Application of Load Generator WaveLoads 2.0 in OWEC Simulation Frameworks

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Summary

WaveLoads is a software for calculation of wave induced loadings on hydrodynamicially transparent structures such as monopiles, tripods and jackets of offshore wind energy converters (OWEC) – developed at the Institute of Fluid Mechanics, Leibniz Universität Hannover. Various wave models for uni- and multidirectional sea states have been implemented to provide appropriate load prediction.

The latest developments have been focused on integrating WaveLoads in simulation frameworks. Interfaces to finite element programs such as ANSYS, Abaqus or MSC Nastran have been further extended. A multibody simulation framework using Adams, FAST/AeroDyn and a DLL-version of WaveLoads gives the opportunity to investigate both the interaction of the wind field and the rotor blade dynamics as well as the influence of wave loading for different sea states. The modular approach allows highly detailed investigations of individual aspects of OWEC structures and provides an important basis for interdisciplinary research projects.

1. Introduction

The design optimization of the support structure of offshore wind energy converters is a key issue towards cost efficient offshore wind energy projects. The design principles have to ensure a long life span and an extremely low failure rate. Meeting these demands requires a reliable simulation framework reflecting the entire offshore wind energy converter (OWEC) system, including its structural dynamics, the load and control interaction and finally the impact on the foundation.

A modular approach in simulation frameworks takes into account the diversity of processes and process interactions of an offshore wind turbine and its associated sub systems. This gives the opportunity to develop highly detailed sub-modules for investigation of individual aspects of OWEC systems.

2. Load Generator WaveLoads

The software WaveLoads is a smulation tool for the calculation of wave induced loadings on hydrodynamicially transparent structures such as monopiles, tripods and jacktes of OWECs.

In 2005 WaveLoads 1.0 has been made available to the public providing different linear and non-linear regular wave theories as well as irregular waves. Since then many new features have been implemented concerning wave kinematics and loads as well as interfaces for the integration in simulation frameworks. These developments result in the new version WaveLoads 2.0 being available for research purposes and for code evaluation.

2.1 Calculation of Wave Loads

Loads due to water waves represent a significant part of the total environmental loads of offshore wind energy converters (OWEC). Profound understanding of different sea states and an adequate wave simulation are essential for a reliable design basis.

Waves entering shallow water show an increase in nonlinear behavior resulting in steeper crests and shallower troughs accompanied by a change in water particle kinematics. Usually, these waves are approaching the shore line in a more or less unidirectional way. In deeper water the direction of the waves and the spreading of the sea state are varying.

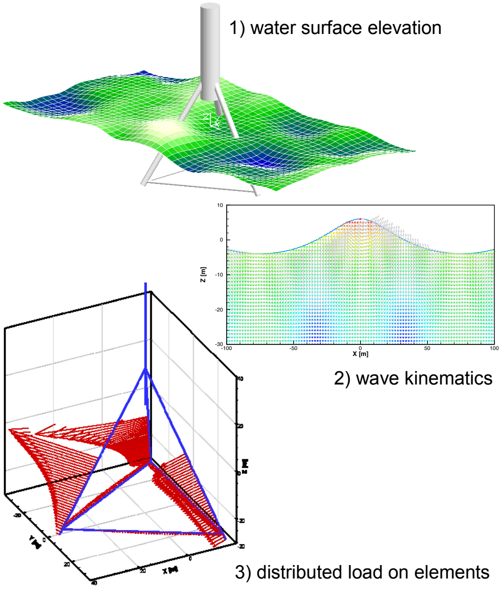


Figure 1: Calculation steps in WaveLoads.

Different regular and irregular wave models for various uni- and multidirectional sea states are implemented in WaveLoads to provide appropriate load prediction:

- Regular waves
  - Linear wave theory (Airy)
  - Stokes 2nd, 3rd, 5th order wave theory
  - Stream function wave theory by Dean, Fenton or Sobey

- Irregular waves
  - 1-D sea state (based on Airy or Stokes 2nd order)
  - Constrained model with embedded individual extreme wave
  - 2-D sea state including waves in different directions of prescribed distribution

The loads are calculated from the resulting wave kinematics using the Morison equation.

2.2 Sea State Modelling

In general, sea states are described by a wave spectrum. An inverse Fourier transform leads to an equivalent sea state in time domain. A discrete formulation is used, which can be interpreted as a superposition of numerous linear waves for velocity potential Φ as well as for surface elevation η. Amplitudes and frequencies are determined from the variance spectrum of water surface elevations and a random phase [1].

As unidirectional theories lead to an over-prediction of wave velocities compared to ocean measurements [2] this model is extended to summation over frequencies as well as directions to take into account the wave's directionality, i.e. for short crested waves.

The directional spectrum $S(f, \theta)$ represents the distribution of wave energy in the frequency domain and its directional spreading. It is given by the product of the variance spectrum $S(f)$ with a spreading function $D(f, \theta)$. The directional function of the 2D-spectrum has influence on the wave crest length and with it on the characteristics of the sea surface. The $\cos^{2s}$-model by Mitsuyasu et al. [3] is parameterized by the spreading parameter s. This gives the opportunity to simulate different sea state conditions like wind waves or swell through variation of the spreading function [4].

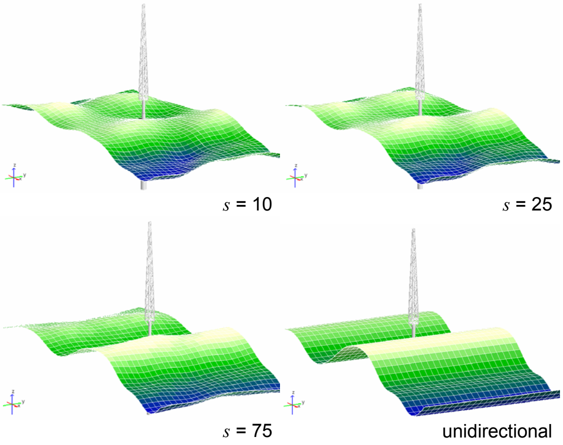

s = 10
s = 25
s = 75
unidirectional

Figure 2: Water surface elevation (scaling factor 5) with variation of the spreading parameter s (H_s = 6,3 m, T_p = 12,5 m).

2.3 Constrained Waves

For the simulation of extreme wave loads the 100 year sea state is used. A regular wave with associated height and period would differ from the random process of the ocean surface in shape and thus in wave kinematics and loads. Simulating a complete 100 year sea state with the superposition approach could not guarantee that the desired extreme wave will be included and would be far to time consuming.

By generating tailored design wave sequences the wave train corresponding to a given sea state can be fitted to predetermined target characteristics in terms of wave height, crest height and period. This wave train serves as input for the calculation of the corresponding water particle kinematics [5].

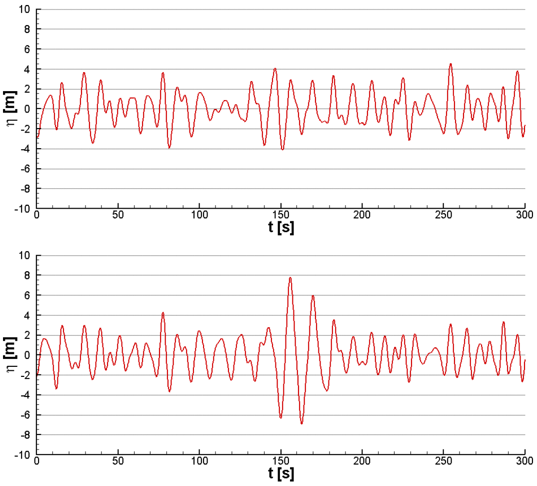


Figure 3: Surface profiles of initial and resulting sequences. H_s = 7.5 m, T_p = 12.5 s, H_{Target} = 14 m, T_{Target} = 14 s, $H_{Crest,Target}$ = 8.4 m, $t_{Crest,Target}$ = 150 s.

3. Simulation Frameworks

To analyze the different processes and especially the process interactions of an OWEC and its associated sub systems, an integrated simulation model had to be realized. Derived from the needs of the participants in the ForWind research group, a modular approach provides the flexible integration of interacting sub models that can be developed independently according to individual needs. With this framework future demands can be fulfilled by extension with further modules for new aspects of simulation or by exchange of modules with models of higher complexity (Fig. 4).

3.1 Finite Element Simulation

WaveLoads can be used as pre-processor for finite element simulations. Interfaces to ANSYS, Abaqus and MSC Nastran provide input files for complete transient analysis with adjacent predefined post-precessing without the need of further user interaction. Wave and buoyancy loads on the structure are provided as time series. Other simulation modules can be integrated through modifications of the finite element input file.

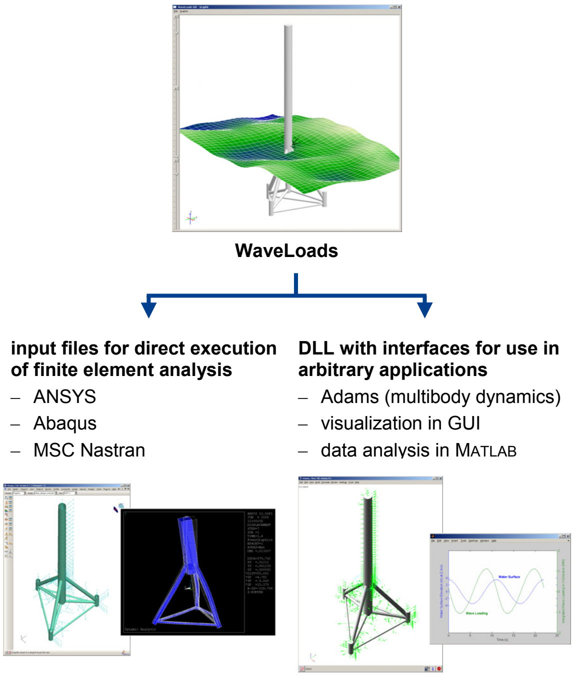


Figure 4: Interfaces in WaveLoads for software integration.

3.2 Multibody Simulation

An integrated simulation approach using modules provided as dynamic link libraries (DLL) gives the advantage of direct data exchange and more flexibility for future developments in existing or in additional modules.

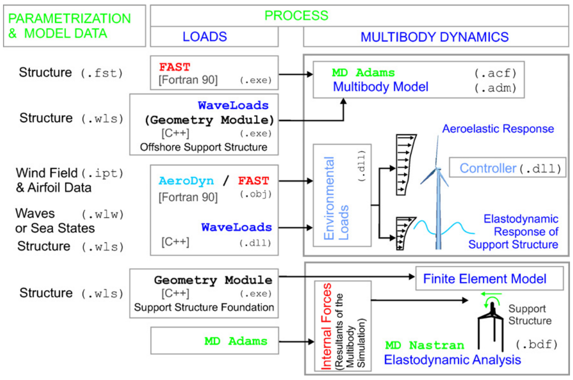


Figure 5: Framework for multibody dynamics.

A dynamic link library of WaveLoads has been developed. It is integrated as load generation module in a multibody simulation framework using MSC Adams. The aerodynamic load module AeroDyn [6] in combination with the multibody dynamics module FAST [7] is used for turbine generation and aeroelastic modeling of the rotor blades. Turbulent wind fields are generated by the ForWind partners and used as input. WaveLoads provides the model data of the support structure.

This setup gives the opportunity to investigate both the interaction of the wind field and the rotor blade dynamics as well as the influence of wave loading from different sea states.

The simulation results can be evaluated independantly or the resulting internal force variables can be used as input values for a more precise finite element analysis.

A graphical user interface (GUI) for a simulation framework with integrated DLL based modules can provide user-friendly input data management and data visualization.

4. Application

The simulation framework can easily be adapted to different offshore structures and load conditions. The pre-processing features implemented in WaveLoads provide fast simulation setup.

4.1 Validation Against Measurements

The finite element simulation approach has been validated with simulations of the research platform FINO 1 and the measurement mast Amrumbank West against modal identification and in-situ measurements.

Figure 6: Models and photos of measurement mast Amrumbank West and research platform FINO 1.

Simulations with different wave models and sea states have been performed. Especially the random wave simulation with directional spreading proved to be a useful approach for modeling a more realistic sea state than with unidirectional waves [4, 8].

4.2 Offshore Code Comparison Collaboration (OC3)

The Offshore Code Comparison Collaboration (OC3), which operates under Subtask 2 of the International Energy Agency (IEA) Wind Annex XXIII, gives the opportunity for code-to-code verification and simulation result comparison.

The NREL 5MW baseline wind turbine [9] is combined with different support structures (Fig. 9).

In the finite element approach using WaveLoads and ANSYS a tripod structure is used with the turbine and blades modeled as 3 mass points of correct weight distribution and inertia (see Fig. 7). The simulation results already show good agreements with those of the participants in the code comparison (Fig. 8). Nevertheless further improvements of the model and the simulation code are in progress

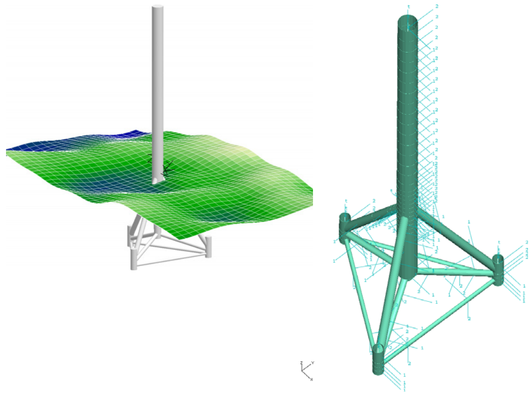


Figure 7: WaveLoads model and finite element model of OC3 tripod structure.

The same tripod is prepared for the multibody simulation. Other than in the finite element approach turbine, rotor blades and control system are modeled and turbulent full-field wind inflow is used as model input.

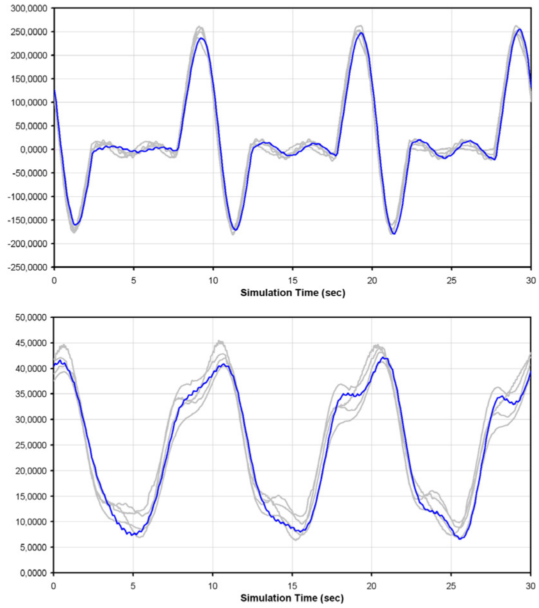
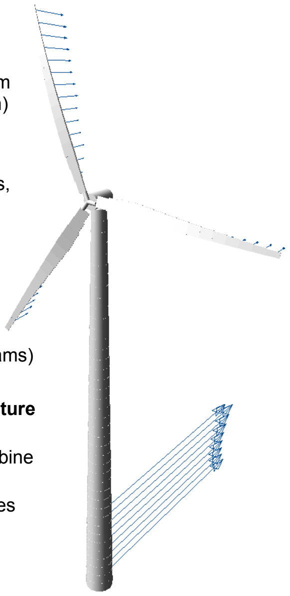


Figure 8: Time series of internal forces (kN) in wave direction in central tube at MSL and in upwind leg.



Wind Loads

- blade element-momentum methods (FAST/AeroDyn)

Wave Loads

- regular or irregular waves, sea states (WaveLoads)

Structural Response

- finite element simulation (ANSYS, Abaqus, MSC Nastran)
- multibody dynamics (Adams)

Analysis of Support Structure Concepts

- 5-MW reference wind turbine (NREL)
- different support structures (monopile, tripod, jacket)
- design optimization

Figure 9: Framework for integral simulation.

5. References

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