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Short communication

Uncertainties in the physical modelling of the wave overtopping over a rubble mound breakwater: The role of the seeding number and of the test duration

A. Romano [a,*], G. Bellotti [a], R. Briganti [b], L. Franco [a]

[a] Roma Tre University, Engineering Department, Via Vito Volterra, 62, Rome 00146, Italy
[b] Infrastructure, Geomatics and Architecture Division, Faculty of Engineering, University of Nottingham, Nottingham NG7 2RD, UK

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ABSTRACT

This paper presents an experimental study on the variability in the wave overtopping discharge on a simple rubble mound breakwater caused by different random starting phases and different lengths of incident wave sequences sharing the same energy density spectrum. A total of 153 small scale laboratory tests were carried out in the wave flume of the Roma Tre University (Rome, Italy) to simulate 8 different spectra producing different levels of overtopping. The seeding of the random number generator used for the starting phases distribution was changed a number of times for each repetition of the same wave condition. The experiments allowed the quantification of how the variability in the wave overtopping grows with the dimensionless freeboard. The experimental confidence intervals have been calculated and compared with those provided by the EurOtop Manual (EurOtop, 2007). The role of the length of the tested wave sequence was also investigated. A sensitivity analysis carried out on the partial overtopping time series has pointed out that shorter time series (at least 500 waves) can be used for overtopping tests, by obtaining a comparable accuracy in average overtopping discharge with respect to the recommended 1000 waves series.

1. Introduction

Wave overtopping has been widely studied using laboratory measurement techniques as well as numerical models. These methodologies form the basis for predictive empirical formulae that include correction factors to take into account scale and model effects (e.g. Briganti et al., 2005; Franco et al., 2009; Geeraerts et al., 2009; EurOtop, 2007; van der Meer and Bruce, 2013; van der Meer and Janssen, 1995).

In the laboratory a structure is tested by generating a sea state described by a wave energy density spectrum. There are few techniques that allow the reconstruction of the free surface elevation time series given a wave energy density spectrum; however, they fall into two categories: the deterministic and non-deterministic ones. The most widely used method within the first category is the Random Phase Method (RPM, Tuah and Hudspeth, 1982), while within the second category the Filtered White Noise Method (FWNM, Nunes, 1981) is well accepted to be suitable to represent natural waves.

The generation process involves a reconstruction of the free surface starting from the density of the energy at various frequencies, i.e. harmonic components. Only the amplitudes of these components are known, while their starting phases are assigned assuming that they follow a uniform random distribution. Each distribution is defined once a seeding number is assigned to a random number generator. It is clear that an infinite number of free surface elevation time series, hence an infinite number of different wave sequences, can be reconstructed from one wave energy spectrum by varying the seeding number (Tuah and Hudspeth, 1982). This variability in wave sequences contributes to the variability of the measured overtopping parameters. Pearson et al. (2001) first analysed the issue using vertical walls, by performing tests using different wave sequences sharing the same energy density spectrum. For the level of overtopping tested, the variability in the measured discharges with the seeding was in the order of 20%.

The same type of variability was discussed in the contest of numerical modelling in McCabe et al. (2013), who studied a seawall, and in Williams et al. (2014) who studied a smooth 1/2.55 slope. This latter work quantified the magnitude of the variability with the seeding at different levels of overtopping. The authors concluded that when the probability of overtopping (i.e. number of the overtopping events divided by the total number of waves) is less than 5%, the numerical estimates of overtopping parameters should be obtained by multiple tests with different seeding.

Furthermore, Pearson et al. (2001) raised the issue of the relationship between the length of the time series and the accuracy of the overtopping estimate. It is generally accepted (see the EurOtop Manual, EurOtop, 2007) that a sequence of 1000 waves should be simulated for

* Corresponding author.
E-mail address: alessandro.romano@uniroma3.it (A. Romano).

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each sea state tested. Pearson et al. (2001) noticed that the overtopping discharge from tests using series of 500 waves, is very close to that from tests with 1000 waves. Williams et al. (2014) numerically tested longer wave sequences, reaching the conclusion that using more than 1000 waves does not affect the overtopping estimate. The same paper (see Table A1) suggests that 500 and 1000 wave sequences provide a very close estimate of wave overtopping parameters except for very small levels of overtopping.

The results obtained by the two studies with shorter wave sequences provided the motivation for this work. In fact, they suggest the possibility of using less than 1000 waves to measure wave overtopping discharge with a comparable level of accuracy. This is worthwhile exploring given the immediate benefit in terms of economic and time savings that shorter experiments would bring. This paper aims at providing an in-depth analysis of the variability of the overtopping discharge in laboratory tests with varying wave sequence seeding. Moreover, starting from the results obtained, partial overtopping time series have been extracted to study the variability of the results using wave sequences shorter than 1000 in order to compare this with that of the recommended length. If the order of magnitude of the variability is the same, it will be possible to consider the use of reduced length time series. In order to achieve this, a large number of small scale tests were carried out in the wave flume of Roma Tre University on a simple rubble mound breakwater. This type of structure has been chosen since it is widely used in coastal protection. The paper is structured as follows: after this introduction a description of the experiments is given, then the experimental results are shown and discussed. Finally the conclusions close the paper.

2. Laboratory experiments

The experiments were carried out in the wave flume at the hydraulic laboratory of the Roma Tre University. The flume is 9.00 m long, 0.27 m wide and 0.50 m high. It is made of plexiglass panels (0.02 m thick) sustained by a steel frame. At one end a piston wave-maker is installed; it consists of a vertical steel plate driven by a remotely controlled electric motor. The effective stroke of the piston wave-maker is 1.00 m. The system is able to generate, using a software developed in-house, both regular and irregular waves (see upper left picture of Fig. 1); in the present experimental campaign no active wave absorption system has been used. Nevertheless, it is worth to cite that for each test we have divided the measured free surface elevation time series into a certain number of time windows and we have checked that the incident significant wave height did not vary significantly over all the windows. Furthermore, we have checked that the spectral shape of the measured signals still represent a JONSWAP spectrum.

The tests were carried out on a simple rubble mound breakwater with a foreshore slope of 1:2.5 (see upper middle picture of Fig. 1). The structure had an impermeable core of river sand (nominal diameter, $D_{50} = 0.5$ mm). The armour consisted of two layers of randomly placed natural stones (density, $\rho_s = 2.6$ t/m^3, $D_{50} = 50$ mm). Furthermore a parapet wall of plastic material was placed on the top of the core behind the landward armour units. The experiments were carried out on flat bottom, due to the small dimension of the flume. This solution posed the problem of the possibility of wave breaking at the paddle; this was avoided by carefully choosing the tested wave conditions.

The overtopping volumes were collected using a chute fixed to the crest of the parapet wall. At the end of the chute a hole, placed on the sloping bottom of the chute itself, allowed the water to flow into a rubber pipe (1.0 m long) that collected the overtopped water into a tank placed outside the wave flume. A load cell was then connected to the overtopping tank in order to measure the volume in time. The sketch of the experimental set-up is shown in the lower panel of Fig. 1.

Four resistive wave gauges were placed along the flume for the measurement of the free surface. The positions of the wave gauges, measured with respect to the rest position of the wave paddle, are $x_{S1} = 1.85$ m, $x_{S2} = 2.10$ m, $x_{S3} = 7.25$ m and $x_{S4} = 7.5$ m respectively. The incident wave conditions in the flume were computed with the Goda and Suzuki (1976) method using the $S1$ and $S2$ gauges away from the structure and the $S3$ and $S4$ at the toe. Very similar results were obtained by the two couples given the short length of the flume.

Using the Goda and Suzuki method (Goda and Suzuki, 1976) it was possible to compute the mean reflection coefficient, averaged for all the tests carried out. This was found to be equal to 0.29. Furthermore, it is important to investigate the presence of energy around the resonance period of the flume. It is known that overtopping is sensitive to long waves in the flume. This model effect might be significant in small scale and for a small facility like that used here. To quantify it,

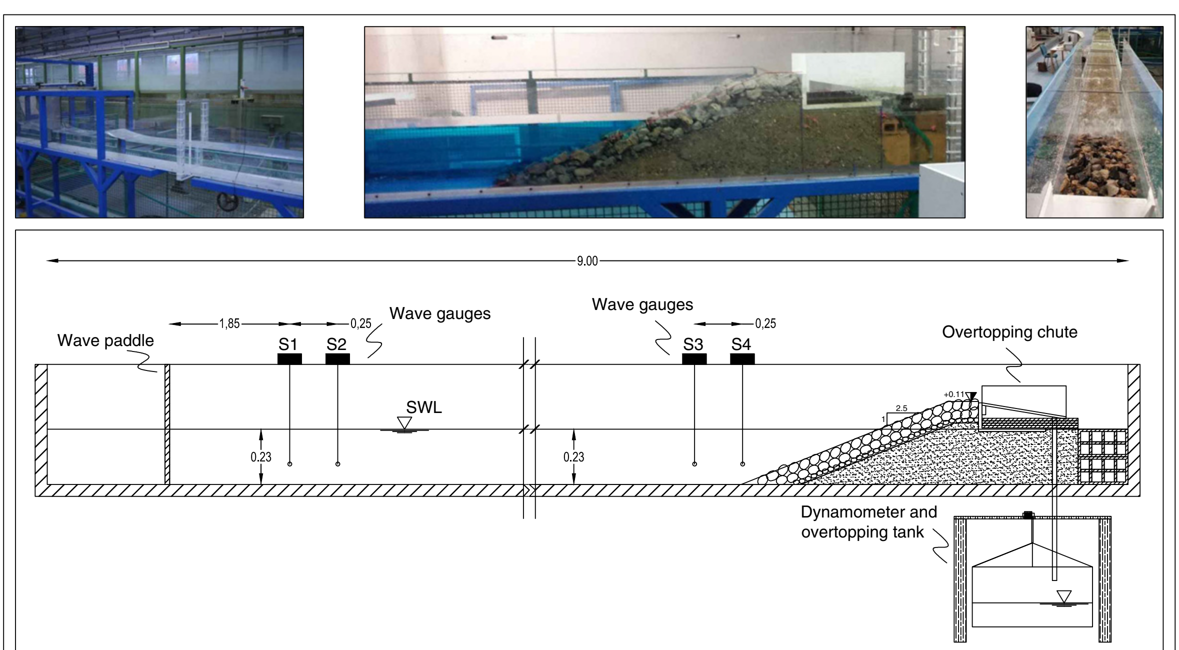

Fig. 1. Upper panels: photos of the wave flume and of the model structure. Lower panel: sketch of the experimental set-up.