Statistics of wave crests from second order irregular wave 3D models

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***In-situ* measurements.** The statistics of the elevation and kinematics of waves in real seas have been greatly based for specific site studies on *in-situ* measurements (North-Sea and Gulf of Mexico oil fields). The incomparable great quality of a measurement is that it includes all the physical phenomena, but unfortunately also those which corrupt the actual observation of waves (mooring behavior and transfer function for buoys, fouling effect for plunged or underwater probes, sea foam or spray effect). To this list will be added the problems of spatial integration, calibration and data transformation and transmission. So it becomes difficult to clean the measurements without degrading the extreme or unexpected events. Moreover the wave instruments furnish point measurements and so the instrumentation might be very expensive and long to build accurate statistics, making cost and duration time not always compatible with the constraints of the project on the site. Apart for some very rich data base, measurements will be used to analyze typical situations and to (in)validate models.

Power spectra versus Wave by wave. More and more information on waves are restricted to information on energy. The hindcast models use better wind fields and assimilate larger amount of data (e.g. satellite). They use better models of generation, interaction and dissipation and profit by the always increasing power of the computers. The satellites, too, furnish spectral information with the SAR (directional spectrum) or the altimeters (Hs).
The so-called “Wave forecast” of the Meteorological Offices consists in the forecast of sea states (Hs, main direction or directional spectrum) and the step to forecast the corresponding stochastic information on the wave kinematics, is a giant step if we know that we have to introduce information on the local currents and winds and to take into account complex phenomena, nonlinearities and breaking. To take such a giant step, the addition of small steps will be necessary, some of them have been already taken that we describe hereafter.

Methodologies for Statistics. The methodologies to furnish statistics of waves inside a sea state starting from spectral information are of different kinds. They can be based on Monte Carlo techniques and development of simulators (*Forristall*, *Prevosto*), or derived from theoretical considerations: Transformed Gaussian process method (*Rychlik*), First Order Reliability Method (FORM) (*Tromans*).

Starting from measurements or from simulation or theoretical methodologies, simplified parameterized models based on a fitting procedure have been proposed as better practical tools for the engineers.
In any case, independently of the methodology, the answers will differentiate from the model of irregular gravity waves taken as starting point.

Linear models. (Wave height considered as the crest-trough amplitude (and this definition could be extended to other parameters, e.g. crest-trough pressure, crest-trough velocity as soon as kinematics is studied under the mean water level) are influenced by the nonlinearity at one higher order of magnitude than the crest or trough amplitudes. This explain the good fitting and quality of models of wave heights based on the linear assumption.

Non linear models . More complicated models have to be considered to take into account the strong effect of the nonlinearities on the crest amplitudes (or other amplitude of the kinematics), e.g. the hybrid model (*Zhang*), the Creamer-transformation (*Creamer*) or the Stokes 5th order correction (*Dawson*). But as an intermediate way, which take into account the wave spreading, irregular 2nd order 3D models have been extensively used and validated for the last years.

Stokes 2nd order based models. Mainly focussed on the aim to produce simple parametric models corresponding to uni-directional or directional sea state and to infinite to intermediate water depth, the Stokes 2nd order model has been used to build and fit crest height probability distribution.
- Nonlinear transformation of a Rayleigh law, where the transformation is dependent of the crest height normalized by water depth (*Jahns*). This model has been fitted later from measurements (*Haring*). It appears clearly wrong in infinite depth where it tends to the Rayleigh law. The fitting used wave staff measurements in the Gulf of Mexico and Waverider measurements in the North Sea. That would explain it.
- Nonlinear transformation of a Rayleigh law, where the transformation is based on the harmonic Stokes expansion (*Kriebel*). The same technique is used in (*Dawson*) with a 5th order harmonic expansion. These models, though based in their principle on narrowband assumptions, do not use a narrowband Stokes expansion. This induces errors in the model, apart in infinite depth where harmonic and narrowband expansion are the same.
The two last ones take into account the 3D structure of the waves.
- Weibull law with the two parameters written as steepness and Ursell number polynomials (*Forristall*). Two different sets of coefficients of the polynomials are fitted on 2D and 3D simulations.
- Nonlinear transformation of a Rayleigh law, where the transformation is based on the narrowband Stokes expansion (*Prevosto*). The two parameters Hs and mean wavenumber are perturbed to take into account the frequency bandwidth, the directional spreading and the water depth. It has a unique expression in 2D and 3D case.

Validity of 2nd order model in extreme situations. The use of 2nd order models has the advantage to work with simple wave models. If these models are used to calculate design crest heights, their validity has to be proved before using such extreme values. A lot of waves generated during the simulations are not physically feasible due to the breaking phenomena, this is not take into account today in these models. The introduction of current is also of great interest as in extreme situations it acts strongly on the nonlinearity of the waves.

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