

Project title	ISEAWIND – Innovative Structural Engineering Approaches for design of off-shore WIND power plant foundations
Project number	TG4-21
Organisation	Chalmers University of Technology, Architecture and Civil Engineering
Project leader	Rasmus Rempling
Other participants	Alexandre Mathern (Industrial PhD student)
Report for	2014-10-01 – 2018-09-30
Participating companies	NCC AB

This report is the final report of the project TG4-21. The project has been carried out as a collaboration project between industry and university. The main results includes several publications and presentations as well as an examination of a Technical Licentiate.

Project description

More than 65% of the power production comes from fossil fuel. At the same time the power consumption will increase with 60% year 2030. This is of course worrying due to the environmental problems associated with burning of fossil fuels. There is a will in society to create change by moving to renewable energy sources; where wind plays an important part as it is verified commercially.

However, the construction industry has identified a need for increasing the body of knowledge with regard to the design and planning of off-shore wind turbine structures (tower-foundation-ground).

The aim is to study the dynamic effects of the complex loading situation of off-shore wind-power plant foundations. The situation is relevant due to the growing concern of design aspects in the engineering community and a broad levelling up of the body of knowledge is essential.

This project has resulted in a Technical Licentiate with unique knowledge in the design, planning and response of off-shore wind power plant structures with focus on the interaction tower-foundation-ground; an essential expertise for the Swedish market of renewable energy sources.

ISEAWIND incorporates four studies, which are all connected to a virtual case-study:

- A. Study of the engineering aspects of off-shore foundations in Sweden. This will be approached by a literature study and case-study of the design and execution of an off-shore wind-farm (e.g. Bockstigen).
- B. Study of the varying load transfer, tower-foundation-ground, for different load and ground situations, as well as uncracked/cracked concrete. With this study we can predict specific details in the structure that need more attention (Study C). This will be approached by an explicit numerical model in which we can vary the load situation and study the load transition of the structure.
- C. Study specific details that are prone to fatigue, e.g. anchor-ring (bolts and concrete), reinforcement and tension rods. This will be approached by implicit numerical models of the specific details.
- D. Optional study outside program time frame: Study of the potential of doing continuous structural health checks by updating numerical analyses continuously with live-data. This will be approached by using live-data of a case-study and feed the loading/deformation history to the models of study B and C.

	2015		2016				2017				2018			
Studies	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
A														
B														
C														
D														

Results

During the reporting period, several studies have been performed.

The first study was an investigation of the engineering challenges for offshore foundations in the Baltic sea. The study includes a survey and combination of data collected from official databases (International and European). The collected data, shows many similarities between Nordic sea and the Baltic sea. However, in order to complete the study, data of geotechnical conditions in the Baltic Sea was needed. The aim of the study has not been fully reached due to this lack of data. The core of the work has been performed at Leibniz University where a joint publication on foundations for offshore wind turbines has been finished and submitted to a scientific journal.

Study on design of three dimensional concrete structures by strut-and-tie models is finished and the results have been presented at a conference. An enhanced and generic three-dimensional strut and tie model has been developed in this work for the design of reinforced concrete foundations and validated with experimental results from tests on four-pile caps found in the literature. The model effectively predicts the ultimate capacity. The consistent three-dimensional geometrical definition proposed for the elements of the strut and tie model ensures an accurate verification at the nodal zones. The strength criterion for bottle shaped struts integrated in the model allows to take into account favourable confinement effects. An automatic iterative procedure has also been successfully applied to adjust the position of the members and to refine the dimensions of the nodal zones under the column with respect to the strength of concrete subjected to a triaxial state of stress.

Numerical FE-study of some experiments performed of load transfer mechanisms in collaboration with Leibniz University. During the spring 2017 and 2018, Alexandre Mathern was a visiting researcher at Leibniz University in Hannover, Germany. FE analyses have been performed on the tests conducted at Leibniz. The aim is to improve the connection between concrete and ductile cast-iron connection for a novel hybrid jacket substructure for offshore wind turbines made of high-strength concrete pipes and connections in ductile cast iron. The results of this study are almost ready for submission.

Several other studies are student work performed at the division of structural engineering, the division of construction management and the division of Geotechnics. The focuses of the MSc theses have been on risk management and structural design. The reports are listed in publications.

The optional study of continuous structural health monitoring has been started and will be continued outside the program and the project.

Fulfilment of SWPTC's goals

Research program criteria	ISEAWIND
Active industry	NCC is active with an industrial PhD and a technical supervisor
Cooperation with other research groups	In the different studies there have been collaboration with research groups at Leibniz University and at Chalmers university.
Researchers are active in international research	Collaboration on experiments and numerical analyses with Leibniz University in Hannover has resulted in joint publications.
Swedish development and production of components	Core purpose of ISEAWIND
Excellent research with the purpose to find optimal wind turbines and its components.	The research team is part of the best research group on numerical modelling of reinforced concrete and has a numerous PhD theses on the subject. The experience of this group will be very valuable for the numerical studies. In studies (Study A and D) the project team will establish international and national collaboration that has documented research excellence.
A well-established research to determine the remaining life of the wind power plant.	ISEAWIND will increase the national body of knowledge for design of wind turbine supporting structures.

Deviations from project plan

There are some deviations from project plan. Study A took a slight turn due to the lack of data. Instead a joint publication with an international University has been submitted for publication. It was found to difficult to treat study B and C separately. Therefore, it was decided to start study C earlier than planned.

Publications

Mathern, A., von der Haar, C., Marx, S. *Concrete structures for offshore wind turbines: current status, challenges, and future trends* Submitted to Renewable & Sustainable Energy Reviews.

Isaksson, J., Tenenbaum, D. (2018) *The effect of soil-structure interaction on the behaviour of onshore wind turbines with a gravity-based foundation*. Master's Thesis in Structural Engineering and Building Technology / Master's thesis in Sound and Vibration, 2018.

Jonsson, E., Tunander, E. (2018) *Alternative evaluation methods for on-shore wind turbines*. Master's Thesis in Infrastructure and Environmental Engineering, 2018.

Wiklund, E. (2018) *Comparison of structural analysis methods for reinforced concrete deep beams*. Master's Thesis in Structural Engineering and Building Technology, 2018.

Mathern A, Chantelot G, Svahn P-O, et al. (2017) *Enhanced strut-and-tie model for reinforced concrete pile caps*. In: International Association for Bridge and Structural Engineering, 39th IABSE Symposium – Engineering the Future, September 21-23, 2017. Vancouver, Canada: IABSE, 2017, pp. 607–614.

Ahlström, M and Holmqvist, C (2017) *Assessment and comparative study of design method for onshore wind power plant foundations*. Master's Thesis in the Master's Programme Structural Engineering and Building Technology, 2017

Ahlgren, E. and Grudic, E. (2017) *Risk Management in Offshore Wind Farm Development*. Göteborg : Chalmers University of Technology (Examensarbete - Institutionen för bygg- och miljöteknik, Chalmers tekniska högskola, no: BOMX02-17-61).

Koch, C., Baluku J., Habakurama, I. I., Mathern, A. (2017) *The challenges of building inner sea offshore wind farms - the cases of Lillgrund and Anholt*, in 9th Nordic Conference on Construction Economics and Organization, June 13-14, 2017, Göteborg, Sweden.

Faruk, Ö.; Mutungi, H. (2016) *Assessment of simulation codes for offshore wind turbine foundations* Master's Thesis in the Master's Programme Structural Engineering and Building Technology, 2016

Habakurama, I., Baluku, J. (2016) *The challenges in installation of offshore wind farms, A case of Lillgrund and Anholt wind farms*. Göteborg: Chalmers University of Technology (Examensarbete - Institutionen för bygg- och miljöteknik, Chalmers tekniska högskola, nr: BOMX02-16-104).

Mathern, A.; Rempling, R. (2015) *Innovative Structural Engineering Approaches for the design of offshore WIND turbine support structures*, Offshore Wind R&D Conference 2015, Research at Alpha Ventus, 13-15 Oct., Bremerhaven, Germany.

Mathern, A.; Rempling, R. (2015) *ISEAWIND - Innovative Structural Engineering Approaches for the design of offshore WIND turbine foundations*, Vindkraftsforskning i fokus konferens 2015, 6-7 October, Uppsala.

External activities

- Presentation at the SWPTC annual conference 14 June 2018
- Research visits at Institute of Concrete Construction at Leibniz University Hannover, January 2018 and June 2018 (2 weeks) to participate in HyConCast experiments

- Presentation at Structural Engineering Day at Chalmers, 24 October 2017
- Attending and presenting at 39th IABSE Symposium, 19-23 Sept. 2017, in Vancouver.
- Presentation at NCC PhD seminar 30 August 2017
- Presentation at the SWPTC annual conference 8 June 2017
- Participated to OFFSHORE WIND ENERGY 6-7 June 2017, in London
- Presentation of project at Leibniz University Hannover
- Research visit at Institute of Concrete Construction at Leibniz University Hannover, March – May 2017 (3 months), presentation of project and plans with visit
- Presentation on Set-Based design at CIR-dagen, January 2017
- Participated to 19th Congress of IABSE, 21-23 Sept. 2016, in Stockholm.
- Presentation of project for Vattenfall June 2016
- Presentation of project for Blekinge Offshore, May 2016
- Participated and presented in course Design of Offshore Wind Turbines (NTNU), in Spring 2016, in Trondheim, Norway.
- Presentation at SWPTC monthly meeting, 4 April 2016
- Presentation of project at HISTWIN+ Workshop, 2 December 2015
- Presentation at NCC Doktorandträff, 24-25 Nov. 2015, in Gothenburg.
- Participated and presented at the conference Maritima Klustret – Västra Götaland, 4 Nov 2015, in Gothenburg.
- Participated and presented at Structural Engineering seminar, 27 Oct 2015, in Gothenburg.
- Participated and presented at the conference RAVE Offshore Wind R&D, 13-15 Oct. 2015, in Bremerhaven, Germany
- Participated and presented at the conference Vindkraftsforskning i fokus, 6-7 Oct. 2015, in Uppsala.
- Presentation of project at SWPTC internal conference, 16 September 2015