WAVE REFLECTION ON DISSIPATIVE QUAY WALLS: AN EXPERIMENTAL STUDY

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Abstract

The paper discusses the influence of slope porosity and model scale for a low reflective vertical quay. Physical model tests were carried out in the small and large scale facilities at Universitat Politècnica de Catalunya, in Barcelona, with regular waves. Matteotti (1991) conducted experiments for similar kind of quay. The results for small scale agree with the Matteotti's ones, but the large scale tests lead to smaller reflection. This is due to the presence of scale effect at small scales. The authors applied the Burcharth et al (1999) approach to treat scale effects, as shown in the paper.

1. Introduction

Several technical solutions can be adopted to build berthing structures in harbor basins; among them a pile wharf and a vertical quay represent ones of the most widespread: the former is a low reflective structure because of the rubble mound at the toe of the piles that dissipates a huge part of the incoming wave energy even though those structures can occupy huge areas in the port basin; the latter reduces the occupancy in the basins but can present severe problems related to the operating conditions, the structural strength and the safety due to the high reflection of the wall. Often a compromise must be found to keep the use of the harbor areas as better as possible and reduce the wave agitation inside the basins.
No-conventional vertical structures can represent an alternative. Antireflective quays and dikes are featured as porous or open structures, and have been experimentally studied over the years (Jarlan 1961,1965; Ijima et al. 1976; Matteotti 1991; Fugazza and Natale 1994; Tanimoto and Takahasi 1994; Suh et al. 2006; Garrido et al. 2010). This paper deals with the reflection response of low reflective vertical quays, whose upper wall, exposed to the incoming waves, is replaced by dissipative cells with rubble mound inside (Figure 1).

The study aimed to well characterize the relationship between the reflection coefficient and the main hydraulic and structural parameters involved in the phenomena. An exhaustive literature is not yet available for such kind of structure: Matteotti (1991) carried out physical tests with monochromatic waves; Faraci et al. (2012) studied how the changes in rubble mound inside the chamber can affect the reflection coefficient. In both cases the experiments have been carried out in small scale facilities. Interest of the authors is also a preliminary analysis of the scale effects by means of large scale tests.

Large and small scale tests have been carried out in the Laboratori d'Enginyeria Maritima of the Universitat Politècnica de Catalunya, in Barcelona (Spain) to study the response of the quay in a wide range of wave heights and periods. Results of small and large scale tests have been compared to analyze the influence of scale effects.

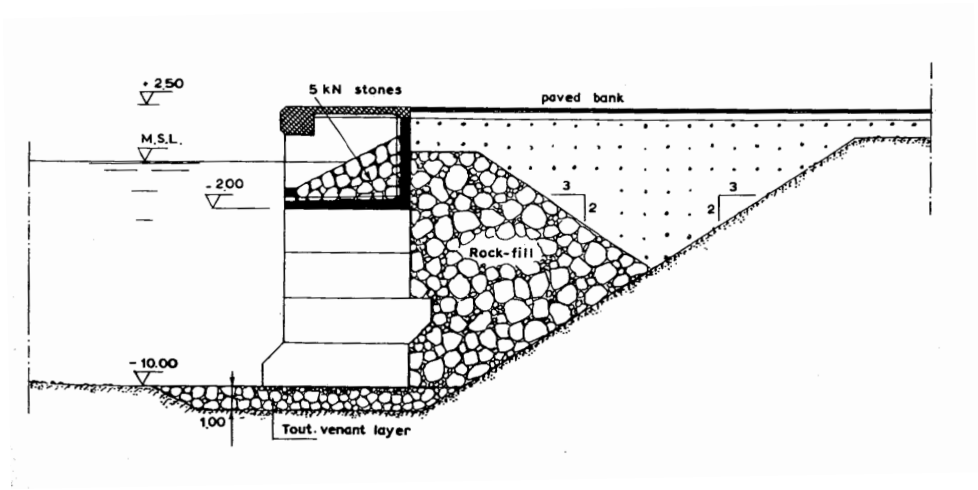

Figure 1. Scheme of the quay as in Matteotti (1991)

2. Laboratory experiment setup

The studied quay can be considered as a mixed structural type between a completely impermeable vertical face and a rock sloping breakwater. Figure 2 shows the cross section of the tested quay in prototype scale.

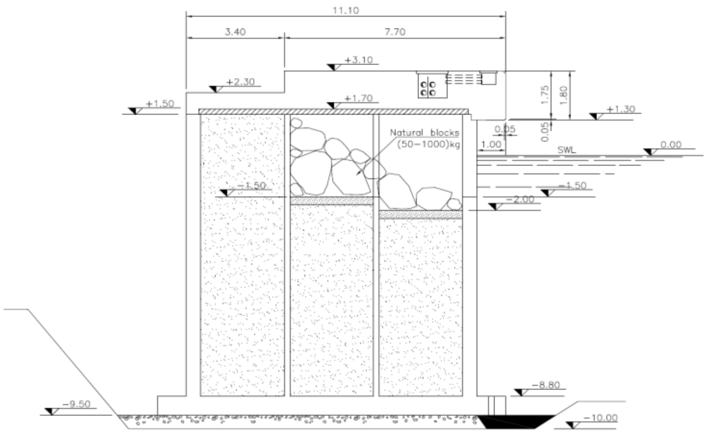

Figure 2. Cross section of the quay tested at LIM/UPC (prototype scale)

Small scale tests (1:33) have been conducted in the so-named CIEMito flume. CIEMito is 18 long, 0.38 m wide and 0.56 m high and is equipped with a piston paddle capable to generate waves up to 0.28m wave heights and wave periods up to 2 sec (Figure 3).

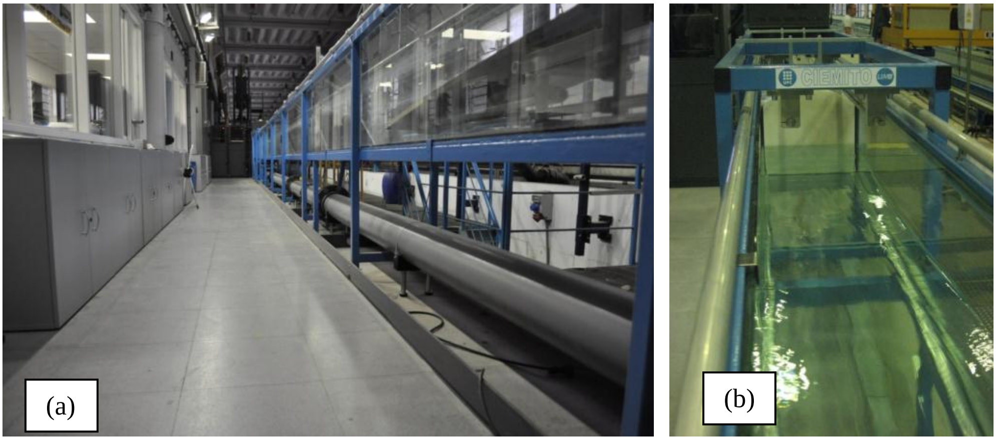

Figure 3. CIEMito wave flume lateral view (a) and piston wave generator (b)

Large scale experiments (1:4) have been carried out in the CIEM flume (Canal d'Investigació I Experimentació Marítima), 100 m long, 3 m wide and 5 m height (Figure 4). The CIEM flume has a wedge type paddle, that allows to generate waves up to 1.5 m wave heights. Figure 5 shows a snapshot of the models in both flumes.

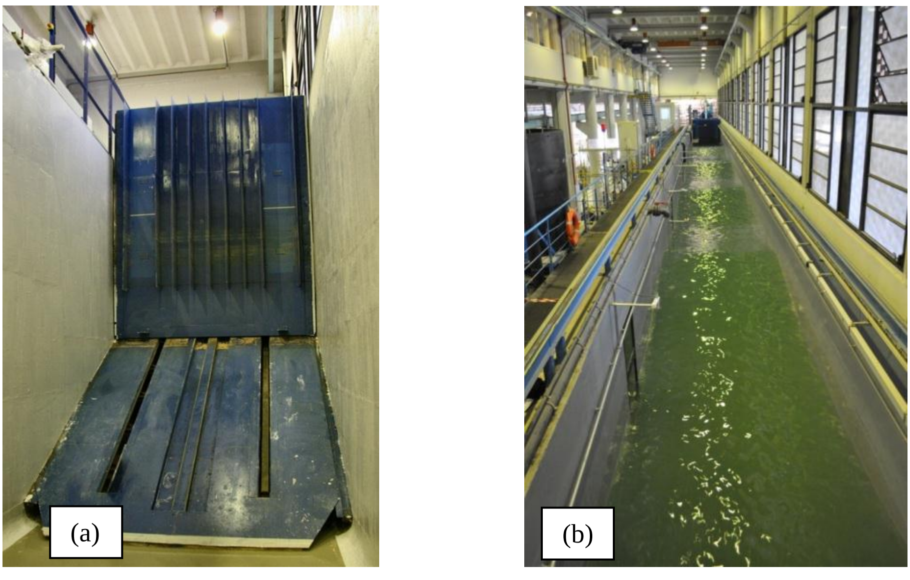

Figure 4. CIEM wave flume: wedge wave generator (a) and overview of the flume (b)

Each regular wave attacks were 20 wave periods long. Wave motions were measured in both scales by means of resistive wave gauges, with accuracy of 1mm: an array of three sensors has been positioned in front of the caisson in order to get incident and reflected waves components; two wave gauges more have been also displaced closed to the wave paddle to measure and check the wave generation. Depending on the scale, more sensors have been installed along flumes for further controls.

Two different values for the rubble mound porosity at each model scale were tested, to investigate the influence of this parameter on the reflection. The chosen values for the small scale are in the same range of the values at large scale to assess the presence of scale effects. In fact, even if the porosity is similar in small and large scale, the fluid viscosity is not scaled and could affect in a different way the flows inside the rubble mound, leading to a different response of the structure as is expected.

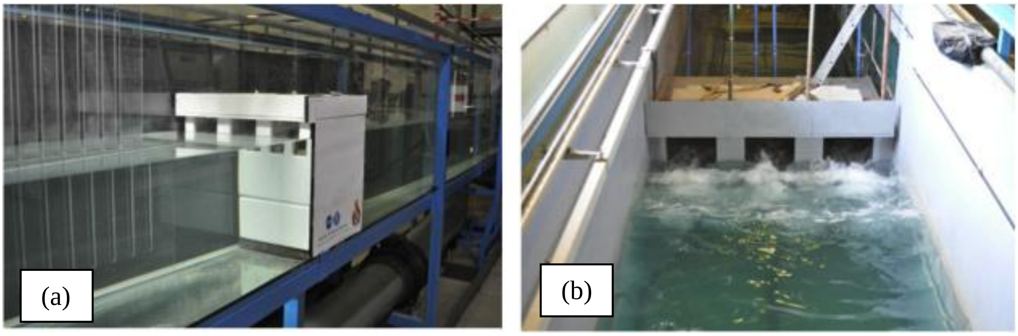

Figure 5. Snapshot of the physical tests in the small scale flume (a) and large scale flume (b) at LIM/UPC

Table 1 shows the prototype characteristics of the regular waves and the values of porosity that have been considered for each model scale.

Table 1. Experimental test setup.

Scale	H (m)	T (s)	Depth (m)	Porosity of rubble mound (-)	# of tests
1:33	1.27 1.5 1.8	6.17-10.72	9.08 9.70	0.319	21
				0.441	21
1:4	1.27 1.5 1.8	5.17-9.19	9.28 9.44	0.357	24
				0.451	24

3. Scale effects in wave reflection

The wave reflection is usually expressed by the reflection coefficient, defined as:

$$C_r = \frac{H_r}{Hi} = \sqrt{\frac{E_r}{E_i}} \qquad [1]$$

where H_r and H_i are the wave height of reflected and incident waves, respectively, and E_r and E_i are the related energies. The reflection coefficient can vary between 0 and 1, where 1 defines total reflection. Generally vertical dikes or jetties present values closed to 1, breakwaters or rubble mounds can show C_r around 0.3, but it should be properly assessed for each structure by means of physical model tests. The choice of the experimental setup can be crucial: small scale models require to treat possible scale effects in those cases where the scale could be very important and affect the results.

Porous structures dissipate wave energy within structure's voids, where turbulent flows are trigged. A geometrically scale physical model following the Froude law may lead to low Reynolds number and large viscous forces (Burchart et al, 1999); the resulting flows can be laminar instead of being fully turbulent within the structure's void. As consequence the model reflects more energy than the equivalent prototype (Wilson and Cross 1972, Hughes 1995).

In the present work the Burcharth'smethod has been applied to calculate a corrected and increased value for the stone nominal diameter in small scale. Burcharth et al. (1999) started from the knowledge of the wave induce pore pressure distribution: through this,the flow field can be estimated that is necessary to choose realistic flow velocities to be used in the scaling procedure. The characteristic pore velocity is calculated as the average value in the most affected area of the rubble mound slope.

Starting from the value of 0.357 for the porosity of the rubble mound slope at large scale model, the corrected nominal diameter in small scale led to a porosity of 0.441 at small scale. In order to compare how similar values of porosity could lead to different results in small and large scale models, the values of 0.451 and 0.319 for the rubble mound porosity were modelled, respectively at large and small scale. In this way two values of porosity for each scale were tested and compared (see Table 1).

4. Results

Due to the monochromatic nature of the wave trains for which just the spectral Mansard & Funke method (1980) can result poorly reliable, the authors chose use and compare both Mansard & Funke (1980) and Goda & Suzuki (1976) methods to calculate the reflection coefficient C_r for each test. Figure 6 shows the variability of the reflection coefficient C_r with the wave period *T*.

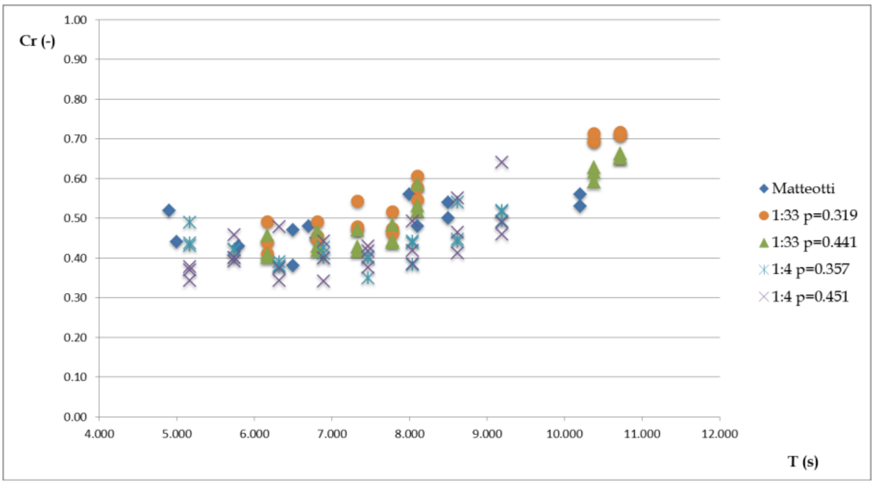

Figure 6. Reflection coefficient *vs* wave period

Both small and large scale test results are shown in comparison with those given in the Matteotti's work. The reflection depends strongly on the wave period, as expected, with variation of up to 40% for the same wave height and different wave periods.

The mean value for the reflection coefficient varies from 0.43 (large scale, p=0.451) up to 0.55 (small scale, p=0.319) where Matteotti found 0.47.

The results of small scale tests agree well with the Matteotti's measurements, carried out in a small scale flume too; on the other hand, the large scale experiments lead to reflection values smaller than those obtained at the reduced scale. Furthermore, a greater porosity leads to a smaller reflection although its influence seems less important numerically than the model scale. The small scale tests with larger porosity (green points in Fig. 6), where the scale effects have been treated, show values for C_r very close to large scale ones (blue points in Fig.6), confirming the relevance of the model scale. The result of the small scale model tests with the lower porosity (orange points in Fig. 6) show the highest values for the reflection coefficient. In that case the laminar flows into the rubble mound are predominant respect to the turbulent ones and the dissipation results lower than in the other three cases.

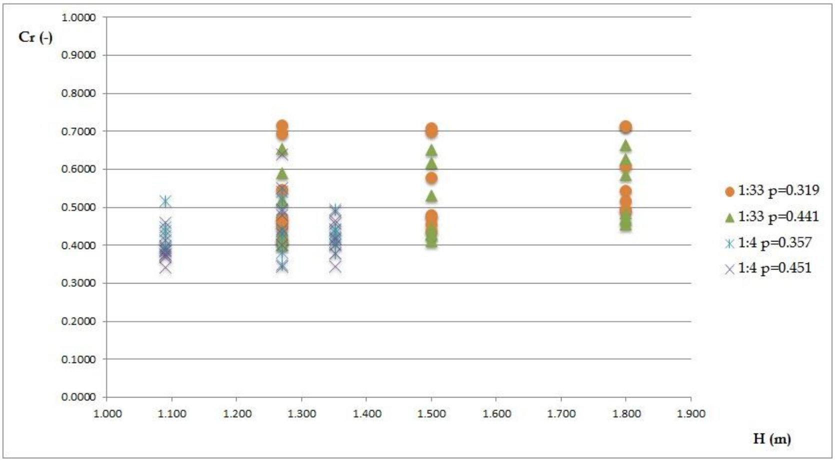

Figure 7. Reflection coefficient vs wave height

The dependence on the wave height does not seem very important if compared with the wave period, in agreement with the Faraci et al. (2012) results. Looking at Figure 7, it can be seen that for the same wave period, differences in the wave high affected slightly the response, leading to variations of Cr of about 8-10%.

5. Discussion of the results and conclusions

Pile structures or vertical walls are largely used as berthing structures or quays in harbor basins. The former type present low reflection but very high occupancy of the basin; the latter one is preferred because of its relatively low occupancy but can lead to very high oscillations inside the harbor. Therefore the research of the last decades is addressed to find a trade-off, by means of new kind of low reflective structure. The wave reflection of a low reflective vertical quay has been analyzed in the present work. The quay is a vertical wall where the upper part, exposed to the waves, is replaced by an open chamber with rubble mound inside. The dissipation of the waves into the voids among the rubble mound units should assure low reflection values.

In detail the work has been focused on the influence of slope porosity and hydraulic model scale. Both small and large scale tests show that a larger porosity leads to a smaller reflection, but the influence doesn't seem so important as well as the choice of model scale. The small scale tests agree with the Matteotti ones, but the results of the large scale tests show a different behaviour, leading in general to smaller values of the reflection coefficient.

Once the scale effects are treated by a correction of the scale of the nominal diameter of the armour stones by applying the Burcharth et al (1999) approach, the results get closer to the ones at the large model scale.

The paper demonstrates that the model scale affects the response of the structure and small scales generally overestimate the wave reflection of porous low reflective quays. It is thus recommended to carry out some of the physical experiments in a large model, to avoid scale effects that should lead to reflections larger at smaller scales than the real ones and simulate the behaviour as well as in prototype.

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