

SUPPORT STRUCTURES FOR OFFSHORE WIND TURBINES – A HOLISTIC DESIGN CONCEPT –

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Summary

Within the optimisation process for offshore wind energy converters (OWEC) one essential part comprises the support structure. At the German test field “alpha ventus” twelve turbines shall be installed in 30 meter water depth where all loads of wind, turbine and waves have to be carried into load-bearing ground. In particular these aspects become more important since thousands of OWECs are planned in the North and Baltic Sea.

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is funding “alpha ventus” with the research initiative RAVE. Priority objective of the RAVE project GIGAWIND *alpha ventus*, which is presented here, is cost reduction for OWEC support structures, which means towers, different types of substructures and foundations. This can be divided in designing lighter support structures on the one hand (material cost) and in optimising the design process on the other hand (personnel cost). Because of the interdisciplinary orientation of the project coverage of all civil engineering problems is intended.

1. Introduction

Comparing with onshore wind energy converters the support structures of OWECs have an essential higher significance. The RAVE initiative covers a big measurement campaign enabling this outstanding research on support structures.



Especially the holistic view on this topic is shown in the following constructional aspects contained in particular projects of GIGAWIND *alpha ventus*:

- Load modelling for waves and its correlation effects to wind,
- Influence of manufacturing aspects on fatigue resistance,
- Corrosion protection for offshore steel structures,
- Reliable load monitoring at global and local parts of the structure,
- Development of new scour protection systems and local scour monitoring,
- Modelling of the load-carrying behaviour for driven offshore piles and
- Automated validation of general structural models.

Algorithms, new methods and software-tools will be developed and shall be validated by measurement data from the test field. With a more efficient design process and by utilisation of design reserves support structures can be provided more economically.

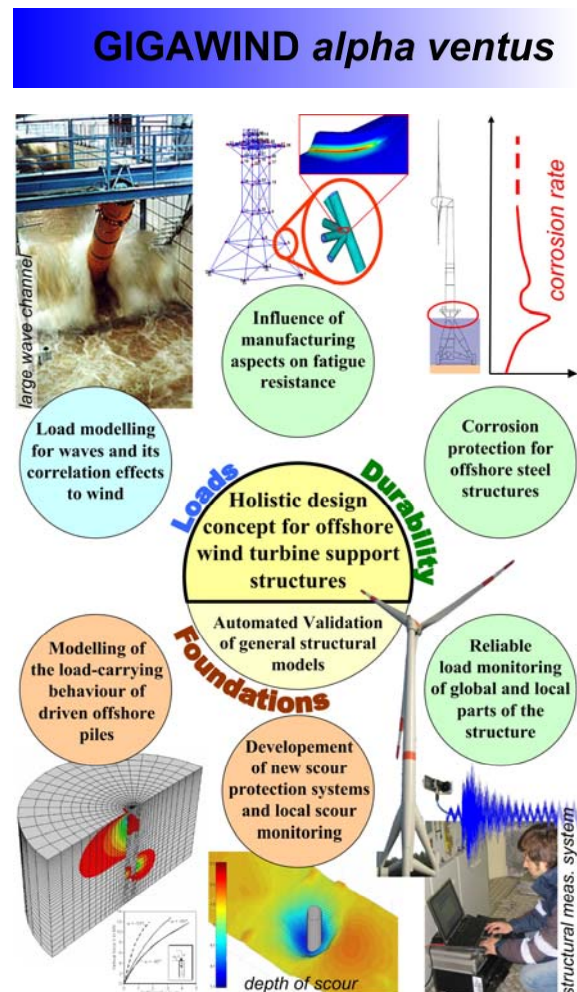


Fig. 1 RAVE project GIGAWIND *alpha ventus*

With the integration of separate computational tools into an easy operable simulation and design package with common interfaces the effort of the design process will be minimised. Objective of the project is a holistic design concept for OWEC support structures, which is build up in a modular way, so further extensions can easily be implemented.

2. Constructional Aspects

2.1 Load modelling for waves and its correlation effects to wind

Cylinder structures are commonly used for offshore constructions in various ways. Predominantly, structures with cylindrical shape are a basic element for the design of foundations of offshore wind power plants. Due to high follow-up costs in case of structure failure and due to uncertainties of loadings, offshore structures are overestimated in most cases. While slamming coefficients of breaking waves are decisive for the prediction of extreme loads, non-breaking wave loads are relevant for the design parameters required in fatigue limit state analysis, since wind power plants in the North Sea are encountered by approximately 3.000.000 waves per year. Reliable wave data has to be considered for the design.

A commonly used method to calculate wave forces on a single isolated cylinder is given by the Morison-equation for non-breaking waves. In addition to the velocities and accelerations under the wave, two empirically estimated coefficients for the drag and inertia components are required. Several studies, mostly based on wave flume experiments, have focused on force measurements and the estimation of the Morison coefficients [6]. Coefficients for North Sea sea states will be derived from field surveys and from the measuring program of the alpha ventus test field and correlated with wind loads. Furthermore, the local pressure distribution of breaking waves will be investigated by physical and numerical modelling.

2.2 Influence of manufacturing aspects on fatigue resistance

The currently applied structural and fatigue assessment of support structures for Offshore Wind Turbines is based on common design rules. Normally, constructions in structural engineering are treated as limited, single structures. This means for instance that varying aspects of manufacturing are considered by high safety factors. Plans exist to build large offshore wind parks in the next years. For manufacturers a change to serial production of support structures is necessary to accommodate the high demand and to stay competitive on the international market.

Series production means the chance to improve the quality of the products by a systematic development of facilities accompanying quality management

system. But these positive effects are so far not considered in design standards and may result in conservatively designed structures. For this reason, parameters like geometry tolerances and aspects of welding like distortions and residual stresses shall be measured parallel to the manufacturing to get more information about their development during the production process. Additional Finite Element Analyses shall expand the parameter field. The received results shall be introduced in the existing design rules. In many cases fatigue assessment is design driver for offshore structures [5]. Hence, for welded jacket structures, one result might be that weld details can be assigned to better fatigue classes. Finally, this may enable lighter and more cost effective structures.

2.3 Corrosion protection for offshore steel structures

The influence of aggressive environment leads to specific requirements for corrosion protection in the atmospheric zone and in the splash zone of steel structures for offshore wind turbines [3].

In this project different corrosion protection systems and sensor application methods for strain measurement will be tested, evaluated and further developed to improve offshore durability and reliability.

To achieve this aim special test coupons will be fixed on the support structures of the offshore wind turbines to be loaded in the aggressive offshore environment. Figure 2 shows an example of a test coupon with different application systems for strain sensors



Fig. 2 Test coupon with online monitoring

Further, a new sensor system for the monitoring of the corrosion process will be developed and tested. This test will provide information about the damage mechanisms that can be detected by the sensor. If the sensor detects damages, the structure can be checked for initial corrosion.

A well-founded evaluation of different corrosion processes in correlation to the applied corrosion protection system will lead to more efficient total corrosion protection concepts for offshore wind parks including reduced corrosion allowance.

2.4 Reliable load monitoring at global and local parts of the structure

For monitoring of OWEC support structure analysis methods and sensor system are of prime importance. Several hardware and software techniques are analysed concerning robustness and validity for the first time. Advices for a monitoring system for in series operation at OWEC support structures will be issued. This includes minimising of needed sensors, application, data acquisition and analysis of measurement data. Main objective is further development of analysis methods [4] which allows for an assessment of the current state of the structures. So calculation of dynamic stress amplitude gives information for safeties in life time prognosis. Different analysis methods for local load monitoring as well as at the global dynamic system are combined to estimate residual load capacity and residual life time.

2.5 Development of new scour protection systems and local scour monitoring

Currently it is not possible to forecast the extent of scours that form around the foundation of offshore wind turbines due to currents at the sea bed. Thus stringent safety factors are currently applied for dimensioning foundations. Within the framework of our research project, investigations of the development of scours around the foundation structures are carried out in the offshore test field, as well as investigations of the usability of foundation piles and limit load analyses. In the end, impacts on the load-bearing characteristics shall be determined and suitable methods for scour protection shall be developed in order to allow efficient foundations in the future. The investigation of the real scour development contains scour monitoring at the offshore structure by analyzing the measured scour depths around the piles and in the near environment of the wind turbine. The analysis of the field measurements is especially used to calibrate a numerical CFD model that will be developed in the framework of the project. Further investigations are carried out by means of physical model tests. Here, the offshore wind turbine is modeled on a scale of 1:10 and 1:40 and tested in the Large Wave Flume (GWK) and the wave flume of the Franzius-Institute respectively.

2.6 Modelling the load-carrying behaviour for driven offshore piles

Most of the existing offshore wind turbines are founded on single large-diameter, open-ended steel piles (monopiles). However, for water depth of 30 m and more like at the "alpha ventus" test field, jacket, tripod or tripile structures with three or four single steel pipe piles located at the edges of a triangle or a square are favored.

For monopiles the horizontal loading is decisive for the design. Regarding the design of the superstructure, the stiffness under transient wind and wave loads is important because it affects the eigenfrequency of the system and with that the operational loads. The current design method (p-y method) is validated only for piles with smaller diameters and has thus to be modified. Moreover, no approved

method exists to determine the permanent displacements of a monopile, which accumulate with cyclic loading. A simulation method developed recently [1] [2] shows that design criteria like the "vertical tangent" approach (the deflection line of the pile under design loads shall at least have a vertical tangent) are too conservative, which shows optimization potential.

For jacket or tripod piles the axial loading is usually driving the design regarding the necessary pile length. Potentials for optimized design procedures exist in the design of piles in dense sands (Achmus et al. 2007) and in the design with respect to cyclic tension loads, which is – in lack of approved sophisticated design methods – usually carried out with conservative approaches.

In scope of the project, computational tools shall be developed simplifying consideration of the design methods in a holistic design.

2.7 Automated validation of general structural models

With the demand of an economic and reliable design optimisation there is combined the need of a close to reality numerical model for the support structure [7]. Validation of general structural models based on dynamic behaviour (eigenfrequencies) shall be automated regarding easy operability in internal routines of the software packages within the holistic design concept. This requires a system identification with eigenvectors on the one hand ensuring that also closely spaced eigenmodes can be identified in internal processes of the software. On the other hand several optimisation methods will be compared and evaluated improving efficiency and convergence behaviour of the validation procedure. Before choosing modifiable parameters there must be done some sensitive analysis to detect suitable parameters for validation. This shall be carried out especially for offshore wind turbines and generalised different typed of structures.

3. Holistic design concept for OWEC support structures

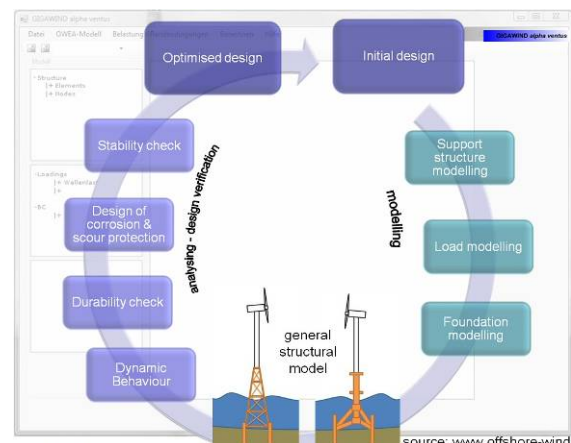


Fig. 3 Optimisation potential in design process

Dimensioning an OWEC support structure has to meet two requirements, safety and cost-effectiveness. Usually this is an iterative process and requires a very efficient simulation and design package as shown above, see figure 3.

Tools for different design aspects are made available, e. g. load models (section 2.1) and validated general structural models (section 2.7). The software package provides interfaces between these tools and thus saves time in the design process. After modelling the general structural system with FEM or MKS the geometric information of the system as well as node coordinates will be transferred automatically to another tool, called *WaveLoads*. Within an internal routine *WaveLoads* calculates node loads from a design wave or specific sea state and gives results back to the structural model.

4. Contacts and partners of RAVE project GIGAWIND alpha ventus

www.gigawind.de

www.rave-offshore.de

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