

# RUN-UP AT RUBBLE MOUND BREAKWATERS WITH SUBMERGED BERM: AN EXPERIMENTAL STUDY

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## ABSTRACT

In the recent years, the effects of climate change are becoming increasingly evident (e.g., Naughten et al., 2023; Pörtner et al., 2022).

Sea level rise, change in the intensity of storm surge, and wave heights are typical consequences of climate change in the coastal environment (e.g., Toimil et al., 2020).

Therefore, coastal structures deployed to protect coastlines and harbors from wave action, may become ineffective due to the potential increase of wave loads, run-up, and overtopping phenomena (e.g., Galiatsatou et al., 2018).

Indeed, several adaptation measures for existing coastal structures have been proposed (e.g., Burcharth et al., 2014).

Past research studies illustrated how the deployment of a berm in the seaward side of conventional rubble mound breakwaters can significantly improve the performance of the structure. (e.g. Van Gent, 2013; Celli et al., 2018; Celli et al., 2021).

Basically, the presence of a berm enhances the wave energy dissipation at the toe of the armor layer. Besides the stability of the structure, this could be effective in the reduction of wave run-up, and overtopping phenomena, potentially.

To investigate the role of the submerged berm on the wave run-up phenomenon, a series of 2D experimental tests is being carried out at the Environmental and Maritime Hydraulic Laboratory (Llam) of the University of L'Aquila (see Figure 1).



Figure 1 - Experimental test on wave run-up at rubble mound breakwater with submerged berm at the University of L'Aquila.

The wave flume (45 m long, 2 m high and 1.5 m wide) is equipped with a piston-type wave generator (stroke 0.75 m) that can be used to generate either regular or irregular waves characterized by target spectra (i.e. JONSWAP, PM, etc.). The wave generator system is equipped with

an Active Reflection Compensation System based on the real-time reflection analysis proposed by Frigaard & Brorsen (1995)

A parametric study is being performed by varying the berm configuration (length  $L_b$  and height  $h_b$ , see Figure 2), the offshore wave conditions ( $H_s$  and  $T_p$ ) and the water depth at the toe of the breakwater ( $h_t$ ), keeping constant the values of the porosity of the berm, the armor layer and the core.

The results of the ongoing experimental investigation will be presented at the conference. They are aimed to provide insight into the efficacy of submerged berms in reducing run-up.

The run-up time histories are being collected by means of an in-house developed digital run-up step gauge (similar to the one developed by Van de Walle et al., 2006), made of several steel rods orthogonal to the slope, operating as electrodes connected to a microcontroller.

At constant frequency the microcontroller checks the status of each electrode (wet or dry), calculating the run-up height according to the position of the last wet electrode.

Based on the experimental results, a new formulation for estimating wave run-up is proposed when submerged berms are deployed.

The idea is upgrading the formulation provided by Van der Meer & Stam (1992) for permeable slopes:

$$\frac{R_{x\%}}{H_s^T} = d \quad (1)$$

where ( $R_{x\%}$ ) is the  $x$  per cent run-up level,  $d$  is a variable parameter according to the run-up level index  $x$ , and  $H_s^T$  is the significant wave height at the toe of the breakwater. Then, the strategy is to include the physical phenomena occurring when incident waves propagate on the berm, affecting the wave heights on the upper slope armor.

Basically, the significant wave height evaluated at the toe of the breakwater should be replaced by the significant wave height evaluated on the berm. In other words, by introducing a new parameter  $\delta$ , equation (1) reads:

$$\frac{R_{x\%}}{\delta H_s^T} = d \quad (2)$$

where  $\delta = \left(\frac{H_s^B}{H_s^T}\right) = f\left(\frac{L_B}{L_W}, \frac{h_B}{h_T}\right)$  and  $L_W$  is the wavelength at the toe of the berm.

To find the dependence of  $\delta$  upon the dimensionless

groups  $\frac{L_b}{L_w}$  and  $\frac{h_b}{h_t}$  the experimental findings will be used. The same approach was adopted by Celli et al., 2018 to find the dependence of the parameter  $\gamma = \left(\frac{H_{2\%}^B}{H_{2\%}^T}\right)$  on the same dimensionless groups.

The usefulness of the formula lies as much in upgrading existing breakwaters as in new structures.

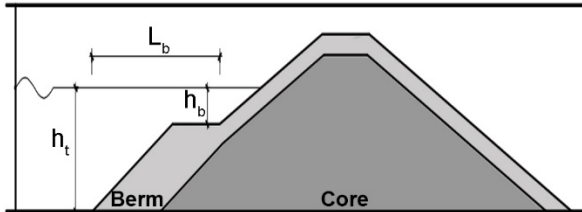


Figure 2 - Sketch of the problem and of the investigated parameters.

REFERENCES

Naughten, Holland & De Rydt, (2023). Unavoidable future increase in West Antarctic ice-shelf melting over the twenty-first century. *Nat. Clim. Change*.

Pörtner, Roberts, Tignor, Poloczanska, Mintenbeck, Alegría, Craig, Langsdorf, Löschke, Möller, Okem, Rama. IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press. 3056 pp.

Toimil, Losada, Nicholls, Dalrymple, & Stive, (2020). Addressing the challenges of climate change risks and adaptation in coastal areas: A review. *Coastal Engineering*, 156, 103611.

Galiatsatou, Makris, & Prinos, (2018). Optimized reliability based upgrading of rubble mound breakwaters in a changing climate. *Journal of Marine Science and Engineering*, 6(3), 92.

Burcharth, Andersen, & Lara, (2014). Upgrade of coastal defence structures against increased loadings caused by climate change: A first methodological approach. *Coastal Engineering*, 87, 112-121.

Celli, Pasquali, De Girolamo, & Di Risio, (2018). Effects of submerged berms on the stability of conventional rubble mound breakwaters. *Coastal Engineering*, 136, 16-25.

Celli, Pasquali, Fischione, Di Nucci, & Di Risio, (2021). Wave-induced dynamic pressure under rubble mound breakwaters with submerged berm: An experimental and numerical study. *Coastal Engineering*, 170, 104014.

Shankar, & Jayaratne, (2003). Wave run-up and overtopping on smooth and rough slopes of coastal structures. *Ocean Engineering*, 30(2), 221-238.

Frigaard & Brorsen, (1995). A time-domain method for separating incident and reflected irregular waves. *Coastal Engineering*, 24 (3-4), 205-215.

Van de Walle, Versluys, Troch, & De Rouck, (2006). Digital step gauge measurement system for wave run-up measurements at full scale and in scale model tests.

Van der Meer & Stam. (1992). Wave runup on smooth and rock slopes of coastal structures. *Journal of waterway, Port, coastal, and Ocean Engineering*, 118(5), 534-550.