OPTIMIZATION OF WAVE OVERTOPPING IN NEARSHORE WAVE ENERGY CONVERTER SYSTEMS

Romosios D. George, PhD Candidate, Aristotle University of Thessaloniki, Civil Engineering Department, +306981038869, georromo@civil.auth.gr
Karambas Theofanis, Associate Professor, Aristotle University of Thessaloniki, Civil Engineering Department, +302310995805, karambas@civil.auth.gr

Overview

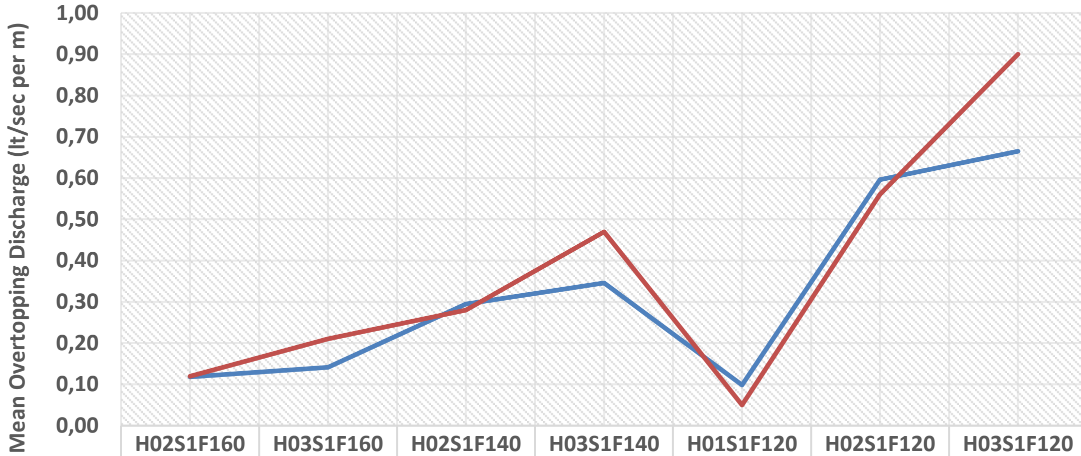
In recent years, there is an increasing interest amongst researchers about novel hybrid concepts of Wave Energy Converters (WEC) incorporated into coastal structures, such as breakwaters and seawalls. The concept of wave energy conversion through the utilization of wave overtopping into a reservoir, thereby effectively creating very low-head hydropower, is a promising option towards this purpose. This paper is presenting data from laboratory tests conducted at the Florence University of Italy (UniFi) wave tunnel tank facilities under the support of the MARINET I Project, and the analysis of the experimental results in order to determine the optimum structure parameters that contribute towards maximizing the wave overtopping volume in a single-layer overtopping reservoir. Special consideration was given on the determination of the geometrical characteristics leading to the optimum performance of the structure, the minimization of the wave-induced loads, ensuring at the same time the maximization of the converter's hydraulic response (wave power capturing capacity). All tests conducted included wave conditions representative of the Mediterranean coastal areas. The test results presented in this paper can provide useful data for the design optimization of an overtopping ramp which can be used as part of a coastal structure that will be able to effectively collect seawater and convert wave energy into electricity. Moreover, the results presented on this paper are expected to significantly contribute on the preliminary evaluation of the anticipated global warming effects and specifically on the implications of high waves, the rising sea water level and the increased storminess, while such a breakwater design should be capable of adding cost sharing benefits due to the integration of a wave energy conversion utility into its structure.

Methods

Two different model ramps were tested under a variety of representative wave conditions. The use of the specific infrastructure leaded to the evaluation of the overtopping characteristics of a medium/small-scaled prototype front reservoir model that can be incorporated into a breakwater structure. Special consideration was given on the determination of the geometrical characteristics leading to optimum seawall performance, minimization of wave induced loads, while at the same time maximization of the converter's hydraulic response (wave power capturing capacity), for wave conditions representative of the Mediterranean area. The physical tests were performed in the wave-current flume provided by the Laboratory of Maritime Engineering of the Civil and Environmental Department (DICeA) of Florence University. The flume s is 37.30m long, 0.80m wide, and it can accommodate a water depth of up to 0.60m. The model of the overtopping device was positioned about 30 m far from the wave maker (in the centre of the 26th sector of the wave-current flume). Two ramps with different slopes were tested, respectively S1 (1:3) and S2 (1:2). The toe of the ramp named S1 was located at a distance of 31.5m from the wave maker, while the toe of the ramp S2 was placed at a distance of 32.20m. Moreover, three different freeboard heights (the vertical distance measured from the still water level to the upper part of the ramp) equal to 0.16m, 0.14m and 0.12m were tested. They are respectively named F160 (water depth 0.50m), F140 (water depth 0.52m) and F120 (water depth 0.54m). The tests which were carried out included a number of sets of regular waves generated at the DICEA laboratory facilities. For each test, a regular wave train was generated, and the volume of water collected in the reservoir was measured. The water collected in the sheltered area after the measurements returned to the wavemaker through the existing recirculation system. In order to collect the overtopping discharges, a tank 0.50m height, 0.60m wide and 0.90m long was placed behind the device. The tank was equipped with four bending load cells (TYPE 54-100-C3 by CELMI s.r.l.), with a measuring load capacity at full scale (FS) of 100 kg and an accuracy of ± 0.01% FS.

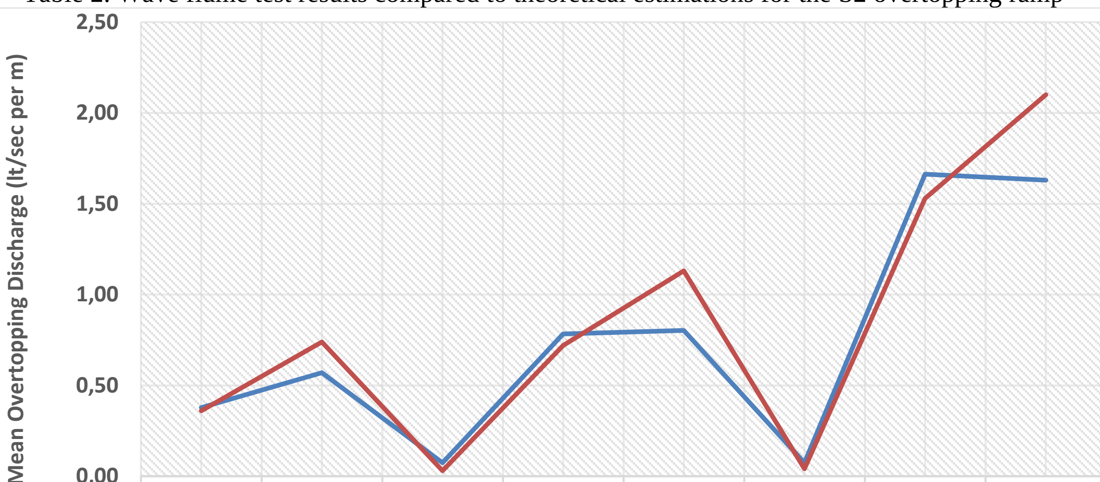
Results

Table 1. Wave flume test results compared to theoretical estimations for the S1 overtopping ramp



	H02S1F160	H03S1F160	H02S1F140	H03S1F140	H01S1F120	H02S1F120	H03S1F120
Theoretical	0,12	0,14	0,29	0,35	0,10	0,60	0,66
Experimental	0,12	0,21	0,28	0,47	0,05	0,56	0,9

Table 2. Wave flume test results compared to theoretical estimations for the S2 overtopping ramp



	H02S2F160	H03S2F160	H01S2F140	H02S2F140	H03S2F140	H01S2F120	H02S2F120	H03S2F120
Theoretical	0,38	0,57	0,07	0,78	0,80	0,07	1,66	1,63
Experimental	0,36	0,74	0,03	0,72	1,13	0,04	1,53	2,1

Conclusions

The purpose of this work was to determine the best geometrical characteristics of an overtopping ramp for maximizing the collected water volume, thus harnessing the maximum potential of the sea waves energy, and also to evaluate the convergence between the theoretically determined mean overtopping discharge volume and its experimentally measured values at the UniFi wave flume. According to the larobatory test results, the optimum ramp slope for maximizing the wave overtopping is the 1:2 (S2 scenario) with a freeboard height of 0,12m, which achieved a mean overtopping discharge rate per metre run of seawall of 2,1 l/s/m. In overall, the S2 case proved to be the best option, since its measured overtopping discharge rate values were higher compared to those of the S1 ramp. As for the differences between the theoretical calculated and the experimentally measured laboratory test results, in most of them their values were close enough, with no significant differences noticed in both cases (S1 and S2 models). It needs to be mentioned, however, that these results are subjected to the typical wave conditions of the Mediterranean Sea, while in other coastal areas different overtopping ramp geometrical characteristics may fit better than the S2 scenario. Finally, since the tests were conducted in a scaled model, future work must be focused on laboratory experiments conducted in ramp models of bigger size, closer to the 1:1 scale representative of a structure purposed to fit in a breakwater for harnessing wave energy.

References

Drew B., Plummer A.R., Sahinkaya M.N. (2009) A review of wave energy converter technology, Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, pp.887-902

Karambas T. (2015) Modelling of climate change impacts on coastal flooding/erosion, ports and coastal defense structures, Desalination and Water Treatment, vol.54, issue 8, pp.2130-2137

Kofoed J.P. (2002) Wave Overtopping of Marine Structures – Utilization of Wave Energy, PhD Thesis Dissertation, Aalborg University, December 2002

Margheritini L., Vicinanza D., Frigaard P. (2009) SSG wave energy converter: design, reliability and hydraulic performance of an innovative overtopping device, Renewable Energy, vol.34, issue 5, pp. 1371-1380

Martins J.C., Goulart M.M., Gomes M.N., Souza J.A., Rocha L.A., Isoldi L.A., Santos E.D. (2018) Geometric evaluation of the main operational principle of an overtopping wave energy converter by means of structural design, Renewable Energy, vol. 118, pp.727-741

Nordstrom K.F. (2014) Living with shore protection structures: A review, Estuarine, Coastal and Shelf Science, vol.150, part A, pp.11-23

Pillai K., Etemad-Shahidi A., Lemckert C. (2017) Wave overtopping at berm breakwaters: Experimental study and development of prediction formula, Coastal Engineering, vol.130, pp.85-102

Romosios G., Kiartzis S., Ice Build-Up on Wind Turbine Blades: Impacts on power performance and anti-icing solutions, Proceedings of the 23rd European Conference on Maintenance and Asset Management, Euromaintenance 2016, Athens, Greece, pp.339-345

Stagonas D., Müller G., Maravelakis N., Magagna D., Warbrick D. (2010) Composite seawalls for wave energy conversion: 2D experimental results, 3rd International Conference on Ocean Energy (ICOE), 6th October, Bilbao, Spain