Numerical modelling of offshore foundations for jacket structures

Nowadays the offshore wind industry continues to push towards larger turbines with capacities greater than 8MW in deeper waters. The realization of such wind farms requires that the costs of the overall offshore wind turbine system are significantly reduced, in order to give the offshore wind industry an increasing edge in the competition with fossil-fuel-based energy sources. The cost-reduction target set can be achieved either by adopting new technologies or by optimizing design methods and existing technologies. One of the areas where cost reductions can be met is in the support structure. For an offshore wind turbine structure, the support structure design typically has some global requirements, e.g. frequency. The global constraints are influenced by both the soil properties and the foundation design. Hence, it is necessary to account for the possibilities of dynamic effects of the soil-foundation interaction in order to achieve reliable responses of the wind turbine structure.

The aim of this thesis is to evaluate the dynamic soil-foundation interaction of offshore wind turbines, focusing on different types of foundations (suction caissons and hollow steel piles), different load conditions (cyclic and dynamic) and soil conditions. Moreover, two approaches were followed in the soil modelling: small strain approach in which elastodynamic constitutive soil model is considered and large strain approach, where elasto-plastic constitutive soil model is taken into account.

The models adopted in this study can be classified as: a) simple analytical formulations and b) continuum finite element models (FEM). In the abovementioned models the soil is simplified as a homogeneous linear viscoelastic material. Existing analytical elastic solutions, which deal with the dynamic soil pile interaction, have been revisited and extended to account for different soil profiles and foundation geometries. Continuum finite element models have been developed for validation of the analytical procedures, and a parametric study has been established to investigate the application range of the simple analytical solutions (foundation length, diameter and bending stiffness, soil stiffness, and depth of soil layer/bedrock). The frequency dependent dynamic stiffness and damping coefficients of floating piles and suction caissons under various loading conditions have been estimated. The outcomes are presented in terms of non-dimensional graphs which show the frequency dependency of the dynamic stiffness and damping corresponding to the different degrees of freedom.

In addition, this research project was focused on modelling the cyclic behaviour of soil. The constitutive models based on perfect plasticity are not capable to reproduce the irreversible strains accumulated due to cyclic loads and to define the stress history of the material. Thus it is fundamental to deploy realistic constitutive models for realistic numerical analyses in order to describe properly highly nonlinear and anisotropic stress-strain behaviour of the soil. Particularly, the soil constitutive model of Manzari and Dafalias (SANISAND, 2004) has been modified in order to solve inefficient performance of the stress integration scheme for soil deposits in the low stress regime. The modified SANISAND (2004) has been implemented in Abaqus. Moreover, drained and undrained compression triaxial tests at DTU GEO-Lab were performed to calibrate the material constants of the constitutive model for Fontainebleau sand. The calibration is necessary for evaluating the model performance for Fontainebleau sand.

Finally a method for integrated design of offshore wind turbine jackets and foundations is proposed by adopting numerical structural optimization. The optimal design problem enables an automatic design process which minimizes the primary steel mass of the jacket and the foundations. Integrated design optimization of jacket and foundation has been performed for two different foundation types (piles and suction caissons), a range of different leg distances, and ten soil profiles.

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