A LABORATORY STUDY ON WAVE OVERTOPPING AT VERTICAL SEAWALLS WITH A SHINGLE FORESHORE

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INTRODUCTION

The existing empirical prediction formulae to determine the wave overtopping characteristics are mainly based on the laboratory measurements with the use of an impermeable foreshore slope in front of the structure. Recently, EurOtop (2016), an updated version of previous overtopping manual has been published with revised empirical equations to estimate mean overtopping discharge rates at plain vertical walls with and without foreshore, see Equations 1 - 3 considering a foreshore slope in front of the vertical wall.

For non-impulsive conditions ($\mathrm{h}^2/(\mathrm{H}_{\mathrm{m}0}\mathrm{L}_{\mathrm{m}-1,0}) > 0.23$),

$$\frac{q}{\sqrt{gH_{m0}^3}} = 0.05\exp\left(-2.78\frac{R_c}{H_{m0}}\right) \qquad (1)$$

For impulsive conditions ($\mathrm{h}^2/(\mathrm{H}_{\mathrm{m}0}\mathrm{L}_{\mathrm{m}-1,0}) \leq 0.23$),

$$\frac{q}{\sqrt{gH_{m0}^3}} = 0.011\left(\frac{H_{mo}}{hs_{m-1.0}}\right)^{0.5}\exp\left(-2.2\frac{R_c}{H_{m0}}\right) \qquad (2)$$

valid for $0 < R_c/H_{m0} < 1.35$

and

$$\frac{q}{\sqrt{gH_{m0}^3}} = 0.0014\left(\frac{H_{mo}}{hs_{m-1.0}}\right)^{0.5}\left(\frac{R_c}{H_{mo}}\right)^{-3} \qquad (3)$$

valid for $R_c/H_{m0} \geq 1.35$

where, H_{mo} is the spectral significant wave height, R_{c} is the crest freeboard of the structure, h is the water depth at the toe of the structure, g is the gravitational acceleration (=9.81 m/s^2), q is the mean overtopping discharge per meter structure width, $\mathrm{L}_{\mathrm{m}-1.0}$ is the wave length based on spectral wave period $\mathrm{T}_{\mathrm{m}-1.0}$ and $\mathrm{s}_{\mathrm{m}-1.0}$ is the statistical wave steepness.

As past studies were mostly carried out at vertical seawalls on a fixed impermeable bed, little knowledge is available on the performance of these processes at coastal structures on a permeable shingle beach. This study presents the baseline overtopping characteristics at a plain vertical wall on an impermeable 1:20 foreshore slope, and compares the results with existing empirical predictions (EurOtop, 2016). In this paper, only the results on mean overtopping discharge and mean sediment rate at vertical walls are reported.

KEYWORDS
Overtopping, mobile bed, sediment discharge and Vertical wall.

EXPERIMENTAL SET UP

The physical model tests were performed in a 2D wave flume within the school of engineering at the University of Warwick. The wave channel has a length of 22 m, an operating depth of 0.40 m-0.70 m and a width of 0.60 m. A sloping beach with a uniform slope of 1:20 was constructed in front of the vertical seawall to generate depth limited waves. The cross section of the experimental set up is presented in Figure 1.

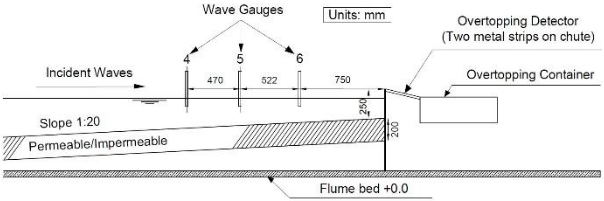

Figure 1 - Cross-section of the laboratory test set-up, as used in Salauddin and Pearson (2018)

A 1:50 length scale was applied to generate random sea wave conditions within the flume. For this study, a matrix of 180 test conditions (wave steepnesses, crest freeboards, water depths, shingle sizes) was performed to investigate overtopping and toe scouring at vertical seawall under both breaking and non-breaking conditions, see Table 1. All the tests are performed with 1000 random waves using a JONSWAP energy spectrum. For the tests on a permeable beach, the sloping foreshore was built with the use of shingle beach materials. In this work, filtered anthracite coal was used as beach materials to represent a permeable shingle bed in front of a vertical seawall. The filtered anthracite crushed coal has a specific gravity of 1.40. As per method described by Powel (1990), at a 1:50 scaling, model beach materials d_{50} of 2.10 mm and 4.20 mm are designed to represent prototype grain diameter d_{50} of 13 mm and 24 mm respectively.

Table 1: Overview of test conditions [refer this table]

Structural configuration	Bed configuration	Toe water depth, h_t [m]	Crest Freeboard, R_c [m]	Deep water wave steepness, s_{op} [-]	Wave height, H_{m0} [m]
Vertical Seawall	wood/shingle d_{50} of 13 mm/ shingle d_{50} of 24 mm)	0.060	0.190	0.02	0.05 - 0.16
				0.05	
	wood/shingle d_{50} of 13 mm/ shingle d_{50} of 24 mm)	0.075	0.245	0.02	0.05 - 0.16
				0.05	
	wood/shingle d_{50} of 13 mm/ shingle d_{50} of 24 mm)	0.100	0.150	0.02	0.05 - 0.16
				0.05	
	wood/shingle d_{50} of 13 mm/ shingle d_{50} of 24 mm)	0.150	0.100	0.02	0.05 - 0.16
				0.05	
	wood/shingle d_{50} of 13 mm/ shingle d_{50} of 24 mm)	0.180	0.140	0.02	0.05 - 0.16
				0.05	
	wood/shingle d_{50} of 13 mm/ shingle d_{50} of 24 mm)	0.200	0.050	0.02	0.05 - 0.16
				0.05	

RESULTS AND DISCUSSIONS

Figure 2 compares the measured mean overtopping rates at a plain vertical wall on shingle beds with overtopping characteristics observed in reference case (impermeable bed) under impulsive conditions. The resulting data points correspond to impermeable bed show an overall good agreement with the empirical predictions for breaking wave conditions. A noticeable reduction on the mean overtopping rate can be reported in Figure 2 with the use of permeable shingle beds when compared with the test results on solid beach configurations. The maximum reduction was observed for the experiments with largest size of shingle beach (d_{50} of 24 mm).

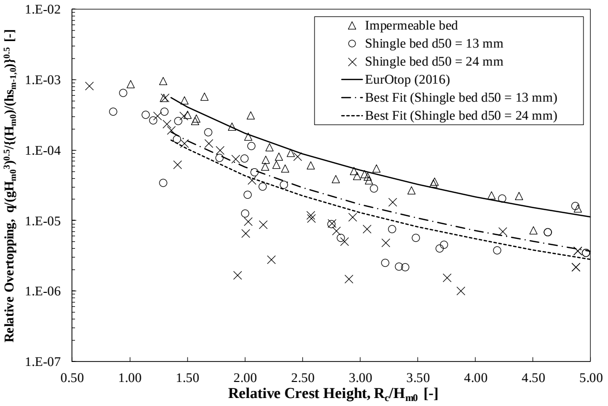

Figure 2 – A comparison between the test results and empirical prediction, subjected to impulsive conditions

The 'best-fit' analysis (R_c/H_{m0} ≥1.35) on the tested conditions showed that the overtopping discharges were reduced by approximately a factor of 3 for shingle beach of d_{50} of 13 mm and around a factor of 4 for shingle beach of d_{50} of 24 mm, when compared to the empirical prediction of EurOtop (2016) for impermeable beach configurations (Equation 3).

Figure 3 shows a comparison between the average overtopping rate at plain vertical walls on the shingle foreshores and impermeable foreshore under non-breaking wave conditions. The results of this study showed that permeable shingle foreshore provides a reduction in the overtopping discharge at vertical seawalls, compared to solid beach configuration. A 'best-fit' analysis was performed on the shingle bed data under non-impulsive conditions which showed that for the tested conditions, average overtopping rates were reduced by approximately a factor of 1.5 for shingle bed of d_{50} of 13 mm and about a factor of 2 for shingle bed of d_{50} of 24 mm when compared to the empirical prediction (Equation 1) of EurOtop (2016).

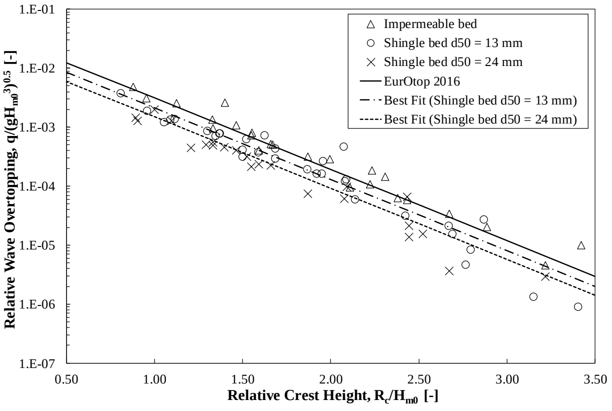

Figure 3 – A comparison between the test results and empirical prediction, subjected to non-impulsive conditions

For the experiments with mobile shingle beds, alongside the mass of overtopped water, the mass of overtopped sediment was simultaneously measured to determine the average overtopping sediment discharge. In Figure 4, the measured average overtopping rate of sediment and water at a plain vertical wall on a shingle foreshore is plotted against the relative freeboard of the structure, subjected to impulsive wave conditions. It should be noted that the overtopping of sediment was not observed for the tested conditions on non-impacting and impacting waves $(h^2/(H_{m0}L_{m-1,0}) > 0.03)$.

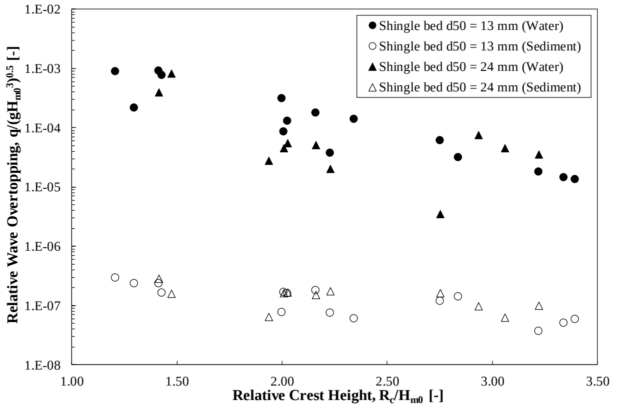

Figure 4 – Mean overtopping discharge of sediment and water at a plain vertical wall with a shingle foreshore

Overall, the data points in Figure 4 demonstrate that measured volume of sediment passing the crest of the structure is around 1% of the volume of overtopped water. However, one of the main impression from this graph is one of very scatter therefore based on the test results it is not possible to derive an empirical relationship through best-fitting analysis for the estimation of sediment.

CONCLUSIONS

Detailed measurements have been carried out to parameterize the mean overtopping rate and mean sediment rate on a plain vertical seawall, for both impermeable and mobile shingle beach configurations. Within experimental limitations, the resulting overtopping characteristics correspond to solid impermeable bed showed an overall good agreement with the predictive method of EurOtop (2016) under both impulsive and non-impulsive wave conditions.

The results of this study demonstrated that the mean overtopping rate is reduced by factor 3 and 4 for d_{50} of 13 mm and 24 mm respectively under impulsive conditions, when impermeable and permeable shingle beaches are compared. The observed reduction factors were 1.5 for d_{50} of 13 mm and 2 for d_{50} of 24 mm for non-breaking wave conditions. Under breaking conditions, in the range of $h^2/(H_{m0}L_{m-1,0}) < 0.03$, the measured volume of sediment passing the crest of the seawall was around 1% of the total volume of the overtopped water.

REFERENCES

EurOtop (2016): EurOtop II - Manual on wave overtopping of sea defences and related structures: An overtopping manual largely based on European research, but for worldwide application.

Pearson (2010): Overtopping and Toe Scour at Vertical Seawalls. Proceedings of the 9th international conference on Coasts, marine structures and breakwaters: Adapting to change, Edinburgh, Institution of Civil Engineers, Thomas Telford Ltd, pp. 598-608.

Powell (1990): Predicting short term profile response for shingle beaches. Wallingford, UK, HR Wallingford, Report SR 219.

Salauddin (2018): Overtopping of vertical structures: new prediction methods to account for shingle beaches. Paper has been accepted for an oral presentation in the 7th International Conference on the Application of Physical Modelling in Coastal and Port Engineering and Science (Coastlab18), 22nd May - 26th May 2018, Santander, Spain.