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# Integrated optimal design of jackets and foundations

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A B S T R A C T

The article proposes a method for integrated design of jackets and foundations using numerical structural optimization. Both piles and suction caissons are examined in both clayey and sandy soil, and several design procedures are taken into account. The optimal design problem enables an automatic design process which minimizes the primary steel mass of the jacket and the foundations. Both leg distance and soil stiffness are found to have a significant influence on the total mass as well as the first natural frequency of the full offshore wind turbine structure. The results indicate that an integrated design approach is valuable in the conceptual design phase. Firstly, the soil characteristics and foundation type have a significant influence on the optimal leg distance for the jacket. Secondly, the jacket mass has a significant influence on the optimal foundation type and foundation design.

## 1. Introduction

The main objective for the offshore wind industry nowadays is to reduce the cost of energy, in order to be competitive with respect to fossil–fuel–based energy sources. Support structures comprise as much as 20% of capital expenditures, and have been identified as areas with high potential for cost reduction [41]. The cost-reduction targets set by industry can be met either by using new technologies or by optimization of design methods and existing technologies. In that regards, structural optimization appears as an attractive approach to investigate any potential cost benefits from the design optimization of the substructure and the foundation.

Optimization of wind turbine components has been well studied in the literature, and for example, a gradient based rotor optimization is presented in Ref. [18]. Integrated design of multiple components of the offshore wind energy turbine, such as of tower and rotor, have been done in e.g. Ref. [2]. Here it was showed that an integrated approach towards optimization can considerably reduce the cost of energy, which often implicates a compromise between rotor and support structure design. However, the foundation was not optimized, since all degrees of freedom of the monopile at the seabed were constrained. Terminology of the main components of the support structures for offshore wind turbines are given in Fig. 1. Detailed design of support structures according to rules and guidelines [22] implies that a large number of load cases must be assessed, which is a computationally expensive and time-consuming task. Many design approaches therefore use a reduced number of load cases [45].

Optimal design of support structures for offshore wind turbines has developed from gradient-free approaches where an aero-elastic software is used as a black-box for the function evaluations [46], towards the use of gradient-based methods [29] and [36]. The advantage of the black-box approach is that the analysis can be state-of-the-art. With gradient-based methods, one has so far been limited to elastic analysis, where the rotor loads are applied as time-series at the tower top. This is a simplification compared to the state-of-the-art aero-elastic analysis, where both the wind turbine generator and wind field are modelled. However, due to the nature of the industry, where turbine designers are unwilling to share models with the support structure designer, a decoupled load model is

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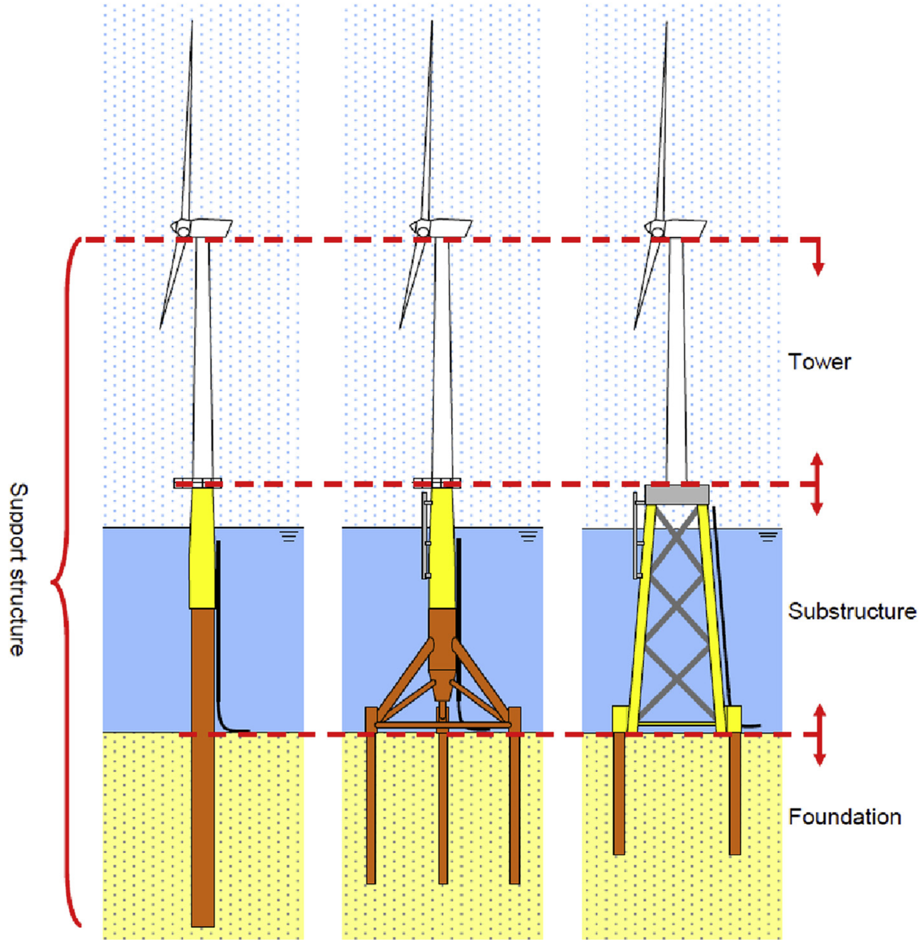


**Fig. 1.** Definition of the main components of the support structure for offshore wind turbines. The jacket substructure can be further divided into the actual jacket, and the transition piece which connects it to the tower. Figure from the UpWind project report [14].

actually industrially relevant. Gradient-based optimization of jacket substructures is presented in Refs. [30] and [11] with quasi-static and dynamic analysis, respectively. In these works, the fatigue and ultimate limit states were assessed during multiple 10-minute load cases. For conceptual design of jacket substructures, a load analysis with static damage equivalent loads, and static extreme loads can be sufficient [38].

Contrary to the mechanical engineering field, in the geotechnical sector numerical optimization methods have been only scarcely investigated in the literature. Few studies have been conducted on the dimension optimization of shallow foundations [24] and pile groups [10]; while the topology optimization of foundations in granular soils was addressed in Refs. [31] and [39]. In the latter ones, a combined method of topology and shape optimization was implemented and linked up to a finite element program. It was shown in Ref. [39] proved that the optimized foundation topologies are more efficient due to the significant improvement of the deformation behaviour when compared to quadratic surface foundations. It is worth mentioning the work [4], in which a general approach to the reliability-based analyses was performed to optimize designs of laterally loaded piles. For a monopile [42], used a genetic algorithm to design a monopile in the frequency domain. Furthermore, a preliminary investigation of pile foundation design using structural optimization was performed in Ref. [37]. The main conclusion derived from the above mentioned study was that structural optimization could effectively find feasible and realistic pile designs for a broad range of soil strengths.

Design requirements on the offshore wind turbine sub structure are defined in terms of fatigue limit state and ultimate limit state, and the utilization of these limit states is checked in all critical points of the structure [14]. Design requirements on the foundation are given in terms of load capacities, defined individually for each foundation type and soil type. To prevent damaging resonance vibrations in the structure, there is also a requirement that the first natural frequency of the structure is non-overlapping with the rotor and blade passing frequencies.

This article presents an integrated design approach using structural optimization, which enables the simultaneous design of foundation and substructure. The advantage of using an integrated design approach is that it requires no manual iterations going back and forth between jacket design and foundation design. The advantage of using structural optimization is that the design process is automatic. The disadvantage of the integrated design approach is that it requires the geotechnical and structural analysis to be