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Field measurements and non-linear prediction of wave celerity in the surf zone

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ABSTRACT

A good prediction of wave celerity in the surf zone is essential for wave propagation modelling in the nearshore. This paper is devoted to a study of wave celerity based on the analysis of data collected during the ECORS 2008 field experiment that took place at Truc Vert Beach, SW France. Here we analyze and quantify the effects of non-linearities and evaluate the predictive ability of several non-linear celerity predictors for high-energy wave conditions. The asymptotic behaviour of the different models for high values of the non-linearity parameter is investigated. Besides, comparisons with data show that the classic bore model is inappropriate for describing wave dynamics when approaching the swash zone. The influence of very low frequency pulsations of the wave-induced circulation on wave celerity is also discussed.

1. Introduction

As waves propagate to shallower water, they become steeper and higher until they break. Broken waves keep propagating shoreward through the surf zone. Immediately after breaking, the wave shape evolves rapidly. Thereafter, waves evolve more slowly as they reorganize into quasi-periodic bore-like waves in the inner surf zone. Very steep fronts are observed, which give to waves a typical saw-tooth profile (see Fig. 1). Waves finally end up in the swash zone where the run-up starts. Thus, waves are increasingly non-linear while they propagate shoreward. This high complexity explains why some basic wave parameters, such as wave celerity, are still not accurately described inside the surf zone.

A good prediction of broken wave celerity, c_b, is essential, as it is a key parameter in nearshore wave propagation models. In phase-averaged wave propagation models, the mass flux, energy flux and wave dissipation depend on c_b. The celerity predictors used in these models rely on the assumption of a given (fixed) wave shape, or at least a slowly variable one, whereas in the surf zone the wave shape can evolve quickly. For instance, broken wave celerity is often predicted using the linear shallow water theory, with the phase speed $c_\varphi \approx (gd)^{1/2}$ (where d is the local water depth), or the classic non-linear bore model [1]. In time-dependent Boussinesq-type models, a parameterization of c_b is also generally required: rough approximations such as $c_b = 1.3(gd)^{1/2}$ are often used (see [2]).

In situ studies of wave celerity are also important for the development of remote sensing techniques (see for instance [3–5]). For example, wave celerity can be computed over a large area from video imaging, and subsequently the bathymetry and its evolution can be estimated through depth-inversion techniques. The accuracy of the results is directly dependent on the knowledge of a good functional relationship between wave celerity and water depth. This accuracy has been found to significantly degrade in the surf zone. Most depth-inversion techniques rely on the linear dispersion relation $c_\varphi = \left(\frac{g}{k}\tanh(kd)\right)^{1/2}$. Holland [3] investigated the validity of this dispersion relation for depth inversion. Using field data, he showed that the linear dispersion relation was commonly leading to depth errors of over 50% inside the surf zone, whereas the average depth estimation error was 3–9% outside the surf zone.

Despite a clear need for validation of the different celerity predictors, only a few works have been devoted to the experimental study of wave celerity. Catalán and Haller [4] compared the predictions of several linear and non-linear models with laboratory data, in application to depth inversion. Concerning field data, a key study was performed by Thornton and Guza [6]. Using a shore-normal transect of pressure and current sensors, they computed celerity spectra, $c_\varphi(\nu)$, from pairs of adjacent sensors, for $d < 7$ m. They observed that the celerities were almost invariant with frequency inside the surf zone, demonstrating that non-linear effects were prevailing over dispersive effects. Thus, the study of wave celerity through the computation of c_φ at different frequencies is not relevant inside the surf zone. In this paper, we analyze broken wave celerity, defining it as the wave front speed. An adequate method

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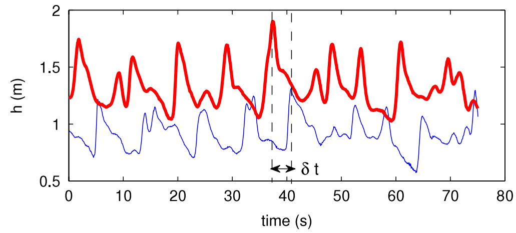

Fig. 1. Example of time series of water depths at two synchronized pressure sensors (the offshore sensor is the thick line).

for its computation is presented in Section 2. This study is based on the analysis of an extensive in situ data set collected during the ECORS Truc Vert 2008 field experiment (Section 3). The influence of wave non-linearities on c_b is examined, in particular for high energy wave events. Then, we evaluate the predictive ability of several non-linear celerity models (Section 4), and finally, the influence of very low frequency pulsations of the circulation on wave celerity is discussed (Section 5). Conclusions are stated in Section 6.

2. Field data and methods

2.1. Description of the study area

The study is based on data collected during the ECORS (SHOM-DGA) field experiment [7], a 6-week period of international fieldwork, carried out in March–April 2008 at Truc Vert Beach. This sandy beach is located on the southern part of the French Atlantic coastline, at approximately 10 km north of the Cap Ferret spit at the mouth of the Arcachon Lagoon.

This double-barred beach has a fairly mild slope of about 3% and typically exhibits an inner bar and rip system in the intertidal domain (see [8]). However, the inner-bar geometry was reasonably alongshore uniform throughout the experiment as a result of quasi-persistent high-energy conditions and high offshore wave angle to the shore. A detailed description of the inner bar evolution is given in [9]. During the field experiment, the tidal range ranged from 2 m to about 4 m, allowing instruments to be deployed safely at low tide while measurements were obtained from about mid tide to high tide.

The offshore wave characteristics were given by a waverider buoy deployed offshore of the study area in 54 m water depth. A very wide variety of incoming swell conditions were encountered during the deployments (see the grey areas in Fig. 2), from small (significant wave height $H_{1/3} = 1$ m) to very large waves ($H_{1/3} = 8$ m), and significant wave periods mostly varying from 6 to 14 s. In particular, four storm events were recorded during the experiment ($H_{1/3} > 4$ m), including a 10-year return storm with $H_{\max}$ larger than 10 m.

2.2. Instrument deployment

Synchronized pressure sensor lines were set up in the cross-shore direction. Several cross-shore transects were deployed consecutively at different locations. Each transect was made up of an acoustic Doppler velocimeter (ADV) in a central location, surrounded by two pressure sensors synchronized in time with the ADV, separated by about 15 m. Data were acquired at a sample rate of 16 Hz.

Instruments were deployed in fairly alongshore-uniform parts of the beach (see Fig. 3). While well-developed inner bar and rip morphology typically results in ubiquitous intense rip current circulations along this section of coastline [10], rip channels only barely form at the end of the experiment during low-energy wave conditions (see [9]), that is, when concurrent broken-wave celerity measurements were not performed. When celerity measurements were performed, rip current circulations were quasi-non-existent because of both the alongshore-uniform beach geometry

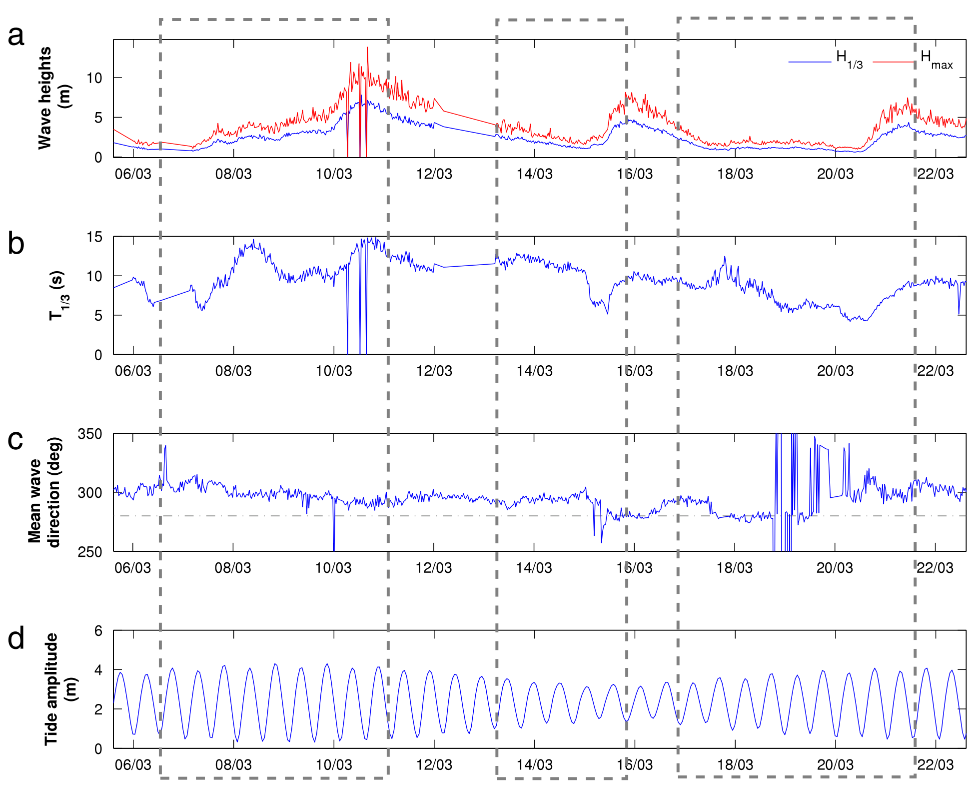

Fig. 2. Time series of wave and tide conditions offshore of the study area (at 54 m depth). (a) Significant and maximum wave heights (m). (b) Significant period (s). (c) Mean wave direction (○), (· — ·): normal incidence to the shore. (d) Tide amplitude (m). The dashed frames mark the successive instrument deployments.