Proceedings of the 9th International Conference on Physical Modelling in Coastal Engineering (Coastlab24)

Delft, Netherlands, May 13-16, 2024

CONFERENCE PAPER, DOI: 10.59490/coastlab.2024.678

NOVEL REAL-TIME DATA ACQUISITION SYSTEM ON HYDRODYNAMIC SIGNALS OBTAINED IN THE LABORATORY

CORRALES-GONZALEZ M.[1], GROSSO D.[2], BESIO G.[1]

1, Department of Civil, Chemical and Environmental Engineering, University of Genoa, Italy, E-mail: manuelalejandro.corralesgonzlez@edu.unige.it, giovanni.besio@unige.it

2, Department of Physics, University of Genoa, Italy, E-mail: daniele.grosso@unige.it

ABSTRACT

Understanding marine dynamics, particularly in coastal areas with high wave activity, cannot be achieved without physical modeling. However, when it comes to downscaled physical wave modeling, accurately recording wave data becomes a challenge, especially near coastlines where disturbances are common. Traditional water surface measurement tools, such as invasive wave probes, have proven to be both inaccurate and impractical. To overcome these limitations, this study presents a new data acquisition system (DAQ) utilizing resistive sensors and wireless transmission protocols to enhance the accuracy of wave measurements in laboratory-scale experiments.

The data acquisition technology effectively measures water surface electric potential by utilizing specialized resistive probes. Additionally, the DAQ is equipped with an automatic calibration system using a vertical potentiometer, providing a cutting-edge solution to calibrate the invasive wave probes usually employed in several types of hydraulic physical modeling. The recorded data is efficiently handled by Arduino® board controllers, allowing for convenient wireless transmission for laboratory usage. This exceptional system surpasses traditional methods, offering a combination of versatility, cost-efficiency, and enhanced accuracy in capturing wave characteristics. In addition to describing the development of controllers and data processing algorithms, this study highlights their seamless integration into a unified solution for superior wave data collection.

KEYWORDS: Wave data acquisition, sensor array, telemetry, environmental data sampling

1 INTRODUCTION

Physical modeling is required to reproduce physical processes when numerical or mathematic tools are not able to solve them. Marine dynamics are measured by a vast amount of instruments allowing the study of the wave, currents, tides, which represent a proper input data for model validating and ocean characterization (Lira-Loarca A.M., 2019). However, marine records particularly the wave records, sometimes are not possible to get them given the tempestuous conditions and the limited availability of measuring instrument installations in certain marine regions.

Due to the above mentioned the downscaled physical wave modeling results an ideal tool to develop engineering studies on coastal and marine environments. In this regard, scaling or similarity laws are used to adjust a physical phenomenon on a real scale to a reduced scale by adapting the physical quantities involved to the prototype (Hughes S.A., 1993). Nonetheless, this size adjustment in the physical models carries some distortion effects that cannot reproduce perfectly the protype event through the scaled physical models (Heller V., 2011).

Wave can be defined as a superposition of waves with different characteristics such as heights, lengths, and wave periods (Holthuijsen L.H., 2010). Wave records in the downsized physical models require an adaptation of the sample frequency to logging the shorter waves. The wave recording in a physical experiment is furthermore conditioned by the instrumental capabilities of the device used to record either the variation of the free surface, the velocity potential or another physical-chemical parameter of the water. In particular, the physical modeling in coastal and marine engineering is performed on the basis of the marine, coastal and/or water-structure interaction processes.

As waves approach the coasts, wave transformation processes cause the waves to flatten out and change direction, making them less regular than those found in deep water (Goda Y., 2000), thus an important energetic content is transmitted throughout the range of wave frequencies. The quality of the recorded signal is therefore of high importance for the study of the entire wave band (Padilla, E. M., and Alsina, J. M., 2020).

The sampling frequency of sea surface measurement instruments should adequately capture the free water surface variation. Moreover, near the coasts and in the presence of obstacles, waves are disturbed, producing turbulence and aeration, which makes the records more inaccurate (Gualtieri, C. and Chanson, H., 2021).

This sampling frequency is of high relevance in laboratory scale experiments which is determined by the type of experiment as indicated by the similarity theory. As indicated by Longo S.G. (2022) , the theory of similarity provides the necessary support to design models and to extrapolate in full scale the measures taken and the results obtained.

In flow modeling the model and the prototype are linked through the Froude model criterion, wherein the inertial forces are balanced mainly by the gravitational forces (Hughes S.A., 1993). Once the downscaled model is created, the instrumentation to record changes in the variables involved in the study must be adapted in sampling frequency and accuracy.

Nowadays, a wide variety of water surface variation measurement instruments are employed, such as pressure gauges, electromagnetic, ultrasonic, and light and ranging detection methods (Rak G. et.al., 2023). The most employed water surface variation logging instruments in laboratory given their practicality and lower cost, corresponds to the invasive (i.e., in contact with the water) logging the electrical potential differential between two metal wires immersed in water, commonly called wave probes. However, these instruments have being substituted by non-invasive data acquisition systems owing to technological advances in recent years (Baker C.M, et.al., 2023).

In this study we introduce a novel remote system for the wireless transmission of data acquired from water surface level gauges, which offers versatility and makes the laboratory work more practical, at a substantially low cost.

The data acquisition system (DAQ) allows to capture the electric potential differential at the water surface by means of probes that record it, and subsequently an automated calibration is carried out by means of the implementation of a vertical potentiometer. This vertical potentiometer system introduces the novel technique of sensor calibration by setting an automated calibration function. In addition, the logged data by the probes are processed by Arduino® board controllers (Ismailov, A.S. and Jo‘Rayev, Z.B., 2022) that consider wireless data transfer, which provides practicality in laboratory work. Both the controllers and the processing of the recorded data were developed by ourselves and are described in detail below.

2 THE IMPLEMENTED DATA LOGGING SYSTEM

Since one of the common approaches in the recording of the free surface variation of water in laboratory experiments is the use of resistive probes, it was decided to optimise this form of recording acquisition. In first instance, the electrical circuit governing the logging system has been designed to obtain the electrical potential differential records, such as the common wave probes used in several wave flumes and basins are, this is by means of two metallic wires in contact with water which measure the voltage differential between them in a way to prevent ion shielding.

A set of Single-Board microcontrollers with a buffer circuit have been developed and designed as probes drivers which consider wireless data transmission. After program the controller board it was possible to define the recording frequency of the vertical position of the free water surface, which can be set from low frequencies, e.g. 0.5 Hz, up to values of 200 Hz. The voltage signals received by the wave probes drivers are firstly processed through an automated calibration (see section 2.1.) allowing to obtain the calibration function for transforming the voltage to vertical distance units.

Henceforth, the real-time recorded data is sent from the gauges to the Wi-Fi router connected to the laboratory network. Each probe drive contents an element identified by a specific Internet Protocol address (IPv4) which is numbered following the wave probes order employed in laboratory, the acquired data from the probes are then sent in binary form to the router.

The broadband of the router as well as the maximum information stream on the receiving computer define the number of wave probes that can be employed, i.e. the stream digital signal in bits per second coming simultaneously from the set of the *n* probes must be captured by the bandwidth of the repeater. The router then redirects the digital signals to a User Datagram Protocol (UDP), and Transmission Control Protocol (TCP) (Malhotra, A. et.al., 2010) on the computer that receive and manage the probe signals independently. In this implementation such management on the receiving computer is particularly performed through the LabVIEW® software (National Instruments, 2022).

In our DAQ, given the requirements on the water free surface recording at different locations along the wave flume, it has been found that the signal from 200 probes can be sent to the repeater (100 Mbit per second), however it has been foreseen to work with a set of 12 probes along the 35 metre long canal. A schematic description is shown in Figure 1.

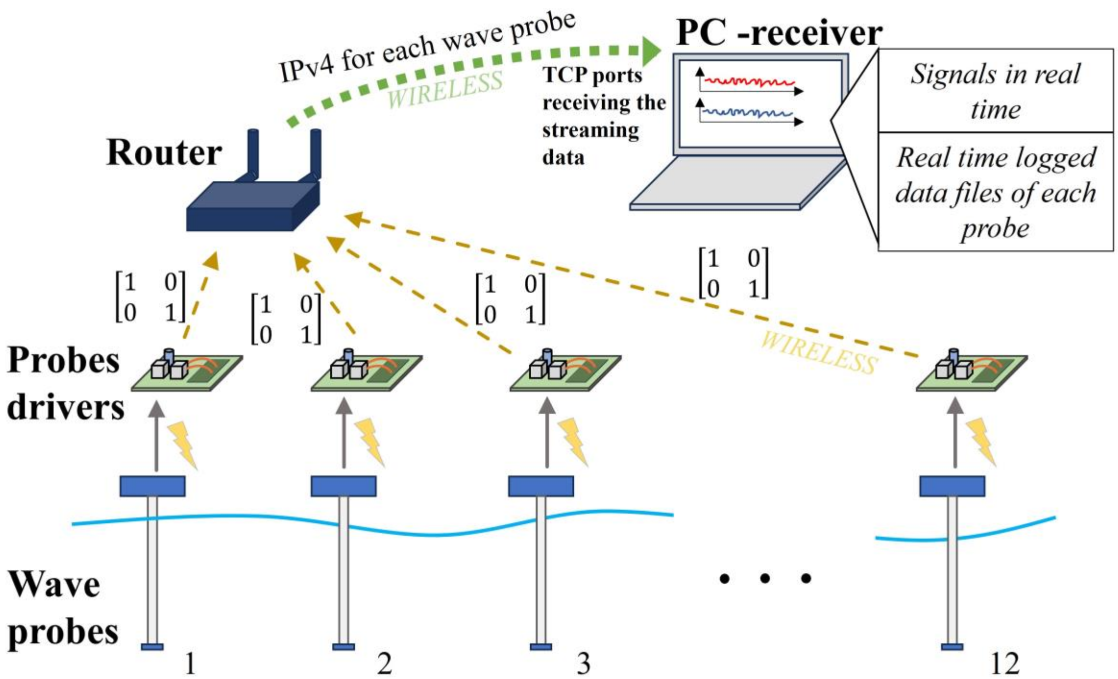

Figure 1. Schematic diagram of the wave probes data acquisition system.

An output file collect the stream logged data for each wave probe independently for every experiment. Each output file contains the date and time, the log in both voltage and millimeters, and the calibration function used with its associated uncertainty. One of the advantages of data saving is that a binary file format was used which is designed for easy interchangeability, is structured, and is capable of high-speed-streaming data saving (National Instruments, 2023).

However, it is required to consider a balance between the sampling rate and the size of the output files, i.e. to define a sampling rate that captures the shorter period waves without losing information of interest but without capturing records that may provide uncertainty such as capillarity effects in the probes, and that would be filtered out in post-processing. Moreover, the stream records are shown up on the computer screen at the records acquisition frequency for the probes selected by the user.

2.1 Automated wave probe calibration

The wave probes are mounted on an automated vertical actuator which allows the probe to move vertically in an automatic and programmed way. The actuator consists of a electrical motor propelled DC rotor which allows to lift or lower the wave probes along the actuator vertical length, as shown in Figure 2.

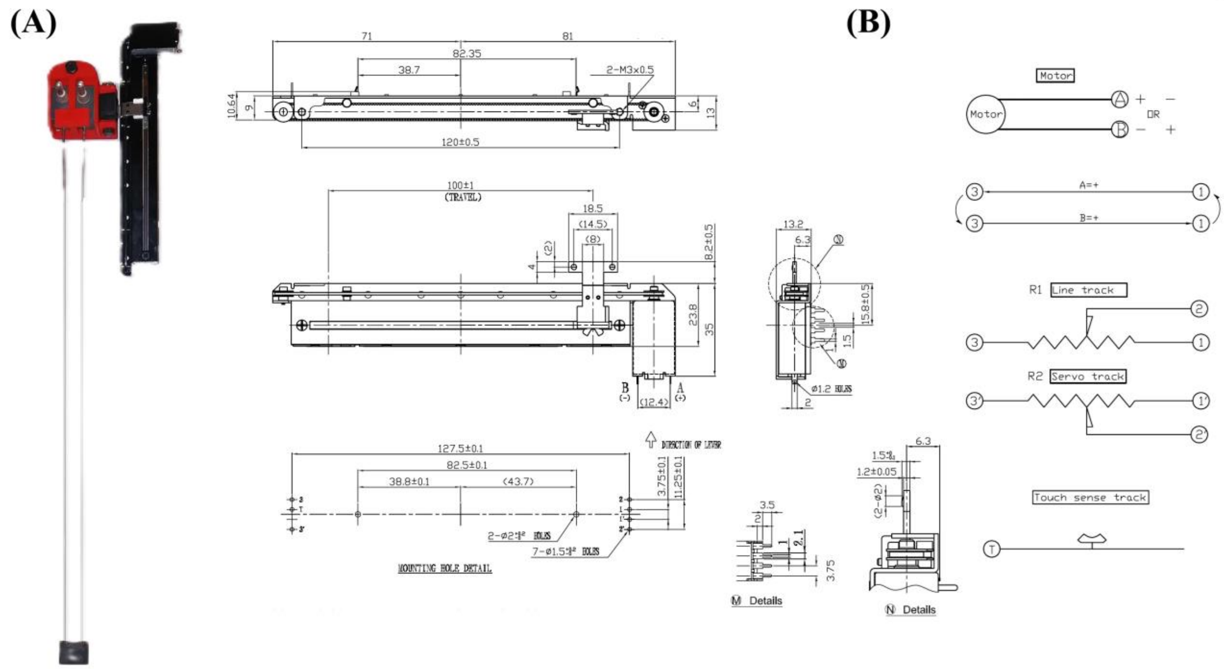

Figure 2. Wave gauge calibration: (A) Wave prober and potentiometer. (B) Electric potentiometer, scheme source: Top Up Industry Corporation (2023)

The wave probe is lifted and lowered at two locations equally space from the experiment logging position wherein the calm water surface is recorded during a period ensuring a uniform record centered in a mean value, given the higher accuracy the records might carried.

The stroke of the vertical displacement of the sensor is previously known. The calibration process is given with the vertical displacement of the probe sinusoidally under calm water conditions. The sensor is raised and lowered from a previously known stroke or distance over a period that provides confidence in the uncertainty statistics of the recordings. Therefore, a sinusoidal voltage signal $A \sin(\omega t)$ is recorded which is interpolated to a function of the same form that transforms the result to units of distance. The actuator system is controlled by the driver board which commands the acquisition of data from the probe, and which is activated through the graphical interface also produced in this study and described below.

The accuracy of the signal depends on several factors in the experiment, amongst them the frequency of the recordings, which can pick up noise that is later estimated as uncertainty associated with the recording. This type of calibration is different from the commonly used way which corresponds to the set of measurements in at least two different vertical positions and then transforming the voltage signal to its corresponding distance by means of a linear regression. This form of calibration therefore does not consider the correct recording of the water along the probe body, where there is a possibility that the measurements are altered by deterioration of the wave probe material.

Among of the benefits of this data acquisition system is its low production cost. Electronic materials such as cables, controller boards adapted for Wi-Fi transmission, soldering, as well as brackets for fixing the system mainly made of 3D printing (PLA), wood, and small format screws, fasteners and washers are insignificant compared to the data acquisition systems offered by companies specialised in this task. Table 1 presents the total cost of materials employed in the proposed data acquisition systems, i.e., for one small wave probe employed in the small wave flume experiment (see section 3), as well as the extrapolated costs for the wave flume which is still in the instrumentation phase.

Table 1. Material costs of producing the wave probes.

Item	Experiment presented in section 3 (€/wave probe)	Future wave flume (€/wave probe)	Future wave flume, 12 probes (€)
Wave gauges	15.5	30	360
Cables, soldering, screws	7.6	18.8	225.6
Metal and wooden supports	9.7	14.1	169.2
Potentiometer	26.0	26.0	312.0
3D printed material	4.3	5.2 †	62.4 †
Controller boards	28.4	28.4	340.8
Total	*91.5*	*122.5*	*1470*

† Mass-based scaled costs

Other costs related to the DAQ are not tabulated above, such as the LabVIEW® software license, which was used to develop the graphical interfaces for managing and saving log signals, or the basic toolkit employed which is found in most laboratories in hydraulic research and university engineering departments.

This system has been developed and currently been tested with simple random waves at Physics Department (DIFI) of the University of Genoa and a probe array will soon be tested under cnoidal, regular, irregular waves based on density energy spectra and solitary waves at DICCA where the probes will be put in production. The major advantage of this system is that it is inexpensive to set up a logging system of several logging sensors without the need to have them connected to each other by any cables thus lightening their management. The new wave flume of the Department of Civil, Chemical and Environmental Engineering (DICCA) of the University of Genoa will employ this optimized data acquisition system as one of the available facilities thanks to the collaborative effort between DICCA and DIFI focused now in to reducing the number of components of the system and increase scalability and efficiency of the system while taking into account portability and keeping the costs as low as possible.

3 RANDOM WAVES TESTING

A series of random wave trains have been performed at the didactic wave flume at DICCA. This flume is 1.37 m long, 0.335 m wide and 0.35 m height (see Figure 3), wherein the random waves can be generated by a by a manual pushing mechanism of the water column which has a rotating hinge at the top of the channel. As we are focused on the data logging and the goodness in the logged data transmissions, the incoming waves features arriving at the wave probes could not be precisely generated by a theoretic wave energy density spectrum or on the basis of some other wave theory.

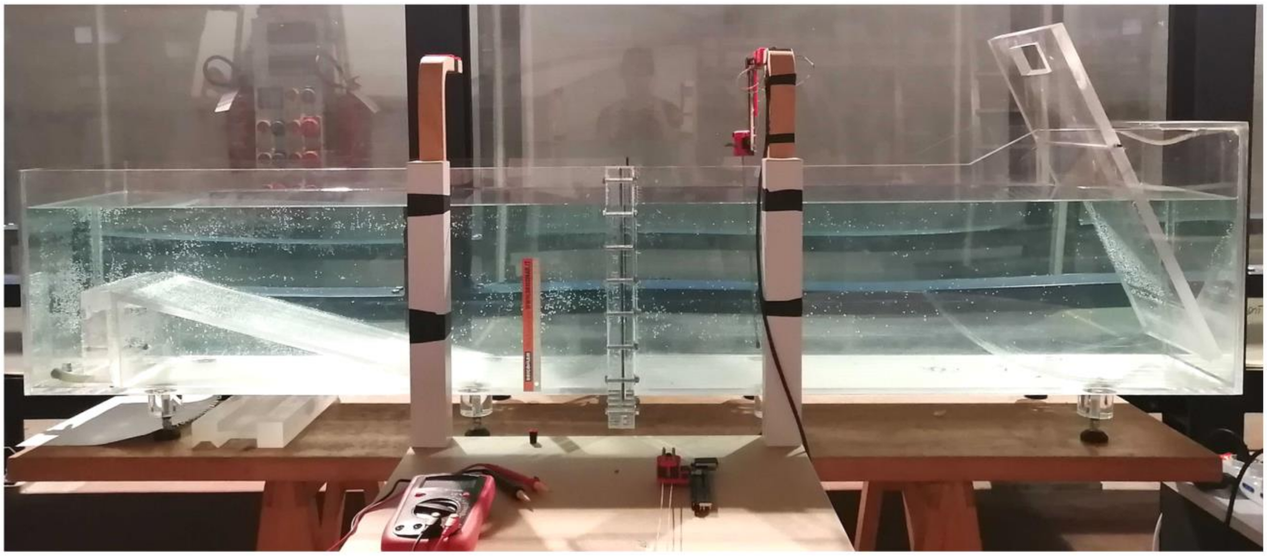

Figure 3. Wave flume and wave probe in the experiment.

One wave probe has been constructed, allowing to measure at high time resolution, i.e. in the order of 100 to 5000 Hz, and considering that the total operating length of the probes is 300 mm, this distance can be translated into a number of 1024 bits recorded by the controller board. Therefore, the logging resolution is decreased if the probe lengths are larger, as in the higher dimensional scale models. In the experiment carried out a recording frequency of 200 Hz has been selected and the vertical resolution in the wave probe was of 3.41 bit per mm, indicating that the Arduino microcontroller employed (Arduino Uno R4 Wi-Fi) was able to manage the logged data.

Figure 4 presents both graphical interfaces used in the management and control of the flow of probe records. It is possible to verify that the digitized records sent at a high frequency, and which in turn are displayed on the interface panels on the right, allowing to control an adequate acquisition of the records, although there is a slight delay in the order of milliseconds from the time the record is taken with the probe to the time it is displayed and saved in the output file by probe.

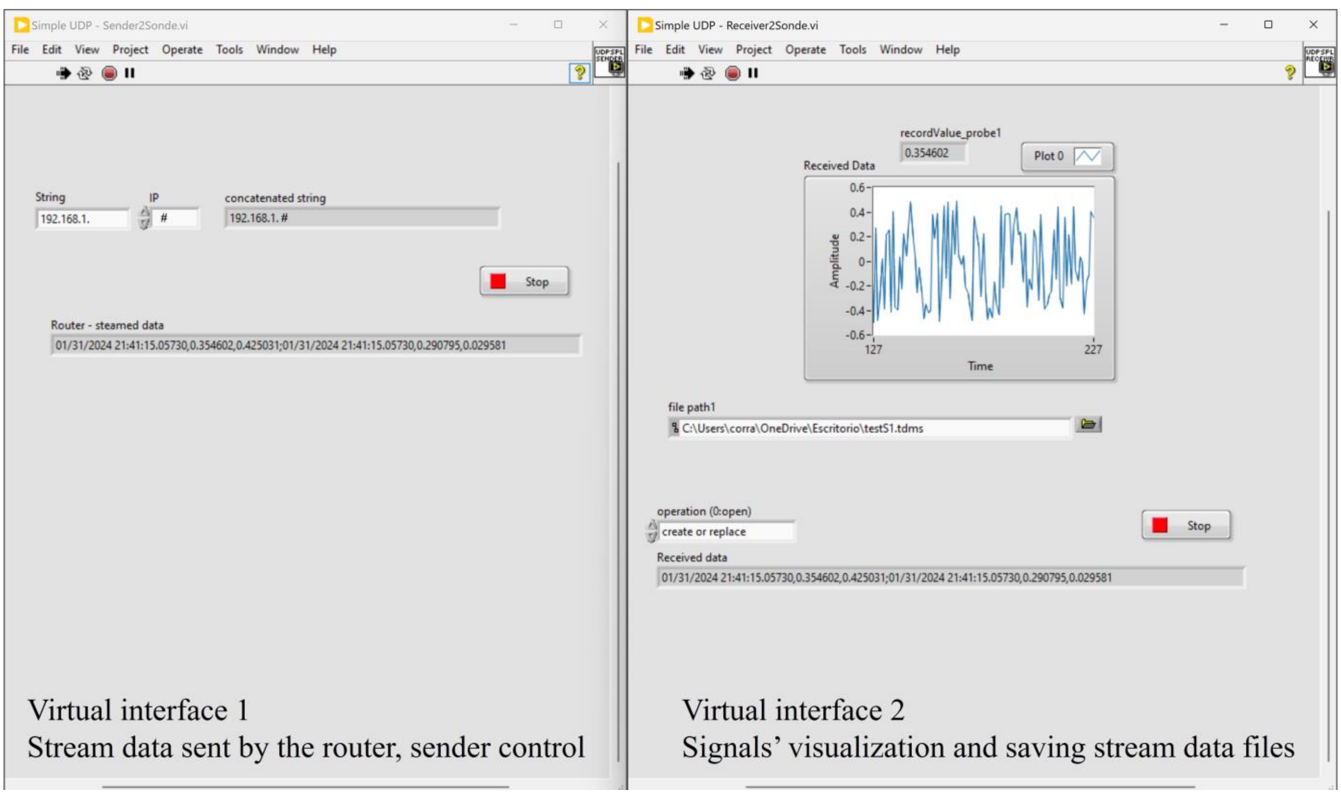

Figure 4. Wave probes signals acquired in the experiment.

4 CONCLUSIONS

An optimized data acquisition system has been developed, wherein its novelty resides in the autocalibration of gauges, the compactness of the single probe, the scalability of the system and the transmission of records through wireless connection. The transmission technology we used is open source and open hardware and is based on Arduino® and LabVIEW® is to manage the streamed data, save data, real-time visualization and processing. It was shown that in addition to providing practicality in laboratory work and high records accuracy, the cost of its production is considerably reduced in comparison with other systems for recording the variation of the free surface of water. The resistive probe system commonly used to record the variation of the free water surface is suitable for transmitting records via wireless communication wave probe driver - Wi-Fi router - receiving computer, due to the maximum traffic capacity limits mainly of the transmitting component (router) and the receiver ports. Furthermore, the DAQ proposed in this study is able to work in a free radius that can extend up to approximately 50 metres in distance, capturing logged data from several wave proves, which are mainly limited by the maximum information streaming rate of the repeater. This data acquisition system will soon be dimensionally extrapolated to the new wave physical modeling facility of the Department of Civil, Chemical and Environmental Engineering of the University of Genoa.

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