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Laboratory Study on the Characteristics of Deep-water Breaking Waves

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Abstract

In this paper, deep-water breaking waves are generated by the method of energy focusing in a wave flume and the intensity of wave breaking is toned by changing input wave steepness. In the experiment, the time series of surface elevation fluctuation along the flume are obtained utilizing 22 wave probes which are mounted along the mid-stream of the flume. The characteristics of wave surface are analyzed. The spectrum are computed for surface elevations by a fast Fourier transform (FFT). It is concluded that the energy keeps stable in low frequencies part and spreads toward the higher frequencies of the first harmonic band as the wave approaching the breaking zone. After the breaking, the spectrum restores almost its initial shape, but the spectrum energy is lost in the high-frequency end of the first harmonic band, which is more appreciable when the wave breaking happens and is stronger. As the energy is spread to higher frequencies for non-breaking wave, the "spectrally weighted wave frequency" f_s becomes bigger and the "spectrally weighted group velocity" C_{gs} become smaller after the wave focusing. When the wave breaking occurs, the loss in energy is obvious leading to f_s decreasing and C_{gs} increasing after wave breaking, which is more appreciable for plunging wave.

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Keywords: energy focusing; wave breaking; wave energy spectrum; characteristic wave parameters

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Instruction

The breaking waves in ocean are a common phenomenon and are important element in many oceanographic and off-shore engineering (e.g. She et al., 1994) The deep-water wave generate whitecaps owing to breaking and the breaking waves bring great impact force when they hit the engineering buildings (e.g. Yu, 1999).The breaking of surface waves in deep water plays a significant role in the air-sea interaction with energy transferring from wind to water, momentum transferring from waves to water, turbulence generating and turbulence-wave interaction and is an important fluid dynamics processes affecting waves growth, surface currents generating and turbulence distribution (e.g. Longuet-Higgins, 1969; Rapp and Melville, 1990). However, owing to the intermittent of waves breaking in ocean, detailed field measurements with high spatial and temporal resolution are very difficult (e.g. Drazen and Melville, 2009). The laboratory provides us with a well-controlled environment in which high-precision, high-resolution measurements can be conducted in order to better understand the characteristics of waves breaking, which is an important way for studying the process of waves breaking.

Rapp and Melville (1990) generated deep-water breaking waves by using of the method of energy focusing in laboratory and the characteristics of energy spectrum evolution were analysed in the wave propagation process. Kway Jasmine et al. (1998) generated breaking waves through wave-wave interactions in frequency and amplitude modulated wave packets and studied the evolution of the wave surface and spectrum for different input spectrum shapes in the wave propagation process. They pointed out the intensity of wave breaking to be correlated to the spectral slope of the higher frequency components beyond the first harmonics. Tulin and Waseda (1999) analysed the nonlinear evolution and spectrum evolution of deep-water wave groups initiated by unstable three-wave systems and it was found that wave breaking increase the transfer of energy from the higher to the lower sideband and bring about an effective downshifting of the spectral energy. Banner and Peirson (2007) developed experimental research on the evolution of wave groups and the process of wave breaking and validated the proposals that the wave energy convergence rate and geometrical steepening at the maximum of an evolving nonlinear wave group controlling the strength of breaking events proposed by Song and Banner (2002). Ma et al. (2010) studied the nonlinear evolution and spectrum evolution of unidirectional focusing waves in intermediate depth water by wavelet transformation in laboratory.

A lot of research has been carried out on focusing waves and the nonlinear characteristics of wave breaking, but it is mainly in shallow and intermediate depth water. Only parts of the wave components are the deep-water waves mentioned in some papers (e.g. Rapp and Melville, 1990; Kway et al., 1998; Drazen, 2006) and the change of wave characteristic parameters such as group velocity and frequency after waves breaking are less studied. In this paper, deep-water waves are generated in laboratory. The changes of wave surface and shape parameters for different breaking intensity (namely non-breaking, spilling breaker and plunging breaker) and the evolution of wave spectrum are analysed. In addition, the changes of group velocity and frequency owing to wave breaking are also studied. These studies provide guides for understanding the breaking characteristics and its influence on wave characteristic parameters and make preparations for further analysis of energy loss, dissipation and turbulence characteristics owing to wave breaking.

1. Experimental Methods and Apparatus

1.1 Focusing Wave Generation

In this experiment, the wave maker was programmed to generate breaking waves in deep water by the method of energy focusing initially proposed by Longuet-Higgins (1974) and subsequently developed and further perfected by Rapp and Melville (1990) and others (e.g. Loewen and Melville, 1991; Kway et al., 1998; Drazen, 2006). In this method a packet of waves of varying frequency are generated in a tank such that the phases add at the desired focal point and generate a breaking event. The mechanism of the method is due to the fast spreading of long waves, and slow propagation of short waves. For the two-dimensional case, according to linear theory, the free surface displacement, $\eta(x,t)$, can be described as

$$\eta(x,t) = \sum_{n=1}^{N} a_n \cos(k_n x - \sigma_n t + \phi_n) \quad (1)$$