Investigations on Scour Development at Offshore Wind Energy Converters in the German Offshore Test Site *alpha ventus*

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ABSTRACT

With the goal to further develop the share of renewable energies on Germany's electricity supply, thousands of offshore wind energy converters are planned and will be constructed in the North- and Baltic Sea by 2030. As a first step, the first German offshore test site *alpha ventus*, where experience shall be gained and made available for future offshore wind farms, is currently under construction and will be equipped with extensive measuring equipment. Today, one of the problems engineers have do deal with when planning and constructing wind energy converters in deep water are scours which may form around the foundation structures. Within this research project, investigations on scouring phenomena around complex foundation structures like the tripod will be carried out amongst others, by local scour monitoring as well as by physical and numerical modelling. Approaches for a determination of the scour development at the foundation structures shall be enhanced and verified by the unique in-situ measurements from the test site.

1 INTRODUCTION AND RESEARCH BACKGROUND

Due to ambitious climate protection targets, the Federal Republic of Germany promotes erecting offshore wind farms with an overall rated power of 20-35 GW in the North- and Baltic Sea to be completed by 2030, with the goal to cover 15 percent

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of Germany's electricity supply by wind energy alone. With the first German offshore wind farm *alpha ventus*, experience shall be gained and made available for future offshore wind farms. The German Federal Environment Ministry (BMU) has launched and is supporting the research initiative RAVE - Research at alpha ventus - with its overall objective of cost reduction for offshore wind energy deployment in deep water. At the test site *alpha ventus*, located 45 km off the coast of Borkum in the North Sea, twelve offshore wind energy converters (OWEC) with a rated power of 5 MW each shall be installed in water depths of approximately 30 metres, where all loads of wind, turbine and waves have to be carried out into load-bearing ground. The test site will be equipped with extensive measuring equipment in order to support all participating research projects with detailed field data.

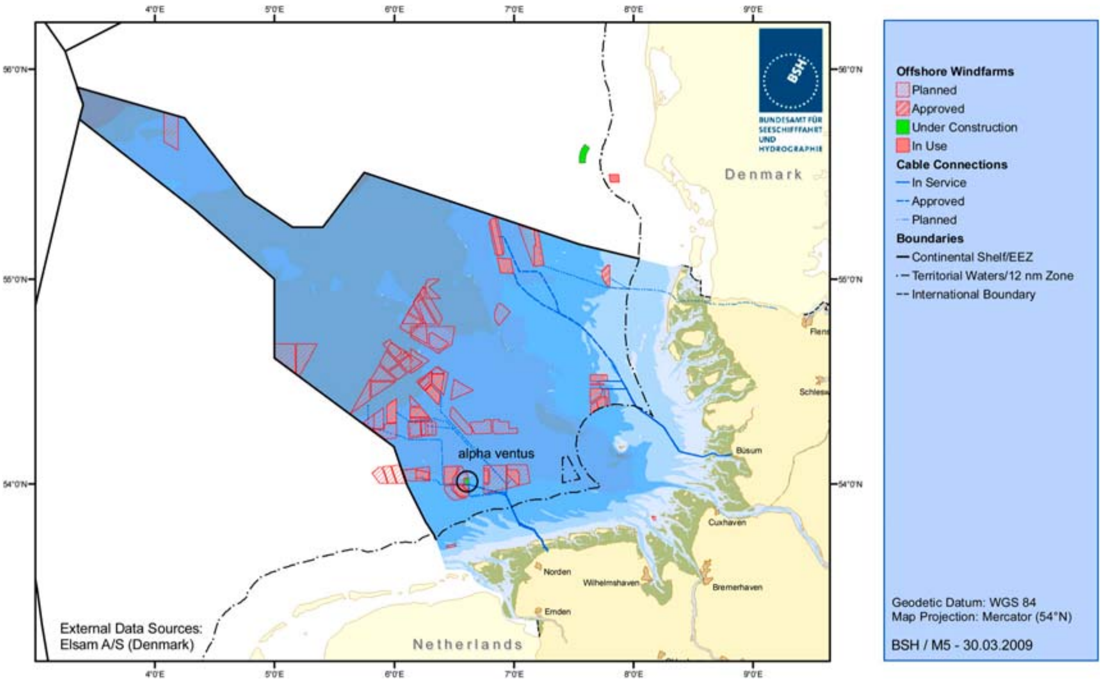

Figure 1. Survey of planned offshore wind farms in the North Sea (BSH, 2009)

One of the research projects within RAVE is GIGAWIND *alpha ventus*, which has been established at the Leibniz University of Hanover mid 2008. It pursues the overall objective to develop a holistic design concept in order to reduce costs for OWEC support structures, i.e. tower, substructure and foundation. GIGAWIND *alpha ventus* contains particular work packages, which are incorporated into the holistic design concept:

- Modelling of wave loads and its correlation 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,

- Local scour monitoring and development of new scour protection systems,
- Modelling of the load-carrying behaviour for driven offshore piles and
- Automated validation of general structural models.

During the three-year project life span, new algorithms, methods and software tools shall be developed and validated by the field data derived from the measuring equipment in the test site, as well as, particularly, from additional laboratory tests.

Engineers planning and constructing wind energy converters in deep water in most cases have to deal with scouring phenomena around the OWEC foundation structures. Within one of the above mentioned work packages, the Franzius-Institute is currently examining scouring phenomena at the OWEC structures in the test site. A general survey of the research activities within this work package as well as first preliminary results are presented in this paper.

2 INVESTIGATIONS ON SCOURING PHENOMENA

2.1 Description and goals of the work package

Regarding OWEC foundation structures it is well known that in most cases, scouring phenomena occur around the foundations, caused by the presence of the structure itself and hence resulting changes in the natural flow regime at the sea bed around and in the near-field of the foundation. The highly-complex interaction between real sea state conditions, tidal or wave-induced currents, the sea bed and the structure leads to effects of vortex formations and turbulences or the occurrence of wave reflection and diffraction, as well as to effects promoting soil liquefaction. All these factors lead to raised near-bottom shear stresses and, thus, an increase of the local sediment mobility and transport rates, which subsequently may lead to scours around the foundation structures.

Due to the problem that the extent and development of scours which may form around complex offshore structure foundations is currently not predictable in detail, OWEC foundations are currently designed on a cost-ineffective but secure-based strategy stemming from oversized structural dimensions. In order to advance a proper engineering design system, the work package therefore predominantly monitors and scientifically interprets the scour development to distinguish between a set of governing parameters and aims to develop adequate techniques for protection and maintenance in order to allow efficient foundation designs in the future.

The methodical examination of the actual scour development contains scour monitoring by analyzing the measured scour depths around the foundation piles and the bed contours in the near-field of the OWEC. These in-situ measurements are especially demanded to calibrate and validate a numerical model that will be developed during the project life span. Further investigations are carried out by means of laboratory tests to study the scouring phenomena in principle for a qualitative verification of the numerical codes used. Here, the foundation structure of the OWEC is modelled on a scale of 1:40 and 1:10 and tested in the wave flume of the Franzius-Institute (WKS) and the Large Wave Flume (GWK), respectively.

2.2 Previous research studies

Numerous investigations have been carried out in the last decades regarding scouring phenomena at foundations for offshore structures, with main focus on comparatively simple structures like vertical cylinders or pile groups. Data have predominantly been obtained from laboratory tests in wave and current flumes or wave basins, see for example Sumer et al. (2002) or Whitehouse (1998), which often led to empirical formulations on spatial and time-dependent scour development. Due to a lack of field data, a validation of the results has rarely been possible. On the whole, the number of investigations on scours caused by waves or a combination of waves and currents is rather limited compared to investigations on scours causes by a unidirectional current. Yet, the outcome of present analyses proposes that for current-only conditions scour depths and extends are much higher compared to scours resulting from waves or an interaction between waves and currents.

2.3 Scour monitoring in the test site

Within the work package, investigations predominantly focus on scouring phenomena at the toe of the OWECs in the test site which are founded on tripod structures. These are manufactured and will be installed by the *areva Multibrid* Company. Due to the complexity of the tripod structure, present approaches being able to calculate the scour development - which have in most cases been developed for single vertical piles or groups of piles - can merely be used as preliminary estimations here.

Within the cooperation RAVE, the scour monitoring at the foundation piles and in the near field of the tripod structure is carried out by the German Federal Maritime and Hydrographic Agency (BSH). Therefore, one of the tripods has been equipped with 19 single beam echo sounders (*Airmar* P66) in the field. Five devices are installed at each pile of the structure and four under the centre tube of the tripod, which are permanently measuring the scour depths around the piles and under the centre structure. This specific local data acquisition programme will be completed by a large-area survey of the sea bed around the field of structures using mutibeam echo sounders. All data will be scientifically evaluated within this work package and then be used for correlation with and verification of the numerical codes. As the field data will be available only later in the project life span and more detailed examinations are needed, laboratory tests are carried out to study the scour phenomena in principle.

2.4 Physical modelling of scours, present work

In the present studies, first investigations on scours and flow patterns at complex structures like the tripod are carried out in the wave flume of the Franzius-Institute (WKS) on a model scale of 1:40, as well as additional investigations on vertical circular piles. These small-scale laboratory tests also serve as a sort of feasibility study for later following experiments in the Large Wave Flume (GWK). For the laboratory tests, a sand bed (moving bed) covering an area of 5.5 m² (which is resulting from a 2.5 m length and a 2.2 m width of the flume) with a bed depth of 40 cm has been installed in the 110 m long wave flume (see Figure 2), in combination with sand traps and a covered pump well. Here, the model structures can be installed in the sand bed by a solid connection to the channel floor. To ensure an almost undisturbed flow in front of the test area, a 12 m long ramp with a slope of 1:30 has been installed. Drainage is used to drain the water in the sand bed when the model is dried up for flattening the bed after a test series.

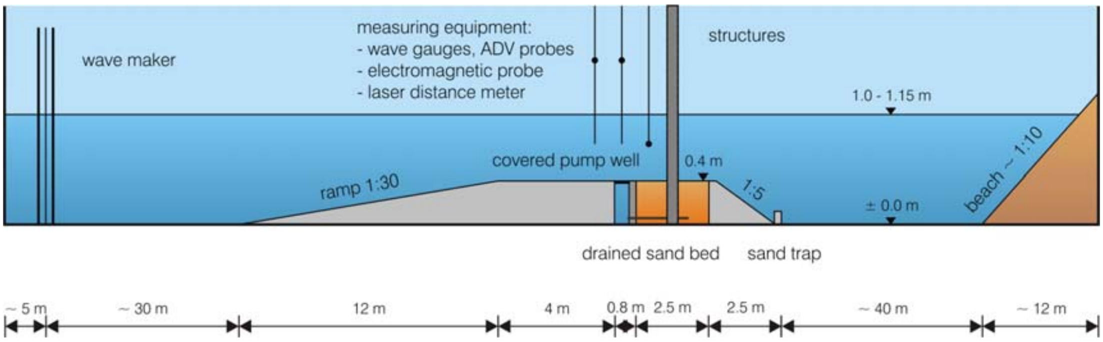

Figure 2. Sketch of the 1:40 physical model setup in the wave flume (no scale)

First investigations in the flume have been carried out for two monopiles with diameters of 150 mm and 50 mm, respectively. Fine sand with a grain size of $d_{50} = 0.15$ mm has been used and is still in use as model sediment for present investigations. Numerous studies of scours caused by waves have been undertaken for a water depth of 60 cm (above the sand bed) and for different wave heights H and H_s and wave periods T and T_p for regular waves and irregular waves (JONSWAP spectra), respectively. For more details, see Table 1. Sea data describing the original wave parameters were taken from field measurements on the German research platform FINO 1, which is located adjacent to the *alpha ventus* test site. For the subsequent investigations on scour development and flow patterns around the tripod under waves, a model has been manufactured out of aluminium on a model scale of 1:40 (see Figure 3) and has been installed pivotable in the flume, being able to modify the rotating direction of the piles relating to the wave direction. Various tests using different experimental configurations of water depth, wave height and wave period have yet been carried out for regular and irregular waves (see Table 1).

Table 1. Boundary conditions for physical model tests in the wave flume

Structure	Water depth d [cm]	Wave height H/H_s [cm]	Wave period T/T_p [s]	Max. number of waves [-]
Monopile, D = 150 mm	60	10 - 25	1.0 - 3.0	5,000 - 9,000
Monopile, D = 50 mm	60	15 - 20	2.0 - 3.0	6,000
Tripod 1:40	60 - 75	10 - 25	1.5 - 3.0	4,000 - 6,000

During all tests, currents, orbital velocities and evolutions of the wave heights are permanently measured using ADV probes, electromagnetic probes (EMS) and wave gauges. The scour development, represented by depth and extent, as well as the near-field of the structure are respectively measured after a defined period of wave cycles by use of a laser distance meter operating under water. Depending on the wave configuration, the measuring interval is 500 to 1,000 wave cycles. The laser device collects the depths either continuously while moved over ground or at defined points, e.g. in a grid or at special points of interest. The positioning of the laser device is undertaken by a controllable positioning platform above the flume being capable to move the device in three axes. This platform is also used for the exact positioning of the ADV probes during the tests. Once a test series is terminated, which is generally the case after 4,000 to 9,000 wave cycles, the water level in the flume is lowered to a level where the sand bed is drained and finally becomes dry. Afterwards the bed is flattened and levelled for the next test series.

Figure 3. Measuring equipment and model setup for the tripod in the wave flume

The thorough analysis of the measured wave-induced scour depths and extends as well as flow distributions is currently in progress. However, first results for the investigations on monopiles already show a good match between measured values and calculated scour developments, whereas calculations have been performed based on empirical formulations from the appropriate literature.

Figure 4 exemplarily shows measured scour depths and bed profiles in the near-field of the structures a) for the monopile with D = 50 mm and b) for the tripod on a model scale of 1:40 after 6,000 wave cycles. Wave conditions leading to these specific scour phenomena are depicted in each subfigure.

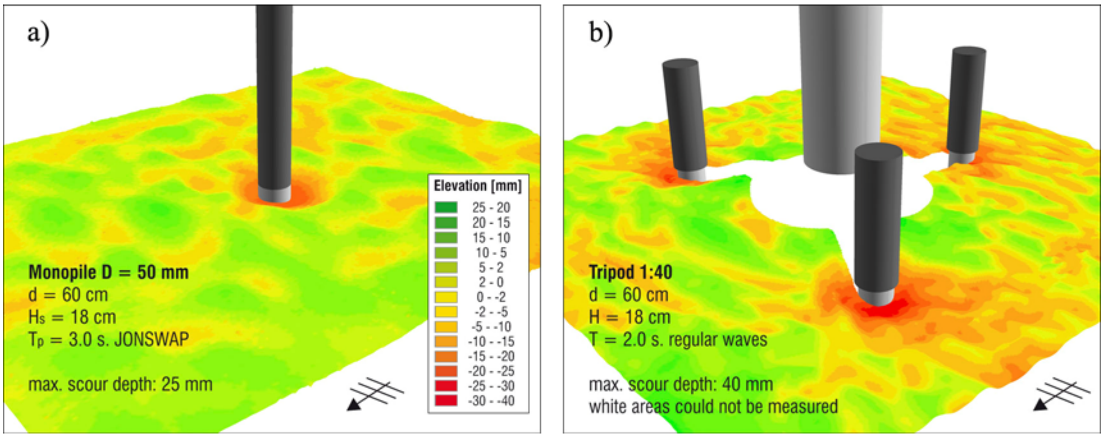

Figure 4. Measured scours for two test series after 6,000 wave cycles: a) Monopile D = 50 mm and b) Tripod 1:40 (represented by tower, piles and pile sleeves). Arrows in the figures depict wave direction in the wave flume.

2.5 Near future investigations

Further investigations in the flume, especially regarding the tripod structure, will be carried out to examine the scour and flow development in detail and to point out significant boundary conditions for the subsequent model tests in the Large Wave Flume (GWK) on a model scale of 1:10. Additional tests will also be performed for monopiles and groups of piles. Furthermore, investigations in the physical model using artificial bottom material with lower densities instead of fine sand will be carried out, as well as investigations on scouring phenomena due to currents and a combination of currents and waves.

3 CONCLUSION

Within our work package, first investigations on scouring phenomena at foundation structures for offshore wind energy converters have been carried out in the physical model. Therefore, a moving bed using fine sand has been installed in the wave flume of the Franzius-Institute. So far, first investigations on monopiles and a manufactured tripod structure on a model scale of 1:40 have been carried out and will be followed by further detailed examinations of scouring phenomena and flow patterns at the structures. Subsequent physical model tests with a tripod structure on a model scale of 1:10 in the Large Wave Flume (GWK) in Hanover are planned. All gained data from the physical models as well as from the unique in-situ measurements from the *alpha ventus* test site shall be used for the verification of our numerical model for scour determination, whose further development has recently started.

AKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the German Federal Environment Ministry (BMU) within the funded project "Ganzheitliches Dimensionierungs-konzept für OWEA-Tragstrukturen hinsichtlich Lasten, Langlebigkeit, Gründung und Gesamtstruktur (GIGAWIND alpha ventus - LUH)" (BMU code 0325032). Project details and cooperation partners can be collected from www.gigawind.de.

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