STOCHASTIC BOUNDARY UNCERTAINTY IN MEAN WAVE OVERTOPPING RATE ESTIMATES

Nikos Kalligeris, National Observatory of Athens, nkalligeris@noa.gr
Timu Gallien, University of California, Los Angeles, tgallien@ucla.edu

INTRODUCTION

Accurate backshore flood prediction requires quantifying overtopping volumes. Wave overtopping can be predicted through empirical formulas (e.g., EurOtop), neural networks or numerical modeling. The first two methods are easy to implement and provide rapid estimates for engineering design. However, empirical estimates reflect average overtopping rates, cannot resolve impulsive individual wave overtopping volumes or infragravity energy, and may differ from observational or numerical estimates by an order of magnitude (e.g., Gallien, 2016). Numerical models present an attractive alternative, however, predictions in phase-resolving models for spectral boundary conditions (BCs) vary due to the stochastic transformation to the time-domain, leading to significant errors in overtopping estimates when the prediction uncertainty is not accounted for.

The numerical or experimental BCs time length plays a key role in the uncertainty of the mean overtopping rate predictions, since longer sampling periods reduce the variation of the mean value according to the theory of statistic inference. Pullen et al. (2007) suggested that using a 1000 input waves leads to reasonably consistent statistical overtopping parameters. Williams et al. (2014) numerically and experimentally considered overtopping discharge uncertainty using 500 simulations of a 1000 input waves for different sets of BCs and showed that discharge uncertainty increases as the number of overtopping waves decreases. The purpose of this study it to derive an analytical formula for the coefficient of variation of the mean overtopping rate, applicable to all cases for which overtopping volumes are Weibull-distributed. Theory is used to provide guidance on estimating the uncertainty of numerical modeling predictions given the number of simulated waves.

THEORETICAL DERIVATION

Assuming overtopping volumes are independent Weibull-distributed random variables (e.g., EurOtop), we develop theoretical formulas for the coefficients of variation of the probability of wave overtopping (CV_{Pow}) and mean overtopping rate (CV_q) as a function of the overtopping probability (P_{ow}) and number of input (simulated) waves (N_w):

$$CV_{P_{ow}} = \sqrt{\frac{1-P_{ow}}{N_w P_{ow}}} \qquad (1)$$

$$CV_{\bar{q}} = \sqrt{\frac{CV_V^2 + 1 - P_{ow}}{N_w P_{ow}}} \qquad (2)$$

CV_V is the coefficient of variation of the individual overtopping volumes, which for the Weibull distribution is expressed as a function of the shape parameter b:

$$CV_V = \frac{\sqrt{\Gamma(1+2/b) - [\Gamma(1+1/b)]^2}}{\Gamma(1+1/b)} \qquad (3)$$

NUMERICAL TEST CASES

Equations 1&2 are compared to results from SWASH simulations for a sample bathymetric profile using four different (offshore) JONSWAP boundary conditions (Figure 1). For each test case, we run 500 simulations of N_w = 1000, changing the stochastic phase shifts in each simulation. The comparison leads to interesting observations for practical applications. The small deviations from the theoretical predictions are discussed.

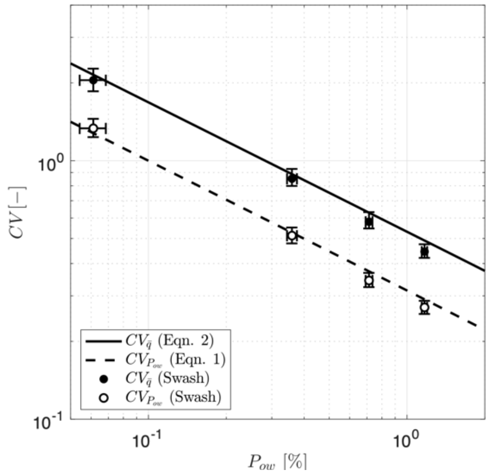

Figure 1 The theoretical prediction of CV_q and CV_{Pow} across a range of overtopping probabilities using N_w=1000 and the average shape parameter b = 0.75. Circles show the SWASH numerical results. The bars reflect the 95% confidence intervals along each axis based on the (500) samples.

REFERENCES

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, Allsop, Bruce, De Rouck, Kortenhaus, Pullen, Schüttrumpf, Troch, Zanuttigh.

Gallien (2016): Validated coastal flood modeling at Imperial Beach, California: Comparing total water level, empirical and numerical overtopping methodologies, Coastal Engineering, vol. 111, pp. 95-104.

Pullen et al. (2007): EurOtop wave overtopping of sea defenses and related structures: assessment manual.

Williams, Briganti, Pullen (2014): The role of offshore boundary conditions in the uncertainty of numerical prediction of wave overtopping using non-linear shallow water equations, Coastal Engineering, vol. 89, pp. 30-44.