ДГКС
Друштво грађевинских
конструктера Србије
ASES
Association of Structural
Engineers of Serbia
SIMPOZIJUM 201
ZLATIBO
15-17. 09. 201

Ana Glišić[1], *Peter Schaumann*[2]

S-26

UPOREDNA ANALIZA OSETLJIVOSTI KONSTRUKCIJA “JACKET” I MONOPIL NA PARAMETRE OPTEREĆENJA

Rezime:

U današnje vreme, dosta pažnje se posvećuje razvoju obnovljivih izvora energije. Energija vetra igra značajnu ulogu u toj oblasti. Iz tog razloga, sve je veće interesovanje za poboljšanjima u mnogim aspektima dizajna vetrogeneratora. Ova studija se bavi ofšor vetrogeneratorima sa aspekta pouzdanosti. Koristeći procenu nesigurnosti, stiče se dublje razumevanje ponašanja konstrukcije. Kako su dominantna opterećenja na noseću konstrukciju vetrogeneratora talasi, proučeno je kako određene talasne karakteristike utiču na konstrukciju. Postupak je odrađen za dva tipa konstrukcija, sa ciljem zaključivanja o prednostima i manama oba tipa.

Ključne reči: energija vetra, analiza osetljivosti, noseća konstrukcija, dejstva talasa

COMPARATIVE ANALYSIS OF JACKET AND MONOPILE STRUCTURES IN SENSITIVITY TO LOAD PARAMETERS

Summary:

Nowadays, much attention is payed to the development of renewable energy resources. Wind energy plays a major role in this issue. That is why there is a growing interest for improving the design process of wind turbines at many aspects. This study deals with offshore wind turbines (OWT) from the reliability aspect. Estimating the uncertainties, a deeper understanding of behavior of the structure is obtained. As waves are the dominant load on OWT support structures, this paper addresses how specific wave characteristics affect the structure. Two structural types of support structures are studied, with the aim to evaluate pros and cons of both.

Keywords: wind energy, sensitivity analysis, support structure, wave load

---

[1] M.Sc., Institute for Steel Construction, Leibniz University Hannover, Germany
[2] Prof. Dr.-Ing., Institute for Steel Construction, Leibniz University Hannover, Germany

1 INTRODUCTION

1.1 GENERAL

In structural engineering practice, much effort has been made to balance between the three most important requirements that should be fulfilled: safety and structural reliability; effects of the structure on the environment; and economic efficiency [1, 2]. Renewable resources of energy make a good compromise regarding all three requirements. For that, and for the reason of growing demands for energy nowadays, there is a growing interest in renewable energy [3]. With respect to Kyoto protocol, many producers turn to renewable energy resources, which leads to a fact that more than 75% of new power capacity installations in EU in the year 2015 are renewable resources. The leading among the new renewable energy resources is wind energy [4].

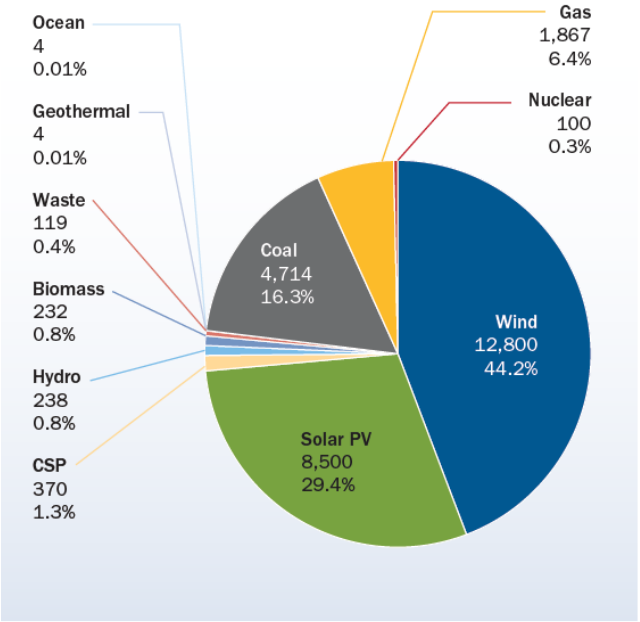


Figure 1 - Share of new energy capacity installations in EU in 2015, source: [4]

In the last decades, even more wind energy is accommodated by moving offshore. That brings up a problem of more complicated and expensive installation, but wide available locations for wind farms and higher electricity output justify the decision to go offshore. Regarding the supporting structures of offshore wind turbines (OWT), monopile is the most commonly used structure in shallow and medium water depths (0-40m), due to relatively easy installation and simple design. For higher water depths (20-50m), jacket support structures are employed due to higher stiffness, as well as smaller surface facing the wave movement compared to monopiles [5].

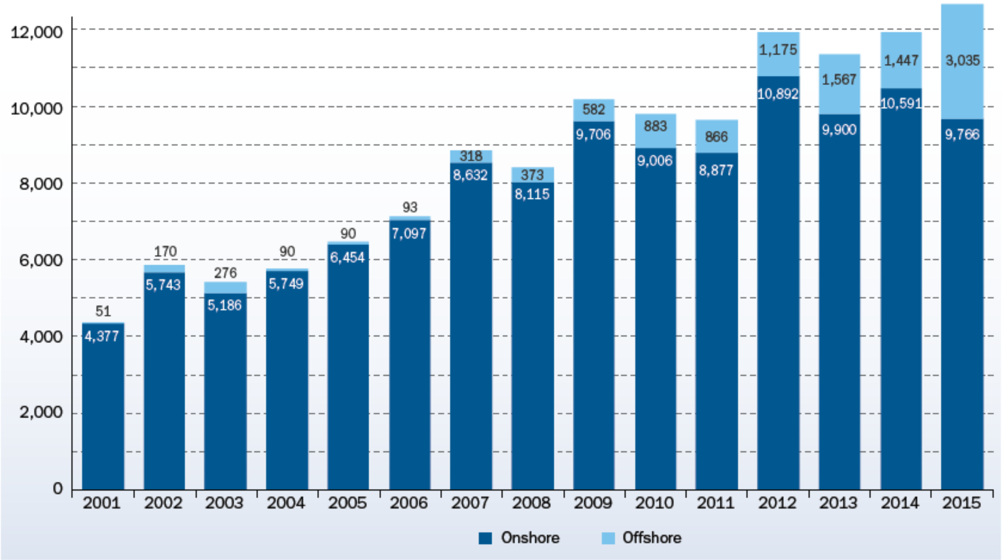


Figure 2 – Growing share of offshore WT installations from year 2001 to 2015, source: [4]

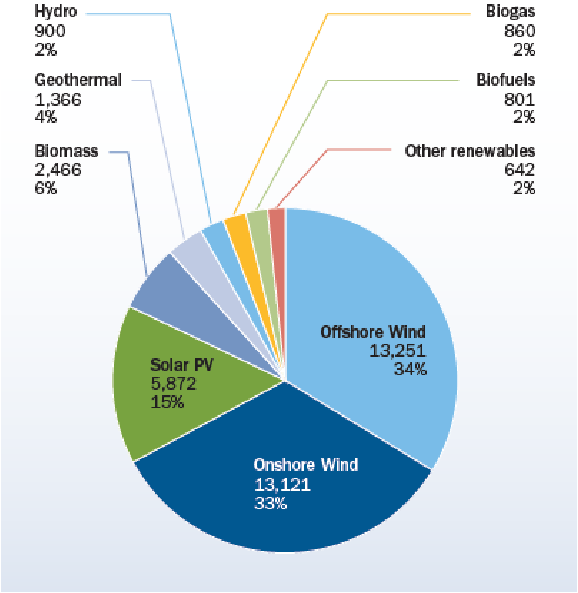


Figure 3 – Renewable energy investments in EU in year 2015 (€ million), source: [4]

1.2 TYPES OF OFFSHORE WINDENERGY SUPPORT STRUCTURES

In the design process of OWT support structures, one of the most important design driving criteria is fatigue. Damage caused by fatigue is accumulated during the structural lifetime through cyclic stresses caused by wind and wave loads [9]. The dominant load on the OWT support structure is the wave load, as it is submerged at most of its height, while the wind turbine tower is mostly affected by the wind. In this paper, the focus is on the wave loads, as only the support substructures are studied.

During the numerical modelling in most of the software packages, sea state is modelled as a superposition of a number of regular waves in order to achieve a very realistic model. This way formed sea state affects the structure and causes stresses that lead to fatigue damage. However, it is not obvious how every single waveform from the sea state contribute to the caused stress. In order to perceive how sensitive are the structures to different wave characteristics (wavelengths, frequencies), sea state is separated into single waves, and each of them is applied to the structure. Stress contribution of every wave is noted and compared with others. Finally, it is stated which of the observed structural types is more sensitive to specific wave characteristics.

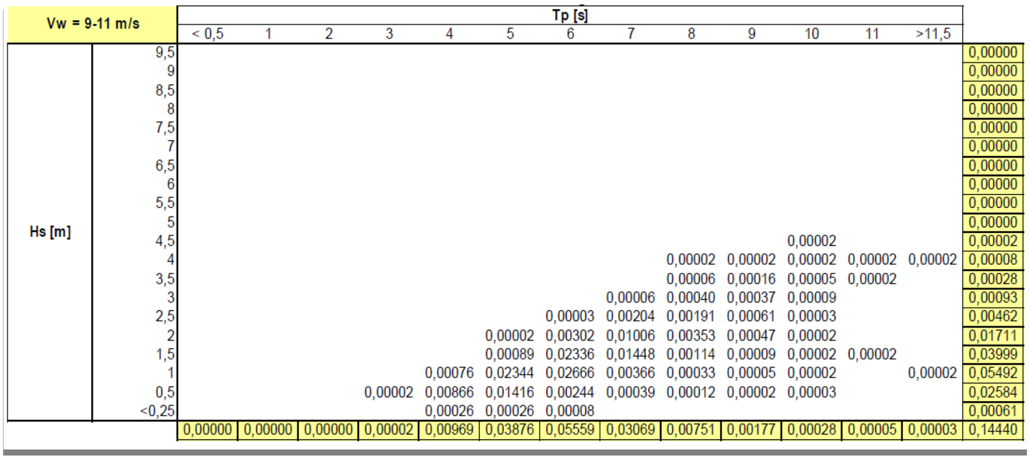
Figure 4 – (a) jacket (b) monopile OWT support structure, [source: DNV GL, 2016]

2 BASIS OF INVESTIGATIONS

2.1 LOAD PARAMETERS

With the aim to study the influences of single waves on the structure and at the same time to stay in a domain close to reality, used wave characteristics are taken from “EU UpWind” project (SES6 No 019945 UPWIND) named “UpWind Design Basis” [6]. It contains 3D scatter diagrams of wave parameters for different wind speeds for two offshore sites in the Dutch North Sea. For purposes of this study, wave parameters from scatter diagrams for K13 Deep Water Site and for the most frequent wind speed of 9-11m/s are used.

Table 1 - Scatter diagram of wave heights and periods for wind speed of 10m/s, source: [6]



Vw = 9-11 m/s		Tp [s]													
		< 0,5	1	2	3	4	5	6	7	8	9	10	11	>11,5	
Hs [m]	9,5														0,00000
	9														0,00000
	8,5														0,00000
	8														0,00000
	7,5														0,00000
	7														0,00000
	6,5														0,00000
	6														0,00000
	5,5														0,00000
	5														0,00000
	4,5											0,00002			0,00002
	4									0,00002	0,00002	0,00002	0,00002	0,00002	0,00008
	3,5									0,00006	0,00016	0,00005	0,00002		0,00028
	3								0,00006	0,00040	0,00037	0,00009			0,00093
	2,5							0,00003	0,00204	0,00191	0,00061	0,00003			0,00462
	2						0,00002	0,00302	0,01006	0,00353	0,00047	0,00002			0,01711
	1,5						0,00089	0,02336	0,01448	0,00114	0,00009	0,00002	0,00002		0,03999
	1					0,00076	0,02344	0,02666	0,00366	0,00033	0,00005	0,00002		0,00002	0,05492
	0,5				0,00002	0,00866	0,01416	0,00244	0,00039	0,00012	0,00002	0,00003			0,02584
	<0,25					0,00026	0,00026	0,00008							0,00061
		0,00000	0,00000	0,00000	0,00002	0,00969	0,03876	0,05559	0,03069	0,00751	0,00177	0,00028	0,00005	0,00003	0,14440

This 2D scatter is only a part of a complete scatter, which includes wind speed as a third dimension. That is why the summarized share of all possible waves is not 1 but 0.14440. For better understanding of this scatter, it is normalized for the case of the given wind speed and plotted as discrete data sequence in Figure 5. Hence, it is clearly visible which of the wave characteristics are the most frequent ones. Each of those single waves is applied to both monopile and jacket OWT support structures. Structures are numerically modelled in FE software package Poseidon, specialized for wave-induced loads [10]. For both structures, numerical simulations of every single waveform from the Table 1 with a duration of 150s are carried out using the FE Poseidon’s Wave Simulator Tool. The stress results are recorded by the set of sensors positioned on the corresponding spots on the structures with the corresponding angles.

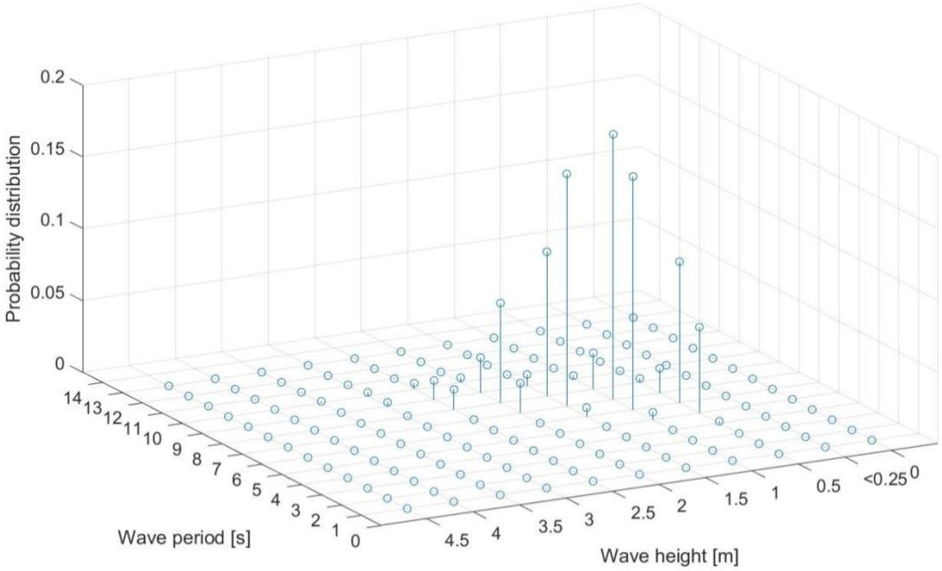


Figure 5 – Probability distribution of wave parameters (discrete data)

2.2 NUMERICAL MODELS

2.2.1 Jacket structure

The jacket structure is designed for a site in the North Sea with water depth of 50m [9]. Chords and braces are steel tubes with diameters of 1.2m and 0.8m respectively. It is supposed to be connected to the soil by four piles, which is modelled as clamped legs at the soil level. Above the soil level, the structure is submerged at a height of 50m. It continues 21.15m above the still water level, where it would be connected with the wind turbine tower by a transition piece [5].

Every wave loading from Table 1 is applied in the direction of 45º with respect to the local coordinate system, which is parallel to the diagonal of the jacket’s footprint. The chosen sensor measures the stress in the structure in the same direction at the bottom of the structure (mudline) at the jacket’s leg that is directly affected by the wave, and thus the mostly stressed one.

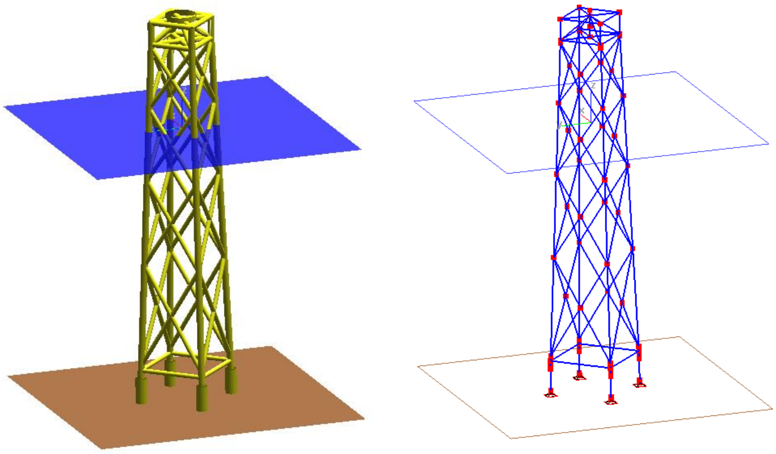


Figure 6 – Jacket (a) 3D numerical model, (b) beam model

2.1.2 Monopile structure

The monopile structure has a relatively simple design. It is made of a cylindrical steel tube with changing cross section diameter and thickness. At the soil level, it continues down into the seabed with length of 35m. The soil is modelled with springs, whose stiffness it obtained using the p-y method [7, 8]. At its bottom, it has an 8m diameter. Above the soil level, it is submerged at height of 40m, where it has a cone part, which reduces the cross section diameter to 6m. It continues 18m above the still water level, where it would be connected with the wind turbine tower that it is supporting, through transition piece [5].

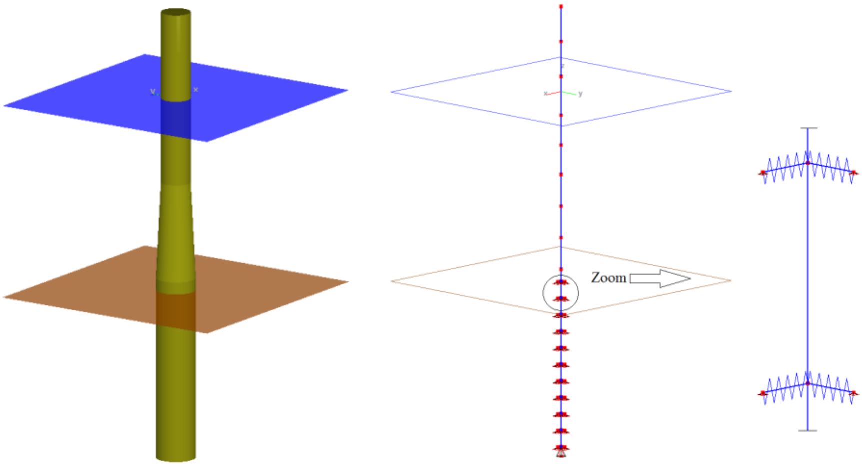


Figure 7 – Monopile (a) 3D numerical model, (b) beam model with spring detail

Every wave loading from Table 1 is applied in the direction of 0º with respect to the local coordinate system. The chosen sensor measures the stress in the structure in the same direction at the bottom of the structure.

After all the simulations have been carried out, the stress results are plotted and compared for different wave parameters for both reference structures. In Figure 8 it is shown how different wave heights influence the stress results, while the wave period is fixed to 10s. Only some of the simulations are shown.

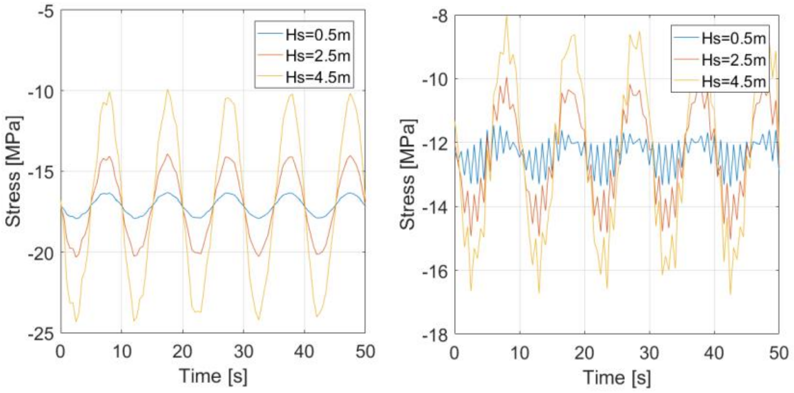


Figure 8 – Stress results for (a) monopile (b) jacket structure for different wave heights

It can be seen that both of the structures stand higher stresses with the increase of wave height, as expected. On the Figure 9, the nominal values of stress amplitudes for different wave heights for both structures are plotted. It is demonstrated that both of dependencies are nearly linear, as the simulations are carried out in the domain of linear deformations without extreme loads. However, the dependency line for monopile is steeper, which shows that monopiles are more sensitive to wave heights compared to jacket structures, due to their geometry.

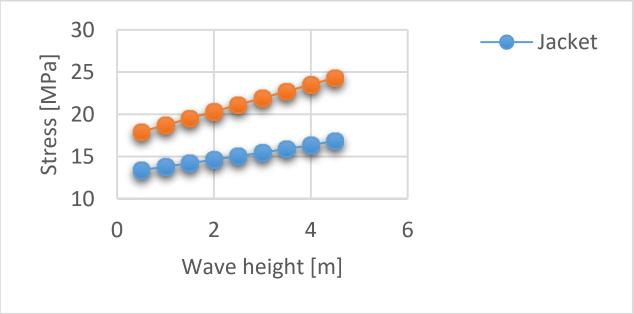


Figure 9 – Stress – wave height dependency for monopile and jacket structure

In Figure 10 it is shown how different wave periods influence the stress results, while the wave height is fixed to 0.5m. Only some of the simulations are shown.

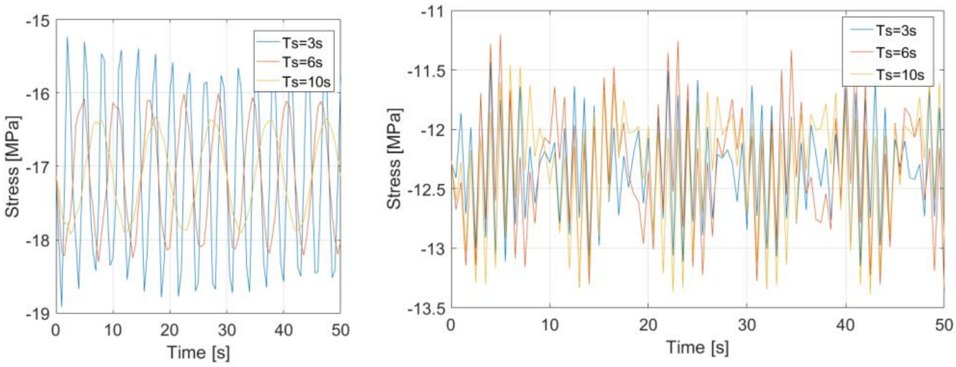


Figure 10 – Stress results for (a) monopile (b) jacket structure for different wave periods

On the Figure 11, the nominal values of stress amplitudes for different wave periods for both structures are plotted. It is demonstrated that the monopile structure has a slight increase of stresses with decrease of wave periods (increase of wave frequency). The gradient of stress increase is higher for lower wave periods (under 4s), as the wave frequencies get closer to the first eigenfrequency of the structure. The jacket structure is nearly insensitive to the examined wave periods. The reason for that is, besides its higher stiffness at footprint, also a higher first eigenfrequency compared to the monopile.

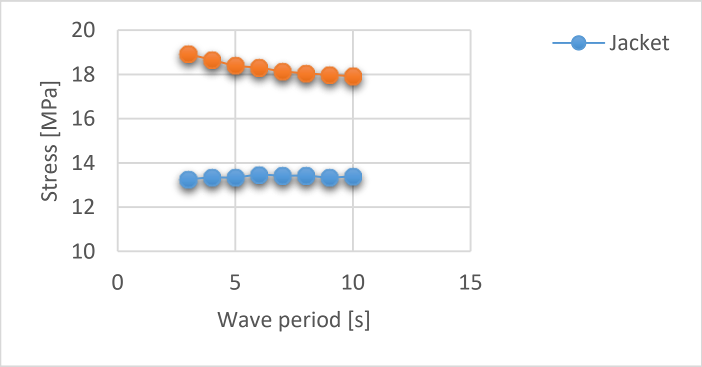


Figure 11 – Stress – wave period dependency for monopile and jacket structure

3 CONCLUSIONS

The obtained results show that the jacket structure is in general less sensitive to wave load parameters compared to the monopile structure. Due to its complex geometry and higher stiffness, the jacket structure shows low linear sensitivity to the increase of wave height and nearly no sensitivity to change of wave period, while monopile shows steeper linear sensitivity to wave heights and sensitivity to decrease of wave periods. This research is focused on one, most frequent wind speed. For a complete overview, other wind speeds as well as the extreme load cases must be taken into consideration. This work is part of a research that deals with all reference wind speeds for the given offshore site, and take the accumulated fatigue damages from stress cycles into consideration. A reasonable choice between the reference structures has to be based on all design load cases and design driving criteria on one hand as well as overall cost efficiency for fabrication, transportation and installation of the structures on the other hand.

REFERENCES

[1] Faber M. H.: *Risk and Safety in Civil Engineering*, Lecture notes, Swiss Federal Institute of Technology, 2007, Zurich, Switzerland

[2] Schaumann P., Bechtel A., et al: *Sustainability Assessment of Steel Constructions for Offshore Wind Turbines*, in: Pehlken A., Solsbach A., Stenzel W. (Eds.): *Sustainable Material Life Cycles - Is Wind Energy Really Sustainable?*, Hanse Studies Vol.9, pp. 25 - 34, BIS, 2014, Oldenburg

[3] Van Der Tempel J.: *Design of Support Structures for Offshore Wind Turbines*, PhD Thesis, Delft University of Technology, 2006, Delft

[4] The European Wind Energy Association: *Wind in power: 2015 European statistics*, Annual statistics, 2016

[5] DNV-OS-J101: *Design of offshore wind turbine structures*, DNV Offshore Standard, 2014

[6] Fischer T., de Vries W., Schmidt B: *Upwind Design Basis (WP4: Offshore Foundations and Support Structures)*, Endowed Chair of Wind Energy (SWE) at the Institute of Aircraft Design, University Stuttgart, 2010, Stuttgart

[7] Pando M. A.: *Analyses of Lateral Loaded Piles with P-Y Curves – Observation on the Effect of Pile Flexural Stiffness and Cycling Loading*, NCDOT 7th Geo^3 T^2, 2013, Raleigh, NC

[8] Achmus M., Abdel-Rahman K.: *Design of Monopile Foundations for Offshore Wind Energy Plants*, 11th ICSGE, 2005, Cairo

[9] Kelma S., Schaumann P.: *Probabilistic Fatigue Analysis of Jacket Support Structures for Offshore Wind Turbines Exemplified on Tubular Joints*, Proceedings of the 12th Deep Sea Offshore Wind R&D Conference, EERA DeepWind’2015, Trondheim

[10] Böker C.: *Load simulation and Local Dynamics of Support Structures for Offshore Wind Turbines*, PhD Thesis, Leibniz University Hannover, 2010, Hanover