3rd Semester and Master's Thesis Ideas 2013

M.Sc. in Civil and Structural Engineering

Clausen, Johan

Publication date:
2013

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

M.Sc. in Civil and Structural Engineering:

3rd Semester and Master's Thesis Ideas 2013

Edited by Johan Clausen

ISSN 1901-7308
DCE Latest News No. 37

DEPARTMENT OF CIVIL ENGINEERING
AALBORG UNIVERSITY

Aalborg University
Department of Civil Engineering
School of Engineering and Science

DCE Latest News No. 37

M.Sc. in Civil and Structural Engineering: 3rd Semester and Master's Thesis Ideas 2013

Edited by

Johan Clausen

May 2013

Scientific Publications at the Department of Civil Engineering

Technical Reports are published for timely dissemination of research results and scientific work carried out at the Department of Civil Engineering (DCE) at Aalborg University. This medium allows publication of more detailed explanations and results than typically allowed in scientific journals.

Technical Memoranda are produced to enable the preliminary dissemination of scientific work by the personnel of the DCE where such release is deemed to be appropriate. Documents of this kind may be incomplete or temporary versions of papers—or part of continuing work. This should be kept in mind when references are given to publications of this kind.

Contract Reports are produced to report scientific work carried out under contract. Publications of this kind contain confidential matter and are reserved for the sponsors and the DCE. Therefore, Contract Reports are generally not available for public circulation.

Lecture Notes contain material produced by the lecturers at the DCE for educational purposes. This may be scientific notes, lecture books, example problems or manuals for laboratory work, or computer programs developed at the DCE.

Theses are monograms or collections of papers published to report the scientific work carried out at the DCE to obtain a degree as either PhD or Doctor of Technology. The thesis is publicly available after the defence of the degree.

Latest News is published to enable rapid communication of information about scientific work carried out at the DCE. This includes the status of research projects, developments in the laboratories, information about collaborative work and recent research results.

Published 2013 by
Aalborg University
Department of Civil Engineering
Sohngaardsholmsvej 57,
DK-9000 Aalborg, Denmark

Printed in Denmark at Aalborg University

ISSN 1901-7308
DCE Latest News No. 37

M.Sc. in Civil and Structural Engineering: 3rd 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. Most of 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.

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. 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.

Many private engineering companies have a homepage on which they state that they would like to collaborate with students on a master project. Examples are:

- Cowi, http://www.cowi.dk/menu/jobs/ungicowi/praktikspecialeogstudiejob/byggeri/Pages/byggeriogdriftforstuderende.aspx
- Grontmij, http://www.grontmij.dk/DK/job-karriere/Studerende/Pages/speciale-projektskrivning.aspx
- Moe, http://www.moe.dk/Karriere/Ledige-Stillinger.aspx?hr=show-job|852?expandform=1
- Niras, http://www.niras.dk/Ung-i-NIRAS/Specialesamarbejde.aspx

The preferred group size for master projects is two to four students. In the interest of students as well as supervisors, single-student projects are generally not recommended. In a short 3rd semester project the minimum group size is three students.

At the third master semester the students have the option of doing a company stay. It is important to notice 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 this catalogue in the last page.

As a final remark, a signed project plan must be handed to the head of the School of Engineering and Science at latest 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

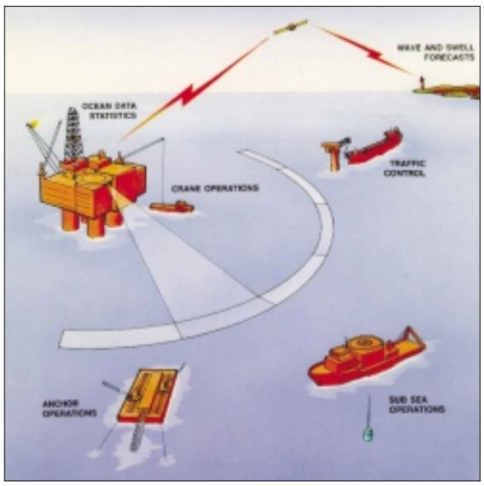
Master Curriculum (danish: Studieordningen) for the M.Sc. Programme in Civil and Structural Engineering at the School of Engineering and Science, Aalborg University. The curriculum can be found at the Study Board of Civil Engineering homepage at http://www.ses.aau.dk/digitalAssets/14/14964_msc_k_250610.pdf. A document template for the project plan is available at the homepage of the School of Engineering and Science at http://www.ses.aau.dk/digitalAssets/32/32582_projektplan_word.doc (Danish version) and http://www.en.ses.aau.dk/digitalAssets/32/32588_project-plan_word.doc (English version)

Aalborg, May 3, 2013 Johan Clausen, *semester coordinator*

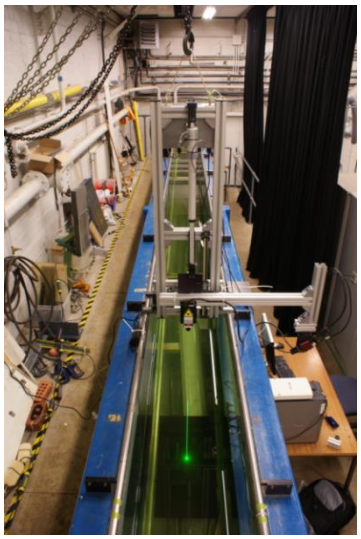
Remote sensing system for wave measurement

Purpose: To develop a non-invasive wave gauge for wave characterization.

Conductance based waves gauges are commonly used for wave measurement in laboratories; however, they require regular calibration and are intrusive. They are prone to inaccuracies, due to the meniscus effect, which can cause hysteresis. On the other hand, remote sensing of waves is potentially more accurate, as it is a non-invasive technique. Using a source of electromagnetic radiation, the light reflected or scattered by the wave, from a source, can be used to measure the waves. For this project, a wave gauge will be developed which measures the wave using lasers or microwaves.



(a)



(b)

Fig.1: (a) Measurement geometry of pulsed Doppler wave and current Radar. b) Example of an optical wave gauge installed in a flume.

Main activities: The project will contribute to the expansion of the wave laboratory expertise by adding a new type of wave gauges. It includes the following activities:

- Installation and calibration of the different components of the wave gauges, including data processing
- Characterisation of waves of different wave period, wave height and wave steepness
- Experimental comparison between performances of conductance based wave gauges and remote sensing wave gauges.

Contact persons: Amélie Têtu, John Lavelle

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

Creating a numerical model of the Weptos wave energy converter and validation by experimental tests.

Purpose: The purpose is to create a numerical model that can describe the movements of the rotor of the Weptos wave energy converter. This would be very useful as it could for example be used to further enhance its performance and reduce structural loads by improving the design and/or setup of the rotor.

The numerical model will not have to be started from scratch, but will be a continuation of a previous similar project that was based on the same setup. However the numerical model will have to be improved and expanded and new experimental tests will have to be performed in order to provide more and better comparable data, which should validate the numerical model and indicate the limitations of the numerical model.

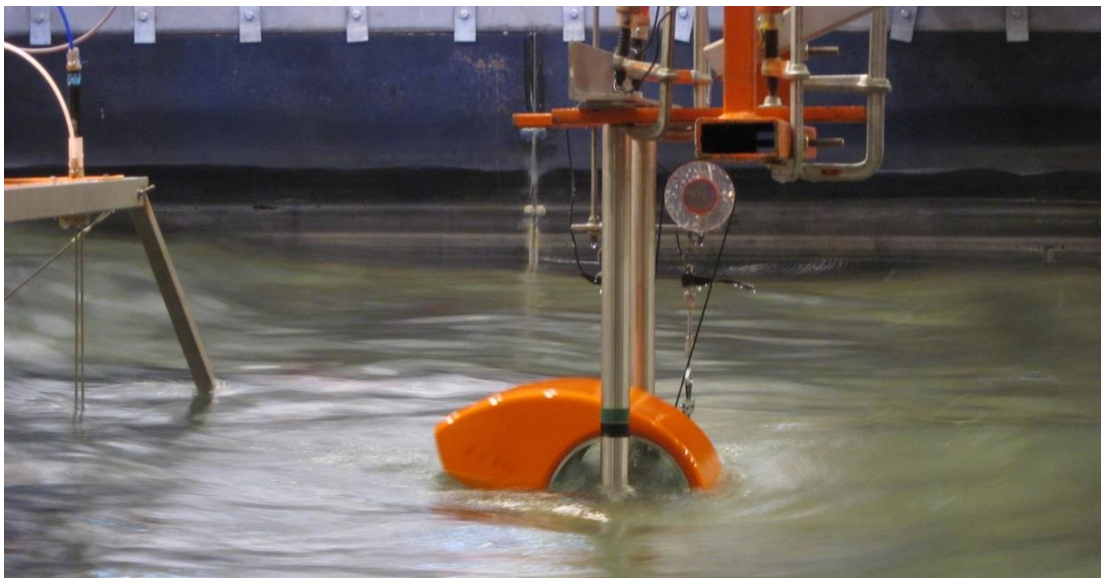


Figure 1: Picture of the rotor during experimental tests.

Main activities: The project will contribute to the on-going research on the subject and thus be very relevant. This project includes the main following activities:

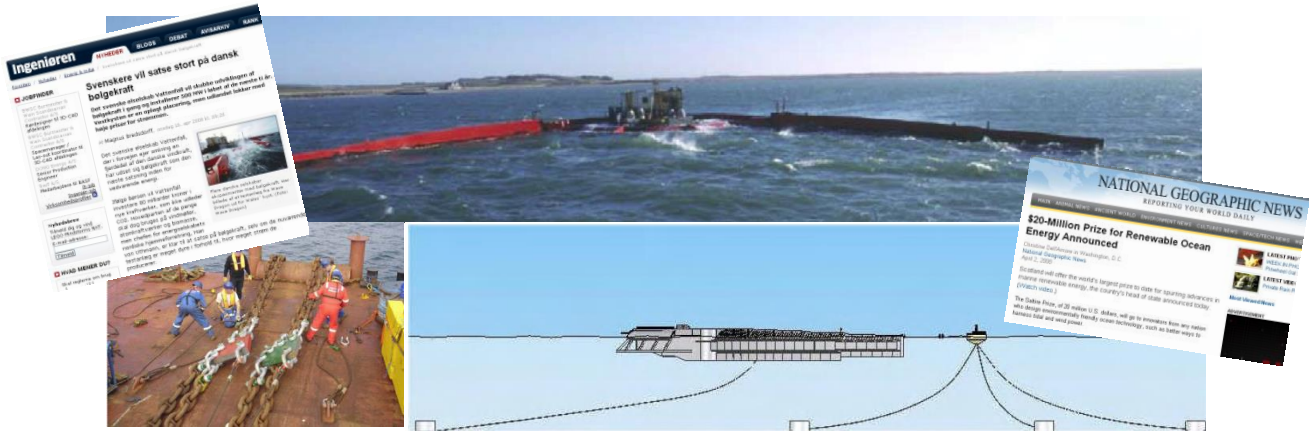
- Further development and enhancement of an existing numerical model.
- Experimental test aiming at validating and showing the restrictions of the numerical model
- Look into the effect of various variables on the performance of the rotor

Contact persons: Arthur Pecher, Jens Peter Kofoed

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

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, eg. 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)

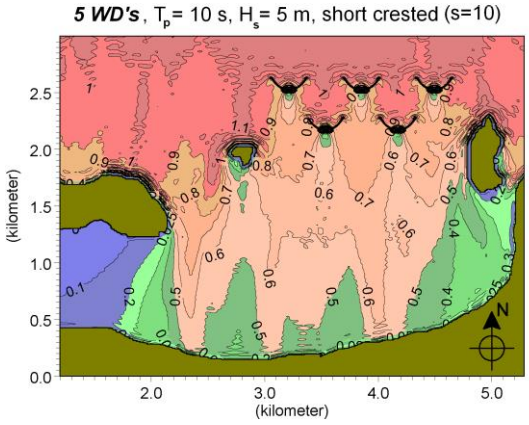
This is one among a large space of options to work within the field of wave energy utilization – if you are interested in participating in the development of the renewable energy industry of the future, please drop by and we will formulate the project that fits your specific interests!

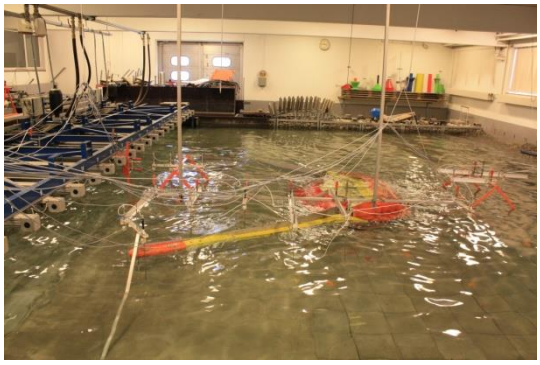
Wave energy converters for use in coastal protection

Purpose: The purpose is to adopt wave energy converters for mitigation of flooding and coastal erosion hazard in the context of increasing storminess and sea level rise. A proposal is to place wave energy converters close to the shoreline for contemporary attenuating wave attacks and thereby produce a secondary benefit.

Physical model tests on a single Wave Dragon wave energy converter have already been performed at AAU in scale 1:50 to measure the wave height reduction behind the device. Measurements from the tests have been used in the calibration of a numerical wave propagation model.

However, additional tests are still needed to perform more detailed analysis on the wave scattering from the devices. Moreover, numerical simulations should be performed to evaluate the influence from the Wave Dragons on the sediment transport in a specific bathymetry.





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 scattering from floating devices positioned in different arrays
- Case study on the influence on wave climate at specific site
- Case study on the influence on sediment transport at specific site
- Theoretical assessment of wave transmission through a wave energy converter

Contact persons: Jørgen Harck Nørgaard, Thomas Lykke Andersen, Thomas Ruby Bentzen

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

Influence from long waves on overtopping and stability of rubble mound breakwaters

Purpose: State of art design formulae for estimation of wave overtopping and wave loading on rubble mound breakwaters are based on relatively steep waves in deep water. However, many sites have waves that are relatively long in shallow water which shown a demand for design formulae that covers also that area.

The purpose is to derive modifications to existing design formulae based on physical model tests to increase the range of validity of existing design formulae.

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

- Experimental modelling of dynamic wave loads on rubble mound breakwater crown walls
- Experimental modelling of wave run-up and wave overtopping of rubble mound breakwaters
- Experimental modelling of stability of armour layers on rubble mound breakwaters

Contact persons: Jørgen Harck Nørgaard, Thomas Lykke Andersen

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

Run-Up on Piles in Irregular Waves

Purpose: Run-up can cause significant loads to entrance platforms at offshore wind turbines. In the Danish wind turbine park Horns Reef 1 several platforms have been damaged due to that issue. Therefore the offshore wind industry is very interested in run-up and the present project can be carried out in cooperation with DONG Energy who has expressed high interests in such project.

Fig. 1: Large scale testing of loads on wind turbine access platforms.

.

A model for run-up in irregular waves is wanted and thus accurate estimations of the kinematics of irregular breaking or nearly breaking waves is needed. For regular waves the stream function theory is well accepted and used. However, for irregular waves a local Fourier approximation exists, leading to an approximation of the stream function in irregular waves. This makes it possible to calculate wave kinematics in waves that are not symmetrical around the wave crest. In the present project such method can be implemented and tested against large scale run-up tests.

Main activities:

- Look at newly performed model tests to quantify importance of wave shape on run-up on piles and loads on secondary structures
- Implementation of Local Fourier approximation code in MatLab or other programming language (good programming skills needed)
- Application of method to newly performed large scale tests. Additional verification tests can be performed in small scale if needed.

Contact person: Thomas Lykke Andersen

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

Stability of Roundheads

Purpose: The roundhead is a critical part of a rubble mound breakwater in terms of armour stability. This critical part is often tested and optimized in hydraulic model tests. These tests usually show that the stability of the armour in the rear sector of the roundhead is the most critical and that armour units on the roundhead need to be of double weight of those on the trunk section to provide sufficient stability. Based on model tests few design formulae have also been derived giving the damage in the critical rear sector.

New model tests at Aalborg University have shown that the critical sector shifts with the wave period and thus the critical sector is not always the rear one. The result is that the existing design formulae are unsafe in such cases.

The purpose of this project is to test the influence of the wave period on the stability of the roundhead and make updated formulae for damage pattern and stability of roundheads. Other main parameters can be varied also.

Main activities:

- Design the breakwater and make a model test programme based on existing knowledge.
- Perform model tests with stability of roundheads in the wave basin
- Derive new design tools for stability of round heads.

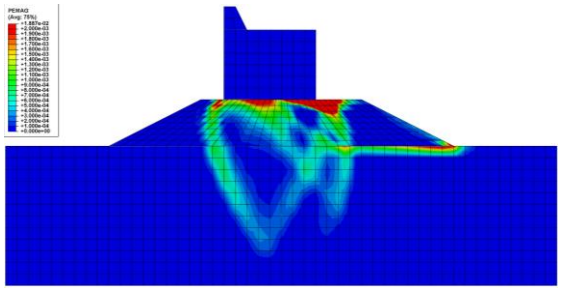
Contact person: Thomas Lykke Andersen

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

Stability of caisson breakwaters subjected to impulsive wave loads

Purpose: Caisson breakwaters are in most cases designed for no sliding. In case of impulsive loading this criteria result is a very wide caisson. On the other hand the duration of the load is very small so the impulse might only cause a rocking or a very limited permanent displacement. The goal of this project is to test existing and new tools for estimating those displacements against results from model tests.

The study can thus include both scaled model tests in the laboratory, numerical finite element modelling in e.g. ABAQUS or other models.



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

- Experimental modelling of structural response of monolithic caisson breakwaters
- Numerical modelling of structural response of monolithic caisson breakwaters and elastic/plastic deformations in foundation material

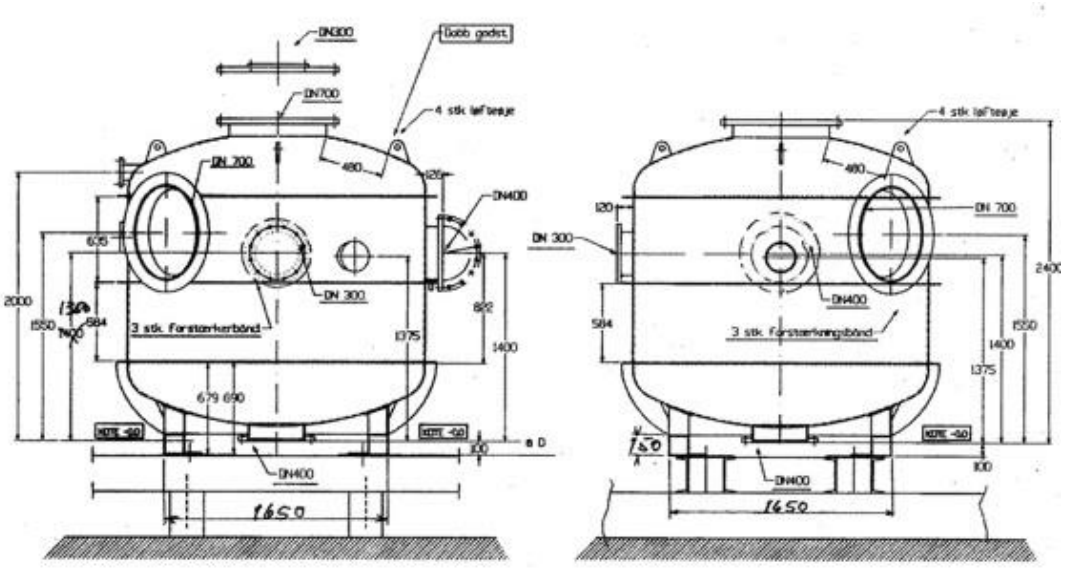
Contact persons: Jørgen Harck Nørgaard, Thomas Lykke Andersen

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

Contact persons: Jørgen Harck Nørgaard, Thomas Lykke Andersen, Lars Andersen

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:

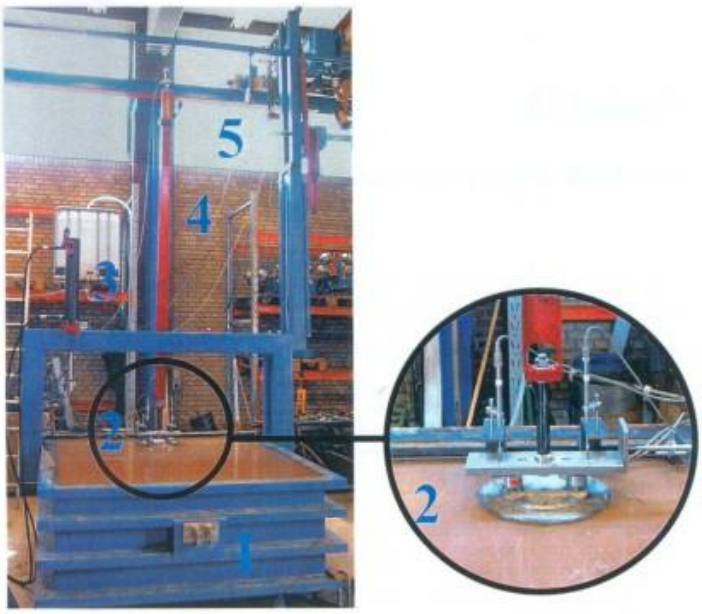
Resultaterne af disse forsøg sammenholdes med resultaterne fra de statiske forsøg. Herved kan det evalueres, om den varierende belastning har indflydelse på fundamentets bæreevne, stivhed samt plastiske deformationer.
Den elastiske opførsel under cyklisk belastning er vigtig for interaktionen med tårnet, 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:** ☒☒☐

Bender elements for the measurement of soil stiffness

Purpose: Using Bender elements to determine the dynamic elastic shear modulus Gmax, for soils.

The measurement of soil stiffness is of great importance to geotechnical design. Especially for analysing and designing constructions such as wind turbines the soil stiffness is a key-parameter.

Resent research have provided dynamic methods for the measurement of soil stiffness at very small strains using piezo-ceramic plates called bender elements.

Main activities: The project can include:

- Getting to know bender elements
- Gathering and analysis of current design material
- Determination of focus areas
- 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: Benjaminn Nordahl Nielsen and Lars Bo Ibsen

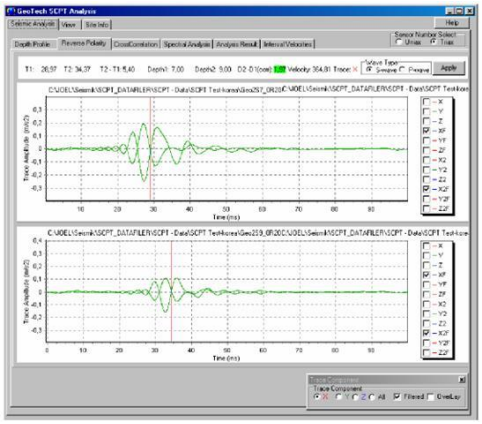
Theory: ☒☒☐ **Experimental work:** ☒☒☒ **Computer modelling:** ☒☐☐

SCPT - Seismic CPT

Purpose: For onshore and offshore constructions there is a growing need for analysing and determination of the elastic soil parameters.

With the seismic CPT adapter mounted on the CPT probe it is possible to carry out CPT and seismic test during the same penetration.

Best practice is needed to be carried out.



Main activities: The project is open with concern to the problem to be analysed. However the focus is on field testing. The project may include:

- Getting to know SCPT – seismic CPT
- Gathering and analysis of current design material
- Determination of focus areas
- Field tests
- Theoretical assessment
- Computational modelling of SCPT

The project can include experimental field testing on different locations in Denmark togheter with geotechnical engineering firms.

Contact persons: Benjaminn Nordahl Nielsen and Lars Bo Ibsen

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

Light Weight Deflectometer

Purpose: The Light Weight Deflectometer offers measuring of the bearing capacity for subsoil and foundation layers directly in the field.

Currently the equipment used is isotope measuring using radioactive sources with is not especially environmental friendly and safe. The LWD gives at direct output for the soil stiffness, however no systematic use for design and analysing have been setup.

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 Light Weight Deflectometer
- Gathering and analysis of current design material
- Determination of focus areas
- Field and laboratory Tests
- Theoretical assessment
- Design model creation / best practise.

The project may be carried out as engineering practice, and it may be possible to perform experimental tests together with Grontmij/Pavement who have introduced the equipment on the Danish market.

Contact persons: Benjaminn Nordahl Nielsen and Lars Bo Ibsen

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. Random errors seem to occur and simulations break down.

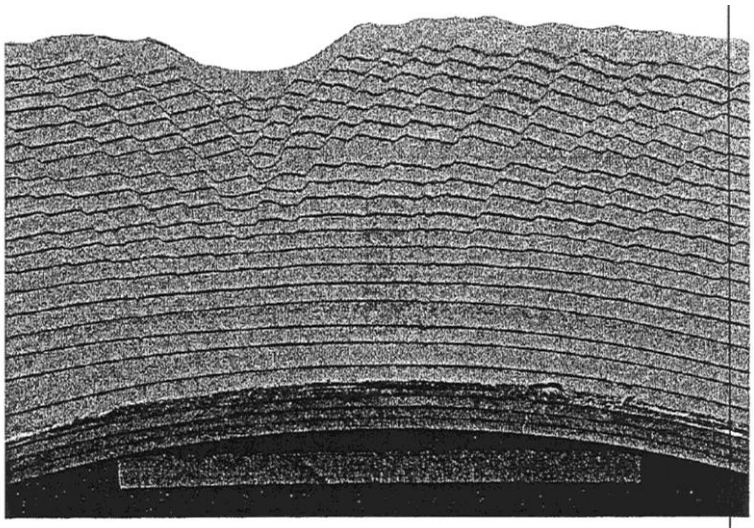


Fig. 8.2 Crestal faults over arch of uniform curvature, simulated in a sand box (Mandl, 1984).

In this project the goal is to examine how we should model non-associated soil behaviour with the finite element method. The different result of different methods could be quantified using simple benchmark calculations, e.g. a surface footing or a sheet pile wall. This project will involve a considerable amount of MatLab-programming.

Examples of main activities:

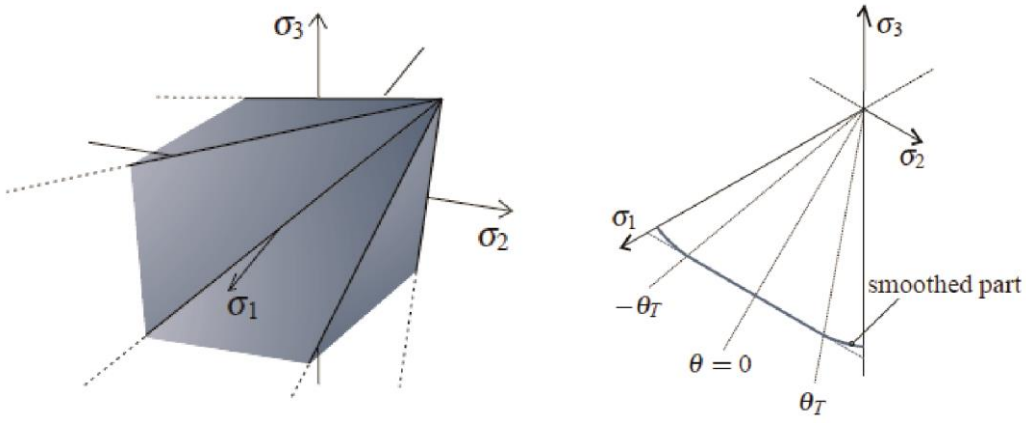
- What are the symptoms of non-associated problems? A computational and literature review.
- What do the commercial codes do (e.g. Abaqus, Plaxis, Ansys)?
- Do we have other methods of remediating the problem?
- Quantification of different results with different methods using own MatLab code

Contact person: Johan Clausen

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

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 parameters and poorer in others.

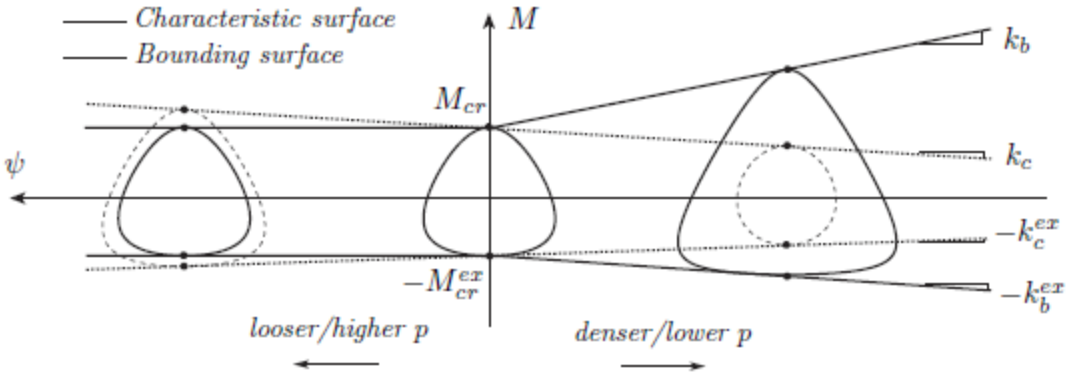
An interest in programming, e.g. MatLab, is essential.

Contact person: Johan Clausen

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

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. Different types of stress update schemes can be examined.



Main activities: The main activity of the project would be to implement a specific material model into a finite element program, which would make it possible to simulate soil structures with cyclic loading.

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

Contact person: Johan Clausen, Lars Bo Ibsen

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

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.

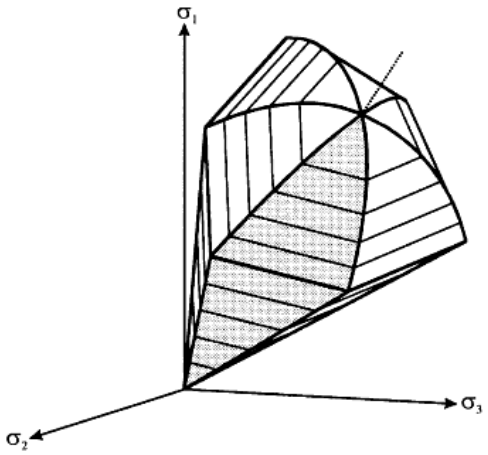


Figure 3. Representation of total yield contour of the Hardening-Soil model in principal stress space for cohesionless soil.

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.

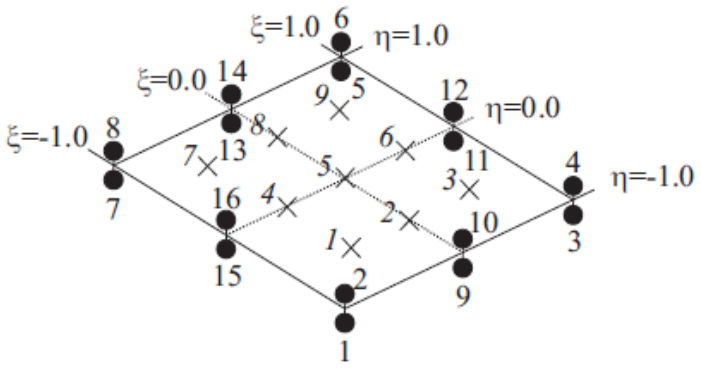
An interest in programming, e.g. MatLab, is essential.

Contact person: Johan Clausen

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

Implementation of interface friction finite elements

Purpose: When designing geotechnical structures the interaction between the soil and the structures, e.g. footings or walls can have a significant impact on the displacement and strength on the overall structure. The interaction can consist of both adhesion and friction. In finite element analyses the interaction can be modelled with so-called interface elements, as it is seen in e.g. the commercial code Plaxis, from the manual of which, the figure below is taken. Several methods of implementing interaction elements exist. The goal of this project is to implement interaction elements in a finite element code in MatLab.



Local numbering and positioning of nodes (•) and integration points (x) of a 16-node interface element

Main activities: Firstly a litterature study on interface finite elements should be carried out. Then one or more types of interface elements should be implemented into a finite element code. The performance of the elements should be compared to existing solutions, e.g. strip footing bearing capacities, where exact solutions are known for different degrees of footing roughness. Other case studies can be carried out, e.g. quantifying the effect of the degree of roughness of sheet pile walls.

If time permits the work can be extended to three-dimensional finite elements.

Contact person: Johan Clausen

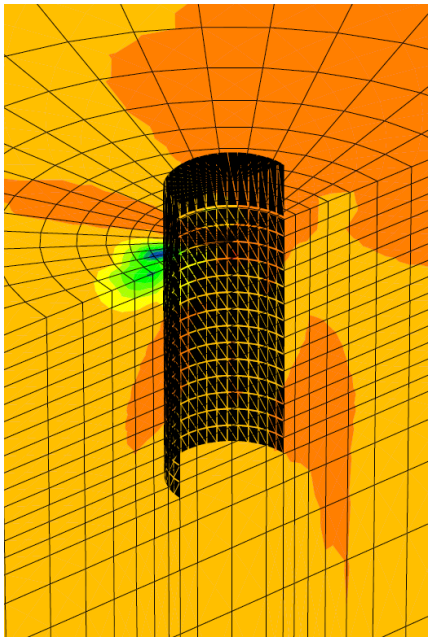
Theory: ☒☒☐ **Experimental work:**. ☐☐☐ **Computer modelling:** ☒☒☒

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

A project in cooperation with

DONG energy

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 persons: Lars Bo Ibsen

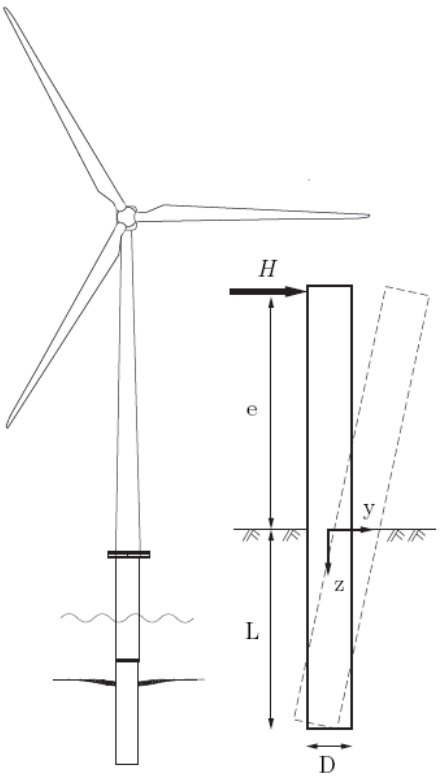
Theory: ☒☒☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☒

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 persons: 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:** ☒☒☐

The influence of uncertain wind climate on turbine loads

Purpose: Before wind turbines are installed, the wind climate on the site is estimated using different flow models and measured using e.g. met masts. The main purpose of these investigations is to estimate the annual energy production, but also to determine the site specific climate parameters (e.g. mean wind speed, turbulence intensity, shear and extreme wind speed) which provide the basis for estimating wind turbine loads.

For many sites the uncertainty related to some of the climate parameters is relative high, because the measurement period is relative short. This can potentially have a high influence on the uncertainty in the wind turbine loads and thereby the reliability of the wind turbine.

The main purpose of the present study is to investigate how uncertainty in different wind climate parameters propagates during the load calculation and influence the wind turbine loads. These models can later be used to estimate the structural reliability and identify site where caution such be taken in the assessment of the design loads.

Main activities: The main activities in the project include:

- Literature review.
- Analysis of wind measurements – Uncertainty in climate parameters
- Analysis of design load cases using Aero-elastic simulations.
- Uncertainty assessment for design loads.

The project will be conducted in co-operation with EMD International A/S which has more than 25 years of experience in site assessment for wind turbines. EMD will provide computer capacity for performing the numerical simulations.

Contact persons: Henrik Stensgaard Toft (hst@civil.aau.dk)

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. the optimal reliability level are 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.

The project is associated the revision of the IEC standards for wind turbine design: 61400-1 and 61400-3 and a new standard (under development) for towers and foundations: 61400-6.

Main activities:

- Optimal reliability level based on maximal economic return life safety requirements, e.g. based on LQI (Life Quality Index) considerations, and including environmental aspects.
- Reliability-based calibration of new partial safety factors and load combinations for IEC 61400-1 (Design requirements), 61400-3 (Offshore) and 61400-6 (Towers and foundations)

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

The project will be connected to ongoing research projects.

Contact person: John Dalsgaard Sørensen, Henrik Stensgaard Toft

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

Reliability and 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 can 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.

The purpose of this project is to establish an overview of risks associated with wind turbine failures. 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:
  - 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 will be connected to ongoing research projects

Contact person: John Dalsgaard Sørensen

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 be 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 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 persons: John Dalsgaard Sørensen, Henrik Stensgaard Toft

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

Project Proposals in Wind Turbine Mechanics and Optimal Vibration Control

A number of project proposals are available in this area:

1. Dynamic Reliability Analysis and Determination of Design Criteria of Wind Turbines based on the Probability Density Evolution Method
2. Three Dimensional Turbulence Modeling for Wind Turbines based on Rapid Distortion Theory and the Evolutionary Phase Model
3. Stochastic Aeoelastic Stability of Wind Turbines based on the Top Lyapunov Exponent
4. Influence of the Geometric Non-linearities and Non-conservative loads (follower forces) on the Aerodynamic stability of Wind Turbines
5. Semi-active Pitch Control of Wind Turbines against Dynamic Stall based on Partial State Observation
6. Semi-active and Active Vibration Control of Edge-wise Vibrations of Wind Turbine Blades
7. Optimal Non-linear Stochastic Control of a Cluster of Wave Energy Point Absorbers in Irregular Sea-states

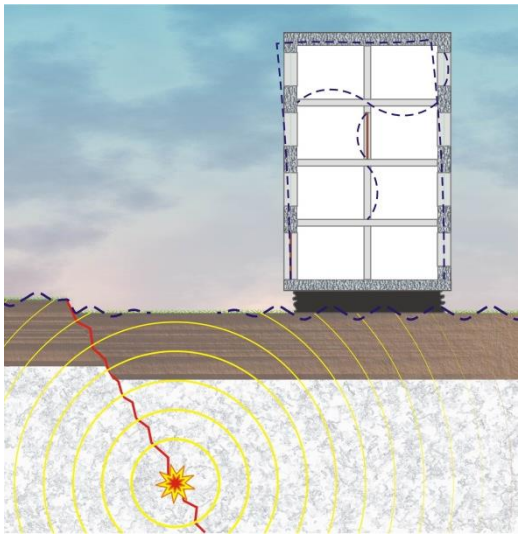
A part of the projects may be carried out abroad as secondment to universities in China (Tongji University, Shanghai), Norway (NTNU) or Ireland (Trinity College Dublin).

Contact person: Søren R.K. Nielsen

Nonlinear analysis of earthquake-induced vibrations

Purpose: Earthquakes are a source to vibrations of large magnitude, each year causing damage to building structures in many regions of the world, often resulting in human casualties. Earthquakes cannot be prevented, but a proper design of a structure may reduce the risk of fatal damage significantly.

Usually, building design is accomplished based on codes of practice and static (or quasi-static) analysis. However, vibration in a building is dynamic by nature, and to fully describe the structural behaviour, time-domain analysis of the building response is necessary. The idea of the present project is to use a finite element model for analysis of a building in order to investigate the occurrence and possible accumulation of damage in a steel or concrete structure during an earthquake. For this purpose, a nonlinear dynamic finite element analysis is carried out.



Main activities: The analysis may be carried out by means of a complex three-dimensional model, utilising a commercial finite-element code such as Abaqus. Alternatively, a simpler two or three-dimensional building may be analysed by a Matlab code developed as part of the project. The main activities may include:

- Literature study of earthquake engineering
- Literature study of nonlinear dynamic finite-element analysis
- Literature study of material behaviour in cyclic response
- Finite-element modelling of a building, possibly including the subsoil
- Formulation of a constitutive model for damage in concrete or steel
- Coding of a nonlinear dynamic solution algorithm in a finite element code
- Parameter studies regarding structural design and material properties
- Design of a building to mitigate damage
- Comparison of finite-element based building design with code-based design.

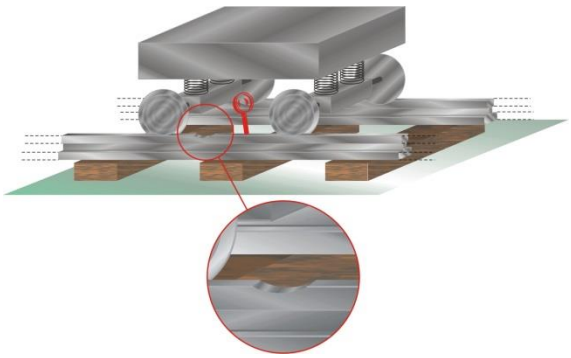
Contact person: Lars V. Andersen and Johan Clausen

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

Traffic induced vibrations

Purpose: Traffic on roads and railways is a source to vibrations that may be a nuisance to people in the built environment. Current design regulations provide limited information about design criteria, and valid models for prediction of vibration levels are generally not available. Usually, vibration levels are measured on "similar" roads or railway tracks, and in similar building structures, and an empirical model is employed for prediction of vibrations in a new building project.

Hence, there is a general need for better prediction tools, and in this project the idea is to develop a method based on computer modelling. The model should include the vehicle, the track or road structure, the subsoil and the building. Focus of the project will be to determine the significance of different parameters, e.g., soil properties, vehicle type, building material or road irregularity, on the vibration levels observed by people in a building.



Main activities: The coupled model consisting of vehicle, track, subsoil and building can be made in a commercial finite-element analysis program (e.g., Abaqus) or, preferably, a Matlab code may be developed for the purpose. In either case, the following items will be part of the project work:

- Literature study of vehicle dynamics
- Literature study of wave propagation in tracks, soil and building structures
- Numerical modelling of vibration transmission through the rails and subsoil
- Modelling of a lorry, bus or train as a multi-degree-of-freedom system
- Modelling of road or track surface irregularities
- Parameter studies for various vehicles, tracks, soils and/or buildings.

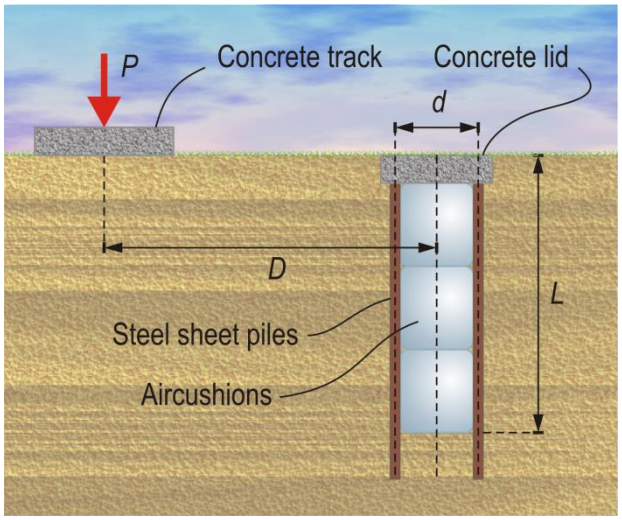
A final goal may be the development of a program for evaluation of vibration levels in building next to a heavily trafficked road or railway.

Contact person: Lars V. Andersen

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

Vibration mitigation in civil engineering problems

Purpose: Sources to vibration cannot be avoided in the built environment. For example, traffic and heavy machinery may cause vibrations that can be transported over long distances through the soil. This is a nuisance to people in residential buildings as well as people working in offices or production facilities. A special problem concerns laboratory, hospitals and concert halls, where only a very small vibration level can be tolerated. To mitigate vibrations caused by external sources, a wave barrier may be introduced. A classical solution is to put an open trench between the source and receiver, but more sophisticated solutions have been proposed. As illustrated on the right, this includes aircushions that maintain the high efficiency of an open trench but keep the soil from collapsing and people, rain and objects from falling into the trench.



Several other possibilities exist, such as soil improvement by grouting or pile installation. Even "intelligent landscaping" has been suggested as a means of reducing vibration levels in the new MAX4 test centre near Lund in Sweden. The idea of the project is to investigate and optimize one or more methods of vibration mitigation and suggest materials, techniques or structures that can be used for dynamic isolation of buildings.

Main activities: Focus of the project may be development of a particular kind of wave barrier, or the problems related to vibration mitigation can be approached in a more general way. The activities of the project may include:

- Literature study of soil dynamics and wave propagation theory
- Numerical analysis of wave propagation in soil
- Optimal design of a wave barrier or wave impeding material
- Mitigation of wave propagation by intelligent landscaping or soil improvement
- Experimental analysis of a wave barrier.

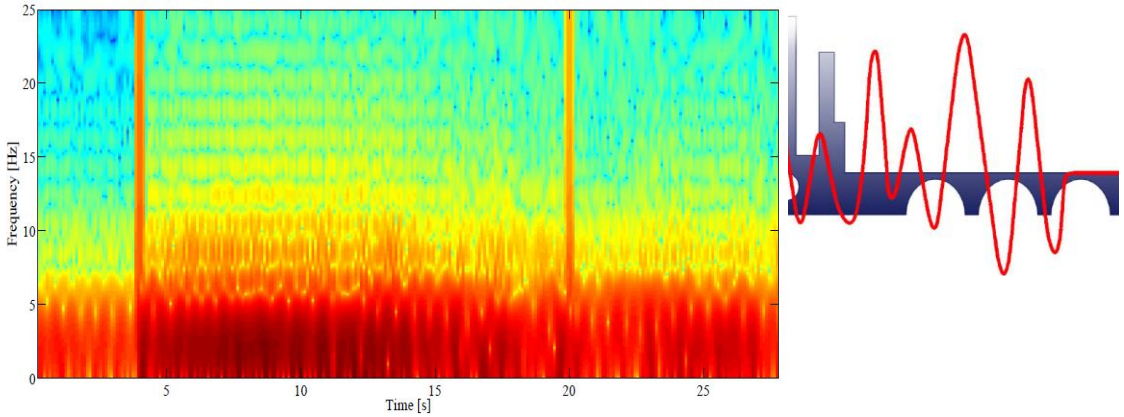
The workload related to theoretical investigations, experimental work and computer modelling may vary depending on the weight put on each item.

Contact person: Lars V. Andersen

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

Experimental Nonlinear System Identification in Structural Dynamics

Purpose: Linear system identification techniques are highly advanced and sophisticated, and as such, they are often used in industry for identification of system's linear modes. However, majority of physical systems is nonlinear, and they consists both of linear and nonlinear system modes. They can be analyzed using linear techniques only under the assumption that systems are linear in certain operational regimes (linearization approach). However, in many cases, this is not sufficient and in order to better understand the nature of the system, it is necessary to perform nonlinear analysis and identify nonlinear system modes. Some of the issues in nonlinear identification are detection of operating regimes where system behaves as a nonlinear, characterization of the type of nonlinearity and identification of nonlinear characteristic function of the system. The present project will look into experimental system identification techniques for time-varying, nonlinear systems. These methods can be further benchmarked on experimental or simulated data.



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 system identification methods for Civil Engineering Structure
- Theoretical and experimental evaluation of system identification methods
- Determination of focus areas
- One or two civil engineering problems dealing with non-linear phenomena will be analysed using theory, experimental work and computer modelling

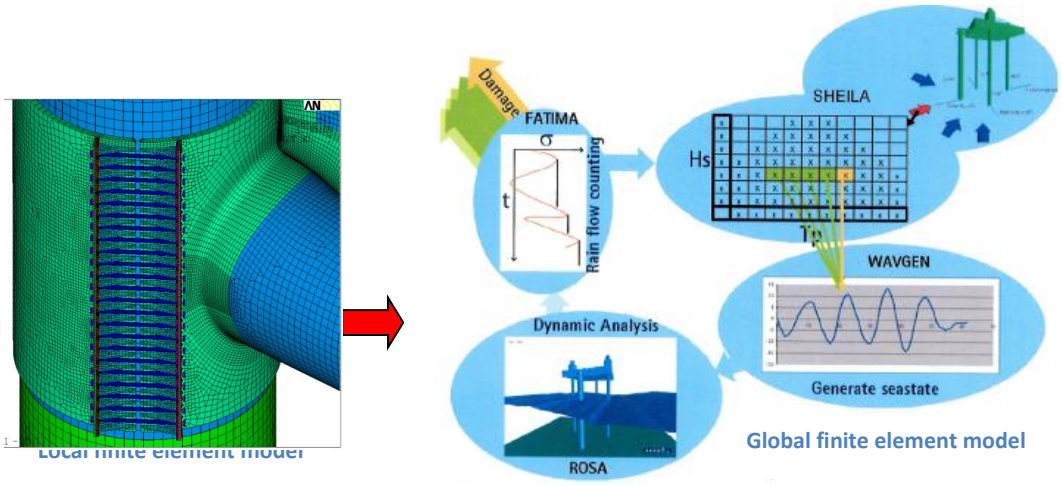
Part of the project can be carried out together with Rambøll (http://www.ramboll.com/Oil-Gas) on experimental data measured at offshore oil & gas platforms.

Contact persons: Poul Henning Kirkegaard, Nevena Perisic

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

Evaluation of Multi-Axial Fatigue Damage

Purpose: Fatigue is one of the most significant failure modes for marine structures and accurate prediction of the fatigue life of these structures is therefore very important for both safe and economic design and operation. In several decades, it has been common practice to base the fatigue life predictions on the stress range of one single stress component. However, welded structures often experience multi-axial loadings, caused primarily by conditions and the geometry of the structure. Recent research has shown that several stress components can have an important impact on the fatigue life of a structure. Thus, a "state-of-the-art" evaluation of multi-axial fatigue approaches is therefore of high interest for the industry.



Main activities:

- Keywords: Literature review – damage models / accumulated fatigue, local finite element modelling (ANSYS), global finite element modelling
- The first part of the project shall be a literature review describing theoretical and practical approaches for analysis of multi-axial fatigue. A comparative study including the different approaches can be made on a Mathcad level. Fatigue prone areas are often analysed by detailed finite element models of local details. The local models are then linked to global analyses and the fatigue life of the component is then determined by e.g. transient fatigue analyses.
- The second part of the project will include establishment of a local finite element of a selected detail. Subsequent implementation of this model into a global analysis model (see **Fejl! Henvisningskilde ikke fundet.**). Ramboll (http://www.ramboll.com/Oil-Gas) will supply a global model and assist the implementation of the local model.

Contact persons: Poul Henning Kirkegaard, Ulf T. Tygesen, Michael Rye Andersen

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

Dynamic Ice Loads

Purpose: With the oil and gas exploration moving further North and an increased need for fixed support of offshore wind turbines/substations in the more cold regions, focus is turned towards the design of structures in cold climate. One of the design challenges is the prediction of ice forces, as the ice forces often are the dominant environmental loading in these regions.

Different ice conditions may be encountered in the high latitude waters, such as level ice sheets, ice ridges and icebergs, each presents distinct risks to offshore platforms. Ice loads acting on a structure depend on many factors including the mechanical properties of both the ice and the structure, failure modes of the ice, and the drifting ice velocity. In additional to the evaluation of the risk and statistical background of ice impact on offshore platforms, it is of great importance to understand, describe and evaluate the extreme static ice load and the fatigue damages from dynamic ice actions , i.e. the fundamentals behind ice-structure interaction.

Main activities:

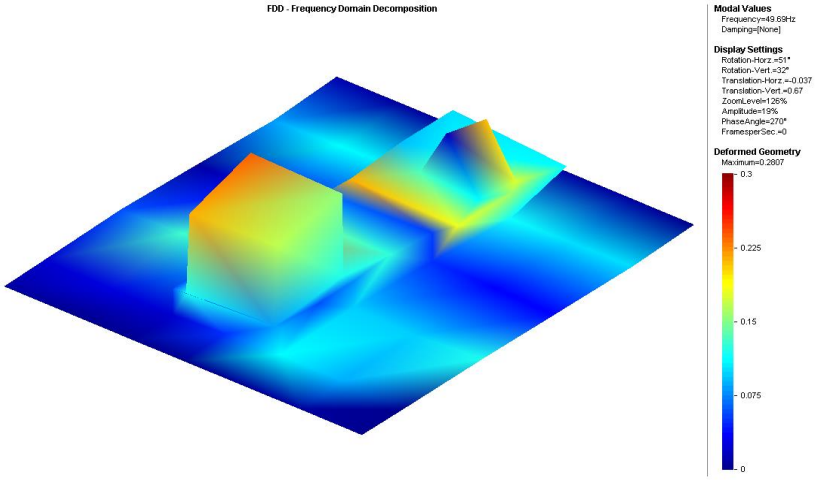
- The first part of the project shall be a literature review determining theoretical and practical approaches for analysis of ice impact on offshore platforms – both in the extreme and fatigue case. A comparison of different ice-crushing models can be performed as a start including an analysis of ice failure mechanisms. It should be the target to determine reasonable ice load calculations principles on single- and multi- legged structures (vertical and inclined legs).
- The second part of the project can include establishment of a statistical background for ice loading on a offshore platform including risk assessment; hence, a reliability based approach to determine the design ice conditions for assessment of the offshore platforms is proposed.
- The third part of the project can be to establish a fatigue estimation model when studying ice-induced vibrations from dynamic ice actions.

Contact persons: Poul Henning Kirkegaard, Ulf T. Tygesen, Jens Rosenville, Michael Rye Andersen

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

Rotating Equipment

Purpose: In connection with constant upgrading and changes to the offshore production facilities new equipment often are installed on the existing platforms. In addition wear and tear of the existing equipment also changes the conditions for the operational conditions which can lead to equipment break down or fatigue damage of the supporting structures. Before installation of new equipment the existing facility is modelled in a FE model software (e.g. ANSYS/ABAQUS/ROSAP) and a dynamic analysis is performed to verify that the new rotating equipment will not contribute to increased vibration in the area. Offshore field vibration measurements are often also performed to identify the problems, updating the FE models and analysing reinforcements or vibration reduction alternatives.



Main activities: Some keywords for a scope for a project could be:

- Set-up of a test arrangement in the vibration laboratory for vibration measurement and analysis of a steel supporting frame for a rotating equipment
- Measurements could consist of accelerometers and/or strain gauges.
- Means of identification of typical vibration issues such as: too flexible supporting structure, resonance, lock-in, vortex induced vibration (VIV), acoustic induced vibration (AIV), piping vibration due to process flow, other.
- Test/analysis of AVM's (anti-vibration-mounts) for damping the vibration transferred to the supporting structure
- Generation of dynamic stiffness (dynamic characteristic of supporting structure)
- Tuned mass dampers studies or other vibration damper principles/designs
- Analyses: Operation deflection shapes, Operational modal analysis (system identification), FE model updating, Load estimation.

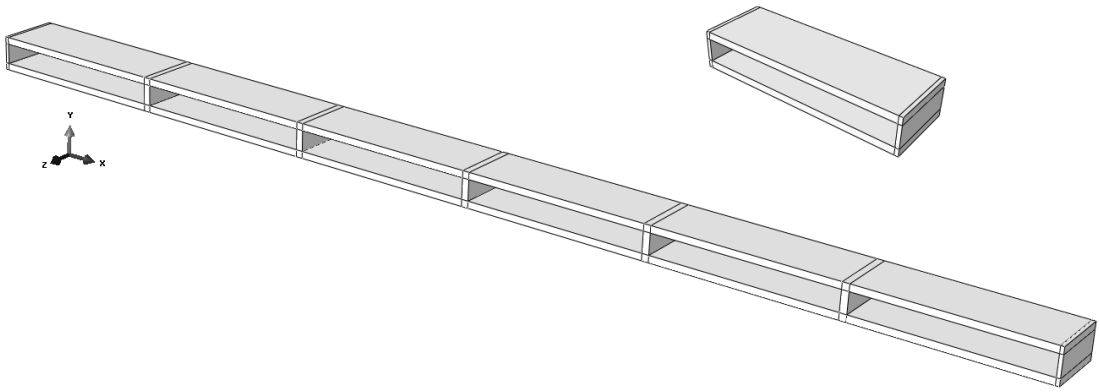
Part of the project can be carried out together with Ramboll Oil&Gas (http://www.ramboll.com/Oil-Gas) on experimental data measured on offshore platforms.

Contact persons: Poul Henning Kirkegaard, Ulf T. Tygesen, Nevena Perisic

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

Modelling and dynamic analysis of periodic structures

Purpose: In a periodic structure, the same geometry is repeated a number of times as illustrated below, where six identical cells are connected to form a beam. Such structures occur in many civil and structural engineering problems. For example, joists and studs are usually placed in a periodic manner in a wooden floor or wall panels, and tunnels may consist of a number of identical segments connected by gaskets at the joints. However, periodicity may also be introduced into structures that are usually not periodic, e.g., by placing additional masses or springs in a periodic manner. This may be beneficial, since periodicity within a structure has a documented effect on vibration transmission. Thus, so-called stop bands will form, in which wave propagation is attenuated dramatically. In a building structure, this can be utilized to avoid transmission of vibrations in frequency ranges where, for example, washing machines or elevator motors are known to induce vibrations. Theoretically, the reference cell may be repeated infinitely many times. Analysis of such structures can be carried out by means of Floquet theory which is a generalisation of Fourier theory. This can be combined with the finite-element method to establish models of railway tunnels, long wall panels, pipelined etc.



Main activities: The following items may be part of the project work:

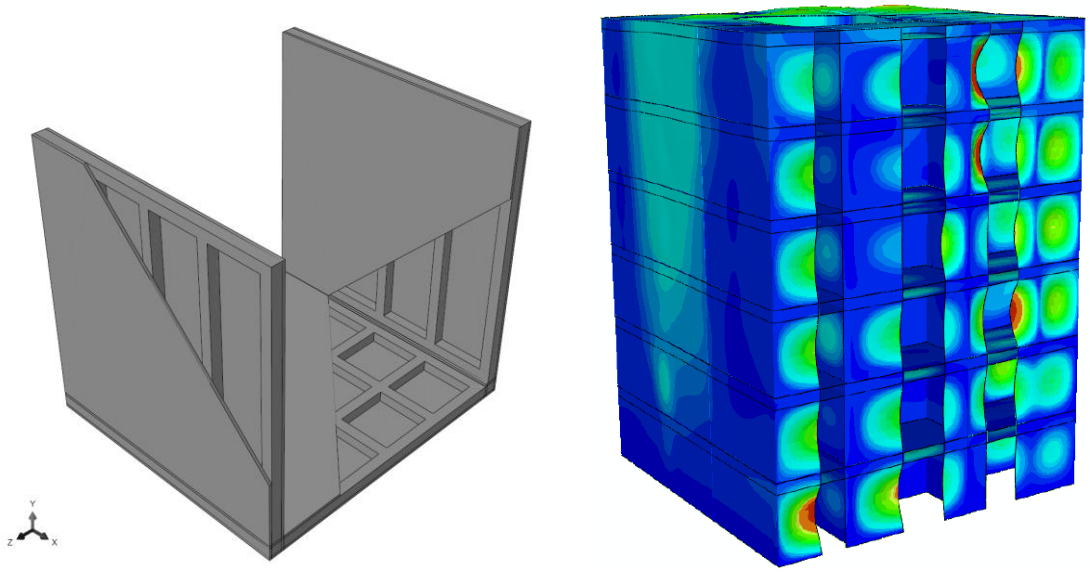
- Literature study of wave propagation in periodic structures
- Numerical modelling of a periodic structure (e.g., a tunnel, panel, or pipeline)
- Analysis of a periodic structure by means of Floquet theory
- Combination of finite-element analysis with Floquet theory
- Experimental analysis of wave propagation in a periodic structure
- Optimization of a periodic structure to minimize vibration transmission in a predefined range of frequencies.

Contact person: Lars V. Andersen

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

Noise and vibrations in lightweight building structures

Purpose: Walls and floors in lightweight timber structures are usually constructed as wooden panels. Depending on the geometry, material properties and boundary conditions, such panels may resonate at different frequencies within the audible range, leading to emission of noise. Furthermore, the panels may serve as waveguides, transmitting noise from one room to another or between floors. The project may concentrate on a global model for a building—or transmission paths may be studied at a local level, e.g. at a junction between a wall and a floor. Alternatively, the project may focus on an optimized design of wall or floor panels where the studs or joists are placed periodically to minimize noise transmission in the audible range.



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

- Literature study of building acoustics
- Formulation of models for dynamic analysis of periodic structures
- Design of joints in building structures for mitigation of noise
- Parameter studies to identify the influence of geometry and material properties on sound transmission in lightweight building structures
- Finite-element modelling of coupled acoustics and structural vibration
- Experimental testing of structural dynamics and acoustics.

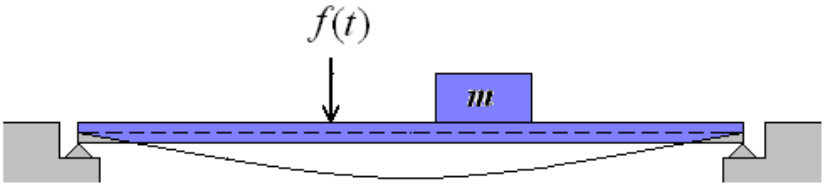
Contact person: Lars Andersen & Poul Henning Kirkegaard

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.

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

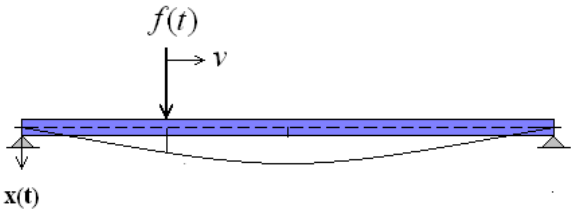
Theory: ☒☐☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

Dynamic human loading and stochastic models for estimating structural responses

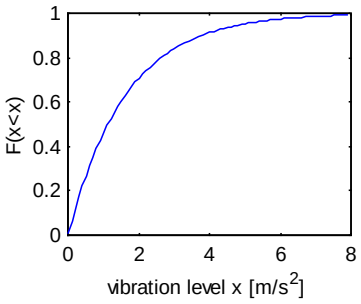
Background: Some civil structures are so slender that their modes of vibration may be excited by the basic frequency of human motion resulting in resonant structural action. The undesired resonant action may for instance occur in footbridges, stadia structures or in open-space office floors as a result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

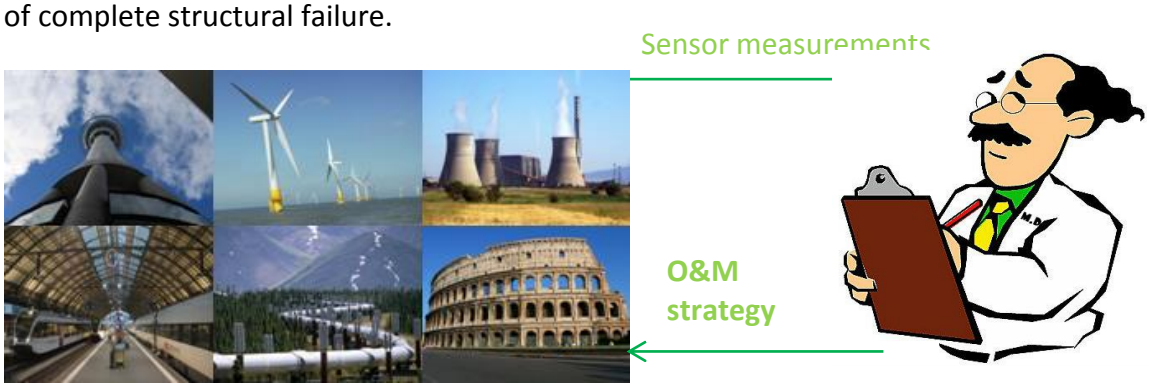
Through the project you will learn how to model the dynamic excitation of humans in motion, deterministically as well as stochastically. You will conduct parametric studies and numerical simulations to highlight essential implications of stochastic modelling of the phenomenon. Experimental verification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

Structural Health Monitoring of Civil Engineering Structures

Purpose: Structural health monitoring (SHM) is the name of a process of continuously monitoring the states of a structural system, with the aim to *detect*, *localize*, *classify, quantify* and *predict* damages in the structure. Presence of the damage in the structure is directly related to structural performance so it is one the major issues with respect of optimal, cost-efficient and safety operation in a wide range of applications (for example, in the case of bridges, wind turbines, offshore structures, buildings, airplanes and many others). Online monitoring of dynamic responses and loads on a structure can be used for extraction of system parameters that can indicate the presence of faults in the system. Early fault detection allows implementation of predictive operation and maintenance strategies and prevention of complete structural failure.



Main activities: The content and application of the project can be shaped by interests of the candidate. For example, load estimation for monitoring of wind turbine gearbox, fault detection and identification of oil and gas offshore structures/ turbine blades/ grout connections, etc. The main activities that project may/will include are:

- Learning about structural health monitoring methods for the selected application
- Classification of different fault scenarios and recognition of their features
- Data pre-processing and indirect measuring of parameters/ signals for fault detection
- Development of a damage detection algorithm

Part of the project can be carried out together with Ramboll Oil&Gas (http://www.ramboll.com/Oil-Gas) on experimental data measured on offshore platforms.

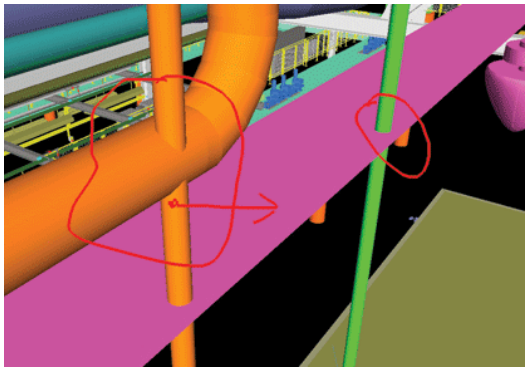
Contact persons: Poul Henning Kirkegaard, Lars Damkilde, Nevena Perisic

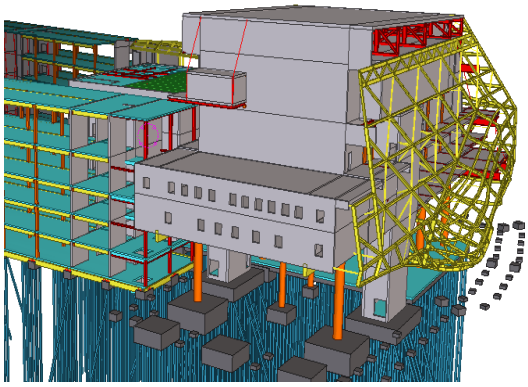
Theory: ☒☒☐ **Experimental work:** ☒☐☐ **Computer modelling:** ☒☒☐

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.

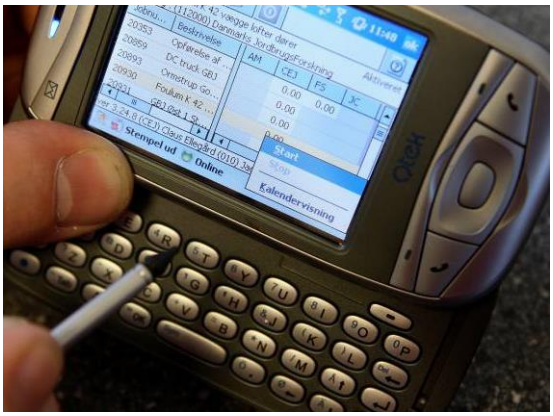
Contact persons: Kjeld Svidt

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

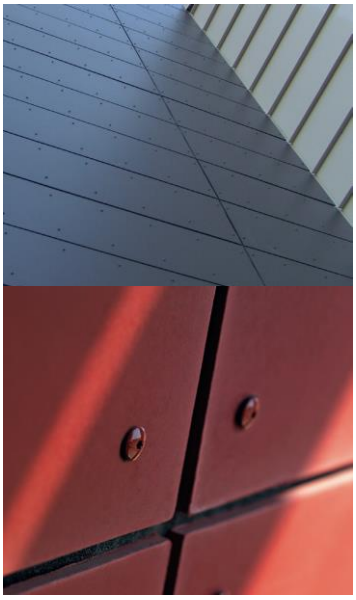
The work may be carried out in collaboration with a construction company.

Contact persons: Kjeld Svidt

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

Carbon dioxide curing of fibre-cement materials

Purpose: The objective of the proposed project is to establish a method for hardening fibre-cement materials in a carbon dioxide atmosphere and to determine the main properties of the hardened products as compared to air cured materials.



Background: Fibre-cement is a cement based fibre reinforced composite which is widely used throughout the world for a number of applications, notably lightweight roofing and cladding. One of the largest European producers of fibre-cement is the Cembrit Group with headquarters and R&D centre located in Aalborg.
Fibre-cement is composed of cement, microsilica, inorganic fillers, and natural and synthetic fibres, and is produced through a highly specialized process. Currently the materials are hardened by simple air curing. It has been found that the rate of hardening may be significantly enhanced by curing the materials in a concentrated carbon dioxide atmosphere. It is also known that such hardening will produce a different microstructure of the hardened material as compared to air curing. As a consequence, the properties of the final products, e.g. moisture induced shrinkage and swelling, resistance against freezing/thawing attack, and strength and stiffness, will be affected.
The proposed production method is environmentally friendly since carbon dioxide is consumed in the curing process.

Main activities: The project is relatively open concerning the specific approach to the subject. However, in any case the activities will include:

- Getting to know fibre-cement products and production
- Literature review of carbon dioxide curing of cement based materials.
- Design and set-up of carbon dioxide curing facilities at a laboratory scale
- Preparation and curing of specimens and measurement of properties as a function of curing method.
- Discussion of results in relation to theory.
- Recommendation of production method based on carbon dioxide curing.

The project will be carried out in close cooperation with the R&D department of Cembrit.

Contact person: Eigil V. Sørensen.

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

Compositon and properties of fibre-cement materials

Purpose: The objective of the proposed project is to provide a basis for optimization of mechanical and durability properties of fibre-cement materials by varying the nature of the components and the mix design of the material.

Background: Fibre-cement is a cement based fibre reinforced composite which is widely used throughout the world for a number of applications, notably lightweight roofing and cladding. One of the largest European producers of fibre-cement is the Cembrit Group with headquarters and R&D centre located in Aalborg.

Fibre-cement is composed of cement, microsilica, inorganic fillers, and natural and synthetic fibres, and is produced through a highly specialized process. Various characteristics of the material, such as moisture induced shrinkage and swelling, and resistance against freezing/thawing attack, in addition to mechanical properties such as strength and stiffness, are important to secure the proper functioning and adequate service life of the products. These characteristics depend on the nature of the microstructure of the material which in turn can be manipulated through the type and relative amounts of the constituent materials in the mix design.

Main activities: The project is relatively open concerning the specific approach to the subject. However, in any case the activities will include:

- Getting to know fibre-cement products and production
- Identification of focus areas based on literature review and theoretical considerations
- Preparation of specimens and measurement of properties as a function of composition variations, at the AAU Concrete Laboratory and at Cembrit's laboratories.
- Discussion of results in relation to theory.
- Recommendation of optimization options.

The project will be carried out in close cooperation with the R&D department of Cembrit.

Contact person: Eigil V. Sørensen.

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 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.
- 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:** ☒☒☐

Precast post tensioned CRC footbridge

Purpose: The objective of the proposed project is to theoretically, numerically and experimentally analyse and optimize post tensioning assemblage of a footbridge based on precast units of ultra high performance concrete.

Background: CRC (Compact Reinforced Composite) is an ultra high performance fibre reinforced concrete consisting of a dense and high strength cement based matrix with steel fibres added to achieve ductility, and with ordinary steel bars as the main reinforcement. Specialized prefabricated CRC units are produced for a wide range of applications by the company Hi-Con A/S in Hjallerup.

For many applications it would be advantageous to assemble precast CRC units in situ by post tensioning to construct long or tall structures. The proposed project will focus on a light and slender footbridge for urban areas. The wall thickness of the units, and thereby the maximum size of the anchorage zone for the tendons, is relatively small in order to minimize the dead weight of the bridge. However, due to the high strength and the ductility of CRC as compared to traditional concrete the forces can be carried by a smaller anchorage region, and it may even be expected that both the anchorage reinforcement and the reinforcement for the splitting tensile stresses generated by the concentrated loads are smaller than known from traditional concrete.

Main activities: The project is relatively open concerning the specific approach to the subject. However, in any case the activities will include:

- Getting to know ultra high performance fibre reinforced concrete (CRC), including potential applications and production and construction of CRC based structures
- By reference to the design of traditional post tensioned concrete structures analyse possibilities for simplifications of the anchorage zone reinforcement and enhancement of the overall performance of a footbridge constructed with precast CRC units, utilizing the special features of CRC.
- FEM-based computations and simulations
- Experimental investigations and validations of the calculations by testing specially produced and designed CRC units

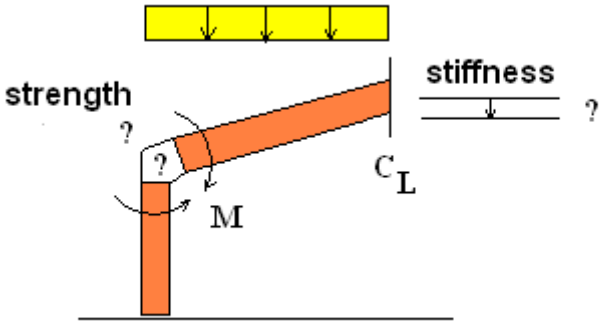
The project will be carried out in close cooperation with Hi-Con A/S.

Contact persons: Lars Pedersen and Eigil V. Sørensen.

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.

Contact persons: Lars Pedersen, Christian Frier

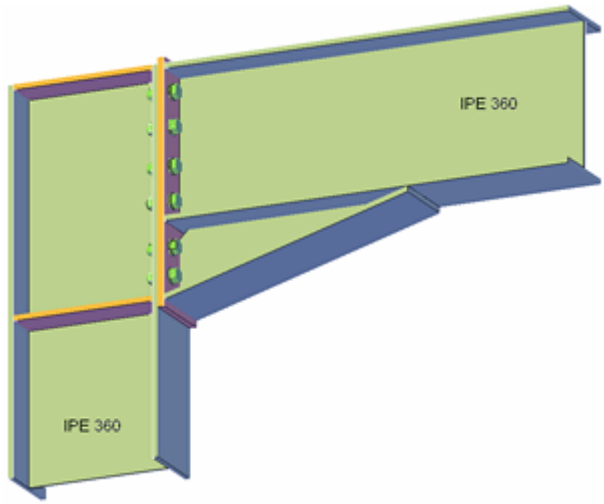
Theory: ☒☒☐ **Experimental work:** ☒☒☐ **Computer modelling:** ☒☒☐

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:** ☒☒☐

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

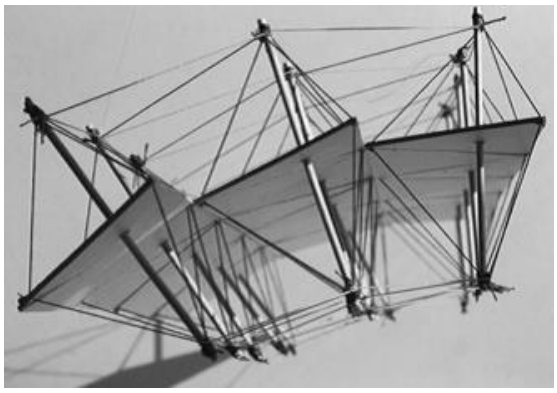
Theory: ☒☐☐ **Experimental work:** ☐☐☐ **Computer modelling:** ☒☒☐

Structural Analysis of Plate Based Tensegrity Structures

Purpose: The concept of combining truss element in compression with pre-stressed cables has been used in traditional tensegrity structures to create a structure with high bearing properties compared with its weight. This type of cable-strut light weight structure can be applied in a variety of applications.

A surface element in Cross Laminated Timber (CLT) is introduced to create a plate based tensegrity structure. Plate based tensegrity structures is composed of plates of various shapes, e.g. triangular, square or hexagonal, which are connected along their edges to form two- and three-dimensional assemblies. To increase the structural depth, each plate is perforated by a single strut oriented normal to the plate. The ends of the strut are connected to the corners of the plate by cables. Finally, the ends of the struts are connected by cables to eliminate the finite mechanisms. The resulting triple-layer structure share many similarities with double-layer grids. The main difference, however, is the middle plate-layer, which functions as shear stiffening roof covering.

Due to the large number of elements in a plate based tensegrity structure, it will contain several states of self-stress *s*, which may cause problems when the structure is to be pre-stressed. Another important issue regarding timber structures is the need for adjusting the member stress-levels during service-life, due to creep-effects and long-term deformation.



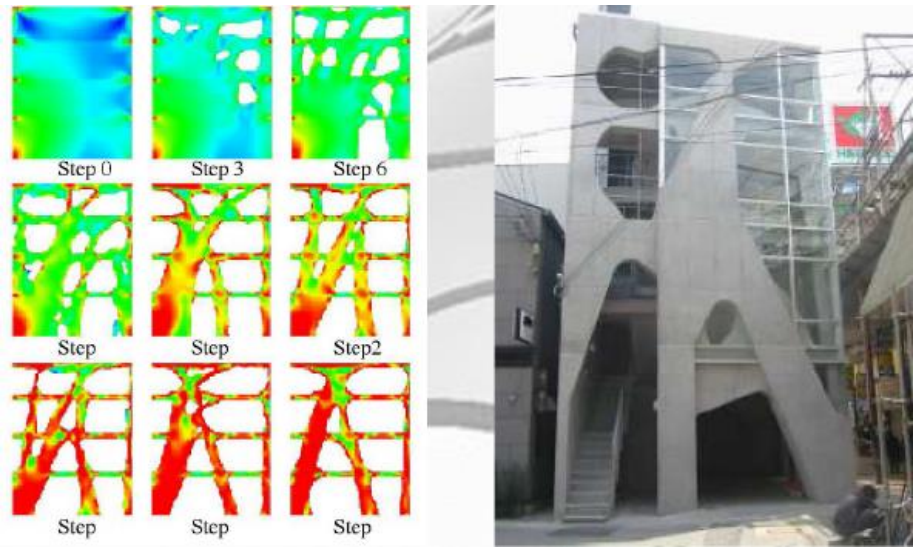
Main activities: The project is relatively open with concern to the problem to be analysed. However, in any case the activities will include:

- Getting to know tensegrity and plate based tensegrity structures
- Theoretical and experimental evaluation of plate tensegrity structures
- Determination of focus areas
- An evaluation of the potential of plate based tensegrity structures and the possibilities of using plate based tensegrity structures in civil engineering.

Contact persons: Poul Henning Kirkegaard, Lars Damkilde, Frederik Hald

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

Structural Design using Structural Optimization



Purpose: In the last few years a number of computational methods have been developed for structural optimization, methods for structural shape optimizationor for topology optimization like evolutionary structural optimization methods (ESO / Extended ESO). Most of these methods are based on dissecting the element into numerous parts for the optimization process and by deleting or adding parts after individually being tested against the design objective, which is achieved by variation of the design variables who are subjected to the design constraints in a process of multiple iterations. Over the past two decades there has been an increasing interest in using what has come to be called Evolutionary Computation (EC) in the analysis and optimization of structural systems. These methods include Genetic Algorithms (GA), Evolution Strategies (ES), Simulated Annealing and other stochastic based numerical methods. Each of these methods shares the drawback that they are very computationally intensive compared to deterministic methods. Furthermore, the computational burden can rapidly increase as the size of the analyzed structure increases. This project will consider how shape and topology optimization methods can be used for structural design.

Main activities:

- Knowledge of shape an topology optimization methods in civil engineering
- Evaluating the FEM program OptiStruct
- Comparative case studies evaluating a broader range of good solutions

Contact person: Poul Henning Kirkegaard, Lars Andersen

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

Structural design of buried pipelines

Purpose: The purpose is to study the design procedure for buried pipelines in pumping systems for water transport (potable water and waste water). The loads include both internal pressure variations because of internal water transients (see figure 3) and external water and soil pressure. The hypothesis is that the design in this area is much more conservative than necessarily because of the complexity of the issue. Significant cost reduction can be expected if the design criteria are changed to build on the basic properties of the materials in combination with modern computer simulations in order to leave the present "rule of thumbs design". Actually a large number of pipelines are under planning and design in Denmark and Europe

Figure 1 .Failure because of high pressure

Figure 2. Collapse because of low internal pressure and soil pres.

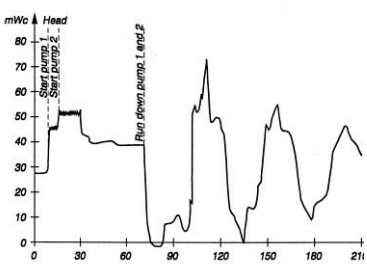


Figure 3. Example of internal pressure variations during pump run-up and pump run-down

Main activities: The project will take inspiration from the actual design of number pumping mains for the transport of waste water in MariagerFjord Municipality where the largest pipeline is 16 km long and has a diameter of 800 mm**.**

Examples of planed activities:

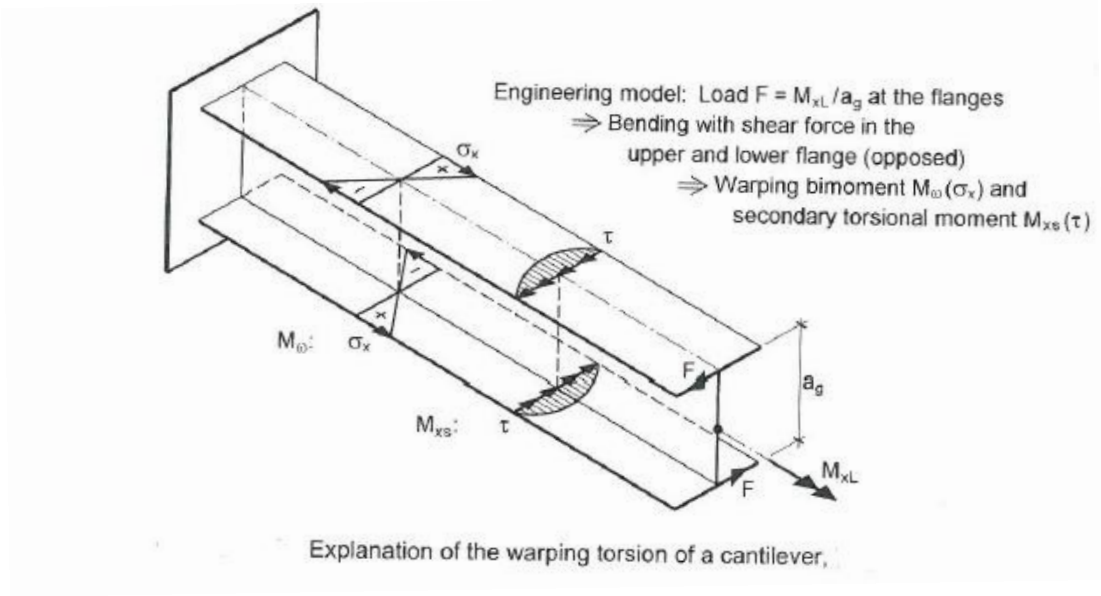
- Study of the design criteria for plastic pipelines
- Experimental and numerical modelling of fatigue caused by long term cyclic loads from water hammer in plastic pipelines (e.g. PE polyethylene pipes as seen on figure 2)
- FEM-modelling of plastic pipelines with loads of soil and water pressure.
- More to come

Contact persons: Lars Andersen, Torben Larsen

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

Implementation of 3D beam finite elements including warping torsion

Purpose: Many standard implementation of three dimensional beam finite elements only account for the simplest form of torsion, which is called St. Venant's torsion. The part of the torsion that stems from warping of the cross section is then ignored. This approximation can be justified for closed cross sections which present a large warping stiffness, but for open profiles, as the one shown in the figure, the neglection of the warping will result in a gross underestimation of the torsional displacement. The goal of the project is to implement a beam finite element that includes warping torsion.



Explanation of the warping torsion of a cantilever,

Main activities: The initial part of the project would be a study of the concept and equations of torsional displacements in beams. As part of this study it could be examined how commercial finite element codes have implemented 3D beam elements.

The next part of the project is then to program a beam finite element that includes warping torsion. This can be done in MatLab or another language of the students preference. A simulation of a simple frame structure can then be used as a verification example. An added challenge is then to couple the elements at the frame corners. The results of this analysis can then be compared to the results from commercial codes, and/or more elaborate simulations using shell or solid elements.

If time permits the composed beam element can be extended to solve bifurcation problems e.g. lateral torsional instability (Danish: kipning).

Contact person: Johan Clausen
Theory: ☒☒☐ **Experimental work:**. ☐☐☐ **Computer modelling:** ☒☒☒

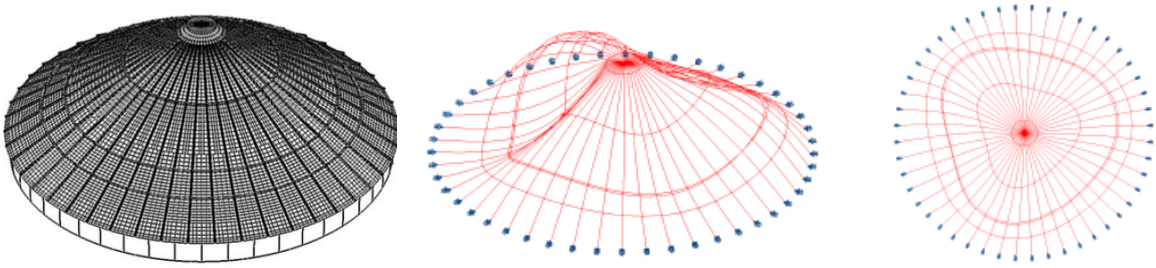
Example of company stay project

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.

ISSN 1901-7308
DCE Latest News No. 37