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Prediction of swash motion and run-up including the effects of swash interaction

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Abstract

Modifications to a model describing swash motion based on solutions to the non-linear shallow water equations were made to account for interaction between up-rush and back-wash at the still water shoreline and within the swash zone. Inputs to the model are wave heights and arrival times at the still water shoreline. The model was tested against wave groups representing idealized vessel-generated wave trains run in a small wave tank experiment. Accounting for swash interaction markedly improved results with respect to the maximum run-up length for cases with rather gentle foreshore slopes (tanβ=0.07). For the case with a steep foreshore slope (tanβ=0.20) there was very little improvement compared to model results if swash interaction was not accounted for. In addition, an equation was developed to predict the onset and degree of swash interaction including the effects of bed friction.

Keywords: Run-up; Swash; Wave groups; Vessel-generated waves; Ballistic model

1. Introduction

Modeling of the hydrodynamics in the swash zone has seen many advances in recent years. It is now fairly well established that swash motion is driven by low frequency infra-gravity motions and bores which collapse at the shoreline and then propagate up the beach face. The two mechanisms do not appear to be exclusive, but rather, one dominates over the other depending on the incident waves and foreshore slope. There have also been several observations and attempts to describe interaction between subsequent swash waves within the swash zone. Holland and Puleo (2001) recently showed that the presence or lack of swash collisions might describe whether foreshores accrete or erode (this was also suggested by Kemp, 1975). On foreshore slopes where swash excursion times are of longer duration than the incident wave period, steepening is expected to occur. In contrast, on beaches where the swash is of shorter duration than the incoming bores, erosion is expected to occur and the foreshore will be flattened.

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The impetus for this study was to gain some insight into swash behavior due to waves generated by moving vessels although it is believed that the results are applicable to a wider range of wave conditions. A moving ship typically generates a set of waves at both its bow and stern as a consequence of pressure gradients along the hull. These waves are often referred to as wash waves and, when measured some distance from the navigation route of a vessel they consist of a group of waves that increase in height to some maximum and subsequently decrease. When these waves reach the shore there is often significant interaction between subsequent waves such that when a wave reaches the shoreline and travels up a beach face it is not always able to complete a full swash cycle before the next wave comes along. This second wave either overtakes the first wave during its up-rush stage (catch-up) or collides with the first wave during the back-wash stage. This interaction between waves continues with each incoming wave, and with respect to the hydrodynamics, the end result is that the maximum run-up will not correspond to the up-rush of the highest wave in the train. This is particularly true for mild foreshore slopes ($\tan\beta<0.1$) where the time it takes for a swash lens to travel up and down is longer than for steeper slopes (Mase and Iwagaki, 1984).

The objective of this study was to develop a simple physically-based approach to describe the shoreline motion while accounting for interaction between subsequent waves in the swash zone. A particular focus on vessel generated waves was also the intent. A description of the shoreline motion due to collapsing bores at the still water shoreline is particularly suitable for modeling swash interaction and, thus, this already well established approach was modified to incorporate swash interaction. An equation describing the onset of swash interaction, including the effects of friction is derived. The equation is tested and numerical results of the model with and without swash interaction for data from a laboratory experiment conducted in part for this study are presented.

2. Literature review

The hypothesis that the time-varying position of the leading edge of the shoreline can be described by collapsed bores that move up and down a slope as a mass of water was first described by Ho et al. (1963) and Shen and Meyer (1963). They derived a set of governing equations, based on the non-linear shallow water equations (NLSWE) together with mathematical and physical interpretations of singularities at the point of bore collapse and maximum run-up. Waddell's (1973) field observations supported the hypothesis. He noted that during the up-rush, and initial stages of the back-wash, the leading edge behaved like a unit mass moving up and down the foreshore under the action of gravity, neglecting friction.

Hughes (1992) applied the non-linear shallow water theory to field data from a number of natural sandy beaches with steep foreshore slopes ($\tan\beta=0.093$ to 0.15). A comparison between measurements and inviscid theory replicated the gross flow behavior of the up-rush well, but overestimated the maximum run-up by as much as 65%. He speculated that the difference in magnitude was due to not accounting for bed friction and infiltration (median grain size diameters of $D_{50}=0.31$ mm to $D_{50}=2.00$ mm). Hughes (1995) added a stress term for bed friction to the non-linear shallow water theory and solved the equations with measured values to obtain an inferred friction value of 0.1 for the up-rush. Similarly, Holland and Puleo (2001) obtained estimates of up-rush and back-wash friction factors by iterating on f using the non-linear shallow water theory (also termed 'ballistic model') and compared the results to measured data obtained at Duck in 1994 ($D_{50}=0.22$ mm). Analysis of over 2000 individual swash events showed that an up-rush friction coefficient of $f_u=0.01$ and back-wash friction coefficient $f_b=0.04$ gave the best results with respect to the minimum overall error between calculated and measured swash trajectories. The authors also noted that during the field campaign, the foreshore slope decreased from about 0.19 to 0.06 and that the foreshore seemed to adjust in order to minimize swash interaction. By iterating on f, they essentially accounted for swash interaction by adjusting the friction terms.

The catch-up and absorption mechanism of swash interaction was explicitly modeled by Mase and Iwagaki (1984) employing empirical data and