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The role of nonlinear wave-wave interactions in the formation of unidirectional extreme waves

Thomas Vyzikas (1), Dimitris Stagonas (2), Christophe Maisondieu (3), Deborah Greaves (1), and Dave Simmonds (1)

(1) School of Marine Science and Engineering, University of Plymouth, Plymouth, UK, (2) Civil, Environ & Geomatic Eng, University College London, London, UK, (3) IFREMER: Comportement des Structures en Mer, Brest, France

Numerous field records and observations have indicated the existence of unexpectedly high waves for the underlying sea state. These waves are rare, but potentially catastrophic events, as the accidents in marine structures and offshore platforms dictate. Extensive research studies by means of numerical and physical modelling have been undertaken in order to identify the formation processes and hydrodynamics of the so called extreme or freak waves, however a consensus regarding their physical mechanisms is yet to be reached. The common factor in the formation of extreme waves is the high concentration of energy at specific frequencies in space and time, which is associated with rapid nonlinear energy transfers between the wave components.

One arguably accepted mechanism for extreme wave generation, also confirmed by field data analysis, is though dispersive focusing of the wave components of the energy spectrum. According to that, the wave components come into phase at a specific location and time, contributing constructively to the overall surface elevation and reproducing the average shape of extreme waves based on NewWave theory. As the steepness of the wave group increases, the process of focusing of the waves becomes highly nonlinear and conventional linear focusing techniques fail to predict accurately the location and time of the extreme wave. Here, a newly developed methodology for focusing of the waves is employed, guaranteeing accurate focusing of the wave group up to its breaking limit.

The numerical modelling of extreme waves spans from nonlinear Schrodinger equations to generalized computational fluid dynamics (CFD) models. Despite their computational efficiency nonlinear wave models become less accurate for increasing wave steepness and cannot handle wave-structure interaction problems. In this study, a fully nonlinear Reynolds-Averaged Navier-Stokes (RANS) open-source model, namely OpenFOAM, is employed for the numerical study of focused wave groups. A two-phase flow solver is used with the Volume of Fluid method for the capturing of the free water surface. Appropriate boundary conditions based on the active wave paddle method of IHFOAM are employed for wave generation and absorption. The numerical results are compared with experimental results of the exact scale, referring to broad-banded unidirectional Gaussian spectra in intermediate and deep waters. The comparison is performed in terms of free surface elevation and kinematics, measured by resistive wave gauges and particle image velocimetry (PIV) method respectively. After validating the model, the obtained time-series of the free surface elevation, surface shape and velocity profiles will be compared with linear and second-order theory predictions, which are commonly used in the design process of offshore structures.

The combination of an effective focusing methodology and a powerful numerical solver is a key element for gaining insight into the nonlinear hydrodynamic processes during the formation of extreme waves. The scope of the study is to illustrate the capacity of the numerical model in simulating steep focused waves and the range of validity of conventional design practices.