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STRUCTURAL BEHAVIOR OF FLOATING BREAKWATERS WITH DIFFERENT MOORING LINES. APPLICATION TO MARINA CORUÑA

Key Words: Floating Breakwater, Mooring System, Marina Coruña, Galicia, Spain

INTRODUCTION

Floating breakwaters (FBW) are marine structures used to reduce high frequency agitation within fishing and recreational harbors, already protected against long period waves by another structure, either natural or manmade. The development of a large number of new marinas and harbors around the world has led to a growing interest in the study of the structural behavior of FBW over the past two decades (Hales, 1981; Olivier, 1994; Cox, 2006). Prototype tests have been carried out and there have also been efforts to formulate the forces that appear between pontoons, both analytically and numerically, resulting in specific design programs for these marine structures.

However, physical modeling of breakwaters in current use is rare. In this study, we offer a description of a model of a floating breakwater already installed and operating at Marina Coruña (43º22´3´´N, 8º23´13´´0) as well as the dynamic results obtained by simulating both elastic and non-elastic types of mooring lines. It is innovative in the field of marine hydraulics due to the fact that 4 degrees of freedom of forces and moments were able to be recorded between two modules of a floating breakwater. These results include wave transmission and most of all, the structural response of the breakwater recorded both at the mooring lines and in between two adjacent modules.

The presented work is part of a project entrusted by the Spanish Ministry of Research and Innovation and the Program of Research, Development and Technological Innovation of Galicia (regional government), and was carried out by the Water and Environmental Engineering Group of the University of A Coruña at the R+D Centre in Building and Civil Engineering of this university (CITEEC).

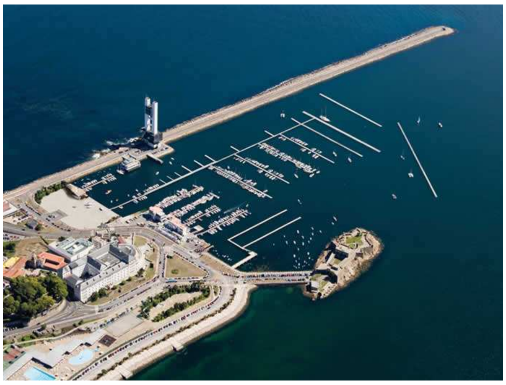


Fig. 1) Aerial view of Marina Coruña, Galicia (Spain). Source: Marina Coruña

PHYSICAL MODEL

The floating breakwater was modeled at a scale of 1:25 to the prototype as 13 hollow pontoons of stainless steel of 48x16x7.6cm^3, each filled with a foam core in order to correctly adjust its physical properties. They were connected in between them using neoprene joints and anchored to the bottom of a wave tank (1000m^2 in area, 1,10m deep) with twenty-eight mooring lines. Three different configurations of the mooring lines were tested: non-elastic mooring lines consisting of steel chain in the shape of a catenary; with and without clump weights; and elastic non-prestressed mooring lines. Aside from this, half of the chains were loosened completely in order to perform tests that would evaluate other potential situations in Marina Coruña.

Once the model was placed in the wave tank, waves were generated using the DHI Wave Synthesizer, being propagated in a direction perpendicular to the breakwater. The simulated heights range from 0.3 to 1.1m with periods from 2 to 6 seconds. Incident and transmitted wave heights were recorded using ten wave probes for the latter determination of wave transmission. Two single axial cells were placed at two mooring lines to measure their tension. A third multi axial cell was placed in between two adjacent breakwater modules to detect forces such as heave shear (Vy), sway shear (Vx), yaw moment (My) and pitch moment (Mx).

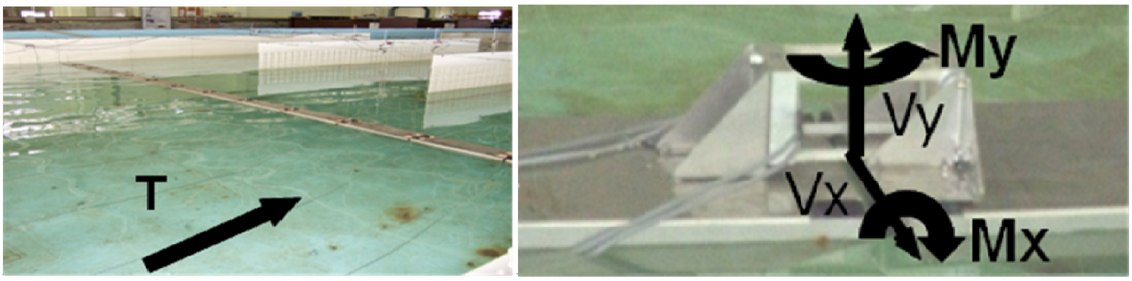


Fig. 2) Physical model of the Marina Coruña FBW and measured forces and moments

WAVE TRANSMISSION

The primary action of a FBW is to inhibit the vertical component of the orbital motion, reducing the height of the incident wave fronts to protect the harbor. In order to estimate the effectiveness of the structure in this sense, the wave transmission coefficient, C_t, is defined as the ratio of the transmitted height (H_t) to the incident one (H_i). Additionally to this parameter, the research group has labeled T_{50} as the wave period in which the transmission coefficient is equal to 0.5. The experiments have clearly shown that the transmission coefficient increases with wave period (T) and height and decreases with tide, as seen in figure 3. It has also been observed the use of clump weights and elastic mooring lines increases the wave transmission, presenting lower T_{50} than with non-elastic lines. In Marina Coruña, the best scenario for transmission efficiency of the FBW is in high tide with all non-elastic lines in the shape of a catenary. This way, all waves with periods less than 3.6s are absorbed in more than 50% by the FBW.

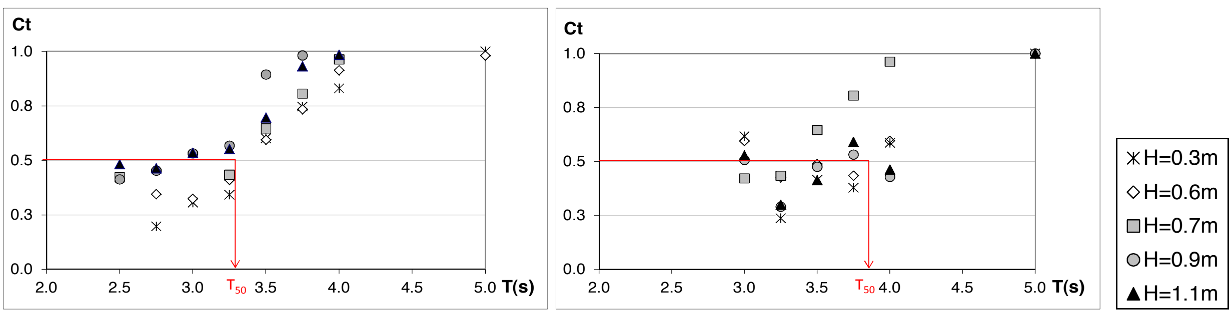


Fig. 3) Transmission coefficients in low (left) and high (right) tide with non-elastic mooring lines

STATIC FORCES

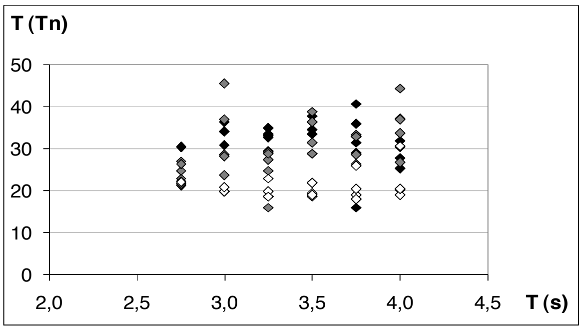
Prior to any wave generation, static forces to which the FBW is subjected to in medium tide at a steady state were recorded and plotted as seen in table 1. In the case of Marina Coruña, the tension in the mooring lines ranged from 7.5Tn when using elastic lines to 16Tn with non-elastic ones. The clump weights added to the non-elastic mooring lines would increase the tension in these in 6Tn. Of all the forces analyzed, both the sway shear (Vx) and pitch moment (Mx) are found to be negligible due to the relative position of the breakwater to the incident wave front.
Therefore, the forces and moments on which this study has focused most of its attention have been the tension at the mooring lines (T), the heave shear (Vy) and the yaw moment (My) for each of the situations tested.

	Catenary non-elastic mooring lines	Cat. Non-elastic lines with clump weights	Elastic mooring lines
T (Tn)	16.0	22.0	7.5
Vx (Tn)	0.3	0.5	0.5
Vy (Tn)	1.3	4.5	1.6

Table 1) Static forces in the FBW

TENSION IN THE MOORING LINES

The tension in the mooring lines was found to remain constant throughout different wave periods, regardless of the type of mooring lines used. Figure 4 shows how the tension at the mooring lines increases with tide (left) and the value of this force in mid tide for the three studied cases (right).
When tested with non-elastic mooring lines, the tension would increase with tide from about 20Tn in low tide to an average of 35Tn in high tide. Also, when half of the lines are loosened, the tension is redistributed among the remaining anchored lines, increasing their value to about 30Tn in medium tide and presenting a much higher dispersion in the data collected.
The use of clump weights and elastic mooring lines show less dispersion in the results of the tension at the mooring lines. This means that the force is distributed in a more evenly matter among the lines, with no peak values.
In the same way as the static forces, clump weights increase the tension in about 10Tn with respect to the non-elastic mooring lines while the elastic configuration lowers this value to about 15Tn.



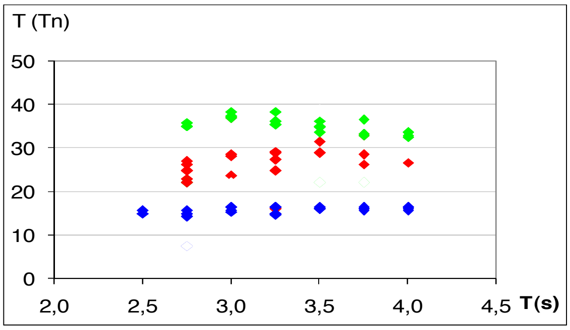


Fig. 4) Left: tensions with non-elastic mooring lines in low (white), mid (gray) and high (black) tides. Right: tensions in mid tide with non-elastic mooring lines (red), clump weights (green) and elastic mooring lines (blue)

HEAVE SHEAR BETWEEN MODULES

Contrary to the tension in the mooring lines which remains constant for all the wave periods tested, the heave shear decreases with wave period and presents much higher values. Its peak value during these tests of 60Tn is achieved for a wave period of 2.75s when the mooring lines are non-elastic and in high tide. This same value is reached in mid tide when half of the non-elastic mooring lines are loosened, being this recorded in between two modules in which the line is still fastened to them, reflecting the importance of the correct attachment of all the mooring lines.

However, this shear stress can be reduced by using clump weights or elastic mooring lines. The figure below shows that in mid tide, the heave shear peak values are no higher than 45Tn when using clump weights and do not surpass 30Tn with elastic mooring lines. In this case, these elements improve overall performance of the breakwater in terms of vertical shear.

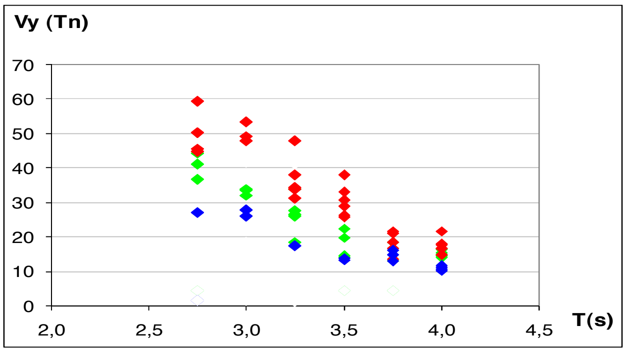


Fig. 5) Heave shear between modules at mid tide when using non-elastic mooring lines (red), clump weights (green) and elastic mooring lines (blue)

YAW MOMENT BETWEEN MODULES

In many cases, it has been seen that the joints between modules of a floating breakwater can present problems and even break. The yaw moment reflects the tension that the unions must bear in order to operate correctly.

This moment in the vertical direction presents a quite uniform response in terms of wave period, with no peak values. Also, similarly to the other forces described before, the yaw moment also increases its value with tide from 70Tn*m in low tide to 200Tn*m in high tide, with much higher values than any other force. The loosening of half of the mooring lines has found to produce no effect on the total yaw moment recorded between modules, for it is the proper mooring lines that absorb the total additional force.

Even though the addition of clump weights or using non-elastic mooring lines reduces the dispersion in the data and therefore the behavior of the FBW is more predictable, these options do not improve the overall structural response of the structure for the yaw moment duplicates its value from 100 to 200Tn*m in mid tide as seen in the next figure.

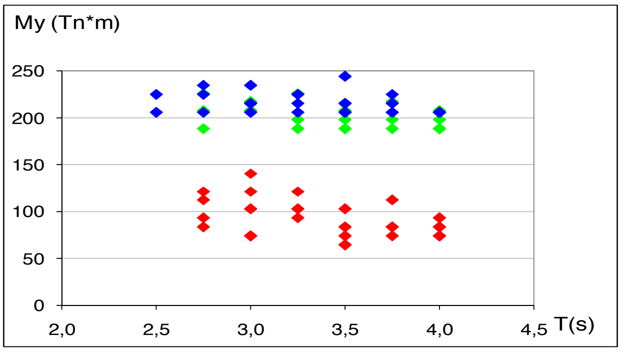


Fig. 6) Yaw moment between modules at mid tide when using non-elastic mooring lines (red), clump weights (green) and elastic mooring lines (blue)

CONCLUSIONS

This R+D project has allowed the expansion of knowledge on the behavior of floating breakwaters in general and at the same time, has served as an analysis of the situation of a particular FBW that is currently in use in Galicia.

By subjecting the FBW to three different types of mooring lines, we were able to determine the effectiveness of each of these solutions in terms of wave transmission and forces supported by the structure.

Regarding wave transmission, the FBW works best at high tide and with non-elastic mooring lines, all anchored correctly in the shape of a catenary to the sea floor. In this case, waves with periods up to 3.6s are correctly absorbed (reducing its height in at least a 50%) by the structure and the marina is protected.

As far as the forces in the structure are concerned, we first found that both the sway shear (Vx) and pitch moment (Mx) are negligible forces due to the relative position of the breakwater to the incident wave front. Nevertheless, all forces increase with tide, whichever type of mooring line is used. For example, the tension at the mooring lines reaches a peak value of 35Tn in high tide with non-elastic mooring lines.

By loosening half of the mooring lines, the most affected forces are the tension at the mooring lines and the heave shear, which both increase their value although not duplicating it with respect to the situation in which all the lines are tightened. The use of clump weights negatively effects the tension at the mooring lines by increasing its value in about 6Tn but, on the other hand, these elements help to offer a more linear and homogeneous response of the breakwater's behavior and also contribute in lowering the heave shear peak values between two modules. However, it has been seen that by using non-elastic lines, both the tension at the mooring lines and the heave shear decrease with respect to non-elastic lines as well as also offering a more linear response.

Though both of these solutions (clump weights and elastic mooring lines) seem to have their advantages, neither of them are able to decrease the fundamental yaw moment between modules and instead, nearly duplicate its value from 100 to 200Tn*m in mid tide.

Aside from this, it has also been seen that the use of elastic mooring lines shows a higher movement of the breakwater once the waves reach the structure, for these lines allow an additional longitudinal movement along them that the non-elastic lines cannot permit.

DESIGN RECOMMENDATIONS

The research group concludes that the election of a mooring system for a floating breakwater is a very complex problem with many parameters which must be taken into account. In any case, the research group recommends that floating breakwaters be equipped with an efficient system at surface level which may allow the monitoring of the tension at the mooring lines to assure that the totality of them are correctly anchored and working simultaneously to protect the marina. If this is not possible and some lines may be loose, adding clump weight to the lines will eliminate peak forces in the lines that are still tight, since they help the breakwater to have a more flexible behavior.

Lastly, it is important to state that the results obtained in this study do not apply to other elastic configurations that may be in use due to differences in length and pre-stress.

ACKNOWLEDGMENTS

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