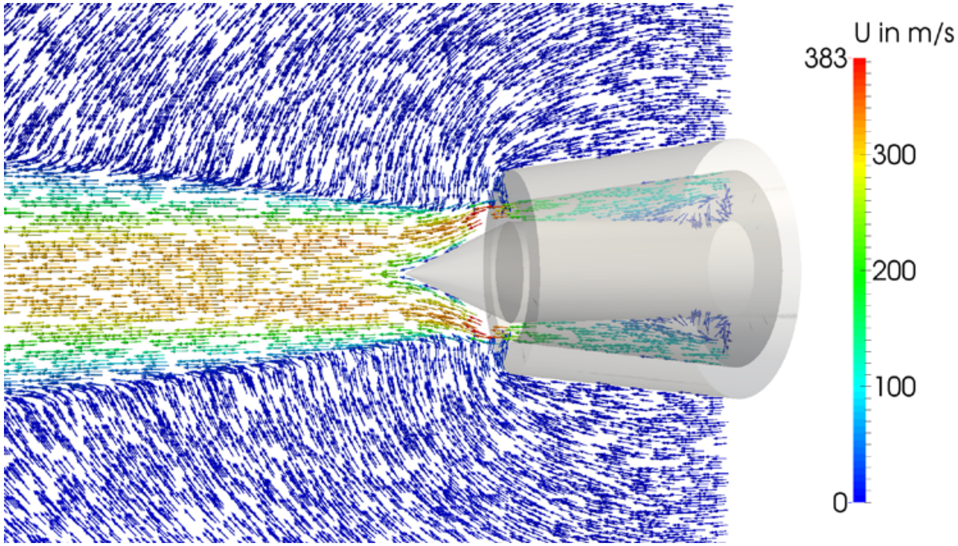


Fig. Gas jet behind flamecasting nozzle

- Macroscale CFD models used for melting, flight and solidification
- More detailed simulations carried out on lower scale with Smoothed Particle Hydrodynamics (SPH) and Discrete Element Method (DEM)
  - ➢ Impact simulations (detailed surface modeling necessary)
  - ➢ Opportunity also for solidification and melting on mesoscale

SPH Equation and Force Discretization

SPH:
- Particle based method for fluid simulations
- Artificial particles as discrete calculation points
- Completely meshfree approach

Basic SPH-equation

$$\langle A(\boldsymbol{x}_i)\rangle = \sum_{j=1}^{N} \frac{m_j}{\rho_j} A(\boldsymbol{x}_j) W(\boldsymbol{r}_{ij}, h)$$

Forces on RHS of NSG (Monaghan, 1988; Morris, 1994)

$$\left\langle \frac{1}{\rho_i} \nabla p_i \right\rangle = \sum_{j=1}^{N} m_j \left(\frac{p_j}{{\rho_j}^2} + \frac{p_i}{{\rho_i}^2} \right) \nabla W_{ij}$$

$$\left\langle \left(\frac{1}{\rho_i} \nabla \cdot \mu_i \nabla \right) \boldsymbol{u}_i \right\rangle = \sum_{j=1}^{N} \frac{m_j (\mu_i + \mu_j) \boldsymbol{u}_{ij}}{\rho_i \rho_j} \left(\frac{1}{r_{ij}} \frac{\partial W_{ij}}{\partial r_i} \right)$$

Weakly Compressibility

Density calculation: summation density approach

$$\rho_i = \sum_{j=1}^{N} m_j W_{ij}$$

- Leads to wrong density at free surfaces
- Re-allignment of SPH-Particles in initialisation and relaxing pre-calculation to fix issue

Pressure calculation with linearised Tait's equation (Batchelor, 1967)

$$p_i = c_0^2(\rho_i - \rho_0)$$

Kernel Function

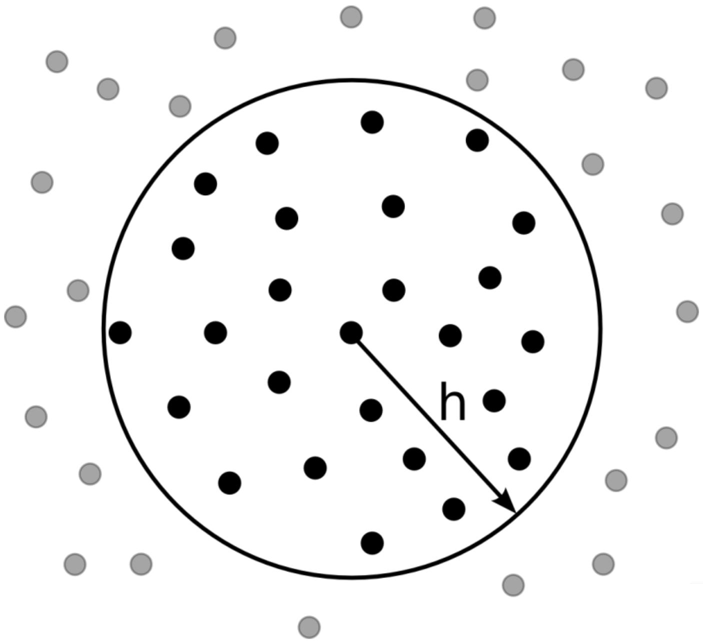


Fig. Calculation domain of centre particle

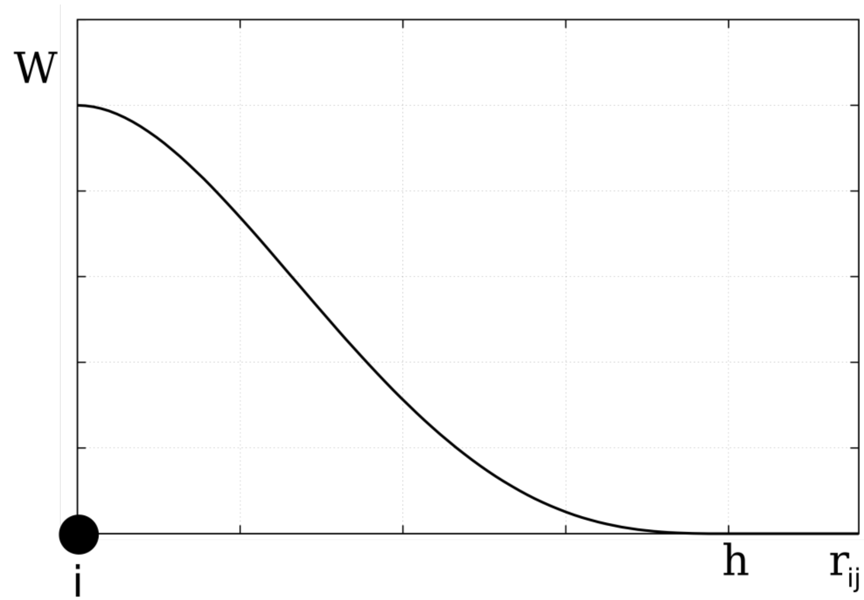


Fig. Lucy kernel function with smoothing length *h*

Lucy kernel function for particle interaction weight (Lucy, 1977)

$$W_{ij} = \alpha_d \begin{cases} \left(1 + 3\dfrac{r_{ij}}{h}\right)\left(1 - \dfrac{r_{ij}}{h}\right)^3 & \dfrac{r_{ij}}{h} \leq 1 \\ 0 & \dfrac{r_{ij}}{h} > 1 \end{cases}$$

Boundary Handling

Free Surface

- Alignement of SPH particles
- Enlargement of particle quantity → density correction

Wall Boundary

- Fixed wall particles
- Kernel interaction

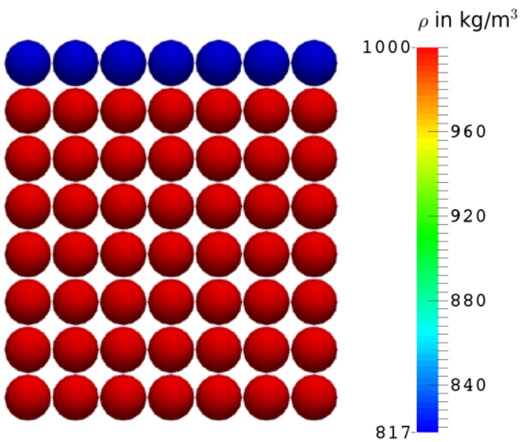


Fig. Initial particle distribution

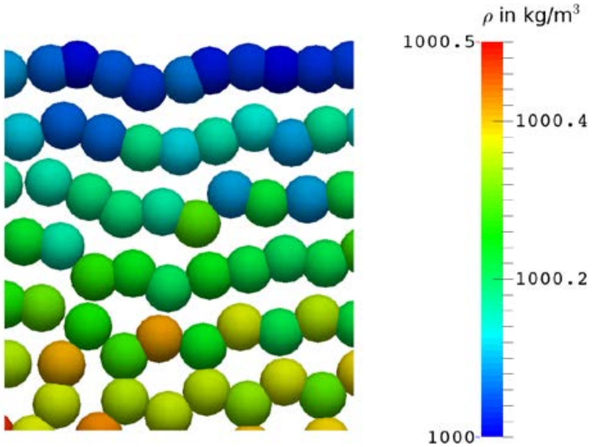


Fig. Relaxing particle distribution

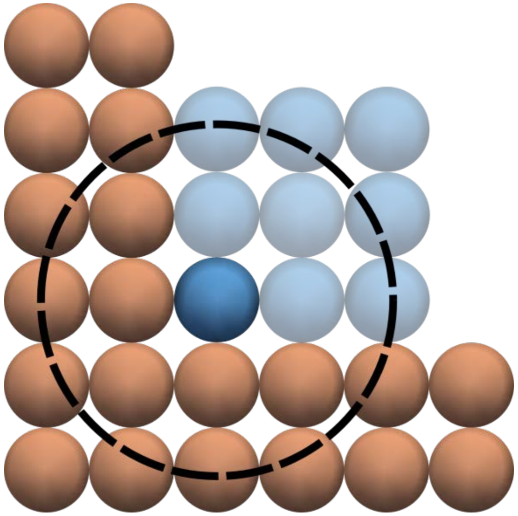


Fig. Wall boundary condition

Calculation Flow

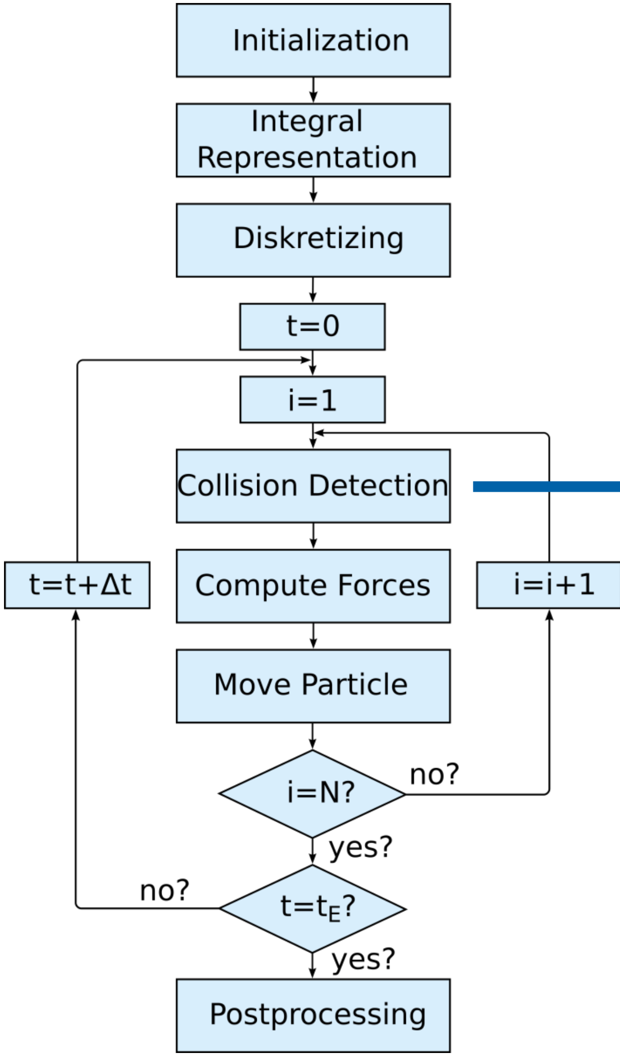


Fig. Flowchart of SPH calculation

- Sweep and Prune Neighbour Search with axis aligned bounding boxes

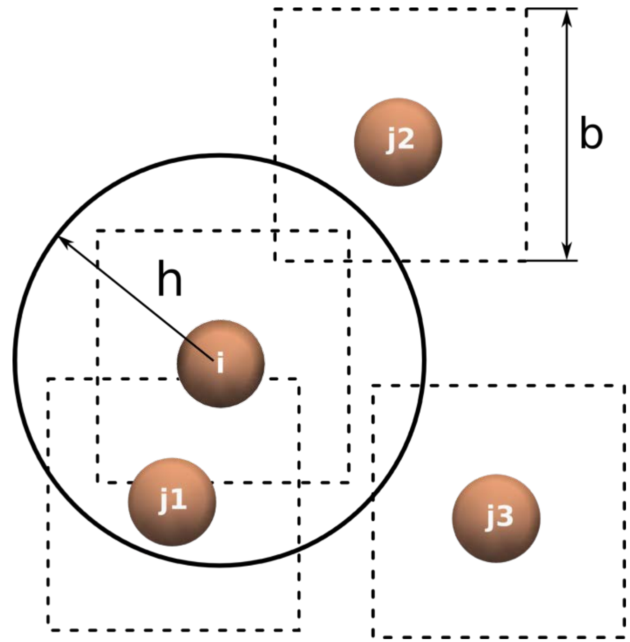


Fig. Neighbour search procedure with axis aligned bounding boxes in the sweep and prune algorithm

Impact – Introduction

- Simulation case: Impact of a 2D cylinder on a free liquid surface

- Process divided in three different phases
  I. Free fall
  II. Impact and cavity formation
  III. Rebound and cavity collapse

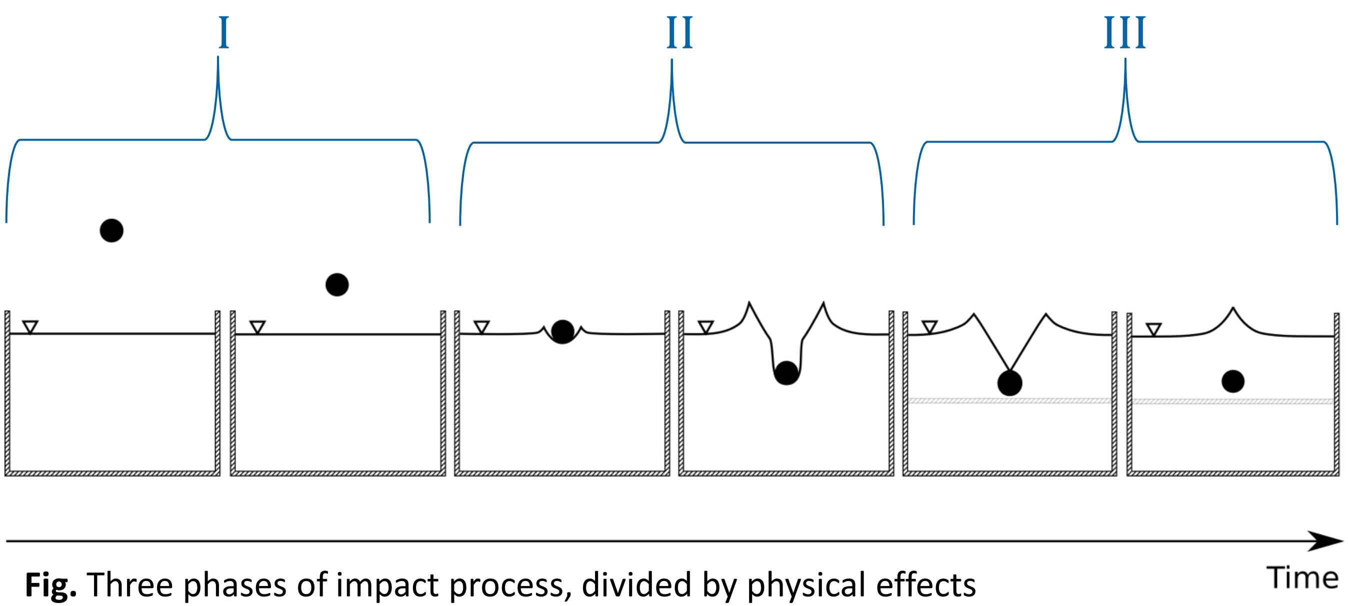


Fig. Three phases of impact process, divided by physical effects

Impact Geometry

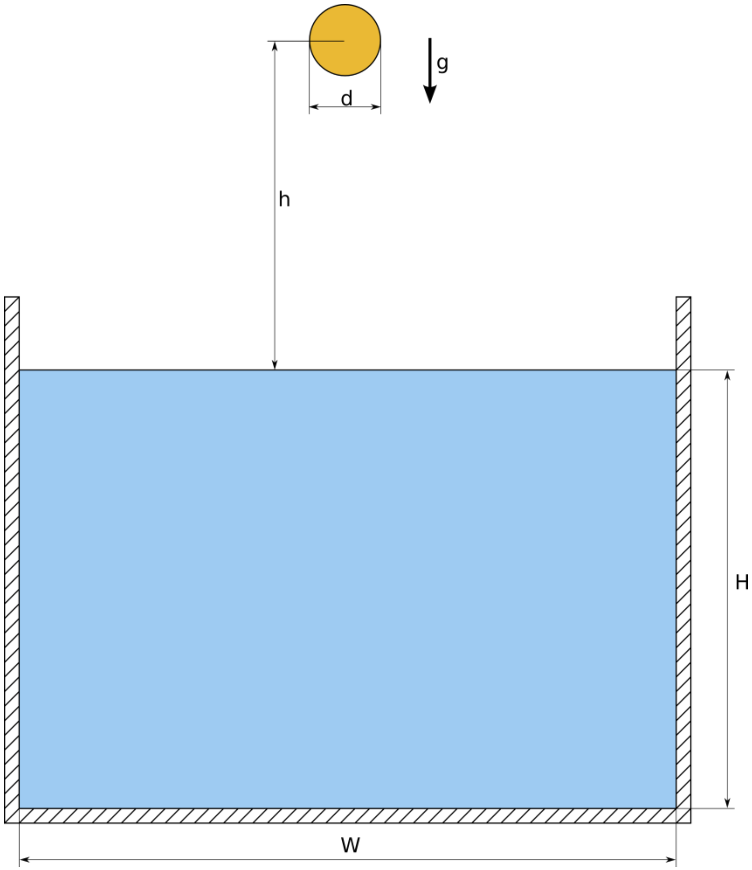
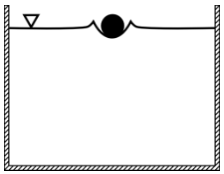


Fig. Initial geometric setup

Geometry parameters			
Falling height	h	m	0.5
Bath height	H	m	0.66
Bath width	W	m	0.99
Cylinder diameter	d	m	0.55

Numerical parameters			
Impact time	t_0	s	0.301
Impact velocity	v_0	m/s	2.955
Particle radius	R	10^{-3}m	0.4297… 13.75
Time step	Δt	s	0.0001
Numerical sound speed	c_0	m/s	31.62
Smoothing distance	h	m	4 Rad

Ligament and Droplet Formation



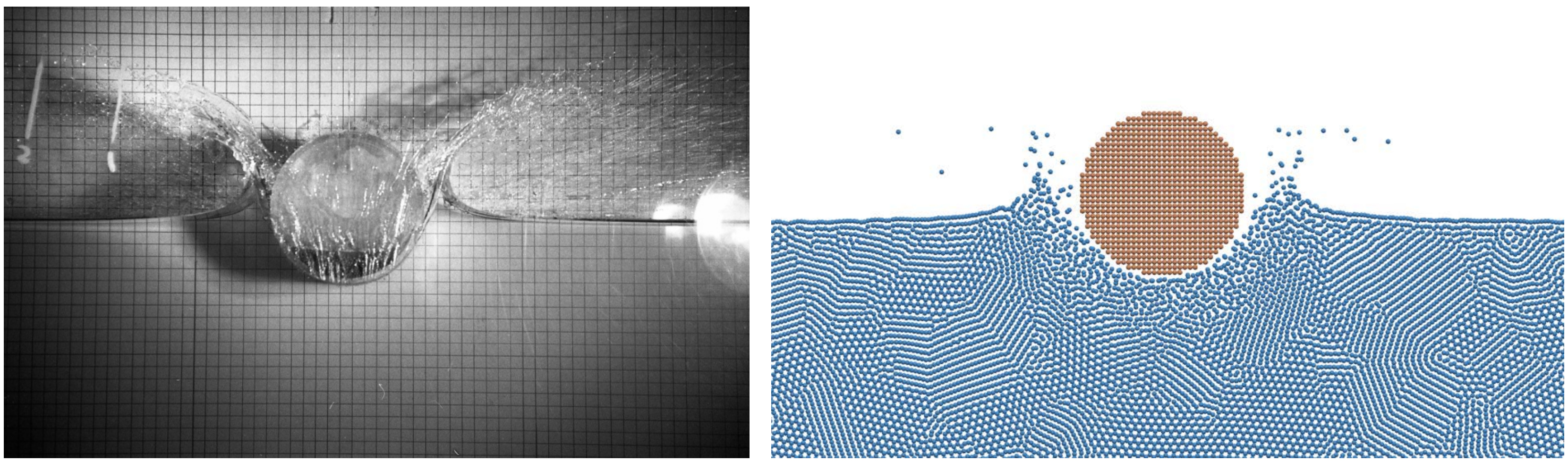
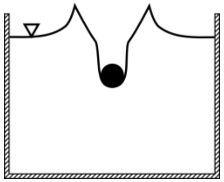


Fig. Qualitative comparison of SPH simulation (right) with photography of experimental investigation (left) (Greenhow and Lin, 1983) - Impact with ligament and droplet formation in Phase II.

Cavity Formation



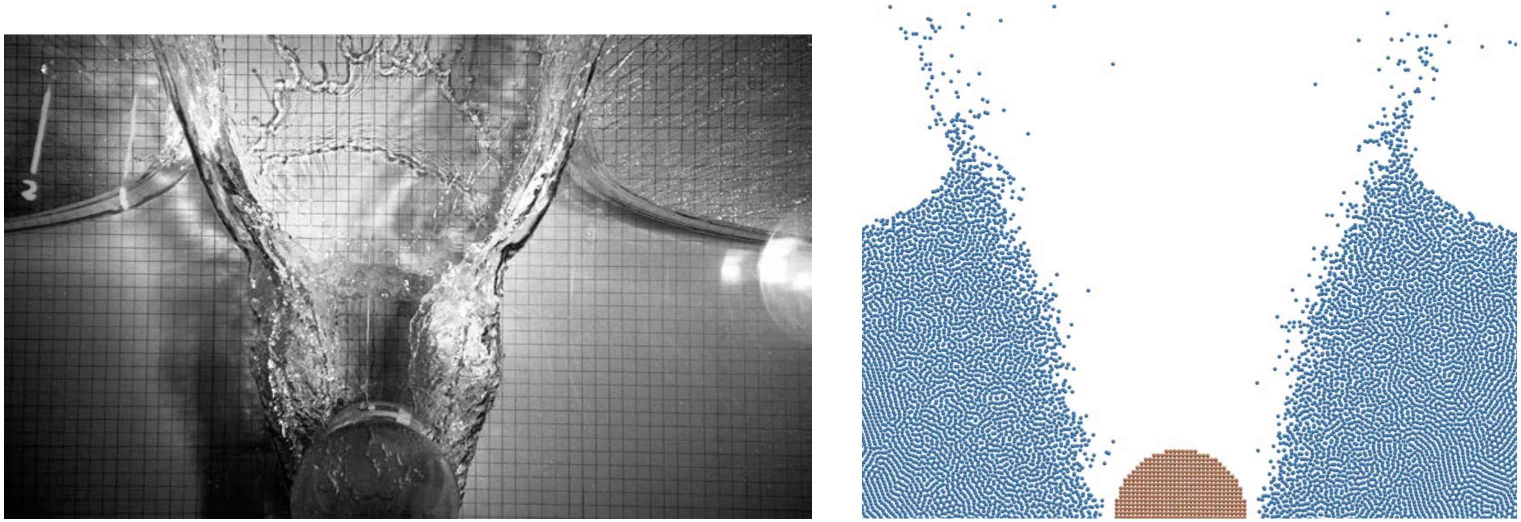
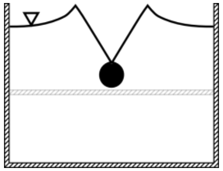


Fig. Qualitative comparison of SPH simulation (right) with photography of experimental investigation (left) (Greenhow and Lin, 1983) - Cavity formation in Phase II

Cavity Collapse



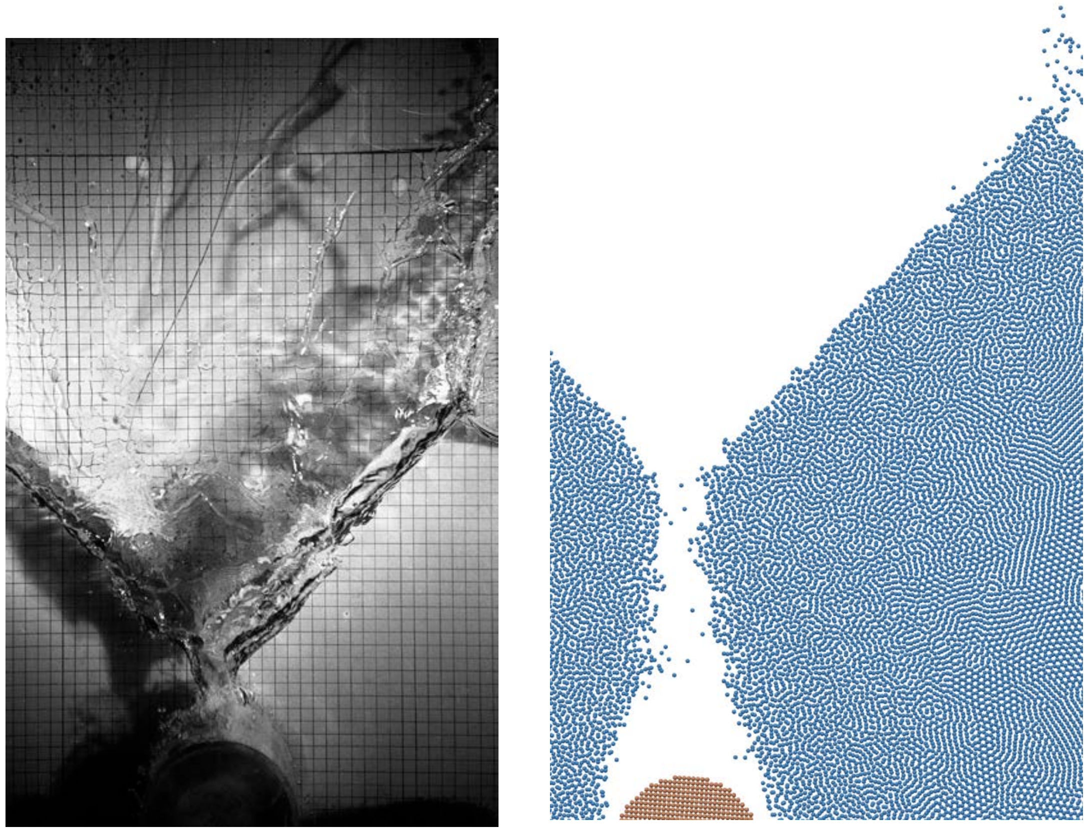
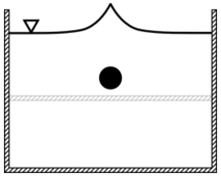
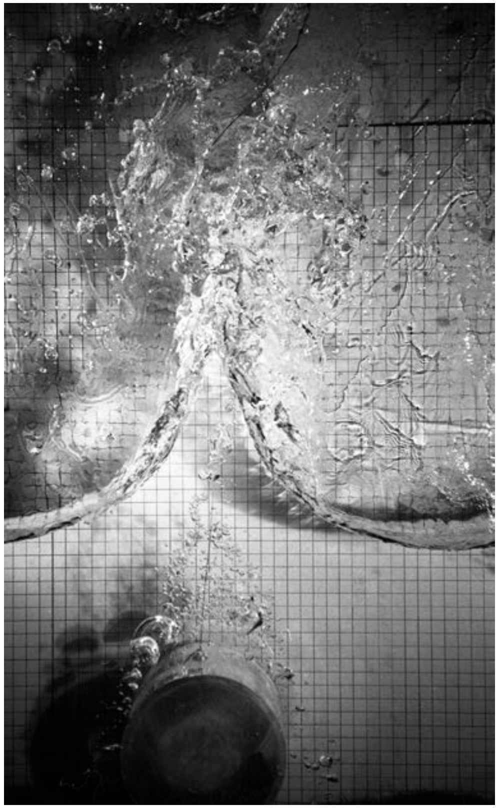


Fig. Qualitative comparison of SPH simulation (right) with photography of experimental investigation (left) (Greenhow and Lin, 1983) - Cavity Closure in Phase III

Worthington Jet Formation





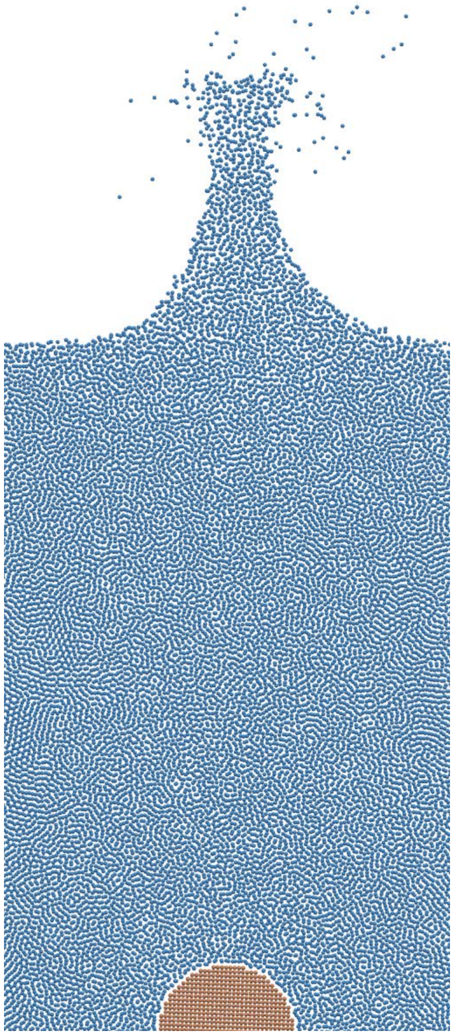
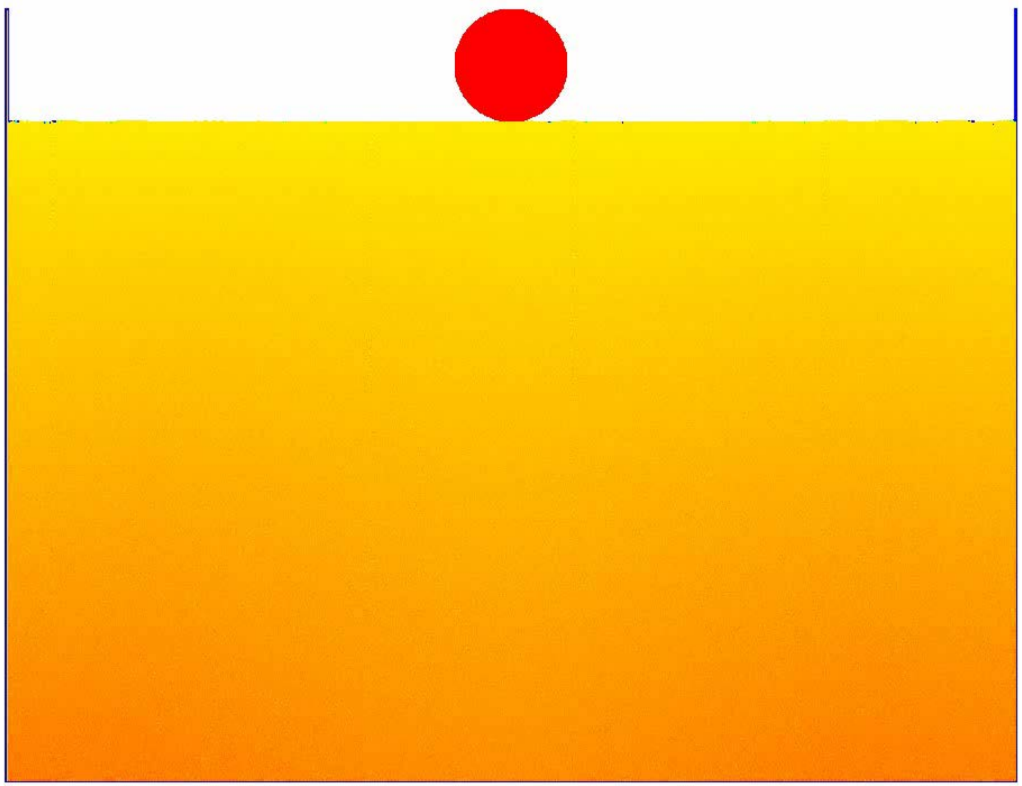


Fig. Qualitative comparison of SPH simulation (right) with photography of experimental investigation (left) (Greenhow and Lin, 1983) - Worthington Jet formation in Phase III.

Density-Wave Propagation



Vid. Density-wave propagation during the impact process.

Quantitative Comparison

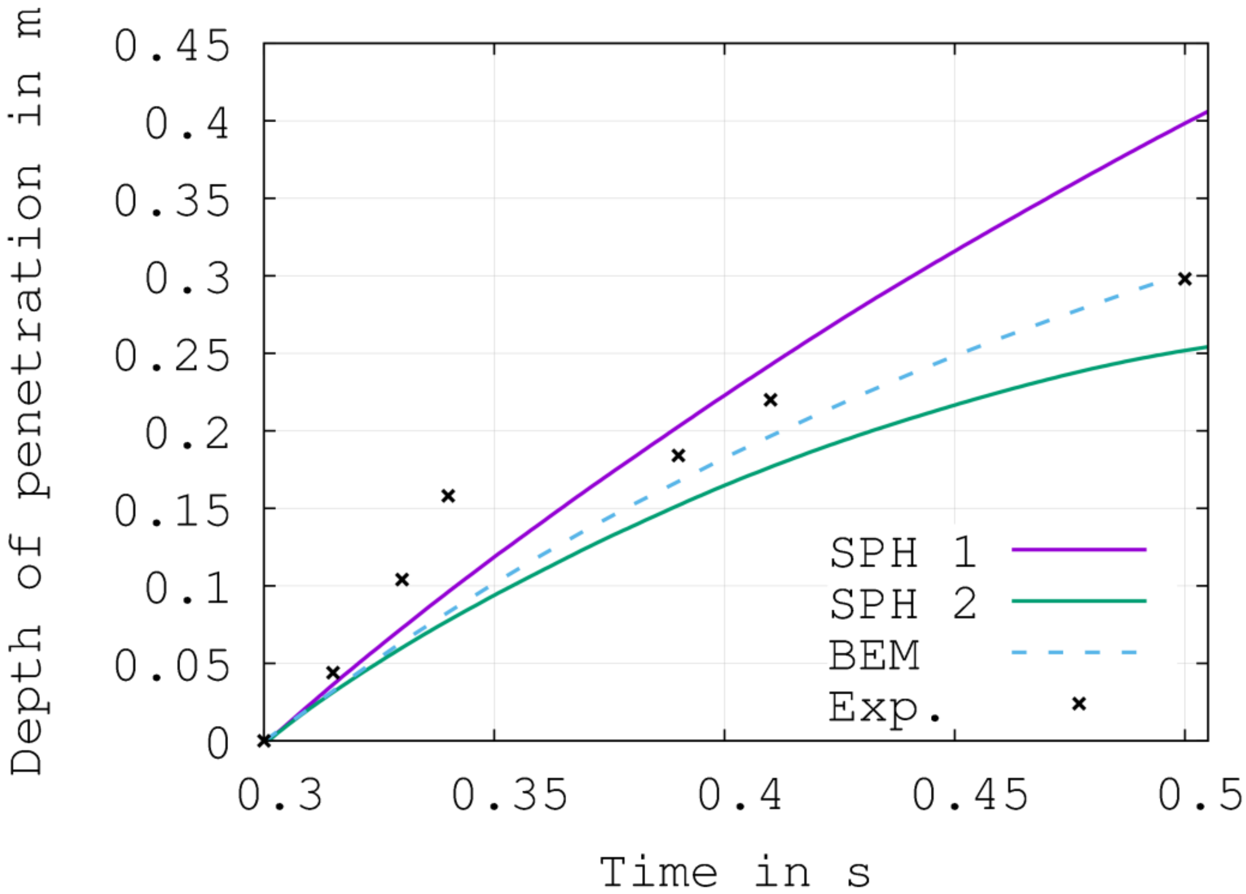


Fig. Quantitative comparison of two WCSPH simulation implementations with experimental data (Greenhow and Lin, 1983) and simulations with Boundary Elemental Method (BEM) (Sun and Faltinsen, 2007).

Variation of Particle Size and Number

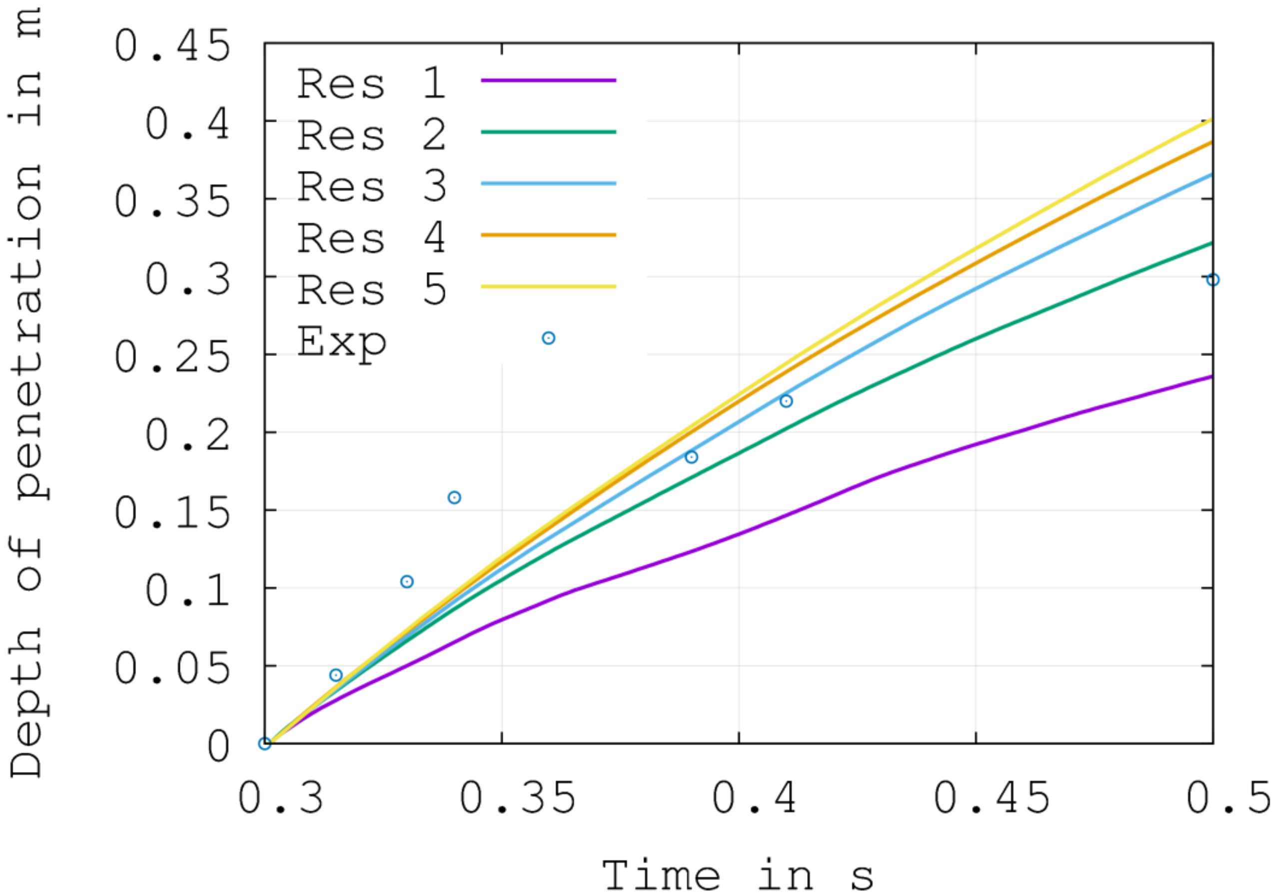


Fig. Comparison of five different particle sizes and numbers.
Res 1: 1065 p., Res 2: 3881 p., Res 3: 14769 p., Res 4: 57577 p., Res 5: 227347 p.

Conclusion and Outlook

What is implemented

- WCSPH method
- Fixed wall particles
- Adjusted neighbour search algorithm
- Lucy kernel function

What needs to be done

- Smoother rigid body geometry
- Overcome tensile instability
- Surface detection, surface tension
- Density contrast interface handling
- DEM-SPH coupling

Acknowledgments

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Fe-ZrO2 TRIP-MATRIX-COMPOSITE

- Prof. Dr.-Ing. habil. Rüdiger Schwarze
- Anton Gladkyy
- Jens Klostermann

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Contact Details

Do we need Particle based CFD for coupling with rigid bodies and granular media?

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References

Greenhow, M. & Lin, W. (1983). *Nonlinear Free Surface Effects: Experiments and Theory* (Report no. 83-19.). Cambridge, MA: Department of Ocean Engineering, Massachusetts Institute of Technology.

Sun, H. & Faltinsen O. M. (2007). Water impact of horizontal circular cylinders and cylindrical shells. *Applied Ocean Research, 28*, 299-311. doi: 10.1016/j.apor.2007.02.002