Geophysical Research Abstracts
Vol. 13, EGU2011-2889, 2011
EGU General Assembly 2011

Energy dissipation mechanisms in spilling and in highly aerated plunging breaking events

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The dissipation mechanisms characterizing wave breaking processes are analysed starting from the results of numerical simulations. The two-fluids numerical model is based on a Navier-Stokes solver for a single incompressible fluid with density and viscosity smoothly varying across the air-water interface. An interface capturing approach is employed which allows to deal with topological changes of the free surface and thus to describe the air entrainment processes that can occur in breaking processes.

In the study, the evolution of periodic wave trains is considered. The initial wave profile and velocity field are assigned as those of a third order Stokes wave, and the initial steepness ε is in the range $0.2 - 0.65$. The Weber number of the simulations corresponds to a fundamental wavelength of about 27 cm. With such conditions, the wave train remains regular for $\varepsilon = 0.2$ and 0.3. A gentle spilling breaking occurs when $\varepsilon = 0.35$ whereas the breaking is found to be of the plunging type for $\varepsilon \geq 0.37$. The analysis is carried out in terms of velocity and vorticity fields, energy contents in both air and water, energy dissipation terms in water, bubble dynamics and spectra of the free surface elevation before and after the breaking. The validity of some important assumptions of the model on the solution are evaluated as well.

For $\varepsilon = 0.35$, surface tension effects suppress the jet formation at the crest and the breaking occur with the growth of a bulge which resembles the shape of the whitecaps in open ocean. A shear layer develops at the toe of the bulge due to the interaction of the fluid in the bulge with the fluid underneath, which is responsible for the dissipation of the extra-energy. At least for the configuration adopted in the present study, the analysis of the local energy density shows that almost all the extra-energy of the wave, i.e. the additional energy of the wave with respect to the highest non-breaking case, is accumulated inside the bulge at the onset of the breaking. The extra-energy is progressively dissipated within three wave periods and, at the end of this stage, the resulting wave is quite similar to the highest non-breaking wave ($\varepsilon = 0.30$).

In the plunging breaking cases, the energy amount dissipated by the breaking process is larger than the extra-energy content of the initial wave with respect to the highest non-breaking solution. For highly aerated breaking events, a significant amount of work is spent in entrapping the air cavity against the action of the buoyancy. In the next stage, the air cavity collapses and fragments into a bubble cloud immersed in a highly rotational flow with large velocity gradients. As a consequence, most of the potential energy accumulated by the entrained air cavities is dissipated by the viscous effects acting around the bubbles. It is found that this mechanism is responsible for the dissipation of as much as 50 % of the total amount of energy dissipated by the breaking process. Although some of the above results were already argued on the basis of experimental observations, the numerical results provide a clearer picture of the phenomenon.