ROGUE WAVE ASYMMETRY IN THE DIRECT NUMERICAL SIMULATIONS OF DIRECTIONAL JONSWAP WAVES

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The direct numerical simulation of primitive water equations is an affordable alternative to the in-situ or laboratory measurements, in particularly when the interest is focused on the long-term evolution or on the detailed consideration of the water wave movement in space and time. In this work we simulate irregular surface waves in the hydrodynamic equations using the High-Order Spectral Method, and focus on the so-called rogue waves, which satisfy the following amplitude criterion, $H/H_s > 2$. Here H is the wave height which we calculate according to the zero-crossing method for the space series of the surface displacement, taken along the main direction of the wave propagation. The term H_s stands for the significant wave height, defined through the surface displacement variance σ, $H_s = 4\sigma$.

The asymmetry between the troughs from the rear and front sides of rogue waves is the particular object of the present study. In our previous simulations of unidirectional waves the typical picture of a rogue waves possesses the trend that most of the rogue waves where characterized by deeper rear troughs (Sergeeva & Slunyaev, 2013; Slunyaev et al., 2016). In the present work we broaden the discussion of the rogue wave front-to-crest asymmetry to the directional case (Slunyaev & Kokorina, 2020).

Each 'momentary' rogue wave is determined as a single wave according to the zero-crossing approach with a large crest and the deepest trough from either the rear or front side of the crest. Correspondingly, each of the rogue waves is characterized by amplitudes of the crest and of the trough, A_{cr} and A_{tr} respectively. Its height is calculated according to the formula $H = A_{cr} + |A_{tr}|$. Then, depending on the wave geometry they are assigned to four categories as shown in Fig. 1. The wave is 'positive' ('Pos') if $A_{cr} \geq |A_{tr}|$; it is 'negative' ('Neg') in the opposite case. 'Front' waves have deeper troughs preceding the large crests, while the following troughs of 'rear' waves are deeper than the troughs from the front sides.

The first case (up-left in Fig. 1) is the reference; it is calculated within the linear theory; when the four types of wave asymmetry should be equally probable. The deviation of the calculated probabilities from the expected values reaches about 2% for the ensemble of about 5 000 rogue waves. The second simulation of a sea state with relatively weak nonlinearity $k_pH_s/2 \approx 0.07$, relatively narrow spread of wave directions, $\theta = 12^\circ$, and moderate JONSWAP peakedness, $\gamma = 3$, exhibits strong crest-to-trough asymmetry (up-right). Here k_p is the peak wavenumber, θ is the spread parameter in the $\cos^2$ function. This result is consistent with the shape of the nonlinear Stokes wave solution. The difference between preceding and following troughs is not found in this case.

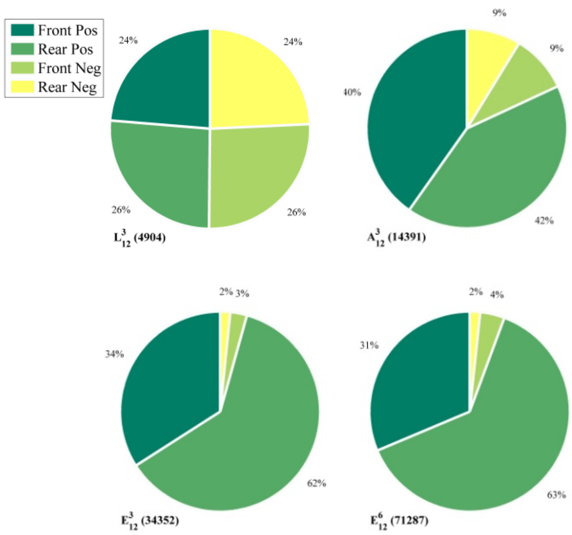

Figure 1 – Typical rogue wave shape distributions depending on the wave steepness and the spectrum peakedness parameters

At steeper wave conditions $k_pH_s/2 \approx 0.12$ (low-left in Fig. 1) the crest-to-trough asymmetry strengthens; only about 5% of the rogue waves are represented by 'holes in the sea'. Meanwhile, the asymmetry between the troughs of rogue waves becomes prominent. Most of the waves in this series have crests higher than the troughs, and the troughs are deeper from the rear sides of the rogue waves. The difference between the front and rear troughs further grows when γ increases from 3 to 6 (low-right). The two types of asymmetries strengthen further when the directional spread grows. In particular, about 75% of the rogue wave shapes under the conditions $H_s = 7$ m, $\theta = 62^\circ$ and $\gamma = 3$ are of the 'Rear Pos' type.

The research is supported by the Russian Science Foundation (RSF) grant No. 16-17-00041.

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