Design of the Western Breakwater for the Outer Port at Punta Langosteira (A Coruña, Spain)

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ABSTRACT

This paper describes the design process and hydraulic stability tests corresponding to the Western Breakwater in the outer Port at Punta Langosteira (A Coruña, Spain). This breakwater is the second phase of the 1.35 km-long secondary breakwater; the first phase was the single-layer Cubipod armored Southern Breakwater. The Western Breakwater is protected with a single-layer 25- and 30-tonne Cubipod armor in the trunk and a double-layer 45-tonne Cubipod armor in roundhead. The design was validated withsmall-scale 3D tests of the two alignments of trunk and the roundhead. 1,360 15- and 25-tonne Cubipod units are being re-used from the Southern and Northern breakwaters, completed in 2012 and 2013, respectively. 6,670 new 25-, 30- and 45-tonne Cubipods were manufactured using 25 vertical formworks and 87 bases, in a 24 hour/day work cycle and 3.5 units/day/formwork with a 6-hour demolding time; 1,100 m^3/day of concrete was consumed and Cubipods were piled up to five levels. The construction of the Western Breakwater started in April 2015; armor is being completed before the winter season and a crown-wall is planned to be built during the summer of 2016.

INTRODUCTION

Located in the southern area of the Punta Langosteira harbor, the 0.9 km-long Western Breakwater is the second phase of the 1.35 km-long secondary breakwater, which is to shelter the harbor from western storms. The 0.45 km-long Southern Breakwater, completed in 2012, was the first phase of the secondary breakwater. Water depths at the roundheads of Southern Breakwater and Western Breakwater were h[m]=8.3 and 22.0, respectively. Construction of Western Breakwater extended from April to October 2015; the armor will be completed before the winter season and a crown-wall will be built during the next summer season. On the Atlantic coast of Spain, the most intense wave storms usually attack during winter; therefore, it was a challenge to complete the armoring of the 0.9-km long Western Breakwater in six months.

The 3.35 km-long main breakwater of this harbor was completed in 2011. Burcharth et al. (2015) described the construction of this enormous double-layer 150-tonne cube armored breakwater, designed to withstand one of the most severe wave climates in the world (design storm: NW, Hs[m]=15 and Tp[s]=18). The maximum water depths of the main and Western breakwaters are h[m]=40 and 22, respectively; tidal range is Δh[m]=5.0.

The Western Breakwater is partially sheltered from the most severe NW storms. Figure 1 shows a wave propagation case used to estimate harbor agitation after the completion of the main breakwater and before constructioning the secondary breakwater; diffraction on the main breakwater strongly affects the waves attacking the secondary breakwater. Design storms for the secondary breakwater, corresponding to start of damage and ultimate limit state (ULS) or failure, were characterized in four points along the secondary breakwater: first straight trunk, curved trunk, second straight trunk and roundhead. The Western Breakwater continued the alignment of the Southern Breakwater and sheltered the Northern Breakwater built in 2013; therefore the 15- and 25-tonne units protecting those breakwaters were re-used for the Western Breakwater.

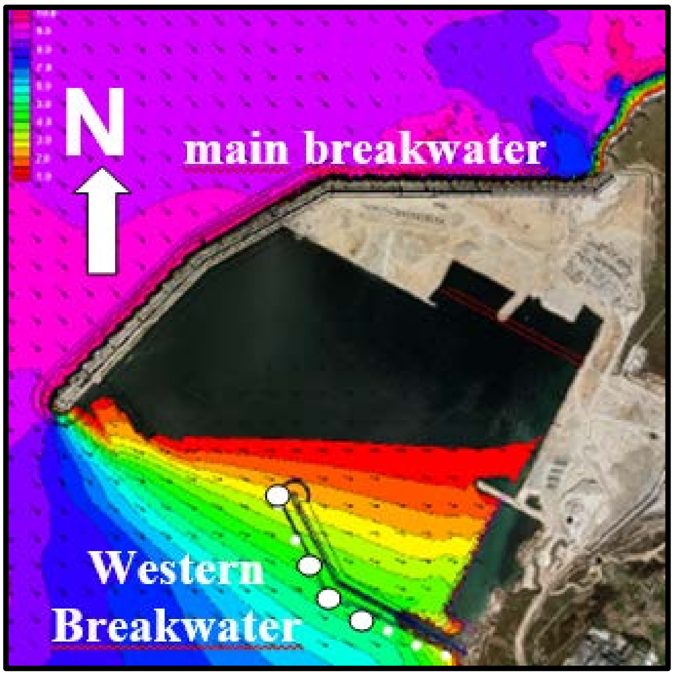

Figure 1. Wave agitation in the Punta Langosteira harbor.

A SINGLE-LAYER CUBIPOD ARMORED BREAKWATER

The first phase of the 1.35 km-long secondary breakwater was a 0.45 km-long breakwater, designed to protect the water intake of the Sabón thermal power station, which was affected by the littoral drift modified during the construction of the main breakwater; the Southern Breakwater was completed in 2012. The second phase of the secondary breakwater included re-using 15-tonne and 25-tonne Cubipods placed in the single-layer Cubipod armored breakwaters completed in 2012 and 2013 to protect the water intake of the Sabón power station (see Corredor et al., 2014), which are sheltered by the Western Breakwater. Referring to low water level (LWL), water depth ranged 0<h[m]<8.3 in the first phase, and h[m]=22 in the second phase.

The Western Breakwater (0<h[m]<22) is located in partially-breaking conditions; it was originally designed with conventional H/V=1.5 double-layer randomly-placed 25-tonne and 50-tonne cube armors. The bidding process allowed for a variety of solutions based on the use of different units for the armor, toe berm, etc. Double-layer or single-layer armoring were considered for the trunk, while only double-layer armoring was permitted for the roundhead. Small-scale 3D physical tests for the trunk and roundhead were required to validate each alternative breakwater design, which had to withstand the prescribed design storms for start of damage (1% armor damage) and ULS (10% armor damage), with return periods T_R(years)>200 and 5000, respectively. Design storms considered JONSWAP (γ=3.3) wave spectra with peak periods Tp[s]=15 and 18, with increasing significant wave height exceeding Hs(m)=6.75 and 8.75 (start of damage and ULS), and Hs(m)=5.15 and 5.85 (start of damage and ULS) to validate the armor layers of trunk and roundhead, respectively.

Before initiating the bidding process, the A Coruña Port Authority provided a conventional double-layer randomly-placed cube armored solution as a preliminary design, following a level III probabilistic approach (see Maciñeira et al., 2015) recommended by Spanish ROM 1.0-09 (2010). This preliminary design was validated with physical tests. 1/51 scale models of the trunk and roundhead were tested by GEAMA (UDC) in the CITEEC wave basin (32.0x34.0x1.2 meters) under unidirectional waves. Once the preliminary design was optimized and validated, a first basic design was available for bidders as well as the validation conditions for hydraulic stability of armor and toe berm, forces on crown-wall and overtopping along the Western Breakwater.

Alternative solutions were allowed in the bidding process, but solutions had to be validated properly following similar small-scale tests. A competitive solution should reduce the construction cost and also the risk associated to armor and toe erosion, crown-wall sliding and overtopping. Fig. 2 shows the plan view of the basic design with a conventional double-layer 25-tonne cube armor in the trunk (A, B and D) and 50-tonne cube armor in the change of alignment and roundhead (C and E).

Several alternative designs for the Western Breakwater were validated using different armor units by different contractors and bidding consortia; the winner of the bidding process was the design using Cubipod armor units presented by the consortium SATO-DRAGADOS-AriasHC-DRACE. The final breakwater design was protected with a H/V=1.5, single-layer 25- and 30-tonne Cubipod armor in the trunk and a double-layer 45-tonne Cubipod armor in the roundhead. To properly justify the final Cubipod design, a preliminary design-by-analogy was first proposed and later validated with the corresponding small-scale 3D physical tests. The trunk stability coefficients for double-layer cube and single-layer Cubipod armors are K_D=6.0 and 12.0 (see Medina et al., 2012), respectively; therefore, a single-layer 25-tonne Cubipod armor (50x6.0/12.0=25) is sufficient to protect the entire Western Breakwater except for the roundhead. This solution allows for a breakwater which withstands higher design storms and significantly reduces the concrete consumption; additionally, this solution may re-use most of the 25-tonne Cubipods placed in the Southern Breakwater, which will be sheltered by the Western Breakwater.

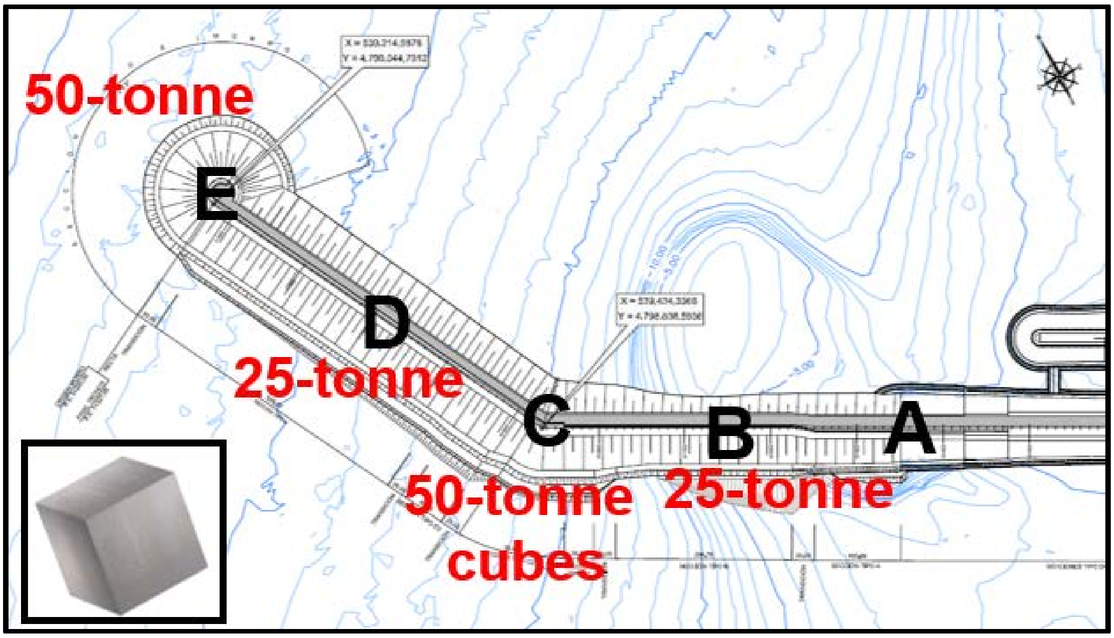

Figure 2. Plan view of the Western Breakwater (basic design using cube units).

The roundhead stability coefficients for double-layer cube and Cubipod armors are K_D=5.0 and 7.0 (see Medina et al., 2012), respectively; a double-layer 37-tonne Cubipod armor (50x6.0/12.0=25) would be sufficient to protect the roundhead. The Cubipod armored design was validated in the same facility as the basic design and also placing models with 1/51 scale; the available Cubipod models in the laboratory were equivalent to 24- and 42-tonne Cubipod units at prototype scale.

Overtopping, wave loads and hydraulic stability of armor layer and toe berm were studied during the tests. Fig. 3 shows the roundhead under wave attack, as well as the curved trunk area after wave storm characterized by H(m)=9.0 and Tp(s)=15 and 18. The trunk was finally protected by a single-layer 25-tonne Cubipod armor in sections A, B and D and by 30-tonne units in C; double-layer 45-tonne Cubipod armor was used in the roundhead.

TRANSITION FROM SINGLE TO DOUBLE LAYER ARMOR

In order to maintain a homogeneous external armor surface, a transition between single-layer and double-layer armor was designed and tested; under-layer thickness was progressively increased for a smooth internal transition compensating two very different armor thicknesses. The small under-layer rocks were placed on the large Cubipod units as shown in Fig. 4; the transition between the single- and double-layer Cubipod armor was tested for above the ULS and no damage was observed.

Figure 3. Roundhead testing, and curved trunk after wave attack Hs(m)=9.0.

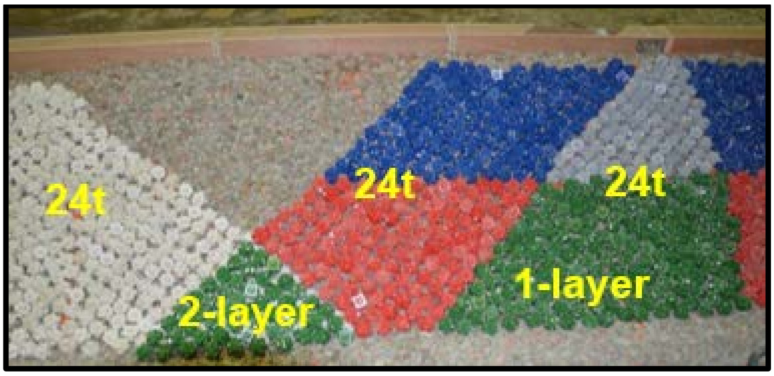

Figure 4. Transition from single-layer to double-layer Cubipod armor.

The model of the trunk (B, C and D in Figure 2) showed no damage to the armor or the toe berm for storms Hs[m]=9.2 (Tp[s]=15 and 18 with Δh[m]=0.0 and 5.0) above ULS (Hs[m]=8.75). The start of damage was observed for Hs[m]=11.1, far above the ULS.

RE-USING 15- AND 25-TONNE CUBIPOD UNITS IN THE TRUNK

The Western Breakwater continues the Southern Breakwater and shelters the Northern breakwater, protected with 15-tonne Cubipod units. 500 25-tonne Cubipod units were recovered from the Southern Breakwater and used in the armor layer of the Western Breakwater. 860 15-tonne units are being recovered from Northern and Sothern breakwaters to be used in the armor crest of the Western Breakwater; wave loads are smaller in the crest and those units allow for a reduced concrete consumption in the new breakwater. Figure 5 shows the cross sections of C (change of alignment) in

Figure 2 corresponding to the basic design (double-layer cube armor) and the final single-layer Cubipod armoring; for the final design, concrete consumption in the trunk was lower than 50% that in the basic design. Economic costs as well as carbon and energy footprints were significantly reduced.

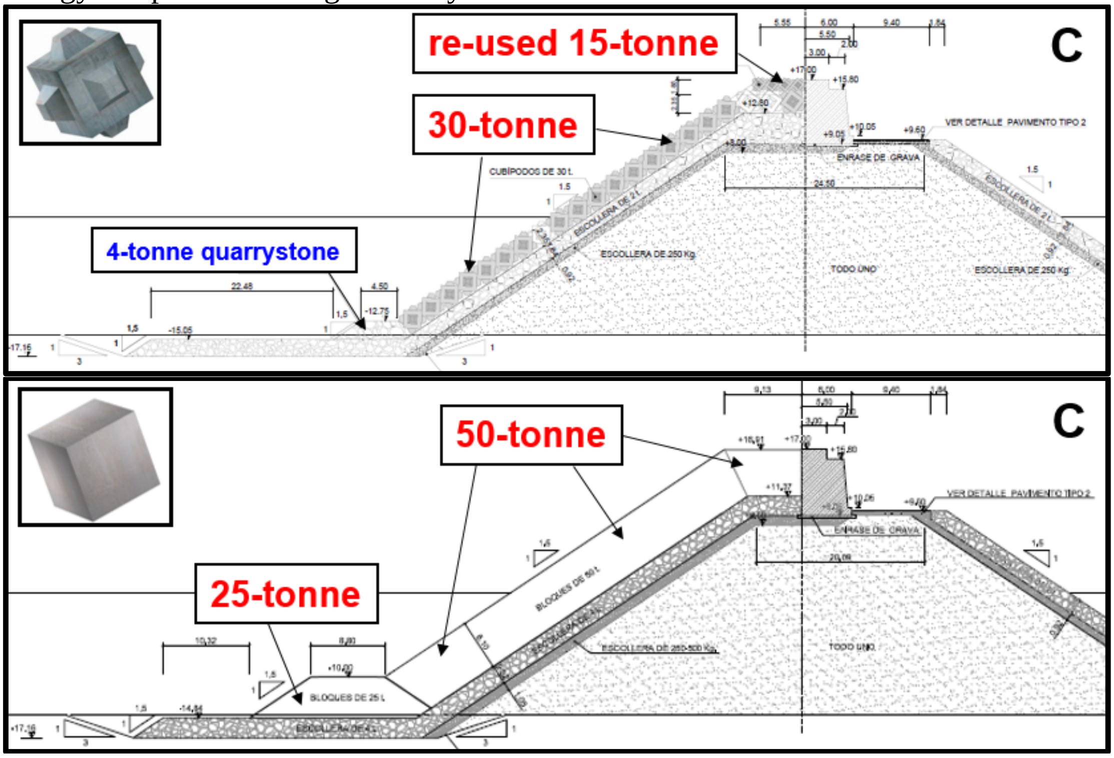

Figure 5. C-cross sections corresponding to basic design and final design.

DOUBLE-LAYER 45-TONNE CUBIPOD ARMOR IN THE ROUNDHEAD

The prototype roundhead was protected with a double-layer 45-tonne Cubipod armor. Figure 6 shows the roundhead model (D and E in Figure 2) which experienced only insignificant damage (D=0.2%) for waves above ULS (Hs[m]=5.85).

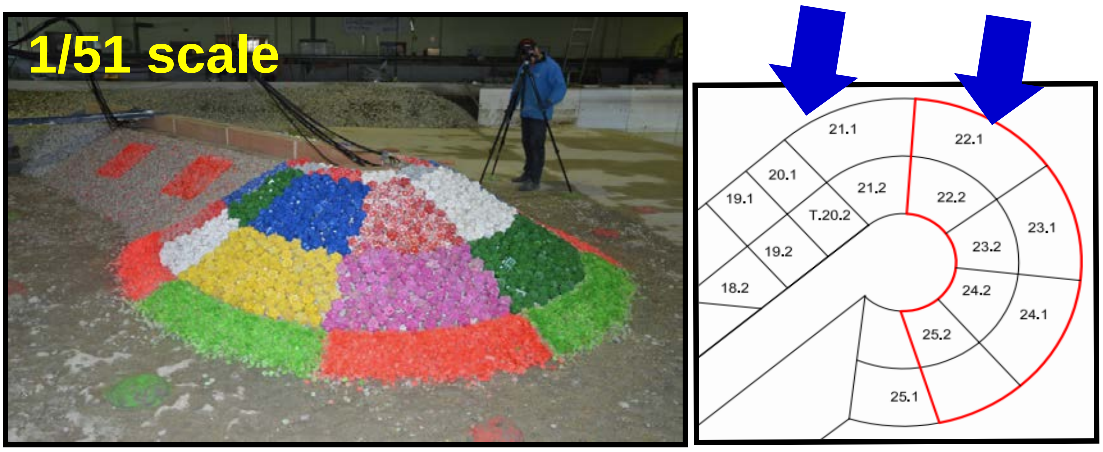

Figure 5. 3D roundhead model.

The roundhead model shown in Figure 5 was protected with units equivalent to 42-tonne Cubipods only in areas 22.1 to 25.2 which include the critical areas of the roundheads (24.1 and 24.2). Units equivalent to 24-tonne Cubipods were used in the other areas of the roundhead and did not show any damage with waves exceeding ULS.

The main objective of the validation tests was to estimate the hydraulic stability of the armor layer and toe berm of the trunk and roundhead models, by attacking four models each (Tp[s]=15 and 18 with Δh[m]=0.0 and 5.0) with increasing significant wave heights. In addition to armor and toe berm damage, overtopping discharges and pressures on the crown-wall were measured in different points in order to verify that overtopping rates and crown-wall stability improved compared to the basic design.

CONSTRUCTION OF THE WESTERN BREAKWATER

Because of the intense wave storms during the winter season, the Western Breakwater was constructed between May and October 2015. The secondary breakwater will almost be completed before the winter season of 2015; the crown-wall, armor crest and pavements will be completed during the 2016 summer season. Figure 6 shows the plan-view of the final design; the armor layer required re-using 1,360 Cubipod units and manufacturing 6,670 new units.

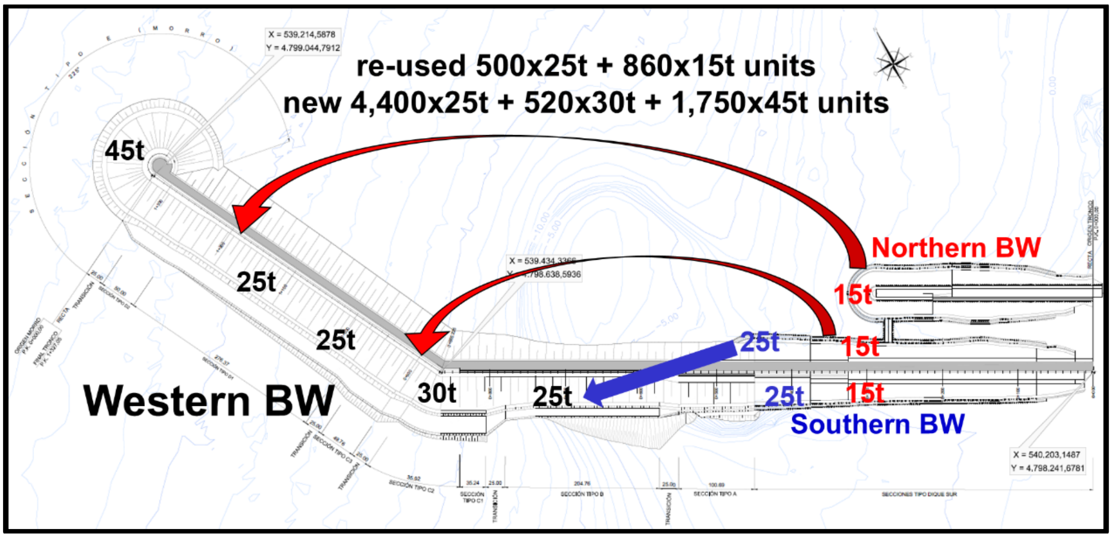

Figure 6. Plan-view of the final design under construction.

Figure 7 shows the block yard for manufacturing and stacking 25-, 30- and 45-tonne Cubipod units. 25 vertical formworks and 87 bases were placed beside an elevated track for the concrete mixer trucks which poured the concrete directly into the formworks. Six hours after vibration, vertical formworks were lifted and placed on a new base; 20 hours after vibration, Cubipod units were moved to the stacking area and the base was prepared for a new formwork. Working in 24 hour/day cycles, 1,100 m^3/day of concrete were consumed. Cubipod units were stacked up to five levels (see Figure 8) in an extensive block yard with no space restrictions.

Fourteen vertical formworks of 10.6 m^3 (25-tonne) with 49 bases were installed on the eastern side of the elevated track; five and six formworks of 12.8 m^3 (30-tonne) and 19.1 m^3 (45-tonne), respectively, were installed on the western side with 38 bases (3.5 bases/formwork). Demolding at six hours (see Figure 9) allowed for manufacturing up to 3.5 units/day/formwork.

Figure 7. Aerial view of the block yard.

Figure 8. 25-tonne Cubipods stacked in five levels in the block yard.

Figure 9. Vertical formwork moving to a new base in the block yard.

The manufacturing of 25-tonne Cubipods was begun in April 2015; one month later, the armor of the roundhead of the Southern Breakwater was dismantled, the Cubipod units recovered and the core, filter and armor layer advanced at an approximate ratio of 400 meters/month. The Western Breakwater was almost completed in October 2015; the crown-wall and armor crest will be completed during the 2016 summer season. Figure 10 shows an aerial view of the Outer Port of A Coruña at Punta Langosteira placing Cubipod units in the Western Breakwater.

Figure 10. Aerial view of the Western Breakwater under construction.

SUMMARY AND CONCLUSIONS

This paper describes the design process of the Cubipod-armored Western Breakwater at Punta Langosteira (A Coruña, Spain). This breakwater completes the 1.35 km-long secondary breakwater of the Outer Port of A Coruña at Punta Langosteira, which is necessary to shelter the new harbor. The secondary breakwater was constructed in two phases; the first phase was the 0.45 km-long Southern Breakwater built in 2012 to protect the water intake of the Sabón power station; the second phase is the 0.9 km-long Western Breakwater which is being constructed between 2015 and 2016. The secondary breakwater shelters the Northern and Southern breakwaters, armored with 15- and 25-tonne Cubipod units; 1,360 Cubipod units are being taken from these breakwaters and re-used in the armoring of the Western Breakwater with a water depth at the roundhead h[m]=22 (LWL) and a tidal range Δh[m]=5.0.

Following a Level III probabilistic approach, the A Coruña Port Authority provided a basic design with a conventional double-layer, randomly-placed cube armoring, and defined the corresponding validation physical tests and ultimate limit state (ULS) for hydraulic stability of the armor and toe berm, overtopping and crown-wall stability. Once the basic design was established, the physical validation tests and the ULS were defined, the bidding process was open for changes in the geometry of the armor units, number of layers in the armor, toe berm, armor slope, etc.; changes in the core and crest elevations, two layers of units in the roundhead and other characteristics were not allowed. Several bidding consortia and multiple validated solutions competed in cost and quality; the project was awarded to SATO-DRAGADOS-AriasHC-DRACE with the Cubipod armored solution, a single-layer 25- and 30-tonne Cubipods armored trunk and a double-layer 45-tonne armor in the roundhead. A transition single- to double-layer armor was successfully tested at 1/51 scale and has been constructed at prototype scale; the thickness of the filter layer progressively increased to maintain a homogeneous exterior surface of the armor when changing the armor thickness. 6,670 newly manufactures and 1,360 re-used Cubipod units were required for the armor layer.

Two models (trunk and roundhead) were tested at 1/51 scale by GEAMA (UDC) in the CITEEC wave basin (32.0x34.0x1.2 meters) under unidirectional waves, using a methodology and facilities similar to those used to validate the basic design. A total of eight models (trunk and roundhead, Tp[s]=15 and 18, Δh[m]=0.0 and 5.0) were tested with increasing significant wave height, from Hs[m]=4.0 to failure or facility limit. All models showed null or negligible armor damage above the prescribed ULS.

The new Cubipod units were manufactured in an extensive block yard with no space restrictions. 25 formworks and 87 bases were installed beside an elevated track for the concrete mixer trucks, which poured the concrete directly into the molds. 24 hour/day working cycles and demolding at six hours allowed for a maximum of 3.5 units/day/formwork and 1,100 m^3/day concrete consumption. Cubipod units were stacked up to five levels. The construction of the 0.9 km-long Western Breakwater was initiated in May 2015, being almost completed six months later, before the winter season. Crown-wall, armor crest and pavements will be completed in the summer of 2016.

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