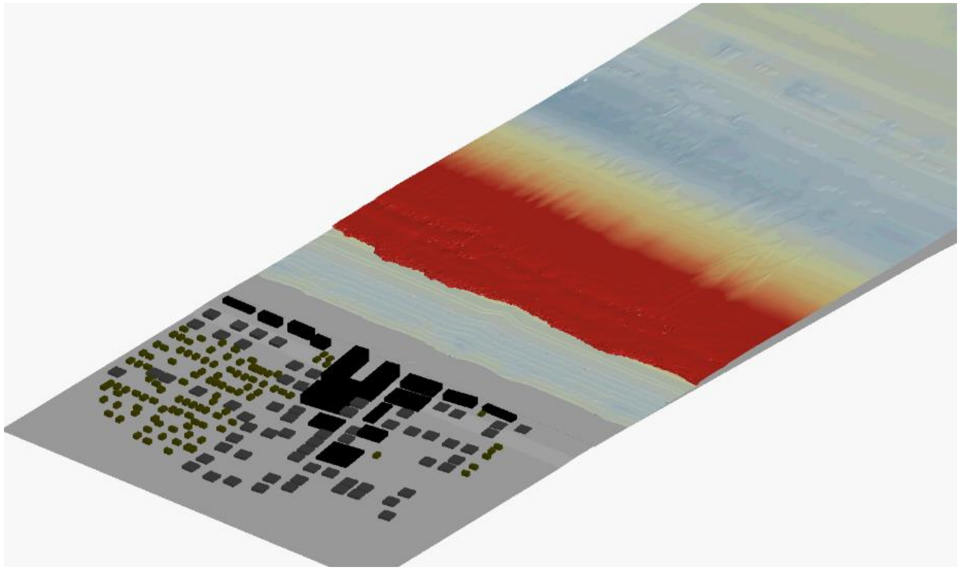
Tsunami coastal impact

The use of VOF-URANS methods with examples

Richard MARCER



Content

- Coastal impact : physics to simulate
- EOLE CFD : a 3D Navier-Stokes code
- Focus on the VOF free surface method
- Examples of validations on academic tsunami test-cases

Coastal impact of a tsunami

- **Complex physics to simulate**
  - **3D**
  - **Breaking**
    - Two-phase flow with possible complex interface
    - Entrapped air bubbles
    - Emulsion (mixing of water and bubbles)
    - Turbulence
  - **Flooding**
    - Friction on bottom, roughness
  - **Fluid / structure interactions**
    - Hydrodynamic loads on structures
    - Possible collapse of the structures
    - Debris moving in the flow

Example of VOF-URANS CODE

EOLE CFD code developed by PRINCIPIA

- Navier-Stokes multi-phase flows
- Structured curvilinear multi-block meshes
- Pseudo-compressibility method
- Dual time stepping
- Second order finite volume
- VOF free surface method
  - Implicit (no CFL constraint)
  - 2 methods
    - Eulerian ("mass" conservation equation)
    - Lagrangian
- Turbulence: 2-equations models (k-ε, k-ω, SST)
- Coupling fluid / structure (rigid body)

EOLE CFD code

- **System of Navier-Stokes equations**

$$\frac{1}{J}\frac{\partial W}{\partial t}+\frac{\partial F}{\partial \xi}+\frac{\partial G}{\partial \eta}+\frac{\partial H}{\partial \chi}=\frac{R}{J} \qquad W=\begin{pmatrix}0\\ \rho u\\ \rho v\\ \rho w\end{pmatrix}$$

  - **Flux terms**

$$F=\frac{1}{J}\begin{pmatrix}\rho\tilde{u}\\ \rho\tilde{u}u+\xi_x p-\vec{\nabla}(\xi).\vec{\tau}_x\\ \rho\tilde{u}v+\xi_y p-\vec{\nabla}(\xi).\vec{\tau}_y\\ \rho\tilde{u}w+\xi_z p-\vec{\nabla}(\xi).\vec{\tau}_z\end{pmatrix};G=\frac{1}{J}\begin{pmatrix}\rho\tilde{v}\\ \rho\tilde{v}u+\eta_x p-\vec{\nabla}(\eta).\vec{\tau}_x\\ \rho\tilde{v}v+\eta_y p-\vec{\nabla}(\eta).\vec{\tau}_y\\ \rho\tilde{v}w+\eta_z p-\vec{\nabla}(\eta).\vec{\tau}_z\end{pmatrix};H=\frac{1}{J}\begin{pmatrix}\rho\tilde{w}\\ \rho\tilde{w}u+\chi_x p-\vec{\nabla}(\chi).\vec{\tau}_x\\ \rho\tilde{w}v+\chi_y p-\vec{\nabla}(\chi).\vec{\tau}_y\\ \rho\tilde{w}w+\chi_z p-\vec{\nabla}(\chi).\vec{\tau}_z\end{pmatrix}$$

  - **External force**

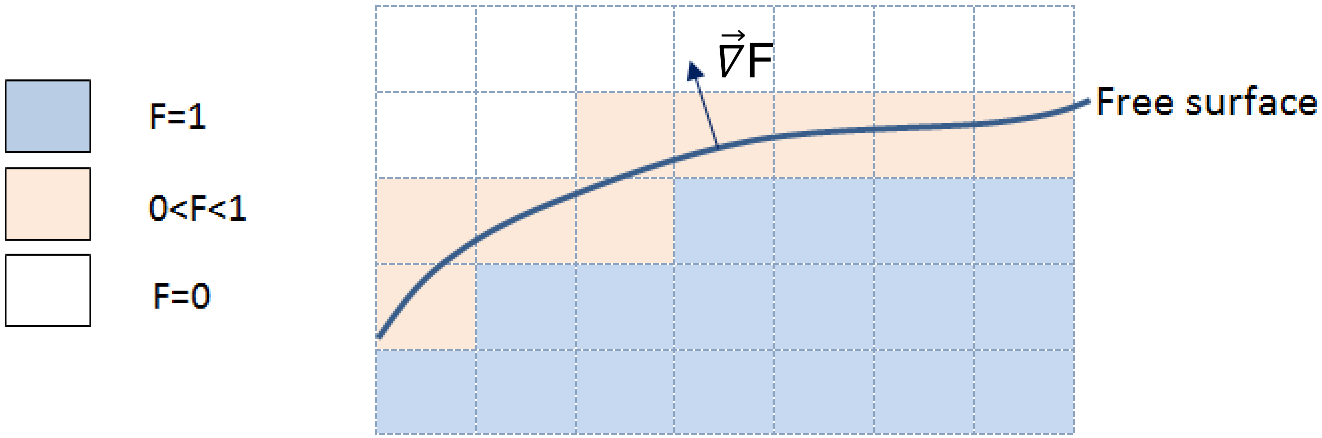
$$R=\begin{pmatrix}0\\ \rho f_x\\ \rho f_y\\ \rho f_z\end{pmatrix}$$

  - **Contravariant velocity components (curvilinear meshes)**

$$\tilde{u}=\xi_x u+\xi_y v+\xi_z w\,;\,\tilde{v}=\eta_x u+\eta_y v+\eta_z w\,;\,\tilde{w}=\chi_x u+\chi_y v+\chi_z w\,;\,J=\frac{\partial(\xi,\eta,\chi)}{\partial(x,y,z)}$$

VOF interface model - concept

- **Two-phase flow with separated phases (interface)**
- **Each cell of the mesh is characterized by the volume fraction of the phase 1 with respect to phase 2 (discrete function F*)***
  - **F=1 : phase 1 (liquid)**
  - **F=0 : phase 2 (air)**
  - **0<F<1 : cells containing an interface phase 1 / phase 2**
  - **Position of the interface determined from the computation of the normal**



Interface advection

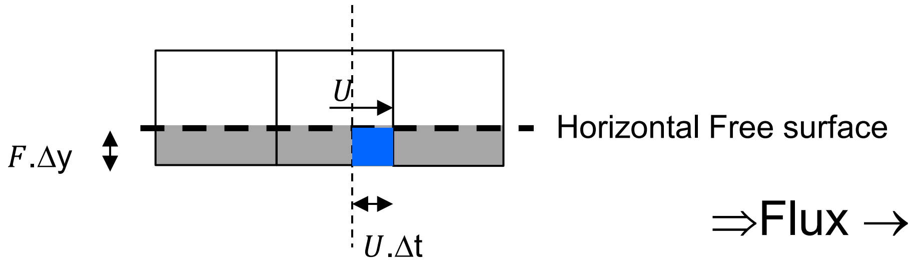
- **Eulerian : conservation equation of the VOF function (F)**

$$\frac{\partial F}{\partial t} + div\left[\rho\left(\vec{U} - \vec{W}\right)\right]F = 0$$

$\vec{U}$ = interface velocity

$\vec{W}$ = grid velocity

  - **Fluxes computation based on a “simplified” representation of the interface slope in each cell**
  - **Example:**

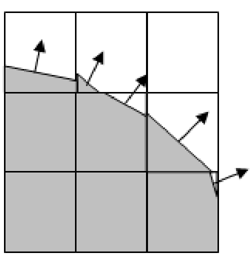


$\Rightarrow$ Flux $\rightarrow F.\Delta y.\ U.\Delta t$

- **Lagrangian (SLVOF)**
  - **Based on more realistic representation of the slope**

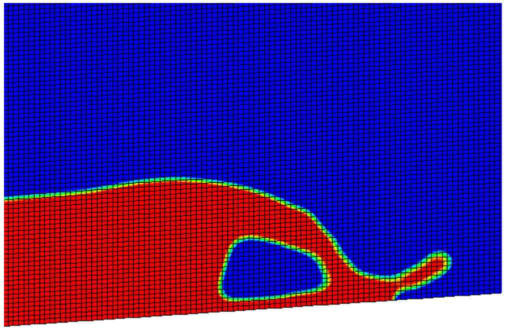
0.3	0.1	0
1	0.8	0.4
1	1	0.9

a :Values of C in each cell



b :PLIC model

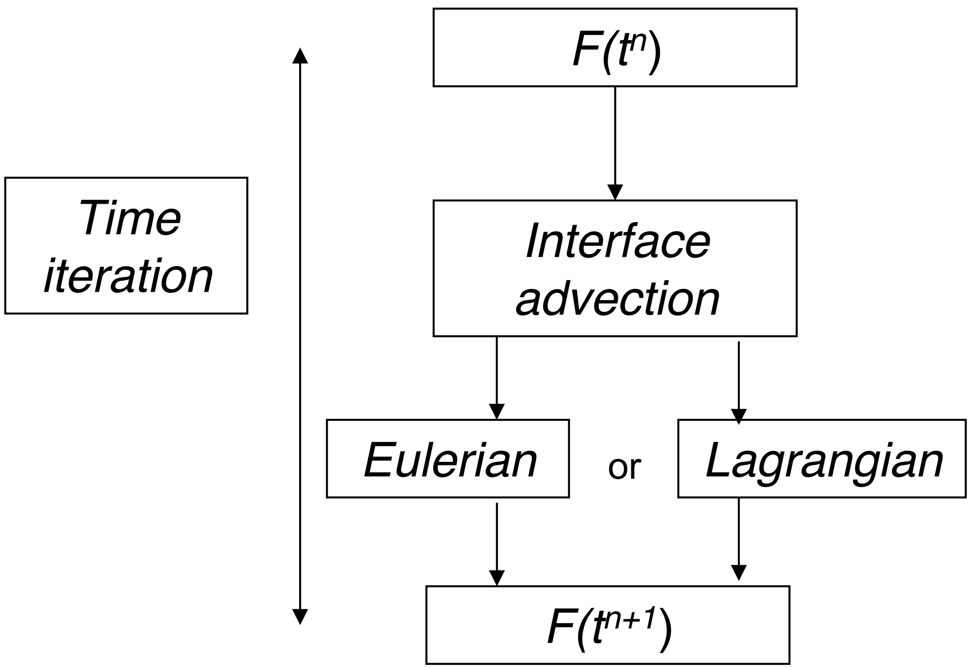
VOF model algorithm



water: $F(t^n)=1$

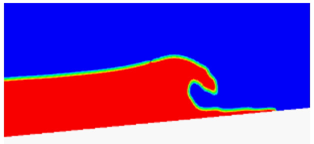
air: $F(t^n)=0$

interface water / air
$0<F(t^n)<1$

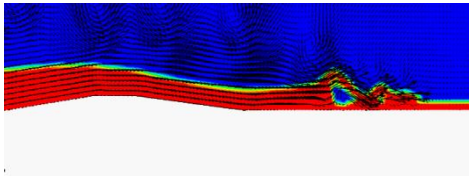


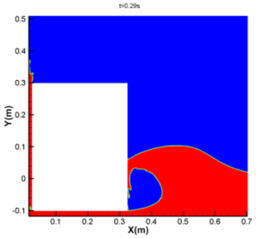
Examples of CFD validations on Tsunami academic cases

- **Solitary wave breaking on a slope**

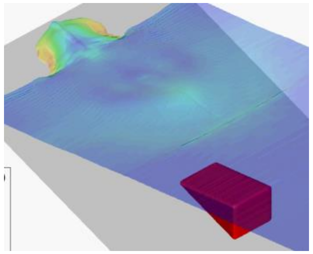


  - Solitary wave on a 2D vertical reef

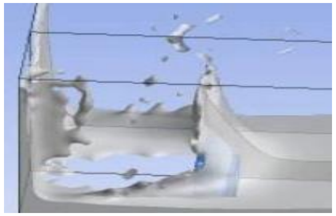




- **Russel's wave generator**

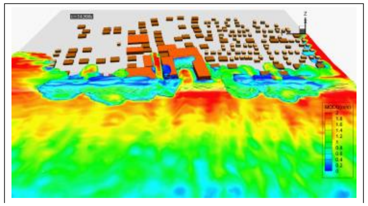


  - Wedge sliding down a 3D slope



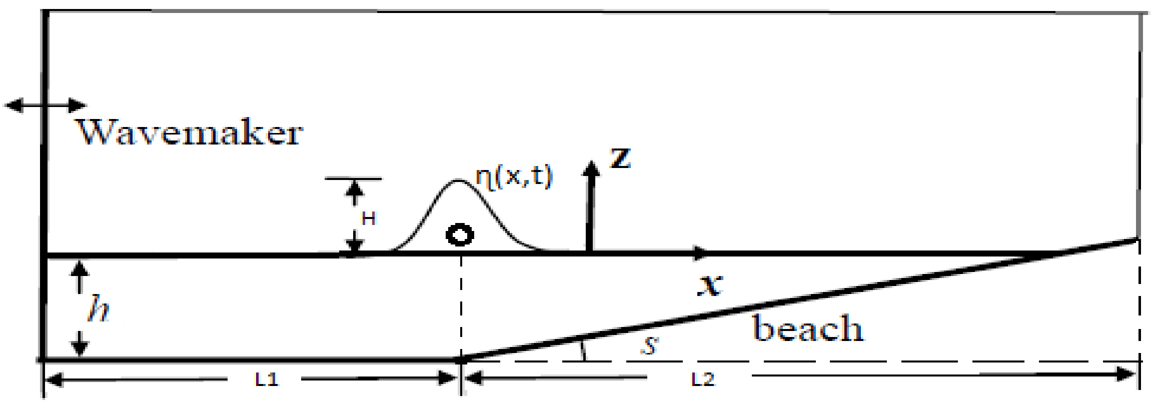
- **Dam break with structure impact**

  - Impact of a tsunami on a urban area



Breaking of a tsunami wave on a constant slope

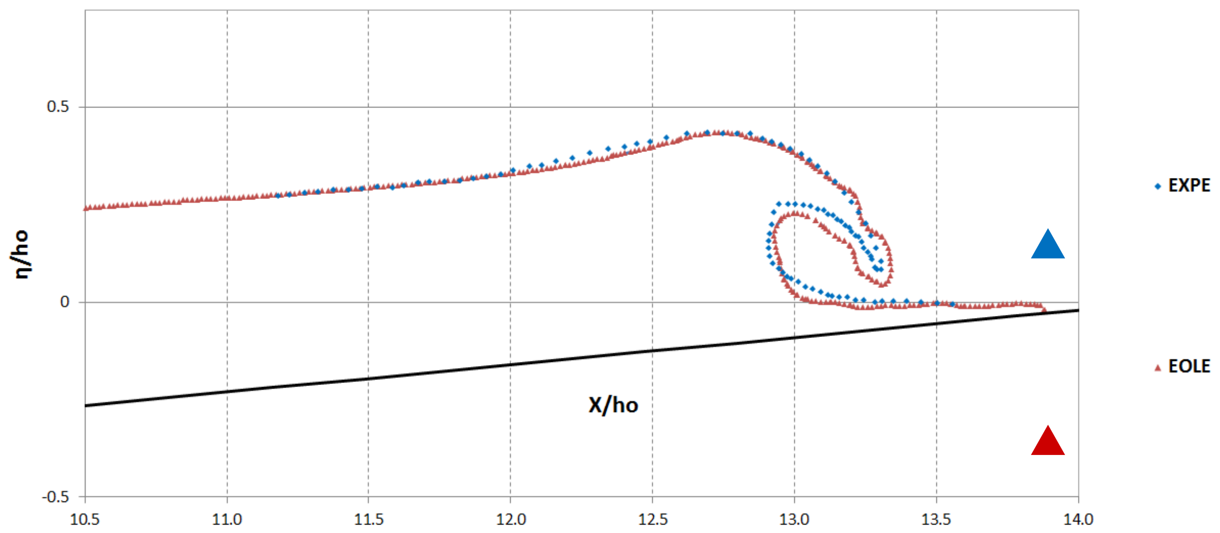
- **Slope 1/15**
- **Solitary wave**
- **Wave amplitude = 0.45 h (h=depth of the channel)**
- **Visualizations of free surface at different instants of the breaking**

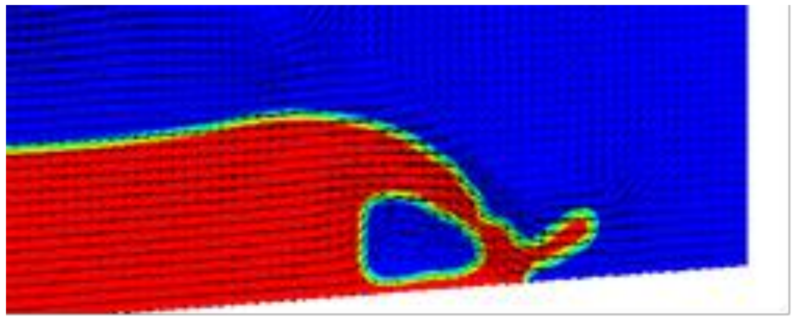


Li and Raichlen, 1998

Breaking of a tsunami wave on a constant slope

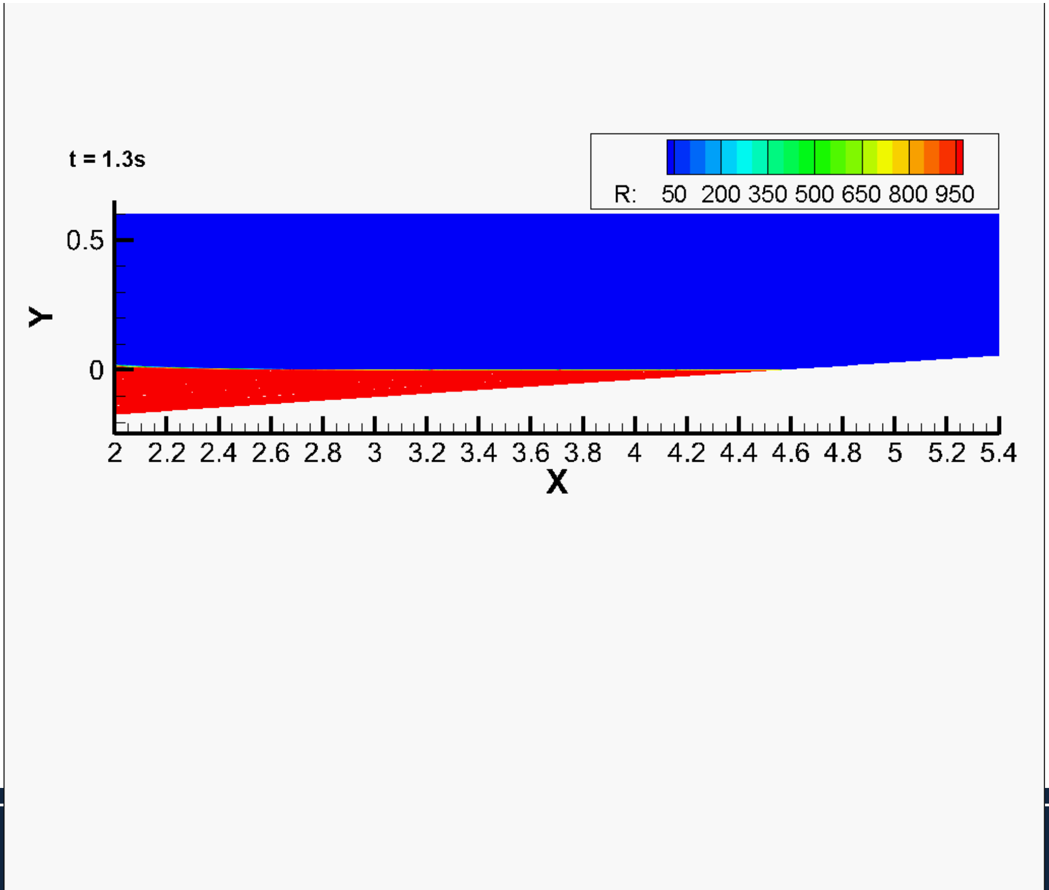
- Simulation with EOLE
  - Plunging wave
  - Splash-up





Breaking of a tsunami wave on a constant slope

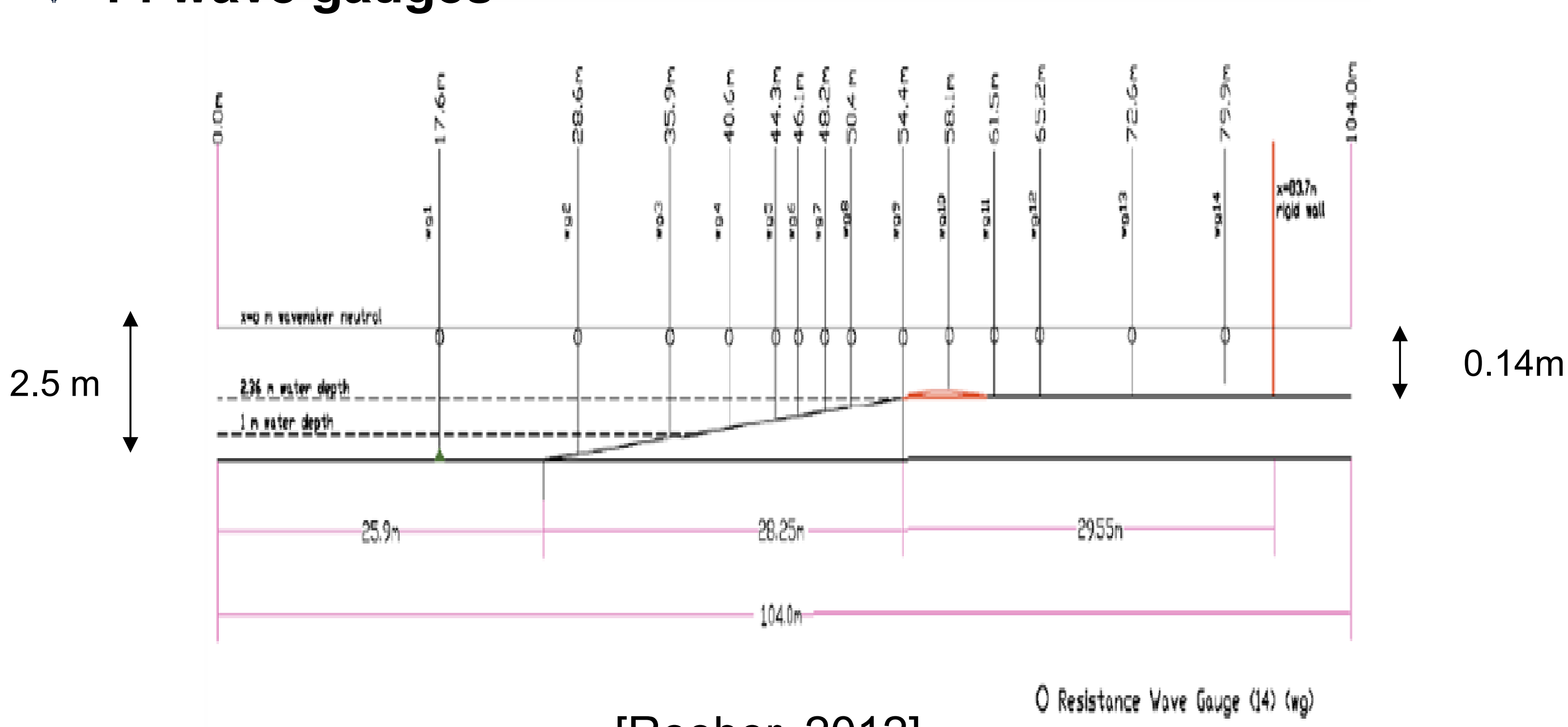
- **Comparison with the code EOLENS (Principia / IMATH)**
  - **Unstructured meshes**
  - **Free surface : color function (not VOF)**
  - **Adaptative mesh**
  - **Compression interface model (possible)**



PRINCIPIA

Solitary wave on a 2D reef

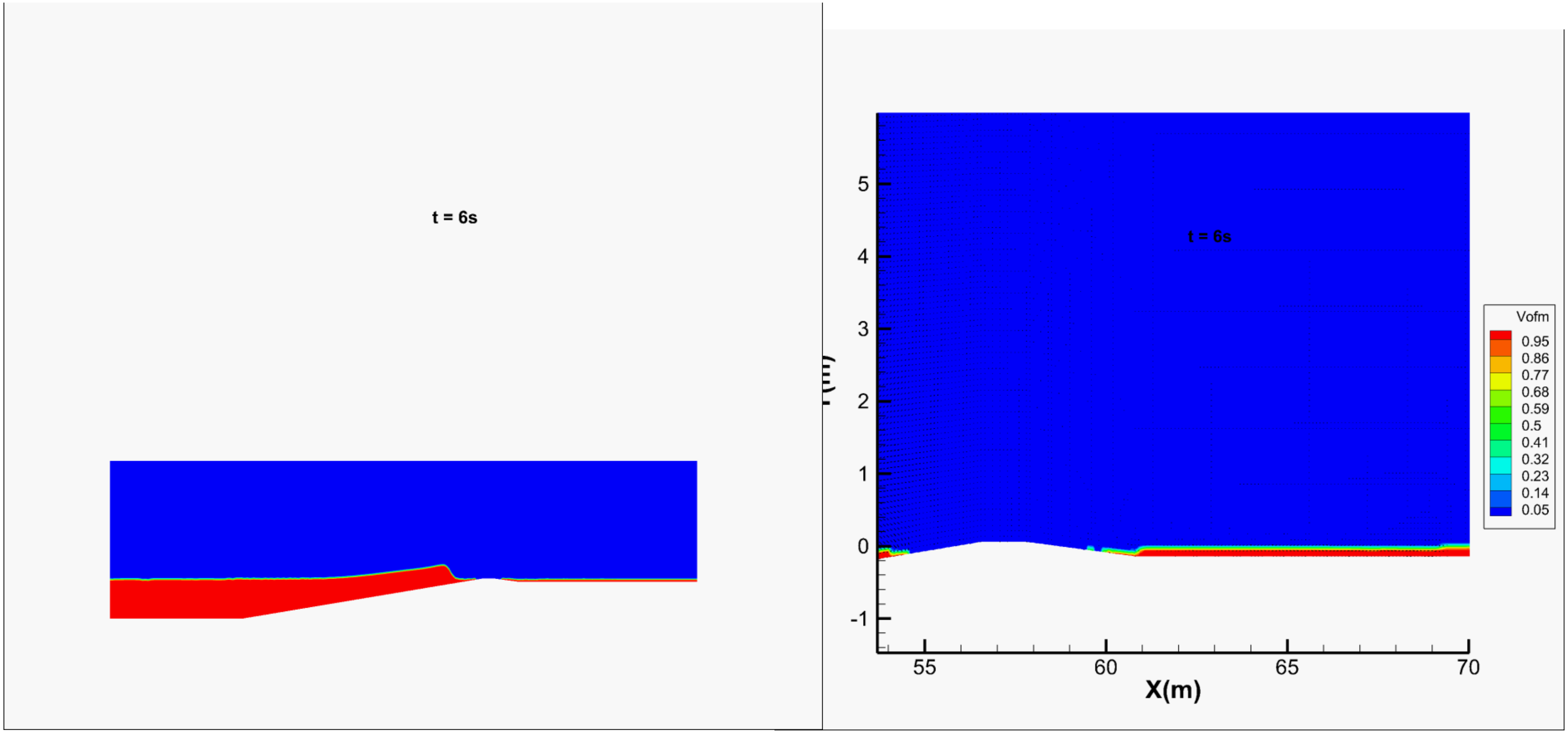
- Emerged reef (initially)
- Propagation, run-up, overtopping, bore and reflection
  - Solitary wave
  - A/h0 = 0.3 (with h0=2.5m)
- 14 wave gauges



[Roeber, 2012]

Solitary wave on a 2D reef

- **Movies**



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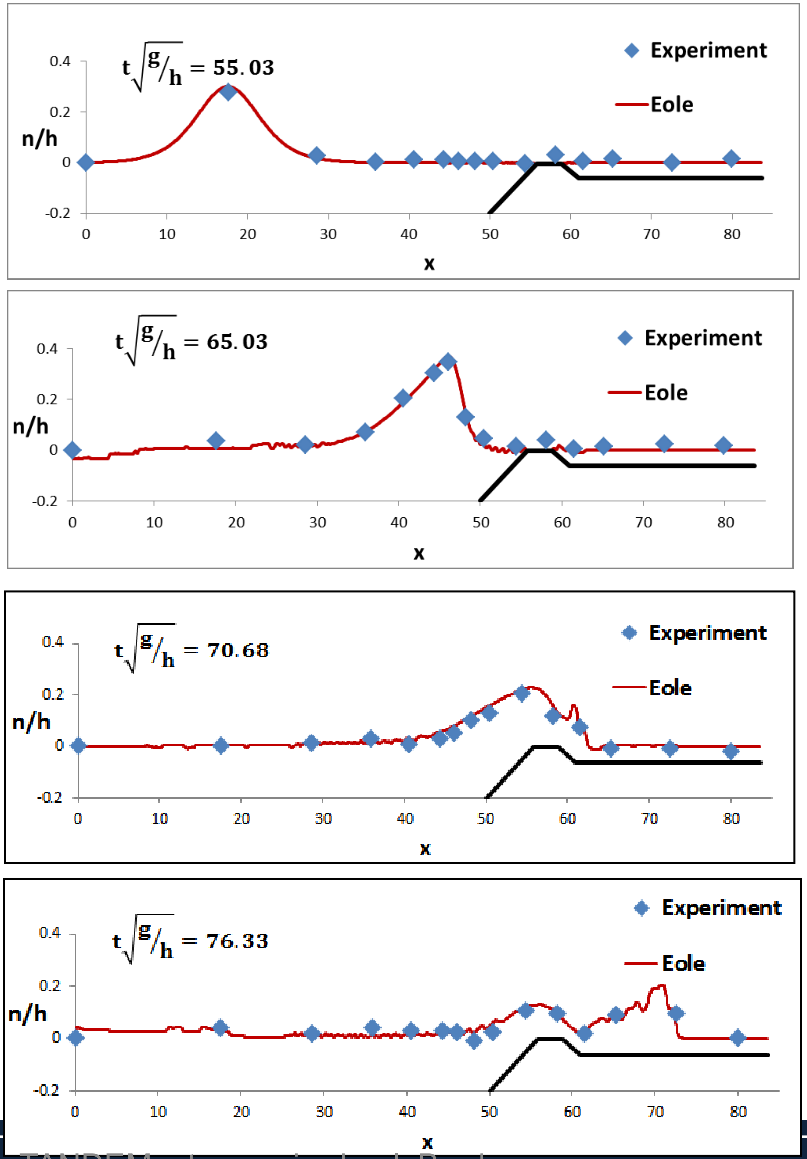
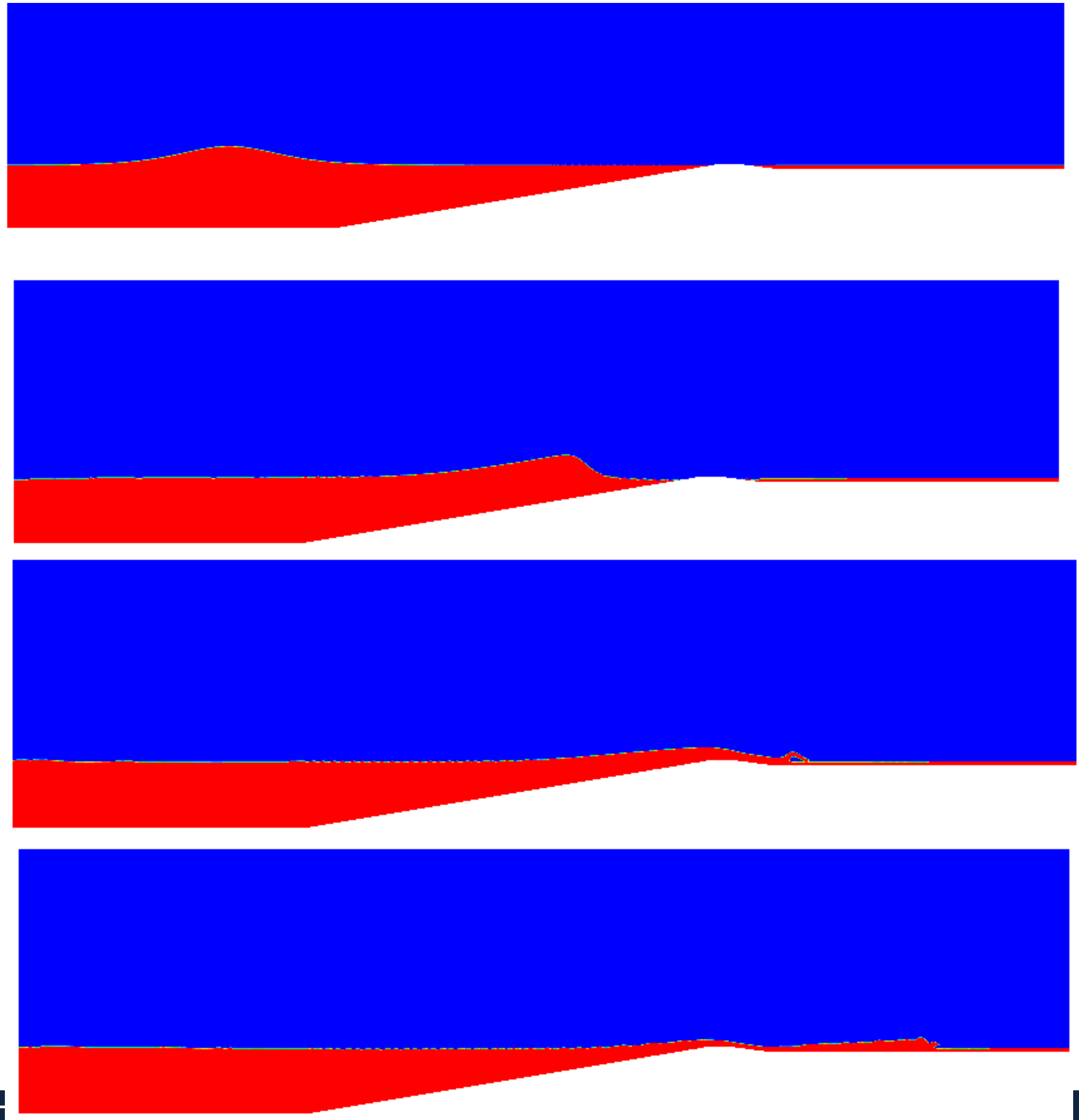
Solitary wave on a 2D reef



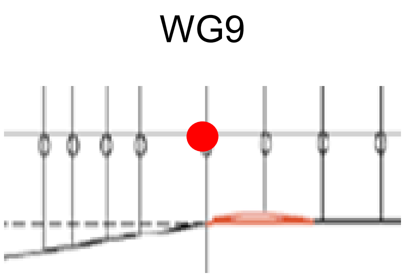


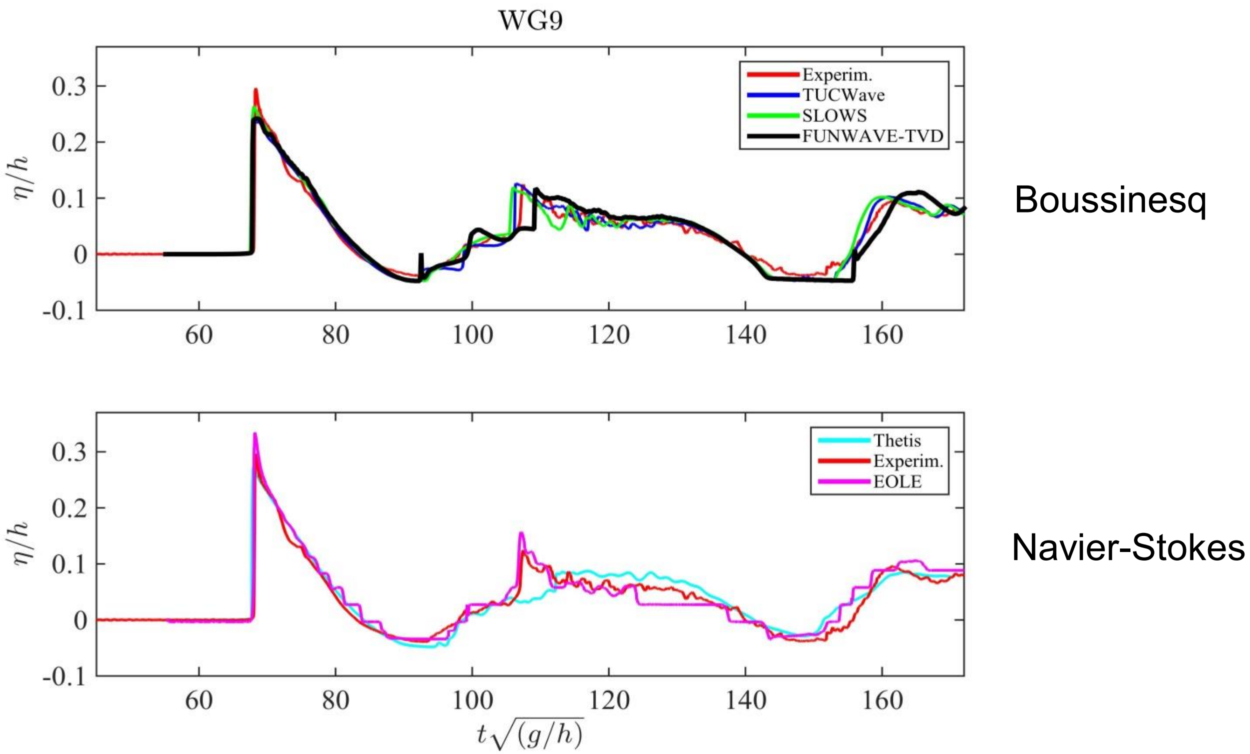
Solitary wave on a 2D reef

- **Example of comparison with Boussinesq codes**

(dedicated paper on progress)

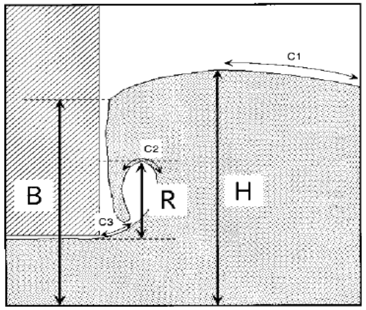
- **Time series of wave elevation in WG9 (breaking)**

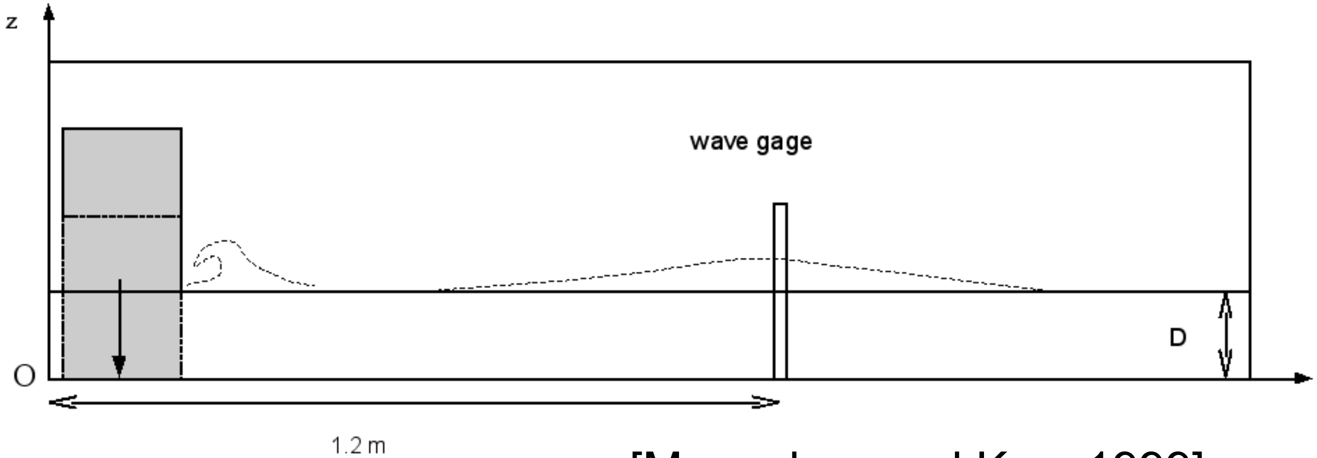




Russel's wave generator

- **Tsunami generation due to the falling into water of a rigid body (massive cliff, ice body)**
  - **Rectangular block**
    - 38.2 Kg, 0.4m tall, 0.3m long
    - T=0: just below the free surface
  - **Depth D (= 0.288m, 0.210m, 0.116m)**
  - **Monitoring**
    - Wave elevation at 1.2m
    - Values of H and B (issued from video measurements)

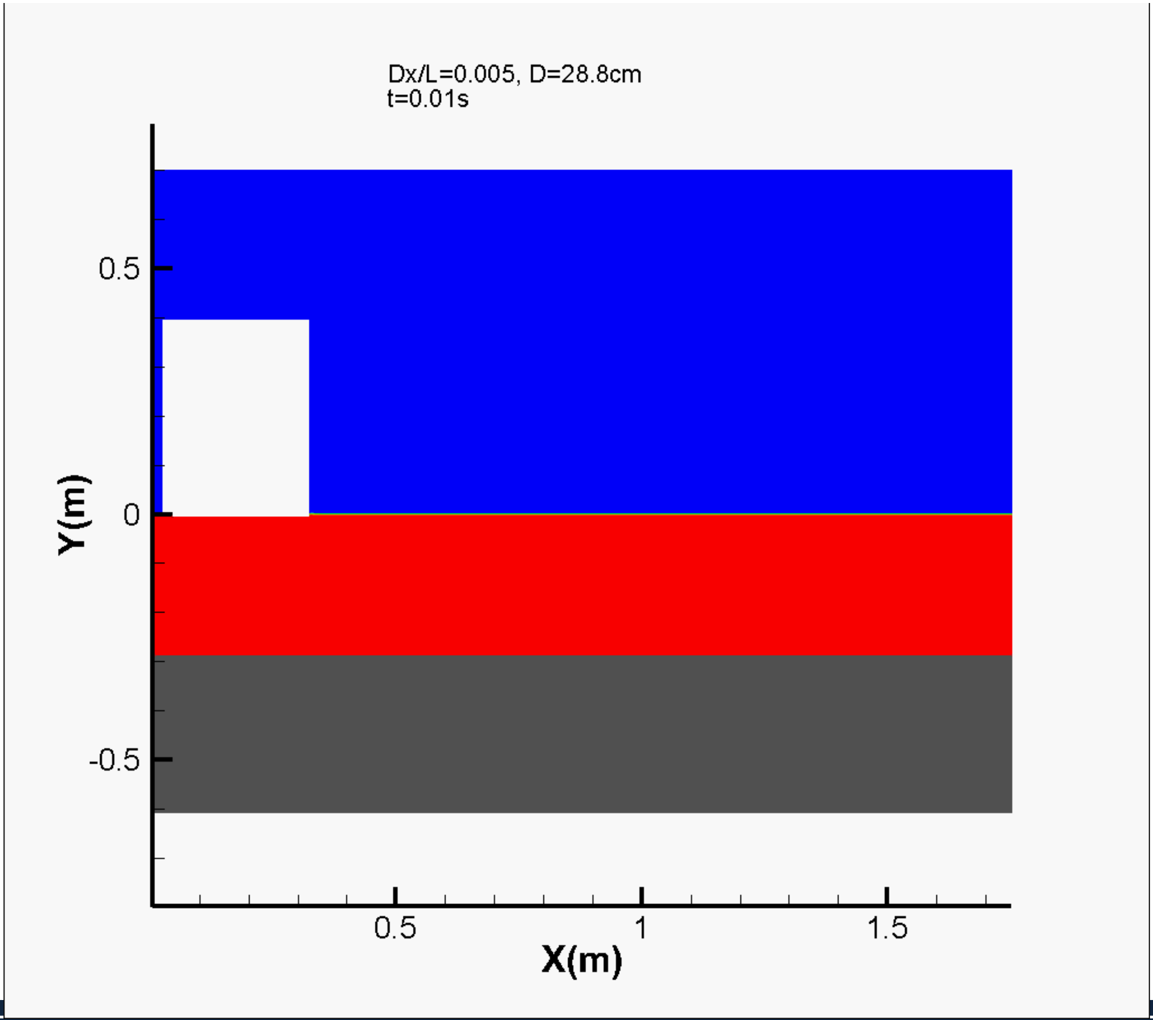




[Monaghan and Kos, 1999]

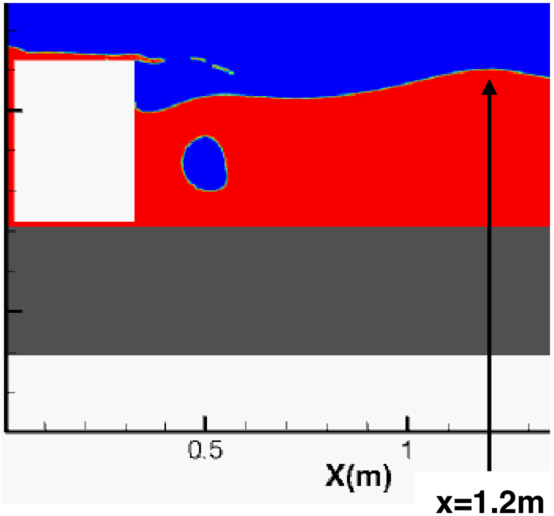
Russel's wave generator - simulation

- **Coupling fluid / structure (rigid body) : free motion in vertical**
- **Movie**



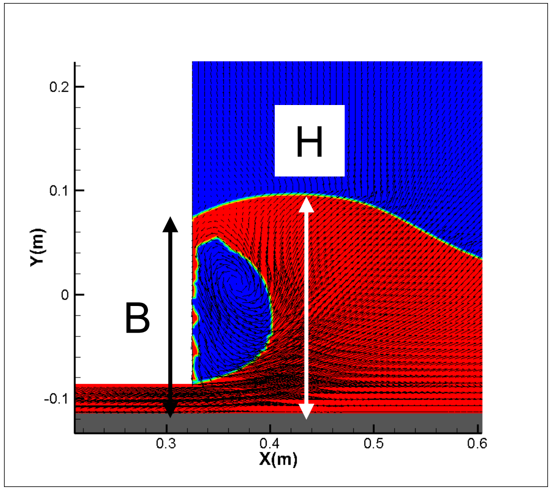
Russel's wave generator

- Wave elevation at X=1.2
- Parameters B and H



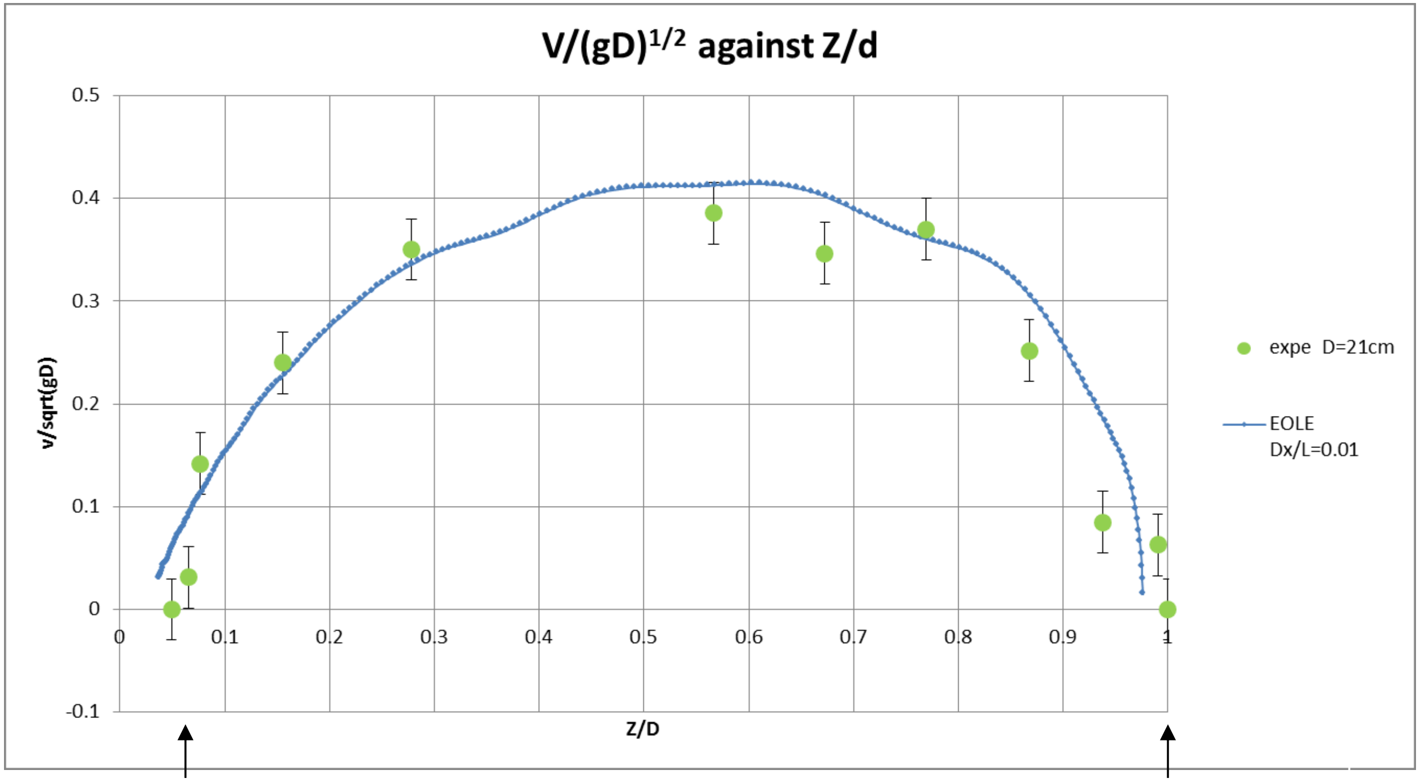
	D(m) : water depth				
	0.116	0.210	0.288	0.210	
	A			B	H
Experiment	0.109 (±0.01)	0.092 (±0.01)	0.093 (±0.01)	0.303 (±0.02)	0.333 (±0.01)
EOLE	0.096	0.094	0.095	0.291	0.317

Elevation at x=1.2m



Russel’s wave generator

- **Velocity versus vertical position**



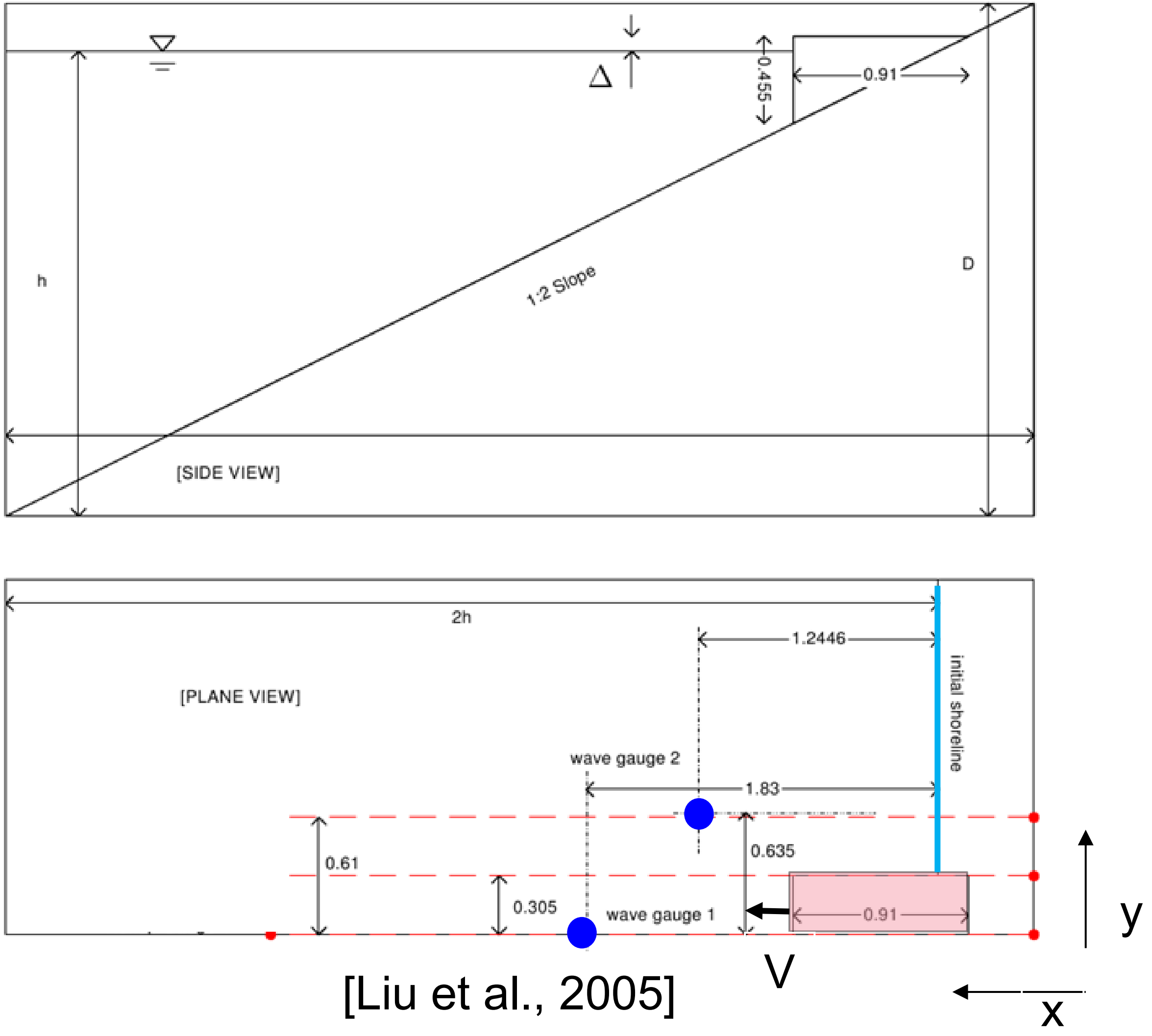
Block approaching the bottom

Entry of the block

Curve to be read from right to left with increasing time

Wedge sliding down on a slope

- Tsunami generation due to submarine landslide
- ½ slope beach
- Monotoring
  - Wave elevation
  - Run-up



[Liu et al., 2005]

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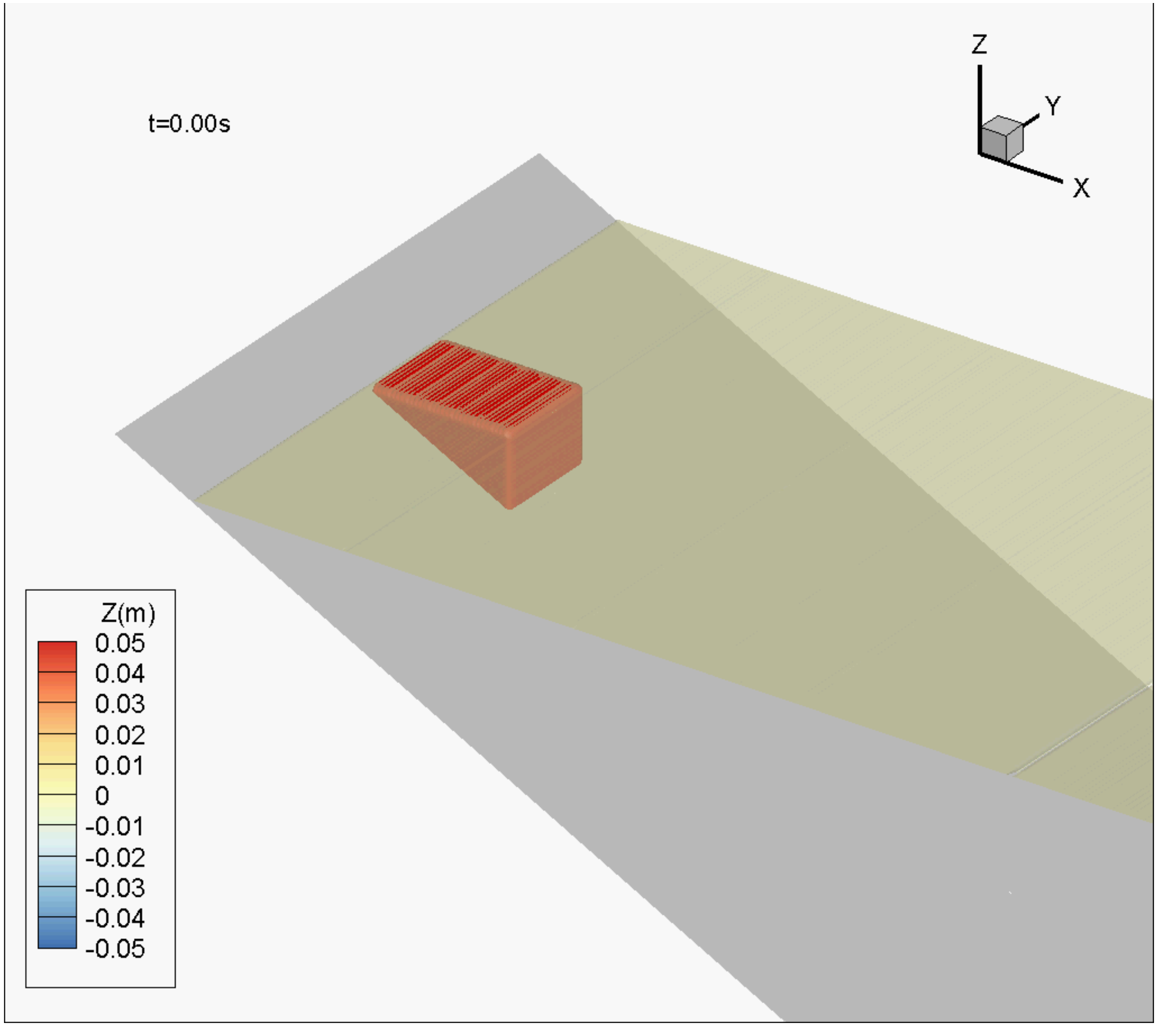
Wedge sliding down on a slope - simulation

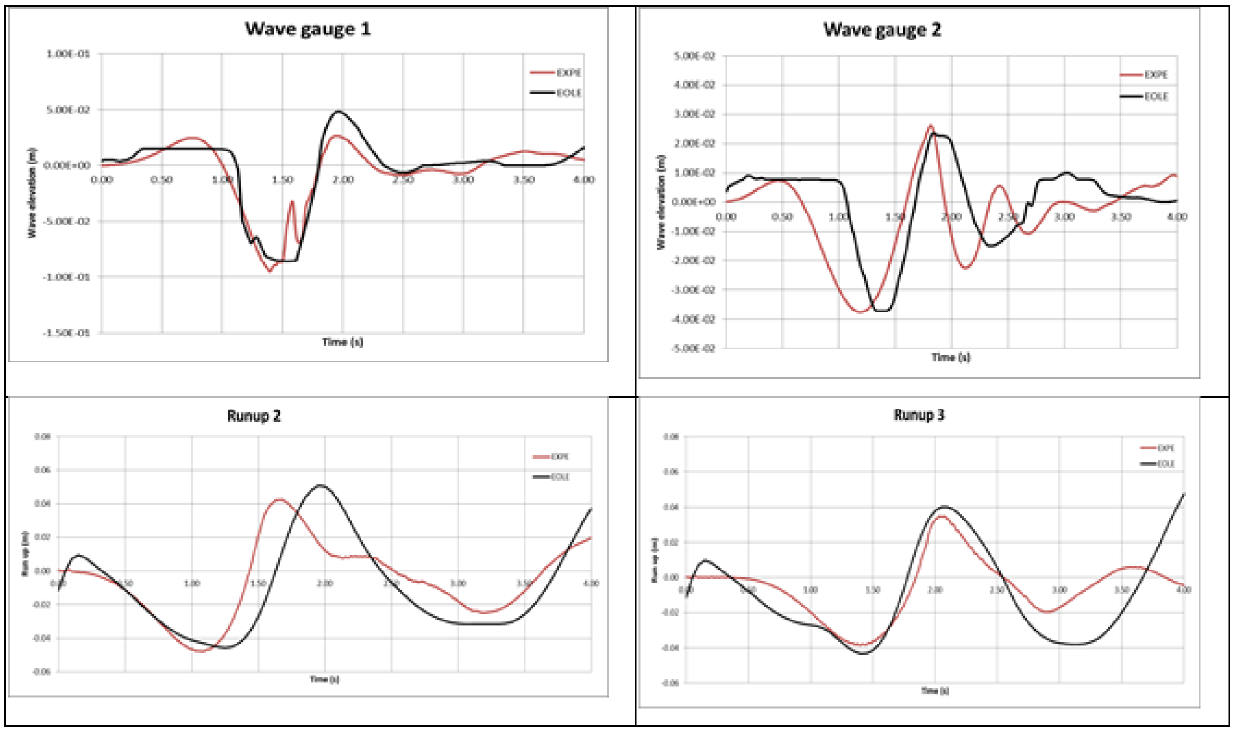
- **Coupling fluid / structure (rigid body) : imposed motion**

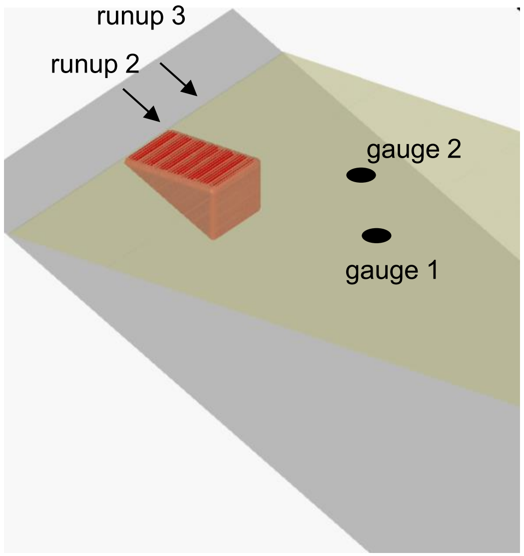
- **Movie**



Wedge sliding down on a slope

- **Comparisons elevation / runup**



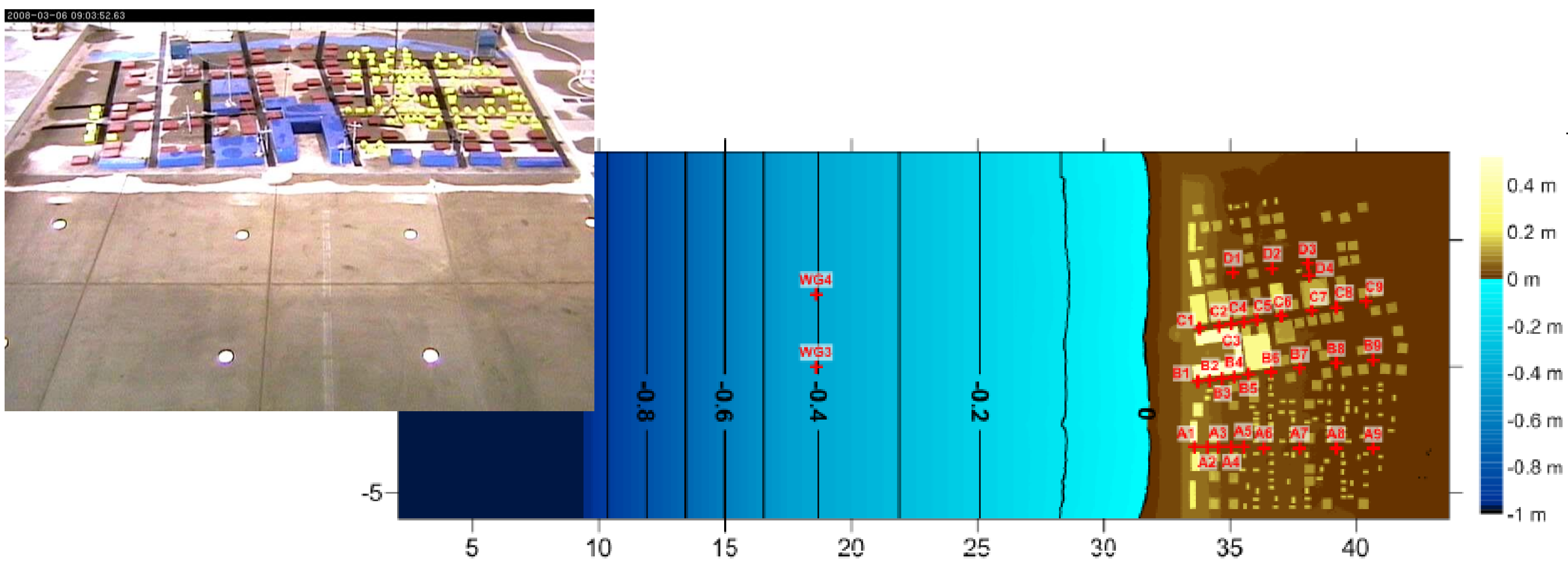


Experiments

EOLE

Tsunami on a coastal urban area

- **Physical model**
  - **1/50 scale of real city of Seaside (Oregon)**
  - **H=0.2m (2.1m depth offshore)**
  - **More than 30 wave elevation / velocity gauges**



[Park et al., 2013]

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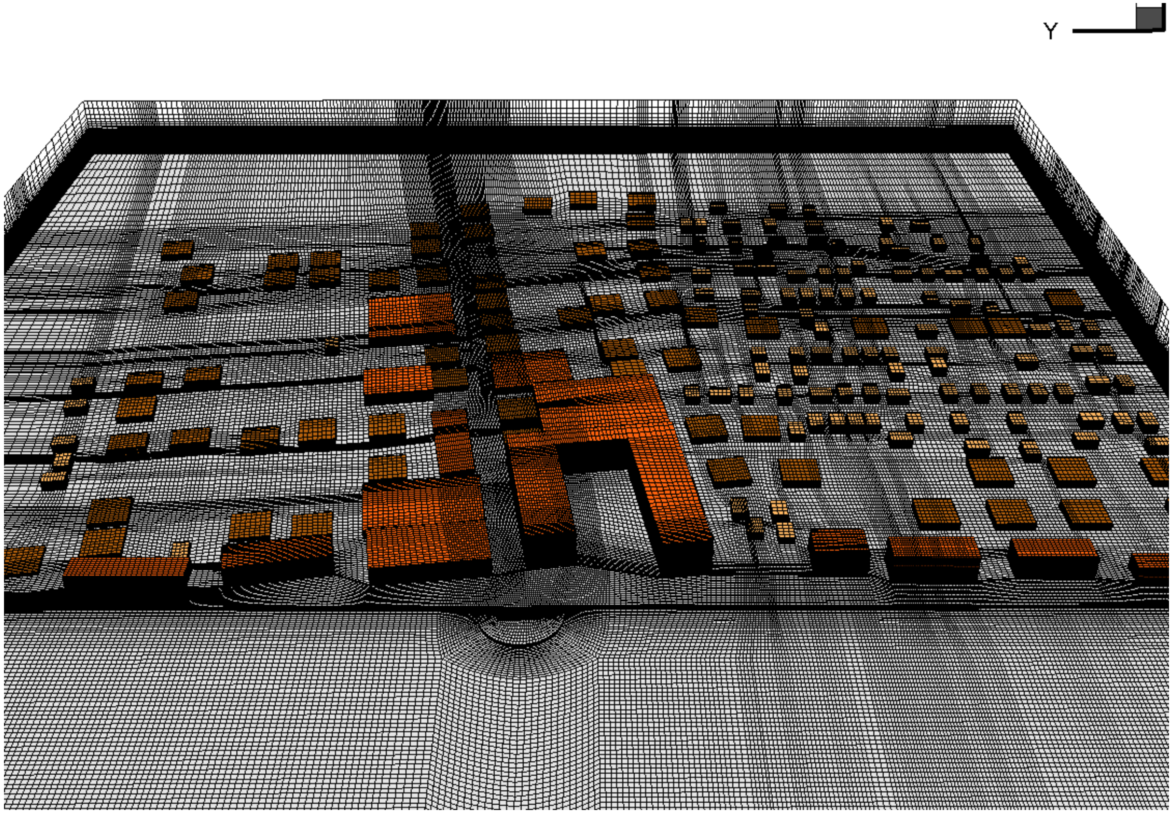
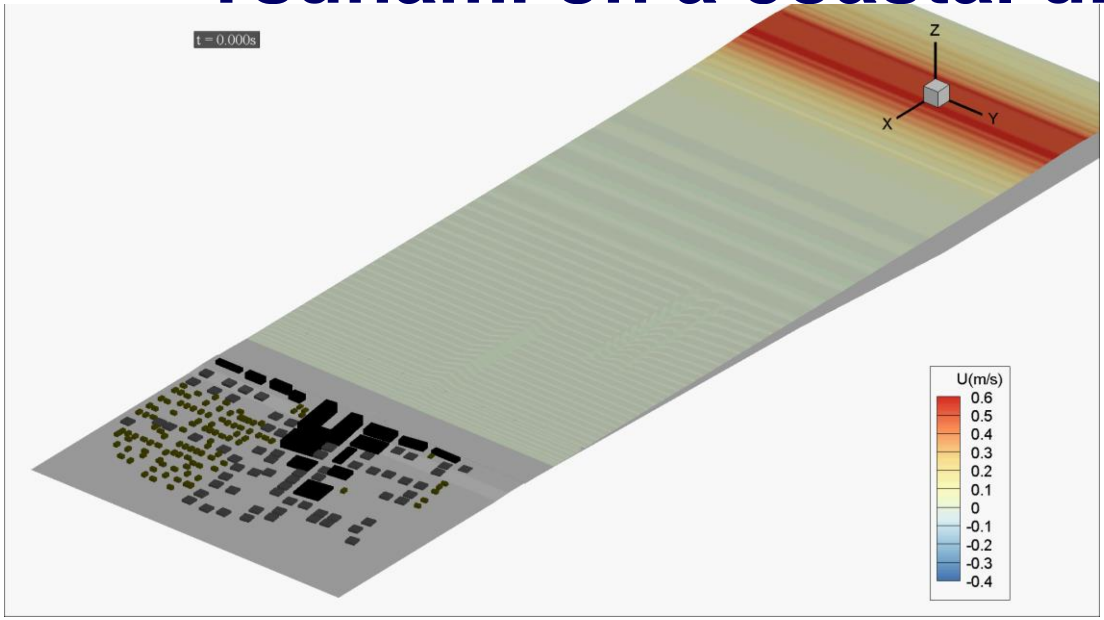
Tsunami on a coastal urban area - simulation

- **Numerical model**
  - **Multi-block mesh: 9M cells**
  - **All buildings included**
  - **Initial solitary wave**



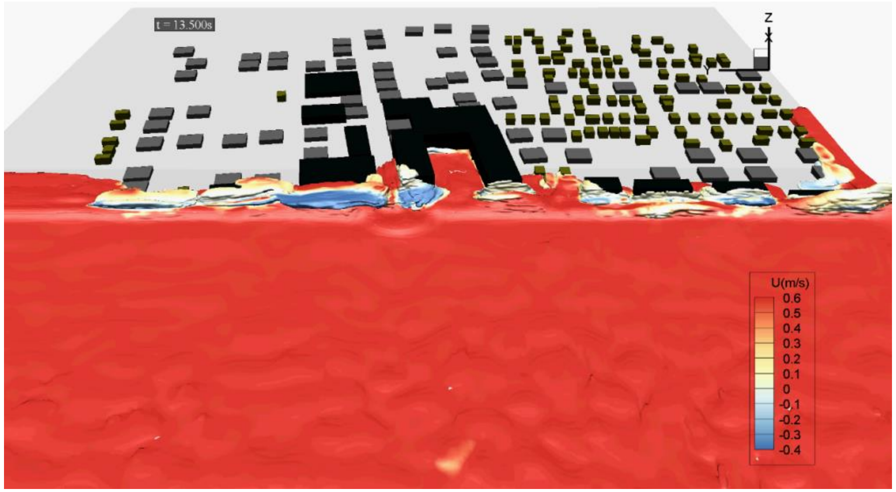
Tsunami on a coastal urban area

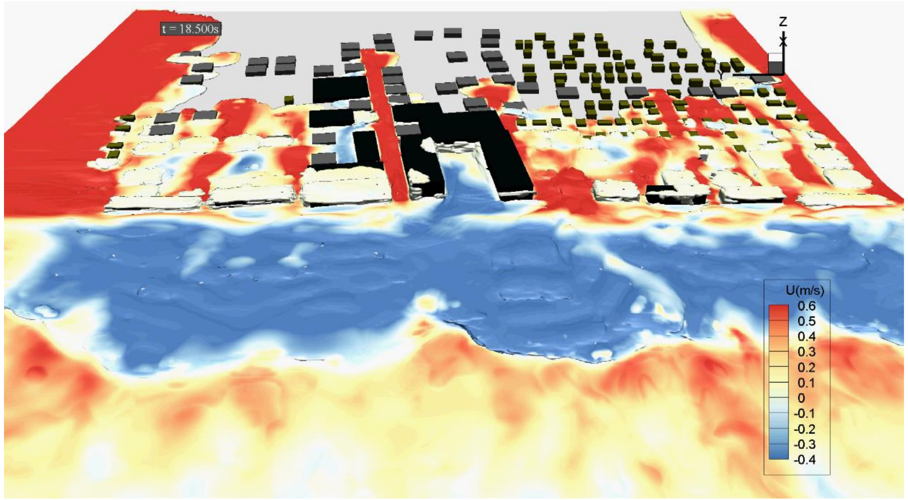
- **Movies**



Tsunami on a coastal urban area

Experiment | **EOLE CFD**





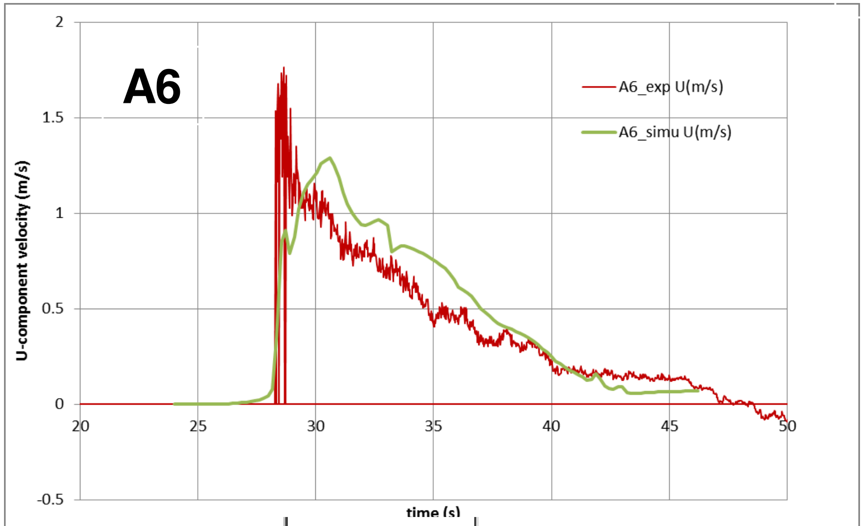
Elevation on gauges A

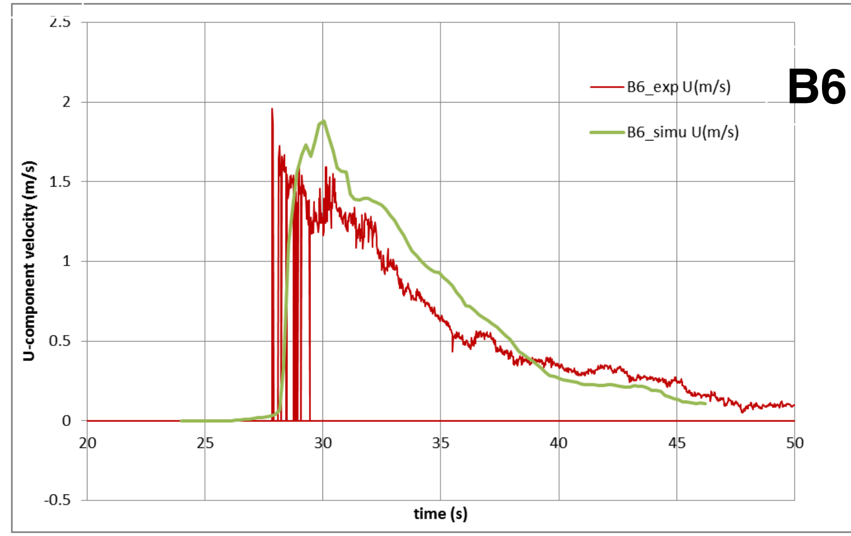
Elevation on gauges C

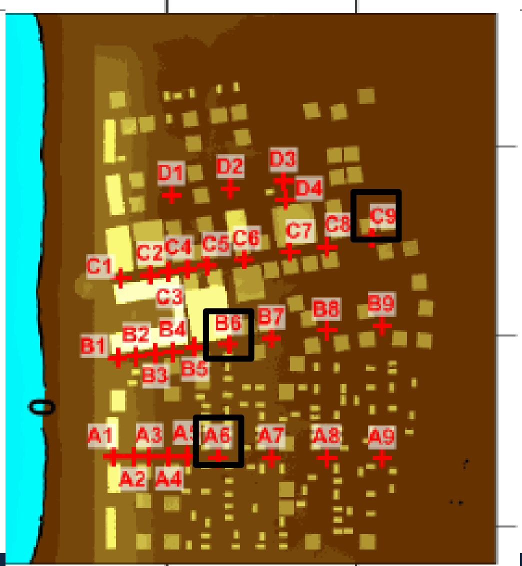
EOLE CFD
experience

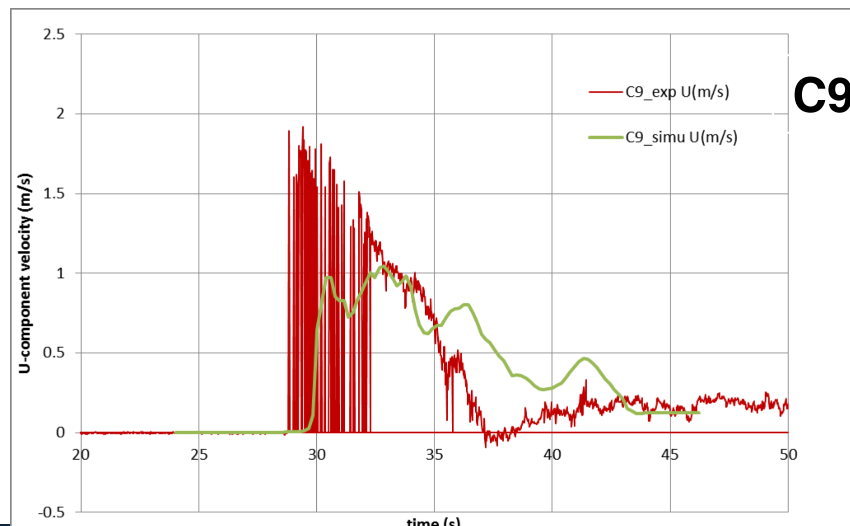
Velocity gauges

EOLE CFD
experience









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Merci pour votre attention !