SUPPORT STRUCTURES OF OWECS IN A WATER DEPTH OF ABOUT 30 M

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ABSTRACT: Against the background of plans for a huge number of offshore wind energy conversion systems (OWECS) in the North and Baltic Sea a group of four institutes at the faculty for civil engineering at the University of Hannover has started a research program at the beginning of this year funded by the German Ministry of Economics and Technology. The purpose of this research program is to improve structural design methods and solutions for support structures of OWECS in respect to safety and economy. Within the research project called GIGAWIND the topics at the Institute for Steel Construction are focused on ultimate limit state, fatigue design and constructional details.

1. INTRODUCTION

The development of the wind energy production to offshore windfarms is the consistent advancement of the wind energy technology with its rapid increase in the past 20 years. The velocities of the wind are more uniform and higher over the sea so that a higher energy yield can be expected. But the effort for construction, maintenance, and grid connection will be significantly higher. On the one hand there are many technical questions for the planning of offshore windfarms to be answered, on the other hand environmental impacts have to be considered. The research program GIGAWIND (www.gigawind.de) at the faculty for civil engineering at the University of Hannover attends to these questions from the technical point of view. The Institute for Fluid Mechanics, the Institute for Steel Construction and the Curt-Risch-Institute for Dynamics, Acoustics, and Measurements, University of Hannover, and the Institute for Soil Mechanics and Foundation Engineering, University of Essen, are the partners in this project which is funded by the Federal Ministry of Economics and Technology of Germany.

The work at the Institute for Steel Construction is embedded in the activities performed by the Institute for Fluid Mechanics on environmental effects (wind and wave loading) and the activities of the Institute for Soil Mechanics on geotechnical problems.

2. REALISED OWEC PROJECTS

The first experiences with OWECS are gained since 1990. At water depths of 5 to 10 m foundations have been fabricated using both, monopiles and gravity foundations. The nominal power of the realised OWECS has been increasing with the development of the onshore wind energy converters. The turbines, which were erected in the year 2000, have a nominal power between 1,5 MW and 2 MW. They have been constructed off shore of Denmark (Middelgrunden), Sweden (Utgrunden) and the UK (Blyth), see Fig. 1. The water at those sites is not very deep. The distance to shore is small compared to sites which are projected in the North and Baltic Sea.

Even if there are no projects realised yet off shore of Germany, there are windparks planned and in the next few years the realisation of some of these projects can be assumed. The planning in the German area of the North Sea refers to water depths of about 30 m and distances to shore up to 50 km. This indicates that the area for which experiences are gained will obviously be left.

3. STEEL IN MARITIME APPLICATIONS

The construction of platforms standing on the seabed are normally built of space trusses with relatively thick walled pipe sections. [4]. For the economic production of this pipes heavy-plates are needed as wide as possible to reduce the number of the pipe sections. The width of this plates are nowadays in the range of 3500 mm to

Projekt		Utgrunden	Blyth	Middelgrunden
Year of realisation		2000	2000	2000
Country		Sweden	UK	Denmark
Manufacturer		ENRON	Vestas	Bonus Energy
Nominal power per OWEC	[MW]	1,5	2	2
Number of blades		3	3	3
Diameter of rotor	[m]	70,5	66	76
Hub height	[m]		58	64
Number		7	2	20
Water depth	[m]	7,0-10	ca. 6	4,0-5
Distance to shore	[km]	8	1	2
Type of foundation		Monopile	Monopile	Gravity foundation

Fig. 1: Realised offshore wind energy projects in 2000

4500 mm; the thickness of the plates between 20 and 90 mm. Normally heavy-plates are utilised in steel grade S355-Offshore. This heavy-plates can be produced either normalised or TM-rolled with thicknesses up to 250 mm resp. 120 mm. In particular the TM-rolled plates can be treated cost-efficient and retain after the welding process beneficial properties concerning the viscosity. Types of steel which are normally used in maritime applications are given in Fig. 2.

The material used in the constructions of maritime applications has to be adapted to the environmental conditions which have to be expected at the sea. Possible low temperatures have to be responded by the respective viscosity of steel at these temperatures. Even if greater plate thicknesses are required, this can be done by using steel grades like the above mentioned TM-rolled steel. With its high values of viscosity the material properties of these steel grades in respect to welding are so good, that preheating of the sections is hardly necessary.

Steel sections

As in other maritime applications, cylindrical sections are suitable for OWECS constructions because of their lower resistance to the water compared to other shapes of cross-sections available. The production of these pipes is possible with wall thicknesses up to 200 mm. Longitudinal welded pipes can be produced without circumferential weldings only with limited diameter and wall thickness, if a higher length has to be reached. Contrary to that, for monopiles of OWECS with the required diameters and wall thicknesses a number of sections with circumferential weldings have to be used.

In order to facilitate the manufacturing of complex joints of space trusses, automated welding procedures have been developed in the last years. These procedures permit the production of such joints with higher precision and velocity (see [2] and [8]).

4. DESIGN AND SAFETY CONCEPTS

The loads of OWECS come mainly from wind and waves. Additionally significant loads can be expected from ice, especially in the Baltic Sea. Like for onshore wind turbines the design refers not only to the ultimate limit state with long return periods (e.g. 50-year wave) but also to fatigue. Alternating stressing due to both, operation of the turbine and wave excitation has to be taken into account (see e.g. [6]).

If the design values of the stresses due to different effects of loading have been determined, the well established assessment methods for ultimate limit state and fatigue design may be applied. The question to answer is, if the probabilistic safety concept, that has been developed for onshore building construction, should be applied to OWECS.

The safety concept for building construction is based on the agreement, that the safety index β has to be at least 3,8 for a return period of 50 years. From this basis the partial safety factors are fixed subject to the distribution of the different impacts (e.g. [1]). With this method the probability of failure per structure and year has a value of 10^{-6} to 10^{-7}. The accepted probability of failure is affected if human life is at risk by failure of the structure, as it is the case for onshore building construction. When the safety concept is applied to OWECS, it has to be considered, that on the one hand the relevant impacts can have different distributions, for example the waves in comparison with the traffic loads for building construction, on the other hand the potential risk for persons is significantly smaller. Schueller [7] points out, that in this case probabilities of failure per structure and year are accepted with values of 10^{-3} to 10^{-4}. From these few points it can be seen, that for an economic design of OWECS the safety concept that is proven for onshore building construction has to be modified to fit the special conditions. This topic is one of those which will be treated within the GIGAWIND project.

Type of steel	Steel grade	Standard	Yield strength ReH [N/mm²] min.
Structural steel	A36	ASTM	250
high-strength normalised structural steel	A 537	ASTM	345
	S355 J2G3	EN 10025	345
	P 355 N	EN 10028-3	345
	50 D	BS 4360 (1986)	345
	A 572	ASTM	380
	55 E	BS 4360 (1986)	430
	P 460 N	EN 10028-3	450
high-strenth, quenched and tempered structural steel	A 678-B	ASTM	415
	55 F	BS 4360 (1986)	430
	S 690 QL1	EN 10137-2	690

Fig. 2: Steel for maritime applications, notations and standards [9]

5. INFLUENCES ON THE STRUCTURAL DESIGN OF OWECS

In principle, OWECS can be designed with different types of foundations. Currently discussed are monopile foundations, gravity foundations, and braced towers which can be realised as space trusses, tripods, or lattice towers. As described above, for the existing offshore wind energy projects gravity foundations and monopile foundations have been used. From the actual investigations of the Institute for Steel Construction significant effects on the structural design of OWECS are presented referring to a monopile foundation as an example of the different types of foundations.

The static system of the monopile is idealised by a spatial beam model. The interaction of soil and structure is realised by linear springs, which are taken into account in the directions of the global axes. The masses of the nacelle and the rotor are represented by a point mass. (see Fig. 3). The influence of the water masses moved with the monopile is considered in the numerical model.

As boundary conditions for the investigated parameters the environmental conditions are matched to the conditions which can be expected for the planned sites for OWECS off shore of Germany. The wind turbine is assumed according to the actual size of OWECS with a nominal power of about 2 MW.

The dynamic behaviour of a construction is significantly identified by the eigenfrequencies. The eigenfrequencies again have an influence on the loads coming from wind and waves because dynamic amplifications can occur, if the eigenfrequencies are in the range of high wave energies or in the range of the excitation frequencies of the operating turbine. The properties of the soil have an clear influence on the eigenfrequencies of monopile structures. For individual projects the characteristic values of the soil have to be determined by soil explorations. To illustrate the dependency, eigenfrequencies calculated for different soil properties are illustrated in Fig. 4. In the upper part of the soil (mud area) the stiffness of the springs is reduced.

In Fig.4 the area is highlighted in which the dynamic soil properties of glacial drift can be expected. Additionally the range of the rotational speed of typical turbines of the mentioned size is marked. In this example the monopile design concept leads to a soft structure for which the 1st eigenfrequency does not differ much from the expected stimulating frequencies. For bigger turbines (3-5MW) lower rotational speeds and probably a higher stiffness of the tower can be expected, so that this problem could be mitigated.

Another important point for the structural design is the usage of the appropriate wave theory for the calculation of the wave forces. In Fig. 5 the application ranges of the different wave theories are illustrated [5]. To give an impression of the misuse of the wave theories, the bending moment at the mudline for a monopile is calculated for the wave situations marked in Fig. 5. The results can be seen in Fig. 6. Especially for wave situations near the breaking wave limit the differences between the wave theories are big and a misuse of the wave theories could lead to an incorrect design.

The required dimensions of the monopile in the worked example with a diameter of 5 m reach the limits of today‘s technical facilities for the installation.

The results for this example illustrate, that monopile foundations will be limited to smaller water depths, if the dynamical behaviour and the maximum loads are taken into account. For a final judgement further investigations are required. This approach is currently improved and adapted to different types of support structures e.g. tripods (see Fig. 7).

6. CONSTRUCTIONAL DETAILS

Although a high level of prefabrication may be assumed for OWECS in order to reduce the time of installation, some site connections have to be arranged. This probably applies for connections between foundation and tower of OWECS. For the installation of platforms for the oil and gas industry often grouted pile-sleeve connections are used to fix the steel structure to the foundation piles (see e.g. [3]). This kind of connections is also used for an existing OWECS (e.g. Utgrunden). The ring flange joint, the typical connection for the sections of onshore wind energy towers, is regularly used in the realised offshore projects.

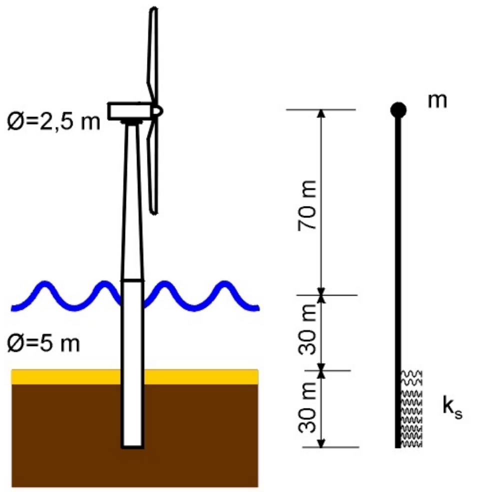

Fig 3: Monopile and model for calculations

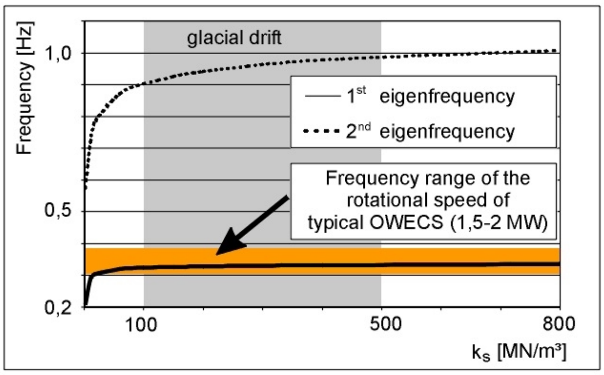

Fig 4: Influence of soil properties on eigenfrequencies of a monopile

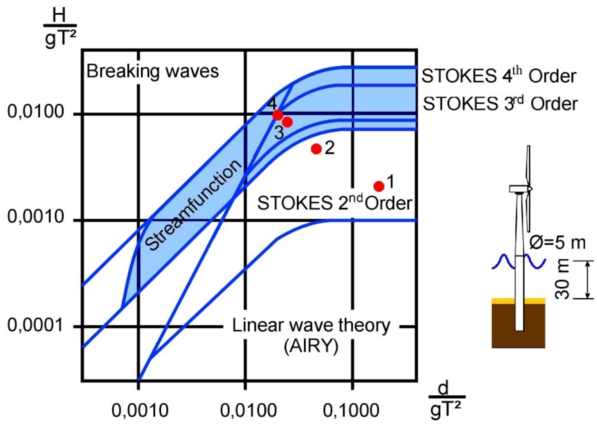

Fig. 5: Application range of wave theories [5] and parameters of exemplary wave situations in Fig. 6

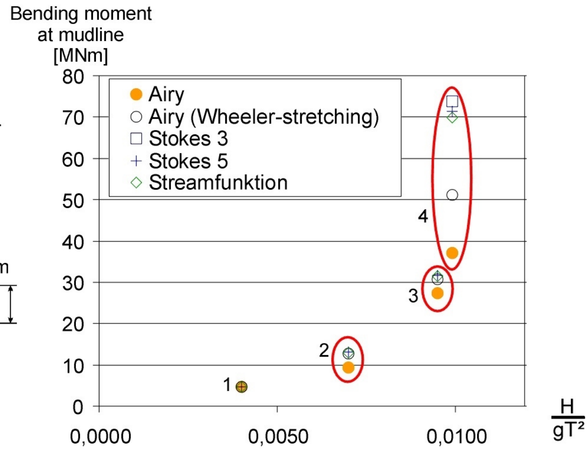

Fig. 6: Bending moments at mudline calculated with the different wave theories

7. SUMMARY

For the development of OWECS the experiences of the oil and gas industry in offshore structures can be seen as a basis. The safety concepts which have been developed for onshore building construction have to be reviewed to match the intended level of both, safety and economics.

As a possible concept a monopile foundation is presented in an example. The results of the first studies permit the conclusion, that design concepts different from monopile foundations will be used for water depths of about 30 m. These other concepts are currently investigated in the GIGAWIND research project in Hannover.

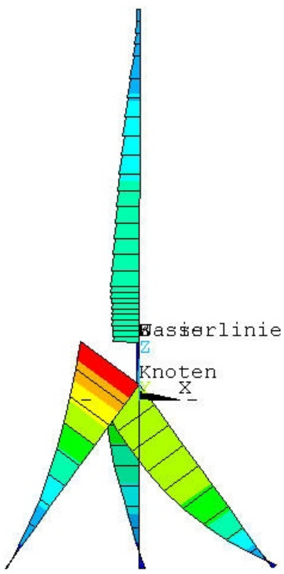

Fig. 7: Bending stresses of a tripod under wind and wave loading

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