Offshore & Dredging Engineering

Technische Universiteit Delft

Response of an Offshore Wind Turbine supported by a Non-Local Winkler Foundation: An Efficient 1-D Time-Domain Model accounting for the 3-D Frequency-Dependent Dynamic Soil Stiffness

With increasing evidence of human-induced accelerated climate change, the need of sustainable, non-polluting, energy sources becomes evident. Offshore wind generated electricity is currently one of the most promising sources of energy to create a sustainable global energy mix. The offshore wind industry has developed rapidly over the last years. The cumulative installed capacity shows an exponential growth. Monopiles remain the most popular substructure type of all installed substructures in Europe. This thesis focuses on calculation methods to evaluate the response of that foundation type.

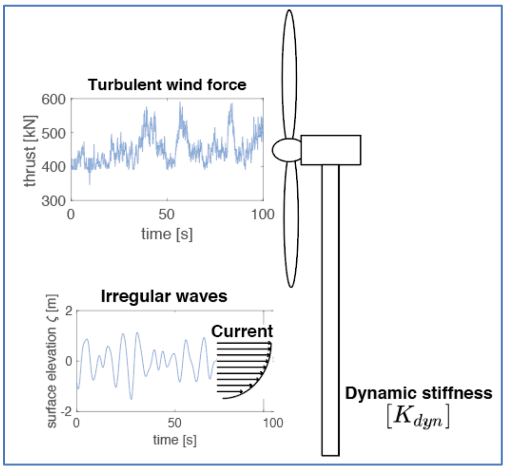
The interaction between a monopile and soil is called soil-structure interaction (SSI). In the offshore wind industry, SSI is commonly modelled as a 1D local Winkler foundation with local nonlinear elastic springs to represent the lateral soil stiffness. The stiffness is often based on semi-empirical relations between the lateral displacement of the pile and the soil pressure (p-y method). This approach neglects the interaction effects between different soil layers and there are uncertainties regarding the validity of applying this method to large diameter, rigidly behaving, monopiles.

In this thesis, a 3D linear-elastic (LE) finite element (FE) model is used to compute 1D global (non-local) complex-valued dynamic soil stiffness, which captures the coupled 3D reactions of soil to the pile. The frequency dependence of local and non-local linear-elastic lateral, rotational and coupling dynamic soil stiffness is analyzed for heterogeneous soil stratigraphy. The effect of different boundary conditions in the 3D model formulation to the frequency dependence of dynamic soil stiffness is analyzed.

The complex-valued-frequency dependent dynamic soil stiffness kernels are approximated by frequency independent coefficient matrices for added mass, damping and stiffness. The performance of the coefficient matrices in terms of representing the complex-valued dynamic soil stiffness is analyzed with cost functions. It was found that the dynamic soil stiffness can be approximated by frequency independent added mass, stiffness and damping coefficient matrices in the frequency range of interest for offshore wind.

A 1D Timoshenko beam model is developed in the frequency-domain and is discretized in space by Euler's central finite difference method. The added mass, stiffness and damping matrices, which represent the non-local Winkler foundation, are incorporated in the model. The SSI response of the 1D model to the dynamic loading is compared with the response of the 3D LE FE model in the frequency domain.

As a last step, a superstructure and turbine are integrated with the monopile SSI model and the total integrated model is transferred to the time domain. Time domain computations are performed for free vibrations, harmonic loading and realistic aero-/hydrodynamic loading scenarios. The transformation into the time domain is important since it allows the user to incorporated nonlinear wave and wind loading and air-turbine interaction effects that are considered to have a major impact on the resulting dynamic system response. The developed time-domain model is computationally very efficient in predicting the time-domain SSI response of an offshore wind turbine for varying loading scenarios.



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