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# Evaluation of XBeach performance for the erosion of a laboratory sand dune

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A B S T R A C T

A new set of laboratory data is used to investigate the bathymetry change of a steep sand dune exposed to waves and high water levels, and subsequently compared to the results of numerical simulations using XBeach. Bichromatic wave boundary conditions are used to simulate a combined short-wave and long-wave field for two water level elevations corresponding to collision with the dune face, and overwashing of the dune crest. In the collision regime case, episodic slumping due to the undercutting of the dune results in sudden erosional events followed by long periods of wave-driven reshaping at the dune toe. In the overwash regime case, morphological changes are faster and sediment transport rates are higher.

The XBeach model was used to simulate wave-driven erosion of the dune at the two water levels observed in the laboratory. The model was not able to precisely recreate the cross-shore spatial variability of significant wave height observed in the experiments, however near-bed wave-orbital and mean current velocities were in good agreement with observations. Following rapid initial adjustment, the model results were in agreement with measured dune morphology at successive times. XBeach was sensitive to several parameters that control the rate of erosion including the critical avalanching slope under water, the threshold water depth and the sediment transport formulation, and performed well after careful selection of the best combination of these parameters. Overall, the model predictions were in better agreement with laboratory observations for dune erosion in the overwash regime case than the collision regime case.

## 1. Introduction

Sand dunes located landward of beaches are common morphological features along coastlines, forming an important first line of defense against coastal flooding. However, extreme storm events that generate large waves combined with storm surges have the potential to cause massive damage to dunes in a very short period of time. Storm surges allow waves to reach the dune faces making them susceptible to erosion and overtopping. When dunes are overtopped, landward regions become exposed to flood waters and eventually large waves, which can result in damage to valuable infrastructure and loss of human life. As an example, Hurricane Katrina (2005) devastated the US Gulf coast, significantly altering barrier island morphology including the Chandeleur islands in Louisiana that lost over 85% of their total surface area [29]. The storm caused over 1830 fatalities and $108 billion USD in total damage [13], attributed mainly to storm surges up to 10 m [4]. In the future, dune systems could become more vulnerable to erosion and overtopping as a result of projected sea-level rise [18] and increasing storm intensity [41].

As a means to address such concerns, Sallenger [28] introduced the Storm Impact Scale to predict the extent of dune erosion. This is based on the extent of wave run-up, dividing it into four regimes namely swash, collision, overwash and inundation. The numerical model XBeach was developed by Roelvink et al. [25] to explicitly resolve long-wave swash motions and simulate the processes in these different regimes. XBeach simulates the sea surface as a series of wave groups and includes long infragravity waves (e.g. 20–200 s) bound to the shorter-period gravity waves (e.g. 1–20 s), causing high shear stresses at the bed that drive morphological changes. The model uses an avalanching mechanism for prediction of episodic slump events due to undercutting of the dune [6] and accounts for different slumping rates in saturated and dry sand [25].

The XBeach model has been shown to perform well in one-dimensional (1D) laboratory test cases of dune erosion [25,36], however calibration is required to reproduce dune erosion under different wave conditions [31]. Simulations of two-dimensional (2D) wave run-up and inundation [17] suggest that the model is capable of reproducing morphological features common to overwash, such as

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foredune erosion, back barrier deposition and washover fans. Lindemer et al. [16] found that barrier island erosion is under-predicted, while Kurum et al. [14] concluded that the addition of vegetation to XBeach improved the accuracy of barrier island overwash prediction. XBeach has been used to predict the 1D morphological changes during storms on different sandy coastlines resulting in good data-model agreement [2]. However erosion at the still water level (SWL) can be over-predicted leading to greater deposition at the lower beach face [34]. XBeach has been shown to be sensitive to input parameters [31,32,20], with a possible source of model error being related to uncertainty of sediment transport in the swash zone [27]. Recently XBeach has been applied to fluvial environments [10], gravel beaches [39], the development of megacusps [19] and the effect of the longshore bathymetric variability on dune erosion [37]. XBeach has also been recently used to successfully simulate dune erosion [40] and barrier island breaching [38] in comparison with field observations.

The objective of this work is to evaluate the performance of the XBeach model for two laboratory experiments of sand dune erosion in the collision and overwash regimes, forced by bichromatic waves to simulate a combined short-wave and long-wave field. This paper is organized as follows: a summary of the laboratory tests is presented in Section 2; a description of the XBeach model and set-up for the present cases are provided in Section 3; the results for waves and currents over a fixed bed, and for morphological evolution of the bed are described in Section 4; and discussion and conclusions are presented in Sections 5 and 6.

## 2. Description of laboratory tests

### 2.1. Experimental set-up

The present dune erosion tests were conducted in a 20.5 m long, 1.7 m wide and 0.7 m deep channel installed at the centre of an existing (26 m long, 21 m wide) rectangular wave basin. This is equipped with a 10.5 m long piston-type wave paddle, which in the present tests was located 2.25 m from the offshore end of the channel and positioned perpendicularly to it so as to generate normally incident waves propagating toward the sand dune located at $x$=23–25 m (see Fig. 1a). The wave paddle is not equipped with Active Reflection Compensation (ARC), and thus some wave energy is reflected from it.

The initial profile was selected to represent a mild beach slope across the nearshore region and a steep subaerial dune. This idealized morphology represents a dune-beach system where at high water levels due to storm surge the waves attack directly on the dune face with a limited surf zone. The initial laboratory profile (Fig. 1b) consisted of a 1:200 offshore slope that transitioned to a 1:1.3 beach dune face with a vertical distance between the dune crest and the dune toe of 0.45 m. The dune crest was located at an elevation of $z$=0.65 m above the basin floor at $z$=0 m. The sediment was a fine silica sand with average grain size $D_{50}$=0.165 mm, $D_{90}$=0.240 mm and a coefficient of uniformity $D_{60}/D_{10}$ = 1.59.

The tests involved measurements of water surface elevation, vertical velocity profiles and bed bathymetry. Water surface elevation along the channel was measured with the aid of eight capacitance-type water level probes with a vertical resolution of 0.1 mm and operated at a sampling rate of 20 Hz. Six probes (P8-P3) were mounted on tripods and positioned as shown in Fig. 1a, with probes P6-P3 located at the channel centreline, and each of P7 and P8 offset 0.25 m from it. The probes P1 and P2, which were also offset 0.25 m from the channel centreline, were mounted on a moveable cart covering the outer surf zone. A 10 MHz Nortek Vectrino II Acoustic Doppler Velocimeter (ADV), with a downward configuration, was used for the velocity measurements. This yields velocity profiles over a vertical range of 0.03 m (0.04–0.07 m from the probe head), with a vertical resolution of 1 mm and accuracy of 1 mms$^{-1}$. The ADV was located at the channel centreline and offset 0.05 m offshore of wave probes P1 and P2. Longitudinal bathymetric profiles along the channel centreline were obtained with the aid of a Micro-Epsilon scanCONTROL 2700 laser line scanner also mounted on the movable cart. The laser profiler has a horizontal range of approximately 0.10 m (dependent on its distance to the surface to be measured) and a horizontal resolution of 0.016 mm. The vertical range of the instrument is 0.30 m with a vertical resolution

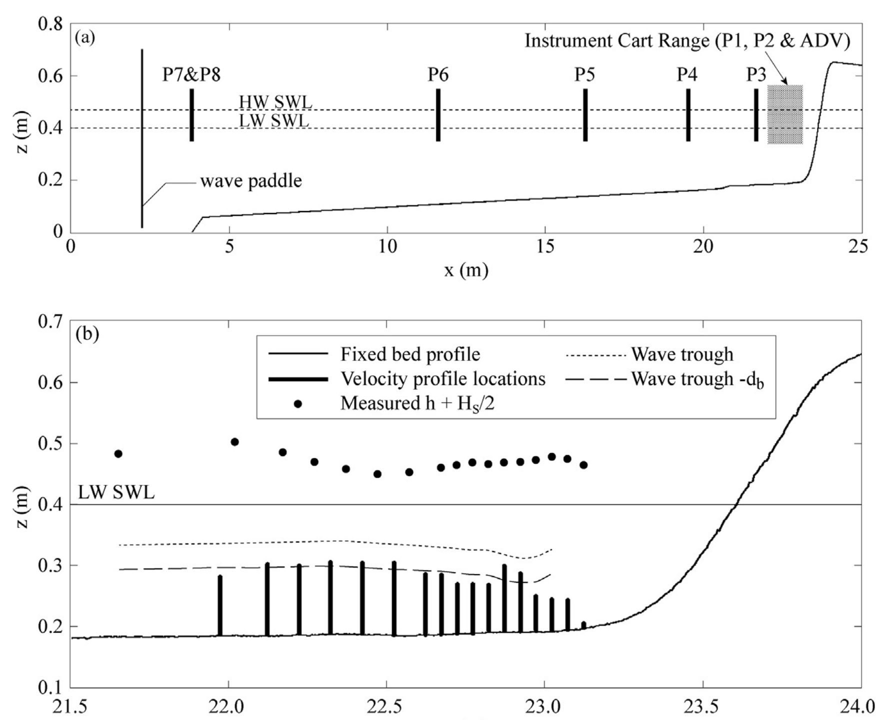


**Fig. 1.** Laboratory set-up: (a) initial beach and dune profile with instrumentation locations and mean still water level (SWL); (b) close-up of the dune profile, locations of velocity profile measurements below the wave trough elevation, and observed total water surface height (SWL + $H_s/2$) for the LW test. Blanking distance ($d_b$) of the sensor was 0.04 m.