Advanced fluid-mechanism interaction in DualSPHysics

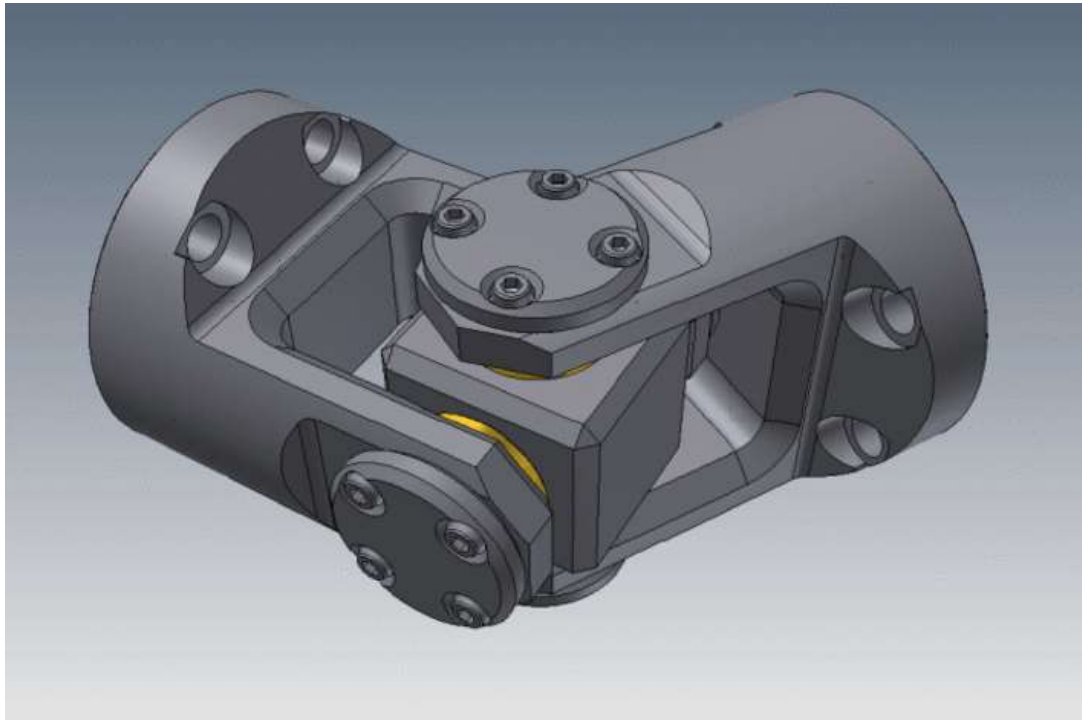
RICARDO B. CANELAS[1], MOISÉS BRITO[1], ORLANDO G. FEAL[2], JOSE M. DOMÍNGUEZ[2], ALEJANDRO J.C. CRESPO[2]

[1]CERIS, INSTITUTO SUPERIOR TÉCNICO, LISBON, PORTUGAL

[2]ENVIRONMENTAL PHYSICS LABORATORY (EPHYSLAB), UNIVERSIDADE DE VIGO, OURENSE, SPAIN

General motivation

Mechanical **contacts** and **constrains** are ubiquitous in natural and industrial processes, ranging from simple linear mechanisms to intricate highly non-linear problems.

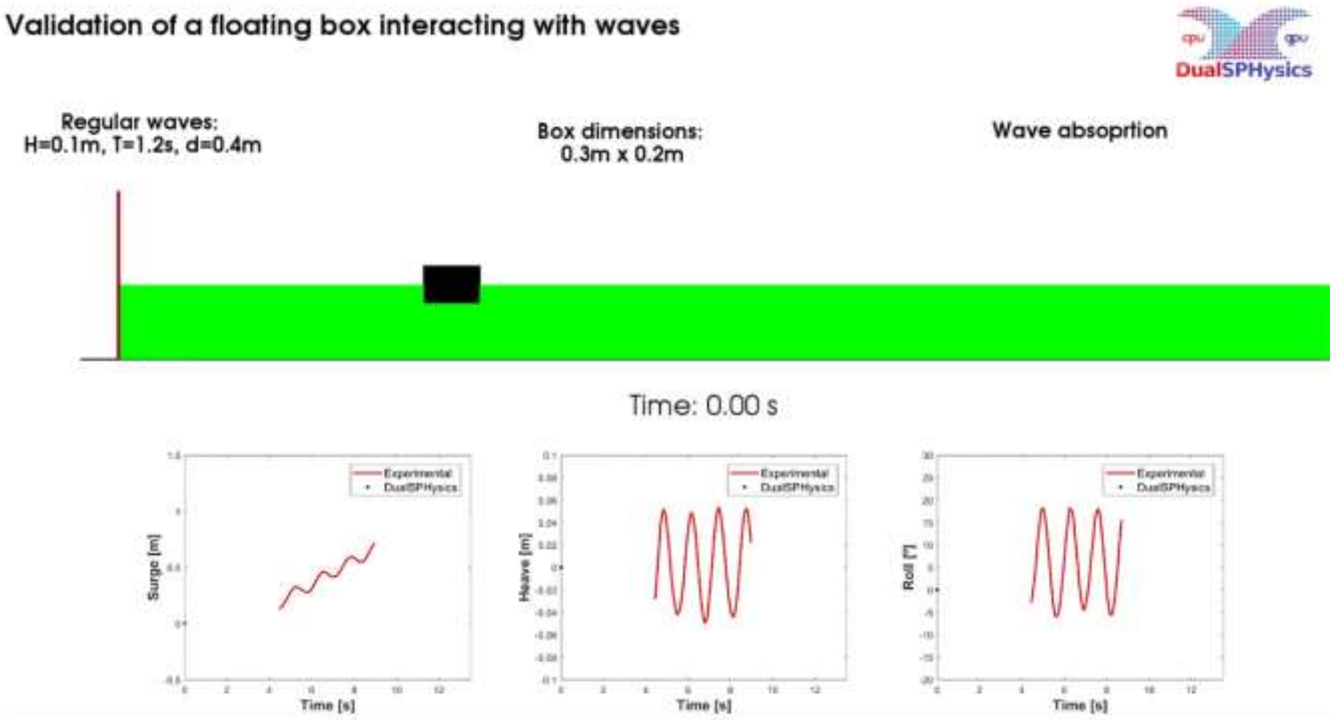


DualSPHysics offers a solid-solid distributed contact discrete element method (**DCDEM)** model, but:

- **Not** unconditionally stable contact description
- Difficult to model **intricate** mechanisms
- Complex **friction** models hurt performance unacceptably for HPC code

Rigid bodies in DualSPHysics

Conserving the **relative positions** of a group of particles, these can be made to describe a solid body.



$$M_I \frac{d\boldsymbol{V}_I}{dt} = \sum_{k \in I} m_k \frac{d\boldsymbol{v}_k}{dt}$$

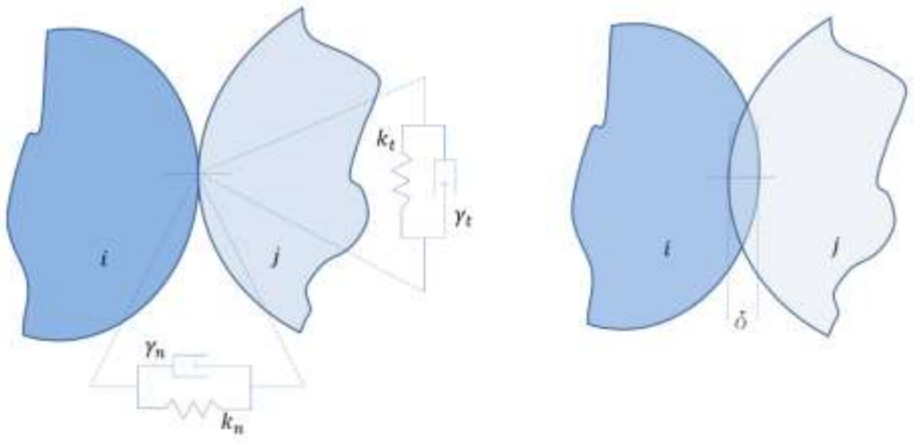
$$I_I \frac{d\boldsymbol{\Omega}_I}{dt} = \sum_{k \in I} m_k (\boldsymbol{r}_k - \boldsymbol{R}_I) \times \frac{d\boldsymbol{v}_k}{dt}$$

$$\boldsymbol{v}_k = \boldsymbol{V}_I + \boldsymbol{\Omega}_I \times (\boldsymbol{r}_k - \boldsymbol{R}_I)$$

The **inertia tensor** is computed on the fly for the system of material points, making no assumptions on shape, *i.e.* it is **exact for the discretized system**.

DCDEM - Soft body model

Approximate **contacts** with a **spring-dashpot model**



Spring displacement is given by body overlap, δ, hence *soft* body. This translates into a **penalty method**, solved with the same explicit schemes as the SPH equations.

Very useful, but laden with issues for generic contact modeling:

- Very stiff contacts induce very narrow stability regions
- Full, long term frictional contacts are prohibitively expensive to model
- Bodies made of a collection of spheres induce geometrical effects - locking, aliasing effects on relative motions...

An explicit penalty method is just **too limited** for our goals with DualSPHysics!

Kinematics with dynamics?

SPH is a **dynamic** model – forces produce accelerations – numerically we work by **impulses**.

Not ideal for stiff problems, as for increasing dt, the impulse goes to infinite…

Classical **kinematics** is trivial for stiff problems – the **simple** ones. **Complexity grows**, unlike in a dynamic framework.

Can we get the best of the two?

DVI - Hard body model

Approximate **everything** with a **Differential Variational Inequality**

$$\dot{\mathbf{q}} = \mathbf{T}(\mathbf{q})\mathbf{v}$$

$$\mathbf{M}(\mathbf{q})\dot{\mathbf{v}} = \mathbf{f}(t,\mathbf{q},\mathbf{v}) - \mathbf{g}_{\mathbf{q}}^{\mathrm{T}}(\mathbf{q},t)\boldsymbol{\lambda} + \sum_{i=1}^{N_c}(\gamma_n^i \mathbf{D}_n^{T,i} + \gamma_u^i \mathbf{D}_u^{T,i} + \gamma_w^i \mathbf{D}_w^{T,i})$$

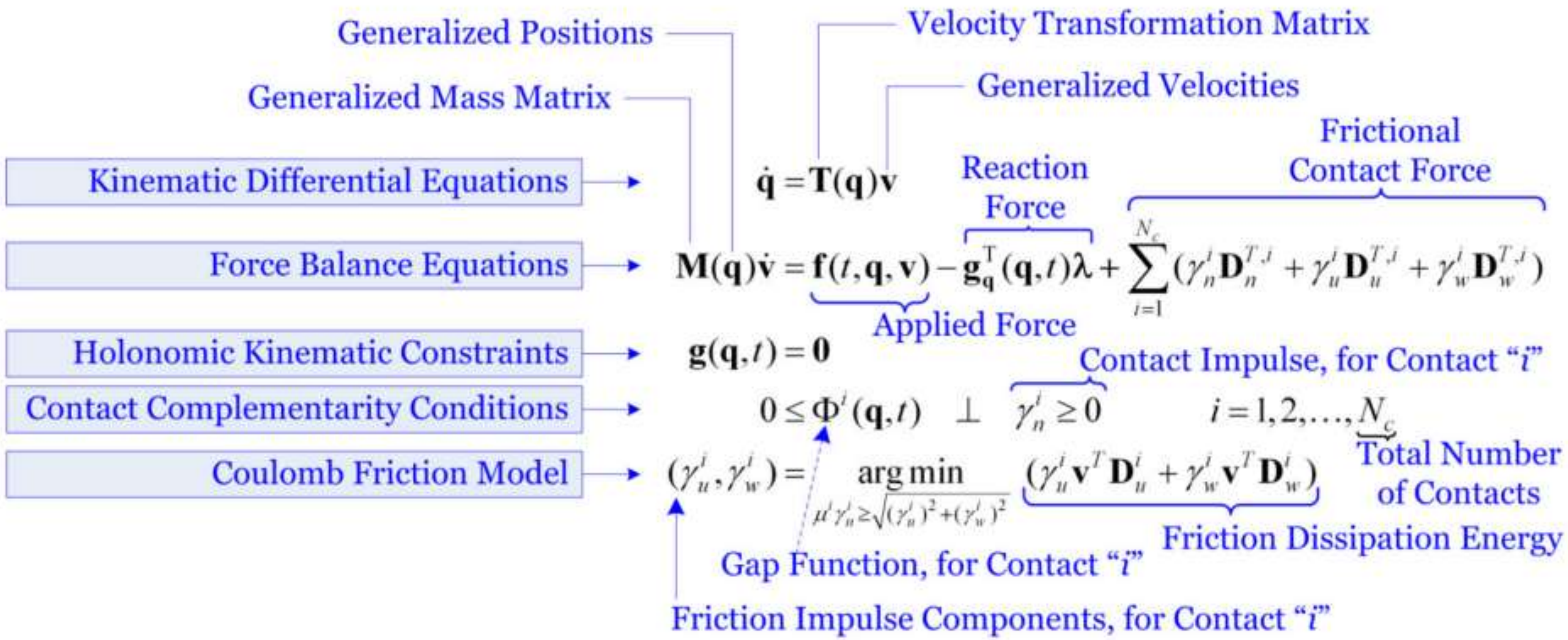
$$\mathbf{g}(\mathbf{q},t) = \mathbf{0}$$

$$0 \le \Phi^i(\mathbf{q},t) \quad \perp \quad \gamma_n^i \ge 0 \qquad i = 1,2,\ldots,N_c$$

$$(\gamma_u^i, \gamma_w^i) = \underset{\mu^i \gamma_n^i \ge \sqrt{(\gamma_u^i)^2 + (\gamma_w^i)^2}}{\arg\min} (\gamma_u^i \mathbf{v}^T \mathbf{D}_u^i + \gamma_w^i \mathbf{v}^T \mathbf{D}_w^i)$$

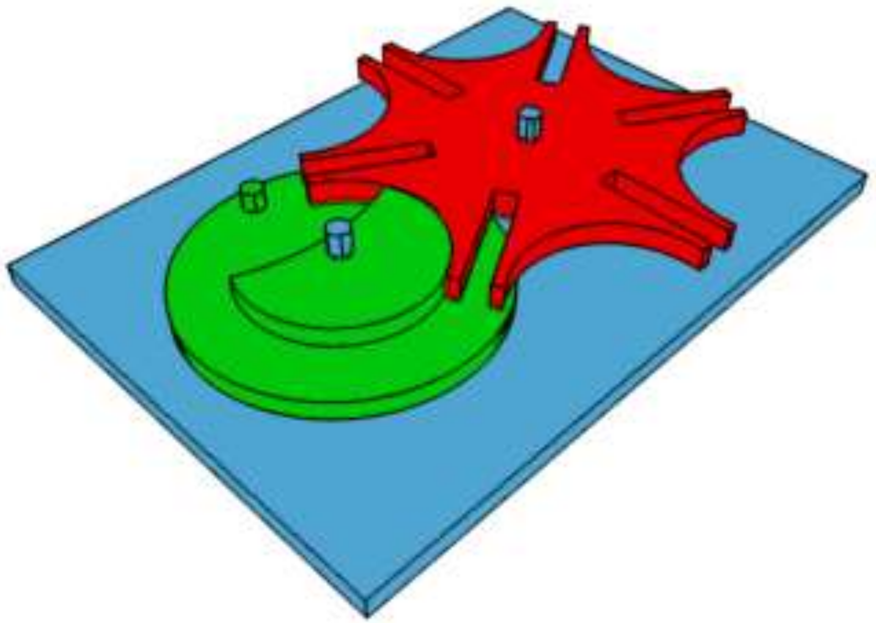
DVI - Hard body model

Approximate **everything** with a **Differential Variational Inequality**



Project Chrono

Project Chrono is a **physics-based** modeling and simulation **library** based on a **platform-independent**, **open-source** design - much like DualSPHsysics

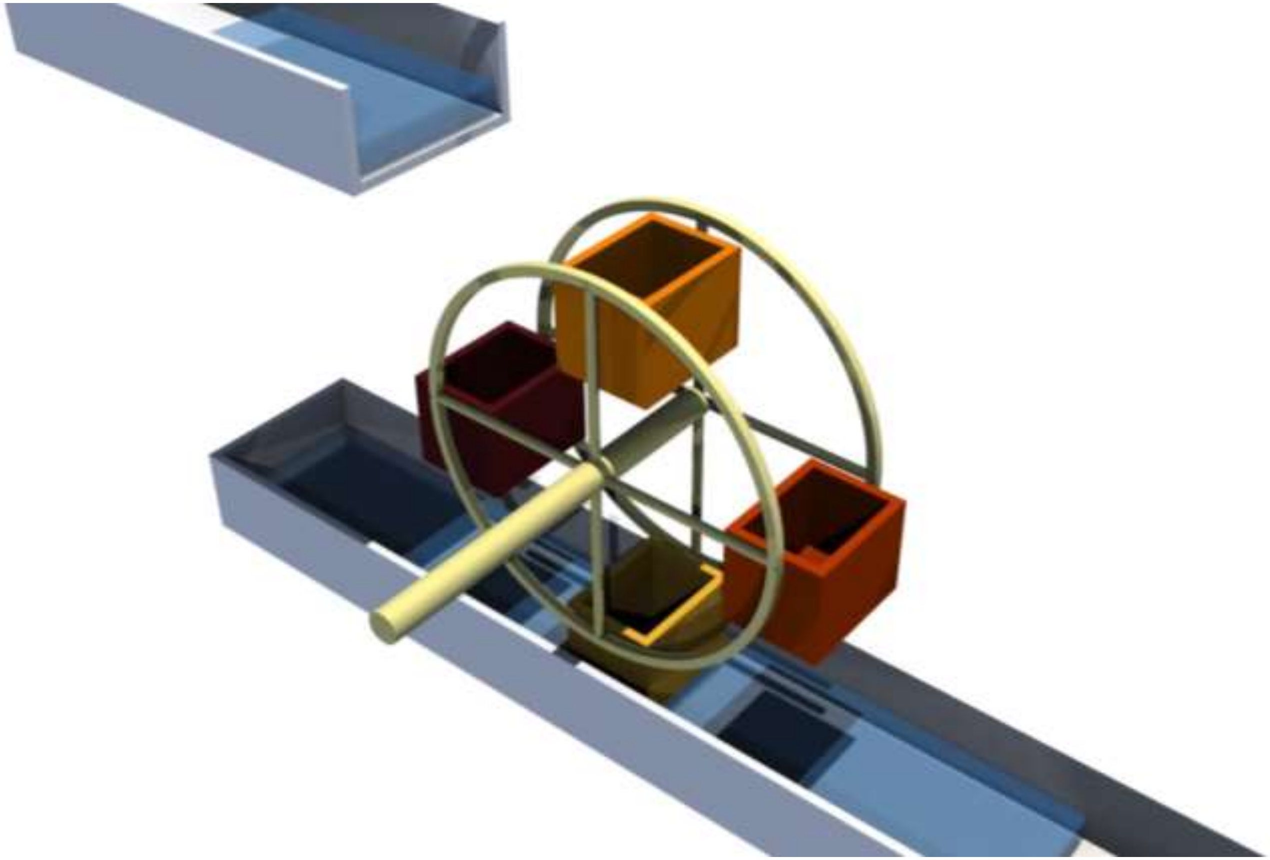


- Wide set of joints (spherical, revolute joint, prismatic, universal joint, glyph, with limits, etc.)
- Unilateral constraints
- Exact Coulomb friction model, for precise stick-slip of bodies
- Springs and dampers, even with non-linear features
- Recent support for linear and nonlinear Finite Element Analysis - Euler-Bernoulli beams, bars, shells, cables.

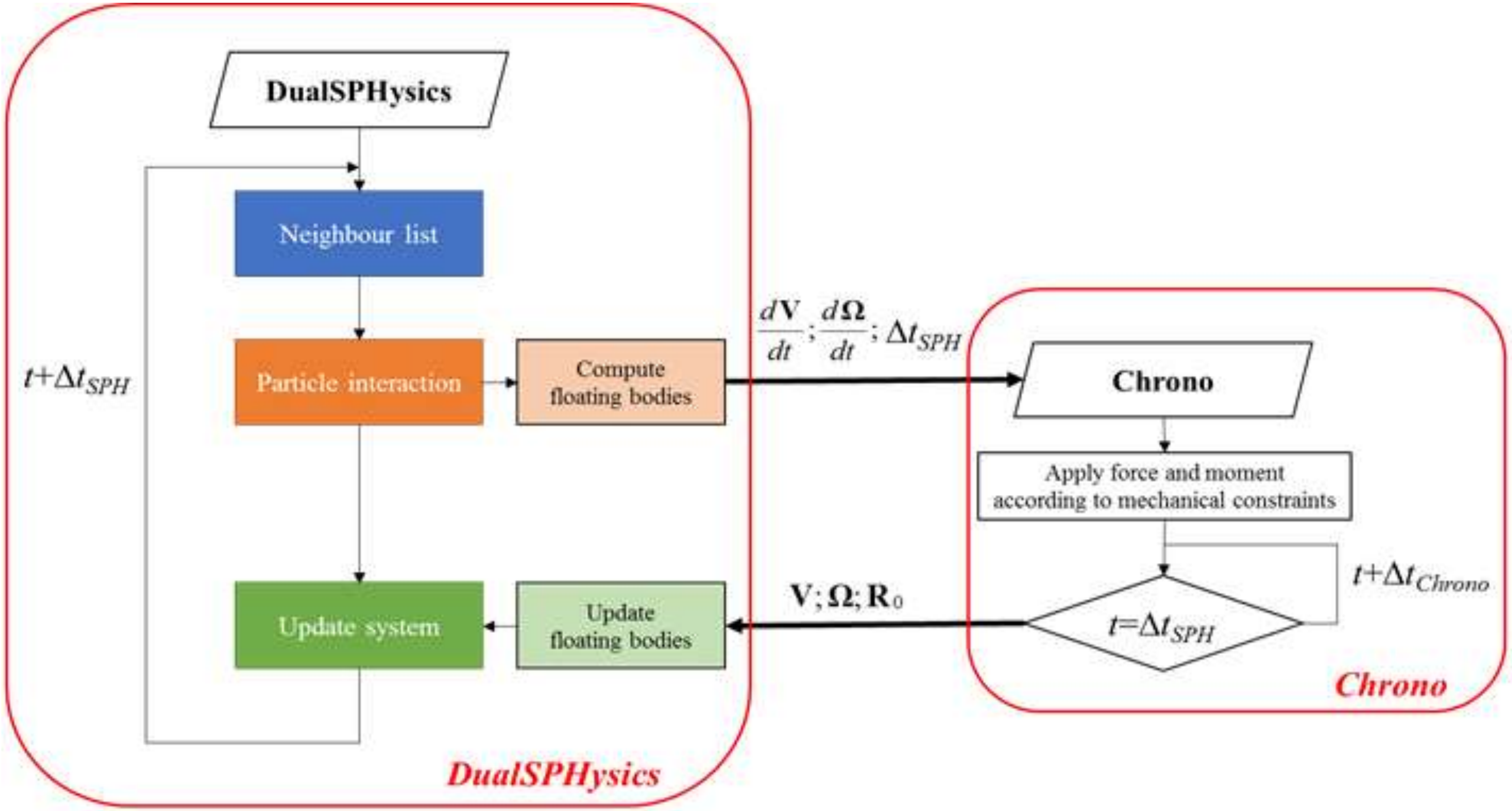
http://projectchrono.org

Implementation on DualSPHysics

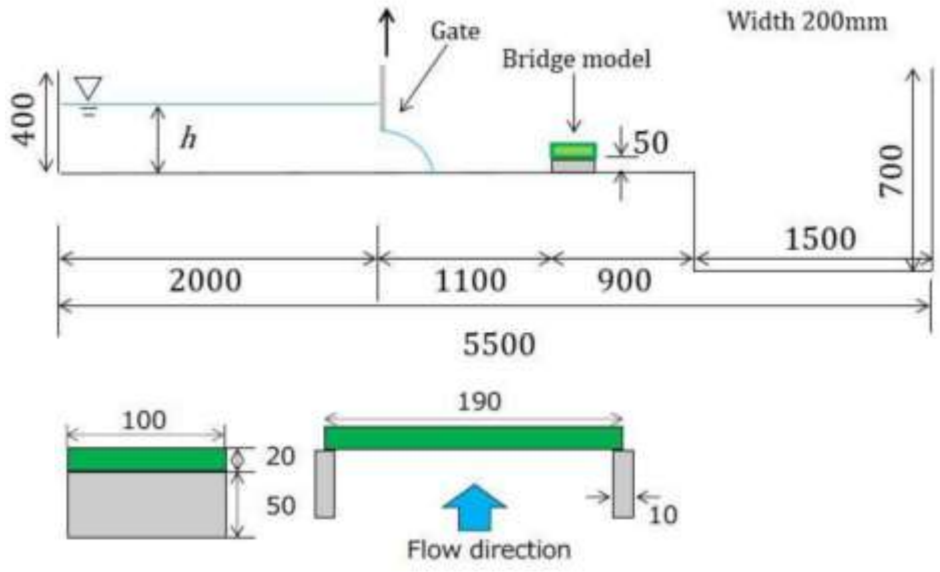
- Problem is cast in CCP form and solved with a novel fixed point iteration method
- Implementation allows for **million+** bodies in Chrono-side to be simulated orders of magnitude faster than DEM
- Geometries are represented by **meshes**
- Mesh is overlaid over the particle distribution, done automatically by **GenCase**
- For simple non-contact problems mesh is not required



Implementation on DualSPHysics

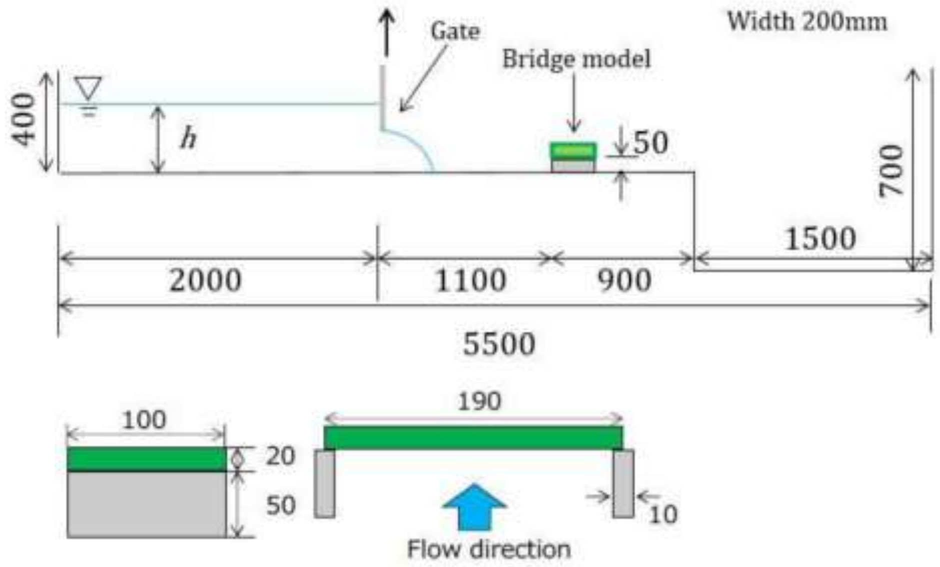


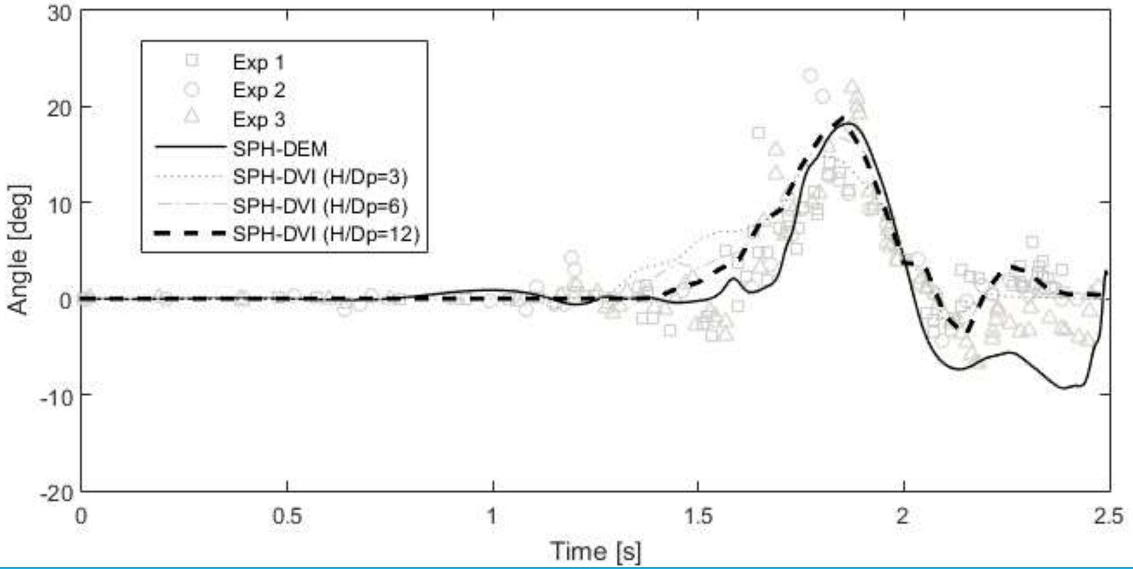
Validations - I

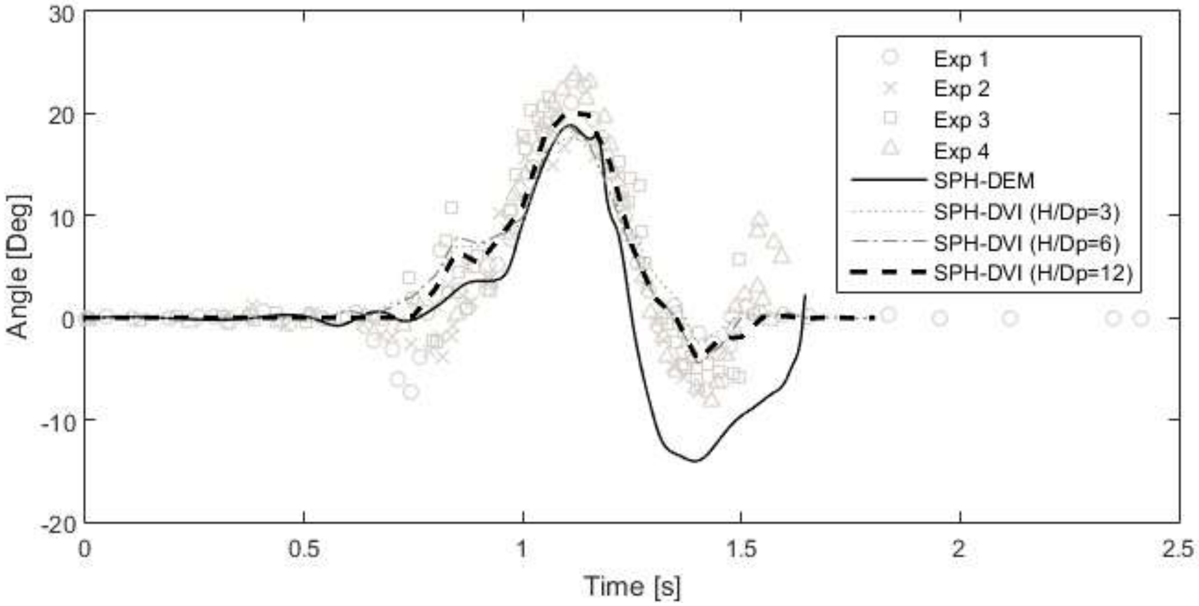


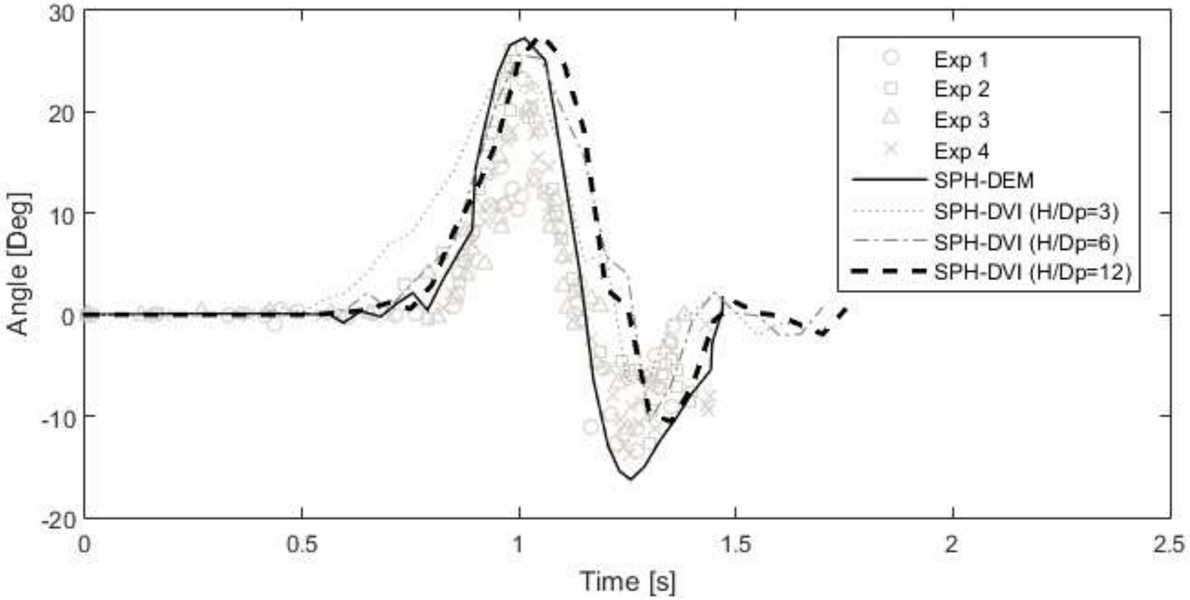
B. Chandra and M. Asai, *Verification and validation of the fluid-rigid body interaction simulation by the smoothed particle hydrodynamics method*, in Proceedings of Computational Engineering Conference JSCES, vol. 21, 2016.

Validations - I

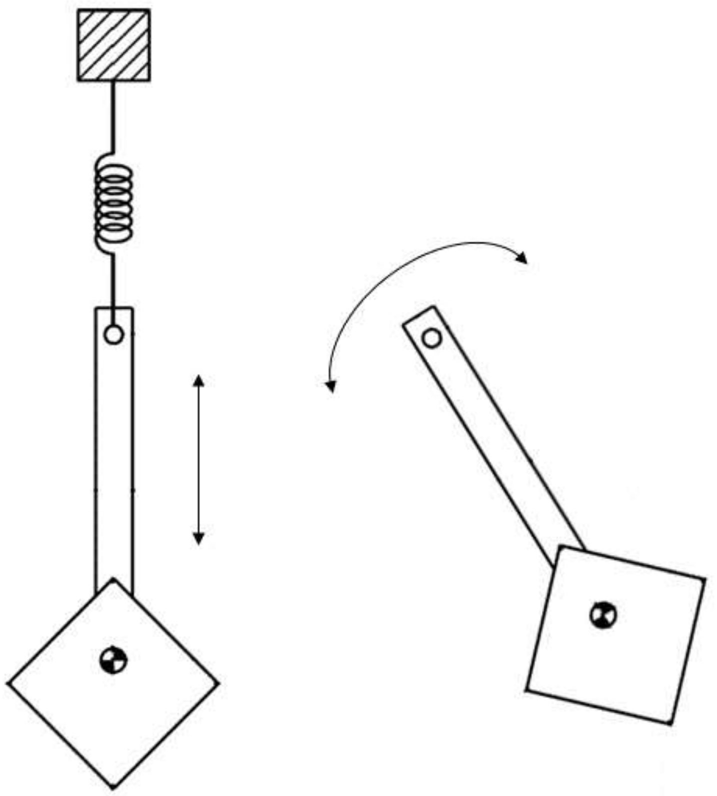


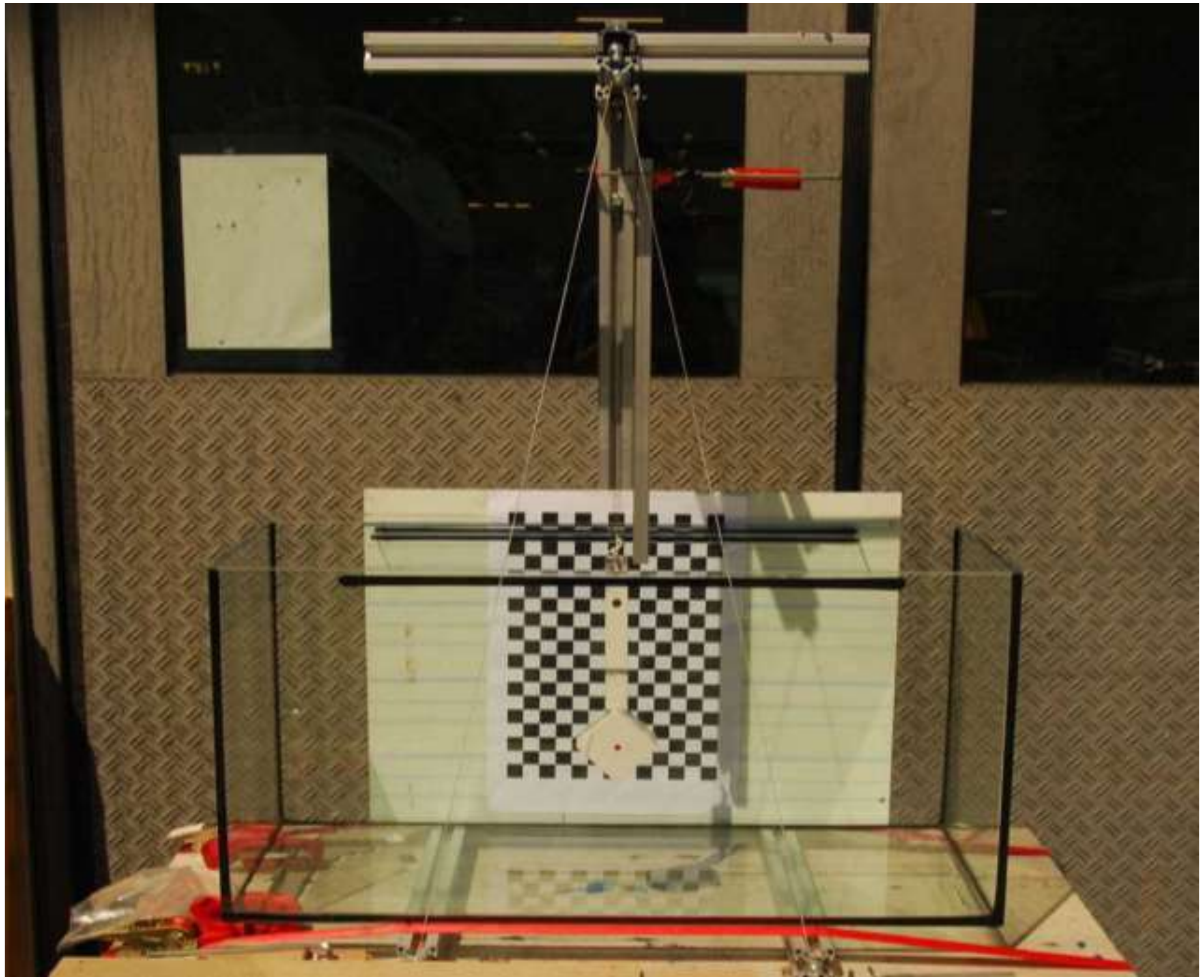






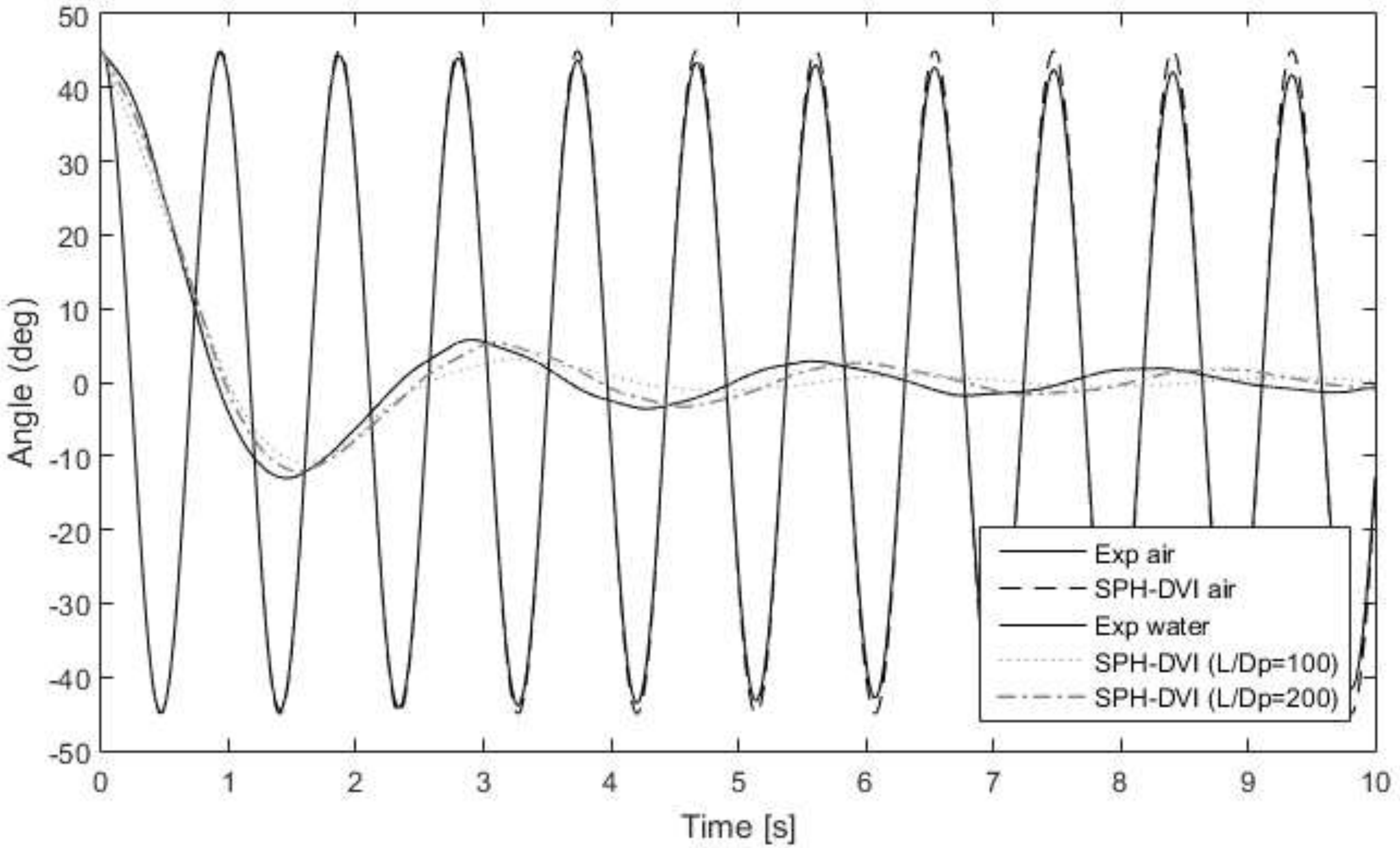
Validations - II



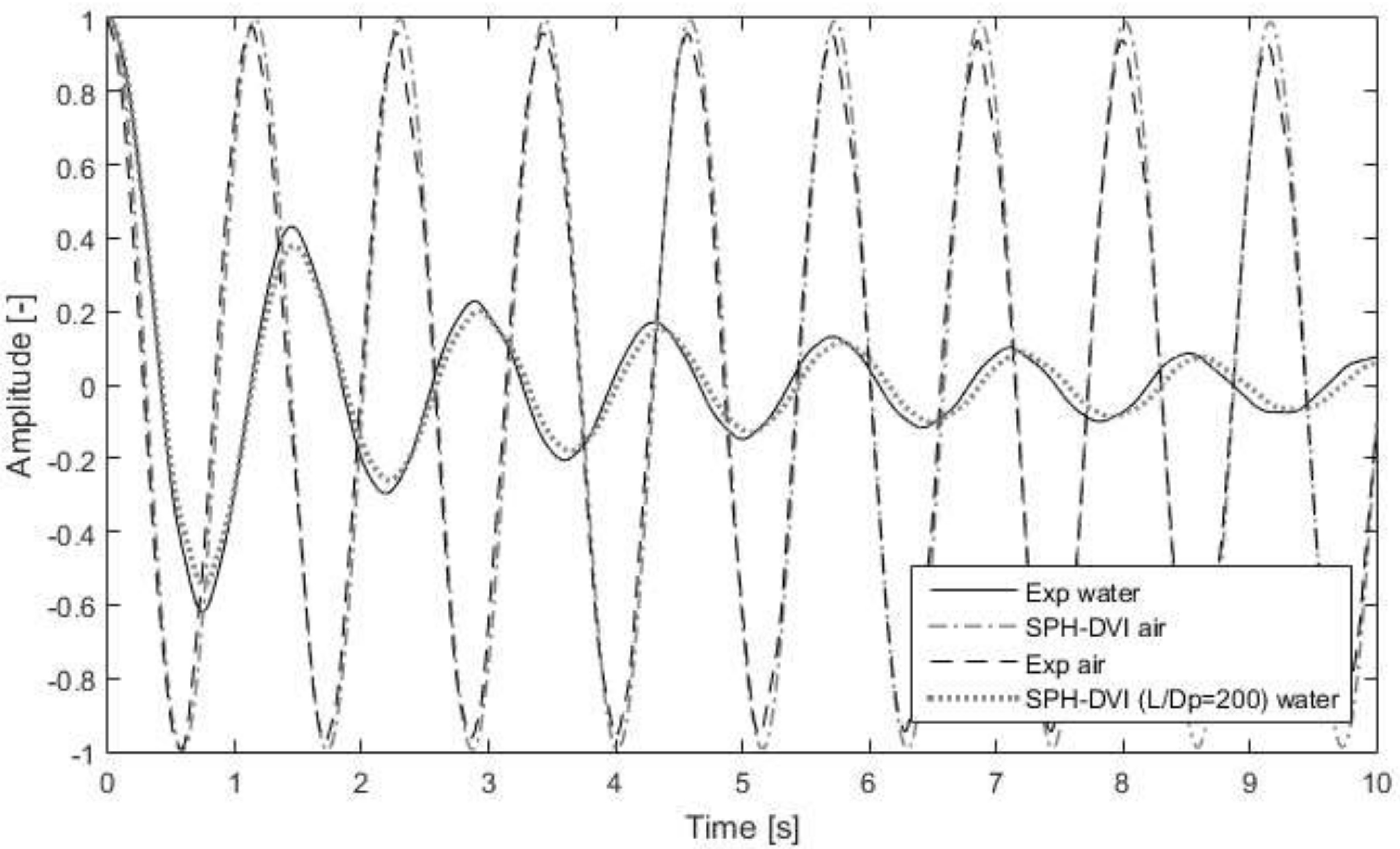


M. Arnold, M. Kretschmer, J. Koch, P.W. Cheng, F. Biskup et al., *A validation method for fluid-structure-interaction simulations based on submerged free decay experiments*, in The Twenty-fifth International Ocean and Polar Engineering Conference. International Society of Offshore and Polar Engineers, 2015.

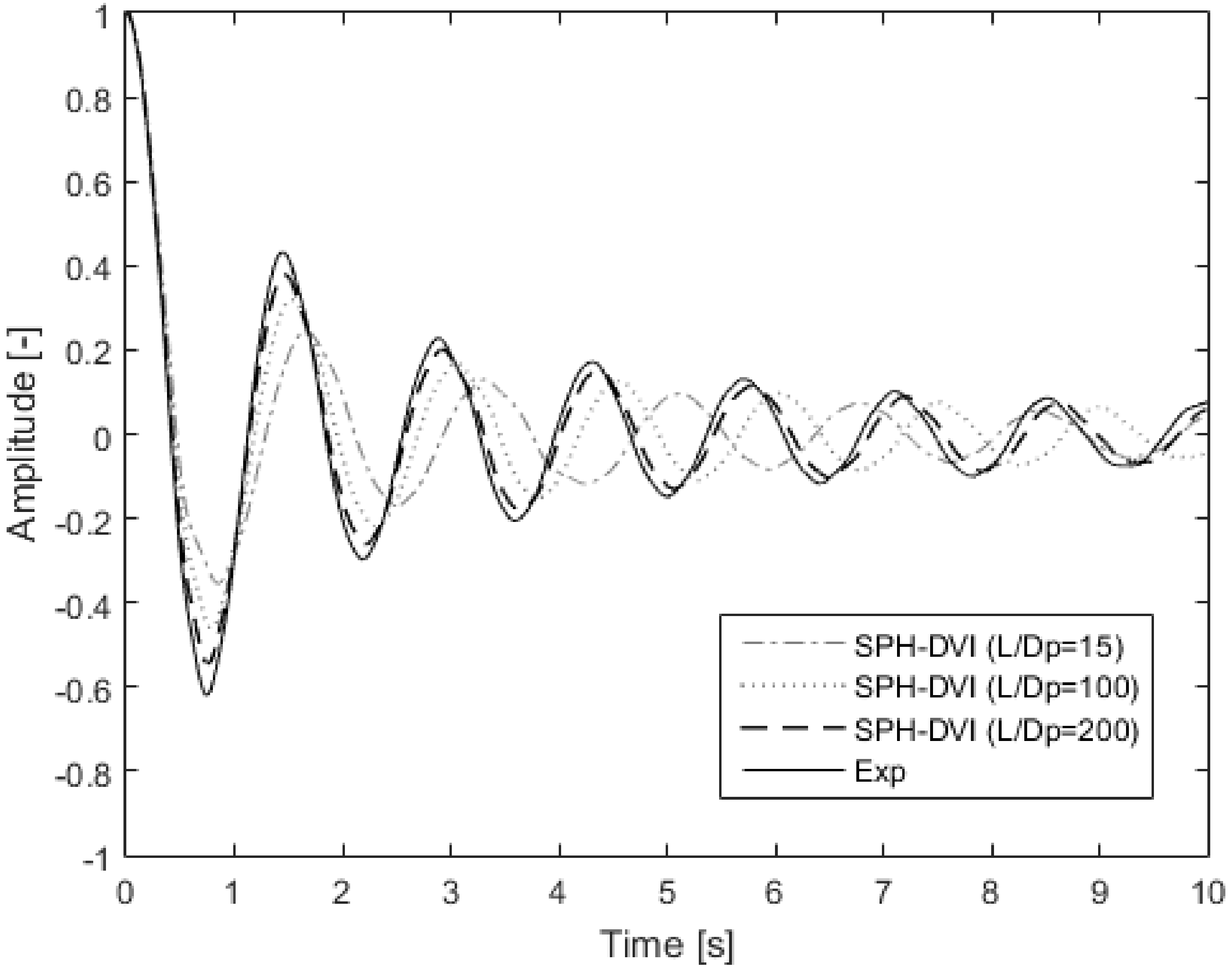
Validations - II

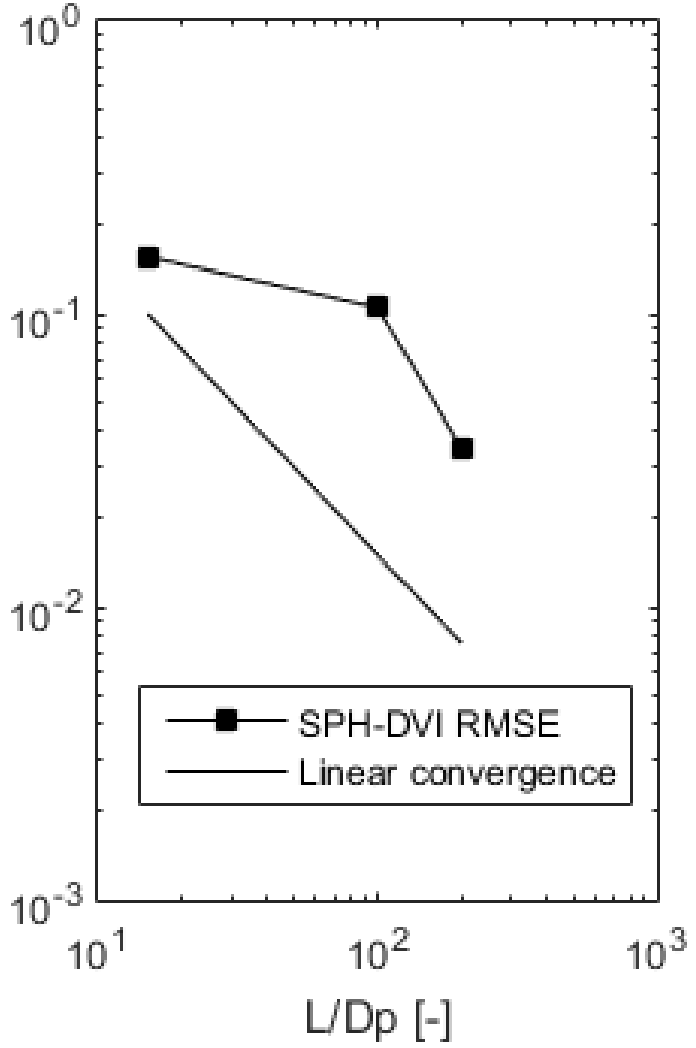


Validations - II

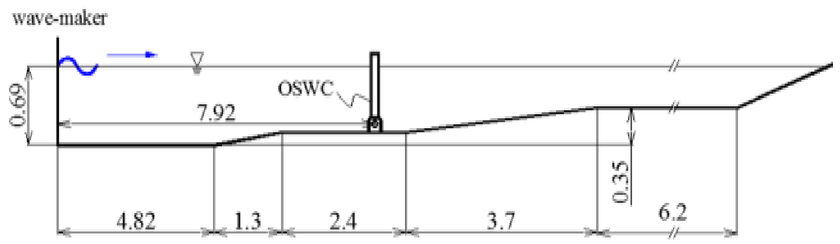


Validations - II

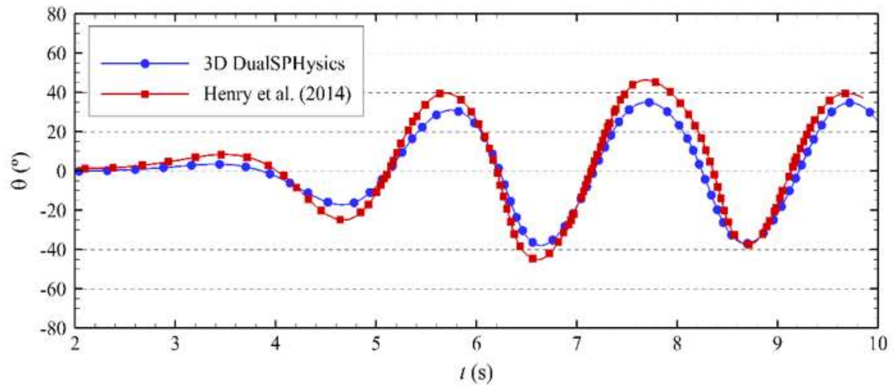


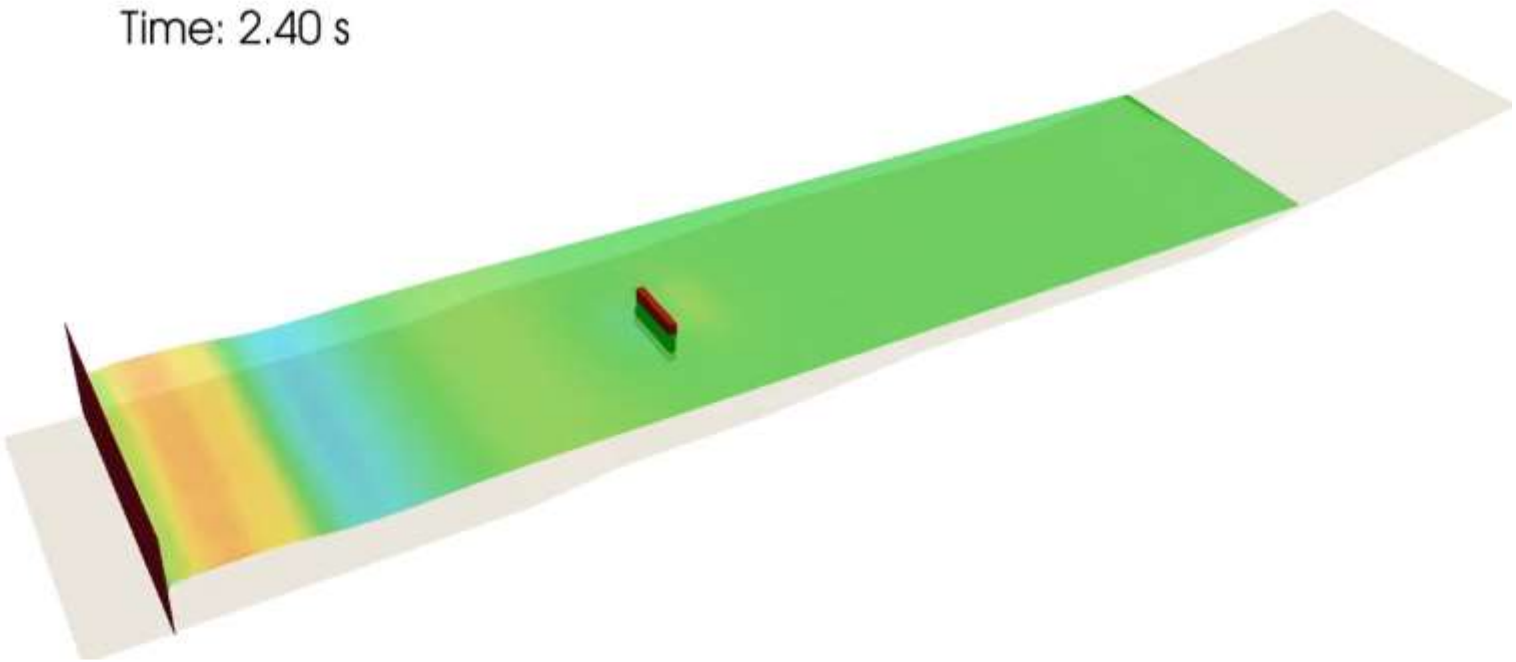


Application to Wave Energy Converters – Wave roller

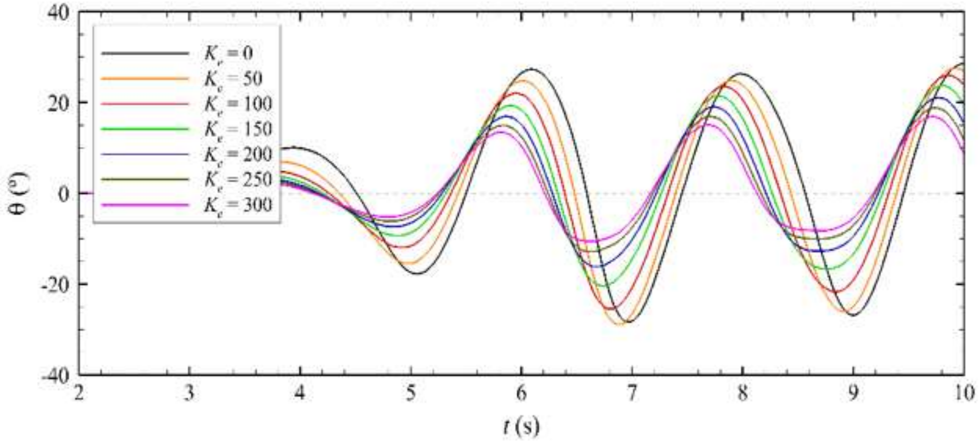


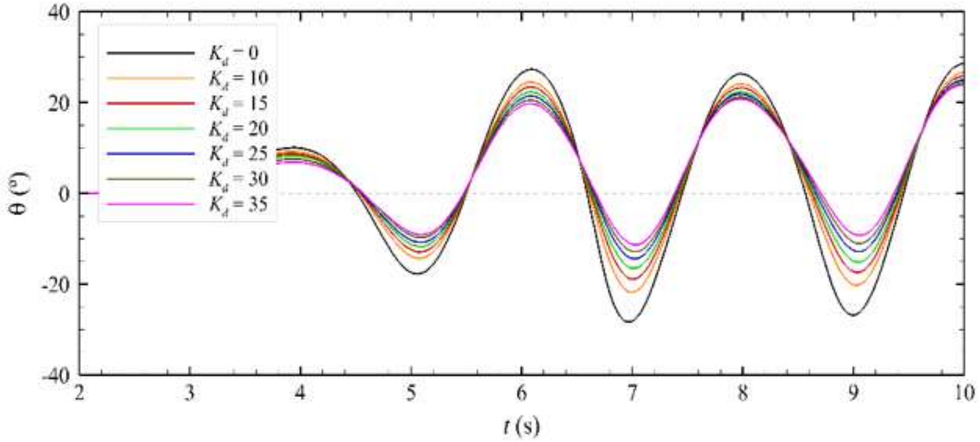
Experimental set up at the Marine Research Group's hydraulics laboratory at Queen's University Belfast.



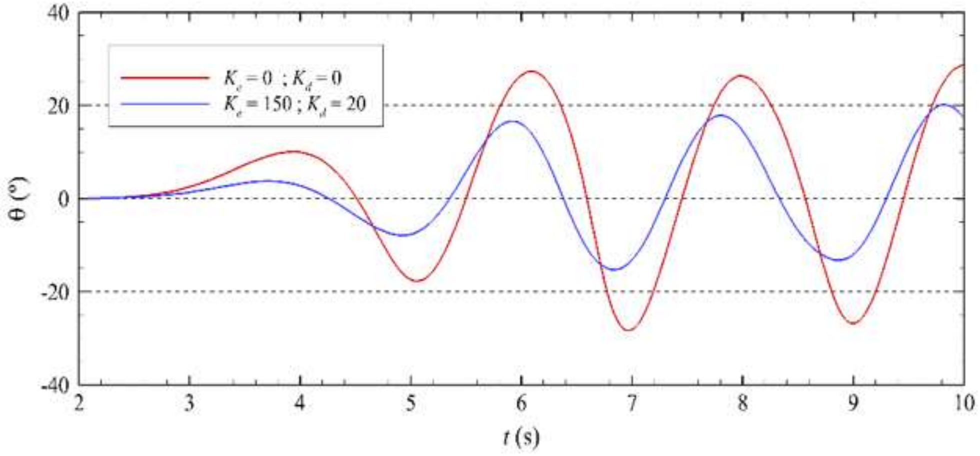


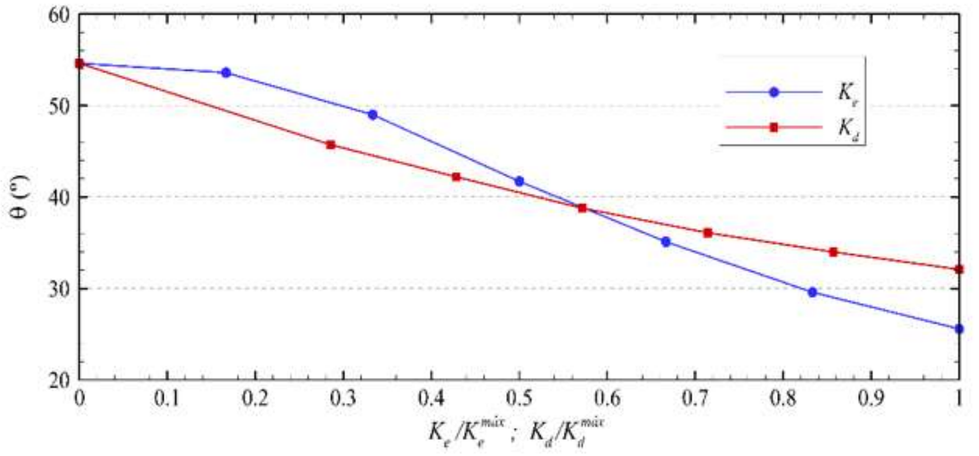
Application to Wave Energy Converters – Wave roller





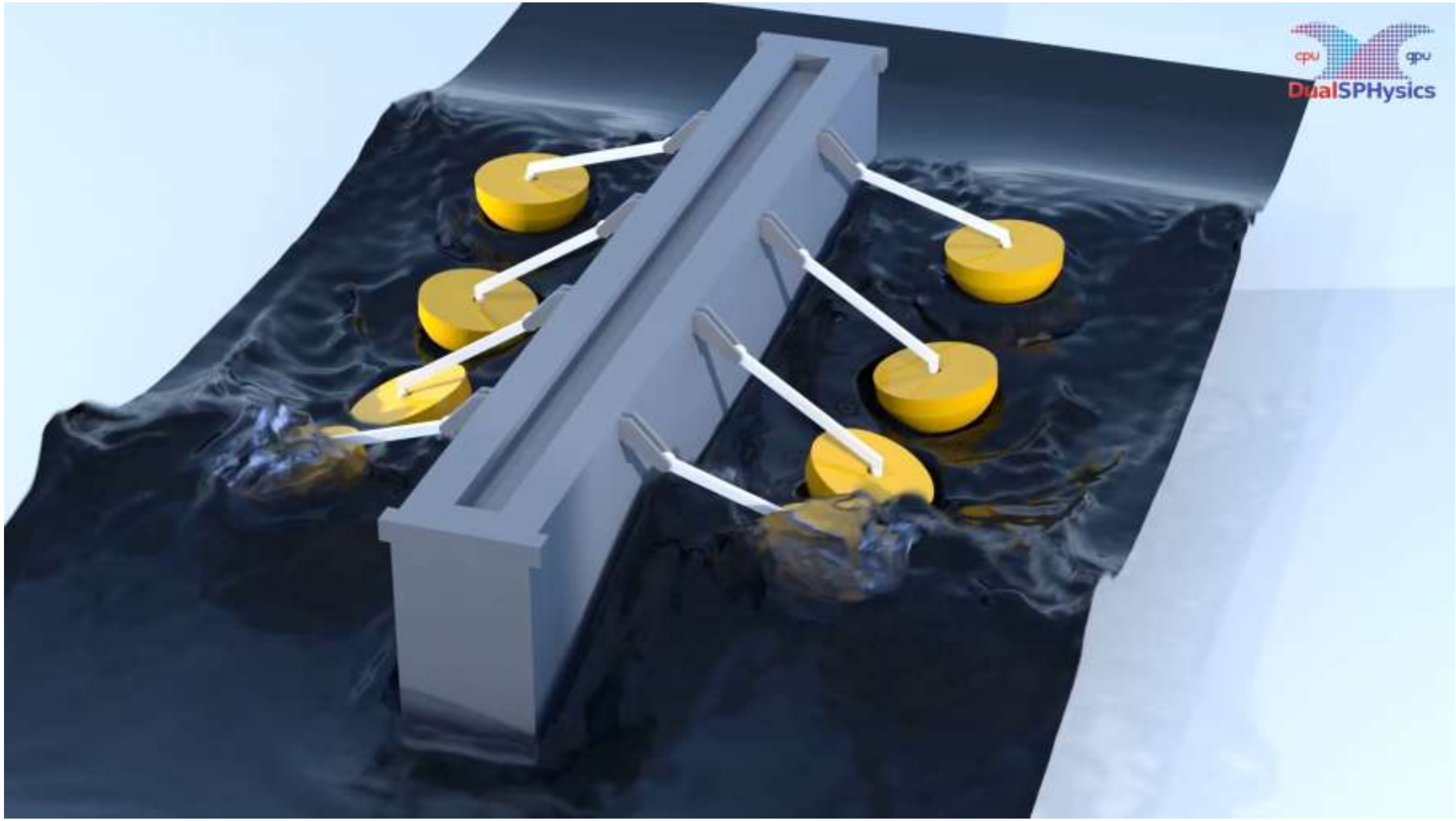
Introducing different values of the elastic coefficient (K_e) and the damping coefficient (K_d), we can go beyond the current experiments.





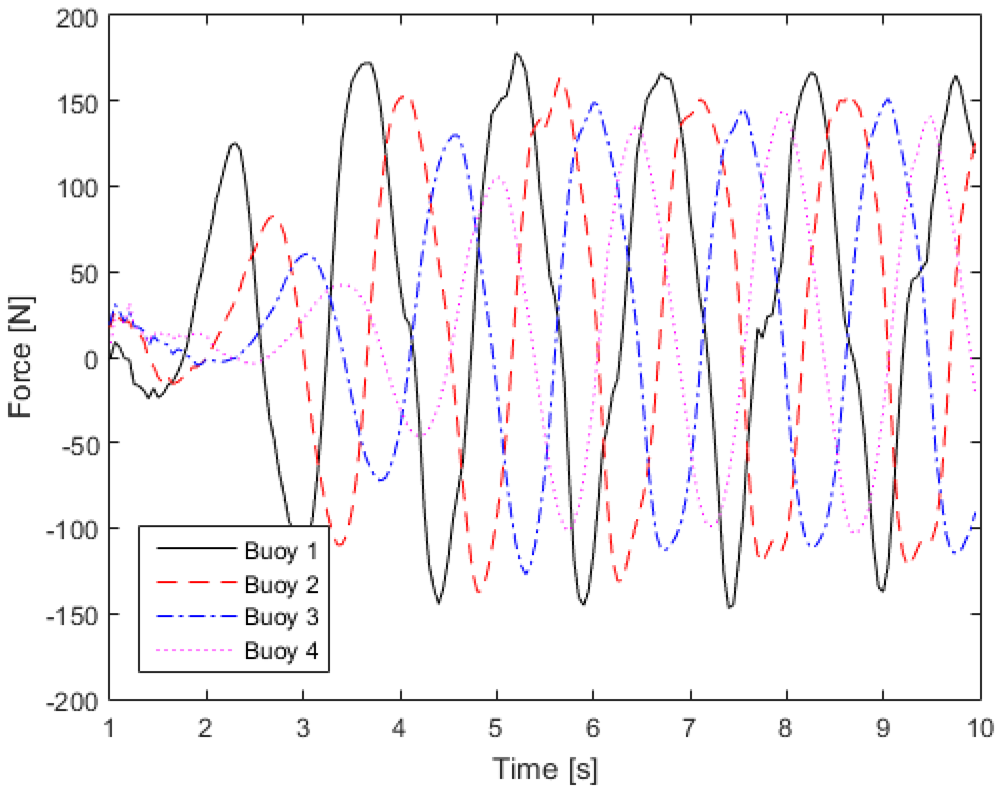
Application to Wave Energy Converters – Wavestar

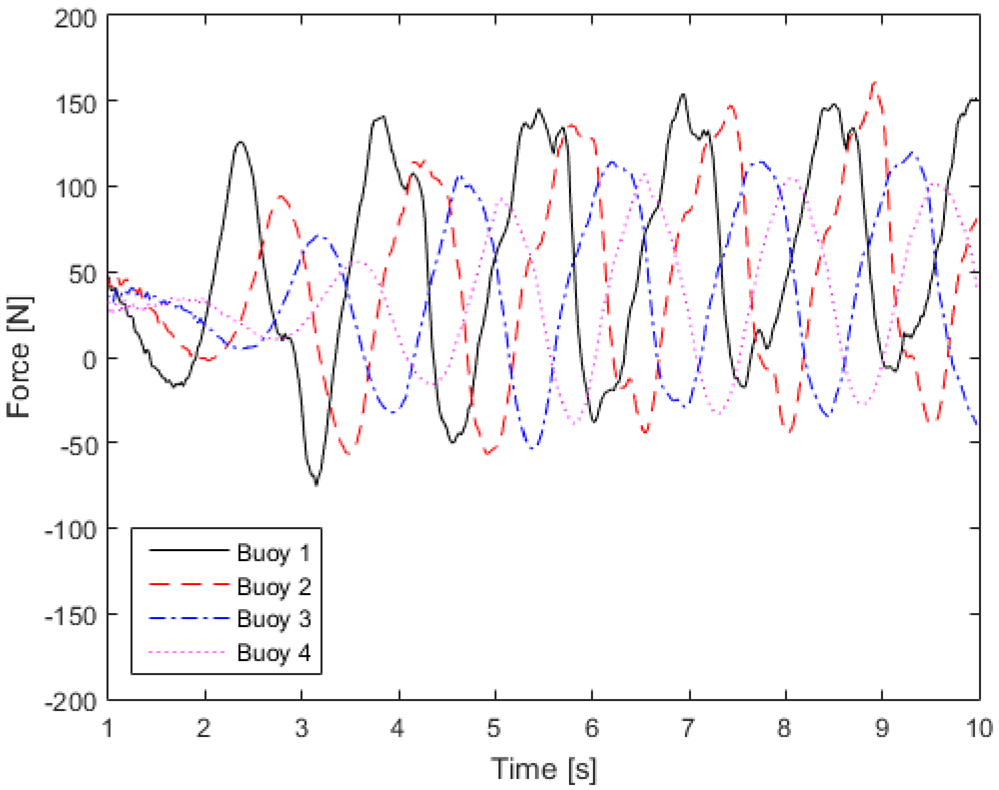
Revolute and spherical joints on the articulated arms and buoys.



Application to Wave Energy Converters – Wavestar

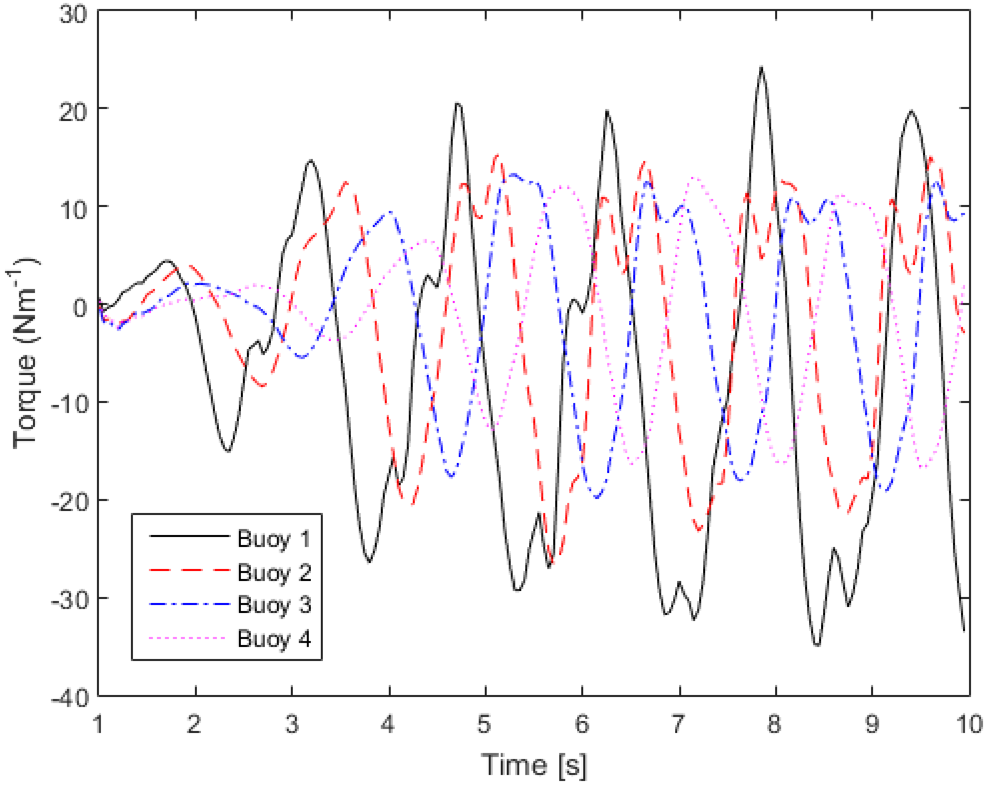
Forces on the buoy link.

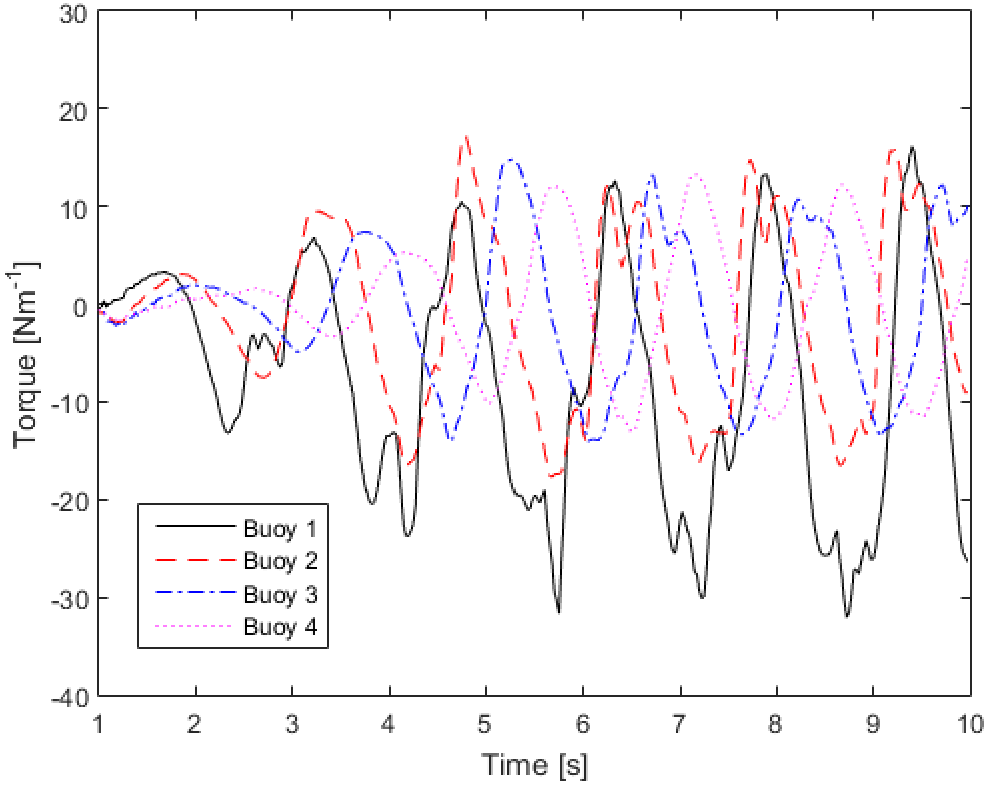




Application to Wave Energy Converters – Wavestar

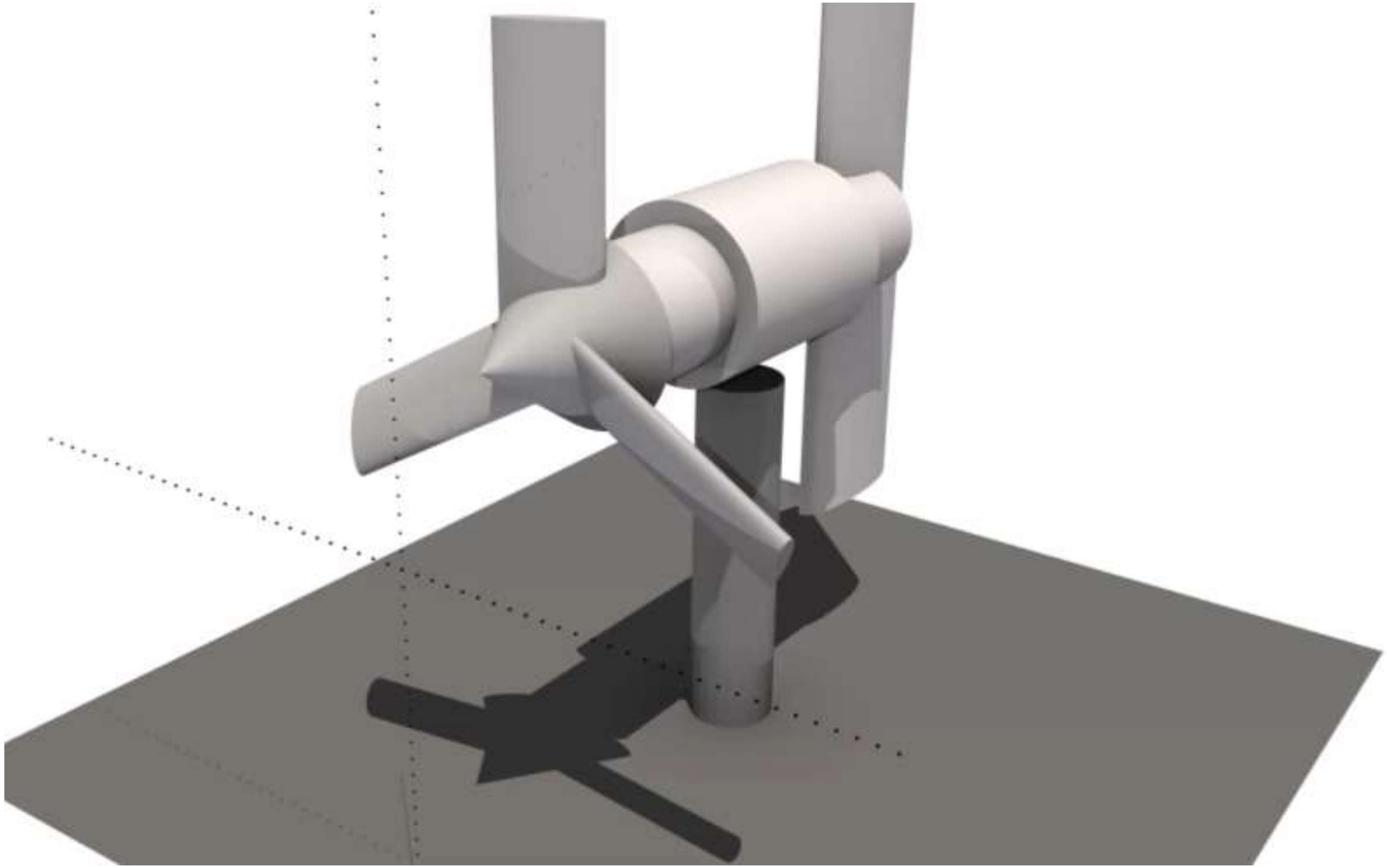
Torque on the buoy link.

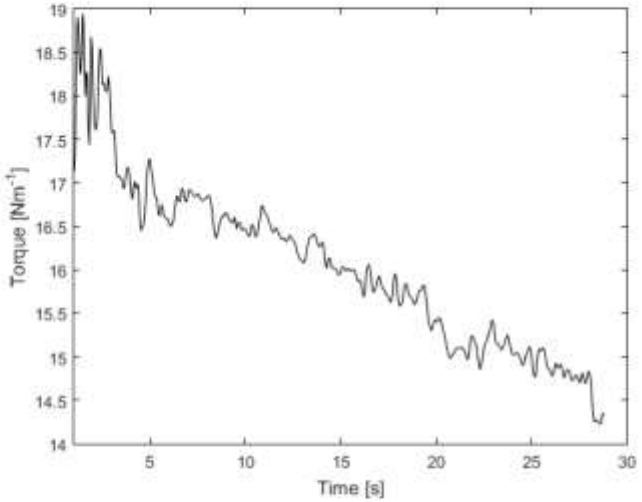


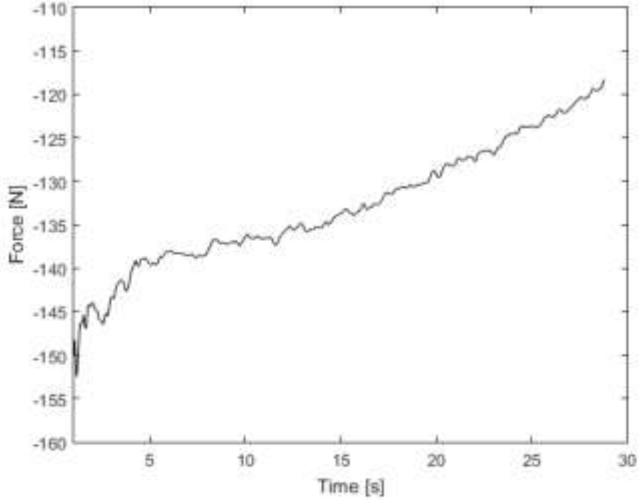


Application to Wave Energy Converters – Tidal turbine

Slow dynamics, free spinning of body and relative rotation of turbine blades. Force and torque on the support.

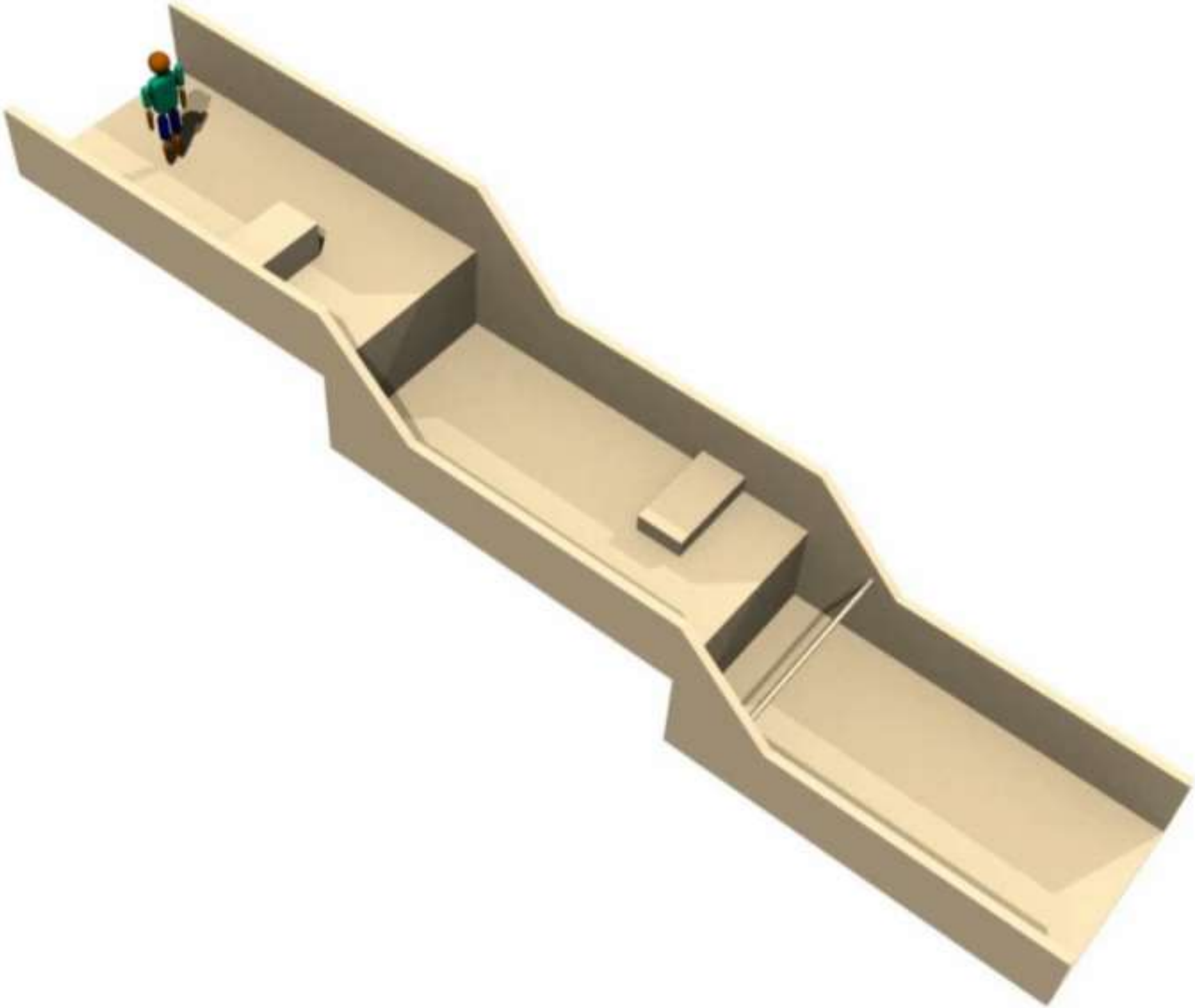






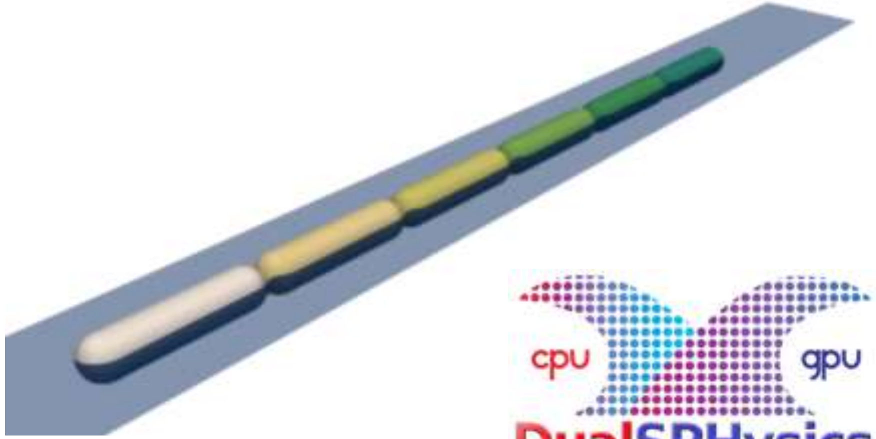
Ragdoll

- Several Links
- Self collision
- Complex geometry



Conclusions and future work

- A fully coupled and robust multi-physics oriented DualSPHysics version was presented
- Simple set-up of large numbers of mechanical constraints, material properties and geometry
- Complex mechanisms such as most WECs, control structures and multi-body floating structures can now be efficiently modeled and pre-designed



- Elastic and elastoplastic bodies (structural analisys)
- Optimize concurent GPU execution