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Numerical Simulation and Mechanism Analysis of Freak Waves in Random Oceanic Sea States

Yunqiu Zhang, Ningchuan Zhang, and Yuguo Pei
State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology
Dalian, Liaoning, China

ABSTRACT

Numerical simulation of freak wave generation in random oceanic sea states described by JONSWAP spectrum is carried out based on the modified four-order nonlinear Schrödinger (mNLS) equation in deep water. By comparison of the variation of each term modulus in mNLS equation and the power spectra for freak wave occurrences, it can be concluded that nonlinear focusing of some components with approximate frequencies to the dominant frequency is one possible mechanism of freak waves. Effects of the relevant parameters on freak wave formation are also discussed.

KEY WORDS: Freak wave; modified nonlinear Schrödinger equation; numerical simulation; JONSWAP spectrum; nonlinear focusing.

INTRODUCTION

With the development of ocean exploitation, people have recently encountered freak waves more and more, and the most famous example is no other than the so-called New Year wave which hit the Draupner platform in January 1, 1995. It is usually thought that a freak wave is an extraordinarily large wave with its height exceeding twice significant height in a wave train and has potentially devastating effects on coastal or offshore structures and ships, so its mechanism has attracted many oceanographers' attention. Various mechanisms have been proposed to explain the formation of freak waves subject to some special conditions (Kharif and Pelinovsky, 2003), such as spatio-temporal focusing of wave groups, geometrical focusing of water waves and wave-current interaction in the linear theory; and nonlinear-dispersive focusing of wave trains for the Korteweg-de Vries equation in shallow water and nonlinear modulation instability of wave trains for the nonlinear Schrödinger (NLS) equation in deep water in the nonlinear theory.

Since the investigation of freak waves on the basis of experimental data still has certain difficulties such as the selection of measured points in situ and the instrumental detection by buoys (Pelinovsky *et al*., 2003), numerical experiments have been developed greatly. At present the model based on the famous cubic NLS equation (CSE) which describes the nonlinear evolution of deep-water wave trains is robust to investigate freak wave phenomenon. Osborne *et al*. (2000) studied these giant waves as solutions of the CSE in both 1+1 and 2+1 dimensions, and demonstrated the ubiquitous occurrence of freak waves for the latter under certain sets of initial conditions. Osborne (2001) further studied analytically freak wave properties based on exact spectral solutions of this equation with an assumption of Benjamin-Feir instability working. Onorato *et al*. (2001) studied freak wave generation in a random sea state characterized by the JONSWAP spectrum, and from extensive numerical simulations concluded that the large values of Phillips parameter and enhancement coefficient increase the probability of this giant wave occurrence, while he also pointed out simulations with higher order models or directly with fully nonlinear equations of motion will be required in order to confirm these results. Pelinovsky *et al*. (2003) researched New Year wave by virtue of spectral analysis and with an application of the CSE to estimate the modulation-instability parameter and regarded this anomalously high wave can be as a result of development of the surface nonlinear modulation instability, namely Benjamin-Feir instability. So it is well known that this instability can cause a local exponential growth of the amplitude to form freak waves in wave trains. The investigation of Dysthe (1979) demonstrated that the predictions of CSE, compared with the exact results of Longuet-Higgins (1978a, b), are fairly accurate for wave steepness $\varepsilon < 0.1$, but beyond this parametric range there is a great difference from the exact results, namely overestimate its marginal stability and instability growth rate to a great extent especially for $\varepsilon > 0.15$. In order to overcome the shortcomings of this equation, Dysthe (1979) deduced the four-order NLS equation considering the mean flow effect. Lo and Mei (1985) modified this equation slightly and presented the modified four-order nonlinear Schrödinger (mNLS) equation. Trulsen (2001) applied a generalized four-order NLS equation for a spatio-temporal numerical simulation of famous New Year wave record, and pointed out that freak waves likely did not suddenly appear from nowhere. Calini and Schober (2002) investigated rogue waves, namely freak waves, by means of the four-order NLS equation with the broader bandwidth assumption, and indicated that homoclinic chaos increases the likelihood of rogue wave formation. Although so many works have done, it is still unknown whether and how freak waves can be formed with the application of the mNLS equation in the random oceanic sea states.