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Three-wave and four-wave interactions of harmonic nonlinear surface waves on deep water

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The dispersion law for deep-water gravitational surface waves of small amplitude, $\omega \sim \sqrt{k}$, allows only for four-wave interactions, with three-wave processes being forbidden by energy and momentum conservation. The situation changes slightly if the amplitude of waves increases and they become nonlinear. Under these conditions, the three-wave interaction is possible and, in the quasi-one-dimensional case, it leads to the formation of multiple harmonics.

We have studied experimentally the propagation of quasi-one-dimensional harmonic waves in the 50x70m Marintek Ocean Basin. The water depth was 3m. Sensors were positioned in different groups along the central axis of the basin in the direction of wave propagation. Waves were investigated within the frequency range 0.4 – 2.5 Hz, for amplitudes 0.068 – 0.2 m. The signal recording time for each set of measurements was typically 300s, corresponding to approximately 200-500 wave crests. The time dependence of the wave shape at each sensor was investigated both by Fourier analysis and in terms of amplitude statistics as functions of time and distance from the wave generator.

All of the harmonic waves studied in our experiments (A=0.068m and higher) were nonlinear, and the three-wave interaction was the dominant process in creating surface turbulence. The effect of four-wave interactions was seen only for waves of much smaller amplitude, reflected back from the remote wave absorber.

An increase in wave amplitude up to $h/\lambda \sim 0.2$ led to the formation of multiple harmonics within the first ten wavelengths, but their Fourier spectrum smeared as the waves propagated along the basin. For high amplitude waves we observed the formation of an inverse energy flux from the pumping frequency towards the lower energy edge of the spectrum.

We will discuss the Fourier spectrum and amplitude, the analysis of the initial harmonic waves and their evolution with time and distance, and the effects of wave interactions for both two and three co-linear harmonic waves.