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Preface

The Nordic Concrete Federation was founded in the 1950s as an example of the new-awakened interest in scientific and technical co-operations between the five countries in the northern Europe, i.e., Denmark, Finland, Iceland, Norway, and Finland. The most substantial examples of the co-operation are the semi-annual scientific journal *Nordic Concrete Research* (NCR) and the series of research symposia. The five countries are organizing a research symposium every third year since 1953 according to a specific schedule. The XXth Symposium on Nordic Concrete Research & Development is the fifth one organized in Sweden and receives the relay-race baton from Norway and Sandefjord.

The current proceedings contain 90 summaries of oral or poster presentations that will be presented in Bålsta 45 km northwest of Stockholm. They are organized in the same order as the Symposium and cover the following themes:

- Admixtures & Aggregates
- Effects of Restraint & Structural Applications
- Durability
- Load-carrying Capacity
- Durable Structures
- Assessment, Service Life, Repair & Strengthening
- Binders
- Future Perspectives towards the Development of Concrete Technologies
- Aesthetics & Environment
- Production Technology
- Fresh Concrete & Hard Concrete Properties
- Numerical Methods

The proceedings also cover some of the papers presented at the Industrial Day, Poster Session, and the joint SVR-JSCE seminar all arranged as parts of the Symposium. All contributions have been reviewed by the Scientific Committee. The proceedings constitute the first issue of NCR in 2008 (NCR 1/2008). For more information of NCR and the Nordic Concrete Federation, please, see www.nordicconcrete.org.

I wish to thank Mr. P. Hult, Mr. Chr. Olsson, and Ms. A.-Th. Söderquist of the Organizing Committee, the members of the Scientific Committee, American Concrete Institute (ACI), Swedish Society of Civil and Structural Engineers (SVR), Japan Society of Civil Engineers (JSCE), the authors and speakers, and the exhibitors for providing the requirements for a successful Symposium.

Stockholm in May 2008

Johan Silfwerbrand

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Session A1
Fresh Concrete & Hard Concrete Properties

Pumpability of Mortar and Concrete as Related to Rheology

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ABSTRACT
The pumpability of concrete was studied in a full scale pumping set-up instrumented to monitor flow through the rotating pump and rubber hose, pressure over the hose and energy consumption in the pump. The flow out of the pump was fairly constant during 30s measurements with fairly linear pressure drop over the length of the hose. Over 49 minutes the pump flow was reduced with 13 % whereas concrete pressure in the hose increased 2,5 times. The electric motor current increased 1,3 times to be able to keep the concrete flow through the system quite constant. The work was financed by Maxit Group, NTNU and the Research Council of Norway through Skattefunn and the COncrete INnovation centre (COIN).

Key words: concrete, rheology, pumping, measurements

1. INTRODUCTION

Pumping of concrete and mortar is a cost effective way of industrializing both ready-mix and pump systems for premixed concrete and mortar. In Norway approximately 50 % of the concrete is pumped at some stage of the placing process while the figures for mortar are significantly lower. Obviously most concrete today is thus pumpable. Pumpability of concrete can be defined as its ability to flow through a pipe by the help of a pump, and also the ability of confined concrete to flow under pressure while maintaining its initial properties. Due to varying types and configurations of pump and pipe/hose from one site to another (capacity, pipe length, height, diameter, material etc), the term pumpability yields for a site-specific pump set-up. Quantification of pumpability of a concrete mix should therefore be by flow or pressure obtained, or pumping energy required for a concrete mix in the actual set-up. One may also quantify to what degree a concrete mix can maintain its fresh and hardened properties after pumping. In a full scale pump set up in the NTNU concrete lab it is possible to study the relation between concrete pumpability and rheological properties.

2. INVESTIGATIONS AND RESULTS

The full-scale silo/continuous mixer/screw-feeder/rotating worm pump/rubber hose set-up from Maxit Group m-Tec was installed in the NTNU concrete lab. Concrete pump flow, -energy use and concrete pressure are measured at different stages in the mix/pump/hose system by instrumentation with load cell, Ampère meter and pressure sensors. Figure 1 shows results on an initially dry light weight aggregate concrete (LWA). It was found that the rotating worm pump produced constant flow, and also pressure and energy consumption were rather constant during the around 30 s pumping measurements, see Figure 1. The age had an influence on the rheology, observed as increased pressure and pumping energy at a quite constant pump flow, see measurements presented in Figure 1 and Table 1. The presented measurements were made on a premix LWA concrete with initially dry LWA repeated over a 49 minute period.

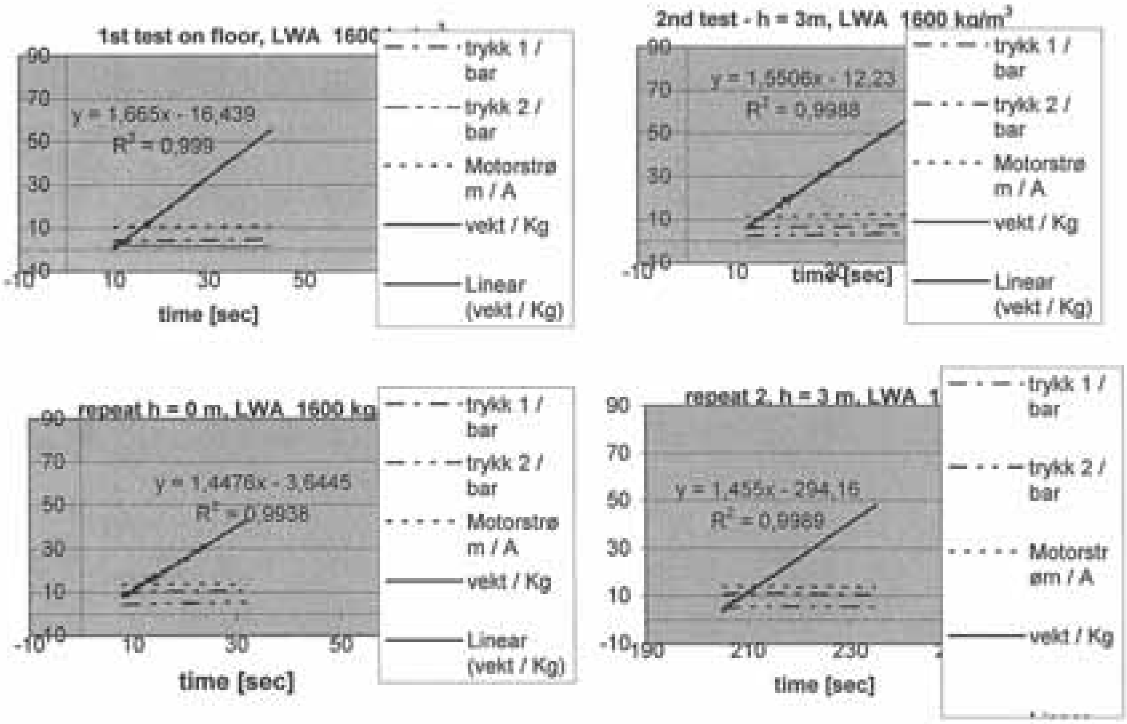

Figure 1 – Flow, -pressure and electric pump current measured with LWA concrete (1600 kg/m³) during a 49 minute period, rotating pump and 26,6 m Ø 45 mm rubber hose, 0 and 3 m height.

Table 1 – Concrete flow, -pressure and electric current in Figure 1.

Parameters	h = 0m, 1st trial t = 0	h = 3m, 1st trial t = +9 min	h = 0m, 2nd trial t = +44 min	h = 3m, 2nd trial t = +49 min
Concrete flow [m/s] (assuming 1600 kg/m³)	1,665kg/s (100%) = 0,66 m/s	1,551kg/s (93%) = 0,61m/s	1,448kg/s (87%) = 0,57 m/s	1,455kg/s (100%) (87%) = 0,57 (m/s)
Concrete pressure start/-halfway [bar]	4,4/1,8 (41%)	7,1 / 3,3 (46%)	10,5/4,9 (47%)	11,0/5,6 (51%)
El. current [Ampère]	10,7	12,2 (114%)	13,7 (128%)	14,1 (132%)

The flow through the rotating pump working at constant frequency of 25 Hz (50 % of max capacity) reduced somewhat over the 49 minute experiment. Two possible causes are; reduced workability at increasing time and reduced driving pressure difference at 3 m height. The height effect (Δp_{3m} = 1600 kg/m³*9.81 m/s² *3 m ≈ 0,5 bar) only reduces the flow in one of the two cases and therefore ageing is probably most important. The ageing includes normal cement dissolution/coagulation/hydration effects in addition to reduced paste volume and -flow since water is absorbed in LWA. Water absorbed in LWA also increases concrete density, contributing to reduce the volumetric flow even more than the flow based on constant density and gravimetric measurements shown in Table 1 and Figure 1. The increasing electric current indicates that the pump work increases to be able to keep the flow almost constant as concrete pumpability is reduced. Our experiences with viscometer measurements and pumpability have so far indicated that reduced pumpability measured as increased pressure at constant flow is mainly related to plastic viscosity.

Robustness of Fresh Self-Compacting Concrete

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Key words: Robustness, rheology, SCC, VMA, CEM.

1. INTRODUCTION

One of the more important factors limiting SCC to become the major part of ready- mixed concrete is the difficulties involved in a steady and variation-free production in terms of fresh properties. The combination of sensitive SCC mixtures and varying properties of constituents together with often relatively tight requirements result in extensive quality assurance which ties a lot of manpower resources and increases costs. The overall aim with this project is to find a concept of how to increase the robustness of SCC. In the present and on-going phase of this project, the ability for different viscosity-modifying admixtures (VMA's) to reduce the variation in terms of rheology to variation in the aggregate moisture is studied using concrete equivalent mortar (CEM).

2. RESEARCH SIGNIFICANCE

If a concept of how to produce more robust SCC mixtures can be found, it will be possible to reduce the costs related to the production of SCC due to less required quality assurance, i.e., manpower. This will also lead to a more secure planning of the casting procedure for the contractor and thus, all together it has the potential to increase the overall use of SCC, which in turn will lead to an increased productivity of the whole concrete construction business.

3. METHODOLOGIES

The overall methodology used in this study is to focus on the rheological response in terms of yield stress and plastic viscosity (according to the Bingham model) of VMA-added CEM's to variations in aggregate moisture. The methodology behind the concept of CEM is that the mortar is designed based on, in this case, a SCC mixture with the coarse aggregate replaced by sand equal to the same total specific aggregate surface. Thus, the total aggregate surface per mixture volume is equal for the CEM and the corresponding SCC and therefore also the degree of water and admixtures adsorbed on the aggregate surface. The rheological measurements are performed using a ConTec 6 viscometer equipped with concentric cylinder measuring system.

4. RESULTS

Totally 7 different VMA's with various chemical compositions have been evaluated so far in this project. The reference mixture is designed with Cem II7A-LL 42.5 R and a crystalline limestone filler Betocarb 8. The superplasticizer used is based on modified polycarboxylate with a 21.5% solid content. The aggregate used is sieved to maximum particle size of 2.5 mm. The rheological response to variations in aggregate moisture is shown in Figure 1 (left). To quantify the robustness, one method is to calculate the area equal to total response in terms of yield stress times the total response in terms of plastic viscosity. The areas relative to the one for the reference mixture using this method are shown in Figure 1 (right). Using this method it is obvious that three VMA's; VMA3, VMA 6 and VMA7 show that they increase the robustness.

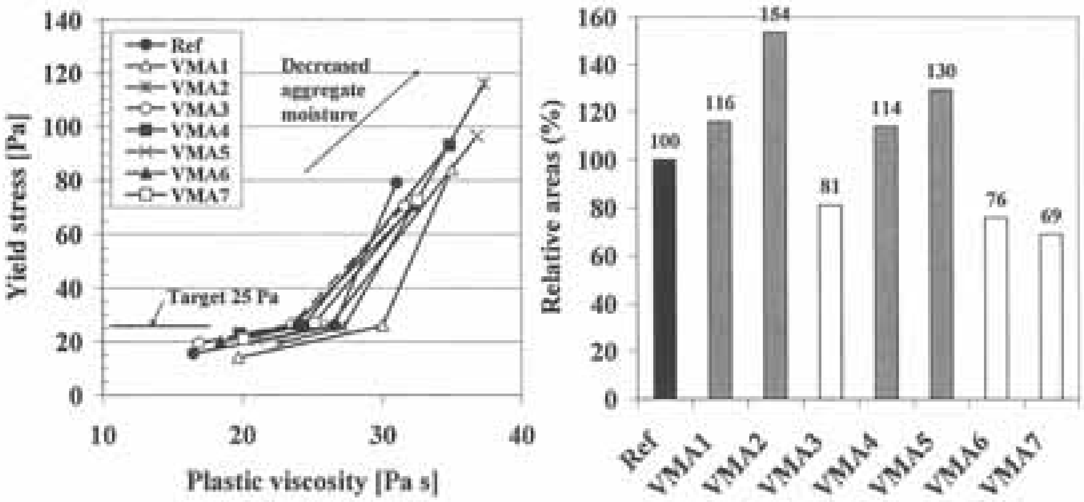


Figure 1 – Rheological response to simulated misjudged aggregate moisture (left) and validation of relative robustness areas for mortars with different VMA's (right.

5. CONCLUSIONS

The main conclusion possible to be drawn from this on-going project is strictly related to the actual mixtures tested and can be stated as follows:
– VMA can increase the robustness of the tested CEM's but this fact is very depending on type of VMA. The best performing VMA, VMA7, reduces the relative rheology area to only 69 % of that of the reference without VMA.

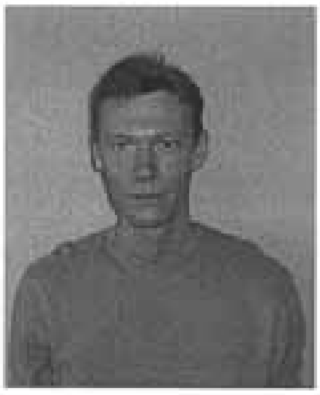
6. FINANCIAL SUPPORT

The financial support by the Swedish Consortium for Financing Basic Research in the Concrete Field is gratefully acknowledged.

7. PROJECT DATA

This is a postdoc project conducted at Université de Sherbrooke in co-operation with Professor Kamal H. Khayat and performed during the years 2007 and 2008.

Influence of "Time in Cone before Testing" on the Flow Properties of SCC Measured by the Slump Flow Test



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Key words: Rheology, self-compacting concrete, slump flow, yield stress, plastic viscosity.

1. INTRODUCTION

Bringing rheology into practice is a major challenge to a more wide-spread use of SCC. It requires tools, which can be applied at job sites and in production plants, while providing unambiguous information about the SCC flow properties. The 4C-Rheometer was developed to serve this need as an equipment that assess the rheological properties in a quick, easy-to-use, and operator independent way [1]. The 4C-Rheometer is a fully automatic setup based on the slump flow test and the yield stress and plastic viscosity derived from the slump flow versus time curve obtained from video analysis. Furthermore, it provides the empirical slump flow value and t_{500} parameter. In conventional rotational concrete rheometers such as the ConTec viscometers and the BTRHEOM the rheological parameters are derived during flow at steady state. In the 4C-Rheometer the concrete is at rest for a short period of time prior to measurement and investigations have been carried out to assess the effect of "time in the cone before testing".

2. RESEARCH SIGNIFICANCE

The rheology of concrete comprises both steady state and time-dependent phenomena. During continuous castings the rheological properties measured at steady state dominate, and the Bingham parameters can be used to describe the rheological properties. At rest, however, the concrete exhibitS a structural built-up referred to as thixotropy. It may reduce the form work pressure, but care must be taking during discontinuous castings e.g. to avoid generation of weak interfaces in horizontal castings. Roussel [2] estimated that the time needed to avoid weak interfaces was 40, 8 and 3 min for a non-thixotropic, thixotropic and highly thixotropic SCC, respectively. Thus, thixotropy is an important property for SCC at rest, and it may potentially affect the results of the slump flow test if the time needed for structural built-up is shorter than the time it takes to perform the test.

3. METHOD

Experiments have been performed using two 4C-Rheometers to investigate if the yield stress, plastic viscosity, slump flow and t_{500} are influenced by the resting time of the concrete in the cone. SCCs with very different rheology but with unknown thixotropic behaviour have been tested. Each batch of SCC was tested at different times and in one rheometer, the resting time was 30 s before each test whereas for the second rheometer it varied between 30 s and 8 min.

4. RESULTS AND CONCLUSIONS

The results show that the resting time has little or no effect on the measured parameters when normal practice is applied, i.e. the cone is filled in one pour and lifting takes place shortly after. For up to two minutes no difference was observed between results from the two rheometers. However, for extended resting times some effect was observed and especially on the plastic viscosity. Some selected results of slump flow and plastic viscosity from one test series are shown in Figure 1.

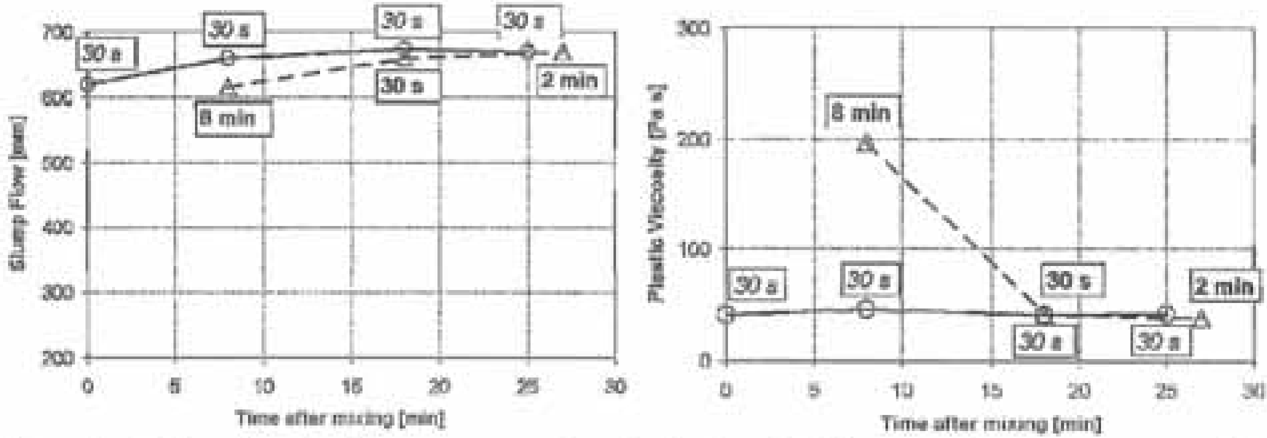

Figure 1 – Selected results from one test series. In the first 4C-Rheometer the resting time was 30 s (solid line) and in the second 4C-Rheometer the resting time varied (dashed line).

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Modelling and Simulation of Mortar and SCC Flow

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Key words: Simulation, SCC, rheology, slump and fresh concrete flow.

1. INTRODUCTION

A computational tool is devised as part of a Ph.D. project to allow prediction of fresh SCC flow behaviour. With its superb form filling properties, SCC is often employed in complex geometries, in closed forms and sometimes with delicate architectural detailing. It is thus important to be able to predict the flow of the fresh SCC, plan the most efficient method of pouring or pumping to ensure proper form filling, surface perfection and to avoid aggregate blocking. The potential of predictions and advanced problem detection of different casting results is to greatly improve product quality, to reduce production time and costs and may also facilitate development of new formwork design.

2. METHODS

Various types of software and simulation methods, such as continuous formulations (Computational Fluid Dynamics, CFD) or discrete approaches (e.g. Distinct Element Method, DEM) are currently used to simulate concrete flow. Both CFD and DEM have been investigated and advantages and shortcomings have been identified. By combining these two methods, large scale simulation using CFD to locate possible problematic areas and the discrete approach to allow a more realistic simulation of blocking is possible. Thus, SCC is modelled as a continuous material on a larger scale and as a suspension of aggregates (the distinct elements) on a smaller scale. The method reduces the number of elements and facilitates SCC flow and aggregate blocking to be modelled using a conventional computer. In this study, both simulation methods are calibrated against the slump flow (Figure 1) which is the most widely used workability test method for SCC on the construction site.

In tests performed on mortar, a CamFlow [1] is used to calibrate the Bingham parameters for the simulation methods. The method assumes an equal height of the spread and describes the apparent material viscosity, η (Pa s), for the slump flow as:

$$\eta = \left(\frac{\rho g v}{A}\right) \Big/ \left(\frac{\Delta r}{\Delta(v/A)}\right) \times \Delta t \qquad (1)$$

where $g = 9.82$ m/s^2, ρ is the material density, Δt measured time step, r the spread radius, A the spread area and v the sample volume.

The dynamic yield stress, τ_0 (Pa), is well correlated to slump diameter considering a predominately viscous flow [2]:

$$\tau_0 = \frac{225\rho g \Omega^2}{128\pi^2 R^5} \tag{2}$$

where Ω is the volume of the material and R denotes the radius of the final spread. The model assumes that the effects of initial inertia and cone lifting speed can be disregarded.

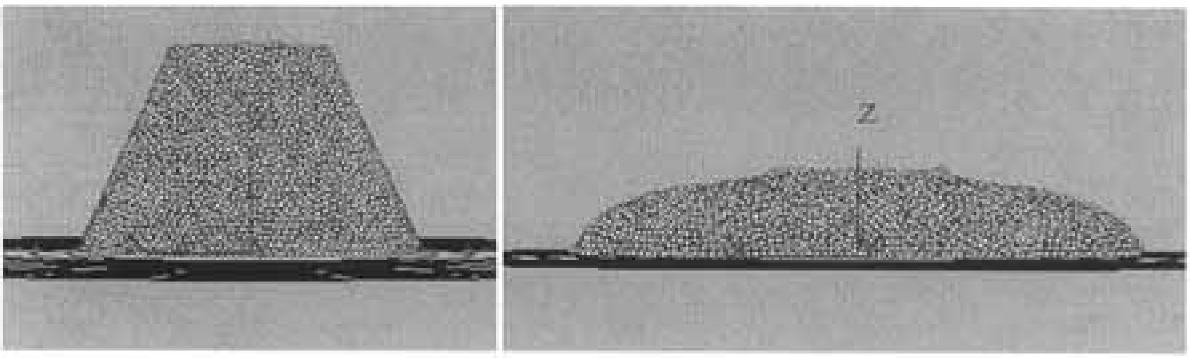

Figure 1 – Simulated slump using the Distinct Element Method (including particles) [3].

CONCLUSIONS

The Distinct Element Method can give extensive information on blocking phenomena. However, for larger scale calculations, due to practical limits in terms of number of particles that can be incorporated in a calculation, the CFD approach using either finite element or finite volume for the calculations can be employed. The modelled material is calibrated against the slump flow to determine the Bingham rheological parameters, which should then work for different geometries, also on a larger scale.

3. ACKNOWLEDGEMENT

Financial support from the Swedish Consortium on Financing Basic Research in the Concrete Field and the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning is gratefully acknowledged.

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Comparison of Two Models for Concrete Flow Behaviour

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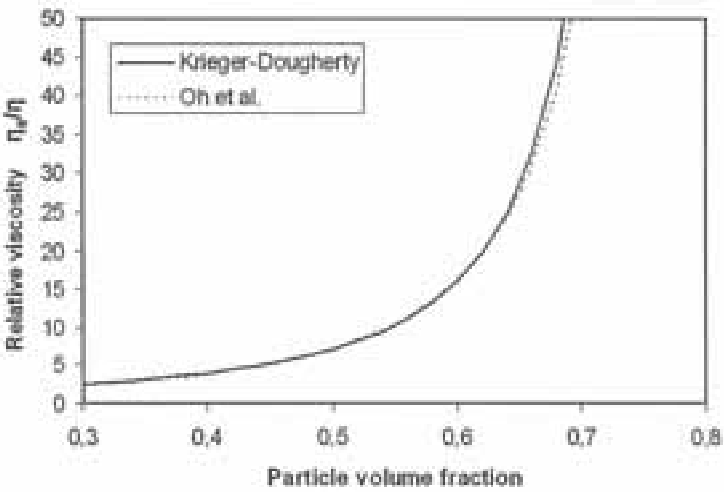
Key words: Concrete rheology, modelling.

1. INTRODUCTION

At the XIX Nordic Concrete Research Symposium, two different articles were presented on basically the same subject: verification of material models that describe the flowability of concrete or cement paste [1, 2]. The first article uses the so-called Krieger-Dougherty equation [3] as a starting point, whereas the second is based on a model put forward by Oh et al. [4]. Each article shows good correlation between experimental results and the model that is tested. It is interesting that the models produce equally well results, as the models at first glance differ in a number of ways, and for that reason it is also interesting to make a comparison of the two models.

2. COMPARISON OF MODELS

Figure 1 shows a graphical representation of the two models.



Kriger-Dougherty:

$$\frac{\eta_s}{\eta} = \left(1-\frac{\phi}{\phi_{max}}\right)^{-[\eta]\phi_m}$$

Oh et al.:

$$\frac{\eta_s}{\eta} = A\cdot\Gamma^{-B}+1$$

where Γ is a function of φ and φ_m.

Figure 1 – Comparison of the Krieger-Dougherty model and the model of Oh et al.

The two models are fitted so they predict the same value for particle volume fractions of 0.50 and 0.60 as if they had been calibrated for two actual measurements (for the Krieger-Dougherty model, the curve corresponds to a maximum particle volume fraction $\varphi_m = 0.80$ and an intrinsic viscosity $[\eta] = 2.5$). It is seen that the two curves are almost identical.

3. CONCLUSIONS

From the very beginning, the approach of Krieger and Dougherty is very different from the approach of Oh, Noguchi, and Tomosawa, when they work out an answer to the question on how to link the presence of rigid particles to flow properties. However, as the comparison of flow equations showed, they end up with formulas, which from a purely mathematical viewpoint are vey similar. In that respect it is not surprising that if both sets of equations are used, they will work much in the same way (either well or poorly).

As such, the model of Oh, Noguchi and Tomosawa is not a new model, it is a modification of the Krieger-Dougherty model. But in the context of concrete technology, their work is both original and valuable concerning at least the following three points:

- The Krieger-Dougherty equation refers to intrinsic viscosity, whereas Oh et al. refer to the Bingham parameters: plastic viscosity and yield stress. In that respect, their work can be seen as a translation of the Krieger-Dougherty idea into Bingham terms. Bingham terms are already well established in the field of concrete rheology.
- Oh et al. so to say take it one step further than Krieger and Dougherty: Krieger and Dougherty only address the problem: What will happen, if an amount of uniform particles is added to a Newtonian fluid? Oh et al. address what will happen if the addition is repeated, but the following times with larger and larger particles. This is equivalent to the situation of fresh concrete, where larger aggregate particles are added to a system of cement paste, which again is a suspension of fine particles in water.
- In the work of Krieger and Dougherty, they do not go into details about the consequence of particle size and particle shape. Oh et al. show how to handle that particle size is not a single value but a wide interval. In the Krieger-Dougherty equation, intrinsic viscosity is a parameter that can vary from suspension to suspension, but no comments are given on what will make the viscosity de- or increasing. From the explanations given by Oh et al., it becomes obvious that intrinsic viscosity among other things depends on particle shape, which they quantify by the surface to volume ratio.

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Concrete Workability and Fibre Content – An Overview

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Keywords: Fibre, fresh concrete, rheology, production technique.

1 INTRODUCTION

This literature study is a shortened version of a State of the art report written for COINs (Concrete Innovation Centre) fibre project. The project will investigate the possibilities of replacing traditional reinforcement in load carrying structures. The focus of the report has therefore been on workability and the optimization of the maximum fibre content. Alternative production methods have also been reported.

2 RESEARCH SIGNIFICANCE

Reinforcing concrete structures is generally a rather expensive and time-consuming process, for designers as well as for constructors. The reinforcement design participates with about 50 % of the total design costs, and with around 30 % of the total work costs. Fiber reinforcement, on the other hand, has the advantage of being significantly less labour-intensive than rebar reinforcement, and thus meets both the demand for improved efficiency and future shortage of skilled workers. Fibre reinforcement is also beneficial because of better corrosion resistance. Replacement of traditional rebar with fibre and/or non-corroding reinforcement will render more economical concrete and slimmer structures with reduced cover thickness. One challenge is, however, that fibres are generally distributed throughout the concrete cross section. Therefore, many fibres are inefficiently located for resisting tensile stresses resulting from applied loads. Depending on fabrication method, random orientation of fibres may be either two-dimensional (2-D) or three-dimensional (3-D). Also, many fibres are observed to extend across cracks at angles other than 90°C or may have less than the required embedment length for development of adequate bond. Only a small percentage of the fibre content may thus be efficient in resisting tensile or flexural stresses. Efficiency factors can be as low as 0.4 for 2-D random orientation and 0.25 for 3-D random orientation. Another challenge is the contradiction between fibre geometry required to allow easy handling of the fresh concrete and that required for the maximum efficiency in the hardened composite: High fibre contents create, a stiff internal structure which counteracts the flow. Fibers which are too long tend, moreover, to "ball" in the mix which again creates workability problems. The practical fibre content is thus limited since a sudden decrease of workability occurs at a certain fibre content depending on the mixture composition and the applied fibre type.

3 RESULTS AND CONCLUSIONS

Workability and maximum fibre volume are governed by parameters such as

- maximum aggregate size
- the type and content of the fibres used
- the matrix composition, amount and workability
- the properties of the matrix constituents
- mixing and placing process

The paste thickness around the particles determines the degree of concrete flowability until the critical fibre content is reached and fibre balling occurs. The maximum fibre content is governed by fibre inter-lock and workability loss due to the long shape and high surface area of the fibre. The literature indicates that the critical fibre content is 2 - 4 vol.% for traditional concretes and SCC. Increasing the fibre content above 2 % seems to demand new casting techniques or a change of the fibre reinforced concrete concept as exemplified by SIFCON and textile reinforced concrete.

Achieving the same mechanical properties as traditionally reinforced concrete will probably demand changes of the matrix's materials in line of high performance concrete and better control over fibre distribution. Some structural applications of fibre reinforced concrete have already been made possible using special high-performance fibre-reinforced composite materials such as DUCTAL®. However, further research is required for a comprehensive understanding and a more widespread use of fibre-reinforced cement-based materials. Quality assurance and quality control systems are needed for further commercializing these composites.

4 PROJECT DATA AND FINANCIAL SUPPORT

COIN - Concrete Innovation Centre - is one of 14 Norwegian Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology (NTNU) and industry partners work in the COIN projects (presently 5 projects). COIN involves moreover 15 - 20 PhD-students, 10 - 20 M.Sci-students and international guest researchers. The research covers a wide range of topics wherein fibre is one of them.

COIN has a budget of NOK 200 million over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and, NTNU (in all approx 15 %). The present COIN partners are the Research Council of Norway, SINTEF, NTNU, Norcem, Unicon, Maxit Group, Borregaard, Spenncon, Rescon Mapei, The Norwegian Public Roads Administration, Veidekke and Aker Kværner.
For more information, log on to www.sintef.no/coin

An Investigation of Bond Strength between Fibre and Concrete

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Key words: Concrete, fibre reinforcement, pull-out tests

1. INTRODUCTION

According to the Norwegian design rule draft for steel fibre reinforced concrete, the fibre reinforced concrete's characteristic strength after cracking ($f_{ftk,res}$) can be calculated by the following equation:

$$f_{ftk,res} = \eta_0 v_f \, \eta_1 \sigma_{fk,max} = \eta_0 v_f \sigma_{fk,mean} \qquad (1)$$

where

- v_f — the volumetric amount of fibre
- $\sigma_{fk,max}$ — the maximum stress in fibres with embedded length $l_b = l_f/2$ at a crack
- l_b — embedment length
- l_f — fibre length
- $\sigma_{fk,mean}$ — the mean stress in all the fibres crossing cracks, with random embedded length and orientation
- η_1 — the relationship $\sigma_{fk,mean}/\sigma_{fk,max}$
- η_0 — the relationship between the normal force resultant in fibres with relevant directional distribution and the force resultant in uniform fibres with the same stress

The aim of the investigation is to learn more about the stress values used in Equation (1).

2. LITERATURE STUDY

Based on several experimental series at NTNU a default value of 500 MPa has been used for steel fibres with end hook, and 250 MPa has been used for polyolefin fibre. However, $\sigma_{fk,mean}$ varies not only with the fibre type but also with the concrete strength, and probably with the concrete mix design as well.

3. RESULTS

Pull-out tests on single fibres shows a significant difference in the behaviour for polyolefin fibre and steel fibre. The maximal fibre tension is, as mentioned earlier, depended on the fibre type. Regarding utilization as load carrying reinforcement in real structures, it is perhaps more important to be aware of the deformation at maximal tension, than the maximal tension itself. The pull-out tests show that steel fibres reach maximal tension at deformations about 1 mm, while the polyolefin fibres reach maximal tension at deformations between 2 mm and 3 mm. It is difficult, if not impossible, to estimate a fibre reinforced beams capacity based on pull-out test on single fibres. This is due to the fact that that there is a huge variance on the stress-deformation relationship from one fibre to another (fibres which may reach the same maximal tension). To compare different fibre types, on the other hand, pull-out test results are reliable, especially if the effect of one of the fibres as load carrying reinforcement is known.

4-point bending tests on small fibre reinforced beams (150x150x600mm) have shown that the crack mouth opening displacement is larger for concrete beams reinforced with polyolefin fibre compared to beams reinforced with steel fibres with end hooks. This correlates well with the results from pull-out tests.

4. PROJECT DATA

COIN - Concrete Innovation Centre - is one of 14 Norwegian Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

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For more information, log on to www.sintef.no/coin

Concrete with Photocatalytic Properties

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Key words: Cement, titanium dioxide, NOx, environment.

1. INTRODUCTION

Nanocrystalline titaniumdioxide has photocatalytic properties. This means that the titanium dioxide reacts with UV-light from the sun. This can be used to degrade dirt, exhaust gases or bad smell. In the Nanocrete project these reactions are tested in concrete in lab, pilot and field tests.

2. THE REACTION

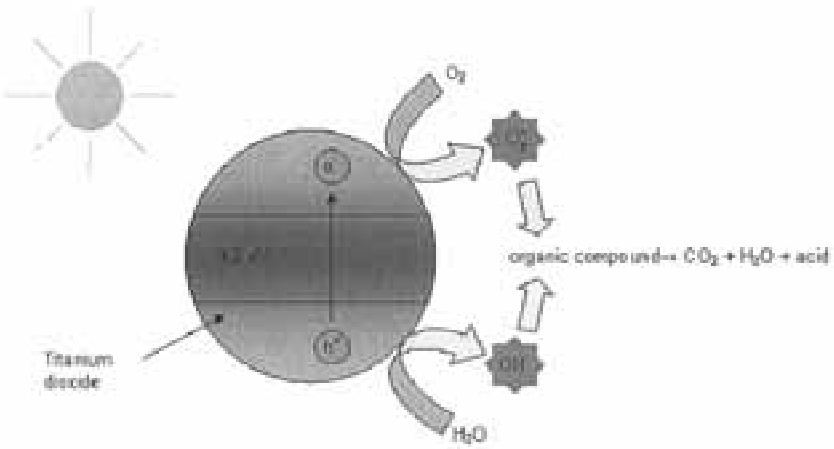

Figure 1 – Titanium dioxide is activated by the UV-light from the sun.

Nanocrystalline titanium dioxide will be activated by the UV-light from the sun. Free radicals are formed that react with organic compounds in the air and will reduce them into carbon dioxide, acid and water. NOx-gases will form nitrates, acid and water.

These reactions have been used for different products like self-cleaning windows from Pilkington [1]. It has also been studied in cement and concrete in the European PICADA project [2].

3. THE PROJECT

Nanocrete is a Swedish-Finnish project investigating the possibilities of using photocatalytic titaniumdioxide in cement and concrete, making use of these reactions in the Nordic climate. The project started in 2005 and will end in 2008. The project is a Eureka project financed by Vinnova in Sweden and Tekes in Finland. The members of the project are material producers (cement and titanium dioxide), concrete producers (both ready mix and precast concrete producers) and research institutes. In the project we have investigated different materials and material combinations; we have looked into different analyzing methods to use for evaluating the effect of the photocatalytic reactions.

3.1 Lab tests

Some of the lab tests made:

- Different reactions have been measured in reaction chambers, with and without UV-light, NOx-reduction and degradation of organic compounds.
- Soiling tests.
- A small lab test for smell reduction.
- Concrete tests for the impact of titanium dioxide on the concrete performance.

3.2 Production tests

Tests how to use the titanium dioxide in concrete production have been carried out. The titanium dioxide is only active on the surface and in contact with UV-light. Different tests are done putting it on the surface or using a surface layer of concrete. Also tests with titanium dioxide in shotcrete are planned.

3.3 Field tests

Several field tests are ongoing. Concrete pavers stones are produced with and without titanium dioxide and placed in the city of Stockholm. Traffic elements are placed in road environment. Wall elements are made with and without titanium dioxide. A NOx-trap is planned for a car parking house.

4. CONCLUSIONS

The laboratory tests have showed a significant reduction of the NOx content. Soiling tests give various results for the self-cleaning ability. The smell reduction test that is done gives a good result. The field tests are not fully evaluated. The greatest possibility with this technique seems to be the NOx reduction that could be of great interest for the environment.

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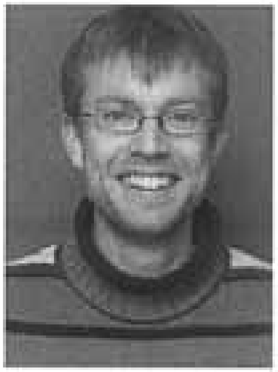
Moisture Redistribution in Screeded Concrete Slabs



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Key words: model, moisture redistribution, cementitious material, vapour sorption isotherms

1. INTRODUCTION

Redistribution of moisture in a screeded concrete slab may occur as a consequence of a change in the ambient conditions or unevenly distributed internal humidity. The redistributed moisture may harm adjacent materials in various deterioration processes, e.g., adhesive degradation, if exceeding a certain humidity level, critical humidity.

The main objective of this research is to develop a quantitative model of moisture redistribution in a screeded concrete slab with flooring with regards to hysteresis. Important material properties were determined for the materials used in the experimental study.

2. RESEARCH SIGNIFICANCE

In this research a qualitative and quantitative model for moisture redistribution in screeded concrete slabs with regards to the sorption isotherm's moisture history dependence is developed. The model may be utilized to quantify the future relative humidity, RH, beneath flooring based on current moisture distribution and vapour sorption isotherms for applied materials.

3. METHOD

This research consisted of an experimental and a theoretical part. Several screeded concrete slabs with PVC flooring were prepared to reproduce and monitor moisture redistribution before flooring and after a certain time of redistribution. In addition several sorption isotherms including scanning curves were determined for four cement based materials, concrete w/c 0.65, C, cement mortar w/c 0.55, M, and concrete w/c 0.4, C_{HCS}, and Floor 4310 Fibre Flow, SFC, by using a sorption balance [1].

A theoretical analysis of moisture redistribution in a screeded slab formed the basis of a qualitative model carefully demonstrated in [2]. This model illustrates variations in vertical moisture distribution and the corresponding moisture path in the sorption isotherm through the completion of a screeded concrete slab covered with flooring. This stresses the scanning curve's effect on the RH level contra in relation to moisture content changes.

A quantitative model is derived from the qualitative model and four assumptions of which two are mentioned here, no additional drying after flooring (A) and isothermal conditions (B). The model takes into account each vertical section's moisture history, hence considering hysteresis.

4. RESULTS

Sorption isotherms including scanning curves were determined for the cementitious materials used in the floor structures, C, M, C_{HCS} and SFC [2].

The stated assumptions may be interpreted into an arithmetic expression by equation (1),

$$RH_{\infty} = \frac{\sum_{\Delta x_i} \overline{RH_i} \cdot d_i \cdot \left(\overline{\frac{\partial w}{\partial RH}} \right)_i}{\sum_{\Delta x_i} d_i \cdot \left(\overline{\frac{\partial w}{\partial RH}} \right)_i} \tag{1}$$

where RH_{∞} represents the future uniform humidity level in [% RH], $\overline{RH_i}$ represents average RH level in [% RH], and, d_i represents the vertical thickness of each material section in [m], $\left(\overline{\frac{\partial w}{\partial RH}} \right)_i$ represents the average moisture capacity in [kg/(m^3 % RH)] evaluated from sorption (scanning) isotherms between current and future RH.

5. FINANCIAL SUPPORT

Financial support for this research project was granted from SBUF, the Development Fund of the Swedish Construction Industry, FORMAS, the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning, Maxit Group AB, NCC Construction Sweden, Strängbetong, and Skanska Sweden AB.

6. PROJECT DATA

This research project started in April 2004 and was finalised in March 2007. The project resulted in a Licentiate in Engineering thesis [2] at div. of Building Materials at Lund University, Lund.

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Session B1
Effects of Restraint & Structural Applications

Shrinkage Cracking of Steel Fibre Reinforced Concrete Overlays

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Key words: Overlays, shrinkage, cracks, steel fibres, restraint, bond.

1. INTRODUCTION

Cracking due to restrained shrinkage is a major concern for e.g. overlays and slabs on grade. A quite common solution is to apply steel fibre reinforced concrete (SFRC) to control crack widths. Major drawbacks are however that design methods for the situation and experimental evidence regarding the potential of steel fibres to provide crack distribution are lacking. A doctoral project was thus conducted (Carlswärd, 2006) with main objectives to assess the effect of steel fibres on shrinkage cracking and to establish a method for the design of SFRC with regard to restrained shrinkage.

2. METHOD

The effect of steel fibres on shrinkage cracking was investigated by exposing thin out-stretched overlay strips cast on rigid concrete slabs (Figure 1) to a harsh drying environment. 10 strips, with varying steel fibre content (0-60 kg/m^3), were cast on each slab (a total of 4) and the development of cracks and de-bonded zones were followed over a period of 3 months.

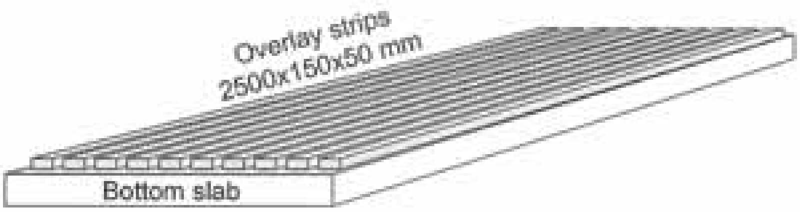

Figure 1 – Test method used to investigate the effect of steel fibres on shrinkage cracking.

3. RESULTS

The cracking response was found to be highly dependent on the bond situation. For strips with high bond strength to the sub-base numerous minor cracks (0,05-0,1 mm) developed irrespectively of reinforcement (Figure 2 a). Some of the strips were however found to be poorly bonded, resulting in internal de-bonded areas. Within such de-bonded zones a single major crack developed for un-reinforced and steel fibre reinforced concrete. It can be seen in Figure 2 (b) that increasing fibre contents gave reduced crack widths for this situation. Notice that the crack width not only depends on the amount of steel fibres, or rather the properties of the SFRC, but also on the length of the de-bonded zone (L_{deb}).

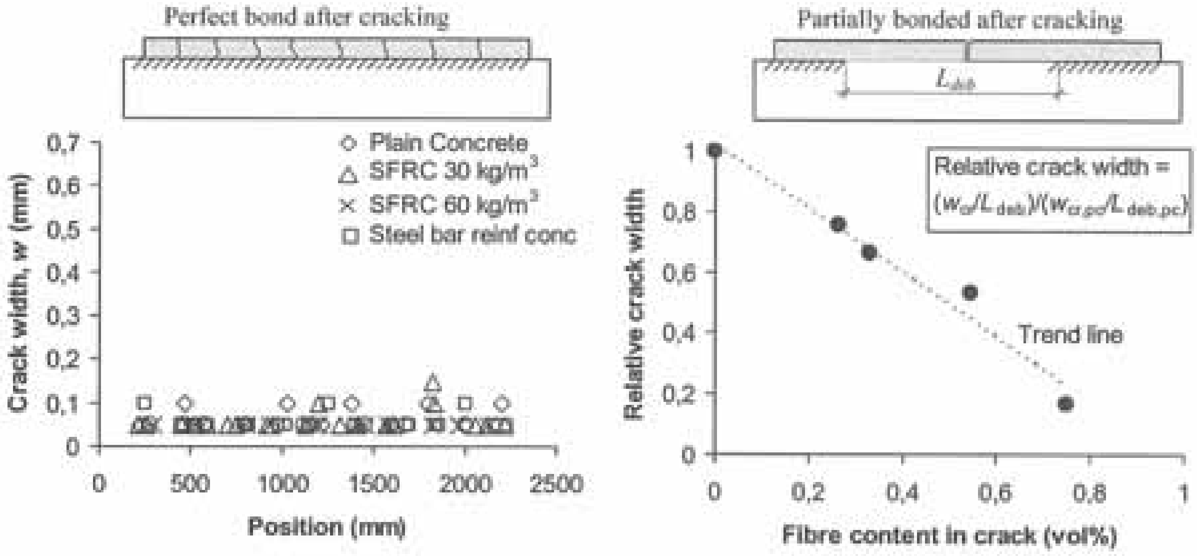

Figure 2 – (a) Crack width as a function of position along the overlay for bonded strips. (b) Relative crack width as a function of steel fibre content for internally de-bonded overlay strips.

4. CONCLUSIONS

Results demonstrated that high and evenly distributed bond strength provides a crack reinforcing effect, thus eliminating the need for steel fibres or other reinforcement (verified for overlays = 50 mm). Crack controlling reinforcement is only required if the bond quality is poor and/or unevenly distributed. Rather high steel fibre contents may however be required to limit crack widths for this situation, possibly up to 60 kg/m^3 or even higher.

5. FINANCIAL SUPPORT

The doctoral project, which was conducted at Luleå University of Technology and Betongindustri AB, was financially supported by Betongindustri AB and the Development Fund of the Swedish Construction Industry (SBUF).

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Modelling of Thermally Induced Cracking of a Concrete Buttress Dam

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Key words: Buttress dam, cracking, finite element model, non-linear material properties.

1. INTRODUCTION

A buttress dam is usually divided into a large number of concrete monoliths, consisting of a front plate with a downstream supporting buttress, sometimes also called dam pillar. In Sweden there are buttress dams over 1000 m long, consisting of up to 70 parallel, 40 m high monoliths. In some dams there are cracks through the buttress, and also at the base close to the rock foundation, [1]. Of special interest is the influence from a vertical, insulating wall in line with an inspection gangway, installed in some 40–50 year old dams.

2. RESEARCH SIGNIFICANCE

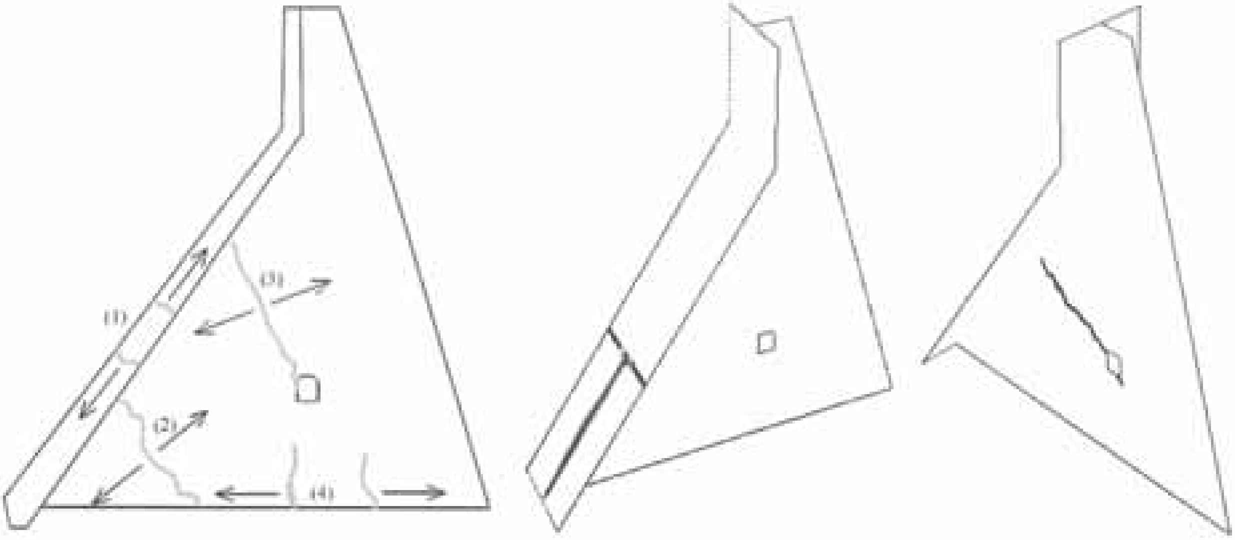
The work aim at understanding the origin of thermally induced cracking in large concrete dam structures and estimation of the risk for further crack propagation.

3. METHOD

Previous finite element analyses of buttress dams investigated the use of elastic material models and non-linear material theory, [2–3]. Within this project a three-dimensional finite element model of shell elements is used together with a non-linear damage plasticity model for concrete. The analysis focuses on the combined effect of restrained thermal displacements and loads caused by water. The seasonal temperature variation and its distribution in the monolith must first be determined and then used as input for calculation of displacements and concrete stresses.

4. RESULTS

Some results are shown in Figure 1. Cracks observed in situ are compared to finite element results obtained for summer temperatures. It is seen that the inclusion of an insulating wall give rise to diagonal cracks (type 3) in the buttress instead of cracks in the front plate (type 1).



From model without an insulating wall

From model with an insulating wall

Figure 1 - Observed and calculated concrete damage for summer conditions.

5. CONCLUSIONS

The results verify that the temperature variation causes cracking at different locations on the dam, cracks (1–4) in Figure 1. The results also show that it is possible, by means of numerical non-linear analysis, to describe and follow the initiation and propagation of many cracks found in situ on these types of dams. The future work will aim at calculation of deformations and stresses within a dam for combinations of various temperatures, water pressure, ice pressure and concrete creep, before and after repair work. The temperature distribution and propagation within the concrete will also be verified with in situ measurements.

6. PROJECT DATA

The work was performed during 2007, in collaboration with Vattenfall and Grontmij, with financial support from Elforsk AB, the Swedish Power Companies R&D association. The authors thank Dr. Manouchehr Hassanzadeh, Dr. Tomas Ekström, Dr. Mattias Unosson and Mr. Jonas Björnström for their valuable participation in the project.

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Tests on Restrained Shrinkage of Shotcrete with Steel Fibres and Glass Fibres


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Key words: Shotcrete, steel fibres, glass fibres, testing, restrained shrinkage.

1. INTRODUCTION

The tests are part of a project for understanding the shrinkage of accelerated shotcrete and handling connected problems.

2. RESEARCH SIGNIFICANCE

Shrinkage cracking in shotcrete drains is a severe problem because the drain is not continously bonded to the rock. Shrinkage is restrained by fixation of the shotcrete in areas several meters apart. Steel fibre reinforced shotcrete in normal applications is strain softening so only one crack develops. For long drainage structures the crack width often exceeds what is acceptable considering durability.

3. METHOD

Test specimens were 150 mm cubes, beams 500x125x75 mm^3 and 40 mm thick restrained shrinkage specimens cast in ring-shaped moulds (outer diameter 253 mm) with a steel core of 171 mm diameter. The fibre type and content were varied. See Table 1.

Table 1. Test specimens.

	Steel fibres	Glass fibres	Test specimen (type, number):		
	50 kg/m^3	26 kg/m^3	Cubes	Beams	Rings
Series 1	No	No	9	0	3
Series 2	Yes	No	9	9	3
Series 3	Yes	6 mm	9	9	3
Series 4	Yes	12 mm	9	9	3

Cast concrete with rheology as shotcrete was used. It had a water/cement ratio of 0,45. The steel fibres were Dramix 30/05 and the glass fibres were of type CEM-Fil 62/2 manufactured by Saint-Gobain Vetrotex with a diameter of 14 μm and lengths 6 and 12 mm, respectively. Specimens were stored in +20 °C and 50 % RH except for the first six days when they were immersed in water.

Cubes and beams were tested at certain times. The rings were observed regularly during more than 250 days.

4. RESULTS

Testing of the flexural beams showed that the hardend shotcrete was clearly tension softening in all series. The rings without fibres cracked after 31 to 38 days. Those with 50 kg steel fibres per m^3 cracked after 43 to 65 days and those with 50 kg steel fibres and 26 kg glass fibres per m^3 had not cracked after 250 days.

5. CONCLUSIONS

The combination of the effect of glass fibres and relaxation due to creep at early ages seems to prevent the shotcrete from cracking during the time when most of the shrinkage takes place.

These promising results make it interesting to continue with an extended investigation where less favourable test methods than the shrinkage rings should be used.

6. FINANCIAL SUPPORT

The project is financed by the Swedish Rock Engineering Research Foundation, SveBeFo.

7. PROJECT DATA

The project has until now been run as a postdoc project, which started in the beginning of 2007 and ended during autumn 2007. See [1].

It is hoped that it will be continued as a PhD project, where a thorough investigation of the material properties of shotcrete will be investigated.

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Practical Experiences on Cracking of Concrete Slab on Ground

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Keywords: concrete floor slabs, cracking, condition investigation

1. INTRODUCTION

Concrete ground floor slabs are the most commonly used floor type in Finland. According to Finnish Guideline for Concrete Floors (BY 45) [1] concrete slabs on grade can be made with concentric reinforcement if slab thickness varies between 80 and 120 mm.
However, in the slabs with concentric reinforcement extensive cracking have been observed in many cases. Typically, cracks reach the reinforcement level and in some cases cracks are open through the slab thickness. Cracking is harmful considering the durability of structure. Chlorides or other chemicals can penetrate through the cracks causing corrosion of reinforcement. On the

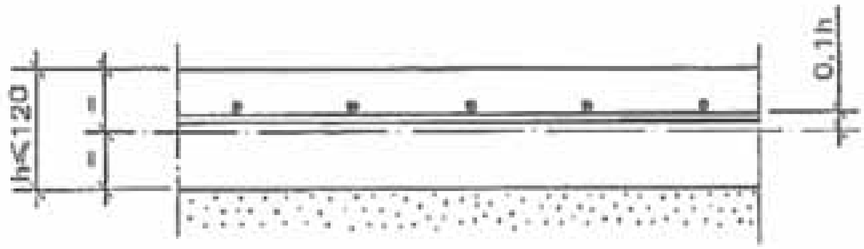

Figure 1 – Concentric reinforcement within the slab [1].

Cracking is caused by the differential shrinkage when the top of the slab dries faster than the bottom of the slab. In addition, the differential shrinkage also causes upward edge curling, which can be problematic when considering flatness of slab surface.

2. METHOD

This research was combination of field investigations and experimental research in laboratory. The data from existing concrete ground floor slabs was gathered from nine condition investigations made by the researchers of Tampere University of Technology (TUT). In addition, two experimental research projects have been carried out concerning curling of floating concrete floors [2, 3].

3. RESULTS

Drying of concrete slab on ground takes place mainly from its upper surface. Drying downward direction is negligible because of the higher moisture content of the sub-base. Moisture gradient will thus be introduced and the slab is subjected to differential shrinkage (due to the drying shrinkage). This produces upward curling of the slab and tensile stresses in the upper surface. Depending on the magnitude of drying shrinkage and degree of the restraining the tensile stresses can be greater than tensile strength of concrete causing cracking to the slab. Cracking of slab can be controlled using adequate reinforcement close to top surface.

According to field investigations extensive cracking (at upper surface of slab) was found in cases where concentric reinforcement of slab was used. This type of reinforcement is not appropriate for crack controll. The reinforcement should be placed as close as possible to the top of the slab.

4. CONCLUSIONS

In Finland it is very common to use concentric reinforcement with ground floor slabs.

Concrete slabs on ground having requirements for crack widths, water permeability or surface coatings should be designed and constructed using both top and bottom reinforcing. Crack control is possible with top reinforcement and loading capacity is ensured with bottom reinforcement.

According to Concrete Codes of Finland (BY50) [4] there is no requirements for cracking of ordinary concrete ground floor slab in Exposure Class X0 and XC1. Finnish Guidelines for Concrete Surfaces (BY40) [5] recommend that the maximum crack width should be less than 0,1 mm and crack length should be less than 500 mm for surface class A. Cracking is not allowable for surface class AA. In slabs with concentric reinforcement it is not possible to meet such requirements.

5. PROJECT DATA

This is an overview from several research projects which have been carried out in TUT during 2001 – 2007.

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Restraint in Early Age Concrete Walls Cast on Slabs Determined by a Semi-analytical Method

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Key words: restraint; early age concrete

1. INTRODUCTION

Large stresses can arise in concrete structures if imposed volume changes are restrained. The stresses can cause cracking that might imply expensive repair and reduction of both durability and function. Today, hardly any contractors overlook the effects of early age restraint stresses. Therefore, there are needs of fast and reliable tools to predict the degree of restraint. Below, an elastic model [1] is presented for the determination of restraint in young concrete elements cast on existing ones, and especially the typical-case wall-on-slab.

2. THE SEMI-ANALYTICAL METHOD (SAM)

By use of the theory of Compensation Plane, [2] [3], and an approach for pre-stressed concrete beams [4], the semi-analytical method (SAM) has been derived. As an application formulation of SAM it is fitted to exactly 2920 3D elastic FEM calculations [1] by using a number of adjustment tools: effects of high walls (resilience) δ_{res}, effective width of slab $B_{a,eff}$, effects of possible softening/slip at joints δ_{slip}, relative location of walls on slabs ω and the degree of boundary restraint γ_{RT}, $\gamma_{RR,y}$ and $\gamma_{RR,z}$. The degree of restraint in the length direction of a structure can then be expressed as

$$\begin{aligned}\gamma_R = \delta_{res}\delta_{slip} - (1-\gamma_{RT})\frac{N_{RI}}{\Delta\varepsilon_c^0 \zeta E_{c28} A_{trans}} \\ - (1-\gamma_{RR,y})\frac{M_{RI,y}(z_{cen}-z)}{\Delta\varepsilon_c^0 \zeta E_{c28} I_{trans,y}} - (1-\gamma_{RR,z})\frac{M_{RI,z}(y_{cen}-y)}{\Delta\varepsilon_c^0 \zeta E_{c28} I_{trans,z}}\end{aligned} \tag{1}$$

where N_{RI}, $M_{RI,y}$ and $M_{RI,z}$ are the normal force and bending moments for obtaining zero strain and curvature. $\Delta\varepsilon_c^0$ and ζE_{c28} are the strain of applied volume change and the modulus of elasticity of the young concrete, respectively. Further, A_{trans} is the transformed cross section; $I_{trans,y}$ and $I_{trans,z}$ are the transformed moments of inertia around the y- and z-axes, respectively; y_{cen} and z_{cen} are the location of the centre of the cross section; and y and z are the distance to the studied point from the centre of the cross section.

In many situations possible effects of softening/slip at joints and the boundary restraint can be neglected. An example of the application of the SAM is shown in Figure 1 assuming a symmetrical structure of rectangular parts and modelling the high wall effects by polynomials and using effective width of slab [1]. Here the restraint variations show good correlation to values from FEM.

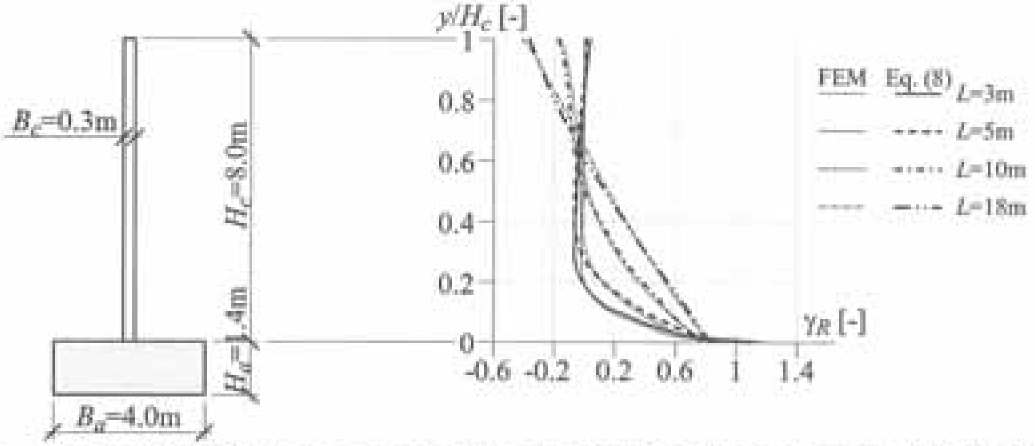

Figure 1 Restraint variation in a centrically located wall on slab determined by the SAM.

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Bonded Tendons in Nuclear Reactor Containments – Testing of Five 30-year-old Prestressed Concrete Beams

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Keywords: concrete, prestress, prestress losses, bonded tendon, creep, shrinkage, relaxation

1. INTRODUCTION

The Swedish nuclear reactors are enclosed by a concrete containment prestressed both horizontally and vertically. The corrosion protection of the tendons can be arranged in several different ways, either by cement grouting (bonded tendons) or e.g. by grease injection (unbonded tendons).

The main objective of this PhD-project is to evaluate the status of the containments with bonded tendons. This regards both the prestress losses and the risk of corrosion on tendons and stressing anchorages. The prestress losses will be estimated by using various models regarding the creep and shrinkage of concrete and the relaxation in the prestressing steel and also by testing of several prestressed concrete beams.

Among the test objects are five beams which, for the past 30 years, have been stored inside of the reactor containment building in the nuclear power plant Olkiluoto in Finland. This paper presents the results from the testing of the prestress losses in these beams. The lengths of the beams are 3 m with a cross-section area of 0.25 m^2. Two different post-tensioning systems are used, for two of the beams VSL type 19 F 13 has been used and for the other three BBRV type 72 F 6 has been used. The initial tensioning forces in the beams are 2.44 MN and 2.52 MN, respectively. The tendons are placed in the centre of the cross-sections.

2. RESEARCH SIGNIFICANCE

The reactor containment is the most important safety barrier in a nuclear power plant. In the event of a serious accident in the reactor, the prestress in the containment wall will ensure the leak tightness of the concrete thus preventing any radioactive discharge to the environment. To be able to monitor the status of the prestressing system, e.g. evaluating models for predicting prestress losses, is therefore of the utmost importance.

3. METHOD

In order to determine the remaining tendon force in the beams the so-called crack re-opening method was used. The beams were subjected to a single point-load at midspan and the load increased until flexural cracks appeared at the bottom. The initial crack was marked and the beam unloaded. The beam was loaded again until the crack re-opened. In order to determine this so-called decompression load, one LVDT-gauge was mounted across the crack. The beam was loaded and unloaded three times in order to increase the accuracy of the measurements. By intersecting the two slopes in the load-displacement diagram, the decompression load was determined, see figure 1. Since the stress in the bottom of the beam is zero at the decompression load, the effective prestress force can be calculated using Navier's formula.

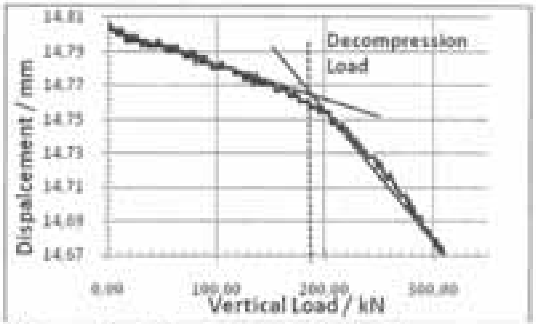

Figure 1 – Decompression load.

4. RESULTS

The prestress losses in the beams were 37%, 38%, 38%, 49% and 60%. The big scatter in the results can be explained by the fact that during the testing of the two beams with the highest losses, splitting cracks occurred and propagated at both ends and did not close after unloading. There was also extensive cracking in the zones surrounding the anchor-plates. This indicates that the anchors have moved inwards during the testing. This leads to a shortening of the tendon thus increasing the prestress losses. For the beam with 60% prestress losses the time between casting and tensioning was 63 days, while for the others, it was more than 135 days. This affects the prestress losses significantly, since the drying of the concrete and therefore also the shrinkage has proceeded during a shorter period of time before tensioning. The shorter period of drying and aging also increases the drying-creep of the concrete.

5. CONCLUSIONS

The prestress losses in the beams are relatively high compared to results from testing of old bridge beams in the literature, which probably is due to that the beams have been stored indoors at approximately 25°C. This increases both the shrinkage and creep of the concrete.

6. FINANCIAL SUPPORT

The project is jointly financed by ELFORSK, the Swedish Electrical Utilities R&D Company, and TVO, a company owned by several industrial and power companies which is in charge of the nuclear power production in Finland.

7. PROJECT DATA

This project is conducted as a PhD-project with duration of five years, started in January 2007.

High Performance Low-pH SCC for Sealing of Deposition Tunnels in a Repostory for Spent Nuclear Fuel

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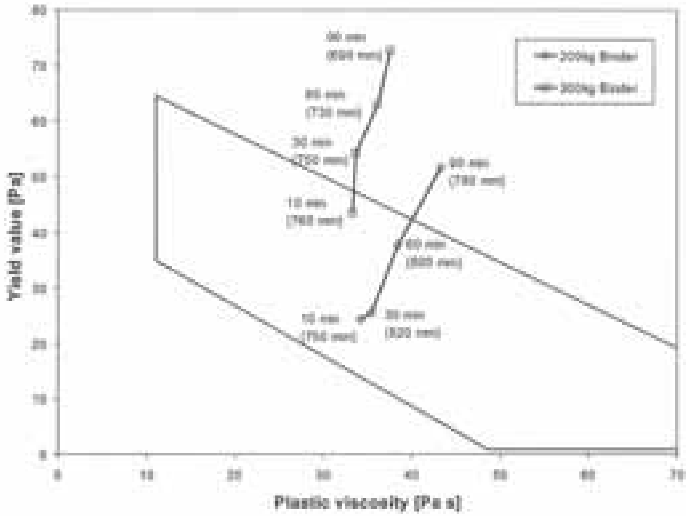
1 INTRODUCTION

In Sweden spent nuclear waste is planned to be deposited in canisters in crystalline granitoid bedrock at a depth of around 500 meters. A concrete plug with a volume of about 100 m^3 is intended to stop water leakage from the deposition tunnels to the main tunnel shafts. This plug is to withstand a hydraulic pressure of at least 5 MPa and has to be free of continuous cracks or gaps. The risk assessment analysis of the repository restricts the maximum pH in the ground water to 11. Normal concrete has a pH above 13; therefore a special type of concrete is required for the construction of the concrete plugs in the repository. Concrete with an internal pH of 11 or less (confirmed by leaching tests) will be denoted low pH concrete in this paper. The construction and geometry of the plugs requires self compacting properties of this concrete.

2 MATERIALS

The basic concept of how to make a low pH concrete is known from earlier projects [1]. To get a pH of 11 the binder must consist of at least 35 to 40 wt. % silica fume. The safety assessment analysis of the repository limits the amount of organic compounds, so filler based SCC was preferred instead of VMA based.



Kg/m^3	200 kg Binder	300 kg Binder
CEM I 42.5 MH LA/SR	120	180
Silica fume (densified)	80	120
Water	165	165
Limestone filler L25	369	269
Sand 0-8 mm	1037	1035
Gravel 8-16 mm	558	557
Glenium 51	6,38	7,08
water/cement	1,375	0,917
water/binder	0,825	0,55
water/powder	0,29	0,29

Figure1 – Mix design of two low pH SCC and rheological properties with corresponding slump flow at different points of time after mixing. Conventional SCC compositions with yield value / viscosity within the dashed box are considered to have good flowability and stability according to [3].

3 HARDENED CONCRETE PROPERTIES

The tested material parameters (at Luleå Technical University) for the thermal stress analysis are strength development at varying temperature levels, heat of hydration, thermal dilation, creep and relaxation. For further information on the performed tests and test setup, see [3]. The stress related parameters like tensile strength, creep and relaxation were determined as well. That generates the material data required for thermal stress analysis of the "young" plug. To deliver additional material parameters for 3D finite element analysis of the "mature" plug, other mechanical properties were tested as well. Both, parameters for short time loading and long time creep were determined. Table 1 summarises some relevant parameters for short time loading.

Table 1 – Mechanical properties of mature low pH SCC for short time loading.

Concrete	Young's modulus [GPa]	Compressive strength [MPa]	Tensile strength [MPa]	Poisson ratio
200 kg binder	38	88	3.3	0.27
300 kg binder	42	113	3.8	0.27

The early autogenous shrinkage was determined with a digital dilatometer according to [4]. The shrinkage after the first 24 hours was measured on beams of 100 x 100 x 400 mm^3 according to Swedish Standard 13 72 15 with some modifications. The specimens were not water cured, measurement started 24 hours after casting and the specimens were sealed with butyl tape. The deformation during the first 24 hours is almost the same for the two tested mix designs (roughly 0.8 mm/m). The shrinkage value of the sealed beams is remarkably low, about 0.2 mm/m for concrete with 300 kg of binder and 0.1 mm/m for the mix with 200 kg of binder. A combined shrinkage curve of dilatometer measurement for the first 24 hours and sealed beams for the following period of time may be the most realistic description for the bulk part of the plug.

4 CONCLUSIONS

It was possible to develop low pH concrete with self compacting fresh concrete properties. The amount of binder was lowered as much as possible and in result the developed heat of hydration is low. The strength development is slow but after longer periods of time high compressive strength values are achieved. The early volume changes were rather large but not unlike conventional SCC and the shrinkage values for sealed conditions were low. The long time material parameters in combination with shrinkage data allow calculations leading to a refined plug design and evaluation of the long time performance of the structure.

ACKNOWLEDGEMENT

We would like to thank Swedish Nuclear Fuel and Waste Co (SKB) for financing this project and allowing publication of the obtained data.

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Session A2
Durability

Performance Tests for Protective Sacrificial Coatings

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Key words: Sacrificial coating, graffiti, Nordic test method, concrete, colour, gloss, porosity.

1. INTRODUCTION

Graffiti defaces building facades and other surfaces all over the world. The cost for cleaning them is estimated to about 100 M Euro per year just in Sweden. Removal of graffiti is a very difficult task with a high risk potential for damaging the surface. As a result of this, many protective coatings facilitating graffiti cleaning are on the market; however their performance on different mineral surfaces has been poorly investigated. This is in part the result of a lack of standardised evaluation methods.

The aim of the project was to develop a test method for evaluation of the performance of the sacrificial anti-graffiti coatings on different mineral surfaces such as natural stone, brick and concrete based on quantitative optical methods.

2. RESEARCH SIGNIFICANCE

To date there are no standardised or commonly recommended methods for the testing of anti-graffiti performance in the Nordic countries. The available recommendations only focus on possible deteriorating effects of the graffiti protective coatings to the substrate, normally concrete. Therefore, an evaluation system for performance of anti-graffiti coatings is advantageous both for producers of the coatings who give the recommendations for suitable applications and for the contractors performing the application thus ensuring good results for the owner of the object.

3. METHODS

The testing was carried out on various inorganic surfaces (natural stones, bricks and concrete). Water absorption measurements [1] were made for all samples before application of the anti-graffiti wax-based coating. This test was aimed to describe the materials' physical properties concerning water absorption ability that is related directly to the sensitivity of a surface to graffiti. Differences in water repellence and absorption were also evaluated with the Karsten testing pipe [2]. Colour and gloss measurements [3] were performed on all samples before and after application of the anti-graffiti; after weathering test of the coated samples; and after the removal of the graffiti paints. The graffiti paints tested were: *Tectyl* rust protection (a mixture of wax and tar); *spray* paints (black, red and blue); *felt tip pen* (black and blue); *leather dye* aniline (red and blue).

4. RESULTS

The photo (Figure 1) presents results of the cleaning of the graffiti. Evaluation of the colour changes was made on the visible remainings of the graffiti. Gloss was measured randomly over the surfaces.

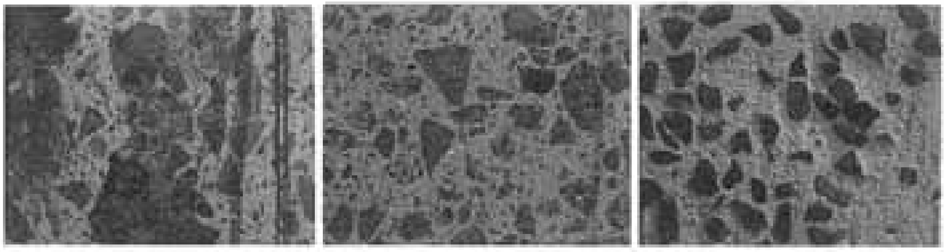

Figure 1 – The samples after the cleaning of the graffiti: reference sample without anti-graffiti protection (left), coated sample (middle) and an example of to high water pressure used for the cleaning.

5. CONCLUSIONS

The method used in this study can be recommended for performance testing of wax-based sacrificial coatings. The evaluation techniques give reliable results concerning aesthetical changes of the appearance of a surface.
The gloss measurements are especially important for evaluation of the surface appearance for polished and susceptible to mechanical erosion surfaces.

The L-value of the CIELa*b* system reflects changes in the grey scale from light to dark and gives the most relevant results, therefore it is recommended for the evaluation of the results.

The water absorption measurements give important indication of the substrate's sensitivity to graffiti paints showing direct correlation between porosity and water absorption.

Further development of the test method should include the frost influence on the performance of sacrificial wax-based coatings.

6. FINANCIAL SUPPORT

The project was partly financed by NICe (Nordisk InnovationsCenter).

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Penetration Profiles of Water Repellent Agents in Concrete as a Function of Time – Determined with FTIR-Spectrometer

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Key words: silane, water repellent agent, FTIR-spectrometer, penetration profile.

1. INTRODUCTION

Water repellent agents (WRA), today mainly consisting of alkylalkoxysilane, contain an organic group (alkylgroup) when fully reacted. The silane is absorbed through capillary suction into the pores, when applied on the concrete surface. The alkoxy groups react in the alkaline environment of the pore solution and a fine network of polymer siloxane forms [1] which turns the concrete from hydrophilic to hydrophobic giving it protection against e.g., chlorides.

2. RESEARCH SIGNIFICANCE

The success of a water repellent treatment is often judged by the visual penetration depth. This method, however, only indicates if the WRA has penetrated the concrete or not. Concrete is an inorganic material meaning that there are no carbon hydrogen bonds. The FTIR (Fourier Transform InfraRed) spectra for concrete and organic materials differ in the region for this bond. The alkylgroup of the fully reacted silane can thereby be detected and quantified by the FTIR-spectrometer. This is an important tool in the understanding of how WRA works.

3. METHOD

Concrete plates with w/c = 0.8 and 0.45, respectively, were used in this experiment. The plates were conditioned at 59 % relative humidity (RH) for six months prior to the treatment with triethoxy(isooctyl)silane. The silane was applied as liquid and the envelope surface of the plates were sealed to ensure a uni-dimensional capillary suction during the treatment.

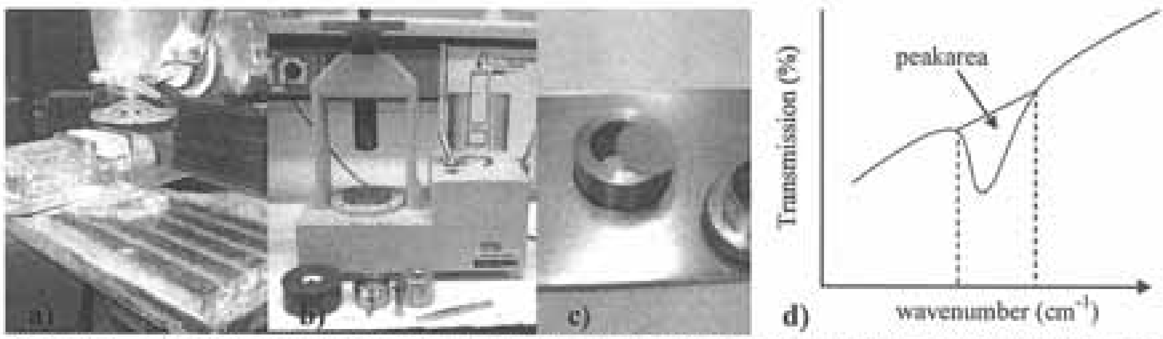

Figure 1 - a) The machine used to grind powder from 1 mm layers. b) Equipment used to press KBr tablets. c) A KBr tablet and the holder for the tablet. d) FTIR-spectra whereas the peak area correspond to a specific concentration of silane.

A grinding machine was then used to collect powder from different depths in the plates. The powder is mixed with KBr and pressed into tablets which are analysed by the FTIR-spectrometer. A peak area in the IR-spectra can then be related to the concentration of polymer siloxane in the tablet. Figure 1 shows the different steps and a detailed description of the method can be seen in [2].

4. RESULTS

Figure 2 shows the penetration profiles for different durations of treatment. A longer duration of contact results in a higher concentration and depth. It can also be seen that a concrete with high porosity (w/c =0.8) is easier to treat than one with a low (w/c = 0.45)

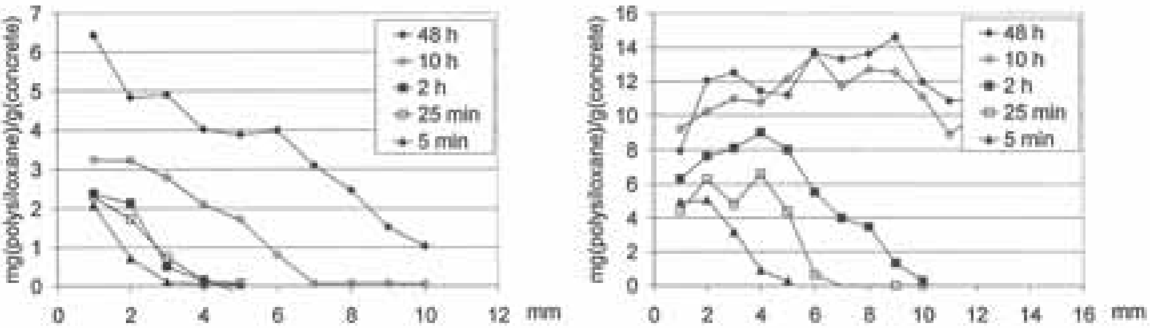

Figure 2 - Penetration profiles of triethoxy(isooctyl)silane on concrete with w/c = 0.45 (on the left) and 0.8 (on the right) for different durations of treatment. The plates were conditioned in 59 % RH before the treatment. Every point represents one tablet.

5. CONCLUSIONS

The duration of contact between the water repellent agent and the concrete is important for the outcome of the treatment. Figure 2 illustrates how the penetration profiles are affected and it is clear that the concentration as well as the depth increases with a prolonged time for the treatment. The FTIR-spectrometer with KBr-tablets is the only method today that can be used for quantification of water repellent agents in concrete. This is an important tool to use in the understanding of how these treatments work. The potential of relating the concentration of water repellent agent to pore volume or cement content in a further development are interesting.

ACKNOWLEDGMENTS

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Concrete Durability Field Testing – Durafield-project

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Key words: Concrete, durability, field testing, salt-frost, frost, chloride, carbonation, ageing

1 INTRODUCTION

DURAFIELD-project (2007 - 2009 + long term period) is Finnish co-operation project with a budget over 450 000 € [1]. This project will keep on and expand the work started in the previous field testing projects: EU 5th framework project CONLIFE (2001 - 04) and Finnish national project YMPBETONI (2002 - 04). In addition to the earlier field testing areas in southern and northern Finland (Otaniemi and Sodankylä) without de-icing salt exposure, one more testing area was established. It is located beside Highway 7 with de-icing salt exposure. 26 concrete mix designs with different cements or binder materials are included; future materials and mix designs can be included later on. Field testing (10 - 20 years) of frost-salt or frost scaling, internal frost deterioration, carbonation and chloride penetration without and partly also with protective impregnations or the use of form linings is performed. Weather data will be collected and long term variation of concrete temperature and relative humidity will be measured. Optical fibres are used to get concrete temperature and water content profiles.

2 RESEARCH SIGNIFICANCE

There is an obvious need to get relevant concrete long term field testing data and compare it with mix design data and laboratory testing results. In Finland, data on concretes with Finnish cements and e.g. ecological binding materials is needed. Also results on the effect of protective impregnations or the use of form linings to reduce chloride penetration are useful. The Durafield-project will offer versatile numerical long term field testing and comparable laboratory testing data on the essential concrete durability properties. Interacted deterioration can be considered and microstructural studies will give interpretive information.

A documentation database will be established. Information on other similar, mainly Nordic, field test projects will be included. This database will maintained non-volatile for decades to serve as a basis for future service life modelling and normative regulations. Applicable quality control systems and methods can also be based on the results.

3 METHODS

Concrete specimen for chloride penetration studies (about 50 specimen) are situated mainly 1.5 m from the road side railing on wooden stands. For some parallel specimen this exposure distance is also 6 m, 8 m and 10 m. Chloride samples will be taken using a profile grinding method and exact chloride profiles will be created. These field results will be compared with chloride diffusion coefficients measured at 3 months of age by the CTH-method (NT Build 492).

Salt-frost scaling studies include 20 concrete mix designs and 80 specimens. These specimens are situated in special metal racks also 1.5 m from the road side railing. Salt-frost scaling and internal deterioration will be monitored exactly. Optical thin section studies will give information on e.g. possible cracking.

In the testing field without de-icing salt exposure there are 6 new concretes for frost deterioration. All the 23 Durafield-concretes are under a roof for sheltered carbonation study. Carbonation results will be compared with the climatic chamber testing with 1 % CO_2.

As a notable part laboratory testing includes frost-salt or frost testing. Scaling and internal deterioration is measured. This testing is performed three separate times - first according to CEN/TS 12390-9. After about one year curing time the test will be repeated with carbonated and non-carbonated testing surface. The aim is to get data on the effect of ageing on concrete scaling. Hardened concrete air void analysis and total air content measurements are also included.

4 RESULTS

The first field testing results will be available after the first winter period in mid-2008. So far results include a lot of exact mix design and laboratory testing data.

Water-binder (w/b) ratio (W_{eff}/(Cement + 2 SF + 0.8 BFS + 0.4 FA) in all mixes was 0.40 – 0.60, with the majority about 0.42. Concretes with 8 different cements or binding materials were included. Tested compressive strength was 33 – 59 MPa. Air content was mainly about 5.5 %, but for some concretes it was designed to be low or there was no air entrainment at all. Air pore structures and distributions were divergent. Optically measured spacing factor varied from 0.18 to 0.50 mm for the concretes with a decent total air content.

Surface scaling in the laboratory (Slab test, 56 cycles) was mainly at the most 0.20 kg/m^2, but for concretes (w/b = 0.42) with poor or no air entrainment it was much higher: 0.80 – 3.5 kg/m^2. Carbonation depth at 1 % CO_2 (56 days) was in all 2.6 – 10.5 mm, with the average value about 5 mm. Chloride diffusion coefficient measured by CTH-method was 1.8 – 21.1 10^{-12} m^2/s for concretes with w/b-ratio 0.40 – 0.50. With protective surface impregnation or with the use of form linings chloride diffusion coefficient was 60 – 70 % of the reference value measured with normal wooden mould surface (w/b = 0.50).

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Frost Dilation Measurements on Dam Concrete with ASR

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ABSTRACT

Testing for durability against combined frost attack and ASR was investigated on a series of cores drilled from a 25 year old concrete dam with slight ASR and surface frost damage. Measured with the PF method the specimens showed a bit low protective air content (PF). Dilation was measured during a single freezing and thawing cycle of moisture conditioned and sealed specimens using LVDT and invar steel frame. Varying effects were studied on the specimens with controlled saturation at freezing. The field concretes responded similarly to what is observed in lab concrete without ASR; existence of critical dilation, deleterious effect of severe pre-drying before saturation, indications of the two mechanisms causing detectable length change depending on freezing (short, long time) and saturation (high, low); fast hydraulic type of expansion vs slower time dependant shrinkage and/or expansion due to transport controlled ice formation. The experiments also illustrated the useful information from the PF-method and from measurements of moisture content in specimens taken from structures.

Key words: ASR, length change, frost dilation test, moisture content, porosity/PF

1. INTRODUCTION

The effect of simultaneous frost and alkali silica reaction (ASR) on deterioration of concrete structures has been addressed in very few studies compared to the amount of research performed on deterioration of concrete due to frost or ASR alone. Generally, pre-existing cracks have been found to accelerate ASR expansion. Unfortunately the effect of varying degree of saturation, which is the main factor for frost damage, has not been investigated in studies of the combined effect of ASR and frost. In addition, when evaluating the possibility of simultaneous ASR and internal frost damage it will be an advantage to use the same damage criterion when quantifying damage due to ASR and due to frost, even though the mechanisms leading to fracture is totally different. Expansion exceeding a certain strain is commonly used for evaluation of both frost- and ASR damage as single mechanisms of concrete deterioration. In order to proceed in the development of methods to determine the durability and service life of concrete structures with combined ASR and frost attack we have therefore assessed length change during freezing of concrete cores taken from a 25 year old dam with both ASR and slight surface frost damage (scaling). The objective was to evaluate the variation in strain due to internal frost attack, as degree of saturation, preconditioning, specimen size and frost attack varied for concrete from existing structures.

2. INVESTIGATIONS AND RESULTS

A series of 100 mm diameter concrete cylinders were taken vertically from the top surface of the 25 year old Sandsavass dam using diamond coring and cut with diamond blade from the 100 mm diameter cores. The suction-and air void porosities of the specimens for frost testing were determined using the PF-method on adjacent specimens. Once-dried specimens were capillary saturated submerged and weighed, the specimen volumes were determined by weighing submerged and finally their pressure saturated weight after 24 hours in 10 MPa water pressure were determined giving the Pore protection Factor (PF). In addition the degree of saturation expressing evaporable water content as fraction of total porosity (DS) and of capillary porosity (DCS) were adjusted for the frost tested specimens after submersion to 100 % DS.

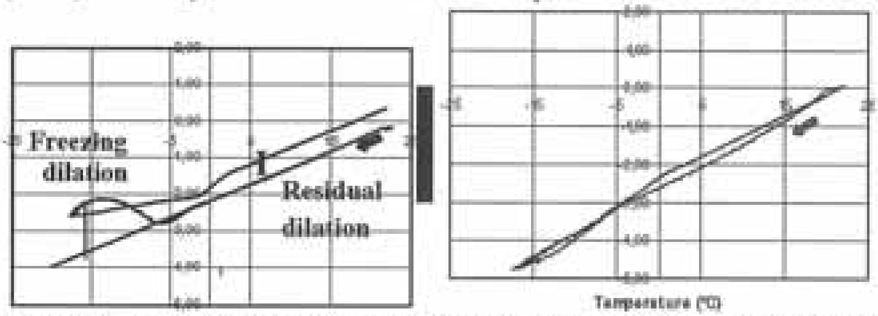

Figure 1 – Freezing dilation of ASR affected specimens slightly dried in air before saturation and freezing; DCS=100% (DS=83%) with max freezing dilation 0.14 ‰ at -16 °C (left) and clear residual dilation, and DCS=92 % (DS=76%) with no freezing- nor residual dilation (right).

Figure 1 also shows that there is contraction during freezing in the concrete whether critically saturated or not. The specimen on the left contracts, apparently as ice formation starts but before the expansive forces dominates, whereas the frost durable specimen on the right only contracts. Similar studies as the ones shown in Figure 1 were made in a series of tests at different intermediate moisture contents revealing the critical dilation. Also a number of other effects on critical dilation were studied; predrying at 105°C before resaturation, keeping the specimens at prolonged time at minimum temperature, performing two consecutive cycles and varying the cross section (half and quarter). As a whole the results showed that the test set-up is well suited to determine durability against internal frost damage on field concrete with ASR. The tests showed a critical dilation, a deleterious effect of severe drying compared to the frost damage observed in specimens with mild drying. The results also confirm that the two frost mechanisms found in the literature on lab concrete without ASR yields for concrete with ASR. These are 1) hydraulic type at high saturation, 2) ice lens formation causing shrinkage at low saturation and increased expansion at prolonged freezing period. The experiments also illustrate the very useful information about DCS and protective air void content from the PF-method. We recommend that further investigations on combined ASR and frost action use strain as damage criterion by exposing specimens with varying ASR expansion to frost dilation testing at different DCS and measuring ASR expansion in specimens with varying residual expansion after freezing at varying DCS.

Critical Chloride Content for Corrosion in Reinforced Concrete

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Keywords: critical chloride content; chloride threshold value; pitting corrosion

1. INTRODUCTION

The most common cause of deterioration for reinforced concrete structures is corrosion of the embedded reinforcing steel, which is in many cases induced by the presence of chloride ions at the surface of the steel in the concrete. The general approach for prevention of corrosion is keeping the aggressive species away from the reinforcement. The parameters thereby controlled are primarily penetration distance (cover depth) and permeability (concrete quality). More and more, ordinary Portland cement is replaced by blended cements in order to obtain a denser microstructure of the cement paste with a high chloride diffusion resistance. However, the beneficial effect of blast furnace slag or pozzolana with regard to the chloride penetration resistance might be compensated by the lower pH that pore water in such pastes normally exhibits [1,2]. For chloride induced corrosion, the pH has been identified as a major factor controlling the tolerable amount of chloride at the steel surface (critical chloride content) [3]. Deciding on cement type is thus a trade-off between prolonging the chloride ingress time and lowering the chloride threshold value. Both are decisive with regard to the time that passes until corrosion is initiated.

2. RESEARCH SIGNIFICANCE

At present, several standardised test methods are available in order to assess the resistance of a certain concrete mix against chloride penetration [4,5]. However, these tests do not take into account the effects of cement type on the chloride threshold. For the critical chloride content, no accepted testing method exists. A lot of research has already been conducted on the topic of chloride induced corrosion in reinforced concrete, but due to the multiplicity of experimental setups used, the results are not comparable and scatter widely. A procedure, applicable to a wide range of systems (including dense concrete), is required to obtain comparable results and to study the effects of various parameters.

3. METHOD

The basic idea is to monitor the corrosion behaviour of an embedded ordinary carbon steel bar in a concrete sample with the chloride content increasing over time. Different techniques to introduce chloride (capillary suction, diffusion, migration) are studied. The samples are instrumented with combined chloride and resistivity sensors that allow the non-destructive measurement of the free chloride content [6]. After depassivation is detected, also the total chloride content is measured. The chloride threshold is thus determined on the basis of both free and total chloride contents.

4. EXPECTED RESULTS

It is expected to obtain a practice-related testing method for critical chloride content in concrete. This allows investigating the influence of various parameters on critical chloride content and provides a basis to e.g. compare certain concrete mixes. Since the work deals with both total and free chloride contents a better knowledge of the importance of bound chloride in the pitting initiation process will result.

5. FINANCIAL SUPPORT AND PROJECT DATA

The authors acknowledge the support of COIN (www.sintef.no/coin). The project presented is conducted as a PhD study.

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Pressure Measurement Inside Concrete During Fire Exposure

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Key words: Concrete, fire, spalling, polypropylene fibres, pressure measurement

1. INTRODUCTION

A deep understanding of the physics involved in the phenomenon of fire spalling of concrete is still lacking. However, during the last 40 years two main theories for explaining the driving force behind fire spalling have dominated: thermal stresses theory and moisture induced pore pressure theory. The influence of the two different proposed driving forces seems to be case dependent. To investigate the dependence, pressure measurements inside fire exposed concrete have been conducted. The results show that the highest pressure is measured inside concrete that does not exhibit fire spalling.

2. RESEARCH SIGNIFICANCE

Generaly, dried low strength ordinary concrete does not spall during fire exposure. This is not always the case for concrete with high moisture content, self compacting and high strength concrete. Without any special treatment, such as the addition of polypropylene fibres or other types of protection, a structure made from these types of concrete is often very susceptable to fire spalling. Fire spalling may take the appearance of small flaking on the surface, progressive flaking in three dimensions, to the extreme sudden explosion of a whole cross section. To be able to better predict this behaviour and optimise protection, the governing mechanism behind fire spalling must be better understood.

3. METHOD

To investigate whether the fire spalling process is governed by moisture induced pore pressure or thermal stresses, measurements of the pressure inside fire exposed concrete have been conducted. The pressure was measured using silicon oil filled 2 mm thick steel pipes described in detail in reference [1]. The pressure measured is not strictly speaking the pore pressure but is related to the pressure in the capillary pore system and can be used to compare pressure in spalling versus not spalling concrete. If the pressure in concrete that spalls is lower than in concrete that does not spall, the moisture driven pressure spalling theory seems unlikely to be the governing factor for fire spalling.

4. RESULTS

In an experimental study on the spalling behaviour of concrete during fire some of the test specimens were equipped with pressure measurement devises. In Figure 1 the pressure measured at a depth of 10 and 15 mm below the surface are shown for two concrete samples, one with and one without an addition of polypropylene (PP) fibres. The concrete without PP-fibres spalled during standard fire exposure while the concrete with fibres did not spall. After approximately 13 minutes the surface of the concrete without PP fibres was spalled away (i.e., the pressure was reduced to zero).

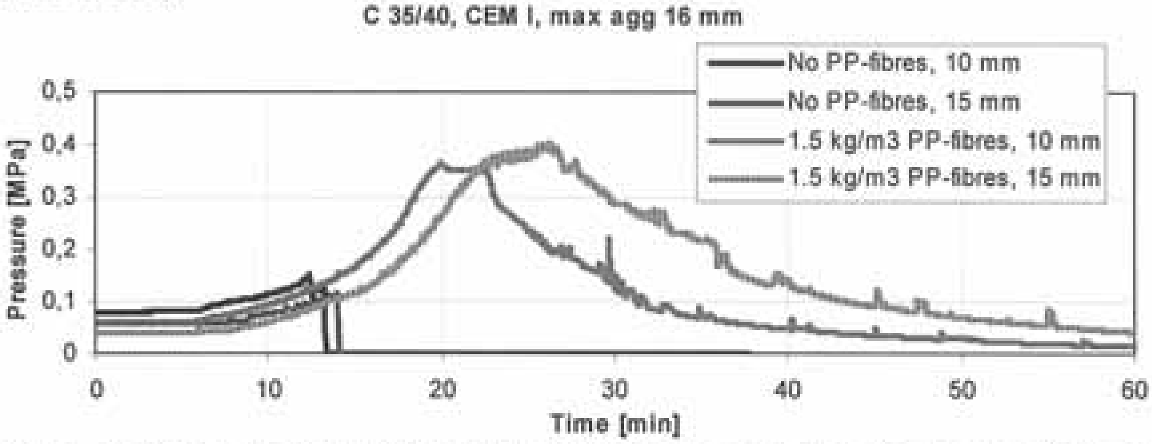

Figure 1 – Comparison of pressure measured inside concrete that spalls or not spalls during fire.

5. CONCLUSIONS

The measurements shown in Figure 1 clearly show that the maximum pressure is higher in concrete that does not spall during fire exposure. Therefore pressure in the capillary system is not the governing mechanism for spalling in the investigated concrete. The results shown here correspond well with a previous study [1] where a self compacting concrete with w/c = 0.65 was tested. These results also show that the function of PP-fibres is not to reduce the pressure in the capillary system to a safe level. A more feasible explanation for the anti spalling function is that PP- fibres increase the moisture transport leading to more relaxing creep in areas where high stresses arise from heating.

6. ACKNOWLEDGEMENTS

This project was supported by the Swedish Road Administration (registration number: AL 90B 2005:16378) which is gratefully acknowledged.

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Session B2
Load-carrying Capacity

Full-scale Failure Test of a Reinforced Concrete Bridge in Order to Calibrate Assessment Models for Load and Resistance

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ABSTRACT

A reinforced concrete railway trough bridge has been loaded to failure. Procedures have been tested for condition appraisal and inspection, load carrying capacity assessment, monitoring, and strengthening. A failure in combined shear, bending and torsion was reached for an applied mid span load of 11,7 MN. This was close to the value that could be predicted by enhanced methods but 20 to 50 % higher than predictions based on common codes and models.

Key words: Bridge, shear, strengthening, ultimate load carrying capacity, failure.

BACKGROUND

Field tests have been carried out on an existing reinforced concrete railway bridge in the European Research Project "Sustainable Bridges", see www.sustainablebridges.net. The project was supported by the European Union 6th Framework Program during 2003-2007.

The bridge was loaded to failure to test methods regarding procedures for condition assessment and inspection, load and resistance assessment, monitoring, and strengthening, SB-Guide [1]. For cost reasons, not many full scale tests to failure are carried out on bridges.

Figure 1 – View of bridge in Örnsköldsvik during testing.

The bridge was a reinforced concrete railway trough bridge with two spans 12+12 m, see Figure 1. It was built in 1955 and was taken out of service in 2005 due to the building of a new high-speed railway, the Botnia Line. The bridge was planned to be demolished in 2006 and instead it was now tested.

CONCLUSIONS

Procedures have been tested for inspection and condition assessment, load carrying capacity, monitoring, and strengthening of a 50 year old reinforced concrete railway trough bridge. In the final test, a failure in combined shear, bending and torsion was reached for an applied mid span load of 11,7 MN. This was close to what was predicted by the methods developed in the project and 20 to 50 % higher than other predictions based on common codes and models. All the predictions were on the conservative side and the failure was initiated by rupture of a stirrup after yielding in both stirrups and longitudinal reinforcement

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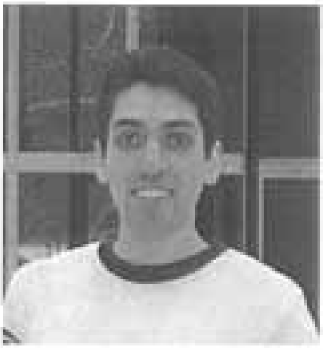
Evaluation of Load-carrying Capacity of Damaged Reinforced Concrete Structures



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Key words: Load-carrying capacity, damage, corrosion, frost.

1. INTRODUCTION AND RESEACH SIGNIFICANS

The most severe types of deterioration in concrete structures are associated with the volume expansion of reinforcing bar and concrete, e.g. reinforcement corrosion and frost-damaged concrete. Corrosion process leads to reduction of the reinforcement area and volume expansion of the steel which generates splitting stresses in the concrete. Through frost process, the volume expansion of frozen water initiates tensile stresses and micro/macro cracks into the concrete. The presented research introduces a methodology to analyze the mechanical behavior, e.g. strength and stiffness, of reinforced concrete structures affected by corrosion and freezing to predict the remaining load-carrying capacity of damaged structures.

2. METHOD

For corroded reinforced concrete structures it is proposed that the effect of corrosion can be modelled as a change in geometry and material properties of the concrete, reinforcing bar and the interface. Models for all these are given in [1]

Concrete:	Removal of spalled concrete by changing the concrete geometry
	Cracked concrete around corroded rebar (e.g. adopting concrete strength)
Reinforcing bar:	Change of rebar area
	Change of rebar yield and ultimate strength
	Change of rebar ductility
Interface:	Modification of bond properties

Rebar area, strength and ductility should be adapted considering type of corrosion, i.e. uniform pitting corrosion.

For frost-damaged structures, it is assumed that the effect of surface scaling can be modelled as a change in geometry such as reduction in dimensions. Furthermore, the effect of internal frost damage is modelled as a change in material properties, i.e. by reducing strength and stiffness. It was concluded that the compressive strength, at least, must be measured in each individual case, for example by compression tests on a few drilled cores. The tensile strength of frost-damaged concrete was found to be markedly lower than if it was estimated from the relations for undamaged concrete.

3. RESULTS

The proposed methodology was tested with the finite element program DIANA using non-linear FE-analyses based on fracture mechanics, for reinforced concrete beams affected by corrosion and internal frost damage. The results of the analyses were compared with available experimental results, and rather good agreement was found, see Figure 1.

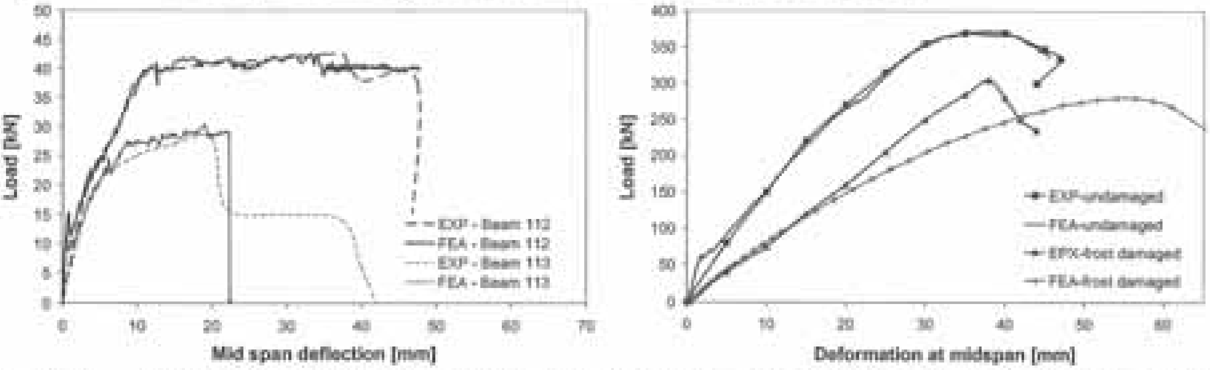

Figure 1 – Comparison between computed and measured load-displacement behaviour for (a) corroded reinforced concrete beam and (b) frost-damaged concrete beam, both tested with four-point bending test set-up.

4. CONCLUSIONS

It is concluded that to enable better prediction of the deformation of frost-damaged concrete beam, further experimental data are needed to determine the shape of the stress-strain diagram and the relation between Young's modulus and the compressive strength. The methodology to analyze mechanical behaviour of corroded reinforced concrete structures enables analysis at different approximation levels, e.g. full 3D solid models, intermediate shell and frame models, to the simplest beam models, depending on the requirements on the results.

5. PROJECT DATA AND FINACIAL SUPPORT

The project started in April 2006 and is intended to be finished in March 2008, leading to a licentiate degree. The project was fully financed by the Swedish Road Administration

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Load-carrying Capacity of Lightly Reinforced Lighweight Aggregate Concrete Walls

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ABSTRACT

The use of prefabricated wall elements of lightweight aggregate concrete with open structure and no or very little structural reinforcement has grown over the past 50 years and constitute now over half of the walls being build in Denmark. This expansion has been accompanied by a number of investigations and resulted in the European product standard EN 1520:2002 with design rules. These rules are based on existing rules in the Nordic Codes, which have been used for 30-40 years. The Danish producers association "Dansk Beton, Elementfraktion –BIH" has organized a large investigation and a test program with over 150 full-scale tests in order to verify and update the design rules. The investigations show that the safety of the traditional rules is more than sufficient and that new rules and formulas for load-carrying capacities should be developed. The new rules along with some of the documentation are presented in this paper and show that it is possible to increase the capacity with over 30 %, using the design principles in the Eurocodes.

Keywords: Load-carrying capacity, lightweight concrete, plain concrete.

1. INTRODUCTION

During the implementation of the European standard EN 1520, it was required to carry out a safety calibration of the formulas for load-carrying capacities and verify if the old formulas were unnecessarily conservative. BIH organised therefore an investigation and a test program in cooperation with Rambøll and DTU, with first eccentric vertical loading of wall elements and secondly both vertical and horizontal loads were applied at different laboratories.

2. MATERIAL MODELS

The old models for the stress-strain curves are based on Ritter's model and assumed a quite conservative variation of the stress-strain curves. Testing of six different types of concrete at BYG•DTU shows that a Eurocode-based curve could be used instead.

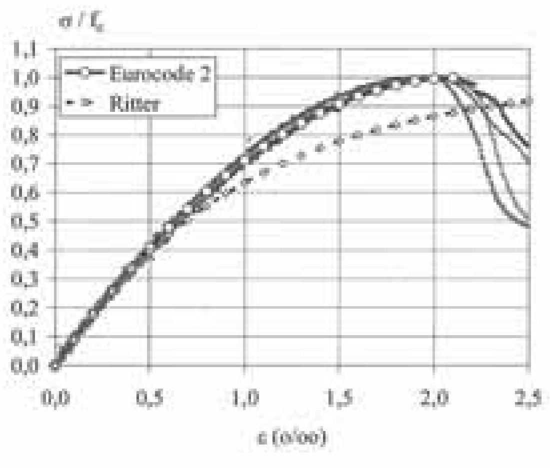

Figure 1 – Observed and fitted stress-strain curves (Average f_c=12 MPa, dry density 1300 kg/m^3).

3. LOAD-CARRYING CAPACITY MODELS

The traditional Ritter-model is essentially an Engesser-model, where the modulus of elasticity depends on the compressive stress and where only the part of the cross-section, symmetrical around the vertical load is taken into account. The model does not include any effect of the reinforcement as the traditional design only uses a minor amount of transport and shrinkage reinforcement. The results of the full-scale tests verify the conservativeness of the traditional design rules and have lead to the development of new and more optimal design formulas based on Eurocode 2's shape stress-strain curves shown in Figure 1.

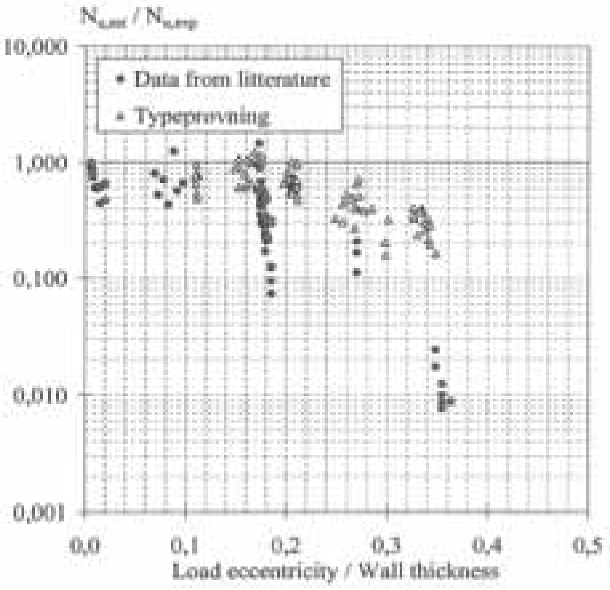

Figure 2 – Ratio estimated capacity ($N_{u,est}$) and experimental ($N_{u,exp}$) versus load eccentricity.

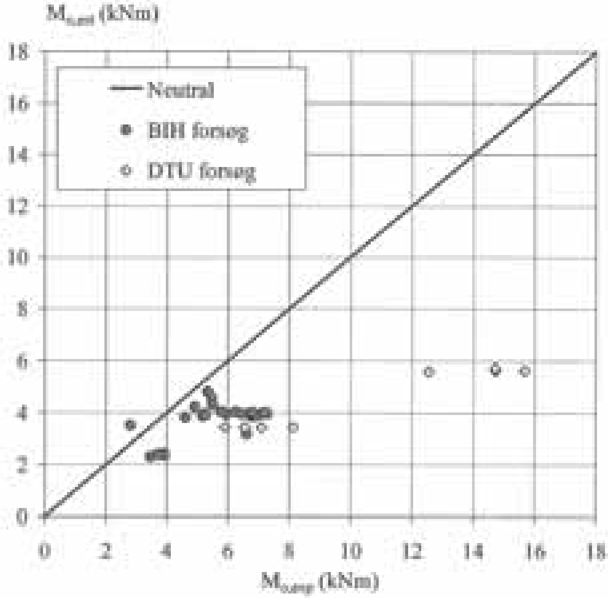

Figure 3 – Estimated 1. order moment ($M_{o,est}$) versus experimental moment ($M_{o,exp}$)

In the case of combined vertical and horizontal loading, the load-carrying capacity is limited by either tensile or compressive failure in the wall, based on nominal cross-section and the Eurocode 2-based stress-strain curve, leading to an estimated 2. order effect.

5. CONCLUSIONS

It has been possible to verify and revise the design formulas, based on Eurocode 2's principles, by using a modified set of formulas. The revised formulas are still conservative as shown on Figures 2 and 3, although they have improved the capacities with up to 25 %.

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Yield Lines in Plates with Reduced, No or Alternative Reinforcement

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ABSTRACT

Walls, panels and plates are often produced with openings (for doors and windows) and loaded transversely, leading to complex distributions of the bending moments and complex models. This can be achieved with the yield-line method, however, this will require some documentation in walls, which are not traditionally reinforced. A full-scale test setup and a down-scaled test setup have therefore been developed for walls and panels with transverse loading, enabling an experimental determination of the yield line pattern and of the load carrying capacities as wall as the load-displacement relationship. This has already been used in several projects [1,2,3,4] with specimens ranging from 12 m^2 and 2 tons in weight and down to 0.5 m^2 and 20 kg, covering masonry, lightly reinforced concrete, concrete reinforced with organic or plastic fibers and also monolitic and multilayer elements. The results support the yield line method for these alternative designs.

Keywords: Load-carrying capacity, lightweight reinforced concrete, masonry, fibres.

1. INTRODUCTION

The yield line method has been a very popular and easy, optimal design method for traditional, reinforced concrete walls and panels. This model requires, however, the structural element to have the necessary plasticity, which may not be the case in cross-sections with lower reinforcement ratios, with less plastic reinforcement or with alternative reinforcement types as fibres – or even if it could be used on masonry. The Danish industry and BYG•DTU have therefore already initiated or finished several projects in this field.

2. TEST SET-UP AND LOAD-CARRYING MODELS

The first test set-up was developed for the full-scale testing of prefabricated masonry walls (app. 12 m^2), using a system with an airbag, placed between the test wall and the supporting wall, as this gives us both an uniform load and a very efficient detection of the crack formation loads. The set-up has later been downsized, allowing for smaller test plates to be cast in a mobile test rig, since this is a more efficient concept – each mix may then provide 3 test panels with cylinders or beams, which can all be heat cured and thus tested within app. 1 week after the casting.

The traditional yield line method is used for all materials, however, each design will require estimations of the bending moment capacity and the bending moment – curvature relationship, based on tested material parameters.

3. RESULT AND CONCLUSIONS

The full-scale test-setup has worked very well and has lead to crack patterns in masonry, corresponding to the traditional tests with simply supported panels of normally reinforced concrete with traditional reinforcement.

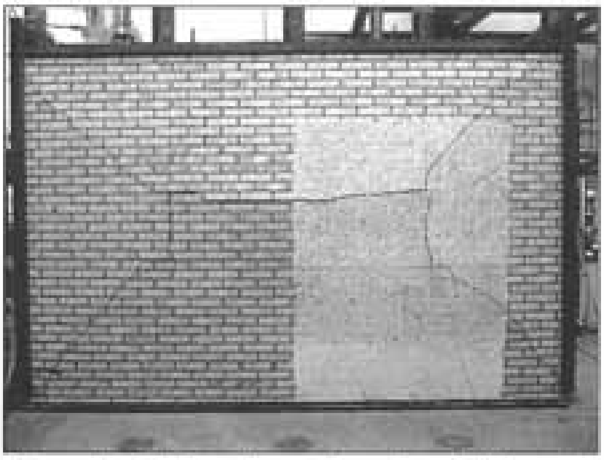

Figure1 – Full-scale testing of prefabricated masonry wall /1/.

Figure 2 – Down-sized testing of concrete panel with a window plate /2/.

The downscaled setup has also performed well for panels with under-reinforced concrete cross-sections with additional, local reinforcement (along windows), for fibre reinforced concrete panels (organic fibres as well as plastic fibres plus a combination of plastic fibres and in some cases additional reinforcement around window holes). Some additional modifications of the supports were developed during the projects and have now lead to crack formations corresponding to the yield line theory.

The use of downscaled test elements (600 x 800 x 30 mm) has been found to lead to a very efficient experimental planning, where we can get a much reduced coefficient of variation in the test results. The typical variation of the capacity is less than 6-8 % as we produce 3 specimens and control samples from one mix and by pacing the in the 60°C warm curing water for app. 3 days, leading to testing 7-10 days after casting. This is a very efficient approach for testing new potential designs for walls and panels and a similar approach is used for panels with in-plane sear loading.

The estimated load-carrying capacities have shown a fair correlation to the experimental capacities (although some wall designs need further work).

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Full-Scale Test on a Pile Supported Floor Slab – Steel Fibre Concrete Only or in a Combination with Steel

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Key words: Short term load test, SFRC, steel fibre concrete, structural floors.

1. INTRODUCTION

The design criteria used for pile supported slabs often called floors on piles (FOP) are in ultimate limit state (ULS) moment- and punching shear capacity. The loads consist of both uniformly distributed (UDL) and concentrated loads. The concentrated loads often have less influence on the design unless they are dense or large. However the long term aspect is often not treated well in design. Design criteria for serviceability limit state are often cracking and deflection (or inclination) booth influenced by shrinkage and creep of concrete and relaxation of steel reinforcement. In long and short term these will be influenced by the thickness, the concrete properties and also the reinforcement of the slab. The object is to study how the FOP slab acts in a full-scale experimental setup where the support conditions and reinforcement vary in short and long term loading.

2 TEST-SETUP

An experimental test was therefore built as an elevated concrete floor on columns and with edges partly connected with sandwich walls simulating a pile supported industrial fibre concrete slab on piles. A bottom slab was cast to constitute a rigid footing. Prefabricated columns give a pattern of squares with sides 3.0 x 3.0 m. The elevated floor (test slab) consists in the A section in Figure 1 of a double layer grid of 3+3 ϕ 12 mm reinforcement bars stretching from column to column and in section B the fibre concrete is un-reinforced. The fibre contents is 40 kg/m^3 and 80 kg/m^3 of Dramix RC-65/60-BN respectively and the concrete is a C30/37, maximum aggregate size is 16 mm and water cement ratio is 0.55.

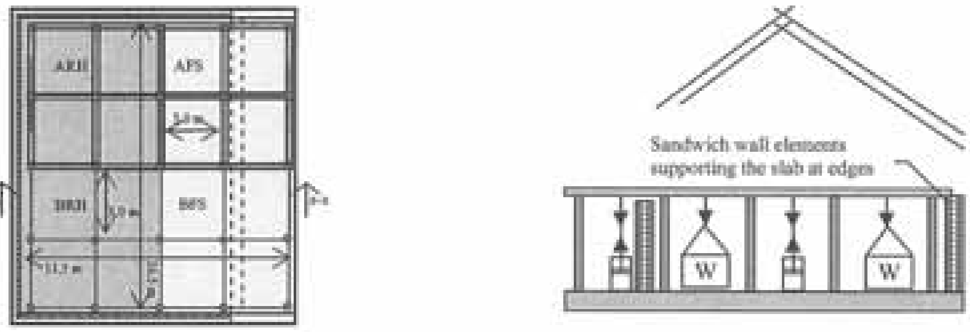

Figure 1 – Principal drawings of the full-scale tests. AFS = type A, free edge support, strain-softening, ARH = type A, rigid edge support, strain-hardening, BFS = type B, free edge support, strain-softening and BRH = type B, rigid edge support, strain-hardening.

3 LOAD PROCEDURE

Load anchors cast into the top slab and a load changing device mounted in the bottom slab served as loading points. A hydraulically induced force pulled the two load points together in steps of 20-50 kN during simultaneous measuring of slab deflection. To measure the long term deflection of the top slab (one year) for the different configurations the loading will be by weights. The long term loads are 50-90 % of tested first crack load in previously loaded section.

4 CONCLUSIONS

The load test started in March and April 2008. Expected deformations was about 50 mm from maximum loadings of about 70-100 kN. The actual maximum loadings varied between 140 to 300 kN where the maximum deflections was 50-65 mm. Preliminary test results will be presented in June 2008 at *NCR&D*, Bålsta. By refining material and structural behaviour higher payloads could be allowed or more safety may be added. For load carrying applications the structural design may trust on strength utilized from a system of fibre concrete and steel reinforcement together. This test indicates possibilities beyond what is worked into current design codes and recommendations.

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Session A3
Durable Structures

Bridge Evaluation through Finite Element Analysis and on Site Measurements Application on the New Svinesund Bridge

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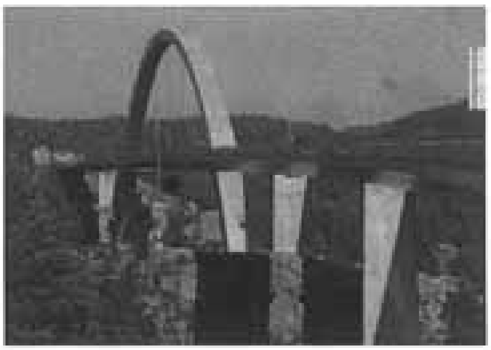
Key words: Finite elements model updating, structural identification, Svinesund Bridge.

1. INTRODUCTION AND RESEARCH SIGNIFICANCE



Monitoring and on-site measurements are increasingly used to control the performance of existing bridges. While proof tests are self speaking, diagnostic load tests and monitoring data must be used together with structural models to provide valuable information. If the benefits from on-site measurements should go beyond verifying structural models it is important to link a structural model and the on-site measurements together to enhance the understanding of the structure.

Finite element (FE) model updating is a tool that utilizes measurement data to increase the accuracy of an initial FE model and allows determining uncertain structural parameter, like boundary conditions, material parameters and interaction between structural parts. In Scandinavia FE model updating has previously been applied on the Forsmo Bridge [1]. This paper summarizes how FE model updating was applied on the world's largest single arch concrete bridge, the New Svinesund Bridge.

2. METHOD

The measurements that were used to update the FE model of the New Svinesund Bridge covered eigenfrequencies, strains, displacements and forces. The measurement programme is described in detail in [2-4]. The initial FE model was based on the designer's model. The updating procedure consisted of two steps. At first manual model refinements were introduced into the FE model to assure that the most important physical phenomena could be described by the model. The manual refinements included the stiffness increase of the concrete due to hydration, non-linear response of the bearings, temperature dependent stiffness of the asphalt layer for the eigenfrequency analysis and the representation of non-structural mass via mass-points. In a second step the FE model was fine tuned through non-linear optimization. The

Nelder-Mead Simplex algorithm [5] was used to change predefined model parameters to improve the agreement of the FE model with the measured data.

3. RESULTS

The FE model refinements introduced led to a significantly improved accuracy of the FE model with respect to the performed measurements. Especially the modelling of the bearings response turned out to be important in order to simulate the behaviour of the bridge in a more realistic way.

Special interest was given to the connections of the arch and the two bridge deck girders, which were designed to provide additional lateral stability to the arch. A parameter study showed that best agreement with measurements was obtained when a rigid connection was assumed in the FE model. This confirmed the designers' assumptions of a critical detail of the bridge.

4. CONCLUSIONS

FE element model updating was shown to be a powerful tool benefit from on-site measurements in an optimal way. It could further be concluded that common simplifications in structural models of bridges can have a significant effect on the accuracy of the models.

5. FINANCIAL SUPPORT

The authors would like to thank the Swedish Road and Rail Administrations, Vägverket and Banverket, for their financial support.

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Repaired Concrete Structures Resistance to Freeze-Thaw Actions in Hydropower Environment

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Key words: Freeze-thaw, Concrete, Repair, Hydro Power.

1 INTRODUCTION

The Swedish Hydropower industry, as it is today, was constructed during the 20th century. Large parts of the hydropower infrastructure are concrete structures like spillways, outlets, in-takes, stilling basins, retaining walls etc. Depending on when a structure was built its ability to withstand deterioration caused by the ambient environment will differ. The hydropower environment in the Nordic countries is, besides the obvious presence of water characterized by rather large temperature differences over the year. In the summer it is not unusual that the temperature exceeds 20 °C. In the colder periods the temperature easily falls below - 20 °C.

The most likely/common cause of deterioration of concrete in hydropower environments are freeze-thaw actions, leaching and abrasion. At some point, independent of the cause of damage, the existing structures need to be repaired. A commonly used repair method is to first remove the damaged concrete. After the removal of the damaged concrete the "new" surface needs cleaning. When the new surface is clean a new concrete layer is pored on top, a so-called overlay.

The repair concrete is required to be "watertight" and resistant to abrasion and freeze-thaw actions. In Sweden the resistance to freeze-thaw actions is, in most cases, determined by standard SS-EN-13 72 44. A repaired structure consists of the original concrete (substrate) and the repair concrete (overlay) together forming a composite material or structure. In some cases there will be a relatively large difference between the properties determining the resistance to freeze-thaw actions for the two materials constituting the composite material. The difference is mainly dependent on the quality of the underlying original structure. The repaired structure's (composite's) ability to absorb water will vary depending on the actual situation, presence of cracks, edge lifting and pervious joint connecting the two materials. The repaired structure's ability to absorb water and resistance to freeze-thaw actions, will not be as it once was for the original structure. It is not entirely certain that a composite material is resistant to freeze-thaw action even though the constituent materials are so according to SS-EN 13 72 44. The reason for this concern is the deviating properties of connecting joint. It is presumably even more uncertain if only one of the two materials (the overlay) is resistant to freeze-thaw actions.

2 RESEARCH SIGNIFICANCE

In short term the significance of this project is to determine whether water uptake combined with freeze thaw action will cause any significant damage to a repaired (composite) concrete structure or not. Since most of the repair works conducted in the Hydro Power Industry today are some sort of overlay, it exists an alternative significance as well. In a larger scope the significance of this project is to create a high competence regarding maintenance issues concerning the concrete structures of the Hydro Power Industry in Sweden.

3 METHOD

Two sets of composite test specimens have been produced. Both sets consist of two materials (overlay and substrate) joined together. According to SS-EN 13 72 44 are the overlay's, in both cases, resistant to freeze thaw attacks. The substrate material used in the first set of test specimens is also resistance to freeze thaw action, but not nearly as resistant as the overlay material. Both the overlay and the substrate of the second set of the tests specimens consists of the same freeze thaw resistant overlay material mentioned above. When the two sets of test specimens are properly cured and conditioned they will be exposed to water uptake and cyclic freezing corresponding to three different type of situations typically found in a Hydro Power environment. As the water uptake and freezing progresses destructive testing as well as non-destructive testing will monitor the consequence of the freeze thaw attacks. The destructive testing that will be used is the splitting test and the non-destructive test that will be used is ultrasonic testing and measurements of the fundamental frequency. The presumed (if any) degradation at the vicinity of the connecting joint will also be monitored by microscopy.

4 RESULTS

The, at the time, available results from these experiments will be presented at the symposium together with the background of the project.

5 CONCLUSIONS

The, at the time, available conclusions from the available results will be presented at the symposium.

6 FINANCIAL SUPPORT

Svenskt VattenkraftCentrum (SVC), Vetenskapsrådet and Vattenfall R&D financially supports the Project.

7 PROJECT DATA

This research project started in the second quarter of 2006. The Licentiate thesis will be published in the last quarter of 2008 or in the first quarter of 2009 at the latest.

Prevention of Crack Induced Corrosion by Increased Concrete Cover

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1. INTRODUCTION

One of the important factors governing durability of concrete structures is reinforcement corrosion, and to prevent degradation associated with it, it is desirable to use large concrete cover. However, requirements in the codes concerning limitation of crack widths at the concrete surface make it difficult to use large concrete covers. Tests [1] indicate, however, that the crack width near the reinforcement bar is less affected by a change in concrete cover than the crack width at the concrete surface. To clarify how the concrete cover really influences the risk of initiation of reinforcement corrosion, i.e. the time until corrosion starts, tests are performed on cracked beams loaded with bending moment. The beams have different concrete covers and are exposed to salt water (chloride concentration of 10 weight-% NaCl) on the cracked surface.

2. EXPERIMENTAL STUDY

Beams with the length 980 mm, width 156 mm and the effective depth 76 mm were manufactured. The tested concrete covers *c* were 20, 40 and 60 mm and the bar diameters were ∅8 mm and ∅12 mm. Two reinforcement bars were used for the diameter ∅8 and one bar for diameter ∅12. The position of the reinforcement bars and the used cross sections are shown in Figure1. The bending moment is induced by using rigs that create a beam span of 950 mm and a concentrated load in the middle of the span 475 mm from the support, see Fig. 2. Two steel stress levels were examined in this test series, 250 MPa which correspond to bending moments of 1718 kNm for ∅8 mm and 1923 kNm for ∅12 mm, and 380 MPa with bending moments 2611 kNm for ∅8 mm and 2923 kNm for ∅12 mm. The cracks were exposed to salt water solution (Cl-conc. 10 wt-% NaCl) via a strip of a special material, Wettex®, with large ability to absorb water. The Wettex® strips were in contact with bowls containing the salt water solution. The design of the rigs created two different exposure conditions, chlorides from above and chlorides from below. The initiation of reinforcement corrosion has been detected by means of the half cell potential technique [2]. A potential larger than -0.11 V interprets a low risk of corrosion and lower than -0.26 V and intermediate corrosion risk. The crack widths were measured with a crack microscope.

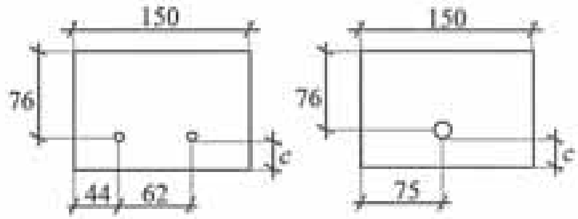

Figure 1 – Cross sections of the tested beams.

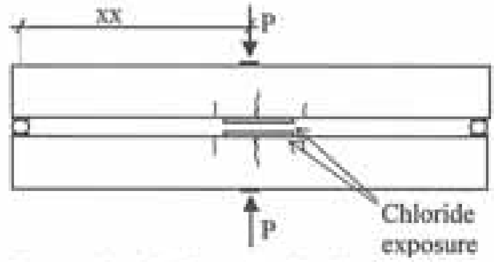

Figure 2 – Schematic loading in the rig.

3. RESULTS

In Table 1 it is obvious that large concrete cover delays the corrosion start for steel diameter ∅12 mm and increases the durability of concrete structures significantly when chloride exposure is from below. Consequently, large concrete cover increases the crack width at the concrete surface. This is confirmed by the results for steel diameter ∅8 mm. For chloride exposure from above the behaviour is the opposite. However, the difference for chloride exposure from above is very small and for lower steel stresses almost non existent. Large steel stresses increase the corrosion risk for both exposure conditions. Both steel diameters have similar behaviour and the steel diameter has no correlation to the corrosion risk. The corrosion start was very obvious in all measurements with a potential increase of at least a factor 5. Current design methods, where only the crack widths at the concrete surface are considered, can on the basis of this study be considered as contra productive.

Table 1 – Measured times for initiation of reinforcement corrosion for beams with 20 and 40 mm concrete cover with steel stresses of 250 and 380 MPa (steel diameter is 12 mm). ">" means that the initiation time is larger than the last noticed time.

Concrete cover (mm)	Steel diameter (mm)	Steel stress (MPa)	Chloride exposure from:	Crack width (mm)	Initiation time (days)
20	1∅12	250	Below	0,250	6
40	1∅12	250	Below	0,433	>59
20	1∅12	380	Below	0,183	0
40	1∅12	380	Below	0,400	>32

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Ice Abrasion on Concrete – Data and Testing

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ABSTRACT

Ice abrasion is a very severe deterioration mechanism on a concrete structure and there are indications that the rate of deterioration may progress very rapidly even on high performance concrete. Field data of depth of ice abrasion on well known concrete compositions exposed to well known ice abrasion load conditions are rare. We have reviewed earlier published field data from e.g. light houses and laboratory data showing that the rate of deterioration depends largely on concrete quality in general and on ice exposure conditions in particular. Therefore we discuss further research possibilities within modeling-, laboratory and field studies in order to proceed in the development of competitive concrete structures for sub arctic and arctic conditions.

1. INTRODUCTION

For the last decades, the performance of concrete structures under severe marine environmental conditions has gained considerable attention. However, there are still a number of unknown factors related to design and material selection of concrete structures exposed to ice abrasion. Published data on this subject have been reviewed in order to identify critical areas of further research and development of concrete structures exposed to ice abrasion. The challenge will be to develop reliable concrete structure solutions that can withstand the ice exposure during the structures operational life.

2. EXISTING DATA

Studies on ice abrasion published in the literature focus on either material properties (strength, normal vs light weight aggregate etc) or ice conditions (temperature, stress, rate of deterioration) and include both development and conduction of lab test equipment and field studies. Some studies more or less ignore material parameters pointing to effects that amplify the damage such as increased ice pressure, confinement of ice, low temperature/hard ice, ice-free concrete surface etc. Other studies point to the reduced ice abrasion of both concrete and rock with increasing material compressive strength. As an example of the variation in test conditions and results reported from the Baltic sea, abrasion rates 0,3 – 11,6 mm/year were observed on 24 reinforced concrete panels with compressive strength 60 – 90 MPa exposed on lighthouses in the period 1986 – 1989 [1]. Tests on concrete cylinders with compressive strength 30 – 60 MPa mounted in the front of an ice breaker, on the other hand, showed 2 – 15 mm abrasion after only 40 km of ice exposure [2]. All available data have been collected and reviewed [3, 4] showing that the phenomenon of concrete abrasion due to sea ice movement is complex, involving different mechanisms and parameters:

- The rate of abrasion increases with increasing ice contact pressure and decreasing ice temperature.
- Ice sliding results in more abrasion than ice crushing.
- The ice abrasion is reduced with increasing material strength as observed in laboratory tests on rock samples and field tests combined with modeling of concrete.
- Use of cement replacements like silica fume and blast furnace slag has a positive effect on the amount of abrasion.

It is important to obtain sufficient control on the effect of both ice conditions (exposure) and concrete parameters (resistance) in controlled experiments (m/s, °C, MPa) since even the simple relationship between compressive strength and ice abrasion seems hard to apply for reliable service life predictions at present. Test parameters and relation between field and lab should therefore be investigated in order to develop simple, repeatable tests limiting future studies to a practical number of material (strength, aggregate, fiber, cement replacements) and ice-exposure parameters (temperature, strength, contact pressure, duration of exposure, exposure mode (ice sliding versus crushing)). One possible approach was recently presented [5]. Furthermore, rock samples from field studies on coastal cliff retreat in Arctic regions [6] could possibly serve as benchmark for deterministic (and probabilistic) service life predictions from new accelerated laboratory tests. A new accelerated test method for laboratory use will be developed at NTNU in order to more easily pre-qualify alternative materials or solutions. As there likely will be a high construction activity (hopefully of concrete structures) in the Sub Arctic areas in the years to come, a model and/or formula predicting the expected concrete abrasion as precisely as possible would be of great interest, both for constructional and economical purposes.

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* COIN - Concrete Innovation Centre - is one of presently 14 Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

Frost Resistant Under-Water Concrete

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SUMMARY

A common type of quay structures are steel sheet piles which are topped with a reinforced concrete beam. This concrete beam has a load bearing function as well as it works as corrosion protection for the steel sheet piles. In a new housing area in Stockholm, Sweden, the architect planned an artificial coast line of 500 m length with only 0.20 m height difference between water and land level. The Nordic climate in Sweden requires a frost resistant concrete. The traditional way of realising such a quay structure is to drive in the steel sheet piles, seal the formwork for the concrete beam, bail the water filled formwork and cast traditional AEA-concrete into the form. In this special case almost the complete formwork would need to be constructed under water and then sealed and emptied from water.
In cooperation with the contracting authority it was decided to change the construction method and cast a frost resistant concrete under water. It was expected that this construction method would be both cost efficient and a promising way to give a healthy construction.

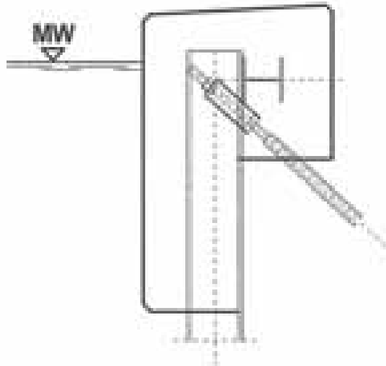

Figure 1 – Cross section of quay.

A new type of frost resistant under water concrete was developed, which is a viscous air-entrained self compacting concrete without water repellent agents. That concrete had to be stable while flowing under water and keeping the entrained air. A filler based air entrained self compacting concrete with addition of VMA was developed in laboratory. The addition of VMA increased the wash- out stability of the concrete. The concrete had to fulfil the requirements for C 32/40 XD3/XF4 with a service life of 100 years. The under-water stability of the mix design regarding aggregate separation and air void system was confirmed on fresh and hardened concrete samples cast under water. The requirement on the air content of the fresh concrete was set rather high due to risk of air loss during under-water casting. The target value for the air content in the fresh concrete was set to 8% in order to ensure at least 5% entrained air in the hardened concrete. That was confirmed by air void analysis on flat polished samples. In cooperation with the contractor, the laboratory mix design had to be adjusted to another type of aggregate.

Intensive testing of the intended construction method and type of concrete were part of the contract between the contracting authority and the contractor. Only if the tests were successful, the contracting authority as well as the contractor would accept the construction to be realised with frost resistant under-water concrete. If the tests failed, the structure would have to be realised in the traditional way with sealed formwork and dry casting. The first step of the site tests was to confirm that the adjusted mix design fulfilled the requirements. Therefore two walls of 4 meter length were cast in a water filled container with the two different mix designs. Drill cores were taken at different heights and compressive strength, air content and frost resistance were evaluated. Both mix design performed as desired, so the adjusted mix design was accepted. The second step of the site tests was the casting of a full scale model of a section of the quay structure in a water filled container. The model was 6 meter long and contained the same amount of reinforcement, built-in steel parts and steel sheet piles as the real structure. The planned casting method with one concrete pump and split pump hose with under water valves was tested as well. The hardened concrete beam was sawn and drill cores were taken from the cross section. The cores were tested on compressive strength, air content and frost resistance. The casting was successful, all steel parts and reinforcement were completely surrounded by concrete. There was no separation of either coarse aggregate or air observed.

In order to ensure a homogeneous concrete without separation of air or aggregate and diminish intrusion of water under the casting process, the casting method is of major importance. A constant flow of concrete has to be ensured and the pumping hose to be inside the already cast concrete the whole casting sequence. The geometry of the quay structuren is complicating the casting even more. The deep part of the beam has to be cast first, followed by the narrow part. This problem was solved by splitting the pump hose and regulating the concrete flow with a valve. This was necessary, because of space limitations at site it was not possible to use two pumps. An under-water valve seals the hose prior to pumping from intruding water.

A detailed test plan with limits concerning air content and slump flow was established in order to ensure high quality concrete and a successful casting. Each truck with ready-mixed concrete was checked on slump flow and air content. Skilled personal from the concrete producer were on site to add admixtures (VMA and superplasticizer, no AEA) if that was necessary. In case the requirements were not met, the concrete batch was rejected. The requirements of the contracting authority were that no drill cores for quality control should be taken from the finished structure. 6 cube samples per section were taken for the first 15 sections. Later the amount of cube samples was reduced 3 samples per section. The samples were tested on compressive strength and scaling at freezing according to Swedish standard 13 44 72 with saltwater. Not a single sample failed the freezing test and all samples had sufficient compressive strength.

In the initial design, cooling of the concrete beam with cast in cooling pipes was required to ensure a structure free of cracks. In order to be able to skip cooling pipes, the heat and stress parameters of the under-water concrete were tested at Luleå Technical University. Strain measurements of one section of the quay structure were performed with cast in strain gauges. The evaluation of the strain measurements resulted in a restraint ratio of the structure which was used in finite element calculations of the thermal crack risk. Using the measured restraint ratio and tested material parameters, the calculations showed that cooling was not required.

ACKNOWLEDGEMENT

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Session B3
Assessment, Service Life, Repair & Strengthening

Operational Service Life Design – A Focus Area in COIN

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Keywords: Service life, durability, chlorides, corrosion, AAR

1. INTRODUCTION

COIN – Concrete Innovation Centre – is one of presently 14 Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The vision of COIN is creation of more attractive concrete buildings and structures. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life.

This paper gives a brief presentation of the COIN project named "Operational service life design" – one of total five main projects in COIN.

2. SCOPE AND FOCUS

Premature deterioration of concrete buildings and infrastructure is a severe challenge, both technically and economically. During recent years Owners of large structures – infrastructures as well as buildings – have therefore focused increasingly on durability. This has repeatedly been expressed as a requirement to a specific design service life, ranging typically from 50 - 300 years.

The main objective of the COIN- project "Operational service life design" is to develop operational and reliable service life models and methods applicable for new design as well as for redesign of concrete structures based on a fundamental understanding of the different mechanisms involved in the deterioration processes.

In this project the main focus is on deterioration of concrete structures due to chloride-induced corrosion. Both the initiation and the propagation period are included, as illustrated in Figure 1 *[taken from fib Model Code for Service Life Design, 2006]*. The following topics are studied:

- Modeling of chloride transport and corrosion process.
- Study of governing durability related parameters like chloride diffusion, critical chloride content and concrete resistivity.
- Service life prediction including effects of durability enhancing measures.

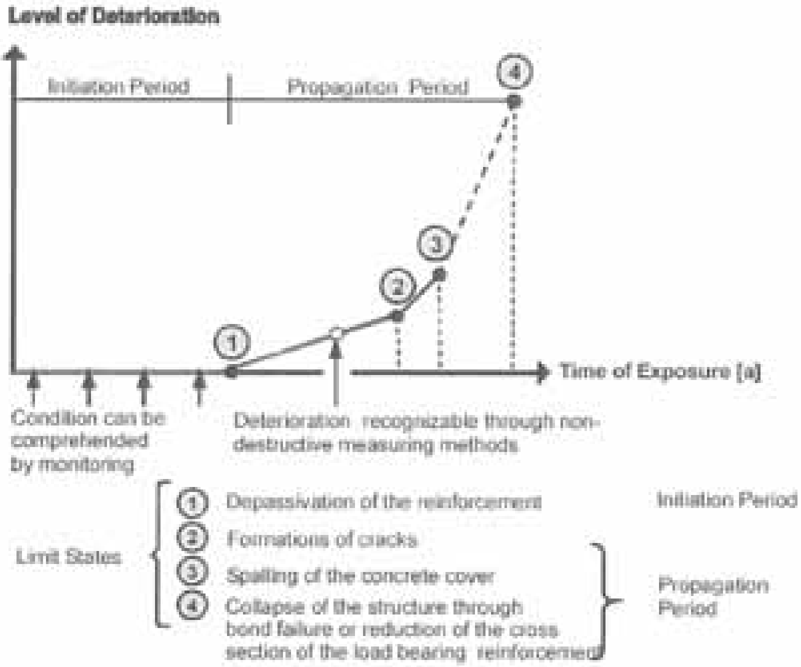

Figure 1— Deterioration process due to reinforcement corrosion.

Furthermore, a more profound understanding of the governing mechanism leading to alkali-aggregate reaction (AAR) is another important topic in this project.

3. PROJECT STATUS AND FINANCIAL SUPPORT

About 11 researchers, two PhD students and four Master students are involved in the COIN project "Operational service life design". So far, seven State-of-the-Art reports are published. Further, a Workshop on "Critical chloride content" has taken place, 5-6 June 2008, at the Norwegian University of Science and Technology (NTNU) in Trondheim.

The work performed in this project is closely linked to ongoing activities within international committees like RILEM and *fib*.

COIN has presently a budget of NOK 200 million over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %). The present industrial partners are:
Aker Kværner Engineering and Technology, Borregaard LignoTech, Maxit Group, Norcem A.S, Norwegian Public Roads Administration, Rescon Mapei AS, Spenncon AS, Unicon AS and Veidekke ASA.

In COIN, about 25 researchers from SINTEF (host), the Norwegian University of Science and Technology - NTNU (research partner) and industry partners, 15 - 20 PhD-students, 5 - 10 MSc-students every year and a number of international guest researchers, are involved in the Concrete Innovation Centre. For more information, log on to www.sintef.no/coin.

Condition Assessment of Anchorage Reinforcement in Hotagen Regulate Dam

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Key words: Long-term effect, degradation process, anchorage, corrosion, injected grout

1. INTRODUCTION

1.1 General

The condition of the regulate dam in Hotagen, 120 km north of Östersund, is poor dure to severe ASR-damages [1]. Therefore a new dam is erected 10 meters downstream. During the demolishing of the dam the anchorage system of the old dam will be assessed. The goal of the project is to evaluate the condition of the anchorage. Since it is rare to assess anchorage of old dams and the assessment during the life of the structure is impossible the knowledge of the degradation process in the anchorage is insignificant. Therefore the anchorage is not allowed to increase the stability in the design of the dam according to the design guideline in Sweden [2]. The condition assessment of the anchorage system in Hotagen will increase knowledge of the state of 40-years old anchorage steel stays. The construction of the new dam, the demolishing and the field tests can only be done when the water level is at the lowest level and must be finished before the spring melting starts and therefore all field activities have to be planned in detail.

2. ANCHORAGE SYSTEM

2.1 Failure modes

The anchorage system increases the safety of stability of dams. It is commonly used for low dams (<5 m) and structural parts where the dead weight isn't enough to maintain the stability in moment (overturn failure) or horizontal loads (slidning failure).

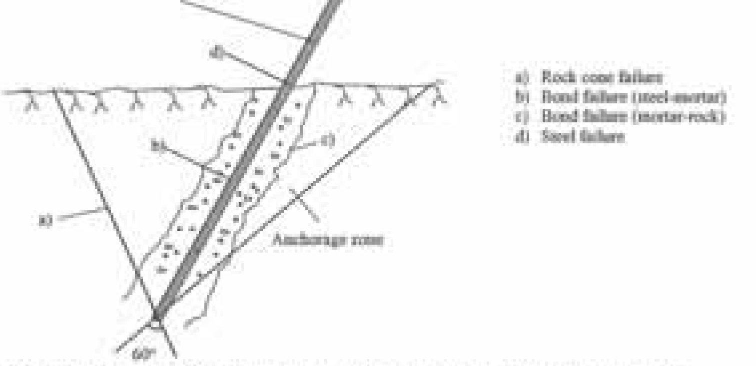

Figure 1 – Failure modes for an anchorage steel stay.

There exist four different failure modes for anchorage, displayed in Figure 1, above. The rock-failure will not be examined in this project since the testing methods will be quite extreme. Also the rock cone failure is independent of degradation. Calculations show that the steel failure is the weakest part of the anchorage. See Table 1, below.

Table 1 – Calculated failure forces of anchorage in Hotagen.

Failure mode	Calculated force (kN)	Calculated force (%) of steel failure
a) Rock cone	149	101
b) Bond (steel-rock)	401	288
c) Bond (rock-mortar)	346	249
d) Steel break	139	100

3. TESTING

3.2 Field testing

Before any field tests can be performed the old dam has to be demolished. To be able to perform the field test the dam has to be demolished with great care. Close to the anchorage and close to the ground hand equipment is used so the anchorage is remained undamaged and the condition can be monitored. A master thesis student, who is studying the anchorage of the Hotagen dam, will monitor and guide the demolish team during the whole process. After the concrete dam is demolished all steel anchorage above the rock ground will be optically scanned. Speial attention will be given to the boarder of the concrete and the rock where water may intense the corrosion. 20 anchorage stays will be tested with a pullout test (up to 25 tonnes) at site. Only severe damages in the mortar will give bond failure since the bond force is more than twice the steel failure force. Three anchorage stay cores will be drilled out. Each core will have a diameter of 125 mm to include also a layer of the surrounding rock. The 3 meters cores will be transported to the laboratory where further tests will be conducted.

3.3 Laboratory work

In the laboratory the cores will be tested more closely. The steel quality will be tested. The leaching in different positions from the ground will be tested to conclude if there is any difference in the leaching process depending on the position of the anchorage in the rock. To been able to detect the bond force of the steel and the mortar the core is cut into 30, 50 and 70 cm specimens. Each specimen is cast into reinforced concrete, which shall correspond to a surrounding rock. To obtain the bond force of the anchorage the steel is pulled out from the core.

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Structural Reliability Analysis of Concrete Dams – Design Concepts

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Key words: Concrete dam, structural reliability analysis

1. INTRODUCTION

During the last decades, probabilistic safety concepts have been developed and introduced for design of infrastructure in many countries. BKR [1] in Sweden and the Eurocodes [2] are based on semi-probabilistic partial factors. However, design of concrete dams is still, in Sweden as well as most of the world, based on deterministic analysis using safety factors. The overall stability of a concrete dam is considered to be sufficient if requirements regarding sliding and overturning are satisfied. The requirements are of the type $\frac{Stabilizing\ force}{Destabilizing\ force} > safety\ factor$.

The basis of structural reliability analysis (SRA) is the identification of a limit state, i.e. distinct events e.g. failure. This limit state is described by a limit state function $g(x_1,x_2,\dots,x_n)$, where $x_1,x_2,\dots,x_n$ are statistically described random variables. The limit state is reached when

$$g(x_1,x_2,\dots,x_n)=0 \qquad (1)$$

For independent and normal distributed variables $x_1,x_2,\dots,x_n$ the probability of failure of the structure corresponds to a safety index β by

$$p_f=\Phi(\beta)\, and\ \beta=\Phi^{-1}(p_f) \qquad (2)$$

β can be calculated by simulation or numerical methods, see [3]. β is compared to a target safety value, given in e.g. Eurocode [2], to evaluate if the analysed structure is safe enough. Typical values of β_{target} (although not calibrated for dams) is 4.8 /year, corresponding to approximately p_f =10^{-6}/year. Focus in the research so far has been on describing the random variables of significance for concrete dams and special attention has been on uplift pressure.

2. RESULTS

A number of theoretical dams of different geometry, that fulfil the requirements according to RIDAS [4], were analyzed by SRA. The result indicates that the deterministic analysis gives a varying level of safety, as the safety index is dependant on dam type, dam height and failure mode, as can be seen in Figure 1. Development of the design concept of dams to semi-probabilistic would result in more uniform safety level. SRA can also be used in assessment of dam stability to prioritize the most urgent dam safety measures.

There are questions concerning the assumed failure modes, where cohesion in the interface between dam body and rock is not included in the Swedish sliding stability requirement, but is included in codes and standards of many other countries. There are also questions concerning the non-overturning requirement for most common dam types, as concrete crushing is likely to exclude the possibility of overturning.

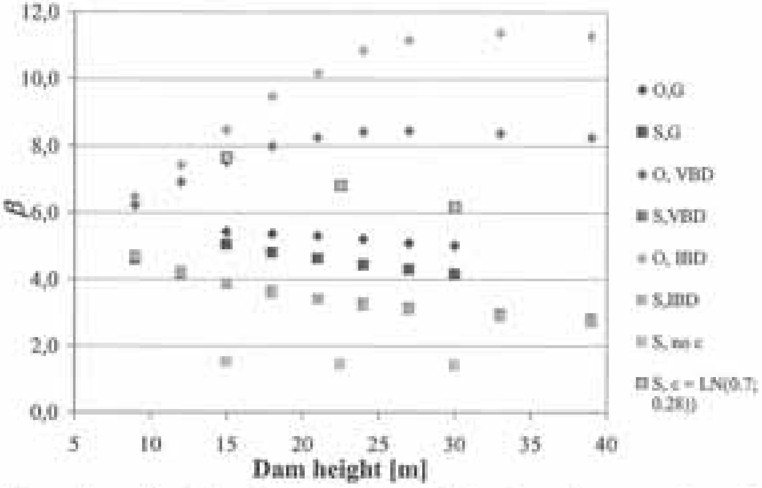

Figure 1 – β as function of dam height. O = Overturning, S = Sliding, G = Gravity dam, VBD = Buttress dam, vertical front, IBD = Buttress dam, inclined front, c = cohesion.

3. CONCLUSIONS

The main conclusions so far, presented in [5], are that

- Society and dam owners want an even level of safety and dams that are "safe enough". The current safety standard in Sweden is inconsistent in its handling of safety, mixing deterministic and semi-probabilistic design concepts. In one example this resulted in over-conservative results, but the opposite can not be excluded.
- SRA may be introduced for assessment of dams, and used for calibration of partial factors for design, but research is necessary in a number of areas; e.g. failure modes, target safety index and statistical description of loads.

4. PROJECT DATA

The Ph.D.project "Reliability-based evaluation of concrete dams" started in June 2004 and was part of the research consortium Väg/Bro/Tunnel and financed by ELFORSK, VINNOVA and Lund University. A licentiate thesis [5] was presented in April 2007. Part two, started in May 2007 and to be finished in Dec 2009, is financed by Svenskt Vattenkraftcenter.

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Structural Assessment of Concrete Railway Bridges

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Key words: Structural assessment, concrete, railway, bridge.

1. INTRODUCTION

For a sustainable development of Europe, there is a need to at least double the railway transports in the coming 20 years. In order to reach this goal, the residual service lives of existing concrete railway bridges need to be extended, at the same time as they are subjected to higher axle loads, higher railway speeds and heavier traffic intensity. Today, many bridges are replaced or strengthened because their reliability cannot be guaranteed based on the structural assessments made.

To meet the future demands, the EU-project Sustainable Bridges was performed from 2003 – 2007. The intention of the project was to develop a "toolbox" of new systems and methods for assessment, strengthening and monitoring of the European railway bridges. The new generation of methods should be directly applicable by railway owners, consultants and contractors.

The part of the work presented here was made to provide enhanced assessment methods for concrete bridges. The results are implemented in the Guideline for Load and Resistance Assessment of existing European Railway Bridges, see Sustainable Bridges [1]. The objective was to summarise and develop methods that are able to prove higher load-carrying capacities and longer service lives for concrete bridges. The research made is reported in detail in a background document, see Sustainable Bridges [2].

2. RESULTS

The work comprises several complementary parts. Improved methods for the determination of in-situ material properties in existing concrete bridges are presented. The methods cover the material properties needed for both for linear and non-linear analysis, for deterministic as well as for fully probabilistic assessments.

Methods for structural analysis on different levels are presented. Recommendations were developed for redistribution of sectional moments and forces from linear finite element (FE) analysis of slab bridges. Non-linear FE analyses showed that lateral redistribution of linearly determined moments is necessary to avoid under-estimation of the capacity when assessing existing bridges. Advanced methods for local resistance analysis are presented, e.g. regarding shear, torsion and bending interaction.

Non-linear analysis is the structural analysis method that provides the greatest potential to discover any additional sources for load-carrying capacity. Furthermore, it gives a better understanding of the structural response, forming an improved basis for assessment decisions. Recommendations are given regarding methods and models to be used in non-linear FE analysis, as well as regarding when such methods are likely to reveal a higher capacity.

Methods are also provided for assessing the remaining structural resistance of deteriorated concrete bridges. Recommendations are given for maintenance of bridges with reinforcement corrosion, and on the effect of the corrosion on the anchorage capacity. Furthermore, a methodology is presented for improved assessment of the fatigue safety for existing concrete bridges. Here, the emphasis is on evaluation of the remaining fatigue life of short-span bridges and secondary elements. The proposed methodology includes (1) a study of the bridge with an evaluation of the reinforcement detailing, (2) an inspection of the bridge and its past performance and (3) a fatigue safety check. It is concluded that for bridges with concrete in good condition, the fatigue safety is in general determined by the steel reinforcement.

3. PROJECT INFORMATION

The Sustainable Bridges project had an estimated gross budget of more than 10 million EUR. The project had 32 partners from 12 European countries. The work presented here is from one sub-group in one work-package. The work was partly financed by the EU commission. Complementary financing for the Swedish parts were obtained from Banverket and Vägverket.

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CFRP and Mineral Based Bonding Agents to Strengthen Concrete Structures

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Key words: Concrete, strengthening, mineral based composites, cracking, FRP, CFRP, MBC.

1. INTRODUCTION

Repair and upgrading of existing concrete structures are becoming more and more common due to degradation processes, changes in structural use, code adoptions, maintenance and economical considerations. Previously, traditional repair and upgrading techniques was limited to enlargement of cross sections with installation of extra steel reinforcement, external prestressing systems or change of loading path. Today, commonly utilised external strengthening systems use FRPs (fibre reinforced polymers) or dry fibres made of carbon (C) and glass (G) which are adhesively bonded to the concrete. These can be designed as laminates, sheets or bars mounted on the surface or as near surface mounted bars in the concrete cover, [1] and [2]. Although strengthening systems using epoxy as the bonding agent have shown good results in form of bonding and application, there exist some drawbacks:
(a) Regulations on handling the epoxies, risk for eczema and toxicity of the components. (b) Freeze/thaw problems due to low permeability and diffusion-tightness. (c) Moisture sensitivity and minimum application temperature of 10 °C.

2. RESEARCH SIGNIFICANCE

Due to the challenges with epoxy adhesives it is of interest to repair or upgrade concrete structures using a mineral based composite (MBC) which has better compatibility to the base concrete due to the use of cementitious bonding agents and FRPs for excellent tensile strength. The fibres utilized in combination with cementitious bonding agents can be designed in different ways. Up-to-date, some of the commonly used designs of the fibres are textiles in form of meshes made from woven, knitted or unwoven rovings of fibres in different directions or unidirectional dry fibres [3], [4] and [5]. In the latter, these textiles are often applied with dry fibres and studies on impregnation of dry fibres with polymers, e.g. epoxy, indicate on much higher bond strength to the cementitious bonding agent compared to the use of non-impregnated fibres. This is due to the low ability of the cementitious bonding agent to penetrate the dry fibre rovings [6]. Considering the bond, it is therefore more advantageous to use impregnated fibres (FRPs) than using dry fibres which is the case in [7] where the impregnated fibres are assigned as a grid with two orthogonal directions.

3. METHOD

The research project of MBC strengthening is divided into three main areas; *materials*, *structures* and *full size application*. In the *material* area the composite action between concrete, mortar and FRP is studied and in the *structure* area laboratory studies on strengthened beams are evaluated and the full scale behaviour of the MBC is studied in the *full size application* area.

4. RESULTS AND CONCLUSIONS

The results from the *material* studies indicate further possibilities of enhancing the mechanical behaviour of the mortar and FRP. On the structural level, shear strengthened beams with MBC reach same levels of load carrying capacity as side bonded epoxy bonded FRPs. It is also noted that the MBC systems are effective in reducing cracks and therefore also may be used as internal crack reinforcement in concrete with lower weight and thinner concrete cover compared to traditional steel crack reinforcement. No significant full size application has yet been done. Overall, the use of MBC as repair, upgrading or crack reducing system has great possibilities applied on concrete structures.

5. FINANCIAL SUPPORT

The research presented in this paper has been funded by several organisations. Here the Swedish Road Administration, the Development fund of the Swedish Construction Industry (SBUF), Sto Scandinavia AB and Skanska Teknik AB are acknowledged for their financial support.

6. PROJECT DATA

The research project of strengthening concrete structures with mineral based composites is a part of a PhD project at Luleå University of Technology which started in 2004 and will end in 2009.

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Innovative Strengthening of Swedish Concrete Trough Bridges

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Key words: Strengthening, flexure, concrete, bridges, CFRP, NSMR.

1. INTRODUCTION

Insertion of bonded carbon fibre rods in grooves in the concrete cover, also denoted Near Surface Mounted Reinforcement, NSMR, has by now earned its position as one of the more powerful tools to repair and upgrade RC structures. Together with other Carbon Fibre Reinforced Polymer, CFRP-systems, such as sheets or laminates, the performance of many different types of concrete structures can be improved. This has also been carried out in the form of pilot studies in a vast number of projects; showing the benefits of CFRP strengthening.

2. RESEARCH SIGNIFICANCE

Need for strengthening or upgrading of concrete bridges are immediate in many cases. An alternative is to replace the insufficient bridge, which might be very costly and also interrupt traffic with additional economical losses as a result, not adding any more value to the client. By using the best strengthening technique and the most suitable materials such extra costs can be avoided. The present work aims to investigate how and when two such possible strengthening techniques can be used and how the methods can be optimised.

3. METHOD

In Frövi a double trough RC railway bridge has been strengthened for flexure in the transverse direction. In the upper part of the bottom slab with CFRP-tubes installed in pre-drilled holes and in the lower part of the slab with bonded rectangular carbon fibre NSMR rods. Results are monitored through strain gauges and fibre optics in the serviceability limit state. Tests have also been carried out in ULS (ultimate limit state). Here the longitudinal concrete beams in a railway trough bridge in Örnsköldsvik were strengthened with NSMR. This bridge was then tested until failure while strains and deflections were monitored.

4. RESULTS

Measurements on both bridges show good utilization of the CFRP material. On the Ö-vik Bridge, strengthening made it possible to change failure mode from flexure to shear and deflections as well as strains were lowered with 15-20% in the steel for the same amount of load compared to the unstrengthened bridge. Results from the Frövi Bridge did however not show the same improvements in deflections and strains. In the Frövi case, contrary to Ö-vik, the loading consisted of the everyday traffic and comparable measurements could only be done on the light weight Regina passenger trains. Due to this only a small portion of the designed serviceability load could be reached. It was enough to give as large strains in the NSMR as in the steel reinforcement and thereby prove a successful installation but not to detect any change in bridge behaviour. Also the internally positioned CFRP-tubes carried load during train passages, which could be verified with strain measurements as well.

Installation of both NSMR and tubes was in Frövi performed by contractors without any traffic interruption. Grooves for NSMR were sawn in an automated process allowing straight grooves and sound working environments. The 9 m long and 38 mm wide circular holes for the tubes were equally drilled with an automated core drilling equipment. After careful adjustments of angle and direction the drill held a constant drill rate; thus minimizing the risk of losing direction on cement/ballast or cement/steel interfaces. In general very few steel bars were however cut and the exit hole missed its estimated position with maximum 3 cm in horizontal direction, which is the least critical. For application of epoxy, efficient results were reached through a series of steps developed by the contractor, leaving the customer with a neat bridge.

5. CONCLUSIONS

Based on experience and results from these two projects as well as previous ones it can be concluded that NSMR is a complete and proven system that can be industrialized and is suitable for operations where flexural strengthening of bridge spans is of interest. CFRP-tubes are not yet as well investigated but the Frövi project proved their efficiency for strengthening the interior of a structure without traffic interruptions.

6. FINANCIAL SUPPORT

Both the Frövi and Ö-vik bridge projects have been parts in "Sustainable Bridges", a research program sponsored by the European Union and incorporating more than 30 partners. More about the project can be read on www.sustainablebridges.net. In excess of that the Swedish Rail Administration, Banverket, has sponsored the Frövi strengthening as well as assisted in technical and administrative questions on both projects.

7. PROJECT DATA

These projects are due to their sizes and multiple research issues shared by several Ph.D.-projects whereof the main author's project about possibilities and challenges with FRP prestressing of concrete structures is one. The bridge projects are finished but the Ph.D.-project is estimated to last until May 2011.

Concrete with Crushed Aggregates

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Key words: aggregates, crushed rock, characterisation, rheology.

1. INTRODUCTION

Natural aggregates are becoming scarcer in parts of Sweden and for environmental preservation the authorities wants to preserve the remains. The only realistic option is to replace it with aggregates from crushed bedrocks. The major challenge is to replace the fine aggregate (0-4 mm). Earlier studies within MinBaS I referens [1] have shown that concrete produced with crushed sand (0-2 mm) leads to higher water demand and loss in compressive strength (equal w/c-ratio) compared to concrete produced with natural sand. Higher water demand and lower compressive strength has to be compensated by higher cement content in the concrete. Based on the earlier experiences [1,2] the cement consumption will increase with 5% due to higher water demand and by 3% due to lower compressive strength. The Swedish government has financed research to overcome these negative effects in concrete production in two new projects, MinBaS II and STEM (2007-2010). The MinBaS II project will deal with guidelines for air classifiers and crushers and durability questions. The Swedish Energy agency (STEM) is supporting a project aiming at developing tools to facilitate the introduction of crushed sands in concrete including a mix design program, guidelines for establishing rock quarries and guidelines for specification of aggregates suitable for concrete production.

2. CHARACTERIZATION OF THE AGGREGATES

The characterization of aggregates > 2 mm does not constitute a big problem. Standard test methods as flakiness index or LT-index and packing properties give good knowledge of what the effect on concrete properties will be. Improvements in the crushing procedures and influences of rock mineralogy on the crushing are easily evaluated. The finer aggregates constitute 25 to 33% wt. % of aggregates in concrete, but constitute 95 to 99% of the total number of aggregate particles in concrete. Moreover, it represents most of the specific area of the aggregates.

It is rather complicated to correctly characterize the properties of the finer parts of the aggregates. In MinBaS I [1] the aggregate particles were characterized by image analysis for determination of mineralogy and particle shapes (F-shape). The 0-0,25 mm fraction was analysed with laser sieve, determination of BET-surfaces and Methylene blue. They also were tested according to the sand equivalent test. The loose packing properties of the 0-0,125 mm, 0,125-0,25, 0,25-0,5, 0,5-1, 1-2 and 0-2 mm fractions were also established.

3. STUDIES WITHIN THE PROJECTS

Aggregates from at least 15-20 different quarries are presently analyzed and characterized. At this NCR & D meeting we will, however, only discuss the use of rheological methods for comparing different crushed sands.

3.1 CamFlow – comparisons of filler fraction

Fillers < 0,125 mm from two different quarries have been studied and compared to a limestone filler and a cement sample. The micromortar was composed with a water to powder ratio of 0.4. The flow of pure cement was 175 mm, the flow of the two fillers (75% cement and 25% filler) was 159 and 166 mm while the lime stone powder (25% filler) was 192 mm. The limestone filler thus has a lower water demand than cement and the two investigated rock fillers have a higher water demand than cement. The method is described in [3].

3.2 Rheology – comparisons of different crushed aggregates

Mortar containing crushed fine aggregate (< 2 mm) from a larger number of quarries have been studied in a viscometer (Contec 4-SCC) suited for coarse particle suspensions. The effect of fines content, specific surface, mineralogy and particle shape was studied [4]. The particle shape was shown to mainly influence the plastic viscosity of the mortar, while the correlation with the yield stress was poor (Figure 1). However, the yield stress of the mortar was shown to increase linearly with the content of fines, due to the increase in total surface area of the aggregate.

In conclusion, the studied mortars with crushed aggregate (similar grading) have a higher water demand mainly due to their different particle shape.

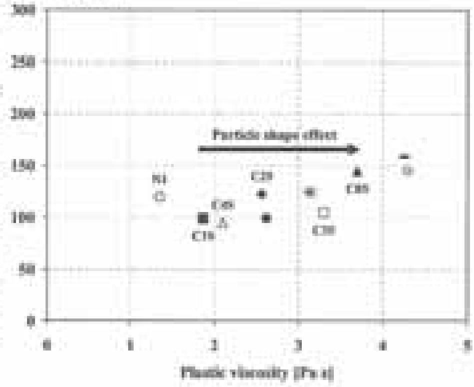

Figure 1. Rheology of mortars containing crushed aggregate with similar grading.

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Concrete Café 2
Binders

Replacement of Cement by Limestone Filler: The Effect on Chloride Penetration in Cement Mortars

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Key words: chloride diffusion, cement, limestone filler.

1. INTRODUCTION

This paper present a further investigation carried out to examine the effect on the chloride penetration in mortars when a certain amount of the cement is replaced by limestone filler, or when limestone filler is added without changing the cement amount. This study is a part of a larger investigation, where other decisive factors concerning chloride-induced reinforcement corrosion, such as, threshold values for chlorides and corrosion rates are studied.

Chloride penetration results from accelerated laboratory experiments previously reported by the author [1], showed that limestone filler can exhibit a detrimental effect on chloride penetration. Other researchers have reported similar observations [2, 3].

2. RESEARCH SIGNIFICANCE

Use of limestone filler in combination with Portland cement is common practice in many countries. Most of the research have emphasised on the effect of limestone filler on the hydration reaction and strength development. The work described here is a contribution to increase the knowledge of the durability effects of limestone addition in mortars and concretes.

3. METHOD

All experiments were performed on mortars samples, material constituents and mix proportions are described in [1].

Chloride diffusion was measured both at the laboratory and at the field. The diffusion cell test method was used for the diffusion laboratory tests. From this kind of test both the effective, $D_{eff,}$ and apparent, $D_{app,}$ diffusion coefficient can be measured.

The field trials were carried out by measuring the chloride penetration profiles of specimen submerged in the sea for about three years. By curve fitting the measured chloride profiles with the error function solution to Fick´s 2nd law, the chloride diffusion coefficient, D_{app}, was estimated.

4 RESULTS

The measured diffusion coefficients for some of the mortars tested, with the associated coefficient of efficiency, *k*, for the mortars containing limestone filler are shown in Table 1. The coefficient of efficiency is a measure of how much of the limestone filler that contributes to a binder effect [1].

Mortars OPC0.5 and OPC0.7 consist of ordinary Portland cement with a water/cement ratio of 0.5 and 0.7. The mortars LR12%, LR24% and LA24% were identical with the reference mortar OPC0.5, with the exception that 12% and 24%, respectively, of the ordinary Portland cement was replaced by limestone filler for LR12% and LR24%, and in the case of LA24%, 24% limestone filler was added to the reference mortar OPC0.5.

Table 1 – Diffusion coefficients and coefficients of efficiency

Mortar	Field		Laboratory		Laboratory	
	D_{app} x10^{-12} m^2/s	*k*	D_{eff} x10^{-12} m^2/s	*k*	D_{app} x10^{-12} m^2/s	*k*
OPC0.5	5.1		3.9		8.42	
OPC0.7	18.1		6.8		21.4	
LR12%	8.4	0.7	3.4	1.7	11.2	0.4
LR24%	13.0	0.2	5.2	0.6	16.4	0.2
LA24%			2.8	0.7	8.07	0,1

In the apparent diffusion coefficient both the ability to bind chlorides and the denseness of the mortar are included, while the effective diffusion coefficient is a measure mainly of the mortars denseness. According to the results in Table 1, the limestone filler has a more favourable influence on the effective diffusion coefficient compared to the apparent diffusion coefficient. The apparent diffusion coefficients measured at the laboratory and from the field exposure deviates from each other, but not so much as would be expected considering the differences in the exposure conditions. The k-values are in close range for both apparent diffusion coefficients.

5 CONCLUSIONS

No negative effect was observed in this investigation on the chloride resistance by incorporating limestone filler in the mortars.

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Alternative Pozzolans as Supplementary Cementitious Materials in Concrete

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Key words: Concrete, cement, pozzolans

1. INTRODUCTION

This paper summarizes a State of the art report on alternative pozzolanic materials. The gained experience form the state of the art report will be used in the further research and work within COIN (Concrete Innovation Centre).

2. RESEARCH SIGNIFICANCE

Environmental concerns both in terms of damages caused by the extraction of raw material and CO_2 emissions during cement manufacture have brought about pressures to reduce cement consumption by use of supplementary materials. In addressing environmental problems and economic advantages, mixtures of Portland cement (PC) and pozzolans are very commonly used in concrete production. This report investigates the opportunities of using materials like calcined clay, light weight aggregate fines, rice husk ash, nano-silica and ground glass as alternatives to the more common pozzolans fly ash, slag, metakaoline and silica fume.

3. RESULTS AND CONCLUTION

Calcined clay seems to be the most promising alternative pozzolan due to the availability in large quanta and relatively cheap price. However, the mineralogy of clays varies a lot, which may influence the reactivity. Clays are rarely found separately and are usually mixed with other clays and with microscopic crystals of carbonates, feldspars, micas and quarts. The calcining temperature and time of clays are crucial, as well as the total content of silica, alumina and iron oxide, in affecting the pozzolanic reactivity of the resulting product. The clay becomes most reactive when the calcining temperature (optimum 700-800 °C) leads to loss of hydroxyls and results in collapsed and disarranged clay structure. Calcined clay seems the most interesting one to focus on in further research both due to the overall availability and low price. The pozzolanic activity depends on the distribution of minerals in the clay and efforts should be taken in finding a few good sources.

Light weight aggregate (LWA) fines consist of clay being burnt to a temperature where sintering and formation of glassy aluminosilicate have occurred. LWA fines ground to 5-10 µm posses a reasonable good pozzolanicity enhancing the durability of concrete when replacing cement. Grinding can however be costly and calcined clay may thus be a better option. Rice husk ash (RHA) is highly pozzolanic and improves both strength and durability of the concrete. Rice husk (RH) consists of about 40 % cellulose, 30 % lignin and 20 % silica, and RHA (14-20 % of RH) contains a large amount of silica (90 %). RHA may be given different chemical and mechanical treatments to improve performance. A cellular microstructure is produced when RH is burnt at temperatures 550-700 °C. This results in a high water demand. Rice husk ash is also of interest as alternative pozzolan, but its availability seems to be concentrated in India and South-East Asia. However, this does not need to be a too big draw-back for international active businesses. Rice husk ash may benefit from some further processing before being used successfully in concrete as an active pozzolan enhancing both strength and durability. Rice husk ash is highly pozzolanic and improves both strength and durability of the concrete.

Nano-silica improves strength and permeability in relative small dosages (0.5-3 % of cement). Nano silica may give important improvement in concrete properties when added well dispersed as for instance as a suspension and not dried particles. Nano silica seems to be an expensive way of obtaining properties that may be achieved by cheaper means and is thus not recommended to look further into. However, an eye should be kept on on-going international research.

Ground, recycled glass seems not to be of interest as an alternative pozzolan for concrete since the reactivity is too slow, but it may be beneficial for rheological properties since it decreases the water demand of concrete. The pozzolanic activity might be increased by finer grinding.

4. PROJECT DATA AND FINANCIAL SUPPORT

COIN – Concrete Innovation Centre – is one of 14 Norwegian Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology (NTNU) and industry partners work in the COIN projects (presently 5 projects). COIN involves moreover 15 - 20 PhD-students, 10 - 20 M.Sci-students and international guest researchers. The research covers a wide range of research topics wherein alternative pozzolans is one of them.

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For more information, log on to www.sintef.no/coin

Comparing Intergrinding and Separate Grinding of Blended Cements

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Key words: separate grinding, intergrinding, multiple component cement

1. INTRODUCTION

This paper gives a brief overview on the findings from the state of the art on intergrinding versus separate grinding of blended cements. A good understanding of the grinding technology is one of the first steps in the development of a multi-component cement. The overall goal is to compose an all-round Portland-composite cement in which at least 30% of the clinker is replaced by supplementary cementitious materials, such as fly ash, granulated blast furnace slag, natural pozzolanas, limestone, etc. Grinding is an important element within the design of such a cement.

2. LITERATURE STUDY

Whether separate grinding or intergrinding is preferred depends on the type of supplementary materials used, their replacement levels, the necessary fineness and on the required strength and durability properties of the blended cement. The main difference between intergrinding and separate grinding of a multi-component cement is that during intergrinding the different components interact with one another. The interactions between the constituents are mostly due to the relative difference in grindability.

In a two-component system some general trends have been observed. In the early period of grinding (at low fineness), the harder component will enrich in the coarser fraction and the softer will dominate the finer fraction of the particle size distribution (PSD). The harder component stays coarser and abrades the softer one. The softer component will get a wider PSD and the harder one will get a narrower PSD. Upon progressed grinding the breakage of the harder component starts and it approaches gradually the smaller and softer ones. As a result, it has been seen that after a considerable time of grinding or at a high fineness, the difference between intergrinding and separate grinding is less than when compared in the early stage of grinding or at low fineness. In three or four component systems the interactions are more complex.
It should be noted that the PSD of the powder after grinding is strongly dependent on the type and the size of the mill.

The interactions between the different components might both reduce or lengthen the necessary grinding time to obtain a certain fineness, or even make it impossible to reach a certain fineness for one of the components by for example one component shielding another.

3. CONCLUSIONS

Based on the findings from the state of the art, it was decided to grind the materials separately in the first stage of the practical study in developing a ternary blended cement. In this way the influence of the fineness of the different components on the cement properties can be well controlled and studied systematically. In this stage grinding will be performed with a laboratory mill of 10 kg capacity. It must be kept in mind that the resulting powder will differ both in PSD and in chemistry from the powder which would be obtained with a full-scale mill.

Whether intergrinding or separate grinding will be chosen for actual production depends on whether it is possible to obtain the desired finenesses of all the components with intergrinding. If not, one or more components could be ground separately. Besides technical feasibility, one should also compare the energy and time demand of both procedures, and the availability and/or cost of infrastructure.

4. PROJECT DATA

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The Reactivity of Fly Ash and Limestone in Cementitious Systems

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Key words: Portland-composite cement, fly ash, limestone.

1. INTRODUCTION

Due to the increasing environmental awareness and diminishing natural resources, there is a growing interest in all-round composite cements in which considerable parts of the clinker are replaced by for example slag, fly ash or limestone. Of particular interest are the ternary cements consisting of clinker and a combination of two of the above named replacement materials. Combining them makes it possible to compensate for their individual disadvantages. This paper gives a brief overview on the findings from two state of the art reports on both fly ash and limestone replacements, and their combination.

2. LITERATURE STUDY

Fly ash reacts relatively slow in combination with ordinary Portland cement. In order to have sufficient early strength development at high replacement levels, different activation options were looked into. A literature review showed that the reactivity of fly ash in combination with clinker strongly depends on the replacement level, water/binder ratio, alkalinity of the cement and curing temperature. The reactivity of fly ash can be improved by mechanical activation and classification. The reactivity seems to be exponentially related to the fineness of the fly ash particles. When discussing chemical activation, it is clear that alkalinity plays a principal role. If the pH of the pore water stays below the 13.3 level, fly ash will hardly react at room temperature. Calcium hydroxide saturation only results in a pH of approximately 12.5. Concentrated NaOH and KOH solutions on the other hand were clearly able to boost the hydration of fly ash. Cement kiln dust (CKD) and sulphates, such as gypsum and sodium sulphate, were tested as activators. The results differed quite a lot as the effect of activators depended on the type of fly ash it was combined with.

Limestone filler addition accelerates the hydration of cement, or more precisely the C_3S phase, by acting as nuclei for CH and CSH precipitation. This accelerating effect gives rise to higher compressive strength at early age, and shorter initial and final setting times. Limestone fillers with a higher fineness have the strongest effect. Part of the $CaCO_3$ interacts with the hydration products. The reaction mechanism of C_3A is changed and calcium carboaluminates form in competition with calcium sulphoaluminates. The hydration of C_3S in the presence of carbonate results in the formation of calcium carbosilicate hydrates.

3. CONCLUSIONS

When developing an all-round blended cement certain constraints are given. The cement has to have a satisfactory strength development between the temperature limits of 5 °C and 30 °C and for a certain water-binder ratio. The fly ash and the limestone filler content have to be optimized with regard to strength. Limestone filler accelerates the early hydration, and fly ash contributes to later strength development due to its pozzolanic reactivity.

A very interesting research topic, concerning ternary cements containing limestone and fly ash, is the interaction of the aluminate phase of fly ash and calcium carbonate of the limestone. The aluminate content of fly ash generally ranges between 20 and 30 %. This is considerably higher than aluminate content of ordinary Portland clinker which is about 4-6 %. The additional amount of aluminate provided by the fly ash could interact with sulphate or carbonate, and form extra binder phase, in the form of calcium carboaluminate hydrates or calcium sulphoaluminate hydrates. These phases could densify the matrix and might contribute to improved durability and/or strength. The fineness of the limestone powder and the fly ash, the ratio between gypsum and limestone powder, and the activation of the fly ash to promote the liberation of aluminate are key parameter in this research topic.

4. PROJECT DATA

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Development of New High Performance Supplementary Cementing Materials

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Keywords: alternative materials, silica fume, requirements.

BACKGROUND

Elkem as Materials is the largest provider of silica fume. The product finds use in several special niches of high performance concrete production, and the global consumption has grown steadily. Today, we estimate that more than 400 000 metric tons are used in concrete – which incidentally corresponds to more than 10 million cubic meters of concrete per annum.

The encouraging developments are, however, marred by clouds – on the horizon, and recently giving problems:

- As too many of customers have experienced, silica fume is a by-product, and production is tied to the profitable production of silicon and ferrosilicon. Such production is particularly at risk in periods with high energy prices – which has happened twice in the last 5 years.

- Also, for the same reason, the availability of silica fume is limited to that which corresponds to the global demand and production capacity for the main products.

ACTIONS INITIATED

In order to look to the future, it has been found useful to look at alternative materials – materials that meet the following criteria:

- They should give performance enhancement that is significantly better than traditional large volume SCM's (e.g. fly ash and GGBS) – approaching that of silica fume.
- They should (eventually) be available in volumes measured at least in millions of tons per annum.
- They should provide support for reduced need for clinker – i.e. reduced CO_2.
- There should be no health issues with the product (in particular crystalline silica).

Elkem as Materials has embarked on this process. Obviously, the specifics of the selection and testing cannot be given here. The presentation will give some more information, including some technical, on this important subject.

The Use of Sludge Incinerator Ash in the Production of Concrete

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Key words: Sludge incinerator ash, full scale production, colour, leaching, durability

1. INTRODUCTION

Incineration of sludge from biological wastewater treatment plants (WWTP) leaves a fine granular waste material. Approximately 10,000 tons of sewage sludge incinerator ash is produced annually in the Copenhagen area by two incineration plants. The sludge incinerator ash (bio ash) represents an environmental problem as it is typically land-filled.

For the potential use of bio ash in concrete a number of barriers exist relating to the lack of documentation of the influence of the ash on concrete properties. To aid in establishing the required documentation of the use of bio ash in concrete a 2½ year project supported by the EU's LIFE programme was carried out.

The project has comprised documentation of variations in the chemical and physical properties of the bio ash over an extended production period, laboratory testing to document the influence of ash property variations on the properties of fresh and hardened concrete including evaluation of the leaching of heavy metals from bio ash concrete, and finally evaluation of full-scale daily production of bio ash concrete.

2. RESEARCH SIGNIFICANCE

In Denmark the use of bio ash is allowed in exposure classes X0 and XC1, if the chemical parameters, density and loss on ignition are declared using the test methods provided in EN 450-1. (Suitability is established by national provisions). If the possible use of ash in concrete is increased to include more severe exposure classes, the amount of waste for disposal can be reduced. The results from this project can be used in the further work regarding the regulation of the use of bio ash in the standards.

3. METHOD

In order to provide the necessary documentation to overcome the barriers for extensive use of bio ash concrete, the project was executed in two major phases:

- Design, construction, implementation and use of systems required for full-scale production of bio ash concrete – as these systems did not exist at the start of the project. Full scale production tests were made, consisting of activities relating to the design and delivery of bio ash concrete including extended testing and follow up on the execution experiences during casting of the concrete.
- Tests in the laboratory and in the field of the properties of the bio ash and bio ash concrete. The test included chemical and mineralogical analyses of the ashes, accelerated durability tests and leaching tests of concrete designed to meet the demands for all exposure classes (divided in 3 groups, as described in the Danish standard DS 2426).

4. RESULTS AND CONCLUSIONS

The results from the tests show that there is a significant difference in the particle size distribution from the two WWTPs due to their different types of incinerators. The ash from the fluid bed oven has approximately 40 weight-% particles larger than 125 µm, where the ash from the conventional multiple hearth furnace is much coarser; with approx. 65 weight-% larger than 125 µm. This ash could not readily be used as a powder in concrete, but was ground down in order to perform laboratory scale testing.

Bio ash is red resulting from the iron used to precipitate phosphorus during the wastewater treatment. Consequently, bio ash concrete also has a reddish gray colour that when used in visible constructions next to "normal gray concrete" results in a distinct undesirable difference in colour, which is one of the main barriers to more extended use of bio ash concrete. In concrete with as little as 7% red bio ash of cement weight, the colour of the concrete is still affected. However, when aluminium is used for precipitation of phosphorus instead of iron, the colour of the ash is lighter and less red. Preliminary results show that to avoid influence on colour only small amounts of bio ash can be used in concrete (300 kg of CEM I + coal fly ash pr. m^3), i.e. 20 – 40 kg/m^3 for light colour bio ash and only 5 – 10 kg/m^3 for red colour bio ash.

The results from establishing the ash handling facilities at the WTTPs and the ready mix plants show that the ash can be handled as any other powder material. The tests from full scale concrete production show that bio ash has a negative effect on the workability and setting time of fresh concrete. However, it was possible to replace 50% of the coal fly ash and obtain reasonable fresh concrete properties while sustaining the economy of the mixture.

With respect to the hardened concrete properties the accelerated durability and leaching tests showed little or no difference between the reference concretes and the bio ash concretes.

5. FINANCIAL SUPPORT AND PROJECT DATA

The project is partially funded by the EU LIFE-Environment programme. The project period was from June 2005 to December 2007. The partners involved in the project were: Avedøre Spildevandscenter I/S, Lynettefællesskabet I/S (wastewater treatment plants with sludge incineration) and rmc producer Unicon A/S with Danish Technological Institute as consultant.