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Hydrolink

MODELLING WATER WAVES WITH GPUSPH

BY ROBERT A. DALRYMPLE, ROZITA JALALI FARAHANI, ALEXIS HÉRAULT, GIUSEPPE BILOTTA AND EUGENIO RUSTICO

The Smoothed Particle Hydrodynamic method has been applied to water waves since Monaghan (1994), who showed, with a few thousand particles, that a numerical wave train on a sloping beach would form a plunging breaker (albeit with very few particles in the plunger). At Johns Hopkins University (JHU), the emphasis has been on determining the ability of this particle method to model all aspects of water waves as they undergo transformation from offshore to the beach.

The model that we currently use is the computer code GPUSPH (Hérault et al., 2010), which is available as open source at www.gpusph.org. The model is very flexible in terms of kernels, viscosity types, as well as kinds of boundary conditions, and has the attractive attribute that it was designed specifically to run on GPUs (Graphics Processing Units), thus greatly accelerating the computations.

Early work on waves at JHU included the impact of a tsunami on a structure (Gómez-Gesteira and Dalrymple, 2004), which was based on the physical experiments of Arnason et al. (2009), showing the wave runup on the front of a square pier, and waves on a beach (Dalrymple and Rogers, 2006). This later paper showed that a plunger in a breaking wave splits into two jets, one that circles around in the tube of the plunging wave and the other jet that splashes forward with water from the toe of the wave. In addition, large vertical vortical structures were associated with the wave front and trailing the breaking wave. The modeling of these waves was done with the computer code SPHysics.

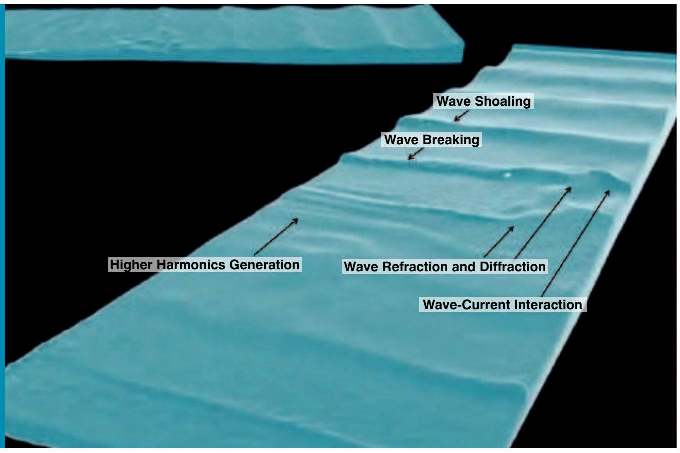

Figure 1 - Two views of water surface modeling the Drønen test. The incident waves are from the upper right and propagate to the beach at bottom. Sand bar located on the left side of the tank. Note the wave-current interaction at the right side of the tank where the rip current is affecting the incident wave train as well as the nonlinear harmonic generation on the left over the bar

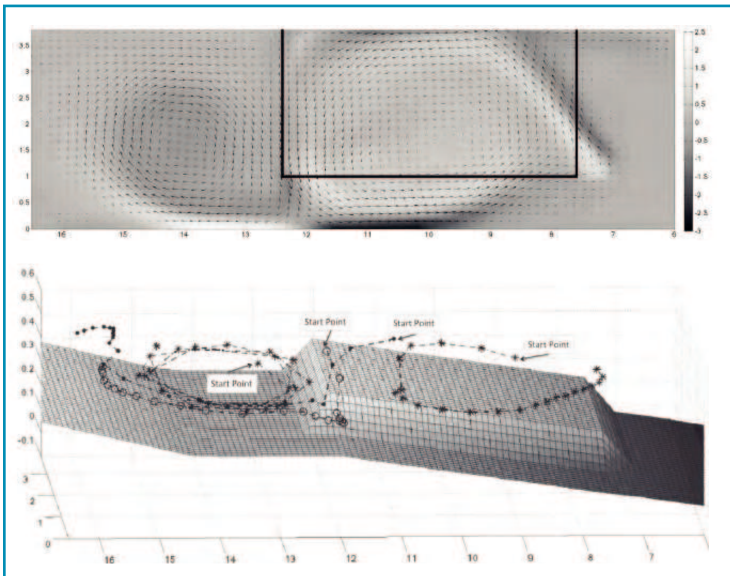

Figure 2 - Top: Velocity vectors and grey-shaded vorticity (s-1) for Drønen test. Box outlines location of sand bar. The two circulation gyres are readily seen; one over the bar and one near the beach. Bottom: Trajectories of particles released at mid-depth

For waves on a beach, the numerical model produced a mean water level set-up at the shoreline, as occurs in real life, therefore the question arose about whether GPUSPH could predict the occurrence of longshore and rip currents that are caused by variations in wave radiation stresses along a beach (which are nonlinear quantities, theoretically). A physical model by Drønen et al. (2002) was used as a test case. This wave tank model consisted of a sloping beach fronted by a channel and then by a rip channel and a 'sand' bar, which caused the incoming waves to break. The breaking process, which reduced the ability of the waves to transport momentum, created both a mean water level variation and driving forces for mean currents. The results are two mean circulation gyres (one over the bar and one inshore) and a rip current flowing out the rip channel. So, GPUSPH can model the waves (with refraction, shoaling, diffraction, breaking and wave-current interaction), but also the momentum-driven flows, such as the nearshore circulation patterns and rip currents.

One of the interesting processes associated with breaking waves is the formation of obliquely descending eddies (ODEs) as presented by Nadaoka et al. (1989). These eddies are found trailing breaking waves in the surf zone, descending from the bubble cloud down into the water column. These 'tornadoes' tilt towards the shoreline, hence the descriptor 'obliquely'.

These structures were also seen in our study of shoaling solitary waves (which are a zeroth order approximation to a tsunami). Validating against the laboratory study of Ting (2006), we found that the spilling solitary wave left a large number of trailing hairpin vortices, as shown in Figure 3.

The source of the hairpin vortices is the turbulent roller region at the face of the spilling

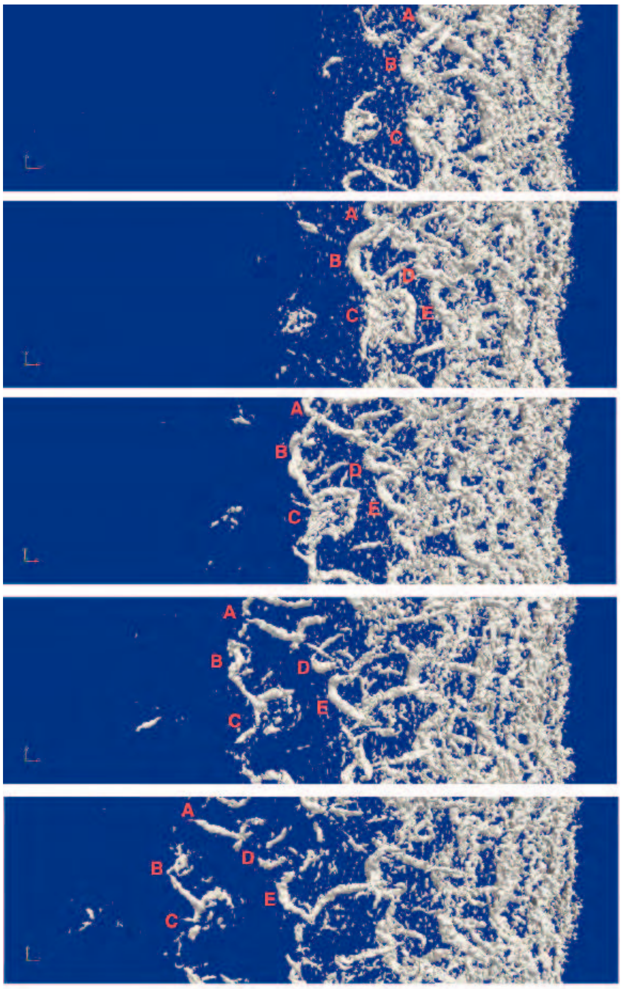

Figure 3 - GPUSPH simulation of the spilling solitary wave of Ting (2006) at different times. Note the trailing vortices as seen moving with the wave front. The letters are used to identify a particular vortex. The lambda-2 criterion was used to visualize the vortices (lamda-2 is defined as the second (in magnitude) eigenvalue of the matrix S2 + Ω2, where S and Ω are the rate-of-strain and vorticity tensors, respectively)

solitary wave. Conceptually we can envision the generation of the hairpins in the same way as hairpins are pulled from a turbulent bottom boundary layer by the flow above it. In our case, the turbulence is at the top, but, when moving with the wave, there is a strong current below with the magnitude of the wave speed. This current pulls the hairpins from the roller region into the mean flow. These hairpins migrate under their own power down into the water column with the curved head down and the legs obliquely oriented towards the roller region – hence these are the obliquely descending eddies.

Conclusions

SPH and GPUSPH can model waves and wave processes, including nonlinear effects. Nearshore circulation, consisting of the time-averaged flow, including rip and longshore currents can be readily seen in SPH models. Coherent turbulent structures known as obliquely descending eddies are explained by the GPUSPH modeling as hairpin vortices dragged out of the turbulent roller region of breaking waves.

Additional modeling, not reported here, shows that GPUSPH can replicate wave forces on structures well and can model nonlinear three-wave interactions, such as subharmonic generation of edge waves.

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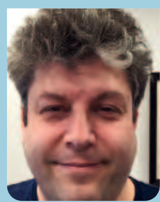

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