Effect of Wind and/or Topography on Ocean Surface Waves

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LONG-TERM GOALS

Our goal is to study the nonlinear dynamics of ocean surface waves in the presence of wind, large structures, bathymetric or shoreline variations.

OBJECTIVES

In this year we have begun two new topics: (1) Nonlinear interaction among wind, waves and currents in shallow seas, and (2) General theory of long waves forced by short waves near a coastline with natural topography and bathymetry. Since this grant expired on April 30, 1998, these new tasks are pursued under the continuing ONR grant "Wave Interactions with Large Topographical and Man-made Structures."

Area 1. Interaction of Wind, Waves and Current in Very Shallow Water

APPROACH

In previous articles on sediment resuspension and transport induced by waves or tides (Mei, Chien & Ye, 1998) we have focussed attention to heavy particles that stay mostly close to the seabed. Fine cohesive particles are known to be suspended throughout the entire sea depth, hence currents both in and above the boundary layers are important. This calls for theoretical models of waves and currents in shallow water. From the observations in large inland waters such as Lake Okeechobee, Florida, it is known that concentration of suspended particles is directly correlated with the wind intensity, i.e., the highest sediment concentration occurs when the wind is the strongest. Hence wind generated waves are responsible for mobilizing (resuspending) particles in shallow seas. Once in suspension, currents transport the fine sediments. In order to provide sound basis for the ultimate prediction of sediment transport. We have therefore begun to study the unstable growth of waves in shallow seas. Available works on wind-wave generation have almost exclusively focussed on deep water and subsequent nonlinear evolution (Hara and Mei, 1991).

For a start we consider a horizontal seabed, and employ the wave-following coordinates. We then assume depth dependent eddy viscosity for the basic flow without waves in both water and air. In particular the basic drift current in the sea is first calculated. For wind generated waves we adopt a constant eddy viscosity near the interface and the sea-bed in order to account for dissipation, $\nu^+=\kappa u_*^+\delta^+$, for air and $\nu^-=\kappa u_*^-\delta^-$ for water where κ is the Karman constant, u_* the friction velocity, and δ the boundary layer thickness. In order to predict nonlinear evolution of wind generated waves, we

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have completed the derivation of the wind-wave couple theory to the third-order in wave steepness kA (in the absence of wind and wind-induced currents). The evolution equation reduces to the Davis-Stewarts on equations well known in the inviscid potential flow theory. Our new equations incorporates the effects of wind input, wind induced drift, wave-wave interaction of within a narrow band, dissipation in the air-sea interface and the seabed, so that the equations are for two dimensional flows but can be extended later for three dimensions.

RESULTS

As first application we have calculated the wind-induced wave growth in shallow water by linearizing our approximate governing equations for small wave steepness during the initial stage of instability. Figure 1 gives sample results for the growth rate at three different wind speeds U_{10} in a depth of h = 12 m where U_{10} is the wind speed at 10 meters above the mean sea level, and C is the phase speed of the unstable waves. Lacking measured data for wind wave generation over finite depth we have so far only compared the computed growth rate in shallow water with the deep-water experiments by Plant (1982). The agreement is of only tentative significance. We have also found that the threshold wavelength for instability. Specifically at a given depth and wind speed or intensity, waves longer than certain threshold value cannot grow. Figure 2 shows the longest waves for chosen wind speed and depth.

IMPACT/APPLICATIONS

Our initial finding that in shallow water, waves cannot be longer than a threshold value for a fixed wind, is different from deep-water wave results. Since the tendency for frequency downshift is expected as fetch increases, well-developed seas will be dominated by very long waves. The above finding sets a limit on the lower end of the wavenumber spectrum.

The nonlinear evolution equation we have derived couples wind, waves, and dissipation, hence will form the basis of computing not only the initial growth but also the long term evolution leading to information on downshift of the spectral peak with fetch. By extending to two-directional waves (3D motion) we shall be able to study vertical circulation cells (Langmuir) in shallow water; a topic so far unexplored but fundamental to the resupension of sediments or coastal pollutants.

Area 2. Long waves generated by short wave over mild topography

APPROACH

The well-known mild-slope approximation has the power of predicting refraction and diffraction of infinitesimal surface waves, while the computational task involves only two horizontal dimensions. The PI has extended it to the second order in wave steepness.

RESULTS

We now have a mild slope approximation for the long waves, which are the consequence of nonlinear interaction of short wind waves. The final revision of a paper will appear in a special issue on "Ocean Wave Mechanics" in *J. Eng. Math.*, Feb 1999. We are still developing efficient numerical solution to the new equations.

IMPACT/APPLICATIONS

The port of Long Beach is one of the many harbors plagued by long period oscillations of typical periods around two minutes, generated by wind waves of typical period of ten seconds. For similar reasons many ports in Japan are forced to close for cargo operations. A successful numerical model will enhance the design and improvement of almost every harbor in the world.

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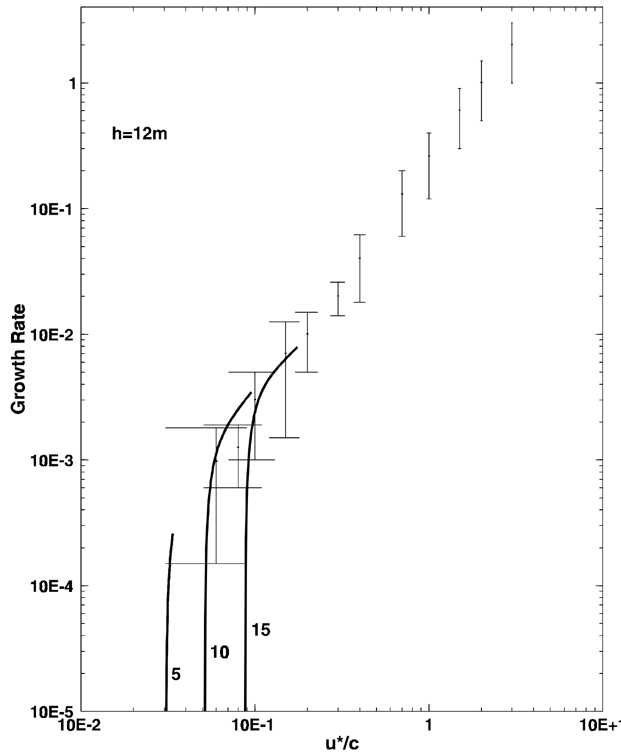

Figure 1. Linearized growth rate of wind induced waves in shallow water for depth h =12m. Solid curves: theory for U_{10} = 5, 10, and 15 m/s. Error brackets show range of experimental data by Plant (1982).

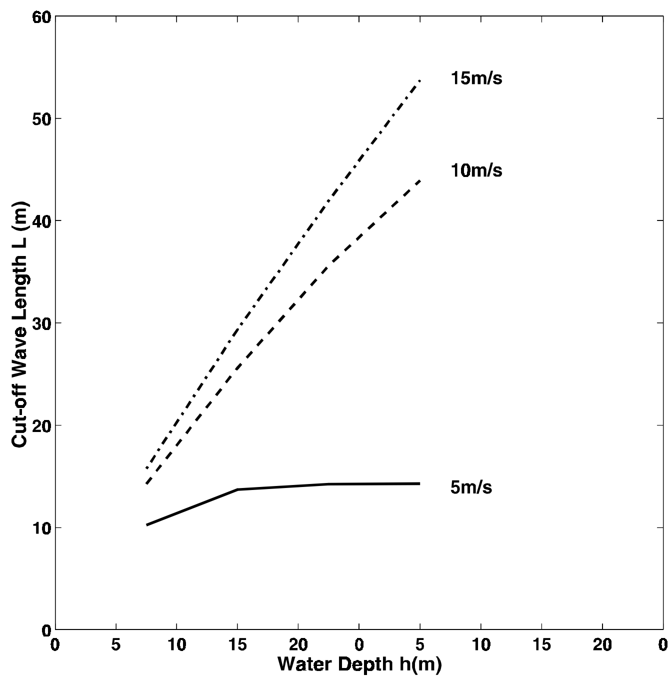

Figure 2. Longest wavelength in water of finite depth for wind speed U_{10} = 5,10 and 15 m/s. Cut-off wavelength corresponds to the margin of instability.