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Ding, Yan; Jia, Yafei; Altinakar, Mustafa S.

Simulations of Wave-Current Interaction using an Integrated Coastal and Estuarine Processes Model

SIMULATIONS OF WAVE-CURRENT INTERACTION USING AN INTEGRATED COASTAL AND ESTUARINE PROCESSES MODEL

Yan Ding[1], Yafei Jia[2], and Mustafa S. Altinakar[3]

Interaction of wave and current is an important hydrodynamic process in coasts and estuaries (especially including river mouths and tidal inlets), as it strongly affects coastal flow dynamics, stirs and conveys sediments, and usually is able to derive significant morphological changes such as deep scours and shoals in inlet channel from a single storm event. Simulation and prediction of waves, currents, and their interaction effect can facilitate design and manage waterways in tidal inlets and accurately assess environmental impacts of water exchanges through tidal inlets in coasts and estuaries. This study uses an integrated coastal/estuarine process model (CCHE2D-Coast) to simulate coastal hydrodynamic processes driven by tides, currents, wind-induced waves, and swell waves. The coupled wave-current models are employed to simulate the wave-current interaction in tidal inlets. For simulations of irregular waves, a multidirectional wave-action model is developed to take into account various wave transformation and deformation processes such as diffraction, refraction, shoaling, wave breaking, wave-current interaction, and whitecapping. The hydrodynamic model is based on the nonlinear shallow water equations to account for hydrodynamic processes induced by tidal flows, wave radiation stresses, turbulence, and bottom friction. The two coupled models are integrated seamlessly by using a single non-orthogonal mesh covering the entire computational domain. The model validations are performed by simulating the coastal hydrodynamics in a laboratory wave tank and Grays Harbor, WA.

Under the circumstance of co-existence of wave and current, wave frequency is changed with water depth and velocities. According to small-amplitude wave theory, the resulting wave number k can be calculated by the following dispersion equation with the Doppler frequency shift:

$$\sqrt{gk\tanh(kh)} = \omega - \mathbf{u} \bullet \mathbf{i}_\theta \tag{1}$$

where g = the gravity acceleration; h = water depth; ω = incident (or absolute) wave angular frequency; $\mathbf{u}$ = depth-averaged velocity vector; $\boldsymbol{i}_\theta = (\cos\theta,\ \sin\theta)$, a unit vector following the wave direction at the angle θ. Two solutions of this quadratic equation are dependent on the strength of ambient current. In the model, the multidirectional wave-action balance equation is solved by taking into account the variations of wave angular frequency due to the wave-current interaction.

In order to validate this integrated model for modeling the wave-current interaction, a number of simulation cases have been done by simulating laboratory wave fields under steady currents (Smith et al. Report CHL-98-31, US Army Corps of Engineers, Vicksburg, MS, 1998), which are to investigate the wave–current interaction and wave breaking in the presence of a steady ebb current at an idealized inlet. As one example, Figure 1 shows the comparisons of wave heights along three on-offshore transects through the inlet, in which the steady ebb current is 21.9 cm/s (i.e. Run 11). The

[1] Research Assistant professor, National Center for Computational Hydro science and Engineering, University of Mississippi, University, MS 38677, USA (ding@ncche.olemiss.edu)
[2] Research Professor and Associate Director, Same Institute (jia@ncche.olemiss.edu)
[3] Research Professor and Director, Same Institute (altinakar@ncche.olemiss.edu)

computed wave heights including the effect of wave-current interaction and wave breaking are in good agreement with the measurements. This model has been also validated carefully for simulating waves and tidal currents at Grays Harbor, WA, from September to November, 1999. To do so, the computed tidal currents were fed back to the wave model every one hour to compute the wave-current interaction. Figure 2 (left) is a snapshot of a computed ebb current, which has been validated by comparing with observed velocities. And it found that the tidal elevations and velocities are in excellent agreement with observations. Figure 2 (right) shows intercomparisons of wave heights at Station 4 located in the middle of the inlet, in which the observed wave heights are obtained from the USACE-ERDC-CHL Dataport (http://sandbar.wes.army.mil/). The results clearly indicate that the wave heights computed with the inclusion of wave-current interaction follow the tidal cycles very well; but without the current effect the computed wave heights cannot catch this wave periodical phenomenon due to interaction between waves and tidal currents. It means that it is important to include wave-current interaction in the simulations in order to improve prediction accuracy of waves.

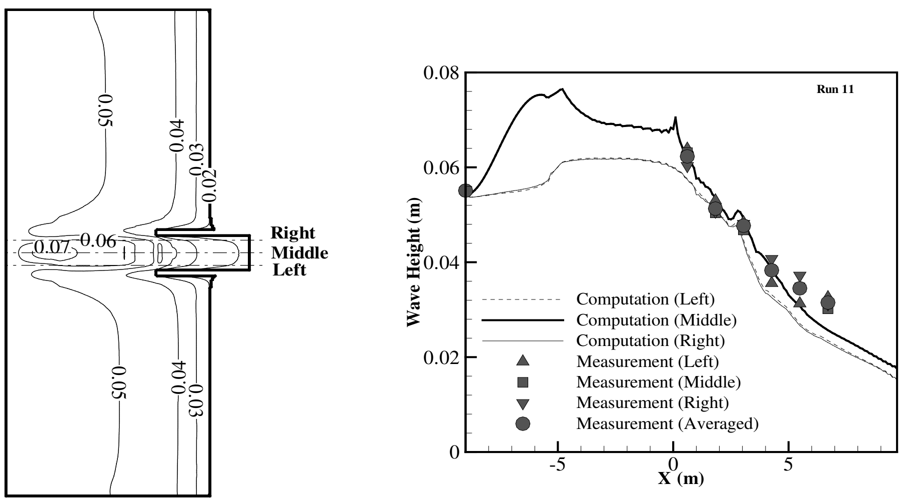

Figure 1 Left: spatial distribution of wave heights; right: comparisons of wave height profiles

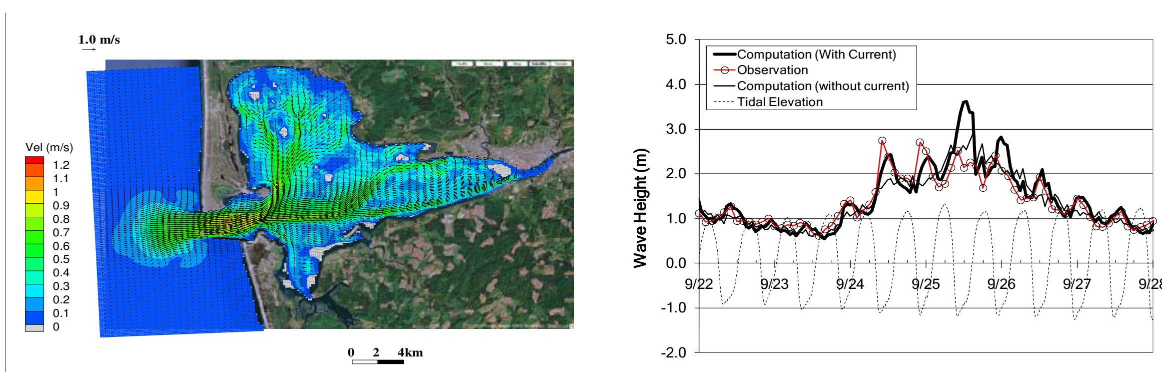

Figure 2 Left: Computed tide current at Grays Harbor, WA; Right: Comparison of significant wave heights at a gauge station