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Effects of nonlinearity on the occurrence probability of large water waves

M. Tanaka

Gifu University, Japan (tanaka@cc.gifu-u.ac.jp)

We have investigated the effect of nonlinearity, or the energy density E, of the field of surface gravity waves on the occurrence probability of waves with large wave heights, which are often called freak or rogue waves. For a fixed value of E, we have constructed 1,500 initial random wave fields all of which correspond to the Pierson-Moskowitz spectrum, and trace their temporal evolution numerically for about 25 periods according to the governing equations for nonlinear surface gravity waves. The numerical method is a combination of high-order spectral method and the 4th-order Runge-Kutta method. We have stored the surface displacement η as function of time t at about 100 observation points which are carefully chosen so as to be almost uncorrelated. Applying zero-down crossing to these time-series of η, we obtained nearly 4 million samples of wave height altogether.

We then evaluated various statistical quantities such as probability density functions of wave height and that of maximum wave height, probability of exceedance, probability of occurrence of freak waves which we tentatively define as those waves which are higher than twice the significant wave height $H_{1/3}$. We repeated this procedure for various values of E.

The results show clearly that the occurrence probability of freak waves increases monotonically as the energy density E of the wave field is increased. While E is small, the probability is smaller than the value predicted by Rayleigh distribution ($\approx$ 1/3000), but for larger E the prediction based on Rayleigh distribution underestimates the occurrence of freak waves. This changeover occurs around E which corresponds to $H_{1/3} \approx$3.2m if the spectrum peak is at 8 sec and that the characteristic wavelength is about 100m. The distribution of the maximum wave height also shifts to larger values when E is increased.