Towards Multiscale Green Sea Loads Simulations in Irregular Waves with the Naval Hydro Pack

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Different procedures and methods for different scales are presented.

Motivation,

Procedure and methods,

Preliminary results.
The objective is a complete numerical framework for green sea load calculation.

- A multiscale framework comprising CFD and a large scale method,
- The large scale method **takes into account the statistical nature of wave loads**, 
- CFD uses the results from the large scale method to compute highly nonlinear wave loads due to green sea.
Three-scale procedure is proposed in this work.

1. Linear seakeeping $\rightarrow$ **exploration of multiple sea states and heading angles** $\rightarrow$ selection of the most adverse condition,

2. Coarse CFD $\rightarrow$ conducting a three hour seakeeping simulation for the selected sea state $\rightarrow$ **detecting green sea events**,

3. Fine CFD $\rightarrow$ **conducting a detailed green sea simulation on the critical part of the deck structure** $\rightarrow$ loads on deck structures.
Figure 1: (a) A spherical surface cutting a polyhedral cell. Red dots are the edge cutting points. Blue lines are the face-interface intersection lines. Green patch is the isoface. (b) The isoface motion is estimated from surrounding velocity data and the isoface is propagated. Isoface at three different times within a time step are shown.

Cell size. Whenever this is satisfied an isosurface calculation will provide a good estimate of the required local fluid distribution information.

The idea of using an isosurface numerically calculated from the volume fractions to represent the interface is inspired by our use of visualisation software, such as ParaView. Numerically calculated isosurfaces are topologically consistent continuous surfaces and straightforward to calculate on arbitrary polyhedral meshes. The numerical representation of an isosurface in a polyhedral cell is a list of the points, where the isosurface cuts the cell edges. See red points in Fig. 1a for an illustration. This list of points represents a face, which cuts the cell into two polyhedral subcells, with one completely immersed in fluid A, and the other completely immersed in fluid B. We will call such a face an isoface. See the green patch in Fig. 1a for an example. We note that if an isoface has more than three vertices, it will generally not be exactly planar. When calculating an isosurface from the volume fraction data, we have the freedom of choosing an isovalue between 0 and 1. Which isovalue should we choose? For surface visualisation from volume fraction data, we usually plot the 0.5-isosurface. This, however, is not a good choice for the surface reconstruction step in an interface advection algorithm, because the isoface in cell $i$ with isovalue 0.5 does not in general cut it into two subcells of the volumetric proportions dictated by the volume fraction, $\alpha_i$. It may for instance occur, that $\alpha_i = 0$, and yet is not even cut by the 0.5-isosurface. Hence, a surface reconstruction model based on the 0.5-isosurface would say nothing about how the 80% fluid A and 20% fluid B is distributed inside this cell. There will, however, exist an isoface with another isovalue, which will cut the cell into subcells of the correct volumetric proportions. An important component of our proposed scheme is an efficient method for finding this isovalue for a given surface cell (see Section 3 for details).

We note that with the use of different isovalues in different surface cells, the union of isofaces is no longer a continuous surface, as it would be if the same isovalue was used in adjacent cells. This is an unavoidable price we must pay to ensure that isofaces cut surface cells into subcells having the correct volumetric proportions.
Step 1: Hydrodynamic coeffs obtained with linearised free surface solver.

- Single-phase simulations with linearised free surface model,
- Efficient wave diffraction and radiation simulations.
Linearised free surface solver agrees well with potential flow methods.
Step 2: Use linear seakeeping methods to assess green water probability.

- Using the calculated hydrodynamic coefficients, **calculate the green water probability for a large number of sea states**, 
- Select the most adverse sea state, which will serve as a starting point for the next step.
Step 3: Calibrate the input spectrum using Higher Order Spectrum method.

Higher Order Spectrum (HOS) method:

- Pseudo-spectral method for solving **nonlinear boundary conditions for free surface waves**, 
- Takes into account **nonlinear wave–wave interaction and modulation**, 
- Appropriate for efficient nonlinear irregular sea state propagation, 
- Applicable for coupling with CFD, 
- Low CPU expense.

Hs = 6.2m  
Directionality constant n =12
Directional wave spectrum is efficiently propagated using HOS.

3 hours of real time simulated in 5 minutes of CPU time.
Low CPU expense of HOS enables fast calibration of input spectrum.

- The selected wave energy spectrum is calibrated using HOS in order to produce the target spectrum,

- Up to 100 three–hour realisations using HOS needed for the calibration → a bit difficult with CFD...
• Comparing HOS and CFD wave spectrum reveals that minimal wave damping occurs in CFD.
Step 4: Perform a three hour CFD seakeeping simulation.

- SWENSE method is used to couple potential flow and CFD,
- Fast and robust simulations with coarse temporal (200 time–steps/period) and spatial (600 000 cells) resolution,
- Small number of nonlinear iterations per time–step is enabled using enhanced 6–DOF–fluid flow coupling.

![Graph showing time and force data](image-url)
Enhanced coupling reduce CPU time by a factor of 4.
Step 5: Detect green water events and perform detailed CFD simulation.

- Customised post-processing tools detect the situations where water on deck occurred in the three hour simulation,
- Select the green water incident which is considered the most dangerous,
- Conduct a detailed CFD simulation with fine spatial and temporal resolution, including complex geometries.
Detailed V&V of green sea loads has been performed.


- Green water pressure is compared at ten locations on deck,
- Nine incident waves are considered,
- isoAdvect geometric VOF method is used for interface tracking,
- Grid, temporal and periodic uncertainty is assessed.
isoAdvector preserves a sharp interface for green water simulations.

Author: Dr. Johan Roenby, DHI.
Pressure peaks and pressure impulses are compared to experiments.

A detailed verification study has been performed for nine waves:

- **Numerical uncertainties** = periodic + discretisation uncertainties,
- **Experimental uncertainties** = periodic + measuring uncertainties,
- 20 wave periods simulated to achieve periodic convergence,
- Four grid levels used: from $\approx 200\,000$ to $\approx 4\,000\,000$ cells.

**Location near the breakwater.**

**Location further from the breakwater.**
Results agree well with experiments.

$H = 13.5 \text{ cm}, \lambda = 2.25 \text{ m}$

$H = 15.0 \text{ cm}, \lambda = 3.0 \text{ m}$

Pressure peaks,

Pressure impulses (time integrals),
All the components of the procedure have been thoroughly validated.

A comprehensive procedure for green water load assessment includes:

- Stochastic nature of ocean waves,
- Complicated geometries.
- **Validated numerical methods:**
  - Higher Order Spectrum method,
  - Linearised free surface solver,
  - SWENSE method with enhanced 6–DOF–fluid flow coupling algorithm,
  - isoAdvector and Ghost Fluid Method for highly resolved green water simulations.

Future work:

- Conduct the complete procedure for an example vessel.
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Questions?