CHAPTER 141

OVERTOPPING REDUCTION IN CROWNWALL DESIGN

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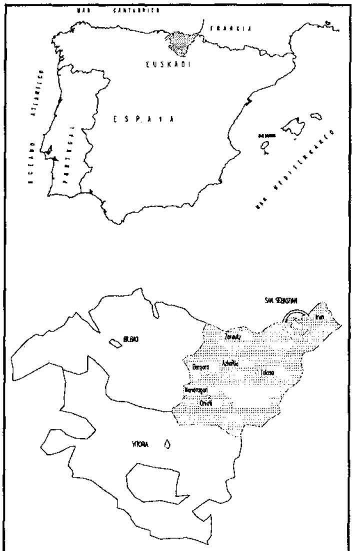

Figure 1. Situation map

1. ABSTRACT

This study for overtopping reduction in crownwall design presents several results of 2D (wave flume) and 3D (wave basin) tests on irregular wave overtopping of different configurations for breakwater sections were obtained by the Applied Hydrodynamics Institute (INHA) in order to improve the design of the small-craft harbour at San Sebastian in the North of Spain (fig.1).

San Sebastian is one of the most well-known and beautiful tourist cities in Europe and for that reason aesthetic as well as environmental aspects of construction had to be taken into account.

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2. INTRODUCTION

The San Sebastian harbour (fig.2) was designed by Europrincipia in 1995. The harbour would like to become a centre of attraction to citizens and tourists, not merely a berthing area for vessels. For this reason the creation of a new shopping and recreational area and urban integration with the city, which is extended to the end of the harbour by a promenade, are some of the issues that have to be dealt with.

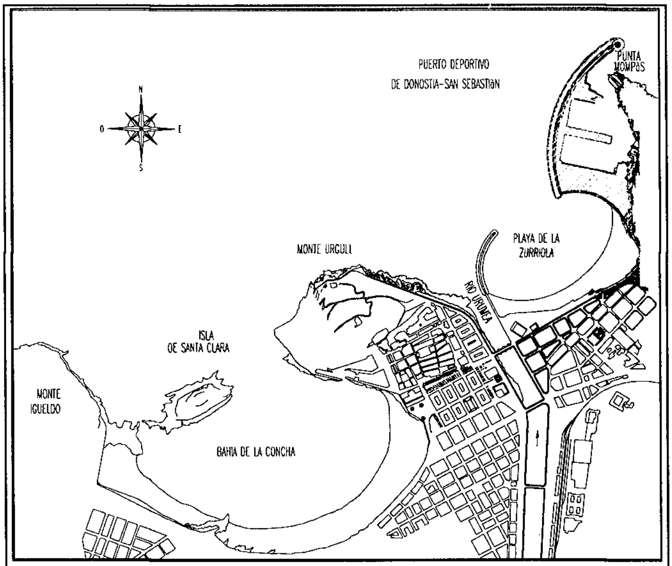

Figure 2:Marina location

From an engineering stand point the most important issue is, however, the wave climate, which is very severe in that area. The design incident wave height is $H_s=10.5m$ at a depth of $h=-20m$ and the average wave period is $T_z=15s$. The tidal regime in this area is hwtl=+4.8m and lwtl=0m. The water depth at the toe of the berm can reach -15m and therefore important non breaking waves can reach the structure. For this reason, and also because the visual impact of a very high crownwall to prevent overtopping would be of significant importance for the city, it was necessary to determine a freeboard height of the crownwall that agreed with both requirements.

Some strategies for improving the performance of the main breakwater of San Sebastian harbour were therefore tested.

The design of a recurved breakwater in plan view (Figure 3) resulted in a reduction of overtopping rates due to oblique wave attack as well as a reduction of wave induced forces in the crownwall. These results can be shown by comparing 2D tests (straight breakwater) and 3D tests (curved breakwater).

3. PHYSICAL MODEL TESTS

The 3D model tests were conducted in a wave basin 28m long, 23m wide and 1.2 m high at scale 1/50 and the 2D model tests were performed at a scale of 1/30 in a wave flume with dimensions of 52m long, 1.8m wide and 2 m high.

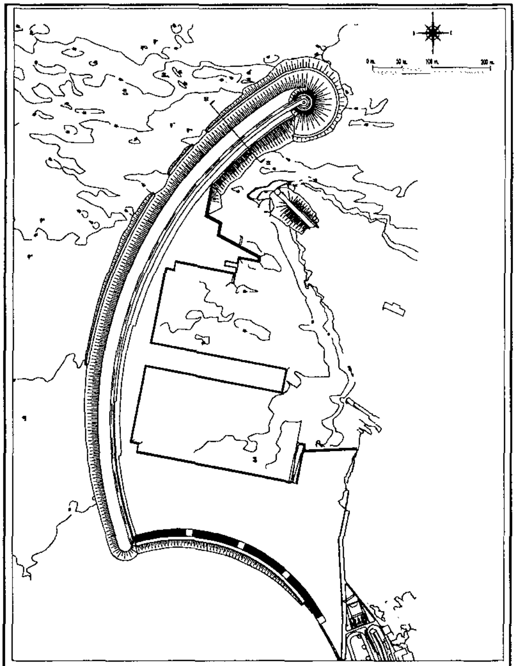

Figure 3: Final breakwater in plan view

In both facilities, tests of irregular waves with a Jonswap type spectrum were considered.

$$S_f = \alpha H_{1/3}{}^2 T_p^{-4} f^{-5} \exp\left[-1.25(T_p f)^{-4}\right] \gamma^{\exp\left[-(T_p f-1)^2/2\sigma^2\right]}$$ with

$$\alpha = \frac{0.0624}{0.230 + 0.0336\gamma - 0.185(1.9+\gamma)^{-1}}$$

$$\sigma = \begin{cases} \sigma_a : f \le f_p \\ \sigma_b : f \ge f_p \end{cases} \quad \sigma_a=0.07 \text{ and } \sigma_b=0.09$$

$$\gamma=1.9$$

The quantity f_p is the frequency at the spectral peak and T_p is the inverse of f_p

with $T_z = 1.3T_p$

The experiments were performed for 4 different water levels, and for 7 significant wave steps.

The section that was compared in 2D and 3D experiments is the one shown in fig.8. (fourth alternative) with a toe depth of 13m.

4. STRATEGIES TO REDUCE OVERTOPPING

The initial design (fig.4), almost a straight breakwater in plan view, was a stepped crownwall with height as reduced as possible in order to minimise visual impact. Rubble mound units were used instead of artificial blocks taking advantage of a nearby stone quarry which is able to provide parallelepipedic blocks of up to 70 Tn perfectly cut with explosives. The main features of this initial configuration are:

- Crownwall height : +14 m
- Weight of slope rubble mound units : 27 Tn
- Length of the berm: 45 m
- Depth of the berm : -5.5 m
- Weight of berm rubble mound units :17 Tn.

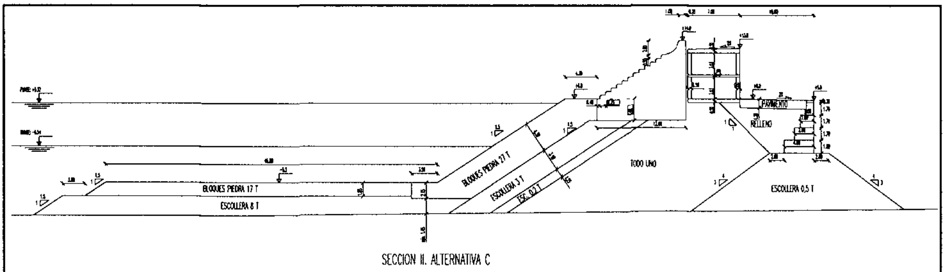

Figure 4: Initial configuration .Stepped crownwall

In order to analytically estimate the wave run-up and the overtopping rate several formulations were used. The initial configuration used the J.P. de Waal and J.W. van der Meer formula proposed in Coastal Engineering 1992. In this formula the expression that describes the average overtopping is an exponential function :

$$\frac{Q}{\sqrt{gH_s^{\,3}}} = 8\ 10^{-5}\exp\left[3.1\frac{Ru2\% - Rc}{H_s}\right]$$

where

$$\frac{Ru2\%}{H_s} = 1.5\,\gamma_f\,\gamma_h\,\gamma_\beta\,\zeta_{p,eq}$$ with a maximum of 3.0 γ_f, γ_h, γ_β

The theoretical values obtained differed from the experimental ones. Some reasons for this can be : the stepped crownwall does not act like a rough slope and, moreover, the stepped crownwall design has a ramp effect, as was shown in the overtopping tests performed.

As soon as the experimental values did not reach the requirements, 4 strategies to reduce overtopping rates were evaluated:

- To raise the height of the berm
- Design a crownwall topped with a recurved wall
- Raise the freeboard of the crownwall
- Design a curved breakwater in plan view.

These strategies were implemented in 4 new design alternatives.

a) First alternative:

In this case, the strategy of raising the height of the berm up to the MWL has the effect of a reduction of the initial overtopping rate as can be seen in several experiments carried out recently by Van der Meer (1990).

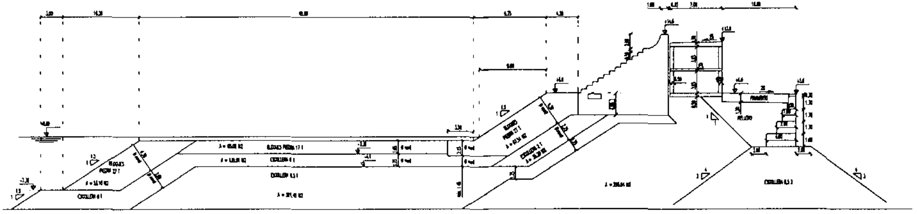

Figure 5: First alternative. Stepped crownwall with fronting berm.

The average overtopping rates for the section described above were still unacceptable. The reasons for these high values of Qr were the relatively low freeboard and the ramp effect induced by the stepped crownwall.

b) Second alternative:

The second design alternative (fig.6) combines three more strategies in order to improve the overtopping rates: raise the freeboard, construct a recurved crownwall and ,finally, design a curved breakwater in plan view.

Raising the freeboard of the crownwall has an immediate reductive effect as expected by theory. Considering the simplified theoretical model of Jensen and Juhl (1987) or Ahrens (1988), the overtopping rate Q is an exponential function of the dimensionless freeboard, F' = F/Hs, with F the freeboard of the structure and Hs the incident significant wave height. The limitation of this strategy is the visual impact of construction, which should be kept to a minimum.

The construction of a crownwall topped with a recurved wall has also a beneficial effect. Experimental tests showed that overtopping rates are considerably reduced due to the effectiveness of the recurved wall.

c) Third alternative:

The third design alternative (fig.7) consisted of reducing the long berm at MWL and constructing a short berm high up the crownwall instead. For this configuration, as can be seen in figure 9, the overtopping rates increased again probably due to the fact that the recurved wall partially blocked by the berm is not effective enough from a hydraulic point of view. Therefore, the rubble mound berm in front of the recurved wall should not reach high up the wall, as in this case the small curve above would be ineffective. This means that the corresponding rubble mound slope produces a ramp effect on the waves, resulting in disappointing performance.

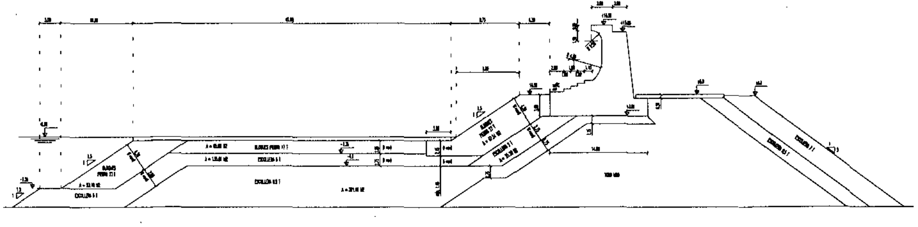

Figure 6: Second alternative. Raised freeboard and recurved crownwall

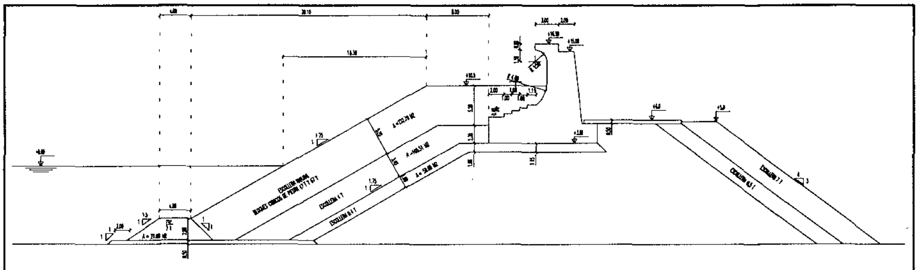

Figure 7: Third alternative. Recurved crownwall with berm high up the wall

d)Fourth alternative:

The final section proposed, corresponding to the fourth alternative (fig.8), has the following characteristics:

- Crownwall height : +16.5m
- Weight of slope rubble mound units : 27 and 47 Tn

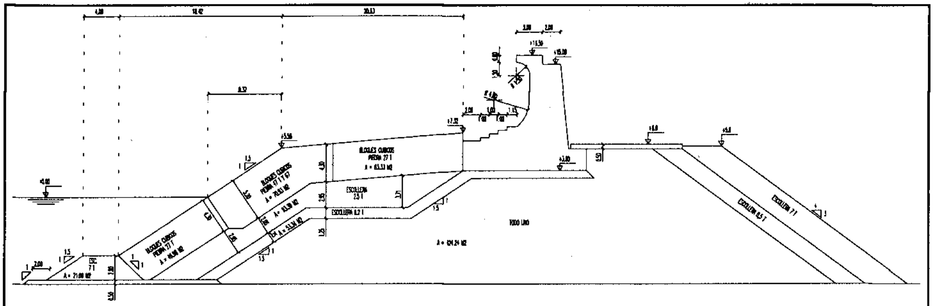

Figure 8: Fourth alternative. Final proposed section

- Length of the berm: 45 m
- Height of the berm : +7.5 m

Figure 9 shows the results of Qr for the four alternatives.

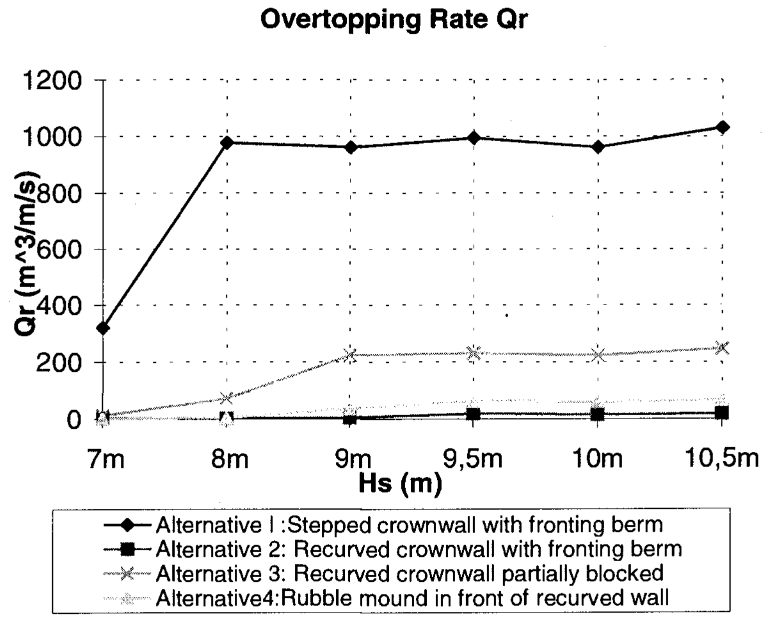

Figure 9: Overtopping results for 3D experiments.

5. COMPARISON BETWEEN 2D AND 3D RESULTS

Up to now, nothing has been said about the effect of a curved breakwater in plan view on the reduction of overtopping.

Figure 10: 3D model tests

Figure 11: 2D model tests

In order to assess such an effect, 2D tests of alternative 4 were performed in a wave flume. Incidentally, stability tests of the crownwall were also performed in order to approve a final design of the breakwater.

Figure 11 shows the good performance of the curved breakwater making the wave return seaward.

Figure 12 shows the differences in overtopping reduction between a straight and a curved breakwater in plan view.

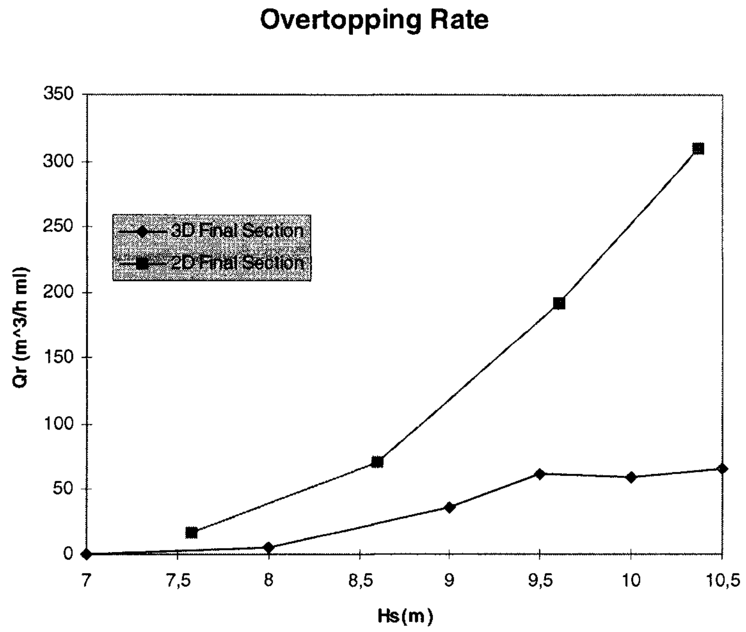

Figure 12: Overtopping rate. Straight 2D breakwater vs. curved 3D breakwater

Apart from possible scale or laboratory effects that may somewhat reduce the difference in the overtopping rate, the tests performed confirm that the curved breakwater considerably improves the hydrodynamic performance of the water flowing along the crownwall, reducing wave overtopping.

All these results could be compared with some state of the art formulas for overtopping rates like for instance Van der Meer's. Unfortunately, the geometry did not meet the hypothesis or requirements to fit these formulas.

6. CONCLUSIONS

The laboratory tests conducted at INHA in Barcelona (Spain) with different configurations of the breakwater of San Sebastian have shown various alternatives as ways to reduce the overtopping rates. First of all, there is a more or less exponential relationship between dimentionless freeboard and overtopping. Moreover, the use of a rubble berm in front of the structure is also an improvement, as is the construction of a recurved crownwall of an appropriate shape. Finally, as determined by comparing wave flume tests with basin tests, the design of a curved breakwater in plan view instead of a straight one considerably improves the hydrodynamic performance of the water flowing along the recurved wall and reduces wave overtopping. This series of strategies makes it possible to design an optimised breakwater compatible with the visual impact limitations of the site.

7. REFERENCES

Ahrens, J.P., and Heimbaugh, M.S., "Seawall Overtopping Model", Proceedings of the 21st Coastal Engineering Conference, Malaga, Spain, June 1988.

Jensen, O.J. and Juhl, J., "Wave Overtopping on Breakwaters and Sea Dikes", International Conference on Coastal and Port Engineering in Developing Countries, Benjing, China, Sept. 1987.

Van der Meer, J.W. and Pilarczyk, K.W, "Stability of lowcrested and reef breakwaters", Proceedings of the 22nd Int. Conf. on Coastal Engineering, Delft, 1990.

Battjes, J.A., "Wave Runup and Overtopping", Report to the Technical Advisory Committee on Protection Against Inundation, Rijkswaterstaat, the Hague, the Netherlands, 1974.

Owen, M.W., "The Hydraulic Design of Sea-Wall Profiles", Proceedings of the International Coastal Engineering Conference, University of Southampton, England, Sept. 1982a

Goda, Y., "Random Seas and the Design of Maritime Structures", University of Tokyo Press, Tokyo, Japan, 1985.