Overtopping formula for vertical tiers-headed breakwaters

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Abstract

The semi-empirical methods are useful tools to understand the wave overtopping phenomena, but uncertainty remains on their applicability. It's necessary to carry out campaign surveys or laboratory tests to support them. In this paper we apply the methods proposed in the European Overtopping Manual (2007) in order to assess the flows over a vertical breakwater, marking the need to calibrate those methodologies to take into account the peculiar geometry of the structural system. This was done by introducing appropriate correction factors. The results show an improved accuracy, among numerical results and physical ones.

Keywords: overtopping; empirical models; tandem breakwater.

1 Introduction

Coastal structures are commonly built to protect coastal zones against storm surges and large waves that may lead to several damages of the landward area, with hazards related to the security and human safety.

The wave overtopping is a phenomenon of wave - structure interaction that consists of waves passing over the crest of the coastal defense in the form of continuous sheet of water, plumes or splash, depending on the seaward geometry of the structure. The overtopping is complex and nonlinear, random in time and volume, set by different geometric – structural and hydrodynamic factors; it occurs for a given value of wave height and depends mainly on the freeboard of the structure as well as of the sea state.

The importance of this phenomenon is often undervalued by the final users, because of the sporadic occurrence of the event. In terms of risk the consequences can consist of different types: danger to pedestrian and vehicles, damage for seawalls, building, infrastructure and ships, internal residual agitation.

The available experimental data point out to the difficult description of the phenomenon in detail. Therefore the assessments of the mean overtopping discharge q and the total overtopped volume V are considered sufficient for the proper design of the coastal structures.

The analysis of the applicability of the predictive methods to vertical seawalls is described in the present paper. A peculiar seawall is studied: its complex configuration is set of its proper geometry and the coupling of the structure with a submerged breakwater.

The results of 2D model tests are shown: they suggested to adjust the methods in order to take into account that rare structural layout.

2 Wave overtopping assessment

The complexity in assessing the overtopping explains the huge development of multiple approaches leading to the estimate of the phenomenon: numerical models (SPH, 2006; VOF, 2007; etc.), empirical methods (Van der Meer et al. 1992, 2003, 2005, Franco 2005; etc.), neural networks (Medina 1999, Medina et al, 2002, EurOto Manual,2007) and physical model 2D and 3D experiments.

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In the last years different European and International projects (VOWS 2000, OPTICREST 1998-2001, CLASH 2002-2005) led to the revisions or implementation of the mentioned above methodologies. These projects prove the growing interest in an holistic and more accurate assessment of the overtopping, leading to the creation of global databases of information. This would take to development of new models and methods (European Overtopping Manual 2007) supported by laboratory test results and measurements in situ, also considering the effects due to the model test scale and the complexity of the factors that affect the phenomenon in reality (wind, fluid viscosity, etc.).

2.1 The European Overtopping Manual (2007)

The European Overtopping Manual is perhaps today's most advanced tool for the assessment of the wave overtopping, as the formulations contained in it and the proposed tools (PC-overtopping and Neural Network) have been calibrated on data from over 10,000 tests performed worldwide and collected in the database of the European CLASH project (2002-2005).

Among the methods proposed in the manual, the empirical formulas and the Neural Network were analysed and applied to the analysed vertical seawall. The choice is derived from the geometric - structural configuration of the study case.

2.1.1 The empirical formulations

The empirical methods are simplified representations of the physics of the process, presented in a dimensionless equation, which relates the mean overtopping discharge to the main factors that characterize the phenomenon.

These methods are generally adjusted on the results of laboratory tests or prototype measurements. Several authors (Bradbury and Allsop 1988, Van der Meer 1992) quantified the mean overtopping discharge rate as a function of the principal geometrical and hydraulic parameters: the significant wave height H_s at the toe of the structure, the peak period T_p or mean spectral periods T_{0m} (in deep water) and $T_{0m-1,0}$ (in shallow water), the depth at the toe of the structure h_s, etc.

Some authors have also analyzed the effects due to: the roughness of the external layer of the seawall, the presence of a berm at the toe, the obliquity of the wave attack. The key relationships are of two types:

$$Q=aRe^{-bR} \text{ or } Q=aR^{-b} \qquad (1)$$

where *Q* is the adimensional mean discharge per meter of crest length and *R* is the non-dimensional crest freeboard defined as the ratio between the geometrical crest freeboard and the incident significant wave height at the toe of the structure. The experimental coefficients *a* and *b* of the equation (1) depend on the configuration of the structure and of the sea conditions at the toe (fig. 1).

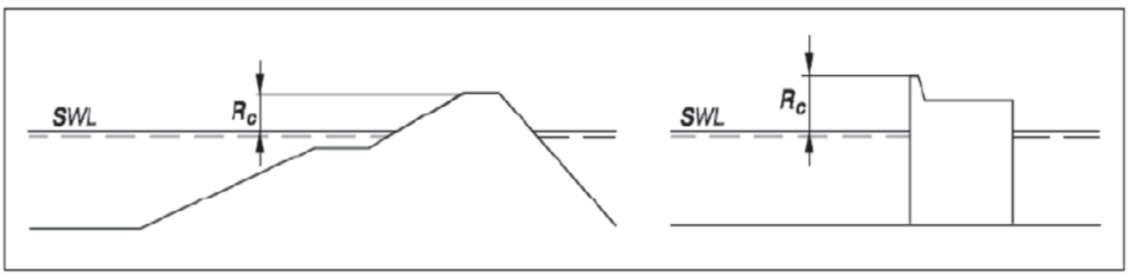

Figure 1: Reference scheme of the overtopping formulations

Referring to the vertical walls, in particular to the Vertical Composite Walls, as defined in the European Overtopping Manual, a fictitious depth value is introduced, taking into account the presence of a toe berm that induces changes on the characteristics of wave:

$$d^*=1.35\,(2d\pi h_s)/(H_{m0} g T^2_{m-1,0}) \qquad (2)$$

where H_{m0} e $T_{m-1,0}$ represent respectively the mean spectral wave height and period at the toe of the structure, h_s is the depth of the bottom close to the structure and d is the water depth in front of the toe berm.

The d^* parameter defines if the phenomenon conditions are impulsive or non-impulsive. The non-impulsive condition occurs when the waves are relatively small compared to the depth at the toe of the structure and have a low steepness. In contrast, the impulsive condition on the vertical walls occurs when the wave height is high compared to the depth, due, for example, to the shoaling bathymetry or structure toe, with waves breaking violently on the wall, creating very high pressures in small time intervals. Under these conditions, jets of water mixed with air are generated, that overtop the sea defences. In this paper we refer to non-impulsive conditions that characterized the carried out tests.

The expression between the mean overtopping discharge and the values of wave height and the crest freeboard in non-impulsive conditions ($d^*>0.3$) is the following one:

$$q/\sqrt{(gH^3_{m0})}=0.04\exp(-2.6\,R_c/H_{m0}) \quad \text{valid for } 0.1<R_c/H_{m0}<3.5 \qquad (3)$$

where R_c represent the crest freeboard.

2.1.2 The Neural Network for the overtopping assessment

The neural network (NN) is a non-linear structure of statistical data organized as a model tools, represented by the links among elements, called artificial neurons. In the past, NN has been successfully applied to the hydraulic engineering (Mase et al. 1995, Medina et al. 2002).

The Neural Network for overtopping assessment, proposed in the European Overtopping Manual has a three layered structured: the first layer contains 15 neurons, corresponding to the number of the input parameters (among these there are the spectral height and average period $H_{m0,toe}$ and $T_{0m-1,0}$ at the toe of the structure, surface roughness, berm width, water depth, obliquity of the wave attack, the seaward slope of the structure, etc.); the last layer contains only one neuron corresponding to the output value of mean overtopping discharge q. The middle one, finally, is the site of the synapses that connect input and output layers. The synapses were calibrated and weighted using the set of the reference data, collected in the database. The Figure 2 shows a scheme of the NN input parameters.

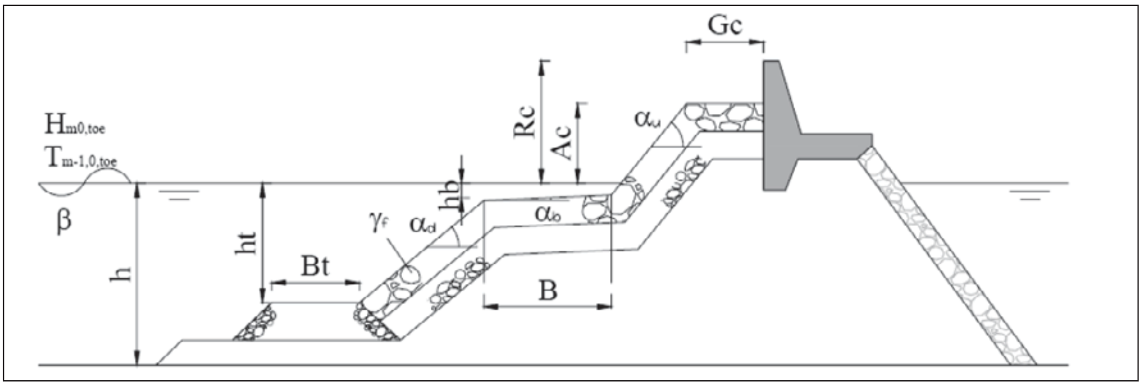

Figure 2: Scheme of the input parameters in the Neural Network for the overtopping assessment

3 The case of study

The main aim of the experimentation was to evaluate the mean overtopping discharge over a tandem breakwater composed by a vertical seawall coupled with a submerged breakwater. In the prototype scale the mean distance between the wall and the breakwater is about 60 m and the submergence of the last one is 4 m. The tests were carried out at the Laboratory Maritime Engineering of the Technical University of Catalunya (CIIRC-LIM/UPC), in Barcelona, Spain.

Another special feature of the vertical structure is its crest, shaped as a flight of steps, with the maximum freeboard equal to 7:35 m above SWL. The lower part of the steps is 2.2 m above the SWL, in prototype scale (Fig. 3).

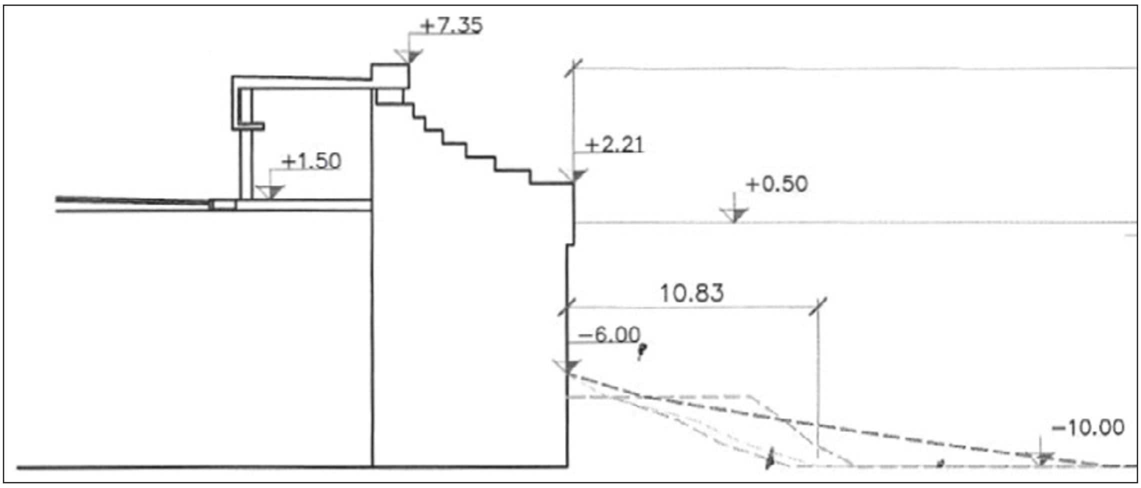

Figure 3: Vertical seawall in prototype scale

The water depth at the toe of the structure is approximately 10.00 m. The outer layer of the submerged breakwater is made of irregular blocks with a volume varying from 5 to 10 mc. This submerged breakwater has the task of dissipating the energy of the incident waves, reducing the possible erosion at the toe of the vertical wall.

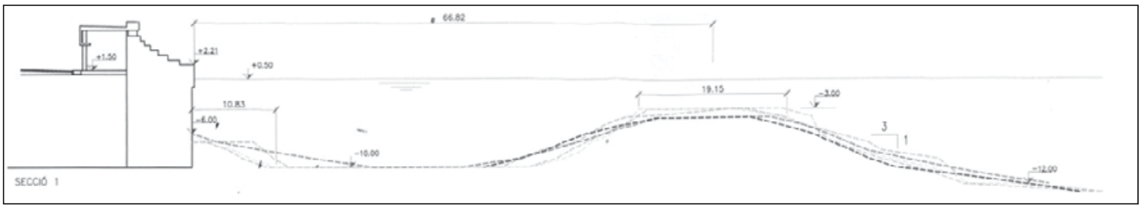

Figure 4: Layout of vertical seawall coupled with submerged breakwater (prototype scale)

The two-dimensional physical model tests were carried out in the small-scale flume, called CIEMito, in the CIIRC-LIM/UPC. The flume is 18 meters long and has a section of 38 cm wide and 50 cm high. The wave generator (piston type) allows the reproduction of irregular and regular wave trains with height up to 28 cm and maximum periods of 2 sec.

Storm surges have been reproduced with JONSWAP spectrum with a γ value of 3.0 and 300 waves for each train, considered as representative of a single storm.

The model scale is 1:50, according to Froude similarity. The model is built mainly in plywood; natural stones are used for the outer layer of the submerged breakwater. The significant wave height varies from 0.065 m to 0.102 m and the peak period from 0.98 s to 1.91 s, in model scale. The choice of the range for the wave characteristics depends on the will to analyze overtopping referring to extreme events with return periods of 1, 5 and 37 years.

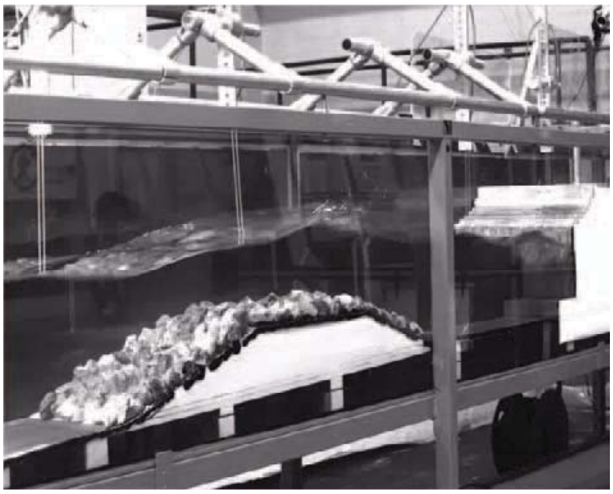

Figure 5: View of the model during the experiments

The surface profile is measured by means of 8 resistive gauges, located along the flume. Analysing the wave signals it was possible to define the transmission due to the submerged breakwater and carry out the reflection analysis using the Mansard e Funke (1980) method. The mean wave overtopping rates were deduced by overtopped volumes collected in tanks, placed on the back of the main structure, and the duration of each test.

Due to the small scale of the tests, the measured discharges are corrected as well as indicated by De Rouck J. et al. (2005).

4 The application of the methods

The preliminary analysis of volumes and overtopping flows using empirical methods, has clashed with the inability to recognize the factors that could take into account the peculiar geometry of the vertical wall and its interaction with the submerged breakwater. The interest was therefore in finding a way that could describe the effects of this layout on the overtopping rate.

Previously it was necessary to analyze the wave surface profile, extracting the incident and reflected waves height from the total ones. Applying the methodology of Mansarde and Funke (1980), by means of the WaveLab software (http://hydrosoft.civil.aau.dk/wavelab), it was possible to reconstruct the effects of reflection due to the main breakwater and determine more precisely the spectral parameters of the incident wave at the toe. A set of tests, performed for the configuration without the submerged breakwater, made possible to assess its dissipative effects on the incident wave.

The main breakwater is similar to a composite vertical wall, as described into the EurOtop: therefore it was necessary to assess whether the wave conditions were non-impulsive or impulsive. The character of each test so calculated was verified also using a video analysis conducted for each experiment. Non-impulsive conditions were found in 77% of the cases. For them, representing the cases with higher probability of occurrence, the analysis, described in this paper, was carried out.

The application of the equation (3) led to high dispersion of results compared with experimental ones. This is because, with the formulations contained in the EurOtop, is not possible to introduce the effects of the studied particular layout on the overtopping flows. A correction factor was calculated by a linear regression analysis. This factor is a function of d^*. In particular:

$$\chi = \psi \sqrt{(d^*)} \qquad (4)$$

for ψ between 1.68 and 1.89, where χ means a correction factor of the quantity R_c/H_{m0} appearing in the exponent of (3).

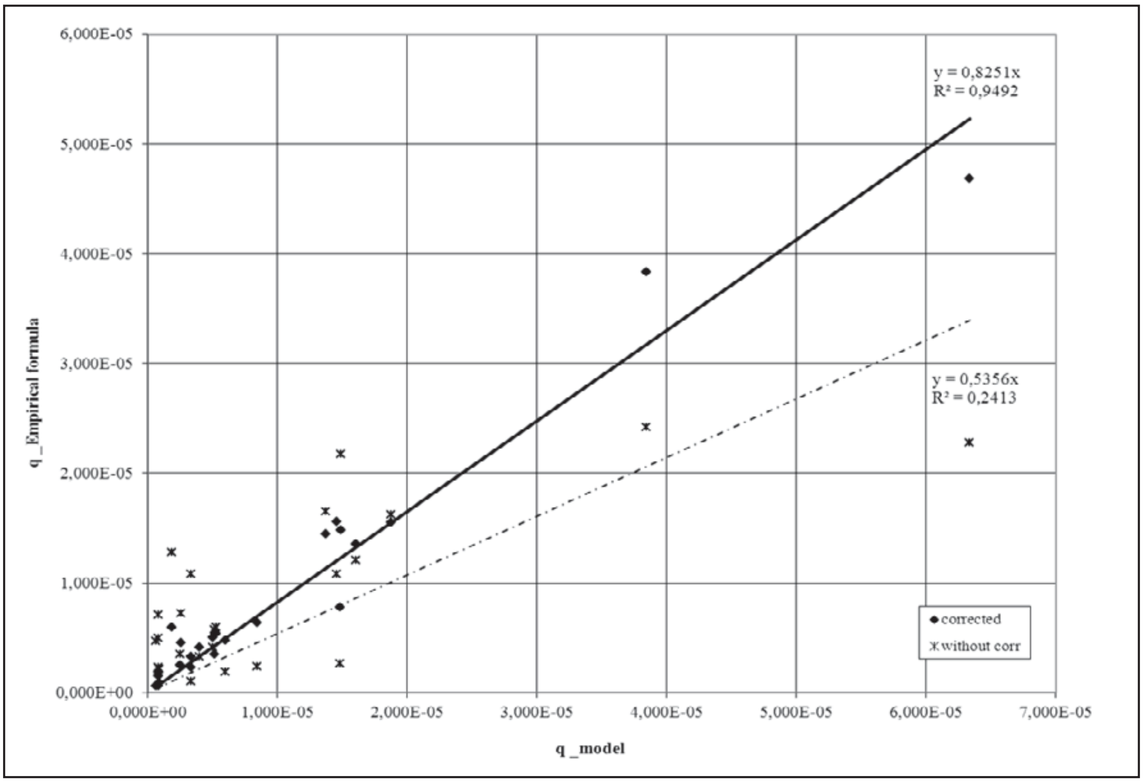

Figure 6: Results of the empirical formula compared with physical ones.

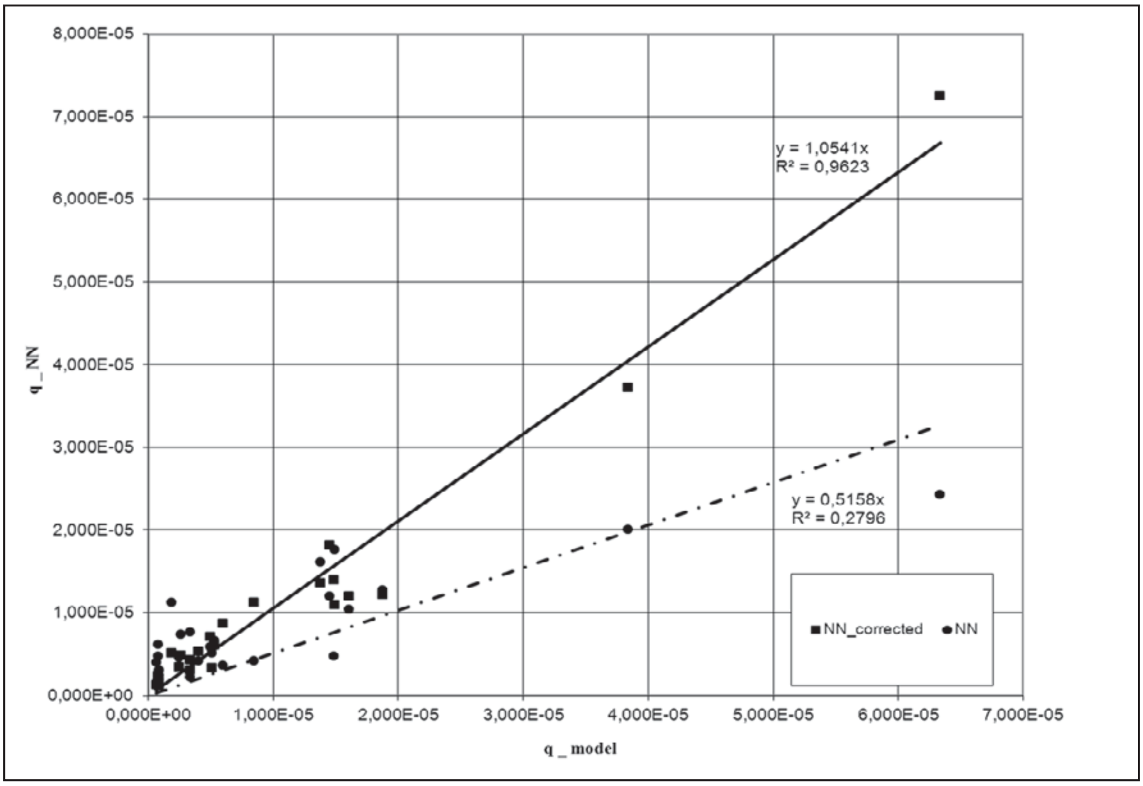

Figure 7: Results of the NN compared with physical ones.

The same analysis was carried out using the neural network for overtopping assessment, described in the European Overtopping Manual (2007). In the NN all the hydraulic and structural quantities were introduced, considering the input freeboard as the maximum freeboard of the staircase. The results show dispersion, if compared with the physical ones. Therefore, because of both the formulas and the NN are calibrated using the same CLASH database, the same correction, found for the empirical formulations, was introduced in the neural network, as a fictitious value for the crest freeboard instead of the real one. In this way, a good accordance is obtained between calculated and measured overtopping discharges.

5 Conclusions and future developments

Nowadays the new planning environmental constrains and landscape demands require engineers to implement non-classical solutions, characterized by more complex structural configurations: the particular details and features of such new engineering choices lead to solutions that cannot be easily classified. This supposes to continually update the existing database in order to represent all the kind of structures.

In this paper we analyse the problems related to the assessment of overtopping discharge over coastal defences by means of predictive methods. In particular, it was checked the applicability of empirical formulas and neural network to a tandem system composed by a vertical seawall and a submerged breakwater.

The application of these methods, based on the CLASH database, highlighted the weaknesses of the models. These are mainly related to the inconsistency of the data set or the lack of data for certain kind of geometrical configurations. In this case it was necessary to introduce a correction factor that could take into account the effects generated by the particular shape of the vertical wall, with a crest shaped as a flight of steps and coupled with a submerged breakwater.

While the European Overtopping Manual remains at the time one of the most useful tools for understanding the overtopping phenomena, the experimental results show the necessity to adjust the proposed methods to the particular structure configurations. Therefore it is advisable to conduct further physical model tests or prototype measurements, by which to extend the applicability of these methods to a greater variety of real cases

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