Geophysical Research Abstracts
Vol. 15, EGU2013-14020, 2013
EGU General Assembly 2013

Instability of Wave Trains and Wave Probabilities

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Design criteria in ocean engineering, whether this is one in 50 years or one in 5000 years event, are hardly ever based on measurements, and rather on statistical distributions of relevant metocean properties. Of utmost interest is the tail of distribution, that is rare events such as the highest waves with low probability. Engineers have long since realised that the superposition of linear waves with narrow-banded spectrum as depicted by the Rayleigh distribution underestimates the probability of extreme wave heights and crests, which is a critical shortcoming as far as the engineering design is concerned. Ongoing theoretical and experimental efforts have been under way for decades to address this issue.

Typical approach is the treating all possible waves in the ocean or at a particular location as a single ensemble for which some comprehensive solution can be obtained. The oceanographic knowledge, however, now indicates that no single and united comprehensive solution is available.

We would expect the probability distributions of wave height to depend on a) whether the waves are at the spectral peak or at the tail; b) on wave spectrum and mean steepness in the wave field; c) on the directional distribution of the peak waves; d) on whether the waves are in deep water, in intermediate depth or in shallow water; e) on wave breaking; f) on the wind, particularly if it is very strong, and on the currents if they have suitable horizontal gradients. Probability distributions in the different circumstances according to these groups of conditions should be different, and by combining them together the inevitable scatter is introduced. The scatter and the accuracy will not improve by increasing the bulk data quality and quantity, and it hides the actual distribution of extremes. The groups have to be separated and their probability distributions treated individually.

We suggest to proceed systematically through the available data sets, by using physical understanding rather than the bulk statistical approach. If the wave trains/fields in the wave records are stable, distributions for the second-order waves should serve well. If modulational instability is active, rare extreme events not predicted by the second-order theory should become possible. This depends on wave steepness, bandwidth and directionality. Mean steepness also defines the wave breaking and therefore the upper limit for wave heights in this group of conditions. Under hurricane-like circumstances, the instability gives way to direct wind forcing, and yet another statistics is to be expected.