Development and Validation of Depth Inversion Algorithms for Barred-Beaches Based on Nonlinear Properties of Shoaling Waves

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LONG-TERM GOAL

The long-term goal of this work is to develop methods for predicting the bottom topography in nearshore regions, based on characteristics of (shoaling) surface waves, measured using remote sensing methods. We are particularly interested in the surfzone region, over barred-beaches, where large wave nonlinearity and breaking occur.

OBJECTIVES

Earlier work used computations in a Fully Nonlinear Potential Flow model (FNPF) and dealt with monotonous topographies and periodic non-breaking waves (Grilli and Subramanya, 1996; Grilli and Horrillo, 1997; Grilli, 1998). There are 6 objectives in this project, which were listed in last years' report. This year, we concentrated on:

- (2) implementing and calibrating a spilling breaker model in the FNPF model, and globally modeling the energy dissipated by breaking waves in the surfzone.

- (5) improving the model computational efficiency for large-size/long-term computations.

- (6) validating both shoaling calculations and depth predictions using field data from Duck SHOWEX experiment, in collaboration with Arete Assoc. (John Dugan and co-workers).

APPROACH

In earlier work, Depth Inversion Algorithms (DIAs) were developed for cylindrical beaches (Grilli, 1998). These were based on inverting a nonlinear wave celerity relationship, obtained from results of direct shoaling computations in a FNPF model. Since the nonlinear celerity also depends on wave steepness, wave height or front-to-back wave asymmetry data was also required, in addition to wave phases, to perform depth inversion.

A similar approach is pursued in this effort. The FNPF model is extended to deal with breaking incident waves, by the addition of a breaker model. The model can now deal with non-periodic waves, shoaling and breaking over barred-beaches. Direct problems are first calculated, and a parametric study of wave characteristics in the region beyond the bar is performed. Modifications/extensions of DIAs

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will be made based on these results. Shoaling calculations and depth predictions will be validated using field data from SHOWEX experiments.
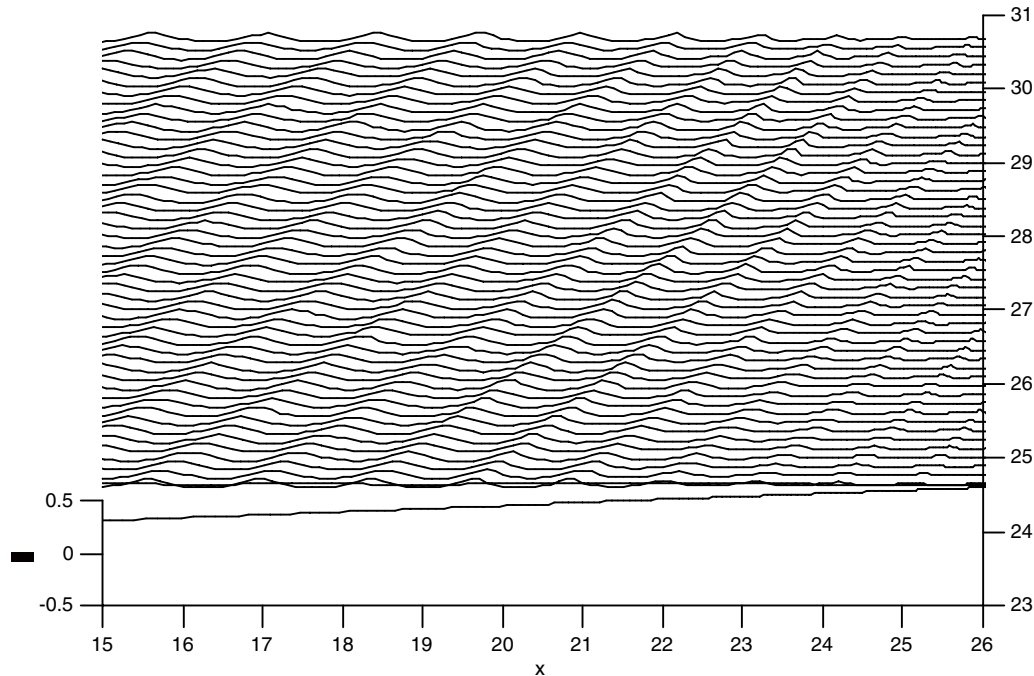

Figure 1 : FNFP computations for the shoaling of periodic waves over plane beach with 1:34 slope. Stack diagram of surface elevations computed as a function of time.

WORK COMPLETED

For non-periodic waves and/or irregular bathymetry, it is desirable to have a means of both preventing wave overturning (which ends FNPF computations) while absorbing the energy of individual breaking waves, in relation to the physical rate of energy dissipation in actual waves. A spilling breaker model is implemented in which the energy dissipation in each broken wave is assumed to be that of a hydraulic jump. A maximum/minimum front slope criterion is used to decide whether a wave breaks or stops breaking (e.g., Schaffer et al., 1993). To absorb breaking wave energy, an absorbing surface pressure distribution is used over each breaking wave crest area, from the point where normal velocity changes sign behind the crest, to the similar point on the wave front face. The (negative) work produced by this pressure against the wave is calibrated real time to equal the energy dissipation in the hydraulic jump. To do so, instantaneous wave characteristics such as height H, celerity c, and depth below crest and trough must be known for each wave. Hence, a wave tracking method is developed, in which individual waves are identified and followed during their shoaling and breaking (see details in Guignard and Grilli, 2000a,b).

The breaker model is calibrated by comparing results to laboratory experiments for mean wave crest height and mean-water-level (MWL) variations, during shoaling of cnoidal waves generated by a piston wavemaker. Such computations are illustrated in Figs. 1-3 for $H_o = 0.095$m, $T = 1$s, and $h_o =$

0.36m for a plane slope $s = 1/34.26$. Breaking is assumed to occur when the maximum wave front slope reaches 36°. Breaking occurs in average from $x_b = 21.5$m, and greater. In Fig. 2, the agreement between experiments and computations for the MWL is quite good. In Fig. 3, mean wave celerity c is compared to that of linear wave theory c_{LWT} and Nonlinear Shallow Water Eq. c_{NSW}. Although linear wave theory predicts wave celerity quite well at the toe of the slope, we clearly see the effect of amplitude dispersion, which makes $c > c_{LWT}$ further up the slope. In the fully developed surfzone, where waves appear like turbulent bores, it is expected that c_{NSW} give a good prediction of wave celerity c. This, however, is only true as far as the slope of the celerity curve, and we see that c_{NSW} overpredicts wave celerity in the surfzone.
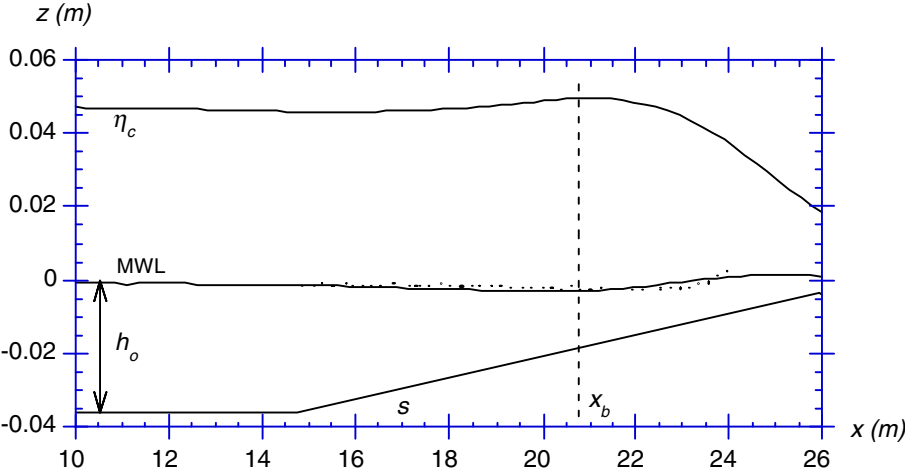

Fig. 2 : Mean calculated wave crest elevation and MWL (note, bottom elevation /10).
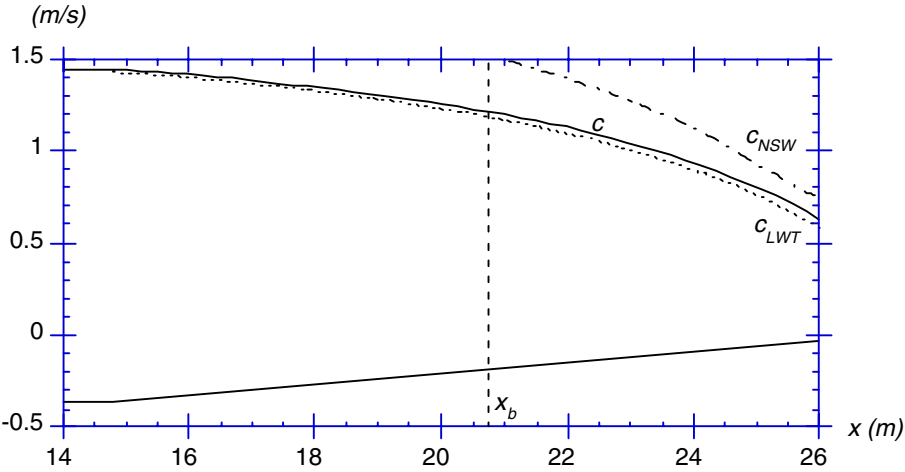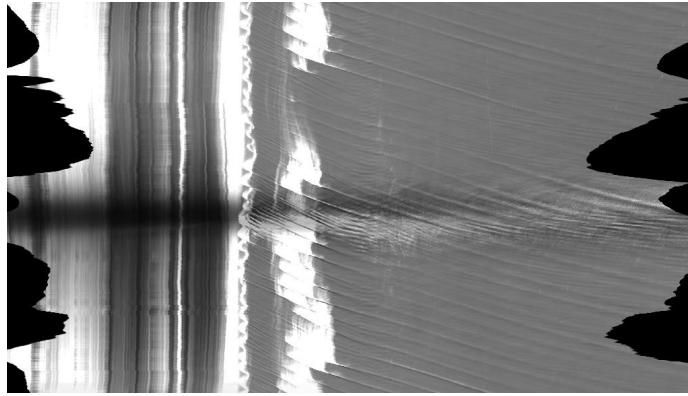*Dots are laboratory measurements of MWL from Hansen (1979)*

Fig. 3 : Mean calculated celerity compared to NSW and LWT celerity.

Fig. 4 : SHOWEX data for swell crest, in time-space plot
(From Williams (2000) at Arete, Assoc.)

A collaboration was established with John Dugan and co-workers (Arete Assoc.) who conducted field experiments at Duck (SHOWEX), using airplane based sensors. An example of the processed data available is given in Fig. 4, where we see swell crest location data (clear lines), in a space (horizontal)-time (vertical) plot, quite similar to Fig. 1. The slope of the crest lines in Fig. 4 gives a measure of the wave celerity. White water indicates the surfzone. Independent measurements of bottom bathymetry and wave height were made, which will allow us to test various nonlinear DIAs on the data, in the region where linear wave theory is not sufficiently accurate for a reliable depth inversion.

Finally, in a parallel, independently supported, work, a three-dimensional fully nonlinear FNPF model, applicable to arbitrary bottom topography, was further developed (Grilli et al., 2000a,b). This model could be used to estimate effects induced on shoaling waves by three-dimensional topographic features, as compared to two-dimensional results.

RESULTS

The FNPF model, with the addition of the experimentally validated breaker model, provides a true numerical wave tank (NWT), in which shoaling and breaking of arbitrary incident waves can be simulated over arbitrary bottom bathymetry. Unlike approaches based on wave theories (such as Boussinesq's), the model keeps full nonlinearity in the equations. Preliminary comparisons with laboratory experiments show a good agreement of model prediction for mean wave height and MWL variations. Such more realistic wave shoaling-breaking simulations will allow us to refine our DIAs in the region where wave nonlinearity and breaking are important. The comparison of numerical results with and use of field data are ongoing and will be reported on later.

IMPACT/APPLICATIONS

The two- and three-dimensional models refined and developed as part of this work constitute robust and flexible nonlinear wave modeling tools, applicable to a variety of ocean and coastal engineering problems. The models were developed as so-called "numerical wave tanks", in which many types of boundary conditions and geometry can be easily specified. In particular, it would be easy to include fixed or floating structures in the models, and to calculate wave-structure interactions. The models were based on a higher-order Boundary Element Method, which is both efficient and accurate.

TRANSITIONS

The two- and three-dimensional modeling work performed in this project is closely related to other (collaborative) wave modeling efforts the PI is involved with : (i) the generation and coastal runup of tsunamis, due to underwater landslides (Grilli and Watts, 1999); (ii) the modeling of three-dimensional breaking waves over various coastal topographies, and the study of their kinematics (Grilli et al., 2000a,b); (iii) the three-dimensional nonlinear wave focusing, as a possible mechanism for creating very large (freak) waves (Brandini and Grilli, 2000).

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