Towards multiscale green sea loads simulations in irregular waves with Naval Hydro pack

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An overview of the current state of the ongoing effort to devise a comprehensive multiscale procedure for determination of green sea loads on ships and offshore structures is given in this paper. The aim of the research is to asses deterministic green water loads on arbitrary deck structures and equipment that corresponds to the stochastic nature of the sea states which the naval object encounters.

First step of the procedure is to calculate the ship motion response for wave spectra which are relevant for the service of the ship. The motion response is calculated using linear seakeeping method in frequency domain. The hydrodynamic coefficients needed for the linear seakeeping calculation are obtained using rapid CFD simulations in Naval Hydro pack where the free surface is modelled as a linearised boundary condition [1]. In this manner, the interface is not resolved, significantly simplifying the meshing process, reducing the number of cells, and increasing the stability and robustness of simulation. Figure 1 shows an example of the vertical force signal acting on the hull in a diffraction simulation, where the free surface elevation is also depicted.

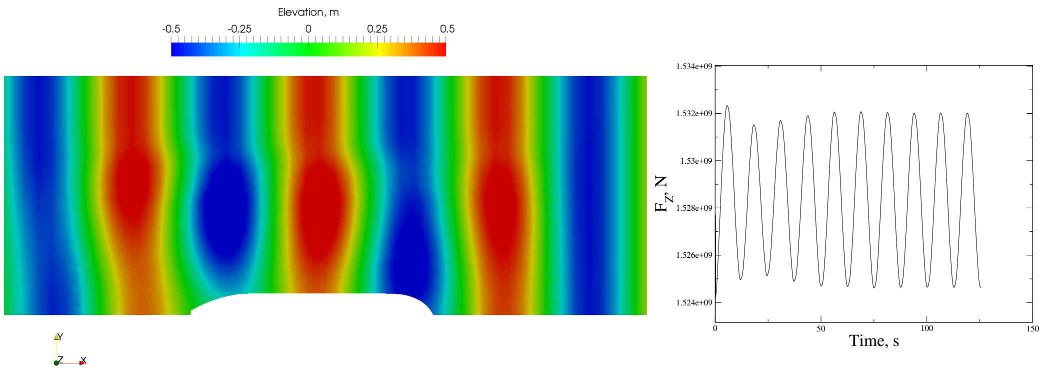


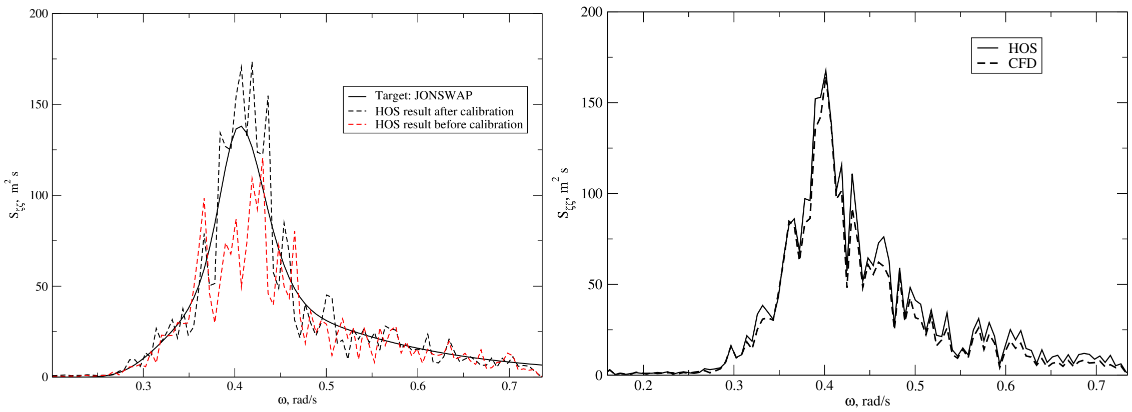
Figure 1: Free surface elevation and vertical force signal from the wave diffraction simulation.

Once the hydrodynamic coefficients are calculated, linear seakeeping theory is used to obtain the motion spectra for relevant degrees of freedom for all relevant wave spectra. Using the motion and wave spectra, the spectra of surface elevation relative to the deck can be calculated, which in turn can be used to calculate the probability of exceedance of the surface elevation over the deck [2]. The wave spectrum exhibiting the largest probability of exceedance is than used in the deterministic study.

The next step is to perform a two–phase global performance CFD simulation, where three hours of selected wave spectrum realisation are simulated encountering the naval object of interest. Motion of the naval object is calculated in order to capture the fully nonlinear interaction with the free surface. In order to obtain realistic motion of the ship, the wave field captured in CFD has to correspond to the selected wave spectrum. In order to achieve this, a nonlinear spectral method based on potential flow theory called Higher Order Spectrum (HOS) [3] is used to calibrate the input spectrum to achieve the target spectrum. Figure 2 shows the comparison of the target spectrum, spectrum obtained before calibration after 3 hours of HOS propagation, and of the calibrated spectrum. The calibration is performed automatically during the HOS simulation, where multiple three hour realisations are run back–to–back in order to calculate the calibration coefficients. Figure 2 also shows the comparison of spectrum obtained in the CFD simulation against the calibrated HOS spectrum used as input. Amount of energy being damped in the CFD simulation is acceptably low.

Coupling of HOS and CFD is in one way, where SWENSE method is used in order to decompose the field into incident (HOS) and diffracted components [4, 5]. SWENSE enables stable simulations of wave propagation with minimum wave damping.

The fluid flow and body motion are coupled in an enhanced manner, accelerating the convergence and enabling lowew number of outer PISO loops per time–step to be used. Vukčević et al. [6] demonstrated that only two PISO correctors



(a) **(b)**

Figure 2: Comparison of wave spectrum: a) Target, non–calibrated and calibrated spectrum obtained using HOS, b) Calibrated spectrum from HOS and from CFD simulation.

per time–step are sufficient to obtain converged solution of the fluid flow–motion coupling. The enhanced coupling is achieved by introducing additional updates of the motion solver after each pressure correction inside the PISO loop, while the grid position is not updated to save CPU time.

Combined together, SWENSE and enhanced coupling of the motion and fluid flow provide fast and robust seakeeping simulations, making a three hour simulation possible in reasonable amount of CPU time. Figure 3 shows the resistance signal in a test global performance simulation of a DTC hull. Half of the domain is simulated by using the symmetry boundary condition in the central plane, which is discretised using 1 600 000 cells. 2 hours and 20 minutes are simulated, which took 7 days and 20 hours on five Intel Xeon Processors E5-2637 v3 with 15M Cache working on 3.50 GHz.

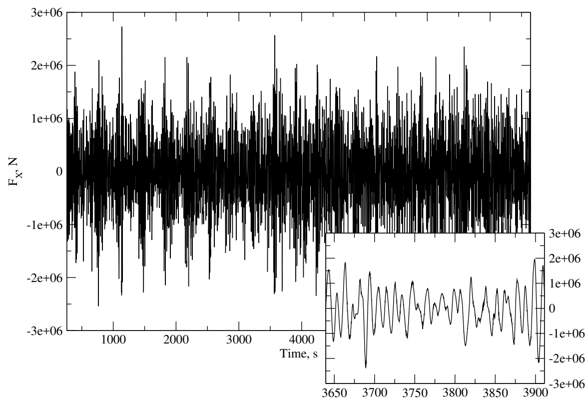


Figure 3: Resistance of DTC hull during a global performance simulation in irregular waves.

During the global performance simulation, the deck wetness is monitored, producing a data history of green sea events. By inspection of the amount of shipped water, duration and location of the green sea event, the most adverse event is selected. For that event, a detailed CFD simulation is performed where only a part of the ship is modelled, whereas the motion of the ship and wave kinematics are imposed from the global performance simulation. Here a fine grid resolution can be used in order to model intricate deck structures and equipment, such as pipes, valves, winches etc. Thus, detailed pressure distributions and loads, as well as water ingress can be predicted.

In order to gain confidence in the capability of the code in assessing pressure loads in a water on deck incident, a detailed validation is performed based on experimental studies published by Lee et al. [7], where a fixed FPSO model is encountered by various regular waves. Pressure is measured on ten locations on deck for 35 encounter wave periods, reporting periodic uncertainty. Figure 4 presents a snapshot from one of the simulations, where the geometry of the FPSO can be observed. In order to resolve the advection of the interface more accurately, a geometric VOF method is used called isoAdvector [8]. isoAdvector enables sharp and accurate advection of the free surface, which is important in case of violent free surface flows that are encountered in green sea events. Figure 5 shows the comparison of the α field in the simulation where isoAdvector is used and in the simulation where conventional algebraic implicit VOF method is used.

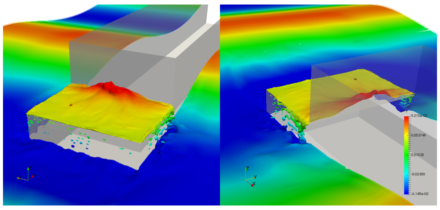


Figure 4: Snapshot of the green sea simulation.

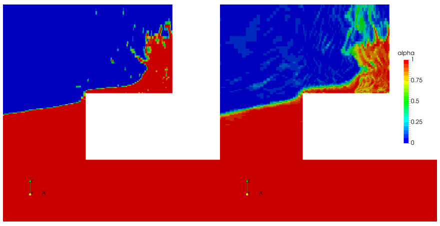
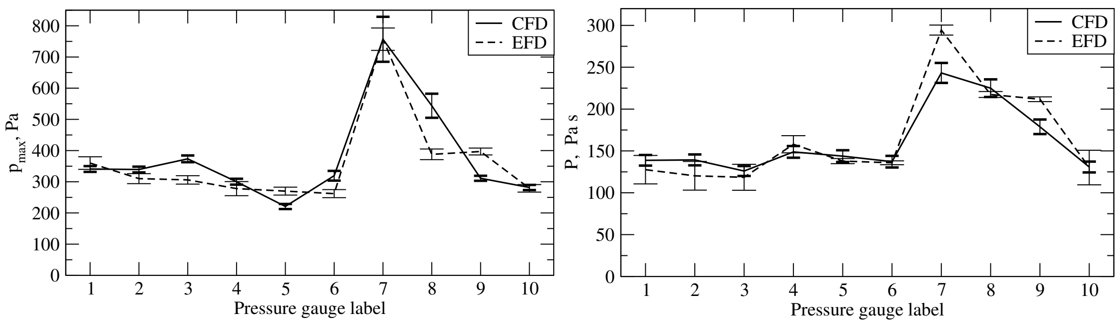


Figure 5: Comparison of the α VOF field in simulation with isoAdvector (left) and with algebraic VOF (right).

In order to compare numerical and experimental data, pressure peaks and pressure integrals in time are compared. Figure 6 shows the comparison of pressure peaks and integrals for one of the wave cases. The abscissa denotes the indication number of the pressure gauge on the deck, while the ordinate presents the average pressure peak and average time integral of pressure during one wave period. Error bars denote the numerical and experimental uncertainties, which are comprised of discretization and periodic uncertainty, and of measuring bias and periodic uncertainty, respectively.



(a) Pressure peak comparison,

(b) Pressure time integral comparison.

Figure 6: Comparison of pressure on deck between experimental and numerical results.

The proposed procedure can be applied in practice whenever a more precise prediction of green sea load on arbitrary deck structure geometry needs to be assessed. The procedure will predict deterministic extreme pressure loads on deck structures for a realistic set of sea states which can be expected based on the location of the naval object.

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