# EXPERIENCE IN WAVES ATTENUATOR STRUCTURES TO PROTECT MARINAS. FUNCTIONAL AND STRUCTURAL DESIGN.

JAVIER SOPELANA[1], ENRIQUE PEÑA[2], FERNANDO LÓPEZ[1],

*1 Aquática Ingeniería Civil, Spain, jsopelana@aquaticaingenieria.com, flopezmera@aquaticaingenieria.com*

*2 University of A Coruña, Spain, epena@udc.es,*

## 1.-INTRODUCTION.

Marinas and Small craft harbors used to be located in such places as estuaries, lakes, channels, rivers and harbour areas, always in swell waves in sheltered areas. However, these areas may also be affected by other types of waves, wind waves or waves generated by vessels and boats.

The concrete floating breakwater "box or cage type" is the most used typology to protect this kind of areas, due to the simplicity of construction, easy mobilization, installation, etc. A foundation based on chains anchors and concrete blocks is commonly used for this king of structures, even though solutions with piles have been recently used in the north of Spain. Several authors have studied this kind of floating structures: Brebner and Ofuya 1968, Hales 1981, Isaacson, 1982, Miller 1984, McCartney, B. 1985, Sannasiraj et al.1998, Williams et al 1998, Gesraha 2006, Cox and Beach 2007, underscoring during the last decade the works developed by Ruol and Martinelli (2007, 2008, 2013), Michailides and Loukogeorgaki (2013, 2014), Peña and Ferreras (2011, 2013, 2014).

Another kind of structures, porous permeable structures, is also commonly used in small craft harbors. The simplest porous structure may be a curtain wall breakwater (sometimes called slotted barrier or wave screen), which consists of a vertical wall extending from the water surface to some distance above the seabed. Different authors have worked on this type of structures: Wiegel 1960, Hayashi 1966, Kriebel 1992, Losada et al 1992, Kakuno and Liu 1993, Isaacson 1998, etc., until Huang et al. 2011 doing a complete review of hydraulic performance and wave loadings of slotted coastal structures. This kind of structures used to be fixed, but vertical slotted floating barrier have been studied by Sopelana et al. 2011.

In this paper, a literature review and conclusions of more than 10 years' experience in these types of structures will be presented (fixed and floating slotted barriers and box type floating breakwaters with different mooring system). The Authors have been working and developing tools and methodologies for the correct design of this structures. The experience gained combines laboratory tests, development of numerical models and experience in field instrumentation.

## 2.- EXPERIENCE DEVELOPED.

A partially submerged vertical floating barrier was design in a research and development project between 2006 – 2008, and patented in 2009. The first approach to achieve an optimum design of the floating structure was the study of a fixed porous barrier. Transmission, reflection and the wave induced force on the structure were studied using eigen function expansion method. This model was validated by comparing results with the experimental results carried out by different authors and calibrated for the case of a partially submerged slotted barrier with experimental tests were carried out at the wave flume of A Coruña University, Spain. Even nowadays, new numerical models to study wave-structure interaction that solves VARANS equations are frequently used, taking into account the computational demand, the model developed is suitable to pre-design structures.

In addition, experimental test the floating barrier (wave flume of Cantabria University, Spain) were used to compared results. The final design was built in the port of Cabo de Cruz (Galicia, Spain), and instrumented during one year in order to measure the real transmission and reflection coefficients as well as the wave induced forces on the structure.

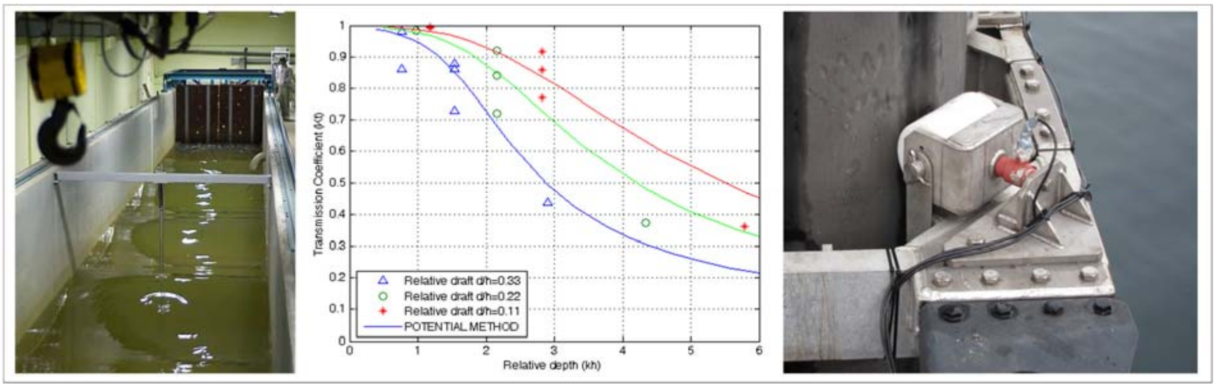


**Figure 1: Wave flume of A Coruña University(left). Model validation with laboratory test (centre), and load cell between floating barrier and pile foundation at Cabo de Cruz harbour (right).**

During 2011 and 2015, several 3D laboratory tests with floating breakwater box type were performed in the wave tank at the R+D CITEEC (Centre in Building and Civil Engineering) of the University of A Coruña. Different tests were carried out (regular and irregular waves, wave direction), and the most important parameters were analyzed: breakwater geometry (depth and width), mooring forces (chain and elastomeric system) and module connector forces.

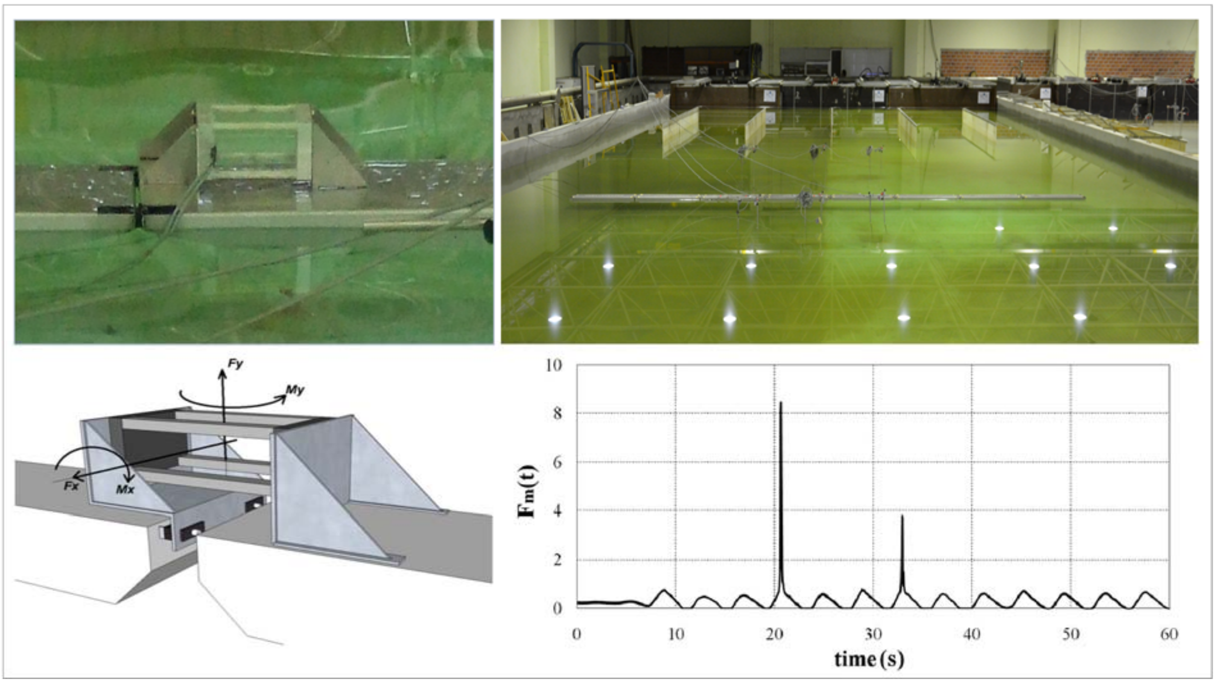


**Figure 2: Floating breakwaters analysis in the wave basin of A Coruña University (top), 3D load cell measures sketch (bottom left) and snapping force results (bottom right).**

Between 2013 and 2015, a research and development project (Center for Industrial Technological Development of the Spanish Government) was performed. Laboratory test was carried out and a new numerical tool for the functional design of floating breakwater was developed. Another project was developed to analyze the failure of Aguete floating breakwater (Galicia, Spain), and interesting results regarding the effects of swell oblique waves to the FBW connectors were concluded.

Regarding field instrumentations, in 2015, the Xufre port floating breakwater (box type) was monitored for 6 months: 2 AWACs were installed to measured incident, reflected, and transmitted waves. In addition, 2 load cells were installed in the chains in order to measure the wave induced force due to structure movements.

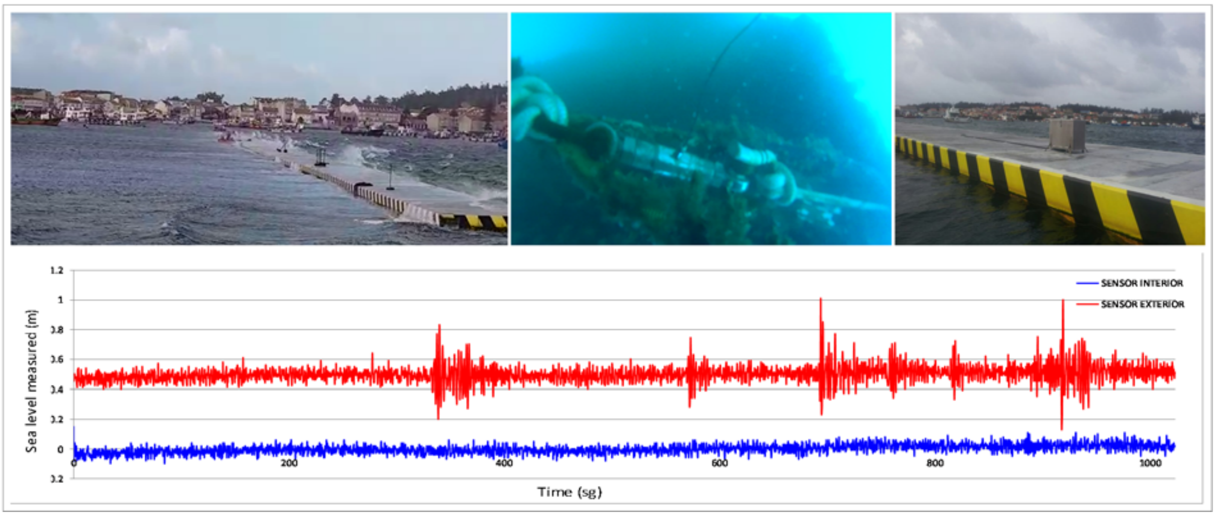


**Figure 3: Floating breakwater field campaign in Xufre port: Wind waves acting (top left), load cell installed (top center), datalogger box instrumentation (top right), and wave induced by vessel movements (bottom)**

Focus on mooring systems, piled moored breakwaters has a lack of studies mainly due to the complexity of analyzing the dynamics of the whole system: soil – pile – breakwater interaction. Last year, complex laboratory test was performed to analyze different aspects of piled floating breakwaters. The most innovative part of the study was the analysis of the rigidity of the system (soil-pile), the number of the rings and the clearance between pile and module. In addition, motions were registered with an IMU device.

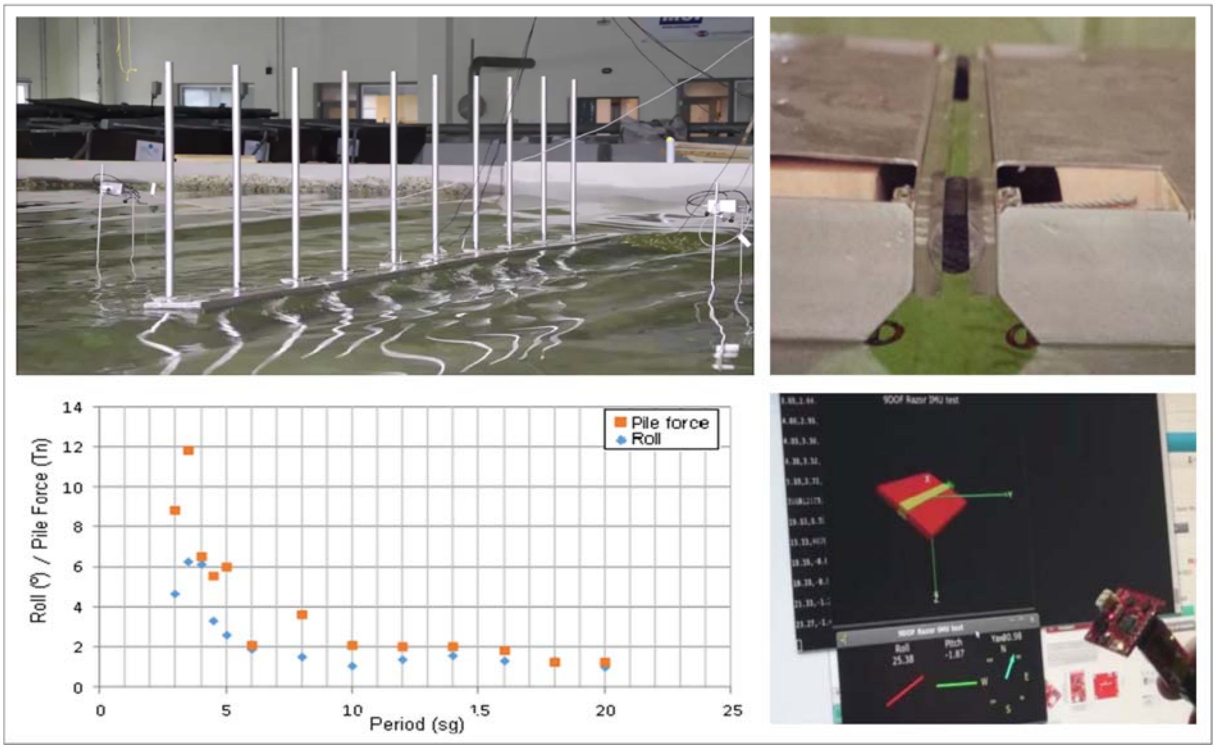


**Figure 4: Piled moored breakwaters analysis in the multidirectional wave basin (A Coruña University).**

## 3.- CONCLUSIONS

The purpose of this document is to present the whole experience and knowledge gained during last decade combining laboratory tests, numerical modeling, and field instrumentation. This experience helped us to understand the complex processes that takes place in this type of structures and contribute to the correct functional and structural design.