Hydrodynamics of an Innovative Discontinuous Double Breakwater, Mixed Modeling: 2D Flume Physics and 3D Digital Modelling

Christian Raffourt, Charlie Vergnet, Vasileios Afentoulis and Philippe Bardey

HYDRODYNAMICS OF AN INNOVATIVE DISCONTINUOUS DOUBLE BREAKWATER, MIXED MODELING: 2D FLUME PHYSICS AND 3D DIGITAL MODELLING

Raffourt, Christian, Vergnet, Charlie, Afentoulis, Vasileios, Bardey, Philippe[1]
Mailing address
Christian.Raffourt@acri-in.fr, Charlie.Vergnet@acri-in.fr, Vasileios.Afentoulis@acri-in.fr,
Philippe.bardey@acri.fr

KEY WORDS

Wave Flume, OpenFOAM, Hydrodynamics, Coastal Structures, Breakwater.

ABSTRACT

An improved design method of shore parallel discontinuous submerged breakwaters with optimal geometry is presented. In particular, the effect of breakwater openings on hydrodynamic conditions around the structures is experimentally and numerically investigated. The challenge of this study is not only validating the experimental findings using numerical methods but also investigating further alternative forms and geometries which cannot be reproduced in the wave flume. This research concerns a submerged coastal structure composed of two shore-parallel rouble mound breakwaters with openings (channels) whose main objective is to limit wave-induced set-up by pumping out and generating transverse seaward flows. Our wave flume (Figure 1), extended 31m in cross-shore and 1.8m in along-shore direction, is equipped with a piston type wavemaker and the sea-bed is represented by movable elements. The main experimental results concern the hydrodynamic conditions in the channels, where offshore-oriented currents are presented. The numerical modeling is performed using OpenFOAM software. After the validation of experimental findings, a second task consists in expanding the structure in along-shore direction. The main objective is to assess the bias committed by the wave flume configuration. Thus, the simulations are realized with identical bathymetry, but for models four and eight times wider than the original one and with either a finite or an infinite structure. The results show that the local three-dimensional flow always exists and is negligibly influenced by reflexions on the wave flume walls. The initial physical model can therefore be considered as the representation of an infinite structure.

1. INTRODUCTION

Our goal is to define the optimal form of shore parallel-discontinuous submerged breakwaters concerning the geometry, volume and materials of these structures. Submerged breakwaters are often associated with wave-induced set-up while the potential energy of the flow increases in the protected area. Therefore, strong return currents are generated in the edge of the structures, causing an intense sediment movement. The intensification of sandbar migration has an adverse impact on the stability of littoral environment, leading to coastline retreat. In order to eliminate this disadvantageous impact, an alternative shape of the breakwater system is proposed with opening (channels) so that potential energy can be dissipated and converted into kinetic energy, while the flow is channelled through the gaps. This work concerns the assessing of hydrodynamic conditions in the vicinity of coastal defence discontinuous structures, while a dedicated study is underway to evaluate the morphodynamic processes in the coastal area.

For the evaluation of hydrodynamic processes physical experiments are carried out in a wave flume extended 31 m and 1.8 m in crosshore and alongshore direction respectively (Figure 1). This wave flume (canal) is equipped with a piston type wavemaker and the sea-bed is represented by a 1/36 scale model. The experimental set-up concerns structures which are characterized by an alongshore non-uniformity. It can be assumed that the initial non-uniformity cannot be fully represented by the scale model but an analogous configuration which includes 1.5 opening on the seaward rouble mound breakwater and 1 opening on the shoreward is used. The experimental procedure is based on Froude similarity law. Numerical simulations are

---

[1] Corresponding author

realized using OpenFOAM software, in order to validate the experimental findings and investigate further the coastal processes around the structures without the constraints of the experiment (side boundary effects, total space dimensions). The numerical model is based on the Reynolds-Averaged Navier-Stokes (RANS) equations. Overall a good agreement between numerical and experimental findings is achieved, while both approaches show that intense offshore-oriented currents are generated in the seaward side of the breakwater system, around the openings. In this work, physical and numerical models collaborate intimately to increase the reliability of our investigations.

2. METHODOLOGY AND MEANS

2.1 Method

The method used for this study is based on a hybrid approach of small scale numerical and physical models. In order to assess the precision and limitations of wave flume experiments, it is necessary to consider the following factors: A) The narrow distance between the lateral boundary- walls of the wave flumes which restrain the flow and affect the three-dimensional characteristics of the fluid motion. B) The parallel application of several similarity laws.

The physical model is therefore supported by a numerical model. The comparison between the physical and numerical results leads to a better understating of nearshore mechanisms. The arithmetical simulations are carried out on a 1:1 scale while the scale of the experiment is 1:36 complying with Froude similarity law but without considering the viscous dissipation. Thus, the level of uncertainty, concerning the experimental scale, can be estimated by comparing the findings of the two methods. Similarly, the impact of the side boundaries of the physical model can also be evaluated. The physical model is the basis for a coherent approach to validating the numerical model. The numerical model makes it possible to assess the biases in experimental parameterizations. In this way, a Feedback connection of two models is achieved.

2.2 Configuration of structures, wave conditions and sea bottom characteristics

The general geometric configuration of the structure is shown in Figure 1. The parameters of this configuration are listed in Table 1. Figure 2 is a side profile of the structure. Moreover, the movable bottom is characterized by 23% seaward slope, 6% slope on the structures and 13% slope on the shoreface. The wave characteristics used as initial conditions are shown in Table 2.

2.3 Physical modelling

2.3.1 Configuration of the model

The experiments are carried out in the 2D wave flume of ACRI IN in Sophia Antipolis. The wave flume is equipped with a sloping bottom, composed of adjustable elements with varying height and inclination, reproducing a two-dimensional bathymetry in the zone of the structures. The piston-type wavemaker generates regular and irregular surface waves based on different spectral approaches including JONSWAP spectrum.

The spatial scale is 1:36. At this scale, the width of the real field section represented in the channel is 64.80 meters and the different categories of armour layers have been defined according to the Hudson similarity law. These categories are mentioned in Figure 2.

A geometrical configuration which includes 1.5 opening on the seaward rouble mound breakwater and 1 opening on the shoreward is applied in order to represent the distribution of the openings of each breakwater.

2.3.2 Instruments

The equipment of the experiment consists of four gauges, four pressure sensors and two reels. Their location is shown in Figure 5. Three gauges (S3, S4 and S5) dedicated to the control of the incident wave characteristics are located out of the bathymetry (Figure 3). The fourth gauge (S6) is placed between the structure and the beach. Two pressure sensors (CP9 and CP10) are located on the shoreward side of the structure and two others (CP5 and CP8) on the seaward side. CP9 and CP5 are positioned in front of the breakwater openings while

CP8 and CP10 are positioned in front of a solid section. The two reels are placed in each of the entire openings of the two breakwaters.

The acquisition frequency is set to 200 Hz, which corresponds to a frequency of 33 Hz in real field conditions.

In addition to the instrumentation listed above, the constant slope range is used as a measuring instrument. Layers of different colors are set in order to define the maximum runup and rundown on the video recordings.

2.3.3 *Wave generation*

The experiments are validated when the value of significant incident wave height H_{m0} doesn't differ more than 5% from the target value defined in Table 2 at a specific offshore location.

The duration of each experiment is 35 seconds which corresponds to a real duration of 210 seconds. This is equal to the time that an individual wave needs to reach the structure and be reflected back to the wavemaker.

2.4 Numerical modeling

The OpenFOAM software is applied for the purposes of this study. OpenFOAM is a free, open source CFD software released and developed by OpenCFD Ltd. OpenFOAM has an extensive range of features to solve anything from complex fluid flows involving chemical reactions, turbulence and heat transfer, to acoustics, solid mechanics and electromagnetics.

An incompressible two-phase flow solver interFoam is used to solve the Reynolds-Averaged Navier-Stokes (RANS) equations with the SST k-ω turbulence model. The PISO algorithm is utilized for the pressure-velocity coupling. The air-water interface is captured via Volume of Fluid (VOF) technique [1].

The dimensions of the model and the applied boundary conditions are described in Figure 6. The numerical model is designed on a 1: 1 scale.

The incident wave is monochromatic according to the linear (Airy's) theory, and the general characteristics are given in Table 2.

At time t = 0, the velocity is uniformly zero. The liquid fraction α in each element is calculated so as to satisfy the following criterion: *if z> z_0 then α = 0, otherwise α = 1.*

The mesh consists of prisms with triangular bases. The horizontal dimension of each elements is approximately 1 m near the structures and widens progressively without exceeding 20 meters. In vertical direction, the elements are distributed in 50 layers.

Each numerical simulation is realized for a total duration of 210 seconds.

3. RESULTS

3.1 Experiment vs numerical model

Figures 8 to 12 show the comparison of results between physical and numerical model. It is noted that a very good agreement of wave elevation record is achieved (Figure 8). The pressures are well represented also by the numerical model, while the velocities in the opening of the breakwater are quite different than that of the experiment (Figure 11). It should be underlined that the level of uncertainty of reels measurements is especially high. Concerning the runup and rundown (Figure 12), there is a good agreement between physical and numerical model. In the surf zone, the two types of modelling present a three-dimensional turbulent flow between the structure and the beach.

3.2 Harnessing model capabilities

The calibration of numerical model is not fully accomplished, but some achievements could be presented. The first scenario concerns a 500 m wide channel with a lateral expansion of the wave flume cross sections. The simulations are carried out using a coarse vertical discretization (Figure 13). In Figure 14, the velocities in one of the openings shows that offshore-oriented currents are obtained, as in the case of the narrower channel.

The second scenario corresponds to a finite narrow breakwater system. Figure 15 shows the crosshore component of velocity in a single point of the computational domain, located at breakwater openings. A strong offshore-oriented current is generated according to the numerical results. Figure 16 depicts bottom shear stresses generated in the vicinity of breakwaters and induced by significant nearshore currents.

5. TABLES AND FIGURES
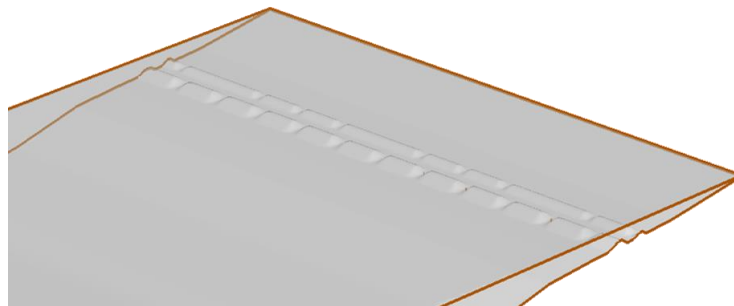
Figure 1: Example of the proposed structure
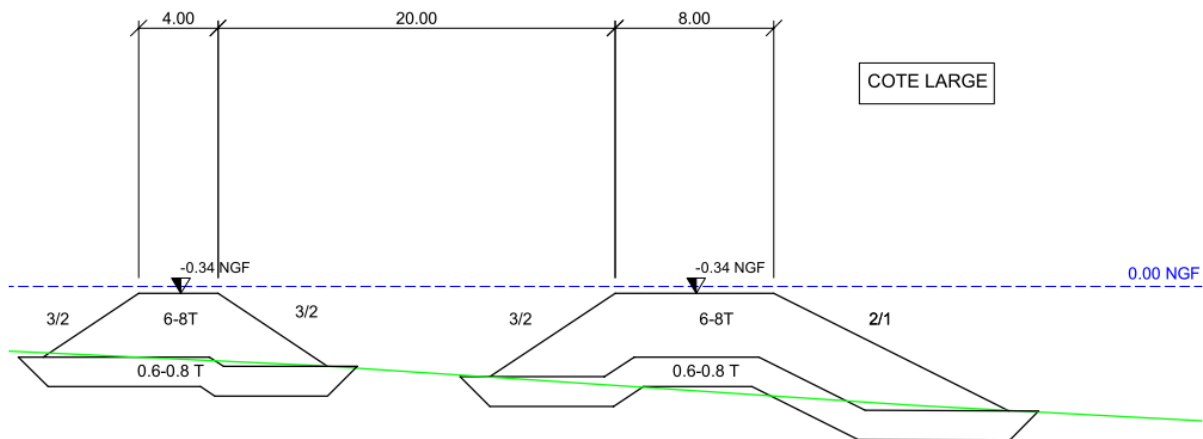
Figure 2: Profile of double breakwater system in wave flume.

Figure 3: Section of the wave flume. The piston-type wavemaker at left. The gauges are represented in fuchsia color, the two rectangles of blue color represent the two windows of the canal, the model is visible at the level of the right window, the sloping beach on the far right is not utilized, the gray vertical lines represent the fixing rails of the adjustable elements , the concrete structure of the wave channel is illustated by the broad gray lines.
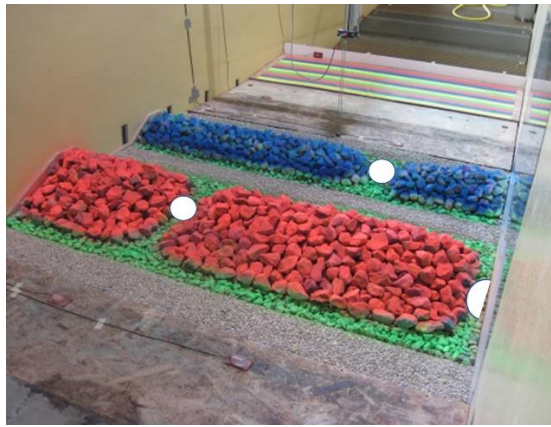
Figure 4: Configuration of the model. With blue the shoreward breakwater, with red the seaward breakwater. The white circles are positioned on the openings. The half-round is positioned on the additional half-opening of the breakwater.
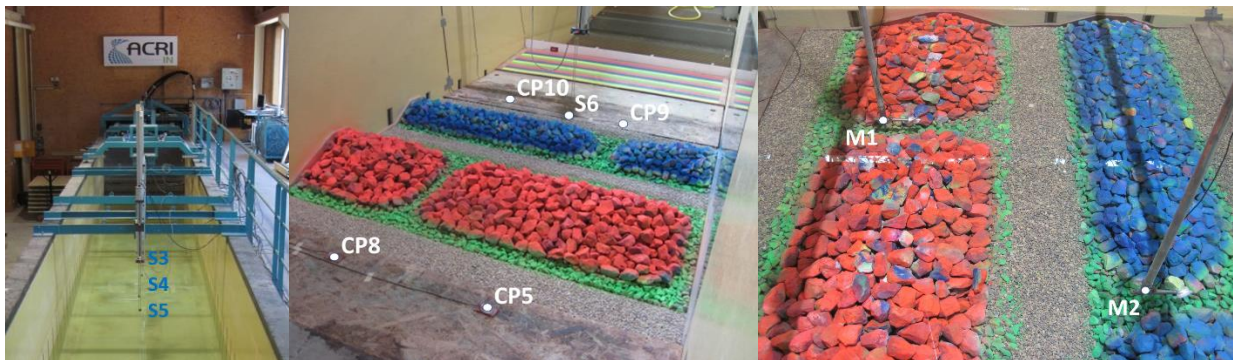

Figure 5: Location of instruments in wave channel. Left: Three gauges controlling the characteristics of the incident wave (S3, S4 and S5), in the center: 4 pressure sensors (CP5, CP8, CP9 and CP10) and a sensor (S6), on the right: two reels (M1 and M2).
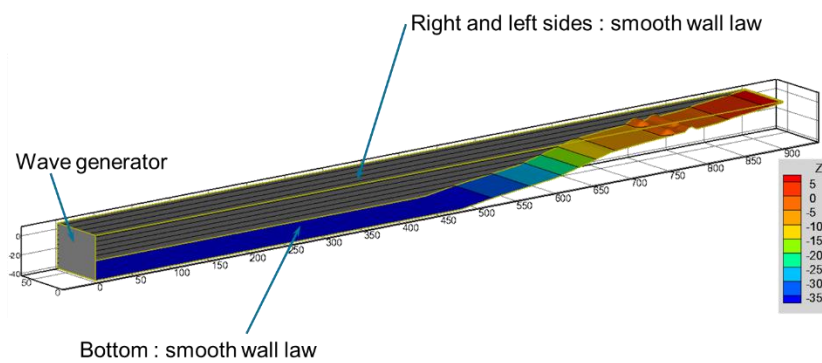

Figure 6: Type of boundary conditions
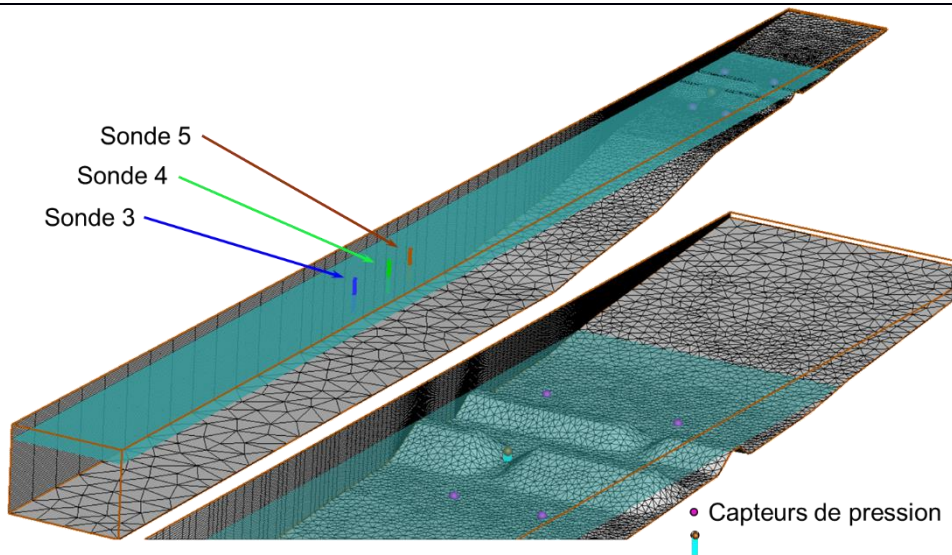
Figure 7: Mesh and probes locations
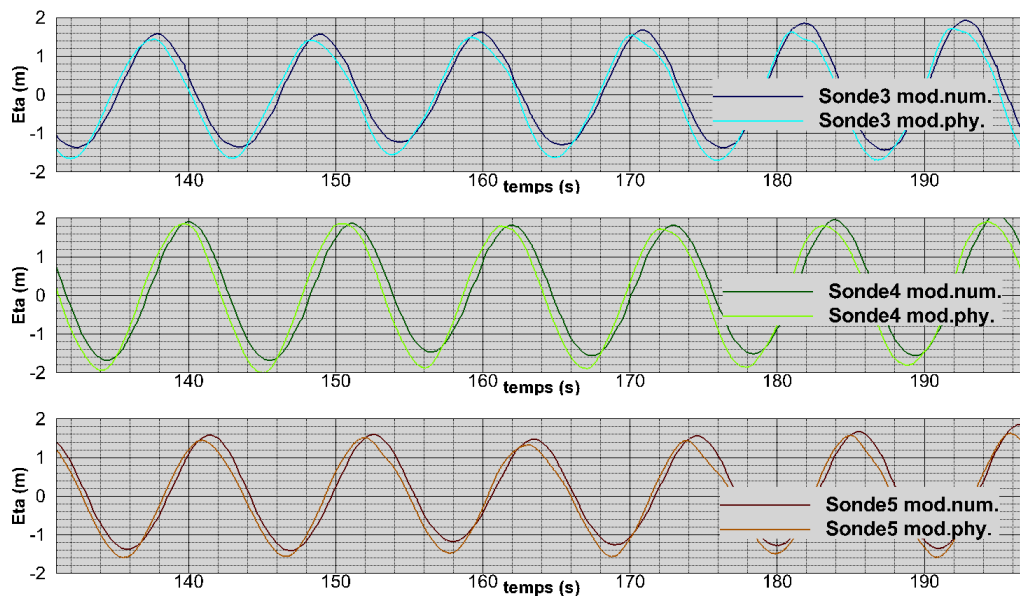
Figure 8: Comparison of free surface elevation for numerical and physical models for S3, S4 and S5.
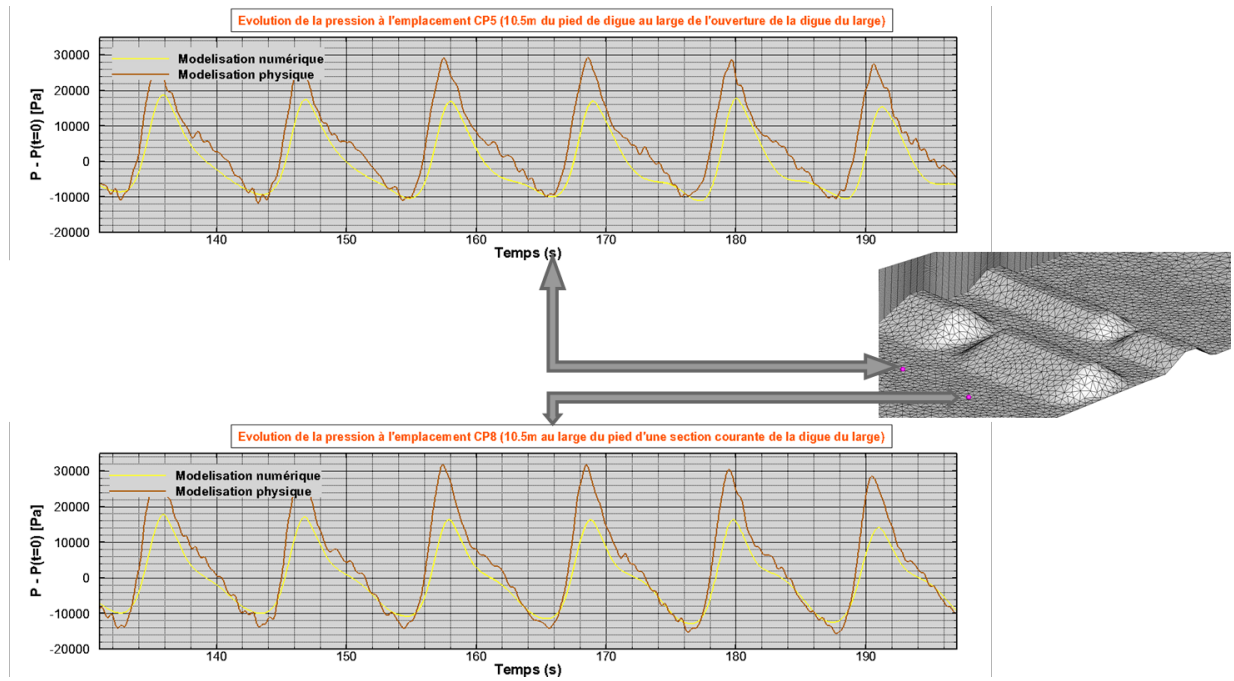
Figure 9: Comparison of pressure for numerical and physical models for CP5 and CP8.
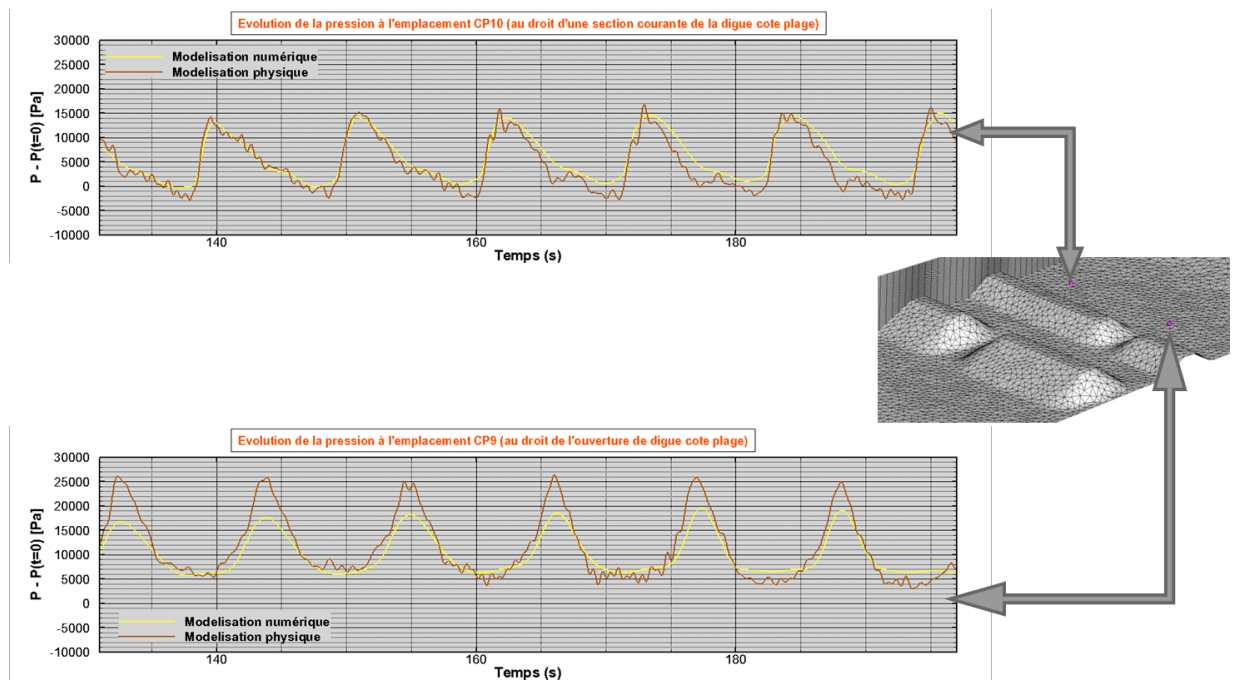

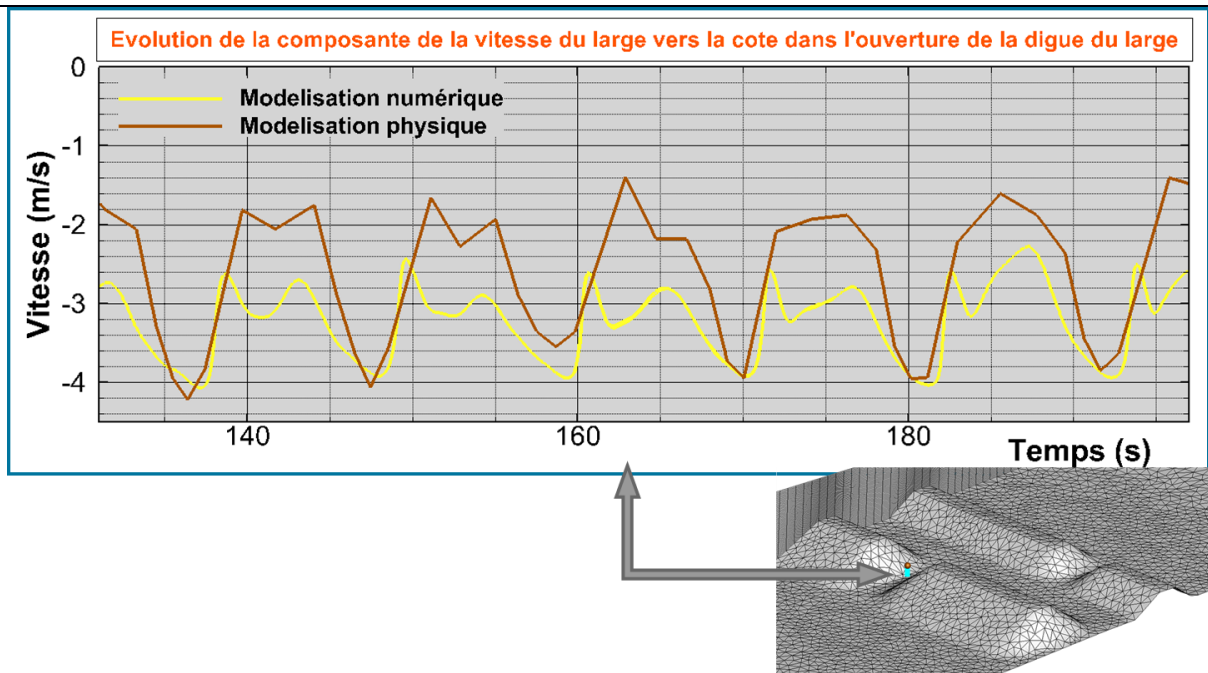**Figure 10**: Comparison of pressure for numerical and physical models for CP9 and CP10.

Figure 11: Comparison of longshore velocity component for numerical and physical models for M1 (negative is oriented land to offshore).
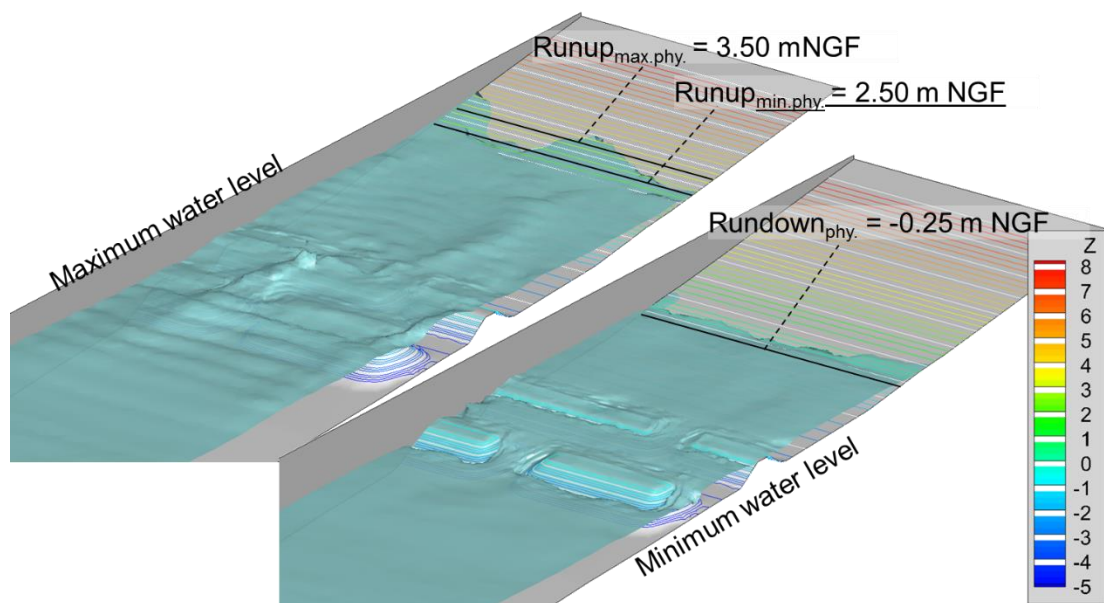

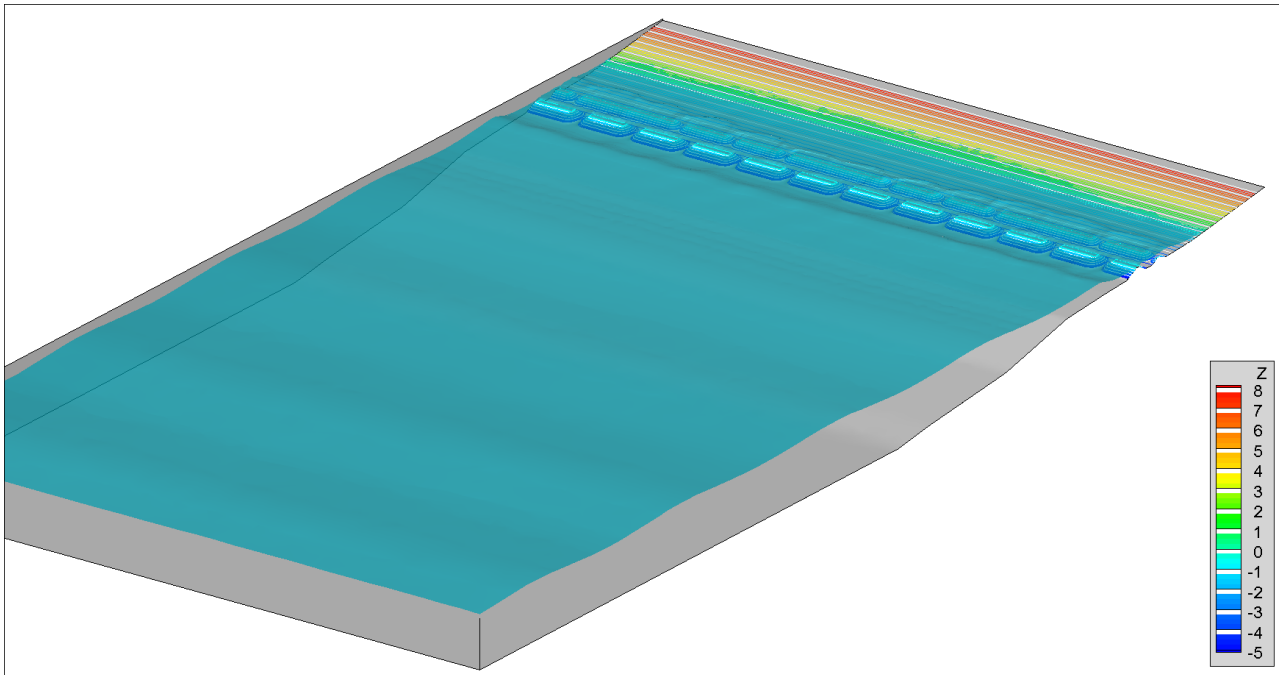**Figure 12**: Comparison runup and rundown for numerical and physical models for M1

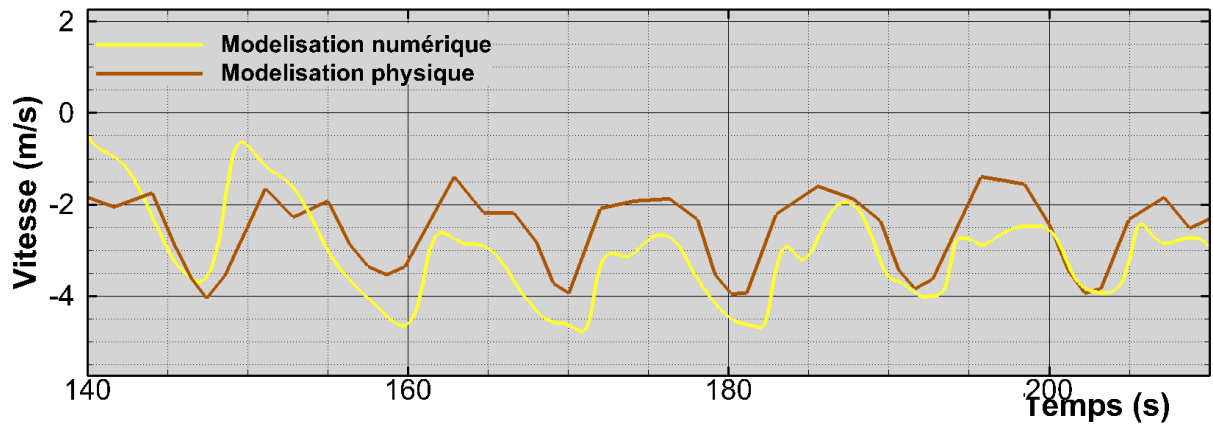**Figure 13**: Wide numerical model

Figure 14: velocities measured in a single point around the opening of the seaward breakwater – Scenario 1.
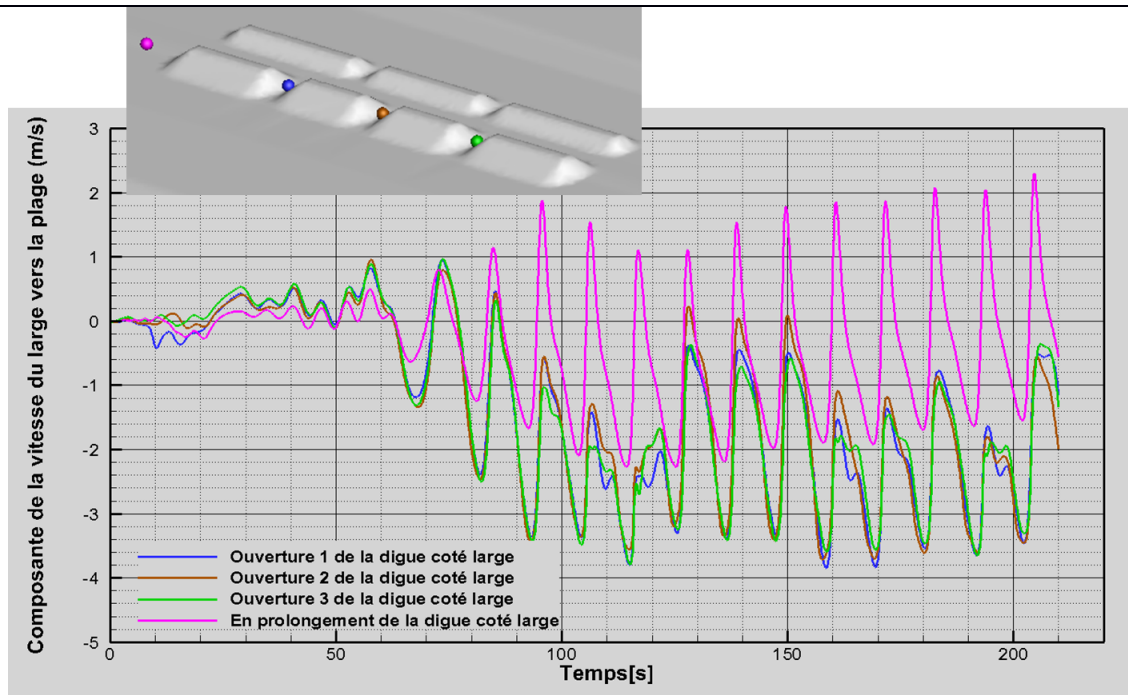
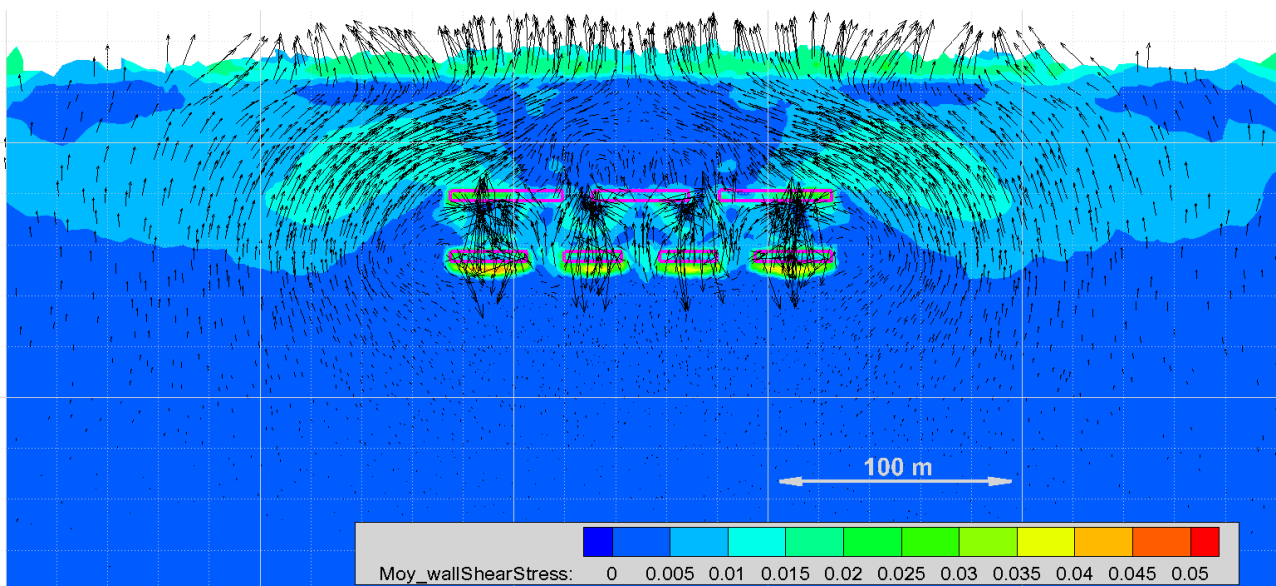**Figure 15**: Longshore velocity component in the openings of the seaward breakwater for the case of scenario 2.

Figure 16: Bottom shear stresses for the case of scenario 2.

	Shoreward Breakwater	Seaward Breakwater
Crest level	-0.34m	-0.34m
Crest width	4.0 m	4.0
Bed slope	3/2	3/2
Seaward slope of structures	3/2	2/1
Length of openings	12m	15m
Slope in the openings	3/2	3/2
Distance between breakwater	24m	

Table 1: Characteristics of structures

Parameter	Value
Still water level	+0.16m
Wave type	monochromatic
Wave Height	3.5m
Period	11s

Table 2: Wave climates

5. CONCLUSIONS

This study concerns a double shore parallel breakwater system, whose performance is investigated using a hybrid numerical and physical modelling. The physical model is carried out in a 1:36 scale physical model. The numerical simulations are realized using the interFoam solver of OpenFOAM free software.

The still uncompleted study enlightens very encouraging findings for both numerical model validation aspects as well as for the use of the wave flume concerning this type of discontinuous works.

A dedicated study is underway to: i) extend the scenarios of numerical investigation for different wave conditions ii) complete the harnessing of numerical model in several channel configurations.

This hybrid modeling could be followed by a further study in wave flume in order to learn more about optimal geometrical configurations.

REFERENCES AND CITATIONS

[1] C. W. Hirt and B. D. Nichols (1981), Volume of fluid (VOF) method for the dynamics of free boundaries, Journal of Computational Physics, 39, pp. 201-225.