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EXPERIMENTAL VALIDATION OF A RANS-VOF NUMERICAL MODEL OF THE WAVE GENERATION AND PROPAGATION IN A 2D WAVE FLUME

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Abstract. This paper focus on the study of free surface variation in a Numerical Wave Flume (NWF) due to a paddle movement. The NWF is the numerical representation of a 12.5 meters long Experimental Wave Flume (EWF) of the laboratory of the University of the Basque Country. The experiments and the numerical simulations are performed in several depths (0.3, 0.4 and 0.5 meters). Besides different velocities for the paddle movement are induced between 0.064 and 0.1 m/s. The numerical simulations are based on an Eulerian Multiphase of two fluids, air and water, more concretely the Volume of Fluid model. The surface variation in two points (6.0 and 6.3 meters from the wave flume start) is studied in both numerical and experimental wave flumes and compared its variation through the experiment time. Besides, the experiments will be analyzed in the wave maker theory. The results show the models quality in the first moments of the experiments, where the reflection does not appear, in which the results from both experimental and numerical simulations are pretty similar.

1 INTRODUCTION

The need of decrease the greenhouse gases emissions is one of the main objectives in order to fight the climate change and the global warming. The United Nations (UN) agreed to aim this decrease, among other objectives, in the Paris agreement [1]. In order to fulfill this purpose, the use of renewable energies seems to be one of the best options. Some technologies like onshore wind or solar have arisen as the most known ones, but the need of augment the number of technologies to harness energy is present [2]. Thus, offshore renewable energies ensue as one of most promising options.

The seas occupy the greater part of our planet surface and, hence, are one of the most important areas for the energy subtraction. In order to harness energy from them, different technologies have emerged as the most attractive ones. Offshore wind has shown encouraging results when fixed, although there are countries that have non-existent or small areas to install this type of technology [3]. The fast decrease in the levelized cost of electricity (LCOE) of the bottom-fixed wind turbines, especially in countries like the UK or Denmark, makes floating wind an appealing technology for those countries that have no continental shelf or those ones that have used the main part of it.

On the other hand, the wave energy, which bases on a very raw technology with promising ideas, is nowadays facing out to engineering challenges focused on the increase of the efficiency. Similar to other research fields, the technology development is carried out with numerical simulations and the corresponding experiments, at a reduced scale, to validate the models used. This procedure aims at the cost reduction in the initial steps of the design process and, once the models are validated, they can be scaled up according to the corresponding similitude laws [4].

Wave flumes allow the possibility to carry out experimental studies of wave energy converters (WEC) at a small scale. The study of the behavior of these devices must be carried out under different conditions, which are representative of the real sea states [5] (Kim et al. 2016). Therefore, the first step, prior to the test of any device, is the characterization of the swell that can be generated in an Experimental Wave Flume (EWF).

In parallel, the corresponding numerical wave flume (NWF) was designed in order to compare results and verify numerical models, following the same approach of other research groups [6]. A NWF is a computational image of an EWF [7], which helps to implement different wave conditions and modifications [8]. In order to do this, Computational Fluid Dynamics (CFD) increase in importance due to the evolution of the processors and the computational power, significantly decreasing the computational time of the simulations.

This work aims at the characterization of the wave generation capabilities of the experimental wave flume (EWF) as well as the validation of a numerical model that reproduces computationally the different sea wave conditions tested.

2 EXPERIMENTAL AND COMPUTATIONAL METHODOLOGY

The waves in the experimental flume are generated using the commercial software Delta-ASDA (V5) that controls the Delta AC (ASDA-A2 series) servo drive and servo motor. The servo motor is connected to a K series linear actuator (KM60-10 roller screw model), which is attached to a paddle submerged in water. The final movement of the paddle is the responsible for generating waves. The data of the surface elevations were acquired using two ultrasonic wave probes (Pepperl+Fuchs UC500-L2-I-V15 model) that were controlled by means of an ad-hoc LABVIEW program [9]. This software makes it possible to obtain experimental values (sampling time interval of $\Delta t = 1/50$ [s]), of the paddle position (x [m]) and the displacement of the free surface (η [m]) as a function of time (t [s]). The Delta ASDA software provides the possibility to specify the desired amplitude (A_p [m]), acceleration-deceleration (a_p [m/s^2], both always equal) and velocity (U [m/s]) of the paddle as an imput variables to establish the linearly oscillating motion. This information permitted the characterization of the waves as they were generated at a certain depth (h [m]), as a function of time (t [s]), in terms of the velocity of the wave propagation (c [m/s]), the wavelength (λ [m]), the wave period (T [s]) and the wave height (H [m]).The laboratory experiments and the numerical simulations were performed in water at several depths (h [m] of 0.3, 0.4, and 0.5), using the piston-type wave maker at different amplitudes ($0.02 < A_p$ [m] < 0.06), constant accelerations-decelerations (a_p of 200 ms) and velocities ($0.03 <$ U [m/s] < 0.1).

The physical effects are modelled on a 2D computational model (STAR CCM+ v12.06) with meshes of different sizes depending on the depth of study. However, the all the meshes have less than 1 million cells in order to optimize the computational cost of the simulations. Each mesh consist different volumes of study. The volumes around the wave maker and the free surface have smaller cells in order to have a better definition of these areas. User-defined functions are used in order to simulate the paddle movement and to study the free surface variation in different points. The study of the free surface variation will be studied too with sections were the volume fraction function is used. When the computational results are obtained, both, computational and experimental are compared in different terms.

2.1 Experimental wave flume (EWF)

The EWF is 12.5 m long, 0.60 m wide, and 0.7 m high. The structure consists of a stainless steel platform surrounded by a laminated and tempered glass walls. The first probe position was set at 6.0 m from the wave generating side, assuming all the generated waves were at that point fully developed. The distance between the consecutive probes was 30 cm, according to the criteria described in [10].

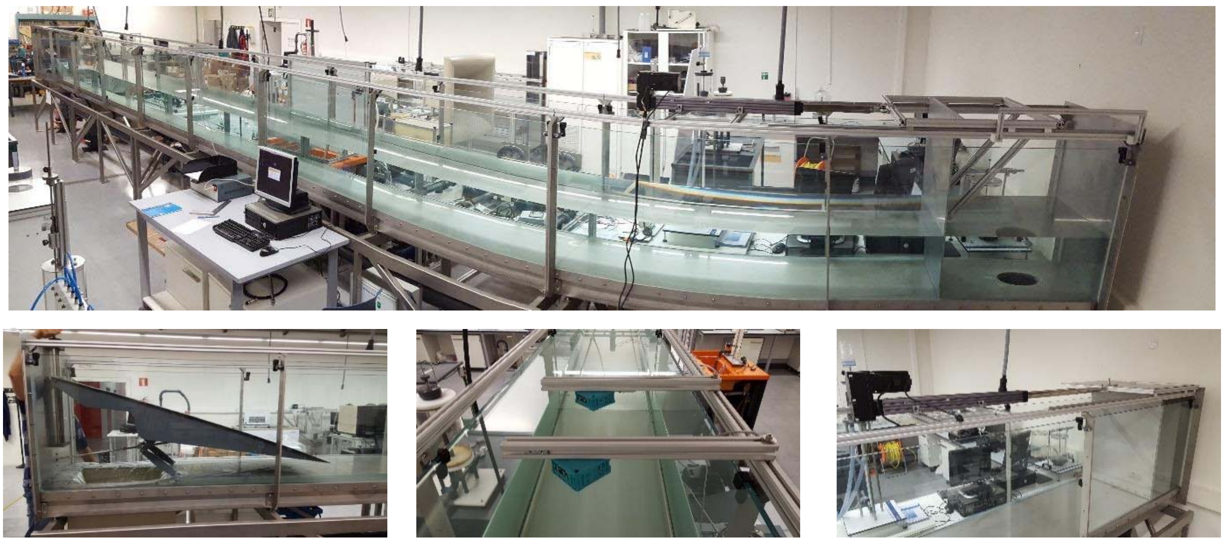

Figure 1: Top: Overall view of the EWF. Bottom: parabolic profile extinction system, wave probes and wave generation system.

The total length of the flume can be divided into three main regions: the wave generation, the wave propagation, and the wave extinction region. For the extinction region A parabolic solid beach, 1.5 m long and with adjustable height and sloping angle, has been designed as extinction passive method.

2.2 Numerical Wave Flume (NWF)

The NWF is a 12.42 m long, 0.7 m high. It aims to simulate the behavior of the EWF and confirm the numerical simulations when comparing them to the experimental results. Besides, two plane sections in position 6 and 6.3 in the X-axis are positioned in order to simulate the existence of the probes.

The simulations are based on the Volume of Fraction (VOF) physical model. The model is suited for simulations of flows where each phase consists of a large structure, with a relative small total contact area between phases [11]. Thus, the model allows to computationally simulate the interaction between two big volumes of air and water that contact in the free surface.

In order to define the depth of each simulation the free surface is determined by defining the y coordinate until the cells have water in the initial moment of the simulation. Then the paddle movement is simulated by using a user created field function. This was made by creating a cyclic motion with constant and opposed velocities. Then the velocity mandates are linked to the sinusoidal wave. This allow us to impose the paddle movement depending on the time of simulation. This movement is determined by taking into account the small acceleration moments, which are neglected, and then the maximum velocity of the paddle is imposed.

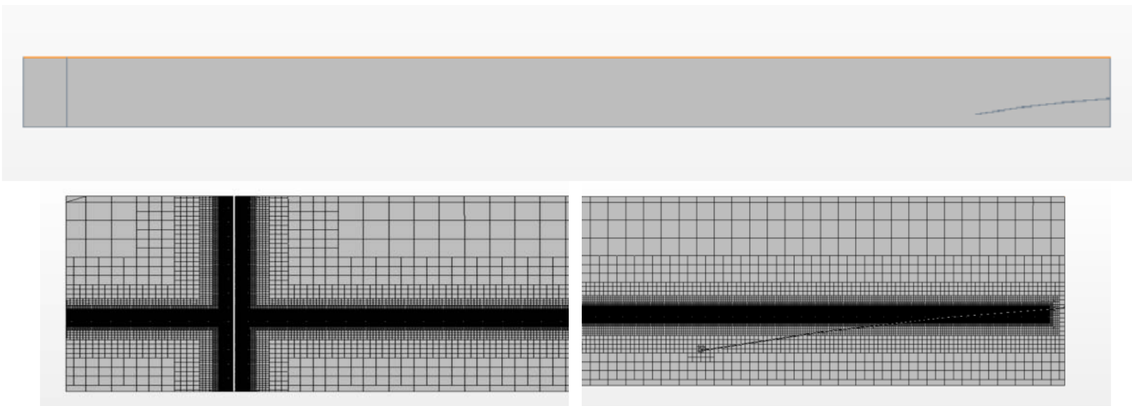

Figure 2: Geometry (up) of the NWF. Mesh construction around the wavemaker (bottom-left) and around the beach (bottom-right).

The computational meshes have different cell sizes depending on the depth of study. This is because the volumes of control for the paddle and the free surface variation are optimized to the wave velocities and heights. Figure 2 shows the mesh for the cases of 30 cm of depth, which has the smaller cells.

Table 1: Relation between depth of study and cell size.

Depth of study (m)	h= 0.3	h=0.4	h=0.5
Cell Size (m)	0.0025	0.0030	0.0039

In Table 1 the relation between the depth of study and the cell size used is shown. Although the sizes are different, the objective of create different meshes was to have the closest value possible to Courant Number equal to 1 in each simulation with a time-step of 0.002 seconds.

3 VALIDATION OF THE CFD MODEL

The main objective of the computational simulations is to test the paddle movement and see if it provokes the same free surface variation in the points were the sensors are located in the EWF. The study focus in the first waves in order to minimize, as much as possible, the effect of reflection due to existence of the beach.

3.1 Experimental campaign

For the purpose of having the best results possible, and see if the type way selected to simulate the free surface variation was correct, different depth and wave periods were simulated. Each simulation studies the free surface variation by a user-defined function called Level, which study the lowest y-coordinate of the cells with a 50% of volume fraction of water or less. That command defines the position of the free surface in the locations where the probes are installed in the EWF.

Table 2: Experiments run with the velocity of the wave maker and the period, as well as the depth of work.

Experiment	Depth (m)	Maximum Velocity of the paddle (m/s)	Period (s)
1	0.3	0.071	0.828
2	0.3	0.072	1.090
3	0.3	0.073	1.363
4	0.3	0.072	1.624
5	0.4	0.078	1.031
6	0.4	0.065	1.473
7	0.4	0.080	1.761
8	0.5	0.089	1.182
9	0.5	0.033	1.417
10	0.5	0.100	1.703

Besides, an average of the volume of fraction of the water in a section plane is made in both locations. Each panel section creates the average of the volume fraction of water in it giving a percentage value that defines the position of the free surface. Both methods are used in order to see if the size of the cells creates a noticeable deviation from or not.

Table 2 shows the main parameter that were taken into account when simulating the movement of the paddle, and in the creation of the meshes. The maximum velocity of the paddle that, which is the constant velocity of it without taking into account accelerations, and the period are used to create the paddle movement equation.

3.2 Comparison of experimental and computational free surface displacement

In order to compare the results from the experiments and the numerical simulations some graphics are made. In them, it can be seen the free surface variation in the experiments and the surface variation of the numerical methods through the length time of the numerical simulations. Then, the experimental data is shorted to the same time range.

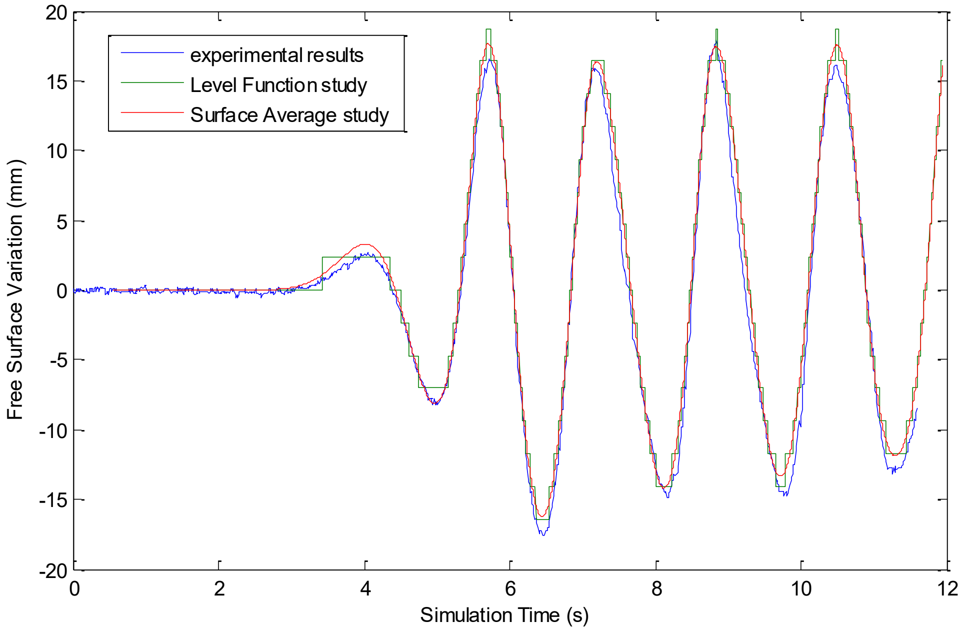

Figure 3: Comparison of the free surface location between experimental and computational signals.

Figure 3 shows the comparison defined above. It can be seen that the free surface variation matches in the three experiments the majority of the time. The blue line is the experimental results, the red one is the results obtained from the average surface of the volume fraction of water and the green one shows the results obtained by the user defined function. The green line is stepped because it measures the y coordinate of the cell and, hence, it cannot be a smoothed line.

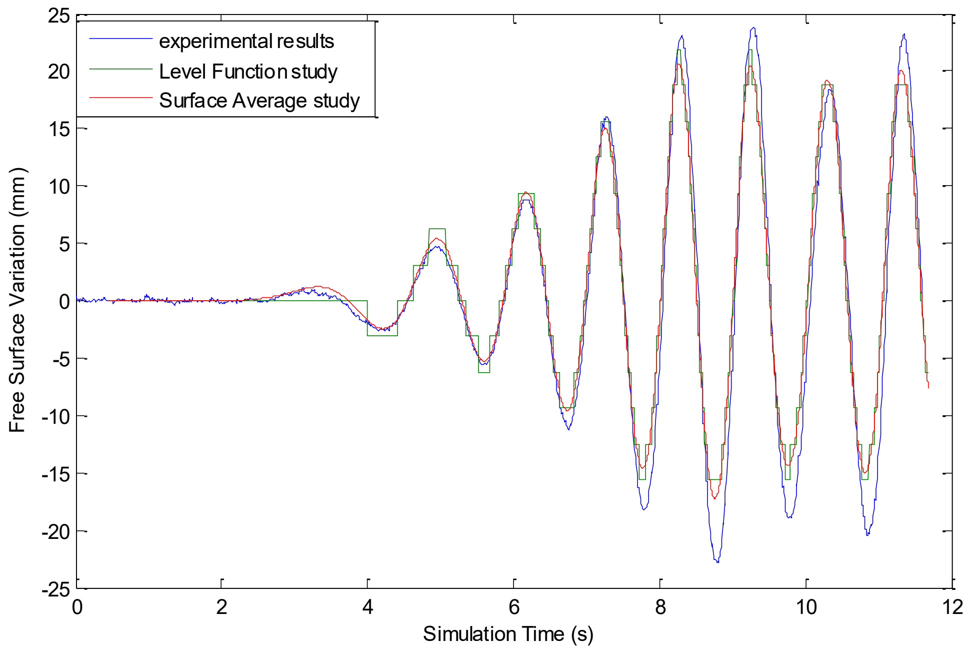

Figure 4: Comparison of the free surface location between experimental and computational signals.

However, reflection has to be taken into account and some of the simulations have shown noticeable differences with the experimental result due to the lower density of the mesh around the beach. This can be seen in Figure 4 where the first waves match perfectly in experimental and numerical results, but an error can be seen in the next waves, were the reflection starts to affect.

This is because the main objective of this phase of research is to see if the behavior of the wave maker and the models used could simulate adequately the EWF results. This has been a success and will be the first step into a better modelling in the future.

4 RESULTS AND DICUSSION

4.1 Wavemaker Theory

The type of wave maker selected is a piston-type one. Wave maker theory takes into account the type of the wave generator and express it graphically making the relation between the wave height, wave number the depth of study and the stroke of the wave maker [12].

The results show a wide range of error between experiments, but always below the 10%. Although the simulations match greatly in the first waves, and that is the main aim of this study, the error increases considerably with the effect of the reflection. This is due to the non-refinement of the mesh around the beach to not increase the number of cells. Because of that, the effect is not simulated correctly and induces an error that affects in the comparison with the experimental results.

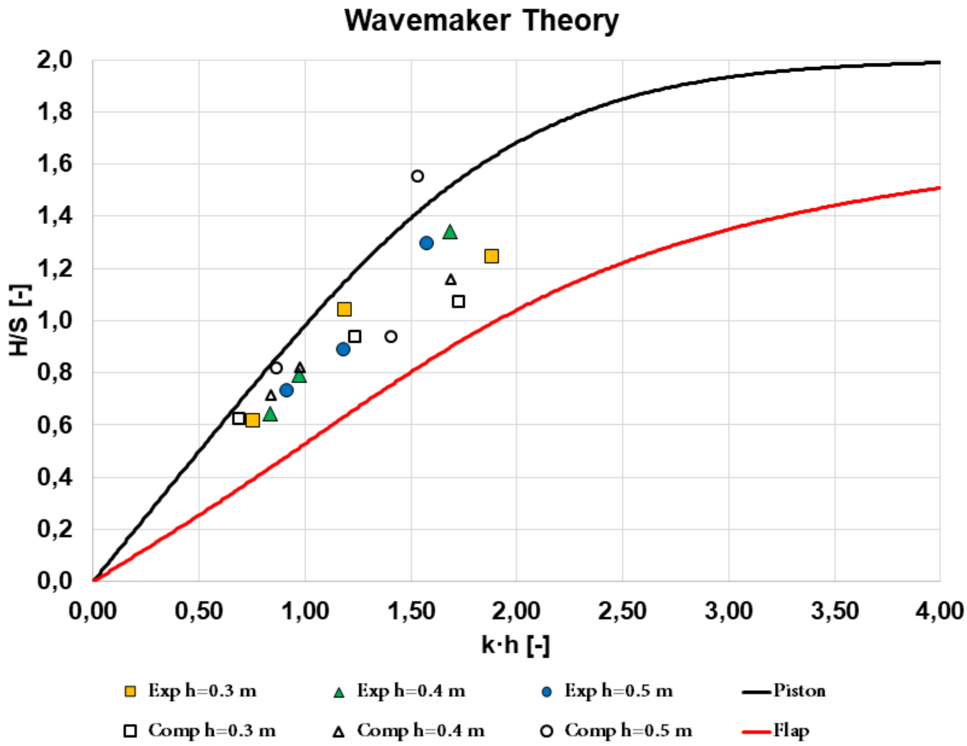

Figure 5: Experimental and numerical results captured in the Wavemaker theory.

Figure 5 shows that the numerical results follow, in its majority, the same tendencies that the experimental results. In the data treatise, the error between the experiments and the simulations does not increase having good matches. Nevertheless, it is important to remember that the reflection was not aimed to be studied in this study and its existence has altered results, in these comparisons between theory, experiments and numerical simulations.

4.2 Phase velocity and period of wave as function of wavelength

Apart from the linear theory, the computational results are compared with the tendency lines created from theory. In this section, both experimental and numerical experiments are compared with these lines, in order to see if the error of the simulations follows the error of the experiments or if it is because of the computational domain.

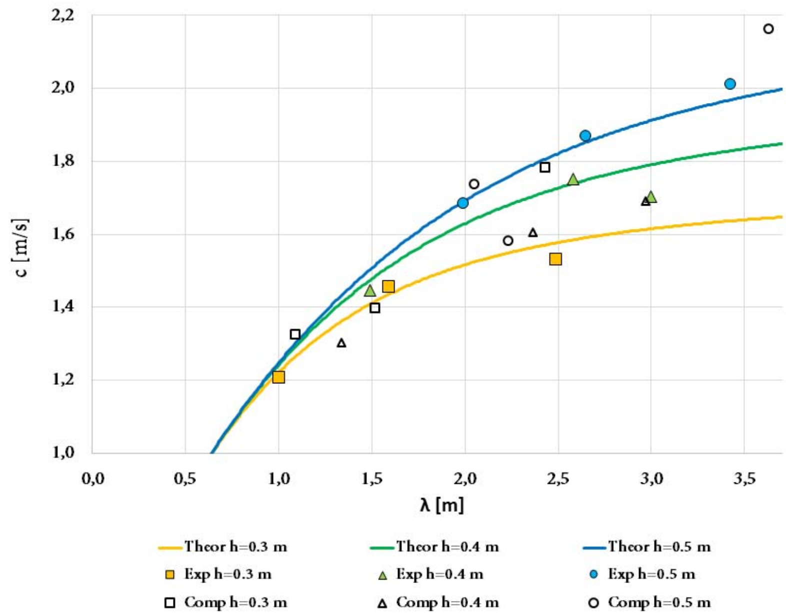

Figure 6: Relation between wavelength and wave celerity.

Figure 6 shows the relation between the wavelength and the wave celerity and the error that both, experiments and numerical simulations, have regarding the tendency lines that are defined by theory. Figure 6 shows that experiments follow closely the tendency lines while the numerical simulations slightly recede from them. Although in the simulations the error between experimental and numerical values is lower than 10%, these errors add up and create the distancing from the theoretical tendencies.

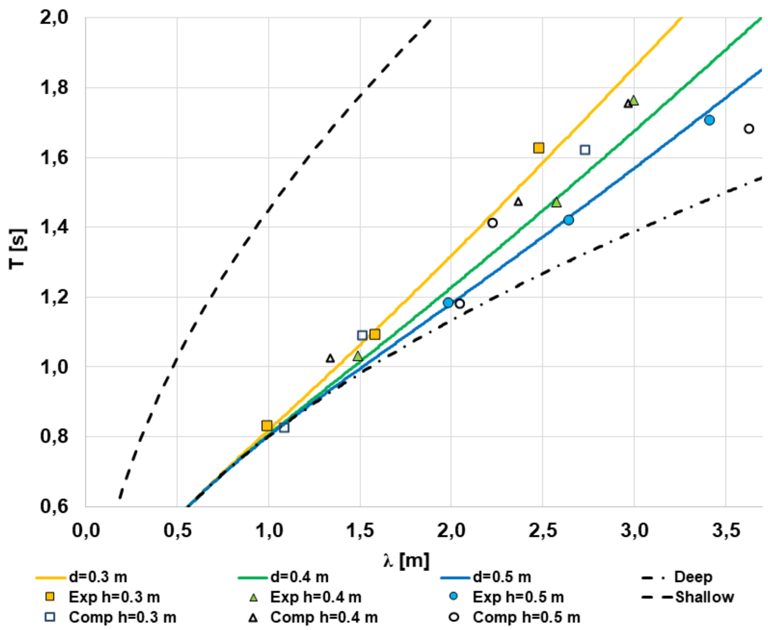

Figure 7: Relation between wavelength and period.

Figure 7 shows the relation between the wavelength and the wave period. In it, it can be observed that the relation between experiments and numerical simulations, the wave period has small errors. Thus, both experiments and numerical simulations follow the theoretical tendencies better than in Figure 6.

5 CONCLUSIONS

Analyzing the results from the nine simulations the first conclusion obtained is that the VOF model approach is correct. The great accuracy of the simulations and the similarity of them in the first waves when the reflection does not affect the measurements, show the success of the approach of the simulations.

However, some modifications in both the grid and physic models have to be done in order to reduce the error when reflection affects to the measurements. Besides continuous improvements in the paddle control of the EWF aim to have more constant waves and approach the theoretical models. Moreover, the inclusion of acceleration in the numerical simulations should create an approximation to the experimental results.

Thus, this study exists as an initial work in the area of numerical simulations of the EWF. Studies of physical effects, as reflection, and of the behavior of offshore structures, as wave energy converters or floating structures for offshore wind, will be the next steps of the research group. With a proper NWF the simulations of a wide range of waves and depths will be possible in order to validate these type of structures.

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REFERENCES

[1] UNFCC (United Nations Framework Convention on Climate Change), Paris Agreement (Spanish), (2015).

[2] F. M. M. Machado, A. M. G. Lopes and A. D. Ferreira, Numerical simulation of regular waves: Optimization of a numerical wave tank, *Ocean Eng.*, (2018) **170:**89–99.

[3] N. Bruinsma, B. T. Paulsen, and N. G. Jacobsen, Validation and application of a fully nonlinear numerical wave tank for simulating floating offshore wind turbines, *Ocean Eng.*, (2018) **147:**647–658.

[4] D. Stagonas, D. Warbrick, G. Muller, and D. Magagna, Surface tension effects on energy dissipation by small scale, experimental breaking waves, *Coast. Eng.,* (2011) 5**8:**826–836.

[5] S. Kim, K. Kim, J. Park, G. Jeon, and H. Chun, Numerical simulation of wave and current interaction with a fixed offshore substructure, *Int. J. Nav. Archit. Ocean Eng.*,(2016) **8:**188–197.

[6] S. Saincher and J. Banerjee, Design of a numerical wave tank and wave flume for low

steepness waves in deep and intermediate water,(2015) **116:**221-228.

[7] U. Izquierdo, G. A. Esteban, J. M. Blanco, I. Albaina, and A. Peña, Experimental validation of a CFD model using a narrow wave fl ume, *Appl. Ocean Res.*, (2019) **86:**1-12.

[8] M. Anbarsooz and M. Moghiman, Fully nonlinear viscous wave generation in numerical wave tanks, *Ocean Eng.*, (2013) **59:**73–85.

[9] National Instruments, LabVIEW 2016 (64-bit) - English. Austin - Texas - United States, (2016).

[10] M. Isaacson, Measurement of regular wave reflection, *J. Waterw. port Coast. Ocean Eng.*, (1991) **117:**553–569.

[11] U. Guide, STAR-CCM + ® Documentation, (2015).

[12] R. G. Dean and R. A. Dalrymple, *Water Wave Mechanics for Engineers and Scientists*. World Scientific, (1984).