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Unsteadiness effects in wave-current interaction in the nearshore

Merrick Haller (1), Jitraporn Phaksopa (2), and Tuba Ozkan-Haller (1)

(1) Oregon State University, Corvallis, OR United States (merrick.haller@oregonstate.edu), (2) Marine Sciences, Kasetsart University, Thailand (jitraporn133@gmail.com)

Typical analyses of wave-current interaction assume the current field to be quasi-stationary and the absolute wave frequency to be time invariant. However, theory tells us that unsteady currents will induce a time variation in the absolute frequency and wavenumber. In this work we first demonstrate, through a large-scale laboratory experiment, observations of absolute wave frequency modulations. The frequency modulations are shown to be caused by both unsteady water depth and unsteady currents due to the presence of low-frequency standing waves in large wave flume. These observations allow a unique verification of the theoretical predictions. New analytic solutions for the variations in frequency and wave height induced by the unsteady currents are then given via a perturbation analysis and the importance of this phenomenon in natural situations is discussed.

Next, we perform a more sophisticated numerical analysis using a coupled model system consisting of the time-integrated Navier-Stokes equations and the wave-action-balance equation including wave breaking dissipation. The model setup again involves standing long waves in an enclosed basin but here the waves and currents are fully coupled. The standing long waves are driven by wave breaking of the incident regular wave field. The coupled numerical system is used to verify the findings from the analytic work regarding variations in absolute frequency. In addition, from this analysis both positive and negative feedbacks between waves and currents are identified and shown to depend on the normalized bed slope. Specifically, for small normalized slopes, the negative feedback reduces the magnitudes of the standing long waves, while on steep slopes the long waves are amplified. The feedback dynamics are shown to correlate with the surf beat similarity introduced by Baldock (2012). This parameter also helps to distinguish between the forcing mechanisms of bound wave release versus time-varying breakpoint forcing.