2D PHYSICAL MODEL TESTS FOR THE CONSTRUCTION STAGES OF A LARGE BREAKWATER. THE CASE OF CORUÑA OUTER PORT (SPAIN)

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Abstract

The paper presents the 2D physical model tests conducted in the CEDEX Large Flume to study the Coruña Outer Port breakwater construction stages. The aims are: (A) to define temporary construction protections and (B) to determine the waves heights during construction at which work must be stopped for the workers' safety. Information about performance during construction is also included.

The breakwater, designed for Hs = 15 m and Tp = 18 s, is a 3,354 m long rubble mound structure with 40 m max. depth, builded with 150 t concrete cubic blocks on the seaward side (2:1 slope), a filter with two 15 t block layers and a layer of 1 t stone and a riprap core. The harbour side is composed of 50 t blocks (1.5:1 slope) and with 5-0.5 t stone filters. It is crowned with a parapet at 25 m.

Several construction stages were studied, involving: 1 t armour stone for core protection, one of the two layers of 150 t blocks and several layouts for the temporary crown protections, using 150 and 50 t blocks.

For temporary protections (A), the model scale was 1:28.5, Tp was 20 s with Hs increasing from 7 m up to the crown failure. For works must be stopped (B), a model scale of 1:27.5 was used, and Tp and Hs being calculated for the first overtopping.

The results show Stage 2 (Figure 1) as the best protection and first overtopping was for Tp = 21 s and Hs = 1,.5 m.

Figure 1. Stage 2. Crown failure (Hs = 11 m; Tp = 20 s)

Introduction

When designing and constructing the Coruña Outer Port, the State Public Ports Body, at the request of the Coruña Port Authority, commissioned CEDEX to conduct a series of studies, including the breakwater (Figure 3).

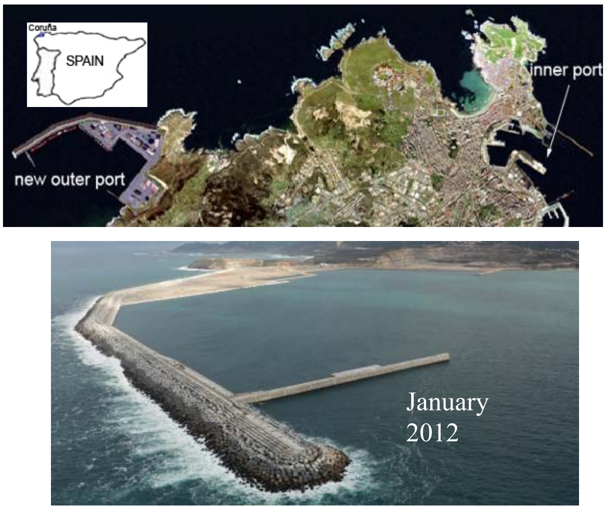


Figure 3. New Coruña Outer Port. Layout and general view.

In the case of the breakwater, these studies involved 2D and 3D physical model tests to check its behaviour. The section type stability, its singular sections (starting stretch, trunk, direction change and head), the overtopping and the different construction stages were analyzed.

This paper presents the physical model tests conducted at those construction stages, conducted for: (A) to define temporary construction protections (CEDEX, 2010), to a scale 1:28.5 and (B) to determine the waves conditions at which contruction must be stopped for the workers' safety, to a scale of 1:27.5 (CEDEX, 2009).

Breakwater Type Section

The main breakwater section type (Fig.4) comprised a seaward armor layer sloping at 2H/1V and a back layer at 1.5H/1V, being composed of 150 and 50 t blocks. It has a riprap core and three filter layers between the core and the main armor layer: 1 t quarry stone, and two 15 t blocks. The main armour layer is supported by a 3-5 t rubble mound berm at -28. m and the back armour layer by a 0.5 t rubble mound berm at -7 m, after which other 5 t are used instead of blocks.

At the breakwater top, the main armor layer crest and the parapet lie at the same elevation (+25 m), so that this element is protected from the waves.
The prototype breakwater toe was at -42 m, and the bottom in the model front was recreated using a ramp sloping at 1.5%, representative of the bathymetry.

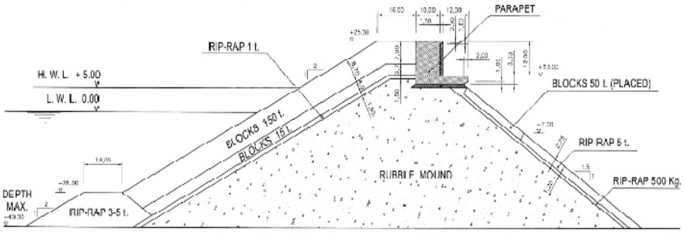


Figure 4. Breakwater. Type Section.

Breakwater Construction stages

Five construction stages were studied for temporary protections (A): 1 t core protection armour stone, one of the two layers of 150 t blocks and several layouts for the temporary crown protections -150 and 50 t blocks- (Fig. 5).

Figure 5. Temporary protections. Stages 1 to 5

The following 7 stages were reproduced for waves at which works must be stopped (B). Fig. 6 shows 1; 4 & 7.

1. Core protected by a 1 t filter layer.
2. Core protected by one 15 t filter layer, leveled at +10 m
3. Core protected by two 15 t filter layer, leveled at +10 m
4. Core protected by one 1 t filter layer with crown berm.
5. Core protected by one 150 t blok layer, leveled at +10 m
6. Core protected by two 15 t filter layer, leveled at +10 m
7. Core protected by one 150 t blok layer with crown berm.

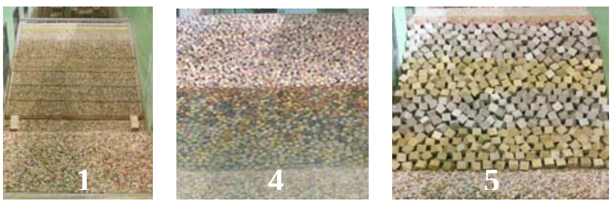


Figure 6. Waves at work must be stopped. Stages 1; 4& 7

Test waves

For (A) temporary construction protections the test were performed with Tp = 20 and Hs, increasing m by m, from 7 m up to the crown protection failure using a Jonswap spectrum (peak parameter γ = 3.3). Each storm was created using successive sea conditions: Hs increasing and four tide phases: low, mean (rising), high and mean (ebbing). The duration of each condition was set so that the number of waves generated was sufficient to ensure the section equilibrium state (610÷690).
For (B) waves at which work must be stopped, a Jonswap spectrum was also used (γ = 3.3) with Tp = 8, 10, 12, 16 y 21 s and Hs increasing from 1 m in 0,2 m steeps until reaching the "stop criterion: water must not reach to the work platform". 500 waves were reproduced at a rate Hmax = 1.9 Hs and three sea levels: 3.0; 4.0 and 5.0 m.

Test characteristics

Test Flume

The tests were conducted in the Large Flume at the CEDEX Experimental Maritime Laboratory (Fig. 7 and 8). The main characteristics of this facility are: 90 m long, 3.6 m wide and depth from 6÷4.5 m; wave generation is by a rotating paddle (dry inner surface, 22.50º max. rotation, 300 KW); regular/irregular wave generation, (max. height: 1.60 m) and active absorption reflected wave system.

Figure 7. Large waves flume. Overview

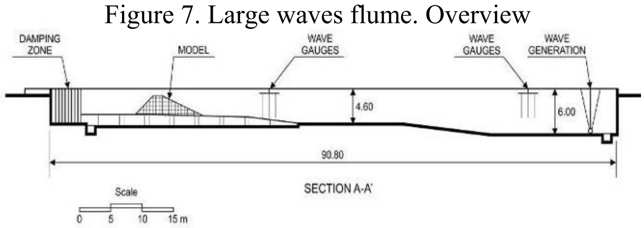


Figure 8. Large waves flume. Model layout.

Similarity law, model scale and scale effects.

As is general practice, Froude's similarity was used to a geometric scale of 1:28.5. This was chosen considering: wave generation capacity to reproduce waves proposed in the test; operating range of the flume wave gauges; model size and scale effects.
The scale effects due to the elasticity forces (Fe), surface stress (Fσ) and viscosity (Fμ) can be disregarded. In the case of Fe, the effect is negligible because water can be considered virtually incompressible. In the case of Fσ, because when the periods are greater than 0.5 s, as is habitual in maritime physical models, the wave movements

are governed by gravitational action not by surface stress forces, and for Fμ because Reynolds model number $(Re)_m$ is > $3x10^4$ for H_D > 0.09 m, so the model flow is turbulent.

$$(R_e)_m = \lambda^{-3/2} (R_e)_p \; ; \quad (\text{Re})_p = \frac{\sqrt{g \cdot H_D} \cdot l_e}{\nu} \tag{1}$$

H_D:Hs start. damage; $l_e=(P/\gamma)^{1/3}$ P: block weight; γ:density

The effects of the core permeability, defined in the breakwater design by Dmax = 100 kg and 5% maximum size D < 1kg, are also negligible, because this element was modelled with sizes somewhat larger than would occur if the geometric scale were applied [Dm = Dp/λ × K, where K = 3.4 for the small sizes, Hughes (1993)]. The grain size distribution curve used can be seen in Figure 9.

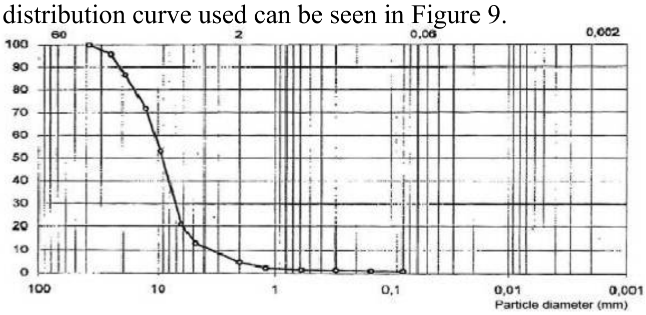


Figure 9. Core grain size distribution.

Test wave calibration.

Before the tests, waves were calibrated to create paddle movements that would make it possible to reproduce waves whose characteristics would adapt to the previously defined JONSWAP spectrum. With a view to this, a record was generated for each one of the waves and water levels whose duration was such that the number of waves was sufficient for statistical analysis, as was indicated earlier.

Characteristic of the model materials.

– Core

The specific weight of the stone is γ = 2.62 gr/cm^3.

– Blocks and quarry stones

The design prototype block density was γp = 2.4 t/m^3. To maintain the model/prototype density ratio $(\gamma a)_p/(\gamma a)_m$ = 1.025 must hold, so it was necessary to manufacture $(\gamma a)_m$ = 2.34 gr/cm^3 model blocks. Although blocks were constructed to reach that density, this was not achieved, which meant that the correction of the conservation model/prototype stability number (Ns) had to be applied (Hudson et al., 1979), to guarantee similarity between the two systems

$$(Ns)_m = (Ns)_p ; \left(\frac{H_s}{\Delta \cdot D_{n50}}\right)_m = \left(\frac{H_s}{\Delta \cdot D_{n50}}\right)_p \tag{2}$$

$D_{n50}=(P/\gamma)^{1/3}$; $\Delta = (\gamma_a/\gamma_w) - 1$; $H_{sm}/H_{sp} = 1/\lambda$

and the model elements weight is obtained by:

$$P_m = \frac{P_p}{\lambda^3} \times \frac{(\gamma_a)_m}{(\gamma_a)_p} \times \frac{\Delta_p^3}{\Delta_m^3} \; ; \quad \Delta = (\gamma/\gamma w) - 1 \tag{3}$$

This criterion was used to take samples were taken from 80 of the 150 t blocks manufactured, the average values being: weight = 6.193 gr, γ = 2.27 gr/cm3 and equivalent side le = (P/γ)1/3 = 13.97 cm, 7.7 mm greater than by applying the geometric scale [23.1 cm, (≈5%) in prototype]. The same procedure was applied to obtain the weights and sizes of the filter blocks (15 t), leading to identical percentage increases for le (≈5%). In both cases the deviation is allowable. Table 1 shows the characteristics of the model blocks manufactured.

Table 1. Model block characteristics.

Block.	Prototype			Model		
	Weight (t)	Dens. (t/m^3)	Block side (m)	Weight (gr)	Dens. (gr/cm^3)	Block side (cm)
Main layer	150	2.4	3.97	6193	2.27	13.97
Back layer	50	2.4	2.75	2064	2.27	9.68
Filter	15	2.4	1.84	620	2.27	6.48

The design density for the berm and filters quarry stone was γ ≈ 2.6 t/m3. A selection was made from the different types and sizes available at CEDEX, in such a way that sizes, adapted to the characteristics of the different layers for the 1/28.5 scale, and the equivalent weights given by the expression (1), determined the values shown in Table 2.

Table 2. Characteristics of the model quarry stone.

Quarry stone	Prototype			Model		
	Weight (t)	Dens. (t/m^3)	Equiv.side length (m)	Weight (gr)	Dens. (gr/cm^3)	Equiv.side length (cm)
Mound	3 - 5	2.6	1.15	100 – 170	2.6	3 – 4
Sea side filter	1	2.6	0.72	28 – 30	2.6	2.1 –2.4
Back armour layer	5	2.6	1.24	148 – 180	2.6	3.98 – 5
Back filter	0.5	2.6	0.57	14 – 18	2.6	1.5 – 2

Model construction.

Construction began with the core, followed by the filters: 1 t quarry stones and 2 layers of 15 t blocks manually placed, making sure that there were no smooth zones, so the main armor layer could have a coarse support (Fig. 10).

When constructing the main armour layer (150 t) a placing pattern, using coordinates, was devised with 40 % porosity, as included in the project. The co-ordinates were established with a gap of 1.50 m between the blocks in each row and in such a way that they were in contact with the ones on the row below, arranged in staggered formation.

To find out the main armor layer characteristics, porosity (p = nº blocks·block vol./armour vol.), packing density (ϕ = 1-

nº layers·k_p·(1- p); k_p = 1.05) and placing density (d = nº blocks/surface armour) were calculated. The porosity turned out to be slightly less than the 0.40 design value and the packing density slightly above 1.20, normal value for blocks placed randomly.

Figure 10. Construction phases.

Test methodology

Wave generation and measurement

The waves generated were measured to make sure they were the same as the test waves proposed. Measurements were analyzed with the Mansard-Funke method, at 50 Hz with 3 gauges to calculate Hs incident and reflected, and the GEDAP application (NRC, Canada) being used.

Stability tests. Damage criteria

For the temporary construction protection (A), the damage at each storm stage was not repaired and the following activities were performed: measuring the section incident/reflected waves, counting the elements displaced in the section zones and photographs and video at the start, during and at the end of each storm stage.

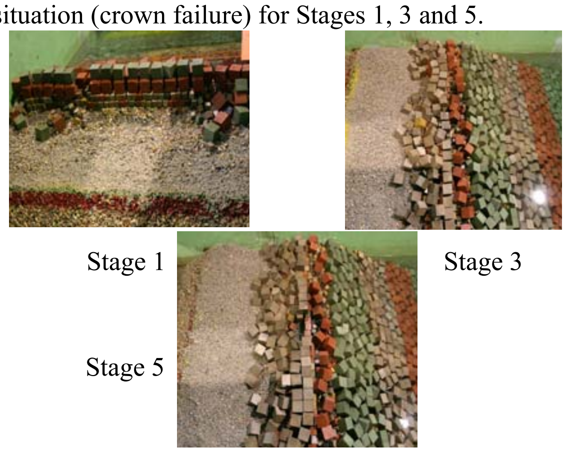
Overtopping measurements

The number of overtoppings were counted.

Test results

(A) Temporary construction protection

By way of ilustration of the behaviour of the 5 construction stages that was tested, in the Fig. 13 is shows the final situation (crown failure) for Stages 1, 3 and 5.



Stage 1

Stage 3

Stage 5

Fig. 13. Construction stages 1-3-5. Final situation Hs= 10 m

The best construction stage performance was for stage 2 (Fig. 14). It failed at Hs = 11 m and Tp = 20 s. Failures for other stages occurred at Hs = 9 – 10 m.

Figure 14. Stage 2. Final situation (Hs = 11 m, Tp = 20 s).

(B) Wave height at which construction must stop for workers safety

First overtopping was for Hs = 1.35 m at Stage 1 with 5.0 m water level and Tp = 21 s and the highest overtopping was for Hs = 6.92 m, water level 3.0 m and Tp = 21 s. Fig. 15 shows the Hs first overtopping values for 5.0; 4.0 and 3.0 m water levels.

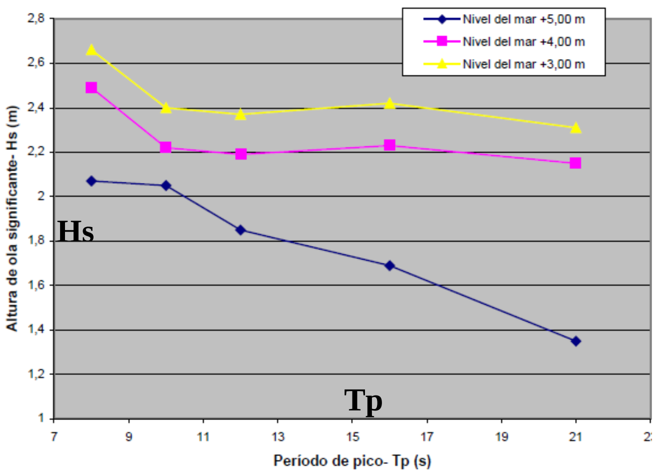


Figure 16. Stage 1. First overtopping. Hs versus Tp.

Breakwater construction test behaviour

Table 3 shows the major storms the breakwater withstood during its construction. Damage only affects stretches under construction and temporary protections, in a similar way to what happened in the physical model test, which can be seen in figures 14 and 17, shown by way of comparison.

Table 3. Langosteira buoy. (40 m deep, near breakwater). Major storms (May 1998-February 2012).

Year	Date	H_S (m)	Hmax (m)	Tp (s)
1998	29/11/98	7.42	13.18	17.24
1999	18/1/99	7.58	13.54	14.30
2000	06/11/00	9.61	14.76	13.40
2001	28/1/01	11.91	18.06	14.30
2002	22/11/02	8.02	10.69	14.30
2003	21/1/03	8.76	13.80	15.30
2004	18/4/04	6.80	10.65	12.50
2005	01/1/05	9.36	14.65	16.70
2006	08/12/06	7.81	13.24	15.30
2007	10/2/07	9.04	13.77	16.70
2008	10/3/08	10.40	15.30	16.70
2009(*)	20/1/09	8.84	13.47	14.30
2009	05/11/09	7.46	11.21	13.20
2010	09/11/10	10.41	16,56	13.40
2011	15/2/11	9,93	15.75	16,70

(*) Buay failure

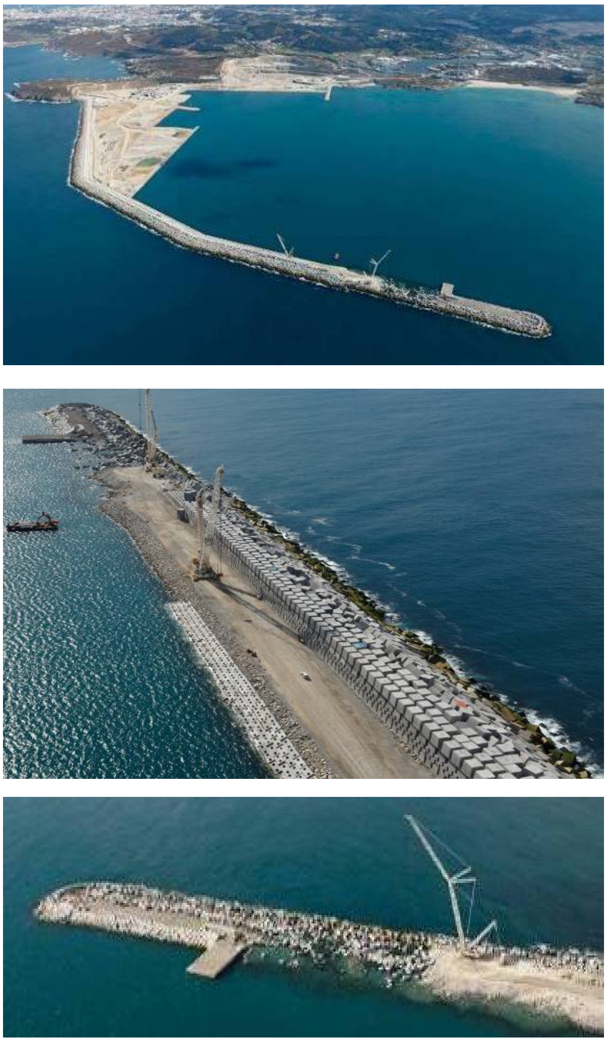


Figure 17. Breakwater state after the 15/2/11 storm. Overview and details

Finally figure 18 shows a breakwater overview in January 2012.

Figure 18. Breakwater. January 2012

Acknowledements

The authors wish to thank the Spanish State Ports Public Body and Coruña Port Authority for commissioning CEDEX to carry out the testing.

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