Aalborg Universitet

Third Semester and Master's Thesis Ideas 2016

M.Sc. in Civil and Structural Engineering

Clausen, Johan Christian

M.Sc. in Civil and Structural Engineering:

Third Semester and Master's Thesis Ideas 2016

Edited by Johan Clausen

DEPARTMENT OF CIVIL ENGINEERING
AALBORG UNIVERSITY

Aalborg University
Department of Civil Engineering
School of Engineering and Science

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Johan Clausen

May 2016

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.

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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.

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

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

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

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

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

At the third master semester the students have the option of doing a company stay. It is important to 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. The student is not allowed to receive a salary from the company, as the stay is considered a full time study, and as such the student still receive SU. (

As a final remark, a signed project plan must be handed to your study secretary October 1st at. This project plan must contain information about the project, in particular regarding the educational goals. These must be defined in accordance with the Master Curriculum (danish: Studieordningen) for the M.Sc. Programme in Civil and Structural Engineering at the School of Engineering and Science, Aalborg University. The curriculum can be found at the Study Board of Civil Engineering homepage at http://www.ses.aau.dk/studienaevn/byggeri/studieordninger/. 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/til-studerende-

ansatte/blanketter-regler/projekter-specialer/ (Danish version) and http://www.en.ses.aau.dk/students-employees/rules-and-regulations/thesis-contract/ (English version). Via the links you will also find guidelines as how to fill out the study plan. The delivery date for the project report will be set by the Study Board. It is usually between January 1-8 for third semester projects and June 1-8 for Master theses. In the study plan, you should state the duration of your project, i.e. the number of ECTS points.

Aalborg, May 23, 2016   Johan Clausen, *semester coordinator*

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.
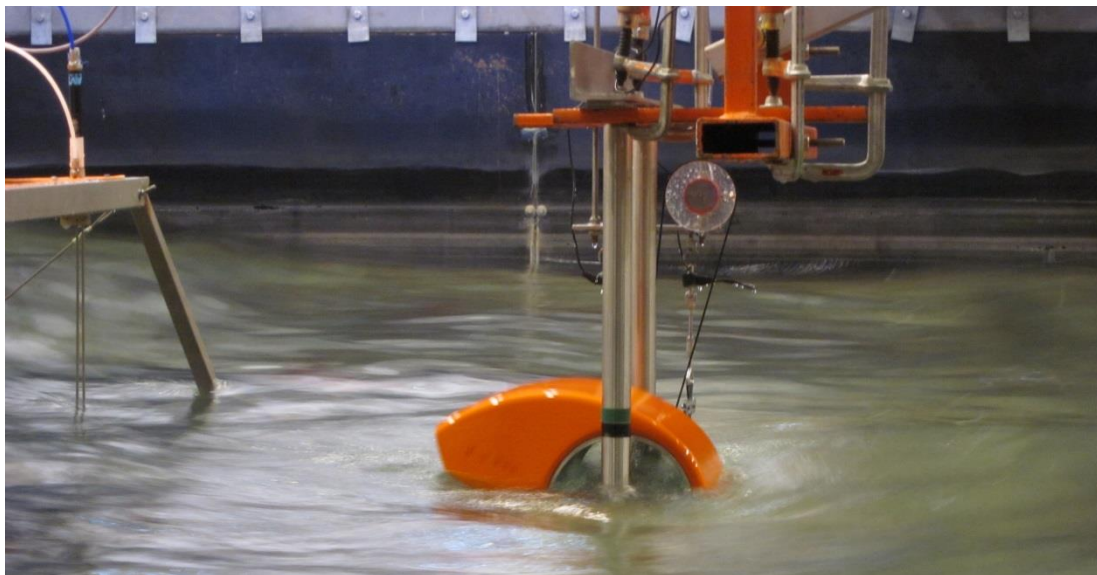
Figure 1: Picture of the rotor during experimental tests.

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:** ☒☒☐

Control of the Weptos wave energy converter

Purpose: The development of the Weptos wave energy converter (WEC) is gaining momentum and it is time to develop a suitable control system. This control system will be composed out two parts, the adaption of the opening angle between the legs, which regulated the available incoming wave power, and the damping presented by the electrical generator system.
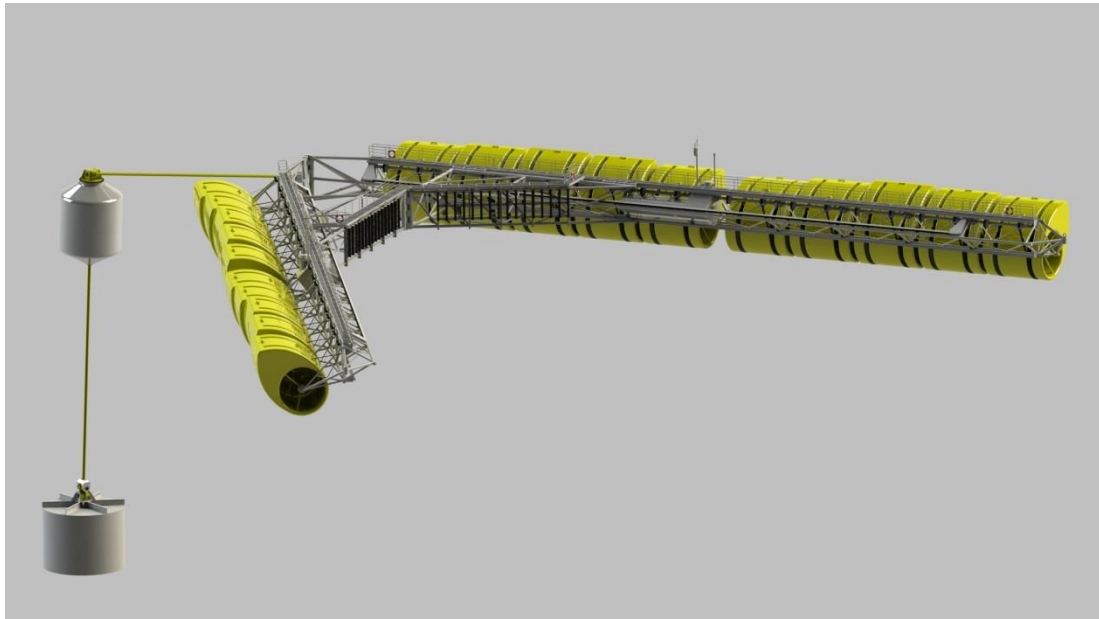
Figure 2: Artist impression of the Weptos WEC

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

Contact person: Arthur Pecher – afsp@civil.aau.dk

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

Experimental study on SALM mooring system for wave energy converters

Purpose: The experimental investigation the influence of various parameters of a "single anchor leg mooring" (SALM) system on the response and loads on a floating wave energy converter.

Figure 3: Artist impression of the Weptos WEC moored by a SALM system

Main activities: The investigation will be composed out of a preliminary quasi-static analysis of the different mooring configurations (depending on the parameters of interest). Possible parameters could be:

- Water depth
- Size and design of the WEC
- Length of the hawser
- Volume of the buoy.

These different mooring configurations will then be tested experimentally in the wave basin. The results and comparison of the both investigations will contribute to the design of the SALM system for the wave energy converters and indicate the reliability of the quasi static analysis. In this case, the results will especially be beneficial for the Weptos WEC and will indicate the response of the device under various conditions and give a feeling on the required safety factors.

Contact person: Arthur Pecher – afsp@civil.aau.dk

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

3D Numerical Modelling of Wave Attack on Coastal Protection Structures

Purpose: The use of 3D numerical wave models for evaluating wave attack on onshore and offshore structures are gaining an increasing interest both in the research sector and in private consultancy companies. In this project, a recently developed open-source three-dimensional numerical two-phase flow solver (IHFOAM, http://ihfoam.ihcantabria.com) specially designed to simulate coastal, offshore, and hydraulic engineering processes, is used to evaluate wave loads on monolithic coastal protection structures. The purpose of this project is to validate the results from the numerical model by comparing to model tests from the wave flume in the AAU laboratory.
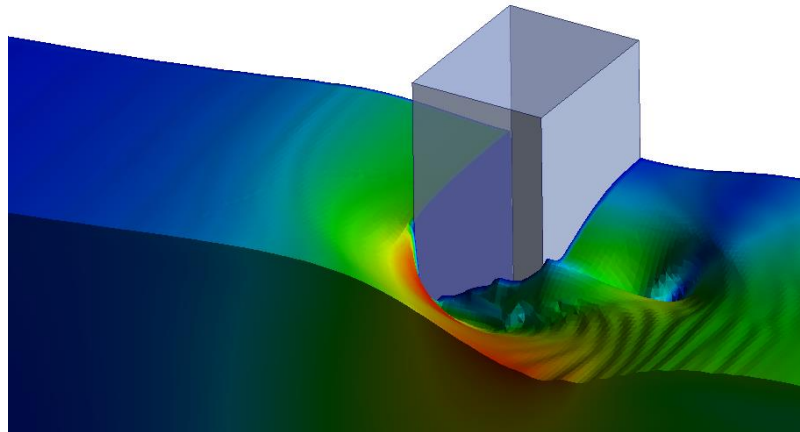
Main activities: The project will contribute to the on-going research on the subject and thus the following activities can be included:

- Gain knowledge on how to simulate wave/structure interaction in a 3D numerical model
- Validation of model output by comparison with results from physical model tests

Contact persons: Jørgen Quvang Harck Nørgaard, Thomas Lykke Andersen

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

Design and optimization of current generation in AAU's new wave basin using CFD

Purpose: The department of Civil Engineering's new building will finish summer 2016. The building includes a new State-of-the-Art wave basin for simulation of combined waves and current. Numerical CFD simulations are needed to optimize the current generation system in order to find proper solutions for turning vanes inside the current inlet etc. The identified optimal solutions should afterwards be tested in the new lab in current only conditions as well as in combined waves and current.
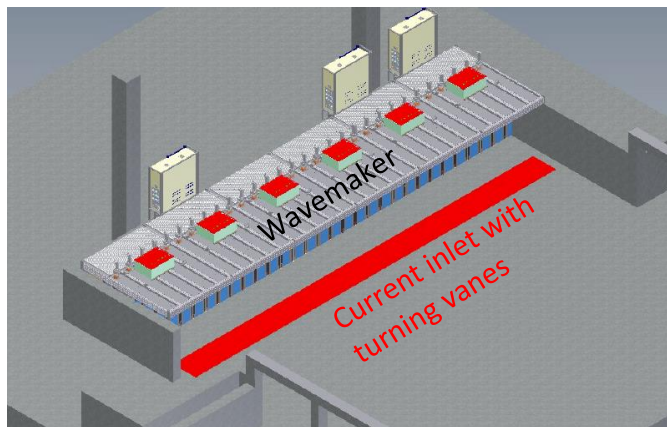
Example of turning vanes

Main activities: The study will contribute to the design of the new wave basin, which will open summer this year at the main AAU campus. The following activities can be included in the study:

- 2D numerical modelling of turning vanes configurations
- Experimental validation of turning vane configurations
- Tuning of the current generation system to have uniform current in the basin
- Experimental validation of combined waves and current

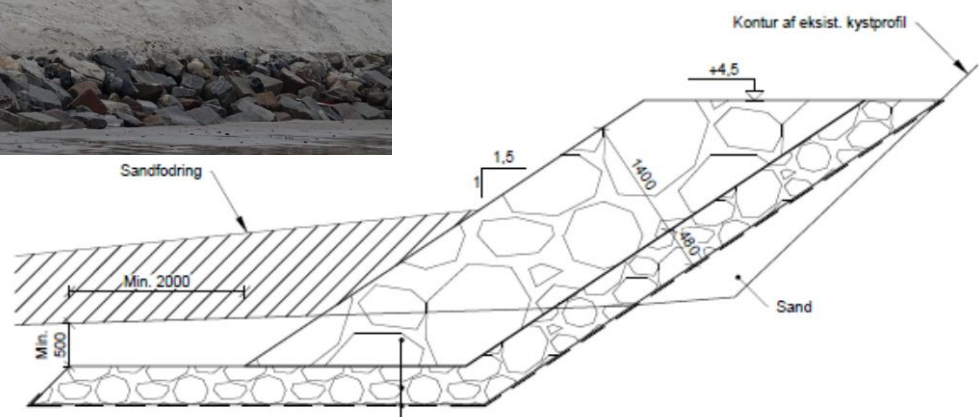**Contact persons:** Thomas Lykke Andersen, Morten Mejlhede Kramer

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

Design of concealed slope protection

Purpose: Hard slope protection is an appropriate last-ditch defence line against acute erosion. This means of protection against erosion has its disadvantages however, not the least of which being increased erosion in front of and near the construction, up to the point where the beach in front of the construction disappears. This disturbance of the coastline means that this type of protection has to be coupled with compensating sand nourishment.

A way of offsetting the disadvantages is to completely cover the hard construction with sand nourishment and organise regular compensating nourishment. Further research into the design of these types of projects is needed. This includes the design of the structure itself (rubble mound for example), as well as the design of the sand nourishment, which implies an understanding of interaction between the beach, the structure and the nourishment.

Main activities: This project will be conducted in close cooperation with The Danish Coastal Authority (Kystdirektoratet) and their experienced coastal engineers.

- Study the evolution of the beach and shoreline around hard slope protection
- Numerical modelling and maybe physical model testing

Contact persons: Thomas Lykke Andersen and Per Sørensen, pso@kyst.dk (Danish coastal authority, Head of coastal research)

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

Inlet to the Limfiord at Thyborøn

Purpose: The inlet to the Limfiord at Thyborøn is constantly increasing leading to increased probability of flooding in the western part of the Limfiord, and increased erosion on the adjacent coast at the Limfiord barriers. The solution preferred by the Danish Coastal Authority (Kystdirektoratet) to control the inlet is to extend the southern jetties in order to protect the fjord against future climate changes.

This project aim to study different solutions for the inlet in order to reduce the coastal erosion, stop the increasing of the inlet and make the access to the navigation channel better. The project will involve optimization of one or more of the solutions.

There are a lot of survey and hydrological data that can be used as background data. There has also been done some Mike 21 simulations of the inlet and the western part of the Limfiord.

Main activities: This project will be conducted in close cooperation with The Danish Coastal Authority (Ksytdirektoratet) and their experienced coastal engineers.

- Study different solutions for controlling the inlet
- Design of one or more of the solutions

Contact persons: Thomas Lykke Andersen and Per Sørensen, pso@kyst.dk (Danish coastal authority, Head of coastal research)

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

Renewal of water in monopiles for offshore wind

Do you want to take part in the development of future renewable energy? In close collaboration with COWI this project aims at developing a new innovative method for preventing corrosion of large offshore wind turbines.

Purpose: Corrosion inside offshore monopiles due to development towards very low pH-values in the enclosed environment inside the monopile is a problem which requires attention and development of new preventive methods. The purpose of the project is to design a passive system, which can ensure sufficient exchange of the water inside a monopile with surrounding seawater.
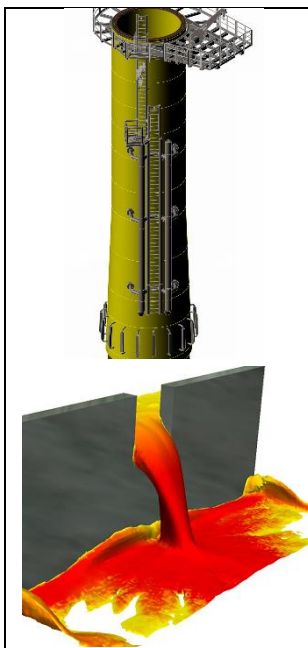
The passive water exchange system is established by fabrication of a finite number of small holes (with diameter of the order of 10-20 cm) in the monopile. Thereby a continuous cyclic flow of water in and out of the monopile domain will be generated due to tidal variations, waves and currents. Due to mixing of the monopile water with sea water the total mass of monopile water will slowly be replaced by sea water. Since the sea water and monopile water will be mixed, the tidal replenishment will not lead to a 100% exchange of monopile water with sea water during a tidal cycle. The actual level of the "water exchange efficiency" needs to be calculated through detailed numerical simulations by CFD or through model tests.

Main activities:

- Development of an advanced CFD model in Star CCM+ or similar package. The model will incorporate modelling of two-phase flow.

- The CFD model shall be used to test lay-outs of water replenishment holes (number and positions) and thereby give an indication of optimal number, size and location of the holes which ensures an optimum mixing between sea water and monopile water.

- Possibly small-scale experimental tests can also be carried out to validate the results from the numerical model.

Contact persons: Morten Kramer, Thomas Lykke Andersen

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

Wave force on offshore monopile with boat landing

Do you want to take part in the development of future renewable energy? In close collaboration with COWI this project aims at developing new wave load methods.

Purpose:

The purpose of the project is develop an advanced CFD model to establish wave loads on monopiles that includes boat landings. The goal is to develop new design guidelines on how to establish the hydrodynamic loads on such structures.

Wind turbines are placed in deeper waters at more and more exposed wave conditions, and therefore the wave loadings are becoming increasingly governing for the monopile design. Established and validated methods have been used for about half a century to calculate hydrodynamic loads on a single cylinder using the so-called Morison equation. However, monopiles for wind turbine foundations includes a number of secondary structures, which may, or may not, increase the loads significantly. Today, there are no properly validated methods that takes account of such secondary structures in the load calculations.
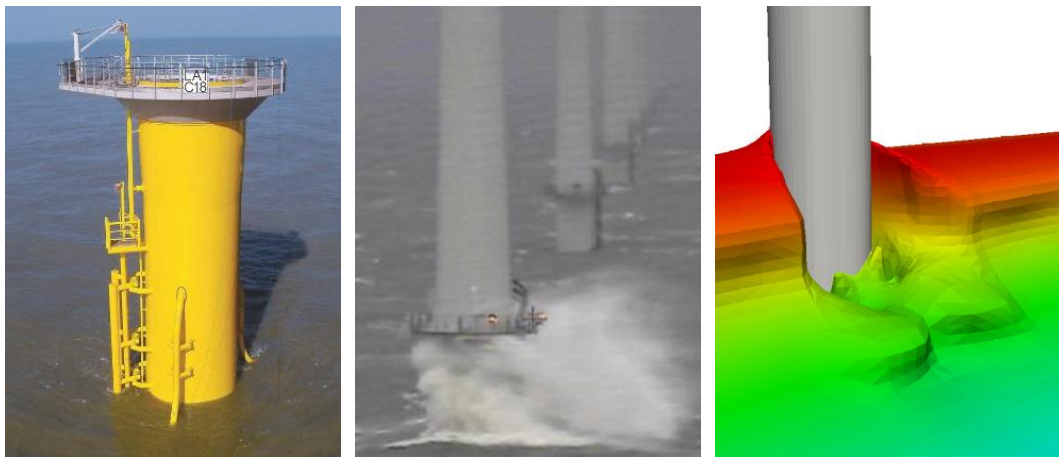
Main activities:

- Development of an advanced CFD model in OpenFOAM, Star CCM+ or similar package. Simulations are performed to establish design loads depending on wave conditions.

- The load coefficients for drag and inertia are extracted, and new methods for wave load estimations are proposed

- Possibly small-scale experimental tests can be used to validate the results from the numerical model.

Contact persons: Morten Kramer, Thomas Lykke Andersen

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

Numerical modelling of fluid–soil–structure interaction

Purpose: Finite-Element Analysis (FEA) is the industry standard for analysis and design in many fields of engineering. However, the standard formulation based on continuum mechanics and a Lagrangian description (elements follow the material) can be very inconvenient for problems with large deformations. This is, for example, the case in many problems related to interaction of fluid, soil, and/or structures.

Over the last few decades, some alternatives to standard Lagrangian FEA have immerged, including Smoothed Particle Hydrodynamics (SPH), the Discrete Element Method (DEM) and Arbitrary Lagrangian Eulerian (ALE) FEA. SPH and ALE are still based on a continuum theoretical framework, but allow (in two different manners) material to deform infinitely, whereas standard FEA has difficulties even at moderate deformations due to severe entanglement. It the DEM, the idea is on the other hand to model each separate grain or particle as an individual (discrete) element.

The idea is to pick up one or more of the novel methods and analyse its advantages, disadvantages and limitations compared with standard FEA. Focus can be on failure of breakwaters, pile driving, slope failure, or another problem involving large deformation and/or fluid–soil–structure interaction.
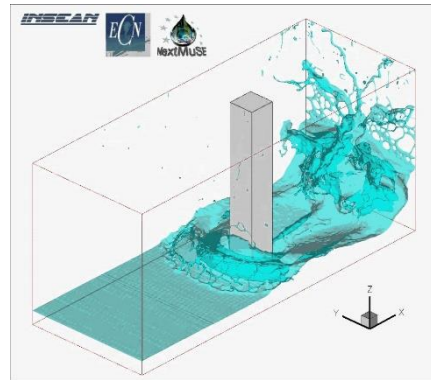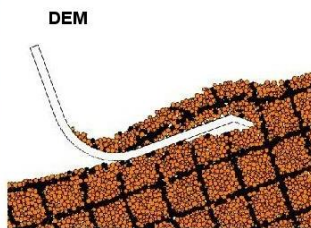
Main activities: The project will contain some (but not all) of the following:

- Learning the key aspects of Smoothed Particle Hydrodynamics (SPH)

- Learning the key aspects of the Discrete Element Method (DEM)

- Learning the key aspects of Arbitrary Lagrangian Eulerian (ALE) FEA

- Studying the differences between selected methods and standard FEA

- Anlysing example cases, e.g. wave impact on a rubblemound breakwater, flow of granular material, or identation or penetration of a pile or cone into soil.

The various methods are all implemented in the commercial program Abaqus that will be used for analysis. The numerical studies and theoretical work can be combined with simple or more advanced laboratory tests to verify or falsify the various models.

Contact person: Lars V. Andersen

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

Geotechnical deformation prediction

Background: A main design driver for geotechnical structures is the deformation of the participating soil masses, which is usually analysed in the service limit state. Numerous methods exist for this purpose, ranging from simple experience-based methods, over continuum mechanics-based hand calculations to the whole palette of more or less sophisticated numerical simulations. The deformation problems are complicated due to several factors such as the time dependency, two (or three) phase materials, the stochastic nature of soils and complex constitutive behaviour, to name a few.
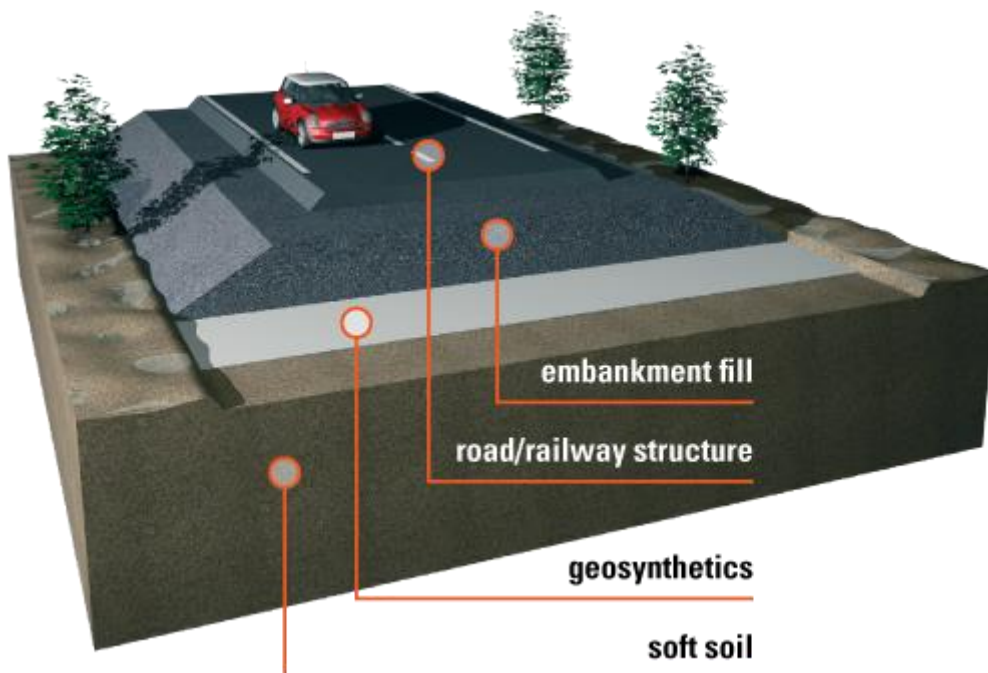
Main activities: An international study of two geotechnical structures is taking place in 2015/2016. Full-scale measurements was carried out on an embankment and a shallow foundation on soft clay. The initial data was released and geotechnicians around the world was invited to calculate their best estimates of the deformation of these structures, using methods of their own choice. This study is the inspiration for this project proposal. The goal is to use different methods for the prediction of deformation of geotechnical structures. The results of the different methods is compared, and the influence of different levels of model complexity is assessed.

**Contact persons:** Johan Clausen, Lars V. Andersen

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

Comparison of Finite Element calculations for geotechnical cases

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

If these variations in the results are significant, it poses a problem for the design engineer who relies on the solutions of the chosen software: What is the correct solution?
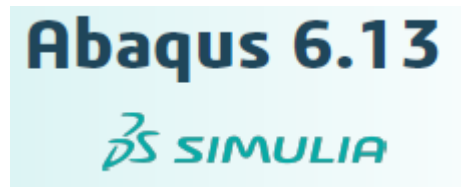
The idea of this project is to examine the variations between different tools for solving geotechnical problems, both qualitatively and quantitatively.

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

Contact person: Johan Clausen, Lars V. Andersen

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

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:

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

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

Contact persons: 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.

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:** ☒☐☐

Soil reinforcement

Purpose: To improve the knowledge about soil reinforcement using geotextiles.

In collaboration with the company Fibertex the aim is to investigate the use of geotextiles in connection with engineered soil. New field studies show that there effect of using geotextiles in fx. Infrastructure project may be of greater interest and have a more significant effect on the bearing capacity of roads than shown in earlier studies.

Main activities: The project will contribute to the understanding of using geotextiles for soil structures.

The activities may include:

- Behaviour of geotextiles
- Use of geotextiles. Fx. roadbuilding
- Laboratory testing
- Field in situ testing
- Theoretical assessment

Contact persons: Benjaminn Nordahl Nielsen and Lars Bo Ibsen

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

Laboratory test of Aalborg Clay

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

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

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

The activities will include:

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

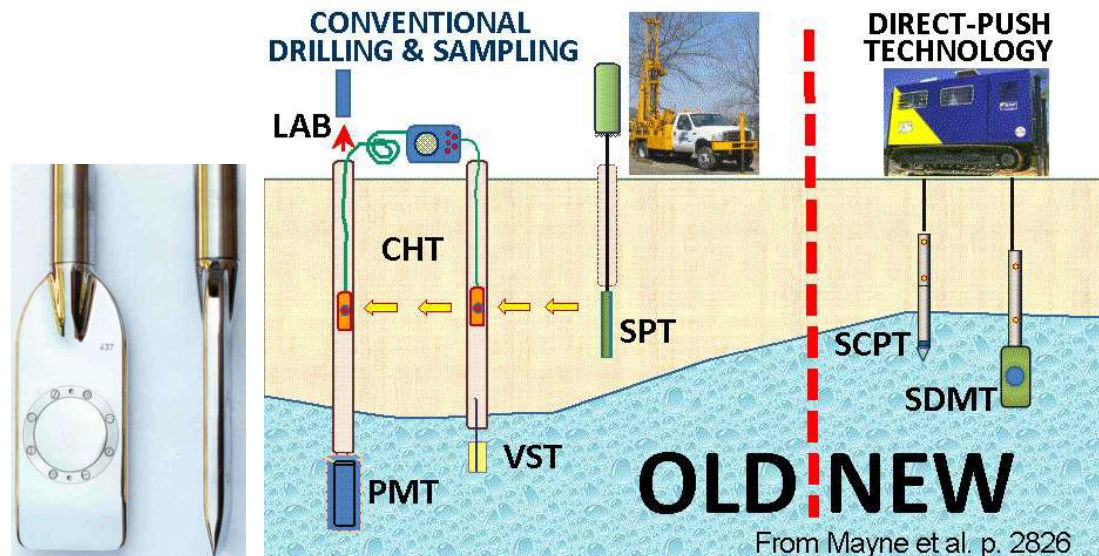**Contact persons:** Benjaminn Nordahl Nielsen and Lars Bo Ibsen

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

SDMT Flat Dilatometer

Purpose: Be the first to try new in-situ soil testing. The SDMT (seismic) Flat Dilatometer offers measuring / interpretation of a series of soil parameters by direct-push technology (M, c_u, K_0, OCR, φ, γ).

Aalborg University has the first SDMT equipment in Denmark.

From Mayne et al. p. 2826

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

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

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

Contact persons: Benjaminn Nordahl Nielsen 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.
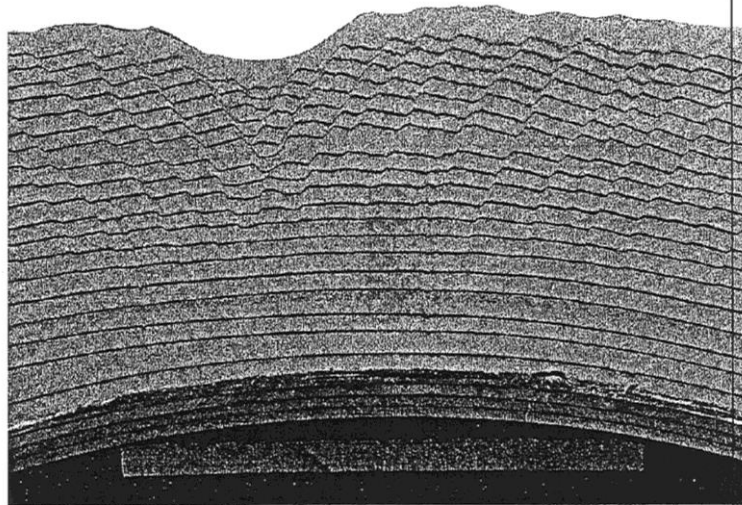

Fig. 8.2 Crestal faults over arch of uniform curvature, simulated in a sand box (Mandl, 1984).

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

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

Purpose: The most often used material model for geotechnical materials is the Mohr-Coulomb material model. For calculation involving more than very simple geometries the finite element method is used for obtaining the solutions to the arising boundary value problems (i.e. load-displacement curves, bearing capacities, etc.). Originally the corners and the apex of the Mohr-Coulomb yield surface caused problems in the numerical implementation, so an approximate yield surface with smoothed, or rounded, corners were used. Today methods for implementing the corners explicitly exist, but the use of the rounded surfaces is still widespread. The implications of using these approximations, however, are not documented in literature.
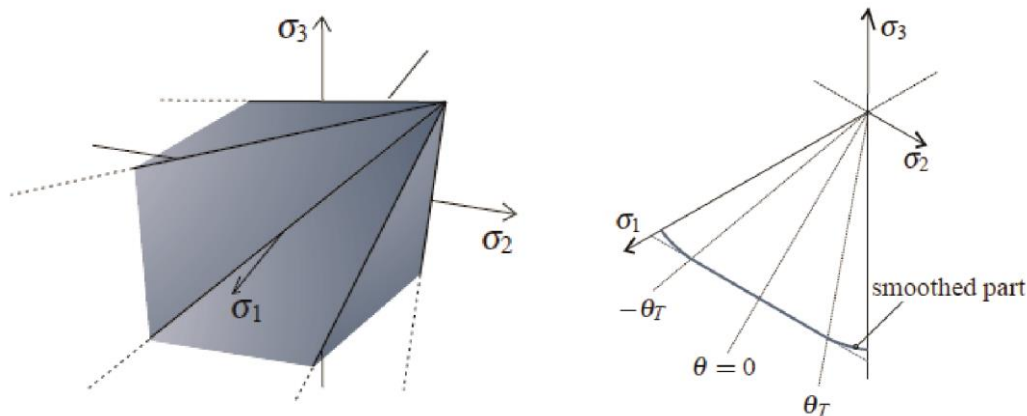
Main activities: Different models for smoothing the Mohr-Coulomb model should be implemented, and maybe also as a user programmable material in Abaqus. Then the implications of using these approximate models should be quantified and compared to the exact Mohr-Coulomb material model. Both with respect to accuracy, computation time and number of iterations. The approximate models may perform better than the exact model in some parameters and poorer in others.

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

Contact person: Johan Clausen

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

Implementation of a plasticity model into the finite element method 2: 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.
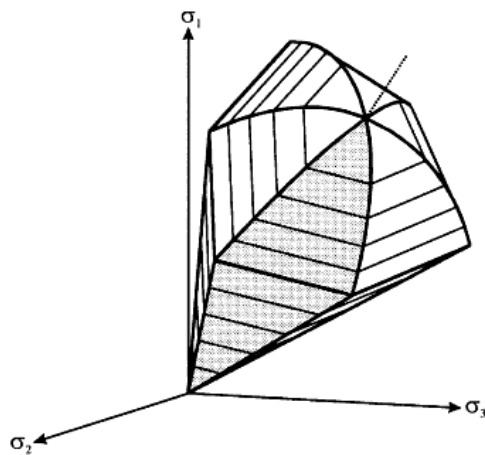
Figure 3. Representation of total yield contour of the Hardening-Soil model in principal stress space for co-hesionless soil.

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

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

Contact person: Johan Clausen

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

Implementation, validation ant testing of a two-surface model for cyclic loading on sand

**Purpose:** For strength calculations the Mohr-Coulomb criterion is often a sufficient material model for soils. If a more precise calculation of the deformation is needed then the simple linearly elastic – perfectly plastic Mohr-Coulomb model is not adequate. This is especially true if the loading is not monotonic or even cyclic. Offshore structures are subjected to time varying loads from wind and waves which means that their foundation will experience cyclic loading. At the same time the allowable deformation is small which means that it is often this criterion rather than the soil strength that governs the foundation design. For these reasons many advanced material models for soils have been developed. If such an advanced model is to be used in practical calculations it must be implemented in a numerical method, e.g. the finite element method.
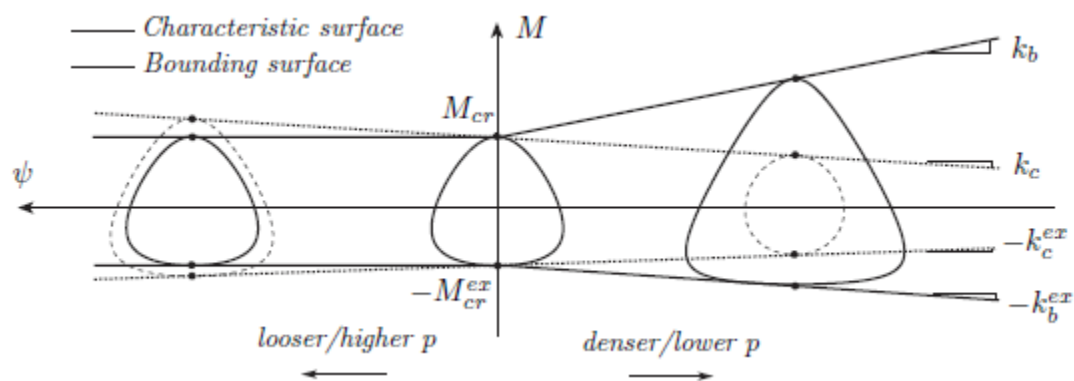
Main activities: Earlier projects have been working with the implementation of the above mentioned model into the finite element method. This project should be a further development of this. The activities could be improvement of the algorithms, implementation of the model as a user-defined model in e.g. Plaxis and/or Abaqus and case studies on structures under cyclic loading.

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

Contact person: Johan Clausen

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

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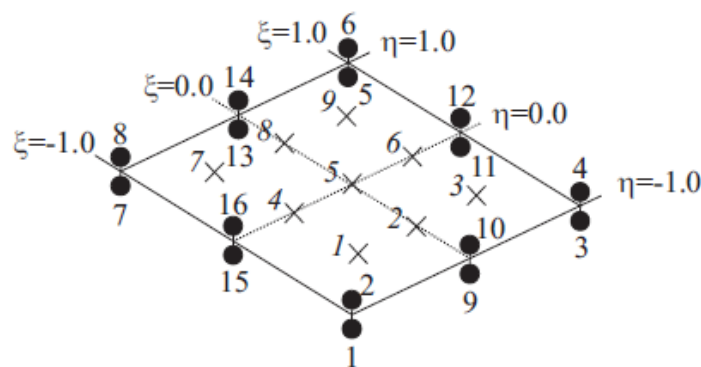
Local numbering and positioning of nodes (•) and integration points (x) of a 16-node interface element

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

Modelling of cyclically loaded monopiles

Purpose: A common foundation type for offshore wind turbines is the monopile. In essence, it is a large steel tube driven or vibrated into the seabed. An example of the proportions is a diameter of 5 m and an embedded length of 30 m. The dominating loads are cyclic in nature, i.e. wind and wave loads. The soil supporting the pile is affected by the cyclic loading, so that the response of the pile will change as the number of load cycles builds up. Usually a degrading stiffness is observed, which must be taken into account when meeting the design criteria of the monopile. A common design criterion in the service limit state is that the accumulated rotation of the pile cap must not exceed 1°.
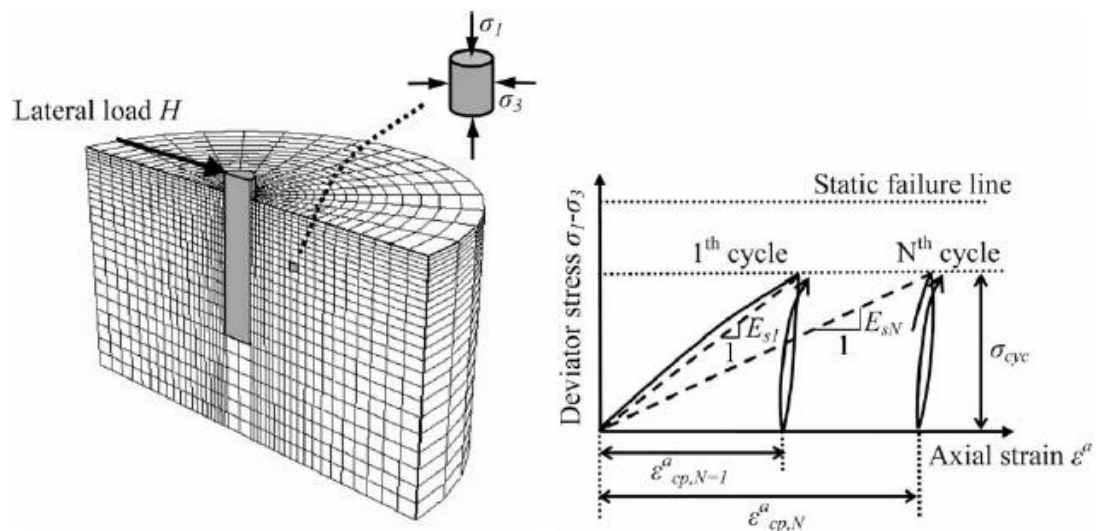

Fig. 2. Degradation of secant modulus under cyclic loading in the pile–soil model (schematic).

Main activities: The modelling of stiffness degradation can be a daunting task if carried out on a high detail level, e.g. three-dimensional geometry, advanced material models, stochastic loads etc. All in all such a detailed procedure is not well suited for design purposes. Simplified methods have been proposed in literature, with which decent estimates of the accumulated rotation should be possible. The goal of this project is to study and implement one or more of these simplified methods. Usually using the Finite Element Method or other relevant calculation tools. In this project, a co-operation with the company Universal Foundation is a possibility.

**Contact person:** Lars V. Andersen, Johan Clausen

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

Extrusion of initially deformed pile / Propagation of damaged pile tip

The monopile is one of the current technologies for wind turbines at water depths of up to approximately 35 metres. Axially loaded piles are currently used as the foundation for jacket substructures in the oil and gas industry. The pile-jacket foundation is also generally considered as the cutting edge foundation solution for offshore wind turbines in deeper waters.

Instability is an issue for piles during installation, where imperfections and boulder impacts during pile driving can lead to structural buckling. The failure mechanism can be an "extrusion" mechanism type, where an initial imperfection of the pile increases as the pile is penetrated through a soil of high stiffness. The Goodwyn A platform was installed on the North West Shelf of Australia in 1992. During installation of the foundation piles, it was discovered that 15 of the 20 driven primary piles were severely crushed at depths of 80 metres or more below the seabed. A crushed pile is illustrated to the right. The effect of the lateral restraint offered by the surrounding soil can be addressed both analytically and numerically. It is suggested to implement a pile-soil model in an ABAQUS finite element analyses by means of p-y springs in a Python script.
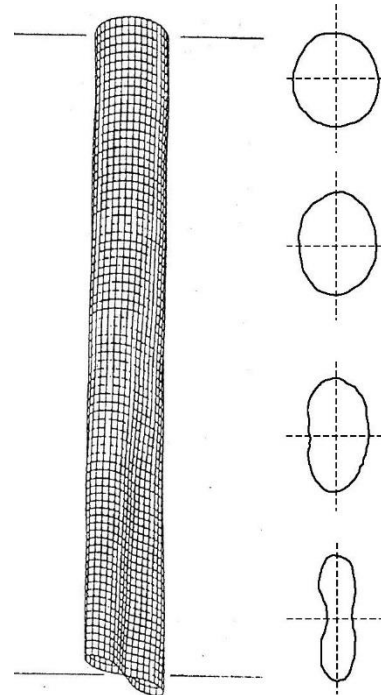
The main activities in the project are:

- Literature study on design of steel shell structures and p-y curves
- Nonlinear finite element modelling of shells
- Python scripting in ABAQUS
- Predicting damaged pile-tip propagation

Contact persons: Søren Madsen and Lars V. Andersen

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

Driveability of piles for offshore wind turbines

Purpose: An increased focus on renewables in general has ignited a spark in market for offshore wind turbines. The industry has a joint mission to lower the cost of energy from offshore wind turbines to make the solutions more competitive in the open energy market. The

installation of piled foundations for offshore wind turbines is today governed by qualified guessing, since soil conditions may vary greatly throughout an offshore wind farm. The ability to predict and complete the driving campaign as effortlessly as possible is more often than not a project deal-breaker.

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

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

Main activities: The project provides valuable insight into a part of offshore wind turbine foundation design that often governs pile wall thickness and thereby influences the total amount of steel:

♦ Understand the basic physical and theoretical principles involved in the driving of large-diameter piles for offshore wind turbine foundations.

♦ Assess state-of-the-art research and methodology within the area of offshore driveability, both in regards to methods for prediction of driving resistance but also in regards to installation techniques.

♦ Based on available driving data from installed offshore wind farms, complete back-calculation using available methods in order to estimate the importance of various model parameters for a good driving prediction.

♦ Using finite element modelling, investigate the soil-structure interaction during installation and provide recommendations for driveability assessment for large-diameter piles for offshore wind turbine foundations.

Contact persons: Martin Underlin Østergaard (muoe@cowi.dk), Lars Vabbersgaard Andersen (la@civil.aau.dk)

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

Design framework and perspectives for offshore wind turbine foundations

Purpose: The design of foundations for offshore wind turbines is still subject to development and on-going research as well as regulations defined by international certification agencies, such as e.g. DNV-GL. The design process often involves multiple parties and areas of competences, so from a designer's point of view it is important to distinguish between what's very important and what's just important. The importance of key design areas varies from project to project, and the key to an efficient design process is to pinpoint the most important areas as early in the process as possible.

A project with

The design process of foundations for offshore wind involves many parties (www.windcarrier.com).

The certifying agency DNV-GL defines requirements for designers worldwide (www.dnvgl.com).

Main activities: The project will be a journey into the world of offshore wind turbine foundation design where the current standard is the basis for all projects:

♦ Decipher the requirements defined in the standard and investigate the different components individually to assess the influence and/or importance to a project such as:

   o Investigate the demand for use of numerical modelling in 3D, and understand the requirements for a valid finite element model, with regards to e.g. choice of material model.

   o Examine the cyclic behavior of offshore wind turbine foundations to assess the importance of cyclic design as well as the proper method for future investigations.

   o Explore into the consequences of oblique (combined) loading on wind turbine foundations to assess the importance for various types of foundations, and the best way to investigate it.

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

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

Geotechnical behaviour and design of suction caissons for offshore wind turbines

Purpose: Lowering the cost of energy for offshore wind power is a joint market task, and the costs related to foundations contribute significantly to the overall cost. As a result, new and innovative types of foundations are developed and the suction caisson is one of these. The suction caisson/anchors has been used in the oil and gas-industry for years, however the concept is new in the market for offshore wind, and the framework for design of such a structure needs to be developed considering all relevant aspects.

A project with
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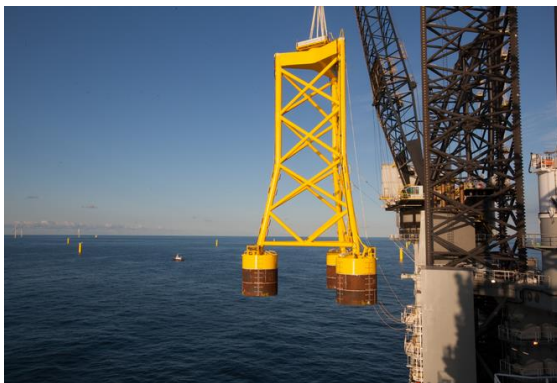
Suction caisson used to found a jacket structure for offshore wind turbines on deep water (www.offshorewindindustry.com).

Suction caisson used a monopod foundation for a metrological weather mast (www.renews.biz).

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

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

Contact persons: Martin Underlin Østergaard (muoe@cowi.dk), Lars Bo Ibsen (lbi@civil.aau.dk)

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

Design of steel shell structures

Shell structures are widely used in civil engineering structures e.g. chimneys, oil & gas structures, wind turbine towers, and offshore foundations. The design of these structures is often performed using the guidelines in EN 1993-1-6 which allow for at least four different design methods:

- Design using simple formulas based on membrane theory
- Linear finite element analysis
- Nonlinear (materials) finite element analysis
- Nonlinear (materials & geometry) finite element analysis

It is normally expected that the more detailed models are the most accurate. This could allow for smaller partial factors of safety if these methods are employed in design. On the other hand, some hidden safety (conservatism) can be built into the simple formulas.

There is a large difference between theoretical solutions and the load carrying of "real" shell structures. One of the primary reasons for this is the imperfection-sensitive behaviour of shell structures. Thus, different methods of modelling imperfections can be compared. The objective of the present work is to compare the different design approaches with public available test results.

The main activities in the project are:

- Literature study on design of steel shell structures

- Nonlinear finite element modelling of shells

- Investigate how to include imperfections

- Various load cases and boundary conditions can be investigated

Contact persons: Søren Madsen and Lars V. Andersen

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

Reliability assessment of existing and temporary structures

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

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

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

Main activities:

- Collect information from literature on assessment of reliability of temporary and existing structures
- Assess and describe methods to obtain the minimum reliability level using risk and reliability-based principles:
    - cost-benefit analyses: minimize lifecycle total expected costs
    - LQI (Life Quality Index) principles: requirements by society
- Transformation of 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

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

Reliability and Risk analysis of Wind Turbines – Planning of Operation & Maintenance

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

The purpose of this project is to apply risk based techniques and Bayesian statistical methods for planning of O&M activities in practical applications (in cooperation with a wind farm operator, see below) incl. modelling of costs and risks in connection with O&M for offshore wind turbines. Further, the aim is to compare different O&M strategies considering a typical wind farm for a limited, but representative application area for O&M.

Main activities:
- Literature survey to give an overview of different methods for O&M planning
- Based on examples from other industrial areas (oil&gas) develop / describe how a Bayesian, risk-based approach can be used for O&M planning
- Illustrative example studies considering O&M for a limited number of components for a typical wind farm

The project will be connected to ongoing research projects.

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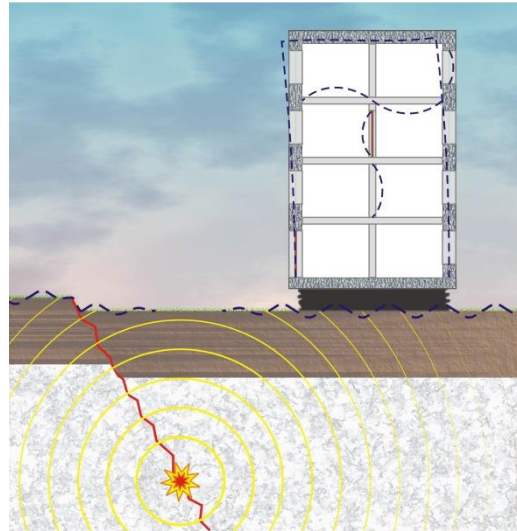
Main activities: The analysis may be carried out by means of a complex three-dimensional model, utilising a commercial finite-element code such as Abaqus. Alternatively, a simpler two or three-dimensional building may be analysed by a Matlab code developed as part of the project. The main activities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

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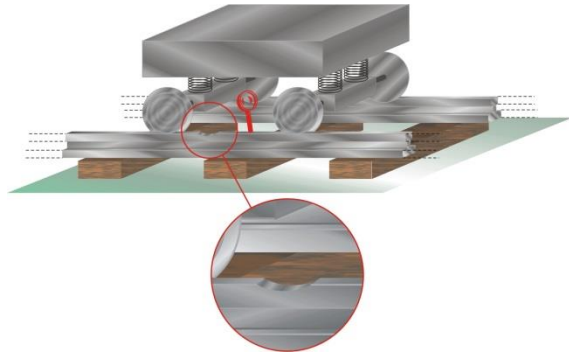
Main activities: The coupled model consisting of vehicle, track, subsoil and building can be made in a commercial finite-element analysis program (e.g., Abaqus) or, preferably, a Matlab code may be developed for the purpose. In either case, the following items will be part of the project work:

- 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.
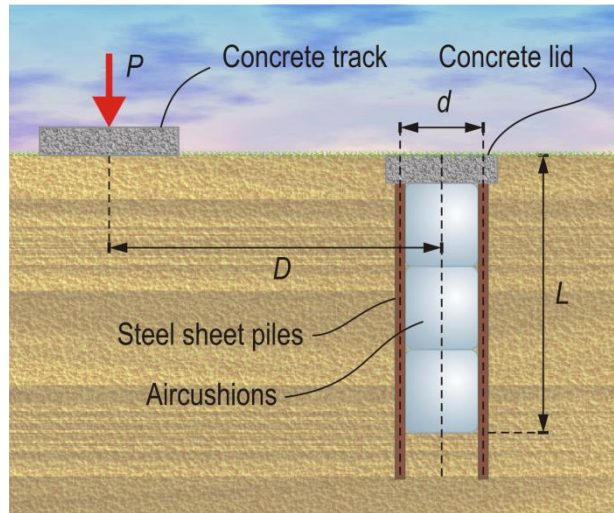
 Several other possibilities exist, such as soil improvement by grouting or pile installation. Even "intelligent landscaping" has been suggested as a means of reducing vibration levels in the new MAX4 test centre near Lund in Sweden. The idea of the project is to investigate and optimize one or more methods 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.
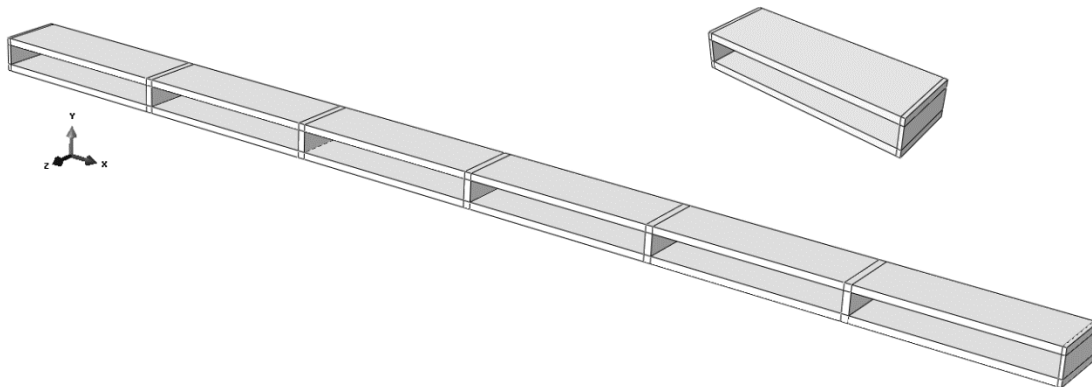
Contact person: Lars V. Andersen

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

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.
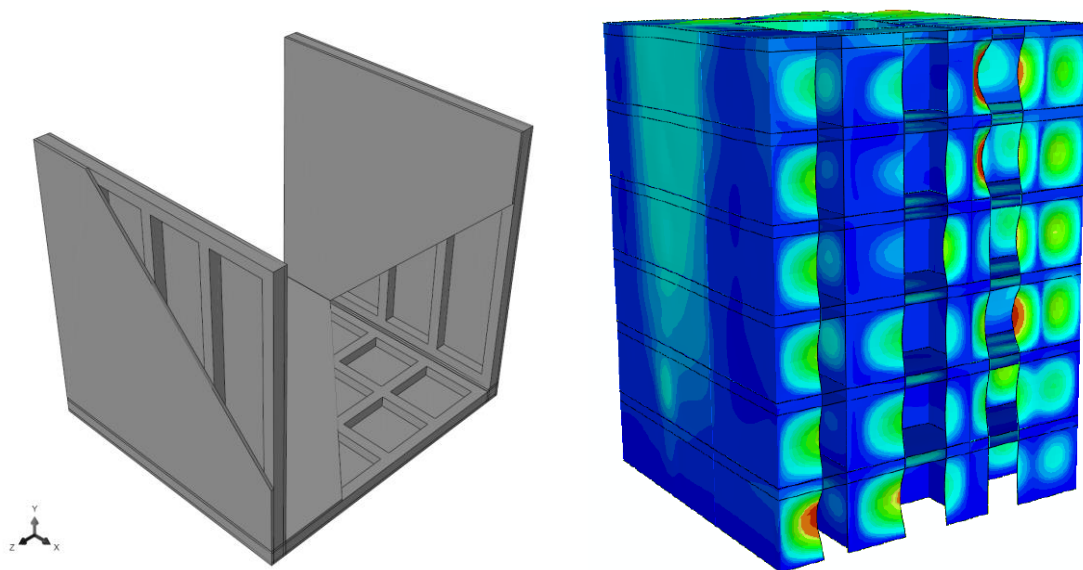
Contact person: Lars V. Andersen

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 V. Andersen

Theory: ☒☒☐   **Experimental work:** ☒☒☐   **Computer modelling:** ☒☒☐
(The relative weight of experimental work and computer modelling is not fixed)

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

$f(t)$

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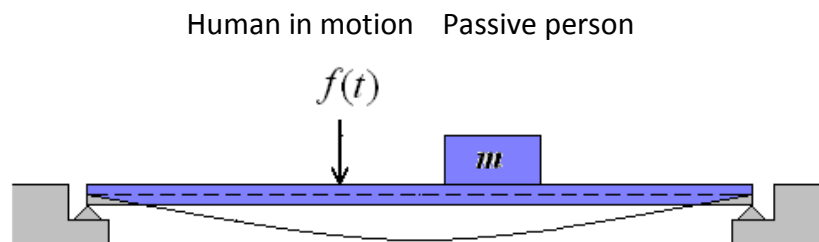
In assessments of vibration levels of slender structures carrying humans (such as footbridges, stadia-structures, or office floors) these models are conventionally employed. But are they reasonable?

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

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

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

Contact person: Lars Pedersen

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

Dynamic human loading and stochastic models for estimating structural responses

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

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

Purpose: The aim of the project is to develop and test stochastic models describing the loading and the structural response. An essential contribution would be to derive statistical distributions of structural responses to human-induced loading, as this would provide valuable information for assessing structural safety or serviceability. Specifically, the risk of exceeding various vibration levels is of interest although it is actually a parameter not given much/any focus in existing design codes.
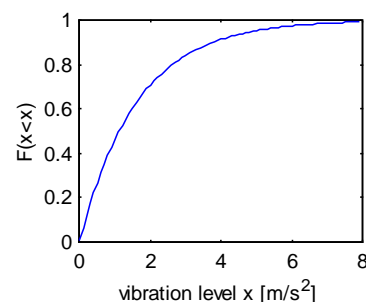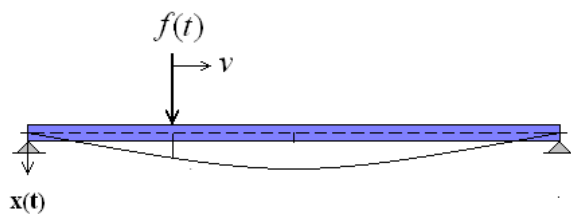
Walking load when $v > 0$ m/s, "Jumping load" when $v = 0$ m/s   Statistical distribution of response

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

Contact persons: Lars Pedersen, Christian Frier

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

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.
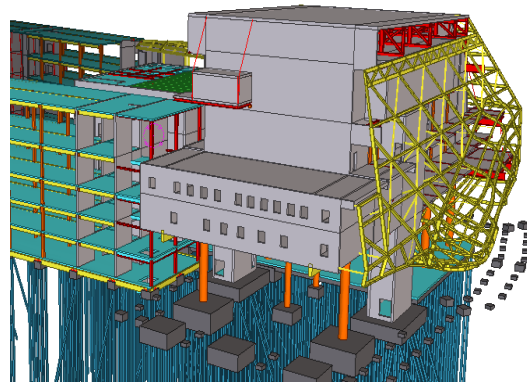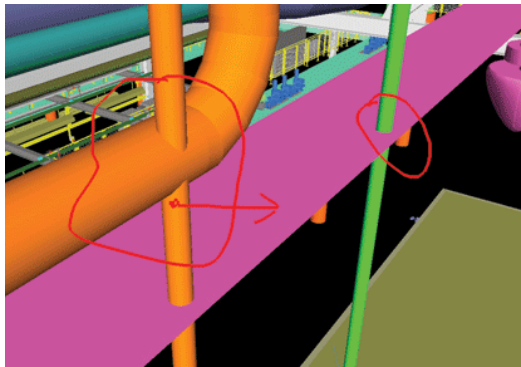
Main activities:

- 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:** ☒☒☐

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

The corner of laminated timber frames

Purpose: Laminated timber frames are, for instance, desirable in structures where the aesthetics of the structure is in focus. A weak point in a timber frame is the frame corner and its strength and stiffness. But perhaps the corner does not need be made of wood?
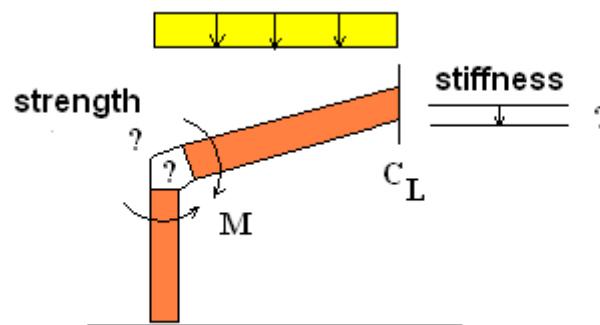
Could a reinforced concrete structure or a steel structure be employed in the corner instead? At least the drawbacks of a corner made of wood might be removed and by employing wood in the remaining part of the frame, the frame would still visually appear much like a full wooden frame.

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

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

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

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

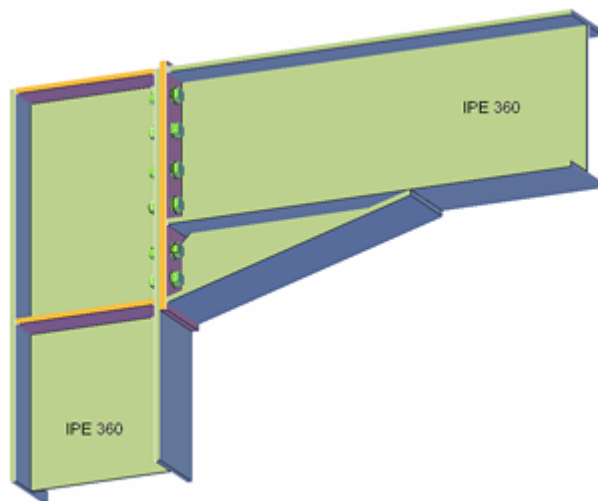**Contact persons:** Lars Pedersen, Christian Frier

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

Analysis of Joints in Steel Structures

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

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

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

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

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

Contact persons: Lars Pedersen

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

Advanced Analysis of Steel Frames

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

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

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

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

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

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

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

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

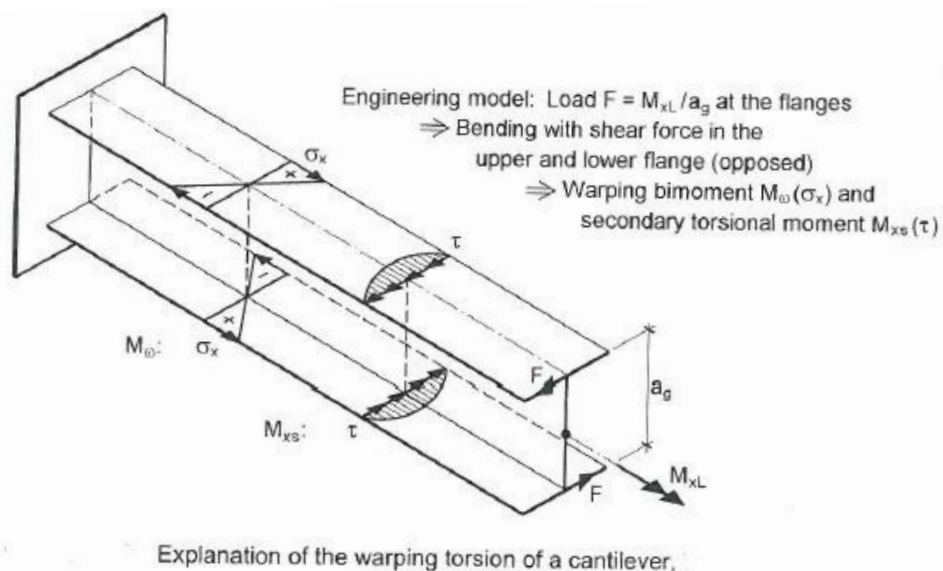**Contact persons:** Lars Pedersen, Johan Clausen
Theory: ☒☐☐　　　**Experimental work:** ☐☐☐　　　**Computer modelling:** ☒☒☐
Suitable project type(s):　　**3ʳᵈ sem** ☒　　　**short master:** ☒　　　**Long master** ☐

Implementation of advanced beam finite elements

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

Explanation of the warping torsion of a cantilever,

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

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

Example of company stay project

Analysis of snow-load induced damage on conical silo roof

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

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

The company wanted to perform a detailed analysis of these collapses to assess the cause(s), and this was chosen as a project for the student doing the company stay.
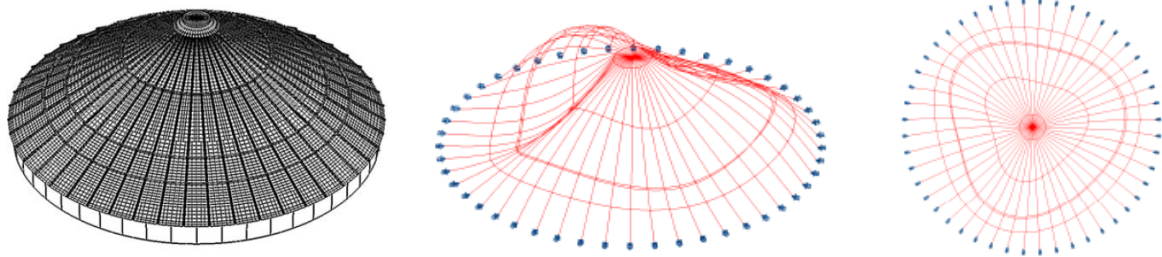
The structure was studied by means of finite element analysis, including non-linear effects such as bifurcation buckling, large displacements and plasticity. Also, different detail levels in the modelling were compared, as was beam and shell models.