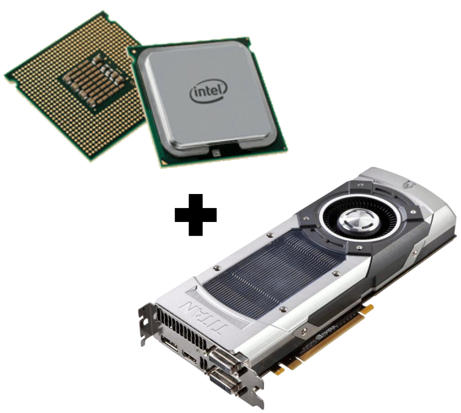
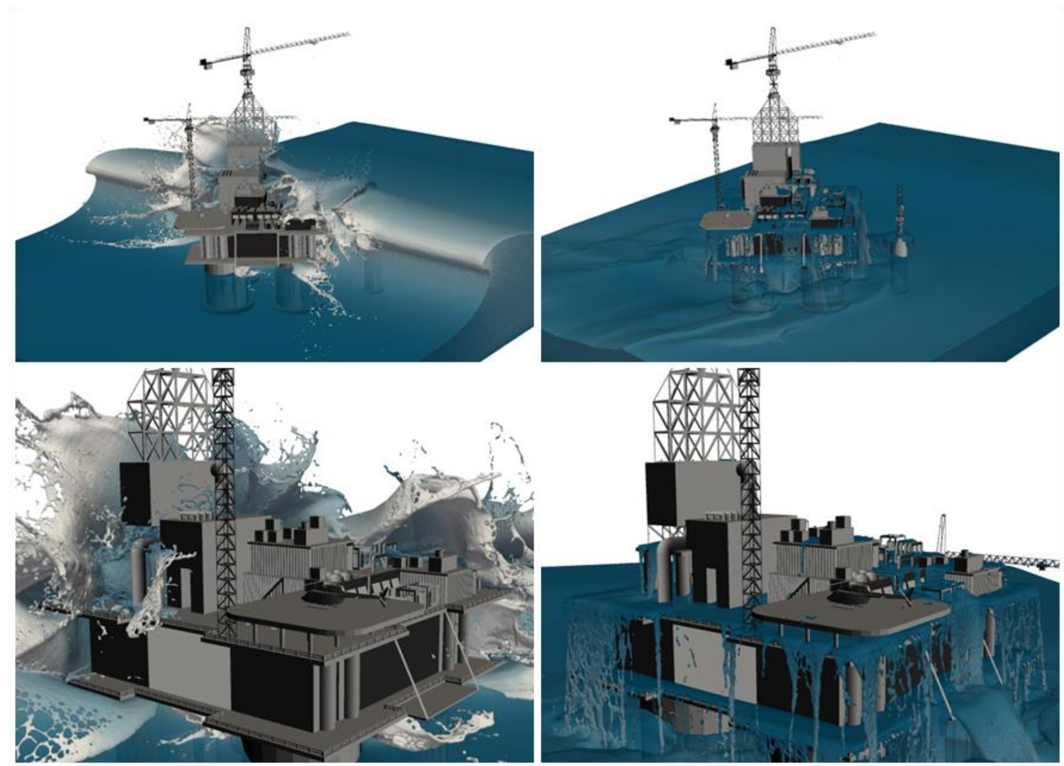
Parallelization of SPH for engineering applications with heterogeneous architectures





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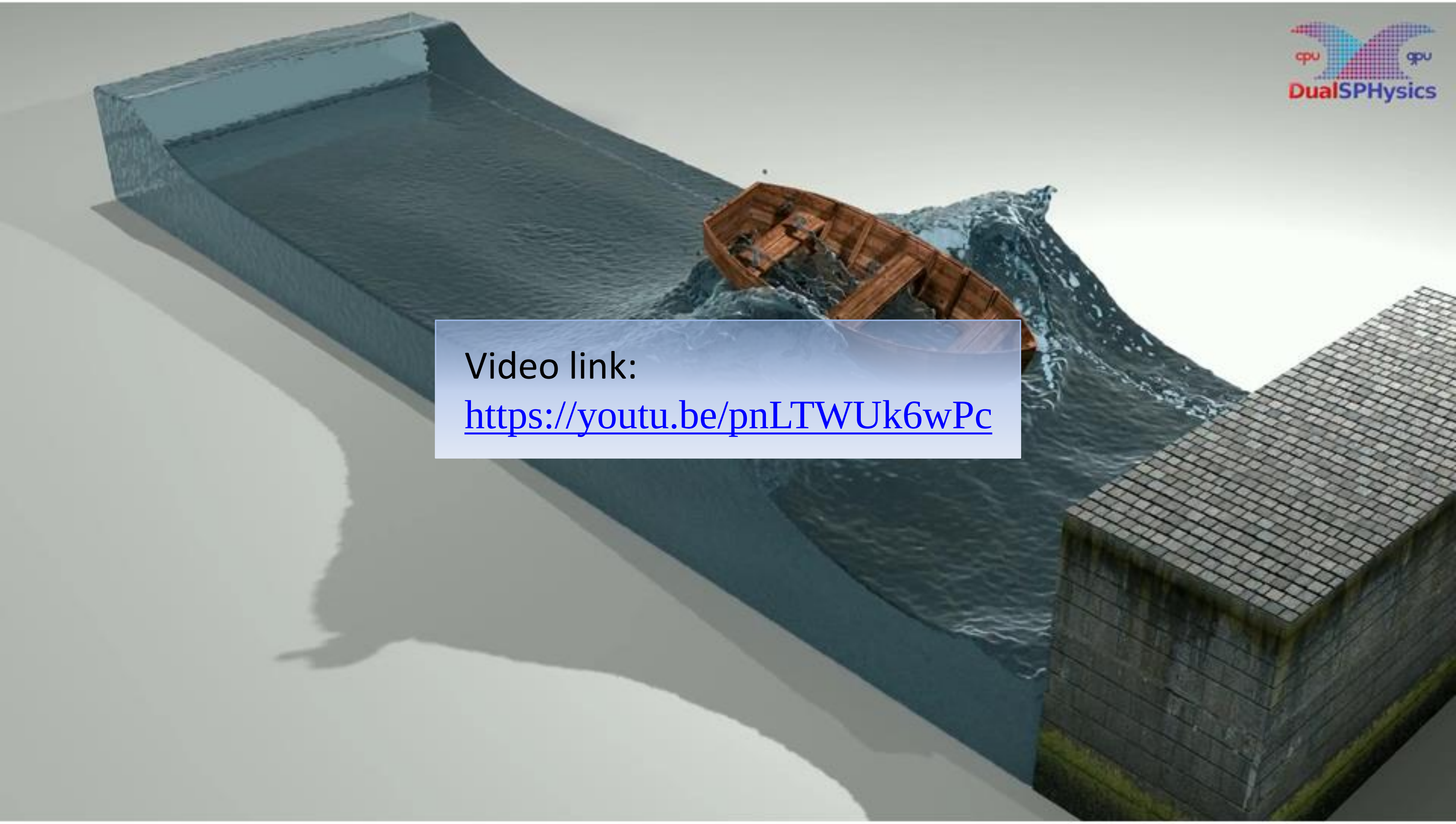
Outline

1. Introduction
   1.1. Numerical modelling
   1.2. Smooth Particle Hydrodynamics
   1.3. DualSPHysics project

2. SPH formulation

3. DualSPHysics implementation
   3.1. CPU acceleration
   3.2. GPU acceleration
   3.3. Multi-GPU acceleration

4. Developments and applications



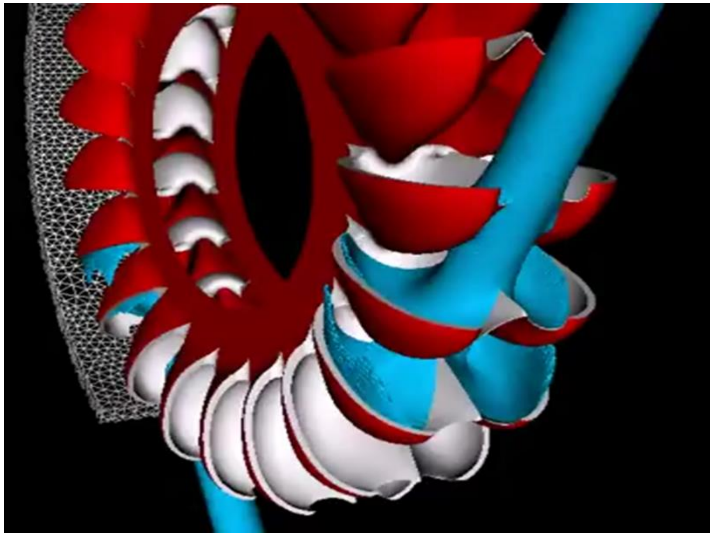
Video link:
https://youtu.be/pnLTWUk6wPc

1.1. Numerical modelling

Computational Fluid Dynamics (CFD) is a branch of fluid mechanics that studies the behaviour of the fluids using numerical modelling.

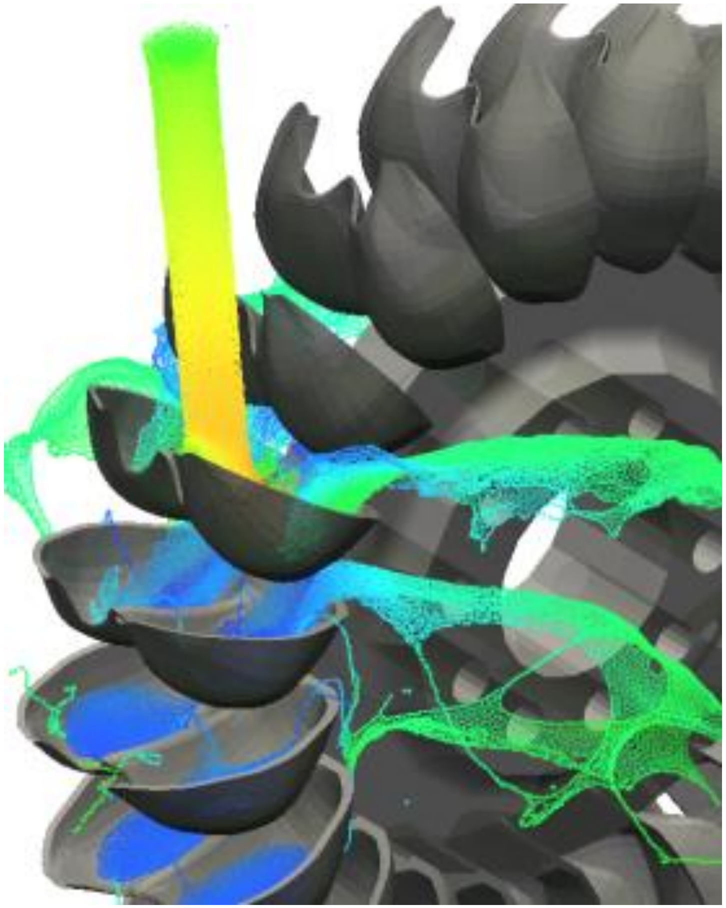
The numerical simulation is a powerful tool that allows for understanding the behaviour of complex systems and even for predicting their evolution starting from initial conditions.

Physical model



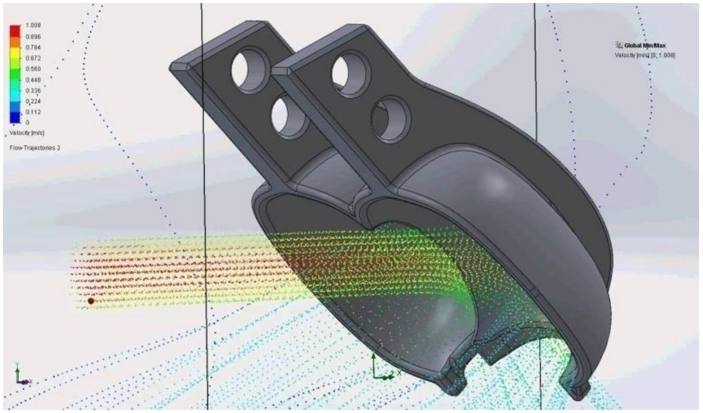
Numerical model

1.1. Numerical modelling



Advantages of numerical modelling:

- Capability to simulate complex scenarios.
- Provide physical data that can be difficult, or even impossible, to measure in a real model.
- Can reduce significantly the number of physical tests.
- Important saving in time and money.



1.2. Smooth Particle Hydrodynamics

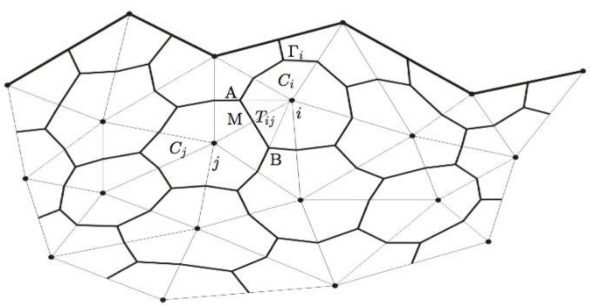
PHYSICAL GOVERNING EQUATIONS

EULERIAN DESCRIPTION
(spatial description)

LAGRANGIAN DESCRIPTION
(material description)

COMPUTATIONAL METHODS

GRID-BASED METHODS



SPH

MESHFREE METHODS

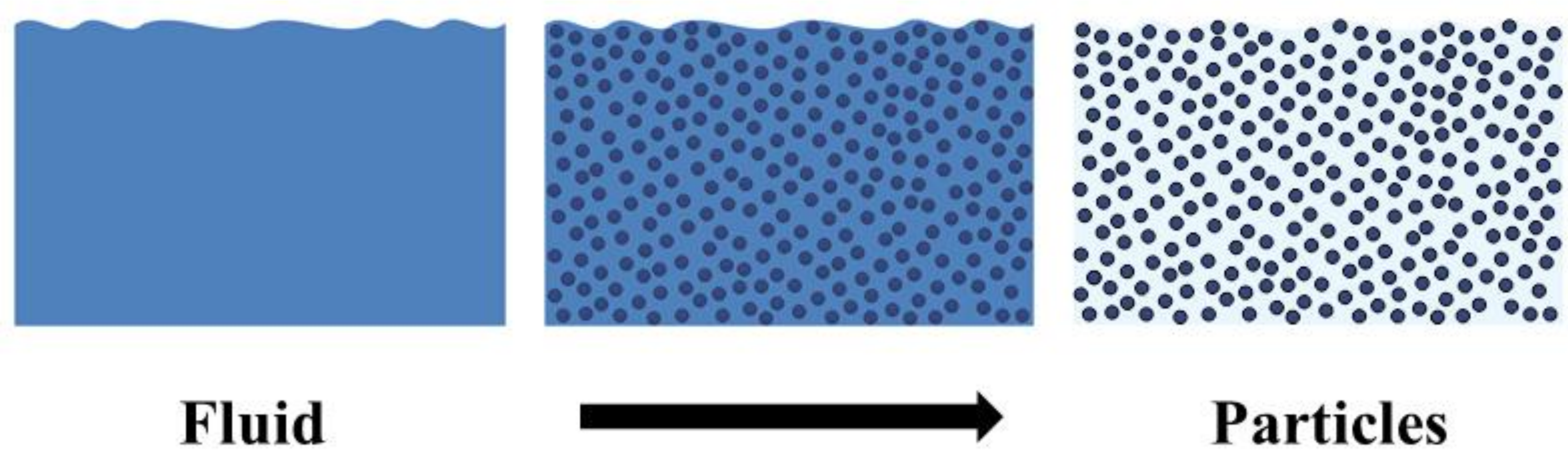
MESHFREE PARTICLE METHODS
(particle represents a part of
the continuum domain)

SMOOTHED PARTICLE HYDRODYNAMICS

1.2. Smooth Particle Hydrodynamics

SPH method was invented for astrophysics during the seventies, but now it is applied in many different fields including fluid dynamics and solid mechanics.

Fluid is represented using particles which move according to the governing dynamics.



Comparing to grid-based methods, SPH interactions are carried out between a given particle and its moving neighbours. Thus, these **neighbours are unknown since they change at each instant.**

1.2. Smooth Particle Hydrodynamics

SPH method was invented for astrophysics during the seventies, but now it is applied in many different fields including fluid dynamics and solid mechanics.

Fluid is represented using particles which move according to the governing dynamics.

SPH is particularly suited to describe a variety of **free-surface flows**:

- Wave propagation over a beach.
- Plunging breakers.
- Wave-structure interactions.
- Solid bodies impacting on water surface.
- Dam breaks.

1.2. Smooth Particle Hydrodynamics

Drawbacks of SPH:

- SPH presents a **high computational cost** that increases when increasing the number of particles.

✚

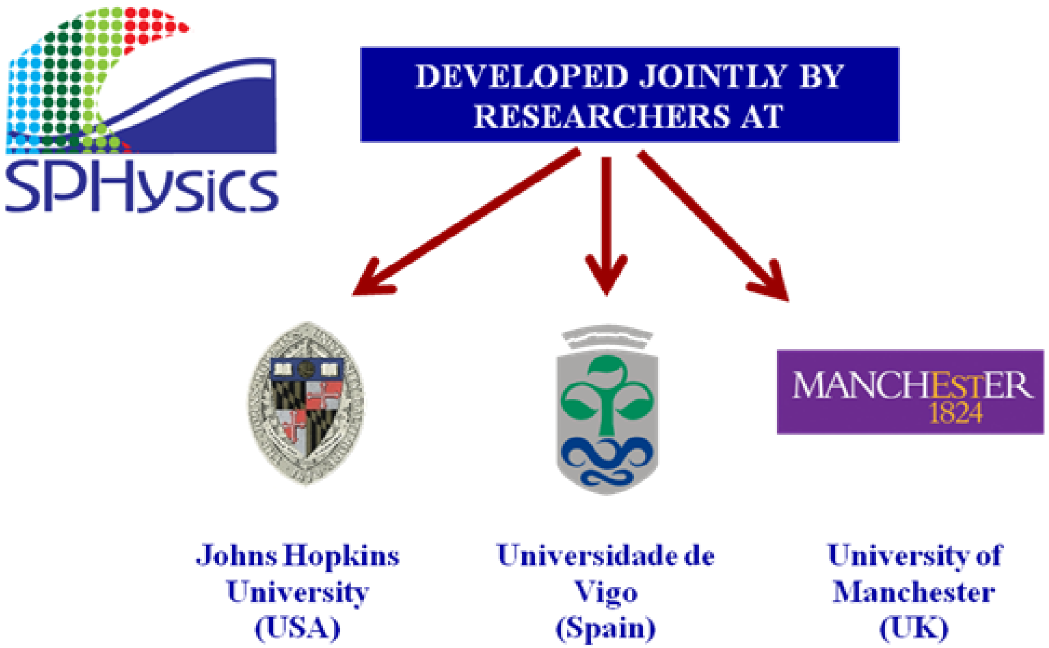
- The simulation of **real problems** requires a high resolution which implies simulating **millions of particles**.

The **time required** to simulate a few seconds is **too large**. One second of physical time can take several days of calculation.

IT IS NECESSARY TO USE HPC TECHNIQUES TO REDUCE THESE COMPUTATION TIMES.

1.3. DualSPHysics project: Origin

The DualSPHysics code was created starting from SPHysics.



SPHysics is a numerical model SPH developed for the study of free-surface problems.

It is a code written in Fortran90 with numerous options (different kernels, several boundary conditions,…), which had already demonstrated high accuracy in several validations with experimental results… but it is too slow to apply to large domains.

1.3. DualSPHysics project: Origin

The problem:

- SPH PRESENTS A HIGH COMPUTATIONAL COST THAT INCREASES WHEN INCREASING THE NUMBER OF PARTICLES
- THE SIMULATION OF REAL PROBLEMS REQUIRES A HIGH RESOLUTION WHICH IMPLIES SIMULATING MILLIONS OF PARTICLES

IT WAS NECESSARY TO INCREASE THE VELOCITY OF THE CODE A FACTOR 100x

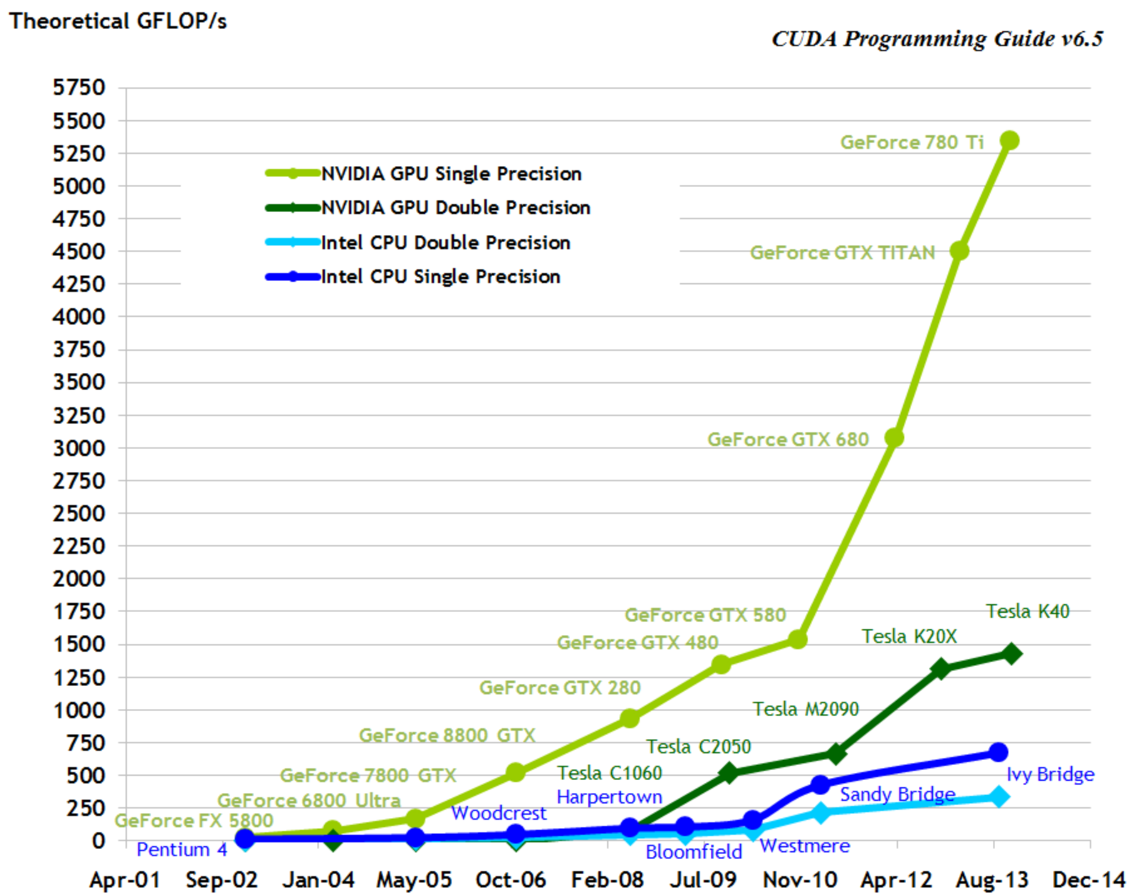
Classic options:

- **OpenMP:** Distribute the workload among all CPU cores (≈4x)
- **MPI:** Combines the power of multiple machines connected via network (high cost).

New option:

- **GPU:** Graphics cards with a high parallel computing power (cheap and accessible).

1.3. DualSPHysics project: Graphics Processing Units (GPUs)



Graphics Processing Units (GPUs)

- powerful parallel processors
- designed for graphics rendering
- their computing power has increased much faster than CPUs.

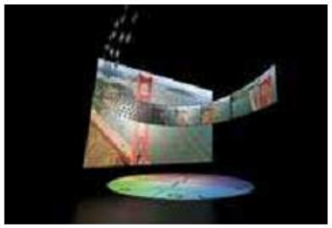
Advantages: GPUs provide the necessary power with very low cost and without expensive infrastructures.

Drawbacks: An efficient and full use of the capabilities of the GPUs is not straightforward.

1.3. DualSPHysics project: Graphics Processing Units (GPUs)

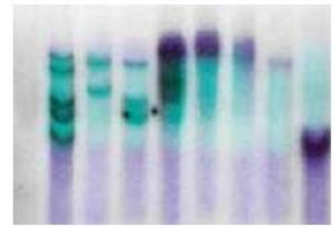
GPUs are an accessible tool to accelerate SPH,
all numerical methods in CFD and any computational method

5X
Digital Content Creation
Adobe

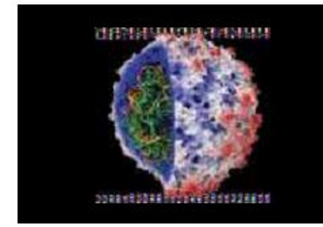


18X
Video Transcoding
Elemental Technologies

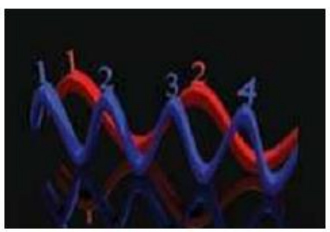
20X
3D Ultrasound
TechniScan



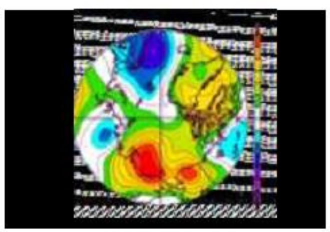
30X
Gene Sequencing
U of Maryland



36X
Molecular Dynamics
U of Illinois, Urbana-Champaign

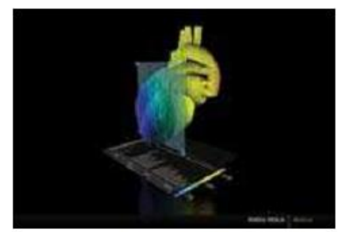


50X
MATLAB Computing
AccelerEyes

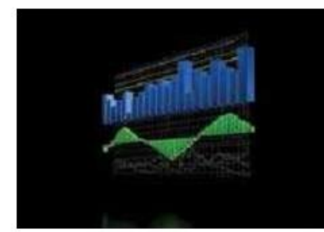


80X
Weather Modeling
Tokyo Institute of Technology

100X
Astrophysics
RIKEN



146X
Medical Imaging
U of Utah



149X
Financial Simulation
Oxford University

http://www.nvidia.com

1.3. DualSPHysics project

First version in late 2009.

It includes **two implementations**:

- **CPU**: C++ and OpenMP.
- **GPU**: CUDA.

Both options optimized for the best performance of each architecture.

Why two implementations?

This code can be used on machines with GPU and without GPU.

It allows us to make a fair and realistic comparison between CPU and GPU.

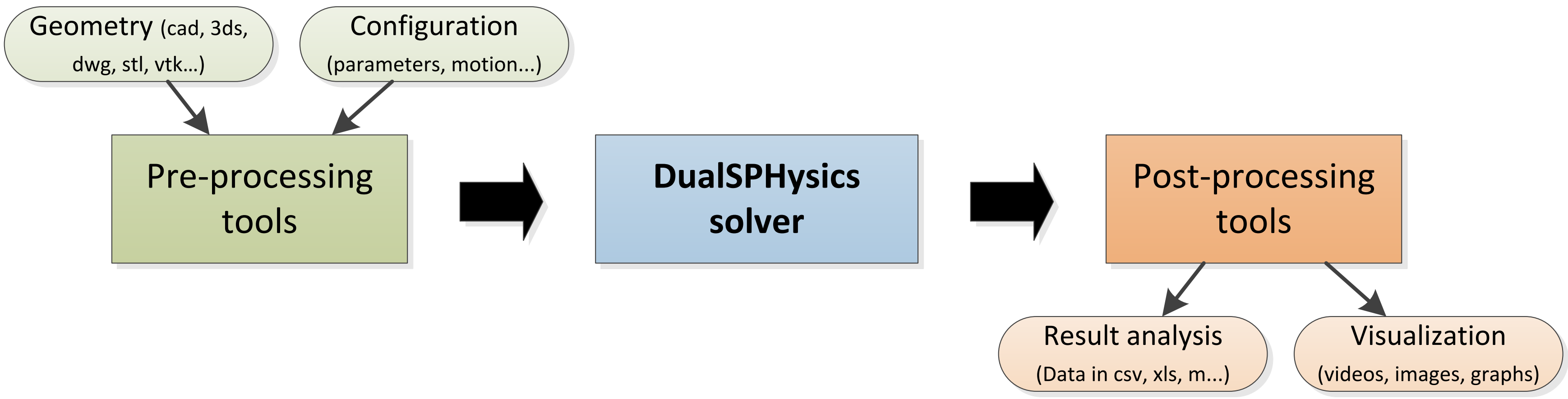
Some algorithms are complex and it is easy to make errors difficult to detect. So they are implemented twice and we can compare results.

It is easier to understand the code in CUDA when you can see the same code in C++.

Drawback: It is necessary to implement and to maintain two different codes.

1.3. DualSPHysics project

DSPH project includes:



Pre-processing tools:

- Converts geometry into particles.
- Provides configuration for simulation.

DualSPHysics solver:

- Runs simulation using SPH particles.
- Obtains data simulation for time intervals.

Post-processing tools:

- Calculates magnitudes using particle data.
- Generates images and videos starting form SPH particles.

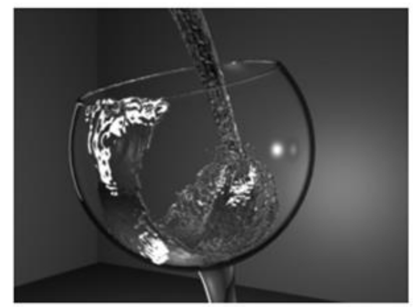
1.3. DualSPHysics project

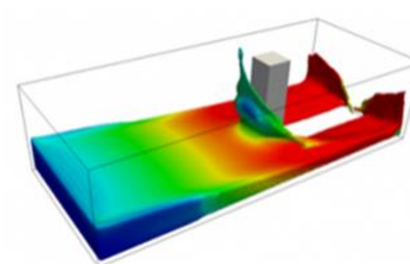
DualSPHysics

Downloads DualSPHysics Project GPU Computing SPHysics Project Validation
Applications Animations References Forums FAQ News Contact

UniversidadeVigo

MANCHESTER 1824
The University of Manchester





DualSPHysics is based on the Smoothed Particle Hydrodynamics model named SPHysics (www.sphysics.org).

The code is developed to study free-surface flow phenomena where Eulerian methods can be difficult to apply, such as waves or impact of dam-breaks on off-shore structures.

DualSPHysics is a set of C++ and CUDA codes to deal with real-life engineering problems.

Contact E-Mail: dualsphysics@gmail.com

www.dual.sphysics.org

1.3. DualSPHysics project

DEVELOPED JOINTLY BY RESEARCHERS AT

Universidade de Vigo (Spain)

University of Manchester (UK)

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Abouzied Nasar
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Dr Xavier Gironella
Andrea Marzeddu

www.dual.sphysics.org

1.3. DualSPHysics project

People working on DualSPHysics project:

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   3.2. GPU acceleration
   3.3. Multi-GPU acceleration

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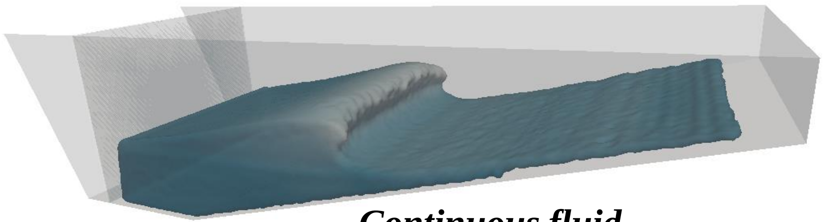
2. SPH formulation

SPH is based on integral interpolants

The fundamental principle is to approximate any function *F*(r) by (kernel approximation)

$$F(\mathbf{r}) = \int_{\Omega} F(\mathbf{r}')W(\mathbf{r}-\mathbf{r}',2h)d\mathbf{r}'$$



Continuous fluid

From **continuous notation** (INTEGRALS)

To **discrete notation** (SUMMATION)

$$F(\mathbf{r}) \approx \sum_{j=1}^{N} F(\mathbf{r}_j)W(\mathbf{r}-\mathbf{r}_j,2h)\frac{m_j}{\rho_j}$$

Particles

2. SPH formulation

SPH is based on integral interpolants

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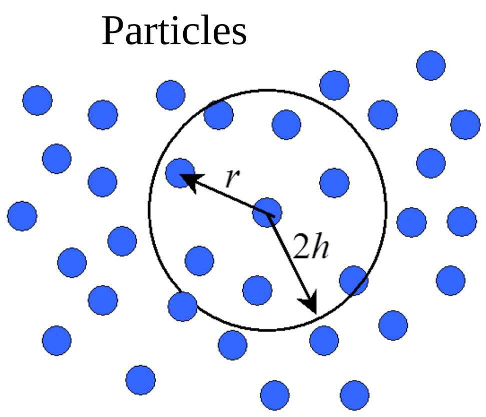

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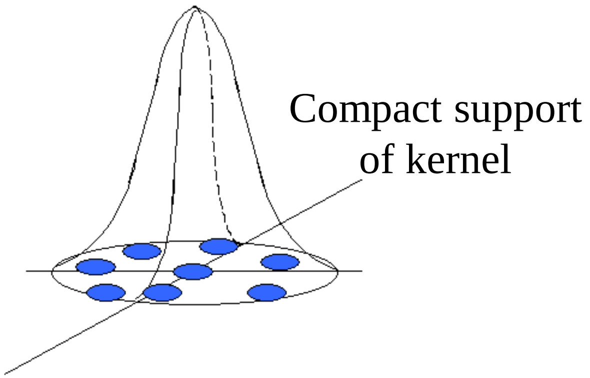

2. SPH formulation

Navier-Stokes equations

Continuous notation (INTEGRALS)

Discrete notation (SUMMATIONS) in SPH form

Conservation of Mass

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho\nabla.\mathbf{v}$$

$$\left\langle \frac{\mathrm{d}\rho}{\mathrm{d}t} \right\rangle = \sum_j m_j \left(\mathbf{v}_i - \mathbf{v}_j\right) \cdot \nabla_i W_{ij}$$

Conservation of Momentum

$$\frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} = -\frac{1}{\rho}\nabla p + \mathbf{F}$$

$$\left\langle \frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} \right\rangle = \sum_j m_j \left(\frac{p_j}{\rho_j^2} + \frac{p_i}{\rho_i^2} \right) \nabla_i W_{ij}$$

Density derivative $\frac{\mathrm{d}\rho}{\mathrm{d}t} \longrightarrow \rho \longrightarrow P$

density — pressure

Velocity derivative $\frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} \longrightarrow \mathbf{v} \longrightarrow \mathbf{r}$

(acceleration)

velocity — position

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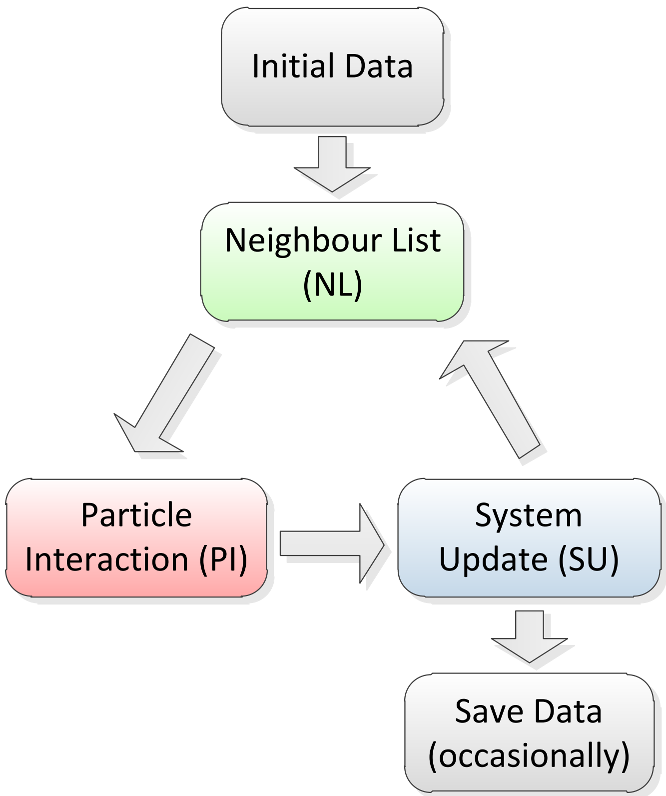
    3.2. GPU acceleration
    3.3. Multi-GPU acceleration
4. Developments and applications

3. DualSPHysics implementation

For the implementation of SPH, the code is organised in **3 main steps** that are repeated each time step till the end of the simulation.



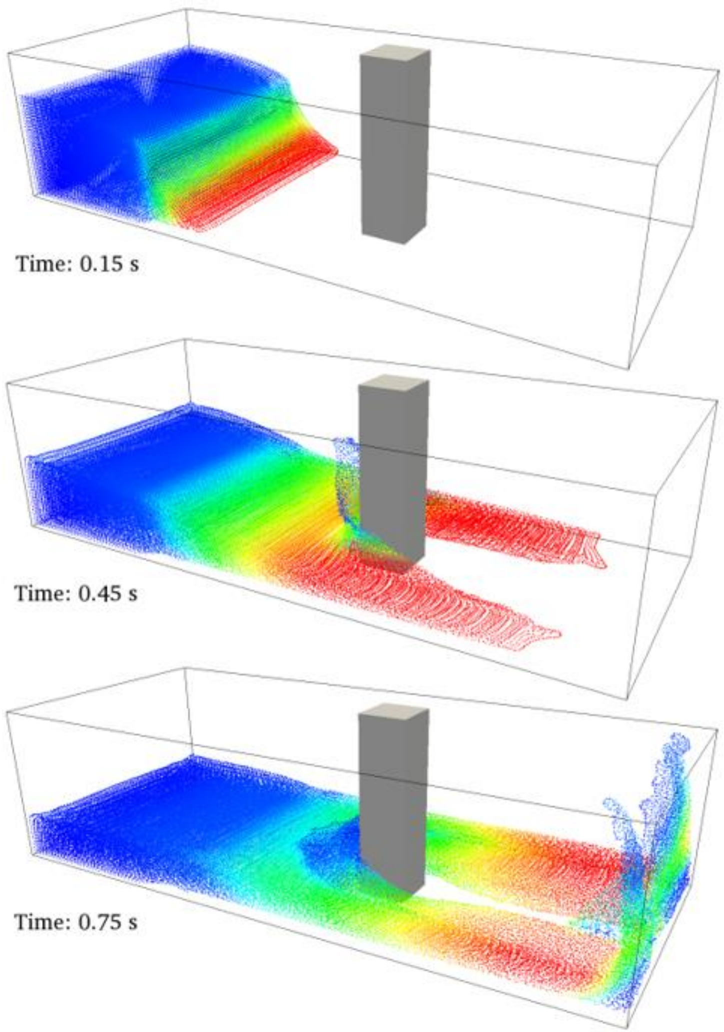
Neighbour list (NL):
Particles are grouped in cells and reordered to optimise the next step.

Particle interactions (PI):
Forces between particles are computed, solving momentum and continuity equations.
This step takes **more than 95%** of execution time.

System update (SU):
Starting from the values of computed forces, the magnitudes of the particles are updated for the next instant of the simulation.

3. DualSPHysics implementation

The SPH method is very expensive in terms of computing time.



For example, a simulation of this dam break

300,000 particles
+
1.5 s (*physical time*)

➡

Takes more than
15 hours
(*execution time*)

3. DualSPHysics implementation

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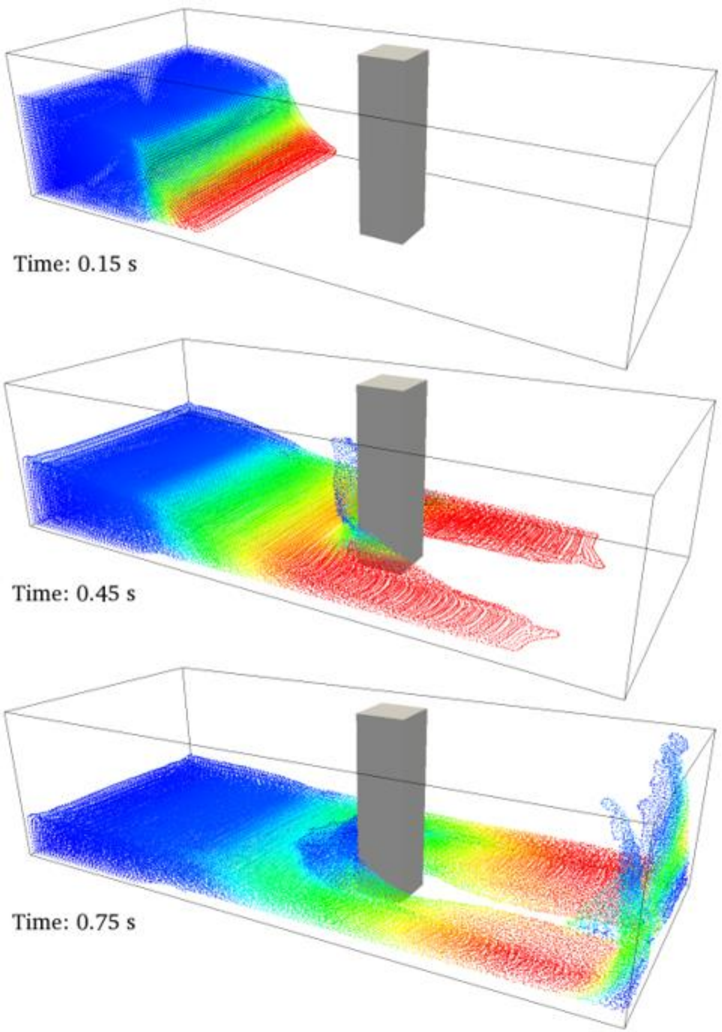


For example, a simulation of this dam break

300,000 particles

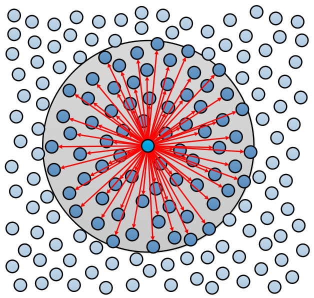
+

1.5 s (*physical time*)

Takes more than **15 hours** (*execution time*)

because:

- Each particle interacts with **more than 250 neighbours**.



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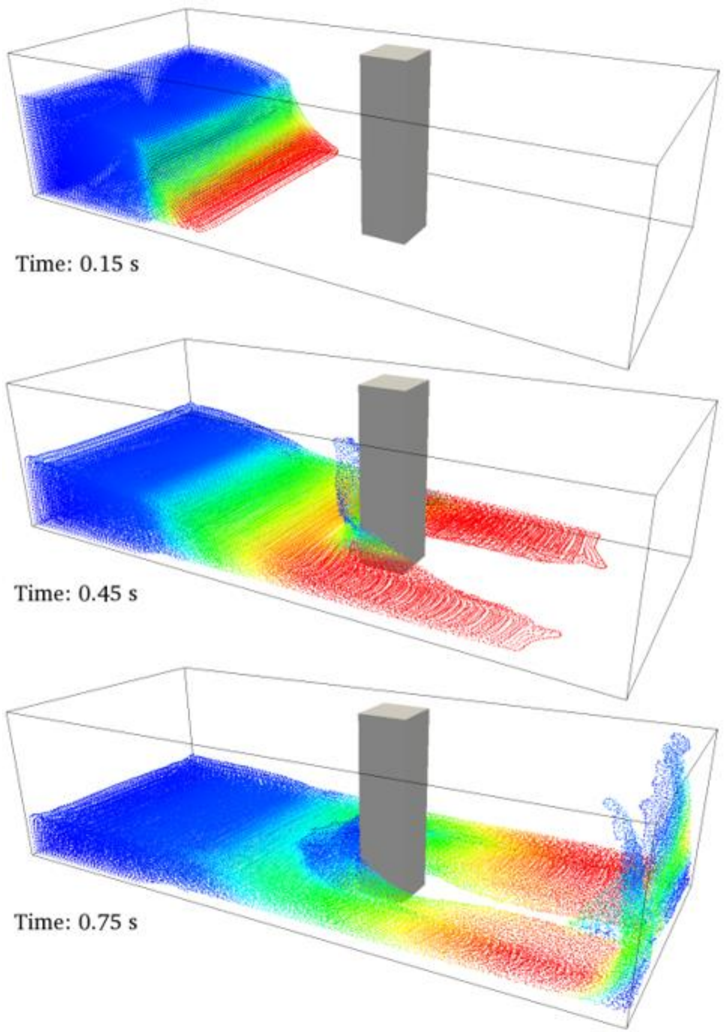

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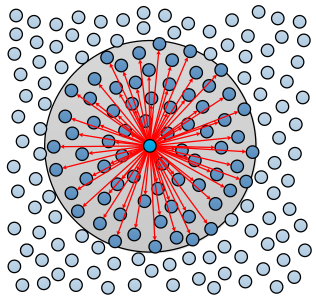
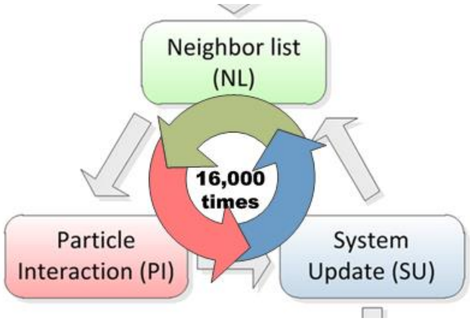


- **Δt=10^{-5}-10^{-4} so more than 16,000 steps** are needed to simulate 1.5 s of physical time.



3.1. CPU acceleration

Previous ideas:

SPH is a Lagrangian model so particles are moving during simulation.

Each time step NL sorts particles (data arrays) to improve the memory access in PI stage since the access pattern is more regular and efficient.

Another advantage is the ease to identify the particles that belongs to a cell by using a range since the first particle of each cell is known.

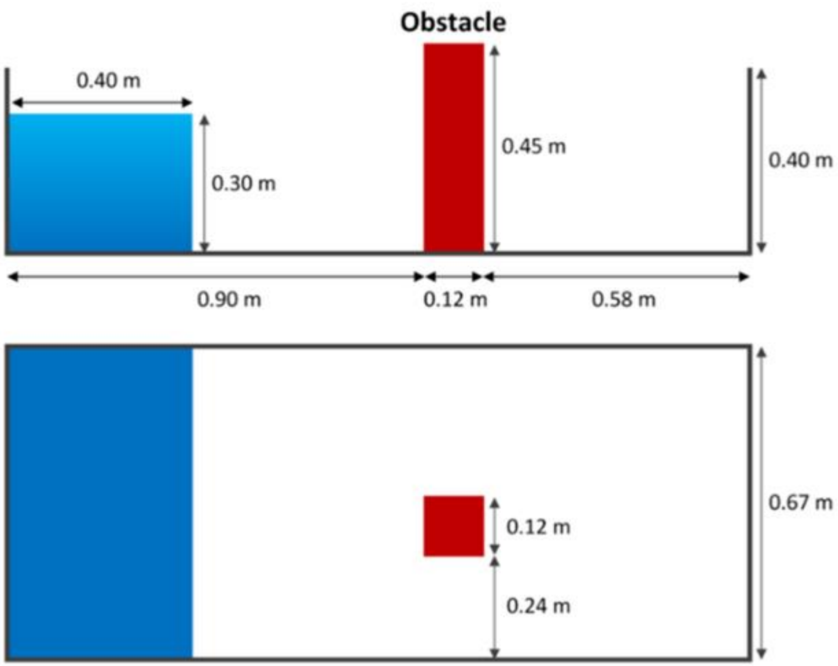
Four optimizations have been applied to DualSPHysics:

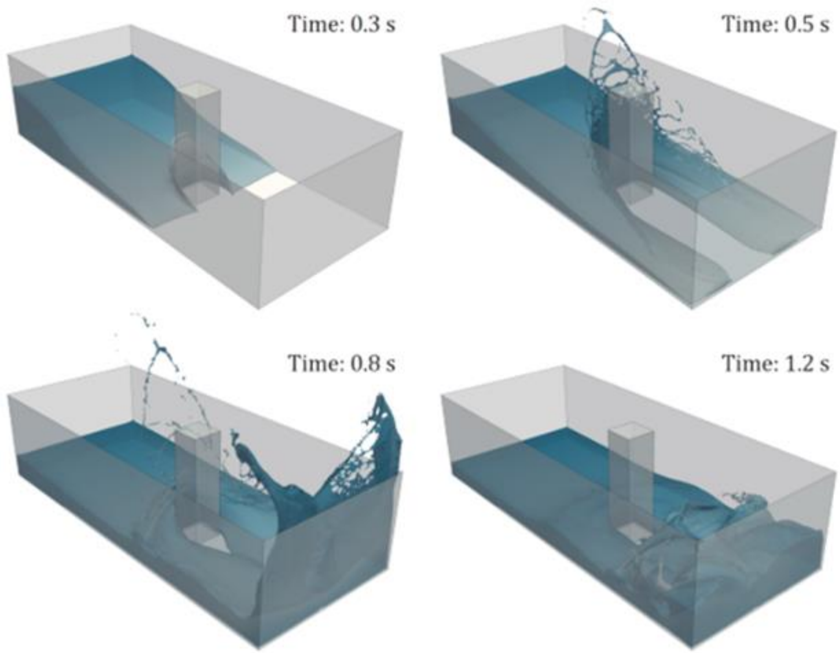
- Applying symmetry to particle-particle interaction.
- Using SSE instructions.
- Splitting the domain into smaller cells.
- Multi-core implementation using OpenMP.

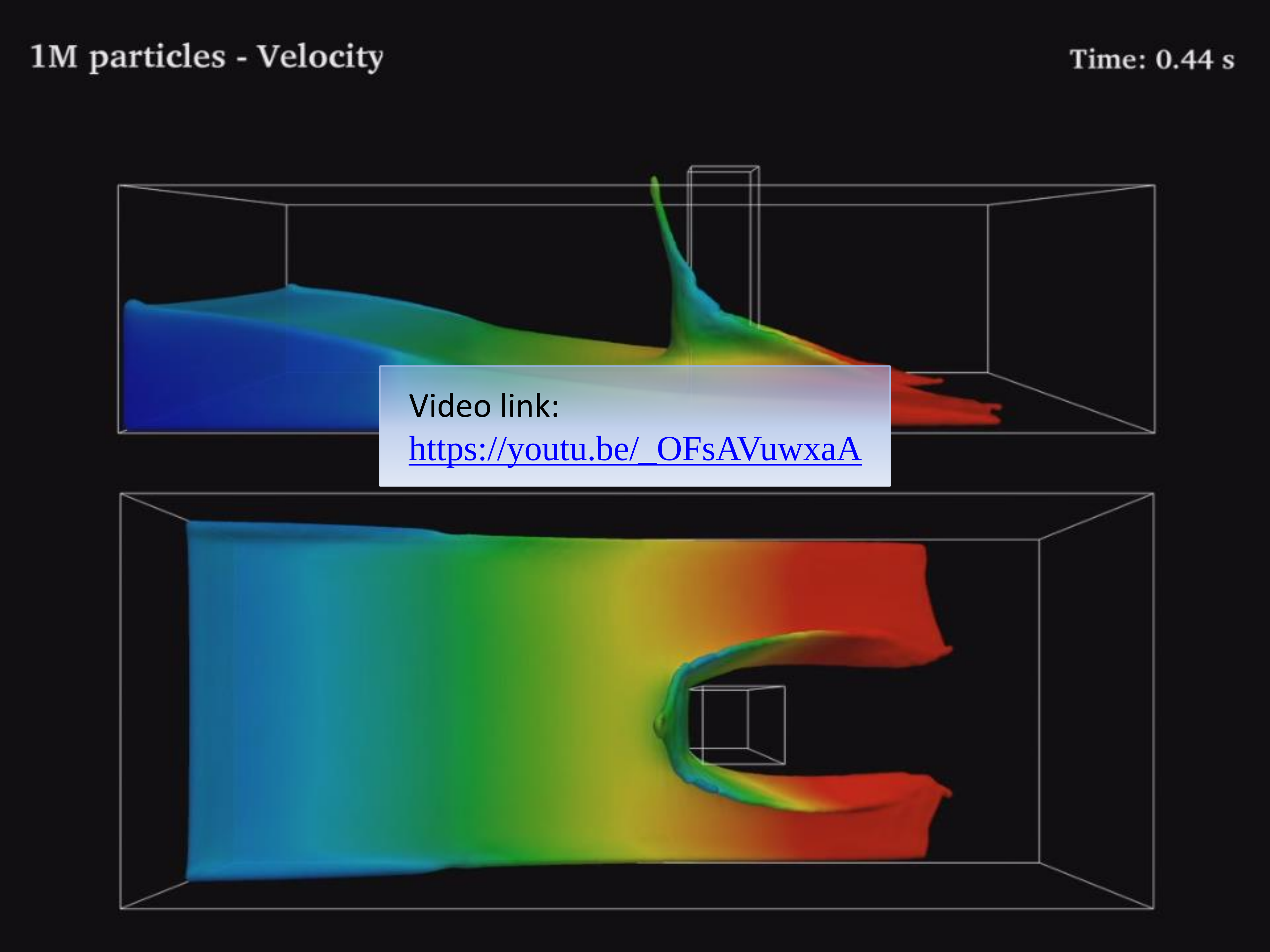
3.1. CPU acceleration

Testcase for results

- **Dam break flow impacting on a structure** (experiment of Yeh and Petroff at the University of Washington).
- Physical time of simulation is **1.5 seconds**.



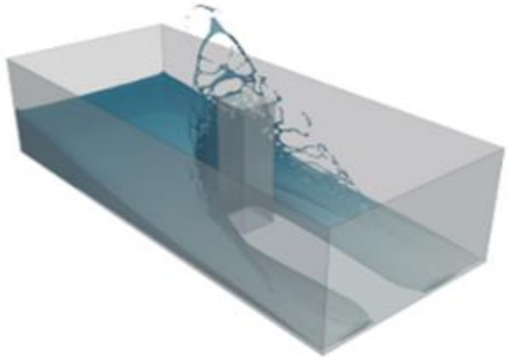




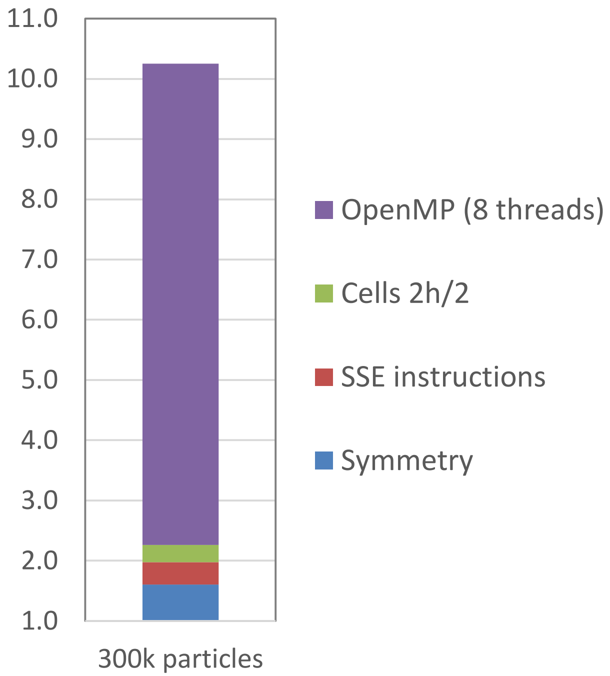
Video link:
https://youtu.be/_OFsAVuwxaA

3.1. CPU acceleration

Speedup for 300k particles applying all optimizations



Speedup 10.25x



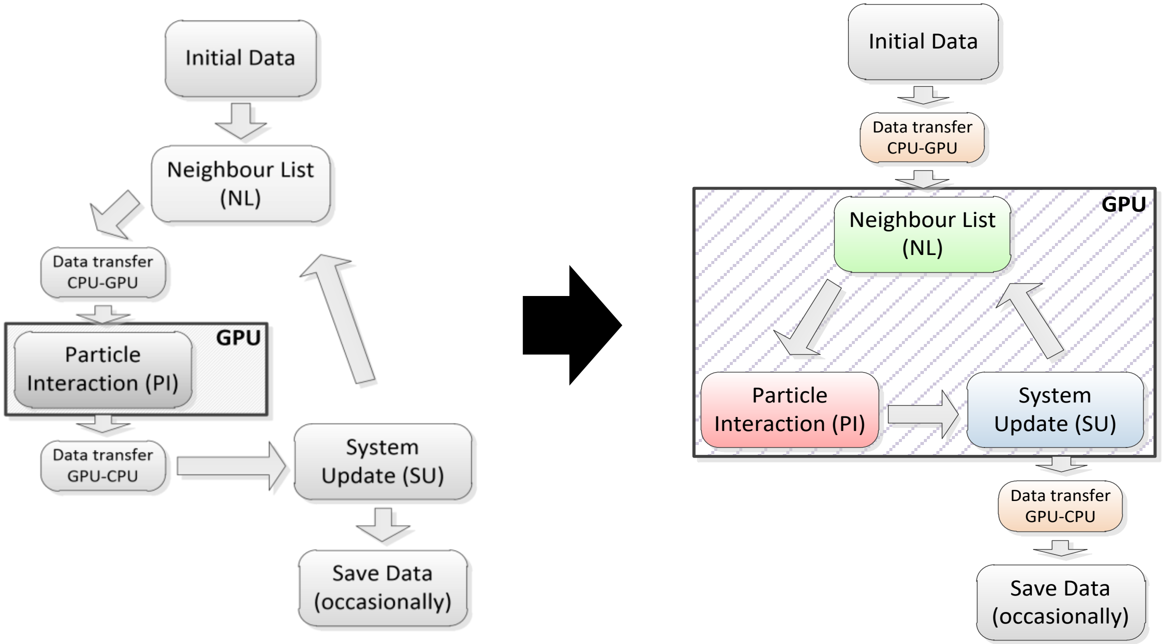
Hardware and configuration for results

- **Hardware:** Intel® Core ™ i7 940 at 2.93 GHz (4 physical cores, 8 logical cores with Hyper-threading), with 6 GB of DDR3 RAM memory at 1333 MHz.
- **Operating system:** Ubuntu 10.10 64-bit.
- **Compiler:** GCC 4.4.5 (compiling with the option –O3).

3.2. GPU acceleration

Full GPU implementation

- DualSPHysics was implemented using the CUDA programming language to run SPH method on Nvidia GPUs.
- **GPU is used in all steps** (Neighbour List, Particle Interaction and System Update).
- This approach is the most efficient since:
    - All particle data is kept in GPU memory and the **transfers CPU-GPU are removed**.
    - **Neighbour List and System Update are parallelized**, obtaining a speedup also in this part of the code.



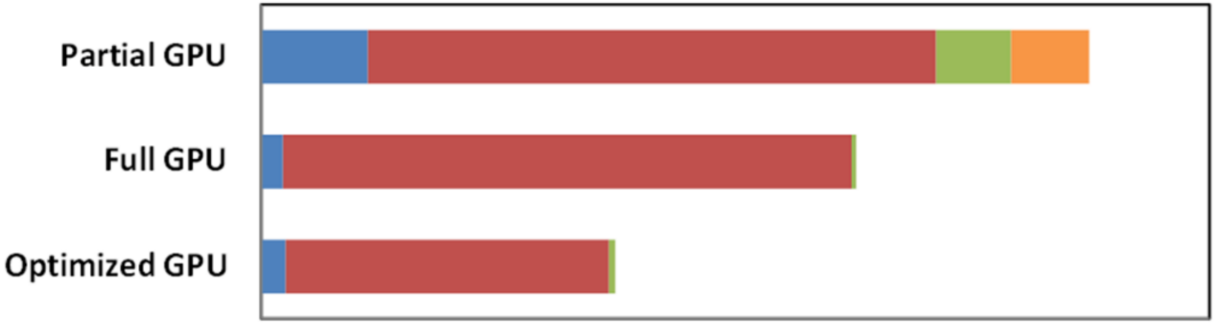
3.2. GPU acceleration

Five optimizations have been applied to DualSPHysics to improve the performance.

- Maximizing the occupancy of GPU.
- Reducing global memory accesses.
- Simplifying the neighbour search.
- Adding a more specific CUDA function of interaction.
- Division of the domain into smaller cells.

3.2. GPU acceleration

Computational runtimes (in seconds) using GTX 480 for different GPU implementations (partial, full and optimized) when simulating 500,000 particles.



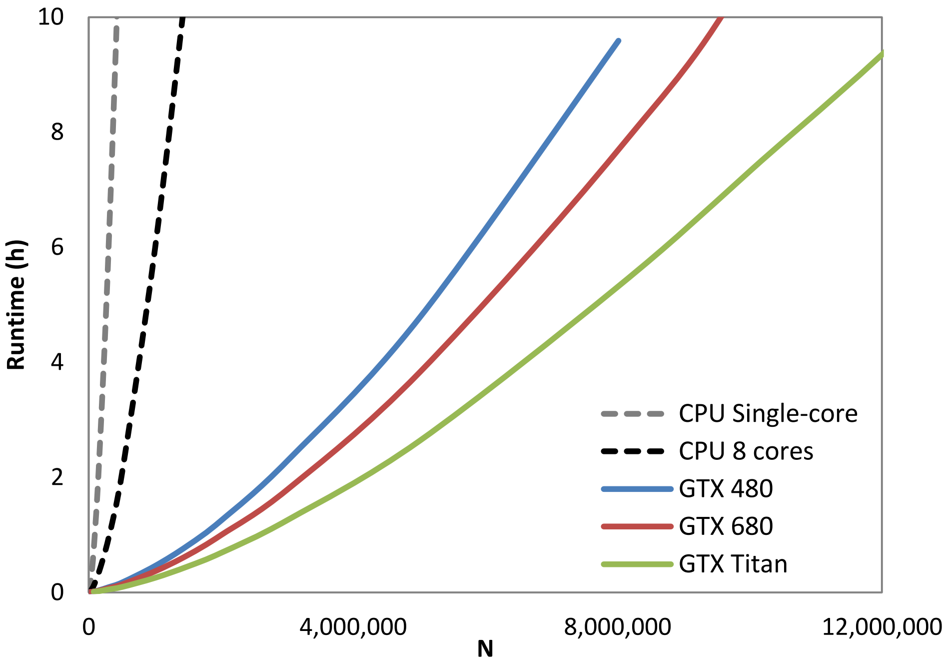
	Optimized GPU	Full GPU	Partial GPU
NL	64.89	58.30	281.62
PI	852.46	1498.50	1496.78
SU	16.78	11.44	198.92
Data transfer			204.97

Full GPU is **1.26x** faster than Partial GPU.

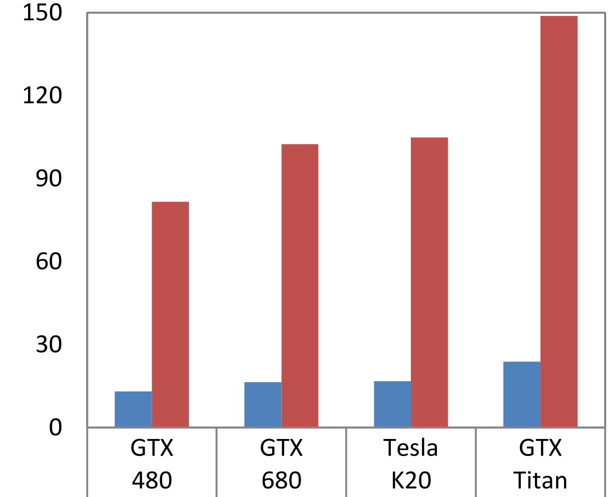
Optimized GPU is **2.12x** faster than Partial GPU.

3.2. GPU acceleration

Runtime for CPU and different GPU cards.



Speedups of GPU against CPU simulating 1 million particles.



	GTX 480	GTX 680	Tesla K20	GTX Titan
vs CPU 8 cores	13	16	17	24
vs CPU Single-core	82	102	105	149

After optimising the performance of DualSPHysics on CPU and GPU...

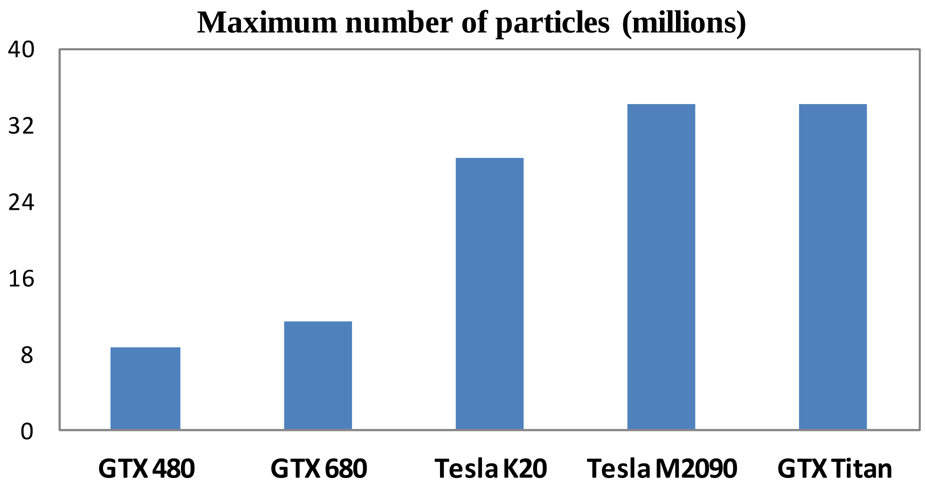
The most powerful GPU (**GTX Titan**) is **149 times faster** than CPU (single core execution) and **24 times faster** than the CPU using all 8 cores.

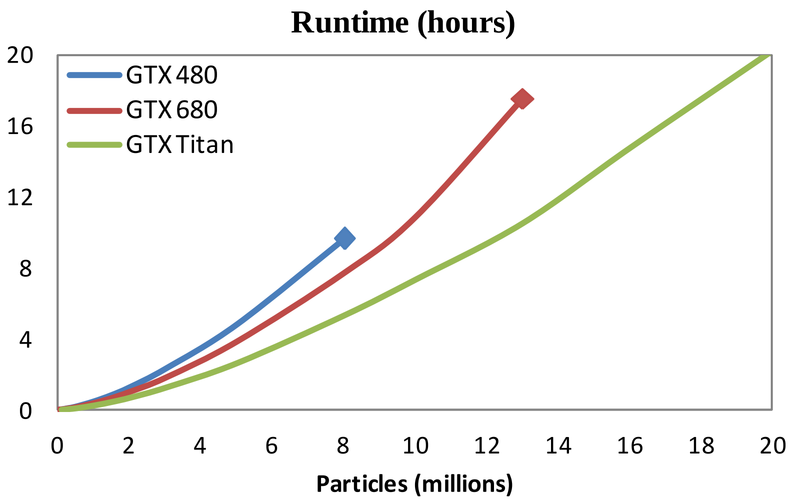
3.2. GPU acceleration

The simulation of **real cases implies huge domains with a high resolution**, which implies simulating tens or hundreds of million particles.

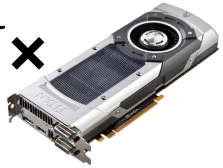
The use of one GPU presents important **limitations**:

- Maximum number of particles depends on the memory size of GPU.
- Time of execution increases rapidly with the number of particles.



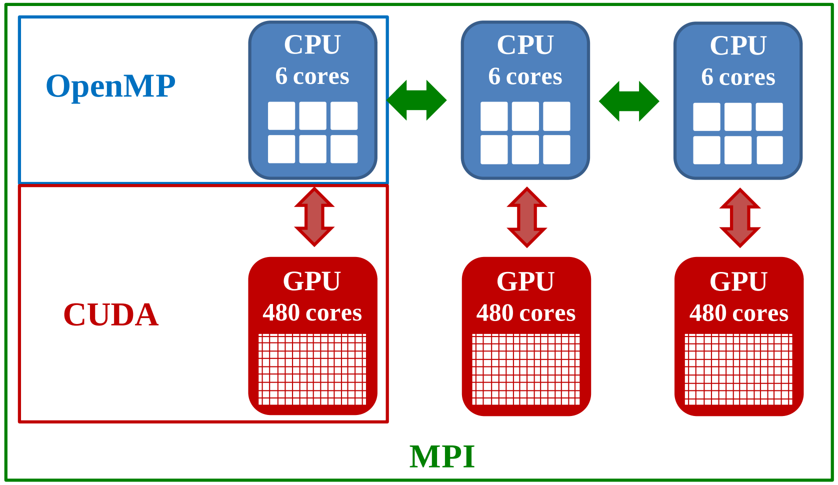


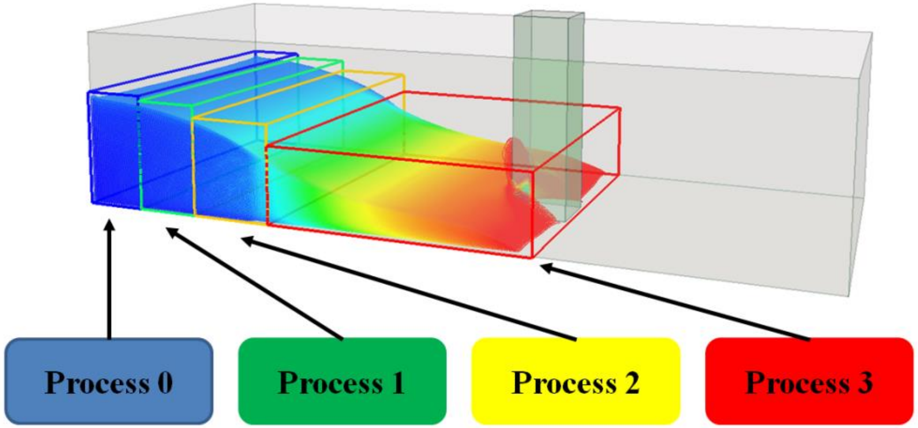
3.3. Multi-GPU acceleration

N×


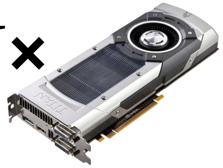
MPI is used to combine resources of multiple machines connected via network.

The **physical domain** of the simulation **is divided among the different MPI processes**. Each process only needs to assign resources to manage a subset of the total amount of particles for each subdomain.





3.3. Multi-GPU acceleration

N× 

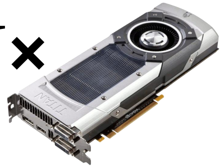
The use of MPI implies an **overcost**:

- **Communication**: Time dedicated to the interchange of data between processes.
- **Synchronization**: All processes must wait for the slowest one.

Solutions:

- **Overlapping** between force computation and communications: while data is transferred between processes, each process can compute the force interactions among its own particles. In the case of GPU, the CPU-GPU transfers can also be overlapped with computation using *streams* and *pinned memory*.
- **Load balancing**. A dynamic load balancing is applied to minimise the difference between the execution times of each process.

3.3. Multi-GPU acceleration

N× 

Dynamic load balancing

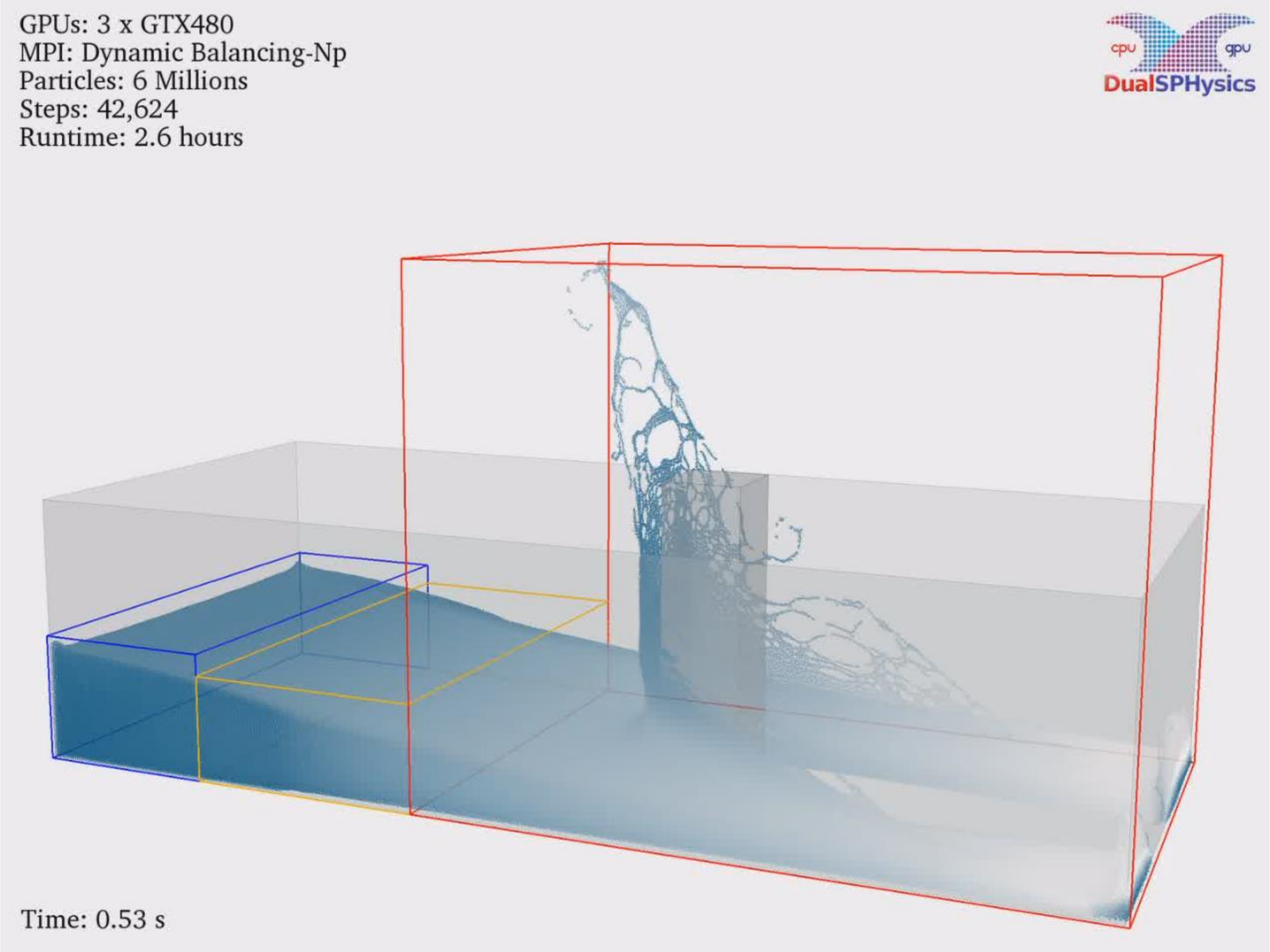
Due to the nature Lagrangian of the SPH method, is necessary to balance the load throughout the simulation.

FIRST approach according to the **number of fluid particles**

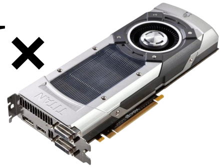
> The number of particles must be redistributed after some time steps to get the workload balanced among the processes and minimise the synchronisation time.

SECOND approach according to the **required computation time** of each device

> Enables the adaptation of the code to the features of a heterogeneous cluster achieving a better performance.

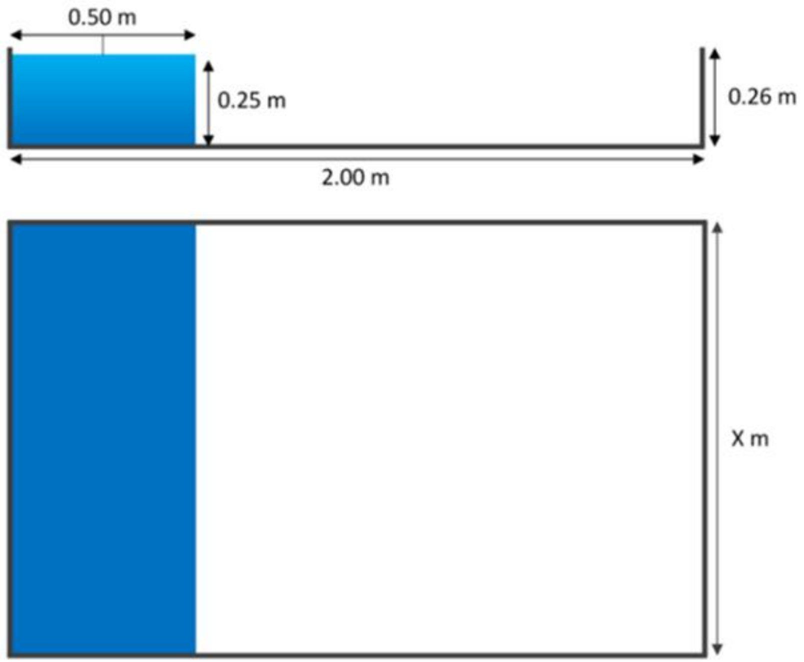

GPUs: 3 x GTX480
MPI: Dynamic Balancing-Np
Particles: 6 Millions
Steps: 42,624
Runtime: 2.6 hours
DualSPHysics
cpu
gpu
Time: 0.53 s

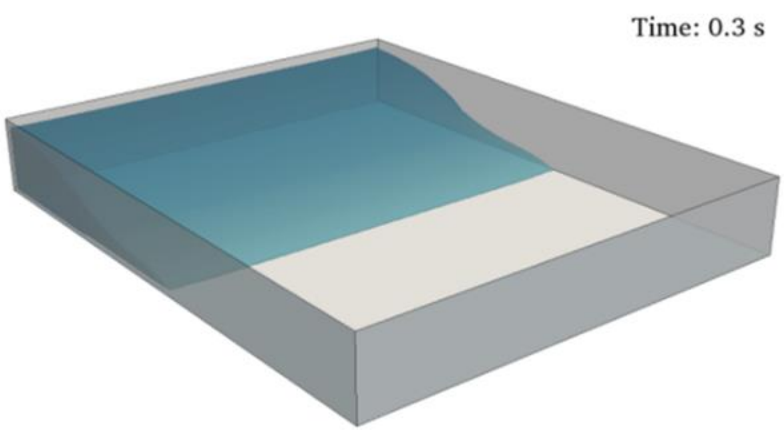
3.3. Multi-GPU acceleration

N×


Testcase for results

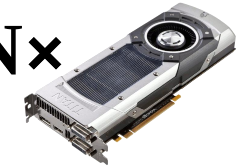
- **Dam break flow**.
- Physical time of simulation is **0.6 seconds**.
- The number of used particles varies from 1M to 1,024M particles.





3.3. Multi-GPU acceleration

N×



Results of efficiency

The simulations were carried out in the **Barcelona Supercomputing Center** BSC-CNS (Spain). This system is built with **256 GPUs Tesla M2090**.

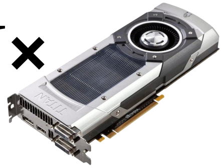
All the results presented here were obtained single precision and Error-correcting code memory (ECC) disabled.

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Activity at BARCELONA SUPERCOMPUTING CENTER:
"Massively parallel Smoothed Particle Hydrodynamics scheme using GPU clusters"

3.3. Multi-GPU acceleration

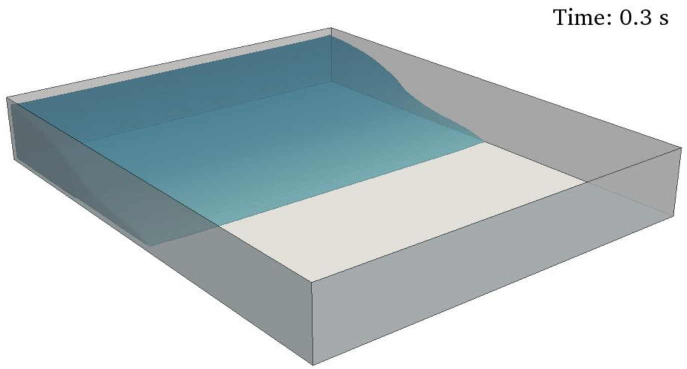
N×

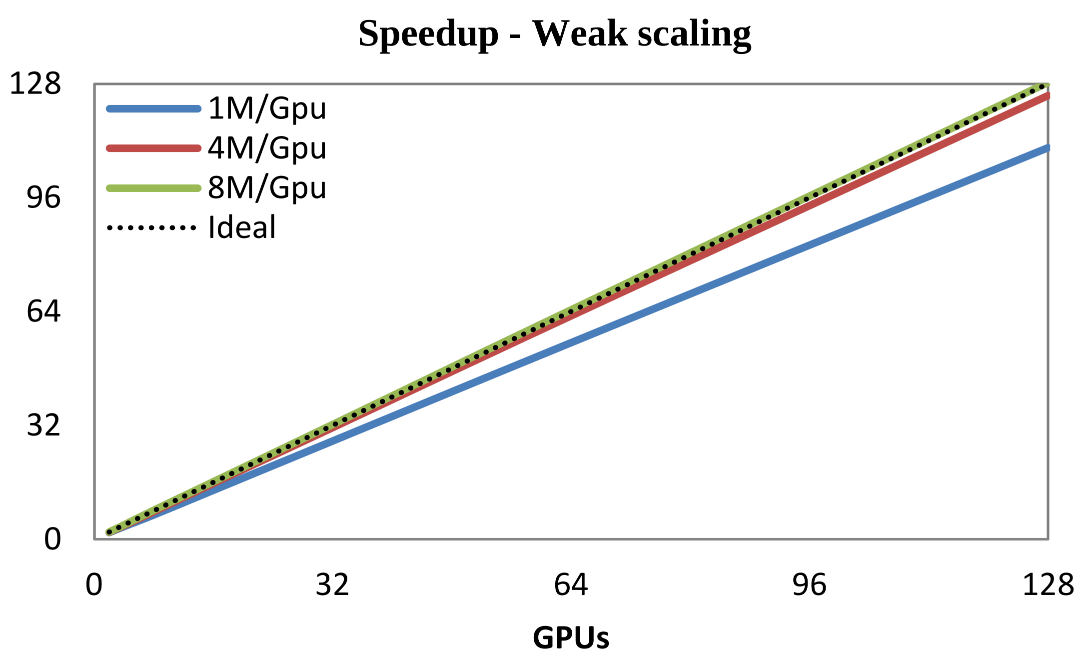


Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Efficiency close to 100% simulating 4M/GPU with 128 GPUs Tesla M2090 of BSC.

This is possible because the time dedicated to tasks exclusive of the multi-GPU executions (communication between processes, CPU-GPU transfers and load balancing) is minimum.

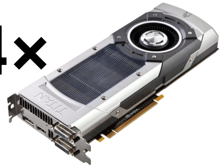




$$S(N) = \frac{T(N_{ref}) \cdot N}{T(N) \cdot N_{ref}}$$

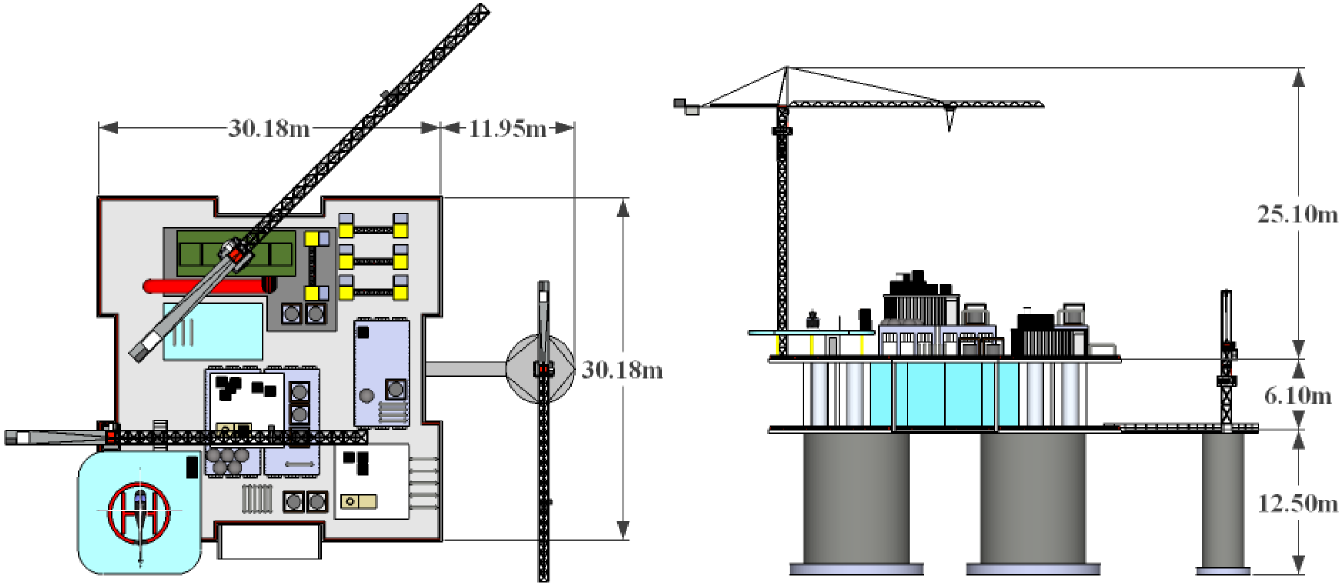
$$E(N) = \frac{S(N)}{N}$$

3.3. Multi-GPU acceleration

64× 

Simulation of 1 billion SPH particles

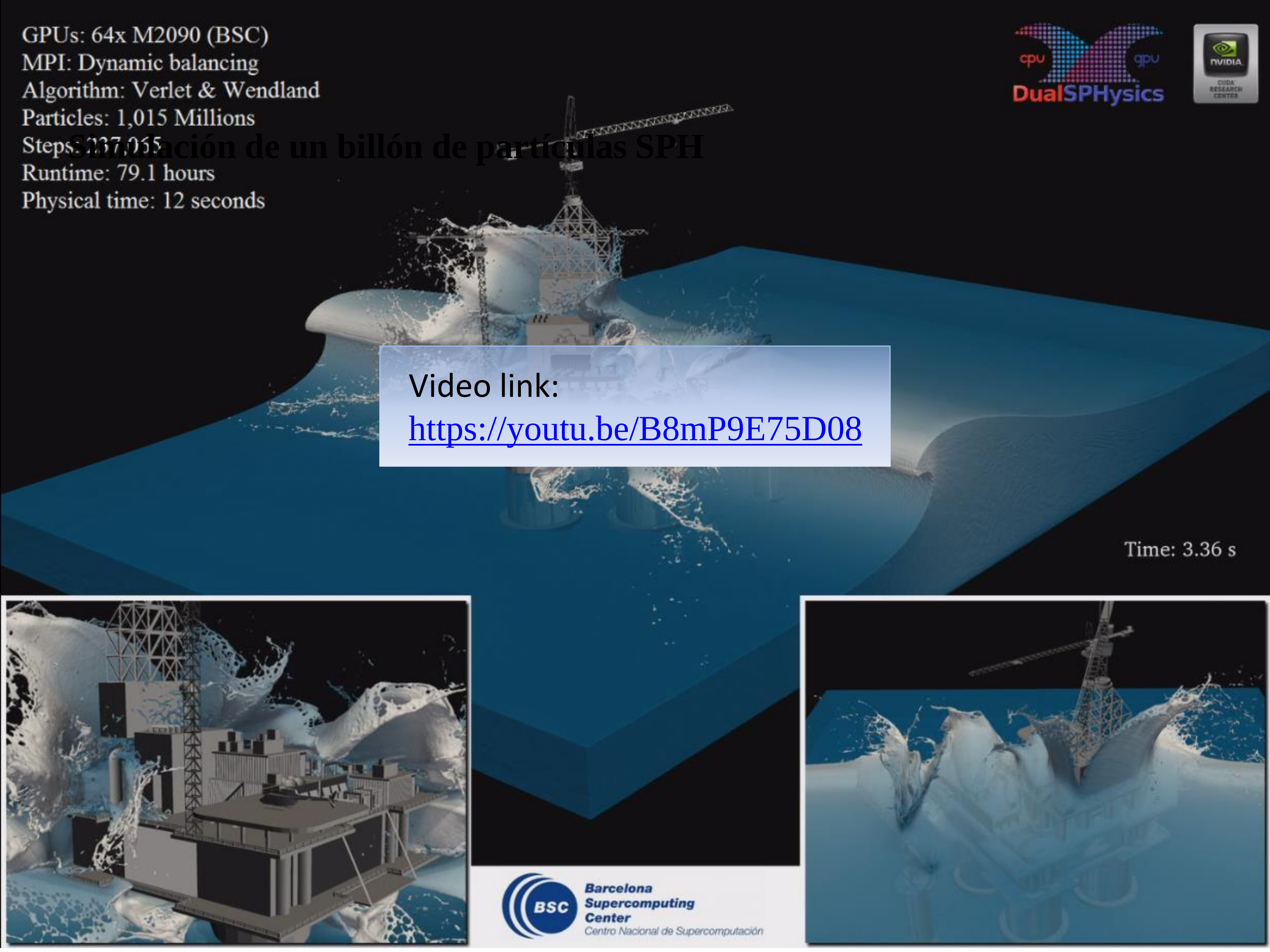
Large wave interaction with oil rig using 10^9 particles



dp= 6 cm, h= 9 cm
np = 1,015,896,172 particles
nf = 1,004,375,142 fluid particles
physical time= 12 sec
# of steps = 237,065 steps
runtime = 79.1 hours

using 64 GPUs Tesla M2090 of the BSC-CNS

Simulación de un billón de partículas SPH



Video link:
https://youtu.be/B8mP9E75D08

3.3. Multi-GPU acceleration

32×

Simulation of a real case

Using 3D geometry of the beach Itzurun in Zumaia-Guipúzcoa (Spain) in Google Earth

32 x M2090 (BSC)

Particles: **265 Millions**

Physical time: **60 seconds**

Steps: 218,211

Runtime: **246.3 hours**

Video links:
https://youtu.be/nDKlrRA_hEA
https://youtu.be/kWS6-0Z_jIo

Outline

1. Introduction
   1.1. Numerical modelling
   1.2. Smooth Particle Hydrodynamics
   1.3. DualSPHysics project

2. SPH formulation

3. DualSPHysics implementation
   3.1. CPU acceleration
   3.2. GPU acceleration
   3.3. Multi-GPU acceleration

4. Developments and applications

4. Developments

UniversidadeVigo

Wave-structure interaction
Coastal protection
Buoyancy of floating objects
Interaction with rigid objects
Simulation of debris flows
Coupling with other models
Design of wave energy devices
High Performance Computing
Advanced visualisation

MANCHESTER 1824
The University of Manchester

Multiphase air-water
Multiphase soil-water
Fuel-tank sloshing
ISPH development

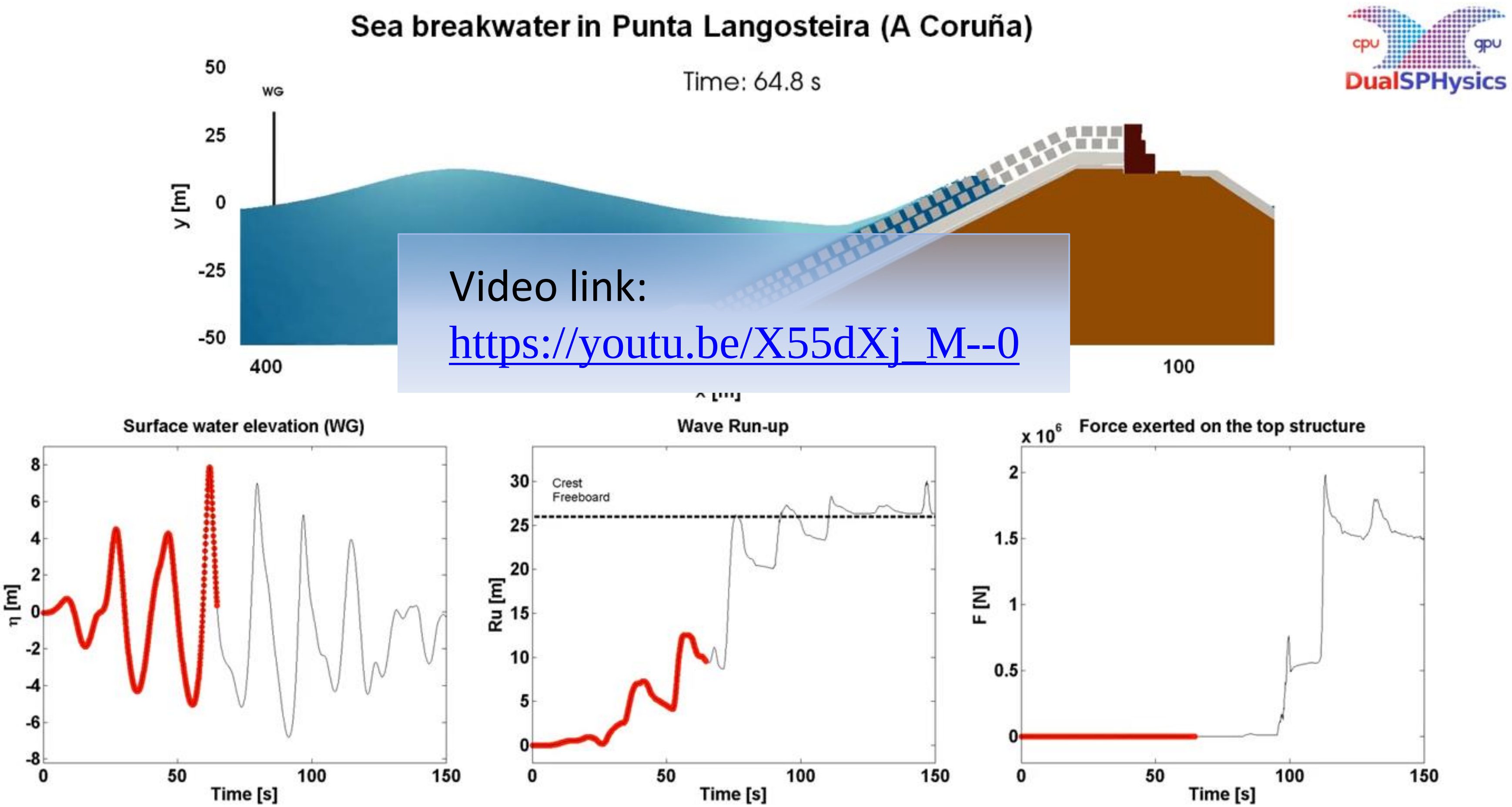
UniversidadeVigo + MANCHESTER 1824 The University of Manchester

New boundary conditions in SPH
Dynamic refinement – variable resolution in SPH
Development of DualSPHysics & RELEASES

4. Applications: Costal protection

The problems we are interested on:

4. Applications: Costal protection



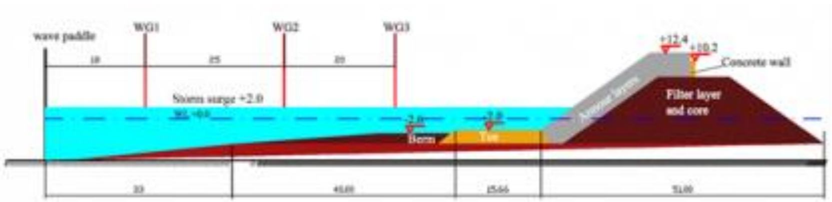
Video link:
https://youtu.be/X55dXj_M--0

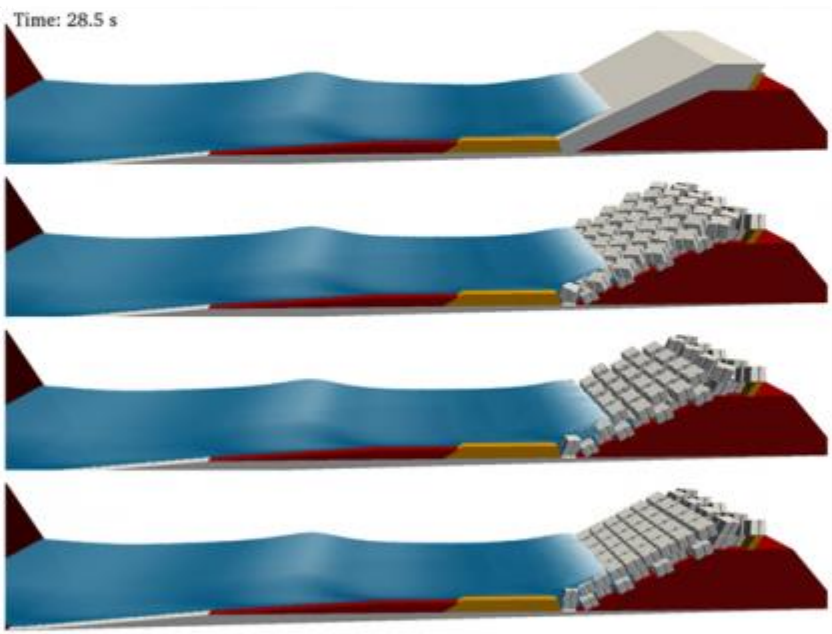
Numerical simulation of wave train impacting on a real armour block breakwater using DualSPHysics software

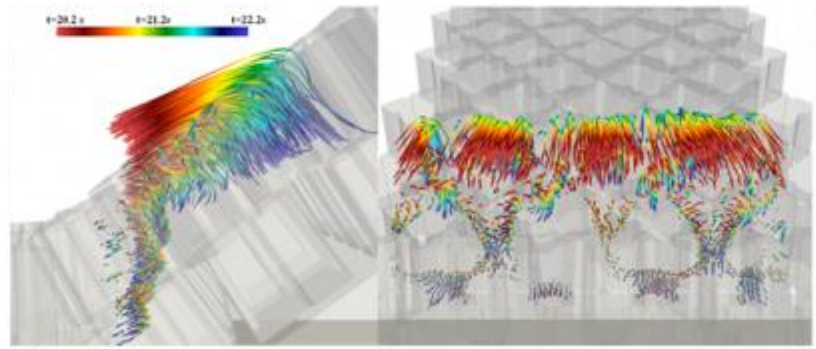
4. Applications: Costal protection

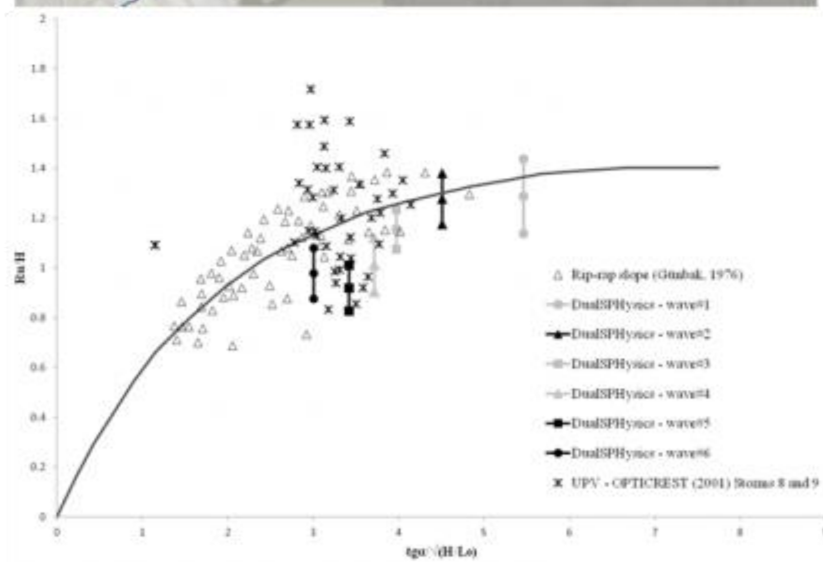
Altomare C, Crespo AJC, Rogers BD, Domínguez JM, Gironella X, Gómez-Gesteira M. Numerical modelling of armour block sea breakwater with Smoothed Particle Hydrodynamics. Computers and Structures, 130: 34-45, **2014**.

Study of the run-up in an existing armour block sea breakwater









4. Applications: Costal protection

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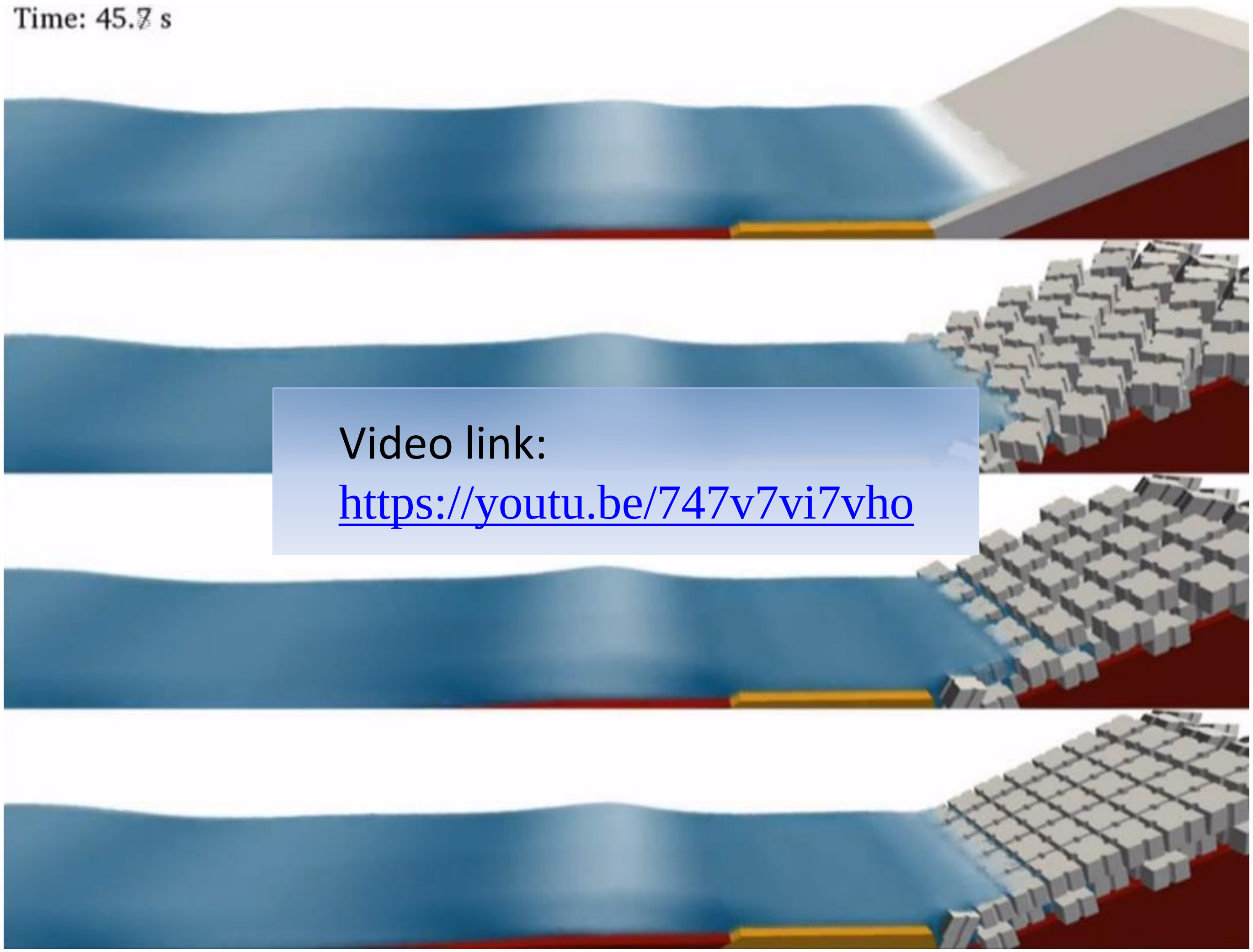
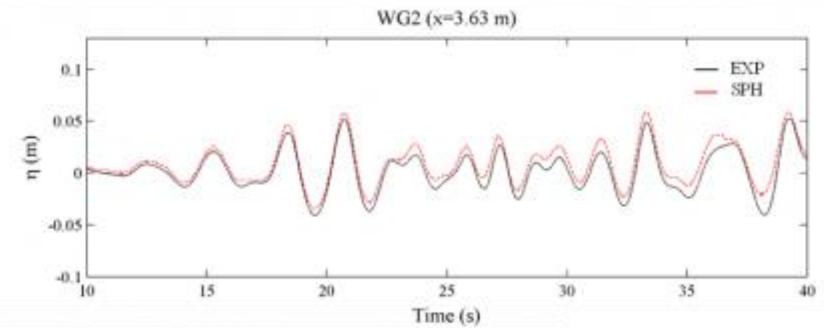


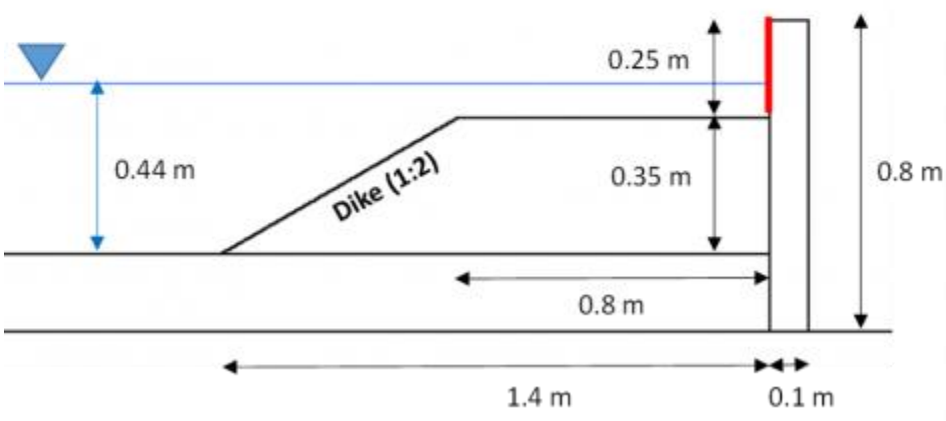
Video link:
https://youtu.be/747v7vi7vho

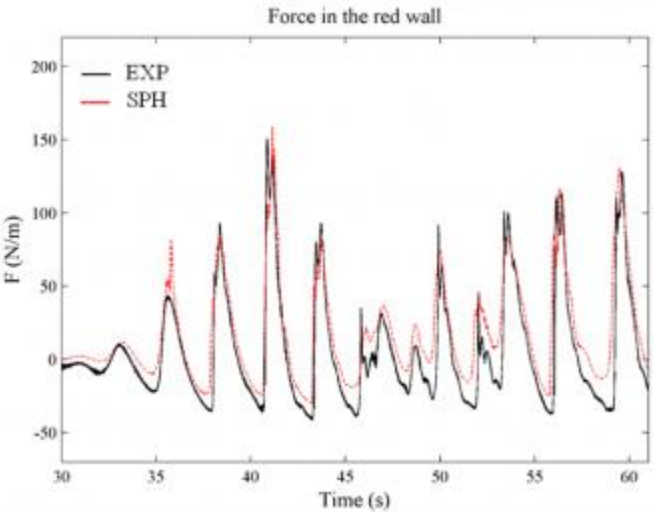
4. Applications: Costal protection

Altomare C, Crespo AJC, Domínguez JM, Gómez-Gesteira M, Suzuki T, Verwaest T. Applicability of Smoothed Particle Hydrodynamics for estimation of sea wave impact on coastal structures. Coastal Engineering, 96: 1-12, **2015**.

Estimation of sea wave impact on coastal structures



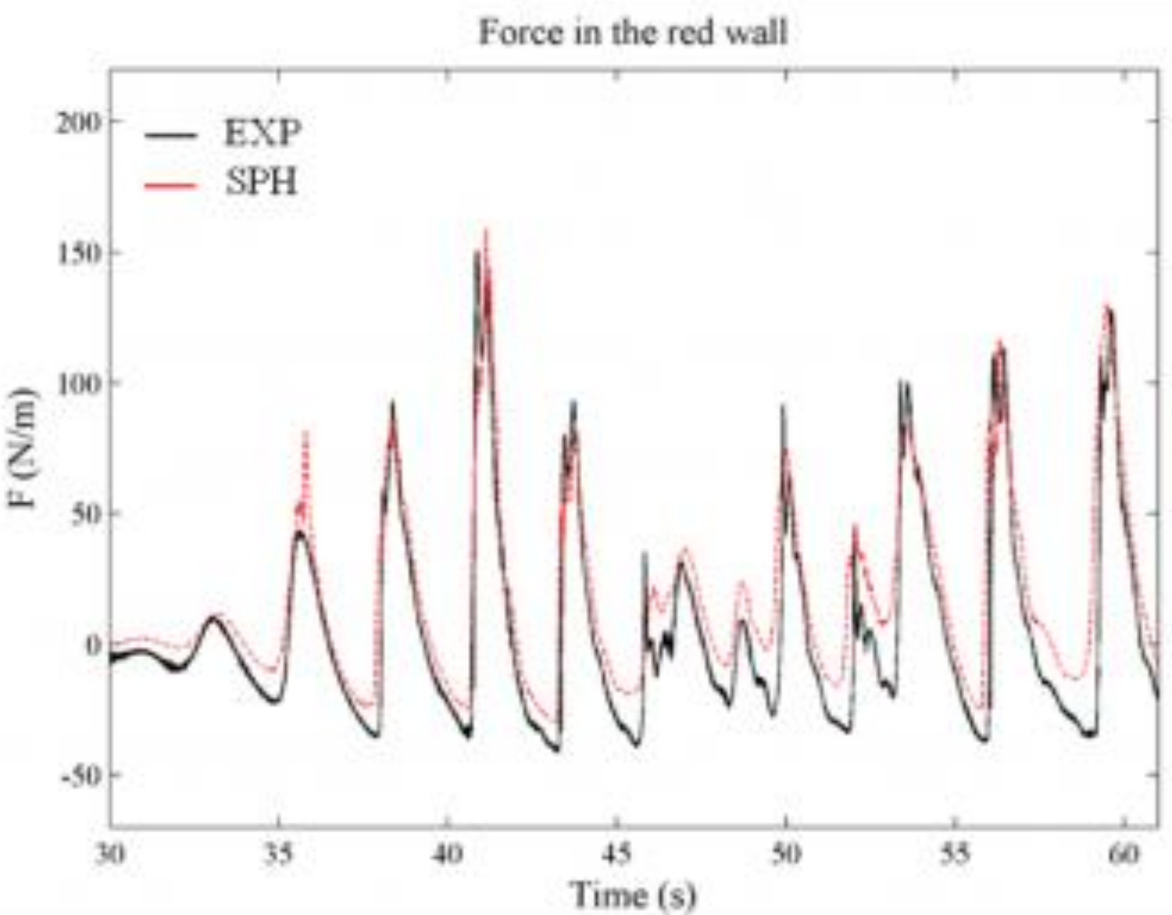




4. Applications: Costal protection

Altomare C, Crespo AJC, Domínguez JM, Gómez-Gesteira M, Suzuki T, Verwaest T. Applicability of Smoothed Particle Hydrodynamics for estimation of sea wave impact on coastal structures. Coastal Engineering, 96: 1-12, **2015**.

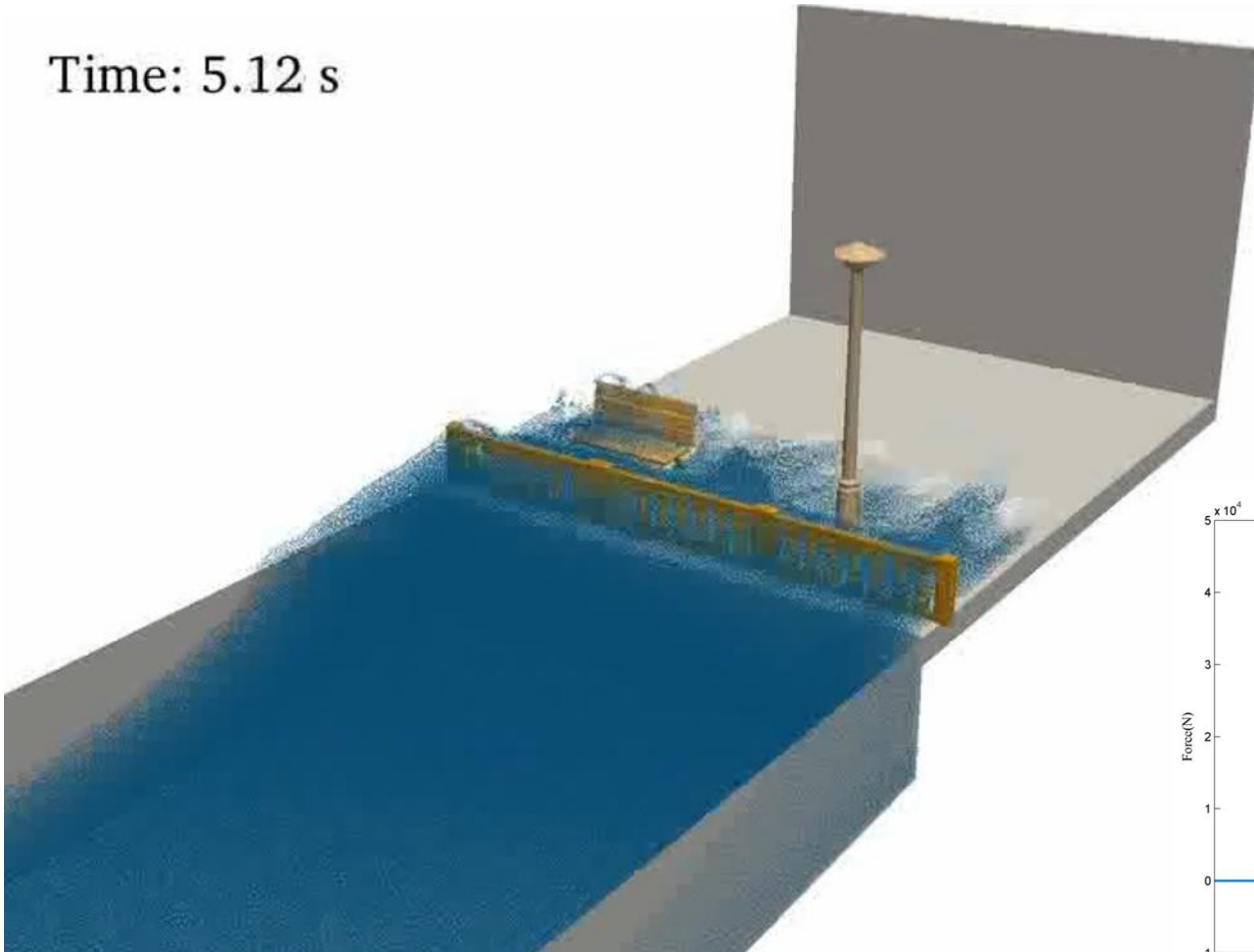
Estimation of sea wave impact on coastal structures

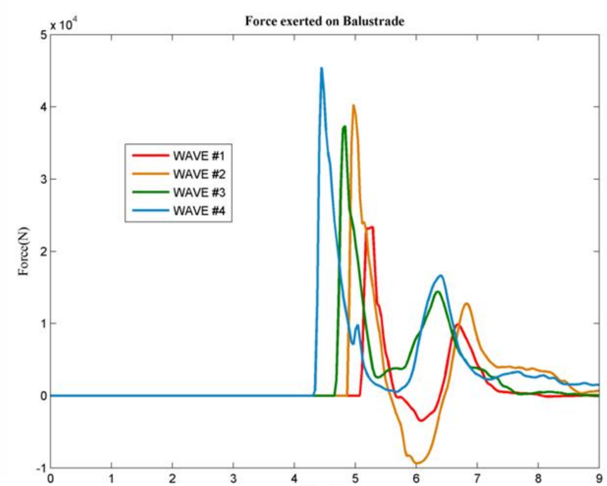


4. Applications: Costal protection

Barreiro A, Crespo AJC, Domínguez JM and Gómez-Gesteira M. Smoothed Particle Hydrodynamics for coastal engineering problems. Computers and Structures, 120(15): 96-106, 2013.

Forces exerted on urban furniture of a realistic promenade

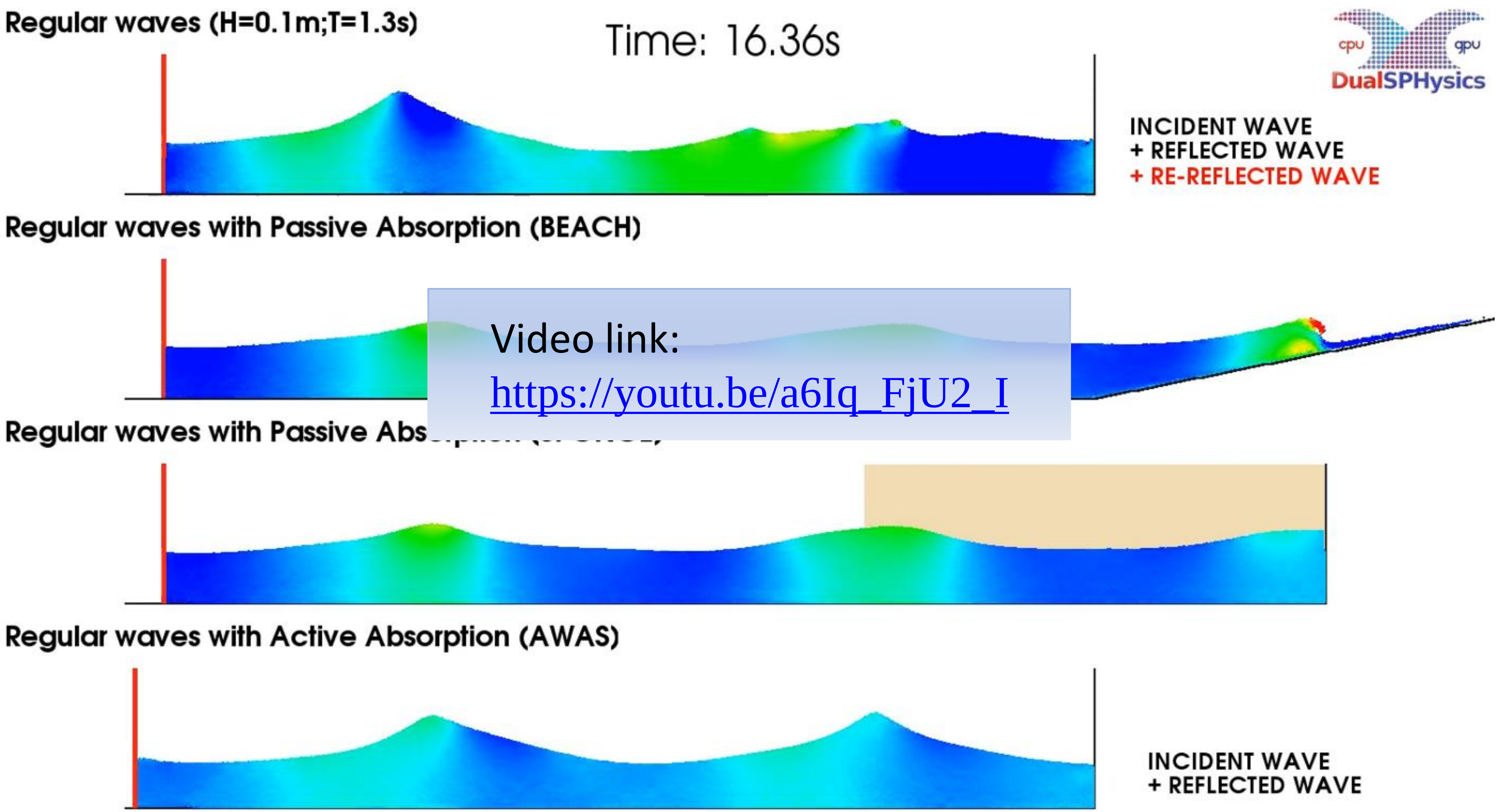




4. Applications: Costal protection

Altomare C, Domínguez JM, Crespo AJC, Gonzalez-Cao J, Suzuki T, Gómez-Gesteira M., Troch P. Long-crested wave generation and wave absorption for SPH-based DualSPHysics model. **UNDER REVIEW**

Wave generation and wave absorption (passive and active)
AWAS system in SPH models



Video link:
https://youtu.be/a6Iq_FjU2_I

4. Applications: Costal protection

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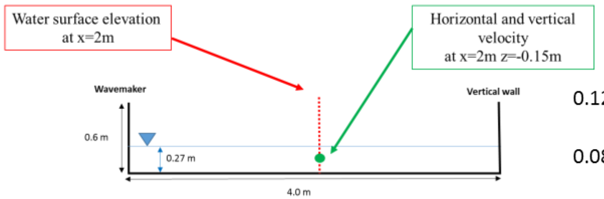
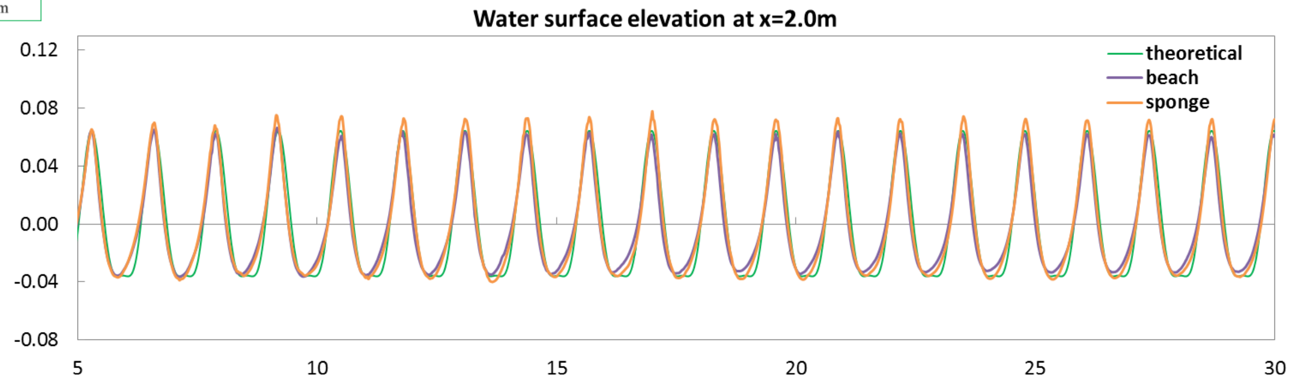
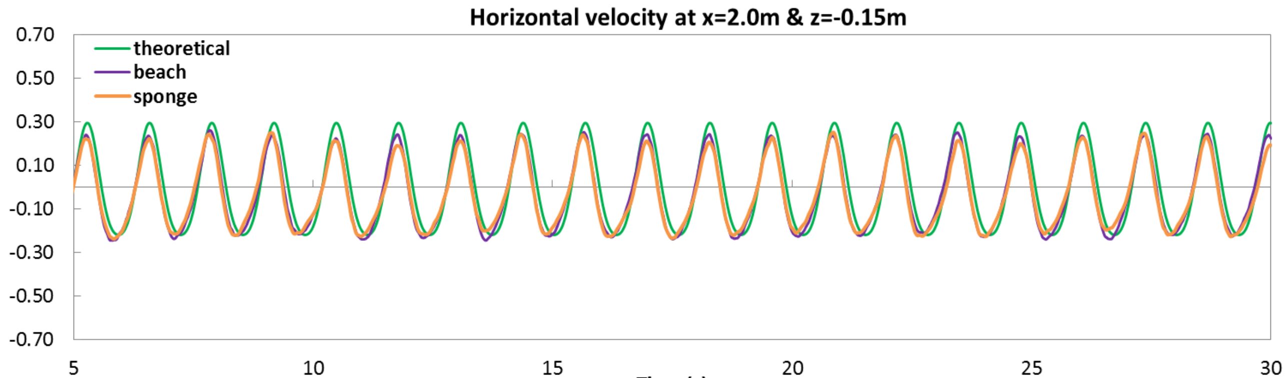
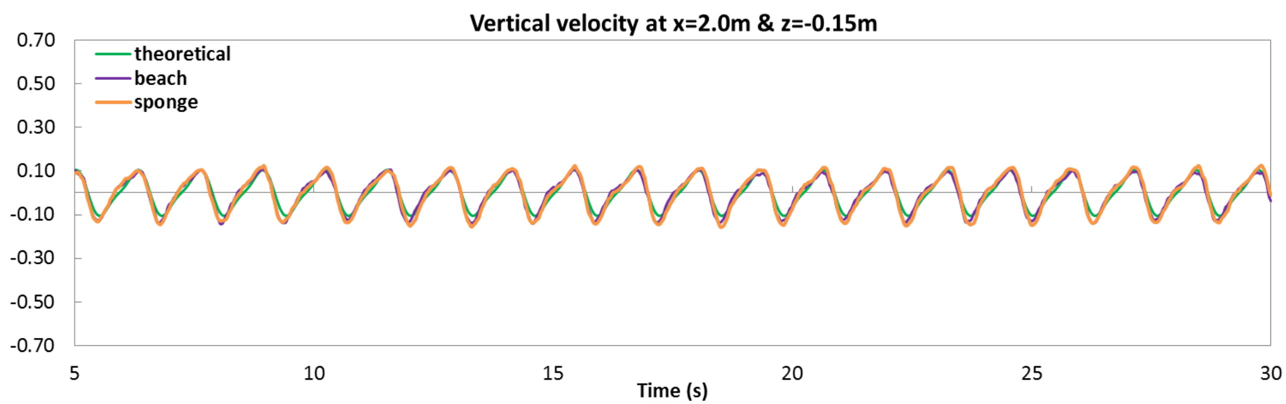






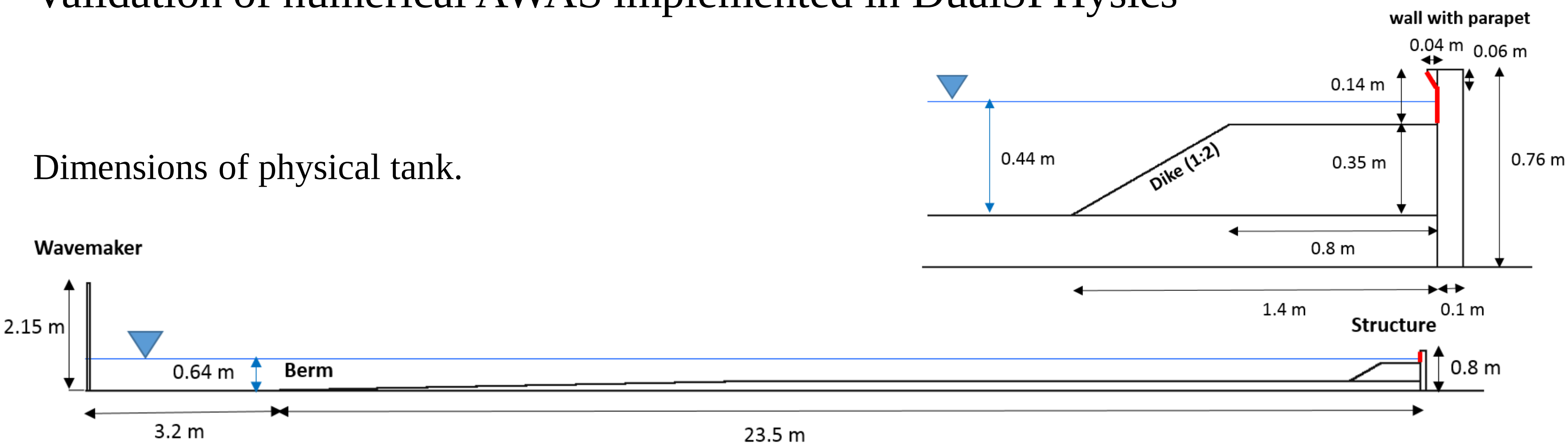


4. Applications: Costal protection

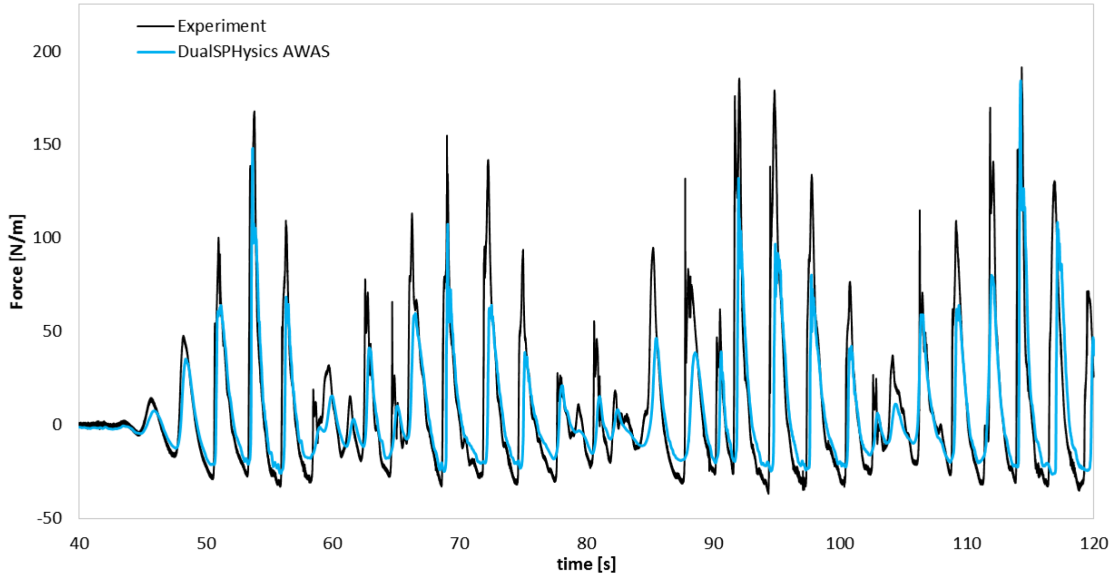
Altomare C, Domínguez JM, Crespo AJC, Gonzalez-Cao J, Suzuki T, Gómez-Gesteira M., Troch P. Long-crested wave generation and wave absorption for SPH-based DualSPHysics model. **UNDER REVIEW**

Validation of numerical AWAS implemented in DualSPHysics

Dimensions of physical tank.



Wave forces exerted against red wall (experimental and numerical values).

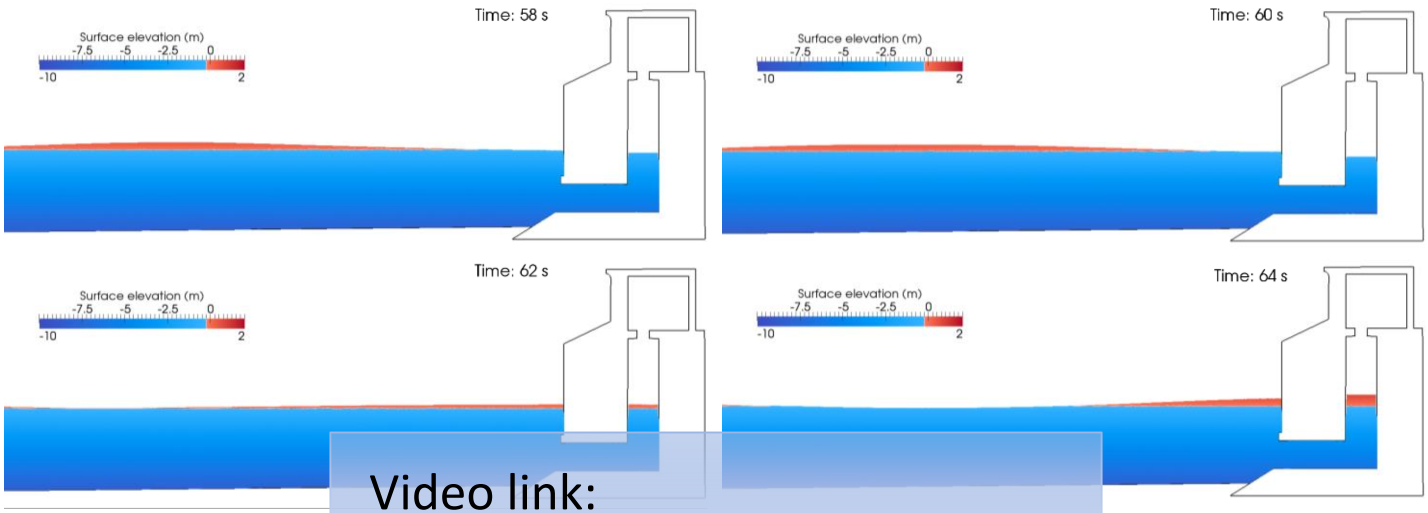


4. Applications: Design of WECs

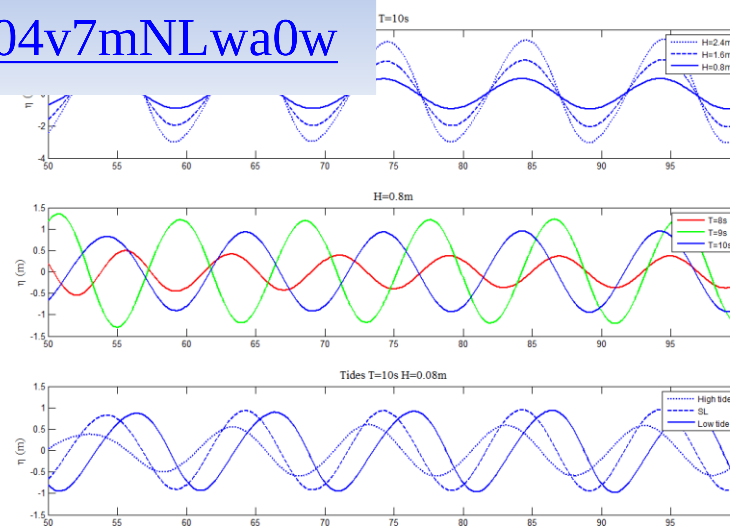
Crespo AJC, Altomare C, Domínguez JM, Barreiro A, González-Cao, Gómez-Gesteira M. Towards simulating floating offshore Oscillating Water Column converters with Smoothed Particle Hydrodynamics.

UNDER REVIEW

OWC plant in Mutriku



Video link: https://youtu.be/04v7mNLwa0w



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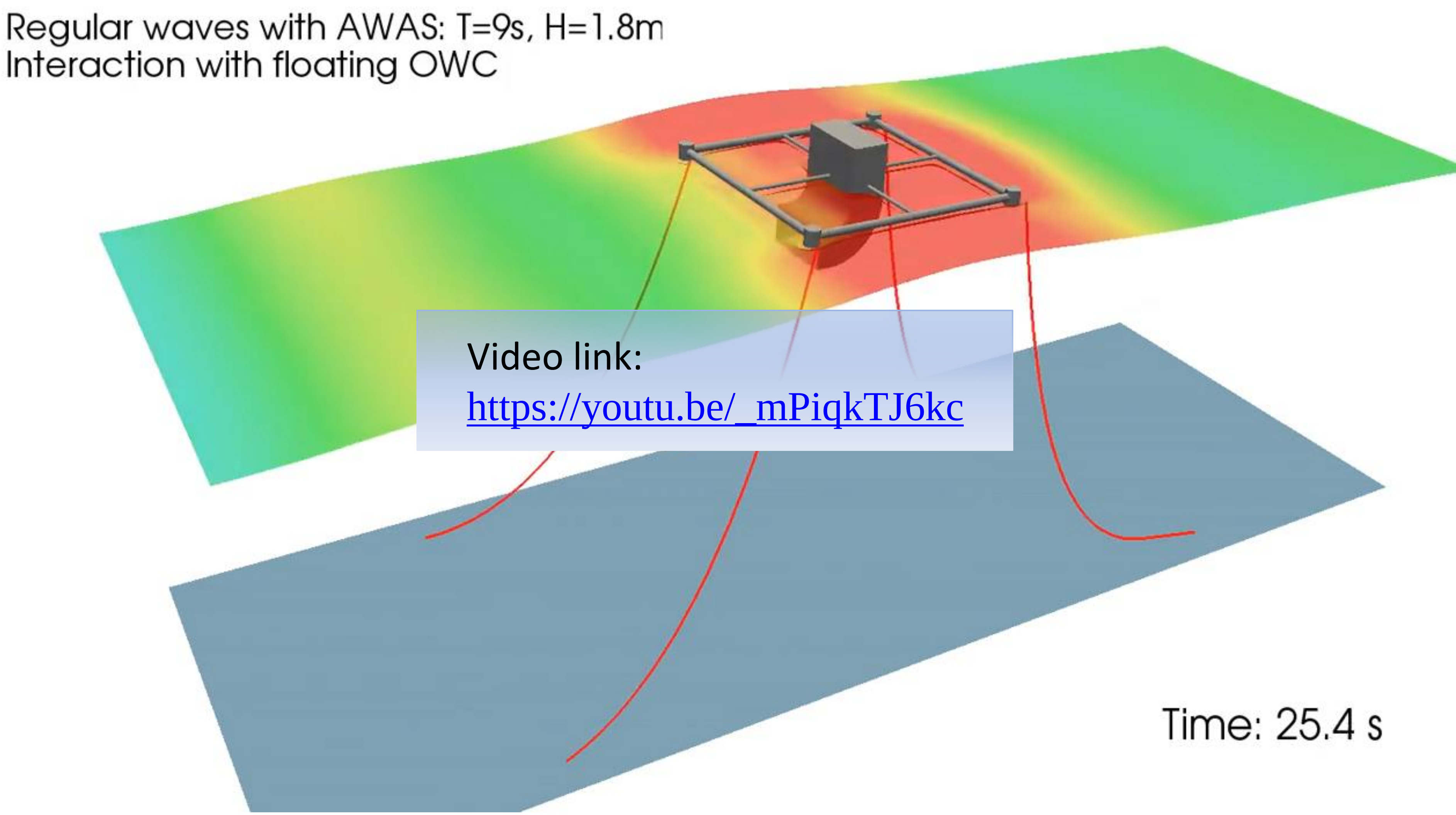
UNDER REVIEW

Floating OWC offshore

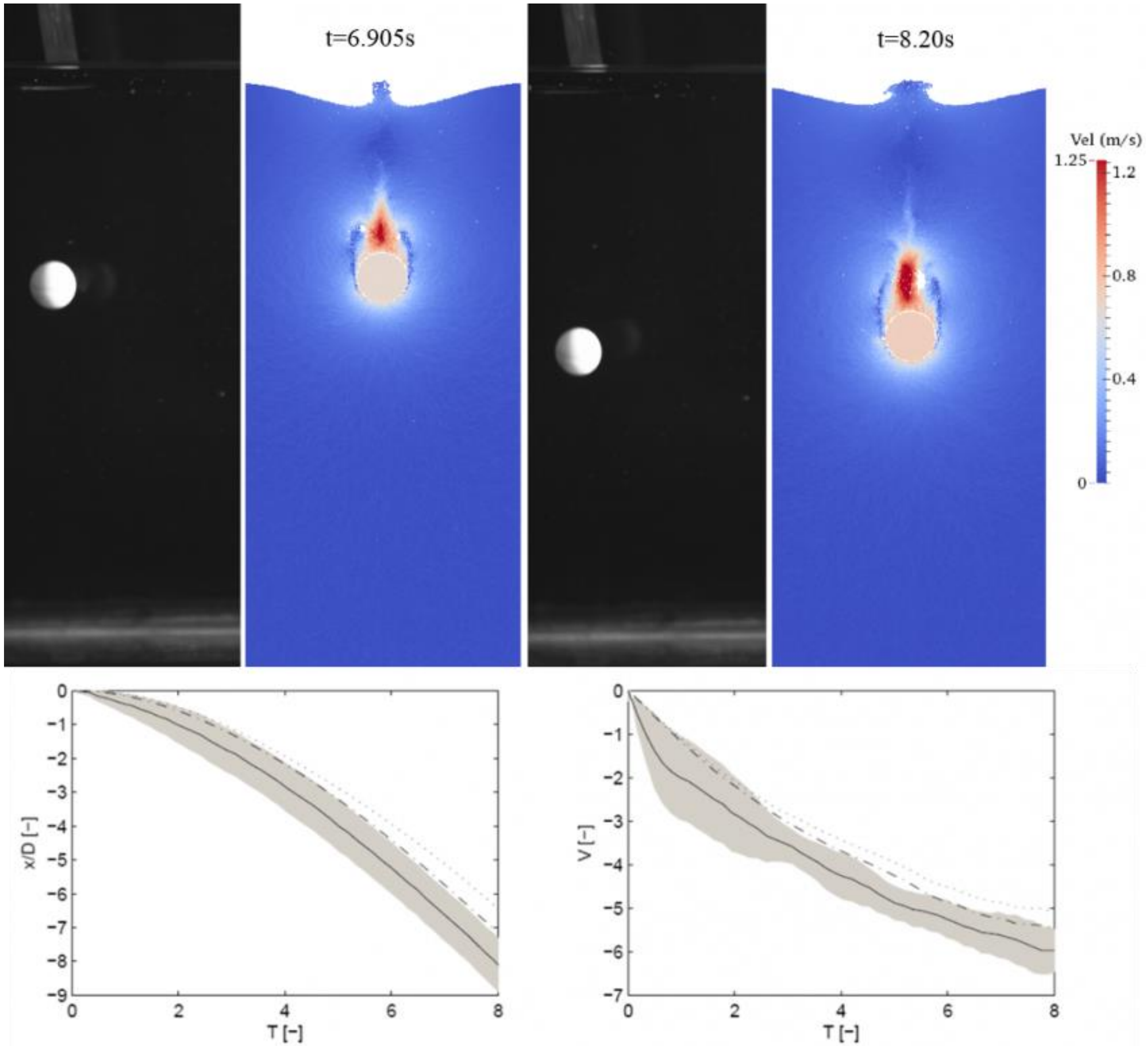


Video link:
https://youtu.be/_mPiqkTJ6kc

4. Applications: Floating objects

Canelas RB, Domínguez JM, Crespo AJC, Gómez-Gesteira M, Ferreira RML. A Smooth Particle Hydrodynamics discretization for the modelling of free surface flows and rigid body dynamics. International Journal for Numerical Methods in Fluids, 78: 581-593, 2015.

Buoyancy of floating objects

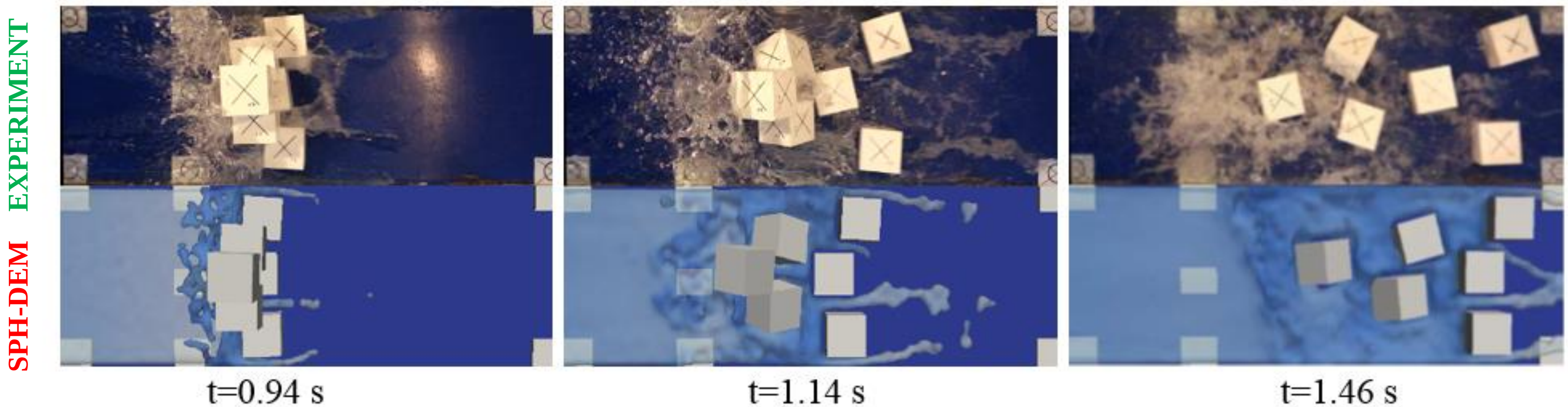


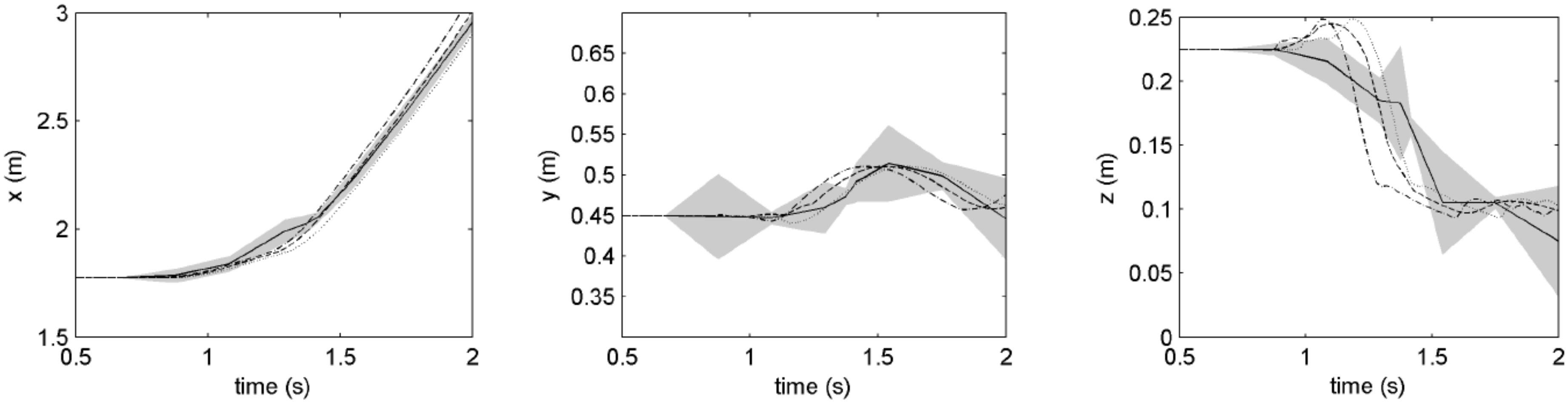
Sinking sphere with $\rho = 2.54\rho_w$. Experimental(-), experimental error region (shaded gray), DualSPHysics $D/dx = 20$ $(\cdots)$ $D/dx = 50$ $(- \cdot -)$

4. Applications: Rigid objects

Canelas RB, Crespo AJC, Domínguez JM, Ferreira RML, Gómez-Gesteira M. SPH-DCDEM model for arbitrary geometries in free surface solid-fluid flows. Computer Physics Communications, **2015**.

Interaction with rigid objects (validation of SPH-DEM).





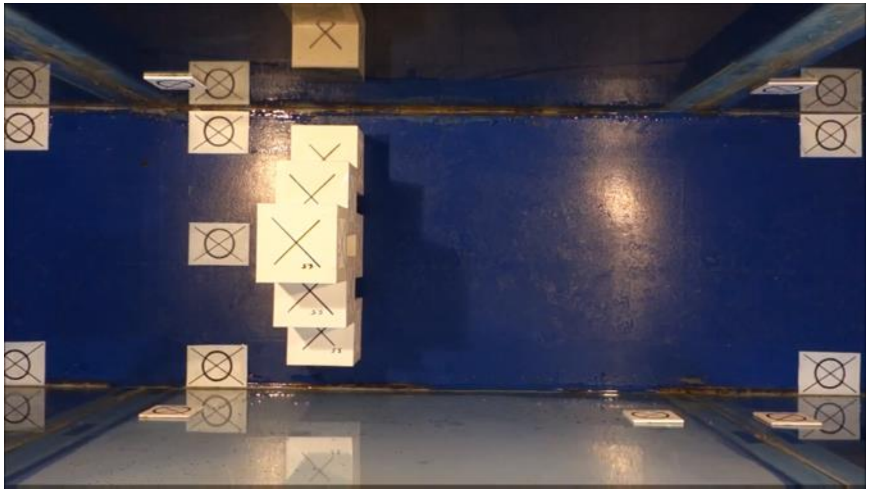
Top left cube: Experimental (-), DualSPHysics L/Dp = 15(--), L/Dp = 10(-.-), L/Dp = 45(…)

4. Applications: Rigid objects

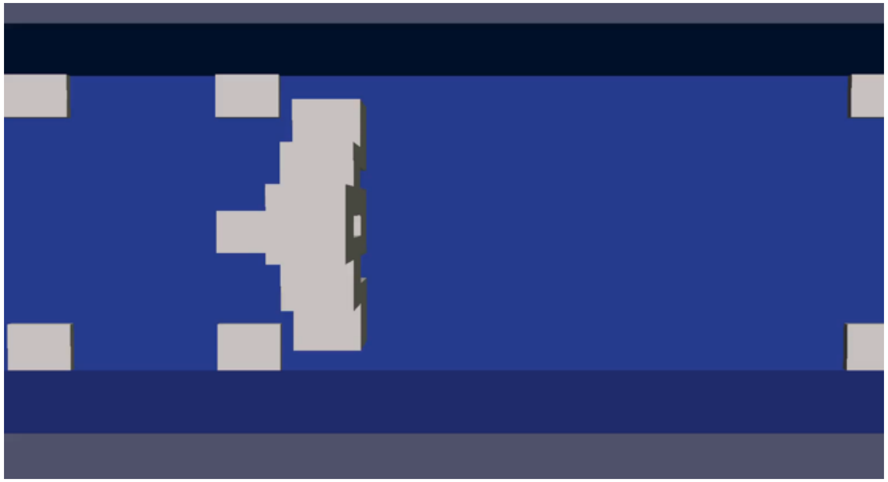
Canelas RB, Crespo AJC, Domínguez JM, Ferreira RML, Gómez-Gesteira M. SPH-DCDEM model for arbitrary geometries in free surface solid-fluid flows. Computer Physics Communications, **2015**.

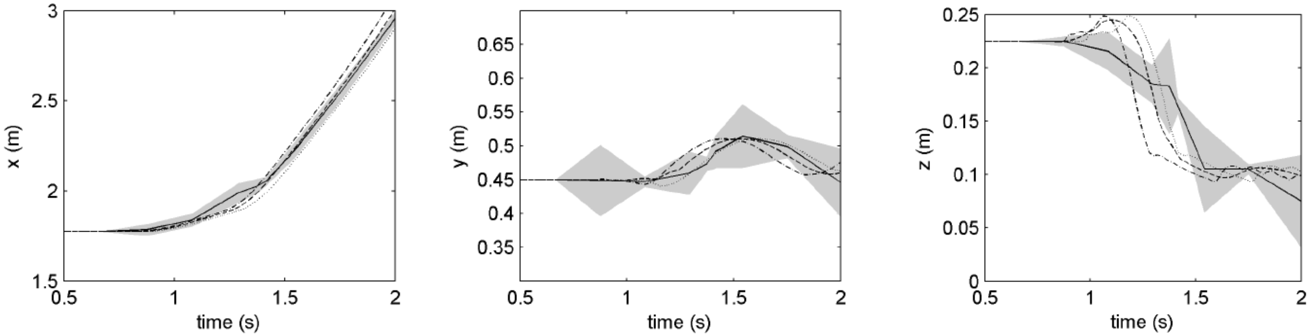
Interaction with rigid objects (validation of SPH-DEM).

EXPERIMENT



SPH-DEM





Top left cube: Experimental (-), DualSPHysics L/Dp = 15(--), L/Dp = 10(-.-), L/Dp = 45(…)

Video link:
https://youtu.be/06o6ggc78zI

4. Applications: Debris flows

Canelas RB, Domínguez JM, Crespo AJC, Ferreira RML. Resolved simulation of a granular-fluid flow with a coupled SPH-DCDEM model. Journal of Hydraulic Engineering.

UNDER REVIEW

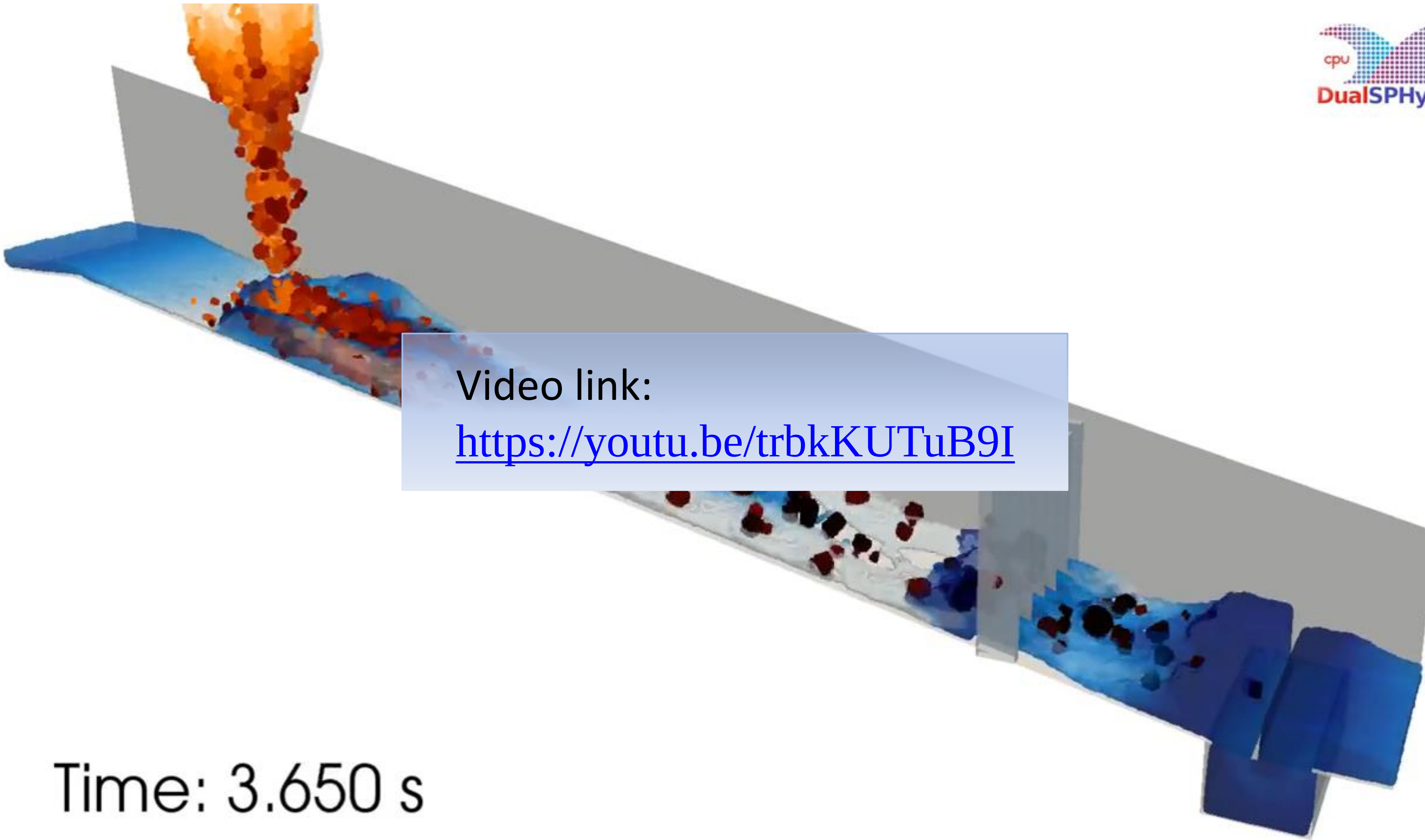
Simulation of debris flows

4. Applications: Debris flows

Canelas RB, Domínguez JM, Crespo AJC, Ferreira RML. Resolved simulation of a granular-fluid flow with a coupled SPH-DCDEM model. Journal of Hydraulic Engineering.

UNDER REVIEW

Simulation of debris flows



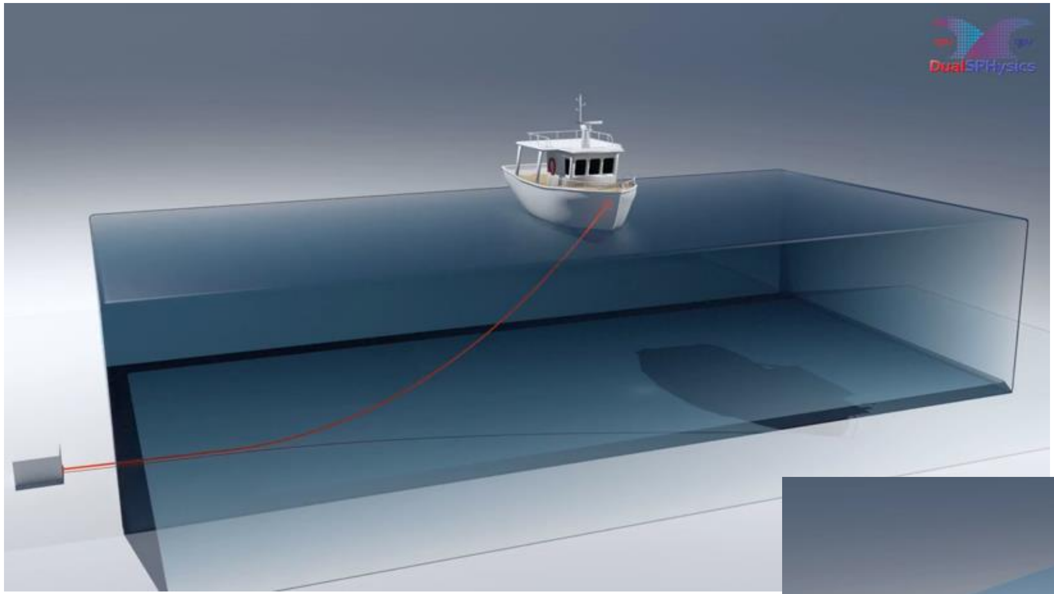
Video link:
https://youtu.be/trbkKUTuB9I

DualSPHysics simulation took 285h for 70s of physical time with close to 3 million particles with 1600 solids

4. Applications: Moorings

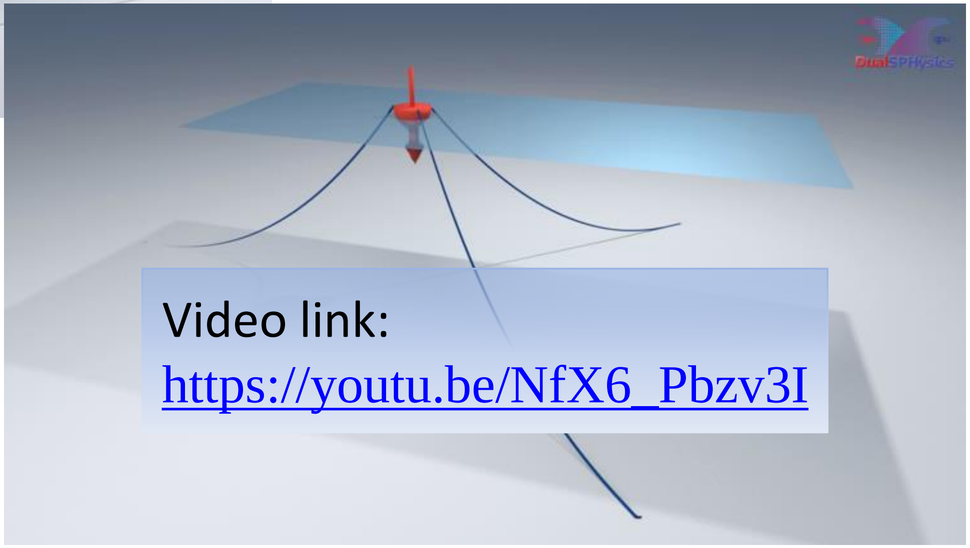
Barreiro A, Crespo AJC, Domínguez JM, García-Feal O, Zabala I, Gómez-Gesteira M. Quasi-Static Mooring solver implemented in SPH. Journal of Ocean Engineering and Marine Energy, 2(3): 381-396.

Moorings implementation



Ship moored

Buoy with several moorings



Video link:
https://youtu.be/NfX6_Pbzv3I

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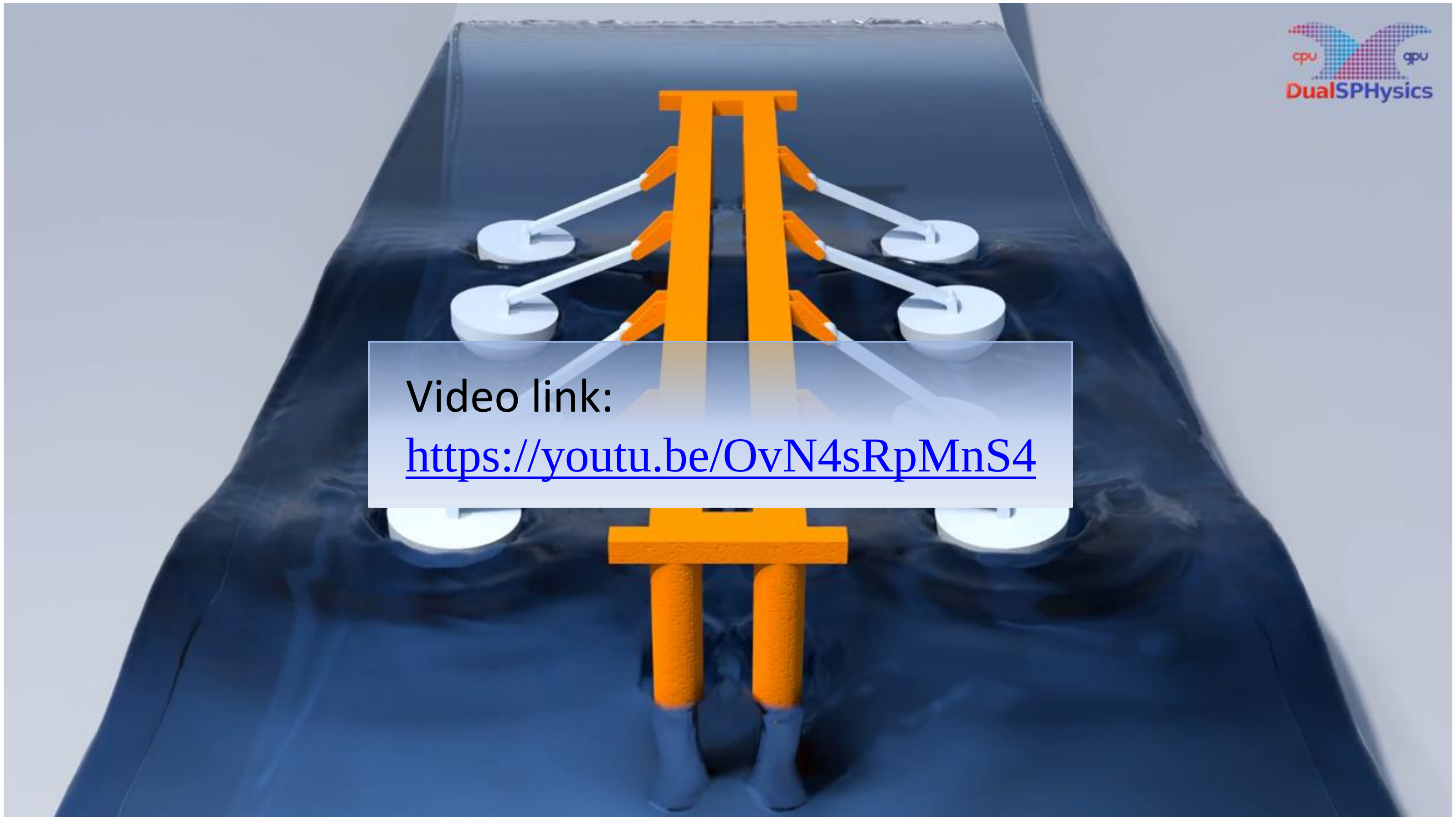
https://youtu.be/IlGe341o-LE

4. Applications: Coupling with Chrono library

More complex machines – WaveStar (Wave Energy Converter)



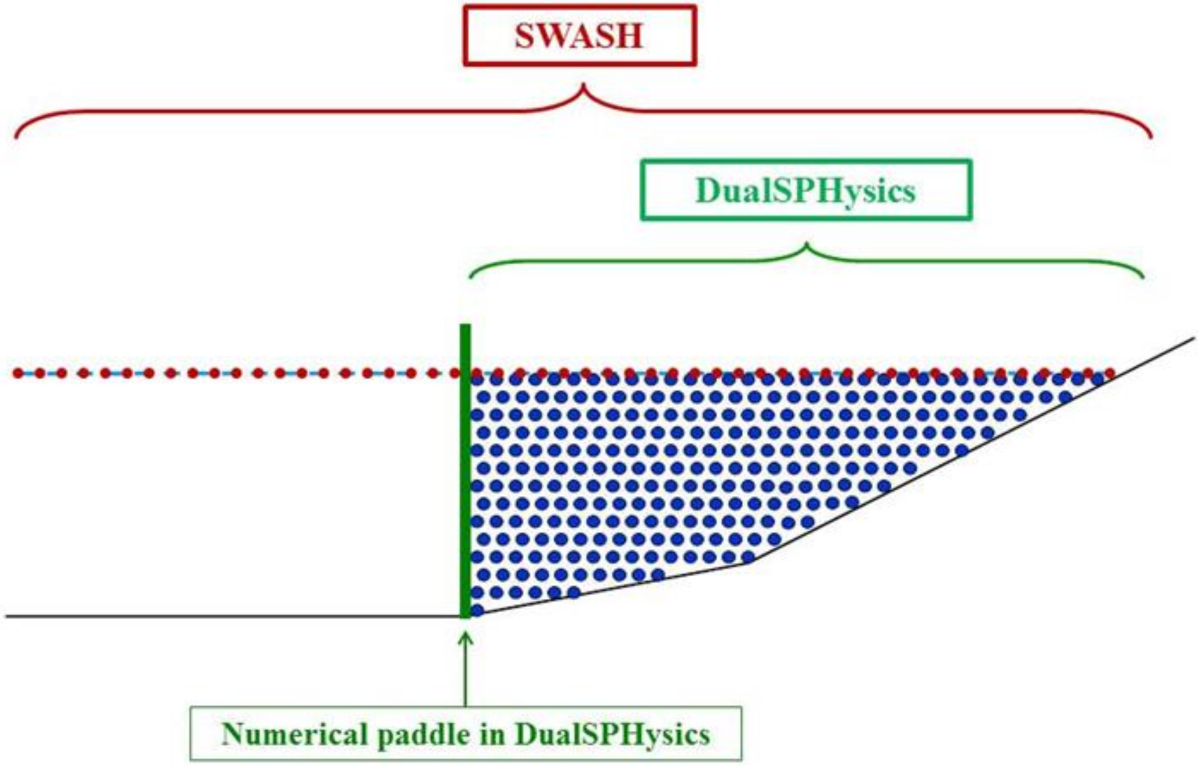
Several serially linked joints, floating elements, complex motions and operational manoeuvres are all possible with the current implementation.

4. Applications: Coupling with SWASH

Altomare C, Domínguez JM, Crespo AJC, Suzuki T, Cáceres I , Gómez-Gesteira M. Hybridisation of the wave propagation model SWASH and the meshfree particle method SPH for real coastal applications. Coastal Engineering Journal, 57(4): 1550024.

Coupling between SWASH and SPH

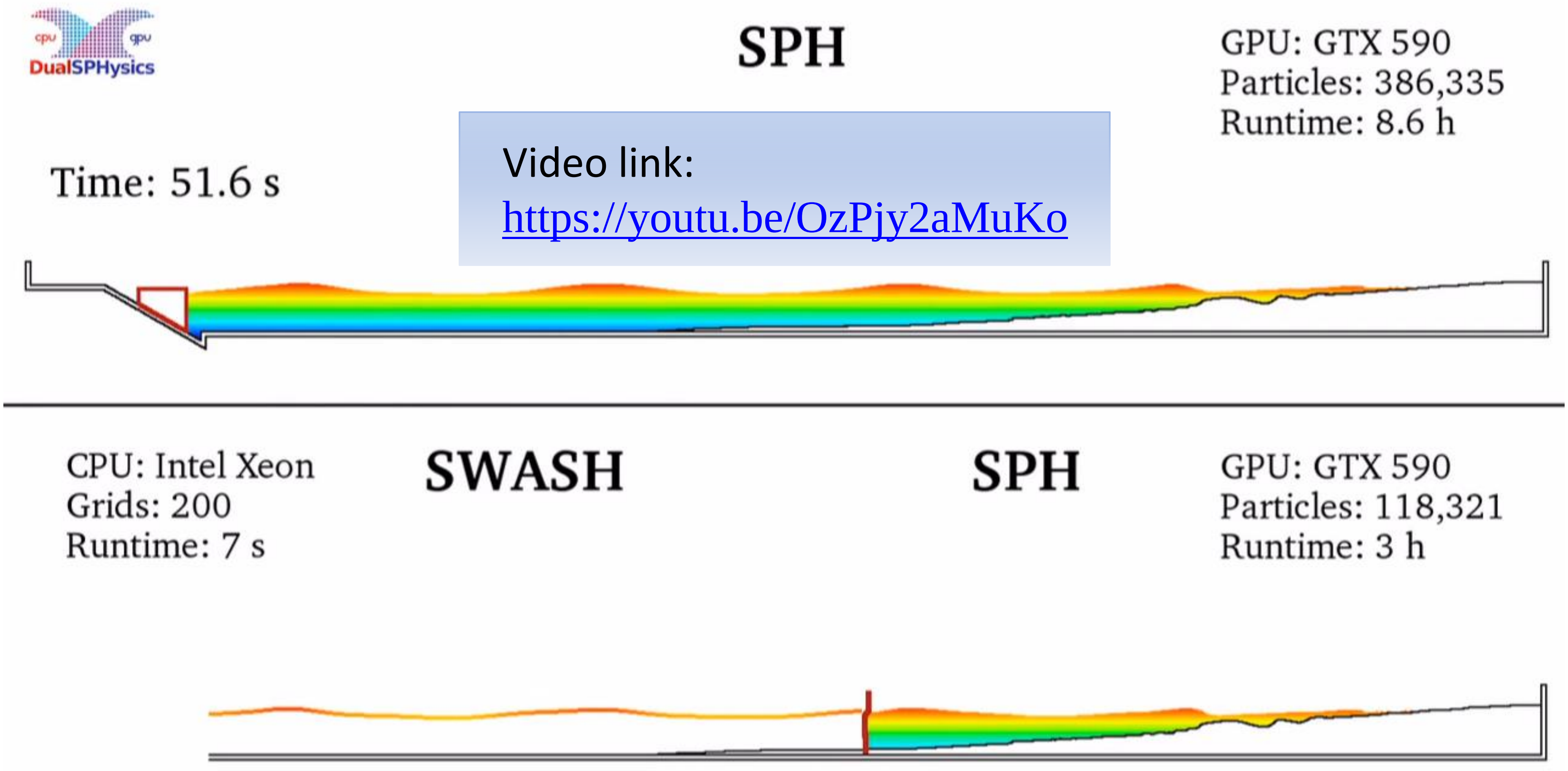
- The study of wave propagation from deep ocean to near shore is difficult using a single model because multiple scales are present both in time and in space.
- A hybrid model is necessary to combine capabilities of a wave propagation model (SWASH) and DualSPHysics.



4. Applications: Coupling with SWASH

Altomare C, Domínguez JM, Crespo AJC, Suzuki T, Cáceres I , Gómez-Gesteira M. Hybridisation of the wave propagation model SWASH and the meshfree particle method SPH for real coastal applications. Coastal Engineering Journal, 57(4): 1550024.

Coupling with wave propagation models - SWASH

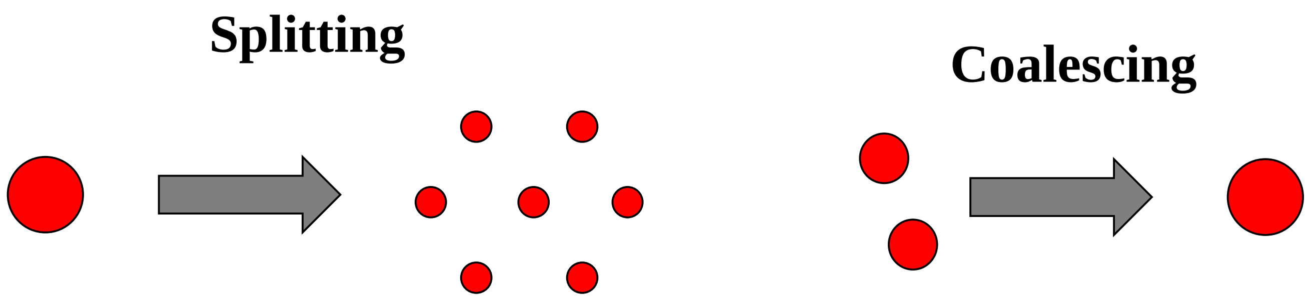


Video link:
https://youtu.be/OzPjy2aMuKo

4. Applications: Variable resolution

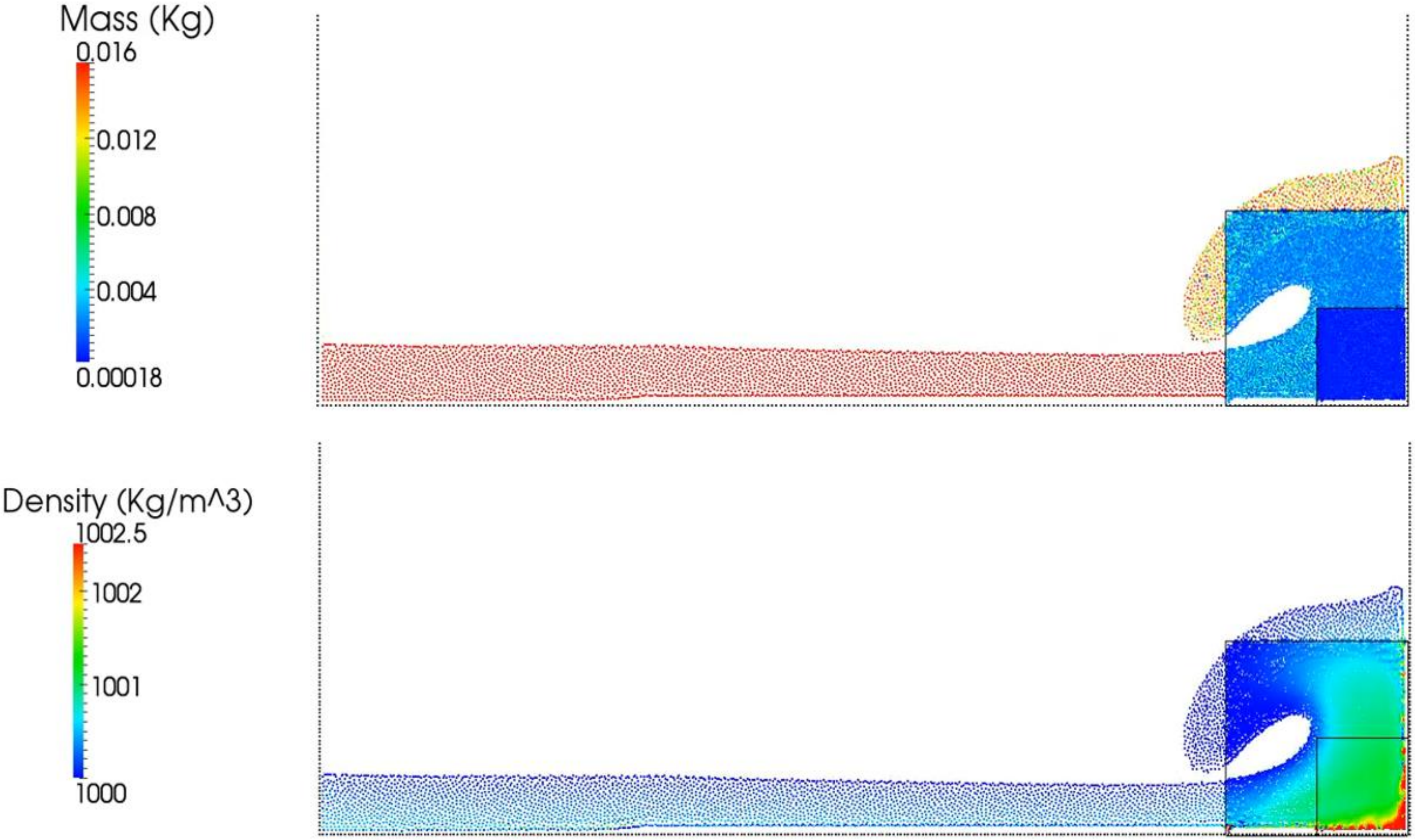
Variable resolution (splitting & coalescing)

- Variable resolution is imperative to simulate large problems with SPH.
- Higher resolution is only used where it is necessary, to reduce the number of particles to simulate.



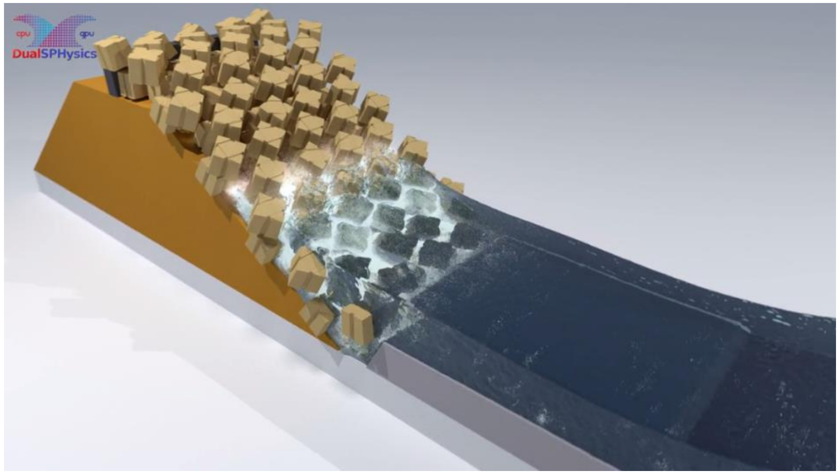
4. Applications: Variable resolution

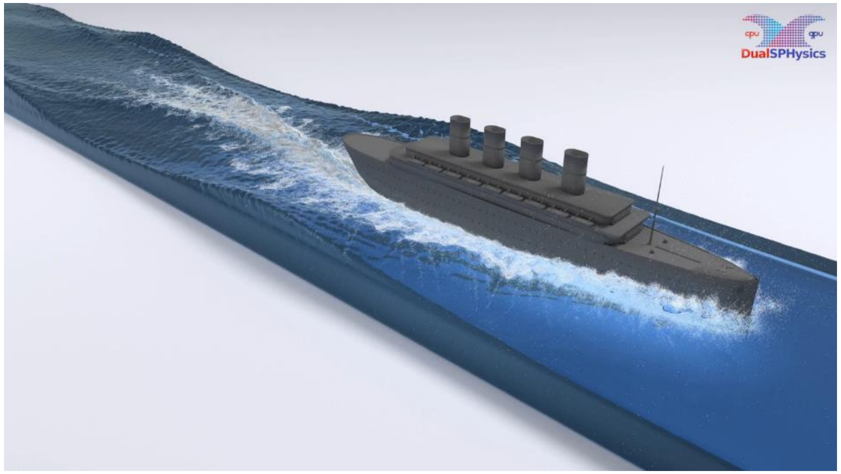
Dynamic refinement with particles with different sizes by means of particle splitting and coalescing procedures.



4. Applications: Realistic visualization

Advanced visualization using Blender





Video link:
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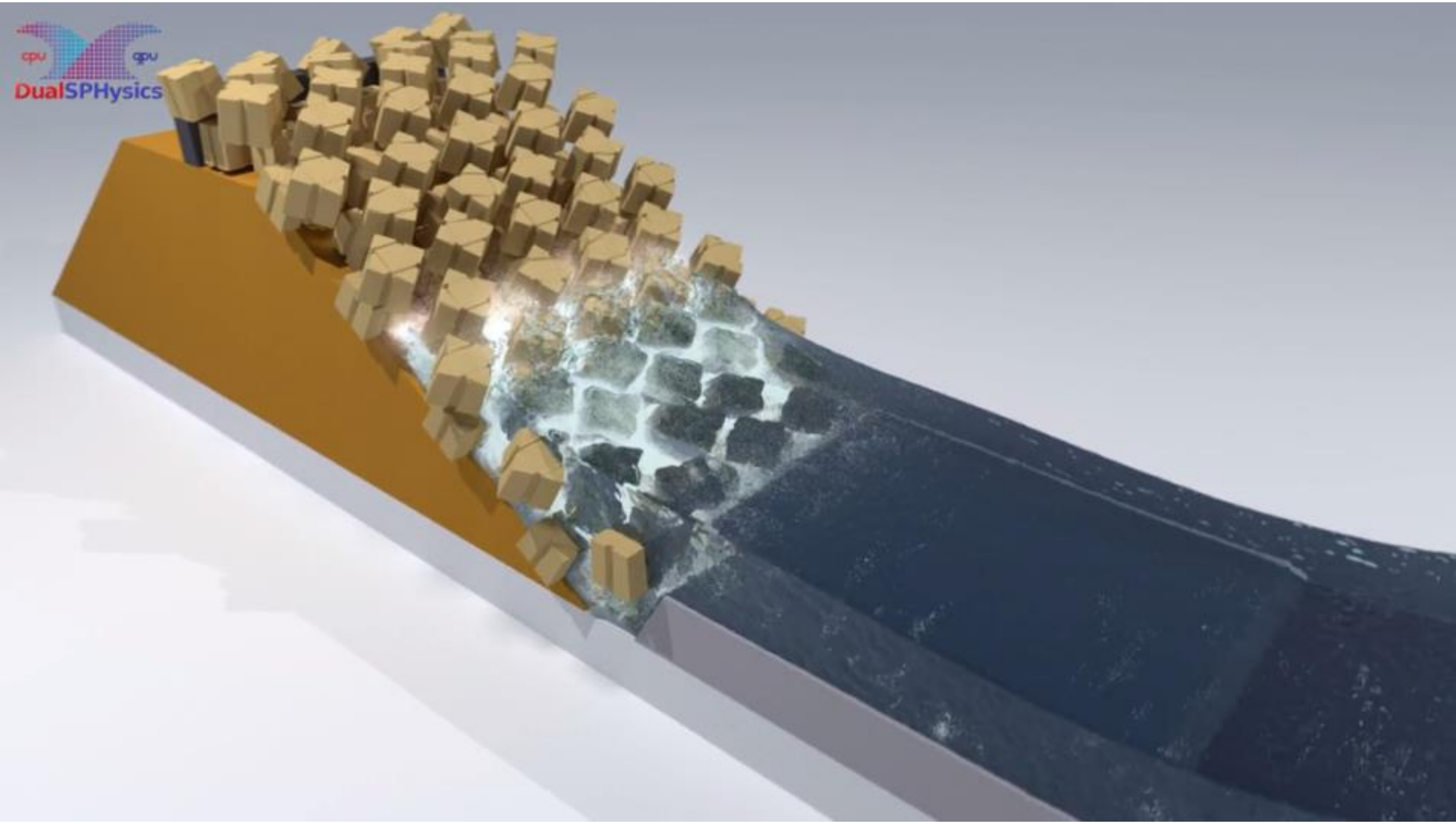
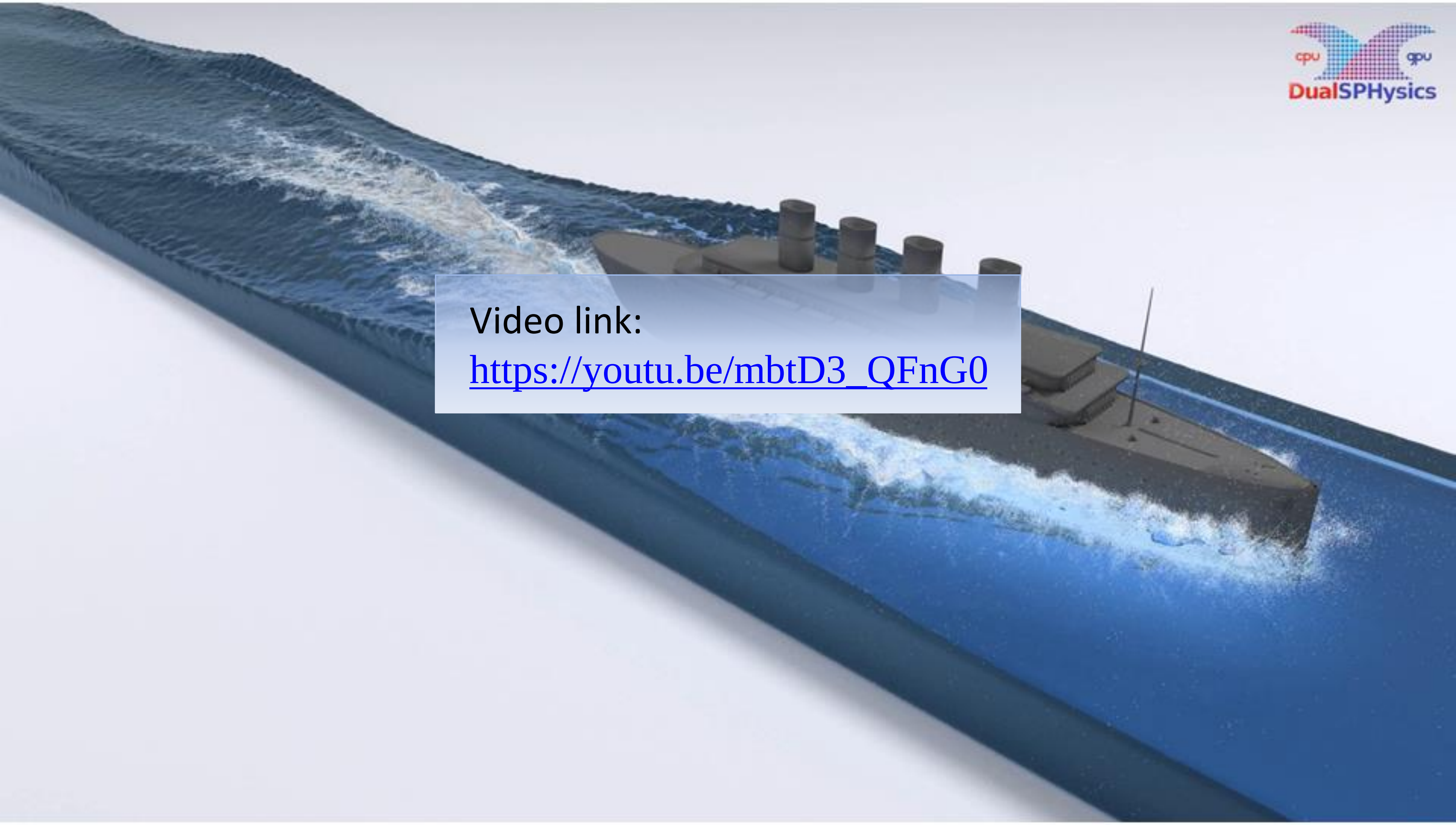

cpu
gpu
DualSPHysics



Video link:
https://youtu.be/mbtD3_QFnG0

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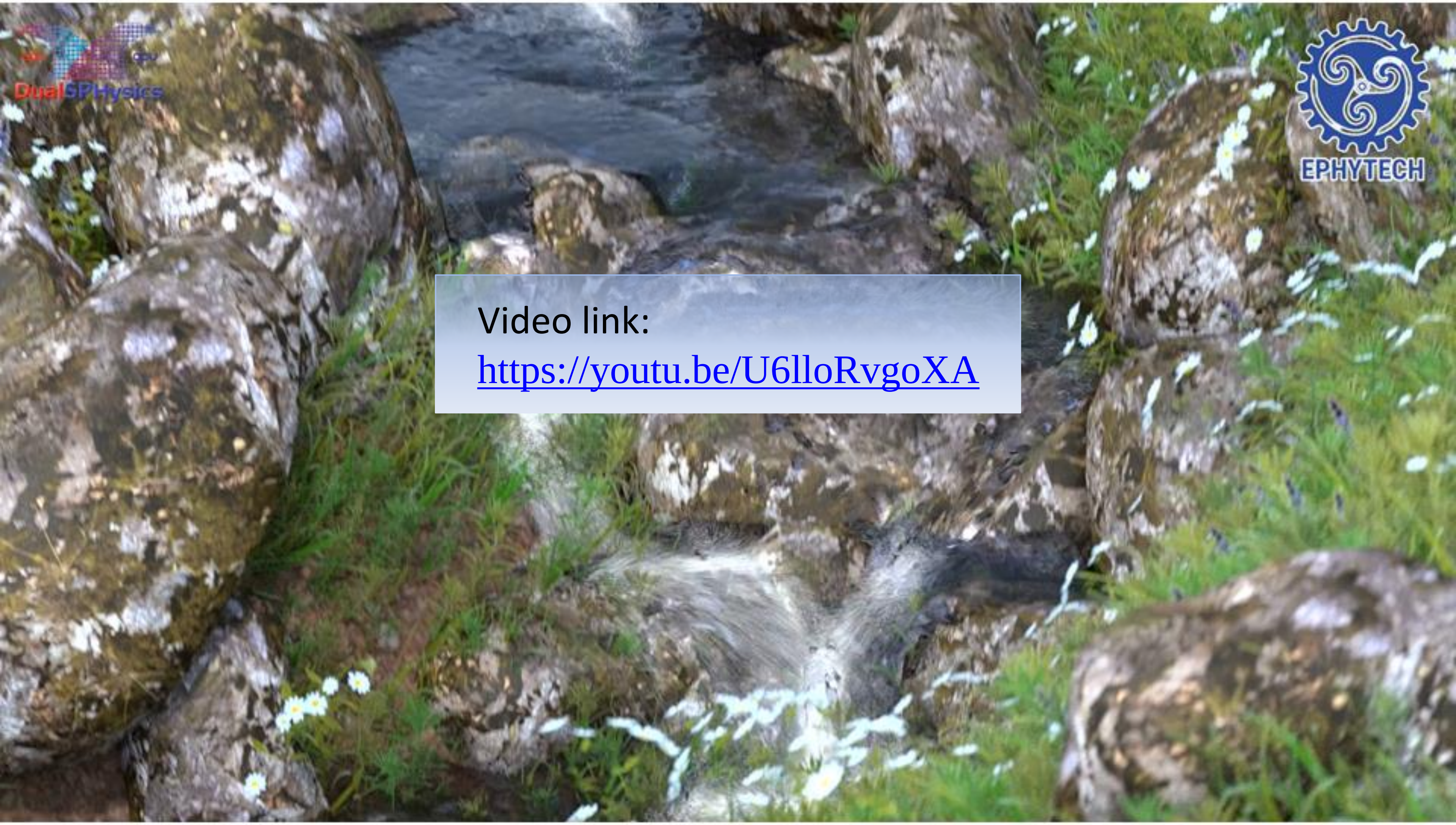
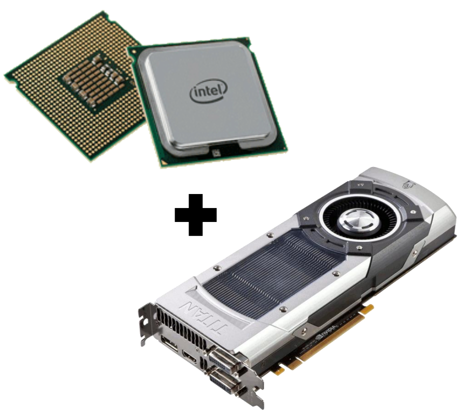
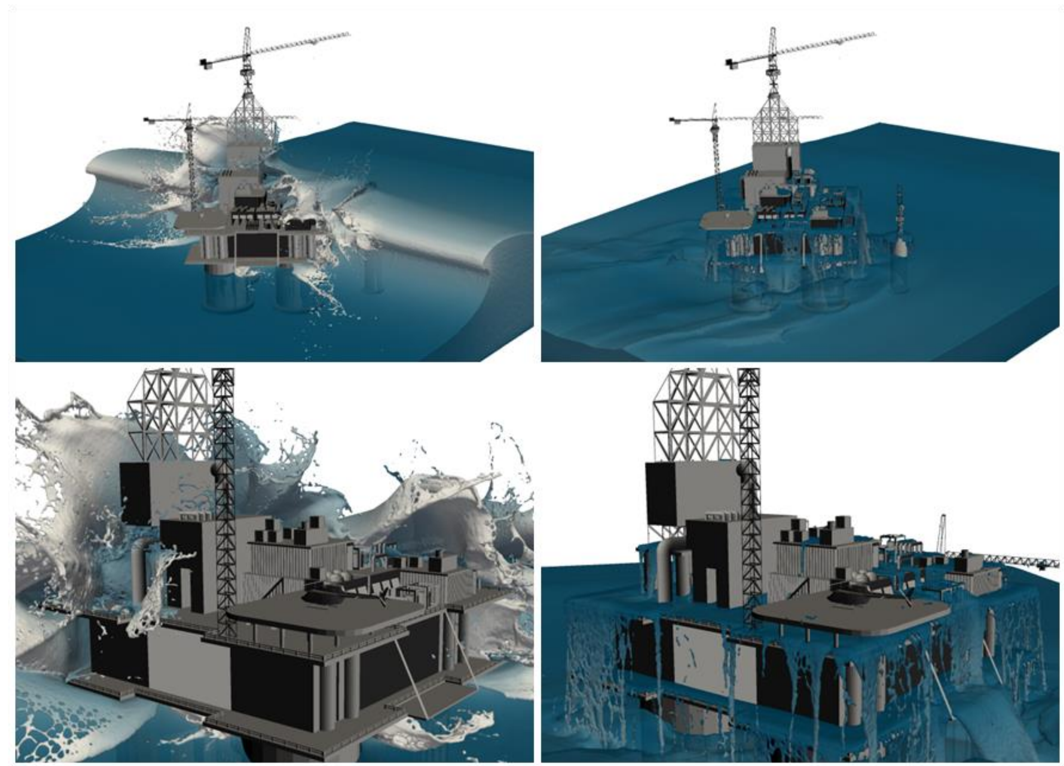


Video link:
https://youtu.be/U6lloRvgoXA

Parallelization of SPH for engineering applications with heterogeneous architectures





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