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Nonlinear Simulation of 3D Freak Waves Using a Fast Numerical Method

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ABSTRACT

This paper uses the QALE-FEM (Quasi arbitrary Lagrangian-Eulerian finite element) method based on the FNPT (Fully nonlinear potential theory) model to simulate 3D freak waves. The efficiency investigation indicates that this method is much faster than other numerical methods in terms of the same accuracy requirement. A snake wavemaker is adopted to generate 3D freak waves by directional energy focusing. The nonlinearity of the freak waves and the seabed effect on the freak waves are investigated. Both overturning and non-overturning freak waves are considered. Some results are compared with those in public domain, good agreements will be shown.

KEY WORDS: Freak waves; Potential flow; QALE-FEM; Energy focusing; Wave Overturning.

INTRODUCTION

Freak waves (also called rogue waves) are extremely large water waves in ocean and may occur in both shallow and deep water. Despite their low possibility of occurrence, they potentially pose severe hazards for mariners and man-made structures. Many incidents considered to be caused by freak waves have been reported, in which a lot of lives (about 542 during 1969-1994) were lost as given by Lawton (2001). The freak waves are now considered as a real threat to human activities in ocean and, therefore, have attracted great attention.

Based on the research (e.g. Baldock and Swan, 1994; Kharif and Pelinovsky,2003) on the physical mechanisms of freak wave generation, the freak waves may be generated by the energy focusing, which concentrates the wave energy in a small spatial area during a short time. Many mechanisms may result in such an energy focusing. They mainly include spatio-temporal (dispersive) focusing (i.e. frequency and/or directional focusing) of transient wave groups (see, for example, She, Greated and Easson, 1997; Johannessen and Swan, 2000; Brandini and Grilli,2001; Fochesato, Grilli and Dias, 2007; Grilli, Dias, Guyenne, Fochesato and Enet, 2007), wave-current interaction (see, for instance, Lavrenov and Porubov, 2006), geometrical focusing due to topography of the seabed (such as Grilli, Guyenne and Dias, 2001; Guyenne and Grilli, 2006) and nonlinear modulation instability(e.g. Zakharov, Dyachenko and Prokoflev, 2006). A good review can be found in Kharif and Pelinovsky (2003).

In order to achieve a good understanding of freak wave properties, many efforts have been made in the laboratory experiments. In those experiments, the freak waves are generated by using the wavemaker. For 2D problems, the motion of the wavemaker is mainly specified by using the following three ways: 1) using a sine function with linearly variable frequency with the largest frequency occurring at start (Touboul, Giovanangeli, Kharif and Pelinvsky, 2006) ; 2) to generate a number of sine or cosine wave components which travel to the same position at the same time (Baldock, Swan and Taylor, 1996; Grue and Jensen, 2006) and 3) the signals exciting the wavemaker are composed of normal random waves and the freak waves(Kriebel, 2000; Clauss 2002). The third way is closest to the fact that freak waves always appear in other random waves. For more reviews, readers may be referred to Ma (2007). By far, the laboratorial research on 3D freak waves is still rare. She, Greated and Easson, (1997) and Johannessen and Swan (2000) studied the property of 3D wave focusing by directional waves, of single frequency or of multiple frequencies. She, Greated and Easson (1997) studied the kinematics of the breaking freak waves. In their experiments, the 3D freak waves are achieved by focusing a number of directional waves, which are generated by using a snake wavemaker, at a specified location.

Alternatively, numerically modeling, instead of experiment, has also been performed in a numerical wave tank. Kharif and Pelinovsky (2003) summarized various levels of approximation, which consist of linear, weakly nonlinear and fully nonlinear models, such as the energy balance equation, the wave-action balance equation, the nonlinear Schrödinger equation, the nonlinear KdV equation and the fully nonlinear potential theory (FNPT). More recently, Ducrozet, Bonnefoy, Le Touzé and Ferrant (2006) extended a high-order spectral method (HOS) to treat fully nonlinear freak waves; Fuhrman and Madsen (2006) used a high-order Boussinesq equation to simulate 3D freak waves. Except for the general flow theory models in which the Navier-Stokes and the continuity equations are dealt with (referred as NS models) and the FNPT models, all other numerical models/equations listed above are not sufficient to deal with overturning waves, which always comes with the occurrence of the extreme freak waves (She, Greated and