IMPROVED SEMI-EMPIRICAL MODEL FOR THE SPECTRAL WAVE PERIOD ON SHALLOW FORESHORES

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INTRODUCTION

The spectral wave period $T_{m-1,0}$ is one of the most widely used characteristic wave periods in coastal engineering for the estimation of wave reflection (Zanuttigh and van der Meer, 2008), wave run-up and overtopping (Altomare et al., 2016; van Gent, 1999), and toe and armour stability (Etemad-Shahidi et al., 2021, 2020), especially in the case of coastal structures on shallow foreshores. These coastal structures are becoming more common due to sea level rise, through adaptation of existing coastal defenses (i.e., hybrid blue-grey nature-based solutions) by e.g., beach and dune nourishments in front of dikes, or through construction of coastal defense structures on existing shallow and very mildly sloped mud-flats and salt marshes, or on reef flats with steeply sloped fore reefs.

An interesting aspect of $T_{m-1,0}$ compared to other wave periods typically used in empirical modelling (e.g., the peak wave period T_p), is that it is able to better represent the energy distribution in the wave spectrum of an irregular sea state in case of more complex spectrum shapes (e.g., double-peaked sea-swell spectra, flattened spectra in surf zones,…). $T_{m-1,0}$ is defined by $T_{m-1,0} = \frac{m_{-1}}{m_0}$, calculated with the spectral moments m_{-1} and m_0, defined by $m_n = \int f^n S(f) df$, for n = -1 and 0. In particular, $T_{m-1,0}$ is able to represent the presence of infragravity (IG) wave energy (0.003 Hz < f < 0.05 Hz) in the spectrum well, even when there is still a significant (even dominant) amount of sea-swell (SS) wave energy (0.05 Hz < f < 1 Hz) present. IG waves affect interactions with coastal structures on a shallow foreshore, so their presence should be included in the description of those physical processes. The spectral wave period is not only a good representation of the relative magnitude of IG to SS wave energy, but also takes the energy distribution over the IG frequency range in the spectrum into account (i.e., higher $T_{m-1,0}$ value for the same IG wave energy at a lower frequency).

The spectral wave period at the toe of a coastal structure $T_{m-1,0,t}$ (subscript "t" for toe) is usually needed in the application of empirical formulas (incident, i.e., without presence of the coastal structure). For an efficient estimation of $T_{m-1,0,t}$ (e.g., in the conceptual design process), Hofland et al. (2017) (hereafter H17) developed the first prediction formula:

$$\tau = 1 + c_1 exp(-c_2 \tilde{h}) + c_3 exp(-c_4 \tilde{h}) \qquad (1)$$

where $\tau = T_{m-1,0,t}/T_{m-1,0,o}$ is the increase of the spectral wave period at the toe relative to offshore, c_1 = 6, c_2 = 4, c_3 = 1, c_4 = 1 are calibration coefficients, and $\tilde{h}$ is the relative water depth at the toe, defined as:

$$\tilde{h} = \frac{h_t}{H_{m0,o}} \left(\frac{\cot\theta}{100}\right)^{c_5} \qquad (2)$$

where h_t is the water depth at the toe, $H_{m0,o}$ is the significant wave height with subscript "o" for offshore, and c_5 = 0.2 is a calibration coefficient. The model of H17 is valid for mild slope conditions $0.02 < \beta_b < 0.35$ (β_b is the normalized bed slope parameter $\beta_b = \frac{\tan\theta}{\omega_{IG}} \sqrt{\frac{g}{h_b}}$).

However, in other studies based on both physical (Gruwez et al., 2018) and numerical modelling (Lashley et al., 2022; Nguyen et al., 2020) of varied foreshore slopes, an important residual dependence of τ on the foreshore slope was observed, that is not taken into account in the prediction model of H17.

In the present work, we evaluate the model of H17 with a re-analyzed and extended dataset, covering a much wider range of foreshore slopes. Based on this dataset, the prediction model is improved.

DATASETS

In order to improve the prediction model for τ, the datasets used by H17 were re-analyzed, and new datasets were collected from the state-of-the-art since H17. This resulted in a new collection of datasets where the effect of spurious waves on τ were minimized and a much larger range of foreshore slopes were included. The new datasets were further homogenized (i) by standardizing the calculation method for both $T_{m-1,0,o}$ and $T_{m-1,0,t}$, (ii) by excluding data where a transition slope influenced τ, and (iii) by correcting the SWL based on the wave set-down in the physical model data. Datasets DS01 and DS02 (Van Gent, 1999) are physical model data for foreshore slopes 1/100 (V/H) and 1/250, DS11 for slope 1/35 (Altomare et al., 2020), and DS14 for slopes 1/20, 1/35, 1/50 and 1/80 (Gruwez et al., 2018). DS13 are numerical data using non-hydrostatic XBeach for slopes from 1/10 to 1/1000 (Lashley et al., 2020).

RESULTS AND DISCUSSION

In Fig. 1 a large residual effect of the foreshore slope is observed for the new datasets compared to the original model by H17. Especially for the very mildly sloping foreshores (< 1/250) and the steeper foreshore slopes (> 1/50). Even though most of the data fall within the applicability range of H17, significant under- and overestimations for most of the data are observed (mild and steep foreshores, respectively), with a coefficient of determination R^2 of 0.14.

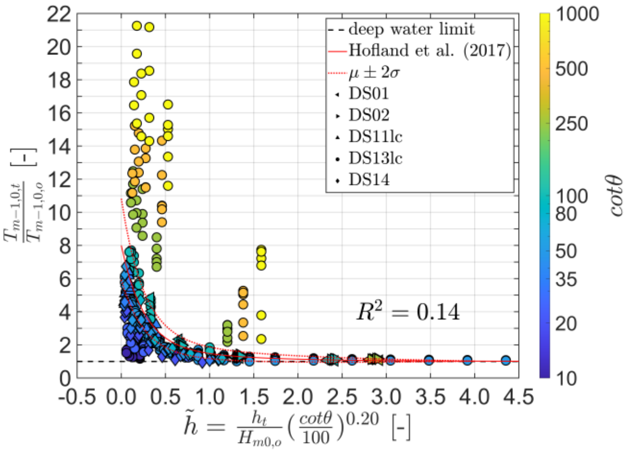

Figure 1 - The relative increase of $T_{m-1,0,t}$ for long-crested waves over mildly sloped foreshores versus relative water depth. Evaluation of H17 with new datasets.

The improved model uses an adapted definition for the relative water depth (Eq. (2)):

$$\tilde{h}_{new} = \left(\frac{h_t + AH_{m0,o}}{H_{m0,o}}\right)\left(\frac{\cot\theta}{100}\right)^{c_{new}} \tag{3}$$

where a proxy for the wave setup ($AH_{m0,o}$, with proportionality coefficient A) was added to the water depth at the toe h_t to prevent unphysical behavior for emergent toe cases (h_t < 0). The best model fit was obtained for $A = 0.5$ and $c_5 = -0.3$ in Eq. (3) and $c_1 = 45.8$, $c_2 = 3.26$, $c_3 = 0.28$ and $c_4 = 0.25$ in Eq. (1), and increased R^2 significantly to 0.96 (Fig. 2). In addition, a similar width of the error band of the improved model was obtained compared to the original H17 model, even though having been fit to a much larger dataset (i.e., 504 data compared to 181 data used by H17).

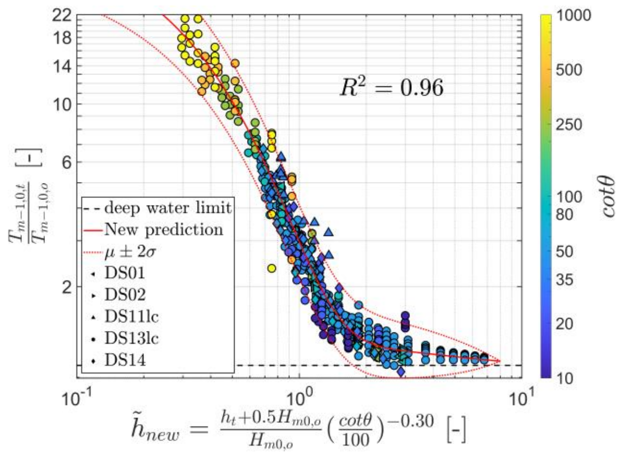

Figure 2 - Improved prediction formula for the relative increase of $T_{m-1,0,t}$ for long-crested waves over mildly sloped foreshores versus the adapted relative water depth.

CONCLUSION

In this work, the prediction model of H17 for the relative increase of the spectral wave period $T_{m-1,0}$ from offshore to the toe of a coastal structure on a shallow foreshore, was evaluated and improved using new datasets. An improved model was mostly necessary because of a large residual effect of the foreshore slope that was observed for the new datasets compared to the original model by H17. The H17 model was also shown to be unable to capture the trend in the new datasets of much larger τ values for decreasing foreshore depth in case of milder slopes compared to steeper slopes.

At the conference, the effects of the wave steepness, steep fore reefs (> 1/10), directional spreading, and free IG waves on τ will be presented as well.

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