Development of a Model for Coastal Waves and Floating Structures

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LONG-TERM GOAL

Our long-term goal is to develop a comprehensive model to predict coastal surface gravity waves in any harbor (or open coastal region where wind generation is not important) and their effect on floating objects (e.g. moored ships) in confined waters. Recent theoretical and applied research will be converted into a practical tool that eliminates the limitations of existing nearshore wave models used by the DoD.

OBJECTIVES

We wish to further develop and provide to the DoD a wave transformation model that includes all key processes such as refraction, diffraction (by bathymetry and structures, islands, etc.), reflection, dissipation by friction and breaking, the effect of tidal (or other currents) on wind waves and swell, and nonlinear wave-wave interactions. The goal is to make the model simultaneously satisfactorily reliable and efficient (for rapid utilization and integration with other models). A further goal is to develop a 3d module (to be interfaced with the wave model) that will utilize predicted wave fields to estimate forces on floating structures in a harbor. The model will be a component in a suite of flow and wave models (e.g. WAM/SWAN, STWAVE, ADCIRC) that can be used for overall simulation of coastal conditions.

APPROACH

The base model ("CGWAVE"), developed previously, is a 2d, finite-element, elliptic model that describes the propagation of waves over an arbitrarily varying sea-bed for the full spectrum of practical wave conditions, irrespective of wave directions and domain shape. Current work involves development of modeling techniques and code modifications to enhance the versatility, reliability, and efficiency of the model. This includes incorporation of new features like improved boundary conditions, dissipation mechanisms (breaking and friction), wave-current and wave-wave interactions, steep-slope effects, faster solution techniques, and field validation. This work is done by Prof. Panchang and his students at U. Maine.

WORK COMPLETED

In last year's progress report, developments pertaining to the following were discussed:

(a) Improved treatment of open boundaries: The assumptions such as constant exterior depths and fully reflecting exterior coastlines (that plagued earlier models used by the DoD) have been eliminated; exterior bathymetric features are properly accommodated.

(b) Improved treatment of coastal boundaries: The assumption of normal wave incidence at partially reflecting coastal/internal boundaries was tackled, and new nonlinear boundary conditions, suitable for all angles of wave approach, were developed.

(c) Inclusion of dissipation for monochromatic wave conditions: Two wave breaking formulations (out of five examined), based on Battjes and Janssen (1978) and Dally et al. (1985), were identified as the most appropriate for use with CGWAVE, and methods were developed to incorporate this nonlinear mechanism in a monochromatic sense.

(d) Improving the speed of model operation for monochromatic wave conditions: A version of the code was developed for performing rapid simulations on DoD High Performance Parallel computers; monochromatic simulations for most regions can be performed in these computers in less that a minute or two (after grid generation).

Additionally, basic developments toward including wave-current interaction were made.

This year, our efforts were directed largely towards the following:

(a) **Computational efficiency for spectral modeling with nonlinear breaking.** For each spectral component, the breaking parameter is a function of the wave height, which is unknown *a priori*. Hence the modeling of this nonlinear process, for each component, requires iteration. Hitherto, breaking was considered as a mechanism that affected each component independently. The various components, therefore, could be distributed among multiple processors for rapid simulations. However, our tests in field applications (and also Chawla et al. 1998) suggest that it is necessary to model breaking as a function of the significant wave height. Otherwise, the monochromatic components were sometimes too small to induce breaking. The results of <u>all</u> components for a particular round of nonlinear iterations are needed before the breaking parameter can be estimated for the next round; i.e. breaking attains a higher level of nonlinearity. While this is easy to incorporate in simple models like the "parabolic approximation" models, it alters the structure of the code for complex-domain models like CGWAVE. U.Maine's code and the DoD's HPC version were modified (with the later attaining a higher level of parallelization). The model was applied to Ponce de Leon Inlet for testing.

(b) **Model validation.** Previously, CGWAVE had been rigorously and successfully validated against a wide range of controlled tests (analytical solutions or hydraulic model tests of idealized bathymetry). Now, model performance in field applications was investigated in detail at six locations: Barbers Point Harbor, Kahului Harbor, Oceanside Harbor, Los Angeles/ Long Beach Harbor, FRF Duck, and Ponce de Leon Inlet. The first four involved harbor resonance, and therefore thousands of simulations were performed for different frequency-direction components. The first three locations were modeled in collaboration with Dr. M. Okihiro of SIO who is performing final analyses of model results and field data and preparing a paper. Pending the results of her final analysis, we expect that this validation study is complete. Results for the Los Angeles/ Long Beach Harbor complex were compared with resonance data collected at over 50 gage locations (Seabergh and Thomas, 1995). Validation at FRF Duck involved 3 different storm events with different (storm-induced) bathymetric conditions. (To be submitted shortly to the "Jnl of Coastal Research". The other results have been tentatively accepted by "Coastal Engg" and submitted to "Adv. in Coastal & Offshore Engg").

(c) **Inclusion of wave-wave interactions.** Analytical formulations describing these interactions within the context of CGWAVE's governing equation have been developed in recent years. Our goal is to include such effects in CGWAVE, thus providing the same level of nonlinearity as the Boussinesq models while simultaneously providing the robustness and stability associated with the finite-element model CGWAVE. This nonlinear mechanism calls for iteration and repeated solution over the whole domain, and in view of the time-intensive nature of the calculations, we first explored how the nonlinear terms behave with the elliptic model. Basic code modifications were made to include the wave-wave formulation of Kaihatu and Kirby (1995). Two preliminary tests were performed. This formulation provided satisfactory solutions for the "tilted cylinder" bathymetry of Whalin (1971). However, initial results show that this formulation may develop instabilities for some regimes, e.g. when applied to the tests of Chapalain (1992). We are attempting to determine if the instabilities are computational or theoretical. These studies are ongoing, and the most robust formulations, including the more rigorous formulations of Tang and Oullette (1997), will be used.

(d) **Wave-current interaction**: Basic code modifications were made to include the effects of background currents. Two test-cases were successfully simulated: waves propagating through a gyre and waves near a beach with a rip current. Two additional modifications, necessary for many realistic applications, were pursued (ongoing). Open boundary conditions that include currents are being developed, and the formulations of Longuet-Higgins (1961), involving waves interacting with shear currents and shore-perpendicular currents, are being used. Further, opposing currents can induce wave breaking, so techniques to juxtapose two kinds of nonlinear mechanisms (breaking and currents) were developed. Initial simulations were performed for the hydraulic model tests pertaining to waves approaching an inlet in the presence of ebb currents (Smith et al. 1998). A flow model developed by Dr. N. Booij at TU Delft was used to generate the flow fields, which will now be input to the wave model. The simulations are continuing. Initial results highlight the importance of wave-angle dependent coastal boundary conditions (developed recently, Steward & Panchang, 2000), necessitating juxtaposition of the associated nonlinearity with the other nonlinear mechanisms (breaking and currents).

(e) **3d module development.** The base code (using rectangular boundary elements) was constructed for 3d simulations in a sub-domain that can include floating (or other) objects like a moored ship. Basic tests had been successfully performed previously for plane wave propagation in an open region and around a pier. Testing was expanded to include wave propagation over a sloping beach and a square step. The code performs satisfactorily in all tests. To accommodate structures with complex shapes like ships, we have developed an initial version of the code using triangular elements. The 3d code is capable of taking wave output from any other wave model on sub-domain boundaries. One time-consuming feature of this developmental work is the difficulty of generating 3d boundary elements for each test case.

RESULTS

As noted above, many improvements have been implemented in the currently operational version. Space permits the demonstration of only a few results, shown below.

Storm Date	**11/18/94**	**09/06/96**	**05/13/98**
Observed /Input: (900 m from shore)	5.14	3.27	3.28
Data, Gauge 625: (568 m from shore)	3.13	2.70	2.67
CGWAVE, Gauge 625	2.54	2.34	2.58
Data, Gauge 641: (239 m from shore)	1.44	1.62	1.27
CGWAVE, Gauge 641	1.39	1.47	1.27

Fig. 1. Above table shows wave height comparisons near FRF Duck. Spectral input, with breaking, using 200 components. Wave heights in m.

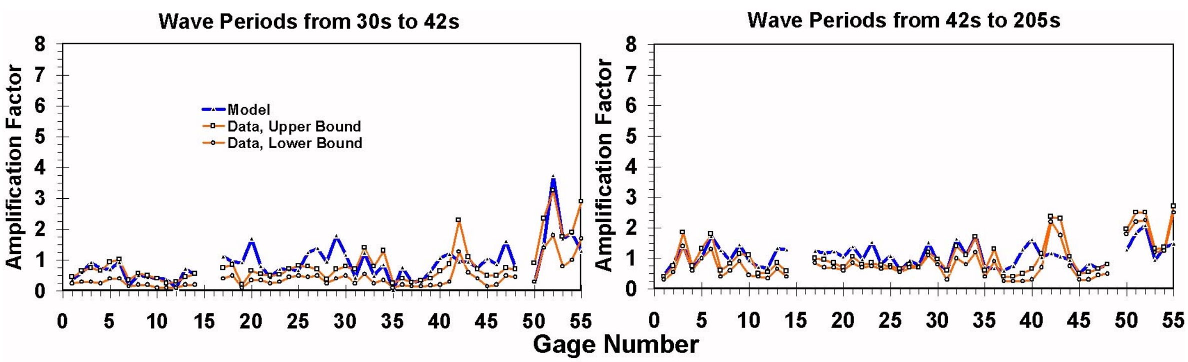

Fig. 2. Model validation: Wave height comparison at several gage locations in Los-Angeles/Long Beach Harbor. Results for indicated wave periods are averaged, per Seabergh & Thomas (1995).

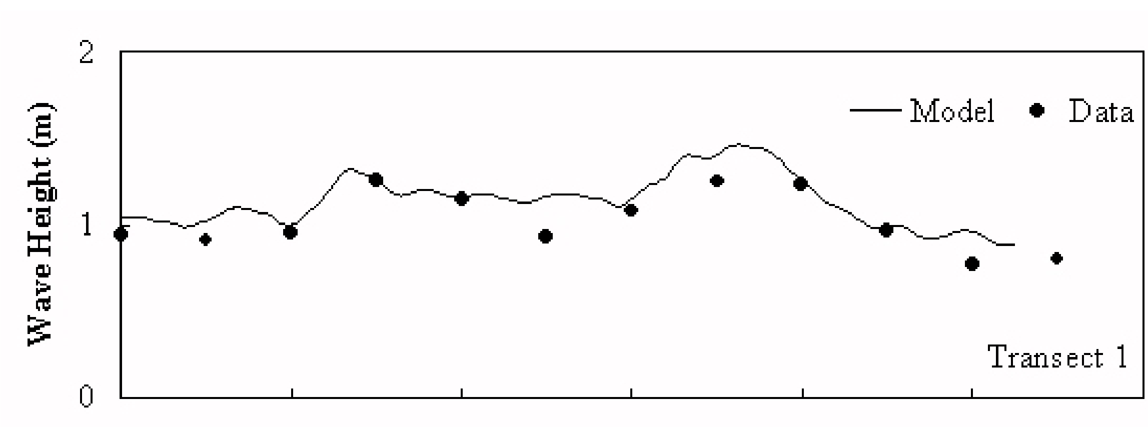

Fig. 3. Model validation: Wave height comparison along a longshore transects in Ponce de Leon inlet, Florida. Spectral input, with breaking, using 66 components.

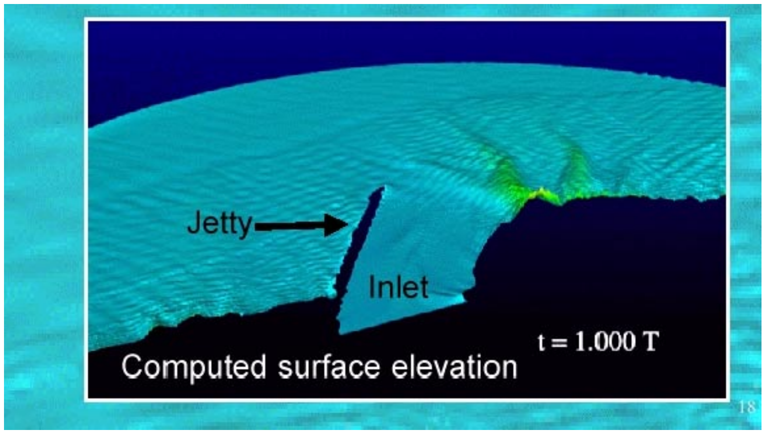

Fig. 4. Model simulation of waves near Ponce de Leon inlet, Florida, using HPC version of CGWAVE (after Bova et al. 2000). Instantaneous snapshot.

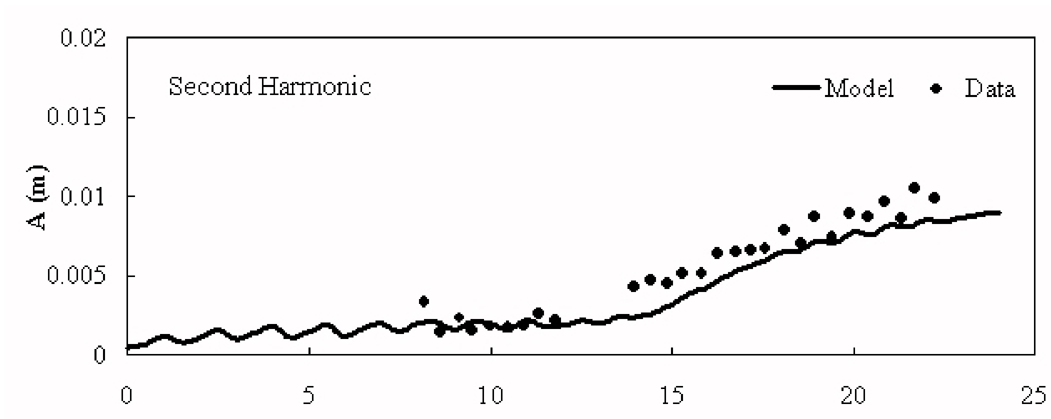

Fig. 5. Simulation of wave-wave interaction, for Whalin (1971) bathymetry. Uses Kaihatu & Kirby (1995) wave-wave coupling. Input A = 0.0098 m, T = 3 s. Only 2nd harmonic shown, which would be zero in linear version.

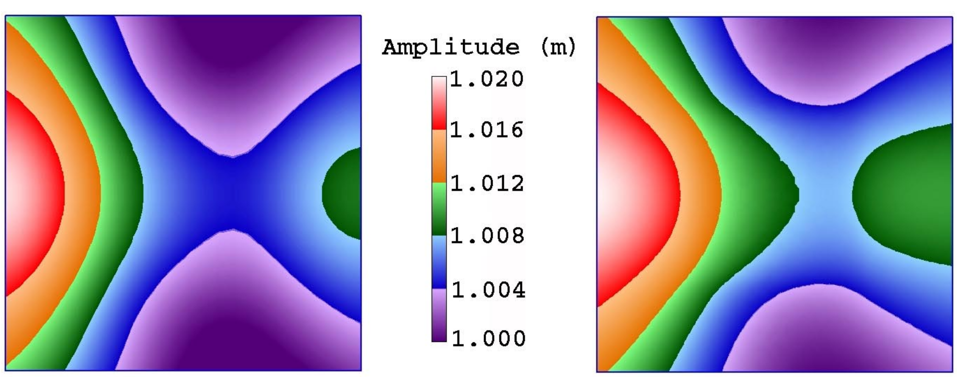

Fig. 6. Wave amplification comparison for wave propagation over square step; new 3d model (left) vs analytical results (right).

IMPACT/APPLICATIONS

The model will provide the Navy with a sophisticated tool for predicting waves in coastal regions with arbitrary shapes and depths. The second module will enable estimation of wave forces on structures such as ships, LCAC's, etc. The predictions may influence naval operations such as amphibious or loading and unloading activities. The model can also be used for civilian harbor projects. (See below).

TRANSITIONS

We have provided the model to Dr. T. Donato of NRL Washington and are assisting him in its usage for his littoral drift work that involves coupling model results with remotely-sensed data. We are working with Dr. L. Hsu of the NRL and Dr. J. Dykes of NAVO (Stennis Space Center) and intend to transfer the high-end version to them. Dr. L. Rosenfield of the NPS has inquired about using the model for applications by the Navy METOC Center in Rota, Spain, to forecast the impact of waves on ships in ports. Dr. Demirbilek of the Army CHL visited U.Maine to work with the PI Panchang and his students for 8 days and to learn about the more advanced features of the model. Dr. E. Thompson, Dr. S. Bratos, and Dr. Demirbilek of the DoD have been using CGWAVE for applications to Milwaukee Harbor, Brookings Harbor, Morrobay Harbor, and Apra Harbor (Guam).

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2 presentations: (1) at the Waves workshop conducted by Dr. Linwood Vincent (Fall 1999), and (2) at the AGU Conference in Washington DC in May 2000.