TÉCNICO LISBOA

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

IBERIAN SPH 2015

SPH MODELLING FOR AIR ENTRAINMENT IN WAVE BREAKING

DIOGO R.C.B. NEVES

OBJECTIVES

The work here performed is part of the PhD thesis on "Air entrainment in wave breaking: experimental analysis and numerical modeling"

Experimental

At LNEC in a 32.4 m wave flume (COI3)

Mesurements:

1. Resistive gauges (Free surface Elevations)
2. Conductivity gauges (void fraction)
3. ADV and UVP sensors (Velocity field)
4. High speed video (velocities and void fraction)

Numerical

To use both RANS and SPH models

OpenFoam (RANS)

DualSPHysics (SPH)

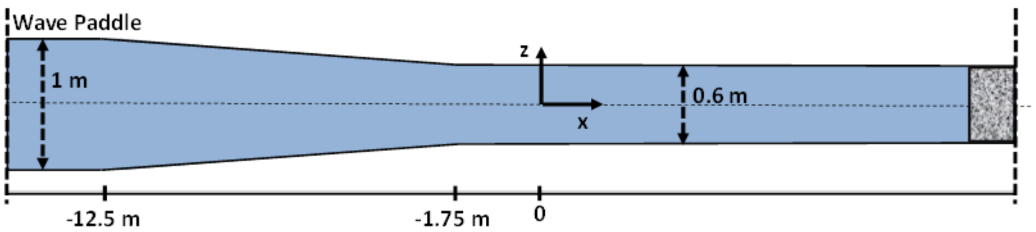
1. Develop numerical tools for wave breaking and air entrainment calculations
2. Numerical results will be validated with experimental data

Wave breaking and Air entrainment

Free surface, velocity field, Wave stresses, Turbulence quantities, Energy dissipation, void fraction

EXPERIMENTAL

Experimental tests will be performed in a 32.4m Wave Flume in LNEC (COI3)

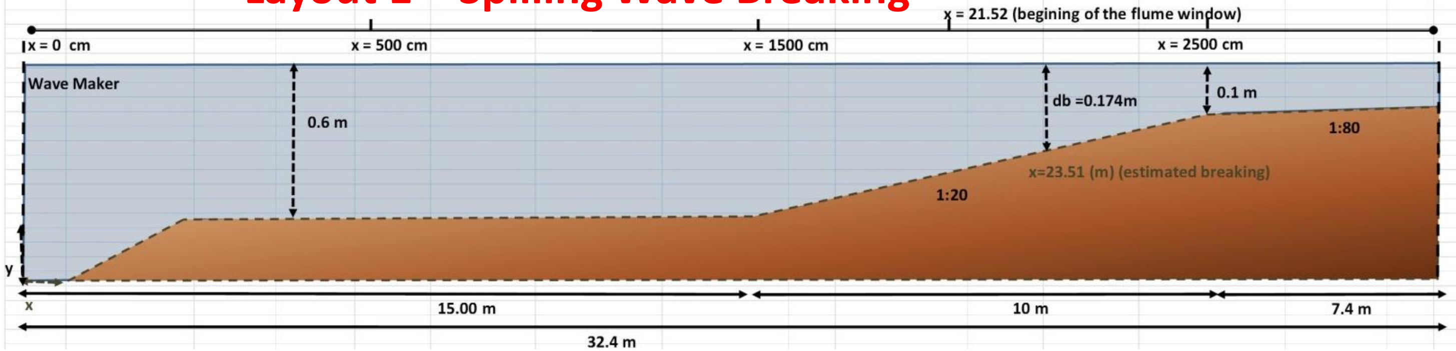


EXPERIMENTAL - NUMERICAL

Two Wave breaking Types will be studied – Spilling and Plunging

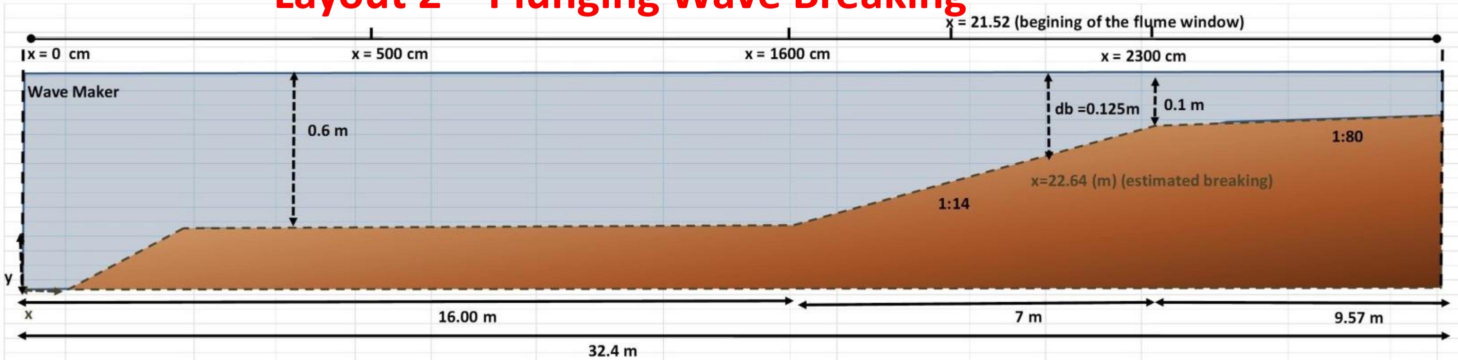
	Period (s)	Generated wave height(m)	Wave lenght (wavemaker) (m)	Main slope	Wave Steepness	Shoalling coefficient	Breaking wave height (m)	Breaking wave depth(m)	breaker depth index	breaker height index	Iribarren	Batjes (1974)	Camenen and Larson (2007)
Layouts	T_o	H_o	L_o	Tan Θ	H_o/L_o	K_s	H_b	d_b	H_b/d_b	H_b/H_o	ξ_o		
1	1.1	0.14	1.83	1.20	0.0765	0.679	0.142	0.174	0.812	1.012	0.181	**Spilling**	**Spilling**
2	4.5	0.1	10.7	1:14	0.0093	0.688	0.154	0.125	1.225	1.537	0.739	**Plunging**	**Plunging**

Layout 1 – Spilling Wave Breaking



- **Spilling break type**
- Main Slope = 1:20
- T_o = 1.1s ; H_o = 0.14m
- d_b = 0.174 m
- ξ_o = 0.181

Layout 2 – Plunging Wave Breaking



- **Plunging break type**
- Main Slope = 1:14
- T_o = 4.5s ; H_o = 0.1m
- d_b = 0.125 m
- ξ_o = 0.739

NUMERICAL MODELLING

Two different numerical models will be applied

OpenFoam

RANS model

Main characteristics:

- Uses VARANS equations
- Finite Volume Method
- Several turbulence models
- Several differencing schemes
- Active absorption of the wave
- Multiphase
- Supports several meshing techniques
- Open Source
- Easily parallelized

DualSPHysics

SPH model

Main characteristics:

- Lagrangian model
- Particle based model
- Solves Navier-Stokes Eqs using SPH method
  - Interpolation kernel
  - Lagrangean form
- Explicit Method
- Uses GPU parallelization
- Open Source
- Easily manages Solid/Fluid Interaction

NUMERICAL MODELLING

Using previous experimental data from wave breaking tests with the same wave flume from Neves et al. (2012)

Objective

Study the wave breaking extension

Measurements

Along the wave flume (25Hz) (simultaneous aquisition):

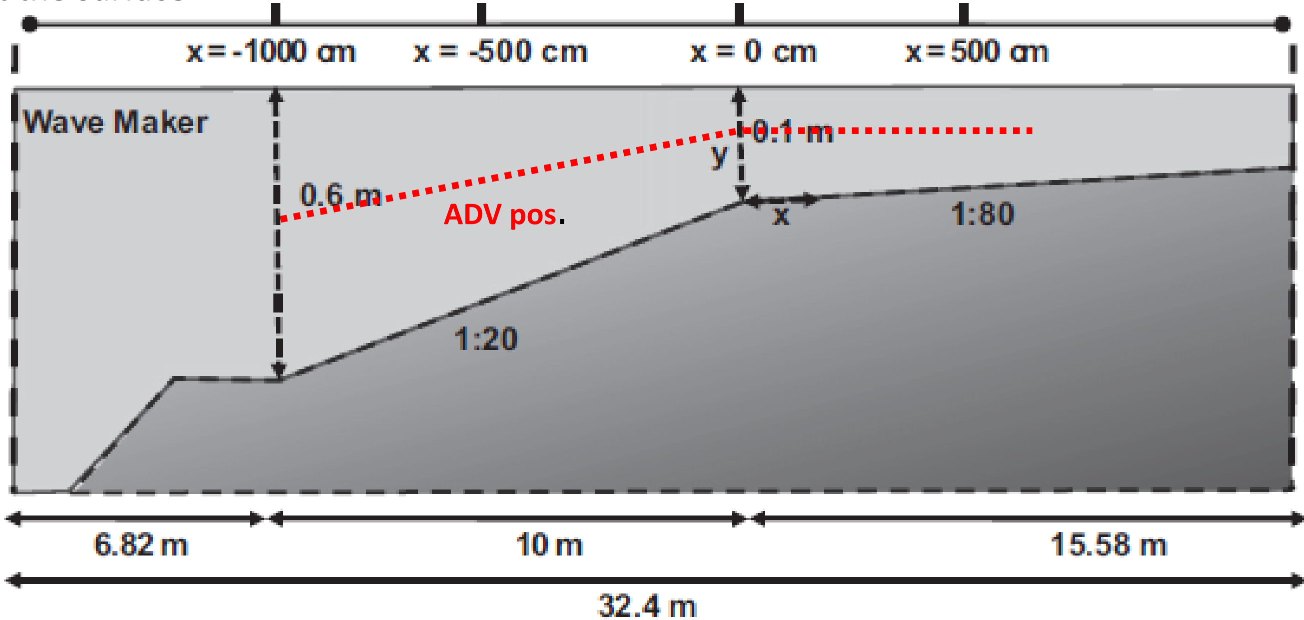
Free surface elevation (resistive wave gauges)

Velocities in the middle of the water column (ADV)

(+u towards de wavemaker)

Visual observation of the beginning and end of the surf zone

Air bubbles appearance at the surface



Generated waves

T = 1.1; 1.5, 2.0, 2.5s

H = 12, 14, 15, 16cm

Test duration

240s

Measurement extension

x=-1080cm and x=560cm

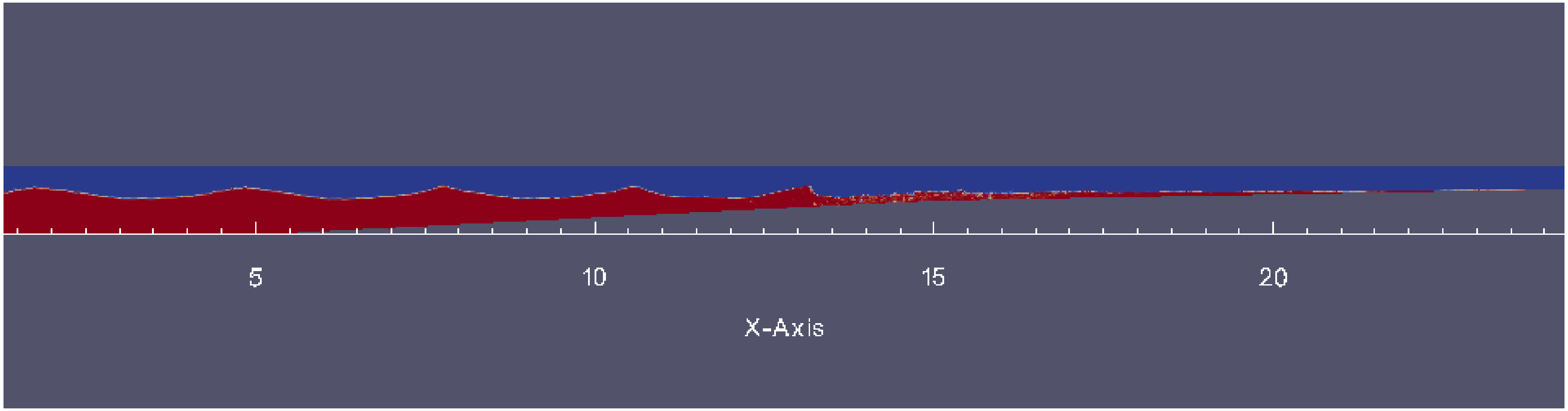
NUMERICAL MODELLING

Using previous experimental data from wave breaking tests with the same wave flume

OpenFoam →

- IHFOAM solver for wave generation (cnoidal theory)
  - Velocity profile imposed
- 2D Mesh with 200000 elements (0.5 mm)
- Using 64 processors ≈1/2 day of calculation
- 60s simulation
- Flume length = 32.4m

T=1.5s H= 14 cm



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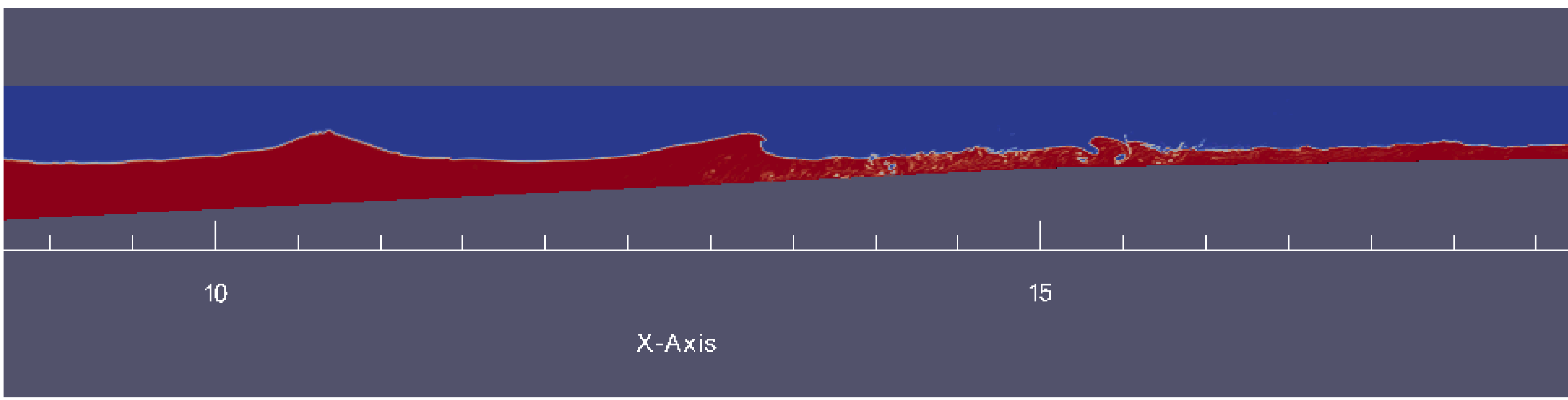


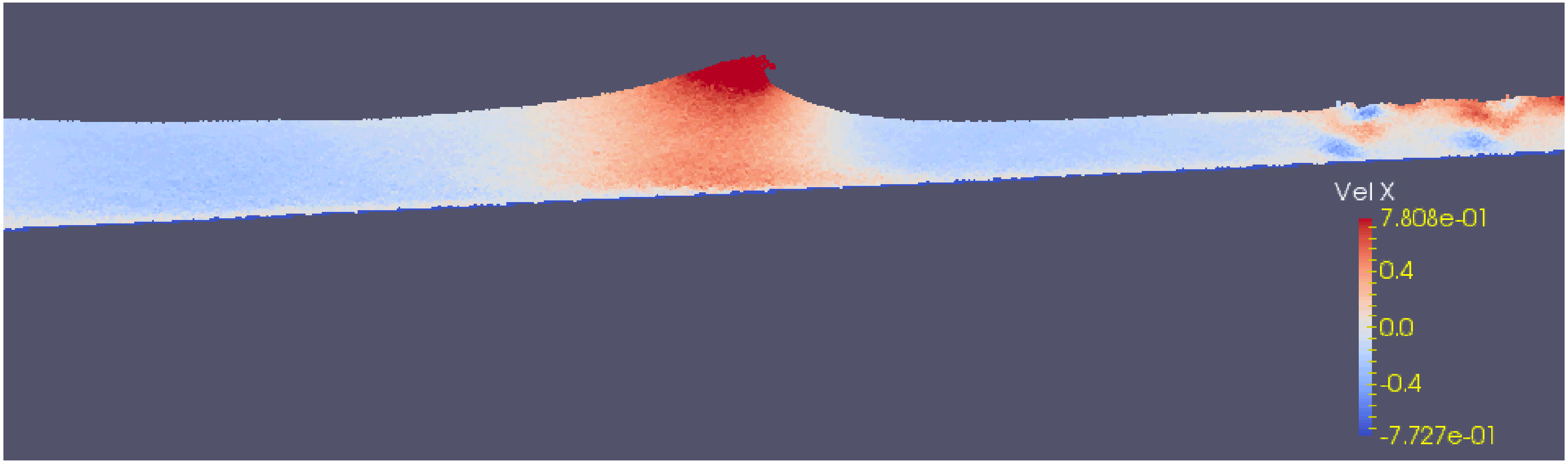
NUMERICAL MODELLING

Using previous experimental data from wave breaking tests with the same wave flume

DualSPHysics

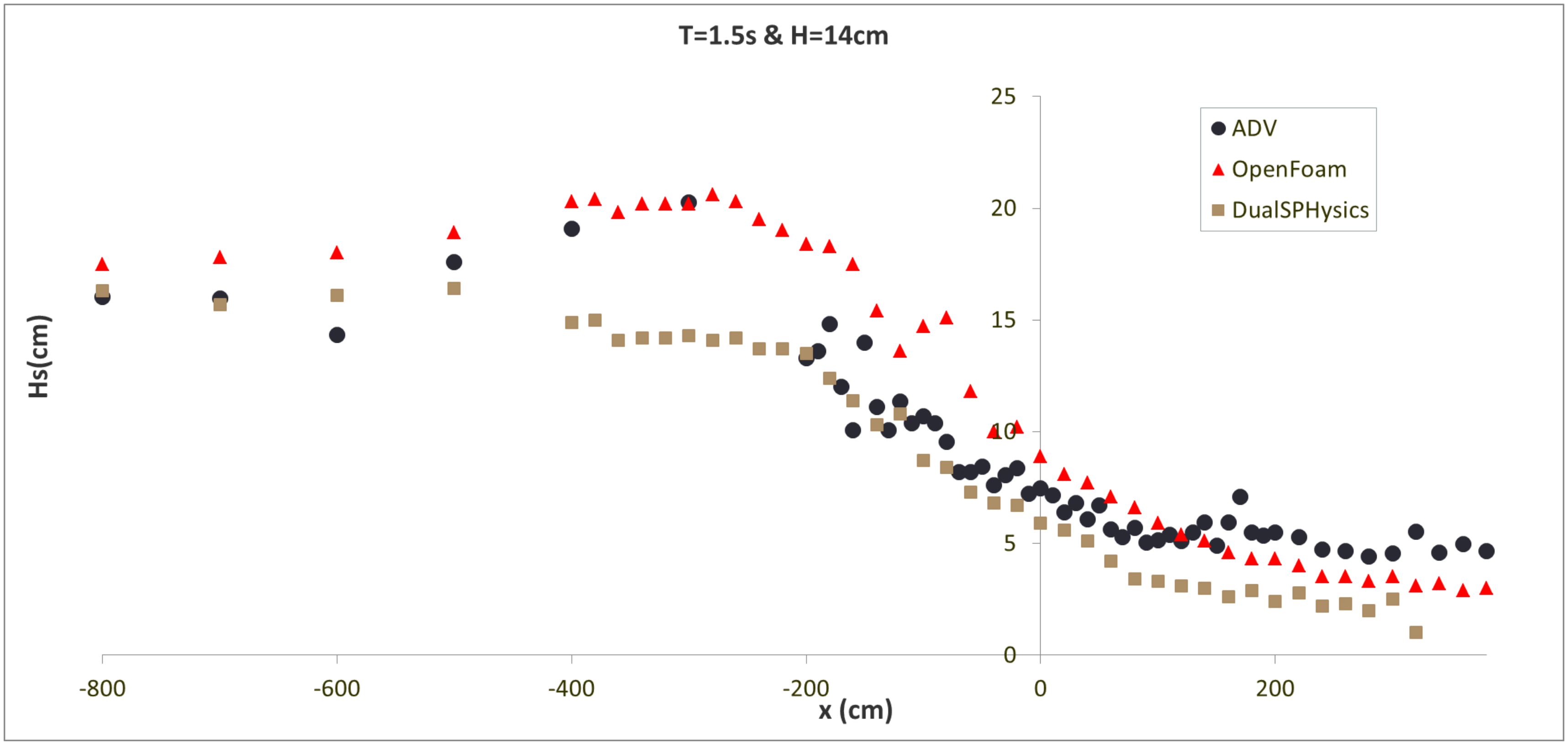
T=1.5s H= 14 cm

- 60s simulation
  - d_0= 0.004286 m
  - Number of particles ≈ 500000
- Without parametrization



NUMERICAL MODELLING

Using previous experimental data from wave breaking tests with the same wave flume



NUMERICAL MODELLING – SPH with air bubbles

Air Entrainment due to Wave breaking is an extremely complex phenomenon

Air Entrainment due to Wave breaking is an extremely complex phenomenon

(Ting & Kirby, 1995)
"The bubble mass in the plunger vortex rises gradually while translates horizontally at velocities below the wave celerity, so that it **appears to move rearward relative to the propagating wave.**"

(Hoque & Aoki, 2008)
"… since **air bubbles are not properly scaled** by the Froude similitude in small-scale models, the effects of air bubbles may have been overlooked in small size experiments."
"… air bubble entrainment–detrainment process itself **contributes greatly to wave energy dissipation** in the surf zone."

(Hoque & Aoki, 2005)
"Studies on surf zone air bubbles are **very limited yet**, probably because the flow fields of broken waves are very complicated after mixing the air bubbles. **It is almost unclear** how these air bubbles affect the fluid motion in the surf zone."

(Mori & Kakuno, 2008)
"qualitative and quantitative bubble characteristics in the surf zone and connections between bubble characteristics and wave breaking are **not well known** owing to the **lack of detail measurements**."

NUMERICAL MODELLING – SPH with air bubbles

Air Entrainment due to Wave breaking is an extremely complex phenomenon

(Hieu, Katsutoshi, & Ca, 2004)
"…The **VOF method** is usually adopted to track the movement of the free surface but the **density difference between liquid and gas is neglected**. As a result, for the case of wave breaking, the trapped air bubbles inside the water and the splashed water in the air **are not fully treated**."; "….The incorporation of the **surface tension** into the model may be necessary for better simulations of air bubbles entrained in the water."

(Bullock, Crawford, Hewson, Walkden, & Bird, 2001)
"Bubbles formed in freshwater tend to be larger than those which occur in seawater and they tend to coalesce more easily. As large bubbles are more buoyant than small bubbles, they rise through the water more rapidly. Consequently, **air can escape more quickly from freshwater than from seawater**."; "…The **physical and chemical properties** of seawater influence the number and size distributions of the bubble population"; "…Temperature, salt concentration, ionic structure and the exudates of marine organisms **were all found to have an effect**."

(Blenkinsopp & Chaplin, 2011)
"bubble size distribution follows a power law with an exponent which decreases with depth."; "that the spectra of bubbles with a **diameter larger than approximately 0.4 mm produced** by wave breaking are **comparable** in freshwater, artificial seawater and natural seawater. However a population of **much smaller bubbles** was also entrained by each breaking event that may **not have been picked up** and which due to its low rise velocity, tends to accumulate over repeated breaking events."

Chanson et al. (2006)
"The results suggest that **classical dimensional analysis is incomplete** and that air entrainment at plunging jets is **affected by physical, chemical, and biological properties other than density, viscosity, surface tension, and salinity**."

Numerical modelling – SPH with air bubbles

DualSPHysics

- Simulations with air bubbles, the bubbles are composed by a set of air particles that are stick together.
- Air Bubbles are defined has floating objects.

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            <rhop0 value="1000" />
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~2000 air bubbles were placed in the wave breaking section

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    </floating>
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    </floating>
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```

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        <PoissonRatio value="0.99" comment="Poisson Ratio (-)" />
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    </property>
</materials>
```

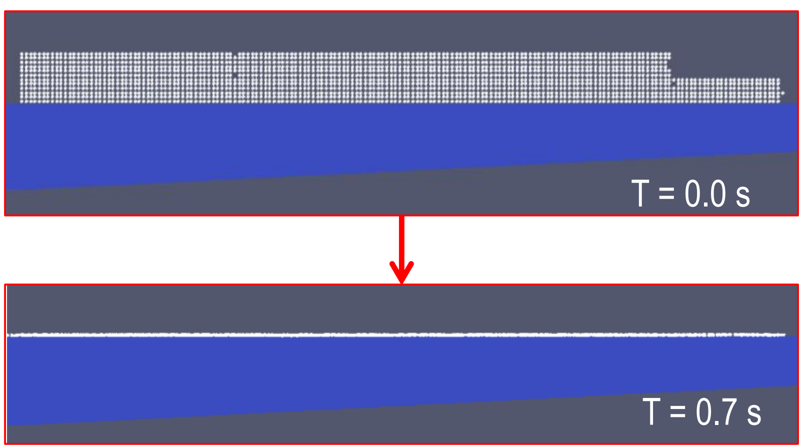

Numerical modelling – SPH with air bubbles

DualSPHysics

- Simulations with air bubbles, the bubbles are composed by a set of air particles that are stick together.
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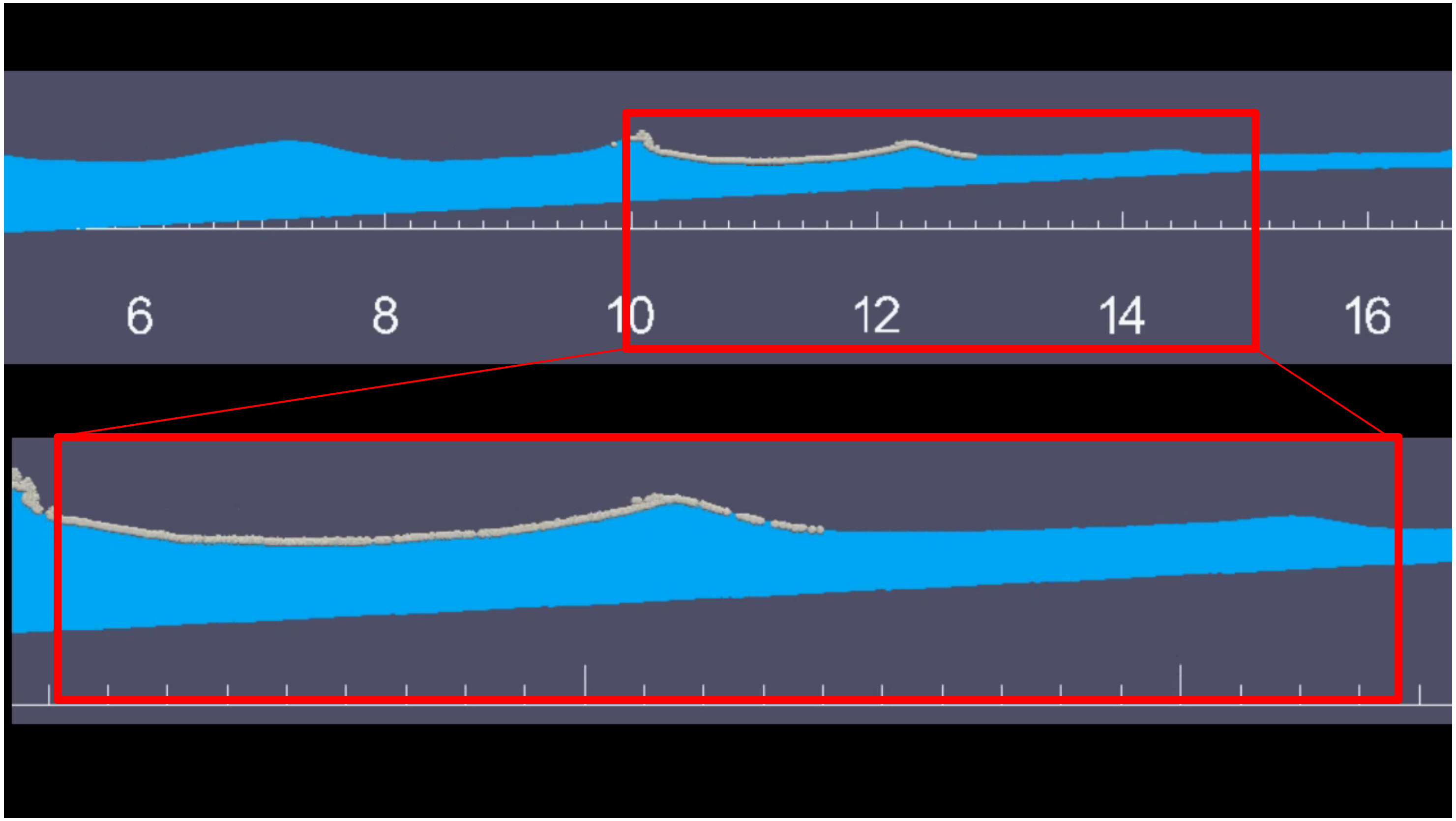
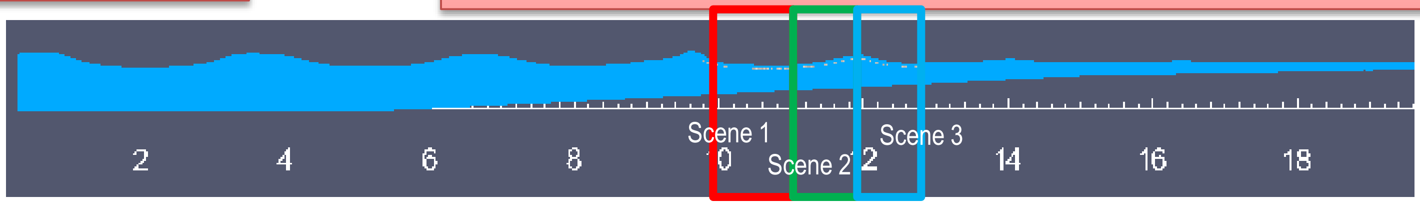
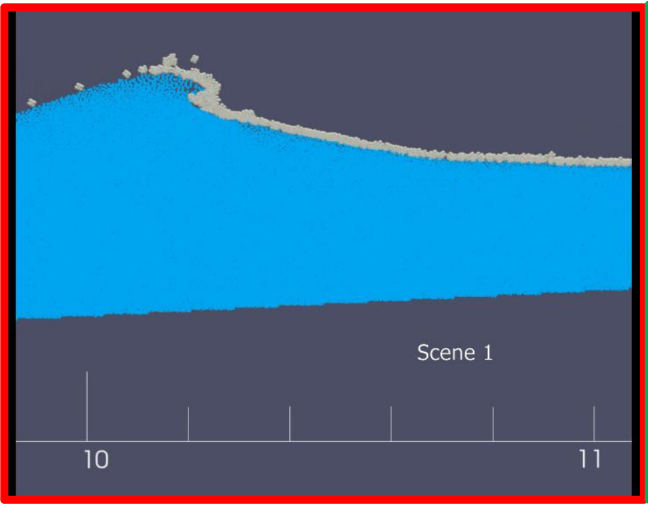


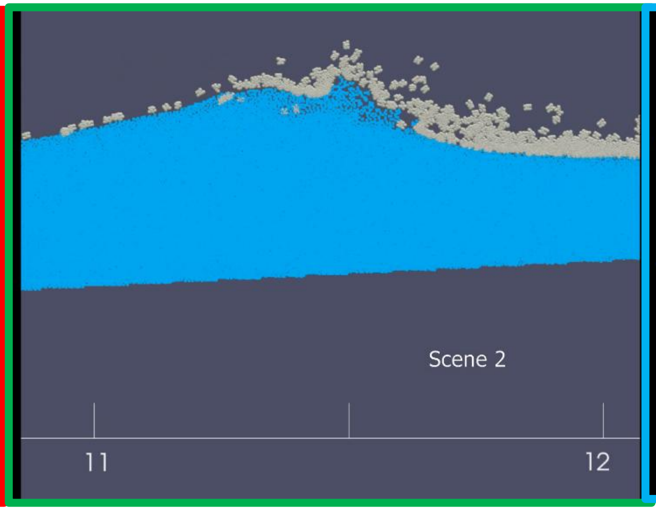
Numerical modelling – SPH with air bubbles

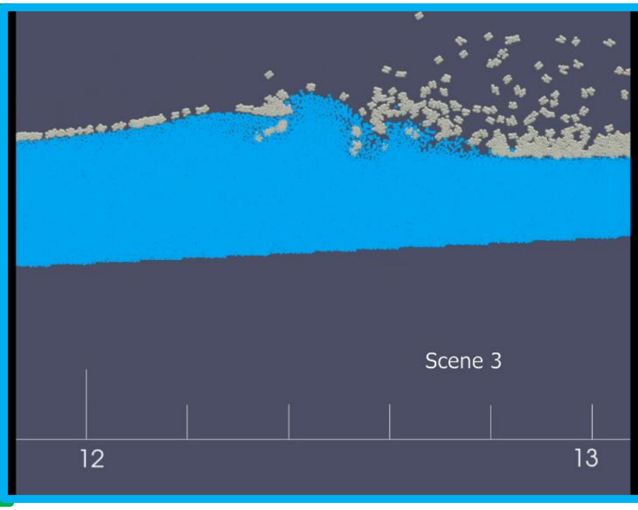
DualSPHysics

- New improvement in SPH: Simulations with air bubbles, the bubbles are composed by a set of air particles that are stick together.
- **Video: Following the first wave**





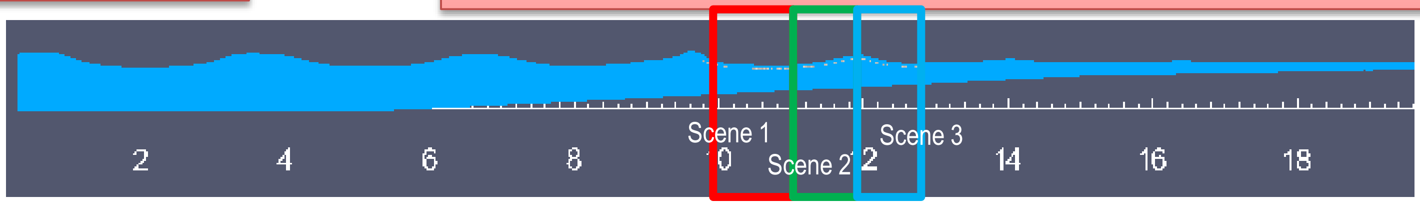


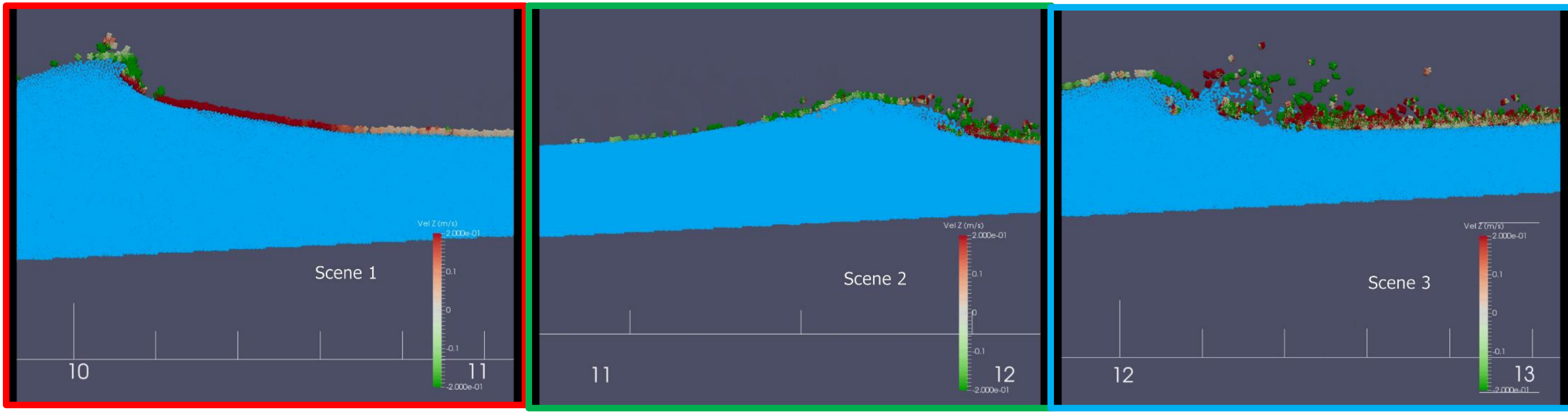


Numerical modelling – SPH with air bubbles

DualSPHysics

- New improvement in SPH: Simulations with air bubbles, the bubbles are composed by a set of air particles that are stick together.
- **<u>Video</u>: Following the first wave (Velocity z)**





Next Steps

DualSPHysics

Next steps:

- Make much more and smaller air bubbles
- Simulate and compare SPH simulations with the experimental tests made in Blenkinsopp & Chaplin (2007)and Blenkinsopp & Chaplin (2011)

Blenkinsop, C. E., & Chaplin, J. R. (2007). Void fraction measurements in breaking waves, (December 2007). http://doi.org/10.1098/rspa.2007.1901

Blenkinsopp, C. E., & Chaplin, J. R. (2011). Void fraction measurements and scale effects in breaking waves in freshwater and seawater. *Coastal Engineering*, *58*(5), 417–428. http://doi.org/10.1016/j.coastaleng.2010.12.006

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