The relation between sand and overtopping for cobble revetments: a numerical approach

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INTRODUCTION

For the extension of the Rotterdam port in the Netherlands, a novel type of coastal defence structure has been built: a dynamic cobble revetment. During the recent years sand has washed-in between the cobbles altering its hydrodynamic performance. Currently no relations exist that can accurately predict this change in overtopping performance. As physical experiments on a scale large enough to prevent Reynolds (permeability) scale effects are both very costly and time consuming, numerical models are becoming a serious alternative (Jacobsen et al., 2015; Losada, et al., 2016). In this study the influence of a decrease in porosity and related cobble layer thickness on the overtopping performance is studied using a numerical model.

COMPUTATIONS

OpenFOAM with the waves2foam toolbox was identified as a suitable numerical model for simulating overtopping on a cobble revetment. For the validation of the CFD model physical experiments conducted in the Delta Flume (scale 1:5) for the design of the Maasvlakte2 revetment (Deltares, 2007), are used. In the experiments cobble layers with and without sand washed-in have been exposed to irregular waves. Overtopping occurred in both experiments. The numerical model has been set up and a thorough mesh sensitivity analysis has been conducted in the process.

Figure 1 - The cobble beach at the northwestern part of the Maasvlakte II, the Rotterdam port extension.

As the cobbles are numerically modelled as a rigid porous medium, the numerical overtopping discharges are obtained by averaging the results of two simulations for each experiment: one using the cross shore profile measured at the start and the other profile measured at the end of that experiment. The validation of the model shows a good capability of the code to numerically reproduce the overtopping discharge measured in the DELTA Flume: discrepancy between 1 to 25% are identified for the cobble layer with and without washed-in sand, respectively. The process of washing-in of sand in the cobble layer is schematized by two dominant processes: (i) change in porosity, and (ii) reduction of the effective cobble layer thickness. 16 simulations of a schematized cobble slope have been completed to quantify these influences on the overtopping discharge.

ANALYSIS

The idea is that a part of the volume of the overtopping wave run-up tongue is sinking into the pores of the cobble revetment and does not overtop; somewhat similar to Van Steeg et al. (2016). In order to capture this behaviour a new dimensionless number, which accounts for the total volume of pores between the cobbles above the mean waterline (pore volume number), is proposed: $(n_p\, R_c \sqrt{1+cot^2\alpha}\ T_c)/\ H_{m0}^2$.

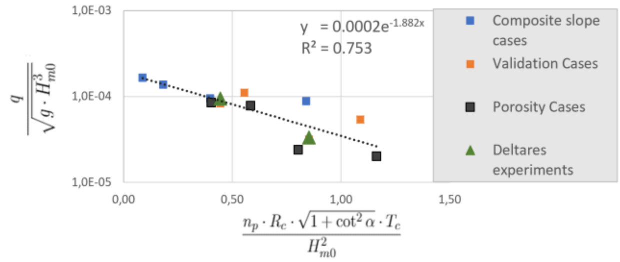

Figure 2 - roughness factor as a function of relative pore volume of the cobble slope.

In which n_p is the porosity, R_c the crest height, α the slope of the revetment above the water line, T_c the effective thickness of the cobble layer above the water line and H_{m0} the spectral wave height. When the relative pore volume number is set out against the dimensionless overtopping discharge, $q/g^{0.5}H_{m0}^{1.5}$, it shows a decreasing logarithmic relation between the pore volume number, and the relative overtopping discharge in the parameter space covered in this research. The volume of pores above the mean water level is thus correlated to a reduction in overtopping. This reduction in overtopping as also formulated as an influence factor for roughness, γ_f, in the general formula for predicting the mean overtopping discharge on a slope (Van der Meer, 2018). γ_f is given as a function of the relative pore volume. The applicability limits of the formula are discussed.

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