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On Frequency-Focusing Unidirectional Waves

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ABSTRACT

Phase convergence to within 1° in mechanically generated waves was achieved at a specified point in a wave flume by frequency focusing. Owing to the presence of nonlinear waves, the crest elevation reaches a maximum somewhat further from the waveboard, where also breaking occurs if the waves are of sufficient size. The critical amplitude for breaking was not in close agreement with previous measurements when normalized with respect to the central wave number of mechanically generated waves. It is suggested however that the limiting conditions are related to the phase speed near the focus point, where the wave group propagates with a considerable degree of coherence not present in a linear model. Predictions of a time-dependent nonlinear numerical model of Baldock and Swan (1994) are found to be in good agreement with the behavior of the crest in this region.

INTRODUCTION

Laboratory experiments on waves or wave loading sometimes call for the generation of large episodic waves in water of uniform depth. Many researchers have described investigations in which individual steep waves (either breaking or unbroken) have been produced by the technique of frequency-focusing, made possible by the dispersive nature of gravity waves. By one of several methods, an individual large wave can be generated at a particular point through constructive interference among a number of wave components.

Three distinct approaches can be identified:

1. **The phase speed method.** Within the limitations of linear theory, wave trains of different periods, traveling at different speeds, simply add up to produce reinforcement or cancellation of water surface displacements. If it can be arranged that several wave trains all come to a common phase at a certain point in the tank, then the combination can be expected to produce a large wave.

In the phase speed method, the waveboard control signal consists of the sum of a number of sinusoidal components at discrete frequencies, whose phases are accordingly chosen so as to achieve mutual reinforcement across the entire bandwidth at a particular point in the tank. This method was used by Greenhow et al., (1982), Rapp and Melville (1990), Baldock et al. (1995) and others.

2. **The reverse dispersion method.** Linear theory can also be used to trace the development of the flow following the impulsive release of a certain volume of water placed on an initially still water surface. From this disturbance (of some assumed geometry) waves travel outwards in both directions. The computed water-surface elevation record at some distant point can be used to derive a waveboard control signal on the basis that if the same waves were run backwards from this point, they would lead to a concentration of energy at the location of the original disturbance. Of course if only one waveboard is used, the incoming waves from the opposite side of the focus point will be absent. This method is described by Mansard and Funke (1982). A similar approach has been used for the generation of specific transient waves (Kim et al., 1992).

3. **The group celerity method.** The front of a regular wave train propagates into still water at a speed equal to the group celerity. On the assumption that the speed of energy propagation is always related in this way to the instantaneous frequency of waves leaving the waveboard, a continuous modulation in the driving frequency can lead to a concentration of energy at a particular point in the flume, before significant reflections return from the beach. The waveboard control signal can be computed from the requirement that the instantaneous group celerity should at all times be what is needed to convey the wave energy to the focus point in the time remaining before the appearance of the focused wave. In deep water, this implies a constant rate of change of frequency (Longuet-Higgins, 1974). This method has been used in measurements of breaking wave forces in conditions where reflections were too large to allow the other methods to work successfully (Chaplin et al., 1992).

A single wave train contains bound waves at frequencies that are multiples of the fundamental, travels faster than the linear theory prediction, and is subject to the effects of reflections, mass transport and various instabilities. When waves of different frequencies are generated simultaneously, they interact to produce new components that do not satisfy the linear dispersion relationship. Consequently, small changes to the waveboard control signal may lead to large and unpredictable changes in the resulting waves, and sometimes energy is lost prematurely when breaking occurs ahead of the focus point.

Accounting for these nonlinearities in the computation of the control signal for the generation of frequency-focused waves may be possible by means of nonlinear numerical modeling, and some progress has been made in this direction, for example by Taylor and Haagsma (1994). But experimentalists often use whatever extreme wave is generated from a waveboard control signal computed from linear theory, perhaps after some empirical intervention to improve the efficiency of the focusing. This approach is inconvenient where similar episodic waves of different heights or frequency content are required at exactly the same point, or where the timing of the event is important. In the experiments described below, these problems were avoided by a simple empirical method that ensured that every one of a number of mechanically generated component wave trains was brought almost exactly into phase at a specified point in a wave flume.

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