Design, installation, capacities and expenses of an indoor multipurpose modular 2D wave flume and circulating water channel

I. Bidaguren, N. Montalbán, U. Izquierdo, I. Albaina, A. Peña, E. Urtaran, J. M. Blanco

Abstract—**In this article all the details related to the design, installation process, working capacities and expenses of a modular indoor laboratory flume are presented. The facility is able to work as wave flume or circulating water channel. Presented cases are 12.5 m and 25 m length wave flumes. Flume width is 600 mm and can be filled up to 700 mm water depth. In this work, a multipurpose 50 m³ underground water storage tank is used to feed the flume. Two types of wave generators are presented, an in-house developed one for regular waves and an externally manufactured one with added options: irregular waves, and active absorption system. At the end of the flume, a parabolic beach has been installed as wave energy dissipation system. A foldable wave generator paddle and a set of pipes and valves, allows working as water channel by recirculating water to the underground storage tank. In the upper part, there have been mounted guides along the whole facility so that different ad-hoc devices can be attached onto it. Among this, we can mention wave gauge module together with resistive wave gauges; digital, low pressure sensor, and CompactRIO controller as data acquisition system. A computer with a Labview program controls all data recording. In this work the design characteristics and operation of the main components of the wave flume are reported in detail.**

Keywords— **Wave flume, Wave interaction device testing, Circulating water channel.**

I. INTRODUCTION

THE University of the Basque Country, in the Engineering Faculty of Bilbao, has a 12.5 m long in-house developed wave flume with a piston type wave maker for regular waves (Fig. 1). Flume is 0.6 m width and can work up to 0.7 m water depth. The design is completely modular, which allows adding new modules and increase the flume length as desired. Recently, an extension of this facility has been acquired, to 25 m long, with an externally manufactured generator with added options: irregular swelling generating capacity and active absorption system of reflected wave. The presented flume design can work as a circulating water channel too thanks to the set of pumps submerged in the 50 m³ water storage tank. The need to build a new wave flume arose in order to increase the valid test time and the ability to generate sea states with irregular swell. Many different applications can be tested in this kind of facilities related to marine renewable energy, civil engineering, coastal engineering, mooring modelling, etc. More specifically, examples of some research done in this flume can be found in [1–5]. In this work, all the details related to the design, installation process, working capacities and expenses of this modular indoor laboratory flume are presented.

II. DESIGN

The flume consists of a lower structure, the seabed structure, lateral glasses (with their structure), a piston type wave generator, a passive wave extinction beach and two multipurpose longitudinal rails on top. Presented cases are 12.5 m and 25 m. So far, all tests have been done with the 12.5 m channel. The current structure is

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represented in Fig. 1. The channel part lays on a lower structure.

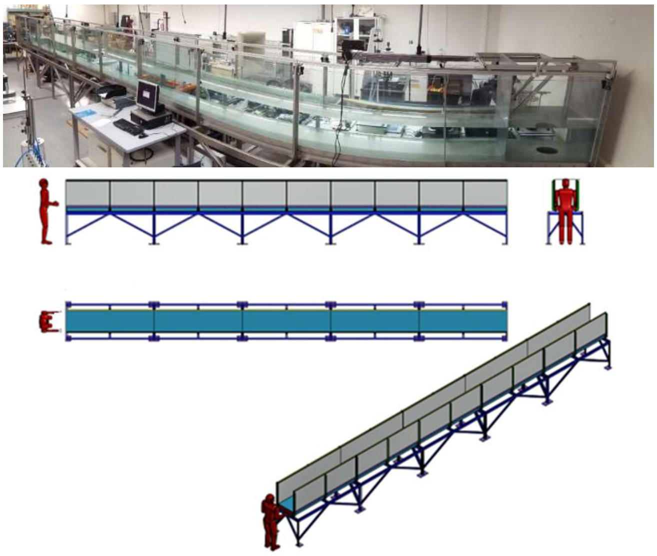


Fig. 1. 12.5 m water channel

A. Lower structure

As it is a modular channel, the length of the flume depends on the number of structures. Each structure dimensions are 2.5 m long, 0.8 m high and 0.9 m wide. The structures are placed one after the other to conform the total channel length. For the case of 25 m long, it will be supported by 10 structures. The current structure, instead, as it is 12.5m long, it is supported by 5 structures. It is made of stainless steel.

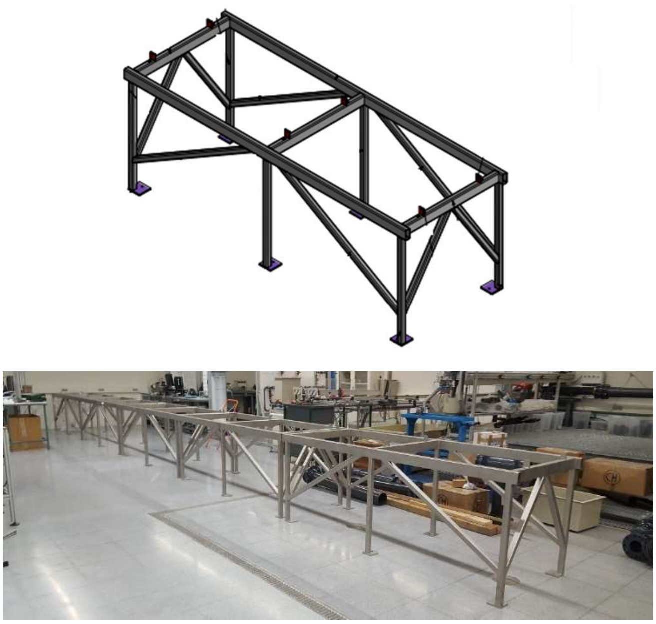


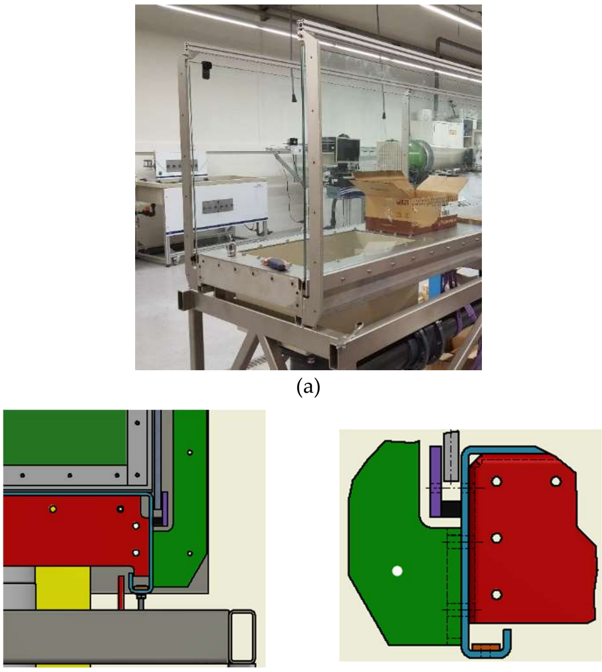
Fig. 2. Main lower structure: One module CAD (Top) and five modules in mounting process (Bottom).

Each lower structure is supported by six legs, by two horizontal bars and three cross bars and strengthened by six diagonal bars. They are all made of rectangular tubular profiles, and they are all welded to each other and reinforced to avoid the relative movement between the bars (translation and rotation). At the bottom end of the legs, there are six steel sheets of 10 mm thick that land on the floor. Each of them helps to distribute the weight of the whole structure. In Fig. 2 the structure is shown.

B. Upper structure

The Upper part is an assembly of different parts that complete the flume, which section is 600 mm wide and 700 mm high. The bottom of the flume (seabed) consists of a 5 mm sheet made of folded stainless steel (blue in Fig. 3) and a sandwich-type assembly, which allows attaching the lateral glasses (gray in Fig. 3 (c)) to the seabed frame using platens (purple). A fine-tuning regulation system allows a perfect alignment of each of the modules with the adjacent. This manufacturing and assembly strategy avoids undesirable whirls effects in water flow.

Each flume module is 2.5 m long, as the lower structure. In the middle and each side of the seabed part there is a 10 mm thick stainless-steel sheet perpendicularly placed inside the seabed part (represented in red in Fig. 3), whose function is to avoid the bending of the seabed, to distribute loads and to join the seabeds with a bolt joint. Platens allows the fitting of the lateral glasses to the seabed frame. The platen is 8 mm thick and 2.5 m long too.



(a)

(b) (c)

Fig 3. Upper structure (flume) over lower structure assembly: (a) Real mounting process. (b) CAD detail of upper structure parts over lower structure. (c) CAD detail of upper structure parts.

In the right, in the centre and in the left of each module, there are six ribs (green Fig. 3 (c)), three on each longitudinal side of the structure. These ribs are used to join all the side glasses vertically one to the other and to the seabed. The platen, the seabed and the glass conform a sandwich type assembly, which is represented in Fig. 3.

The assembly is conformed by the seabed, the rib, the platen, the glass and the lower structure.

1) Water outlet module

In this module, where the wave extinction system is placed, the seabed has a square shaped hole as water outlet which is connected to the water tank placed below the laboratory floor by pipes. In Fig. 4 and Fig. 5 this seabed is represented.

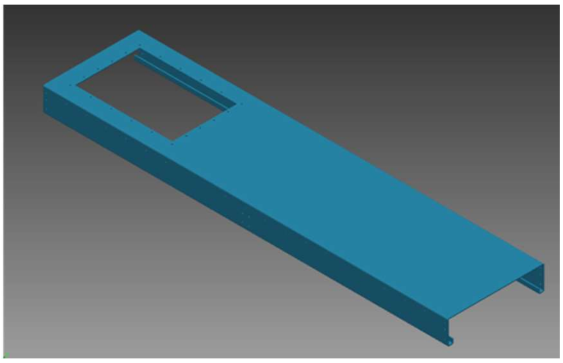


Fig 4. Flume seabed structure. Water outlet part (Hole dimensions 400 mm x 600 mm).

Fig. 5. Outlet module details

2) Water inlet module

In this module (Fig. 6 and Fig. 7), which coincides with the part where the wave generator is placed, the seabed has a circular hole as a water inlet which is connected to the water storage tank by pipes.

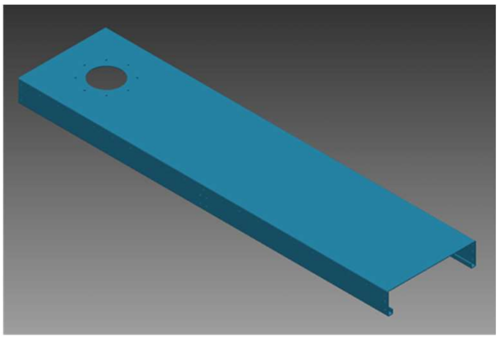


Fig. 6. Flume seabed structure. Water inlet part (Hole dimension ø200 mm).

Fig. 7. Inlet module bottom detail.

3) Upper rails

In the upper part, just above each of the lateral glasses, there have been mounted profile-guides along the whole facility so that different ad-hoc devices can be attached onto it, such as testing models or necessary instrumentation.

C. Loads

In order to withstand the building admissible load requirements, the width of the structures has been set to 0.9 m, and the total number of supports per module to 6. In Table I all the relevant information in relation to loads is contained. For the 25 m long one, same support pattern will be continued until the desired facility length.

To sum up, the floor of the laboratory needs to support 683.5 kg/m², a condition that, as can be seen in Table I, is fulfilled with a floor that can withstand up to 700 kg/m².

III. HYDRAULIC SYSTEM

D. Hydraulic system of the 12.5 m channel

The presented channel is placed above the underground water storage tank. The flume is oriented so that the side of the dissipation system is the one that is set on top of the storage tank. Below the seabed, and across all the lower structures, a pipe runs along the channel. A group of three centrifugal pumps mounted in a parallel arrangement and equipped with a frequency converter form the pressure group that supplies water to the channel. The water forks to enter the channel from the two inlets, placed in each of the extremes of the flume. A general scheme of the installation system can be seen in Fig. 8 and a detailed view in Fig. 9:

TABLE I
LOADS IN THE 12.5 M CHANNEL

Weight of the structure	1650 kg
Equipment	350kg
Water	5690 kg
Total	**7690 kg**
Surface	11.52 m x 0.9 m = 11.25 m^2
Overload of forged use	700 kg/ m^2
Kg/m^2 of the structure	**683.5 kg/ m^2**
Number of laying platens	30
Number of support points	22
Extreme supports	192.25 kg
Double intermediate supports	384.5 kg / 0.045 m^2
Single non-extreme support	384.5 kg / 0.025 m^2

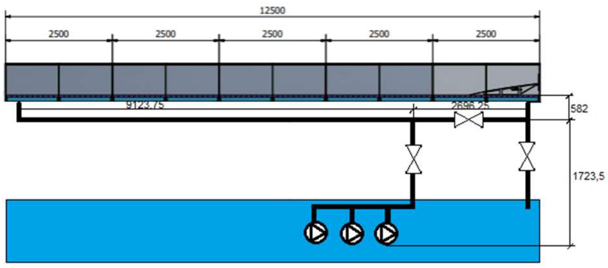


Fig. 8. Hydraulic installation. Underwater pumps in water storage tank and piping scheme.

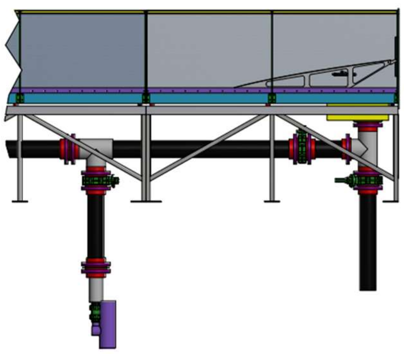


Fig. 9. CAD detail of the extinction end of the facility. Note the piping with valves and principal hydraulic accessories.

Taking into account the different elements positions and the head losses due to the accessories and the pipes, the approximate equation of the installation is (1):

$$H_I = 2.81 + 1.54 \cdot 10^{-7} Q^2 \quad (1)$$

TABLE II
VARIABLES AND UNITS FOR HYDRAULIC INSTALLATION EQUATION (1)

Symbol	Quantity	Unit
H_I	Installation pressure head	m
Q	Flow rate	m^3/s

The pumps that boosts the water to the flume is an AISI 304 stainless-steel submersible electric pump, Pedrollo BC15/50-ST model. This kind of pumps are advisable for the drainage of foul and loaded waters in the domestic, civil and industrial sector. They are equipped with a two-channel impeller which allow the pumping of liquids with the presence of suspended solids up to 50 mm short fibre size. For this particular case, three pumps are placed in parallel inside the water tank which is placed bellow the flume. Fig. 10 shows the pump installation.

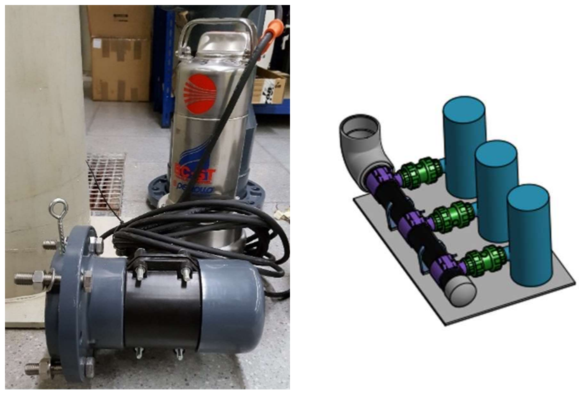


Fig. 10. Pump and installation scheme

The equation for each pump is given in the datasheet, and the curve for the three pumps group is (2):

$$H_P = 14.8 - 0.016 \frac{Q}{3} \quad (2)$$

TABLE III
VARIABLES AND UNITS FOR PUMPS EQUATION (2)

Symbol	Quantity	Unit
H_p	Pumping pressure head	m
Q	Flow rate	m^3/s

All this hydraulic details are plotted in Fig. 11. Blue line represents equation (1), the installation curve. Remaining three lines represent the pressure head curve of the pumping group when working with one (yellow), two (red) or three pumps (green, equation (2)). Operating point details when working with three pumps are in Table IV. As an example, at this hydraulic working point, if working with 200 mm water depth, circulating water velocity is 0.3 m/s.

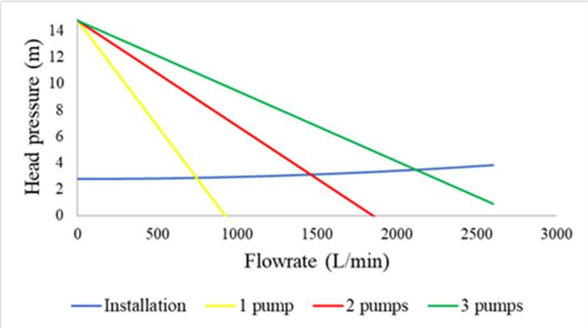


Fig 11. Operating points

TABLE IV
VARIABLES AND UNITS FOR FIG. 11

Symbol	Quantity	Value	Unit
H	Pressure head	3.5	m
Q	Flow rate	2119.27	L/min
f	Frequency	50	Hz
n	Angular speed	2900	Rpm
P	Power	1.1	kW

IV. WAVE GENERATION

As the wave flume focuses on developing two-dimensional wave trains, the structure must be narrow enough to avoid three dimensional effects. It also must be long enough to guarantee fully developed waves. As a whole, the system must be divided into three different regions: generation, propagation and extinction areas.

Generation area: it consists of the wave maker and the length of the flume where the wave is directly affected by the inertia of the movement of the paddle. Its length depends on the characteristics of the wave.

Propagation area: it consists of the section of the flume where the fully developed wave travels along the flume without suffering any significant modification on its wavelength, period, height or shape. This is the proper zone to carry most of research activities.

Extinction area: dissipation system is described in next section "Wave Extinction System".

Two types of wave generators are presented in this work, an in-house developed one for regular waves and an externally manufactured one [6] with added options: irregular swelling, and active absorption system for reflected waves. The paddle position is controlled in real time by a closed loop.

A. *Regular wave generator*

The channel works with a piston-type wave maker, one of the most widely used in modern flumes along with flap-type wave makers. Piston wave makers are suitable for the reproduction of waves in waters defined as shallow in relation to the wavelength of the wave, i.e., the relation $h/\lambda < 0.05$ must be fulfilled. However, waves in waters of an intermediate depth ($0.05 < h/\lambda < 0.5$) can be generated with piston wavemakers too.

The paddle is driven by a piston that pushes and pulls the structure which is perpendicularly attached to the paddle forward and backward, in function of the requirements of the selected wave and the tide level. The paddle is partially submerged in water. The system of the paddle is represented in Fig. 12.

Fig. 12. CAD detail of the Piston-type paddle (700 x 600 mm) with top railed bracket.

The commercial software for wave generation is called Delta-ASDA (V5), which controls the servomotor which in turn controls the linear actuator that moves the paddle. The software controls the position to which the servomotor must displace its movement according to the Stokes 2nd order equations for linear swelling. The position is determined by PUU unity values. In our case, being a sinusoidal cyclic motion, each cycle has been defined with 720 points. Therefore, each "step" corresponds to 0.5º of a circle. This circle, in turn, is defined as the outline of a circular cam (see Fig. 13). It is therefore treated as if a position-based motion of a cam with a given contour were being generated. These 720 points are calculated from the tide height (h, m), the wave height (H, m) and the wave number (k, rad/m), that must be provided by the user. This way, several types of regular waves can be generated.

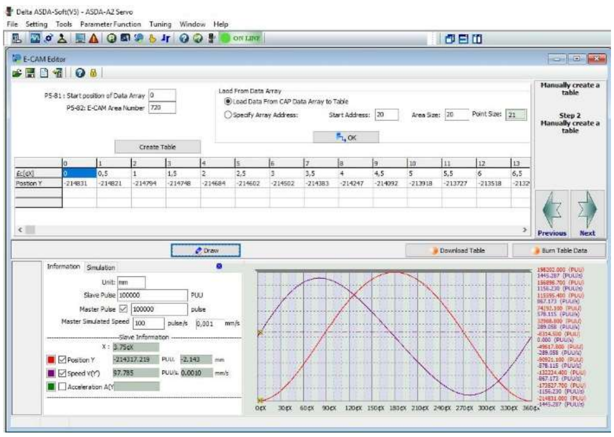


Fig. 13. Delta-ASDA software screenshot

1) *KM60-10 roller screw*

The regular wave generator is driven by an ASD-A2-0721-M servo drive, an ECMA-C20807RS servomotor and a KM60-0600-10-NA-P10-JKA lineal actuator.

The roller screws convert the rotary motion produced by a motor into linear motion. They can carry heavy loads for thousands of hours. The piston function is taken by the

K Series linear actuator KM60-0600-10-NA-P10-JKA, which can act as a replacement for pneumatic and hydraulic cylinders in linear motion control applications. Unlike most actuators that utilize ball screws, this actuator uses a planetary roller screw, which assures long life and high resistance to shock, an improvement against ball screw actuators. The standard K Series actuator design includes an anodized aluminium housing offering a high level of corrosion resistance. The standard main rod is plated steel with a stainless-steel rod end insert. It is prepared to be mounted with an ECMA-C20807RS servomotor. The Table V contains all the performance specifications of the KM60-10 roller screw.

TABLE V
KM60-10 PERFORMANCE SPECIFICATIONS

Model No.	KM60-10
Nominal frame size	60 mm
Screw lead	10 mm
Maximum force	3 kN
Linear speed at maximum rated RPM	833 mm/s
Dynamic load rating	6.8
Life at maximum force	115.3 km
Maximum input torque	6 Nm
Maximum rated RPM input shaft	5000 rpm
Maximum stroke	600 mm

2) *Delta ASD-A2-0721 servo drive and ECMA-C20807RS servomotor*

The ASD-A2-0721-M servo drive works at a rated output power of 0.75 kW and an input voltage of 220 V either in one or three phases. Anyway, the power supply given is 230 V in one phase and 50 Hz. The ECMA-C20807RS servomotor also works at a power of 0.75 kW, at 3000 rpm and 2.39 Nm. Its maximum velocity is 5000 rpm at 1.43 Nm and a couple peak of 6.9 Nm.

The Delta AC Servo Drives also feature a built-in electronic cam (E-Cam) function, which provides an excellent solution for synchronized motion applications. This drive series supports various industrial communications protocols like CANopen or EtherCAT, which are the one that the wave channel uses. The full-closed loop control, auto notch filter, vibration suppression and gantry control functions help to perform complex motions that require high precision and smooth operation and to reduce the effect of backlash and flexibility from the machine. It contains a 20-bit superior resolution incremental encoder (1280000 p/rev) which can eliminate unstable commands at low speed, smooth motor operation and enhance the accuracy of positioning, and a 17-bit absolute encoder. The Capture and Compare functions for high-speed pulses offer stepless positioning. It includes up to 1 kHz frequency response, which means that the settling time is below 1 ms. The driving system is supported by ASDA-Soft configuration software.

B. *Irregular swelling generator*

For the 25 m long wave flume a new wavemaker will be mounted, that generates both kind of swelling: regular and irregular. Paddle tracking is managed with AwaSys [7] software which registers the theoretical and real values. Active absorption of swelling can easily be configured thanks to the resistive gauges mounted on the paddle. It has plenty security functions and many auto-checking and system calibration routines implemented on the software.

Regular swelling can be generated in different ways in accordance with their respective theory:

- Linear theory
- Complete second order theory
- Cnoidal wave theory with shallow water wave generation
- Ad-hoc unified generation based on stream function theory input.

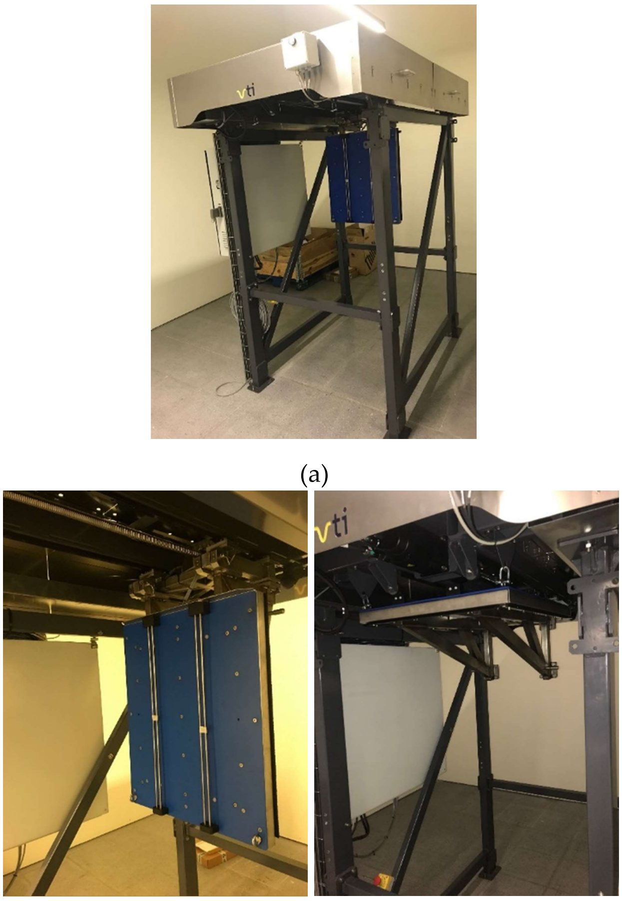
Linear theory results in fake free higher harmonics waves [8] which do not have a constant form. This can result especially obvious for shallow water waves (small h/L relation) and for steep waves (large H/L relation).

This spurious second harmonic can be eliminated using the second order theory and super harmonics of higher order are eliminated using the approximate stream function [9].

It can also generate first or second order regular swelling for given height, and period and irregular swelling and focused irregular waves with 13 predefined spectrum (Pierson-Moskowitz, JONSWAP, Bretschneider, etc.) and user defined spectrum. With the predefined spectrum, composite sea states can also be generated. Another method of generation of focused irregular waves or freak waves is basing on Gaussian Wave Packets. In addition, singular waves can be generated (focalized waves, singles waves such as tsunamis, N-waves, etc.).

Irregular swelling is generated based on the random phase, random complex spectrum or filtered white noise methods and ad-hoc unified generation based on Boussinesq numerical model input.

Waves can also be created specifying the position of the paddle (user defined position). It can be adjusted with or without active absorption. The paddle has a sounding line installed which measures the height of water. This height is directly read by AwaSys [7]. If the active absorption system is activated, the incident wave coming from reflection is identified in order to correct it by adding (by superposition)a wave 180º out of phase with the incident one. This strategy produces an overlapped signal leading to the desired wave pattern without the reflected contribution. The 2-D active absorption system for wave flumes is based on the SIRW-method by Frigaard and Brorsen, created in 1995 with the aim of separating the incident and reflected waves in real time [10]. Finally, the paddle has the option to be folded in order to work with circulating water (Fig. 14).



(a)

(b) (c)

Fig. 14. Wave generator for 25 m long flume. (a) General view. (b) Paddle in working position. (c) Paddle in folded position for circulating Twater channel mode.

V. WAVE EXTINCTION SYSTEM

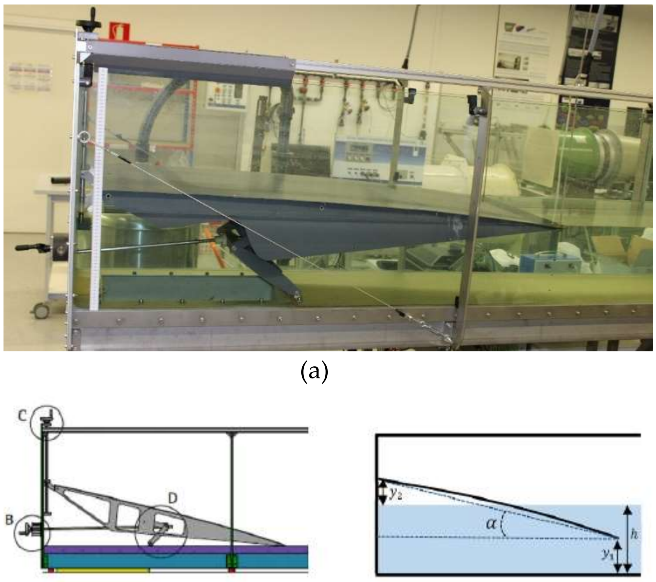
At the end of the flume, a parabolic shaped beach of 1.5 m length has been installed as passive wave energy dissipation system. An in-house developed manual regulation system sets the optimal position of this device: it allows to modify the height, the slope and the elevation.

The dissipation system is made of various parts that make its displacement possible. It has two hand cranks that are connected to a worm screw each. They are for the horizontal and the vertical displacement respectively. At the bottom of the sheet, there are a series of ribs that are separated by 173,3mm each and are made to hold the sheet and guarantee its mobility as they are connected to the worm screws. The ribs and the horizontal worm screw are connected by the straight arm of a jack. It is connected to the worm screw by an inside threaded cylindrical element that has a linear displacement through the screw. Another straight arm is used to connect the worm screw with the seabed by means of a rotating union in this last element. The scheme of this last assembly can be seen in Fig. 15 in point D. A Z shaped jack arm connects the vertical worm screw with the dissipation system.

Therefore, when any of the two hand cranks are activated, the worm screw rotates, making the jack arm move horizontally or vertically, depending on which of the hand crank is being activated. This will move the dissipation system vertically or horizontally.

The adaptive geometry of the body optimizes the dissipation of the incident waves, being able to adapt its position to the specific wave. Several dissipation options have been tested as published in [11]: height, slopes and perforated surfaces. The parabola that defines the shape of the body is based on Ouellet and Datta [12] and follows (3):

$$y = 200 + 0.023x - 9 \cdot 10^{-7}x^2 \quad (3)$$



(a)

(b) (c)

Fig. 15. Wave extinction system. (a) General view. (b) CAD detail with B and C tunning screws. (c) Drawing with main parameters.

This structure is considered a passive system, because the wave energy is partially dissipated, which means the wave is partially reflected. Active systems, instead, they neutralize the energy of the incident wave and avoid reflection. A detailed description of the resulting absorption capacities of AwaSys combined with an VTI servo controlled can be found in [13]. The geometry determines the amount of energy absorbed by the system. In this case, the parabolic profile, it produces a highly effective absorption with lower use of the available length of the flume, which leaves more space for experimental purposes. It also depends on other physical properties of the absorption system (profiles, position, slope and roughness). Perforations on the surface of the absorption system could reduce reflection as well.

When an incident wave is partially reflected, it travels towards the opposite direction of the flume creating a resultant water surface elevation. This term refers to the superposition of the reflected and the incident wave. The parabolic absorption system can be characterised in with a reflection coefficient as a function of the Iribarren number (4).

$$Ir = \frac{\tan(\alpha)}{\sqrt{H/\lambda_0}} \quad (4)$$

TABLE VI
VARIABLES AND UNITS FOR IRIBARREN EQUATION (4)

Symbol	Quantity	Unit
Ir	Iribarren number	-
α	Sloping angle	rad
λ_0	Wavelength	m
H	Height	m

α is formed by the imaginary straight line that joints the extreme points of the surface and the free surface of water [11].

VI. CAPACITIES

A. Wave flume capacities

The capacities of the 12.5 m length flume, which has the paddle for regular wave generation, have been tested experimentally. By the wavemaker theory [14], a theoretical relation between the piston movement and the generated waves has been obtained. Experimental results have been compared to the ones predicted by this theory. In general, experimental values follow the theoretical trend, with slight differences in wave height, which can be solved by increasing the stroke. The above-mentioned results are represented in Fig. 16.

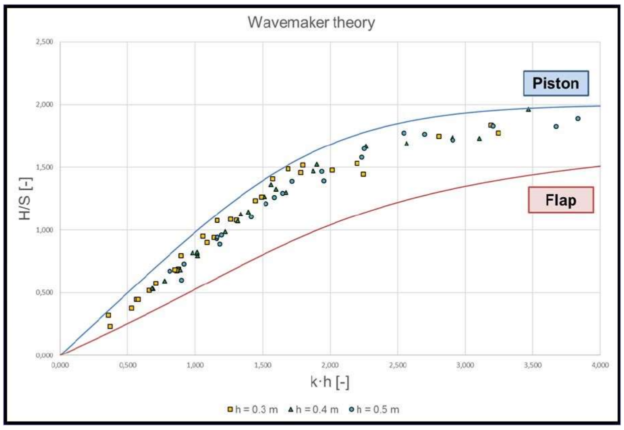


Fig. 16. Wave maker theory. Three different depths tested, h_1=0,3 m (yellow square), h_2=0,4 m (blue triangle) and h_3=0,5 m (green circle)

Therefore, the flume is able to cover the wide range in the Le Méhauté chart (see Fig 17). Waves corresponding to linear theory, Stokes' 2nd and 3rd order and Cnoidal waves have been generated [5].

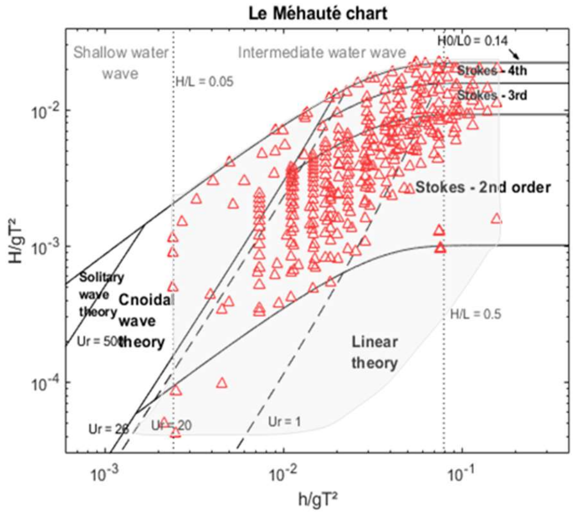


Fig. 17. Parametric footprint with Wave Flume limits in "Le Mèhautè" chart.

B. Circulating water channel capacities

The flume can also work as water channel by recirculating water to the underground storage tank, and therefore, increasing flume research versatility. Working as a water channel, the water enters the flume from the circular hole of the water inlet subset below the paddle and comes out from the water outlet subset, the square shaped hole placed under the dissipation system. This is illustrated in Fig. 18.

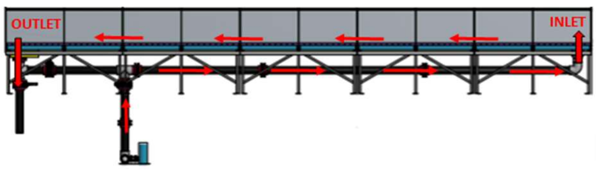


Fig. 18. Flow path scheme working as circulating water channel

VII. DATA ACQUISITION SYSTEM

In relation to the data acquisition system, we can mention wave gauge module together with resistive wave gauges; digital, low-pressure sensor that is fully conditioned and temperature compensated; and CompactRIO controller as data acquisition system (National Instruments, cRIO-9063 model) with an inputs voltage module (National Instruments-9205, C-series). The communication protocol is based on EtherCAT.

The flume is equipped with two UB500-F42-I-V15 ultrasonic sensors placed on the upper guides, approximately in the middle of flume. Their analogic outlet range is between 4 mA and 20 mA. They have the ability to supress a perturbing object, to compensate the temperature, to synchronize and to adjust the direction of the measuring. See specific characteristics in Table VII. All the test data are monitored and recorded by LabVIEW in-house developed applications (see example Fig. 19).

TABLE VII
TECHNICAL CHARACTERISTICS OF THE ULTRASONIC SENSOR

Detection range	30-500 mm
Adjustment range	50-500 mm
Blind area	0-30 mm
Standard	100 mm x 100 mm
Transducer frequency	Aprox. 390 kHz
Answer delay	Aprox. 50 ms

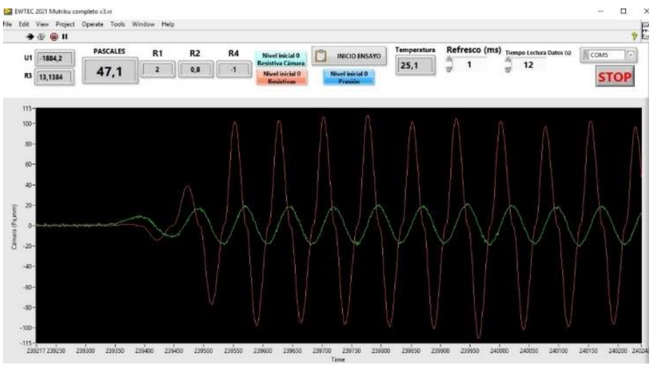


Fig. 19. OWC chamber experiment monitoring by LabVIEW application.

A core of the PC processor is exclusively dedicated to the real time control of the mechanical paddle at 300 Hz. It works independently from the rest of the programs to ensure its integrity. The wave generation instructions are calculated in real time by the software and sent to the control loop at 50 Hz. The control loop makes plenty of operations in real time.

VIII. COSTS

Some of the most relevant expenses of the main components are presented in tables VIII and IX, which demonstrate the cost effective of this indoor laboratory where small scale models can be tested.

TABLE VIII
STRUCTURAL COSTS

Part	Price (€)/unit	Quantity	Total
Flume seabed L=2500	368	3	1104
Extreme metal sheet	36.27	15	544.05
Central rib	42.85	10	428.5
Right rib	40.55	10	405.5
Left rib	40.55	10	405.5
Seabed with square shaped hole	379.5	1	379.5
Seabed with circular hole	379.5	1	379.5
Lower structure	430	5	2150
Seabed frame	84.55	1	84.55
Toughtened Lami glass of 5	209.8	8	1678.4

For the hydraulic system, the costs of the pipes, the accessories, the joints and bolts and the pumps must be considered. The total price of accessories, pipes and joints and bolts ascends to 1675 € and the cost of the three pumps ascends to 1070 €.

TABLE IX
COSTS OF THE DRIVING SYSTEM

Article	Quantity	Price (€)/Unit
KM60-0600-10-NA-P10-JKA linear actuator	1	1387
KMST-60 pair of fixings	1	102
SD-A2-0721-M servodriver	1	461
ECMA-C20807RS servomotor	1	295
5 m motor cable set	1	99
ASD-IF-SC5020 inlet/outlet connector	1	37
USB programming cable, UC-PRG015-02A 1.5 m	1	13

As for the new 25 m channel a new paddle and software have been bought, Table X contains the cost of these expenses.

The price includes the design, manufacturing, installation, implementation, training and documentation for the operation and maintenance of the system.

TABLE X
COSTS OF THE DRIVING SYSTEM

Concept	Price/Unit
Awasys wave generation program for piston-type wave generator paddle with active reflected wave absorption system	18 900 €
Piston type paddle with servo	26 550 €
Taxes (21%)	9 721 €
TOTAL (taxes included)	**54 994.5 €**

IX. CONCLUSIONS

To sum up, this technical recommendation provides to any research group with useful guidelines and details necessary to construct their own domestic modular wave flume, being good value for money and unachievable otherwise. The differences between the presented two flume lengths and characteristics are remarkable, being so obvious that the improvements of the 25 m flume will bring benefits such as a very substantial increase in test time, due to the higher length; the ability to continue generating the desired swelling, due to the active absorption system, and more realistic sea-state conditions for more accurate results, due to the irregular wave generation function.

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