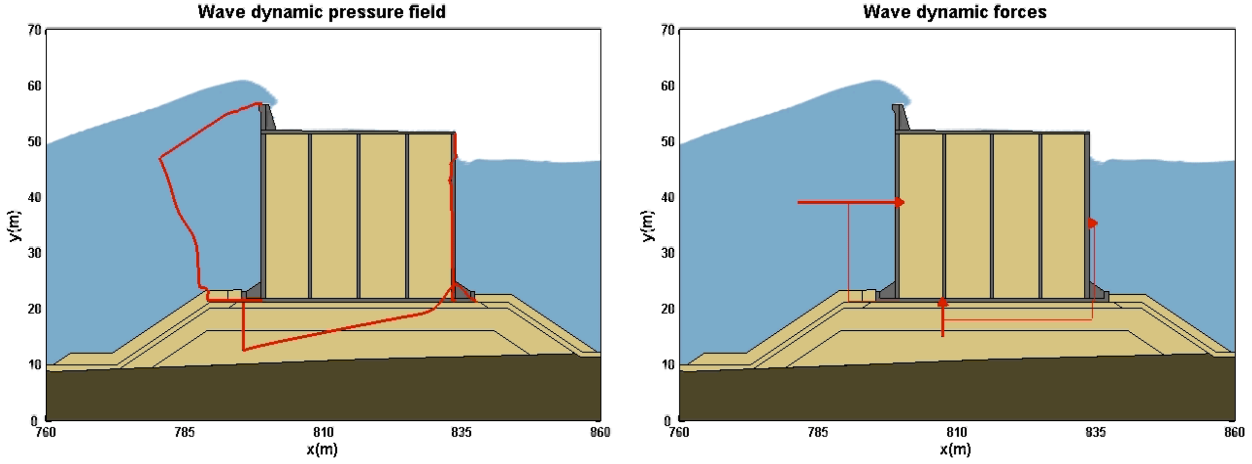
IH-2VOF Model

Mathematical/Numerical description



Maria Maza (mazame@unican.es)

1. INTRODUCTION

1. INTRODUCTION

OUTLINE

1.1 Wave transformation processes. Scope of application of the model

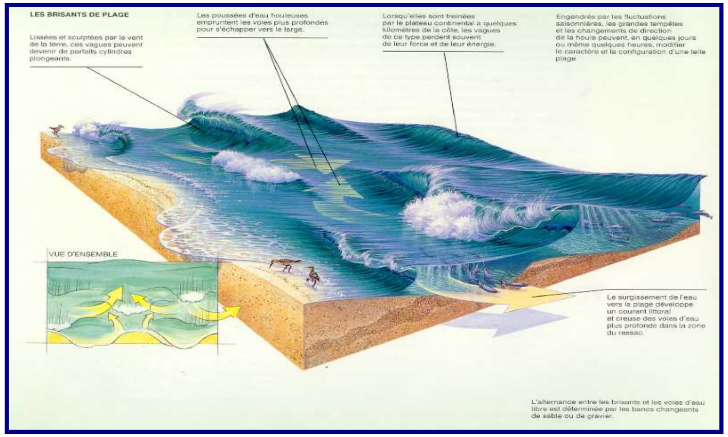
1.2. Approaches of study

- physical experiments
- numerical modeling

1.3 Why Navier-Stokes Models in coastal engineering?

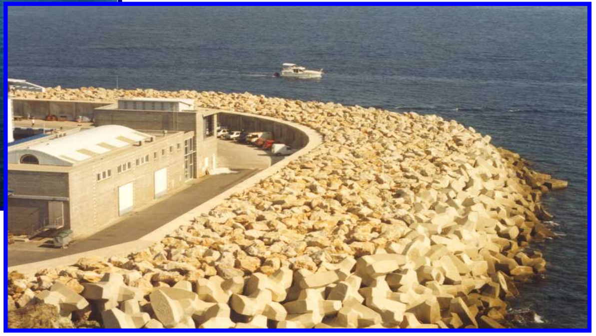
1.1. Wave transformation processes

- General aspects



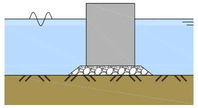
Wave transforms

Coastal structures

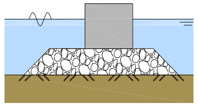


1.1. Wave transformation processes (Typology of coastal structures)

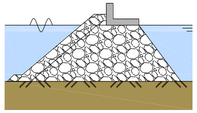
Seaward slope geometry



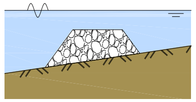
Vertical breakwater



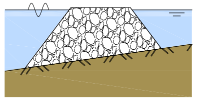
High-mound breakwater



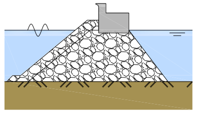
Rubble-mound breakwater



Submerged breakwater

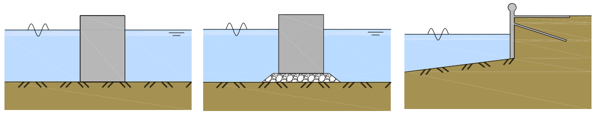


Overwashed breakwater

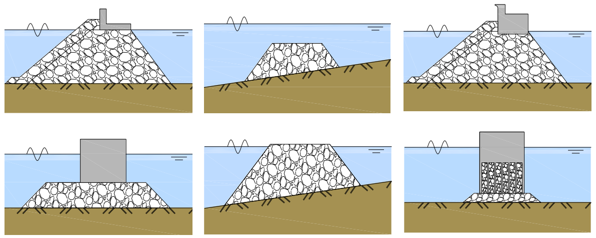


Non-overtopped structure

Permeability

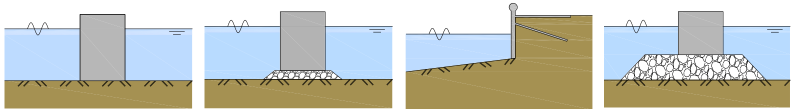


Impervious structure

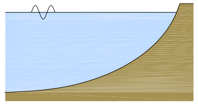


Porous breakwater

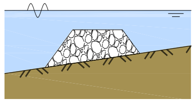
Energy



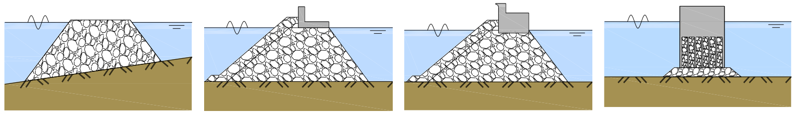
Reflective sctructures



Disipative structure

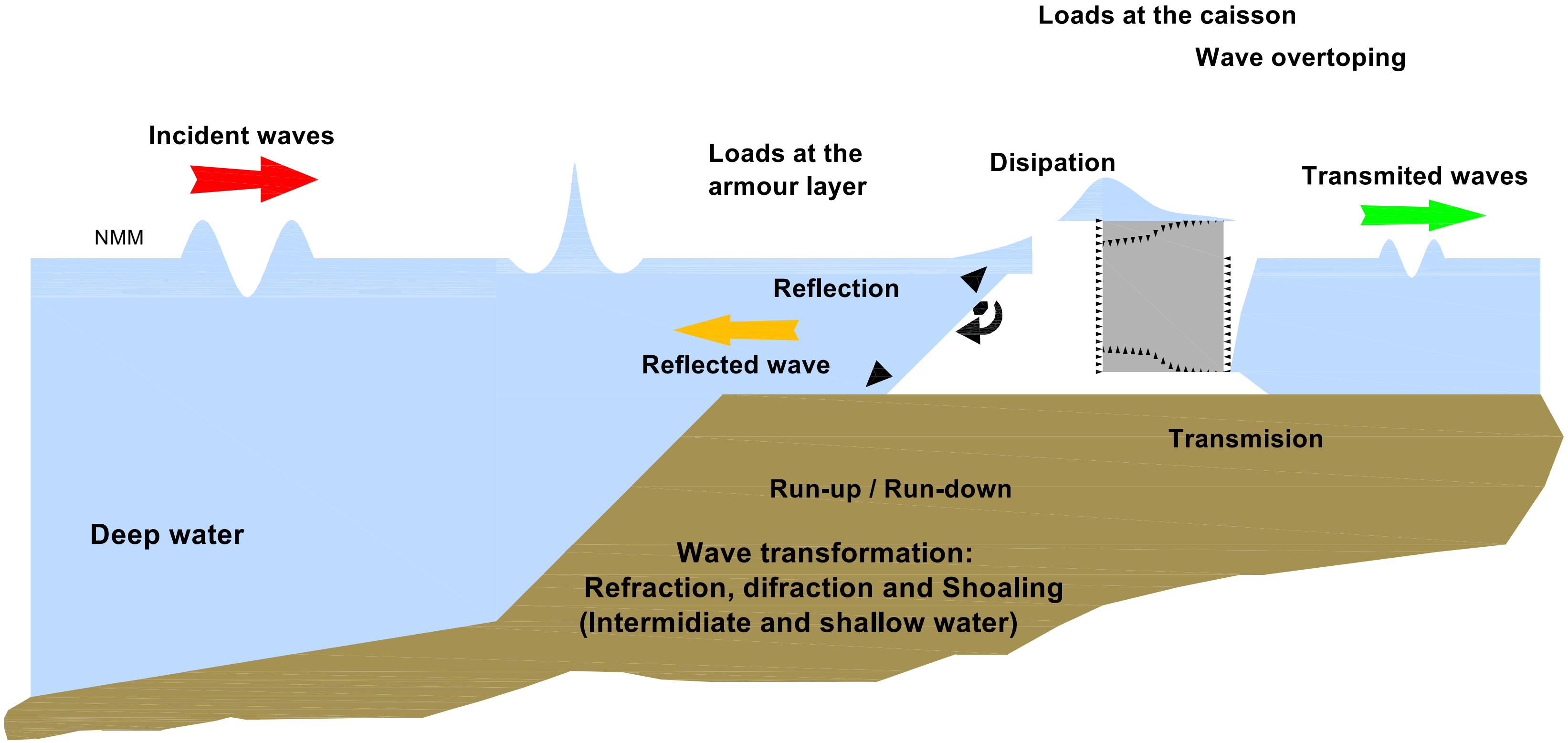


Transmited wave energy



Mixed struutres

1.1. Wave transformation processes (Wave interaction with coastal structures)



Seaward **Leeward**

1.1. Wave transformation processes (Design analysis)

Functional analysis of the structure

- Any coastal structure is designed based on fulfill some requirements to be used.
- The lost of such as conditions implies failure: lost of functionality ("usability")
- Structural damage cannot appear

Structural failure of the structure

- Total or partial lost of the characteristics of the structure established in the design
- Structural damage: recovered or unrecovered

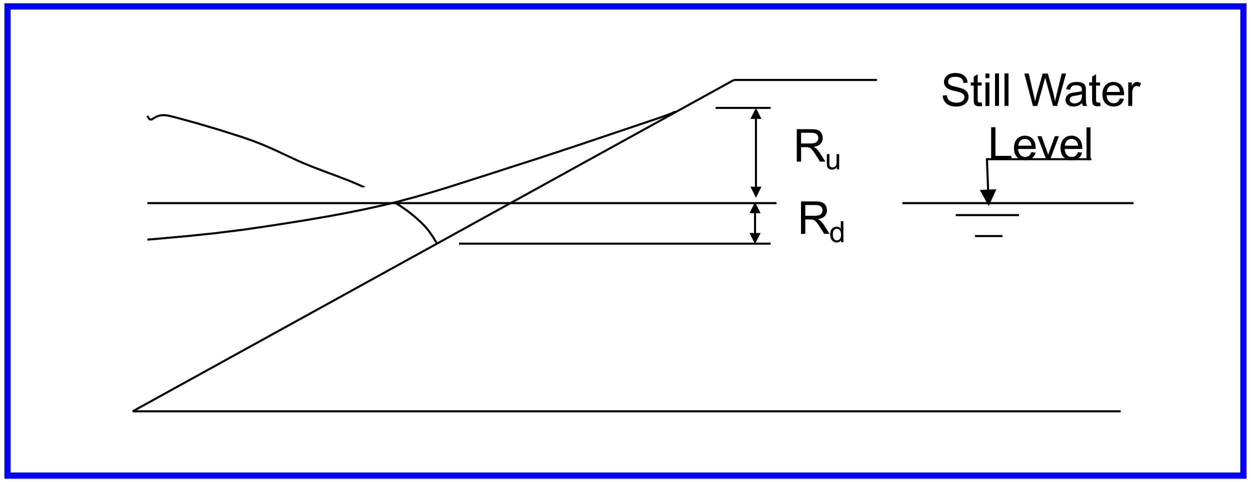
1.1. Wave transformation processes (Design analysis: Functionality)

Run-up (R_u): Vertical distance above SWL reached by the waves

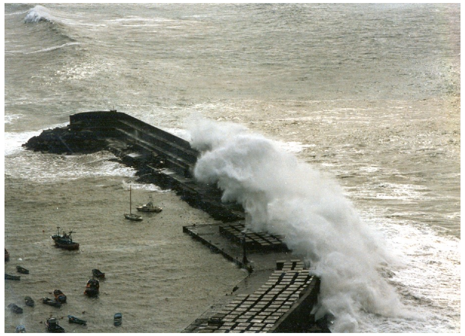
Run-down (R_d): Vertical distance below SWL reached by the waves

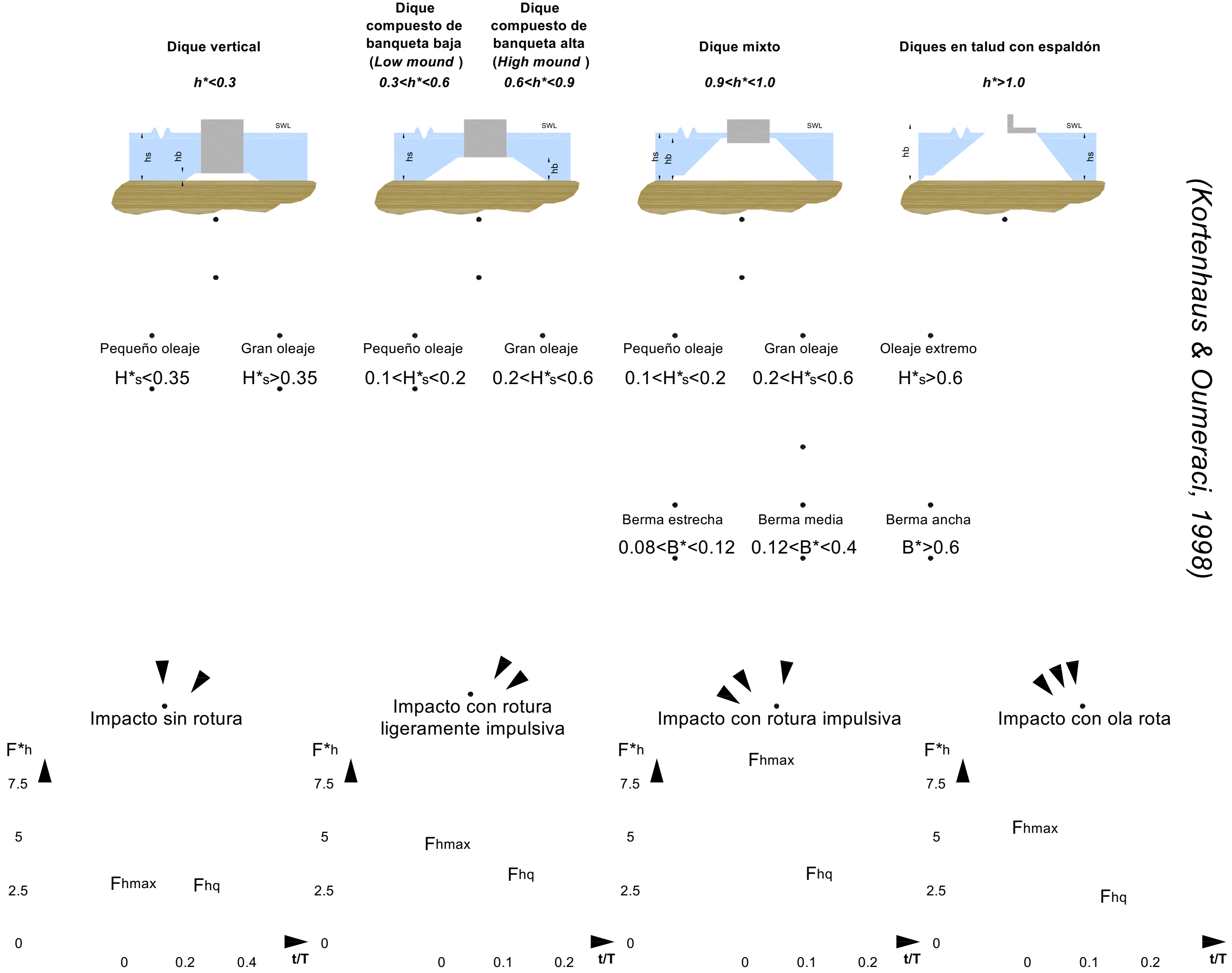
Overtopping discharge (q): Amount of water per unit time exceeding the breakwater crest

Wave Transmission: Wave agitation behind the structure



1.1. Wave transformation processes (Design analysis: Stability)





Dique vertical
h*<0.3

Dique compuesto de banqueta baja (*Low mound*)
0.3<h*<0.6

Dique compuesto de banqueta alta (*High mound*)
0.6<h*<0.9

Dique mixto
0.9<h*<1.0

Diques en talud con espaldón
h*>1.0

Pequeño oleaje
$H^*_s < 0.35$

Gran oleaje
$H^*_s > 0.35$

Pequeño oleaje
$0.1 < H^*_s < 0.2$

Gran oleaje
$0.2 < H^*_s < 0.6$

Pequeño oleaje
$0.1 < H^*_s < 0.2$

Gran oleaje
$0.2 < H^*_s < 0.6$

Oleaje extremo
$H^*_s > 0.6$

Berma estrecha
$0.08 < B^* < 0.12$

Berma media
$0.12 < B^* < 0.4$

Berma ancha
$B^* > 0.6$

Impacto sin rotura

Impacto con rotura ligeramente impulsiva

Impacto con rotura impulsiva

Impacto con ola rota

(Kortenhaus & Oumeraci, 1998)

1. INTRODUCTION

OUTLINE

1.1 Wave transformation processes. Scope of application of the model

1.2. Approaches of study

  - physical experiments
  - numerical modeling

1.3 Why Navier-Stokes Models in coastal engineering?

1.2. Approaches of study (Physical tests)

Classical approach: → **PHYSICAL TEST**

Mainly two-dimensional and small-scale tests

For development of most of the formulations used for design

Problems:

- Froude scaling → Mach or Reynolds numbers are not conserved
- Processes related with breaking and turbulence are not very well modeled
- Not all the magnitudes of interest can be recorded

Economical cost:

- number of experiments → repeatability of experiments
- Large scale experiments → expensive

Results with a narrow range of applicability

New motivations: aesthetic, economical
and environmental reasons

1.2. Approaches of study (Numerical modelling)

WE NEED NEW METHODS TO IMPROVE THE WAVE-STRUCUTRE INTERACTION ANALYSIS

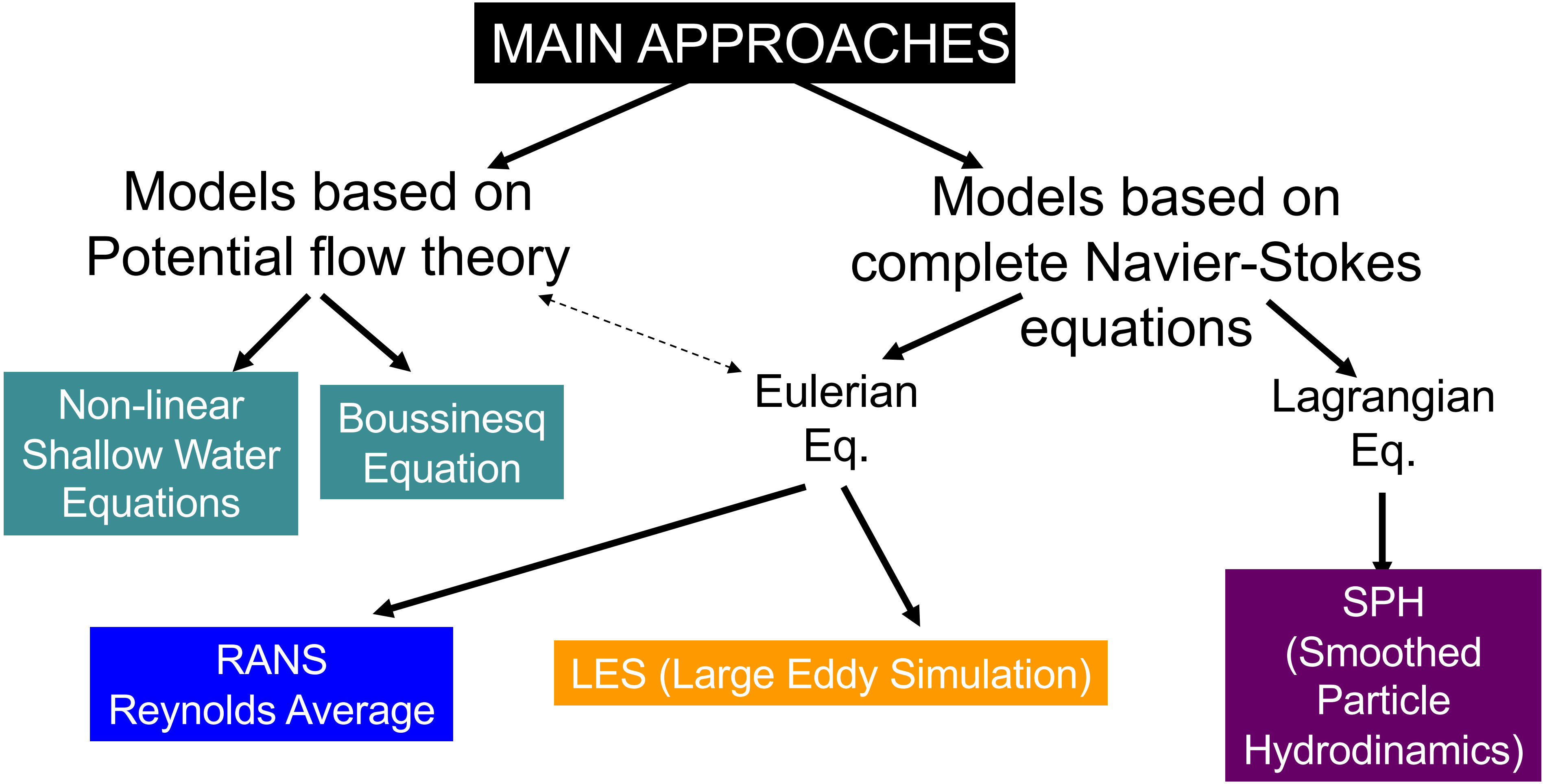
Motivation

Objective

PROVE THE CAPABILITY OF NAVIER-STOKES MODELS TO GO BEYOND THE EXISTING MODELS AND TO SHOW ITS POTENTIAL FOR FUTURE APPLICATIONS IN COASTAL AND HARBOUR ENGINEERING

Use a Navier-Stokes models as an ENGINEERING TOOL

1.2. Approaches of study (Numerical modelling)



MAIN APPROACHES

Models based on Potential flow theory

Models based on complete Navier-Stokes equations

Non-linear Shallow Water Equations

Boussinesq Equation

Eulerian Eq.

Lagrangian Eq.

RANS
Reynolds Average

LES (Large Eddy Simulation)

SPH
(Smoothed Particle Hydrodinamics)

1.2. Approaches of study (Numerical modelling)

Non-linear Shallow Water Equations / Boussinesq

- Pros: cheap according to the computational cost, efficient, long simulations (reliable statistics) …

- Cons: Wave breaking have to be triggered, vertical structures cannot be simulated, overtopping cannot be calculated, pressure field is not provided, wave dispersion, …

SPH (Smooth Particle Hydrodynamics) models

- Pros: non-linear interaction in the fluid, pressure field is obtained, multi-connected free surface, …

- Cons: ongoing research, porous media flow is not solved, highly diffusive, pressure field needs to be tailored adapted …

Navier-Stokes models → RANS

- Pros: non-linear interaction in the fluid, pressure field is obtained, multi-connected free surface, porous media flow, turbulence is considered, …

- Cons: high computational cost, efficiency, methodology of use in coastal engineering

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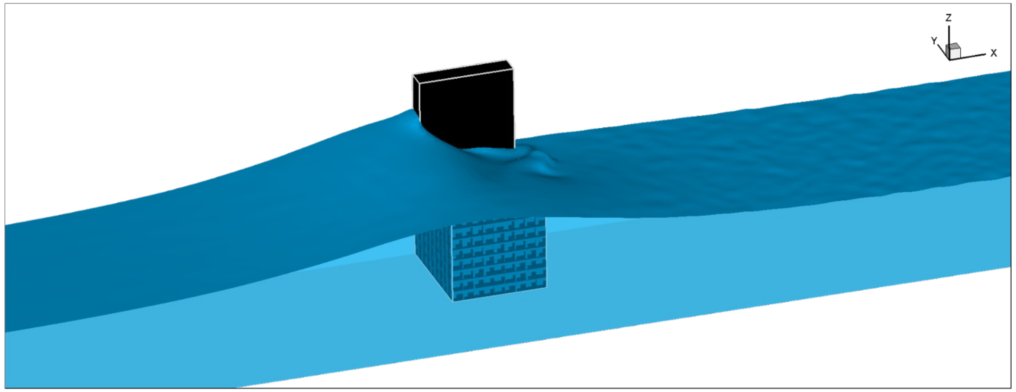
1.3 Why Navier-Stokes Models in coastal engineering?

Why Navier-Stokes Models in coastal engineering?

- The number of underlying assumptions is quite low comparing with other approaches
- Non-linear flow characteristics during wave transformation are considered
- Wave dispersion is intrinsically included in the equations
- Breaking is not triggered artificially
- Wave induced flow is solved in the vertical (2D or 3D)
- Wave-induced turbulence can be considered
- Huge potential to find new insights in physical process which are nowadays studied with simplified models due to their complexity
- Parallel computing

  (not IH-2VOF)



Weak points of Navier-Stokes models when applying to coastal engineering

- Although their use is quite common in other fields (mechanical, aerospace, chemical, etc.), it is not very common in civil engineering
- The computational cost is high and can not solved for large domains or long periods.
- The cost of commercial software is quite high and a special training is required to get accurate results
- There are specific issues related with the wave induced flow which are not correctly solved and/or not implemented in commercial software packages: wave generation, wave absorption, porous media flow
- The use of a massive computing machine is required to be used for complex problems and geometries.
- There is a lack of a methodology to be applied to coastal engineering problems

2. IH-2VOF MODEL

OUTLINE

2.1 Mathematical model

- Navier-Stokes equations
- VARANS equations

2.2 Numerical implementation

- Computational domain
- Partial cell method
- Volume of Fluid Method
- Solving procedure
- Computational cycle

…

2. IH-2VOF MODEL

…

2.3 Wave boundary condition

- Introduction
- Methods
- Wave absorption

2.4 Mesh generator: CORAL

2. IH-2VOF MODEL

OUTLINE

2.1 Mathematical model

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…

IH 2VOF

2.1 Mathematical model (Navier-Stokes equations)

- Mass and momentum conservation equations:

$$\boxed{\vec{\nabla}\cdot\vec{V}=0}$$

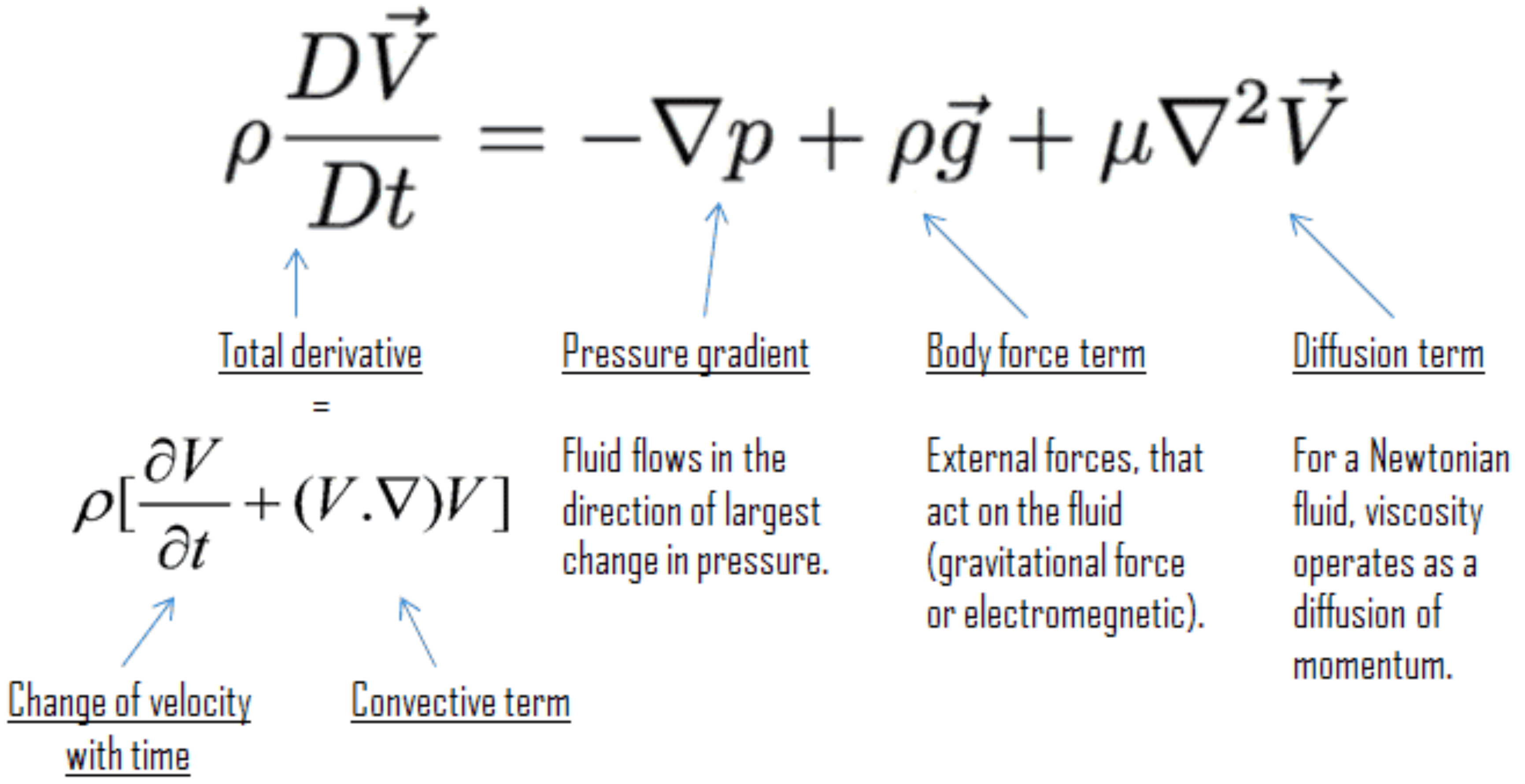
$$\boxed{\rho\frac{D\vec{V}}{Dt}=\rho\vec{g}+\nabla\cdot\sigma_{ij}}$$

4 Equations and 10 unknowns

$$\sigma_{ij}=\begin{pmatrix}\sigma_{xx} & \sigma_{xy} & \sigma_{xz}\\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz}\\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz}\end{pmatrix}=\begin{pmatrix}-p & 0 & 0\\ 0 & -p & 0\\ 0 & 0 & -p\end{pmatrix}+\begin{pmatrix}\tau_{xx} & \tau_{xy} & \tau_{xz}\\ \tau_{yx} & \tau_{yy} & \tau_{yz}\\ \tau_{zx} & \tau_{zy} & \tau_{zz}\end{pmatrix}$$

2.1 Mathematical model (Navier-Stokes equations)

- Terms in momentum equations:



$$\rho \frac{D\vec{V}}{Dt} = -\nabla p + \rho \vec{g} + \mu \nabla^2 \vec{V}$$

Total derivative

=

$$\rho[\frac{\partial V}{\partial t} + (V.\nabla)V]$$

Change of velocity with time

Convective term

Pressure gradient

Fluid flows in the direction of largest change in pressure.

Body force term

External forces, that act on the fluid (gravitational force or electromegnetic).

Diffusion term

For a Newtonian fluid, viscosity operates as a diffusion of momentum.

Reynolds Average Navier-Stokes Equations

Equations in the fluid region

$$u_i = \overline{u_i} + u_i' \;\; ; \;\; p = \overline{p} + p'$$

$\overline{\mathrm{u}_{\mathrm{i}}}$: mean velocity (ensemble average)

u_{i}' : turbulent fluctuation

u_{i} : instantaneous velocity

2.1 Mathematical model (Navier-Stokes equations)

Continuity Equation:

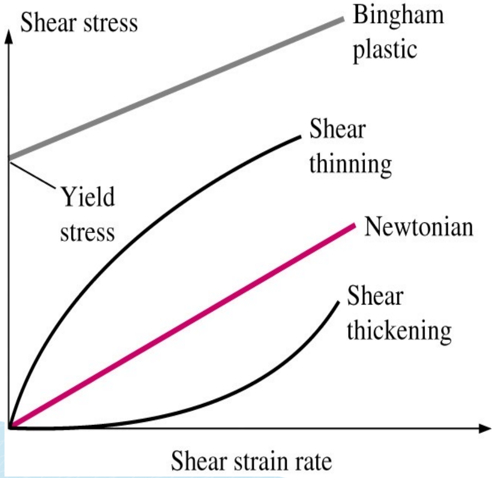
$$\frac{\partial \overline{u_i}}{\partial x_i} = 0$$

4 Equations

Unknowns

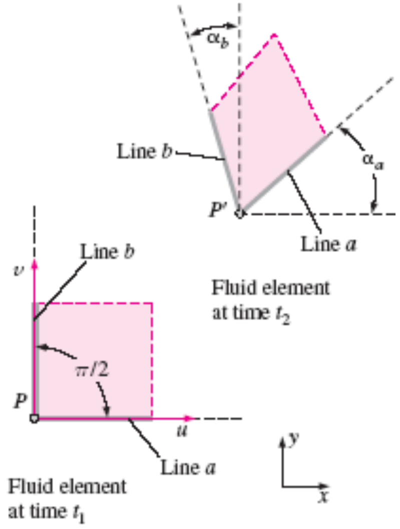
Momentum Equations:

$$\frac{\partial \boxed{\overline{u_i}}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \boxed{\overline{p}}}{\partial x_i} + \frac{1}{\rho}\frac{\partial \boxed{\overline{\tau_{ij}}}}{\partial x_j} - \frac{\partial \boxed{\overline{u_i' u_j'}}}{\partial x_j} + g_i$$



$$\overline{\tau_{ij}} = 2\mu S_{ij} \qquad S_{ij} = \frac{1}{2}\left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right)$$

μ dynamic viscosity (Ns/m^2)



2.1 Mathematical model (Navier-Stokes equations)

Nonlinear Reynolds stress closure model

Shih et al. (1999)

$$\overline{u_i'u_j'} = \frac{2}{3}k\delta_{ij} - 2\nu_t S_{ij}$$

$$-\frac{k^3}{\varepsilon^2}[C_1(\frac{\partial \overline{u}_i}{\partial x_l}\frac{\partial \overline{u}_l}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_l}\frac{\partial \overline{u}_l}{\partial x_i} - \frac{2}{3}\frac{\partial \overline{u}_l}{\partial x_k}\frac{\partial \overline{u}_k}{\partial x_l}\delta_{ij})$$

$$+C_2(\frac{\partial \overline{u}_i}{\partial x_k}\frac{\partial \overline{u}_j}{\partial x_k} - \frac{1}{3}\frac{\partial \overline{u}_l}{\partial x_k}\frac{\partial \overline{u}_l}{\partial x_k}\delta_{ij})$$

$$+C_3(\frac{\partial \overline{u}_k}{\partial x_i}\frac{\partial \overline{u}_k}{\partial x_j} - \frac{1}{3}\frac{\partial \overline{u}_l}{\partial x_k}\frac{\partial \overline{u}_l}{\partial x_k}\delta_{ij})]$$

Eddy viscosity

$$\nu_t = C_d\frac{k^2}{\varepsilon}$$

Reynolds stresses are dependent only on the mean velocity gradients and the characteristic scales of turbulence characterized by the turbulent kinetic energy *k* and its dissipation rate *ε*

2.1 Mathematical model
(Navier-Stokes equations)

k- ε turbulence transport model

k-equation:

$$\frac{\partial k}{\partial t}+\overline{u}_j\frac{\partial k}{\partial x_j}=\frac{\partial}{\partial x_j}[(\frac{\nu_t}{\sigma_k}+\nu)\frac{\partial k}{\partial x_j}]-\overline{u_i'u_j'}\frac{\partial \overline{u}_i}{\partial x_j}-\varepsilon$$

e-equation:

$$\frac{\partial \varepsilon}{\partial t}+\overline{u}_j\frac{\partial \varepsilon}{\partial x_j}=\frac{\partial}{\partial x_j}[(\frac{\nu_t}{\sigma_\varepsilon}+\nu)\frac{\partial \varepsilon}{\partial x_j}]+2C_{1\varepsilon}\frac{\varepsilon}{k}\nu_t S_{ij}\frac{\partial \overline{u}_i}{\partial x_j}-C_{2\varepsilon}\frac{\varepsilon^2}{k}$$

where $$\nu_t=C_d\frac{k^2}{\varepsilon}$$

2.1 Mathematical model (Navier-Stokes equations)

Coefficients

k-ε turbulence transport model:

$$C_{1\varepsilon} = 1.44 \quad C_{2\varepsilon} = 1.90 \quad \sigma_{k} = 1.0 \quad \sigma_{\varepsilon} = 1.3$$

Nonlinear Reynolds Stress Closure Model:

$$C_d = \frac{1}{3}\left(\frac{1}{3.7 + S_{\max}}\right) \qquad C_1 = \frac{1}{185.2 + 3D_{\max}^2}$$

$$C_2 = \frac{1}{58.5 + 3D_{\max}^2} \qquad C_3 = \frac{1}{370.4 + 3D_{\max}^2}$$

where $S_{\max} = \frac{k}{\varepsilon}\max\left(\frac{\partial \overline{u_i}}{\partial x_i}\right)$ $\quad D_{\max} = \frac{k}{\varepsilon}\max\left(\frac{\partial \overline{u_i}}{\partial x_j}\right)$

2.1 Mathematical model (Navier-Stokes equations)

Boundary conditions:

k-e turbulence transport model

Free surface: no flux condition

$$\frac{\partial k}{\partial n} = \frac{\partial \varepsilon}{\partial n} = 0$$

Solid wall: log-law turbulent boundary layer

$$\frac{u_n}{u_*} = \frac{1}{\kappa} \ln \frac{E u_* y}{\nu}$$

RANS equations

Free surface: zero shear stress

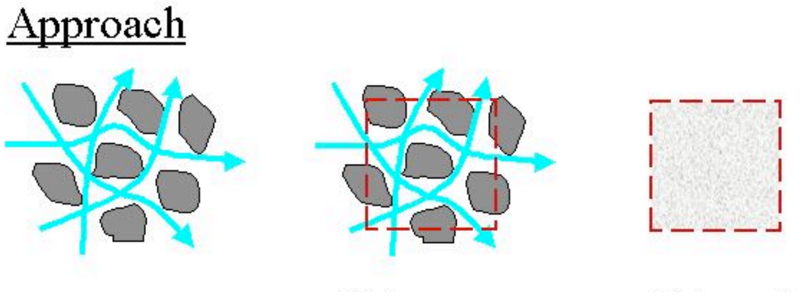
$$\tau_s = 0 \qquad \tau_n = p$$

Solid wall: non-slip condition

$$u_t = u_n = 0$$

2.1 Mathematical model (VARANS equations)

Volume-averaged equations



$$\langle a \rangle = \frac{1}{V_f} \int_{V_f} a \cdot dV$$

V: control volume
V$_f$: volume of V occupied by fluid
n: porosity= V$_f$ /V

Averaging control volume >> pore size (microscopic)
<< characteristic length scale of the flow (macroscopic)

$$\langle a \rangle_D = \frac{1}{V} \int_{V_f} a \cdot dV$$

seepage concept $\left\langle \overline{u_i} \right\rangle = \overline{u_i} + \overline{u_i''}$

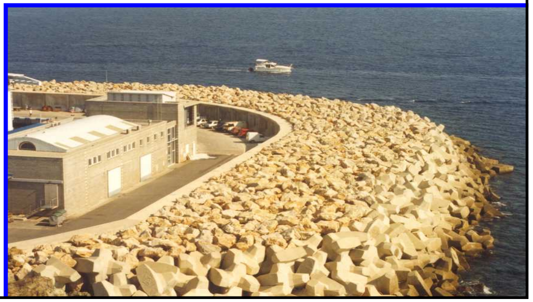
$$\langle a \rangle_D = n \langle a \rangle$$

$$n = \frac{V_f}{V}$$

$\left\langle \overline{u_i} \right\rangle$: Ensemble-volume averaging velocity field

$\overline{u_i}$: Ensemble averaging velocity field

$\overline{u_i''}$ Residual



2.1 Mathematical model (VARANS equations)

Momentum equations:

$$\frac{\partial q_i}{\partial t} + \frac{q_j}{n(1+c_A)}\frac{\partial q_i}{\partial x_j} = \frac{n}{\rho(1+c_A)}\left[-\frac{\partial < \bar{p} >}{\partial x_i} - \frac{\partial \rho < \overline{u_i' u_j'} >}{\partial x_j} + \frac{\partial < \bar{\tau}_{ij} >}{\partial x_j} + \rho g_i\right]$$

$$-\frac{n}{1+c_A}\left[\frac{\alpha \nu (1-n)^2}{n^3 D_{50}^2} q_i + \frac{\beta(1-n)}{n^3 D_{50}}\sqrt{q_1^2+q_2^2}\, q_i\right]$$

Formulations for porous induced drag:

Authors	a	b
Kozeny (1927)	$36\kappa\frac{(1-n)^2}{n^3}\frac{\nu}{gd^2}, \kappa = 5$	0
Ergun (1952)	$150\frac{(1-n)^2}{n^3}\frac{\nu}{gd^2}$	$1.75\frac{1-n}{n^3}\frac{1}{gd}$
Engelund (1953)	$\alpha_E\frac{(1-n)^3}{n^2}\frac{\nu}{gd^2}$	$\beta\frac{1-n}{n^3}\frac{1}{gd}$
Ward (1964)	$\frac{\nu}{gK_s}$	$\frac{c}{g\sqrt{K_s}}, c = 0.550$
van Gent (1995)	$1000\frac{(1-n)^2}{n^3}\frac{\nu}{gd_{50}^2}$	$1.1\frac{(1-n)}{n^3}\frac{1}{gd_{50}}$
Liu *et al.* (1999b)	$200\frac{(1-n)^2}{n^3}\frac{\nu}{gd_{50}^2}$	$1.1\frac{(1-n)}{n^3}\frac{1}{gd_{50}}$

2.1 Mathematical model (VARANS equations)

$$F_{drag} = \frac{\alpha \nu (1-n)^2}{n^3 D^2_{50}} q_i + \frac{\beta (1-n)}{n^3 D_{50}} \sqrt{q_1{}^2 + q_2{}^2}\, q_i$$

Friction coefficients

- -Linear friction coefficient → α
  - + α=200
  - +Limited influence (Lara, 2002)
- -Non linear friction coefficient→ β
  - + β depends on geometry, flux, etc…
  - +Has been calibrated at laboratory scale
  - +A prototype scale calibration is needed

Non linear friction coefficients typical values		
Autor	**Descripción**	**β**
Lara (2002)	**Wave breaking over porous slopes**	**0.2**
Garcia (2005)	**Submerged sea dikes**	**1.2 (core) 0.8 (External layers)**
Guanche (2007)	**Vertical and composite breakwaters**	**Vertical: 0.8 (Ext.layer) 1.1 (core) Composite: 0.8 (core); 1.1 (Int.layer); 0.7 (Ext.layer)**

2.1 Mathematical model
(VARANS equations)

k-equation:

$$\frac{\partial <k>_D}{\partial t}+\frac{q_j}{n}\frac{\partial <k>_D}{\partial x_j}=$$

$$\frac{\partial}{\partial x_j}[(\frac{<\nu_t>_D}{n\sigma_k}+\nu)\frac{\partial <k>_D}{\partial x_j}]+<\overline{u_i'u_j'}>\frac{\partial q_i}{\partial x_j}-<\varepsilon>_D+n\varepsilon_\infty$$

e-equation:

$$\frac{\partial <\varepsilon>_D}{\partial t}+\frac{q_j}{n}\frac{\partial <\varepsilon>_D}{\partial x_j}=\frac{\partial}{\partial x_j}[(\frac{<\nu_t>}{n\sigma_\varepsilon}+\nu)\frac{\partial <\varepsilon>_D}{\partial x_j}]+$$

$$C_{1\varepsilon}\frac{<\varepsilon>_D}{<k>_D}<\overline{u_i'u_j'}>\frac{\partial q_i}{\partial x_j}-C_{2\varepsilon}\frac{<\varepsilon>_D^2}{<k>_D}+C_{2\varepsilon}n\frac{\varepsilon_\infty^2}{k_\infty}$$

$$<\nu_t>_D=C_d\frac{<k>_D^2}{<\varepsilon>_D}=n<\nu_t>$$

Transport equations for k and ε:

small scale turbulence quantities:

Generation of turbulence smaller than the volume averaging scale

Nakayama and Kuwahara (1999):

$$\varepsilon_\infty = 39.0\frac{(1-n)^{2.5}}{n}(q_1^2+q_2^2)^{3/2}\frac{1}{D_{50}}$$

$$k_\infty = 3.7\frac{(1-n)}{\sqrt{n}}(q_1^2+q_2^2)$$

OUTLINE

2.1 Mathematical model

- Navier-Stokes equations
- VARANS equations

2.2 Numerical implementation

- Computational domain
- Partial cell method
- Volume of Fluid Method
- Solving procedure
- Computational cycle

…

2.2 Numerical implementation

Finite differences:

rectangular domain, strutured orthogonal mesh

Free surface reconstruction based on a VOF technique (VOF function)

Solid boundary:

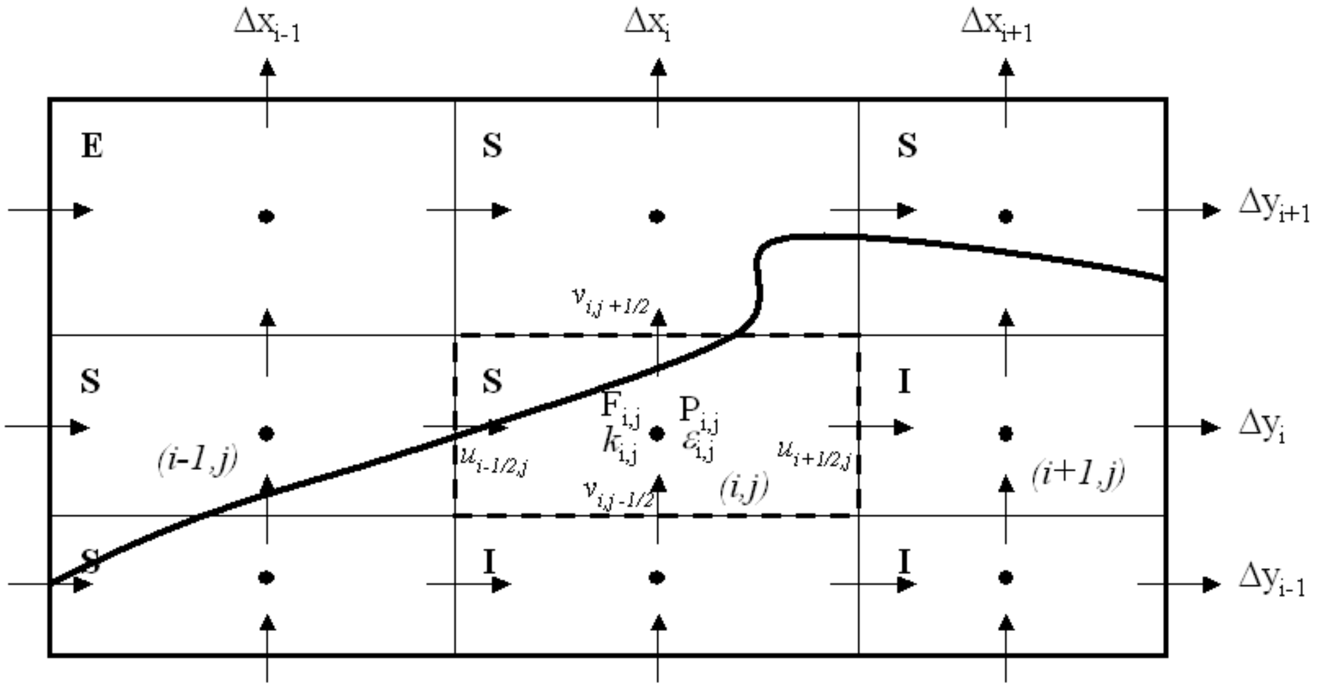
partial cell treatment (infinite density, openness function)

Two step projection method (Chorin, 1968 and 1969)

2.2 Numerical implementation (Computational domain)

Finite differences:

- rectangular domain
- Structured orthogonal grid
- Center of cell: Pressure, VOF, k, ε
- Cell edges: Velocity



2.2 Numerical implementation
(Volume Of Fluid, VOF, Technique)

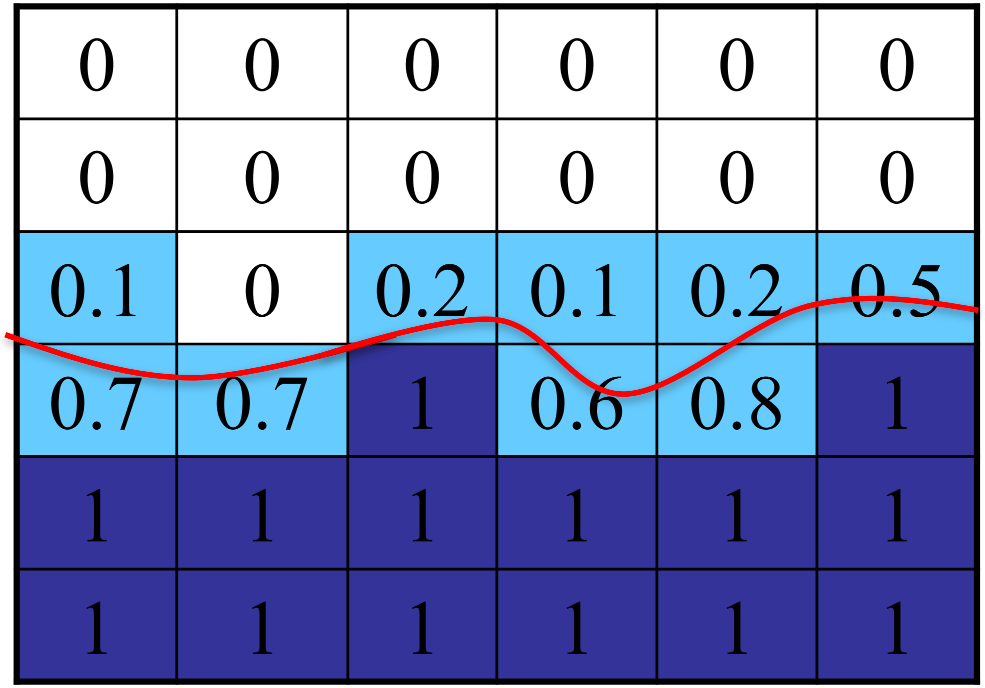
Hirt & Nichols, 1981

$$\frac{\partial F}{\partial t}+\frac{\partial}{\partial x}(uF)+\frac{\partial}{\partial y}(vF)=0$$

$$F=\frac{\rho}{\rho_f}$$

$$\left|\frac{\partial F}{\partial y}\right|>\left|\frac{\partial F}{\partial x}\right| \qquad \frac{\partial \mathrm{F}}{\partial \mathrm{x}}<,>0$$

Free surface reconstruction



0	0	0	0	0	0
0	0	0	0	0	0
0.1	0	0.2	0.1	0.2	0.5
0.7	0.7	1	0.6	0.8	1
1	1	1	1	1	1
1	1	1	1	1	1

$$\left|\frac{\partial \mathrm{F}}{\partial \mathrm{y}}\right|>\left|\frac{\partial \mathrm{F}}{\partial \mathrm{x}}\right|, \qquad \frac{\partial \mathrm{F}}{\partial \mathrm{x}}>0\Rightarrow \text{free surface on right side}$$

2.2 Numerical implementation
Solving procedure
(two step projection method, Chorin 1968)

$$\frac{{\color{red}u_i^{n+1}} - u_i^n}{\Delta t} + u_j^n \frac{\partial u_j^n}{\partial x_j} = -\frac{1}{\rho^n}\frac{\partial {\color{red}p^{n+1}}}{\partial x_i} + g_i + \frac{\partial \tau_{ij}^n}{\partial x_j}, \qquad \frac{\partial {\color{red}u_i^{n+1}}}{\partial x_i} = 0,$$

Predictor step

$$\frac{\tilde{u}_i^{n+1} - u_i^n}{\Delta t} = -u_j^n \frac{\partial u_j^n}{\partial x_j} + g_i + \frac{\partial \tau_{ij}^n}{\partial x_j},$$

Projection step

$$\frac{u_i^{n+1} - \tilde{u}_i^n}{\Delta t} = -\frac{1}{\rho^n}\frac{\partial p^{n+1}}{\partial x_i}, \qquad \frac{\partial u_i^{n+1}}{\partial x_i} = 0,$$

Pressure Poisson Equation (PPE)

$$\frac{\partial}{\partial x_i}\left(\frac{1}{\rho^n}\frac{\partial p^{n+1}}{\partial x_i}\right) = \frac{1}{\Delta t}\frac{\partial \tilde{u}_i^{n+1}}{\partial x_i},$$

Corrector step

$$\frac{u_i^{n+1} - \tilde{u}_i^{n+1}}{\Delta t} = -\frac{1}{\rho^n}\frac{\partial p^{n+1}}{\partial x_i}$$

…

2.3 Wave boundary condition

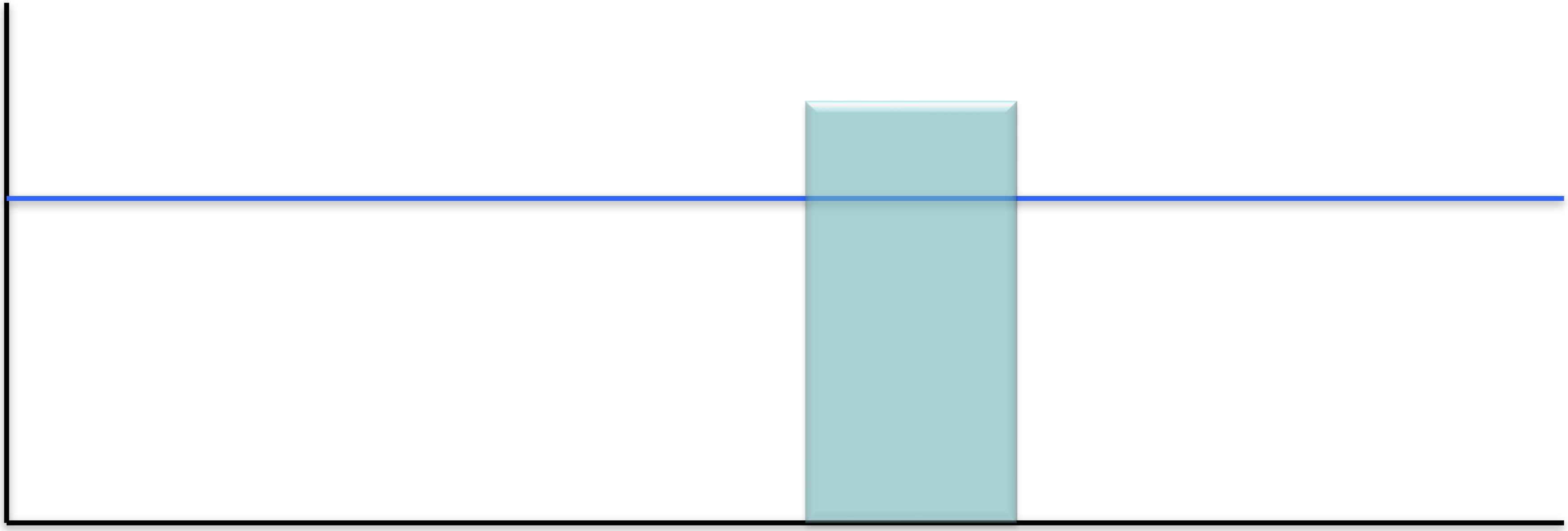
- Introduction
- Methods
- Wave absorption

2.4 Mesh generator: CORAL

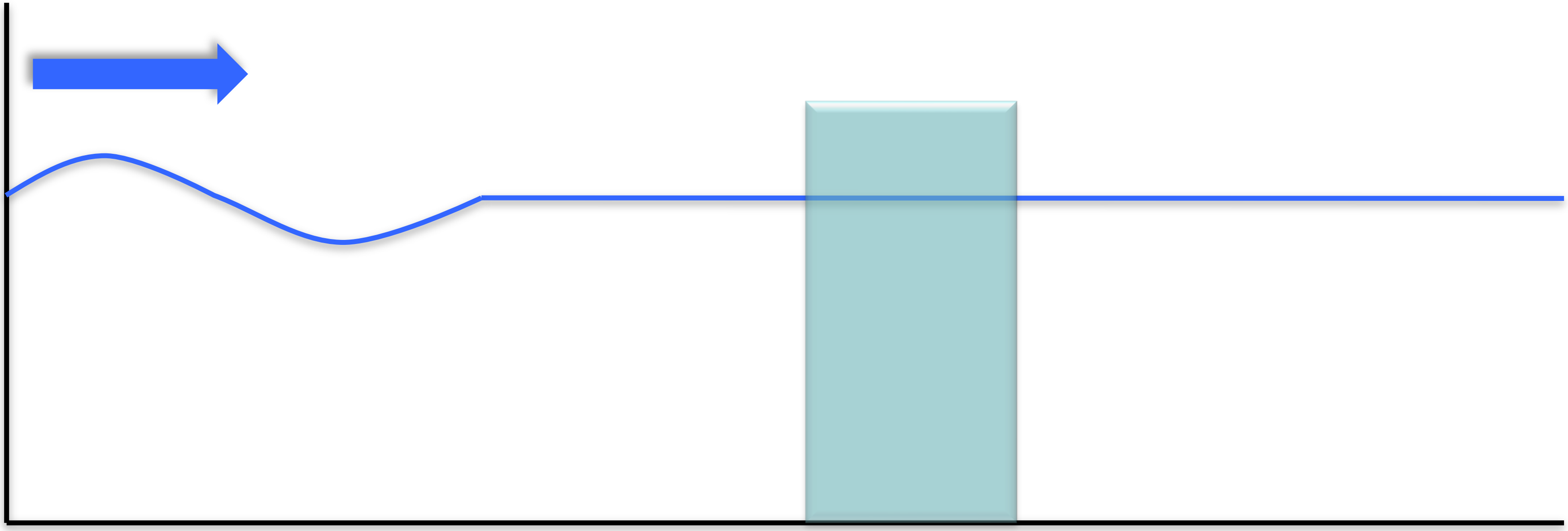
2.3 Wave boundary condition
Introduction

- Numerical simulations of nearshore hydrodynamics are carried out for a computational domain that is usually limited by fictitious boundaries.
- Boundary conditions need to be specified along these open boundaries in order to simulate the effect induced on hydrodynamics inside the computational domain by processes occurring outside
- The boundary condition suited for nearshore simulations should generate the incoming wave motion and absorb the outgoing waves. It is thus referred to as absorbing-generating boundary condition.

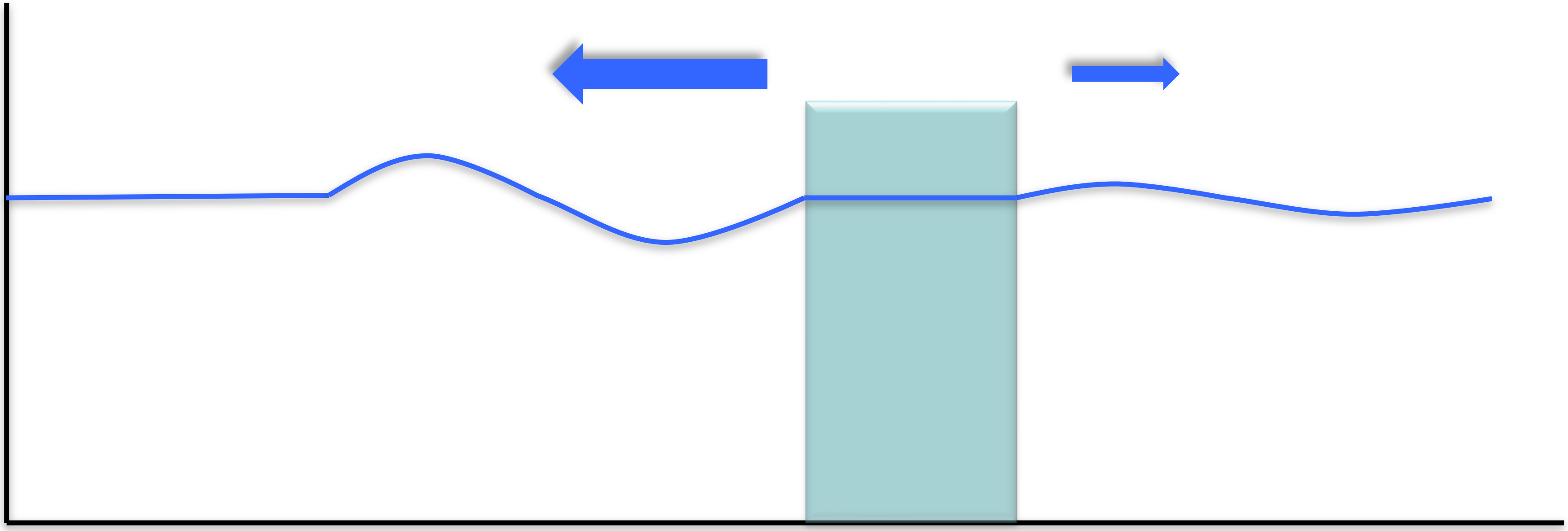
Active Wave Absorption Methodology



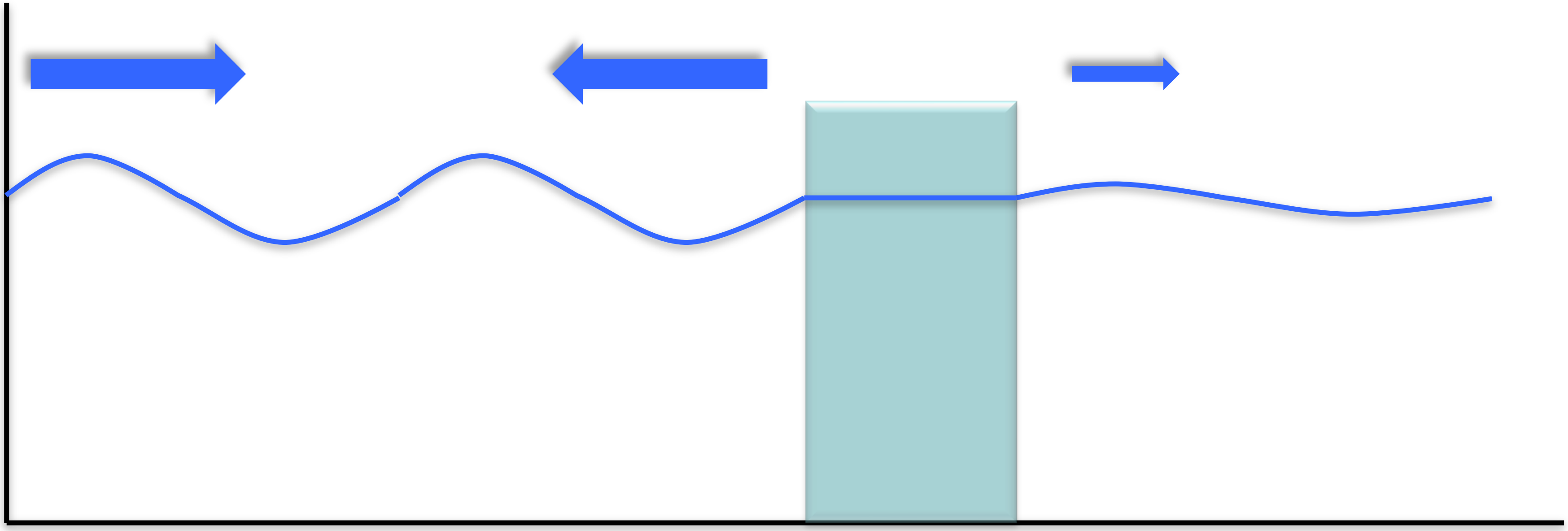
Active Wave Absorption Methodology



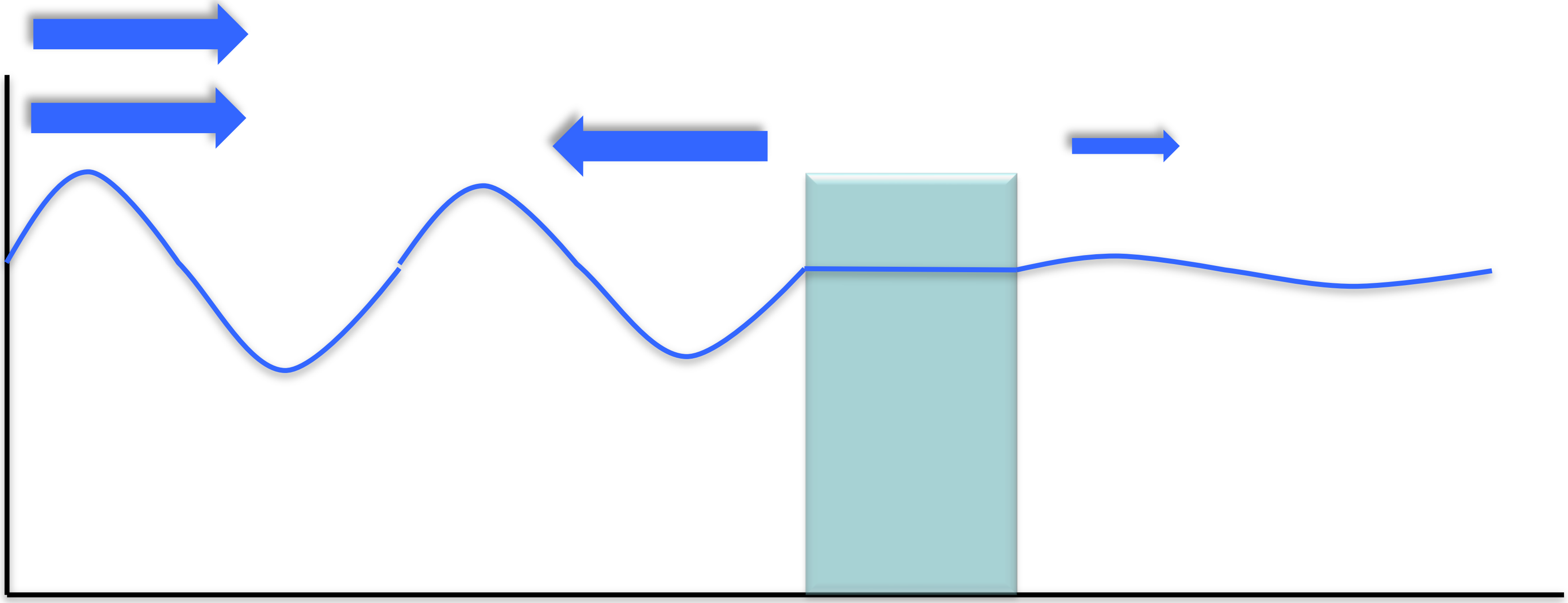
Active Wave Absorption Methodology



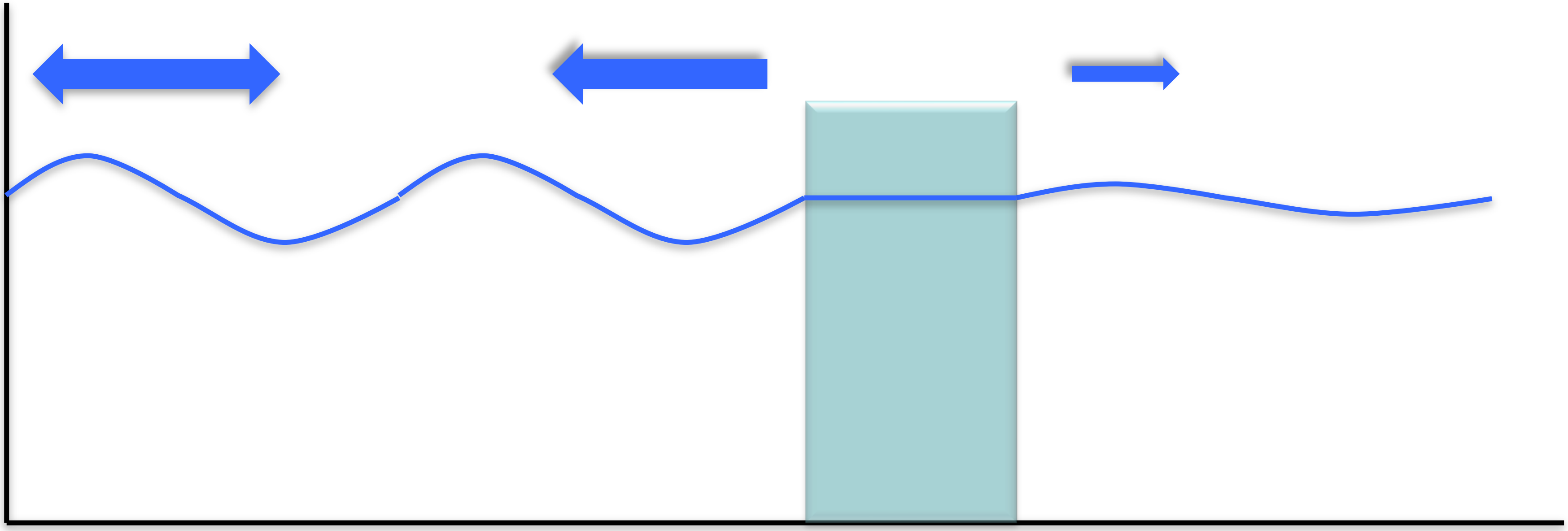
Active Wave Absorption Methodology



Active Wave Absorption Methodology



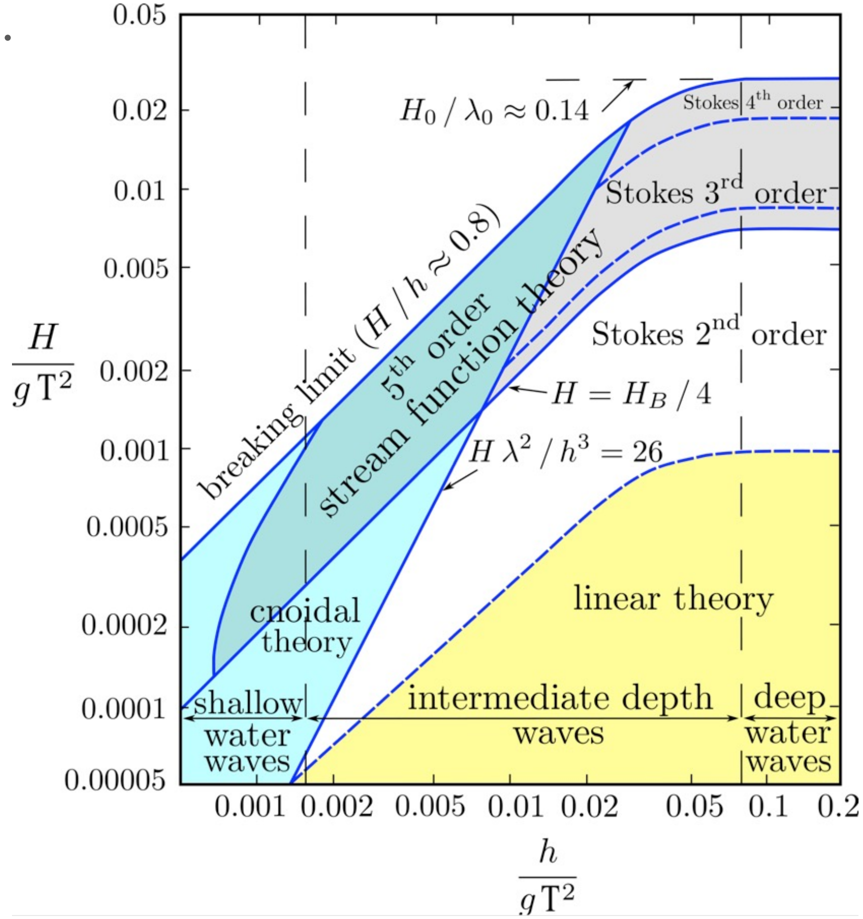
Active Wave Absorption Methodology



2.3 Wave boundary condition
Methods

- Wave generation is the key factor for a coastal engineering model.

- Currently IH-2VOF supports 2 methods.
  - Dirichlet boundary condition
  - Moving boundary method



Dirichlet Boundary Condition

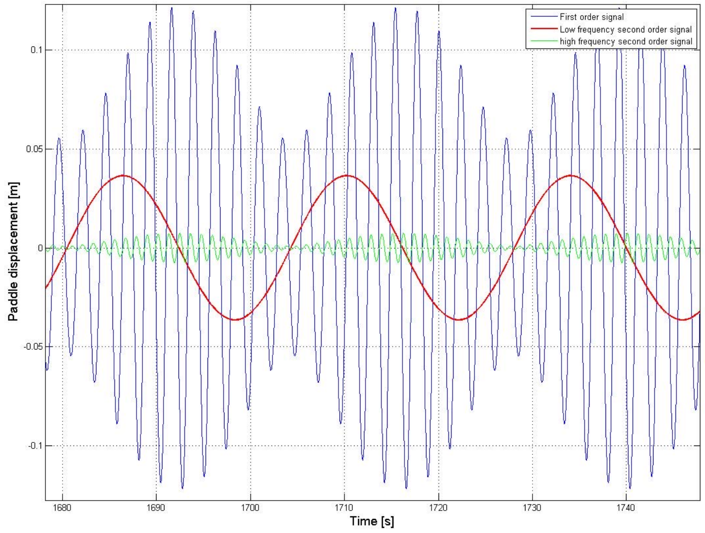
- The numerical study of wave motion in the nearshore requires a wave generation algorithm able to reproduce the incoming wave conditions
- A convenient approach able to accurately reproduce incoming waves is based on imposing the theoretical free surface and the velocity field at the open boundary.
- VOF gets value 1 under free surface, 0 otherwise.
- Free surface and velocities for each cell in the first column are specified as input at a given sampling rate.
- Values are linearly interpolated as the simulation advances, and fixed in the boundary.

Dirichlet Boundary Condition

Theories implemented

- Regular waves:
  - First order
  - Second order
  - Fifth order (not in the GUI yet)
  - Cnoidal
  - Solitary

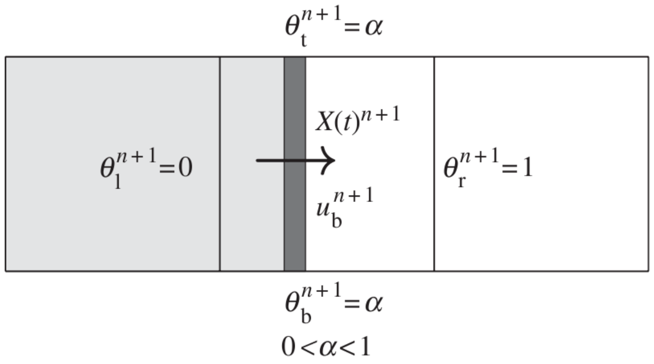
- Irregular waves:
  - First order
  - Second order (LH62 wave theory)



Example of second order corrections for Bichromatic waves

Moving Boundary Method

- This boundary condition replicates a piston type wave maker. It needs the paddle position as input.
- Velocity is then calculated as a first order forward derivative of position.
- The interaction of the paddle with the water makes use of openness coefficients and the virtual boundary forces.
- The moving wave maker appears as a source term in the momentum equation determined by the body surface velocity.



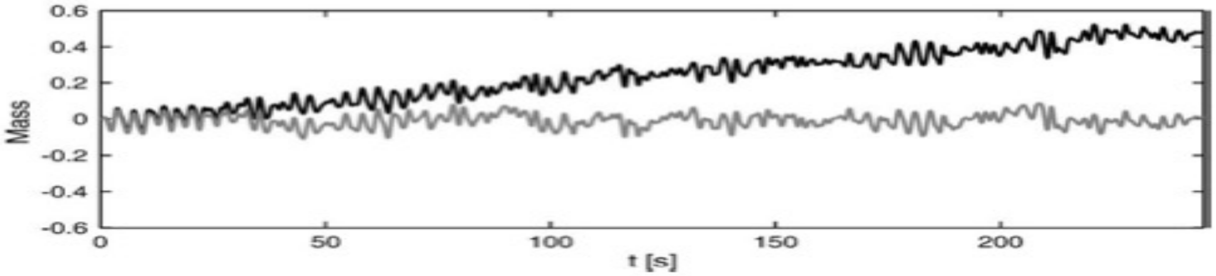
Wave Absorption Methods

The problem of wave absorption at the boundary in numerical models involves both incoming and outgoing waves.

Two main goals of wave absorption can be identified:

1. absorption of the reflected long waves which propagate toward the boundary
2. avoid of unrealistic total mass increase/decrese inside the computational domain.

An absorption routine is needed to achieve a significant improvement in the wave generation at the boundary



Wave Absorption Methods

- Wave absorption allows simulations.
  - Smaller domains.
  - Longer runtime before increasing agitation.

- Perfect absorption is idealistic: results up to 10% reflection are very good.

- Currently 2 supported methods
  - Active wave absorption
  - Passive wave absorption: Sponge layer

Wave Absorption Methods

- Active wave maker absorption is also included in the model using the same procedure followed in physical flumes. Theory has developed in: Review of Multidirectional Active Wave Absorption Methods (Schäffer & Klopman, 2000)

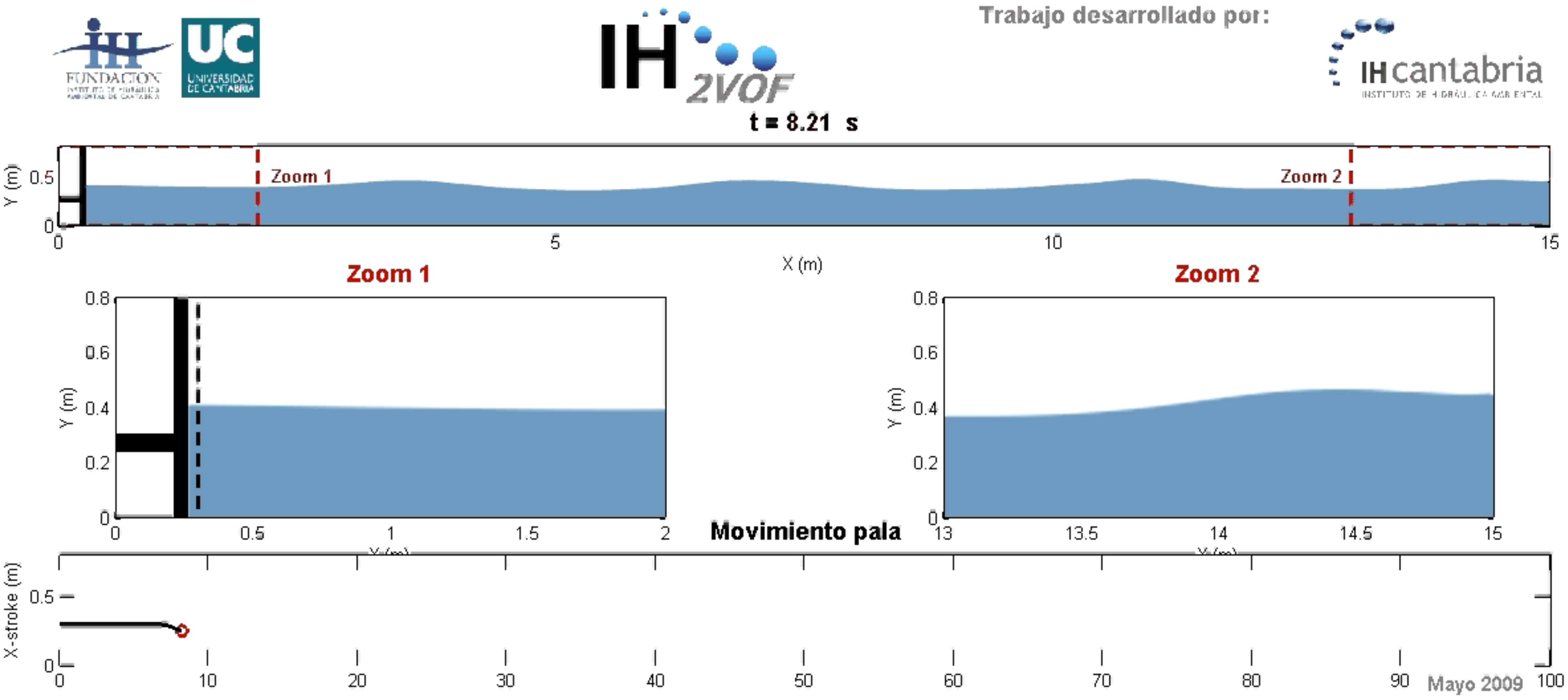
- The system absorbs depending on an input value: water level at the boundary.

- It is based on linear long wave theory: it has proven to work fine for waves outside this assumption.

$$U \cdot h = c \cdot \eta \qquad c = \sqrt{g \cdot h} \qquad U = -\sqrt{\frac{g}{h}}\,\eta_c$$

$$\eta_c = \eta_{\text{measured}} - \eta_{\text{theoretical}}$$

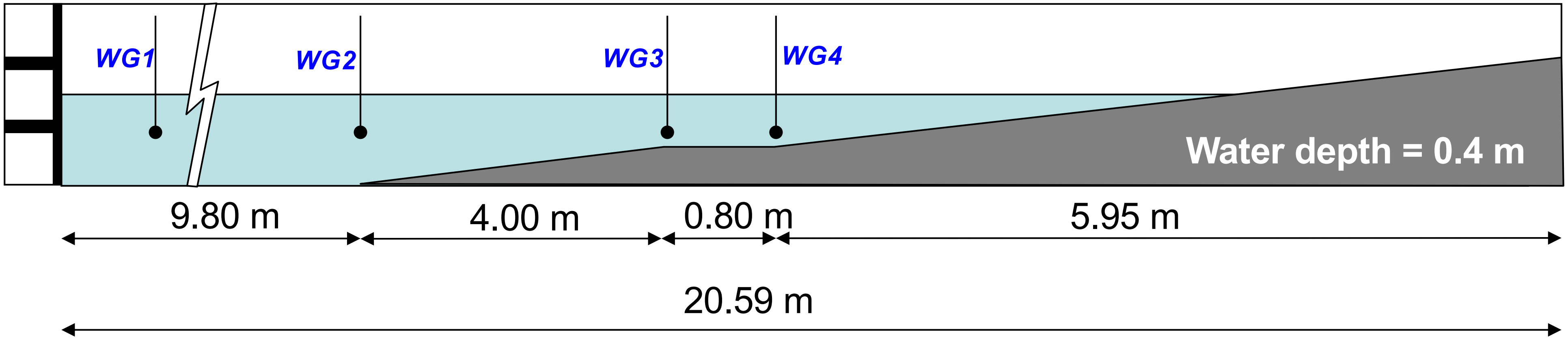
2.3 Wave boundary condition
Wave absorption



2.3 Wave boundary condition
Wave generation-absorption (comparative analysis)

Experimental set-up

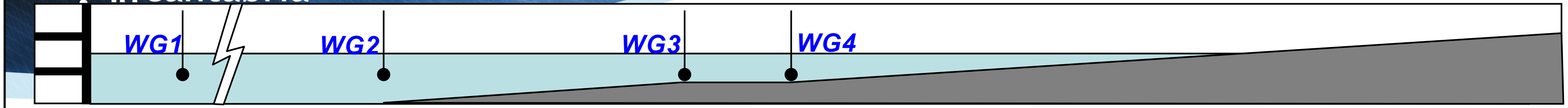
Δx = Δy =0.01 m

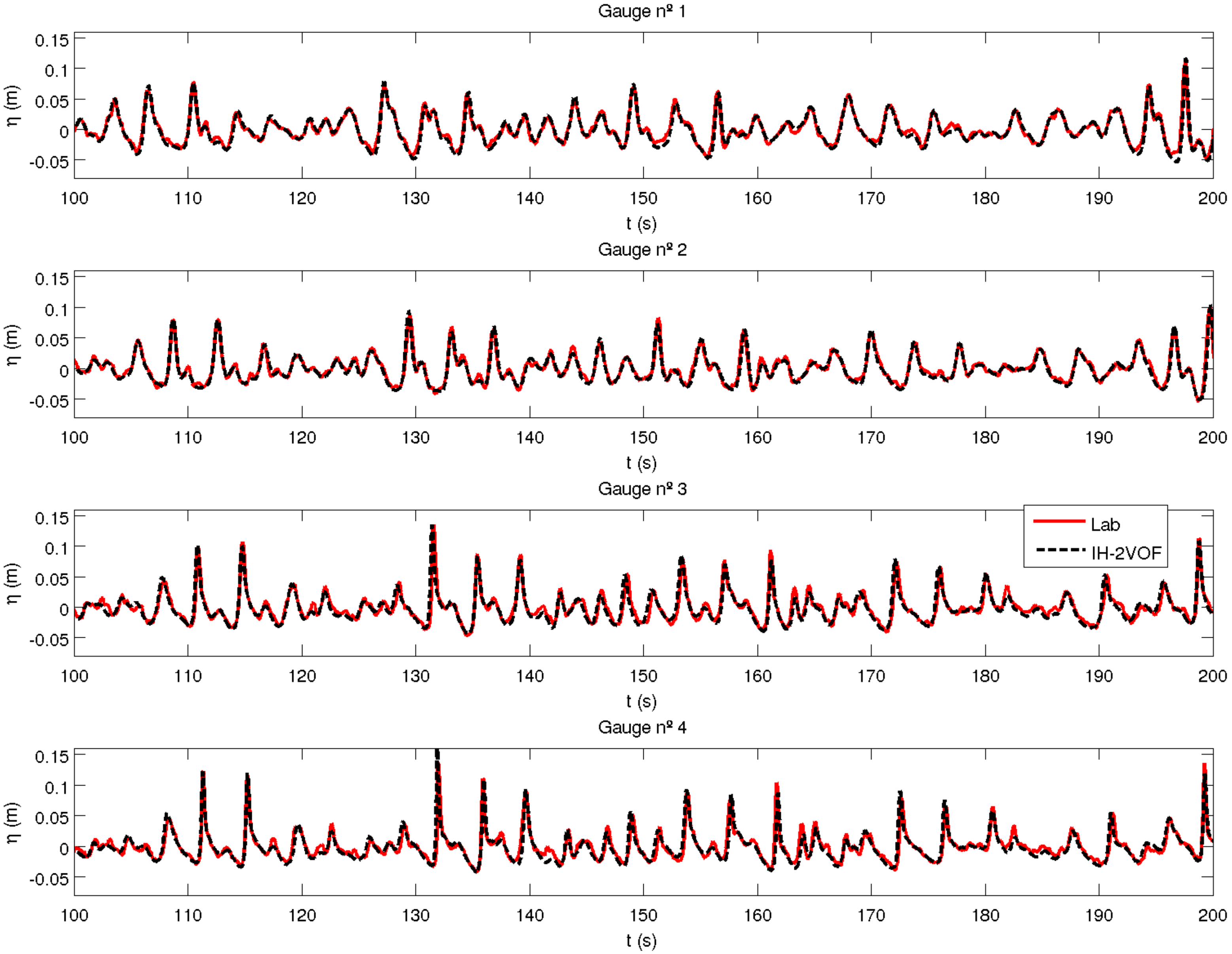


Wave characteristics:

Wave Charac.	*Solitary*	*Regular*	*Random*
H (m)	**0.02-0.16**	**0.05, 0.10 ,0.15**	**0.05, 0.07, 0.10**
T (s)	**-**	**1.5, 2, 3, 4**	**1.5, 2, 3, 4**

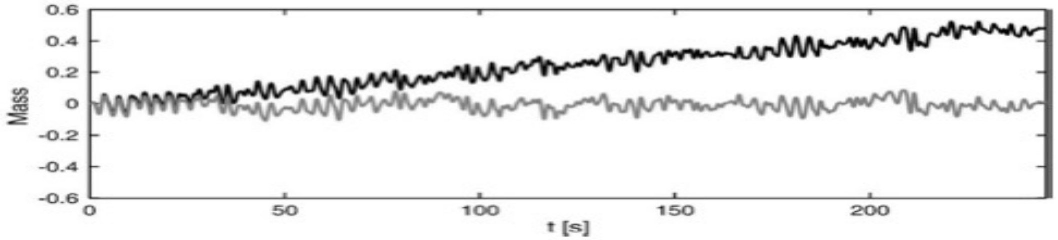
2.3 Wave boundary condition





Active Wave Absorption Methodology

- It ensures better stability for long simulations
  - It prevents the rise of water level due to the unbalance between wave crest-trough.
  - It allows a great percentage of reflected energy to flow out, avoiding its unbounded increase within the domain.
  - It does not noticeably increase the computational cost.
- Preferred among dissipation zones
  - They increase the domain in around 2 wave lengths.
  - They tend to increase the mean level due to the added friction.



Conclusions

The simultaneous wave generation and absorption problem is of great importance for a detailed study of wave transformation on coastal waters.

The challenge is in specifying incident waves through an inflow boundary with the presence of offshore wave radiation.

Different algorithms are implemented in the IH-2VOF model in order to achieve a high accuracy of the generation and the absorption routines

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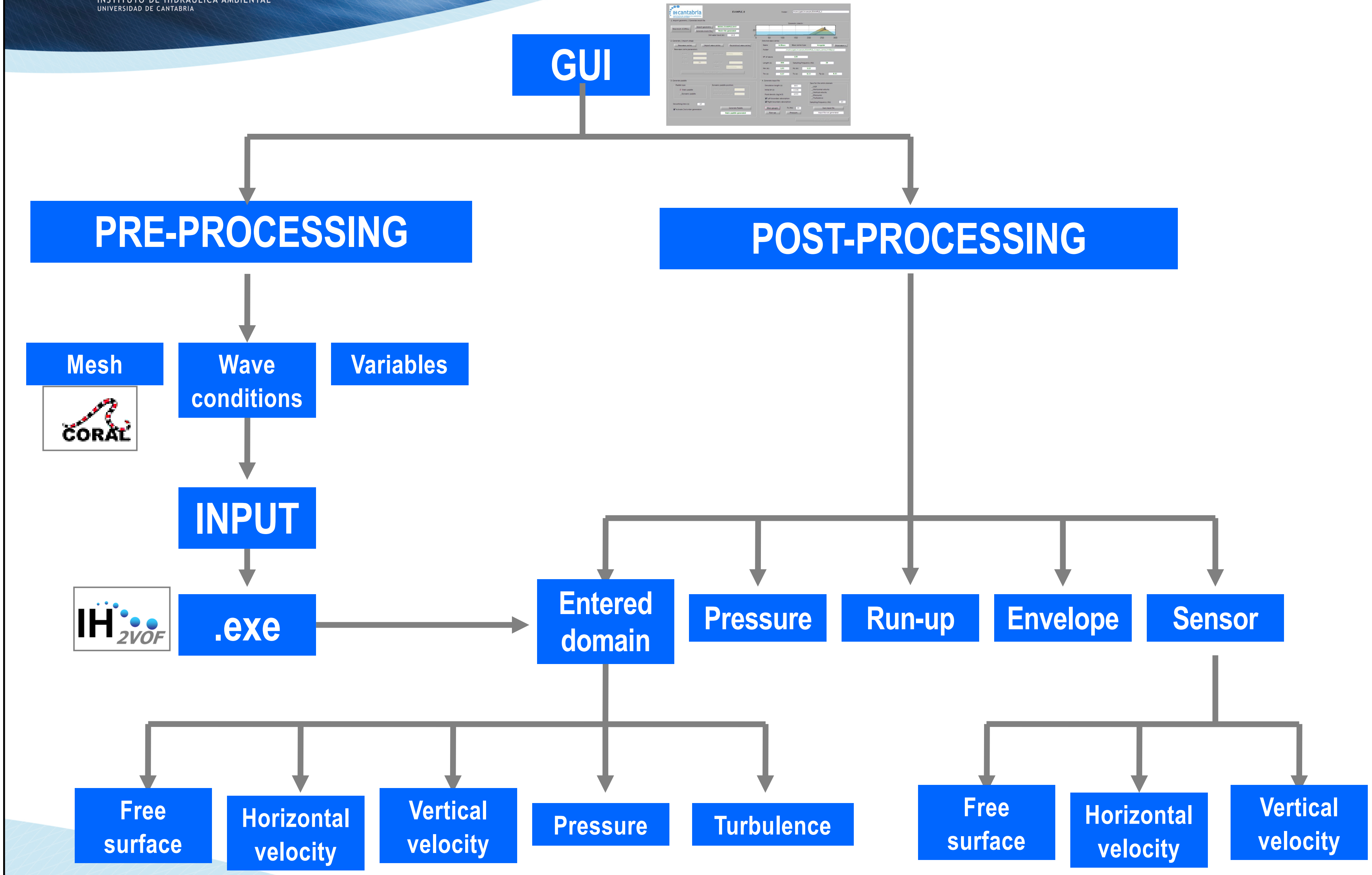
2.3 Wave boundary condition

- Introduction
- Methods
- Wave absorption

2.4 Mesh generator: CORAL

GUI Flow chart



GUI

PRE-PROCESSING

Mesh

CORAL

Wave conditions

Variables

INPUT

IH 2VOF

.exe

POST-PROCESSING

Entered domain

Pressure

Run-up

Envelope

Sensor

Free surface

Horizontal velocity

Vertical velocity

Pressure

Turbulence

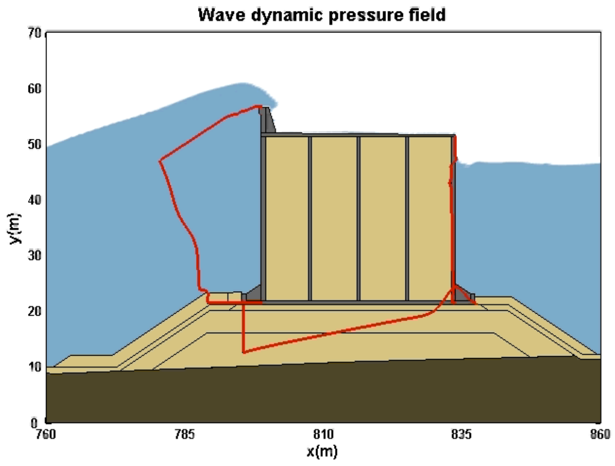
Free surface

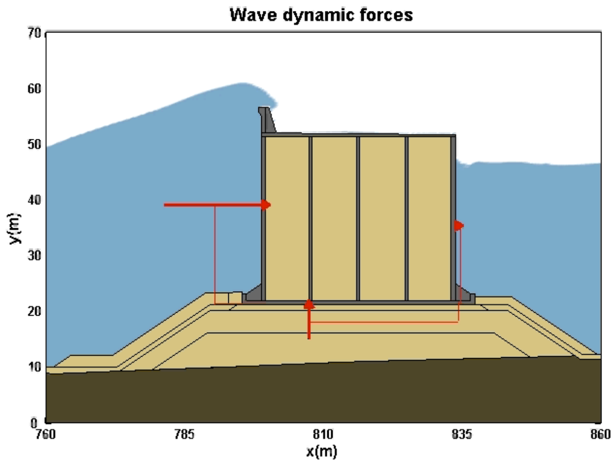
Horizontal velocity

Vertical velocity

IH-2VOF Model

Mathematical/Numerical description


Wave dynamic pressure field


Wave dynamic forces

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