15º
CONGRESSO
DA ÁGUA

RUN-UP MEASUREMENTS UNDER VERY OBLIQUE WAVE INCIDENCE

Rute LEMOS[1], Vera PINA[2], João Alfredo SANTOS[2,3], Conceição FORTES[1], Maria Teresa REIS[1]

1. LNEC - Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101, Lisboa, rlemos@lnec.pt, jfortes@lnec.pt, treis@lnec.pt

2. ISEL – Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Rua do Conselheiro Emídio Navarro, 1, Lisboa, A41697@alunos.isel.pt, jasantos@dec.isel.ipl.pt

3. CENTEC – Centre for Marine Technology and Ocean Engineering, Universidade de Lisboa, Av. Rovisco Pais, Lisboa

ABSTRACT

Under the scope of the HYDRALAB+ transnational access project, the so-called RODBreak was conducted in the directional wave basin at the Marienwerden facilities of the Leibniz University Hannover (LUH). A stretch of a rubble-mound breakwater was built in the wave basin with a very gentle slope and an armour layer made of Antifer cubes, at the roundhead and adjoining trunk, and rock, at the rest of the trunk.

A set of scale-model tests was carried out to extend the range of wave steepness values analysed in wave run-up, overtopping and armour layer stability studies, focusing on oblique extreme wave conditions, with incident wave angles from 40º to 90º.

The present study focuses on the analysis of measured wave run-up values obtained in a physical model and on its variability with wave parameters and wave obliquity.

PalavrasChave: rubble-mound breakwaters; run-up; oblique waves; physical modelling; RODbreak

1. INTRODUCTION

Most climate scenarios predict the sea-level rise, as well as increased intensity and frequency of storms (IPCC, 2013). Wave breaking / run-up / overtopping and their impact on the stability of rubble-mound breakwaters (both at trunk and roundhead) are not adequately characterized yet for climate change scenarios. The same happens with the influence of high-incidence angles on such phenomena.

To ensure an adequate performance for these coastal protection structures in such scenarios without having to increase the breakwaters' dimensions and the associated costs, it is mandatory to understand the influence of the wave attack angle on their response in what concerns wave run-up, wave overtopping and hydraulic stability.

In particular, wave run-up characteristics on coastal structures are crucial for predicting the occurrence of overtopping, for studying coastal flooding and/or for evaluating the impact of this phenomenon on people's safety, on the integrity of goods and infrastructure, and on the normal performance of economic activities at the areas protected by these structures.

2. SCIENTIFIC BACKGROUND

Several former investigations on wave run-up and overtopping of impermeable and permeable coastal structures aimed at quantifying the influence of oblique waves on mean overtopping discharge, water layer thickness and velocities through the development of empirical formulas of a reduction factor for wave obliquity (e.g. Nørgaard *et al.*, 2013). However, most of the formulas did not consider very oblique wave approach.

The existing data gaps triggered the present experimental work, whose main goal is to contribute to a better understanding of the phenomenon and optimize the calculation of the wave run-up for the freeboard design.

Previously to the RODbreak project, and aiming to fill this gap. Bornschein *et al* (2014), under the CornerDike-project, investigated wave run-up and wave overtopping under very oblique wave approach which revealed low influence of very oblique wave attack on wave run-up than in wave overtopping.

3. SCALE MODEL, INSTRUMENTATION AND WAVE CONDITIONS

A stretch of a rubble mound breakwater (head and part of the adjoining trunk, with a slope of 1(V):2(H)) was built in the wave basin of the LUH to assess, under extreme wave conditions (wave steepness of 0.055) with different incident wave angles (from 40º to 90º), the structure behaviour in what concerns wave run-up, wave overtopping and damage progression of the armour layer. Two types of armour elements (rock and Antifer cubes) were tested. The trunk of the breakwater is 7.5 m long and the head has the same cross section as the exposed part of breakwater. The total model length is 9.0 m, the model height is 0.82 m and its width is 3.0 m.

Fig 1 presents the physical model as well as a profile with detailed model dimensions.

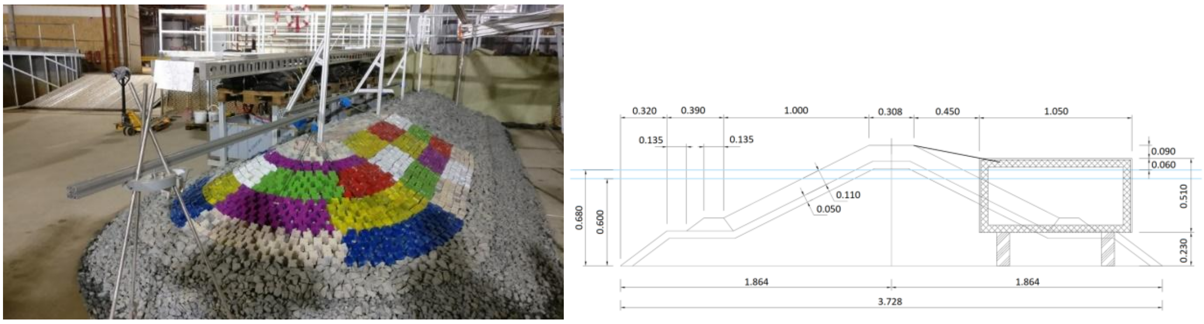

Fig. 1. Breakwater model

Incident and reflected sea waves were measured with three arrays (Fig. 2) made of six acoustic wave gauges. For the same propose, there were also 3 acoustic gauges in front of the structure. On the other hand, to measure the wave runup, five capacitive wave gauges were deployed over the armour layer: two at the head and three along the trunk. Finally, there were 3 acoustic wave gauges at the crest of the breakwater to identify the overtopping events. Fig. 2 presents the plan view of the breakwater model, where three different equipment categories can be distinguished according to the variables measured: sea waves; run up and overtopping.

Test series comprised long and short crested waves. Two water depths of 0.60 m and 0.68 m and five incidence wave angles (40^{o}, 55 ^{o}, 65 ^{o}, 75 ^{o} and 90 ^{o}) were considered for long crested waves, while for short crested waves only one water depth (0.60 m) was considered and 2 incident wave angles (40º and 65º), with a directional spreading of 50º. Given one water depth and one incident direction, it was possible to carry out one sequence of at least 4 tests for different wave conditions acting on the model (Hs = 0.100 m, 0.150 m, 0.175 m and 0.200 m and the corresponding peak periods Tp = 1.19 s, 1.45 s, 1.57 s and 1.68 s). A total of 52 tests were made.

4. RESULTS

In the present study, it was considered data from the test series T17-T20, conducted with a water depth of 0.60 m and Dir=65° (angle between the wave direction and the normal of the breakwater) and from the test series T40-T44, which were run with the same wave conditions and direction but with a directional spread of 50° (short-crested waves).A temporal analysis was carried out in the time series of the free surface elevation measured at each test at the wave gauges deployed at the head and the trunk of the breakwater following Götz, M. (2019) aproach. One of the computed wave run-up heights was $Ru_{2\%}$, which is is the wave run-up level, measured vertically from the still water level that is exceeded by 2% of the number of incoming waves (EurOtop, 2018). Ru_{max} and Ru_{min} were also calculated.

Table 1 presents the wave run-up results obtained during test series T17-T20 and T40-T44 (short-crested waves). The run up results refers to the gauges located at middle of the trunk and at the head of the breakwater, perpendicularly to the breakwater crest. The wave parameters (H_s and T_p) are those obtained in arrays 3.1 and 3.2 located on the vicinity of wave run-up gauges 4.1.2 and 4.1.4 respectively (see Fig. 2).

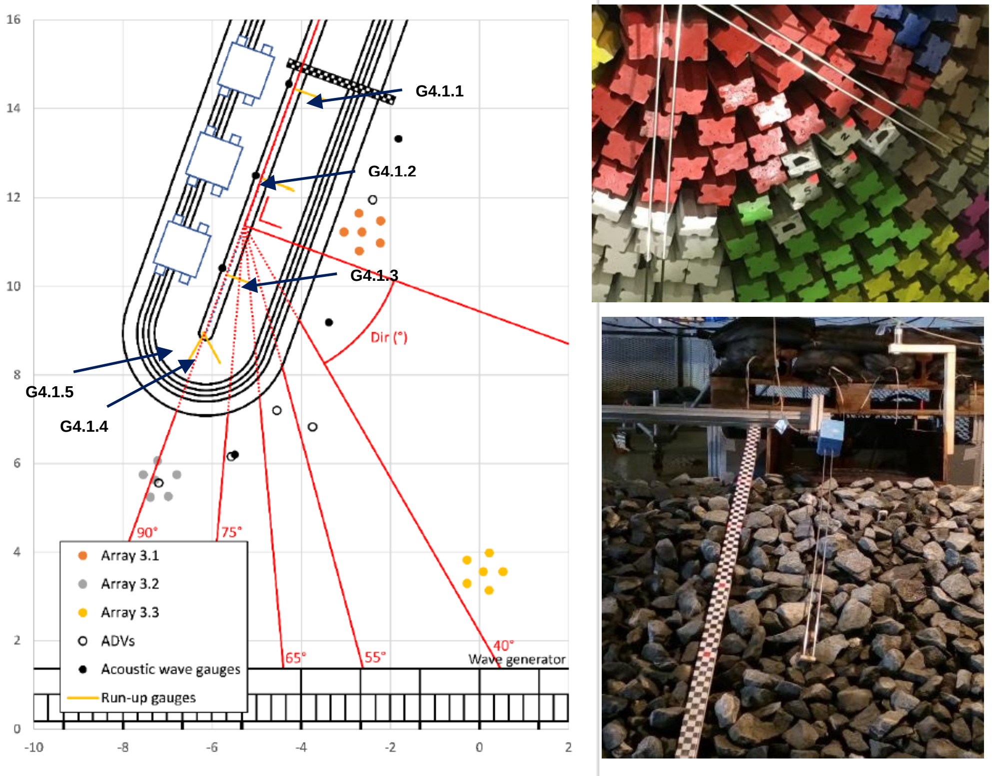

Fig. 2. Plan view of the model and equipment and wave directions

Table 1. Wave characteristics and wave run-up measured with gauges G4.1.2 and G4.1.4 for long and short-crested waves

		Target parameters		Measured parameters			Run up			
Test	Direct. Spread	Hs (m)	Tp (s)	Array	H_s (m)	T_p (s)	Gauge	Ru2% (m)	Rumax (m)	Rumin (m)
T017	0	0.1	1.19	3.1	0.106	1.205	4.1.2	0.0675	0.0787	0.0300
				3.2	0.107	1.205	4.1.4	0.1151	0.1338	0.0250
T018		0.15	1.45	3.1	0.157	1.460	4.1.2	0.0836	0.0981	0.0307
				3.2	0.151	1.460	4.1.4	0.1805	0.3840	0.0252
T019		0.175	1.57	3.1	0.174	1.575	4.1.2	0.0900	0.1134	0.0300
				3.2	0.171	1.575	4.1.4	0.1770	0.2108	0.0260
T020		0.2	1.68	3.1	0.191	1.695	4.1.2	0.1460	0.1951	0.0300
				3.2	0.193	1.695	4.1.4	0.1934	0.3836	0.0252
T040	50	0.1	1.19	3.1	0.099	1.198	4.1.2	0.0763	0.0879	0.0300
				3.2	0.110	1.205	4.1.4	0.1127	0.1387	0.0250
T041		0.15	1.45	3.1	0.133	1.460	4.1.2	0.0926	0.1073	0.0302
				3.2	0.152	1.460	4.1.4	0.1674	0.3785	0.0268
T042		0.175	1.57	3.1	0.149	1.575	4.1.2	0.1041	0.1227	0.0305
				3.2	0.174	1.575	4.1.4	0.1957	0.3787	0.0262
T043		0.2	1.68	3.1	0.171	1.709	4.1.2	0.1103	0.1346	0.0306
				3.2	0.193	1.709	4.1.4	0.2103	0.3790	0.0262
T044		0.2	1.68	3.1	0.203	1.869	4.1.2	0.1410	0.3169	0.0300
				3.2	0.238	1.869	4.1.4	0.2538	0.3761	0.0250

Fig. 3 presents the relative run-up, given by $Ru_{2\%}/H_{m0}$ as a function of the breaker parameter. This parameter, also known as surf similarity or Iribarren number is defined as $\xi_{m-1,0} = \tan\alpha/(H_{m0}/L_{m-1,0})^{½}$, where α is the slope of the front face of the structure and $L_{m-1,0}$ being the deep water wave length $gT_{m-1,0}^2/(2\pi)$. The relative run-up is given by $Ru_{2\%}/H_{m0}$.

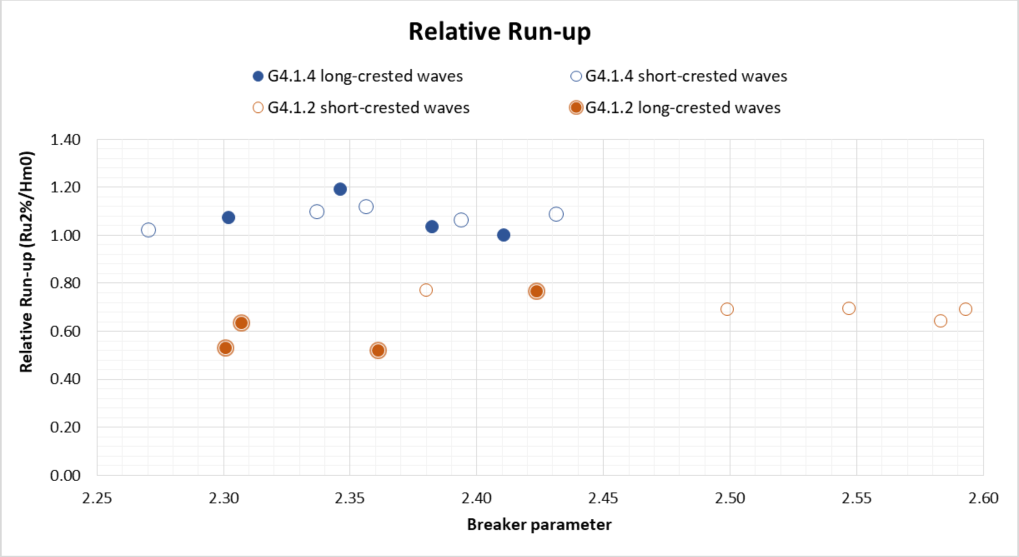

Fig. 3. Relative run-up as a function of the breaker parameter, for G4.1.2 and G4.1.4 for long and short-crested waves

5. DISCUSSION

The presented test cases (water depth of 0.60 m; Dir=65°) carried out with long and short-crested waves show that for those conditions, run up heights measured at the breakwater roundhead are higher than those measured at the trunk, both for long and short-crested waves. For tests with long-crested waves, the relative run-up measured at the middle of the trunk (trunk stretch with of rock armour units) seems to decrease with the wave height except for the highest wave height. In the wave gauge at the breakwater roundhead (made of regularly placed Antifer-cubes), relative run-up slightly increases with the lowest wave heights, decreasing with the highest wave heights. Tests with short-crested waves showed less variability of the relative run-up for both run-up wave gauges. The processing and analysis of the data obtained in the other tests is still going on.

AKNOWLEDGMENTS

This project has received funding from the H2020 research and innovation programme under grant agreement No 654110, HYDRALAB+. The project To-SEAlert, Ref. PTDC/EAM-OCE/31207/2017 is also acknowledged.

REFERENCES

Bornschein, A., Pohl, R., Wolf, V., Schüttrumpf, H., Scheres, B., Troch, P., Riha, J., Spano, M., Van der Meer, J. (2014). Wave run-up and wave overtopping under very oblique wave attack (CORNERDIKE-project). Proc. HYDRALAB IV Joint User Meeting, Lisbon, July.

EurOtop (2018). Manual on Wave Overtopping of Sea Defences and Related Structures. An Overtopping Manual Largely Based on European Research, but for Worldwide Application. Van der Meer, J.W., Allsop, N.W.H., Bruce, T., De Rouck, J., Kortenhaus, A., Pullen, T., Schüttrumpf, H., Troch, P. and Zanuttigh, B., www.overtopping-manual.com

Götz, M. (2019). Wave Run-Up at Mole Structures. Master Thesis, Technische Universitat Dresden.

IPCC, Climate change (2014). Synthesis report. Contribution of working groups I, II and III, in: R.K. Pachauri, L.A. Meyer (Eds.), Fifth Assessment Report of the Inter. Panel on Climate Change, IPCC, Geneva, 2014

J.Q.H. Nørgaard, T. Lykke Andersen, H.F. Burcharth, G.J. Steendam (2013). Analysis of overtopping flow on sea dikes in oblique and short-crested waves, Coast. Eng. 76, 43–54.