IMPLEMENTING THE AWASYS WAVE ABSORPTION SYSTEM IN A PECULIAR WAVE FLUME

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Abstract

This paper describes the implementation of a dynamic absorption system of reflected waves, AWASYS (Troch, 2005), in an old and geometrically peculiar wave flume of LNEC (National Laboratory of Civil Engineering). The paper starts by describing the problem to solve, that is, how to absorb unwanted re-reflections existing in the flume, presenting the theoretical foundations of existing 2D active absorption, along with its advantages and disadvantages. A comparison between wave records obtained in six wave gages located in the middle of the flume, either using the system ON or OFF is the main result obtained with this work. The parameters compared were the wave height, peak period and reflection coefficient, obtained for both situations. Comparisons made between incident and target wave spectra for the selected wave conditions are also discussed in the paper.

1. Introduction

One problem generally associated with physical experiments in flumes is the presence of re-reflected waves produced by the wave paddle. In nature, this does not happen. This problem can be solved by using a dynamic absorption system. This is done by applying a so-called absorbing wave maker where the wave generator, besides generating the incident waves, also absorbs waves reflected from the test structure, thus avoiding re-reflections at the paddle. One of such systems is called AWASYS, designed and programmed at Ghent University, Belgium, by Troch (2005), although largely based on the AWASYS system developed by Frigaard and Christensen (1994) at the Aalborg University, Denmark.

Back in 2006, the AWASYS system was purchased to the University of Ghent in order to enable active wave absorption inside WF1 (Irregular Wave Flume no. 1) – see Figure 1 a), an irregular wave flume, 1.6 m wide, 49.4 m long, cuboid shaped. This is the most used wave flume of LNEC. AWASYS performed and still performs very well on this flume.

In 2008, LNEC decided to transpose this system to the larger WF2 (Irregular Wave Flume no. 2) – see Figure 1 b), also an irregular wave flume, but longer, 3.0 m wide, 73.0 m long. This flume is also of cuboid shape although at the end it also has an enlarged section, 11.0 x 3.0 m^2. A number of tests were then performed to make sure the system was as effective as possible for this flume with physical characteristics quite different than WF1. One came out with an optimum layout and although not as effective as in WF1, AWASYS results were quite satisfactory.

More recently, another wave flume, WF3 (Irregular Wave Flume no. 3) was made available at LNEC's experimental facilities – see Figure 1 c). This is a very old wave flume (the oldest of the three), not used for many years, and one considered to implement the AWASYS system to this flume also. This is a peculiarly shaped flume, quite different from the cuboid shape of the others.

Figure 1. Three different wave flumes at LNEC. a) WF 1, b) WF 2 and c) WF 3.

So, how does AWASYS work in such a particular flume? This paper describes the implementation of AWASYS in this geometrically peculiar wave flume and tries to answer that question.

The paper starts by describing the problem to solve, that is, how to absorb unwanted re-reflections existing in the flume, and it presents the theoretical foundations of existing 2D active absorption, along with its advantages and disadvantages. A brief explanation of the principles of operation of the active absorption AWASYS, implemented as a module of a software package for simulation, generation and acquisition of waves inside flumes, SAM (Capitão, 2002), follows. The underlying theory that leads to solving the problem of dynamic absorption of reflections and practical procedures for implementation of the system in the WF3 flume are provided and some general indications of how the system can perform (albeit with limitations) in this new setup, as an adaptation from other experimental conditions, is provided. Finally, the paper proceeds to a series of verifications, by testing AWASYS system on a set of varying reflection conditions.

2. Implementation of the AWASYS in WF3 flume

The testing of physical models in wave flumes with varying reflection coefficients requires the use of both a theory for the wave generation and a theory for the wave absorption. Indeed, since usually the purpose of the testing is to determine the impact (or consequences) of the waves in the models under study, which inevitably creates waves reflected by itself, it is important to empower the system with a mechanism that enables absorption (absorption system) so that "re-reflected" waves produced by the mechanism of generation (paddle) are eliminated by the system. Broadly speaking, wave absorption systems generate waves in response to the detected reflected unwanted waves.

2.1 Details of the AWASYS system

The AWASYS (Troch, 2005) system is an active wave absorption system that allows the wave paddle to simultaneously generate the incident waves and absorb the spurious reflected waves. Surface elevations are measured at two locations inside the wave flume by using two inline gages. The reflected wave train is separated from the measured wave field by means of FIR

(Finite Impulse Response) digital filtering and subsequent superposition of the measured elevation signals. An additional incident wave train is determined in order to absorb the reflected wave train.

This system uses time domain FIR digital filters applied to the measured incident and reflected wave trains near the wave paddle. For this, simultaneous measurement of the free surface elevation in two probes placed in a far field, typically about 3 m from the paddle, separated from about 30 cm each other. In each step, the (unwanted) reflected waves are separated from the incident waves using digital filtering. The paddle movement required to absorb the reflected waves is computed and added to the original paddle movement (Frigaard and Christensen, 1994). Very briefly, the method comprises the following steps:

1. The incident wave is propagated onto the structure, which subsequently is reflected in some extent in the opposite direction, to the paddle. This reflected wave occurs in nature but the reflection of this reflected wave by the paddle does not occur in nature. That is the wave one wants to eliminate;
2. Two wave gages near the paddle measure incident and reflected waves by using real-time digital filtering;
3. The reflected waves are back-propagated to the paddle using Fourier Transform operations;
4. Using the system's hydrodynamic transfer function (Bièsel and Suquet, 1951) and the intrinsic paddle transfer function (obtained by dynamic calibration), the signal to feed the wave paddle as to absorb the unwanted reflecting waves may be then computed;
5. Finally, that correction signal is added to the target incident signal.

2.2 SAM software

SAM software (Capitão, 2002) is an integrated software package for use in irregular wave flumes and tanks in experimental facilities of hydraulic laboratories. This software package, which has been in use at LNEC for some years, is designed to characterize, to numerically simulate, to generate, to acquire and to control the sea wave agitation in flumes.

One of its' modules is the SAM MOD 3 (Generation and Acquisition): Simultaneous generation and acquisition of signals with or without active (real-time) absorption of unwanted reflected waves, which now uses the AWASYS wave absorption system, also coded in National Instruments' LabVIEW©. This module simultaneously produces electric signals to feed the servo-motor/valve of the wave paddle and also enables the acquisition of data from wave gages.

2.3 WF3 wave flume and AWASYS configuration

AWASYS wave absorption system was implemented in the old wave flume WF3 of LNEC (Figure 2). As can be observed in Figure 2 b), this flume exhibits a peculiar geometry as viewed from above, since its width is not constant but it narrows in a section in the middle of the flume. Back in the fifties, when this flume was designed and constructed, this peculiar geometry was devised to improve hydraulic behavior of the flume, by preventing unwanted transversal waves, and, at the same time, to enable an increase of the regular wave heights (due to shoaling) produced by the limited capabilities of the original wave paddle. What seems to be nowadays a curious layout, was at that time an approach to get better hydraulic behavior (with regular waves), and also higher waves with a limited stroke power of the paddle.

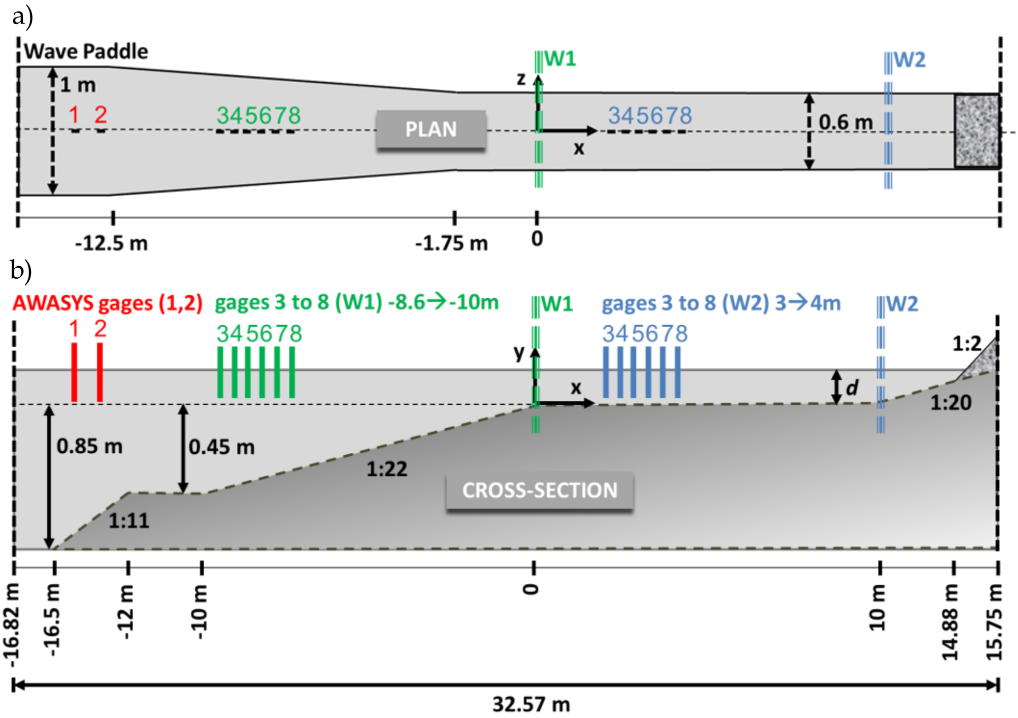

Figure 2. Geometric characteristics of LNEC's WF3 wave flume. a) plan view; b) cross-section view (exaggerated vertical scale).

The system was implemented and verified in WF3 flume. A piston type wave paddle was used to generate and absorb the waves. The maximum stroke is 0.40 m and the paddle displacement is accomplished by using a step motor (electric actuator). Before each test session, probes (in this case, resistive gages) were calibrated, providing information on the hydrodynamic feedback. A prior, dynamic, calibration of the paddle was also performed to compute the paddle transfer function and FIR coefficients filters were found to optimize the performance of the system. Dynamic calibration of the wave paddle was performed by changing the steering signal, in voltage steps of 1 Volt, and determining the displacement of the paddle. AWASYS FIR filter coefficients were computed using "FIR Design" module of AWASYS.

3. Test setup

WF3 flume is equipped with a piston-type wave maker controlled by AWASYS system. It was instrumented with 10 resistive-type wave gauges that were placed along the flume, a first array of two wave gauges located in front of the wave-maker, at a distance 2.99 m and 3.24 m from the paddle, necessary to the dynamic wave absorption system, Figure 3 a), and a second array of 8 wave gauges of the same type located in the middle of the flume, separated by 20 cm, between x = -10 m and x = -8.6 m, for a set of tests entitled "W1", or between x = 3 m and x = 4.4 m for tests entitled "W2", Figure 3 b). See also Figure 2.

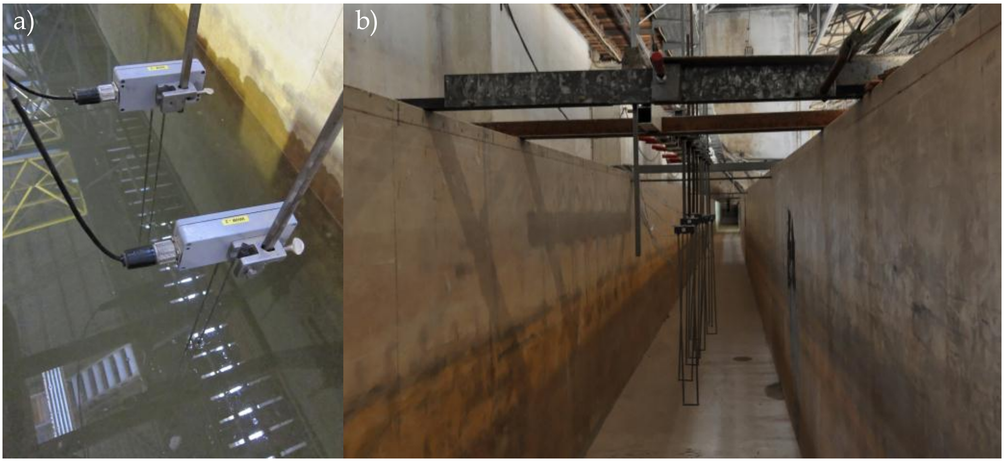

Figure 3. Wave gauges: a) the first array of two gauges close to the paddle and b) the second array of eight gages close to the structure.

WF3 was set up and, depending on the test, the AWASYS system was switched on and off to test the validity and the suitability of this system on this particular experimental flume with such a characteristic geometry. For all tests, the first 8 probes (out of 10), named 1 to 8 in Figure 2, were used, the first two of which (closer to the wave paddle) belong to the AWASYS system. The water depth, d, at the section where the flume bottom is horizontal (between x = 0 and x = 10 m) was 0.10 m for tests W1 and 0.30 m for tests W2 – see Figure 2.

A number of simulations were considered in this study, some considering a vertical wall for set of tests W1, and others for set of tests W2. At the beginning, a vertical wall was imposed at location x = 0, for W1 tests – see Figure 2. This was a location that implied a very short wave flume. One found out later that this would make that waves got breaking very soon, usually at a location impinging the wave gages. Actually, the position of the vertical wall as described was associated with two main potential problems: first, it is located on a sloping beach, second it is located on the joining part, in the plan, of the flume. This was not desired since the wave gages do not give good values for the measurements due to bubble activity at that location.

Therefore, a second position for the vertical wall was tried out (see Table 1 and Figure 4). This new position was considered for set of tests W2, at location x = 10 m – see Figure 2. For this second position, a number of different beach configurations were tried out: 1) Just the vertical wall, giving a high reflection coefficient (reflection coefficient r0~0.70), see Figure 4 a); 2) with a blanket covering that vertical wall (reflection coefficient r0~0.60), see Figure 4 b); 3) with a vertical wall with holes in it (reflection coefficient r0~0.30), see Figure 4 c); and with an absorbing beach, starting at the position where the vertical wall was (reflection coefficient r0~0.15), see Figure 4 d).

In order to test the methods, a number of numerical and physical tests were performed using SAM and WF3 wave flume. The tests included different types of target waves, both regular waves and irregular waves.

Table 1. Types of flume end setup for the reflection tests

TR	**Total Reflection** (quasi total reflection with brick wall) , where a brick wall, either at position W1 or W2, was constructed; r0 ~ 0.70
BR	**Blanket Reflection** (average reflection with blanket covering brick wall); r0 ~ 0.60
HR	**Hole Reflection** (low partial reflection with brick wall holes) where the brick wall was rotated 90 degrees so as to have its holes in line with the wave propagation, so as to have a low partial reflection coefficient; r0 ~ 0.30
AB	**Absorbing Beach** (low reflection with slope beach covered by blankets), where the slope beach was covered by blankets in order to attain a lower reflection coefficient; r0 ~ 0.15

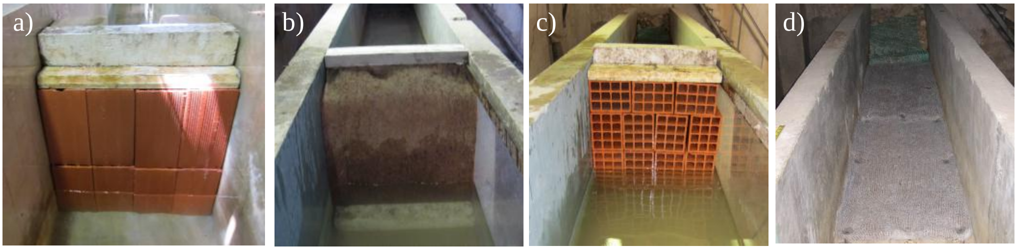

Figure 4. Types of flume end setup for the reflection tests. From left to right : a) TR - Total Reflection, b) BR -Blanket Reflection, c) HR - Hole Reflection and d) AB - Absorbing Beach.

Different combinations of wave height, H, and period, T, were then used for the numerical and physical simulations. A total of 23 wave records were numerically simulated (17 regular and 6 irregular).

One started with regular waves, which propagated with permanent form, with constant height and period, for constant depth and cross section. These characteristics were devised using the numerical simulation module of SAM software.

Also irregular waves were produced using the same module of SAM software. A JONSWAP spectrum was used, with spectrum width λ = 3.3, using the same values of height and period as in regular waves.

Regular wave records were identified as H[06, 08 or 10]T[11, 15 or 20]_[W1 or W2]_[TR, BR, HR or AB], with the following correspondence (e.g., "H08T15_W2_HR", for a record of regular waves with height 0.08 m, period 1.5 s with a wall of type HR at position W2):

-H[06, 08 or 10] for wave heights of 0.06, 0.08 and 0.10 m;

-T[11, 15 or 20] for wave periods of 1.1, 1.5 and 2.0 s;

-[W1 or W2] for locations (sets) W1 and W2;

-[TR, BR, HR or AB] for conditions as described in Table 1.

Similarly, irregular wave records were identified in the same manner, but were suffixed by "i_", (e.g., "i_H10T20_W2_TR", for a record of irregular waves with significant height 0.10 m, mean period 1.5 s with a wall of type TR at position W2).

Descriptive time-domain statistics (root mean square wave heights and corresponding standard deviation, skewness and kurtosis) based upon data obtained along the flume were computed. Also, a frequency-domain analysis was carried out at selected points of the flume for completeness.

4. Results and discussion

The reflection analysis´ module of SAM was used to analyze the results of wave gage's measurements. This module enables separation of incident and reflected spectra in wave flumes, using Goda & Suzuki (1976) and Mansard & Funke (1980) methods.

Figure 5 shows two examples of comparison of the incident wave spectra and associated performance of active wave absorption system, of both regular (H=0.6 m; T=1.5 s) and irregular (HS=0.6 m; TP=1.1 s) waves, considering the full reflective brick wall (TR) at position W2. AWASYS system was switched off (_off) and on (_on) respectively. In this figure, S* is the target spectrum.

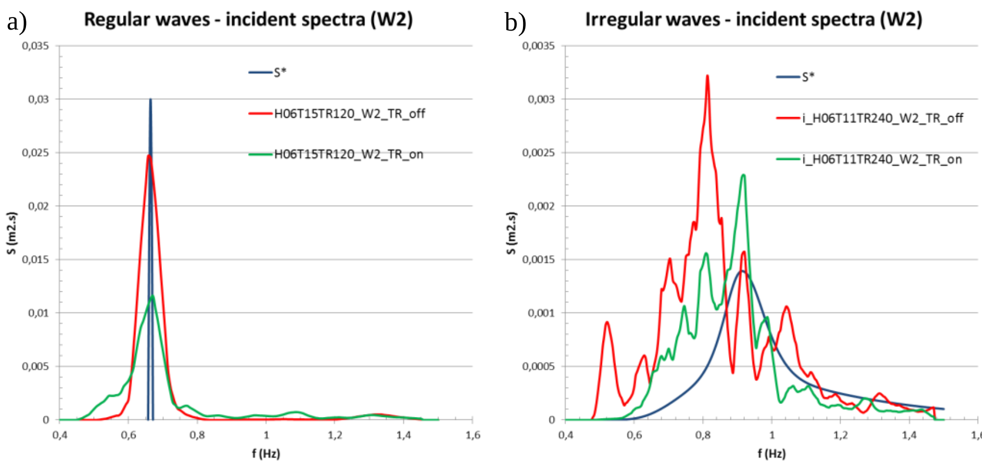

Figure 5. Performance of active wave absorption system, considering a full reflective brick wall (W2). Incident spectra calculated with AWASYS on and off conditions, for: a) regular (H=0.6 m; T=1.5 s); and b) irregular (HS=0.6 m; TP=1.1 s) waves.

One found out that, for regular waves:

- An increase of about 35% in wave heights was observed at all wave gages. This is the visible effect of the flume narrowing. This increase was accounted for in the calculations and comparisons made in Figures 7 to 9;
- AWASYS reduces the re-reflections only a little, by the order of 10%. In certain tests, the attenuation was minimal;
- Some spectral spread was observed, which is broader when AWASYS is on.

Concerning the irregular tests,

- The same increase of about 35% in wave heights was observed;
- In certain tests, there was an increase of re-reflections when AWASYS was on (!);
- A change in peak periods is observed mainly when AWASYS is off;
- A careful choice of cutoff frequencies has to be made to prevent numerical instabilities in the reflection analysis.

On the other hand, simulations show very good agreement between target periods (peak period) and obtained periods. This occurs for both regular and irregular simulations and also with AWASYS system on and off, although slightly better when the system was engaged.

Globally, the system doesn’t reduce the reflections as well as one would expect, compared with the system off. In certain tests, the attenuation was minimal (see e.g. H06T15_W2_HR, Figure 8), where r0 showed values of 0.41 vs. 0.33 (off and on respectively), but others showed better efficiency (e.g. H06T15_W1_TR, Figure 6 and Figure 8), where r0 showed values of 0.42 vs. 0.19 (off and on respectively).

Only one test was made for the Blanket situation (BR), since one found this setup to be not a static one, implying that an operator was needed to guarantee that the blanket was not moving due to the water percolation. There was no time available to properly set this situation, and therefore this set of tests was abandoned. However, one found, for the only test made (H06T11_W2_BR, Figure 8), that a great amount of absorption was introduced with this blanket positioned on the vertical wall. Reflection coefficients were computed for this case as approximately 0.44, for both situations (AWASYS on and off).

The following figures (from Figure 6 to Figure 8) show the obtained results for the regular wave tests using SAM´s reflection analysis module to compute incident and reflected wave heights considering wave gages 3 to 6 (Mansard & Funke method).

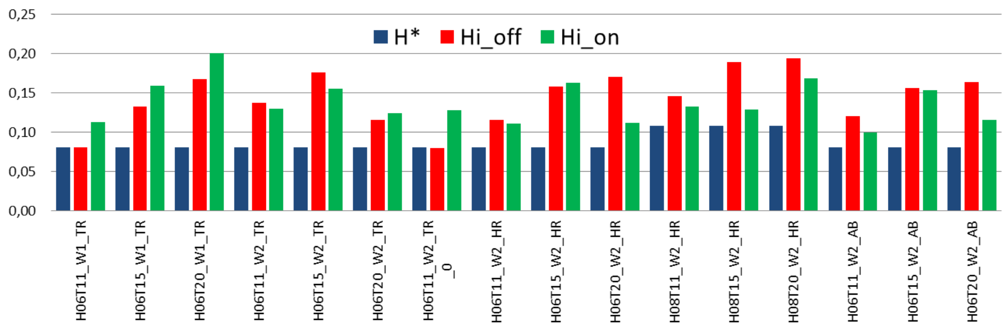

Figure 6. Regular waves with wave height H. Comparison of target wave heights H* with incident wave heights Hi for conditions AWASYS off and on (_off and _on).

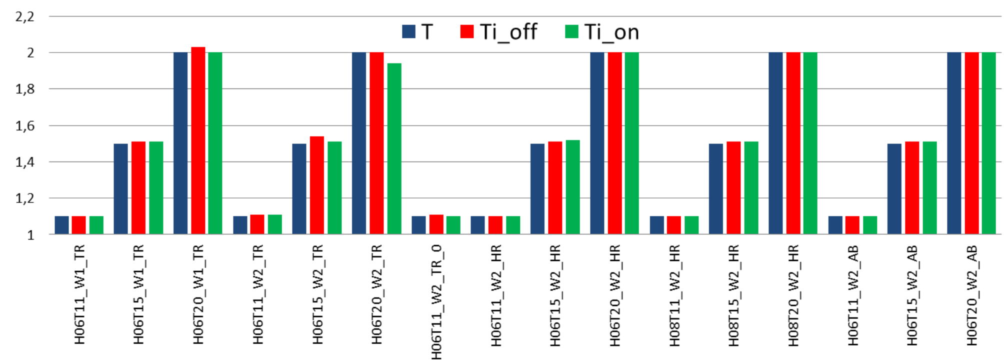

Figure 7. Regular waves with wave period T. Comparison of target wave periods T* with incident wave periods Ti for conditions AWASYS off and on (_off and _on).

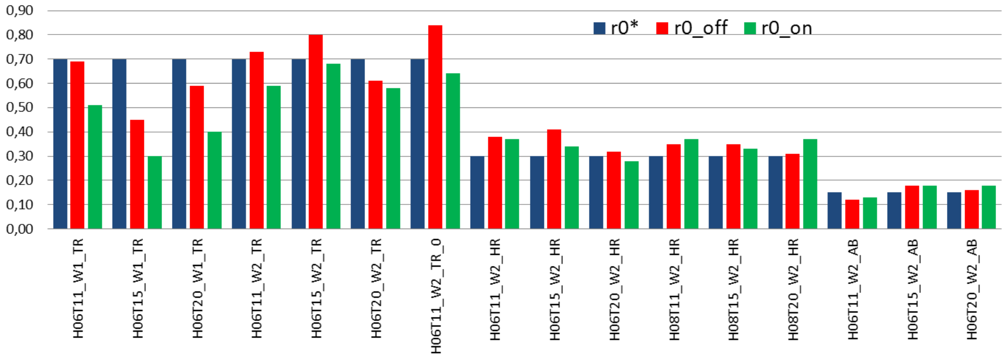

Figure 8. Regular waves. Comparison of target (estimated) reflection coefficients r0* with obtained reflection coefficients for conditions AWASYS off and on (_off and _on).

Concerning the wave heights, one can observe that: for the vertical wall at position W1 (W1_TR) the attained values of Hi are higher than the targets, being even higher when the AWASYS system is on. This behavior may be due to the proximity of the wall to the wave maker in position W1; for the other results (W2_TR), the values of Hi are also higher than the target, although for some waves the value is higher and for others is lower with AWASYS system on and off respectively.

Concerning the wave periods (Figure 7), one can observe that the target period, T, is reasonably well attained for all the waves.

Finally, the reflection coefficients show that for the vertical wall in total reflection conditions (W1_TR and W2_TR) the system is able to slightly reduce the reflection coefficients; for the remaining tests the AWASYS system has an almost neutral effect.

Similar results were obtained for the irregular wave tests.

5. Conclusions

From this rather limited number of tests made for this paper, one can conclude that AWASYS system is not effective enough to be considered in this flume, although a slight improvement of the wave field with AWASYS on was observed. However some erratic behavior is apparent. It should be noted however that the AWASYS system was purchased to be used in other, very different, wave flume, where its efficiency was already tested and good (although not excellent) results were obtained.

The geometrical peculiarities of this WF3 flume may explain some of the bad results one obtained with these tests. We cannot be sure about this reason, since we did not make tests on a wave flume with the same length and width but without those complex flume segments both in plan and in cross-profile. A recent work of Didier and Neves (2010) with numerical wave flumes with similar geometrical shapes suggests this same result.

Finally, one should mention that reflection computations were done using the M&F method which assumes that the wave gages are positioned in the same water depth. This was not the case for all the tests. For the W1 tests the wave gages were located on the part of the flume with a 1:22 slope bottom. This clearly violates M&F assumptions, although a not very serious error should be expected from this simplification. Also, during the tests significant electromagnetic noise was observed, which may have negatively affected the measurements made by the wave gages and, consequently, the AWASYS performance.

Although this implementation was not that successful, we will try to counteract this geometrical constraint with some other measures like the installation of the system wave gages not in line with the propagation, in the centre of the flume, but transversally. We also will study how the paddle transfer function may (or may not) be dependent on the water depth.

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