

Three Dimensional Modeling of Breaking

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LONG-TERM GOALS

Smoothed Particle Hydrodynamics (SPH), a meshless Lagrangian numerical method, is used to examine the complicated three-dimensional flow field in breaking waves. SPH has an advantage over other computational methods to examine this problem as it allows for vorticity and splashing of the fluid. Here we are addressing the important issue of the source of vorticity in waves as they propagate and break in very shallow water, and we are discovering the mechanisms for breaking wave turbulence in the surf zone. More specifically, we are identifying the formation mechanisms for coherent turbulent structures observed in the field and laboratory, such as obliquely descending eddies, downbursting, and the hydrodynamics of the splash-up following a plunging breaker.

OBJECTIVES

The following objectives were proposed for this project: Verify and test 3-D SPH code for breaking waves on beaches. Optimize for parallel computing. Examine splash-up in detail, particularly as a function of wave characteristics. Develop and verify a combined SPH and Boussinesq model. Utilize the model (with parallel coding) to determine the mechanisms of obliquely descending eddies and 'fingers' within plunging breakers. Characterize the parameters and scales of the coherent turbulent structures. Examine splash-up in detail, particularly as a function of wave characteristics. Analyze the physics embedded within the breaking wave by examining the various contributions to vorticity. Examine extensions to two-phase and three-phase flows--water, air, and sediment.

APPROACH

We are continuing the development a Lagrangian fluid particle scheme to study breaking waves—in particular, the formation mechanisms of coherent turbulent structures that occur within the surf zone. At Johns Hopkins University (JHU), Prof. Robert A. Dalrymple (PI) and Dr Ben Rogers (Post-doctoral Research Fellow—FY04) have spent much of the last year developing further enhancements to 2-D and 3-D SPH codes that had been developed previously and verified for various wave propagation problems (Dalrymple and Knio, 2001, Gómez-Gesteira and Dalrymple 2004).

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14. ABSTRACT Smoothed Particle Hydrodynamics (SPH), a meshless Lagrangian numerical method, is used to examine the complicated three-dimensional flow field in breaking waves. SPH has an advantage over other computational methods to examine this problem as it allows for vorticity and splashing of the fluid. Here we are addressing the important issue of the source of vorticity in waves as they propagate and break in very shallow water, and we are discovering the mechanisms for breaking wave turbulence in the surf zone. More specifically, we are identifying the formation mechanisms for coherent turbulent structures observed in the field and laboratory, such as obliquely descending eddies, downbursting, and the hydrodynamics of the splash-up following a plunging breaker.					
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WORK COMPLETED

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- Implementation of physically correct description of viscous effects for free-surface flows within the SPH formalism
- Development of a Large Eddy Simulation (LES) type sub-particle-scale (SPS) formulation for compressible flow within SPH.
- Implementation of the SPH-SPS in 2-D and 3-D
- Validated for (i) solitary wave propagation on a flat bed, and (ii) a weakly plunging breaking wave
- Implemented sediment concentration into the fluid and the interaction with the bed—that is, sand deposition and erosion.

FY 05

- Parallel versions of the SPH-SPS for 2-D with and without sediment transport have been developed.
- A hybrid Boussinesq finite element—SPH code has been developed with one-way coupling between the models.
- Higher resolution modeling has further elucidated wave breaking mechanisms, such as obliquely descending eddies, downbursting, and splash-up.
- Suspended sediment transport on a sloping beach has been examined with the higher resolution, parallelized, SPH code.
- A compressible fluid wave theory has been developed to provide a theoretical underpinning of the choice of sound speed in the SPH wave model.

RESULTS

The resolution of the model in 2D and 3D has increased to a level that the development of turbulence within breaking waves can be followed through time and the mechanisms are beginning to be unravelled. Last year, we showed how downbursting (Kubo and Sunamura, 2001) could be described by our 2D model. This year, the 3D version of the JHU SPH code is capable of handling 500,000 particles and this higher resolution, while not yet fully satisfactory, is an order of magnitude greater than last year. For example, in the Figure 1 (upper panel) , a side view of a breaking wave on a slope is shown just after touchdown of the plunger jet. The formation of the splash-up, which is a second forward-breaking of the wave, is shown. By tracking the trajectories of the SPH particles, we have seen that the fluid that comprises the splash-up comes, in part, from the “rebound” of the plunging breaker and in part from the underlying fluid. More detailed examination of the wave revealed that the

splash-up is not really a rebound of the plunger from the water surface, but it is the result of the plunging jet penetrating the toe of the wave. Since the speed of penetration is slower than the fluid flow in the jet, water splashes from the indentation created by the jet. The splash occurs in both the forward and backwards directions. The forward splash is then the splash-up.

The lower panel of Figure 1 shows an overhead view of the vertical vorticity on a horizontal plane. The initiation of vorticity by the touchdown of the plunging jet is shown and, in the lower panel of Figure 2, the coalescing of this vorticity into counter-rotating vortices after the crest passage is shown. These vortices form what are known as obliquely descending eddies, which is born out by looking at the vorticity over the depth in a vertical plane (looking shoreward); Figure 3.

The suspended sediment transport under breaking waves in a closed 2-D wave tank is shown in Figure 4. The sediment is modeled by solving a SPH version of the advection-diffusion equation for sediment concentration, which means that each of the SPH fluid particles have a given concentration of sediment. In the results, showing the transient startup of a wavemaker, the sediment is picked from the bottom and is moved in an oscillatory manner by the wave motions. The sediment concentration is higher under the breaking wave crest, where the horizontal velocities are high.

One of the important advances to be made for SPH is the development of a hybrid model that couples the computationally intensive, but highly resolved, SPH code to a more efficient, but less descriptive, model in the offshore. For example, Boussinesq models are reasonably efficient at propagating waves ashore; however, they can not treat the details of breaking. By coupling the two models, a better surf zone and run-up are provided. We have developed a one-way coupled model between a finite element Boussinesq model and SPH. The Boussinesq model provides the boundary information for the SPH model; however there is no feedback from SPH to the Boussinesq code—such as would occur for wave reflection from a beach. The one-way model has been used to examine waves seiching in a basin to date.

A linear wave theory for waves on a compressible fluid was developed to show the effects of compressibility on wave propagation. For fluids that are slightly compressible, which is one of the prime assumptions of the SPH methodology, the resulting dispersion relationship shows that the wave lengths and celerities given by a compressible theory do not differ significantly from an incompressible wave theory. For the case that the compressibility is significant and the sound speed in the water slows to become comparable in magnitude to the wave speed, large errors can occur. Further these errors are worse in shallow water, just where the model is being applied. The major conclusion is that, if the compressibility of the water is chosen such that the speed of sound in the water is at least ten times that of the water wave speed, then the discrepancy between compressible and incompressible wave celerities is insignificant. This sound speed is still much lower than the actual speed of sound. (Using the actual speed of sound requires us to use extremely small time steps—slowing down the sound speed allows a bigger time step.)

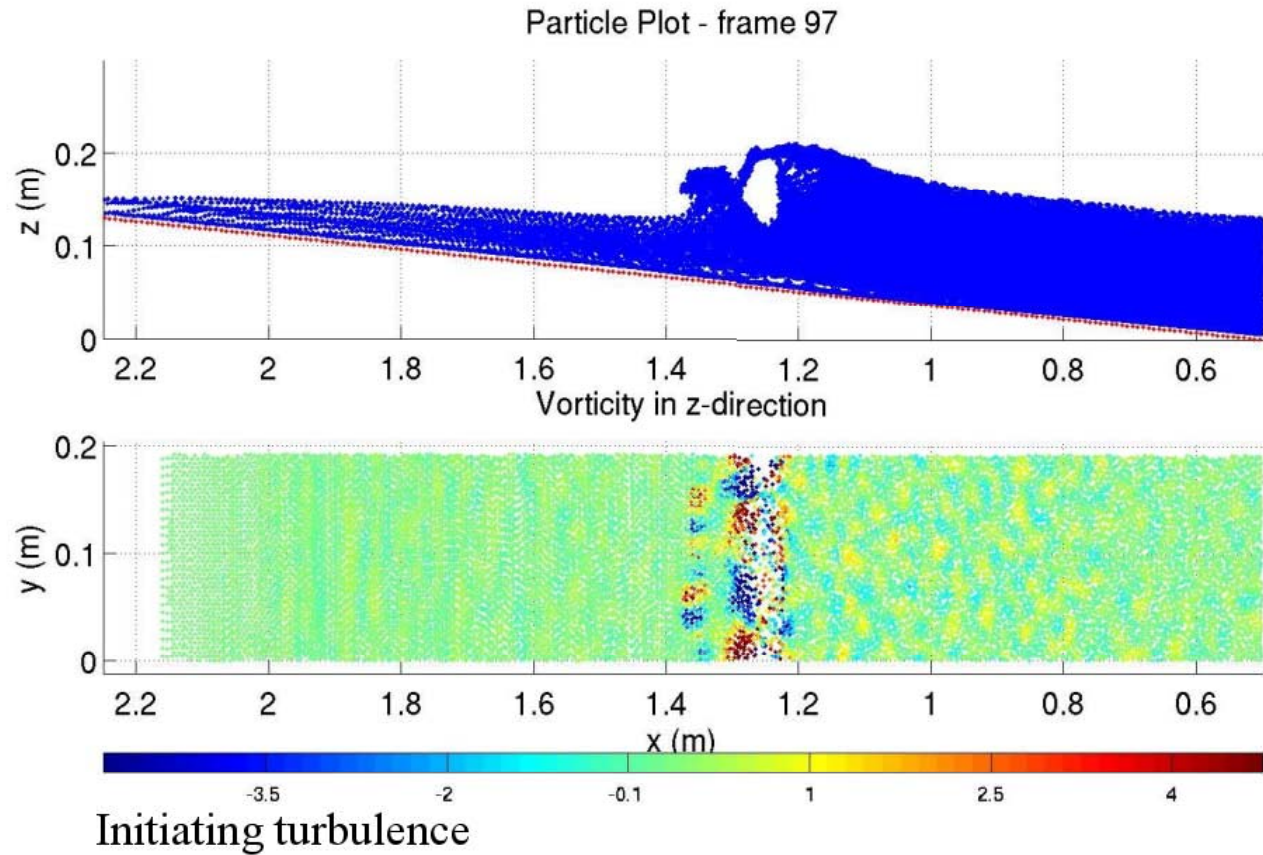


Figure 1. 3-D plunging breaker on a sloping beach just after plunger touchdown. Note the beginning of the splashup in the upper sideview panel. The lower panel is a view from above showing the generation of vertical vorticity.

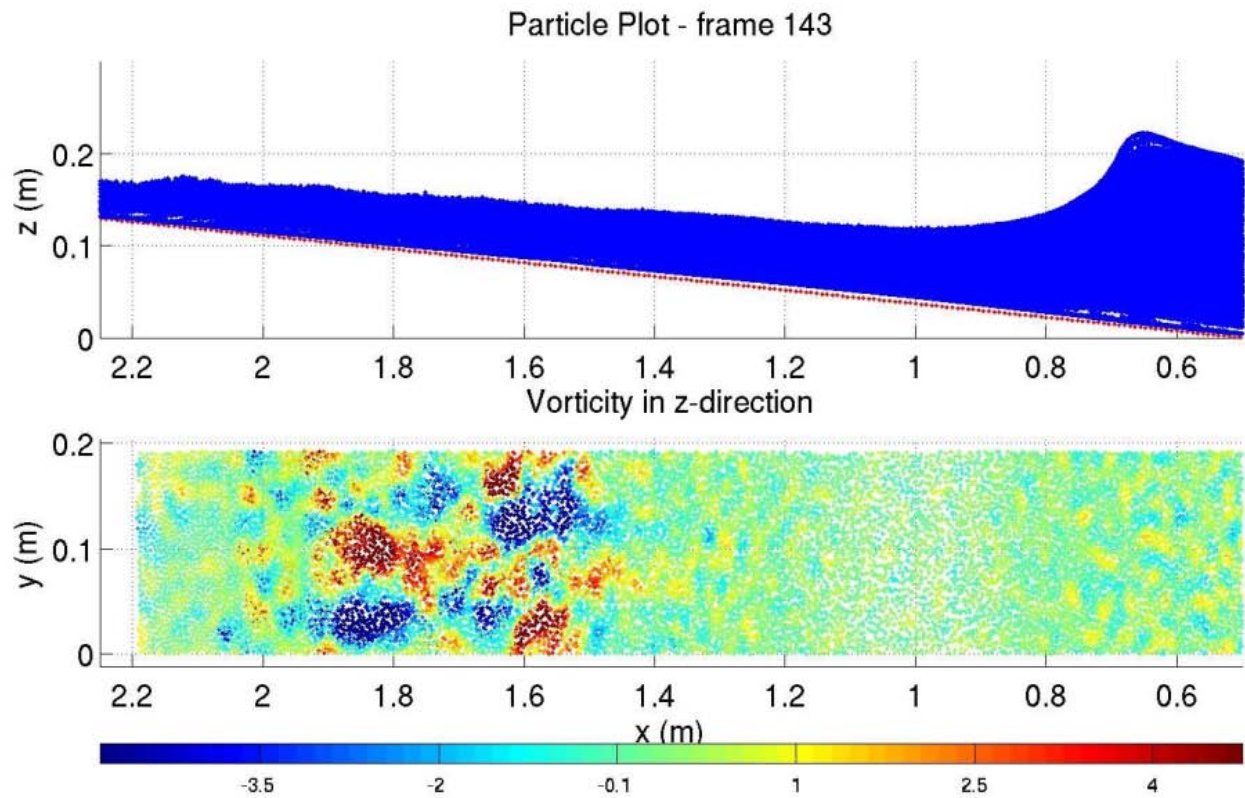


Figure 2. Upper panel shows that the plunger in Figure 1 has propagated out of the frame and the next wave is approaching. The vertical vorticity in the lower panel, created by the plunger, has now coalesced into two counter-rotating eddies (shoreward of 1.8 m).

Velocity cross-sections

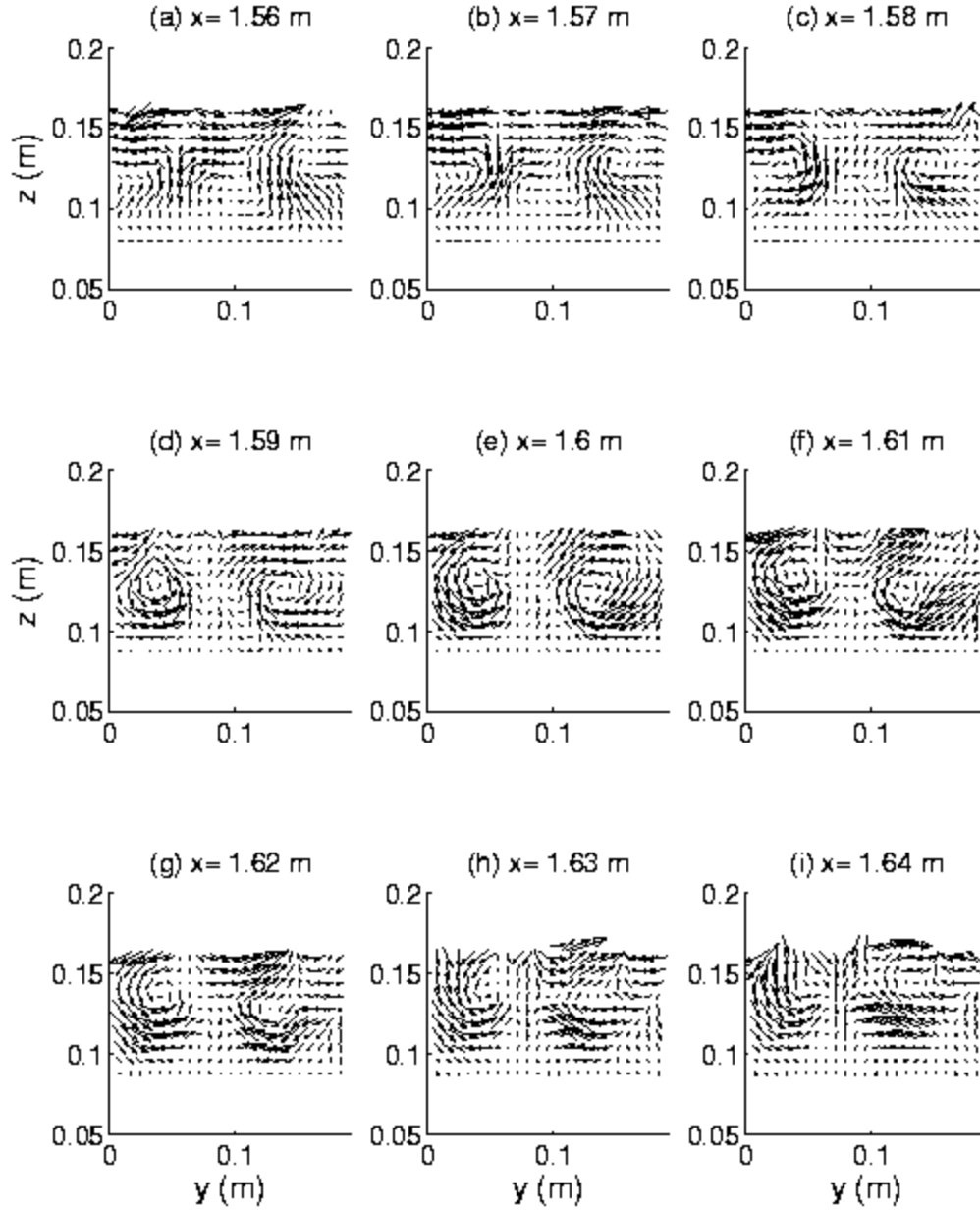


Figure 3. Counter rotating vortices due to the breaking wave showing their dependence on depth. From the location $x=1.59$ m shoreward to $x=1.64$ m, the pair of counter-rotating eddies rise towards the surface, as expected for obliquely descending eddies (Nadaoka et al., 1989)

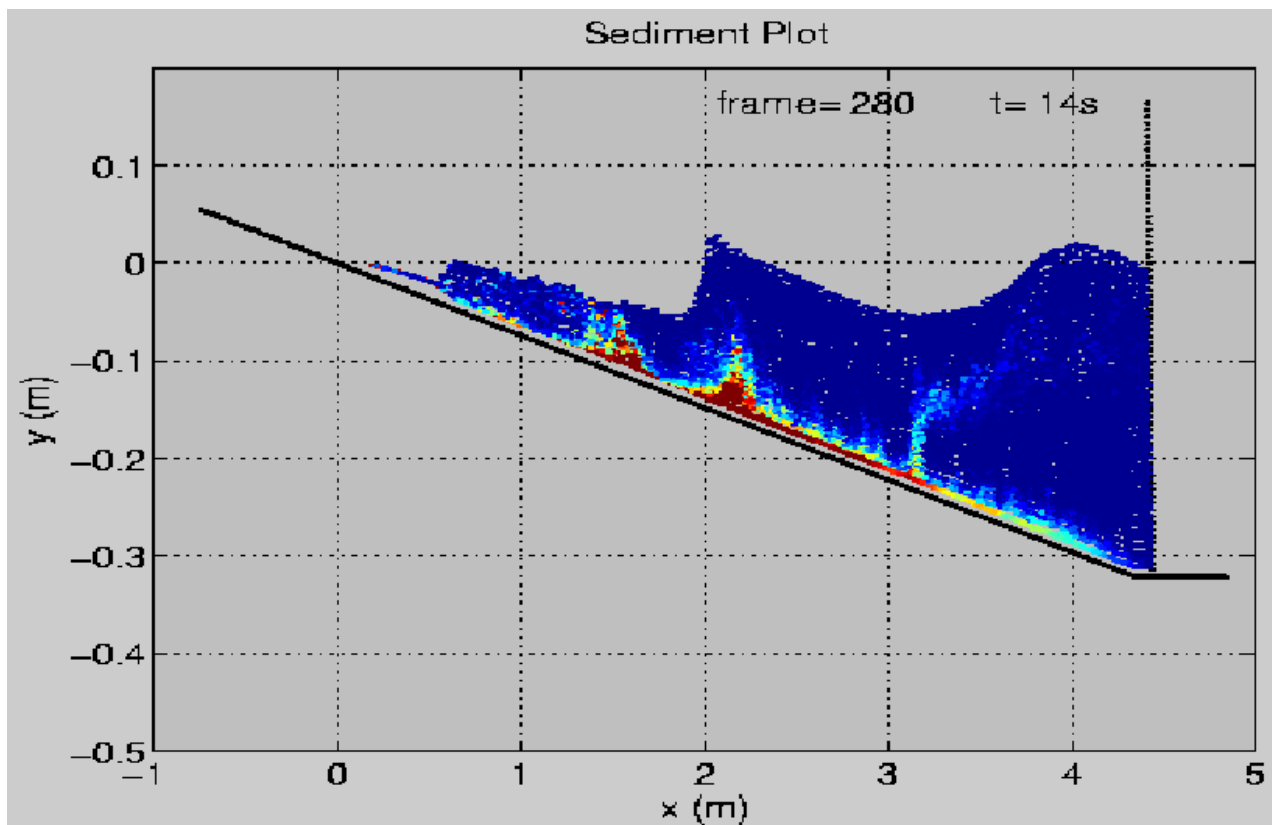


Figure 4. *The suspended sediment transport in a wave tank with a sloping sandy beach. The wavemaker is at the right and the color coding shows that high concentrations (red) of sediment occur under the wave crest. A residual tank circulation of sediment laden water is shown closer to the wavemaker.*

IMPACT/APPLICATIONS

The SPH methodology has been shown to be capable of providing details about the fluid flow in breaking waves that allows for the explanation of phenomena not previously adequately understood. High resolution SPH models can be used to provide detailed descriptions of the nearshore zone. Coupled with another wave model, such as Boussinesq, a hybrid SPH model would provide a large, highly resolved, look at an entire surf zone.

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