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Numerical models were developed to predict the propagation and transformation of the time-dependent wave field across the nearshore zone, nearshore circulation including longshore, undertow and rip currents, and instantaneous and mean water levels including wave runup and swash on beaches. The inclusion of time-dependence permitted the study of evolving wave and current fields, including the generation of low frequency waves and shear instability of the currents. The developed two-dimensional and three-dimensional models were extensively validated by comparison to laboratory experiments conducted in this project and available field experiments.

Equipment purchases and upgrades allowed the laboratory studies of breaking waves, and the associated turbulence, bottom friction, undertow, swash, runup, overtopping, and overwash in the University of Delaware's Precision Wave Tank, Directional Wave Basin, and Sand Beach Wave Tank.

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Final Progress Report

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TABLE OF CONTENTS

NEARSHORE WAVE AND CIRCULATION MODELLING

Statement of the Problem Studied

Erosion of protective shorelines, shoaling of navigational channels, and flooding due to storm surges occur when ocean waves, currents, and wind drive the water in the nearshore zone. The fluid motions carry sediment along the shorelines in both the offshore and alongshore directions. Accurate prediction of this sediment transport requires precise predictions of the nearshore hydrodynamics.

The goal of this project was the development of predictive numerical models to determine the propagation of the time-dependent wave field across the nearshore zone, nearshore circulation (including longshore and rip currents), and instantaneous and mean water levels (setup and runup). The inclusion of time-dependency permits the study of evolving wave and current fields, including the generation of low frequency waves and shear instability of the currents. The developed two-dimensional and three-dimensional models were extensively validated by comparison to laboratory tests conducted in this project and available field experiments. Equipment purchases and upgrades ($50,000 per year matching funds from the University of Delaware) permitted the laboratory study of breaking waves, and the associated turbulence, bottom friction, undertow, runup, and swash in the University of Delaware's Precision Wave Tank, Directional Wave Basin, and Sand Beach Wave Tank.

The project was managed by the Center for Applied Coastal Research in collaboration with Cornell University. The Ocean Engineering Laboratory for the Center was refurbished with new laboratory space, offices and a computer control room using $250,000 matching funds contributed by the University of Delaware. The research efforts were subdivided into five task areas: wave modelling, wave breaking, low frequency motions, swash/runup, and numerical codes. A task leader had the responsibility to coordinate the research activities in each task area. The Center's existing close cooperation with the USACE Coastal Engineering Research Center strengthened and augmented the research efforts.

Summary of the Most Important Results

A 2D (two-dimensional) horizontal Boussinesq model was developed. A numerical algorithm based on the 4th-order Adams-Bashforth-Moulton for time-stepping was developed and tested against existing laboratory data for wave propagation. To extend the application of the model to deeper water, modified Boussinesq equations were derived in terms of the velocity potential at an arbitrary elevation and the free surface displacement. The optimal elevation was determined by minimizing the relative errors of the phase and group velocities over a range of depths from zero to half of the equivalent deep-water depth. This extension alleviated some of the difficulties associated with choosing maximum starting depths during numerical simulations. The improved 2D horizontal Boussinesq model was further extended to include nonlinear effects to all orders. This extended model was shown to provide improved predictions of the heights and forms of shoaling waves as well as the internal flow field relative to the weakly-nonlinear Boussinesq model. This model was also extended to incorporate an eddy viscosity model for wave breaking and shown to be capable of predicting the decay of wave height and the third-moment statistics of the surf zone wave field. A user's manual was developed for this model and released to a group of testers in 1996. Extensive testing of the model against the DUCK'94 field experiment was undertaken in collaboration with the nearshore oceanographers at Scripps Institute of Oceanography. The model was found to be an accurate predictor for wave spectral transformation, wave height decay and evolution of third moment statistics.

A comprehensive nearshore circulation model was developed to predict the wave-induced 3D (three-dimensional) circulation. This model solves the depth-integrated, short-wave averaged equations of horizontal momentum for the 2D horizontal variations of the current and low frequency waves together with analytical solutions for the vertical distributions of horizontal velocities. A general absorbing-generating boundary condition was developed for the model which allows waves reflected or generated inside the computational domain to propagate out of the computational domain through the boundaries without disturbing the waves propagating into the domain through the same boundaries. This boundary condition was found to be more accurate than other existing boundary conditions. This circulation model was applied to predict low frequency waves generated by wave groups and circulation patterns on a beach with a significant longshore bathymetry variation such as that observed during the DUCK'94 field experiment.

As for wave runup and swash, a 2D horizontal shallow-water model was developed to predict the oscillatory and steady fluid motions in the swash and surf zones under obliquely incident waves. This model was shown to be in fair agreement with available field and laboratory data. A 2D vertical model was also developed to predict the vertical variations of fluid velocities, shear stress and turbulence intensity. A quasi-3D model was developed by combining the 2D horizontal and vertical models. This model was applied to elucidate the dispersion effects due to the vertical variations of instantaneous horizontal fluid velocities on the cross-shore variations of the wave height, setup and longshore currents. Comparisons with laboratory and field data have indicated that the dispersion effects on the longshore current profile are significant for regular waves but secondary for irregular waves. The longshore current profile on a barred beach was predicted to be sensitive to alongshore non-uniformity unlike planar beaches.

To examine the detailed turbulent flow field, we also modified the volume of fluid (VOF) method and coupled it with the k-ε turbulent transport equations. This new model was tested by comparing numerical results with several laboratory experiments, including the runup of breaking solitary waves and turbulence measurements in periodic breaking waves. The surface profile, mean velocity field and turbulent energy intensity were in good agreement.

In the Precision Wave Tank, an experiment was conducted to measure the vertical variations of fluid velocities in the near-breaking region using a laser doppler velocimeter. This experiment was used to validate the improved Boussinesq model. Another experiment was performed to measure the vertical variations of fluid velocities outside and inside the surf zone.

The analyses of the measured turbulent flow and bottom boundary layer flow on a rough bottom indicated the applicability of the formula for the bottom friction factor for nonbreaking waves even inside the surf zone as well as the reasonable accuracy of the assumption of local equilibrium of turbulence in the surf zone. This unique data set was also used to develop a new simple kinematic undertow model by combining a logarithmic profile in the bottom boundary layer with a parabolic profile in the interior layer.

For the Directional Wave Basin, we developed software to generate the wavemaker command signals, automatically calibrate the wave gauge array, and acquire and reduce wave data. Experiments were conducted to test the improved Boussinesq model. To assist the development of experiments in the Directional Wave Basin, the SUPERDUCK field data was analyzed using the Maximum Likelihood and Entropy methods for directional spectra and the Hilbert transform method for wave group structure. The data analyses indicated that the incident wave climate might have forced the low frequency, non-dispersive motion in the surf zone during SUPERDUCK.

In the Sand Wave Tank, experiments on wave overtopping and overwash on dunes were conducted to generalize swash and runup modelling. A new wavemaker was installed to generate waves as large as 0.3 m and conduct sand transport experiments in near prototype scale. The experiments were used to elucidate the overwash processes as well as to validate the generalized numerical swash model.

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Reports of Inventions

None.