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Generation of Task-related Freak Waves and Critical Wave Groups

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For the design of safe and economic offshore structures and ships the knowledge of the extreme wave environment and related wave/structure interactions is required. A stochastic analysis of these phenomena is insufficient as local characteristics in the wave pattern are of great importance for deriving appropriate design criteria.

This paper describes techniques to synthesize deterministic task-related 'rogue' waves or critical wave groups for engineering applications. These extreme events, characterized by local parameters like tailored design wave sequences, are integrated in a random or deterministic seaway with a defined energy spectrum. If a strictly deterministic process is established, cause and effect are clearly related: at any position the non-linear surface elevation and the associated pressure field as well as the velocity and acceleration fields can be determined. Also the point of wave/structure interaction can be selected arbitrarily, and any test can be repeated deliberately. Wave-structure interaction is decomposable into subsequent steps: surface elevation - wave kinematics and dynamics - forces on structure components and the entire structure - structure motions (Clauss, 1999).

Firstly, the generation of linear wave groups is presented. The synthesis and up-stream transformation of arbitrary wave packets is developed from its so-called concentration point where all component waves are superimposed without phase-shift. For a target Fourier wave spectrum a tailored wave sequence can be assigned to a selected position. This wave train is linearly transformed back to the wave maker and - by introducing the electro-hydraulic transfer function of the wave generator - the associated control signal is calculated. Based on this technique the seakeeping behaviour of ships or offshore structures is efficiently determined with just one single model test (Clauss and Kühnlein, 1995).

The generation of steeper and higher wave groups requires a more sophisticated approach as propagation velocity increases with height. With a semi-empirical procedure the control signal of extremely high wave groups is determined, and the propagation of the associated wave train is calculated by iterative integration of coupled equations of particle positions. With this deterministic technique "freak" waves up to 3.2 m high have been generated in a wave tank (Clauss and Kühnlein, 1997). As a special application, this technique is used to analyze the capsizing mechanism of ships in tailored transient wave packet sequences (Clauss and Hennig, 2001).

In many applications the detailed knowledge of the nonlinear characteristics of the flow field is required, i.e. wave elevation, pressure field as well as velocity and acceleration fields. In this case a finite element method developed by Wu and Eatock Taylor (1994; 1995) is used to determine the velocity potential, which satisfies the Laplace equation for Neumann and Dirichlet boundary conditions. The Neumann boundary condition at the wave generator is introduced in form of the first time-derivative of the measured wave board motion. To develop the solution in time domain the forth order Runge-Kutta method is applied (Clauss and Steinhagen, 1999). Starting from a finite element mesh with 8000 triangular elements (401 nodes in x-direction, 11 nodes in z-direction, i.e. 4411 nodes) a new boundary-fitted mesh is created at each time step. Lagrangian particles concentrate in regions of high velocity gradients, leading to a high resolution at the concentration point. This mixed Eulerian-Langrangian approach has proved its capability to handle the singularities at intersection points of the free surface and the wave board. Excellent agreement of numerical and experimental results is observed.

So far, nonlinear wave groups in an ideal fluid have been discussed. If viscous effects are also considered an approach of transient viscous free surface flow computation with RANSE/VOF solver is used. As an application, an artificial reef - modeled as a submerged permeable wall - has been investigated: Using an unstructured grid, the dissipation loss is explained by overtopping phenomena and subsequent recirculation of the flow locked in chambers between filter elements. Jet flow between filter components is also fostering high energy loss. Due to non-linear wave/filter interactions long low-frequency incident waves with substantial erosive impact are transformed into irregular wave trains with high-frequency wave energy components, which cause less erosion to the sea floor (Clauss and Habel, 2000).

In general, extremely high "rogue" waves or critical wave groups are rare events embedded in a random seaway. The most efficient and economical procedure to simulate and generate such a specified wave scenario for a given design variance spectrum is based on the appropriate superposition of component waves or wavelets. As the method is linear, the wave train can be transformed down-stream and up-stream between wave board and target position. The desired characteristics like wave height and period as well as crest height and steepness are defined by an appropriate objective function. The subsequent optimization of the initially random phase spectrum is solved by a Sequential Quadratic Programming method (SQP). The linear synthetization of critical wave events is expanded to a fully nonlinear simulation by applying the subplex method, developed by Rowan (1990). The domain space is decomposed into smaller subdomains which are minimized by the Nelder and Mead simplex method (Nelder and Mead, 1965). Improving the linear SQP-solution by the nonlinear subplex expansion results in realistic 'rogue'-waves embedded in random seas (Clauss and Steinhagen, 2000).

In case of extremely high 'rogue' waves, however, embedded in irregular seas at target position we may observe local differences in wave characteristics if the resulting wave sequence is compared to the target wave train. Consequently, a subsequent optimization process is required to obtain the design wave sequence. As an alternative to the numerical optimization of the wave generation control signal by the nonlinear subplex method an experimental simulation technique has been developed (Clauss et al., 2001). For a given design variance spectrum, the SQP-method yields an optimized phase spectrum which corresponds to the desired wave characteristics at target position. The wave generator control signal is determined by transforming this wave train in terms of the complex Fourier transform to the location of the wave generator. The measured wave train at target position is then iteratively improved by systematic variation of the wave board control signal which is based on the linear SQP-optimization with subsequent non-linear subplex improvement. To synthesize the control signal wavelet coefficients are used. The number of free variables is significantly reduced if this signal is compressed by low-pass discrete wavelet decomposition, concentrating on the high energy band. Based on deviations between the measured wave sequence and the design wave group at target location the control signal for generating the seaway is iteratively optimized in a fully automatic computer-controlled model test procedure. As this new experimental technique can cope with breaking waves it is a promising procedure for synthesizing model rogue waves or critical wave groups for wave/structure interactions.

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