2nd Iberian Workshop
Ourense, 3rd and 4th December 2015

DualSPHysics

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SPH applied to coastal engineering problems“

(validating the SPH concept)

ALTOMARE, CRESPO, DOMINGUEZ, SUZUKI

Vlaamse overheid

UniversidadeVigo

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http://www.flandershydraulicsresearch.be/

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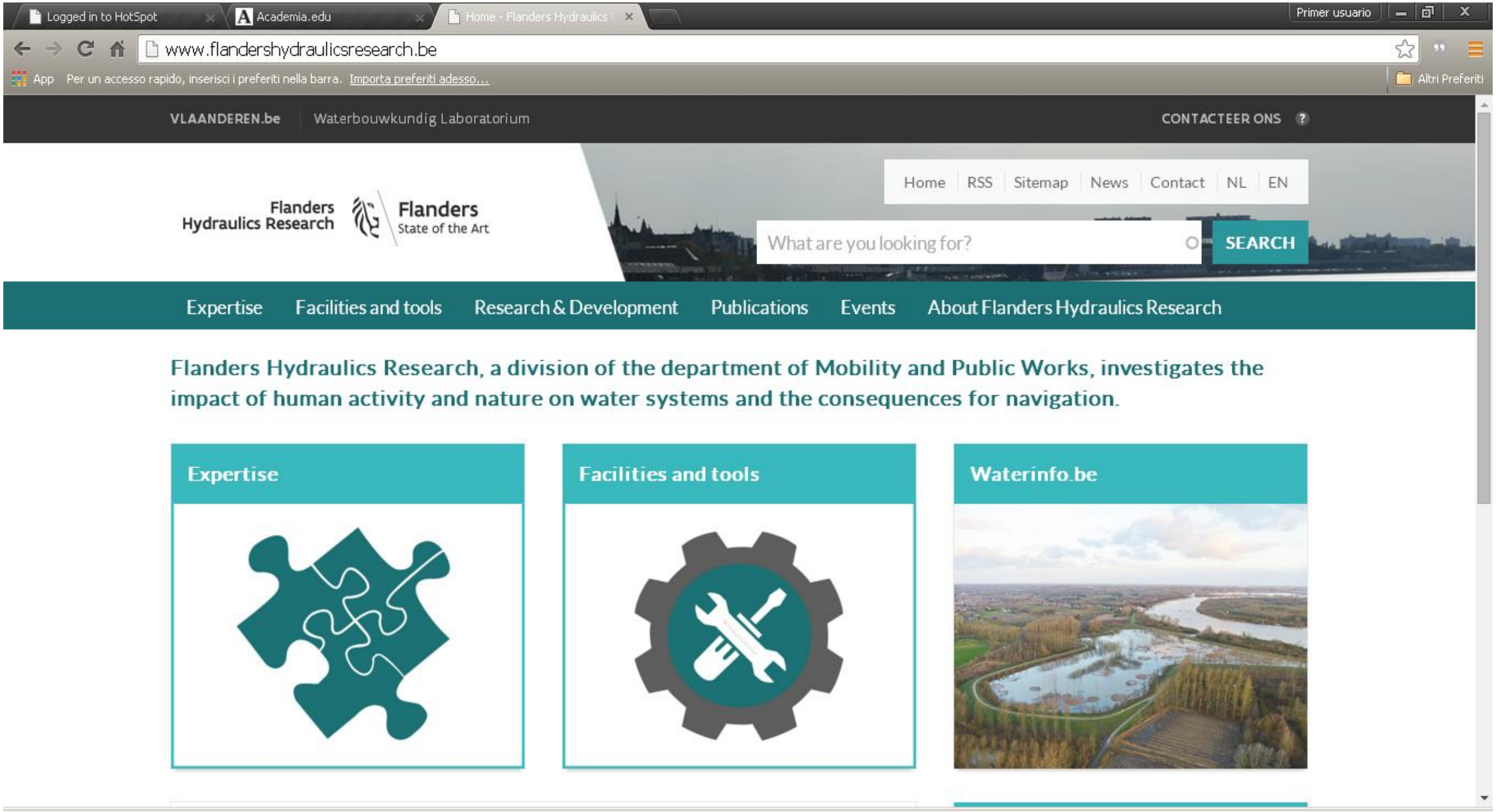


Flanders Hydraulics Research, a division of the department of Mobility and Public Works, investigates the impact of human activity and nature on water systems and the consequences for navigation.

Questions…

To express the "Model Skills" and to describe the uncertainties in SPH?

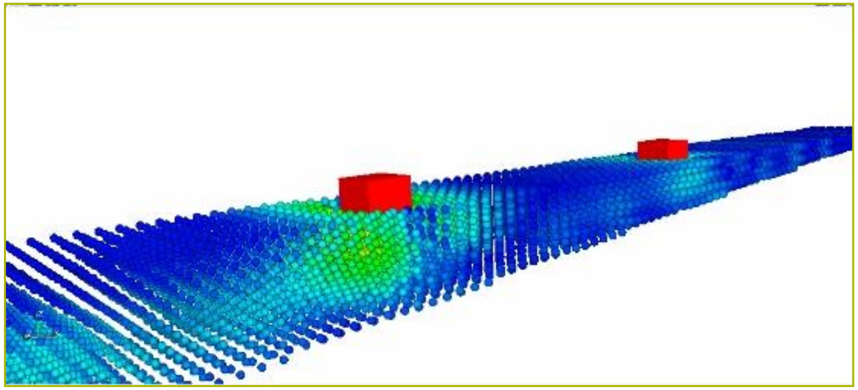
$$\frac{\textit{resolution - reliability}}{\textit{uncertainty}}$$

Questions...

The act or process of separating something into its constituent parts or elements (Collins Dict.)

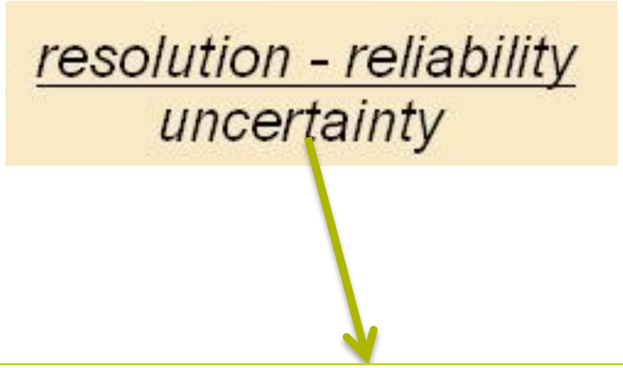
resolution - reliability
uncertainty

PARTICLES



Questions…

To express the "Model Skills" and to describe the uncertainties in SPH?



$$\frac{\textit{resolution - reliability}}{\textit{uncertainty}}$$

The condition of being uncertain, not fixed, doubtful, puzzled. (Collins Dict.)

Uncertainties exist but we must and we are fixing it!!

Uncertainties in SPH/DualSPHysics

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- Resolution (smoothing length, h)
- Boundary conditions
- WCSPH
- Viscosity
- …….

NUMERICAL

- Wave Generation and Absorption

Wave modelling

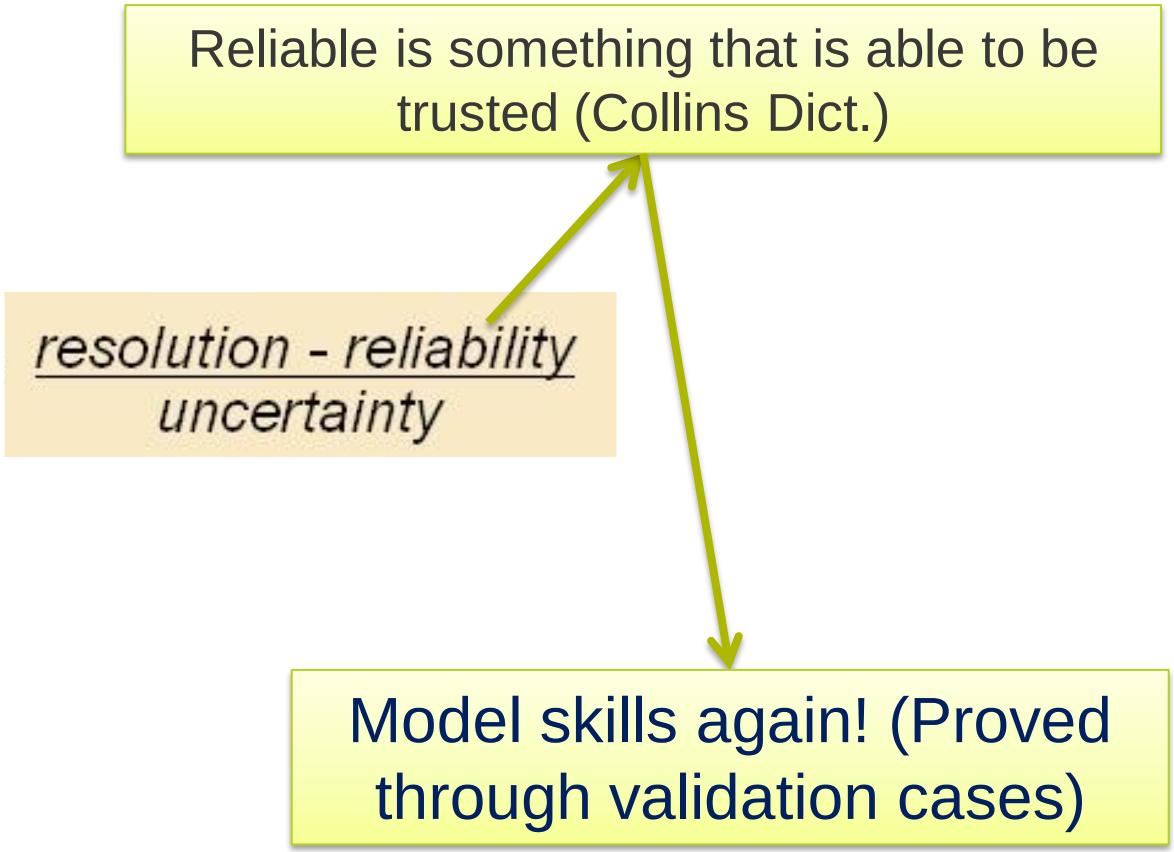
- Data used (bathymetry, roughness, waves and WL meas.)
- Stochastic nature of the analyzed phenomena

PHYSICAL, MEASUREMENTS!!

Don't judge a numerical model without questioning the the physical one!

Questions…

How does Modeling Uncertainty relate to Measurement Uncertainty ?



Reliable is something that is able to be trusted (Collins Dict.)

$$\frac{\text{resolution - reliability}}{\text{uncertainty}}$$

Model skills again! (Proved through validation cases)

Proofs of reliability

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DualSPHysics has been recently validated and applied to coastal engineering problems typical of the Flemish coast!!!

1) **Wave run-up on armour block breakwater (Zeebrugge)**
2) **Wave impact on storm return walls (Zeebrugge & Blankenberge)**
3) **Wave impact on buildings in shallow foreshore conditions (Belgian and Dutch coast)**

1) Wave run-up on armour block breakwater (Zeebrugge)

Proper modelling of the armour layout:

- *Block shape and dimensions*
- *Block interspace*
- *Slope pattern*

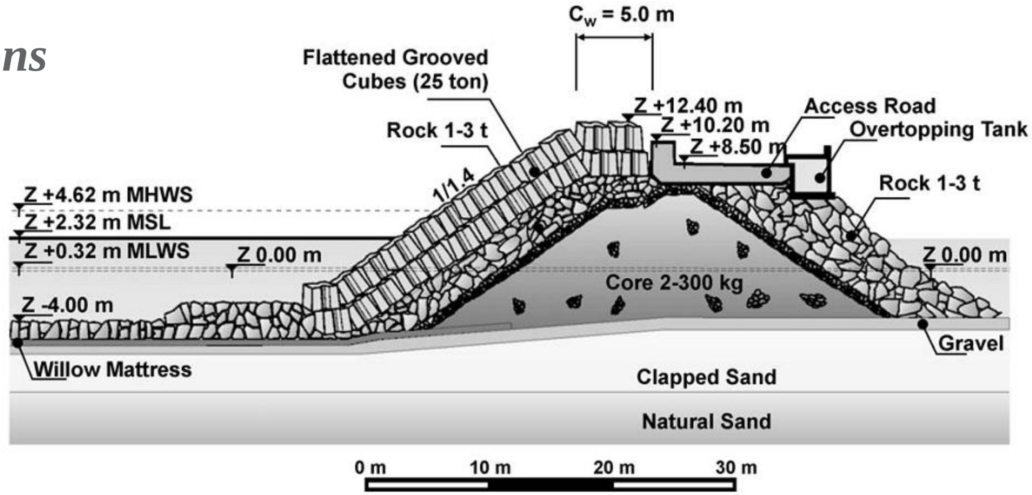
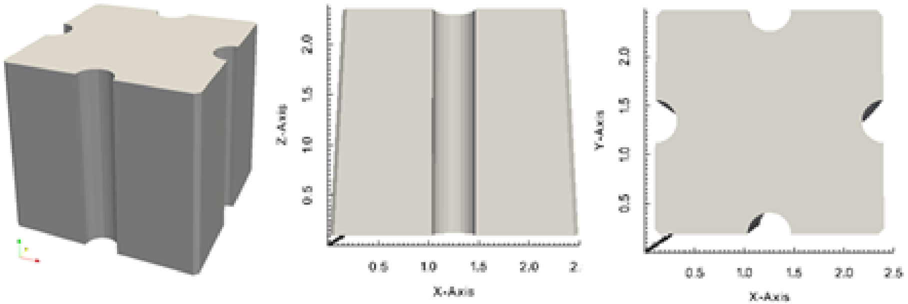


Fig. 2. Cross section of the Zeebrugge rubble mound breakwater at the location of the wave overtopping tank.

DETAILED DESCRIPTION OF THE FLOWS !!!

Zeebrugge reference geometry (Belgium)



The size of the numerical simulation depends on the initial inter-particle distance

dp = 0.15 m => h = 0.225 m

The SPH domain contains **2,146,095 particles** with 187,353 representing the boundaries

1) Wave run-up on armour block breakwater (Zeebrugge)

Contents lists available at ScienceDirect

Computers and Structures

journal homepage: www.elsevier.com/locate/compstruc

Numerical modelling of armour block sea breakwater with smoothed particle hydrodynamics

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[a] Laboratori d'Enginyeria Maritima (LIM-CIIRC), Universitat Politecnica de Catalunya (UPC), Spain
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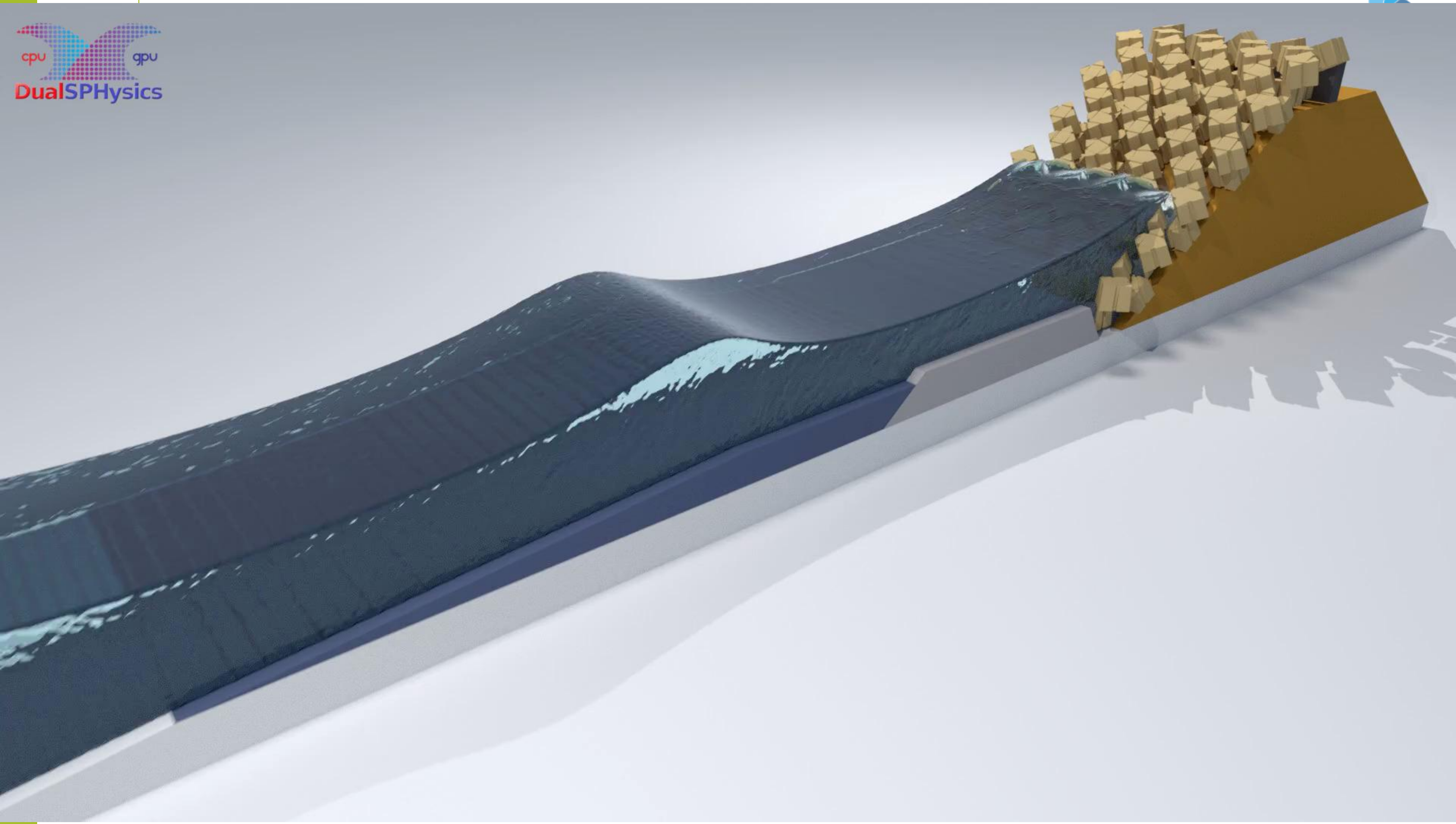
ABSTRACT

The application of smoothed particle hydrodynamics (SPH) to model the three-dimensional fluid–structure interaction for waves approaching a rubble mound breakwater is presented. The main aim is to model the armoured structure and to validate its response under the action of periodic waves. The complex geometry is represented by grooved cubic blocks such that the surrounding gaps within the breakwater seaward layer require a large number of particles to obtain a sufficiently detailed description of the flow. Using novel computer architecture solutions such as graphics processing units (GPUs), the fluid-structure interaction is modelled with SPH particles between armour blocks that are representative of the real structure. The open-source GPU code, DualSPHysics, enables the simulation of millions of particles required for the accurate simulation of the run-up on an armoured structure. SPH has been proven to be a suitable method for practical applications in coastal engineering. In the present work the run-up heights are computed and compared with empirical solutions and experimental data. Reasonable agreement is obtained for the run-up due to regular waves over a range of surf similarity numbers from 3.0 to 5.5.

1) Wave run-up on armour block breakwater (Zeebrugge)



SPH TO NUMERICALLY COMPUTE SURFACE EQUIVALENT ROUGHNESS

1) Wave run-up on armour block breakwater (Zeebrugge)

Rough structure: 3 different patterns

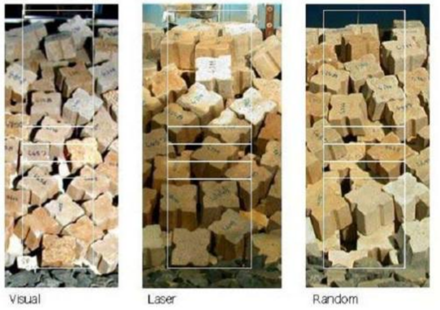
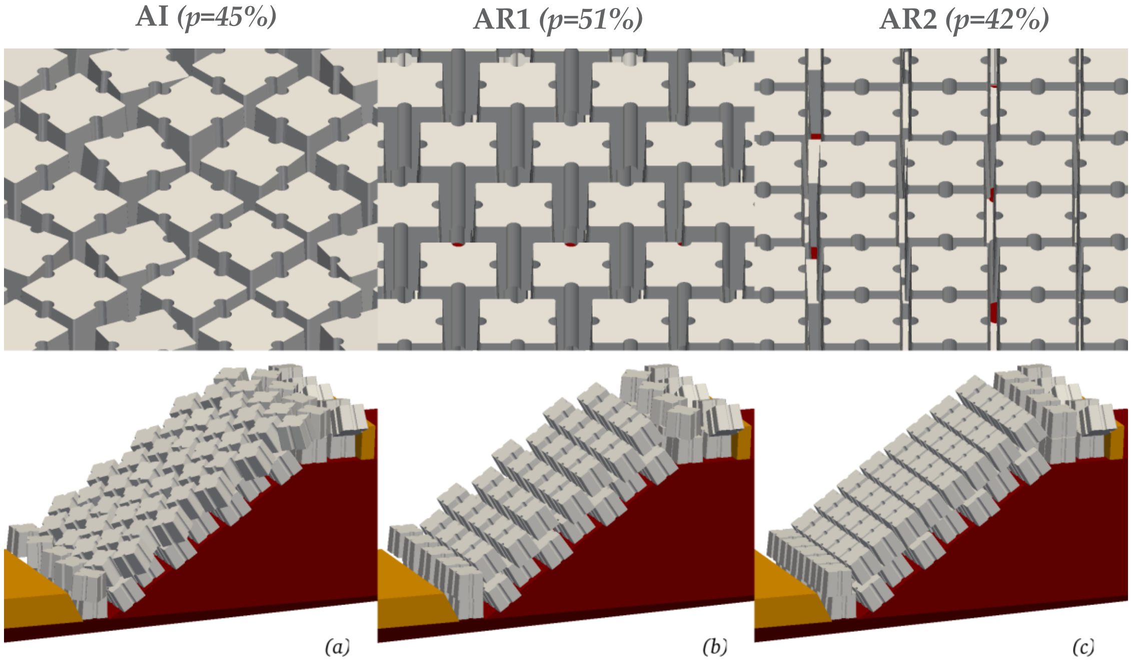


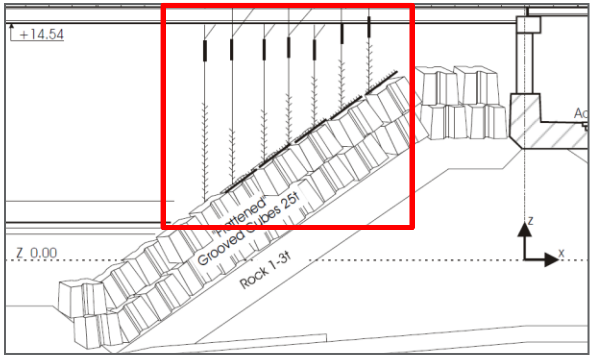
Figure 51: Photos of different armour layers tested at LWI, together with the different water levels and the width of the overtopping tray (indicated by white boxes)


AI (*p=45%*)
AR1 (*p=51%*)
AR2 (*p=42%*)

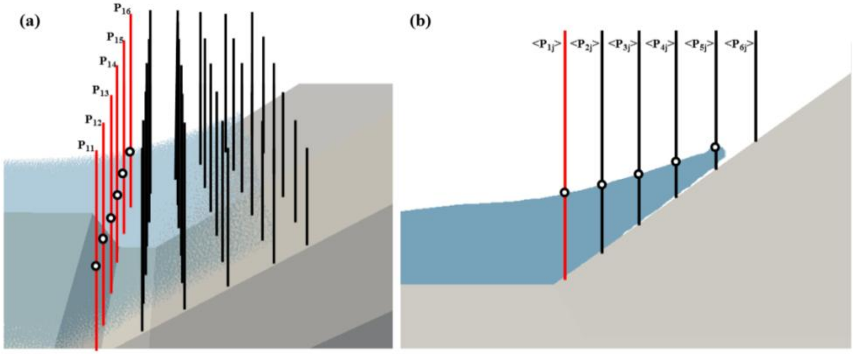
Different wave conditions

	wave#1	wave#2	wave#3
H_0 (m)	2.0	2.8	3.36
T (s)	7.5	7.5	7.5
ξ	4.51	3.99	3.65

Measurement system: **IN THE FIELD**



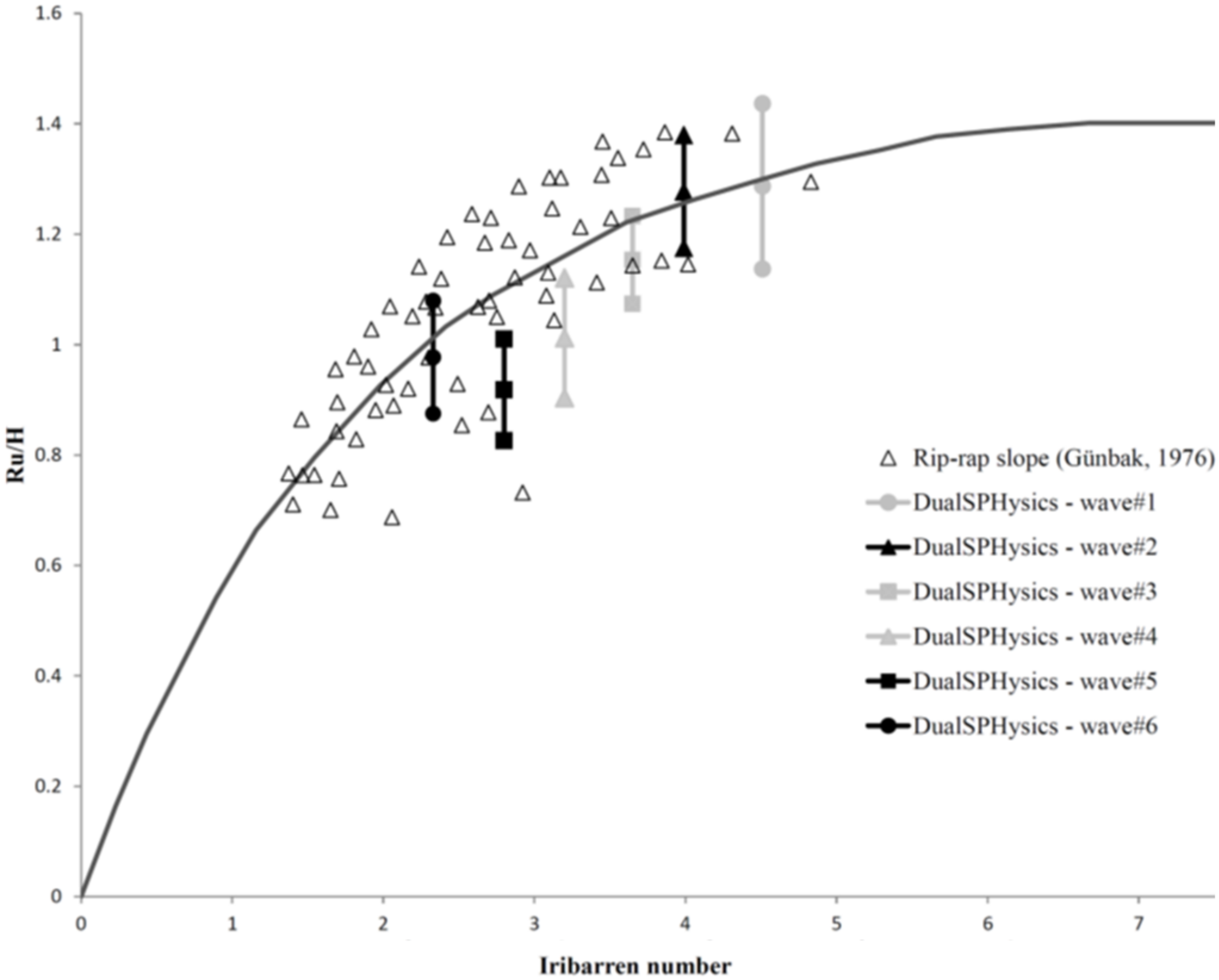
NUMERICALLY



1) Wave run-up on armour block breakwater (Zeebrugge)

Comparison with experimental results

$Ru^n = Ru/H$



2) Wave impact on storm return walls (Zeebrugge & Blankenberge)

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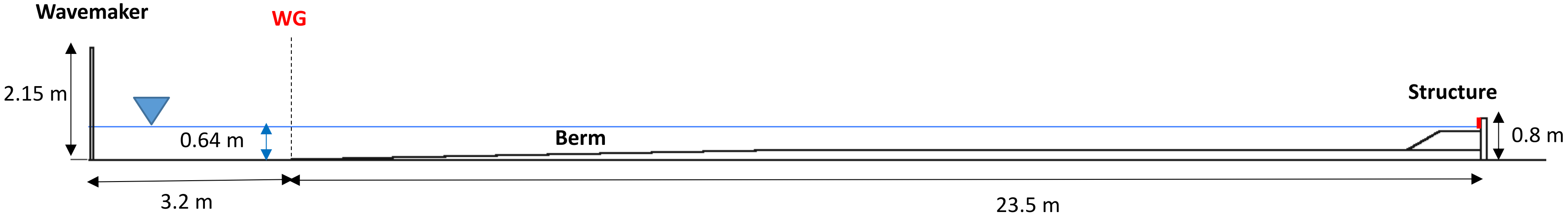
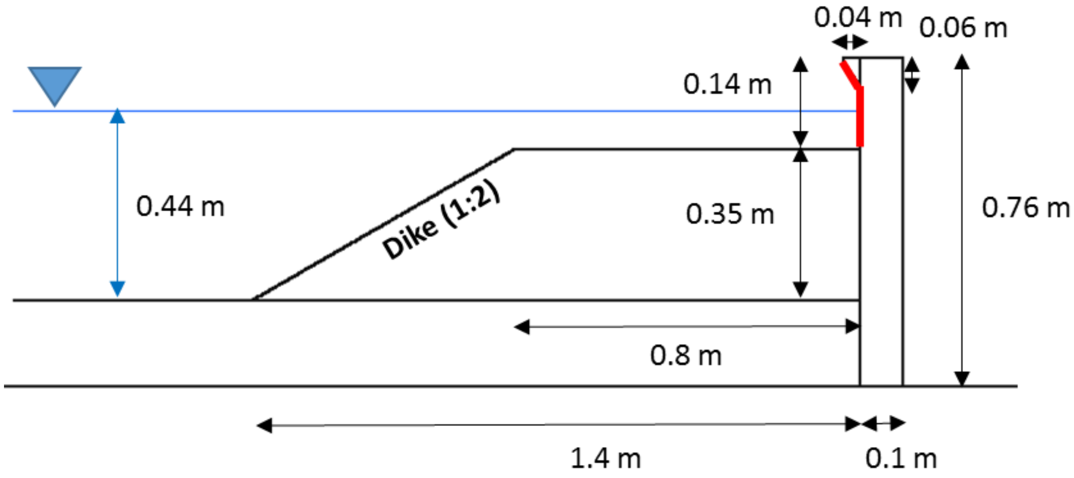
Assessment of wave loadings on the dikes and storm return walls in the Blankenberge Marina





H_{m0}=0.101m

T_p=2.683s

2) Wave impact on storm return walls (Zeebrugge & Blankenberge)

Comparison between numerical and experimental water surface elevation

Coastal Engineering 96 (2015) 1–12

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Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Applicability of Smoothed Particle Hydrodynamics for estimation of sea wave impact on coastal structures

Corrado Altomare [a,b,*], Alejandro J.C. Crespo [c], Jose M. Domínguez [c], Moncho Gómez-Gesteira [c], Tomohiro Suzuki [a,b], Toon Verwaest [a]

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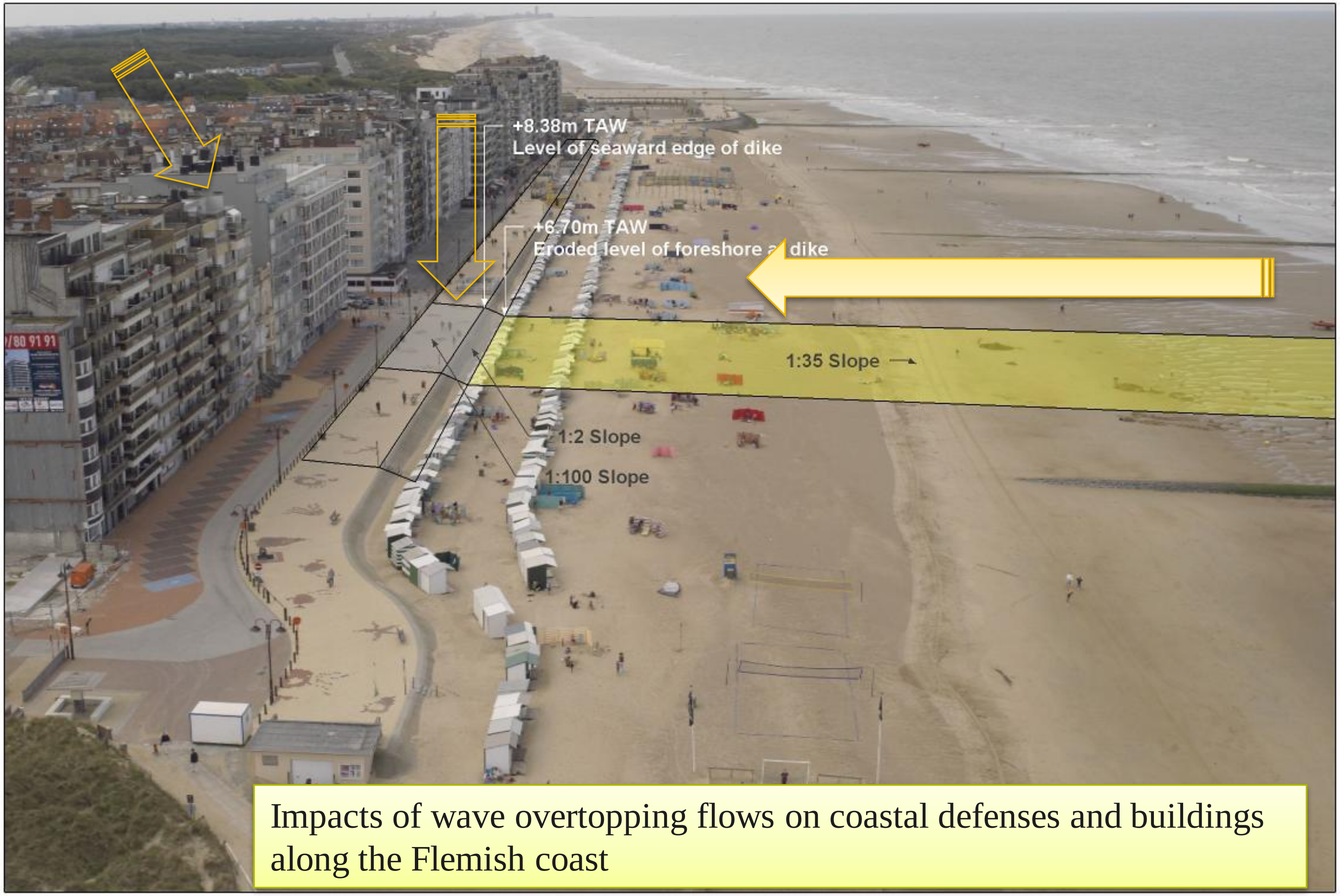
Numerical modelling
Coastal structures

ABSTRACT

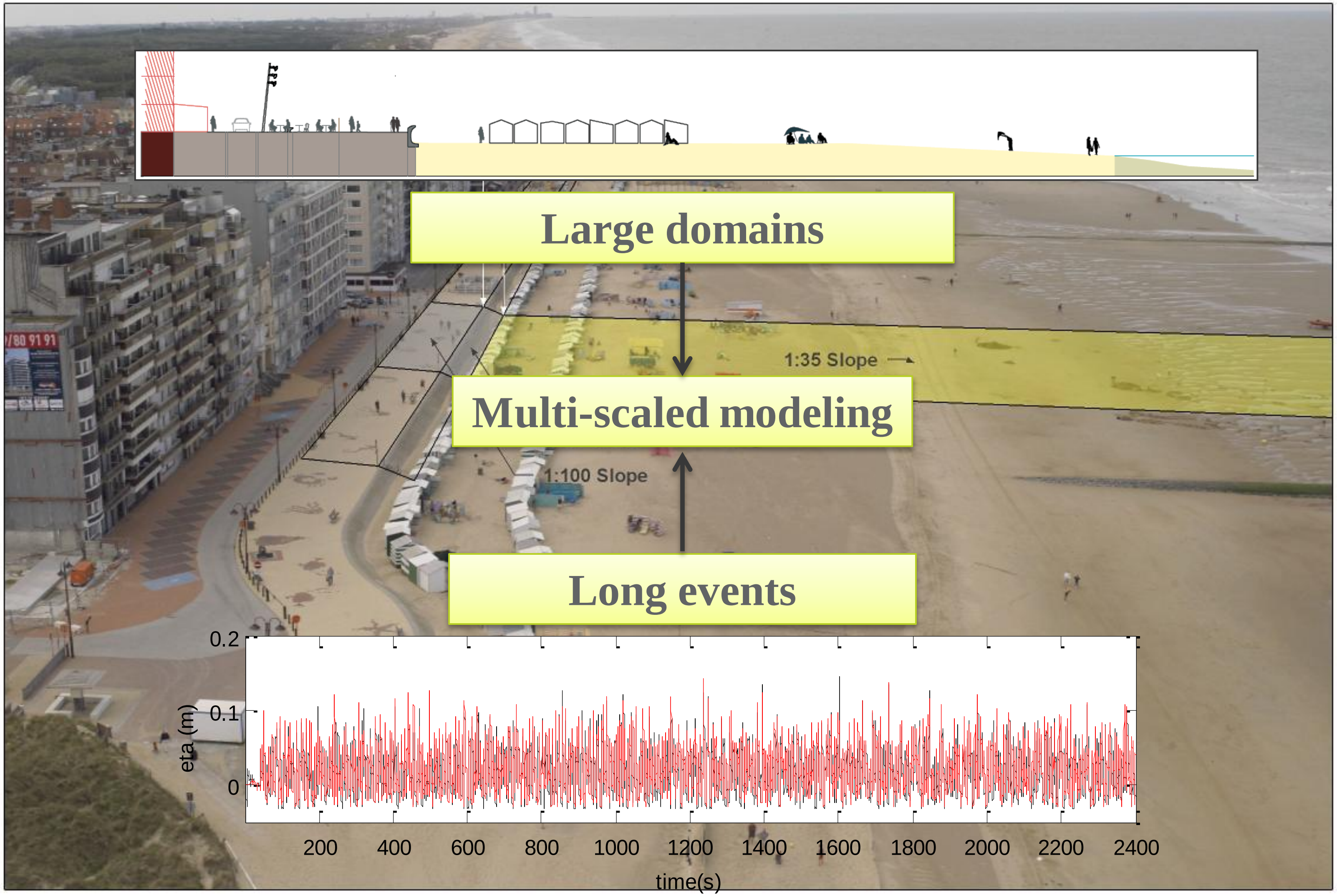
The present work describes the validation of an SPH-based technique for wave loading on coastal structures. The so-called DualSPHysics numerical model has been used for the scope. The attention is focused on wave impact on vertical structures and storm return walls. For vertical quay walls, the numerical results have been compared with analytical and semi-empirical solutions. Later on, the wave impact on storm return walls has been modelled and the results have been compared with experimental data. Regular and random waves have been simulated. Despite the model limitations (e.g. lack of an active wave absorption system), good agreement is achieved with the formulae predictions and experimental results which proves that DualSPHysics model is becoming an alternative to some classical approaches and can be used as complementary tool for the preliminary design of coastal structures.

3) Wave impact on buildings in shallow foreshore conditions



Impacts of wave overtopping flows on coastal defenses and buildings along the Flemish coast

3) Wave impact on buildings in shallow foreshore conditions

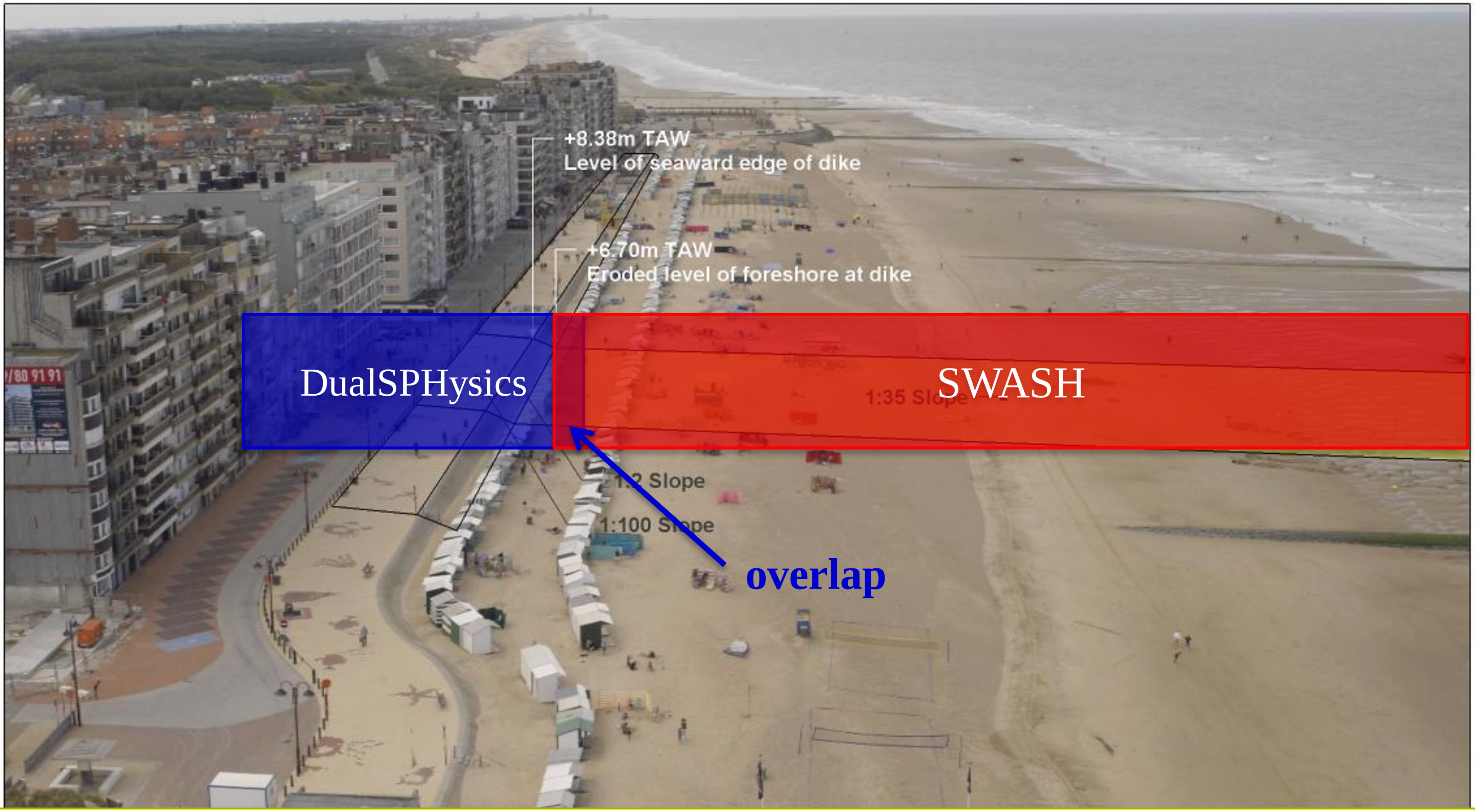


Large domains

Multi-scaled modeling

Long events

3) Wave impact on buildings in shallow foreshore conditions

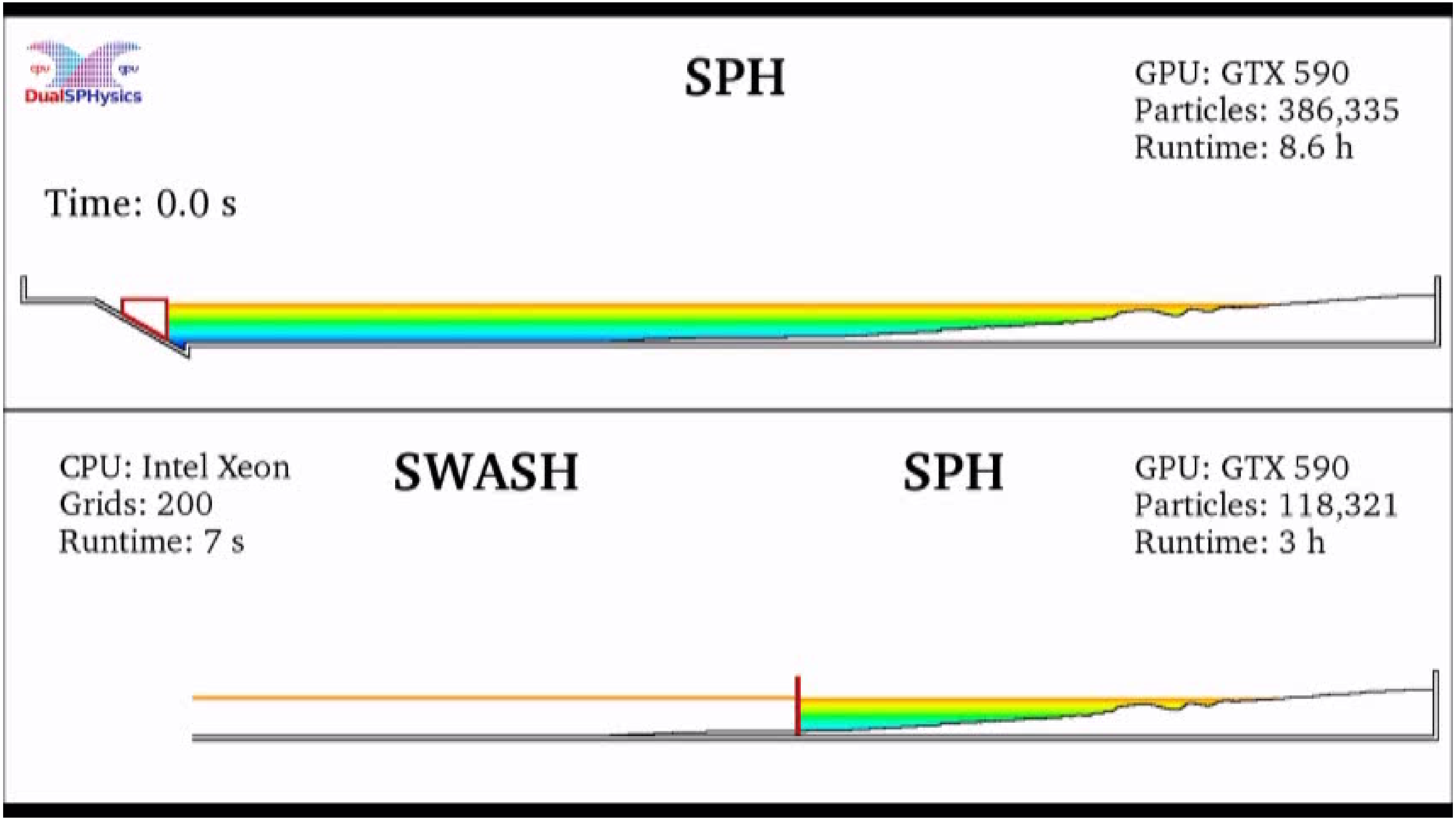


C. Altomare, J.M. Domínguez, A.J.C. Crespo, T. Suzuki, I. Caceres, M. Gómez-Gesteira.

HYBRIDISATION OF THE WAVE PROPAGATION MODEL SWASH AND THE MESHFREE PARTICLE METHOD SPH FOR REAL COASTAL APPLICATIONS.

***Coastal Engineering Journal*, under review.**

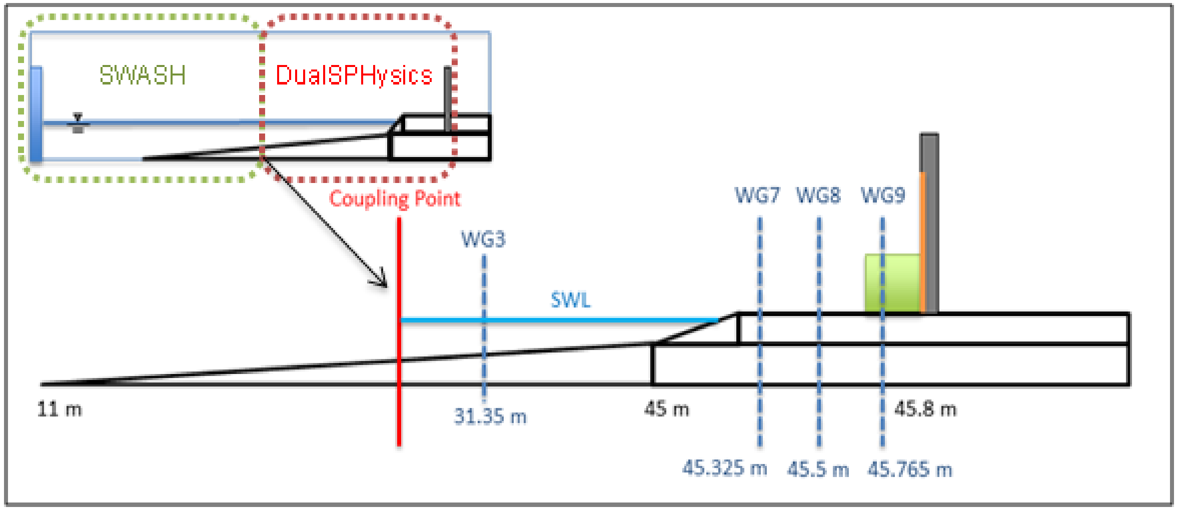
3) Wave impact on buildings in shallow foreshore conditions

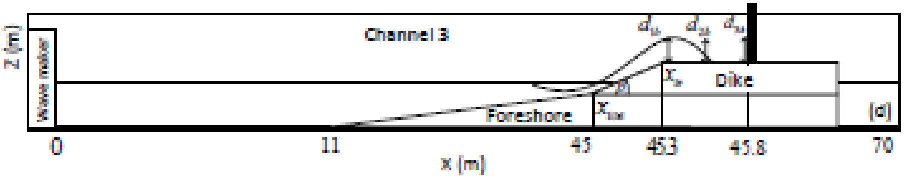


3) Wave impact on buildings in shallow foreshore conditions

Initially, the coupling point to hybridize SWASH and DualSPHysics has been chosen at a distance from the physical wave paddle equal to **30.24 m** because this location corresponds to the position of one of the resistive wave gauges located in the physical flume at Flanders Hydraulics Research.

H_0 = 0.2 m, T_0 = 4 s, h_0 = 1 m





Coastal Engineering 95 (2015) 94–104

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Coastal Engineering

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ELSEVIER

Forces on a vertical wall on a dike crest due to overtopping flow

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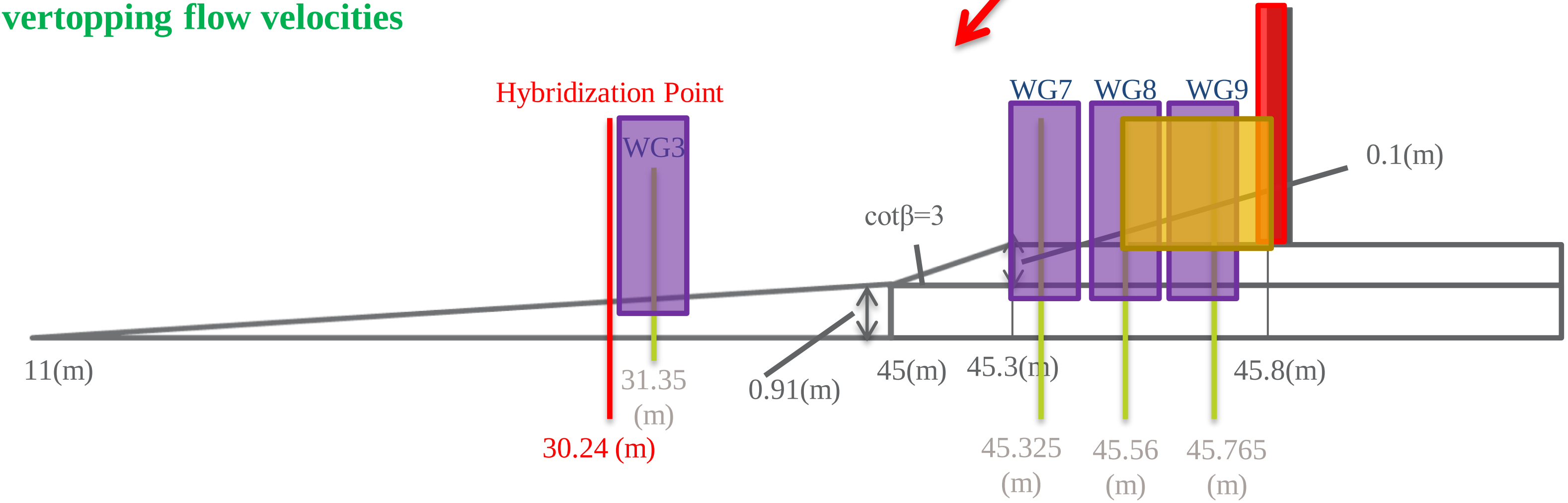
[d] Ghent University, Technologiepark 904, B-9052 Ghent, Belgium

3) Wave impact on buildings in shallow foreshore conditions

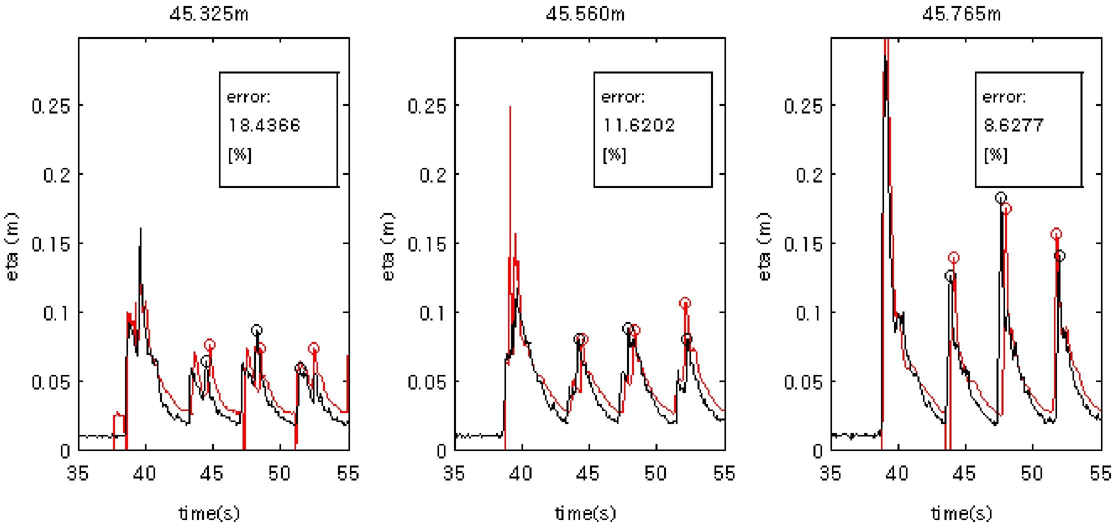
- ◆ Initial hybridization point at x=30.24m.
- ◆ Comparison of numerical results with experimental data (Chen et al., 2015) for sensitivity analysis.
- ◆ Identification of candidate hybridization points to find the best compromise between accuracy and computational cost.

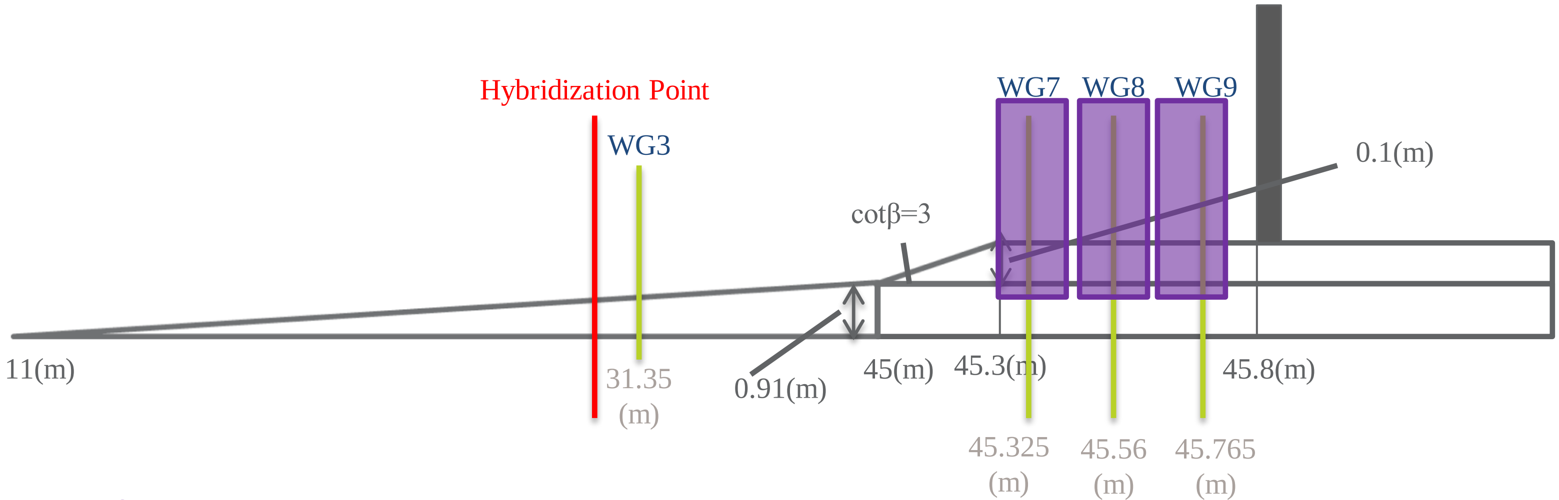
- **Water surface elevation and overtopping layer thickness**
- **Overtopping flow forces**
- **Overtopping flow velocities**



3) Wave impact on buildings in shallow foreshore conditions

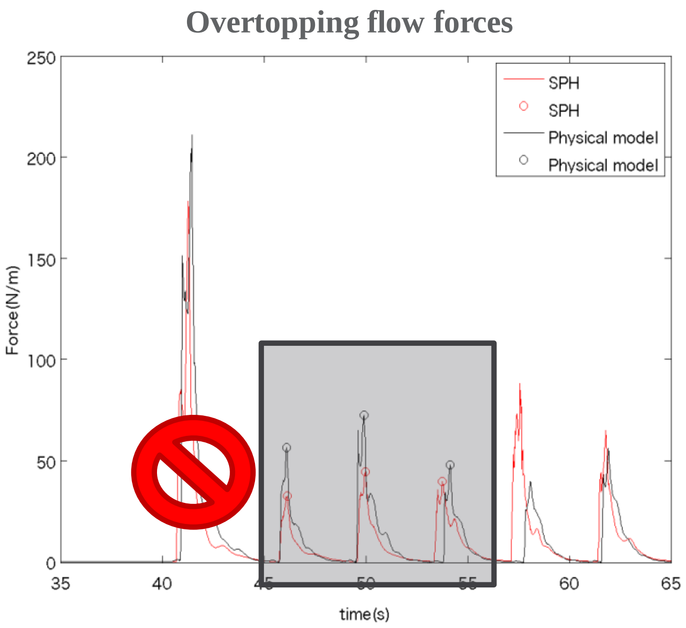
Overtopping layer thickness at WG7, WG8 and WG9

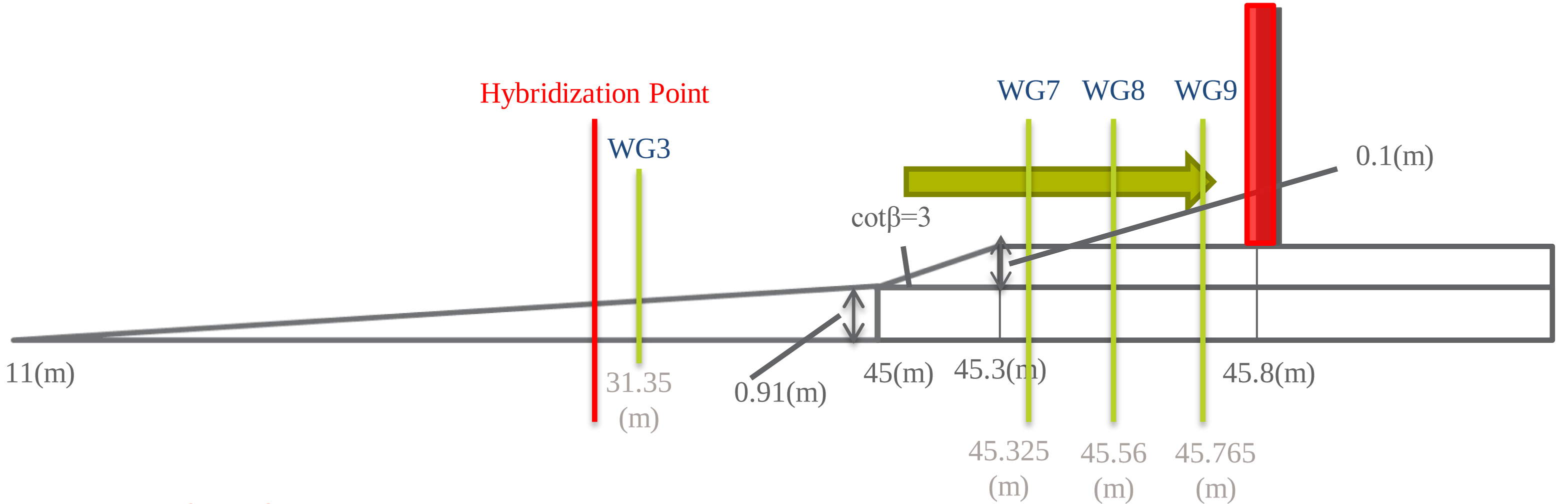




- **Water surface elevation and overtopping layer thickness**

3) Wave impact on buildings in shallow foreshore conditions

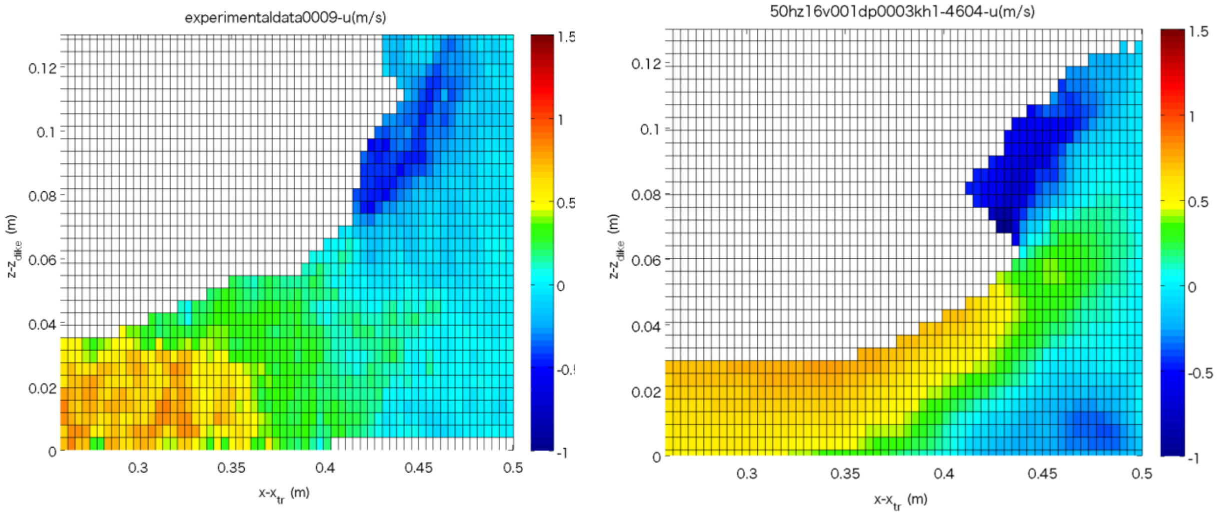

Overtopping flow forces



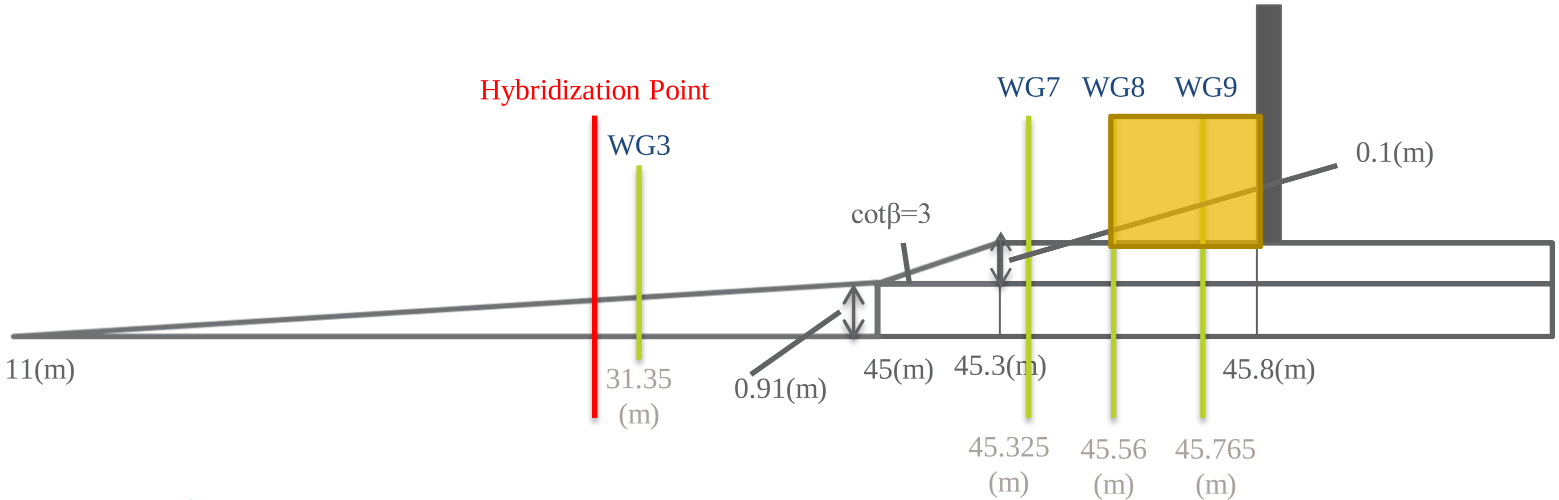
- **Overtopping flow forces**

3) Wave impact on buildings in shallow foreshore conditions

Overtopping flow velocities (preliminary results)



A good compromise between accuracy and run time is found → **≈60% of the physical domain modeled only by using SWASH with speedup of 4-6 times the only DualSPHysics simulation**



- **Overtopping flow velocities**

Let’s go back to Uncertainties…

- Resolution (smoothing length, h)
- Boundary conditions
- WCSPH
- Viscosity
- …….

NUMERICAL

- Wave Generation and Absorption

Wave modelling

- Data used (bathymetry, roughness, waves and WL meas.)
- Stochastic nature of the analyzed phenomena

PHYSICAL, MEASUREMENTS!!

Don’t judge a numerical model without questioning the the physical one!

WAVE GENERATION AND ABSORPTION

Regular waves

Irregular waves (Frigaard et *al.*, 1993)

- **Airy (1st Order)**
- **2nd Order Waves (Madsen, 1971)**

Piston

Flap

- **Passive Absorption (dissipative beach, sponge area)**
- **Active Absorption (Shaffer and Klopman , 2000)**

WAVE GENERATION: IMPLEMENTATION WITH SPH

The wave generation in DualSPHysics mimics the conditions of physical wave facilities.

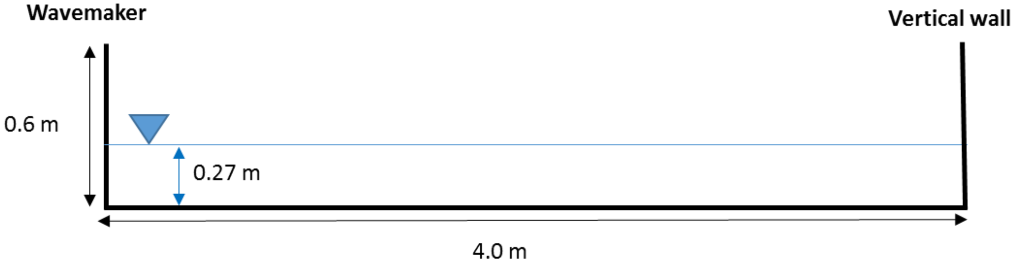
- The wave-maker (piston or flap) consists of a rigid body formed by boundary particles.
- The motion of the wave generator is prescribed controlling its position (linear or angular) at each instant of time.

In this work all the analysis is performed using only the piston-type wave-maker

WAVE GENERATION: RESULTS WITH DUALSPHYSICS

The generated waves are:

- Regular waves: H=0.1m, T=1.3s.
- Irregular waves: H_{m0}=0.1m, T_p=1.3s (JONSWAP spectrum).



Type of paddle: Piston - Regular

Movement direction: (1,0,0)

Depth: 0.266

WaveHeight: 0.1

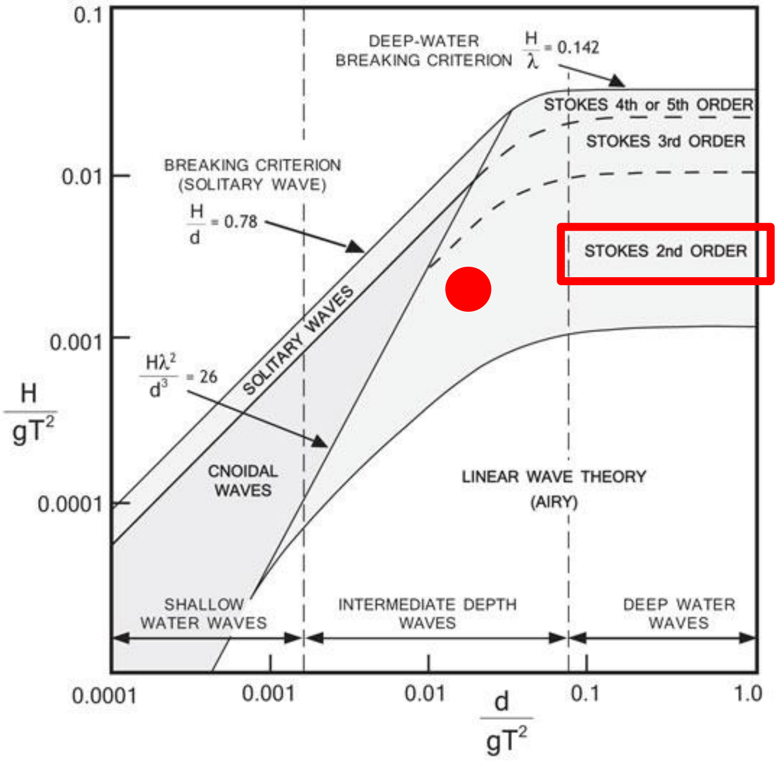
WavePeriod: 1.3

WaveLength: 1.8774

Relative depth (d/L): 0.141685 (Transitional water)

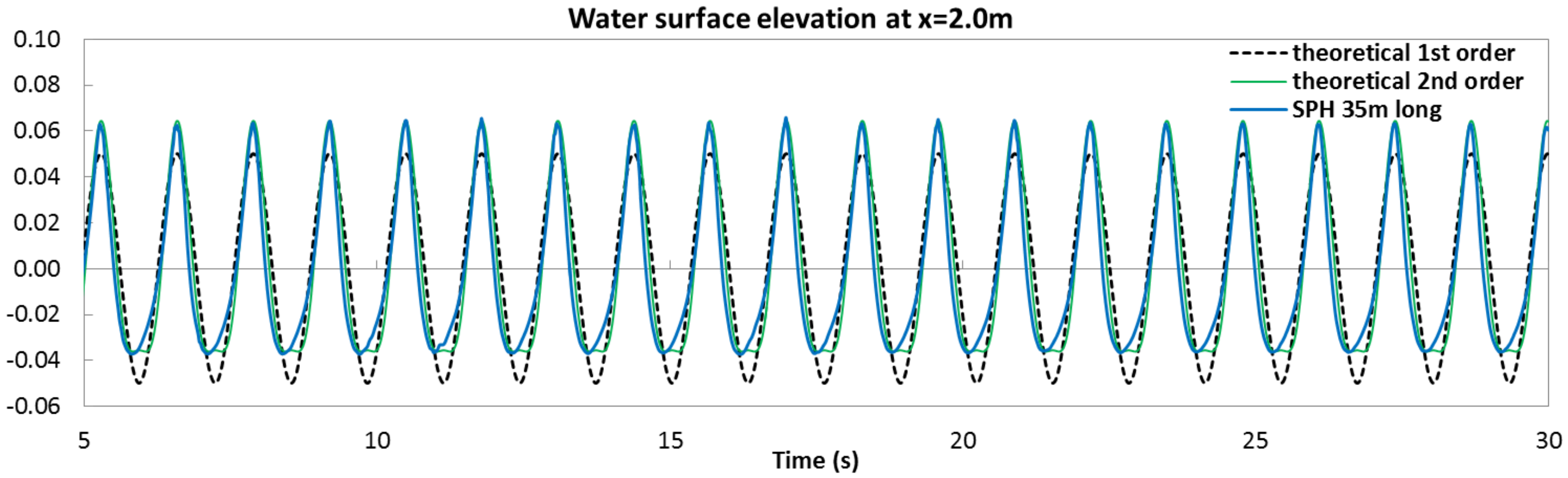
Stroke: 0.113686

Le Mehaute, 1969



Wave Generation: Results with DualSPHysics

Regular waves: *H*=0.1m, *T*=1.3s



Comparison between theoretical and numerical water surface elevation for regular waves.

1st order AIRY
2nd order STOKES

Wave Generation: Results with DualSPHysics

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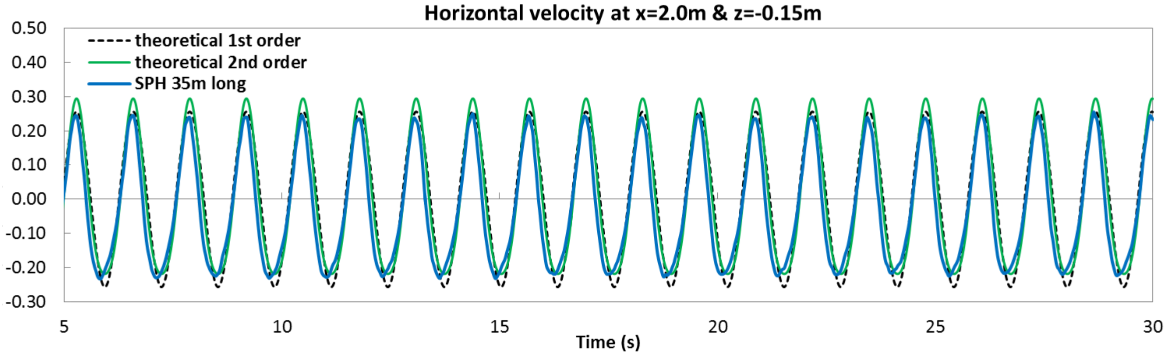
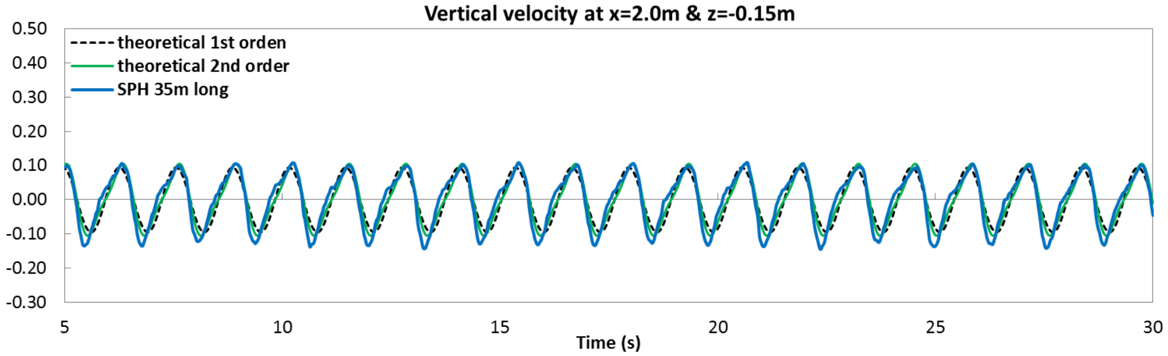
Regular waves: H=0.1m, T=1.3s



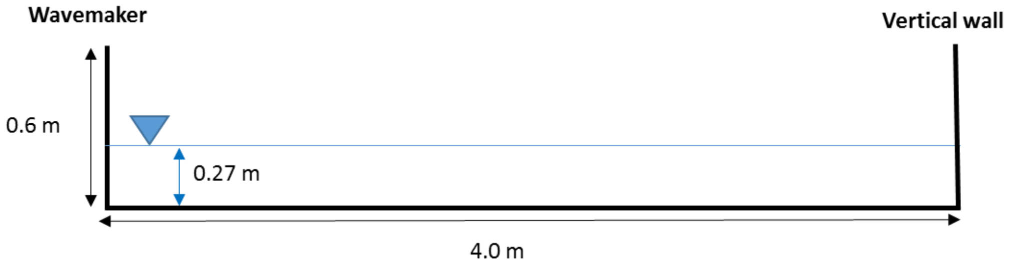


Comparison between theoretical and numerical water surface elevation for regular waves.

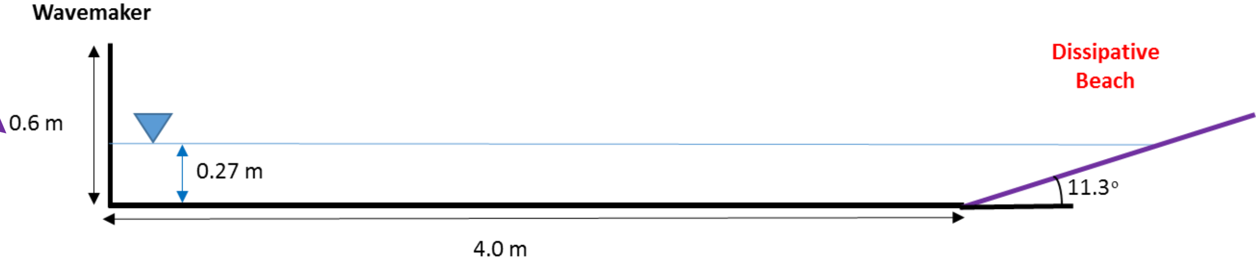
1st order AIRY
2nd order STOKES

PASSIVE WAVE ABSORPTION: IMPLEMENTATION

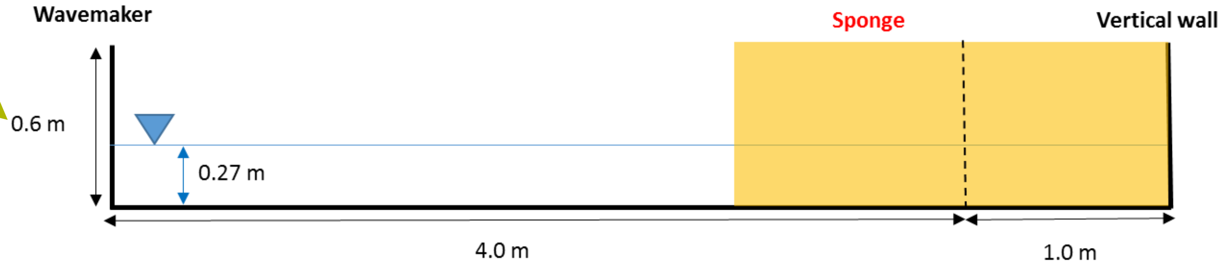
This system can be either:



- dissipative beach



- a “sponge” area



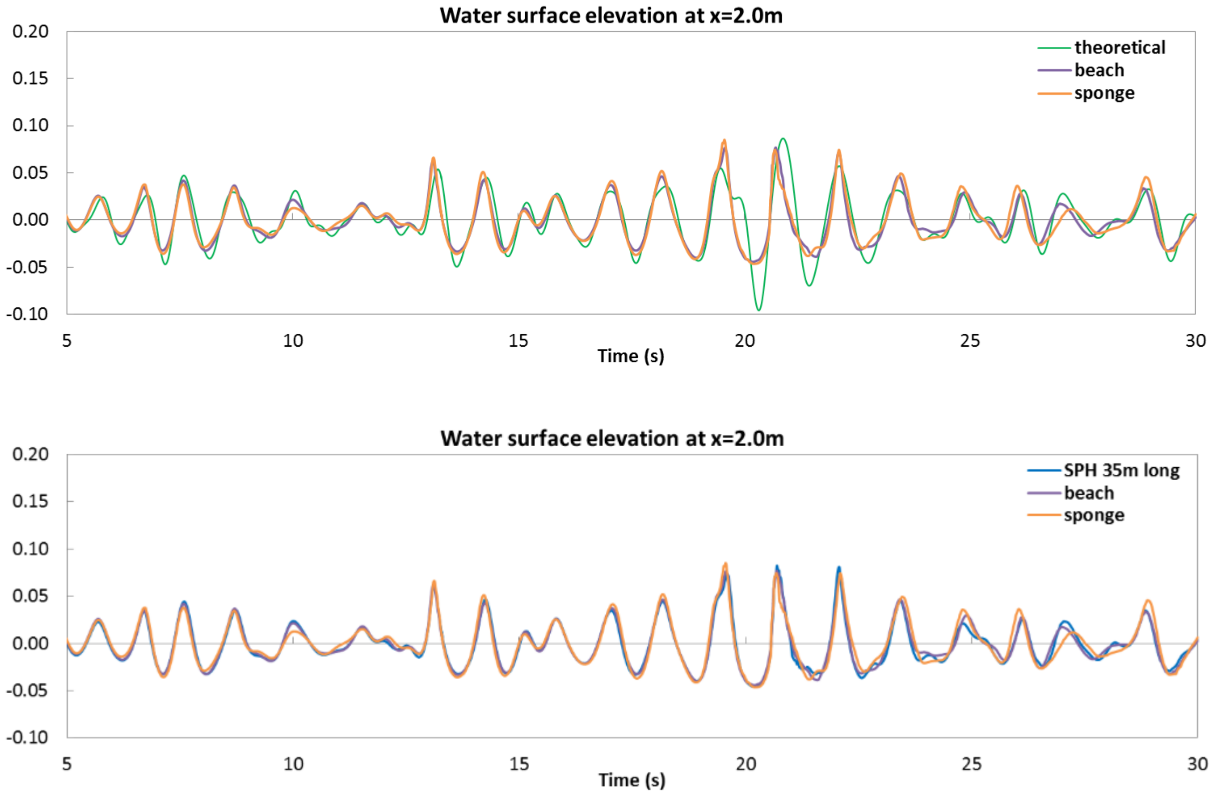
$$v_i^{new} = f(x_i) \cdot v_i$$

$$f(x_i) = min\left(1, \left(1 - \frac{L_s - x_0 - x_i}{L_s}\right)^5\right)$$

applied at each time step

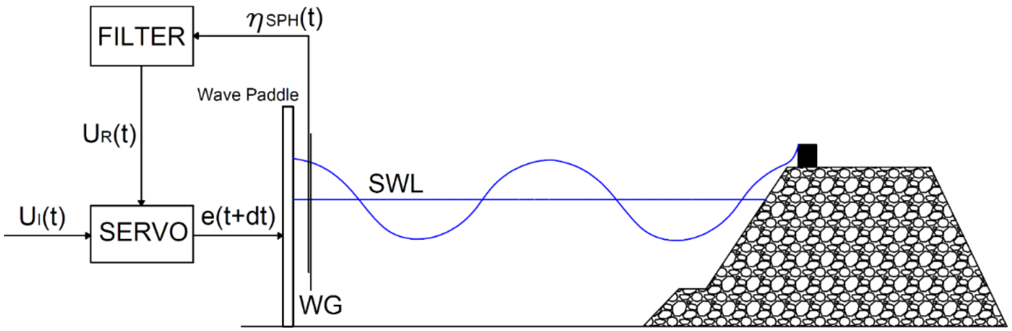
PASSIVE WAVE ABSORPTION: RESULTS WITH DUALSPHYSICS

Irregular waves: H_{m0}=0.1m, T_p=1.3s (JONSWAP spectrum).



Water surface elevation for irregular waves using a dissipative beach and a sponge layer.

ACTIVE WAVE ABSORPTION: *AWAS-η*



$$\eta_R(t) = \eta_I(t) - \eta_{SPH}(t)$$

Reflected wave at $\mathbf{5} * \boldsymbol{dp}$ from the piston

FILTER

$$U_R(t) = \eta_R(t)\sqrt{g/d}$$

Velocity correction (uniform velocity field)

+

$$U_I(t) = \omega \frac{S_0}{2} \sin(\omega t + \delta)$$

Theoretical wave maker velocity

$$U_C(t+dt) = U_I(t) + U_R(t)$$

Corrected wave maker velocity

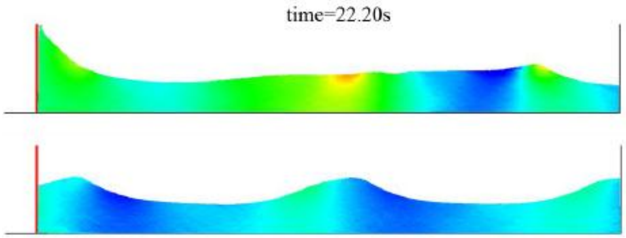
SERVO

$$e(t+dt) = e(t) + (U_C(t+dt) + U_C(t))\frac{dt}{2}$$

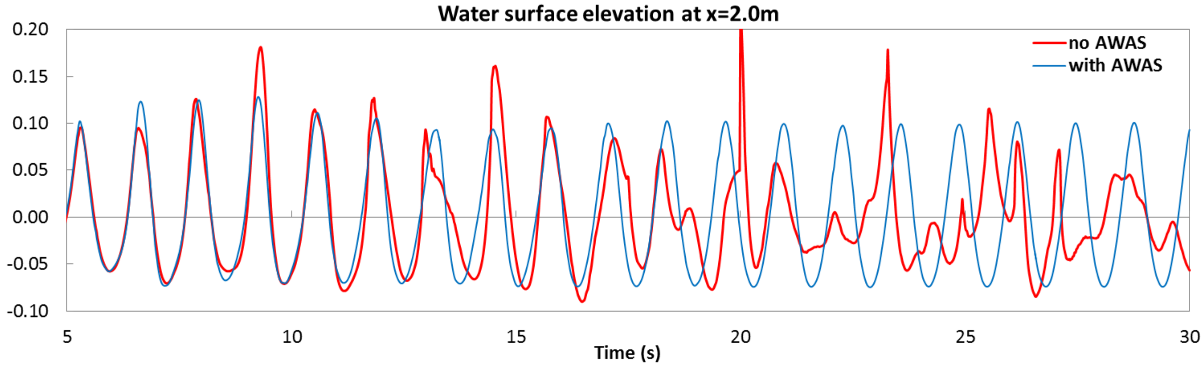
Wave maker position at $\boldsymbol{t+dt}$

(Shaffer and Klopman , 2000)

ACTIVE WAVE ABSORPTION: RESULTS WITH DUALSPHYSICS



Target wave	Absorption	Incident wave height	Wave period
H=0.100m T=1.3s	None	0.118m	1.28s
	AWAS-η	0.105m	1.28s
H_{m0}=0.100m T_p=1.3s	None	0.134m	1.37s
	AWAS-η	0.095m	1.28s



Piston position and water surface elevation for regular waves with and without AWAS.

Accuracy for regular and irregular waves

CONCLUSIONS

- **DualSPHysics is proved to be a reliable tool for Coastal Engineering**

- **Wave run-up, overtopping and forces are accurately modelled.**

- **DualSPHysics has been successful coupled with SWASH model: large domains can be now simulated, with reduced computational cost.**

- **The SWASH+DualSPHysics coupling heighten the capabilities of both models**

- **Wave generation and wave absorption have been implemented in DualSPHysics.**

- **1st and 2nd order wave generation theories, Regular and random waves, Piston and flap**

- **Passive absorption and Active absorption: *AWAS-η***

The new functionalities of DualSPHysics allows studying new engineering problems (->Alex talk)

Particles, "fluids" and violent impacts!

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THANKS