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Estimates of uncertainties in near-shore hydraulic boundary conditions in design studies

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Accurate estimates of local wave climate properties are an important issue in the design of sea defence structures. Due to several processes in shallow foreshores the local wave characteristics can be significantly different from those at open sea. The wave conditions at open sea are often available from measurements or in the form of predictions generated by large scale numerical wave models. These open sea wave conditions must then be translated appropriately to the near shore position of the coastal defence structure. For this translation numerical wave models can be used. In this way important local physical processes are explicitly taken into account such as wave breaking and the generation of low-frequency energy on shallow foreshores, non-linear wave behaviour and frequency dispersion. Nevertheless, several uncertainties remain and one of these is the foreshore's bed position. In fact, sandy foreshores can vary significantly during storms, while seasonal or other long term variations or trends may be present as well. Field measurements at the Petten Sea Defence in the Netherlands have revealed bed variations of the order of 1 m during storms.

In the present study an uncertainty analysis has been carried out to verify how such variations (actually: uncertainties) in the foreshore's bed position affect the translation of open sea wave conditions to a near shore position. An existing and validated 2D Boussinesq-type wave model has been applied to simulate the wave transformation from offshore to near shore at the Petten Sea Defence. Boussinesq-type wave models are an attractive way to model wave dynamics in coastal regions, since they can take into account all important local physical processes.

A stochastic model has been developed for a realistic and quantitative description of the uncertainties in the bed profile. From the probability distributions of the (random) parameters in this model, an ensemble of realisations has been generated. For each of these realisations of the bed profile the model has been applied to obtain an estimate for the near shore wave parameters such as the significant wave height and the wave period. This ensemble of estimates provides an (empirical) probability distribution of the near shore wave parameters. From this distribution all kind of statistical properties (mean, spread, skewness, quantiles, etc.) and uncertainty measures ($e.g.$, confidence interval) can be derived.

Analysis of the results showed that there can be a significant spread in the distribution of both the wave height and the wave period. Based on realistic variations in the bottom profile, the 5%-quantile ($i.e.$, the value that is exceeded in 5% of the model simulations) of the wave height is 19% higher than the value based on the reference bottom profile, whereas the 5%-quantile of the wave period is 20% higher than value of the wave period based on the reference bottom profile. The latter reflects an increase in the amount of low frequency energy. In design studies such large uncertainties in near shore hydraulic boundary conditions may significantly affect the design and assessment of the safety of the sea defence structures. $E.g.$, in case of the design of the crest level of a sea defence, the amount of low-frequency energy is of special importance, since the low-frequency waves significantly affect processes like wave run-up and wave overtopping at sea defences. An increase of both the wave height and the wave period requires significant higher crest levels. Or stated otherwise, neglecting uncertainties in the bottom profile results in a crest level that has a significant lower safety level than the safety level on which the crest level design is based.