Geophysical Research Abstracts
Vol. 20, EGU2018-9406, 2018
EGU General Assembly 2018

Evolution of crest speed in nonlinear focused wave groups

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Wave breaking is a key process in the dissolution of carbon dioxide in the World's oceans as well as an important consideration for hydrodynamic loading, such as slamming and wave-in-deck loading, on offshore structures. It is widely accepted that the onset of wave breaking occurs when the horizontal fluid particle velocity exceeds the crest speed. Whilst significant research has been dedicated to the former, the latter has received little attention for focused wave groups.

As irregular waves become nonlinear, two competing mechanisms influence the crest speed. The first concerns the increase in the phase velocity for nonlinear waves described by Stokes in regular waves and the second involves reducing the crest speed due to free-wave spectrum broadening. The influence of the first mechanism on irregular waves was demonstrated by Fedele (2014) who used the Zakharov equation to examine the effect of nonlinearity. The second mechanism was examined experimentally by Johannessen and Swan (2001) who showed a reduction in the crest speed for highly nonlinear waves. This can be explained by the local broadening of the spectrum in the proximity of large events due to rapid resonant interactions (Gibson and Swan, 2007).

The present study has generated deep water, unidirectional focused wave groups based on JONSWAP spectra. The results from a fully-nonlinear boundary element model (BEM) have been compared to linear random wave theory (LRWT), which highlights the influence of spectral bandwidth and wave steepness on crest speed evolution. Compared to previous studies that used tophat spectra (Johannessen and Swan, 2001) or chirped wave groups (Barthelemy et al., 2015), the present study employs realistic spectra found in the oceans.

The results show that for nonlinear focused waves groups the BEM crest speed reduces by up to 10% more than the linear estimates. This is in contrast to Barthelemy et al. (2015) who noted a slight increase in crest speed for nonlinear chirped wave groups, however, the present results are in agreement with Johannessen and Swan (2001); this indicates that the underlying spectrum has a key influence on crest speed. Although a permanent interaction exists between the two nonlinear mechanisms, the present work suggests that in realistic ocean waves the crest speed reduction is dominated by the rapid spectral widening and energy transfer to the high frequencies.

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