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Laboratory Measurements of Breaking Inception and Post-Breaking Dynamics of Steep Short-Crested Waves

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ABSTRACT

Monochromatic short-crested waves have been produced in a laboratory flume using a shaped wavemaker. Breaking has been observed to occur near the peak in the amplitude modulation of these waves, over a range of local wave steepness. The conditions for inception and the post-breaking morphology (breaker area, height, length) and dynamics were observed photographically, and are quantified. Breaking inception was observed over a wide range of wave steepness (Hi/gT^2) from 0.011 to 0.0335. The latter is in excess of the Stokes limiting steepness for planar waves, and an explanation is suggested based on calculated reductions in crest orbital velocity due to short crestedness. Variations in breaker severity from one wave cycle to the next were observed and are believed to be due to the disturbances left in the water by preceding breakers. A small jet was observed at the initiation of the breaking wave, and a simple estimate of jet dimension is given, based on observed breaker growth rates.

INTRODUCTION

Research interest in deep water spilling breaking waves has grown rapidly during the last decade. A number of observational laboratory studies in wave tanks has centered on the search for steepness criteria for the inception of breaking: Ochi and Tsai (1983), Ramberg and Griffin (1987) and Bonmarin (1989). The first of these utilized irregular planar waves, and the others initially monochromatic planar waves; the longest of the tanks used was 39.4 m (Ochi and Tsai). In another study, Su (1986) measured the self-excited distortions of initially planar waves in a tank 106 m in length, and he also observed the inception of breaking. Other experimental studies of planar wave instability have been carried out by Melville (1982). Observations of breaking waves at sea have also been made by Weissman et al. (1984) and by Holthuijsen and Herbers (1987). A striking anomaly exists between the criteria that emerged from the planar wave studies in the shorter laboratory tanks ($H_i/gT^2 \cong 0.02$), and from observations at sea ($H_i/gT^2 \cong 0.0067$). An explanation is offered by the data of Su taken in his long tank, who observed breaking, at values of H_i/gT^2 intermediate to the values mentioned above, the value declining as the fetch to breaking increases. The role of modulation instability on the route to breaking, at least for long fetches, is strongly suggested by the laboratory studies of Su and of Melville, and gives particular importance to the systematic at-sea observations of Holthuijsen and Herbers relating to the common occurrence of a breaking wave when that wave was a part of a modulated wave group. Much clearly remains to be understood about the breaking inception process both for short fetches (as in short laboratory tanks), and for longer fetches. The situation was recently reviewed by Tulin and Li (1992).

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Steady breaking waves have been created in the laboratory by towing hydrofoils in tanks — Duncan (1981, 1983), Mori (1986) and Battjes (1971). These, especially Duncan's detailed measurements of breaker dimensions, have allowed Cointe and Tulin (1986) to provide a model of steady breakers as a low-energy eddy traveling with the wave on its front face, and supported in place against gravity by frictional forces on the streamline separating it from the underlying wave below. This model allows a detailed analysis and prediction of breaker dimensions, onset and stability, which fit well with experimental data.

Breaking waves at sea are not steady, but transient, and Longuet-Higgins and Turner (1974) had proposed to model dynamic spilling breakers as a turbulent, aerated density current growing from inception and accreting mass due to entrainment, until it decays due to dissipation. This model has also been used by Cointe (1987) to model dynamic breakers numerically.

These isolated theoretical studies of dynamic breaking suffer from a lack of observational data to corroborate them. Especially lacking are knowledge of the initial conditions for the jet that occur at the initiation of breaking, and of factors related to friction and entrainment.

In a laboratory study of monochromatic directional waves in a tank of 18.2 m in length, we were able to produce spilling breakers on short-crested waves; we have taken the opportunity to observe them and to measure both the conditions for inception and the dimensions of the breakers throughout their growth and decay. These are believed to be the first laboratory data relating to the breaking of short-crested waves, and providing detailed observational information on the breaker dynamics. A property of the monochromatic directional waves produced in our tank is that a crest is periodically and strongly modulated as it travels downtank, unlike the case of monochromatic planar waves. Indeed, as we shall see, this modulation, due entirely to wave interference effects, caused breaking to occur at fixed positions in the tank. These data are therefore also believed to be the first where breaking is strongly coupled with substantial wave amplitude modulation.