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Breaking water waves

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THE PAPER addresses three basic questions about breaking water waves: why do they break, when do they break, and how do they break.

WE ARE STILL at an early stage in the study of breaking waves. The basic question of "Why?", "When?" and "How?" do receive answers, but in many cases they are incomplete, or imprecise. For example we know very little about the violent splashing which often accompanies wave breaking and descriptions of that phase of breaking are only just emerging. On the other hand good progress has been made in recent years in describing two-dimensional irrotational waves including the initial phase of wave breaking as a wave overturns and a falling sheet of water is formed. This presentation is biased towards these studies.

1. Why do waves break?

DISTURBANCES: wind moving objects, such as ships; and changes in water depth are all disturbances which may, or may not, cause wave breaking. Such disturbances are often involved in the generation of waves.

Instabilities have often been described as a cause of wave breaking; studies of the nonlinear evolution of instabilities show that, although they can be a primary cause of breaking, the actual occurrence of breaking is not closely linked to the initial small disturbance. The full nonlinear evolution of two-dimensional instabilities has been calculated for the alternate-crest instability of LONGUET-HIGGINS (LONGUET-HIGGINS and COKELET [34]), the BENJAMIN-FEIR [8] modulational instability (DOLD and PEREGRINE [16]) and TANAKA'S [61] instability for waves higher than those with the maximum energy density by TANAKA, DOLD, LEVY and PEREGRINE [62] for the solitary wave, and JILIANS [26] for the deep water wave.

Evolution towards breaking occurs after an initial instability but also in other circumstances: the example of long nonlinear waves in shallow water is well-known and their steepening has now been studied to the initial breaking stage. Recent work by TELES DA SILVA and PEREGRINE [68] explores this evolution with two-dimensional irrotational flow computations. Examples are shown in Fig. 1. Waves of height less than 0.3 times the depth develop undulations and do not break. Waves that are focussed in space or time are another example.

2. When do waves break?

For simple two-dimensional examples this question can now be answered by direct computation. Comparisons with experiment show good agreement. On the other hand

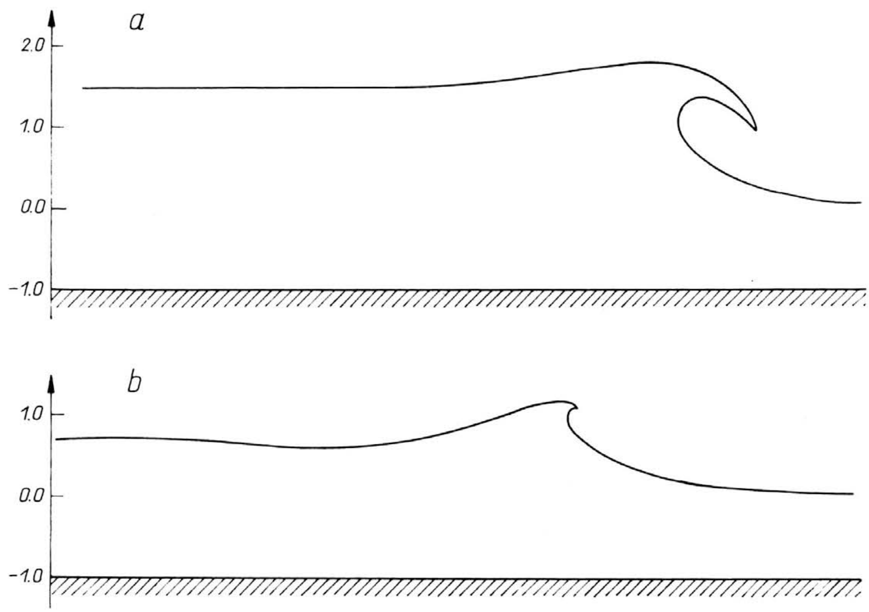

FIG. 1. Long shallow water waves steepened and evolved to breaking.
a) Initial wave of height 1.5 times the depth in front. b) Initial wave of height 0.7 times the depth in front. Diagrams courtesy of F.TELES da SILVA.

computations have also given some surprises. This has been particularly marked in a recent study of solitary waves meeting a submerged semi-circular cylinder resting on a flat bed. All the practical examples of breaking induced are contrary to our initial expectation and for some of these examples of breaking we have yet to find a satisfactory explanation. They include waves which break backward and forward at the same time. See COOKER and PEREGRINE [11], a full account including satisfactory comparison with experiments is given by COOKER, PEREGRINE, VIDAL and DOLD [12].

To predict when waves break it is not necessary to describe details of the breaking process. Comparisons between weakly nonlinear theory for deep water waves and computation in two dimensions and experiment in three dimensions indicate that satisfactory predictions are possible with some suitable "allowance" for the final, brief, highly nonlinear evolution toward breaking.

3. How do waves break?

Answers to this question are still in the observational stage of study. Even the initial overturning is still not understood, despite detailed numerical solutions and some reasonable approximate analytical solutions. My own observation, based on many computations and experiments, is that breaking takes many forms. Some sort of initial jet, however small, is not universal, but if a jet occurs the only common feature appears to be a convergence of surface fluid to create it. Initial study of converging flow has given us some amusing free surface profiles, see Fig. 2.

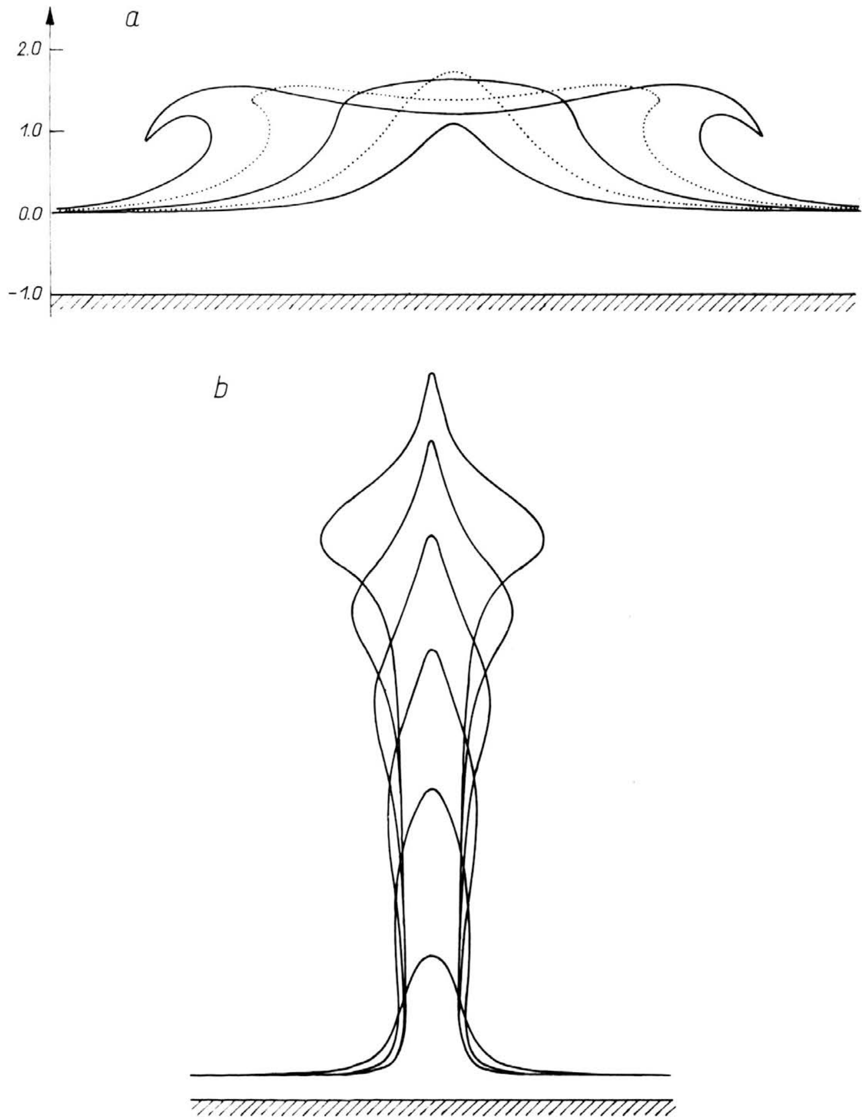

FIG. 2. Surface profiles arising from conditions corresponding to converging streams with an initially flat surface. Diagrams courtesy of A.ANDERSON.

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