# Research on Support Structures in the German Offshore Wind Farm alpha ventus

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## Summary

RAVE – "Research at alpha ventus" coordinates different projects connected to the German offshore test site "alpha ventus". One of these projects is GIGAWIND *alpha ventus* taking the OWEC support structures into focus. The main objectives in this field of structural design are foremost the reduction of both material and personal costs. This endeavour primarily requires a holistic view on the design process encompassing the following design aspects: *Load modelling* – analysis of multidirectional wave loads for the estimation of optimized sea state coefficients and correlation with wind loads. *Fatigue* – varying influence of manufacturing aspects represented by large safety factors. *Corrosion* – corrosion protection for offshore steel structures. *Monitoring* – reliable load monitoring at global and local components of the structure. *Scour* – development of new scour protection systems and local scour monitoring. *Foundation* – modelling of the load-carrying behaviour of driven offshore piles. *Validation* – Automated validation of general structural models. With the integration of separate computational tools into an easy operable simulation and design package with common interfaces the efforts focusing on the design process will be minimised. Overall objective of the project is to conceptualize and develop a holistic design concept for OWEC support structures, which is achieved in a modular approach in order that updated routines and further extensions can be easily implemented.

## 1. Objective

The Federal Republic of Germany promotes and advocates erecting offshore wind energy farms with an overall rated power of 20-25 GW in the North- and Baltic Sea until 2030. Within the framework of the research initiative RAVE aiming to optimisation and cost reduction of further offshore wind farms, investigations are carried out on the first offshore wind energy converters (OWEC) being installed in water depths of approximately 30 meter in the offshore test site alpha ventus in the North Sea about 45km north-east of the Island of Borkum. Since offshore wind energy technology isn't yet explored very well, only early cost optimisation promises economic efficiencies for outstanding projects, where one of the biggest optimisation potential is expected in the field of support structures.
Priority objective of the RAVE project GIGAWIND *alpha ventus*, which is presented here, is cost reduction for OWEC support structures (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. The RAVE initiative covers a big measurement campaign like strain gauges, acceleration sensors or water pressure sensors enabling this outstanding research on support structures. One of the initiated work packages for example focuses on the efficient design and optimization of OWEC supporting structures, and, predominantly monitors the development of scour phenomena at the toe of the structure and develops countermeasures to cope with these effects for adequate protection and maintenance. First results of the work package will be presented here. Especially the holistic view on this topic is shown in the following design aspects contained in GIGAWIND *alpha ventus*.

## 2. Design Aspects

### 2.1 Load modelling for waves and its correlation effects to wind

Cylindrical 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 energy converters. Due to intense 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 energy converters in the North Sea are encountered by roughly 3.000.000 waves per year. Hitherto, reliable wave data have to be acquired and processed for an adequate design study.
A commonly used method to calculate wave forces on a single isolated cylinder is given by the Morison-equation for non-breaking waves.

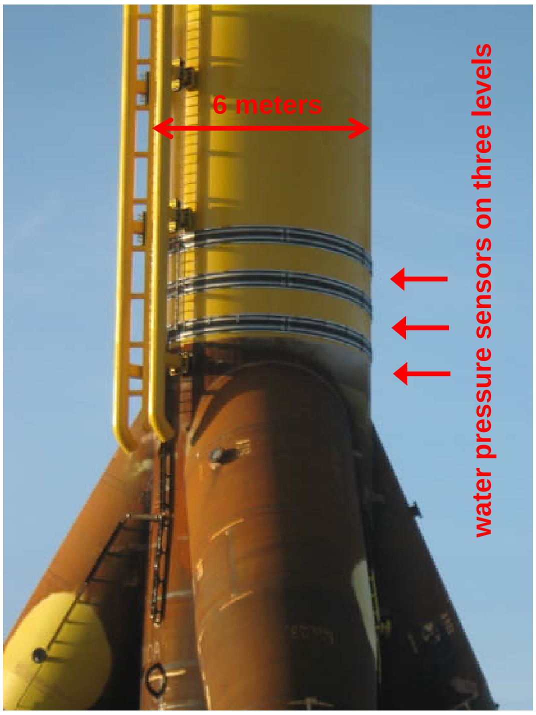


Fig. 1 Multibrid Tripod with measurement system (source: DEWI)

In addition to the velocities and accelerations beneath 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 (s. figure 1) and correlated with wind loads. This will provide information about major wind directions and duration in combination with the developing wave climate at the test field. Therefore, connections between wind fields and approaching wave trains will be estimated and their intensity, direction and time shift will be pointed out. 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 energy converters 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. This investigation will be carried out at the OWEC Jacket Quattropods for alpha ventus with aid of the Scottish manufacturer BiFab.

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

Steel structures for offshore wind energy converters are heavy affected by aggressive of salt-water. Different corrosion rates in atmospheric zone, in the splash zone and in the submerged zone lead to specific requirements for corrosion protection on these levels [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. One of this investigations is based on a new developed mineral coating enclosed by a textile layer.

To achieve this aim special test coupons will be fixed on the support structures of the offshore wind turbines to be loaded in the

Fig. 2 Test coupon with online monitoring

aggressive offshore environment. Figure 2 shows an example of a test coupon with different application systems for strain sensors.
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 advancement of analysis methods [4] detecting the current state of the structures and localising and quantifying structural damages. First step is early damage detection using proportionality of dynamic stress measured by strain gauges and dynamic velocity measured in the point of biggest displacement. Changes of the proportionality are a very sensitive indicator for structural damages. In a second step assessment of damage is done by solving a multi-parameter eigenvalue problem. In a validated numerical model of the undamaged structure there are parameterised specific segments of the structure. Eigenfrequencies are entered from the actual state of the structure. The inverse use of the multi-parameter eigenvalue problem leads to the identified loss of stiffness in each segment. This can be imagined like virtual scanning of the structure.
Different analysis methods for local load monitoring as well as at the global dynamic system like shown above are combined to estimate residual load capacity and residual life time.

### 2.5 Development of new scour protection systems and local scour monitoring

Due to the fact that the extent of scour phenomena which may form around the foundation of wind energy converters, are currently not being able to forecast owing to the highly-complex interaction between real sea state conditions, i.e. waves and currents and concurrently the structure and the sea bed, rigorous safety factors have yet to be applied to cope with adequate design parameter for the calculation of the foundations dimensions.
Within this project predominant aim is to determine impacts on the load-bearing characteristics and derive suitable methods for scour protection. Investigations on the scour development are conducted to distinguish in between a set of governing parameter in order to advance a proper engineering design system. The methodical examination of the real development contains scour monitoring at the offshore structure by analyzing the measured scour depths and contour profile around the piles and in the near-field of the OWEC. These in-situ measurements are especially demanded to calibrate a numerical CFD model that will be developed within this project. Further investigations are carried out by means of laboratory tests to study in principle the scaled scour phenomena for quantitative verification of the employed numerical codes. Here, the foundation of the OWEC 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 Hannover, respectively.
On the whole, impacts on the wave and current load-carrying structural behavior shall be determined by linking autonomous numerical models for morphology - structure interaction and suitable methods for scour protection shall be developed in order to allow efficient foundations in the future.

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 favorized.
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 [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.

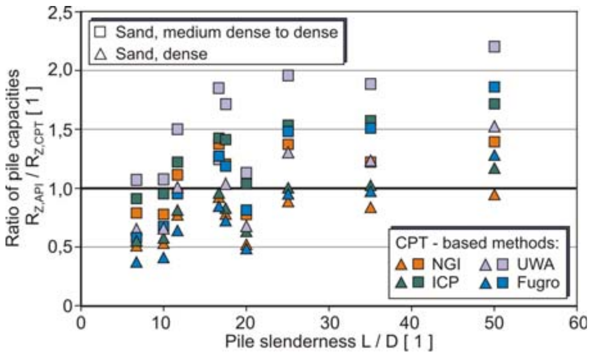

Fig. 3 Comparison of tensile pile capacities in sand soil according to the usual approach (API) and according to recently developed method

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 [1] 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 figure 3 a comparison of tensile pile capacities according to the usual API approach and according to recently developed CPT-based methods is given, which indicates that the capacity of piles with a ratio of embedded length L to diameter D less than 15 in dense sand are underestimated.
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 as shown in other topics of this paper 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. For identification of measured signals there are used auto regressive models, which also allow calculation of eigenvectors. The comparison of numerical and measured eigenvectors shall be done with MAC-criterion. On the other hand several optimisation methods like Newton iteration, secant method, genetic algorithms or nested intervals will be compared and evaluated improving efficiency and convergence behaviour of the validation procedure. Before choosing modifiable parameters there must be done some sensitivity analysis to detect suitable parameters for validation. This shall be carried out especially for offshore wind turbines and generalised for different typed of structures.

## 3. Holistic design concept for OWEC support structures

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 in figure 4.

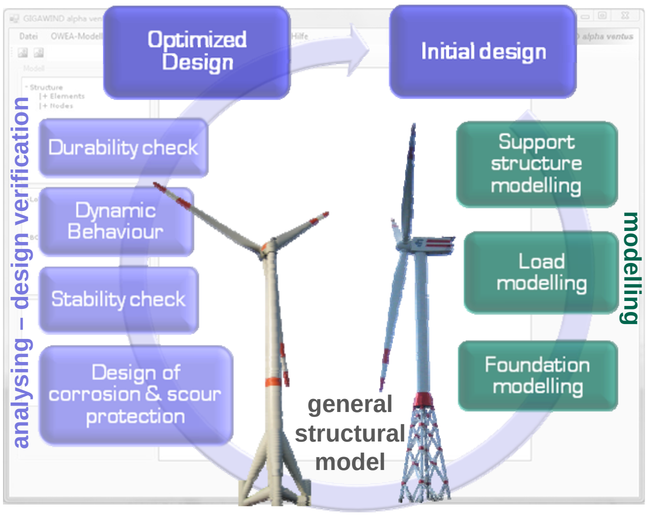


Fig. 4 Optimisation potential in design process

Algorithms, new methods and software-tools will be provided by several work packages of GIGAWIND *alpha ventus* and shall be validated by measurement data in alpha ventus. With a more efficient design process and by utilisation of design reserves support structures can be provided more economically.
For example load models (section 2.1) and validated general structural models (section 2.7) are made available. 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.
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.

## 4. References

[1] Achmus, M.; Abdel-Rahman, K.; tom Wörden, F.: „Geotechnical Design of Piles supporting Foundation Structures for Offshore Wind Energy Converters", *17th Int. Offshore (Ocean) and Polar Engineering Conference (ISOPE-2007)*, Lisbon, Portugal, July 1-6.

[2] Achmus, M.; Kuo, Y.-S.; Abdel-Rahman, K.: „Zur Bemessung von Monopiles für zyklische Lasten". *Bauingenieur*, Bd. 83, Heft 7-8, 2008.

[3] Momber, A. W.; Stenzel, V.; Plagemann, P.; Schneider, M.: „Combined Field – Laboratory Studies on Corrosion protection Conceptions for Offshore Windenergy Towers." *4th Intern. Symp. On Protective Coatings*, Bombay, Nov. 2006.

[4] Rolfes, R.; Lynch, J.; Gerasch, W.-J.; Haake, G.; Reetz, J.; Zerbst, S.: „Integral SHM-System for Offshore Wind Turbines Using Smart Wireless Sensors." *Proceedings of the 6th International Workshop on Struktural Health Monitoring*, Stanford, 11.-13. September 2007, DEStech Publications, Inc., 2007.

[5] Schaumann, P.; Wilke, F.: „Fatigue Assessment of Support Structures for Offshore Wind Energy Conversion Systems". *ForWind Annual Report 2006*, pp. 36-40, 07/2007.

[6] Woltering, S.; Daemrich, K.-F.: „Nonlinearity in irregular waves from linear LAGRANGEian superposition.“ *Proceedings of 29th International Conference on Coastal Engineering*, Lisbon, Portugal, ASCE, 2004.

[7] Zielke, W. et al: . „Validierung bautechnischer Bemessungsmethoden für Offshore-Windenergieanlagen anhand der Messdaten der Messplattformen FINO 1 und FINO 2“, *GIGAWINDplus annual report 2006*, Hannover, April 2007.

## 5. RAVE project GIGAWIND *alpha ventus*

GIGAWIND alpha ventus is a compounded project within the RAVE initiative called “Holistic Design Concept for OWEC Support Structures on the base of measurements at the offshore test site alpha ventus”. All working packages are shown in figure 5. Following partners belong to the project:

**Leibniz Universität Hannover**

- Institute for Structural Analysis (coordination) www.isd.uni-hannover.de
- Institute for Steel Construction (deputy coordination) www.stahlbau.uni-hannover.de
- Franzius-Institute for Hydraulic, Waterways and Coastal Engineering www.fi.uni-hannover.de
- Institute for Building Materials www.baustoff.uni-hannover.de
- Institute of Soil Mechanics, Foundation Engineering and Waterpower Engineering www.igbe.uni-hannover.de

**Fraunhofer-Gesellschaft**

- Institute for Wind Energy and Energy System Technology www.iwes.fraunhofer.de

**REpower Systems AG**
(Cooperation partner)

**Multibrid GmbH**
(Cooperation partner)

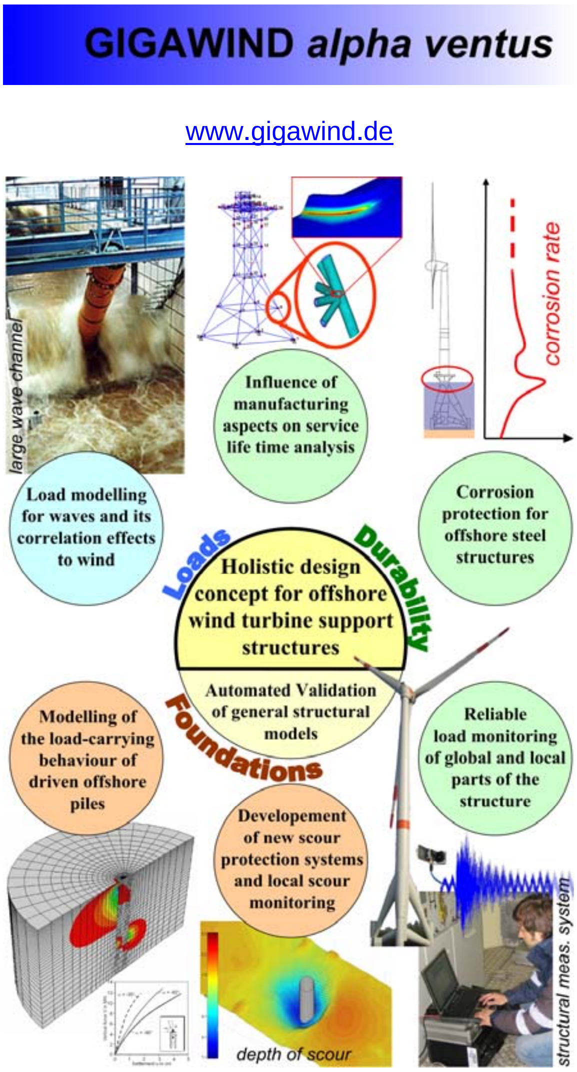

Fig. 5 RAVE project GIGAWIND *alpha ventus*

Homepages for further information:
www.gigawind.de
www.rave-offshore.de
www.alpha-ventus.de