© 3rd IAHR Europe Congress, Book of Proceedings, 2014, Porto -Portugal. ISBN xxx-xxxx-xx-x

3D HYDRAULIC STABILITY TESTS AND CONSTRUCTION OF SINGLE-LAYER CUBIPOD ARMORED BREAKWATERS AT PUNTA LANGOSTEIRA (A CORUÑA, SPAIN)

M.E. GÓMEZ-MARTÍN[1], A. CORREDOR[2], M. SANTOS[2], E. MACIÑEIRA[3] & J.R. MEDINA[4]

[1] *Universidad de Alicante, Alicante, Spain, esther.gomez@ua.es*

[2] *SATO (OHL Group), Madrid, Spain, acorred@ohl.es, mosantos@ohl.es*

[3] *Universidade da Coruña, A Coruña, Spain, emacineira@udc.es*

[4] *Universitat Politècnica de València, Valencia, Spain, jrmedina@upv.es*

Abstract

This paper describes the design process, hydraulic stability tests and construction logistics of single-layer Cubipod armored breakwaters in the Port of Punta Langosteira (A Coruña, Spain), located on the Atlantic coast of Spain. The environmental, geotechnical, economic and logistic conditions favored randomly-placed Cubipods in single-layer armoring. 3D hydraulic stability tests of single-layer Cubipod armored breakwaters proved useful to validate the final design with 15-tonne and 25-tonne Cubipod units.

Keywords: Armor Stability; Cubipod; Construction; Single-layer

1. Introduction

The 3.35 km-long primary breakwater in the Port of Punta Langosteira (new Exterior Port of A Coruña, Spain) was completed in 2011; it is a double-layer 150-tonne cube armored breakwater designed to resist Hs[m]=15 and Tp[s]=18 at water depth h[m]=40 (LWL) and tidal range Δh[m]=4.5 (see Maciñeira et al., 2009). Recently, two new parallel breakwaters have been constructed perpendicular to the shoreline in the southern area of the Port of Punta Langosteira. These new breakwaters will protect the water intake at the Sabón thermal power station. The northern breakwater is a 300 m groin and the southern breakwater is 450 m. The southern breakwater is also the first phase of the 1350 m Punta Langosteira secondary breakwater, which is necessary to complete harbor sheltering of the new port and will be completed in the coming years.

Fig. 1a shows the location of the Port of Punta Langosteira on the Atlantic coast of Spain and Fig. 1b shows a wave propagation case used to estimate harbor agitation after the construction of the primary breakwater and before the completion of the secondary breakwater; the primary breakwater modifies the waves attacking the secondary breakwater.

The roundhead of the southern breakwater is the most highly exposed area of the secondary breakwater, being H_s[m]=5.85 and T_p[s]=18 for T_R[years]=140. Waves are diffracted from the roundhead of the primary breakwater in the same direction as the two new breakwaters, which are protected with H/V=1.5 slope, double-layer 6-tonne quarrystone and single-layer 15-tonne and 25-tonne Cubipod armors. The aim of this paper is to describe design conditions, 3D hydraulic stability tests and factors influencing the construction of these two new single-layer breakwaters.

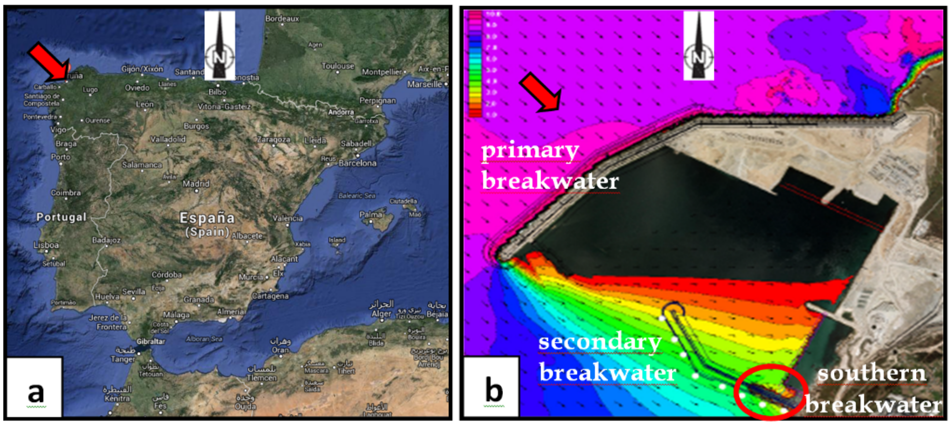

Figure 1. (a) Punta Langosteira location (A Coruña, Spain) and (b) Punta Langosteira harbor agitation after the construction of the primary breakwater.

2. Design conditions

Waves diffracted from the roundhead of the primary breakwater in the Port of Punta Langosteira are directed to the new southern breakwater and northern groin. Table 1 shows design storms for the secondary breakwater after wave propagation in the eight white points along the secondary breakwater plan (see Fig. 1b), corresponding point 3 to the roundhead of the 450 m southern breakwater, described in this paper.

Table 1. Design storms in eight different points of the secondary breakwater after the construction of the primary breakwater.

Hs [m]	point 1	point 2	**point 3**	point 4	point 5	point 6	point 7	point 8
H_s (T_R=5 YEARS)	3.21	4.31	5.09	5.00	5.05	4.51	4.05	3.26
H_s (T_R=20 YEARS)	3.49	4.67	5.52	5.42	5.47	4.87	4.37	3.52
H_s (T_R=50 YEARS)	3.65	4.85	5.73	5.62	5.67	5.04	4.53	3.66
H_s (T_R=140 YEARS)	3.75	4.96	**5.85**	5.74	5.78	5.15	4.62	3.74
H_s (T_R=500 YEARS)	3.96	5.16	6.06	5.94	5.98	5.33	4.78	3.89

Point 3 will be the most highly exposed area of the secondary breakwater. The first phase of the secondary breakwater (new southern breakwater) is situated in shallow and intermediate waters, on a sandy and rocky sea-floor, at water depths up to h[m]=8.3 (LWL) at the toe of the roundhead.

Located in partially-breaking conditions, the southern breakwater ($8.3<h_{max}[m]<13.3$) and the northern groin ($5.2<h_{max}[m]<10.2$) were originally designed with conventional H/V=2.0 and 1.75 slopes, double-layer 35-tonne and 20-tonne cube armors, which aim to withstand design storm conditions: $H_s[m]=5.85$ and $T_p[s]=18$, with water levels $0.0\leq\Delta h[m]\leq4.5$. The roots of both breakwaters are protected with a conventional H/V=1.5 slope and a double-layer 5-tonne quarrystone armor. Fig. 2a shows the location of both breakwaters which will protect the water intake at the Sabón thermal power station, and Fig. 2b shows the original design with a double-layer of concrete cubes.

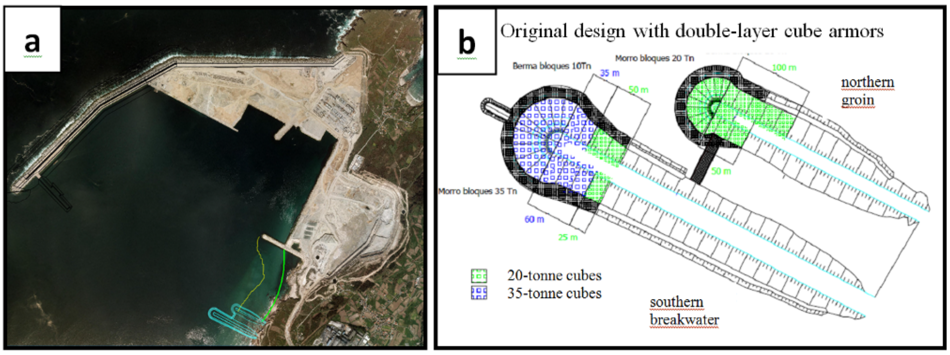

Figure 2. (a) Location of the new southern breakwater and northern groin, and (b) original design with conventional H/V=2.0 and 1.75 slopes, double-layer 35-tonne and 20-tonne cube armors.

In order to optimize the size and position of the cubes, specific 3D hydraulic stability tests (E:1/45) were conducted previously, by the Port Authority of A Coruña, in the wave basin (33.0x32.0x1.2 meters) at the Centro de Innovación Tecnológica en Edificación e Ingeniería Civil (CITEEC, Universidade da Coruña, Spain). Fig. 3 shows the 3D wave basin and 1/45-scale model with double-layer 5-tonne quarrystone and double-layer 20-tonne and 35-tonne cube armors as tested at the CITEEC.

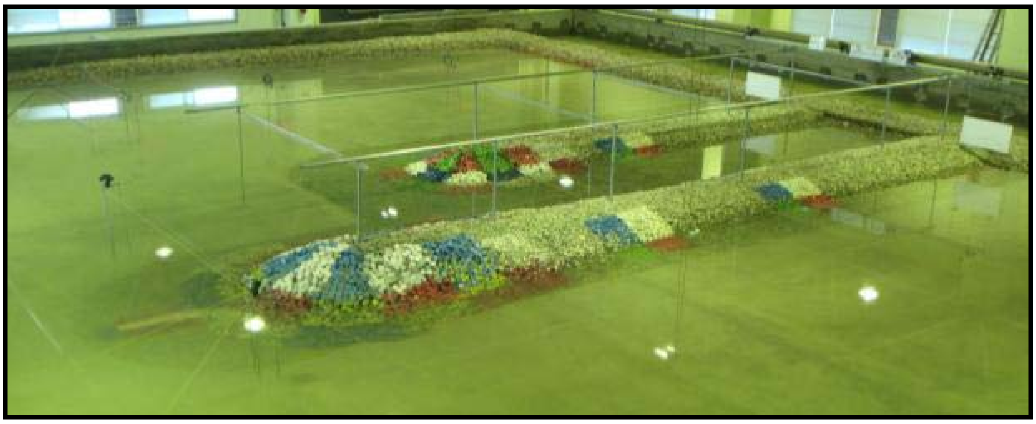

Figure 3. 3D wave basin and 1/45-scale model with double-layer 5-tonne quarrystone and double-layer 20-tonne and 35-tonne cube armors.

JONSWAP (γ=3.3) irregular wave runs of 1500 waves were generated for each wave step (Hs[m]=4.0, 5.0 and 5.8) at each water level (LWL: Δh=0.0 and HWL: Δh=4.5m) until 9000 waves attacked the double-layer 35-tonne and 20-tonne cube armors with H/V=2.0 and 1.75 slopes. The design storm (Hs[m]=5.85 and Tp[s]=18) displaced 10 cubes in the southern and northern heads and 22 cubes in the southern and northern trunks.

3. 3D hydraulic stability tests with single-layer Cubipod armors

In order to optimize the breakwaters, the original double-layer 20-tonne and 35-tonne cube armors with H/V=2.0 and 1.75 slopes were substituted by single-layer 12.1-tonne and 23.2-tonne Cubipod armors with H/V=1.5 slope. The sandy and rocky seafloor can generate some local scour problems, but not significant differential settlements. In these conditions, the H/V=1.5 slope, single-layer Cubipod armor is the most reliable and cost-efficient solution (see Corredor et al. 2013).

3D hydraulic stability tests with single-layer 23.2-tonne and 12.1-tonne Cubipod armored breakwater models were conducted at the CITEEC wave basin (33.0x32.0x1.2 meters). A 1/45-scale was used to model the design storm conditions (H_s[m]=5.85 and T_p[s]=18 for T_R[years]=140) with three water levels (Δh[m]=0.0, 2.5 and 5.0) as well as higher-than-design storm conditions. The southern breakwater was designed in partially-breaking conditions, with the roundhead toe at water depth 8.3<h[m]<13.3 while the northern groin was designed in breaking conditions with the roundhead toe at 5.2<h[m]<10.2. Fig. 4 shows the cross sections and plan view of the new design with H/V=1.5 slope, single-layer 12.1-tonne and 23.2-tonne Cubipod armors.

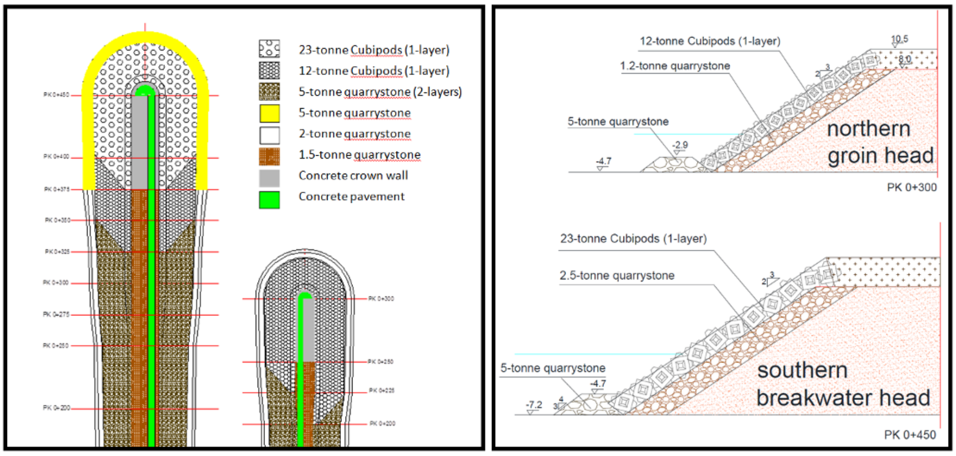

Figure 4. New design with H/V=1.5 slope, single-layer 12.1-tonne and 23.2-tonne Cubipod armors: (a) top view and (b) cross sections (roundheads).

JONSWAP (γ=3.3) irregular wave runs of 1500 waves were generated for each wave step (Hs[m]= 4.0, 5.0 and 5.8) at three water levels (LWL: Δh[m]=0.0, MWL: Δh[m]=2.5 and HWL: Δh[m]=5.0). After these 1500x(3x3)=13500 waves attacked the structures, significant wave height was increased above design storm, and an irregular wave run of 1500 waves was generated with Hs[m]=6.4, Tp[s]=18 and Δh[m]=5.0, storm conditions which correspond to

T_R[years]>500. Test conditions were progressively worsened above design storm, until Hs[m]= 7.0 and 7.6, with Δh[m]= 5.5, 6.0 and 6.5. Crest elevation was Rc[m]=+11.4 (referring to LWL); it was not possible to continue worsening the wave conditions without significantly changing the test conditions in the basin.

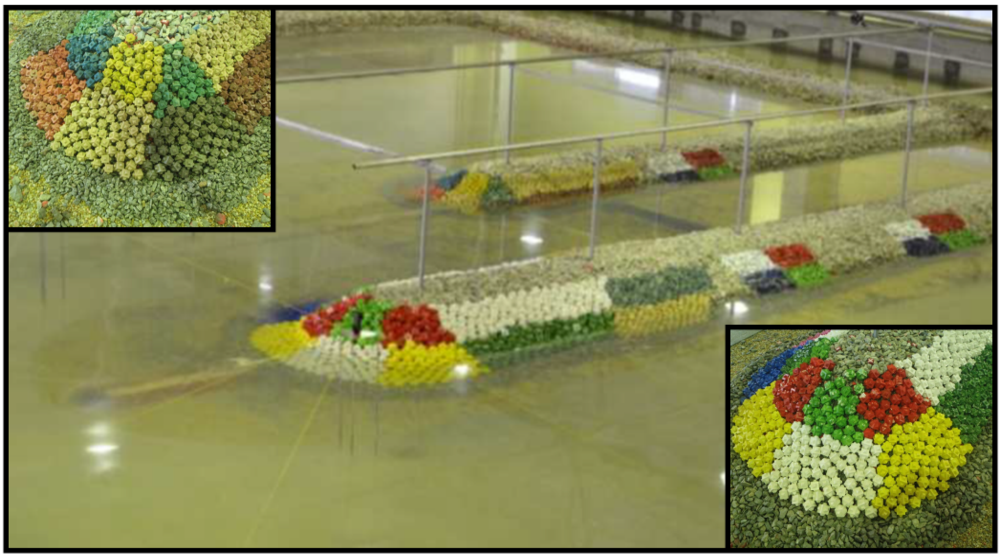

Figure 5. 3D CITEEC wave basin and 1/45-scale model with double-layer 5-tonne quarrystone and single-layer 12.1-tonne and 23.2-tonne Cubipod armors.

Fig. 5 shows the 1/45-scale models tested in the CITEEC wave basin after design storm, using a single-layer of Cubipod units equivalent to 23.2 tonnes in the southern breakwater roundhead and 12.1 tonnes in the southern breakwater trunk and northern groin head and trunk. No units were removed at the LWL (Δh[m]=0.0) and MWL (Δh[m]=2.5), and only one unit in the southern breakwater and two units in the northern groin were removed at the HWL (Δh[m]=5.0).

In order to study the resilience of the single-layer Cubipod armors, accumulated armor damage (removed units) was measured when significant wave height was increased above design storm. No significant damage was observed after the storm conditions corresponding to T_R[years]>500: H_s[m]=6.4, T_p[s]=18 and Δh[m]=5.0; only one additional unit was removed from the northern groin. The hydraulic stability was much higher than that required for the design storm conditions (T_R[years]=140); only one and three Cubipod units were removed in the southern and northern breakwaters, respectively, after (3x3+1)x1500=15000 waves above the design storm conditions (T_R[years]>500). Test conditions were progressively worsened above design storm; H_s[m]=7.0 and 7.6 and Δh[m]=5.5, 6.0 and 6.5 which caused only minor damage to the southern breakwater. The single-layer Cubipod armor showed a significant degree of resilience; when one unit was removed, the neighboring units shifted slightly to close the gap.

These tests with Cubipod units equivalent to 23.2-tonnes and 12.1-tonnes at prototype scale, validated the final design of the new breakwaters. The Cubipod weights were increased by 8% and 24% to define the final 25-tonne and 15-tonne Cubipod units used at prototype scale.

Although the 15-tonne Cubipod armor requires 7.4% more concrete than the 12-tonne armor, the cost is only slightly higher considering other logistical aspects such as the number of units to be placed on the slope and the number of frameworks necessary to produce the units. Compared to the original double-layer, H/V=2.0 and 1.75 slopes, 20-tonne and 35-tonne cube armor, tested in CITEEC up to the design storm (Hs[m]=5.85 and Tp[s]=18), the single-layer 15-tonne and 25-tonne Cubipod armor reduced concrete consumption by more than 60% and guaranteed a hydraulic stability much higher than that required for the design storm conditions.

4. Construction of single-layer Cubipod armored breakwaters

The Port of Punta Langosteira had several gantry cranes available in one of the block yards used for the primary breakwater, which was completed in 2011. The most critical aspect of the new breakwater construction was the limited time available to complete the southern breakwater. As intense storms are common in winter, the construction not only had to begin at the end of the summer of 2012 (contract award in September 2012) but it also had to be completed before the onset of the intense winter of 2012. The 450 m southern breakwater was nearly completed during the autumn of 2012, and the 350 m northern groin was completed in the summer of 2013.

4.1High production rates.

One block yard for the main breakwater at the Port of Punta Langosteira was equipped with 80-tonne gantry cranes which were used to manufacture, handle and stack Cubipod units (see Fig. 6). 1000 25-tonne and 600 15-tonne Cubipod units were required for the southern breakwater while 1000 15-tonne Cubipod units were required for the northern groin. Ten 10.6 m^3 and six 6.4 m^3 articulated vertical formworks, described by Medina et al. (2011), produced thirty 25-tonne and eighteen 15-tonne Cubipod units per day (435 m^3/day). Three mould bases per vertical formwork were employed. Three units/day per formwork were produced in 24 hour/day work cycles.

Figure 6. Block yard, gantry cranes and stacking of 15-tonne and 25-tonne Cubipod units in three levels.

The moulds were placed on both sides of an elevated one-way track, so concrete could be poured directly into the formworks (see Fig. 7). A layer of compacted gravel with excavated holes was laid to stack the first layer of Cubipod units. Gantry cranes were used to stack the prefabricated units and to move the moulds between bases. Double pressure clamps efficiently handled the Cubipod units; both 25-tonne and 15-tonne units were stacked at three levels in closed arrangement (mean porosity was approximately 30%).

Figure 7. Production line of 25-tonne Cubipod units.

At the site the temperature from October to December averaged 13.2ºC. Unreinforced concrete HM-30 (characteristic compressive strength: 30 MPa) of plastic consistency (dry mix for the lowest temperature) and without any additives, was used to produce Cubipods. In the case of the southern breakwater construction, there was not enough time (28 days) between stacking and placement on the armor slope to obtain 30 MPa (characteristic compressive strength), due to schedule requirements. Thus, some Cubipods were placed after stacking them for 15 days to obtain a minimum of 20 MPa. No unit breakage was observed during handling, stacking or placement.

4.2 Single-layer armor placement

The placement of the single-layer 25-tonne (roundhead) and 15-tonne Cubipod (trunk) armor of the southern breakwater was quickly completed, during the autumn of 2012. A 600-tonne crawler crane was used to place the 1000+600 Cubipod units following the recommended placement grids for a single-layer Cubipod armor and H/V=1.5 slope, with an armor porosity of 40%. Single and double pressure clamps and SATOGRAB recovery clamps were used to handle and place Cubipod units on the armor slope; however, the best placement rates were obtained using single pressure clamps specifically designed for each Cubipod size (10.6 m^3 and 6.4 m^3). Fig. 8 shows the 600-tonne crawler crane, equipped with single pressure clamps, handling and placing 15-tonne Cubipod units on the southern breakwater.

The armor of the southern breakwater was constructed in 24 hour/day work cycles, obtaining an average placement ratio of 80 Cubipod units per day (4 units/h). No units were broken during the handling and placement processes.

Figure 8. Single pressure clamps handling and placing Cubipod units on the armor slope.

The placement of the single-layer 15-tonne (roundhead and trunk) armor of the northern groin was completed during the summer of 2013 (2 months). A 220-tonne crawler crane, equipped with pressure clamps and working up to 24 hour/day work cycles, obtaining an average placement ratio of 80 units per day, was used to place the 1000 15-tonne Cubipod units following the placement grids for a single-layer Cubipod armor and H/V=1.5 slope, with an armor porosity of 40%. Fig. 9 shows the advanced construction of the southern breakwater (1000 25-tonne and 600 15-tonne Cubipods) and the northern groin (1000 15-tonne Cubipods) at the end of July 2013.

Figure 9. The southern breakwater and the northern groin at the end of July 2013.

5. Conclusions

The southern breakwater and the northern groin of the Port of Punta Langosteira (A Coruña, Spain) are single-layer Cubipod armored breakwaters using massive unreinforced randomly-placed concrete armor units. The sandy and rocky sea bottom favored an economically-efficient design with single-layer Cubipod armors over the conventional original design with double-layer cube armors. In order to optimize and validate the final design, 3D 1/45-scale hydraulic stability tests were carried out at the CITEEC (A Coruña, Spain). The final design with Cubipods showed no damage from higher-than-design-storm conditions (H_s[m]=6.4>5.8, T_p[s]=18 and Δh[m]=5.0>4.5) and a greater resilience to much-higher-than-design-storm conditions with the maximum water depth at the toe of the roundhead being h[m]=13.3 (HWL). The final design was a single-layer 25-tonne (head) and 15-tonne (trunk) Cubipod armor for the southern breakwater, and a single-layer 15-tonne (head and trunk) Cubipod armor for the northern groin, with H/V=1.5 slope; this design with single-layer armors and lighter units, meant relevant construction cost savings and reduced concrete consumption by more than 60%, with the consequent reduction of energy and carbon footprints.

Time was the major restriction for this project, the contract was awarded in September 2012 and the 450 m southern breakwater had to be nearly completed before the intense winter wave climate. The breakwater was finally completed in the autumn of 2012, thanks to the extensive block yard equipped with several 80-tonne gantry cranes near the construction site. Ten 10.6m^3 and six 6.4m^3 Cubipod formworks and three bases/formwork produced thirty large 25-tonne units/day and eighteen small 15-tonne units/day, working 24 hour/day cycles (3 units/day/formwork). Gantry cranes were able to move the formworks and stacked the Cubipod units in three levels. The Cubipods were placed on the southern breakwater starting in autumn and before completing the production of the 1000 large 25-tonne and 600 small 15-tonne units. As concrete compression strength was not a critical issue and due to schedule requirements some 25-tonne and 15-tonne Cubipod units were handled and placed after only 15 days of hardening time (characteristic compressive strength of 20 MPa<30 MPa), but no unit breakage was observed during the handling, stacking or placement. On average, the crawler crane placed 4 Cubipod units/hour (80 units/day). The 350 m northern groin was completed during summer 2013; 1000 15-tonne Cubipod units were required. Placement grids with armor porosity of 40% allowed for an efficient placement at prototype scale, and the natural tendency of Cubipods to be randomly placed facilitated the unit placement as designed.

Acknowledgments

The authors thank Debra Westall for revising the manuscript.

References

Corredor, A., Santos, M., Peña, E., Maciñeira, E., Gómez-Martín, M.E. and Medina, J.R. 2013. 'Designing and Constructing Cubipod Armored Breakwaters in the Ports of Malaga and Punta Langosteira (Spain).' [CD-ROM], *Proc. Coastal, Marine Structures and Breakwaters 2013*, ICE, Edinburgh, UK.

Maciñeira, E., Noya, F., and Bajo, V. 2009. 'Breakwater construction at new port in Punta Langosteira, A Coruña, Spain.' *Proc. Coastal, Marine Structures and Breakwaters 2009*, ICE, Thomas Telford Ltd., Vol 1, 532-543.

Medina, J.R., Gómez-Martín, M.E, Corredor, A., Torres, R., Miñana, J.V., Fernández, E., Menéndez, C.F. and Santos, M. 2011. 'Prototype drop tests of cube and Cubipod armor units.' *Journal of Waterway, Port, Coastal and Ocean Eng.*, ASCE, 137(2): 54-63.