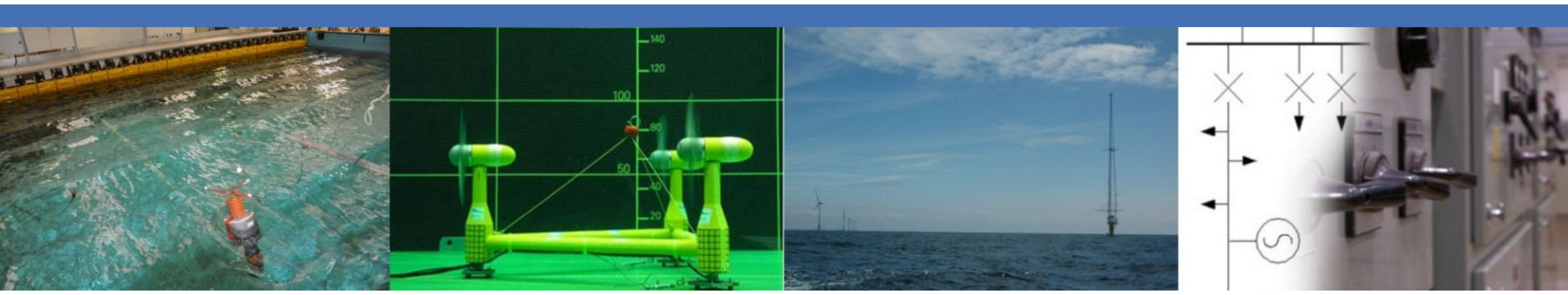
MARINET

Marine Renewables Infrastructure Network

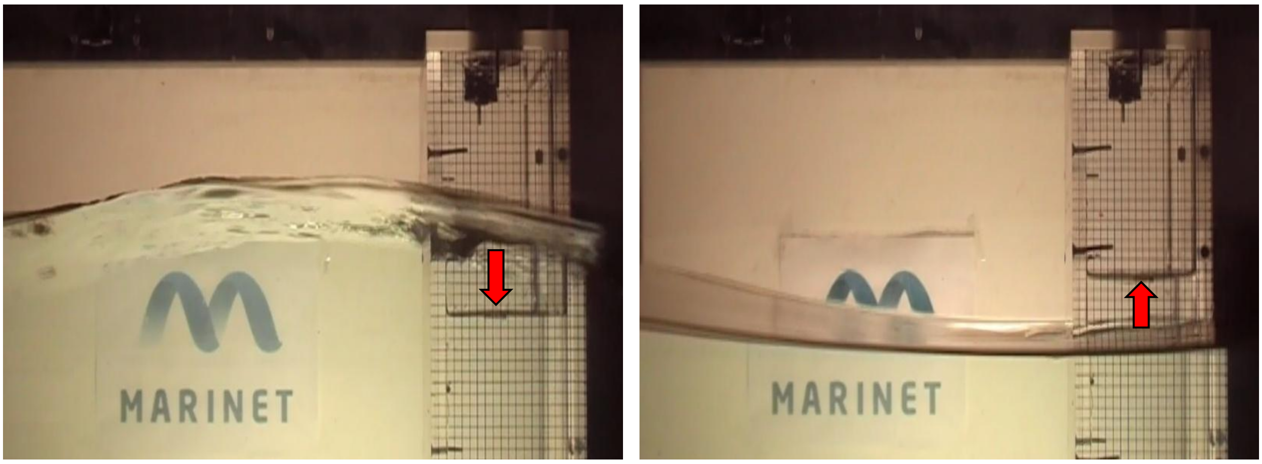


Infrastructure Access Report

Infrastructure: Wave-Current Flume WCF - University of Florence
www.labima.unifi.it

***User-Project*: LBM4OWC**

WATER WAVE INTERACTION WITH AN OSCILLATING WATER COLUMN WAVE-ENERGY CONVERTER: EXPERIMENTAL VALIDATION OF LATTICE BOLTZMANN NUMERICAL SIMULATIONS



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SEVENTH FRAMEWORK PROGRAMME

ABOUT MARINET

MARINET (Marine Renewable Infrastructure Network for emerging Energy Technologies) is an EC-funded network of research centres and organisations that are working together to accelerate the development of marine renewable energy - wave, tidal & offshore-wind. The initiative is funded through the EC's Seventh Framework Programme (FP7) and runs for four years until 2015. The network of 29 partners with 42 specialist marine research facilities is spread across 11 EU countries and 1 International Cooperation Partner Country (Brazil).

MARINET offers periods of free-of-charge access to test facilities at a range of world-class research centres. Companies and research groups can avail of this Transnational Access (TA) to test devices at any scale in areas such as wave energy, tidal energy, offshore-wind energy and environmental data or to conduct tests on cross-cutting areas such as power take-off systems, grid integration, materials or moorings. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users, with at least four calls for access applications over the 4-year initiative.

MARINET partners are also working to implement common standards for testing in order to streamline the development process, conducting research to improve testing capabilities across the network, providing training at various facilities in the network in order to enhance personnel expertise and organising industry networking events in order to facilitate partnerships and knowledge exchange.

The aim of the initiative is to streamline the capabilities of test infrastructures in order to enhance their impact and accelerate the commercialisation of marine renewable energy. See www.fp7-marinet.eu for more details.

Partners

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University College Cork, HMRC (UCC_HMRC)
Coordinator
Sustainable Energy Authority of Ireland (SEAI_OEDU)

Denmark
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Danmarks Tekniske Universitet (RISOE)

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About This Report

One of the requirements of the EC in enabling a user group to benefit from free-of-charge access to an infrastructure is that the user group must be entitled to disseminate the foreground (information and results) that they have generated under the project in order to progress the state-of-the-art of the sector. Notwithstanding this, the EC also state that dissemination activities shall be compatible with the protection of intellectual property rights, confidentiality obligations and the legitimate interests of the owner(s) of the foreground.

The aim of this report is therefore to meet the first requirement of publicly disseminating the knowledge generated through this MARINET infrastructure access project in an accessible format in order to:

- progress the state-of-the-art
- publicise resulting progress made for the technology/industry
- provide evidence of progress made along the Structured Development Plan
- provide due diligence material for potential future investment and financing
- share lessons learned
- avoid potential future replication by others
- provide opportunities for future collaboration
- etc.

In some cases, the user group may wish to protect some of this information which they deem commercially sensitive, and so may choose to present results in a normalised (non-dimensional) format or withhold certain design data – this is acceptable and allowed for in the second requirement outlined above.

Acknowledgement

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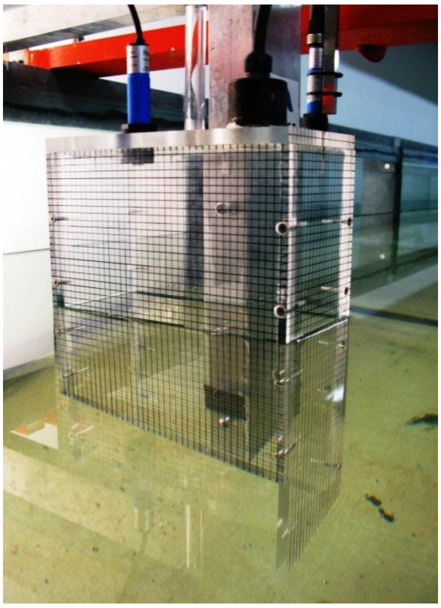
Legal Disclaimer

EXECUTIVE SUMMARY

The short-term aim of this project is to validate the accuracy of Lattice Boltzmann 3D numerical simulations of an OWC-WEC, comparing it to the experimental data obtained from physical model tests that have been conducted in the wave-current flume of the University of Florence. The results include tests on the virtual LB flume and on the physical flume concerning wave generation and wave interaction with OWC-WEC device . The data include incident and reflected/radiated and transmitted waves, measurements of internal free surface oscillations, pressure and mass flow rate.



CONTENTS

1 INTRODUCTION & BACKGROUND

1.1 INTRODUCTION

Many authors presented works devoted to the numerical modelling of Oscillating Water Column (OWC) and most of these studies were performed using traditional computational fluid dynamics (CFD) methods and the multiphase Volume Of Fluid (VOF) model in the wave generation and in the interaction between waves and the OWC.
The open-source Palabos library is a lattice Boltzmann (LB) library that was developed for general-purpose CFD, and includes a VOF-based free-surface flow solver that is suitable for modelling wave interaction with marine renewable energy devices. This library – and the LB model in general – shows outstanding performances in the field of high performance computing and close-to ideal scaling has been observe on machines with tens of thousands of cores.
In this project the wave-current flume at University of Florence has been used to validate the accuracy of LB 3D numerical simulations of an OWC-WEC and, further, to support the development of a hybrid-composite modelling tool for the optimizing of OWC devices and WECs in general.

1.2 DEVELOPMENT SO FAR

1.2.1 Stage Gate Progress

Previously completed: ✓
Planned for this project: ➲

STAGE GATE CRITERIA	Status
Stage 1 – Concept Validation	
• Linear monochromatic waves to validate or calibrate numerical models of the system (25 – 100 waves)	➲
• Finite monochromatic waves to include higher order effects (25 –100 waves)	➲
• Hull(s) sea worthiness in real seas (scaled duration at 3 hours)	
• Restricted degrees of freedom (DofF) if required by the early mathematical models	
• Provide the empirical hydrodynamic co-efficient associated with the device (for mathematical modelling tuning)	➲
• Investigate physical process governing device response. May not be well defined theoretically or numerically solvable	➲
• Real seaway productivity (scaled duration at 20-30 minutes)	
• Initially 2-D (flume) test programme	➲
• Short crested seas need only be run at this early stage if the devices anticipated performance would be significantly affected by them	
• Evidence of the device seaworthiness	
• Initial indication of the full system load regimes	
Stage 2 – Design Validation	
• Accurately simulated PTO characteristics	
• Performance in real seaways (long and short crested)	
• Survival loading and extreme motion behaviour.	
• Active damping control (may be deferred to Stage 3)	
• Device design changes and modifications	
• Mooring arrangements and effects on motion	
• Data for proposed PTO design and bench testing (Stage 3)	
• Engineering Design (Prototype), feasibility and costing	
• Site Review for Stage 3 and Stage 4 deployments	
• Over topping rates	

STAGE GATE CRITERIA	Status
Stage 3 – Sub-Systems Validation	
• To investigate physical properties not well scaled & validate performance figures	
• To employ a realistic/actual PTO and generating system & develop control strategies	
• To qualify environmental factors (i.e. the device on the environment and vice versa) e.g. marine growth, corrosion, windage and current drag	
• To validate electrical supply quality and power electronic requirements.	
• To quantify survival conditions, mooring behaviour and hull seaworthiness	
• Manufacturing, deployment, recovery and O&M (component reliability)	
• Project planning and management, including licensing, certification, insurance etc.	
Stage 4 – Solo Device Validation	
• Hull seaworthiness and survival strategies	
• Mooring and cable connection issues, including failure modes	
• PTO performance and reliability	
• Component and assembly longevity	
• Electricity supply quality (absorbed/pneumatic power-converted/electrical power)	
• Application in local wave climate conditions	
• Project management, manufacturing, deployment, recovery, etc	
• Service, maintenance and operational experience [O&M]	
• Accepted EIA	
Stage 5 – Multi-Device Demonstration	
• Economic Feasibility/Profitability	
• Multiple units performance	
• Device array interactions	
• Power supply interaction & quality	
• Environmental impact issues	
• Full technical and economic due diligence	
• Compliance of all operations with existing legal requirements	

1.2.2 Plan For This Access

1. *Validation of the Lattice Boltzmann Method virtual flume for regular waves;*
2. *Use of the Lattice Boltzmann Method virtual flume as a numerical laboratory for investigation on the OWC system.*

2 OUTLINE OF WORK CARRIED OUT

2.1 INTRODUCTION AND MOTIVATION

Many efforts on numerical modelling of Oscillating Water Column have been done so far: time and frequency-domain, 2D or 3D CFD simulations using Reynolds-Averaged Navier-Stokes (RANS) approaches can be found in literature. We are developing a fully 3D LES approach based on the lattice Boltzmann method (LBM), which is a popular alternative to traditional Navier-Stokes solvers such as finite-element and finite-volume methods. The short term aim of this project is to validate the capability and the accuracy of our 3D free surface LBM to simulate OWC, through a comparison with experiments on a wave flume. The long term objective is to develop a LBM wave-flume and use it as a virtual laboratory for the studies of the OWC devices. As a consequence of the large computational effort needed in this case, the LBM method seems a good choice thanks to its good capability to parallelize on many cores.

2.2 MODEL DESCRIPTION

The physical model tests were performed in the wave-current flume provided by the Laboratory of Maritime Engineering of the Civil and Environmental Department (DICeA) of Florence University (www.labima.unifi.it).
The flume is about 37.0m long, 0.80m wide, 0.8m high and it can accommodate water depths up to 0.60m. It is equipped with a piston type wave make that can generates regular and irregular waves up to about H=30cm for t=1.2s;

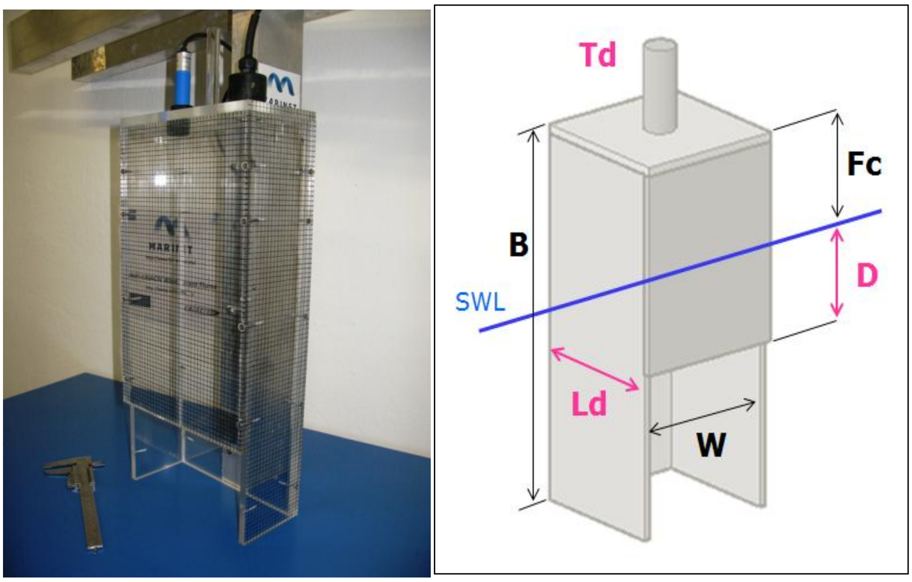


Figure 2.1. Picture and 3D schematic view of the OWC model.

A picture and a schematic drawing of the tested OWC model is shown in Figure 2.1. The OWC model is a rectangular-shaped box. It has been built according to the Froude similarity, with a representative scale factor 1:50th. The material selected for the construction was the methacrylate, in order to allow the observation of the phenomena occurring inside the chamber. The lateral and wall thickness were 8mm while the back and frontal wall thickness were 10mm. The length of the OWC chamber (Ld) was 8cm (internal net value) and the capture width (W) was 18.6 m (internal net value). The back wall length (B) was 45cm and the lip draught (D) was 22cm. The freeboard (Fc) was 12cm. To mimic the presence of a turbine a pipe with given length and different diameter values was used (see Table 3).

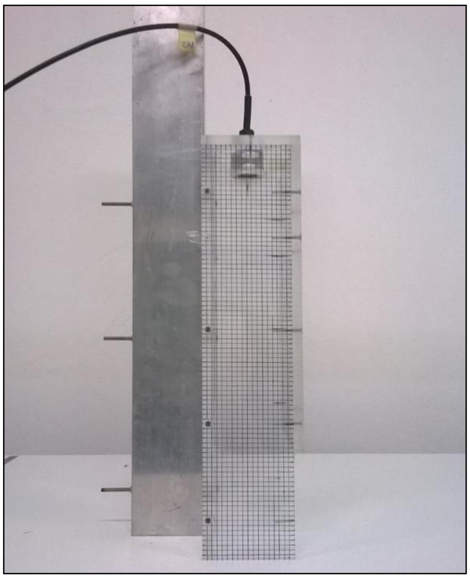


Figure 2.2. OWC model – side view

With the purpose of keeping the OWC in a fixed position, with respect to the bottom of the wave flume, the model was firmly connected to a steel bar as shown in Figure 2.2. The vertical axis of the OWC model was located 22.00m far from the wave maker. The flume bottom was horizontal and the water depth was 0.51m, see Figure 2.3.

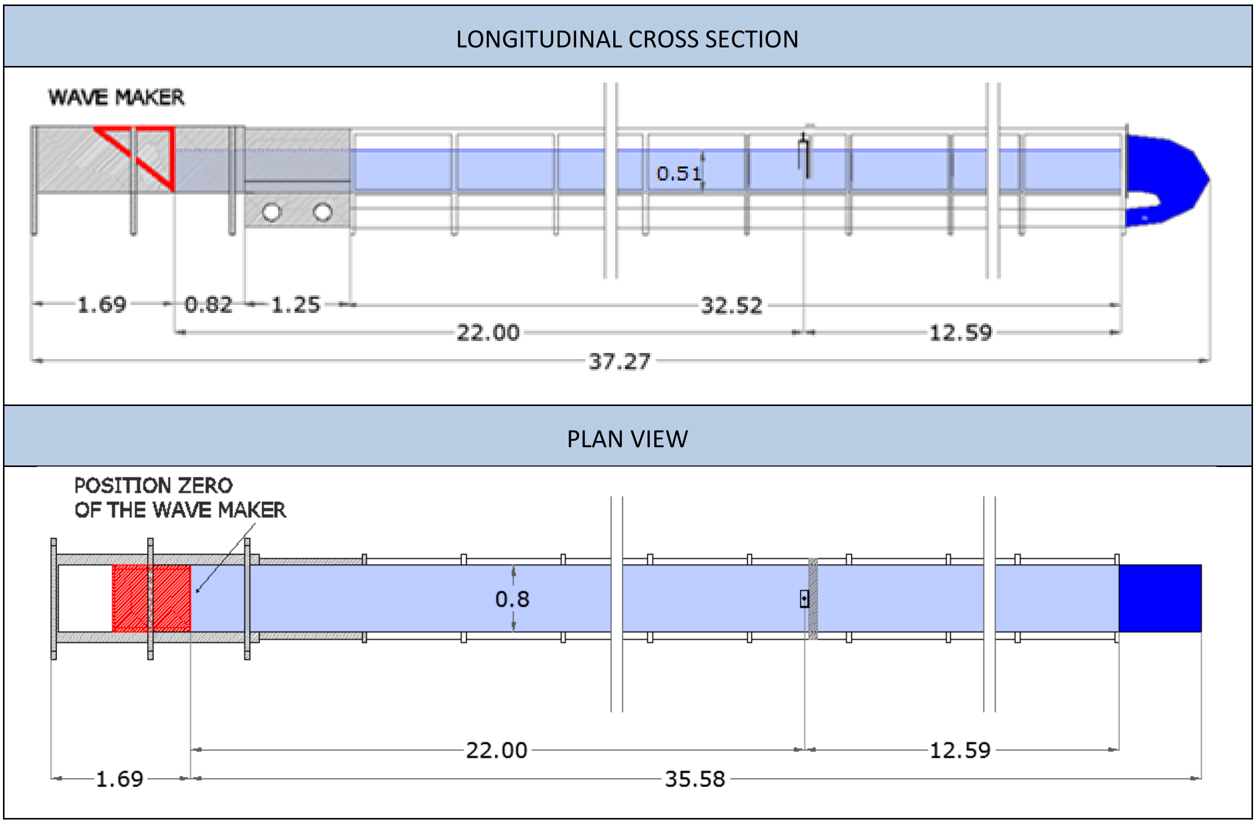


Figure 2.3. Position of the OWC model in the wave flume of Florence University.

The OWC model was equipped with an ultrasonic distance sensor to measure the internal free surface motion and with a differential pressure sensor to measure the pressure oscillation inside the pneumatic chamber.

The ultrasonic distance sensors (Series 943-M18 F4V-2D-1C0-330E by HONEYWELL) (see Figure 2.4) have a declared accuracy of 1mm (the sensing distance interval is from 60mm to 500mm far from the sensor head).

Max. sensing distance:	500 mm
Min. sensing distance:	60 mm
Switching frequency:	100 ms
Repeatability:	0,2 % or ±1 mm

OUTPUT	TERMINATION	REFERENCE
0-10 V	Connector	943-F4V-2D-1C0-330E
0-10 V	Cable	943-F4Y-2D-1C0-330E
4-10 mA	Connector	943-F4V-2D-1D0-330E
4-20 mA	Cable	943-F4Y-2D-1D0-330E

Figure 2.4. Ultrasonic distance sensor HONEYWELL Series 943-M18 F4V-2D-1C0-330E.Picture and technical data sheet.

The pressure transducer is a capacitive transmitter (Series 46X, by KELLER) with a full scale (FS) of 100mbar and an accuracy of ± 0.1% FS (see Figure 2.5).

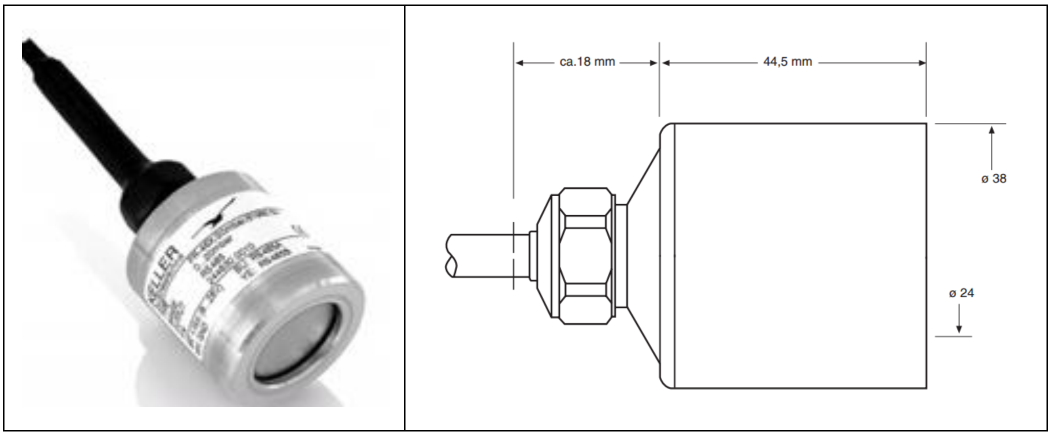


Figure 2.5. Pressure transducer- KELLER Series 46X. Picture and technical drawing.

The ultrasonic distant sensor and a the pressure transducer that were located on the OWC roof where at a distance of 50mm from the top cover centre, in which the vent was located (Figure 2.6 and Figure 2.7). Due to the inherent characteristics of the ultrasonic distance sensor and its positioning inside the air chamber, we noted after the tests that it was able to measure the elevation of the internal free surface up to a max value of about +50mm from the still water level, thus limiting the possibility of the measurements of internal surface elevation. No problems were recognized for measuring the lowering of the internal free surface .

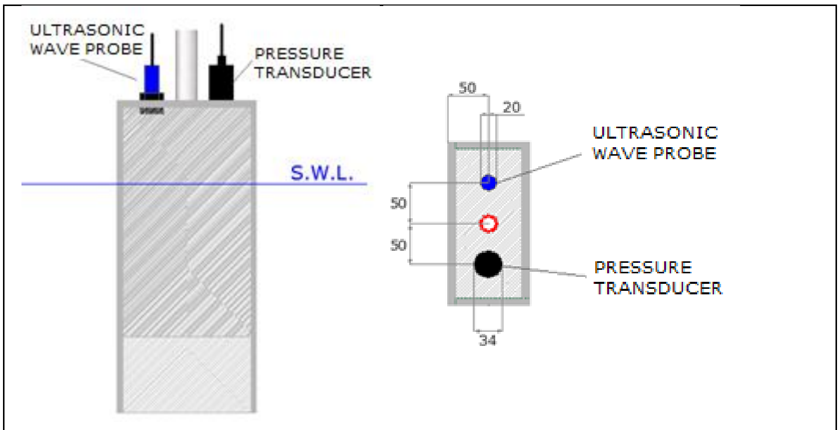


Figure 2.6. Location of ultrasonic distance and pressure sensors on the top of the OWC model (all dimensions in mm).

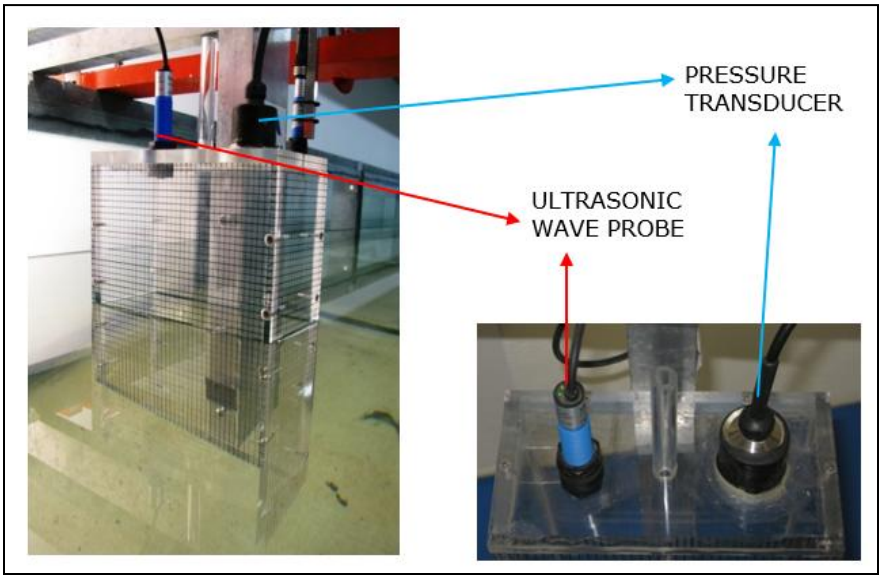


Figure 2.7. OWC model setup in the UNIFI wave-current flume (left: front view, right: top view).

Moreover, to acquire the incident, reflected and transmitted waves, five ultrasonic distance sensors were used as Wave Gauges (WG) and were deployed along the wave-current flume as depicted in Figure 2.8.

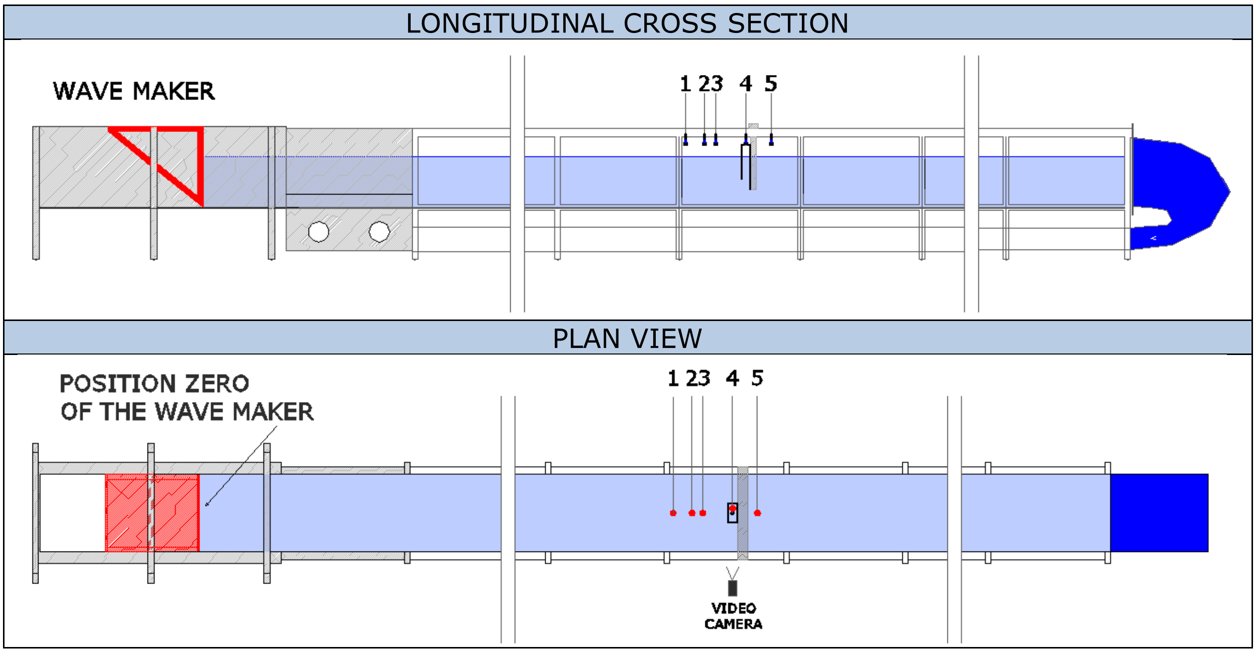


Figure 2.8. Location of the ultrasonic sensors along the UNIFI wave-current flume.

The distance of each probe from the OWC and from the wave generator, was selected according to Mansard & Funke reflection analysis method (Mansard & Funke, 1980) (see Table 1). Moreover, the minimum distance between the reflecting structure of the OWC and the wave gauges array was kept equal to about one wave length.

Table 1: Distances of the ultrasonic probes along the UNIFI wave-current flume.

ARRAY	ULTRASONIC PROBE	Distance from the wavemaker [m]	Relative Distances [m]
Array 1	WG1	21.40	21.40
	WG2	21.59	0.19
	WG3	21.70	0.11
Array 2	WG4	22.00	0.30
Array 3	WG5	22.25	0.25

To investigate the intrinsic resonance frequency of the OWC device, additional tests for all the vent conditions were carried out, in absence of wave attacks.

Two different initial internal free surface levels (tests named RES1 and RES2) were settled inside the OWC chamber, by sucking the air from the duct connecting the OWC vent with the outside. The air suction process was performed in about 2s then the vent was closed, the system was set at rest and finally the vent was opened thus letting the water column oscillates for restoring the equilibrium state (data were acquired for about 50s).

In particular, RES1 and RES2 tests were obtained setting the internal free surface elevation respectively of +5cm and +7cm. It is important to note, as previously mentioned in the present report, that due to the ultrasonic sensor (WG4) limits, during the RES2 tests the exact value of the maximum level inside the chamber was not measured (see Figure 2.9) thus that just the visual measurements (characterized by a accuracy of 2mm-3mm)can be used for the post-processing data analysis.

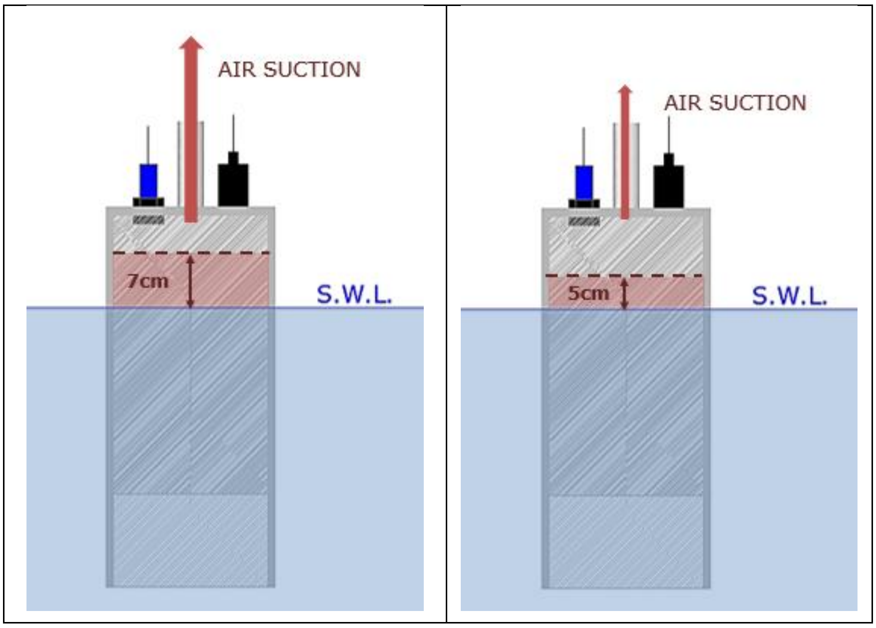


Figure 2.9. Schematic representation of the internal free surface levels settled as initial conditions for the resonance tests.

In order to provide a qualitative knowledge of the hydrodynamic processes taking place inside the OWC's chamber, the inner water surface displacements were also monitored by video records. The camera was placed outside of the flume and a grid with a mesh of 5mm was drawn on the front and side walls of the OWC (Figure 2.8 and Figure 2.10).

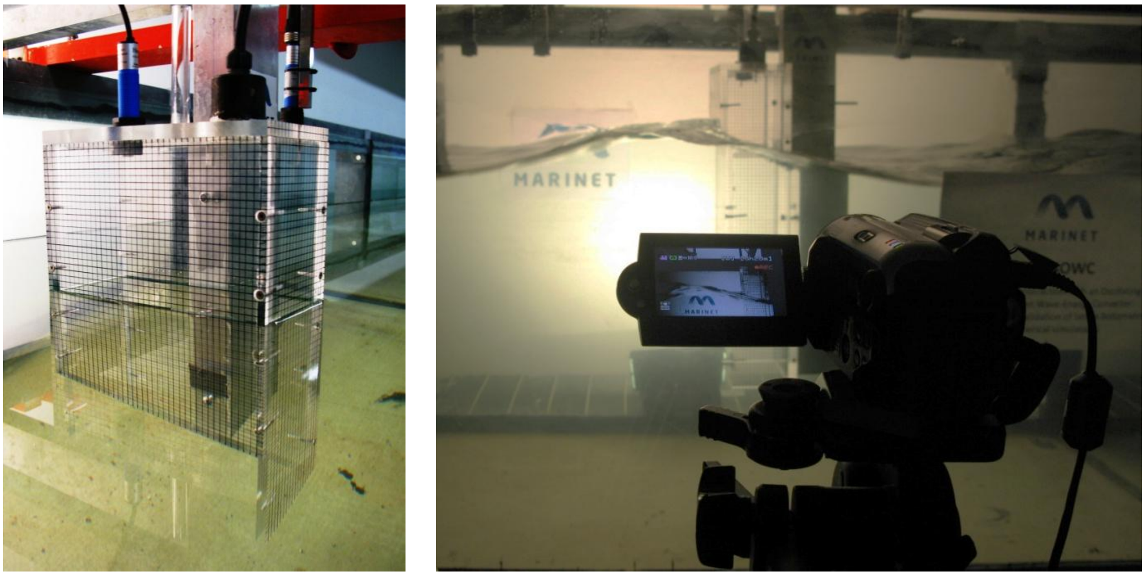


Figure 2.10. Video camera and measuring grid.

2.3 Tests

2.3.1 Tests on the virtual flume

Typical experimental-waves have been simulated into the virtual flume. The range of waves that was planned to be used in experiments were also simulated by the numerical model:

- 0.6 s < period T < 1.3 s
- 2 cm < wave height H < 8 cm

Waves in the numerical model were generated by imposing a sinusoidal force field in a given sub-model boundary condition domain. A present further developments are going on to generate waves with a virtual piston type wave maker.

As preliminary benchmarks for the numerical model, the numerical waves were compared to theoretical values for linear waves, from the point of view of the dispersion-relation (i.e. the theoretical model for linear waves that indicates how propagates a wave of given parameters). The model results fully succeeded these benchmark tests.

2.3.2 Tests on the waves-OWC interaction

Data on air pressure into the OWC device and mass flow rate through the turbine (modelled as a pipe pf given diameter) has been obtained from the numerical model. The algorithm used to perform the coupling between water and air into converter is briefly schematized in Figure 2.11.

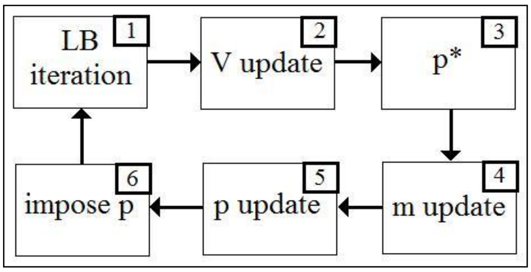


Figure 2.11. Coupling algorithm for numerical model. LB means lattice Boltzmann.
V, p and m are respectively volume, pressure and mass of air into the OWC's chamber.

2.4 Results

2.4.1 Numerical tests on the virtual flume

The 3D virtual flume has been implemented with the lattice Boltzmann library Palabos ; waves that are consistent with dispersion relation can easily be created. Figure 2.12 and 2.13 are examples of wave propagating along a part of the virtual flume.

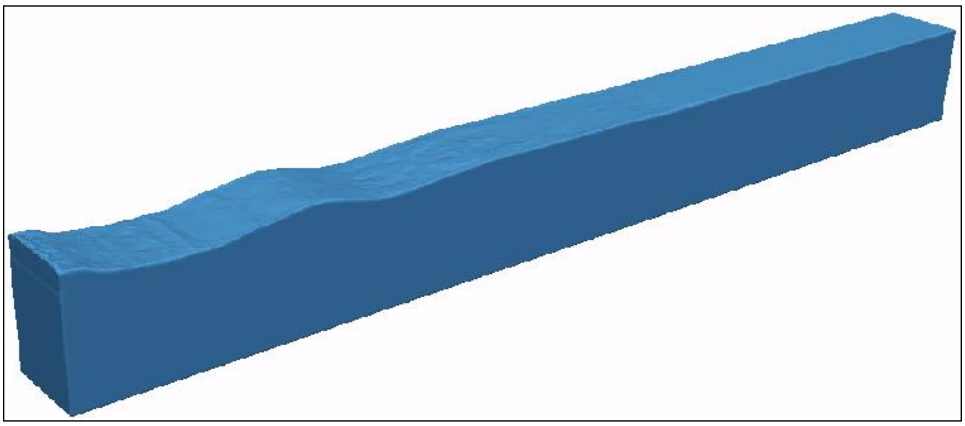


Figure 2.12. Wave propagation along the virtual flume

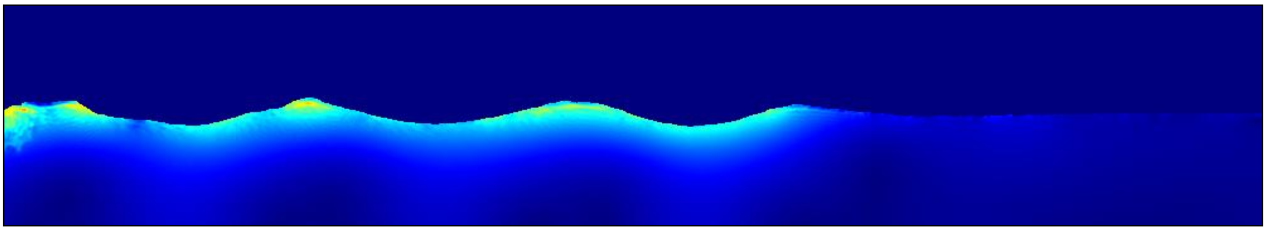


Figure 2.13. Wave propagation along the virtual flume. The contour plot refers to the velocity field.

2.4.2 Numerical tests on the flume-OWC coupling

A two-way, strong coupling has been implemented. Figures 2.14 and 2.15 illustrate possible visualizations of the simulation. Water changes air pressure into converter, while air pressure into converter changes water behaviour in the chamber. The simulation mimics the experiments, so the turbine is modelled as a pipe so one can use the pressure drop law (e.g. Hagen-Poiseuille's law or the turbulent theoretical/empirical law) to express the flow as a function of the pressure drop between inside and outside the air chamber.

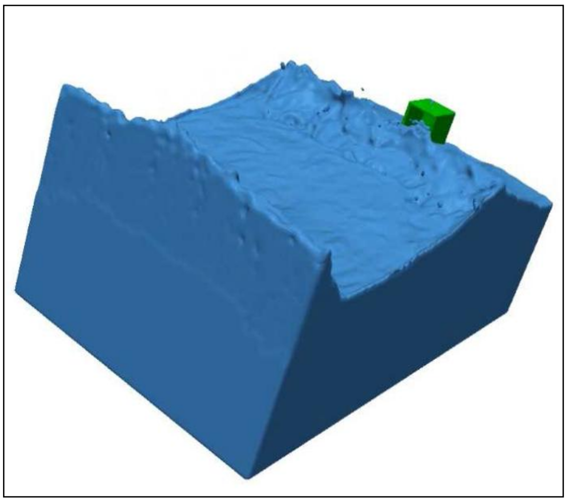


Figure 2.14. Converter interaction with water – 3D view

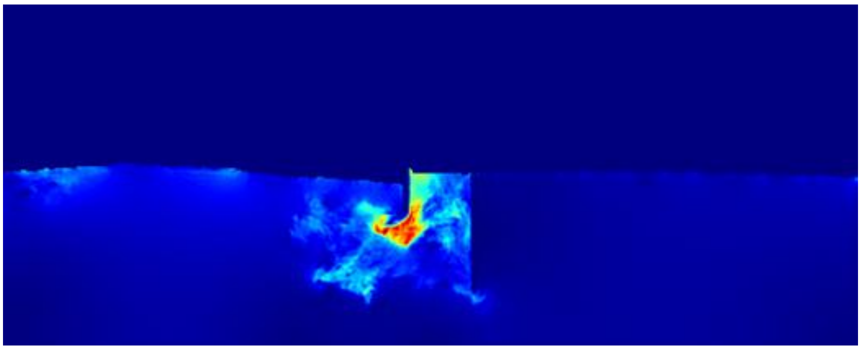


Figure 2.15. Converter interaction with water – 2D velocity view.

2.4.3 Physical tests on the flume

The experimental tests were performed simulating three regular waves. Waves were characterized by the same wave height of about 4cm and three different periods as reported in Table 2.
The wave characteristic parameters were obtained by analysing, in time domain, a selected time window:

- t_1 is the instant in which the first wave propagates under the sensor. It was identified from the data registered at the sensor;
- t_1^* is the instant in which the first wave propagates under the sensor as resulted from a estimation based on the group velocity, C_g , The group velocity was computed according to the linear theory. It is given by: $t_1^*=D/C_g$ (where D is the distance of the sensor from the wave maker);
- t_2 is the initial time instant used to perform the data analysis;
- t_3 is the final time instant used to perform the data analysis.

The time steps t_2 and t_3 identify an interval consisting of *n* waves of the fully developed regular wave train, at the position of the probe. For the present experimental campaign $4 \leq n < 10$. Moreover, since the waves are reflected at the end of the wave-current flume and travel in the opposite direction, the time step t_3 was chosen to be less than the time step t_r, during which the first reflected wave reach the probe . The time step t_r was 16estimated as:

$$\boldsymbol{t_r} = \frac{\boldsymbol{D_r}}{\boldsymbol{C_g}}$$

In which D_r is the total distance travelled by the wave and is given by adding the wave flume length to the distance between the end of the flume and the sensor.

In Table 2, the wave parameters obtained by analyzing the data collected at the probe WG3 (see Table 1 and Figure 2.8) are reported, for each wave attack that were reproduced in absence of the OWC model (configuration T0L0V0). The wave parameters are expressed as a confidence interval taking into account the absolute errors *δH and δT,* respectively for the height and the period measurements. The absolute errors were obtained as the mean of the difference between the maximum and minimum values.

Table 2: Wave parameters acquired at the probe WG3 in absence of the OWC model (configuration T0L0V0).

TEST CODE	H [cm]	T [s]
T0L0V0H01	4.4 ± 0.9	0.70 ± 0.00
T0L0V0H02	4.8 ± 0.5	0.90 ± 0.00
T0L0V0H03	4.8 ± 0.6	1.10 ± 0.05

Moreover, three turbine damping effects were tested, changing the OWC top covers, previously equipped with a specific vent diameter. In Table 3 the three different diameters of the vents are reported. The sizes of the vents are chosen as a ratio of the top cover surface of the device.

Table 3: Characteristics of the different vent conditions tested.

VENT CODE	Ratio of vent to top cover area	Vent Diameter [mm]
V1	0.5%	8
V2	1%	14
V3	2%	20

After the model construction and instruments setup described above, the calibration of the sensors used for the experimental study was carried out. First the calibration of the wavemaker was performed.

The array of wave probes (WG1, WG2 and WG3) was used as a benchmark array to set, through an iterative process, the obtain the planned values of wave height and period. During the tests, the data of the free surface displacements within the OWC chamber as well as pressure and waves behaviour outside the OWC, were collected with sampling frequency of 20Hz, and converted to physical variables by using the corresponding calibration coefficients.
For the configuration tested, in addition to the three different diameters of the vents described above, a totally closed vent condition was studied. Moreover, in order to have a measure of the waves in absence of the device, a configuration obtained removing the OWC and using the same displacement for the wave probes was also performed. All the tested configurations and the related characteristics of the OWC model are reported in Table 4.

Table 4: Configurations tested.

CONFIGURATION CODE	DESCRIPTION
T0L0V0	- No device
T1L2V0	- Ld=100mm - D=220mm - Vent totally closed
T1L2V1	- Ld=100mm - D=220mm - Vent diameter=8mm
T1L2V2	- Ld=100mm - D=220mm - Vent diameter=14mm
T1L2V3	- Ld=100mm - D=220mm - Vent diameter=20mm

To understand the processes involved inside the OWC chamber with respect to the incoming waves on the model, the trends of the acquisitions at the wave probe WG4 inside the chamber were analysed together with the water level measurements, acquired just outside of the model at the wave probe WG3 (see Figure 2.8).
In Figure 2.16 the trends obtained for the four different vent conditions of the OWC, tested under the regular wave H02 (H=4.8cm, T=0.9s), are reported. Particularly, in order to describe a full developed behaviour, the registrations refer to the last 10 seconds of simulation.

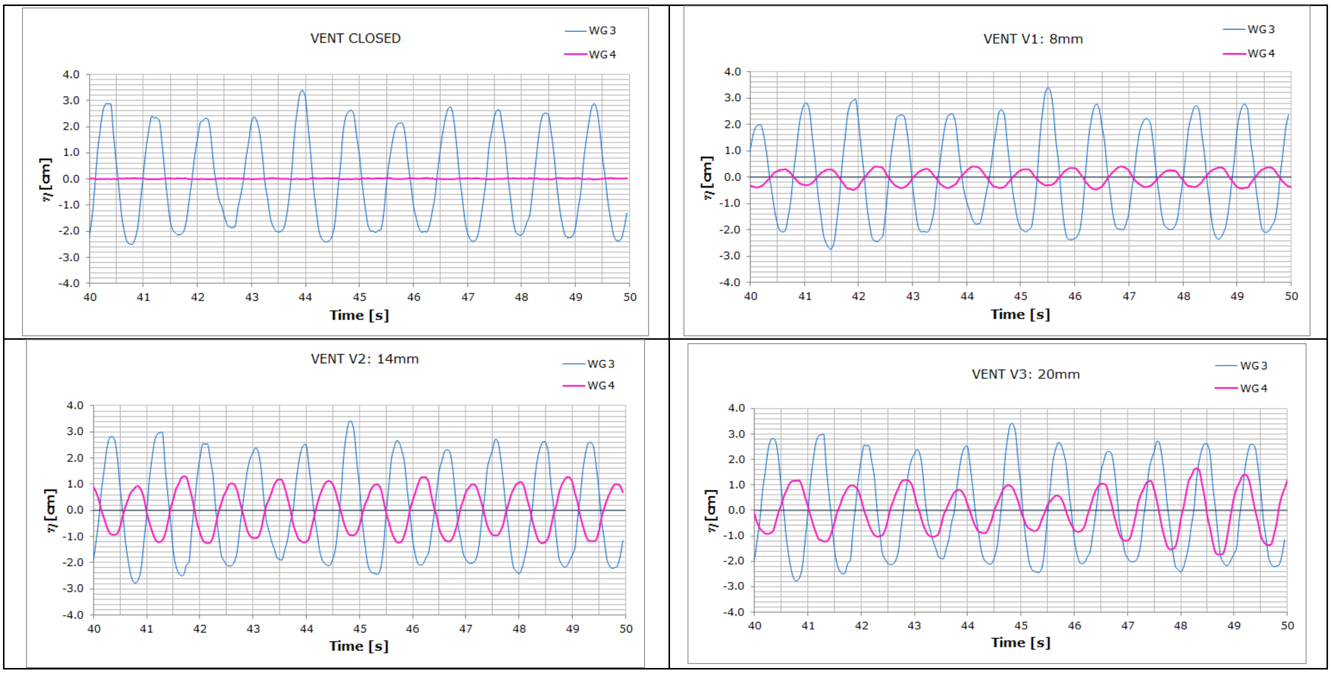


Figure 2.16. Surface elevation trends acquired outside the OWC (WG3) and inside the OWC (WG4) for each vent condition under the regular wave attack H02.

Although, the measurements shown in the figure above are referred to two wave probes located at two different positions, by means of video recordings it was be possible to confirm that the trend of the oscillations inside the OWC chamber was mostly not in phase with those of the incoming wave outside the OWC (Figure 2.17).

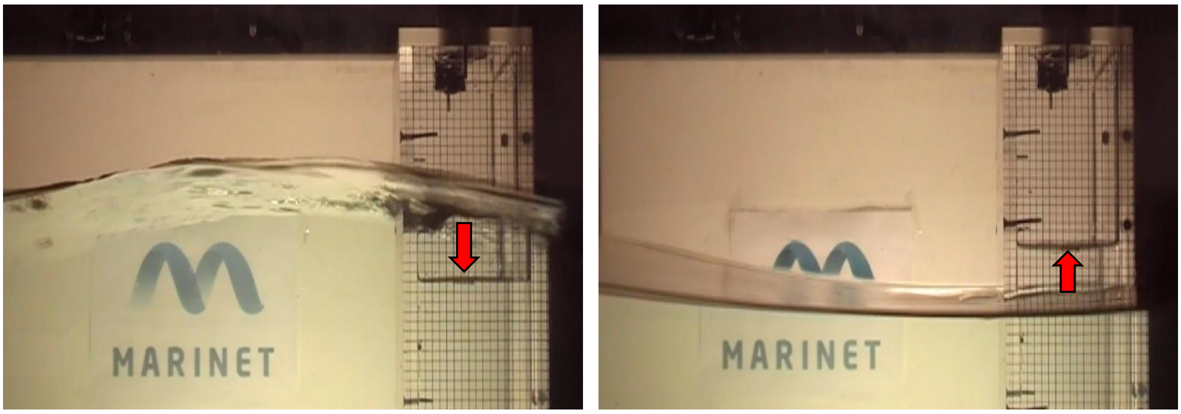


Figure 2.17. Picture captured during the video recording of the T1L2V3H02 test. The picture shows the different phase observed between incoming wave and water column oscillations inside the OWC (indicated by the red arrow).

As for the free surface displacements also the pressure measurements were performed for each vent conditions and wave attack simulated.

In Figure 2.18, as an example, the trends of the pressure acquired in the OWC chamber for the regular wave H02 (H=4.8cm, T=0.9s) and the four different vent conditions, are reported.

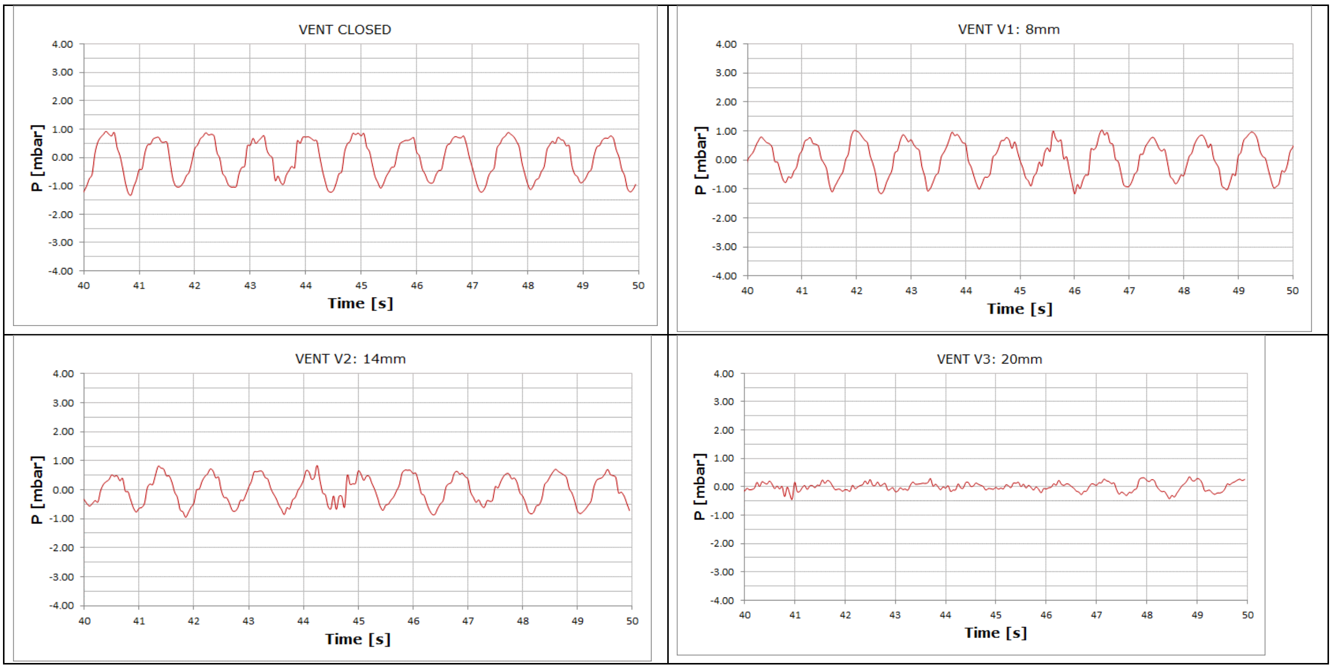


Figure 2.18. Pressure measurements acquired inside the OWC for each vent condition under the regular wave attack H02.

Analysing the data acquired during the resonance tests, RES1 and RES2, it was possible to note that the water column oscillations as well as the related pressure variations occurred only for the tests with the larger vent diameter (V3), respectively named: T1L2V3RE1 and T1L2V3RE2 (see Figure 2.19).

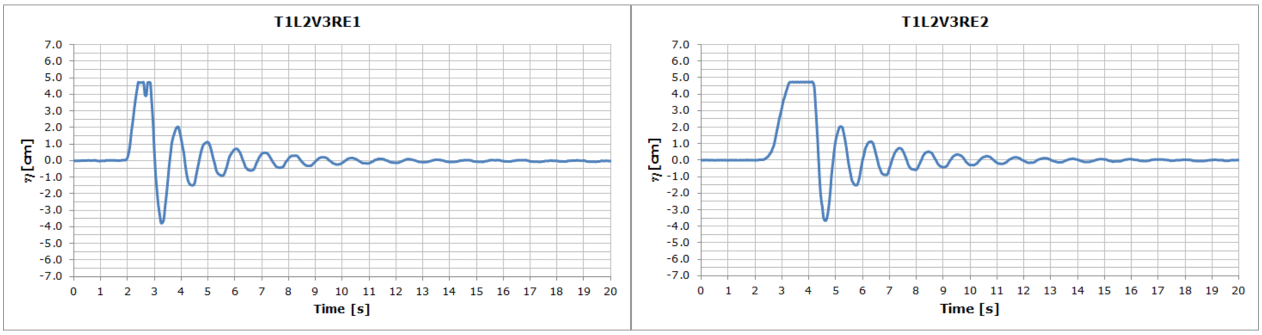


Figure 2.19. Water level measurements acquired at the WG4, inside the OWC chamber for the RES1 and RES2 tests.

This result is also confirmed by the Fourier analysis, performed to separate the motion components in all the different frequencies. The Figure 2.20 shows the results obtained through the Fast Fourier Transform (FFT), in which it is possible to note that a peak of frequency of about 1Hz occurred only for the resonance tests correctly performed T1L2V3RE1 and T1L2V3RE2.
This could mean that for the OWC geometry T1L2 and the turbine damping condition V3 the best performance should be achieved with a wave incident frequency of about 1Hz.

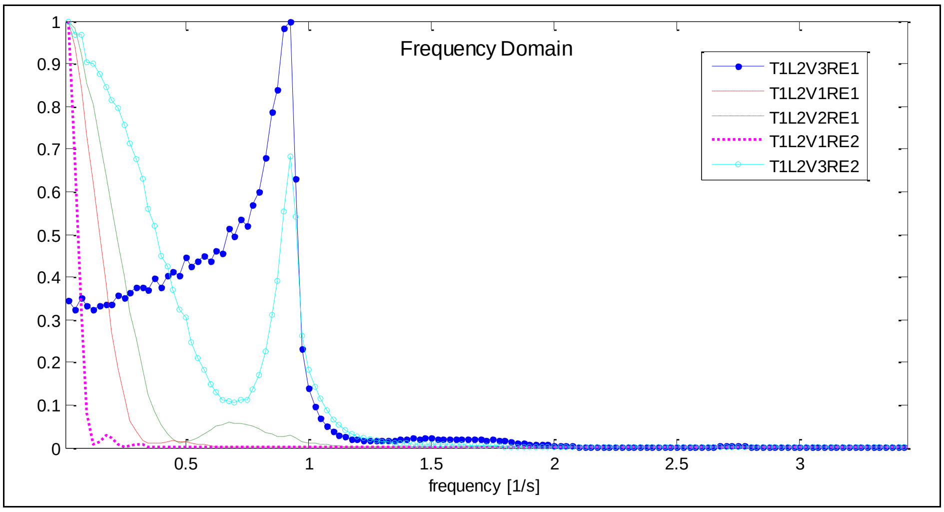


Figure 2.20. Fast Fourier Transform (FFT) results for the resonance tests.

2.5 Analysis & Conclusions

2.5.1 Virtual flume

As shown below on figure 2.21, which is an example for typical experimental wave, the dispersion relation for linear waves is well respected. However, we observed that due to low space definition in terms of point vs wave height, waves dissipate too quickly. Thus, we are investigating on this dissipation problem to ensure that for good resolution simulations, the dissipation is close to the real one.

Parameter		Real value	Virtual value
H_0	[cm]	4.1	4 ± 0.3
T	[s]	0.99	0.98 ± 0.2
L	[m]	1.49	1.4 ± 0.2
c	[m/s]	1.5	1.46 ± 0.2

Figure 2.21. Verification of the dispersion relation.

2.5.2 Virtual coupling

Data extracted from the simulations of coupling between air and water inside the OWC's chamber are given in figure 2.22, where one can see how pressure, flow and volume of air into the OWC chamber are related to each other.

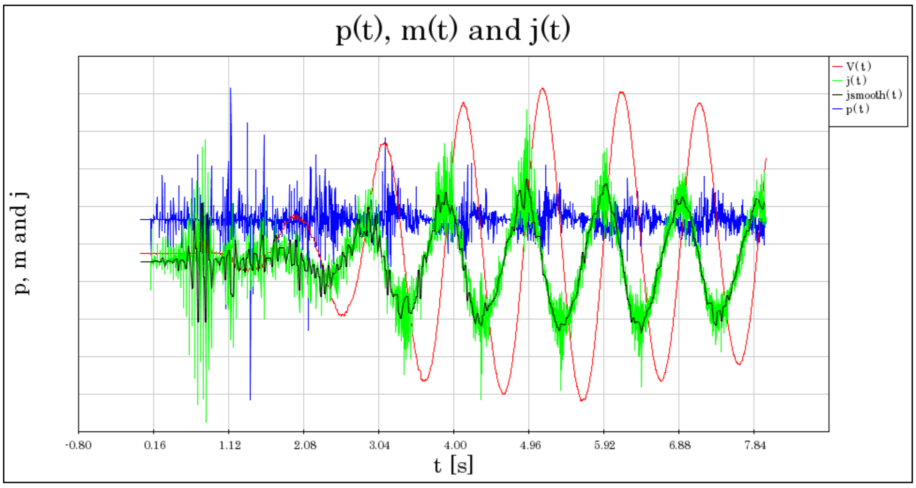


Figure 2.22. Data coming from converter's coupling with water. Different parameters are expressed dimensionless (i.e. normalized to the maximum value they takes). Same OWC geometry as described in section 2.2 "MODEL DESCRIPTION" except the lip draught that is 11 cm. The vent radius is 10mm. Wave period = 1s, wave height = 6cm.

In addition, from the data for the mass of air into the chamber along time, one can obtain the efficiency (see Fig. 2.23) of the numerical device by assuming that m(t) is well approximated by a sine function, as shown in Fig. 2.24.

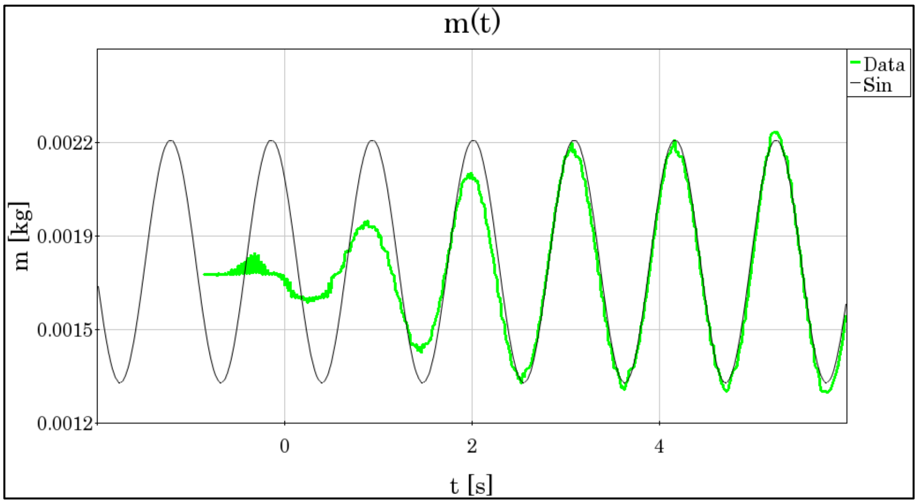


Figure 2.23. Mass data along time can be well approximated by a sine function, permitting to extrapolate the efficiency of the numerical device.

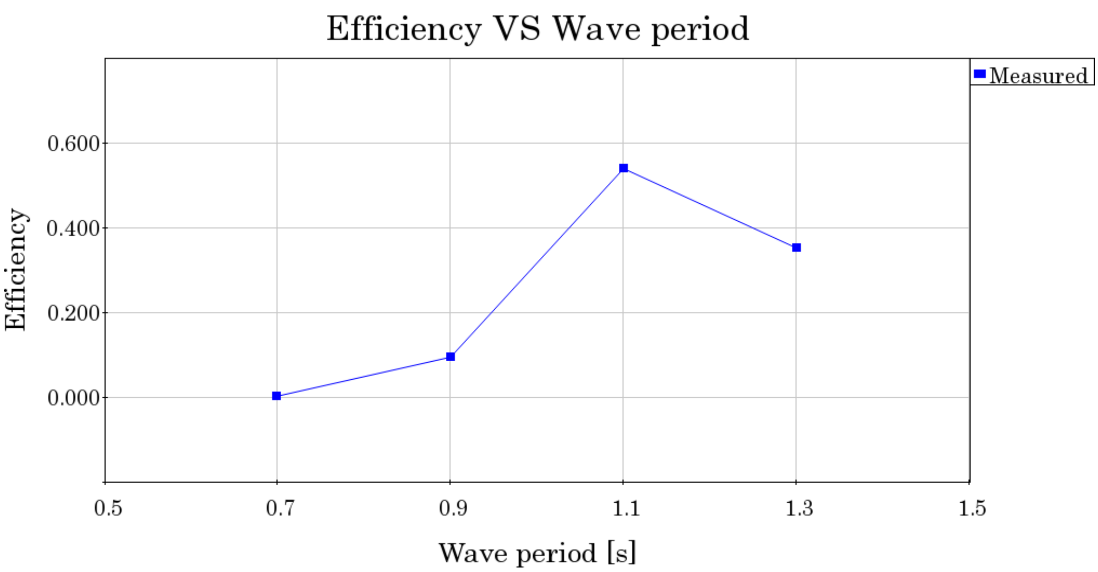


Figure 2.24. Efficiency of the numerical device as a function of the wave period. One can observe that a peak is observed at the resonance period of the device (see Fig. 2.23 below), as expected. Same OWC geometry as described in section 2.2 "MODEL DESCRIPTION". Vent radius : 4mm. Wave height = 4.3cm.

2.5.3 Preliminary comparison between numerical and experimental models

Decay test permit to get rid of the wave generation problem; Fig. 2.25 shows the experimental-numerical comparison in this case. The natural frequency of the experimental device is about $0.91 s^{-1}$ for the experimental device and $0.89 s^{-1}$ for the numerical one. The amplitude, much more sensible to the parameters of the coupling, is however less matching.

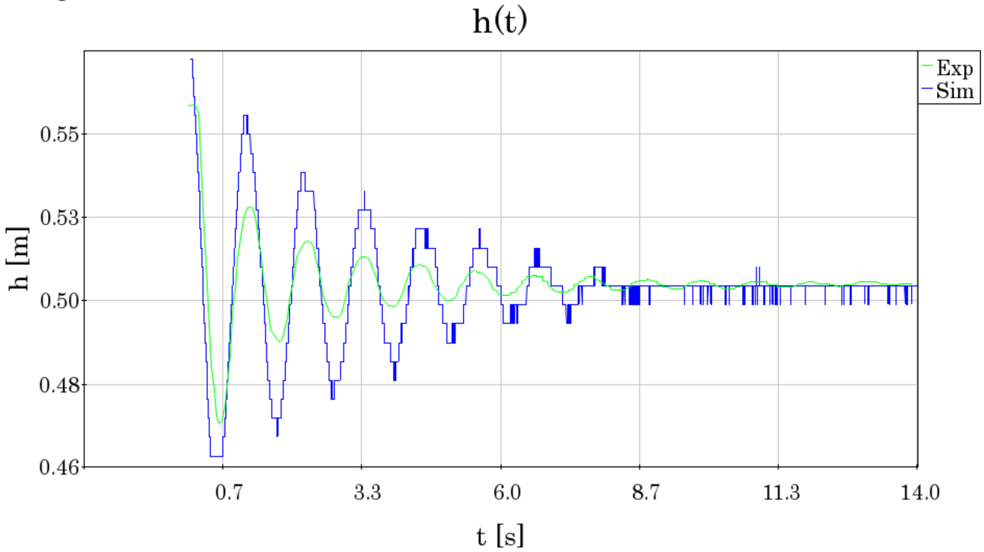


Figure 2.25. Water level into the converter as a function of time for experimental data (green) and numerical data (blue), acquired during a decay test with an initial load of 7 cm. Same OWC geometry as described in section 2.2 "MODEL DESCRIPTION". Vent radius : 10mm.

In addition to the decay test, one can of course compare the wave height in the case of wave attacks (see Fig. 2.25). As a consequence of the complex physics of the air into the pipe orifice, the coupling model for the simulation does not reflect the reality, and the introduction of a coupling parameter is needed in order to tune the coupling. Fig. 2.26 shows a few values of this parameter and their effect on the water height into the converter as a function of time.

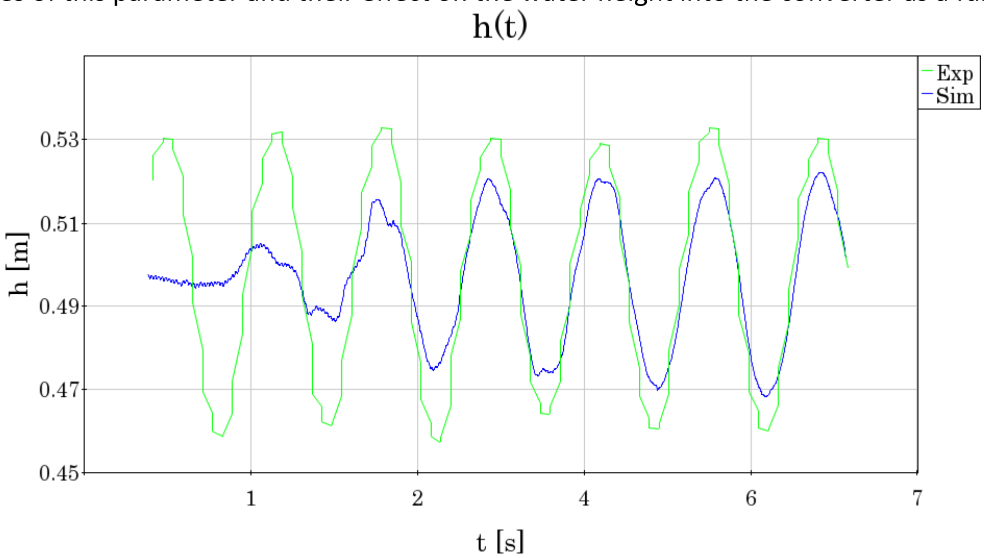


Figure 2.26. Water level into the converter as a function of time for experimental data (green) and numerical data (blue), under wave attacks H03. Same OWC geometry as described in section 2.2 "MODEL DESCRIPTION". Vent radius : 10mm

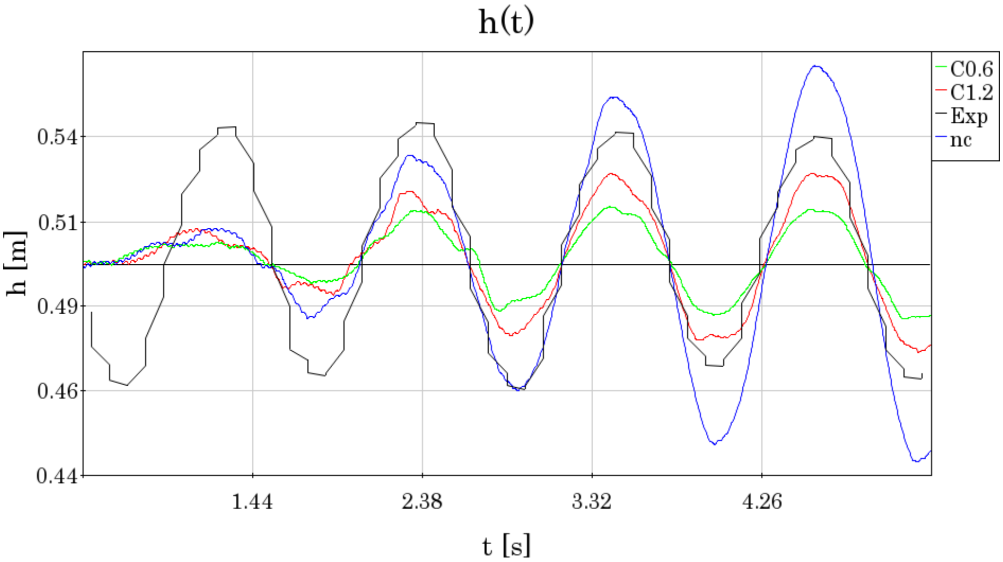


Figure 2.27. Water level into the converter as a function of time for experimental data (black) and numerical data (coloured lines) under wave attacks H03. The green and red lines correspond to different numerical coupling parameters, while the blue line is the curve acquired with the coupling algorithm disabled. The numerical curves are growing because the simulation is at its beginning and the wave train is not completely installed before about 4 seconds. Same OWC geometry as described in section 2.2 "MODEL DESCRIPTION". Vent radius : 10mm.

2.5.4 Experimental Data Naming And Data Base Structure

Summarizing the Table 6 shows the code and its description chosen in order to catalogue the data acquired during the tests.

Table 5: Codes of the data

CODE	DESCRIPTION
T1	OWC Type – small (100x200mm)
T0	No device
L2	Lip draught -220mm s.w.l.
L0	No device
V0	Vent closed
V1	Vent Diameter 8mm
V2	Vent Diameter 14mm
V3	Vent Diameter 20mm
RE1	Resonance with a load of 50mm
RE2	Resonance with a load of 70mm
H01	Regular wave H=40mm, T=0.7s
H02	Regular wave H=40mm, T=0.9s
H03	Regular wave H=40mm, T=1.1s
H00	Acquisition of the level zero

The diary of the experimental activity is reported in the following table:

CODE	DATE	HOUR	NOTE
T1L2V3RE2	15/04/2014	17.55	
T1L2V2RE2	15/04/2014		No Acquisition
T1L2V1RE2	14/04/2014	16.31	

T1L2V3RE1	15/04/2014	17.52	
T1L2V2RE1	15/04/2014	15.57	
T1L2V1RE1	14/04/2014	16.26	
T1L2V3H03	15/04/2014	17.33	
T1L2V2H03	15/04/2014	14.39	
T1L2V1H03	15/04/2014	11.10	
T1L2V0H03	15/04/2014	11.46	
T0L0V0H03	14/04/2014	17.30	
T1L2V3H02	15/04/2014	17.10	
T1L2V2H02	15/04/2014	15.00	
T1L2V1H02	15/04/2014	10.55	
T1L2V0H02	15/04/2014	11.34	
T0L0V0H02	14/04/2014	17.17	
T1L2V3H01	15/04/2014	16.40	
T1L2V2H01	15/04/2014	15.29	
T1L2V1H01	14/04/2014	12.33	
T1L2V0H01	14/04/2014	15.00	
T0L0V0H01	10/04/2014	17.13	
H00	15/04/2014	11.31	
H00	14/04/2014	14.54	

The data have been saved in a data base having the following structure:

code T3L1V0H01 **date** 14-4-14 **time** 10:30							
time[s]	**WG1[cm]**	**WG2[cm]**	**WG3[cm]**	**WG4[cm]**	**WG5[cm]**	**PT1[mbar]**	**AN1[cm/s]**
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

In which:

- WG1, WG2….WG5 are the code respectively of the water levels acquired by the five ultrasonic wave gauges displaced along the wave-flume;

- PT1 is the code of the data acquired by the pressure transducer

3 MAIN LEARNING OUTCOMES

3.1 PROGRESS MADE

3.1.1 Progress Made: For This User-Group or Technology

1. *Validation of the virtual flume :* the use of the LBM to develop a virtual flume has been proved to be a promising approach to build a powerful tools for study and optimize the OWC device. The benchmark tests have been quite satisfyingly succeeded and the possibility to calibrate the numerical code has been demonstrated. A strong dissipation, which seems to tend to disappear while increasing the numerical definition in terms of numerical nodes (lattice sites) vs wave height , is observed.
2. *Numerical investigation on the OWC power :* data suitable for optimizing the OWC device, by using a balanced methodology based on a synergetic approach that combines the use of numerical and experimental method, were obtained.

3.1.1.1 Next Steps for Research or Staged Development Plan – Exit/Change & Retest/Proceed?

- Quantitative comparison on the measured efficiency between numerical model and experiments
- Further investigations on the numerical dissipation, finalization of the calibration and verification procedures
- Parametric study devoted to the optimization of a OWC device

3.1.2 Progress Made: For Marine Renewable Energy Industry

3.2 KEY LESSONS LEARNED

- Verifying that the Lattice Boltzmann resolution is enough in regard with the waves wavelength is not sufficient; one has also to ensure that the ratio wave height – lattice spacing is big enough (at least approximately 20 site per wave height).
- Physics of coupling, and more specifically change of mass air into converter due to pressure drop, is difficult to model. The flow may be transitional between laminar and turbulent. Moreover, the hydrodynamic entry length is larger than the pipe length, in particular for laminar flow.

4 FURTHER INFORMATION

4.1 WEBSITE & SOCIAL MEDIA

Website:

http://www.labima.unifi.it/CMpro-v-p-18.html
http://www.fp7-marinet.eu/access_user-projects.html

YouTube Link(s):

https://www.youtube.com/user/coastlab
https://www.youtube.com/channel/UCtQxAiX3XOIjRzbJ9v7kgpw