Velocities and Accelerations in Breaking Waves

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Abstract. The unexpected occurrence of unusually large waves has been documented on numerous occasions. While little is known about the statistics of these waves, even less is known of the dynamical conditions under which they occur. Nonlinear interactions among individual waves travelling within a group have been identified as an important mechanism in the formation of giant waves in the ocean. In this study, the non-linear packet-focusing technique is used to generate steep, plunging waves in a laboratory flume. The kinematics of these waves are measured just up-wave of the onset of plunging, and these results are compared to those of a superposition model, a modified stretching model, and a model based on Stokes 3rd order developed for the present study. The present model represents the velocity beneath the plunging breakers significantly better than the two other models.

Key Words: Wave kinematics, extreme waves, ringing effect, wave forces, wave accelerations.

1. Introduction.
Breaking waves play an essential role in air-sea interactions, and in assessment of impact loads on both fixed and floating coastal structures, platforms and ships see Kjeldsen (1997). Further breaking waves are very important for mixing and spreading of oil pollution in the upper surface layers of the sea. The dynamic action of the crest of a plunging breaker thus becomes particularly important. Even now when theoretical and numerical treatments of the breaking problem have progressed, controlled experimental measurements for development and calibration of numerical ocean basins are needed. The present investigation reports synoptic measurements and analysis of particle accelerations and velocities of plunging crests in deep water wave groups. Further a third order simulation technique is developed in order to predict wave kinematics in extreme waves.

2. Experiments.
One series of experiments was performed in the large (40 m long 2.60 m wide) Air-Sea Interaction Simulation Facility of the I.O.A. laboratory of the I.R.P.H.F. Institute, located in Marseille. The wave generation technique developed by Kjeldsen (1982) was used for production of plunging breaking crests in deep water wave groups. A visualization technique, Bonmarin (1989), makes the wave profile visible and an associated image analysis process allows measurements of both the water surface geometry, crest front steepness and asymmetry (IAHR/PIANC 1986), as well as detailed measurements of accelerations of tracer particles dragged away by breaking and broken waves, see Fig. 1. and Fig. 3. Ten experiments designated by the reference of A11 to A21 were performed. Another series of experiments was performed in the large wave tank at the Canada Centre for Inland Waters. The tank dimensions are 100 m in length, 4.5 m in width and the water depth for all runs were 1 m. Just upwave of the breaking wave, the water surface elevation was measured with a surface piercing capacitance wave staff, and the velocity was measured with an acoustic Doppler current meter. Replicate tests were performed to measure the velocity at various depths beneath the surface. See Skafel et al. (1997).

3. Results.
A Lagrangian measurement technique is needed in order to measure particle accelerations accurately in non-linear waves, see Lonquet-Higgins (1986). In order to develop such a technique the wave-following properties of the tracer particles were mapped. A calibration experiment was performed with a symmetric regular wave with steepness $\kappa = 0.31$. Fig 2 shows the measured trajectory, and a theoretical trajectory predicted by second order wave theory. A significant Stokes drift in agreement with the theory was obtained. This relative good agreement between experiment and theory validates the choice of the floating particles. In the breaking waves the different steps of the measurements were i) the reconstruction of the trajectory of the floating particles (see Fig 4), ii) measurements of their celerity, and iii) the measurement of their acceleration, these two last measurements being deduced from the trajectory. Fig 5 shows an example of measured horizontal velocities of particles P1, P2, P3 and P4, shown in the experiment as it develops in Fig. 3. The horizontal velocities are normalized with the wave phase velocity c. Particle 4 reaches a horizontal velocity equal to the wave phase velocity, as it can be seen. Fig 6 then shows measured horizontal accelerations of the particles P2, P3 and P4, normalized with the gravity acceleration. The horizontal acceleration of particle P4 reaches a value of 1.55 times the gravity acceleration. Fig 7 shows the vertical acceleration of the particles P2, P3 and P4. Particle P3 reaches a value 0.78 times the gravity acceleration. The acceleration of the floating particles increases rapidly in the