Third Semester and Master's Thesis Ideas 2018

M.Sc. in Civil and Structural Engineering

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Edited by Thomas Lykke Andersen and Johan Clausen

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August 2018

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M.Sc. in Civil and Structural Engineering: Third Semester and Master Projects Ideas

The following pages contain a list of project ideas proposed by the scientific staff at the Department of Civil Engineering, Aalborg University, and a number of companies. The project ideas in this catalogue may form the basis for long and short master projects as well as regular 3rd semester projects at the M.Sc. programme in Civil and Structural Engineering. On some of the project proposals it is stated which type of project the proposal is suitable for. For the rest of the proposals this question should be discussed with the potential supervisor.

Each project description provides a brief overview of the purpose as well as the main activities. Further, a weighting between theoretical analysis, experimental work and computer modelling has been proposed. Usually, this weighting can be changed slightly in accordance with the wishes of the students. The contact persons listed will usually act as supervisors. Questions regarding details about each proposed project should be directed at the contact persons. The contact details can be found via a person search on the university home page. Furthermore, other ideas for projects may be discussed with a potential supervisor. In this aspect the proposals in this catalogue can reveal the expertises and research areas of the different supervisors.

Many private engineering companies have a homepage on which they state that they would like to collaborate with students on a master project. Find out more on the individual company home pages.

The preferred group size for master projects is two to three students. In the interest of students as well as supervisors, single-student projects are generally not recommended. In a short third semester project the recommended minimum group size is three students, some supervisors may require more.

At the third master semester, the students have the option of doing a company stay. It is important to realise that this is not a traditional internship, but rather a third semester project carried out in cooperation with a private or public company. An example of a successful subject for such a company stay is also given in the last page of the present catalogue. The student is not allowed to receive a salary from the company if the student also receives SU.

A final remark about master projects: A signed thesis contract must be handed to your study secretary at latest October 1st for long master projects and March 1st for short master projects. The contract must contain information about the project, in particular regarding the educational goals. These must be defined in accordance with the Master Curriculum (danish: Studieordningen) for the M.Sc. Programme in Civil and Structural Engineering at the School of Engineering and Science, Aalborg University. The curriculum can be found at the Study Board of Civil Engineering homepage at http://www.ses.aau.dk/digitalAssets/361/361362_2017-10-13-msc-bygge--og-anlaegskonstruktion_ver2.pdf. The thesis contract template is the online

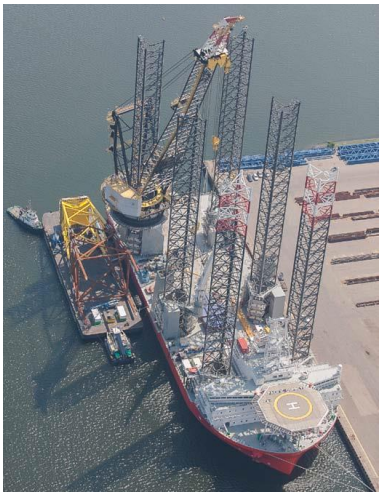
form available at the homepage of the School of Engineering and Science at http://www.ses.aau.dk/til-studerende-ansatte/blanketter-regler/ansoegningsskemaer-blanketter/thesis-contract/. The delivery date for the project report will be set by the Study Board. It is usually around June 8 for Master theses. For third semester projects, the thesis contract is not needed.

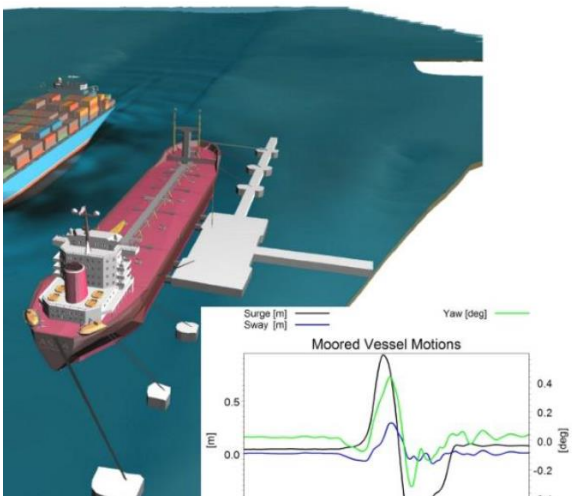
Aalborg, April 12, 2018 Thomas Lykke Andersen and Johan Clausen

Mooring behaviour of vessels in ports

Purpose: The purpose is to make use of a mooring analysis tool within the MIKE 21 MA suite and assess the suitability of the existing design guidelines in PIANC on allowable wave disturbance for assessment of downtime in ports.

A newly featured tool being available in the MIKE21 software toolbox from DHI is supposed to be used/ validated in combination with e.g. physical model tests and/or state of art knowledge for the evaluation of moored vessel response in ports. The tool can be coupled with a Boussinesq model to simulate the floating behaviour of moored vessels in a port. The most used guidelines on "allowable" wave disturbance in ports are relatively primitive and the present project should investigate alternative and more sophisticated methods.





Main activities: The project will contribute to the on-going research and development on the subject and thus the following activities can be included:

- Combined numerical modelling of wave disturbance and floating behaviour of moored ships in a port
- Validation of MIKE 21 MA suite for modelling of moored ship movements

Contact persons: Jørgen Harck Nørgaard, Thomas Lykke Andersen

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

Wave loads on concrete caisson during installation

Purpose: The purpose is to estimate the wave loads on a concrete caisson during installation where it is filled with water and before ballast material is installed. Under such situation there will be wave induced pressure on also the inner walls. COWI has estimated that omission of these pressures may lead to a significant contribution to the overall fatigue loads on the caisson walls. This project aims at studying the wave induced loads on the wall of the caisson (numerically and/or through model tests) and is carried out in close cooperation with COWI and actual projects.

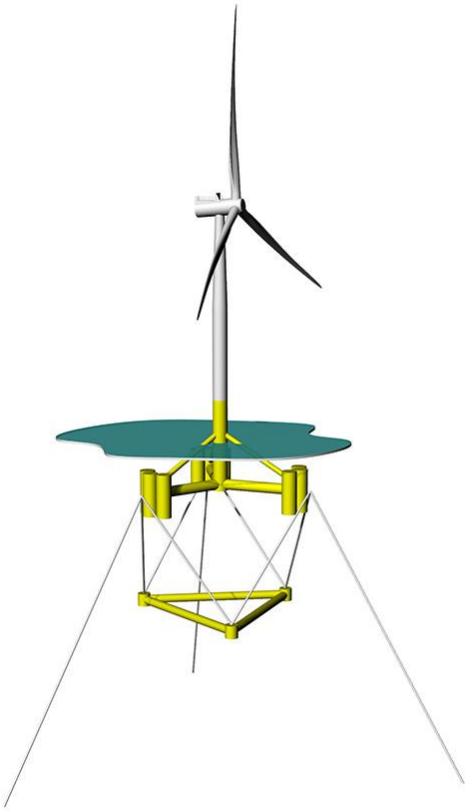
Main activities: The aim is to develop a simplified model for the loads on the caisson walls before the caisson is ballasted. In order to develop and calibrate such model CFD modelling and/or experimental model tests should be carried out.

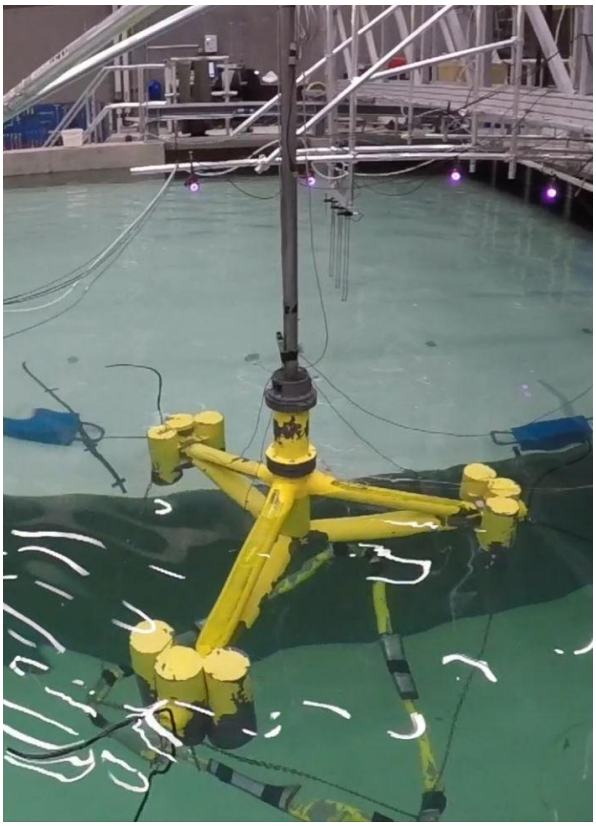
Contact persons: Thomas Lykke Andersen, Morten M. Kramer

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Optimization of floating offshore wind turbines

Purpose: Wind turbines are placed in deeper and deeper waters and thus bottom fixed structures will not continue to be the cheapest alternative. Several different design are begin developed globally, and some have already been deployed. One of the most promising designs is the TetraSpar, developed by former Siemens Wind Power CTO Henrik Stiesdal. The loads and responses of floating wind turbine are still associated with some uncertainty and the purpose of the project is to quantify and reduce this uncertainty by application of advanced methods (numerical and/or experimental). The work can be focus in any combination of the following topics: hydrodynamics, moorings, anchors, power cables, installation, and structural design.





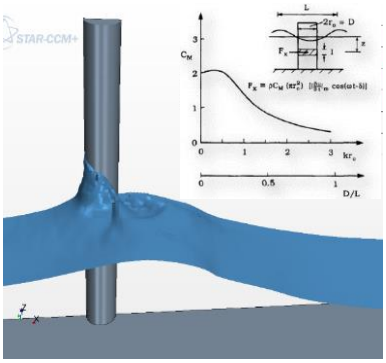
Main activities: Depending on topics chosen the main activities will vary. Numerical modelling will likely form the basis of the project, while comparisons to experimental investigations or analytical solutions are optional.

Contact persons: Morten Thøtt Andersen

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Validation of methodology for assessment of hydrodynamic loads on a large diameter monopile offshore wind turbine foundation in irregular waves



Purpose: To assess application of MacCamy-Fuchs (MC-F) correction in Morison formulation for large diameter monopiles subject to irregular waves.

Morison formulation has been originally suggested for slender cylindrical objects subject to regular waves. For modern monopile foundations characterised by a large diameter, loads calculated in accordance with the formulation in a classical way turn to be conservative as the theory does not include diffraction of shorter waves. It has been proven by MC-F theory that for relatively short regular waves and large diameter objects a diffraction of waves is meaningful and a correction to the classic Morison formulation has been suggested. The MC-F theory is based on experiments with regular waives. In irregular sea states however, waves are described by a characteristic wave height, period and related spectral distribution of component regular waves. Thus irregular waves are a random composition of a number of such regular waves. There are at least two approaches to MC-F correction of Morison formulation. One looking at the sea state as such (characteristic wave height and period) and when judged applicable for the MC-F correction, correction are applied to all component waves. Another option is to look at the component regular waves within the irregular sea state and apply correction only to those waves where the correction has originally been suggested by MC-F theory. Designers dealing with simulations would like to understand applicability of both methods and how their results compare to an actual experiments in irregular sea conditions or corresponding simulations.

Main activities: : Project shall focus on comparison of loads on a monopile foundation obtained through (1) a Morison formulation with different approaches to MC-F correction and through (2) direct simulations (CFD or similar method) of an irregular sea state. The results shall consider sizes of monopiles used nowadays and in the nearest future and the sea states should be based on the North Sea characteristics. The results are to be presented for a range of sea states and the project may attempt to formulate a general conclusion valid across various sea states and monopile sizes. The project should point the method which would be regarded as the most accurate. Project may also formulate a novel method for taking into account a wave diffraction in assessment of loads on a monopile foundation.

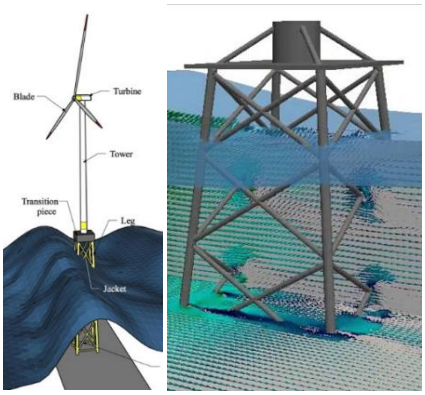
As an option the simulation work may be backed by a set of scale tests in a wave flume or similar.

Contact persons: Thomas Lykke Andersen, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Assessment of wave loads on a jacket type of offshore structures



Purpose: To develop a guideline for assessment of wave loads on jacket type substructures for offshore wind applications. The guideline shall indicate how Morison formulation should be used in context of a jacket structure, how to evaluate influence of shadow effects and how to treat non-cylindrical structure elements like i.e. nodes.

Jacket type of foundation is a truss-like supporting structure featuring on one hand a complex topology but which, on the other hand, is composed of simple and considerably slender tubular elements. The latter suggests that a suitable simulation model should be based on cylindrical elements with broad application of Morison formulation. One of the assumption of the formulation is that the wave passes undisturbed through the structure. That is however not completely true as one can imagine that a structure element encountering the wave creates a wake behind which might influence forces at other, not so distant elements. Yet another topic is wave flow around more massive and more irregular structure elements as jacket nodes. Intuitively, the total wave induced force at this part of the structure seems to be larger than a simple summation of loads derived from corresponding parts of adjoining beams.

Main activities: Project will by means of Computational Fluid Dynamics (or similar) investigate flow of an irregular wave across the jacket type object. Investigation shall focus on detecting and evaluating of influence of closely spaced jacket members on the wave flow including massive and irregular elements as jacket nodes. Loads on particular elements in the complex jacket structure are to be evaluated and compared with corresponding loads calculated with the Morison formulation. The project shall suggest a methodology for calibration of Morison formulation depending on geometry and topology of a jacket structure, preferably in an analytical way.

Additionally the project may suggest a setup for a scale test that could be used to confirm both assumptions of numerical simulations and the outcome.

Contact persons: Thomas Lykke Andersen, Dariusz Eichler (Vattenfall)

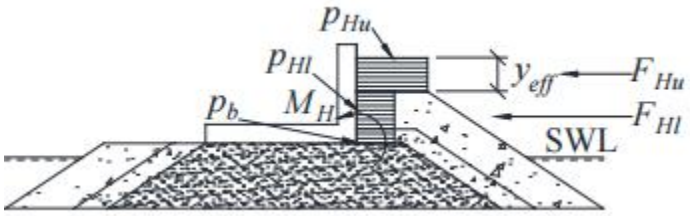
Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

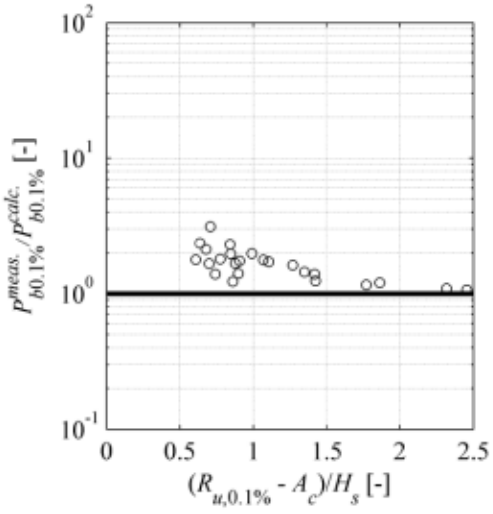
Reanalysis of wave loads on breakwater crown walls

Purpose: The purpose is to extend the formula by Nørgaard et al. (2013) for wave load calculation on breakwater crown walls. The formulae can be extended to include the roughness effect from the armour units. Furthermore, is the prediction of the pressure at the corner (p_b) under-predicted when the wave run-up is equal to or below the crest elevation A_c. Therefore, modifications to the present formula should be performed such that the formula is also valid for low run-up levels.

New tests in the flume at AAU should also be performed if white spots in previous tests are identified.

Contribution: The project can contribute to an on-going PhD study that is working with response of structures exposed to long waves, and the suggested project is a natural extension of this work.





Main activities:

- Extend present formulae to include different armour types and low wave run-up levels

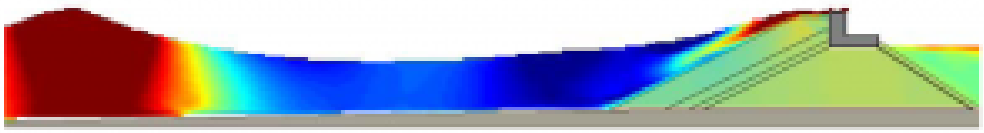
Contact persons: Mads Røge Eldrup, Thomas Lykke Andersen

Theory: ☒☒☒ **Experimental work:** ☒☒☐ **Computer modelling:** ☐☐☐
Suitable project type(s): **3rd sem:** ☐ **short master:** ☒ **Long master:** ☐

Wave height distributions and wave attack on coastal protection structures in highly nonlinear deep and depth limited irregular wave conditions

Purpose: Most state of art design formulae for estimation of influence from wave attack on coastal protection structures (stability of superstructures, stability of armour layer, wave overtopping, etc.) are based on relatively linear wave conditions. However, many coastal protections structures are located in relatively shallow water wave conditions with long waves, i.e. non-linear wave conditions.

Recent research has indicated that the existing design tools might provide unsafe predictions in non-linear wave conditions and moreover existing wave height distributions are seen to underestimate the highest wave heights during a storm. The purpose of this study is to evaluate the influence of wave non-linearity and to derive modifications to existing design formulae and wave height distributions based on physical model tests or numerical models.



Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

- Experimental and/or numerical modelling of wave height distribution in deep and depth limited non-linear wave conditions
- Experimental and/or numerical modelling of wave run-up, wave overtopping, and armour stability on rubble mound breakwaters in non-linear wave conditions
- Experimental and/or numerical modelling of dynamic wave loads on rubble mound breakwater crown walls in non-linear wave conditions

Contact persons: Jørgen Quvang Harck Nørgaard, Thomas Lykke Andersen

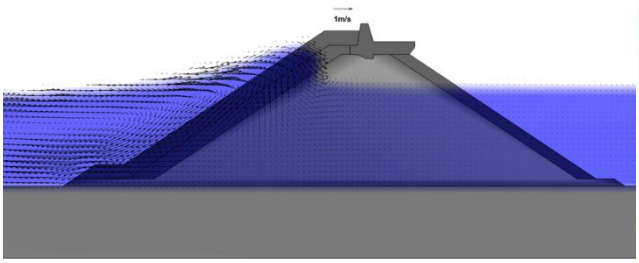
Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(**s**): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

Influence of breakwaters permeability on wave overtopping

Purpose: The purpose is to investigate the overtopping discharge for breakwaters with different core permeabilities and crest widths. Today the most used overtopping formulae are only separating into *Permeable* and *Impermeable core*. Therefore, new model tests and/or numerical simulations (CFD-VOF) should be performed to clarify the effect of permeability on overtopping.
The tests made in the numerical model should be verified/calibrated against physical model tests performed in the new wave flume at AAU.

Contribution: An on-going PhD study has found that overtopping caused by long waves is underestimated by state-of-the-art formulae, and the suggested project is a natural extension of this work.

Example of numerical model



Example of physical model

Main activities:

- Clarify relevant permeabilities and cross-sections to study
- Experimental and/or numerical modelling of overtopping discharge

Contact persons: Mads Røge Eldrup, Thomas Lykke Andersen

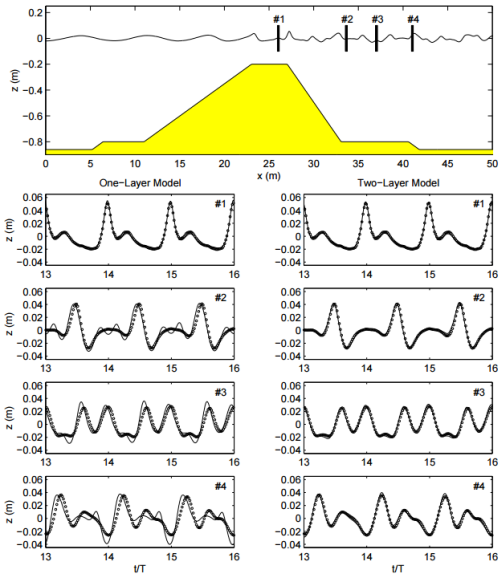
Theory: ☒☐☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem:** ☐ **short master:** ☐ **Long master:** ☒

Improvement of numerical boussinesq wave model

Purpose: The COULWAVE numerical boussinesq wave model (open source) is an extension of the traditional depth integrated bousinesq model to two vertical layers. The additional layer makes it possible to use the model in deeper water than the conventional model. The model might be used for example to transform offshore waves into shallow water with inclusion of the nearshore effects (shoaling, wave breaking and nonlinear wave interactions).

In COULWAVE so far only 1st order irregular wave generation has been implemented and only up to two vertically layers. The purpose of this project is to extend the COULWAVE model with 2nd order wave generation and to increase the number of vertical layers. By increasing the number of layers the computational effort is also increased and thus implementation of GPU support might be relevant to decrease the computational time. The extended model should be validated by physically experiments in the new wave flume at AAU.

Contribution: The improved model would contribute to the existing wave generation software AwaSys developed at AAU by providing a surface elevation for the shallow water wave generation.



Main activities:

- Extend the COULWAVE boussinesq wave model with 2nd order generation
- Extend the COULWAVE boussinesq wave model to more than two vertical layers
- Speed optimizations of code (for example GPU support)
- Validate results by experiments in the new wave flume

Contact persons: Mads Røge Eldrup, Thomas Lykke Andersen

Theory: ☒☒☒ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem:** ☐ **short master:** ☒ **Long master:** ☒

Wave breaking in a fully nonlinear potential flow spectral element model

Purpose: The purpose is implement, verify and validate three levels of fidelity in modelling wave breaking in a fully nonlinear potential flow (FNPF) model. The FNPF model is based on the based on the spectral element method (SEM) – an unstructured arbitrarily high order numerical model based on sigma-transformed coordinates. The use of sigma-transformation makes that wave breaking cannot be naturally handled by the model but needs to be approximated in some way.

In the project different approaches to modelling wave breaking will be tested, initially the eddy viscosity concept and the wave roller concept.

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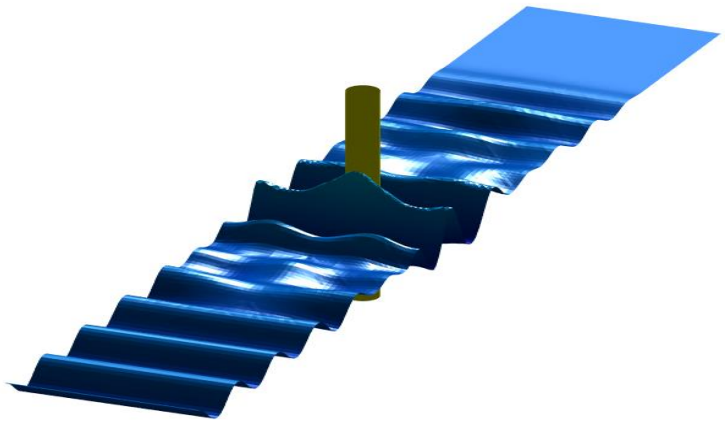


Main activities: The project will contribute to the on-going development of the model and the following activities can be included:

- Study of theoretical breaking models
- Implementation into the numerical code (requires skills in either matlab or C++)
- Verification and validation against standard test cases

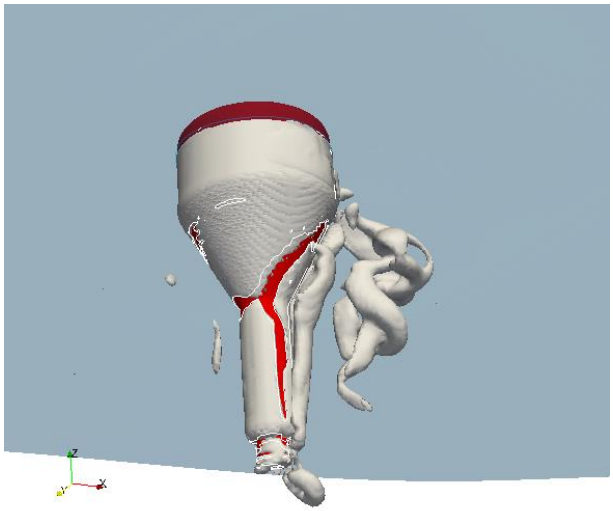
The project will involve co-operation with external parties (DTU, Denmark and INRIA, France).

Contact persons: Claes Eskilsson

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

Turbulence modelling in CFD simulations of wave energy converters

Purpose: The use of CFD in wave energy applications have sky rocketed the last, say, 5 years. That said, CFD for wave energy applications is still in the validation phase, i.e. the numerical solutions are compared to experimental data. Recently, studies looking into stringent verification and validation (V&V) procedures have been put forward. However, so far these studies have focused on the numerical uncertainties and overlooked the modelling uncertainties. The major source to modelling errors is expected to be due to the turbulence modelling. This project will look into the contribution of turbulence models to the total uncertainty of CFD simulations of wave energy converters.



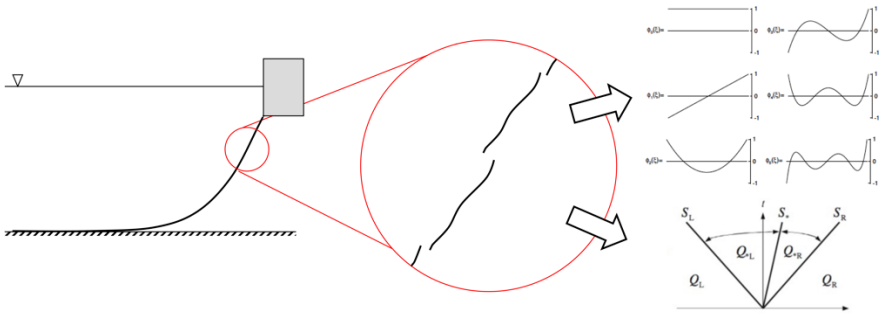
Main activities: The project will be computationally heavy, and the students are expected to learn to use the OpenFOAM CFD solvers. There will be theoretical study – and possible implementation – of turbulence models in OpenFOAM (requires some programming in C++). The use of V&V techniques will be employed to estimate the uncertainty of modelling errors.

Contact persons: Claes Eskilsson

Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☐

Influence of ground models in mooring cable dynamics

Purpose: MooDy is a mooring cable dynamic solver based on *hp*-adaptive finite element techniques. It has been found that this numerical setting is more sensitive to the applied ground model (acting on the part of the cable lying on the seafloor) than mooring cable codes based on the lumped-mass method. Presently only a bilinear spring-damper ground model acting on the local nodes is implemented. The purpose of this project is twofold: (i) to test other ground models proposed in the literature and (ii) to investigate a better way to incorporate the ground than directly on the local nodes as this is introducing noise into the higher order discretization.



Main activities: The project will contribute to the on-going development of the model and the following activities can be included:

- Study of used ground models in mooring dynamics codes
- Implementation into the numerical code (requires skills in C++)
- Estimation of uncertainties introduced by the ground models

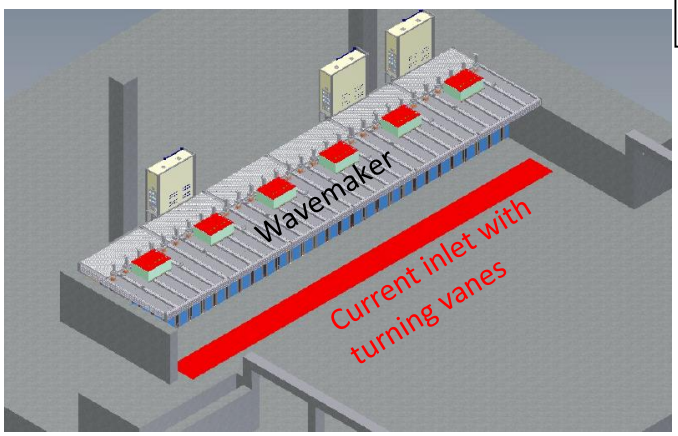
The project will involve co-operation with external parties (Chalmers, Sweden).

Contact persons: Claes Eskilsson, Guilherme Moara Paredes

Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☐

Testing and optimization of the current generation system in AAUs wave facilities

Purpose: The new wave flume and basin includes the possibility for simulating combined waves and current. Numerical CFD simulations has been done in previous master thesis. Based on that project an initial design for the inlets for current generation system has been defined. This design will be installed summer 2018 and should be tested during the present master thesis. If needed the design might be further optimized by utilization of CFD. The new test setup should then be used to study loads on structures in current only conditions as well as in combined waves and current.



Example of turning vanes

Main activities: The study will contribute to the design of the new wave flume and basin. The following activities can be included in the study:

- Experimental verification of initial design by comparision with existing CFD models.
- Further optimizations in CFD in case it is needed.
- Experimental validation of combined waves and current.

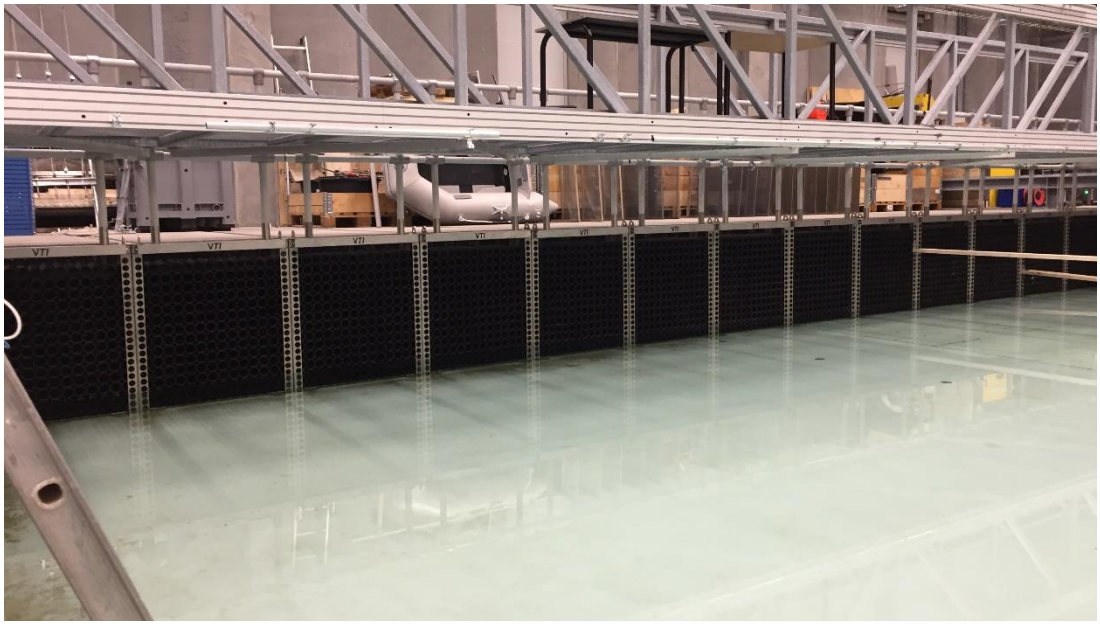
Contact persons: Thomas Lykke Andersen, Morten Mejlhede Kramer

Theory: ☒☐☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

Optimisation of passive wave absorbers

Purpose: The purpose is to optimise the current passive absorption system in the new laboratory at Aalborg University. In order to do that, individual plate absorbers are tested with respect to their performance in term of absorption, reflection and transmission properties for different wave conditions. The optimisation is made by performing laboratory tests in the flume and basin. The key objective is to reduce generation of high-frequency waves which occur for the present absorber layout. Configurations of an array with multiple plates are also tested, and a mathematical model is made to predict the performance.

Contribution: Preliminary tests have been performed, but a more in-depth study on the wave condition is wanted. The influence of the wave height, wave period and water depth is wanted.



Main activities:

- Clarify the absorption capability for an array of perforated plates and the influence of different wave heights, wave periods and water depths.
- Experimental study of the reflection coefficient for a passive absorber.

Contact persons: Mads Røge Eldrup, Thomas Lykke Andersen

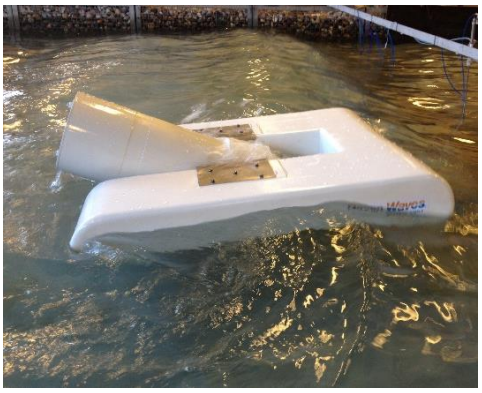
Theory: ☒☐☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☐☐
Suitable project type(s): **3rd sem:** ☐ **short master:** ☒ **Long master:** ☒

LOPF wave energy converter shape optimisation

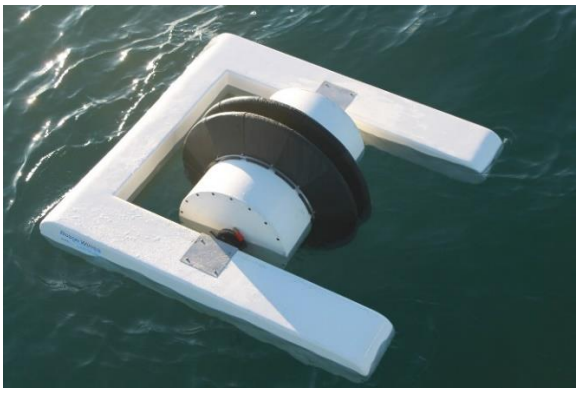
Purpose: The purpose is to increase the energy conversion efficiency of the LOPF wave energy converter by investigating the optimal shape of the device by means of numerical analysis.

Small and medium model tests of the LOPF wave energy converter have already been performed on two different versions of the device, showing an interesting absorption capabilities, but also some shape related issue. In particular the machine does not orient itself toward the wave direction decreasing the overall efficiency.

In addition, by understanding the underpinning working principle of the machine it is possible to increase further the hydrodynamic efficiency.
http://www.resenwaves.com/



Version 1



Version 2

Main activities: The project will foster the development of the LOPF wave energy converter and the main activities are expected to be:

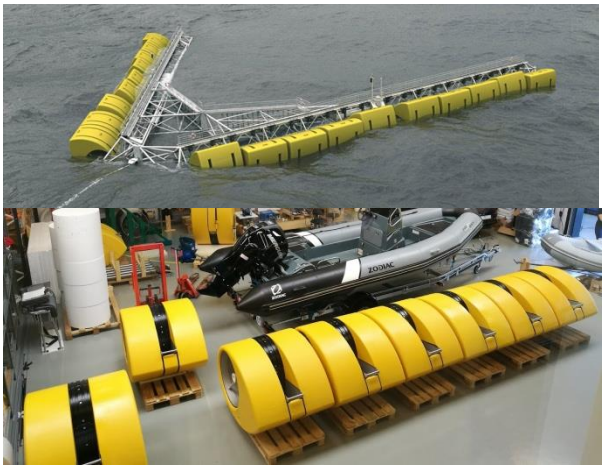
- Numerical modelling of the LOPF wave energy converter (using WAMIT or NEMOH)
- Validation of the numerical model using the pre-existing experimental data
- Optimisation of the LOPF for maximum wave energy extraction
- Depending on timing, laboratory work may be available as part of the validation of numerical results

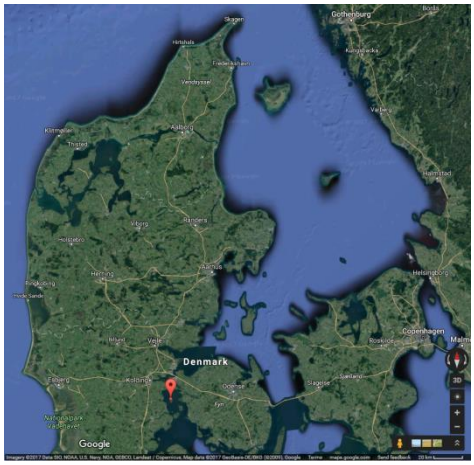
Contact persons: Adi Kurniawan, Francesco Ferri

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☐

Analysis of performances of the Weptos wave energy converter

Purpose: The Weptos wave energy converter (WEC) is an A-shaped floating structure that absorbs wave energy through multiple wave absorbing bodies, the rotors. The prototype was launched in the spring of 2018, with a location in Lillebælt between Jylland and Fyn in Denmark, north of the small island Brandsø at a water depth of 10 m. The prototype with 20 approx. 1 m rotors is equipped with PLC control, a power-take of (PTO) drive train and electrical generators (2x 3 kW PMGs with back-to-back AC/DC/AC inverters). In addition to acquisition of the produced power of the PTO system at different stages of conversion, also the mooring force, the motion of the structure and the position of the opening angle is monitored and recorded continuously. For the characterization of the environmental conditions a TRIAXYS G3 Directional Wave Buoy was deployed. Sufficient data are gathered to enable evaluation of performance of the device and will be used in the current project for the analysis of performances of the Weptos prototype.





Main activities:

- Establishment of a database for the data acquired during the test campaign.
- Performance evaluation in terms of energy production and losses throughout the system.
- Evaluation of the performance of the mooring system. Validation of the initial mooring design.

Contact persons: Amélie Têtu, Jens Peter Kofoed

Theory: ☐☐☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☐

Control of the Weptos wave energy converter

Purpose: The development of the Weptos wave energy converter (WEC) is well under way with a machine being deployed in Lillebælt, Denmark. This system has so far been tested with simple control strategy and could gain in efficiency by developing a suitable control system. This control system will be composed out of two parts: the adaption of the opening angle between the legs, which regulated the available incoming wave power, and the damping presented by the electrical generator system.

Main activities: The control system of renewable energy systems is not a new topic. However it has not been optimised yet for this particular application. Therefore first a thorough literature review has to be performed. Based on previous laboratory test results, smart control systems have to be presented. These can then be tested and further improved by performing experimental tests in the wave basin on real laboratory models.

Contact persons: Amélie Têtu, Jens Peter Kofoed

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☐ **short master:** ☐ **Long master** ☒

Wave climate at the Nissum Bredning test site

Purpose: The purpose of the project is to define the wave climate at the Nissum Bredning test site. The test site is located south west from Aalborg and is run by DanWEC in close collaboration with AAU. The test site is equipped with a network of pressure sensors to measure the surface elevation and a wind sensor, giving both speed and direction of the wind.

The Nissum Bredning is situated in the western Limfjord at the Danish North Sea coast. Predominant west winds make this location suitable for testing scaled wave energy devices in real marine conditions. In order to effectively design the machine for a particular location, detailed wave conditions are required. The network of pressure sensors enables the establishment of the wave climate including directionality of the waves, which is valuable information for future developer interested in testing their device at the test site.

Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

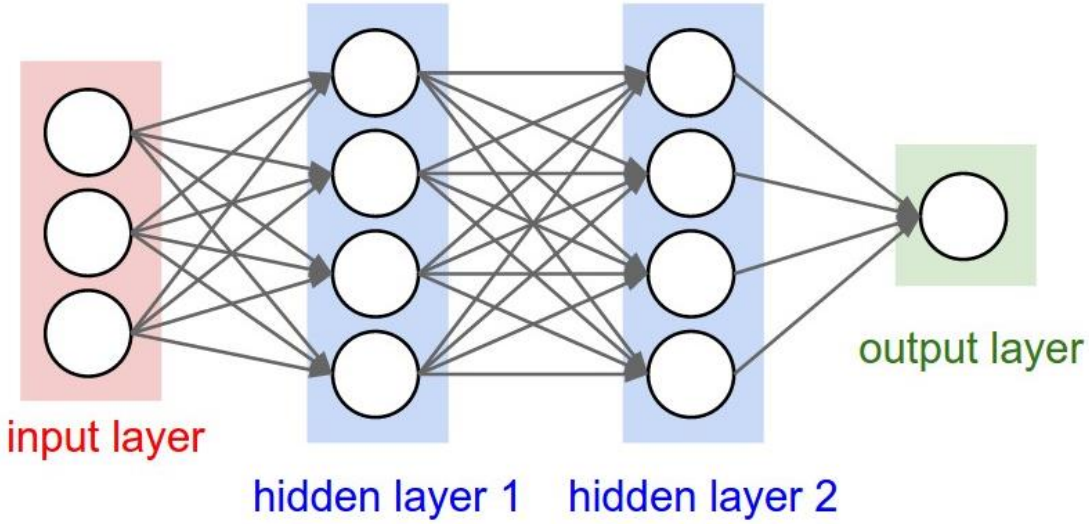
- Optimisation of the network sensor and gathering of data.
- Establishment of the wave climate at the test site based on the measurements including data quality control.
- Establishment of online monitoring of the wave climate

Contact persons: Amélie Têtu, Morten Kramer

Theory: ☒☐☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☐

Forecast of wave conditions at DanWEC test site

Purpose: Forecast of wave conditions is of primordial importance for planning installation, operation and maintenance of wave energy converters, which can account for more than 25% of the cost of energy. At DanWEC, the Danish test center for wave energy, a forecast model has been developed in collaboration with DHI group through an ongoing project. This model is run at DHI and is rendered available for DanWEC during the current project life time. In order to ensure that DanWEC has a reliable tool for predicting the wave climate at the test site, a forecast model needs to be developed. Autoregressive model or machine learning model are examples of models that could be developed for this purpose.



Main activities:

- Literature survey to give an overview of the different models that can be used for forecasting wave climate.
- Establishment of the model for forecasting wave climate at the test site.
- Establishment of online display of the wave climate forecast

The project will be connected to ongoing research projects.

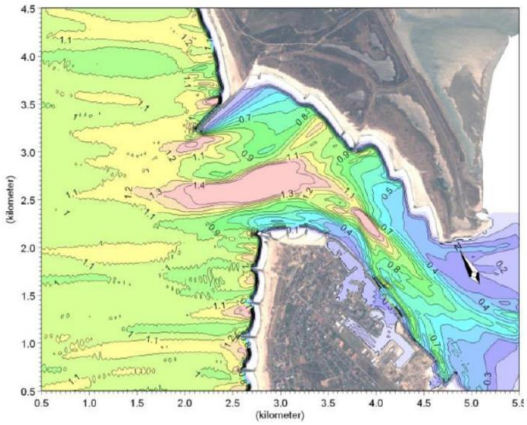
Contact persons: Amélie Têtu, Jens Peter Kofoed

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☐ **short master:** ☐ **Long master** ☒

Evaluation of closing the Thyborøn Channel to reduce the coastal erosion at down drift beaches along the Danish West Coast

Purpose: Recent research has shown a potential for protecting the Limfjord against storm surges by installing a storm surge barrier in Thyborøn channel. The storm surge barrier can be closed temporarily during storms, which significantly reduce the extreme water levels in the fjord. The high flow velocities into the fjord during storms brings large amount of sediments into the fjord. The present situation is thus that the sediment, which accumulates inside the fjord, is missing in the sediment budget at the west coast, which results in erosion.

The purpose of this project is to use numerical models to analyse whether the storm surge barrier can have a positive effect on the coastal erosion at down drift beaches close to Thyborøn channel, since the flow into the fjord will be much less and thus a much smaller part of the long-shore sediment transport at the west coast is expected to enter into the Limfjord. For the study, there is an opportunity for cooperation with the Danish Coastal Authority.



Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

- Evaluation of the processes leading to coastal erosion near the Thyborøn channel
- Numerical modelling of the influence of closing Thyborøn channel during storm on the coastal erosion at neighbouring beaches

Contact persons: Jørgen Quvang Harck Nørgaard, Thomas Lykke Andersen

Theory: ☒☒☐ Experimental work: ☐☐☐ Computer modelling: ☒☒☒
Suitable project type(s): 3rd sem ☐ short master: ☒ Long master ☒

Understanding the erosion affecting Danish Coast

Purpose: Some parts of the West coast of Denmark suffer from severe erosion and longshore transport is consistent. Nørlev Strand, a small village in the North-West coast of Denmark, in Hjørring Kommune, has been in the center of a dispute, because coastal erosion here is making houses fall into the water. Some claim the fault of the erosion is directly related to costal protection works realized few kilometers south. What is part of the natural evolution of the coastline and what is caused or accelerated by men intervention? Answering this question is necessary in order to attribute responsibilities and find a solution to the problem.

Main activities: Depending on the interest of the students, the project could be completely numerical (MIKE 21 software), or the numerical part could be implemented by experimental investigation (Hydraulic and Coastal Engineering Laboratory). The analysis can be limited to few kilometres of coastline or extended to a wider area.

- Numerical simulations describing and predicting coastal evolution under the influence of waves and currents
- Investigation of coastal protection solutions (numerical and/or experimental analysis)
- More holistic approaches that include cost calculations and cost/benefit analysis are also encouraged.

Contact persons: Peter Frigaard

Theory: ☒☐☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

New method for soil compaction

Purpose: To develop new methods for compacting sand in the laboratory and possibly also the field.

Currently, different methods are used for compaction of sands. In the laboratory e_{max} and e_{min} (Relative density) is measured using a stamping method, and for model testing the soil is being compacted using rod vibrators, giving a possibly variating compaction. In the field, sand is compacted using a vibrating plate compactor. All methods however are time-consuming since they are performed manual.

Main activities: The project is relatively open with concern to the problem to be analysed and can include:

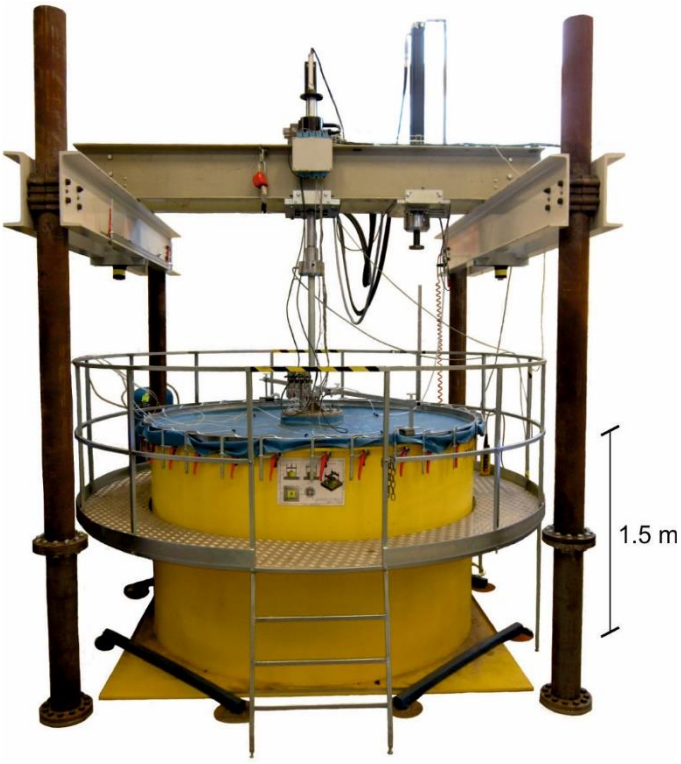
- State of the art study
- Laboratory Tests
- Field testing
- Reliability
- Design model creation / best practise.

It may be possible to co-operate with Department of Mechanical and Manufacturing Engineering as regards to designing a robot that are able to perform the compaction.

Contact persons: Benjaminn Nordahl Nielsen, Lars Bo Ibsen
Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Design of indoor test facilities

Purpose: Take part in designing our new indoor test facility/sandbox that will be used for model testing.



Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

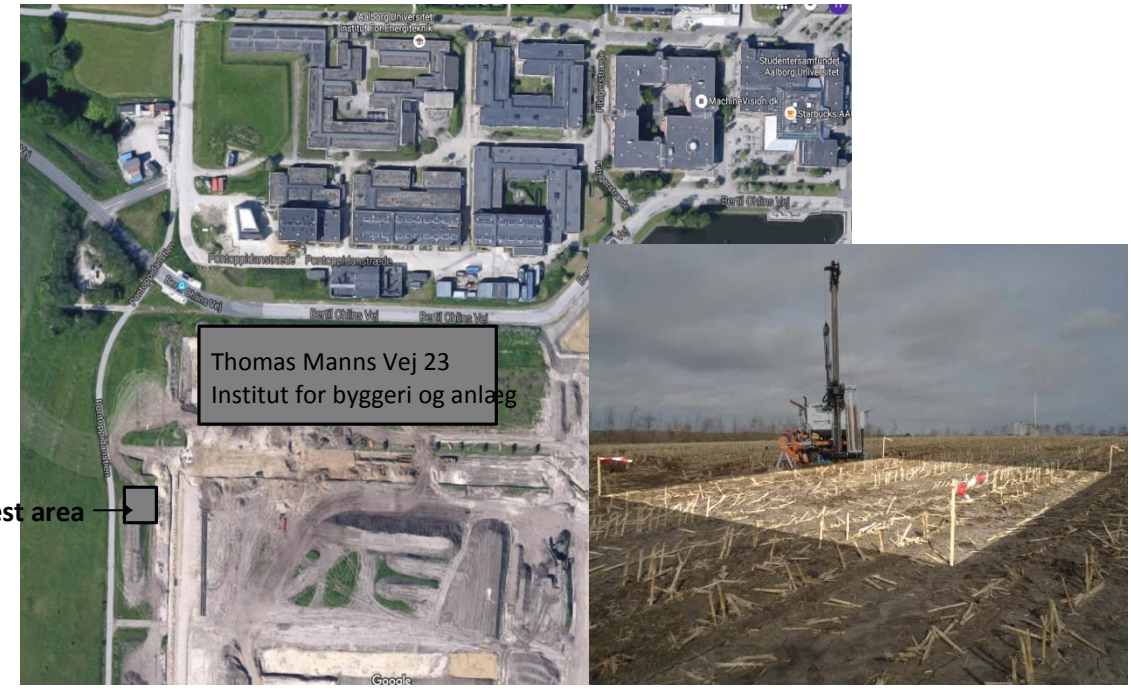
- State of the art
- Boundary conditions
- Sand behaviour at low stress levels
- How to control the water level
- How to prepare and compact the sand in the box
- Numerical models of which foundations models that could be examined in the sand box

Contact persons: Lars Bo Ibsen, Benjaminn Nordahl Nielsen

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Design of outdoor test facilities

Purpose: Take part in designing our new outdoor test facility that should be used for designing climate roads and development of CPT correlations.



Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

- State of the art
- Boundary conditions
- Size, depth and excavation of the test area
- Sand behaviour at low stress levels
- How to control the water level
- How to prepare and compact the soil at the test site
- Numerical models of which foundations models that could be examined

Contact persons:
Benjaminn Nordahl Nielsen, Søren Dam Nielsen, Rikke Holmsgaard

Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☐

Electric vane test

Purpose: Contribute to the geotechnical society by using the new electric vane test in order to examine the reliability and application of the vane test.

The vane test is a highly used in situ test method. In Denmark the vane test is applied in almost all projects, but recently, geotechnical engineers are questioning whether or not the vane test result are sufficiently reliable. This is partly because the vane tests are not conducted with enough consistency and the correlation between vane results and undrained shear strength (especially in organic soils) are not evident. By applying a new electric vane test, which should be less operator dependent new investigations can commence. Find the presentation from the DGF meeting concerning the vane tests:
http://www.danskgeotekniskforening.dk/sites/default/files/pdf/pdf2018/Moede%201.%202018/JDA%20-%20In%20situ-styrkem%C3%A5ling%20i%20organiskholdig%20jord.pdf

A project with

Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

- State of the art study
- Field and laboratory Tests
- Interpretation of data
- Reliability
- Theoretical assessment

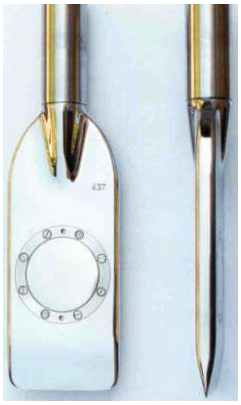
Contact persons: Rikke Holmsgaard, Benjaminn Nordahl Nielsen

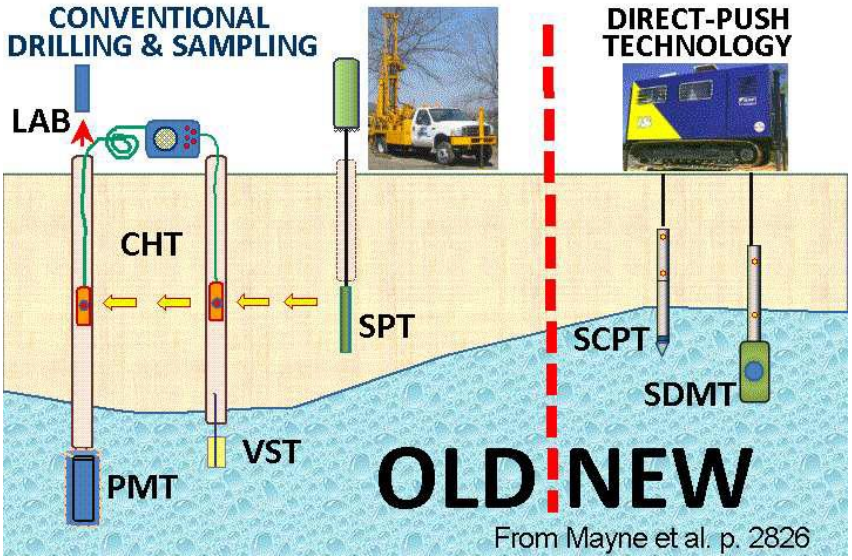
Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☐☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Rock the soil: SDMT Flat Dilatometer

Purpose: Try the new in-situ soil testing. The SDMT (seismic) Flat Dilatometer offers measuring / interpretation of a series of soil parameters by direct-push technology (M, c_u, K_o, OCR, φ, γ).

Aalborg University has the first SDMT equipment in Denmark.





Main activities: The project will contribute to the introduction of the DMT and SDMT technology in Danish soils. The activities will include:

- Setup of equipment
- Interpretation of data
- Field and laboratory Tests
- Theoretical assessment
- Best practise.

It may be possible to perform experimental field tests together with external company.

Contact persons: Benjaminn Nordahl Nielsen, Rikke Holmsgaard, Lars Bo Ibsen

Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☐☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

CPT based soil strength correlations

Purpose: Contribute to the geotechnical society by developing new approaches to determine soil strength parameters from CPT.

Today the Cone Penetration Test (CPT) is increasingly being applied to geotechnical projects. Still, there exist no uniform methods on how to interpret strength parameters from the CPT measurements. Aalborg University has CPT rig which makes it possible to conduct CPTs and collect undisturbed soil samples at places where it is impossible for other boring rigs.
Watch the CPT rig at https://www.youtube.com/watch?v=zf_eRpbo1C0

Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

- State of the art study
- Setup of equipment
- Field and laboratory Tests
- Interpretation of data
- Theoretical assessment

Contact persons: Rikke Holmsgaard, Benjaminn Nordahl Nielsen, Søren D. Nielsen

Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☐☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Aalborg Clay

Purpose: To improve the knowledge about soil parameters for late glacial clay

In connection with the "Musikhuskvarteret" a number of borings have been performed taking undisturbed samples in "Aalborg Clay" for laboratory testing in this project. CPT's and in situ testing make it possible to setup new interpretations of soil parameters.

Main activities: The project will contribute to the ongoing understanding of Danish late glacial clay soils.

The activities will include:

- Consolidation tests
- Triaxial tests
- Bender tests
- Using CPT and in situ testing
- Theoretical assessment

Contact persons: Benjaminn Nordahl Nielsen, Rikke Holmsgaard, Søren D. Nielsen

Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☐☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Determination of small-strain stiffness of soils

Purpose: There are several measures of the stiffness of soils. These stiffness's are not only stress dependant, they are also strain dependant. In dynamic geotechnical problems, the strain levels are usually very small. Hence, the soil will have a relative high stiffness. The small strain shear modulus (G_{max}) can be determined using Bender Elements. This project will focus on how to use Bender Elements for measuring the small strain shear modulus of soils.

Main activities: The project can include:

- Introduction to bender elements
- Gathering and analysis of current design material
- Laboratory tests and theoretical assessment
- Computational modelling
- Design model creation.

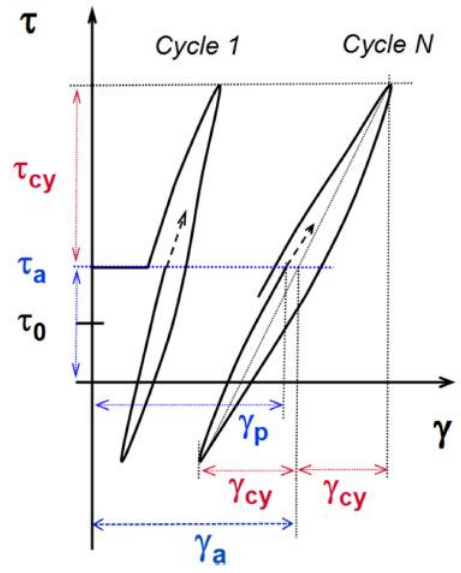
Part of the project may be carried out together with geotechnical firms taking soil samples and making input for actual design problems.

Contact persons: Søren Dam Nielsen, Lars Bo Ibsen

Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Cyclic Behaviour of Soil

Purpose: Offshore structures are exposed to cyclic loading, mainly from wind and waves. Therefore, the soil surrounding the foundation will experience cyclic loading as well. Cyclic soil behaviour is very complex and both strength and deformation parameters may change with cyclic loading. How they change depends on the nature of the cyclic load in terms of: load frequency, load amplitude and mean value. Even though research on the field has been carried out for the last 20 years, there is still no standardised guideline on how to predict the soil response from cyclic loading.



Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

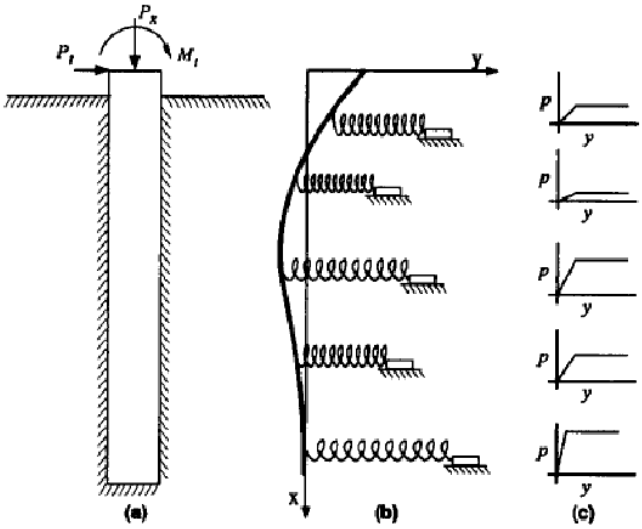
- Literature study on soil behaviour due to cyclic loading.
- Performing cyclic triaxial tests.
- Calibrate one or more existing models to predict cyclic load effects.
- Develop new models to predict cyclic load effects.

Contact persons: Søren Dam Nielsen

Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

FEM implementation p-y-curve analysis of monopiles

Purpose: Monopiles is a foundation solution often used for offshore structures subjected to large lateral loads, such as wind turbines. The response of monopoles is three dimensional and very difficult to predict using analytical methods. On the other hand, full 3D numerical modelling is slow. A an often chosen compromise is to model the pile using beam theory and then take the soil response into account via a series of non-linear springs representing the lateral soil pressure. The spring characteristics are given by the so-called p-y-curves. When implemented into the finite element method this is a very time-efficient method and the level of detail can be scaled to suit the analysis need.



The goal of this project is to create a finite element code with the ability to perform p-y-curve analysis on monopiles. An interest in programming is essential. The number of phenomena included in the code can be scaled to suit the specific project.

Examples of main activities:

- Analysis of the structure of non-linear finite element codes
- Literature study on p-y-curve formulations
- Programming the needed code
- Comparing results with existing codes and/or 3D FEM results

Contact person: Johan Clausen

Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Development of driveability model for piles for offshore wind turbines

A project with COWI

Purpose: An increased focus on renewables in general has ignited a spark in market for offshore wind turbines. The industry has a joint mission to lower the cost of energy from offshore wind turbines to make the solutions more competitive in the open energy market. The installation of piled foundations for offshore wind turbines is today governed by qualified guessing, since soil conditions may vary greatly throughout an offshore wind farm. The ability to predict and complete the driving campaign as effortlessly as possible is more often than not a project deal-breaker.

Up-close of installation of offshore piles (www.4coffshore.com).

A vessel used for installation of piles for offshore wind turbines (www.cape-holland.com).

Main activities: The project seeks to develop a method for accurate driveability predictions based primarily on theoretical considerations and back-calculation of driving logs from real-life installation of piles for offshore wind. The method will be based on existing methods, which are validated and subsequently modified through calibration:

- Assess state-of-the-art research and methodology within the area of offshore driveability and understand the basic physical and theoretical principles involved in the driving of large-diameter piles.
- Based on available driving data from installed piles, complete back-calculation in order to validate existing methods.
- Based on existing methods and available data for back-calculation, develop a theoretically founded method for robust and accurate driveability predictions for various ground conditions.

Contact persons: Martin Underlin Østergaard (muoe@cowi.dk), Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

FE based dynamic analysis of driving of a pile into soil with an impact hammer

Purpose: To develop a methodology for FE based dynamic analysis of pile driving into soil. The methodology shall preferably be based on implicit solver solution and should allow for analysis of stresses in the pile structure during pile driving.

Installation of a monopile in seabed by driving with an impact hammer is a process where the pile structure is subject to repeatable high dynamic stresses. That imposes on the structure a degree of fatigue accumulation that in the design stage is usually assumed to reach a level that would correspond to up to 10% of fatigue accumulation allowed during the life time of the structure. That obviously has an impact on design where one of the objectives is to assure an operation lifetime.

The other uncertainty during pile driving is buckling stability of a pile under high dynamic stresses. Specially the lower part of the pile which is embedded in the soil is usually optimised thanks to low utilisation under ordinary operation loads but is subject to high dynamic loads under installation. In order to properly assess risk of buckling of the embedded part of the pile a reliable method for assessment of stresses and pile stability would be highly desired.

Main activities: The main scope of work is to simulate pile driving under highly dynamic loads induced by impact hammer and including friction forces of the soil. The simulation model shall reflect realistically properties of dynamic forces and behaviour of the structure. The analysis should allow for retrieval of stress time series for further fatigue and buckling analyses.

It is assumed that explicit solver might need to be used. As a target however it is anticipated that a corresponding methodology with application of an implicit solver is developed. Should a study of differences between this, two approaches demonstrate deficiencies of the implicit solver, a method for overcoming them shall be suggested.

Yet another challenge is a simulation of a case with a hammer delivering a longer impact and with higher energy like e.g. Blue Piling by Fistuca. Then a risk of buckling and fatigue exposure might be different due to less dynamic character of the impact and thus different effect on pile structure.

Contact persons: Johan Clausen, Dariusz Eichler (Vattenfall)

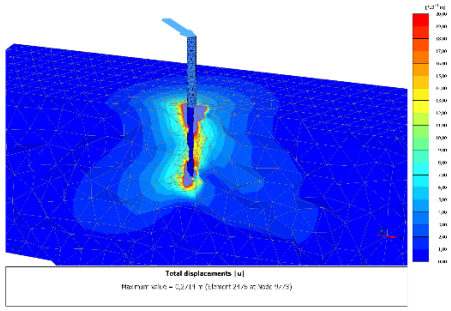
Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Dynamic analysis of monopiles for offshore wind

A project with COWI

Purpose: When designing foundation structures for offshore wind turbines, the dynamic performance of the structure, regularly characterized by the eigenfrequency, is often driving the design due to fatigue loading. Through measurements on foundation structures, e.g. monopiles, with operating wind turbines, it is possible to assess the dynamic performance and compare to the design. In order to optimize the design of a monopile, the dynamic performance must be estimated as close to reality as possible. The dynamic performance is strongly influenced by the stiffness of the pile-soil interaction; hence, the ability to predict the correct pile-soil stiffness for use in dynamic analyses is paramount.

Installation of a wind turbine on a monopile (www.4coffshore.com).



Finite element modelling of a monopile.

Main activities: The project seeks to improve existing and develop new methods for estimating pile-soil stiffness for use in dynamic analyses through theoretical considerations and back-calculation of real-life measurements, ultimately developing a robust model for estimating the eigenfrequency of the as-built monopile:

- Understand the basic physical and theoretical principles involved in the estimation of eigenfrequencies for monopiles.
- Develop a simple model to assess the eigenfrequency to understand and quantify the impact of the pile-soil stiffness.
- Based on available data from installed offshore wind farms, complete back-calculation using available 1D methods for estimating pile-soil stiffness and if possible improve existing or develop new methods for this purpose.
- Using finite element modelling, estimate the dynamic performance and compare to examined 1D methods and in-situ measurements.

Contact persons: Martin Underlin Østergaard (muoe@cowi.com), Johan Clausen

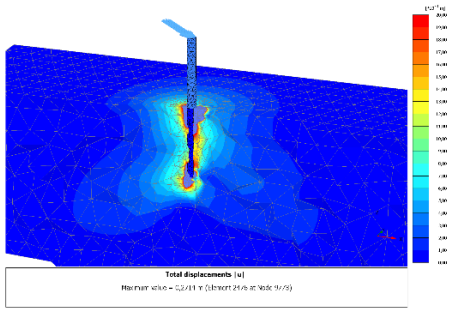
Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Development of best practice for finite element modelling of monopiles for offshore wind

A project with COWI

Purpose: Due to a strong demand for optimization of the foundation structures for offshore wind turbines, new tools are incorporated in the design process, and finite element (FE) modelling has become increasingly important. As for all FE models, the quality of the output is dependent solely on the quality of the input and the model setup. Since the use of FE modelling for offshore wind is relatively new, a so called "best practice" has not yet been developed. However, the recent investigations done in connection to the DONG-led PISA-project has provided a useful basis for developing best practices.

Sketch drawing of a monopile.



Finite element modelling of a monopile.

Main activities: The project aims at developing a best practice for FE modelling of foundation structures for offshore wind through considerations regarding theoretical soil behaviour and available constitutive models as well sensitivity analyses of input:

- Understand and establish the basic parameters for FE modeling of foundations as well as the individual importance of these.
- Develop FE model and compare total pile response to that obtained from simpler models, e.g. Winkler-models using various p-y formulations.
- Compare FE model to pile load test results and perform calibration and assessment of chosen constitutive model.
- Based on assessment of suitability of various constitutive models as well as elasticity of input parameters and experience regarding model setup, develop a best practice for FE modelling of offshore foundation structures.

Contact persons: Martin Underlin Østergaard (muoe@cowi.com), Johan Clausen

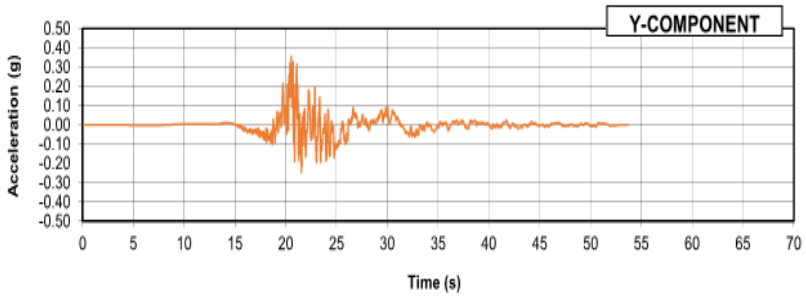
Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Earthquake design of monopiles

A project with COWI

Purpose: The offshore wind farms are moving to new regions, and new design scenarios are continuously introduced due to shifts in environmental climate and loading. Especially the Asian market for offshore wind is growing rapidly and natural hazards, like earthquakes, need to be accounted for to a much greater extent compared to e.g. European wind farms. Depending on the soil conditions, an earthquake can have a large impact on the structure, through e.g. liquefaction of the supporting soil and kinematic soil-structure interactions. This impact needs to be accounted for in the design.

Sketch of a monopile.



Example of acceleration time series from earthquake.

Main activities: The project aims at investigating available methods for aiding the design of monopiles for the offshore wind industry placed in regions with frequently occurring earthquakes. The following items can be considered in this investigation:

- Understand the concept of soil liquefaction and other earthquake-induced impacts on design of monopiles.
- Conduct literature review and develop a state-of-the-art of existing methods (e.g. based on p-y springs) for accounting for liquefied soil in design of laterally loaded piles.
- Develop a Winkler-based tool to assess the impact of different methods for accounting for liquefied soil.
- Using commercial software, like e.g. PLAXIS, FLAC or LPILE, conduct an assessment of the laterally loaded pile accounting for relative deformation between soil and pile caused by movement of the soil volume.

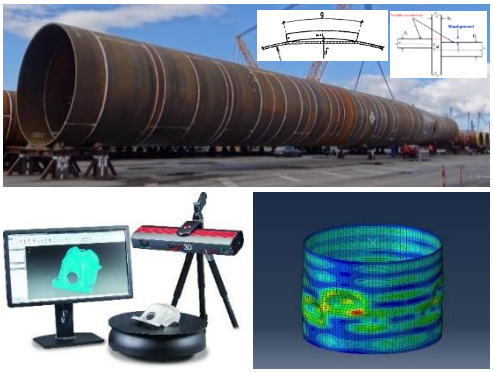
Contact persons: Martin Underlin Østergaard (muoe@cowi.dk), Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Scanning based systematisation of imperfections in monopile type of offshore wind supporting structure

Purpose: To develop a methodology for estimating and categorising imperfections of monopiles based on scanning.



Monopile has been by far the most popular type of offshore wind turbine foundation with ever growing number of application and sizes. And this is due to size, and particularly diameter to thickness ratio, that these structures are considered as thin-walled and as such are sensitive to fabrication imperfections. Both buckling and fatigue resistance can be to a large extent influenced by such imperfections. Monopile manufacturers are normally obliged to control tolerances under they Quality Assurance procedures. It is however unknown what a statistical representation of imperfections in newly produced structures is. Findings of measurement campaigns, if confirming anticipation of statistically smaller imperfections, might lead to evidence based reduction of safety factors in design and thus savings in material and overall cost of energy.

The easiest way of verifying a shape of a monopile and identifying imperfections is by scanning which is relatively quick and high fidelity process. Due to length of the pile it would be beneficial to mount a scanning device on a self-propelled vehicle like a robot tractor or a drone. The obtained images will depict actual geometry well but images cannot be directly used for a control purpose. Instead, geometry needs to be described in terms of standard dimensions like diameters and length, and imperfections as a measured ovality, flatness, indent or misalignment. Then imperfections can be categorised, put into statistical record and used for update of design procedures and safety factors.

Main activities: Project will examine scanned geometries of monopiles and evaluate their applicability for the fabrication tolerance control purpose. The task will be to fit first order (primitive) geometries into particular parts of the scan representing monopile segments. And subsequently the fitted geometry will be compared with the scan and imperfections will be identified and measured. The results of the work shall be a semi or a fully automated procedure for determining fabrication imperfections. The work shall also include recommendations regarding scanning procedure and required resolution. The methodology may include compensation procedures for gravity caused deformations of the monopile in the scanning position.

Contact persons: John Dalsgaard Sørnsen, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Offshore wind suction bucket on an industrial scale

SIEMENS Gamesa
RENEWABLE ENERGY

Purpose: The project aims to develop a modular suction bucket design to the Siemens jacket concept for a +10 MW turbine. Objectives have been to create a modular bucket where modules can be produced in existing industrial manufacturing facility. In this project the aim is to demonstrate install-ability and in-place capabilities of design in laboratory environment.

Foundation costs of offshore wind including production and installation represent 20-30% of the total costs of deploying an offshore wind park. Lowering costs of foundations is a key element to lower the total Levelized Cost of Energy (LCoE) for offshore wind. Suction buckets are one of the most promising seabed interfaces technologies in the industry.

Main activities: The project will focus on developing a working framework for the design of suction anchors used for the offshore wind industry, covering subjects such as, but not limited to:

Siemens Jacket concept for +10 MW wind turbine.

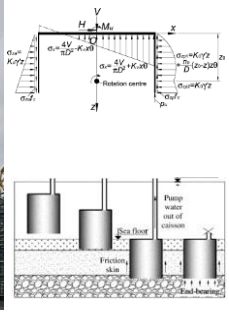
- Installation of suction anchors using pressure and the challenges associated with this in various types of soil.
- The tensile and compressive capacity considering loading direction, loading rate and cyclic loading that are comparable to an offshore storm event.
- Laboratory testing to assess the impact of various types of loading (e.g. cyclic) to a typical offshore soil and the soil mechanics involved.
- Small-scale testing to assess the behaviour of the suction caisson/anchor during different loading and soil conditions.

The Project will be in close corporation with Siemens Wind Power and Universal Foundation A/S

Contact persons: Lars Bo Ibsen (lbi@civil.aau.dk)
Theory: ☒☒☒ **Experimental work:**. ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Analysis of installation and bearing capacity of a suction caisson used as a base of an offshore wind turbine supporting structure



Purpose: To develop a simple tool for preliminary assessment of installation and capacity of a suction caisson used as a support of a jacket type of offshore wind turbine foundation.

Traditional way of installation of offshore wind turbine foundations, be it a monopile or a jacket, is driving piles into the seabed by large hydraulic hammers. The operation is time consuming and is associated with generation of noise that might be harmful to the ocean fauna. Furthermore, piling is not always available depending on ground conditions of the seabed. Application of suction caissons appeared to be an attractive solution to piles, especially for a jacket type of foundations. Designing a complete suction caisson is a complex process and sophisticated tools are used for predicting installation and operational in-place capacity. Typically, there are no resources and/or complete data to perform such a task at an early stage of design. Concept developers desire a simple tool for approximate assessment of feasibility and required size of a suction caisson.

Main activities: Based on detailed FE (or alike) simulations, an analysis of installation and bearing capacity of a suction caisson constituting a part of a jacket type of offshore wind turbine foundation will be perform. Simulations shall be conducted for typical soils suitable for application of a suction caisson. Analysis of results will be used to formulate a simplified rule for assessment of desired size of a suction caisson. The simplified formulation is anticipated to take into account magnitude of wind and wave loads, topology of the supporting structure and soil properties. Through a comparison of the suggested methodology with detailed analyses a degree of accuracy shall be evaluated. The tool shall be available in form of a piece of software.

The tool may be validated against results of the full scale tests performed by Vattenfall.

Formulation of the simplified tool may be accompanied by (or even fully based on) a novel soil-structure-interaction methodology that will prove to be less time consuming and/or more accurate than present standard methods.

Contact persons: Lars Bo Ibsen, Søren Dam Nielsen, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

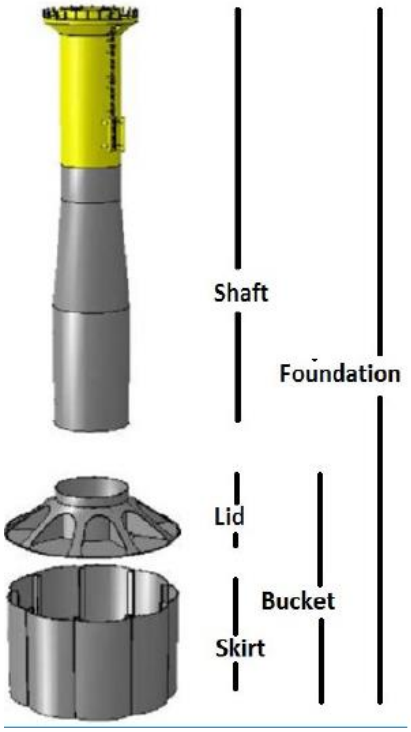
Develop a new mono – bucket for a +10 MW wind turbine

Universal Foundation

Purpose: The project aims to develop a modular mono bucket design for a +10 MW turbine. Objectives are:

1. Create a modular bucket where modules can be produced in existing industrial manufacturing.
2. Demonstrate install-ability and in-place capabilities of design in laboratory environment.

Foundation costs of offshore wind including production and installation represent 20-30% of the total costs of deploying an offshore wind park. Lowering costs of foundations is a key element to lower the total Levelized Cost of Energy (LCoE) for offshore wind. Suction buckets are one of the most promising seabed interfaces technologies in the industry.



Main activities: The project will focus on developing a working framework for the design of the mono bucket used for the offshore wind industry covering subjects such as, but not limited to:

Installation of suction anchors using pressure and the challenges associated with this in various types of soil.

Bearing capacity considering loading direction, loading rate and cyclic loading that are comparable to an offshore storm event.

Laboratory testing to assess the impact of various types of loading (e.g. cyclic) to a typical offshore soil and the soil mechanics involved.

Small-scale testing to assess the behaviour of the mono bucket during different loading and soil conditions.

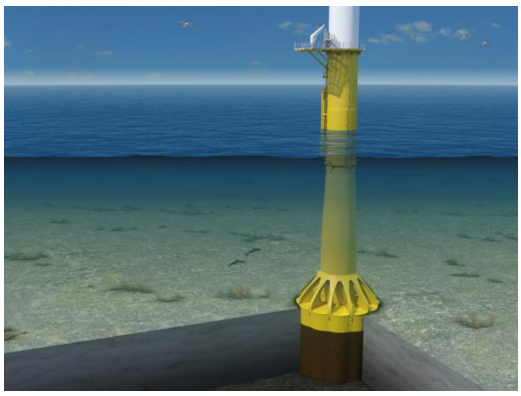
The Project will be in close corporation with Universal Foundation.
Contact persons: Lars Bo Ibsen (lbi@civil.aau.dk)

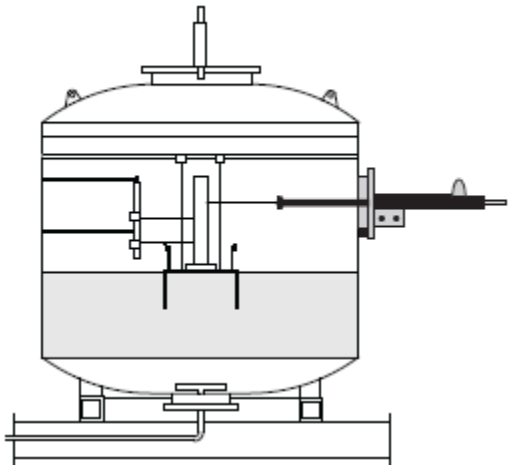
Theory: ☒☒☒ **Experimental work:**. ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Cyclic Behaviour of Offshore Foundations

Universal Foundation

Purpose: Offshore structures are exposed to cyclic loading, mainly from wind and waves. Therefore, the soil surrounding the foundation will experience cyclic loading as well. Cyclic foundation behaviour is very complex and both strength and deformation parameters may change with cyclic loading. How they change depends on the nature of the cyclic load in terms of: load frequency, load amplitude and mean value. Even though research on the field has been carried out for the last 20 years, there is still no standardised guideline on how to predict the foundation response from cyclic loading.





Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

- Literature study on foundation behaviour due to cyclic loading.
- Performing cyclic model tests in the pressure tank.
- Calibrate one or more existing models to predict cyclic load effects.
- Develop new models to predict cyclic load effects.

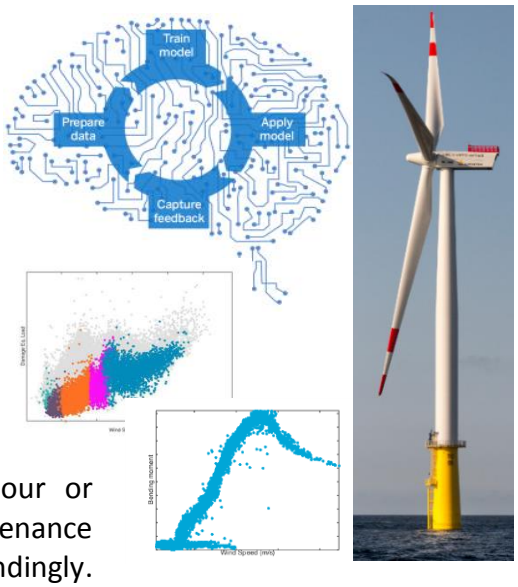
The Project will be in close corporation with Universal Foundation.

Contact persons: Lars Bo Ibsen
Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

VATTENFALL

Machine Learning for Structure Health Monitoring of offshore wind foundation structures

Purpose: Results of the project shall be a review of possible applications of Machine Learning to analysis of Structure Health Monitoring data collected at offshore wind turbine supporting structures.



Offshore wind turbines due to their large number in a windfarm and remote distance to shore are usually equipped with Condition Monitoring Systems. The role of CMS is to provide online data to control centres for surveillance and analysis. Sensors within a CMS are designed such that any abnormal behaviour or damage can be detected in time and a maintenance or repair work can be scheduled correspondingly. So far continuous condition monitoring has been covering the turbines and it was a rare case when the similar systems have been installed on supporting structures. Growing demand for clean and inexpensive energy forces however developers to cut costs and push designs to boundaries. In relatively uncertain offshore environment it means that surveillance of the structures becomes necessary. Usually Structure Health Monitoring systems are installed only on a few foundations within the windfarm. That imposes requirements that data collected from both CMS and SHM systems need to be used wisely in order to produce results valid for all windfarm foundations. The systems deliver a vast amount of data which demands large storage and processing capacity as well as complex analysis tools. But on the other hand, the amount of collected data opens not yet explored opportunities for obtaining conclusions and predictions that might bring direct benefits to the asset owner. Like a qualified assessment for lifetime extension, early warning on undesired development or verification of design methodologies, just to name a few.

Main activities: Project shall explore possibilities of application of Machine Learning or other Artificial Intelligence techniques for the purpose of structure integrity management. The applied techniques will utilise data obtained through a typical CMS and SHM systems installed at offshore windfarms. The goals of analyses will be defined taking into account benefits for either existing windfarms or new projects and might cover the whole lifecycle of an offshore wind turbine foundation including design, Operation & Maintenance as well as remaining operational life assessment.

Contact persons: Jannie Sønderkær Nielsen, Lars Damkilde,, Dariusz Eichler (Vattenfall)

Theory: ☒☒☒ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Comparison of Finite Element calculations for geotechnical cases

Purpose: Many finite element software packages that are used for geotechnically related computations exist. Some are specialized for geotechnical problems and others are general purpose programs. Even though the initial problem is well defined, e.g. a surface footing on a Mohr-Coulomb soil, different programs can arrive at different solutions for the sought-after results, be they stresses, displacements or bearing capacity. This can be due to, for example, variations in the numerical implementation, or different formulations of the material models.

If these variations in the results are significant, it poses a problem for the design engineer who relies on the solutions of the chosen software: What is the correct solution?

The idea of this project is to examine the variations between different tools for solving geotechnical problems, both qualitatively and quantitatively.

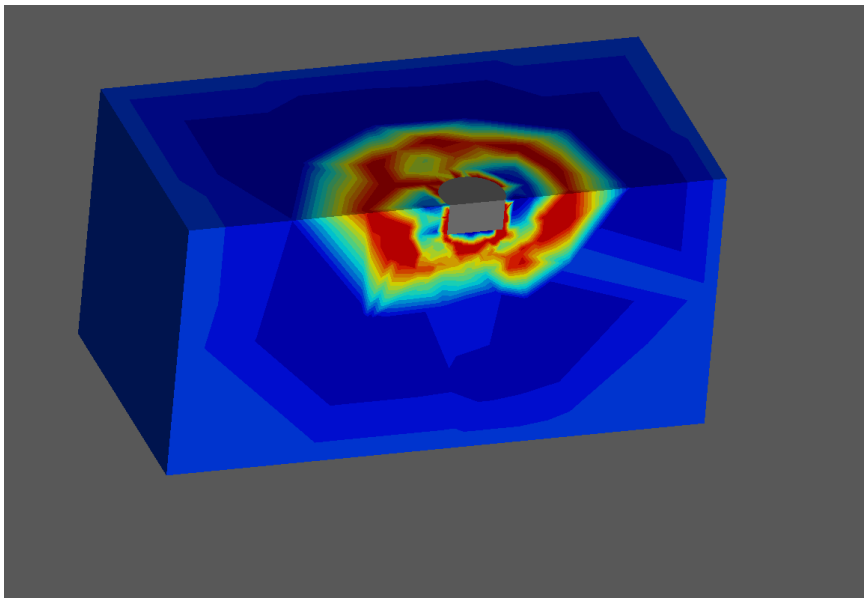
Main activities: One or more geotechnical calculation cases should be chosen. Ideally one of them with a known solution to which numerical results can be compared. Then the problems are modelled using different numerical tools, of which some relevant examples can be seen in the above figure. Inhouse codes, e.g. written in MatLab, can also be used. The calculation cases should range from a simple bearing capacity calculation to some problems with higher complexity according to the interest of the student and capabilities of the chosen software packages. Examples are: Advanced constitutive models, seepage, consolidation, interface elements, staged construction, slope stability.

Contact person: Johan Clausen, Søren Dam Nielsen

Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☐

Calibration of the Bearing Capacity Formula for Mono Bucket Foundations by OptumG3

Purpose: The purpose of this project is to calibrate the bearing capacity formula to mono bucket foundations based on upper and lower bound solutions. Upper and lower bound solutions for 3D geotechnical problems are now possible to establish in the Finite Element program OptumG3. Other programs may also be used for comparison and or validation.



Main activities: The main activities of the project will include the study of upper and lower bound solutions both theoretical (in 2D) and by numerical modelling. The work will mainly consist of:

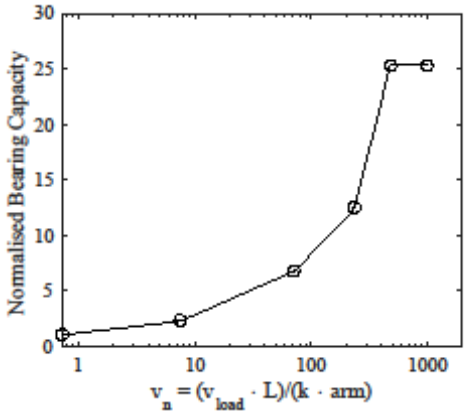
- Numerical modelling
- Calibration of the bearing capacity formula
- Study of failure mechanisms

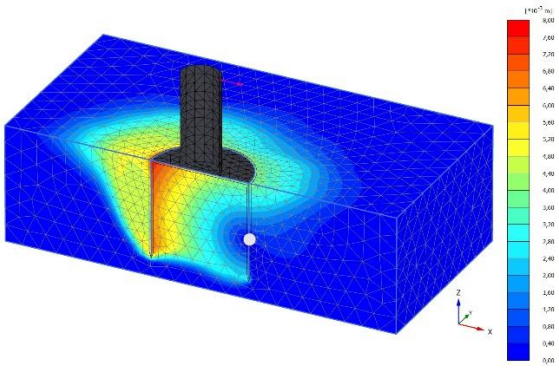
Contact persons: Søren Dam Nielsen, Benjaminn Nordahl Nielsen, Rikke Holmsgaard

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

Investigation of partly undrained soil behaviour using Finite Element Modelling.

Purpose: For many geotechnical structures the ULS design often consider sand as a drained material and clay as an undrained material. However, for offshore structures the load duration is so short partly- of fully undrained response is present in sandy soils. For some structures, such as the bucket foundation, this will lead to the generation of negative excess pore pressure, which increases the ultimate capacity of the foundation. This effect has been proven by model testing. The aim of this project is to investigate whether it is possible to simulate these effects by commercial finite element programs, such as Plaxis 3D.





Main activities: The main activities of the project will include the drained, partly and fully undrained soil behaviour and simulations hereof in Finite element programs, such as Plaxis 3D.

- Study of drained, partly- and fully undrained soil behaviour.
- Numerical modelling
- Comparison with existing laboratory results

Contact persons: Søren Dam Nielsen, Rikke Holmsgaard, Benjaminn Nordahl Nielsen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

Cloning the numerical method of Plaxis

Purpose: The most wide spread software, at least in Europe, for numerical geotechnical calculations is the Plaxis software suite. The numerical method used by Plaxis is an elasto-plastic incremental scheme, which is somewhat unusual, compared to the textbook chapters on elasto-plastic finite element codes. The stiffness matrix is formed only once in the beginning of the analysis, as opposed to formation in every iteration according to the standard Newton scheme. The disadvantage of the Plaxis method is that the number of equilibrium iterations soars. This is partly remedied by using so-called overrelaxation during the equilibrium iterations. A great advantage, however, of the Plaxis method is that it is robust when simulating non-associated plasticity models. Much more so, than the standard Newton scheme. To make use of this robustness when calibrating user-made material models, it will be very beneficial to have a "home-made" finite element program using the Plaxis method.

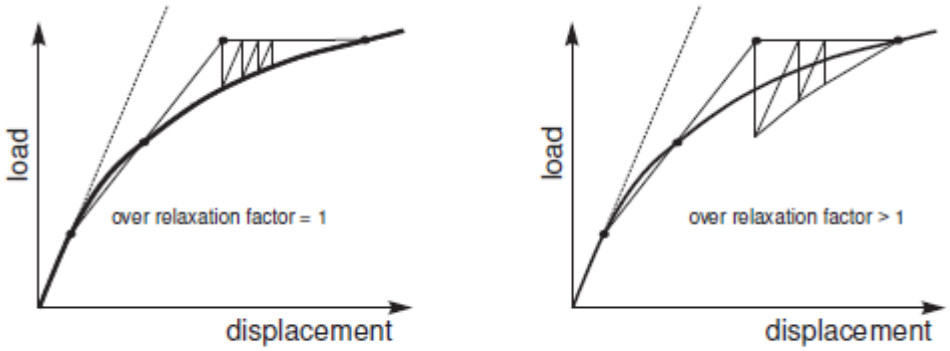


Figure 7.21 Influence of over-relaxation

Main activities:

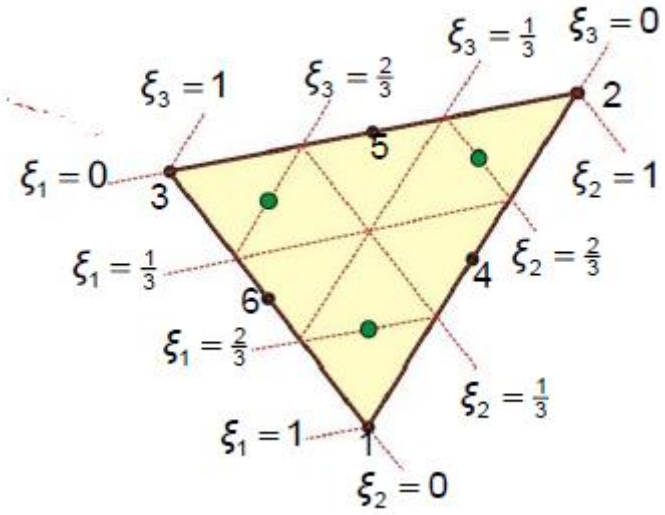
- Study the structure of non-linear finite element codes.
- Study the over-relaxation procedure
- Implement the numerical scheme of Plaxis into a home-made FEM program
- Test the robustness of the code and compare results with results from the Plaxis program.

Contact person: Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Improved locking mitigation of 2d and 3d finite element simulations

Purpose: A well-known problem in finite element calculations is the "locking phenomenon" which can manifest itself when nearly incompressible simulations are performed. Locking results in slow convergence and slow program runs. Near-incompressibility is an often seen behaviour in geotechnical simulations, so the user should be aware of the locking problem. A number of methods exist for mitigating the locking problem, and in this project these methods will be explored, primarily in home-made finite element codes but commercial codes can also be considered.



Main activities:

- Study the structure of non-linear finite element codes.
- Literature study of the locking phenomenon and methods of mitigation.
- Implementation of one or more locking mitigation methods a home-made FEM program.
- Compare the performance of the different methods.

Contact person: Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Improved FEM-modeling of non-associated plasticity

Purpose: The most common material model for soils is the Mohr-Coulomb model where the soil strength is controlled by the cohesion and the friction angle. The deformation during plastic flow is controlled by the dilation angle. When the model is associated, i.e. friction angle = dilation angle, reliable calculation methods are abundant both in the elasto-plastic as well as the rigid-plastic case. Experimental observations, however, predicts that the dilation angle should be much lower (often ~30°) than the friction angle. Unfortunately, this causes a lot of computational problems. Random errors seem to occur and simulations break down.

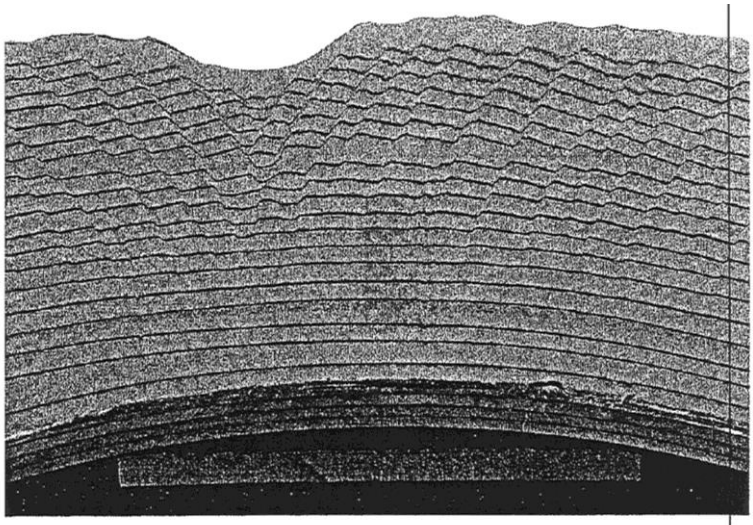


Fig. 8.2 Crestal faults over arch of uniform curvature, simulated in a sand box (Mandl, 1984).

In this project, the goal is two-fold: 1) The influence of non-associated plasticity on e.g. bearing capacities should be quantified. This is very relevant, as design codes, e.g. the EuroCode base the design formulae on associated plasticity. 2) Examination on how different methods can be used to run finite element analyses using non-associated material models.

Examples of main activities:

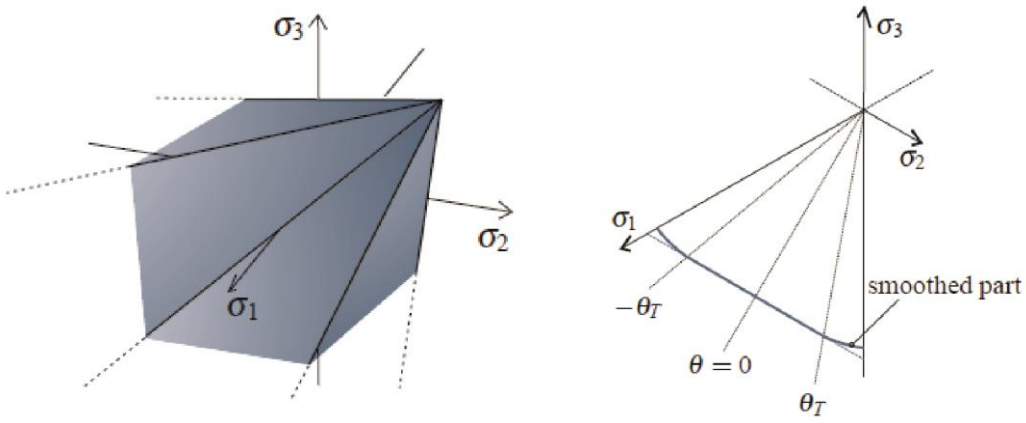
- What are the symptoms of non-associated problems? A computational and literature review.
- What do the commercial codes do (e.g. Abaqus, Plaxis, Optum2G)?
- Do we have other methods of remediating the problem?
- Quantification of different results with different methods

Contact person: Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Implementation of a plasticity model into the finite element method 1: Rounded Mohr-Coulomb

Purpose: The most often used material model for geotechnical materials is the Mohr-Coulomb material model. For calculation involving more than very simple geometries the finite element method is used for obtaining the solutions to the arising boundary value problems (i.e. load-displacement curves, bearing capacities, etc.). Originally, the corners and the apex of the Mohr-Coulomb yield surface caused problems in the numerical implementation, so an approximate yield surface with smoothed, or rounded, corners were used. Today methods for implementing the corners explicitly exist, but the use of the rounded surfaces is still widespread. The implications of using these approximations, however, are not documented in literature.



Main activities: Different models for smoothing the Mohr-Coulomb model should be implemented, and maybe also as a user programmable material in Abaqus. Then the implications of using these approximate models should be quantified and compared to the exact Mohr-Coulomb material model. Both with respect to accuracy, computation time and number of iterations. The approximate models may perform better than the exact model in some parameter combinations and poorer in others.

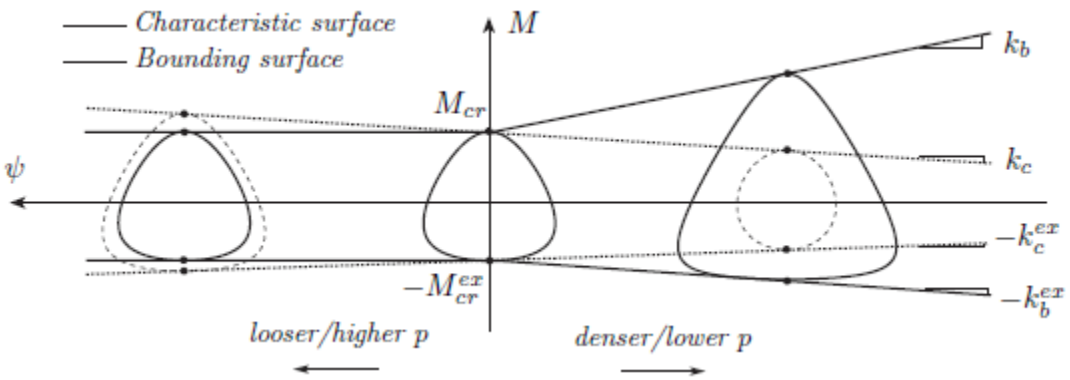
An interest in programming, e.g. MatLab, is essential.

Contact person: Johan Clausen

Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Implementation of a plasticity model into the finite element method 2: A two-surface model for cyclic loading on sand

Purpose: For strength calculations the Mohr-Coulomb criterion is often a sufficient material model for soils. If a more precise calculation of the deformation is needed then the simple linearly elastic – perfectly plastic Mohr-Coulomb model is not adequate. This is especially true if the loading is not monotonic or even cyclic. Offshore structures are subjected to time varying loads from wind and waves, which means that their foundation will experience cyclic loading. At the same time, the allowable deformation is small which means that it is often this criterion rather than the soil strength that governs the foundation design. For these reasons many advanced material models for soils have been developed. If such an advanced model is to be used in practical calculations it must be implemented in a numerical method, e.g. the finite element method.



Main activities: Earlier projects have been working with the implementation of the above mentioned model into the finite element method. This project should be a further development of this. The activities could be improvement of the algorithms, implementation of the model as a user-defined model in e.g. Plaxis and/or Abaqus and case studies on structures under cyclic loading.

An interest in programming, e.g. MatLab, is essential.

Contact person: Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Implementation of a plasticity model into the finite element method 3: The Plaxis Hardening Soil model

Purpose: For strength calculations the Mohr-Coulomb criterion is often a sufficient material model for soils. If a more precise calculation of the deformation is needed then the simple linearly elastic – perfectly plastic Mohr-Coulomb model is not adequate. For this reason, various advanced constitutive models for soils have been developed over time, with the aim of correctly modelling the total stress-strain path of the soil, in order to be able to accurately predict the displacement of geotechnical structures in the service limit state. Probably the most popular advanced soil model for practical use is the so-called Hardening Soil model. Its popularity is probably due to two reasons: 1) It is available in the popular geotechnical software Plaxis 2) the model parameters include the Mohr-Coulomb parameters together with some stiffness parameters, which are fairly easy to obtain from laboratory testing. As of yet the model is not available in other software codes. Therefore, the goal of this project is to implement the hardening soil model in an in-house finite element code and possibly export it as a user material into Abaqus.

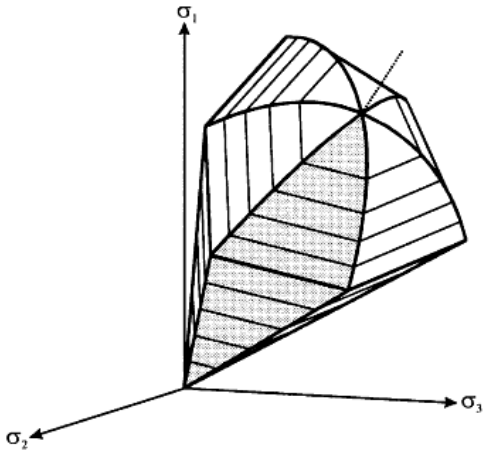


Figure 3. Representation of total yield contour of the Hardening-Soil model in principal stress space for cohesionless soil.

Main activities: The main activity of the project would be to study and implement the Hardening Soil model into a finite element program, and compare results with e.g. results from Plaxis.

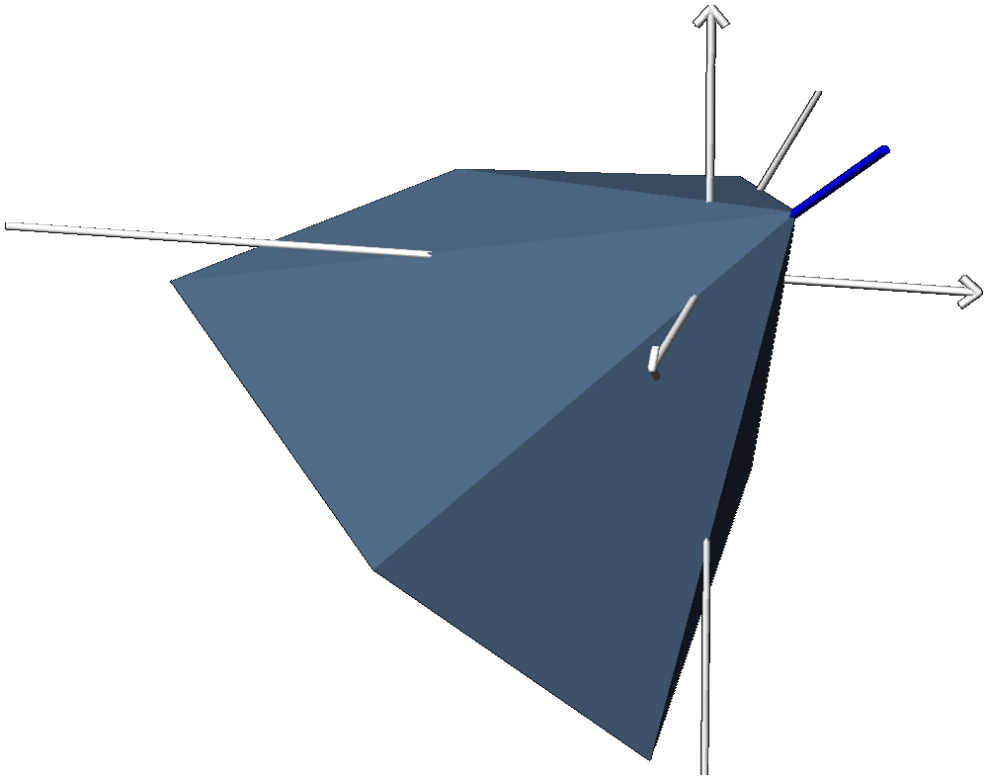
An interest in programming, e.g. MatLab, is essential.

Contact person: Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Implementation of a plasticity model into the finite element method 4: Extended Mohr-Coulomb

Purpose: For strength calculations, the linearly elastic - perfectly plastic Mohr-Coulomb model is often sufficient for modelling the soil. If a more precise calculation of the deformation is needed, then one option is to turn to more advanced material models. Another option is to extend the classical Mohr-Coulomb model to suit the needed phenomena. An obvious extension to the model is to include a hardening response, i.e. to include an evolution of the yield surface and/or plastic potential surface. Other options could be to combine the Mohr-Coulomb model with non-linear elasticity, or perhaps a compression cap to simulate particle crushing.



Main activities: A study of the chosen extensions should first be conducted, along with a study of non-linear finite element coding. Next, the chosen extensions should be implemented. If time permits, user material models for Abaqus and/or Plaxis could be created.

An interest in programming, e.g. MatLab, is essential.

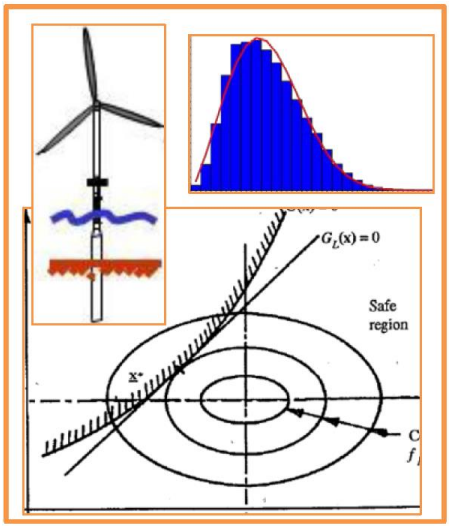
Contact person: Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Reliability based design of offshore wind turbine foundation

Purpose: To develop and demonstrate framework for design of an offshore wind turbine foundation with application of probabilistic methods. The suggested methodology shall be able to verify values of safety factors given in present design standards and indicate potentials for reliability based optimisation. The project is proposed by Vattenfall.



State-of-the-art methodology for design of supporting structures is based on prescribed safety factors that are to reflect uncertainty of design parameters such as load and response. Furthermore the safety factors are usually regulated according to the consequences of a potential failure. The design framework presented in standards is built on experience and based on typical design solutions. Whenever a design concept and/or probability profile of design variables deviates from a typical ones considered in standards, the safety factors are challenged and the result can be either over conservative or even unconservative. The former being economically undesired and the latter dangerous as giving false feeling of safety.
Technology as well as technical knowledge constantly develop and the design variables can now be described more precisely and specifically depending on the application. This builds a ground for more direct design methods based on stochastic approach and reflecting the real (on the contrary to assumed) nature of design variables. That will definitely allow for designs optimised according to their specific application and a desired risk profile.

Main activities:
The main scope of work is to define a framework for analysis of reliability of design of an offshore WTG foundation. The work shall be based on a deterministic model that is controlled by a defined set of variable parameters. The parameters are to be described in a stochastic way and reflect, to a practical degree, realistic probability distributions of particular design variables. By application of probabilistic methods the framework shall allow for assessment of reliability of the design by means of reliability index or similar.
Furthermore, the work should include sensitivity studies and for selected parameters demonstrate influence of their modified stochastic characteristics on the final design.

Options: Yet another challenge is a reliability based optimisation of a design. The work should be concentrated on creating a framework allowing for optimisation of a design based on both cost and reliability.

Contact persons: John Dalsgaard Sørensen, Jannie Sønderkær Nielsen, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Reliability based planning of inspections of foundations in a large offshore wind farm

Purpose: To develop and demonstrate framework for planning of inspections of wind turbine foundations in a large offshore wind farm. The methodology shall be based on probabilistic approach and allow for determination of inspection schedule for individual foundations from the structure reliability point of view. The framework shall utilise effect of numerous foundations featuring similar design and subject to similar external conditions. The project is proposed by Vattenfall.

Normally foundations are designed in such a way that the inspections are not necessary. This is achieved by selecting relevant safety factors. However, there might occur extraordinary conditions that impose an inspection requirement. This could be on intention, where savings are anticipated by introducing an inspection regime in the design phase and thus allowing for reduction of safety factors. But this could be also due to unforeseen structural integrity issues of a serial character that invalidate design assumptions and where inspections are seen as a risk mitigation measure.
Inspections of offshore structures are relatively expensive and inspecting every foundation at a fixed interval and regardless of findings is impractical. The reliability based approach offers a methodology to plan inspection intervals according to change of structural integrity reliability level and allow for upgrades of reliability should inspection not reveal any failures or damages. Thus intervals can be designed such that reliability level is always kept above an allowable limit.

Main activities:
The main scope of work is to define a framework for planning of inspections of foundations based on probabilistic methodology. The framework shall include a timewise degradation model for reliability of structure integrity, shall utilise stochastic model of inspection quality in terms of failure detection and take advantage of a large number of foundations of the same type and exposed to similar external conditions.
Result of the work shall be demonstrated in form of an inspection plan designed for a specific wind farm optimised according to inspection quality and number of similar foundations.

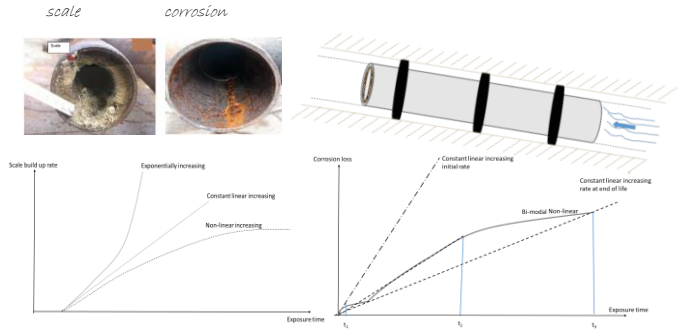
Options: Include in the model a variability of both designs and external conditions across the wind farm.

Contact persons: John Dalsgaard Sørensen, Jannie Sønderkær Nielsen, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Reliability analysis of offshore wells: interaction of fatigue, corrosion and scale

Purpose: The production tubing of oil & gas wells constitutes a main component within the primary barrier to avoid leakage of production fluids into the secondary barrier and into the environment. Despite corrosion is identified as a main degradation mechanism which affects the performance of the tubing in terms of 'fluid containment', other failure mechanisms need to be considered such as fatigue crack growth due to pressure cycles during service and presence of scale (deposit inside tubing) of various types.
Therefore, an extended analysis of the failure mechanisms, which the tubulars may be subjected to, is important in order to have the necessary models to evaluate the reliability considering risk of burst, pipe wide longitudinal cracking and corrosion pit holes.
Fragility analysis is a method widely used in reliability engineering to evaluate the probability distribution of damage levels with respect to specific failure mechanisms and associated probability of failure for structural components. The methodology will be applied to model the behaviour at failure of a typical tubular section in between 2 elastomeric packers (possibly pup joints too) with FEM analysis, the spatial and temporal variability of corrosion is introduced, while scale accumulation can be modelled as a counting process where the thickness of the scale increases over time.



Objectives:
The aim is to identify failure modes for the tubing in the wells, where different mechanisms are interacting and calculate fragility curves with respect to service pressure, corrosion rate and scale thickness.

Main activities: The project will contribute to the on-going research in DHRTC (Danish Hydrocarbon Research and Technology Centre) and the following activities can be included:

- Numerical modelling of a typical production tubular
- Case study of a segment of tubular affected by corrosion and internal scale
- Develop calculation code for fragility and reliability analysis

Contact persons: Simona Miraglia, John Dalsgaard Sørensen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☐ **short master:** ☒ **Long master** ☒

VATTENFALL

Welding technology for improvement of fatigue performance of thick plate butt welded joints in wind industry structures

Purpose: Review of welding procedures with potential to improve fatigue performance of thick plate butt weld joints by influencing weld parameters important for fatigue resistance.

Post-welding residual stresses and geometry of a weld reinforcement in butt weld joints are obvious parameters that influence fatigue performance of a welded joint. The former by contributing to surface crack opening and the latter by generating local stress concentrations.

It has been proven by the Joint Industry Project SLIC (fatigue test program targeting fatigue performance of thick plate butt welds) that number of cycles to failure can be directly related to geometry of the weld face. When looking at geometric parameters, it has been found that an angle and curvature of a weld toe (i.e. at transition between flat surface of the adjoining plate and the bumpy surface of weld face) contributed most to fatigue performance of a butt weld joint. Height and width of the weld reinforcement could also have played an important role. By designing a welding process such that all of this parameters are minimised, stress flow through the weld could be streamlined and fatigue performance of a welded connection would be improved.

Main activities: Project shall make a review of state-of-the-art technologies with respect to welding procedures for assembly of thick plates in wind industry structures. Review and analysis of various methods should focus on post-welding residual stresses, on geometry of weld face as well as other parameters potentially influencing fatigue performance. Project shall explore welding procedures with potential of improving parameters important for fatigue performance and suggest a complete welding procedure proposal. Reasoning presented in the thesis might be supported by respective simulations.

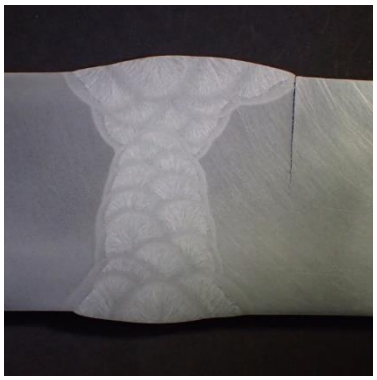
As an option a demonstration of the suggested improvement could be done by producing actual weld samples, performing measurements and tests.

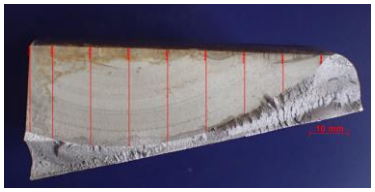
Contact persons: John Dalsgaard Sørensen, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Surface crack growth magnification factor for assessment of thick plate butt weld joints by Linear Elastic Fracture Mechanics





Purpose: Results of the project shall be a set of formulas for evaluation of magnification factors specific for assessment of crack growth in a butt weld joint. Formulas shall be applicable for assessment of butt joints of topology and geometry common in wind industry, e.g. towers and monopile foundations.

Surface crack parameters for fracture mechanics assessment as well as specific methodology for cracks in a flat plate are well described in literature and appropriate standards. Challenges arise when an analysis has to be done for a flaw in a structure detail that features stress concentrations. It is acknowledged that stress distribution around a crack in a flat plate and in a detail with stress concentrations will be different. In order to be able to use the known methodology also to the latter group of details it is necessary to evaluate that difference and establish a set of dimensionless magnification parameters, known in literature as M_k factors. Such a work with application of Finite Element Analysis (FEA) has been done in the past for a general type of a welded joint detail. The analysis has been based on fillet weld connection for a variety of different geometries of attachment element and variety of weld toe angles. A set of formulations approximating results of FEA have been proposed. It is however uncertain whether the proposed methodology is sufficiently accurate and allows to represents real physics of crack propagation in a butt weld joint. As fracture mechanics analysis of butt welds is rather common in wind industry, it would be desired to have a methodology dedicated specifically to this type of joints.

Main activities: Project shall focus on topologies and geometries of butt welds used in supporting structures of wind industry. A FEA based parametric study of crack growth is to be performed for an applicable range of geometrical weld joint parameters and crack sizes. The results of FEA in form of respective magnification factors shall be approximated to analytical formulas with dimensionless parameters representing weld joint geometry as an input.

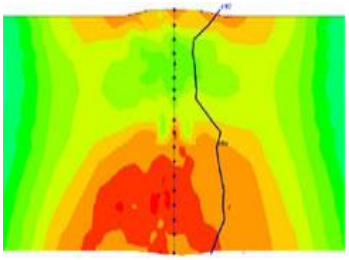
The work shall demonstrate differences in fatigue lifetime for various geometrical parameters of butt welds and compare to S-N based method of fatigue assessment.

Contact persons: John Dalsgaard Sørensen, Lars Damkilde, Dariusz Eichler (Vattenfall)

Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Fracture mechanics methodology for prediction of surface crack growth in thick plate butt joints with high post-welding residual stresses.



Purpose: To present a methodology for fracture mechanics based evaluation of crack growth in joints with high post-welding residual stresses. The project shall further describe uncertainties of the method with respect to evaluation of residual stresses and shall indicate existing knowledge gaps.

Post-welding residual stress in a welded joint is a common phenomenon but evaluation of stress level and distribution in a joint is challenging, given different welding procedures, stress shakedown effect and local plastic deformations under extreme loads. Nevertheless residual stresses in welded joints are usually very high, up to yield level, and unevenly distributed. A methodology for crack growth assessment available in the industry standards suggests to account for that by application of a crack growth curve for a higher R-ratio (maximum over minimum test stress ratio). It is though not clear how accurate the methodology is, given that the actual stresses and thus stress ratios along the crack front will change with crack depth and for different applied load ranges. Local plasticity of areas where combination of residual and operational stresses exceeds yield point, adds further complexity to the analysis. It would be then desired to work out a reliable methodology that takes into account realistic residual stress distribution and would allow for more accurate prediction of fatigue lives of welded joints.

Main activities: Based on study of literature and industry standards within fracture mechanics (FM) project shall establish state-of-the-art and identify gaps being a potential for inaccuracy of present methodologies. The study shall also cover distribution of post-welding residual stresses in butt weld joints of thick plates both without and with post-welding treatment/stress release.

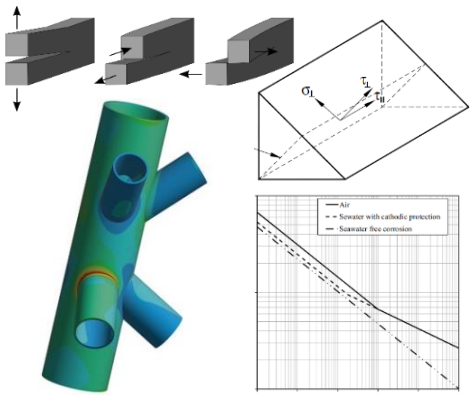
An analytical FM method or modification of an existing method taking into account residual stresses shall be suggested. The methodology shall be validated by finite element simulation of crack growth through the plate thickness and compared with existing benchmarks, if available. All assumptions shall be listed and knowledge gaps identified leading to suggestion for further work.

Contact persons: John Dalsgaard Sørensen, Lars Damkilde, Dariusz Eichler (Vattenfall)

Theory: ☒☒☒ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Fatigue assessment of joints under multiaxial stress exposure with focus on nodes of a jacket type of wind turbine offshore foundation



Purpose: To develop a methodology for evaluation of fatigue resistance of nodes of a jacket type of wind turbine offshore foundation taking into account multiaxial distribution of local stresses and load exposure history.

Jacket type of supporting structure features complex topology of component beams and rather complicated geometry at nodes, i.e. junction points of beams. Direct effect of complexity of the topology is an equally complex load pattern. That implies that weld details at node connections are subject to variable multiaxial stresses. Normally fatigue of structure details is assessed against S-N curves which are a convenient way of calculating an accumulated effect of varying stresses. S-N curves however are usually formulated based on results of tests with a uniform distribution of stresses and of a strictly defined magnitude. The phenomenon of crack initiation and propagation in such a test is usually based on Mode I of crack development with some degree of Mode II. That is not the case for jacket details where all three modes are involved. For a S-N curve approach based principally on effect of normal stresses it is not very clear how accurate it turns to be if normal stresses are accompanied with shear stresses related to Mode II and III of crack development.

Main activities: The work shall focus on identification of load patterns typical for a node of a jacket foundation in offshore wind applications. Through an FE based analysis the project will establish stress distributions in selected weld details around the joints. Then fatigue capacity will be evaluated by means of procedures presented in relevant standards using applicable S-N curves. For the comparison the scope of work will include a Fracture Mechanics analysis of crack growth in the details subject to the same load pattern. In order to demonstrate an applicability of a linear fatigue accumulation model, crack growth analysis will be also performed for different sequences of particular load groups in the load pattern. Fracture Mechanics procedure shall take into account all three modes of crack growth.

The outcome of the project shall be formulated as a recommendation regarding methodology for fatigue assessment of jacket node welded connections exposed to a multiaxial and variable stress conditions as well as a setup of a test for validation of the proposed methodology and results of fatigue analyses.

Contact persons: John Dalsgaard Sørensen, Lars Damkilde, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☒
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master:** ☒

VATTENFALL

Methodology for structural assessment of nodes of jacket type of offshore wind turbine foundations

Purpose: Results of the project shall be a guideline for structural assessment of nodes in jacket type structures for offshore wind applications. The guideline will focus on which type of FE models for assessment of nodes are the most practical for the purpose of determination of Stress Concentration Factors (SCF) in jacket nodes and for representation of node stiffness in a beam-based simulation model of the whole jacket.

Jacket type of supporting structure features on one hand a complex topology but on the hand is composed of considerably simple and slender tubular elements. The latter means that a suitable simulation model should be based on beams which are faster to solve and thus allow for analysis of a large number of load cases, which is typical for assessment of a jacket structure. Joints of cylindrical elements however introduce extra stiffness/flexibility that cannot be easily handled by a model completely composed of beams. Then nodes are replaced by super-elements representing stiffness matrix of a node alone and simulations are carried out with such a hybrid model.

When internal forces in a model are determined through simulations, super-elements can then be again used to retrieve local stresses in a node with the calculated forces as an external load. Alternative to that could be to assess local stresses directly by means of calculated internal forces and corresponding SCF calculated beforehand for each node detail. Both approaches to determination of local stresses require though a realistic FE model of a node structure that is usually executed in 3D and built of either solid or shell elements.

Main activities: The exercise is to compare two models of a jacket node, respectively with shell and solid elements, and analyse pros and cons including quantitative evaluations. Within the project a number of simulations will be performed in order to demonstrate and to evaluate differences in terms of accuracy as well as time consumption and workload. The exercise is to be performed for both aspects of node assessment: stiffness and local stress. Conclusions shall be formulated as a set of recommendations on how to build a proper model. Additionally, an analytical model for calculation of stiffness and SCF purely dependent on geometry and topology of the nodes would be desired because of a potential for major acceleration of the design process, provided that reasonable accuracy of the approach is documented.

Contact persons: John Dalsgaard Sørensen, Lars Damkilde, Johan Clausen, Dariusz Eichler (Vattenfall)

Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Influence of corrosion pitting on fatigue resistance

Purpose: To establish a relationship between degree of corrosion pitting in steel structures and increased likelihood of fatigue failure.

Offshore wind turbine structures are mostly made of steel and exposed to harsh working conditions one of them being corrosive environment. Corrosion, by causing damage to a smooth surface of a structure member, has a non-reversible effect on its fatigue performance. It is particularly pronounced in case of corrosion pitting whose irregular shapes and aggressive character creates conditions for local stress concentrations and thus increased exposure to crack initiation and fatigue.
Existing standards treat corrosion in terms of fatigue uniformly without looking into details of corrosion morphology. Moreover, current fatigue assessment methodologies based on S-N curves do not take directly into account a timewise aspect of development of corrosion. Neither is it possible to assess fatigue resistance of structures which were initially exposed to corrosion and covered by corrosion protection afterwards.
As corrosion and fatigue are going to remain a major challenge for offshore wind structures, industry needs to know much more about interaction between the two.

Main activities: The project will mainly look at the effect of corrosion pitting in structural steels by analysis of shape of the corroded surface. Examples of corrosion pitting, including description of corrosion pits such as development time, size and shape, representative for offshore structures shall be collected and systemized. Each category of pitting shall be subject to Finite Element Analysis in order to evaluate a corresponding stress concentration factor (SCF) and thus forming a reference matrix for assessment of severity of corrosion in terms of increased risk of fatigue. The project may also cover a fracture mechanics (FM) approach and investigate influence of pit forms on crack initiation and growth.

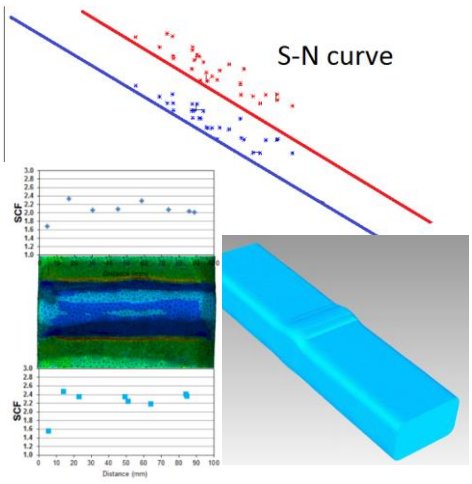
It is anticipated that project will perform a review of existing standards and, based on knowledge collected throughout the project work, will suggest how to handle information about corrosion pitting while assessing fatigue for offshore steel structures.
Project shall suggest a research programme that will address the remaining issues and thus will allow closing identified knowledge gaps.

Contact persons: John Dalsgaard Sørensen, Dariusz Eichler (Vattenfall)

Theory: ☒☒☒ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem:** ☒ **short master:** ☒ **Long master:** ☒

VATTENFALL

Butt weld joint 3D geometry and notch stress approach to fatigue assessment based on S-N curves



Purpose: To establish a relationship between butt weld joint 3-dimensional (3D) geometry and its fatigue resistance. Evaluation of applicability of a generic notch stress S-N curve for the purpose of fatigue assessment.

Fatigue is one of the main drivers in design of offshore foundations. Fatigue resistance of a weld joint is to a large extent dependent on geometry of the weld face. It is particularly pronounced by comparison of "as-welded" joints and "ground-flush" joints where the weld face has been removed by grinding. It is anticipated that S-N curve based assessment could take an actual geometry of a weld into account. This could be accomplished by a generic local stress S-N curve where effects of stress concentrations in the weld would be normalised and such an S-N curve would be related to a stress in a very local weld detail. It is anticipated that such a curve could turn to be universally applicable for all welded joints but would require scaling upon weld geometry by a representative Local Stress Concentration Factor (LSCF) assessed by either a Finite Element Analysis (FEA) or a parametric formulation.

Main activities: Project shall be based on results and post-mortem data from fatigue test programme executed within the Joint Industry Project SLIC. A series of FEA using the actual geometry of tested joints will be performed to document distribution of local stress concentration areas and correlation with fatigue failure initiation points. Respective LSCF related to notch stresses will be calculated and a generic, local stress based S-N curve will be formulated. A methodology for extracting geometry from actual weld samples by scanning and a following FEA is to be investigated and presented in form of a guideline.

Another part of the project should focus on Fracture Mechanics (FM) model of crack propagation in the weld joint. Model of the weld joint will be 3D and will assume the crack initiation point at location with the highest LSCF. Results of the analysis shall demonstrate conformity of the FM with the SLIC test results. The FM analysis may be additionally performed for a specimen with multiple cracks and will demonstrate mechanism of the first crack arrest and new crack initiations and mobilisation of the first crack again until the final failure .

Contact persons: John Dalsgaard Sørensen, Lars Damkilde, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Revision of formulations for assessment of buckling resistance of wind turbine supporting structures built of large thin-walled tubulars

Purpose: To investigate a possibility of an update of present methodology for evaluation of buckling resistance of large thin-walled tubulars used in supporting structures in wind industry, e.g. towers and monopile foundations.

There is a notion in wind industry that the buckling assessment methods used nowadays might be overly conservative and not reflecting the load patterns encountered by a wind turbine supporting structure. Moreover, the production processes constantly improve accuracy of an assembly resulting in smaller geometrical imperfections. It would be desired to capitalise on that development and directly include fabrication tolerances as a part of the buckling assessment equation.

Main activities: Project shall focus on topologies, dimensions and fabrication tolerances of supporting structures common in wind industry at present and with an appropriate projection into future. A study of loads and associated buckling failure modes shall be presented along with review of present buckling resistance assessment methods used in wind industry.

A series of Finite Element (FE) parametric studies of buckling, covering a range of structure dimensions and including fabrication tolerances as well as different load patterns is to be performed. The collected result database shall be used to draw general conclusions and, if possible, to obtain generic formulations that will be used along with present buckling assessment methods or will replace them completely. Such defined methodology shall be further validated against known benchmarks. If deemed desired, a scope of necessary tests to validate applicability of the method is to be formulated.

Additionally the project may have a look at buckling assessment of a structure embedded in soil both while driving into a ground by high impact hammers and later in operation. Here both large highly dynamic forces as well as elasticity of the surrounding soil create different boundary conditions compared to the over-ground part of the structure.

Contact persons: Lars Damkilde, Johan Clausen, Dariusz Eichler (Vattenfall)

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

VATTENFALL

Analysis of design alternatives to a typical solution for a connection between suction caisson and a leg of a jacket type supporting structure for an offshore wind turbine

Purpose: To perform an analysis of a range of different solutions for the connection where assessment of solutions will be based on criteria of structure integrity, manufacturing friendliness and cost.

A jacket type of an offshore wind turbine foundation is typically fastened to the sea bottom by piles. In this solution piles are driven to the seabed before the jacket is installed. Fastening of the jacket to piles is executed by grouting. Installation of a pre-piling solution is rather complex and time consuming. It is neither suitable for all soils as e.g. with underlaying rock.

Therefore recently a jacket offshore foundation with a suction caisson at each leg as a way of fastening the foundation to the seabed has been proposed. Installation of such a jacket is conducted in one-go by pumping water out of a caisson and thus "sucking" it to the seabed. Solution is promising and developers are planning to use it more widely.

A typical connection between a suction caisson and a jacket leg is however rather abrupt. This brings complexity to the structure design and manufacturing. Especially welding of a jacket leg to the caisson is a difficult operation and subject to a quality issues. Industry would welcome a more production friendly solution keeping the capabilities of a suction caisson as a base for a jacket foundation.

Main activities: Project will suggest a range of different solutions for the connection. Each of the solutions shall possess a required capacity in terms of strength that will be proven by FE analysis. Then solutions will be subjected to thorough analysis of cost and production friendliness. The latter will include division between processes conducted inside a workshop and in atmospheric conditions at an assembly yard.

Project may also suggest innovative solutions related to a suction caisson based jacket type of offshore wind turbine supporting structure.

Contact persons: Lars Bo Ibsen, Lars Damkilde, Johan Clausen, Dariusz Eichler (Vattenfall)

Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Risk-informed decisions for up-classification of existing bridges

Purpose: The purpose is to develop a framework for risk-informed decision support, when existing bridges need to be up-classified to allow for passage of larger trucks, than they were originally designed for.

Bridges are designed to meet certain classes, which determines how large special truck that are allowed to pass the bridge. Often, large trucks need to find alternative routes, if the classification of bridges of the nearest route is insufficient. However, although the bridges were originally designed to have a lower capacity, it might have larger capacity than assumed in the design. Tests such as proof loading and material testing can be performed to reduce uncertainties of the bearing capacity, and an up-classification might be possible, without any strengthening. However, proof loading is expensive, and there is a risk that the bridge might collapse during the test, therefore cheaper tests might be preferable, although less accurate. To provide rational decision support for those decisions, a risk-informed decision framework can be made for testing of existing bridges considering e.g. costs of material testing, costs of proof loading, costs of advanced modelling, and risk of failure during proof loading.

Main activities:

- Reliability analysis of existing bridges
- Reliability updating using proof loading and material testing
- Inclusion of advanced nonlinear models through e.g. response surfaces
- Formulation of cost models
- Development of decision framework based on the Bayesian decision theory

The project will be performed in collaboration with COWI.

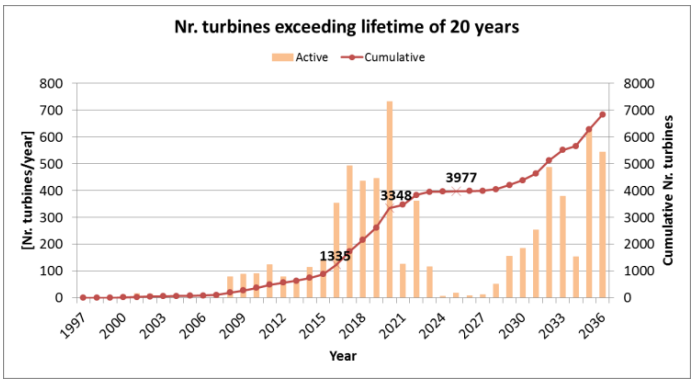
Contact persons: John Dalsgaard Sørensen, Jannie Sønderkær Nielsen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Life extension for wind turbines

Purpose: The purpose of this project is to contribute to optimal decision making in relation to life extension of ageing wind turbines.

Within the next few years, thousands of wind turbines in Denmark will reach their design life time of 20 years. However, if it can be shown that the risk of structural failure upon continued operation is acceptable, the turbine should be allowed to continue operation. For example, the fatigue life usage can be estimated using load observations or SCADA data. Although not critical for safety, the condition of non-structural component influence expected maintenance costs, and is relevant to consider for profitability. Inspections and testing can also be used to assess the current health of components.



Main activities:

- Literature survey on life extension for wind turbines
- Assessment of fatigue life usage based on data
- Reliability analysis of wind turbines
- Reliability updating using data from tests
- Estimation of maintenance costs

The project will be connected to the ongoing research project LifeWind with participation of industrial partners.

Contact persons: John Dalsgaard Sørensen, Jannie Sønderkær Nielsen,

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Risk-informed operation and maintenance for offshore wind turbines

Purpose: The purpose of this project is to apply risk-based techniques and Bayesian statistical methods for planning of O&M activities in practical applications incl. modelling of costs and risks in connection with O&M for offshore wind turbines.

Costs to operation and maintenance (O&M) of offshore wind turbines are large, typically more than 25% of the cost of energy. The costs consist of planned maintenance and corrective maintenance due to failure of components such as gearboxes, electrical components and blades, due to e.g. wear and fatigue. One main contributor to the high offshore O&M uncertainty and costs is the dependence on weather windows. In other engineering areas such as the offshore oil & gas industry and civil engineering bridges, rational approaches to planning of O&M have been developed. These approaches are based on risk and reliability-based techniques where it is possible to plan rationally future actions based on available information at the time of decision and models for costs and uncertainties.



Main activities:

- Literature survey to give an overview of decision problems and methods for O&M planning
- Development of risk-based decision models and illustrative examples for selected problems e.g.
    - Optimal planning of inspections and maintenance for selected components
    - Combining several types of data for diagnostics using Bayesian methods
    - Short term decisions based on probabilistic weather forecasts

The project will be connected to ongoing research projects and can contain external collaboration.

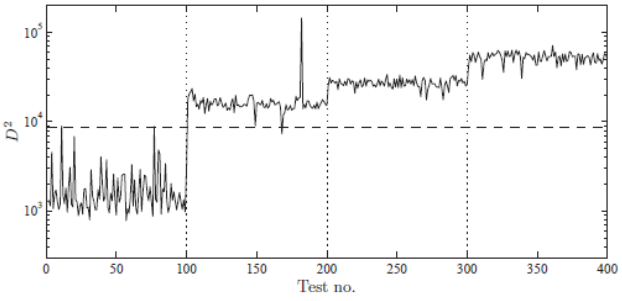
Contact persons: John Dalsgaard Sørensen, Jannie Sønderkær Nielsen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Value of information of structural health monitoring for wind turbine blades

Purpose: The purpose of this project is to quantify the value of information of structural health monitoring for wind turbine blades.

For offshore wind turbines, operation and maintenance costs are large. To reduce the need for expensive blade inspections and unexpected repairs, structural health monitoring (SHM) systems can be used to monitor the condition, for example using vibration-based detection methods. However, SHM systems are not perfect, and impose an extra cost. Therefore, the profitability of SHM should be quantified. This can be done using the concept of value of information (VoI), originating in the Bayesian decision theory, which has gained interest within many areas of civil engineering in the recent years.



Main activities:

- Modelling of the reliability of structural health monitoring
- Formulation of decision models
- Estimation of expected costs and VoI using Bayesian decision analysis
- Sensitivity studies

The project will be made in co-operation with a manufacturer of a structural health monitoring system, Brüel & Kjær Sound & Vibration.

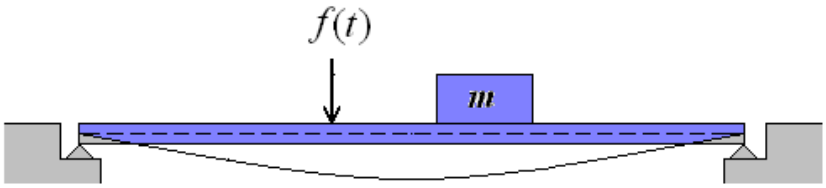
Contact persons: Jannie Sønderkær Nielsen, Martin Ulriksen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

Dynamic human-structure interaction

Background: In static calculus, passive (sitting/standing) humans are modelled as a rigid mass attached to the structure. In dynamics, humans in motion (people walking or jumping) are modelled as a dynamic load bringing the supporting structure into vibration.

Human in motion Passive person



In assessments of vibration levels of slender structures carrying humans (such as footbridges, stadia-structures, or office floors) these models are conventionally employed. But are they reasonable?

Purpose: The aim of the project is to study mechanisms of human-structure interaction focusing on areas where the models mentioned above are inadequate. Prior to codifying new models describing the phenomena, they need to be properly researched.

In the project you will plan and conduct experiments striving to highlight the true mechanisms of human-structure interaction on slender structures. Measured vibration data will allow you to calibrate alternative models of the interaction accounting for the flaws in existing models.

Implications of findings (new models of the interaction) you may illustrate through computer simulations of structural response to the dynamic loads generated by humans.

Contact person: Lars Pedersen

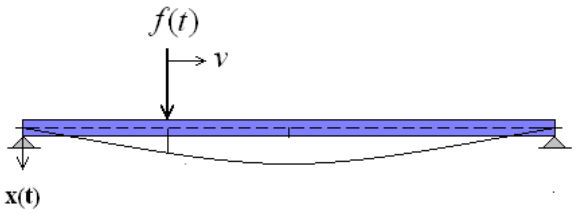
Theory: ☒☐☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☐

Dynamic human loading and stochastic models for estimating structural responses

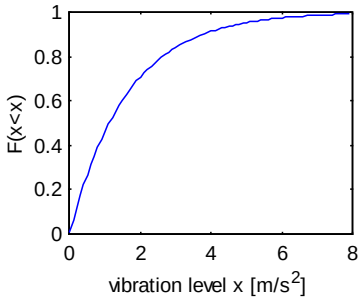
Background: Some civil structures are so slender that their modes of vibration may be excited by the basic frequency of human motion resulting in resonant structural action. The undesired resonant action may for instance occur in footbridges, stadia structures or in open-space office floors as a result of walking or jumping.

Codes and standards handle the phenomenon semi-empirically or even fully deterministic although fundamentally the loading generated by humans in motion is stochastic.

Purpose: The aim of the project is to develop and test stochastic models describing the loading and the structural response. An essential contribution would be to derive statistical distributions of structural responses to human-induced loading, as this would provide valuable information for assessing structural safety or serviceability. Specifically, the risk of exceeding various vibration levels is of interest although it is actually a parameter not given much/any focus in existing design codes.



Walking load when v > 0 m/s, "Jumping load " when v = 0 m/s



Statistical distribution of response

Through the project you will learn how to model the dynamic excitation of humans in motion, deterministically as well as stochastically. You will conduct parametric studies and numerical simulations to highlight essential implications of stochastic modelling of the phenomenon. Experimental verification of models is a possibility if so desired.

Contact persons: Lars Pedersen, Christian Frier

Theory: ☒☐☐ **Experimental works:** ☐☐☐ **Computer modelling:** ☒☒☒
(The amount of experimental work can be decided during the project)
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☐

Finite-element modelling of reinforced concrete

Purpose: Reinforced concrete is widely applied as a construction material in civil engineering. Concrete is a complex material, both chemically and mechanically, and the formulation of material models demands a deep knowledge of the behaviour during casting, curing, utilization and, eventually, degradation. The introduction of reinforcement results in a composite material. In this case, the interaction between the concrete matrix and the steel reinforcement must be accounted for as well.



The idea in this project is to use advanced finite element calculations, e.g. via ABAQUS, to model reinforced concrete. Different methods should be compared, and a comparison with analytical methods should also be included. The project may focus on the analysis of a particular problem or structure.

Main activities:

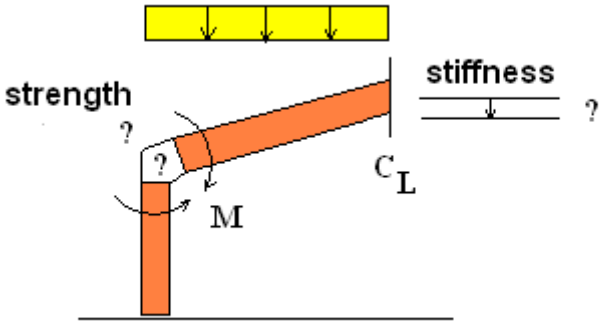
- Formulation of material models for concrete. This can be both built-in models in Abaqus and user supplied models, or any other software.
- Modelling of interfaces between concrete and reinforcement
- Finite-element analysis of reinforced concrete structures
- Comparison of FE models with standard design methods.

Contact person: Johan Clausen

Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☐

The corner of laminated timber frames

Purpose: Laminated timber frames are, for instance, desirable in structures where the aesthetics of the structure is in focus. A weak point in a timber frame is the frame corner and its strength and stiffness. But perhaps the corner does not need be made of wood?



Could a reinforced concrete structure or a steel structure be employed in the corner instead? At least the drawbacks of a corner made of wood might be removed and by employing wood in the remaining part of the frame, the frame would still visually appear much like a full wooden frame.

Main activities: The aim of the project is to explore the stiffness and strength of a timber frame employing different solutions in the corner of the frame (steel and/or reinforced concrete and using the full timber frame as reference).

In the project you will develop numerical and analytical models for the various solutions and full-scale tests will be conducted aiming at verifying the strength and stiffness predicted by your models.

Should your investigations reveal that solutions with steel or reinforced concrete in the corner of the frame are feasible (in terms of strength and stiffness) it might indicate a potential for a new type of frame structures.

The project might involve co-operation with external parties having an interest in mapping the potential of alternative solutions for timber frames.

Contact persons: Lars Pedersen, Christian Frier

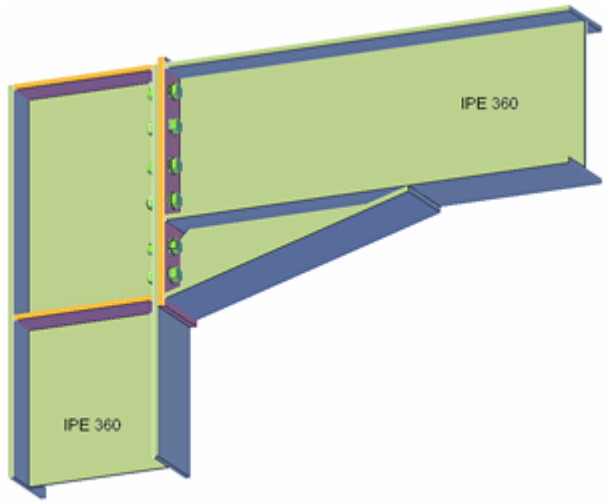
Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☐

Analysis of Joints in Steel Structures

Purpose: Joints in steel structures are frequently made using fasteners. These are not fully rigid which may play a role in terms of behaviour of the steel frame.

The purpose of the project is to investigate how flexibility in joints influences various global characteristics of the steel frame, and to study how Eurocode models these influences.

Another item of interest is to explore the load bearing capacity of joints made using fasteners (analytically, numerically, and experimentally) and to compare results with Eurocode models.



Main activities: The project is relatively open with concern to the problem to be analysed. However, in any case the activities will include:

- A mixture of analytical, numerical and experimental investigations
- Comparison of results with Eurocode models.

Contact persons: Lars Pedersen

Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☐

Advanced Analysis of Steel Frames

Purpose: In ultimate limit state analyses of steel frames compression forces and bending moments are of concern, as they may lead to global instability manifested in either buckling or lateral torsion failure.

The design guide Eurocode sets up procedures for evaluating the ultimate limit state and actually, Eurocode (EC) suggests a number of different design approaches to choose from. Some EC-approaches are more simplifying than others, and this means that the final evaluation of the ultimate limit state depends on the method chosen for the evaluation. Or does it?

The purpose of the study is to highlight and quantify load carrying capacity of steel frames employing different methods, ranging from basic methods to more advanced methods (in all methods FE-analyses are required but to various degree of complexity).

In the initial part of the study, focus will be on analysing a reference steel frame, but in order to highlight the degree of differences in calculated load carrying capacities it is useful to extend the study. This, for instance, by studying a range of steel frame configurations or to conduct some other type of parameter study focusing on sensitivity of outcome of your calculations to input assumptions related to structural modelling.

Main activities: Besides, from a literature review focusing on the background for EC-guidance focus will be on

- Implementing and describing procedures
- Finite element modelling and analyses
- Parameter and sensitivity studies

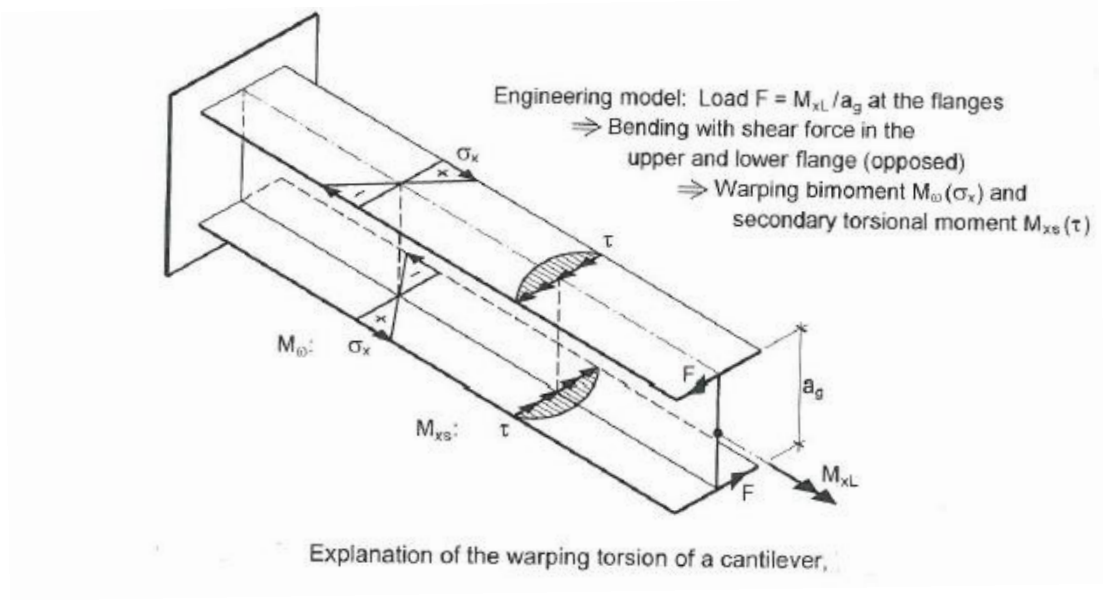
so as to provide an overview of load carrying capacities of steel frames as computed using different methods.

As part of the study it might be useful also to analyse one of the steel frames which recently collapsed due to heavy snow loads.

Contact persons: Lars Pedersen, Johan Clausen
Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐
Suitable project type(s): **3rd sem** ☒ **short master:** ☒ **Long master** ☐

Implementation of advanced beam finite elements

Purpose: The Eurocode for steel now makes is possible to use advanced finite element modelling to document the safety of steel structures. In the classical method interaction formulae for each steel member is used based on the linearly elastic section forces. The new method, however, allows for non-linear modelling and the documentation for larger portions of the structure at a time, i.e. not for every member. To be able to use this new method, non-linear models must be applied together with 3D elements. If possible, beam elements are preferred over shell and solid elements as the latter two result in soaring numbers of degrees of freedom. Many standard beam elements, however, do not account for the needed non-linear phenomena, or even the proper formulation for torsion.



Explanation of the warping torsion of a cantilever,

Main activities: Study, development and implementation of beam finite elements that incorporates one or more of the aspects of the advanced phenomena needed to use the new method in the steel Eurocode. These phenomena are large displacements, buckling (Euler and lateral torsional), torsional behaviour and material nonlinearities (plasticity). An interest in the finite element method and programming, for example using MatLab, is essential.

Contact person: Johan Clausen
Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒
Suitable project type(**s**): **3rd sem** ☒ **short master:** ☒ **Long master** ☒

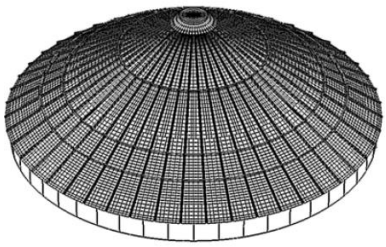
Example of company stay project

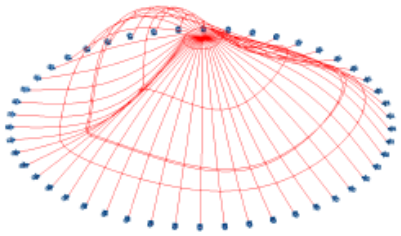
Analysis of snow-load induced damage on conical silo roof

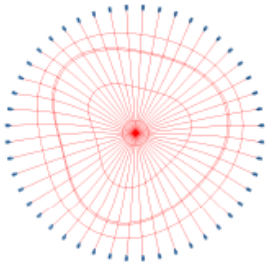
Company: Cowi, Aalborg Office
Company type: Consulting engineering company
Webpage: www.cowi.dk, www.cowi.com
Location: Aalborg

In the winter of 2009/2010 heavy snowfalls occured in Northern Jutland in Denmark. The ensuing large snowloads caused several roof collapses throughout the region. Among these were the several roofs of silos for crop storage. Crop silo structures are typically composed of corrugated steel sheets stiffened by steel profiles.

The company wanted to perform a detailed analysis of these collapses to assess the cause(s), and this was chosen as a project for the student doing the company stay.







The structure was studied by means of finite element analysis, including non-linear effects such as bifurcation buckling, large displacements and plasticity. Also, different detail levels in the modelling were compared, as was beam and shell models.

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