3rd Semester and Master's Thesis Ideas

M.Sc. in Civil and Structural Engineering

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Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

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Edited by Johan Clausen

ISSN 1901-7308
DCE Latest News No. 9

AALBORG UNIVERSITY
Department of Civil Engineering

Aalborg University
Department of Civil Engineering
School of Civil Engineering

DCE Latest News No. 9

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Johan Clausen

April 2009

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Published 2009 by
Aalborg University
Department of Civil Engineering
Sohngaardsholmsvej 57,
DK-9000 Aalborg, Denmark

Printed in Denmark at Aalborg University

ISSN 1901-7308
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M.Sc. in Civil and Structural Engineering:
3rd Semester and Candidate Project 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. Most of the project ideas in this catalogue may form the basis for long and short candidate projects as well as regular 3rd semester projects at the M.Sc. programme in Civil and Structural Engineering.

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 act as primary supervisors. Questions regarding details about each proposed project should be asked to these persons. Further, other ideas for projects may be discussed with a potential supervisor.

The preferred group size is two to four students. In the interest of students as well as supervisors, single-student projects are generally not recommended.

As a final remark, a signed project plan must be handed in one month after the initiation of the project. This project plan must contain information about the project, in particular regarding the educational goals of the project. These must be defined in accordance with the Master Curriculum as well as the Study Programme Guide for the M.Sc. Programme in Civil and Structural Engineering at the School of Civil Engineering, Aalborg University. A document master for the project plan is available at the homepage of the School of Civil Engineering: www.bsn.aau.dk.

Aalborg, 30 April 2009 Johan Clausen, *semester coordinator*

Influence of climate changes on storm surges in the Limfjord

Problem: Storm surges (stormfloder) from the North Sea penetrate through the Thyborøn Channel to the western and central part of the Limfjord and cause flooding along the coasts of the fjord. In January 2005 the highest storm surge ever observed in the Limfjord induced severe damage on several locations particularly on the cities of Løgstør and Skive.

Because of the expected climate changes both the mean sea level and the storm surges are expected to increase. Furthermore an increase in the wave run-up on the dikes will be seen as well. Accordingly the question whether it should be necessary to close the Thyborøn Channel has come into focus.

A closure of Thyborøn Channel is a complex political and technical task. A closure will include the establishment of a dam across the channel, a sluice for remaining of the water circulation and water quality during normal weather conditions and a ship lock for the navigation. Before a decision can be taken comprehensive feasibility studies should be carried out. A central point will be the modelling of the flooding in the Limfjord in respect to the climate changes for both an open and a closed channel.

Substance of project: The objective is to determine the storm surge water levels on a number of critical locations in the fjord for a future situation where influence of the climate changes has taken place. The driving forces are the water levels in the boundaries (North Sea and Kattegat) and the wind shear stress at water surface. The method is to transform a number of real historical storm surges from the past to the new conditions and make the simulations with the 3-dimensional hydrodynamic model MIKE 3 (DHI- Institute Water and Environment). The digital topographic model (the so-called bathymetry) of the fjord already exists. Data for water levels at the boundary and the wind fields shall be procured from The Danish Meteorological Institute and the Coast Directorate. The direct results of the project could be maps showing the areas expected to be flooded in respect to the related exceeding probability for the flooding.

Supplementary aspects which can be included in the project:

- Design of structures (dam, sluice, ship lock)
- Sediment transport and coastal protection
- Wave impact on structures
- Geotechnical stability of structures

Contact person: Thomas Lykke Andersen and Torben Larsen

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

Run-Up Generated Slamming Loads on Access Platforms for Offshore Wind Turbines

Purpose: When a breaking wave hits a pile a very significant run-up can be generated. This gives rise to extremely large loads on the platform typically around 50 metre water head of slamming pressure. These loads are significantly higher than accounted for in the design of the Horns Reef 1 wind turbine park and as a consequence some damage has been observed. The same problem actually exists in a number of other parks.

Therefore, Aalborg University has previously carried out model tests to clarify these loads. However, it is expected that the load model can be significantly improved by using a different measurement method for the run-up.

In this project several experimental measurement methods for the run-up should be considered and a detailed test programme performed with the method selected to be the most accurate.

Main activities: The main activity is design of the laboratory model and performance of model tests to clarify more detailed the run-up height. Main activities are:

- Design of laboratory model
- Perform initial tests to estimate the uncertainty related to run-up measured by surface elevation gauge, video recordings and a step gauge
- Detailed test programme with the optimum measurement method
- Propose a run-up design formula according to the obtained model test results
- Calibration of slamming load model to previously performed model tests and/or new performed model tests

Contact person: Thomas Lykke Andersen

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

Projects on Breakwater Design

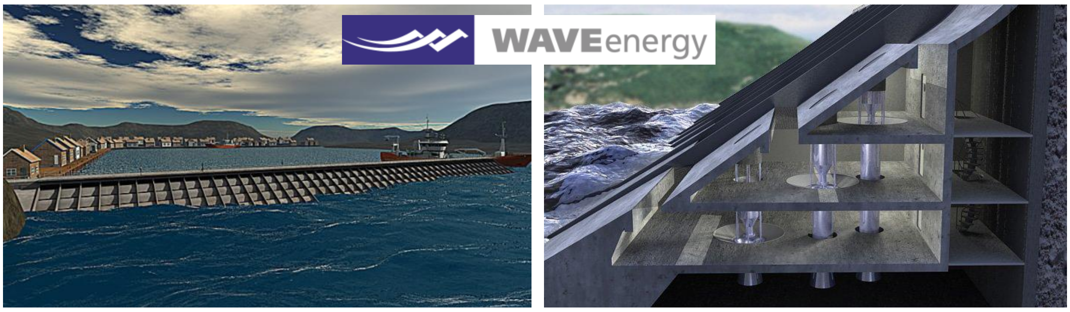
Purpose: A number of different projects are available within breakwater design. We can discuss different possibilities within caisson breakwaters and rubble mound breakwaters depending on main interest area.

The main activity would for most projects be laboratory model tests but also projects with detailed computer modelling are available.

Contact person: Thomas Lykke Andersen

SSG Breakwater Wave Energy Device

Purpose: The Sea-wave Slot-cone Generator (SSG) is a wave energy converter of the overtopping type initially designed to be installed near shore and on breakwaters for coastal and harbour protection, as illustrated below. The device is being developed by the Norwegian company WaveEnergy AS, in cooperation with Aalborg University. The device accumulates the overtopping water in a number of reservoirs at a higher level than average sea water level, for efficient capture of the energy in incoming waves. The potential energy in the stored water is, on its way back to the sea, converted into electricity, as it passes through specially designed low head turbines. The project will focus on one or more of the following key performance aspects of the geometrical design of the SSG – energy capture, structural loadings, overtopping over the whole structure, wave reflections from the structure. The goal is to provide design tools based on laboratory tests, supported by theoretical and numerical calculations, for each of the investigated aspects.



Main activities: The work involved in this project can be divided into the following items:

- Planning of experimental setup – wave conditions, scaling, instrumentation.
- Carrying out the laboratory testing in the wave tank.
- Data analysis.
- Generalize results and compare to existing information from literature on related issues.
- Apply obtained results in a case study.

The project can be carried out as a 9. semester, half year master or one year master project.

During the project a close contact to the developer WaveEnergy AS is possible.

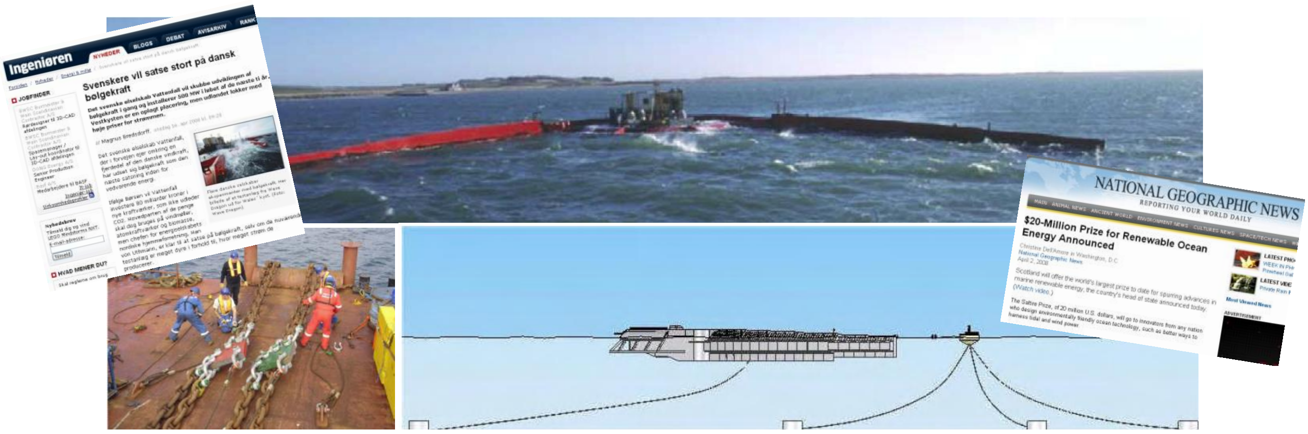
Contact person: Jens Peter Kofoed

Theory: ☒☒☐ **Experimental Work:** ☒☒☒ **Computer Modelling:** ☒☐☐
(Depending on preferences - the project can be focused to fit your interests)

This is one among a large space of options to work within the field of wave energy utilization – if you are interested in participating in the development of the renewable energy industry of the future, please drop by and we will formulate the project that fits your specific interests!

Mooring of floating Wave Energy Converters

Purpose: Currently, the race towards developing the most cost efficient wave energy converters is dramatically picking up in speed. One important element of this development is the design of cost efficient mooring systems. In the proposed project focus will be on generic design and comparison of different mooring layouts for a slack moored floating wave energy device. This could be an overtopping based device, such as the Wave Dragon, or other device types, eg. LEANCON, DEXA, Pelamis, etc. Traditionally, this type of mooring systems is of the catenary type, using heavy steel chains attached to anchor blocks at the sea bed. However, other options exist, e.g. using weights and floaters on lighter moorings lines. This option should also be explored and compared in terms of cost efficiency.



Main activities: The work involved in this project can be divided into the following items:

- Design basis – device, location, environmental conditions (wave, wind, current), soil conditions, etc.
- Design criteria – loadings on mooring system, performance requirements, etc.
- Design of mooring systems – different alternatives. Involves analytical/ numerical calculations and/or laboratory tests.
- Design of anchor points – different alternatives gravitation/piling/suction buckets. Involves analytical/numerical calculations and/or laboratory tests.
- Estimation of economics of the various alternatives.
- Conclusions – pros and cons of the alternatives.

The project can be carried out as a 9. semester, half year master or one year master project.

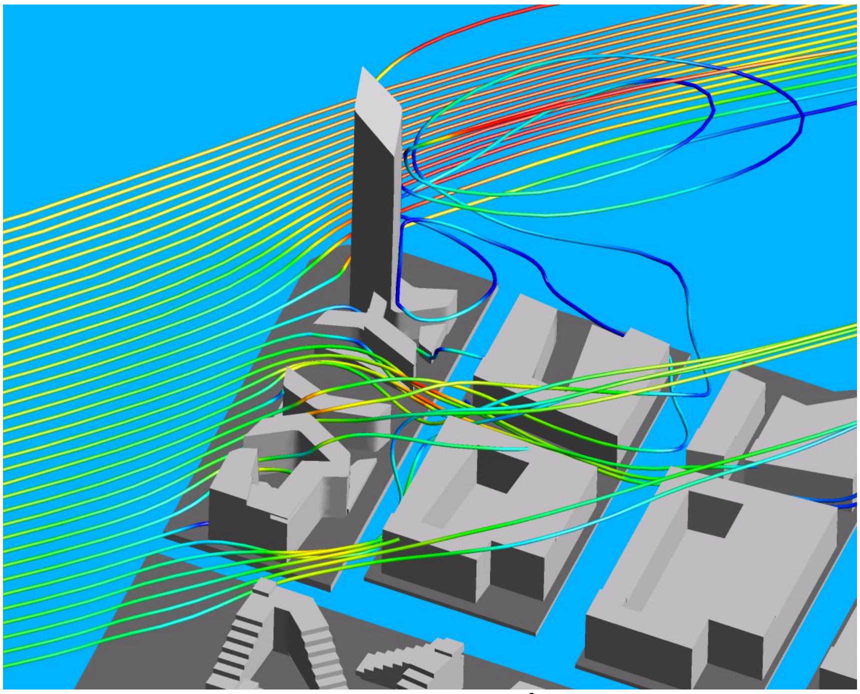
Contact person: Jens Peter Kofoed

Theory: ☒☒☐ **Experimental Work:** ☒☒☐ **Computer Modelling:** ☒☒☐
(Depending on preferences - the project can be focused to fit your interests)

This is one among a large space of options to work within the field of wave energy utilization – if you are interested in participating in the development of the renewable energy industry of the future, please drop by and we will formulate the project that fits your specific interests!

Wind comfort modelling around tall buildings

Purpose: Tall buildings create their own local wind climate. In certain circumstances this can result in amplification of both the mean wind velocity and of the turbulence. This can generate very uncomfortable or even unsafe wind situations at ground level. The challenge is to combine the vision of the architect with methods of the civil engineer. CFD models are a strong tool for evaluating local wind climate. However, the results from a CFD model can be difficult to translate into variables which correspond to comfort levels and safety levels for pedestrians. The purpose of this project is to use CFD to study interaction between wind around tall building and operational criteria for comfort and safety for pedestrians.


Streamlines around Light*House, Århus, Denmark

Main activities: This project will involve field, laboratory and computational methods. The main activities are:

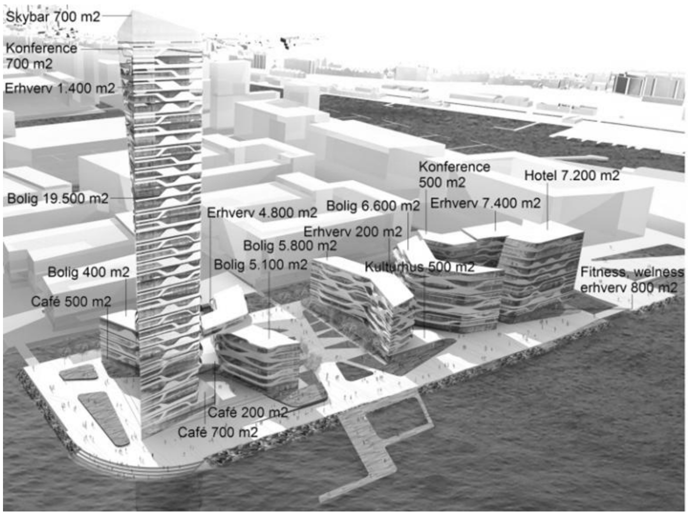
- CFD modelling of existing tall buildings
- Comparison between CFD simulations and field measurements (local tall buildings)
- Scale experiments in water flume to generate reference data.
- Evaluate different turbulence models with respect to comfort criteria
- Test different methods to avoid uncomfortable wind climate.

Contact person: Michael R. Rasmussen

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

Fundering af Light*house på Århus Nordhavn

Purpose: Light*house er et bolig- og erhvervsområde, der skal opføres som led i et større byggeprojekt, hvor den nuværende containerterminal på Nordhavnen i Århus skal omdannes fra industriområde til byområde. De eksisterende pier på havnen skal omdannes til en række kunstige øer, og på den yderste ø ud mod Århus Bugt skal bebyggelserne, der under ét kaldes Light*house, opføres. Områdets varetegn skal være et Danmarks højeste hus, 142 meter, placeret yderst på den anlagte ø ud mod Århus Bugt. Under hele området skal der anlægges et underjordisk parkerings-anlæg. En af de geotekniske udfordringer i forbindelse med byggeprojektet bliver at undersøge, hvordan højhuset kan funderes under hensyn-tagen til anlæggelsen af parkeringskælderen samt påvirkninger fra de omkring-liggende bygninger. Projektet gennemføres i samarbejde med Grontmij | Carl Bro



Main activities: Dette projekt tager udgangspunkt i højhus-byggeriet Light*house på Århus Nordhavn Hovedfokus er hvor-dan styrke og deformationsegen-skaber for den tertiære ler, der på lokaliteten findes til 70 - 90m dybde, kan bestemmes ud fra geotekniske forsøg og hvordan disse resultater kan anvendes i 3D finit element modellering.

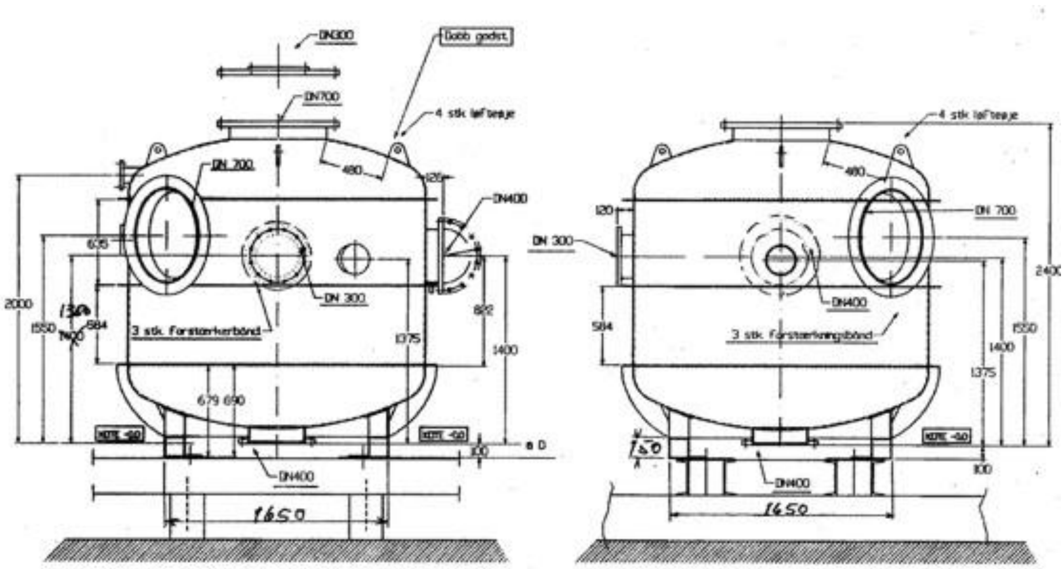
- Jordens egenskaber analyseres ud fra boreprøver samt CPT-boringer foretaget på projektlokaliteten. I forbindelse med boringerne er der foretaget vingeforsøg, og der er optaget en række prøver hvorudfra vandindhold, kalkindhold, pH-værdi samt konsistensgrænser er bestemt.
- Intakte prøver fra boringerne analyseres vha. konsolideringsforsøg , **c**onstant **r**ate of **s**train-forsøg (CRS-forsøg) og triaxialforsøg.
- Alle de foretagne undersøgelser anvendes til at bestemme, hvordan jordens egenskaber varierer med dybden. Forsøgsresultaterne anvendes til at kalibrere de numeriske beregningsmodeller.
- Der gennemføres 3D Plaxis beregninger af sammenspil mellem funderingen af højhuset og parkeringskælderen.

Contact person: Lars Bo Ibsen

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

Bøttefundamentets styrke- og deformationsegenskaber ved cyklisk belastning

Purpose: De kræfter der virker på vindmøller, transient og cykliske i natur, giver anledning til elastiske oscillationer og muligvis til liquefaction af sandet inde i bøtten. Sådan sand liquefaction vil sandsynligvis føre til fuldstændige bæreevnesvigt, hvorfor liquefaction skal undgås.



Main activities: Forholdene, der kan føre til sådanne tilstande, skal undersøges og fastlægges ved eksperimenter. En forsøgstank indeholdende faciliteter til udlejring af jorden samt mulighed for statisk og transient og cyklisk belastning er udviklet i dette forår ved laboratoriet for fundering, Aalborg Universitet, se figuren. Tanken ønskes gennem dette projekt at blive gjort fuld operationel. Tankens belastningssystem er opbygget således, at det kan benyttes til cykliske udmattelsesforsøg. Herved kan risikoen for liquefaction undersøges:

Resultaterne af disse forsøg sammenholdes med resultaterne fra de statiske forsøg. Herved kan det evalueres, om den varierende belastning har indflydelse på fundamentets bæreevne, stivhed samt plastiske deformationer.
Den elastiske opførsel under cyklisk belastning er vigtig for interaktionen med tårnet, og dette skal kortlægges ved hjælp af eksperimenter, analyse og beregning på baggrund af elasticitetsteori udfra de udførte forsøg noget til sidst.

Contact person: Lars Bo Ibsen

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

Bøttefundamentets styrke- og deformationsegenskaber ved installation i ler

Purpose: 3-D numerisk simulering af forskellige typer af bøttefundamenter installeret i ler foretages. Deres anvendelighed til offshore vindmøller undersøges med henblik på forståelse af deres opførsel under normale og ekstreme laster når den funderes i ler.

Main activities: Resultater fra en række modelforsøg (fra afsluttet afgangsprojekt) skal simuleres numerisk og sammenlignes med resultater fra analytiske modeller.
I de numeriske simuleringer vil der blive arbejdet med en avanceret konstitutiv model for jorden, Single Hardening modellen, og det tilsigtes at jord/struktur behandles så realistisk som muligt. Denne model er implementeret i det kommercielle finite element program 3D PLAXIS som eksternt defineret materialemodel. Materialeparametre findes fra triaksialforsøg udført på jordprøver fra de relevante offshore lokaliteter og fra kalibrerede CPT-forsøg udført ved siden af borehullerne.

De simulerede bøttefundamentforsøg er de ovenfor beskrevne modelforsøg og de forsøg. Disse inkluderer udrænede forsøg, i hvilke bøtterne er påvirket af moment, horisontale og vertikale kræfter. De numeriske analyser er i stand til at simulere ændringen i størrelse og form af brudfladen i H-M/D planet, svarende til de eksperimentelle observationer.

Contact person: Lars Bo Ibsen

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

Advanced probabilistic geotechnical site assessment for offshore wind farms

Purpose: Ved opførelse af store vindmølleparker til havs udgør funderingen ikke kun en betragtelig del at anlægsudgiften 25 - 35%, men er også den del af projektet, der indeholder de største usikkerheder. For at reducere disse usikkerheder foretages et omfattende geotekniske undersøgelsesprogram, hvilket kræver en stor investering tidligt i projektforløbet. Kravet til minimering af fundamenternes deformationer gør, at det altid er anvendelsesgrænsetilstanden, der bliver dimensionsgivende, dvs. at de elastiske parametre styrer designet. Ved in-situ forsøgene bestemmes de plastiske materialeparametre, der anvendes til brudanalyse, med stor nøjagtighed, mens de elastiske parametre bestemmes med stor usikkerhed. Der er derfor i dag en konflikt mellem de parametre, der driver designet, og det man får ud af de udførte in-situ forsøg. Fokuset er i dag forkert og bør drejes mod en bedre bestemmelse af de elastiske parametre. Dette projekt fokuserer på at udvikle en in-situ test metode, der sikre bedre bestemmelse af de elastiske designparametre. Ideen er at udvikle en ”intelligent sandsynlighedsbaseret teststrategi”, der kombinerer informationen, som er indhentet ved seismiske undersøgelser, med in-situ forsøg i form af ”Seismic Cone Penetration Test”. Herved kan de elastiske parametre fastlægges med stor nøjagtighed. Dette vil resultere i mere økonomiske funderingsløsninger idet de elastiske parametre i dag fastlægges alt for konservativt - dermed overdimensionerede fundamenter. Samtidigt forventes den nye teststrategi, at bidrage til en reduktion af det nødvendige antal in-situ målinger, hvorved den samlede omkostning til fundering af havbaserede vindmøller kan reduceres markant.

Main activities: Med projektets mål for øje vil forskningen fokusere på følgende:

- Udvikle og teste SCPTu målemetoder.
- Formulerer en metode til tolkning af SCPTu forsøgene. Tolkningen skal sikre pålidelig fastsættelse af både de elastiske og plastiske materialeparametre.
- Udvikle en metode der kan beskrives de målte parametre som stokastiske variabler og fastlægge variationen med dybden.
- Tilvejebringe tilstrækkeligt statistisk grundlag for at kunne udtale sig om variationen af materiale- parametre i horisontal retning.
- Formulering og opstilling af den sandsynlighedsbaserede teststrategi.

Dette projekt kan også gennemføres i relation til motorvejsbyggeri hvor samarbejdspartnerne vil være Vejdirektoratet.

Contact person: Lars Bo Ibsen

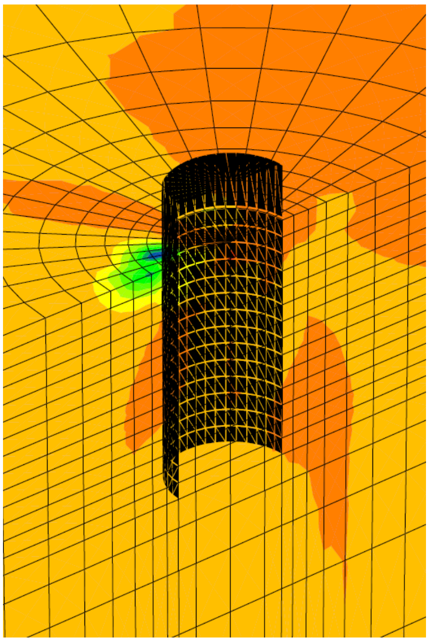
Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

Offshore Wind Turbine Foundations: Numerical evaluation of *p-y* and *p-Q* curves for piles in sand

A project in cooperation with

Purpose: The interactions between soil and laterally loaded piles are typically accounted for by use of *p-y* curves. A *p-y* curve defines the relationship *p*(*y*) between the soil resistance *p* arising from the non-uniform stress field surrounding the pile mobilised in response to the lateral pile displacement *y*, at any point along the pile. The *p-y* curves adopt the Winkler approach by uncoupling the response of various layers in the soil and can therefore easily include effects of non-linearity, soil layering and other soil properties.

Currently, *p-y* curves represent the state-of-the-art for design of monopiles in the offshore wind industry. However, the currently used p-y curves are clearly inadequate. Firstly, the current stiffness-formulation does not include diameter effects. This is of great importance since pile stiffness for often becomes the primary design driver for offshore wind turbine foundations. Secondly, the resistance of the pile toe is not considered in the current *p-y* methodology. Simple analytical considerations indicate that the ultimate moment resistance of a stiff monopile may increase by 25% if the pile toe resistance is included. Thus, the main emphasis of this project is to numerically evaluate diameter effects of p-y stiffness and evaluate the pile toe resistance in terms of *p-Q* curves.



Main activities:

- Develop a 3D finite element model of a monopile in PLAXIS (or ABAQUS).
- Calibrate constitutive behaviour to simulate Aalborg University Sand no. 1.
- Verify model by comparison to small-scale model tests performed in the pressure tank. (note: the scope of work does not include the model testing)
- Use numerical model to evaluate representative *p-y* and *p-Q* curves.

Contact person: Lars Bo Ibsen / Anders Augustesen

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

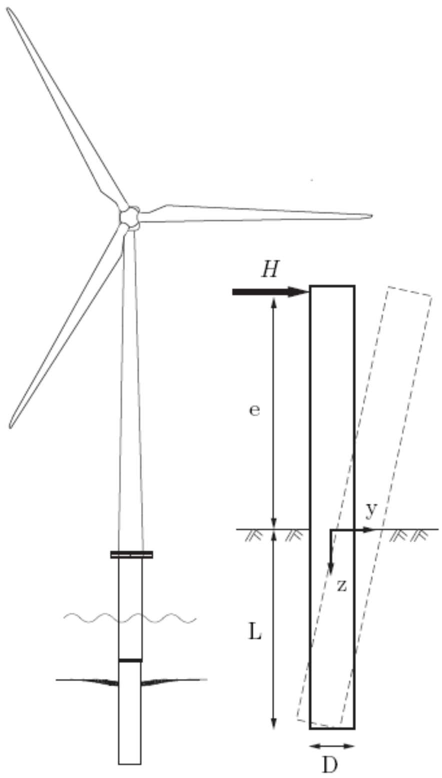
Offshore Wind Turbine Foundations: Response of Stiff Piles to Long-term Cyclic Loading

A project in cooperation with

DONG energy

Purpose: There are several foundation concepts for offshore wind farms. Most current foundations are monopiles, which are stiff piles with large diameters, installed 20 m to 30 m into the seabed. The design of monopiles relies on standards and empirical data originating from the offshore oil and gas sector. However, the loading of an offshore wind turbine is very different in both magnitude and character to oil and gas installations. It is characteristic for offshore wind turbines that the sub-structure will be subjected to strong cyclic loading, originating from the wind and wave loads. This leads to accumulated rotation of the wind turbine tower, adversely affecting its ultimate strength or fatigue life. The long-term movements of the foundation may significantly impact all parts of the wind turbine, including the support structure, machine components and blades. Therefore, it is of great importance to investigate the effects of cyclic loading.

Series of laboratory tests shall be conducted using the pressure tank at AAU. The model tests must be conducted on a stiff pile installed in saturated sand and subjected to between 100 and 1000 cycles of combined moment and horizontal loading. A typical design for an offshore wind turbine monopile should be used as a basis for the study, to ensure that pile dimensions and loading ranges are realistic. A non-dimensional framework for stiff piles in sand must be applied to interpret the test results.



Main activities:

- A series of laboratory tests should be conducted on stiff piles in the pressure tank at AAU.
- Results should be used to develop methods assessing the change in stiffness and the accumulated rotation of a stiff pile due to long-term cyclic loading.

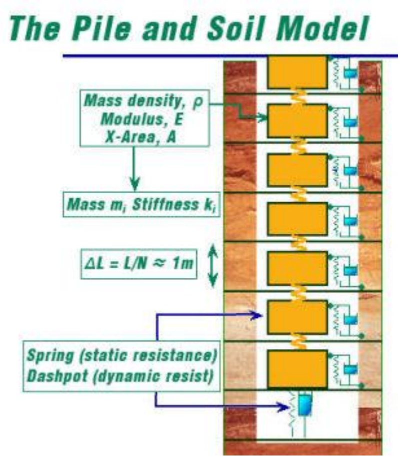
Contact person: Lars Bo Ibsen and Anders Hust Augustesen

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

Driveability of large piles

Purpose: Foundation of offshore wind turbines is primarily done using large monopiles being either drilled or driven into the soil. The driving of the pile is a critical operation and pile refusal due to hard soil might require a drive-drill-drive installation procedure to obtain required penetration depth. In addition to pile refusal problems, too many blow count will give additional fatigue and thereby reduce the total lifetime of the pile. During the installation of Barrow Offshore Wind Farm both types of problems occurred. On Barrow 30 monopiles with an OD of 4.75 m where installed on 23 m water depth.

In the design phase a driveability analysis is conducted in order to assess possibilities for driving the planned monopile as well as expected life time reduction due to driving. The driveability takes into account the actual soil characteristics, the monopile design and the planned driving equipment. Due to uncertainties and interpretations associated with the driveability analysis wrong results occur as the example on Barrow shows.



Main activities: The project will be executed partly at NIRAS and partly at Aalborg University containing the following activities:

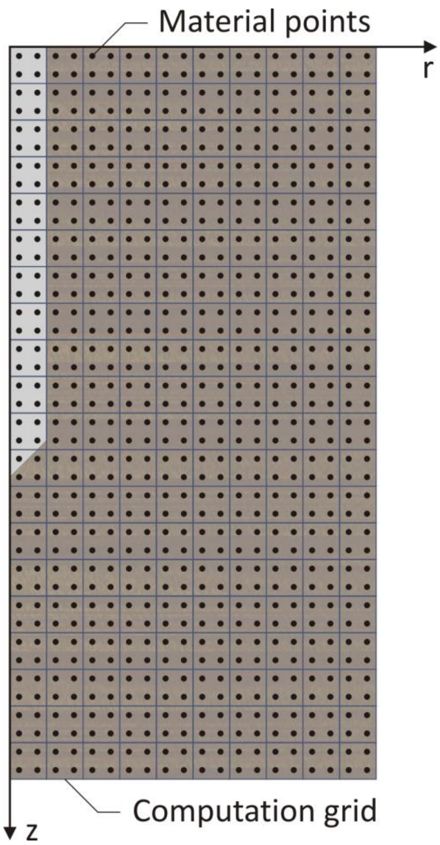
- Analysis of soil profiles and driving records from installation of MP on Barrow
- Driveability analysis using Glrweap (commercial software based on a mass-spring model) and correlation to results from Barrow
- Driveability analysis using Flac (FD software for analysis of large displacements)
- Back-calculation from actual driving record and registered resistance to driving to soil characteristics.

Contact persons: Anders Augustesen and Lars Andersen

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

Particle-based model of pile driving and CPT

Purpose: The Material-Point Method (MPM) has emerged as a computational tool for the analysis of dynamical problems related to civil engineering. Based on continuum mechanics, the method is developed from the principle of virtual work. However, in contrast to the standard finite-element method, the integration points carrying the material properties and state variables are allowed to move through the computational grid. This is ideal for the analysis of problems involving large deformations and contact between different materials and structures. Hence, the MPM is a promising tool for simulation of geotechnical problems such as pile driving and cone penetration testing (CPT).



Currently, a PhD project is being carried out at the Department of Civil Engineering, Aalborg University, regarding the analysis of landslides by utilisation of the so-called Generalised Interpolation Material Point Method (GIMP). This method is a further development of the MPM. The idea of the project is to develop a computer code based on the GIMP for the analysis of pile driving and CPT.

Main activities: The GIMP is a relatively new method, and this project is directly related to some of the ongoing research at the university. The main activities are:

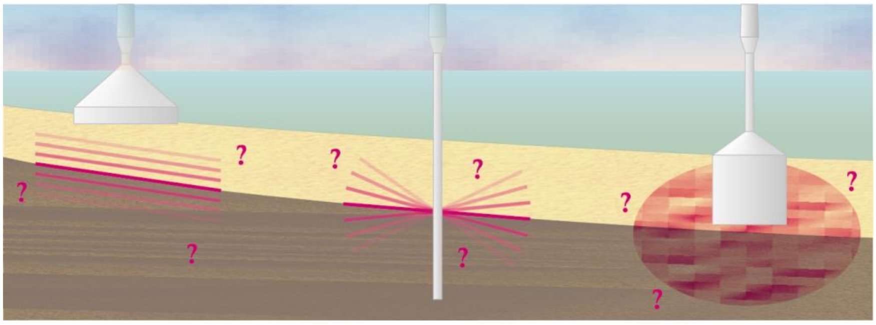
- Getting to know the MPM and the GIMP
- Formulation of the GIMP in cylindrical (axisymmetric) coordinates
- Programming the GIMP in MatLab or Fortran 95
- GIMP-analysis of CPT and/or pile driving
- Comparison of the GIMP results with experimental results.

Contact person: Lars Andersen

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

Stochastic modelling of soil

Purpose: Soil is a heterogeneous material at different levels. Thus, the ground is stratified, i.e. several soil deposits lie on top of each other, and the material within each layer is in itself heterogeneous on a local scale as seen in the figure. However, when geotechnical analysis are carried out by computational methods, soil is usually modelled as a locally homogeneous material and the position of interfaces between two different material, e.g. sand and moraine, are based on few tests. This is a huge problem because failure in the soil will always find its way through the weakest part of the material. Hence, failure figures in real heterogeneous soil may be significantly different from the ones achieved by computational analysis ... and so may the bearing capacity and deformations.



Another interesting problem is related to the dynamics of soil. Recent research indicates that even a very sophisticated model can only predict the ground vibration from metro tunnels with an accuracy of 10 to 15 dB. This means that the actual ground motion may be about four times higher than the predicted response. The main reason is believed to be the missing consideration of heterogeneity.

Main activities: The project may focus on the bearing capacity and deformations of foundations or alternatively the ground vibration from, for example, railways. In any case, the activities to be carried may include:

- Studying the theory of soil mechanics and/or soil dynamics
- Developing models of the spatial variation of soil properties
- Creating a finite-element model for stochastic analysis of soil
- Parameter studies of bearing capacities and deformations or vibrations
- Comparison with the results of other models or tests
- Updating the design criteria for foundations.

Contact person: Lars Andersen

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

Design models for soil structures with geotextiles

Purpose: Geotextiles are widely used throughout the world in four main functions: Separation, filtration, drainage and protection. Fibertex is the 4th biggest producer of nonwoven geotextiles in Europe, and is situated in Aalborg East.

The current design material available for soil structures with geotextiles is very "scattered", and the purpose of the project is, through analysis and laboratory testing, to get an overview and develop new or enhance the existing design models.

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

- Getting to know geotextiles
- Gathering and analysis of current design material
- Determination of focus areas
- Tests and theoretical assessment
- Computational modelling of geotextiles
- Design model creation.

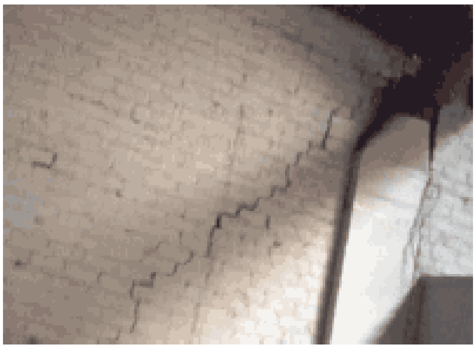
Part of the project may be carried out as engineering practice, and it will be possible to perform experimental tests at the laboratory facilities of Fibertex A/S.

Contact person: Lars Andersen

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

Vibrations from “beautiful” roads

Purpose: Over the last decades, asphalt roads in the inner cities have been replaced by concrete or natural cobblestone pavements. This is, for example, the case in Boulevarden and parts of Østerå in Aalborg. In addition to this, ramps and bumps have been established in order to reduce the speed of traffic. However, this has led to induced levels of ground and airborne noise. The uneven surface of the road implies that vibrations are generated by the passage of the wheels. Waves are then transmitted via the ground, possibly leading to nuisance for people and damage on structures in the surrounding environment. The question arises as to whether it is possible to design a pavement of high quality regarding the architecture as well as comfort and safety.



Main activities: The project concerns the analysis of vibrations from vehicles on pavements with different surfaces and subsequently the design of the road and the substructure. The following items may be part of the project work:

- Numerical modelling of vibration transmission through the road and subsoil
- Verification of the computational model by dynamic testing
- Design of a road surface with regard to a minimisation of the vibrations
- Design of the substructure in order to reduce the transmission of waves.

The work may be carried out in collaboration with a producer of pavement stones or road construction material.

Contact person: Lars Andersen

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

Advanced analysis of sheet pile walls

Purpose: Sheet pile walls are often used as a retaining structure. These walls are, in Denmark, usually designed using Brinch-Hansens method, which have been employed for over fifty years. With the introduction of powerful computer codes it is now possible to apply more advanced methods and material models than the Mohr-Coulomb model. These models should make it possible to obtain more economical designs, and, more importantly, they should be able to predict the displacements much more precisely.

The aim of the project is to investigate modern methods of carrying out calculations on sheet pile walls. Does it make a difference compared to the classic methods if advanced material models and calculation methods are applied? It may be possible to collaborate with consulting engineers, in order to obtain information concerning the methods, do measurements on real structures, etc. Also laboratory experiments may be carried out. The focus of this project can vary to a great extent according to the interests of the students.

Main activities can include:

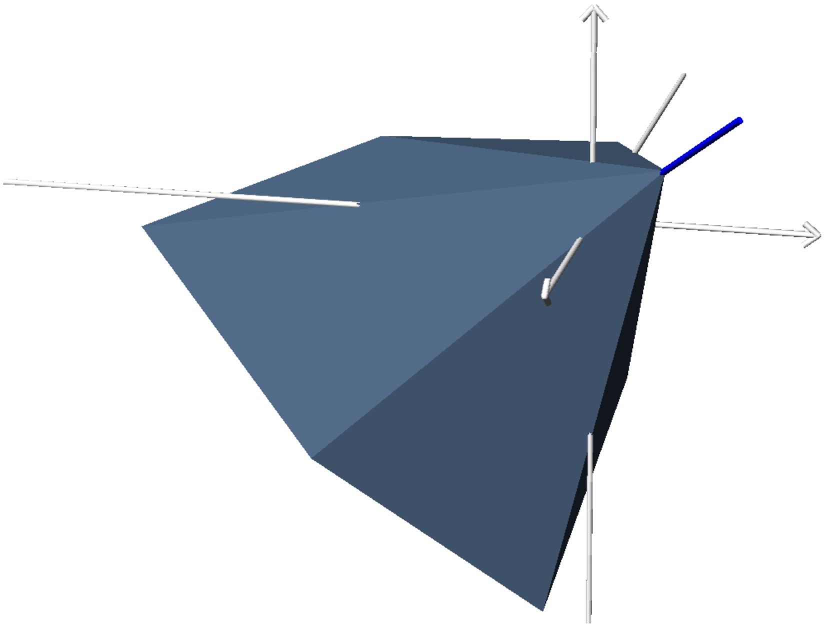
- Literature study of methods of sheet pile wall design.
- Advanced models in commercial FEM-packages (Plaxis, Abaqus, etc.).
- FLAC-models.
- Parameter assessment in the advanced models.
- Interpretation of real life measurements.
- Model experiments in the laboratory.

Contact persons: Anders Hust Augustesen and Johan Clausen

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

Efficient inclusion of water flow forces in the modelling of soil behaviour

Purpose: In geotechnical problems there is often a pressure gradient which causes a water flow through the soil body under consideration. This water flow can have a considerable effect on the strength of the soil body. In extreme cases this can lead to the phenomenon known as liquefaction. In simple calculation methods a uniform flow can be taken into account. In complicated cases where either the geometry, the flow pattern or both are non-trivial, numerical methods are called for. The most often used numerical method for geotechnical applications is the finite element method.



Recently a new numerical scheme for integrating the constitutive equations was developed at AAU. This method focuses on carrying out the calculations in the principal stress space (the figure depicts the Coulomb criterion in principal stress space). One of the goals of this project is to include the flow forces in this formulation. Experiments could also be carried out in order to assess the validity of the formulation.

Main activities can include:

- Literature study of methods of calculating water flow through a soil body (e.g. Biot’s theory).
- Development and implementation of a FEM-scheme to efficiently include water forces in calculations (in MatLab or Fortran).
- Design and setup of one or more experiments to quantify the effects of water flow in a soil body.

Contact persons: Johan Clausen, Anders Hust Augustesen and Lars Damkilde

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

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 strength 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.

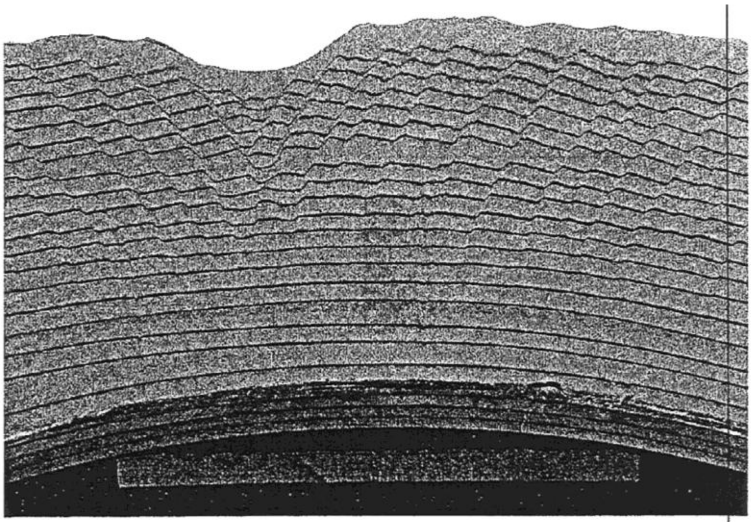


Fig. 8.2 Crestal faults over arch of uniform curvature, simulated in a sand box (Mandl, 1984).

Random errors seem to occur and simulations break down. Some, or all, of these problems are maybe related to the formation of strain localisations, so-called shear bands, see the figure. One of the solutions to these problems may be to employ the extended finite element method to model the strain localisations, which will be the focal point of the project.

Main activities:

- Getting to know the extended element method (XFEM).
- Implementing XFEM for simple problems in MatLab or Fortran.
- Literature study of the problems relating to non-associated plasticity.
- Quantification of the problem when using the classic finite element method.
- Implementing strain localisation and shear banding using XFEM.

Contact persons: Johan Clausen and Lars Damkilde

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

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 develop an ABAQUS model that can be applied to the finite-element analysis of reinforced concrete structures with a complex geometry, e.g. curved shells. The goal is to construct of a model that facilitates both a genuine model of the respective materials and, not least, a realistic description of the interfaces between concrete and steel. The project may focus on the analysis of a particular problem or structure.

Main activities:

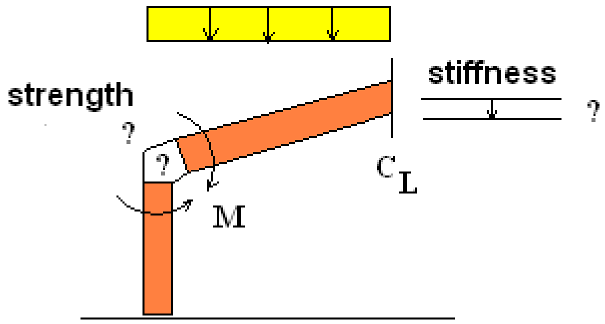
- Formulation of material models for concrete
- Modelling of composite shells in ABAQUS
- Modelling of interfaces between concrete and reinforcement
- Finite-element analysis of reinforced concrete structures
- Comparison of FE models with standard design methods.

Contact person: Lars Andersen / Eigil V. Sørensen / Christian Frier

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

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.

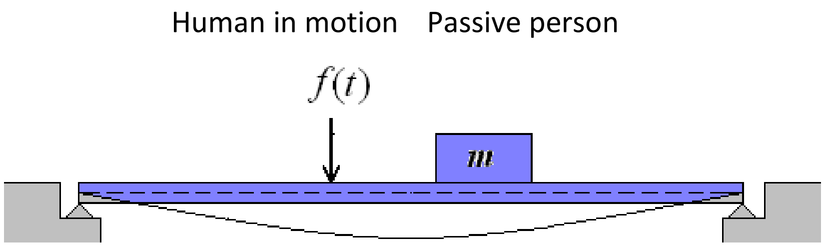
The project might involve co-operation with external parties having an interest in mapping the potential of alternative solutions for timber frames.

Contacts: Lars Pedersen/Christian Frier

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

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.



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: Lars Pedersen

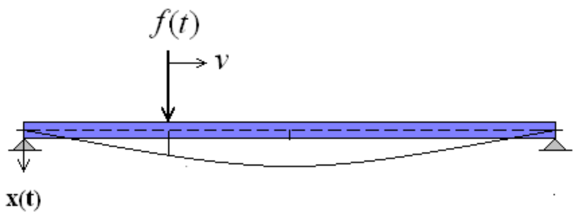
Theory: ☒☐☐ **Experimental work:.** ☒☒☐ **Computer modelling:** ☒☒☐

Dynamic human loading and stochastic models for estimating structural responses

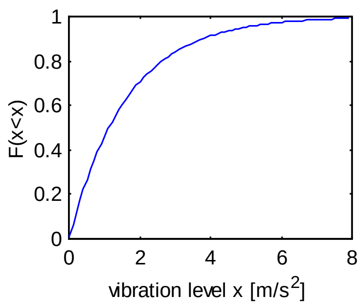
Background: Some civil structures are so slender that their modes of vibration may be excited by the basic frequency of human motion resulting in resonant structural action. The undesired resonant action may for instance occur in footbridges, stadia structures or in open-space office floors as a result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

Contacts: Lars Pedersen/Christian Frier

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

(The amount of experimental work can be decided during the project)

Risk analysis of Wind Turbines

Wind turbines are a building / machine with many structural (tower, blades, foundation, …), mechanical (gearbox, bearings, …) and electrical (generator, …) components. The complete wind turbine is a complicated system where failure of some of the components can have serious consequences. Failure of a component may not only be critical for the wind turbine itself but also for the environment. The consequences for the environment can be loss of electricity supply which is serious if the supply from a complete offshore wind farm is lost. Another consequence in case of full or partial failure of e.g. a wind turbine blade is that people, buildings, etc. can be hit by a part from the wind turbine thrown several hundred meters away. In case of wind turbine icing also the risk of ice-fragments thrown away from the blades can be important.

The purpose of this project is to establish an overview of risks associated with wind turbine failures and icing. This includes description of failure modes, failure rates and consequences. Further to describe a methodology to assess these risks quantitatively and how to establish acceptable risks.

Main activities:

- Literature survey to give an overview of risks associated with wind turbine failures and icing:
    - failure modes
    - failure rates
    - consequences
- Use principles from risk analysis to describe a methodology to assess
    - Risks related to the wind turbine itself
    - Risks related to the environment
    - What are the acceptable risks?
- Selection of representative part of the whole wind turbine system and implementation in a computer program using existing algorithms
- Illustrative example studies

The project can be made in cooperation with an external partner

Contact person: John Dalsgaard Sørensen and Henrik Stensgaard Toft
Theory: ☒☒☐ **Experimental Work:** ☐☐☐ **Computer Modelling:** ☒☒☐



Collapse of wind turbine at Djursland, February 2008 – wind turbine parts thrown up to 400 m away!

Reliability assessment of existing and temporary structures

Generally reliability requirements and partial safety factors are related to permanent structures, e.g. with a design lifetime equal to 50 years. This is for example the case in the Eurocodes. For existing structures and for temporary structures, e.g. structures during execution and structures only used for a short time interval, no design requirements can generally be found in the codes, but are highly demanded by industry.

Both for existing and temporary structures it is sometimes argued, that the reliability level could be chosen lower than for permanent structures. But is that reasonable - e.g. for structures where people can be in danger in case of failure? And if the reliability level in some cases can de lowered, how much can the partial safety factors be decreased?

For existing structures, e.g. concrete bridges, information will often be available, e.g. in the form of measured concrete compression strengths of test samples, measured traffic loads, ... How can such information be used to assess the reliability of the structure, and eventually decrease the partial safety factors?

Main activities:

- Collect information from literature on assessment of reliability of temporary and existing structures
- Assess and describe methods to obtain the minimum reliability level using risk and reliability-based principles:
    - cost-benefit analyses: minimize lifecycle total expected costs
    - LQI (Life Quality Index) principles: requirements by society
- Transformation of reduced reliability level to reduced partial safety factors and/or reduced characteristic loads.
- Select one or more illustrative structures (an existing structure and/or a temporary structure), and for the selected structure(s):
    - Stochastic modelling of loads and strengths
    - Assessment of minimum reliability level to be required
    - Estimation of evt. reduced partial safety factors

Contact person: John Dalsgaard Sørensen
Theory: ☒☒☐ **Experimental Work:** ☐☐☐ **Computer Modelling:** ☒☒☐


Optimal Reliability Level for Wind Turbines

Description: For very large civil engineering structures such as bridges, high-rise buildings, offshore platforms, etc. are the optimal reliability level sometimes calculated in order to minimize the costs during the design life. For wind turbines could the optimal reliability level for the individual components (blade, hub, tower, foundation etc.) also be calculated and specified in the standard. The benefits of this to the society are enormous since wind turbines as opposed to normal civil engineering structures are series produced allowing for a more refined assessment of the reliability.

The purpose of the present project is to formulate models for the optimal reliability level for different components of the wind turbine. These models will be dependent on the initial cost of the wind turbine, the expenses to operation and maintenance and the risk for failure of the turbine. Also the risk for human fatalities and environmental aspects should be taken into account.
Based on the formulated models will the optimal reliability level for the individual components be determined by optimization and compared to the existing reliability for wind turbines and other civil engineering structures.

Main activities:

- Formulation of the optimal reliability level such that the owner obtains the maximal economic return by maximizing the total expected benefits minus costs to construction, operation, maintenance, repair and possible failure.
- Formulation of the reliability level which is optimal for the society, e.g. based on LQI (Life Quality Index) considerations, and including environmental aspects.

The models should be formulated for the main wind turbine components.

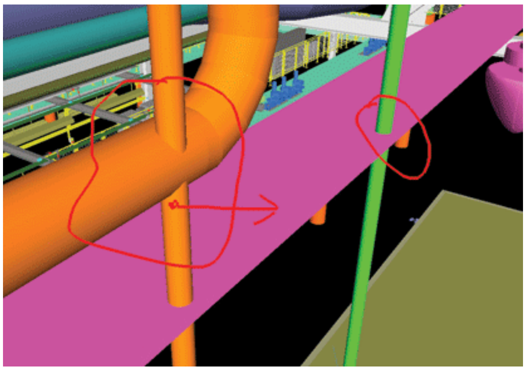
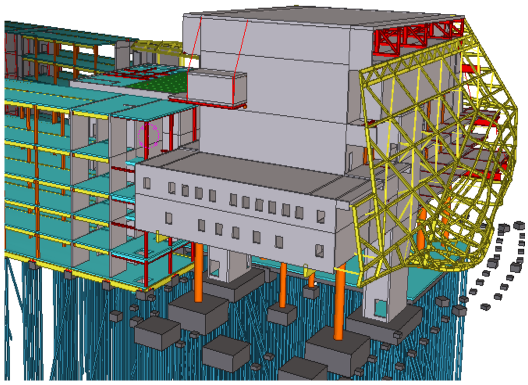
Contact persons: John Dalsgaard Sørensen and Henrik Stensgaard Toft

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

Structural modelling and design coordination

Purpose: The construction industry is changing from traditional CAD drawings to more intelligent 3D object based models of the entire building. There are many attempts to improve the structural design process by making a better connection between object based CAD systems and structural simulation tools. The simulation tools can be more or less integrated with specific CAD systems or they may exchange data through open international standards. An important issue for the structural engineer is also the often complicated coordination with requirements from other disciplines such as architecture, HVAC etc. New IT tools are introduced to assist this coordination.

The purpose of this project is to identify critical elements of the integrated design and coordination process and examine how new methods and information technology can assist us in the future construction industry.

Main activities:

- Identify strength and limitations in current practices and identify opportunities with upcoming technologies in the area
- Review of enabling Information and Communication technologies (ICT), including software, data models, international standards, and human computer interaction tools
- Examine today's possibilities with existing tools
- Identify needs for new ways of working and from that derive a list of requirements on technical solutions
- Demonstrate possible solutions for the near future and describe issues for future development

The work may be in collaboration with a consulting engineering company.

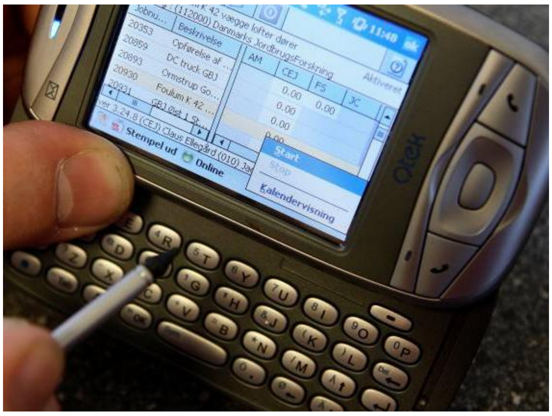
Contact person: Kjeld Svidt, Per Christiansson

Theory: ☒☒☐ **Experimental Work:** ☒☒☐ **Computer Modelling:** ☒☒☐

Future information technology at the construction site

Purpose: In recent years, the construction industry has started changing from traditional 2D CAD drawings to more intelligent 3D object based models of the entire building. Such models give us a number of new possibilities for planning and controlling the activities at the construction site through advanced 4D models and possible links between the physical construction components and the virtual building model. New information and communication technology can improve the communication of correct instructions at the right time for the construction work as well as capturing information for quality assurance and as-built documentation.

The purpose of this project is to identify important problems within the area and propose solutions for future use of state-of-the-art information technology at the construction site.



Main activities:

- Identify current practices and problems in traditional construction projects
- Review of enabling technologies, software, hardware, international initiatives
- Test existing methods, software, hardware
- Identify needs and requirements for new solutions
- Build early prototypes with more or less functionality for initial tests

The work may be carried out in collaboration with a construction company.

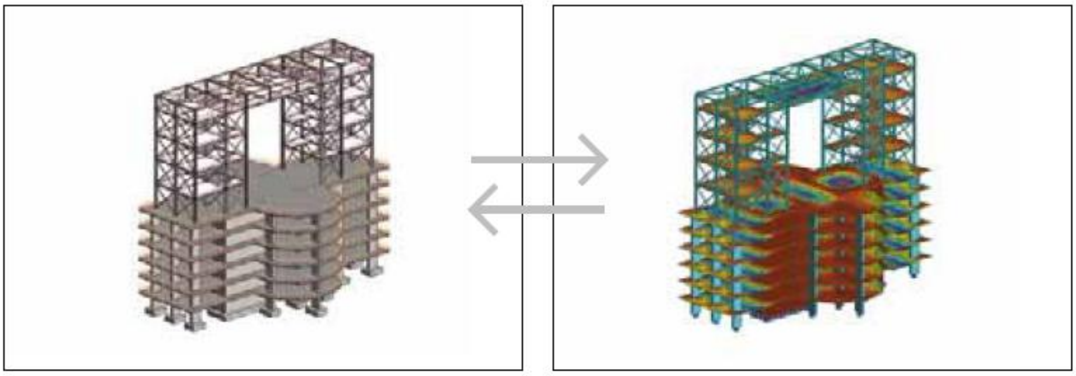
Contact person: Kjeld Svidt, Per Christiansson

Theory: ☒☒☐ **Experimental Work:** ☒☒☐ **Computer Modelling:** ☒☒☐

Structural modelling and analysis using BIM tools

Purpose: Although 2D and 3D modeling software has been used for decades to analyze and design structures, over the past few years a wave of new 3D modeling tools are allowing structural engineers and designers to create models for documentation and coordination as well. As a result, more and more structural engineering firms are embracing the Building Information Modeling (BIM) movement. BIM software is based on the object-oriented programming paradigm, in which instances of structural members are assembled to create a building structure. Each member possesses the information and functionality that fully defines it. In other words, a beam element knows its properties (e.g. material, sectional properties…), as well as its purpose within the structure (i.e. a horizontal member on level X, spanning between column Y and girder Z). The resulting BIM model contains a wealth of information which can be useful for inter-discipline coordination as well as internal coordination. Recently many add-on BIM tools have been presented which integrated the structural analysis of e.g. reinfored concrete and steel structures into the BIM framework.

The purpose of the present project is to perform an evaluation of add-on tools for structural analysis.



Main activities:

- Identify strength and limitations in current add-on BIM tools and identify opportunities with upcoming technologies in the area
- Modelling and structural analysis of different structures and comparison with with theory and traditional FEM results.

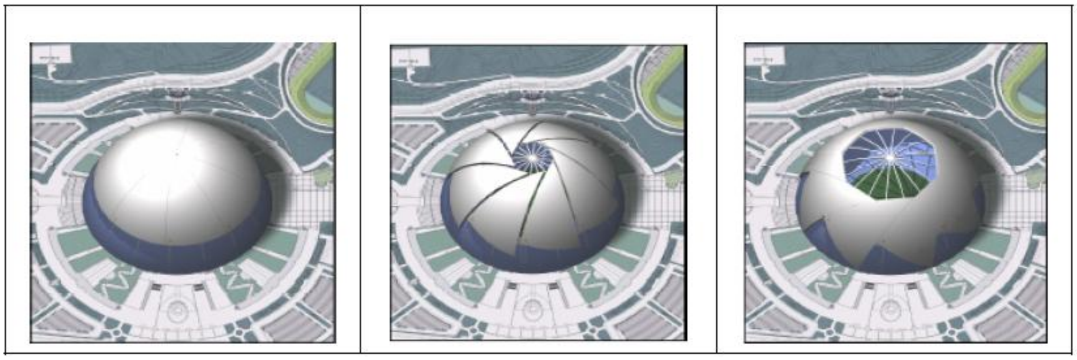
The work may be in collaboration with RAMBØLL.

Contact person: Poul Henning Kirkegaard, Kjeld Svidt

Theory: ☒☒☐ **Experimental Work:** ☐☐☐ **Computer Modelling:** ☒☒☒

Multibody dynamics and control of flexible kinetic structures

Purpose: The project will consider the behaviour and approaches to the design of so-called kinetic structures, i.e. structures that can be moved after assembly (or move by themselves by means of built-in motors) from a "fully closed" or compacted configuration to a "fully deployed" one, in which the structure features its functionality, and vice-versa.



In particular, the final aim will be to establish the feasibility of implementing active, semi-active or passive control techniques both during deployment and in the deployed configuration. An actively controlled deployable structure belongs to the class of "Smart Structures". Smart structures concepts have been developed since relatively long time in aeronautics, astronautics and in robotic mechanics, where the use of electronic devices and innovative materials has been traditionally very intensive because of their fundamental importance. In the structural engineering field, smart structures concepts and namely active control techniques have been introduced very recently and apart from a very limited number of real- world applications are mainly a subject of research, compared for instance to other innovative techniques for the reduction of vibrations in buildings.

For the analysis of the flexible kinetic structure the multibody system (MBS) method and a time-variant system control method will be considered.

The present project could be made as a part of a later ph.d.-project.

Main activities: The project will be related to ongoing research at the university where the MBS method is used related to wind turbines and kinetic structures. The main activities in the project will be:

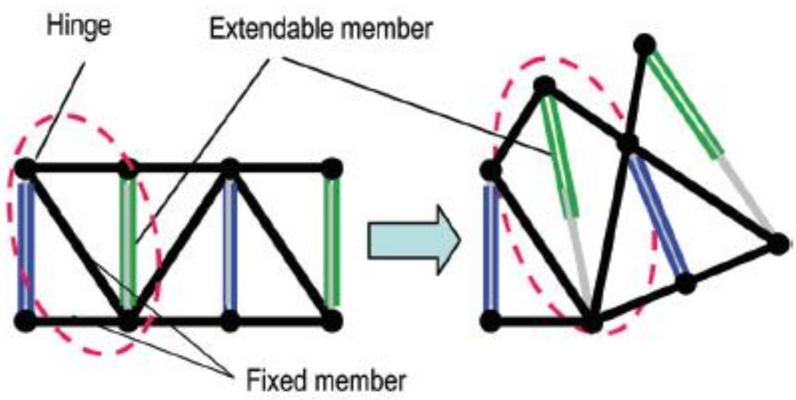
- Getting to know the MBS method (FEM method)
- Getting to know active, semi-active and passive control methods
- MBS modelling of a kinetic structure and implementation of a control method.

Contact person: Poul Henning Kirkegaard/ Søren R.K. Nielsen

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

MBS modelling of kinetic structures

Purpose: Kinetic structures follows a new trend emerging in architecture related to the physical movement of structural building elements that can result to the spatial movement of a structure as an entirety or just part of it. More particularly, this kind of architecture can be defined as: Buildings and/or building components with variable mobility, location and/or geometry. Structural solutions must be considered in parallel both the *ways* and *means* for kinetic operability. The *ways* in which a kinetic structural solution performs may include among others, folding, sliding, expanding, and transforming in both size and shape. Shape control within architectural kinetic structures is a natural extension to the practice of engineering and architectural design. Structural shape control is of major interest within responsive architecture because it is the primary ingredient needed to produce building envelopes that change shape.



Developing of responsive kinetic architecture requires that one could simulate such a mechatonic system as a multibody system (MBS) combined with a shape control method.

The present project could be made as a part of a later ph.d.-project.

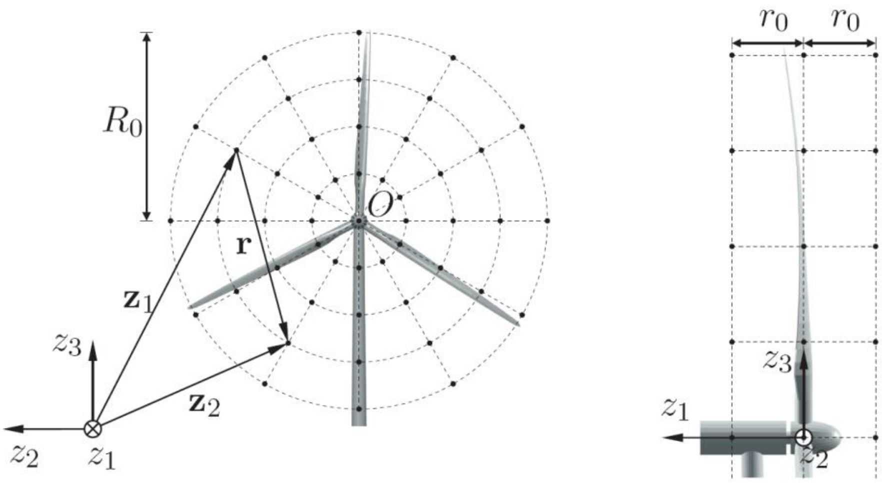
Main activities: The project will be related to ongoing research at the university where the MBS method is used related to wind turbines and kinetic structures. The main activities in the project will be:

- Getting to know the MBS method (FEM method)
- Getting to know shape control methods
- MBS modelling of a kinetic structure using the software packages ADAMS and Simulink.

Contact person: Poul Henning Kirkegaard/ Søren R.K. Nielsen

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

Turbulence Modelling for Wind Turbine Applications



Purpose: Turbulence processes are of considerable importance in the analysis of the dynamic response and reliability of wind turbines. Hence, design codes require a proper modelling of this stochastic phenomenon in the design of the structures. In the project it is attempted to model the turbulence by passing a white noise vector process through a specific filter. The idea is to calibrate the coefficients of this filter in a way that the filter output represents the cross spectral density matrix of the turbulence vector.

In general there exist two approaches toward modelling this phenomenon; non-parametric and parametric methods. It is aimed that both of the approaches are covered in the project and proper stochastic models that allow realization of turbulence fields will be developed. The aim of the project is to develop a code capable of generating turbulence realizations for various specifications of the turbulence field i.e. power spectrum, field grid etc. with ability of interpolating the turbulence between the grid points and connect it to the FAST aeroelastic code. Calibration is demanding for both computer time and memory. For this reason an essential subject of the project will be the use of parallel computing techniques.

Main activities:

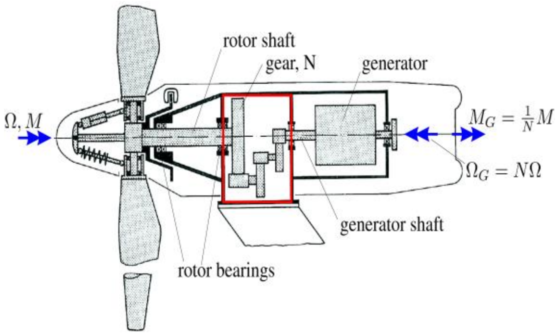
- Getting knowledge of turbulence modelling techniques.
- Programming a turbulence generator based on available methods.
- Comparison of results of different modelling techniques.
- Programming a bridge that connects the developed turbulence generator to the aeroelastic code (FAST).

Contact person: Søren R.K. Nielsen, Mahdi Teimouri Sichani

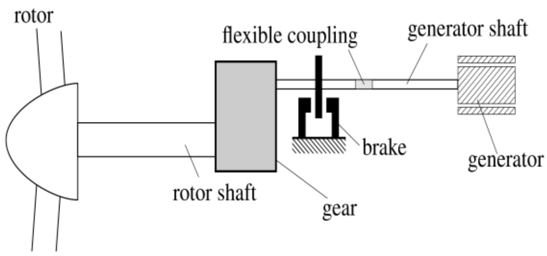
Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

Estimation of Low Failure Probabilities of Wind Turbines

Purpose: Estimating low failure probability of wind turbines is typically done by assuming the epochal extremes in a 10 minute interval are distributed according to some asymptotic extreme value distribution and extrapolating the results to 50 years. In this regard parameters of the distribution function are needed to be estimated via numerical simulations.



a)



b)

Unfortunately conventional Monte Carlo simulation is not an efficient way of estimating low probability events. To circumvent this problem variance reduction Monte Carlo methods such as importance sampling or splitting methods might be considered alternatively. The basic idea is that only a fraction of the Monte Carlo simulations are used in estimating failure events. These methods try to identify and simulate this fraction only, hence resulting in considerable reduction in computation cost. The project is a follow up of an ongoing M.Sc. project in Department of Civil Engineering. In the present project the focus will be on the reliability of the control system of the turbine (pitch, yaw, generator, brakes). The aim of this project is to implement the variance reduction methods into an aero elastic code (FAST) on a simulated wind turbine model.

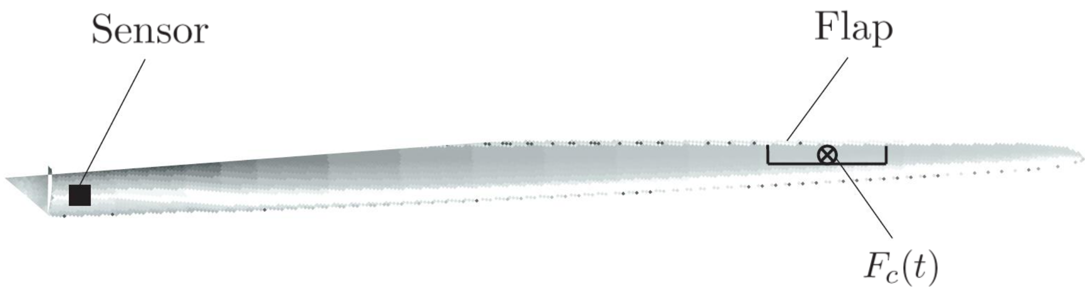
Main activities:

- Getting knowledge of the variance reduction methods.
- Programming a benchmark on the variance reduction methods.
- Estimating failure probability of the wind turbine.
- Comparing results of different methods on a simulated wind turbine.

Contact person: Søren R.K. Nielsen, Mahdi Teimouri Sichani

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

Active Vibration Control of Blade



$$m\ddot{q}(t) + c\ddot{q}(t) + k\ddot{q}(t) = -c_c\dot{q}(t) + k_c q(t) + F(t)$$

$$\omega_0^2 = \frac{k - k_c}{m} \quad , \quad \xi = \frac{c + c_c}{2\sqrt{m(k - k_c)}}$$

Purpose: Wind turbine wings are exposed to extreme wind load of both a great static deflection from the middle wind and dynamic supplement deflections. Both can be counteracted by active control by way of a flap which regulates the lift on the wing. The modal control force $F_c(t) = -c_c\dot{q}(t) + k_c q(t)$ is here described in the form of a component in opposition with the modal velocity $\dot{q}(t)$ and a component in the phase with the modal displacement $q(t)$. If c_c and k_c both are positive, this corresponds to an increase of the viscose damping and a reduction of the stiffness, respectively, when these terms are transferred to the left side.

Normally the sensors are strain-gauges placed at the hub of the blade whereas the control force is applied at the flap i.e. these are separated (non-collocated control). This may introduce instability phenomenon such as observation and control spill-over effects in the vibration control. Further, only one control force actuator (the flap) is available, whereas several blade and for-aft vibration modes are to be controlled. The subject of the project is to derive an optimal control law, which considers these problems.

Main activities:

- Getting knowledge of the vibration control algorithms.
- Knowledge of aerodynamics and aeroelastic codes.
- Developing a code for the controller design.

Contact person: Søren R.K. Nielsen, Mahdi Teimouri Sichani

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

ISSN 1901-7308
DCE Latest News No. 9