Gross list of project ideas within the Danish Expert Centre for Infrastructure Constructions

Introduction

This document contains a gross list of project ideas for the Danish Expert Centre for Infrastructure Constructions.

In the following each project idea is very briefly described with respect to purpose, content and expected results. Furthermore the expected project type is stated (TI project, Ph.D project, Post Doc. Project, M.Sc. project, etc.)

The project ideas are divided under the headings from the application, which are “Materials”, “Execution”, “Construction” and “Service Life models”.

General for all projects

Many of the project ideas presented in the tables below include looking on different types of concrete mix designs. For the Femern Field Exposure Site in Rødby Havn, 15 different types of concrete have been produced based on different binder combinations. These concretes are very well documented and will be followed and documented during the next 10 years. Thus, it will be obviously to base the investigations and research in the different projects presented below on the Femern binder combination, if approval is given by Femern A/S. Furthermore a general approach is to illustrate the differences and the consequences for durability aspects when SCC and conventional slump concrete respectively is used.

Titles of proposed project ideas

Materials

Id	Title
M1	Long term durability of sea water exposed concrete constructions
M2	Chloride binding and models for transportation
M3	Chloride threshold value
M4	Frost resistance
M5	Alkali – Silica Reactions / Alkali – Carbonate reactions
M6	Self healing of cracks

Execution

Id	Title
E1	The influence of faults in the execution phase on long term durability
E2	The influence of rheology and casting procedure (SCC) on long term durability
E3	Influence of hardening temperature on the development of properties of concrete containing substantial amounts of fly ash or slag
E4	The influence of temperature, cement and binder composition on the risk of delayed ettringite formation
E5	Developing a re-usable experimental setup for obtaining more accurate input parameters for hardening simulations of temperature and stress
E6	The effect of surface treatment on the long term durability
E7	The effect of form cloth on long term durability of concrete structures

Construction

Id	Title
C1	The effect of micro defects/cracks on carbonation, chloride and sulfate ingress
C2	The consequences of cracks and the understanding of the damages in the interface between the concrete and the reinforcement
C3	Durability of steel fibre reinforced concrete structures exposed to sea water
C4	Combined effect of mechanical fatigue and deterioration
C5	The effect of mechanical stress levels on rebar corrosion
C6	New repair methods, strategies and materials
C7	Methods for determination of remaining service life

Service life models

Id	Title
S1	Verification and updating existing models for prediction of service life
S2	New design tools for durability

Materials

M1 **Long term durability of sea water exposed concrete constructions**	Project type
Purpose The project aims is to evaluate the long term durability of Danish sea water exposed concrete constructions made with different types of concrete by characterizing the microstructure of young as well as old concrete exposed to sea water under the optical microscope and in the scanning electron microscope. Particularly the effect of different binder combinations on the apparent resistance to sulfate attack and chloride ingress will be investigated, e.g. two questions that this project seek to answers is: - do we see more evidence of sulfate attack in old concrete made with cement that where sulfate resistant than in more modern concrete with sulfate resistant cement, fly ash and silica fume? - Is it possible to see how the chloride is bound in the concrete and hence potentially explain differences in threshold values? *Content* Baring in mind the importance of investigating different binder combinations a selection of existing Danish sea water exposed concrete structures for further investigation is made. The selection will also take into account the content of the DTI thin section archive, however, it is expected that some additional coring of samples from structures of interest will be needed. As much information about the selected concrete structures as possible will be collected, i.e. age, mix design, position where existing samples are taken, etc. The microstructure of the concrete of the selected structures is characterized by optical and scanning electron microscopy. Hopefully, for some structures it will be possible to have samples of relatively young concrete as well as older concrete, so that the development of the microstructure can be described. It is not expected that it will be possible to find existing structures covering all binder systems of interest, and certainly not young concrete. For this reason the project hopes to be able to used samples from the many different concrete types at the Femern exposure site in Rødby Havn. The part of the micro analysis involving chloride is expected to contribute valuable information regarding chloride binding, i.e. there is a strong synergetic connection to project M2 described below. Another element of the micro analysis will be SEM-EDX analysis aimed at investigating the presence of different sulfate phases and changes in which phases are dominant over time. The inward progression of micro-structural changes with time is essential. Can it be quantified how chloride binding evolves over time? Can and how can sulfate attack develop over time with the formation of distinct micro-	Project has been initiated at DTI. Cooperation with the Danish Road Directorate and other external partners, who have access to relevant data is foreseen.

structural features (e.g. zoning)?

For all the selected concrete structures in the project a (birth) certificate will be issued describing the microstructure of the concrete ideally including how it has developed from very young to mature and eventually old concrete.

Expected results

- Establish an overview of how the microstructure of Danish sea water exposed with very different binder combinations appears
- Establish the development in sulfate and chloride containing phases over time
- Generate valuable scientific input aiding the process of selecting suitable binder combinations for sea water exposed concrete.

M2 **Chloride binding and models for transportation**	**Project type**
Purpose The purpose is to develop valid models for transportation of chlorides and models for where the chlorides are bound in the microstructure. This will give input to more reliable service life prediction of the concrete structure. *Content* – Formulation of hypothesis for chloride binding – State of the art of previous research – Analysis of where the chlorides are bounded in the microstructure (inner or outer hydration product) – A study of which parameters are affecting the chloride binding – Development of a test method for measuring the amount of chlorides available for initiating the corrosion processes *Expected results* – A method to determine how the chloride ions are bounded in the microstructure and how this bounding will develops over tim – Knowledge about chloride binding will makes it possible to specify more precise requirements to e.g. the C_3A content in the cement – Knowledge about chloride binding in the microstructure will also give input to understanding of the differences in the chloride threshold value for different types of concrete binders	Project has been initiated at DTI. Proposed as a Ph.D/Post Doc project. Probably a M.Sc. will be initiated.

M3 **Chloride threshold value**	Project type
Purpose The purpose is to develop a standard test method for measuring the chloride threshold value which initiates the corrosion process in different types of	Project has been initiated at DTI .

concrete. Furthermore, the purpose is to analyze which parameters that affect the level of the threshold value. This will together with the results from the chloride binding project give input to the service life prediction of the concrete structure. *Content* – State of the art study of chloride threshold value aspects – Development of test method to measure the chloride threshold value of different types of concrete – A study which parameters are affecting the level of the chloride threshold value like potential, conditioning, environmental chloride concentration – Development of a method to determine the content of free chlorides in the porewater – Participation in the RILEM committee in order to be able to discuss the results with international experts and also try to make sure that the method developed in this project can be used as basis for future European and international standards – Effect of SCC – Effect of corrosion inhibitors and other surface treatment – Relevance of cracks and micro defects – input from other activities. *Expected results* – Danish consensus about a method for measuring threshold values for different types of binders, which makes it possible to range the threshold values of different concrete binders relatively. – Input to service life models and corrosion initiation on existing structures	Proposed as a PhD/post doc project. Probably a M.Sc. will be initiated.

M4 **Frost resistance**	Project type
Not finished *Purpose* *Content* *Expected results*	Perhaps a M.Sc. project

M5 **Alkali – Silica Reactions / Alkali – Carbonate reactions**	Project type
Purpose Future large infrastructure projects in Denmark might make use of aggregate source not previously seen in Danish projects. Such foreign aggregate could consist of limestone or dolostone, i.e. the minerals calcite or dolomite that we have very limited experience with in Denmark. Such rock types particularly those containing dolomite may cause expansive alkali silica or	Perhaps a M.Sc. project

alkali carbonate reactions in concrete. The purpose is to investigate and document this type of deterioration in the concrete.

Content
A literature study will be performed and a state of the art report prepared. Contact will be taken to international experts on alkali carbonate reaction and samples of reactive rock will be collected for thin section preparation.

Expected results
- State of the art report
- Overview of the possible problems by using aggregate from other origins than normally used in Denmark
- Thin section library of known alkali carbonate reactive rock types from around the world established at DTI

M6 **Self healing of cracks**	Project type
Purpose The purpose is to investigate the possibility of adding something (e.g. microcapsules containing substances e.g. lime-producing bacteria that are released upon breakage to heal cracks) to the concrete that is activated when the concrete cracks and subsequently heal the cracks so that e.g. transport of chloride ions into the concrete is inhibited. *Content* A literature review of potential technologies proposed and their current state of progression toward industrial scale implementation. Based on the literature review the most promising technologies are tested in laboratory in an attempt to establish proof of concept. *Expected results* - State of the art report - Proof of concept testing on two most promising technologies initiated	Perhaps DTI project Perhaps a M.Sc. project

Execution

E1 **The influence of casting defects and critical construction details**	Project type
Purpose The purpose is to investigate the significance of casting defects and critical construction details (joints, cracks, honeycombing, spacers, etc.) on the long term durability of concrete structures. *Content* – Investigation of casting joints (warm and cold, SCC vs. slumpconcrete) – Investigation of too little vibration according to the HETEK guideline – Effect of vibration, poker vibration tracks, distance between the placement of the poker vibrator – Adhesion between reinforcements spacers and concrete – Variations in flow properties of SCC – effect on the quality of the execution – Production of 2-3 concrete blocks for the Femern exposure site in Rødbyhavn containing deliberate defects *Expected results* - Better understanding of the influence of various defects and construction details on the durability of concrete constructions, i.e. how important is it to make avoid the defects. - Is SCC performing similar to conventional slump concrete? What are the special challenges to SCC in this respect, and how may they be overcome?	Project has been initiated at DTI Proposed to be supplemented with master projects.

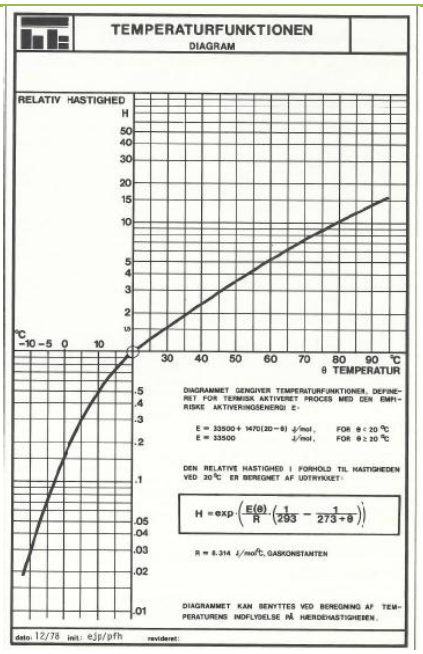
E2 **The influence of rheology and casting procedure (SCC)**	Project type
Purpose The purpose is to investigate the influence of the rheology of SCC and the casting method on the micro / macro structure of the concrete and thereby the long term durability. Blocking, segregation, inadequate form filling, poor encapsulation of reinforcement and spacers and warm casting joints are all examples on unwanted phenomena that may result from poorly chosen combination of concrete rheology and casting method or may be the result of poor control of the concrete production leading to large variation in concrete rheology from batch to batch. *Content* The topics will be investigated:	Probably DTI project

- The influence of rheology (concrete composition) on the thixotropy of concrete. Thixotropy is an important parameter in terms of controlling form work pressure and the risk of multilayer casting.
- The combined effect of exposure/curing conditions and thixotropy on the risk of multilayer casting.
- The influence of maximum size aggregate and rheology (concrete composition) in general on the risk of blocking, inadequate form filling, reinforcement and spacer encapsulation. The influence of different casting procedures will be evaluated as well.

Expected results

- Better understanding of the property thixotropy including a method for its measurement that will allow drafting of guidelines on how to control form work pressure and reduce risk of multilayer casting.
- Better understanding of how rheology and casting procedure interact and can be chosen to limit the risk of blocking, segregation and inadequate form filling while still obtaining good embedment of reinforcement and spacers.
- Documentation of the long term durability of SCC

E3 **Influence of hardening temperature on the development of properties of concrete containing substantial amounts of fly ash or slag**	Project type
Purpose Conversion from heat development to strength development is in Denmark done using the maturity concept. The maturity is estimated from on Figure below, which is based on data for pure Portland cement concrete published by Per Freisleben Hansen in 1977. To our knowledge no attempt has been done to verify if the Figure is also valid for other more modern powder combinations, e.g. combinations containing fly ash and slag.	Probably DTI project



Accordingly, it is of interest to carry out experiments to determine the influence of temperature on the maturity development of concrete used today, i.e. if the activation energy is the same as for pure Portland cement concrete.

Content
For a reference pure Portland cement concrete and series of fly ash and slag concretes the activation energy is determined at different temperatures. The strength development of the concrete are determined.
The microstructure of selected concretes is investigated using optical and scanning electron microscopy to provide information on how it develops over time. Likewise the chloride migration coefficient (NT Build 492) and some the chloride bulk diffusion testing is carried to provide information as to how hardening temperature influence rate at which the microstructure become less and less permeable, i.e. how hardening temperature may influence long-term durability.

Expected results
- Input to maturity calculations of concretes with substantial amounts of fly ash and slag
- Understanding of how temperature history influences microstructure in relation to chloride ingress into fly ash and slag concretes.

E4 **The influence of temperature, cement and binder composition on the risk of delayed ettringite formation**	Project type
Purpose Typically the requirements to the contractor carrying out the construction of Danish infrastructure project s will include that the temperature of the	Probably DTI project

concrete during the hardening period shall not exceed 60-65°C. The requirement to maximum temperature often makes it necessary to use cooling pipes in the concrete. This is an expensive solution. The reason behind the maximum temperature requirement is that higher temperatures may increase the risk of so-called delayed ettringite formation (DEF) in the concrete, which might lead to expansion of the paste and cracking of the concrete. However, not all concrete is equally susceptible to DEF. Particularly the cement mineralogy, cement chemical composition, use of supplementary cementitious materials, and temperature history seems to influence the risk of DEF.

It is therefore of interest to investigate under which conditions concretes used in are prone to DEF if at all.

Content
The knowledge about existing Danish infrastructure concrete will be scrutinized looking for information relating to DEF.

A suite of concretes including pure Portland cement concrete (different cement types), fly ash concrete, 3-powder concrete and slag based concrete will be investigated. The concretes will be cast and exposed to different curing regimes. Each curing regime consist of a pre-curing at room temperature followed by a ramp up of temperature to maximum, followed by a period at maximum temperature and finally a ramp down.
Following curing the microstructure of the concretes will be characterized by optical and scanning electron microscopy. Specimens will be stored in different moist environments and the length change and weight gain followed over time. It may well be necessary to follow the specimens for some years in order to get the full picture of the potential for expansion.

Expected results

- Knowledge about whether typical Danish infrastructure concretes are susceptible to DEF. Perhaps enough documentation can be obtained to be more detailed on the maximum temperature requirement, i.e. maybe somewhat higher temperatures can be allowed in some cases.
- Methodology developed for evaluating if a particular concrete is prone to DEF

E5 **Developing a re-usable experimental setup for obtaining more accurate input parameters for hardening simulations of temperature and stress**	Project type
Purpose The project aims to establish a foundation for being able to perform more accurate temperature and stress calculations that will ultimately allow optimization of the curing process while eliminating the risk of crack formation, i.e. obtaining best possible durability at a minimum cost.	Probably DTI project

Content
Development of a test set up for determination of more precise input parameters for temperature and stress calculation regarding:

- Formwork including insulation and surface protection
- Cooling pipes of different materials, different dimensions, different flow rate and different water temperature

The test setup will be a concrete block very well insulated on all edges and on one surface. There will be cooling pipes cast into the block, and there will be many thermo-couples installed in order to measure the temperature profile in the concrete and in the cooling pipes. The test setup can be reused as many times as wanted.

In order to test insulation or cooling effects, the concrete block is heated to a given temperature for example corresponding to the adiabatic temperature rise. During this heating the free surface is insulated in order to obtain uniformly distributed temperature in the concrete. After heating the test of surface heat transmission or the test of cooling effects can be performed in the following way:

Test of formwork and/or the insulation is performed by mounting these on the free surface. The effect of wind speed is emulated by use of "wind tunnels". The temperature in the concrete are measured during cooling and the insulation effect can be predicted/calibrated using 4C-Temp&Stress.

After heating of the block, cooling pipes to be tested are connected to the water supply, and the cooling starts using a fixed flow rate and water temperature. Based on the cooling effect the input data concerning cooling pipes can be estimated/calibrated using 4C-Temp&Stress.

Expected results:

- More precise input parameters for temperature and stress calculation concerning both surface insulating effects and cooling pipes will result in a more precise calculation and a better optimization of the hardening process without increased cracking risk.

E6 **Analysis of the influence of surface treatment on the long term durability**	Project type
Purpose Many different surface treatment products are on the market, and some claim to increase long term durability of concrete. The effect is presumably related to a reduced interaction with water, i.e. the transport into the concrete is mitigated by the surface treatment. Can this effect be documented? Is it effective if the concrete is permanently under water? Is the effect long lasting? *Content* The project will investigate some selected surface treatments applied to a	Perhaps a M.Sc project

range of different concrete types that has different curing histories. The interaction with water and ions will be tested. Subsequently, samples of concrete will be subjected to accelerated weathering and testing of interaction with water and ions performed again.

Expected results
Documentation as to whether or not surface treatments provide improvement of the long-term durability.

E7 **Effect of form liner on long term durability of concrete structures**	Project type
Purpose Correctly used form liner should drain water from the concrete surface and hence reduce the w/c-ratio at the surface of the concrete. This effect presumably leads to reduced rate of chloride ingress resulting in improved durability of the concrete. Can this effect be documented and is the use of form liner without any draw backs in terms of e.g. increased risk of surface cracking. *Content* Several types of form liner will be used in combination with different concrete types. The concrete types tested should vary in w/c-ratio and in binder type, i.e. the effect of different particle sizes (e.g. silica fume) and high volume content of powder (high fly ash content) should be investigated. 1x1x0,2m concrete blocks will be cast with vertically with form liner on one side. The chloride migration coefficient and microstructure will be investigated comparing the lined surface with the opposing non-lined surface. One 2x1x0,2m concrete block will be produced and exposed at the Femern exposure site at Rødbyhavn. *Expected results* Documentation as to whether or not form liner provides improvement of the long-term durability.	Perhaps a M.Sc project

Constructions

C1 **The effect of micro defects/cracks influence on carbonation, chloride and sulfate ingress**	Project type
Purpose For at least 20 years it has been know that low water cement ratio and high contents of in particular silica fume in concrete results in micro-cracking of the paste. However, it is still unclear to what extend this cracking influence e.g. transport properties of the concrete and thereby the durability. This project aims to investigate the influence of micro defects in the concrete paste on the long term durability of the concrete structures. *Content* Concrete compositions developing different degrees of micro-cracking are selected and specimens cast for characterisation of microstructure and testing of durability parameters. It is envisioned to make use of internal curing by superabsorbing polymers or saturated porous aggregate such as pumice to make concrete with low degree of micro cracking. The testing of durability parameters should reveal if the degree of micro cracking has any influence on durability, e.g. chloride ion ingress and maybe frost resistance. *Expected results* Documentation regarding significance of the influence that micro cracking of the paste has on long term durability.	Perhaps this project shall be included in the M1 project regarding long term durability of existing concrete constructions exposed to seawater.

C2 **The consequences of cracks and the understanding of the damages in the interface between the concrete and the reinforcement**	Project type
Not finished *Purpose* The purpose is to analyze the consequences of cracking and understand the development in cracking in the interface between concrete and reinforcement to be able to develop models for cracking and related influence on chloride ingress. *Content* – X-ray techniques and testing – …. *Expected results*	Two Ph.D/Post.doc projects are proposed: 1. X-ray techniques for monitoring of rebar corrosion (experimental) 2. Modeling of rebar corrosion

C3 **Durability of steel fibre reinforced concrete structures exposed to sea water**	Project type

Not finished *Purpose* The purpose is to evaluate the durability of steel fibre reinforced concrete constructions exposed to sea water, including combined solutions where fibres are used together with traditional rebars *Content* *Expected results*	Probably M.Sc projects

C4 **Combined effect of mechanical fatigue and deterioration**	Project type
Not finished *Purpose* Relevant for an edge beams where cracks are opening and closing – what happens? *Content* *Expected results*	Probably DTU projects

C5 **The effect of mechanical stress levels on rebar corrosion**	Project type
Not finished *Purpose* relevant for eg edge beams where cracks are opening and closing – what happens? *Content* *Expected results*	Probably DTU projects

C6 **New repair methods, strategies and materials**	Project type
Purpose In connection with concrete construction “finish and repair works” includes filling out core holes, recesses, cable boxes. This kind of work is typically not very well described in the specifications how this shall be done and which types of products shall be used. The purpose of this project is to prepare a description / guideline for how to carry out such finishing work and still ensure an adequate durability of the concrete construction.	Probably a DTI project and / or partner projects

Content
It is important to distinguish between the different strategies for finish and repair work depending on the different situations:

1. Repairs to be carried out as a part of the construction phase to be able to fulfill the requirements (making good)
2. Repairs needed after end of service life (120 or 100 y),
3. Repairs to be carried out in case of non conformity situations and
4. Repairs connected to the necessary maintenance.

This project will investigate different strategies, methods and products and make investigations of different solutions.

Expected results
A guideline for optimal repair strategies, methods and products to be used in different situations. This guideline can be used as basis for specifications.

C7 **Methods for determination of remaining service life**	Project type
Purpose The ongoing development of new techniques for monitoring and non-destructive testing (NDT) of concrete structures offers new and more advanced methods for condition assessment of infrastructural constructions. This project aims to investigate the possibilities of enhancing the methods for determination of remaining service life of constructions in the infrastructure by the use of these new techniques. *Content* Investigation of State-of-the-Art in monitoring and NDT Identification of promising areas for further development and initiation of new R&D projects within these areas Initiating larger F&U projects within this topic. **….** *Expected results* A new F&U project to continue these activities will be started up.	Probably a project to be initiated with funding coming from EU or others

Service life models

S1 **Verification and updating existing models for prediction of service life**	Project type
Purpose *Content* *Expected results*	Will probably only be started up with-in the Expert centre and continued by financing from EU

S2 **New design tools for durability**	Project type
Purpose *Content* *Expected results*	Will probably only be started up with-in the Expert centre and continued by financing from EU