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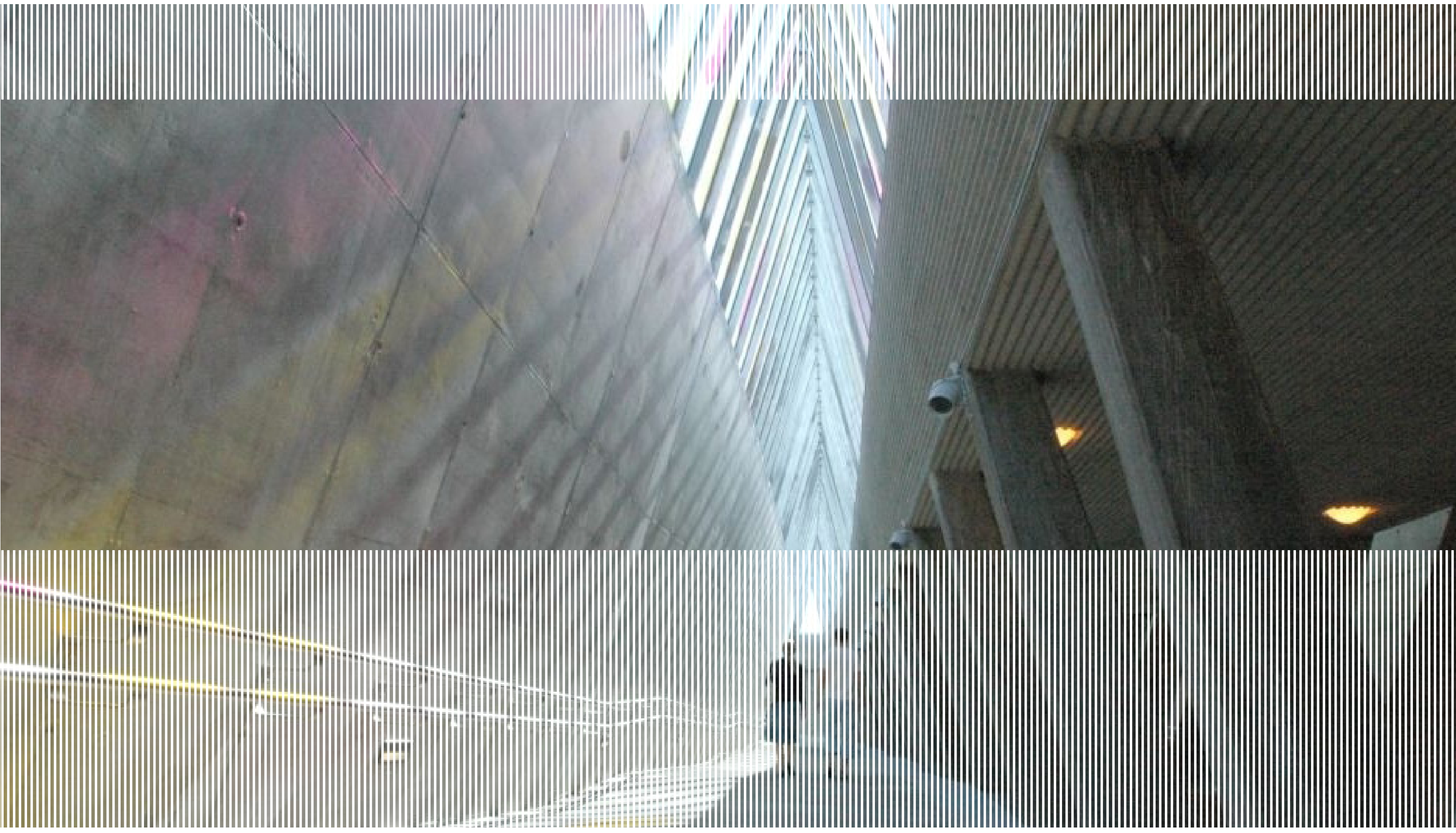
SINTEF Building and Infrastructure Gunrid Kjellmark (editor)

Concrete innovation in Norway 2007–2014, COIN Final Seminar, Trondheim, Norway, 2–3 December 2014

COIN project report 82 – 2015



SINTEF Building and Infrastructure

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COIN Project report 82 – 2015

COIN Project report no 82
Gunrid Kjellmark (editor)
Concrete innovation in Norway 2007–2014, COIN Final Seminar, Trondheim, Norway 2–3 December 2014

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Preface

This study has been carried out within COIN - Concrete Innovation Centre - 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.

The vision of COIN is creation of more attractive concrete buildings and constructions. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life. The primary goal is to fulfil this vision by bringing the development a major leap forward by more fundamental understanding of the mechanisms in order to develop advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

The corporate partners are leading multinational companies in the cement and building industry and the aim of COIN is to increase their value creation and strengthen their research activities in Norway. Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

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, work on presently eight projects in three focus areas:

- Environmentally friendly concrete
- Economically competitive construction
- Aesthetic and technical performance

COIN has presently a budget of NOK 200 mill 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 %).

For more information, see www.coinweb.no

Tor Arne Hammer
Centre Manager

Summary

COIN was initiated as a Centre for research based innovation (SFI) by The Research Council of Norway. The COIN-programme started in 2007 and lasted for eight years and ended in 2014.

A closure seminar was arranged in Trondheim 2 and 3 of December 2014 to mark the end of this period and to present results from the research, focusing mainly on its usefulness.

This report assembles the presentations from these two days.

Table of contents

1 Introduction

December 2nd 2014

Chairman: Tor Arne Martius-Hammer

12.00 – 12.10	**Welcome**	*Tor Arne Martius-Hammer, COIN's centre manager*
12.10 – 12.20	**Introduction**	*Terje F. Rønning, COIN's chairman of the board*
12.15 – 12.30	**About COIN**	*Einar A. Hansen, COIN's originator*

COIN

Betonginnovasjon i Norge

Resultater fra forskningssenteret COIN (2007–2014)

SINTEF

SINTEF

COIN – Partners

The Research Council of Norway

Present Partners:

KVÆRNER, MAPEI, NORCEM HEIDELBERGCEMENT Group, SINTEF, NTNU, SKANSKA, Statens vegvesen, unicon CEMENTIR HOLDING, VEIDEKKE, weber SAINT-GOBAIN

Sub-contractors:

HEIDELBERG TECHNOLOGY CENTER, metso, NORSTONE HEIDELBERGCEMENT Group, VELDE, ReforceTech

Past Partners:

Borregaard LignoTech, Spenncon

SINTEF

Financing

Total: NOK 250 mill

RCN: NOK 76 mill

Partners: NOK 30 mill in cash
NOK 140 mill in-kind

SINTEF

PhD-students - status Dec 2014

Name	FA	Subject	Start	End/ Defence
Klaartje de Weerdt	1.1	Cements with low CO2 outlet	Jan 2007	Feb 2011
Ueli Angst	3.2	Modelling critical chloride content and corrosion proc.	Apr 2007	May 2011
Sindre Sandbakk	2.2	Fibre reinforced concrete	Aug 2007	Nov 2011
Håvard Nedrelid	3.3	LWAC – testing and modelling	Jan 2007	Apr 2012
Kien Hoang	1.2	Controlling hydration development	Aug 2009	Dec 2012
Markus Bernhard	3.3	Development of super LWA	Aug 2010	Aug 2013
Linn Grepstad	3.3	Hybrid structures	Sep 2007	Sep 2013
Jan Lindgård	3.2	AAR: Lab. testing vs field performance	Jan 2007	Oct 2013
Ya Peng	2.1	Rheology and stability of concrete	Apr 2010	Mar 2014
Egil Møen	3.3	Ice abrasion	Aug 2007	Mar 2015
Giedrius Zirgulis	2.2	Fibre	Sep 2010	Mar 2015
Mahdi Kiumarsi	3.2	Structural effects of reinforcement corrosion	Aug 2011	Mar 2015
Rolands Cepuritis	2.3	Industrially produced aggregates	Aug 2011	Nov 2015
Karla Hornbostel	3.2	Electrical resistivity	Nov 2009	Oct 2015
Anja B. E. Klausen	3.1	Crack-free concrete structures	Oct 2009	Oct 2015
Elena V. Sarmiento	2.2	Flowable concrete/ fibre concrete	Aug 2011	Oct 2015

SINTEF

Did we reach the goals?

The RCN-application:

"The vision of COIN is creation of more attractive concrete buildings and constructions. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialised construction, improved work environment, and cost efficiency during the whole service life.

The centre will strive to fulfil this vision by developing advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production".

SINTEF

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COIN

Did we reach the goals?

CRI-objectives:

- stimulate innovation through long-term research
- attract research activities to Norway
- create an active co-operation between industry and research institutions
- promote development of internationally leading research environments
- stimulate education of researchers in important fields for the industry

SINTEF sfi

COIN

Results – reported in nearly 150 scientific publications

- Products
- Patent
- Guidelines
- Simulation tools
- Test methods
- Workshops/conferences

SINTEF sfi

COIN Concrete Innovation Centre

CIC 2014

Concrete Innovation Conference

- "Belite calcium sulfoaluminate ternesite (BCT)" – a new environmentally friendly binder, by HeidelbergCement Technology Center in Germany
- "Smart dynamic casting" – robotized casting of complex concrete elements, by ETH Zürich
- "ZÜBLIN Earthquake Column" – a novel solution to design earthquake resistant columns, by Ed. Züblin AG, Germany
- "Climbing robot for corrosion inspection and monitoring" – a climbing robot for condition control, by ETH Zürich

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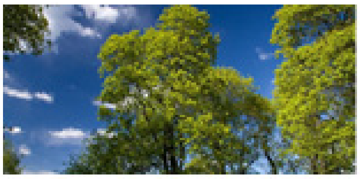
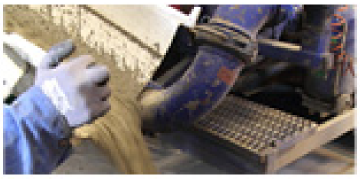
COIN

Focus Areas





1) Environmental friendly concrete structures

Binders with low emission and reduced resource consumption

Utilisation of concrete in low energy building concepts

2) Competitive construction

Stable and robust highly flowable concrete with controlled surfaces

High tensile ductile strength concrete

High quality manufactured sand for concrete

3) Technical performance

Crackfree concrete

Service life

Structural performance

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More information on www.sintef/coin.no

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COIN Seminar: Introduction

COIN December 2nd 2014 – Terje F. Rønning

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COIN "Assets"

- Research with innovation focus
- Addresses public & sector strategic agenda
- Joint venture Research & Industry :
- Mutual involvement = precondition for success
- Consortium > Value chain >> ∑ [single actions]
- External interest / publicity (From whom ..?)
- International levelling of research & Co-op.
- Public funding support
- Volume / Critical mass
- Ability to address flexibility & organisational issues
- Adequate support functions
- AND some challenges, but today we celebrate!

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All have their own agenda, but ....?

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General targets & functions

- Arena for innovation
  - Between Industry & Research & Education
  - Cross-enterprise joint venture
  - Enterprise AND Sector strategic issues
  - Value creation
- Arena for developing ORGANISATIONAL environment

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Arena for recruitment & education (PhD) development

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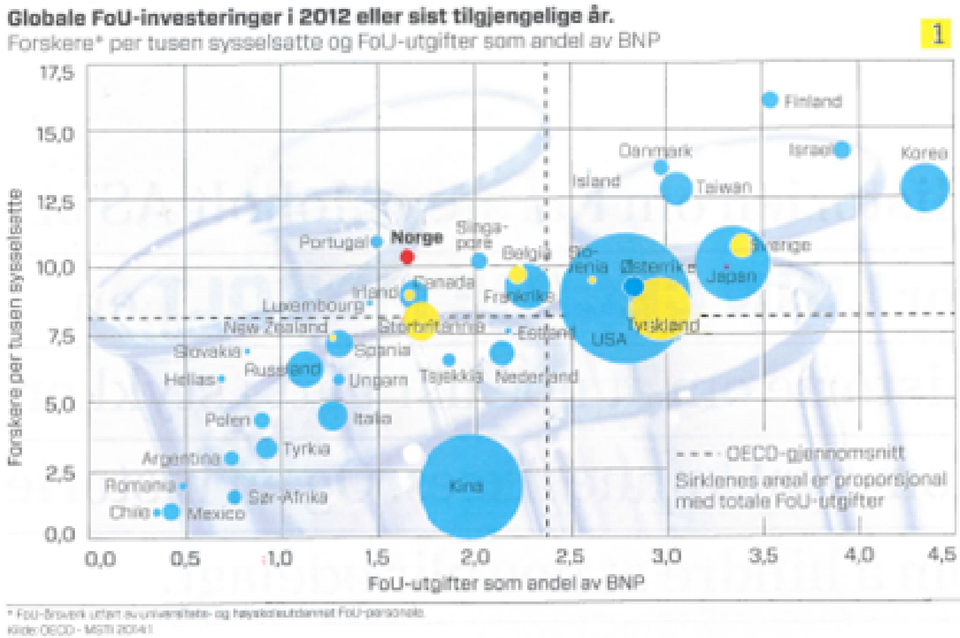
Nos. of researchers per 1.000 employees ....



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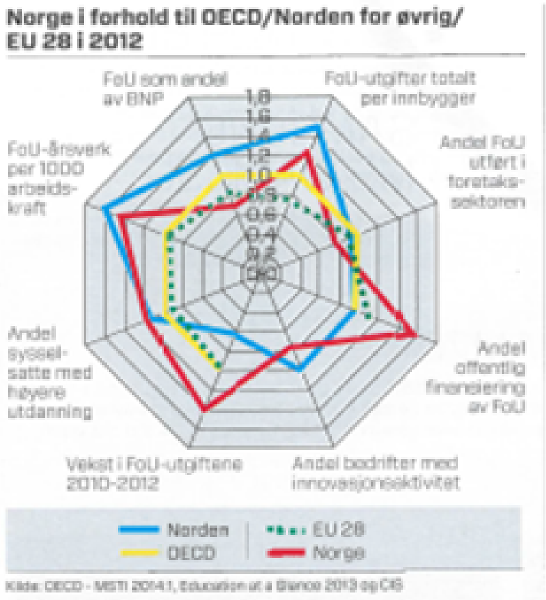
COIN Significance ?



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Industrialized Construction Sector

Can we manage .....

Industriell byggenæring?

Industrialisering må til for å bygge bedre og billigere – ikke bare for økt inntjening, men også for det samfunnsansvar vi som delvis skjermet næring har. Men kan byggenæringen bli industriell? Samlet er vi i dag ingen industri – vi er en næring med håndverkere forsøkt satt i system.

Øyvind Skarholt 30.08.2012 Adm. direktør i Byggevareindustriens forening

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Now – what ?

New arena for joint strategies discussions ?

- Interim group at work.
- Watch – Follow – Attend!

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Today

ENJOY
&
Pose questions

Thank you !

HEIDELBERGCEMENT

TRONDHEIM KOMMUNE

COIN - The Dream

Einar Aassved Hansen, City Executive Urban development
COIN Seminar "Concrete Innovation in Norway 2007- 2014"

1

COIN

Concrete anno 2004

- Low public image
- The industry talks about technology and volume sales – not addressing solutions
- Criticized for a lack of understanding of their customers needs
- *"We have made enough research – time to implement"*
- No funding from the Research Council

Yet:

- A major concrete research effort in the period 1980 – 2000
- Documented a yield rate of 19 on R&D investments (2002)
- Innovation can release a huge value creation potential (BAE-council, 2002)

- Concrete Day October 2004. Goal: pride, inspiration and motivation. The message: *"We have just started – the possibilities are endless"*

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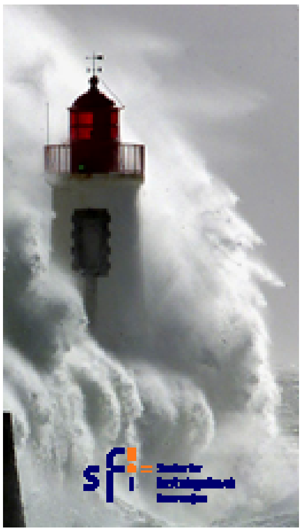
Winter 2005
The SFI Scheme is launched



Objectives:

1. Promote innovation by supporting long-term research
2. Make it attractive for enterprises that work on the international arena to establish R&D activities in Norway
3. Support close cooperation between R&D intensive companies and prominent research institutions
4. Promote the development of industrially oriented research groups that are on the cutting edge of international research
5. Stimulate researcher training in fields of importance to the business community

SINTEF

The birth of COIN

- Spring 2005: Design of overall objective and topics
- June 2005: Promoting the dream to Norcem and NTNU
- Summer 2005: Discussion with companies; participation and R&D strategies
- October 2005: SINTEF and NTNU Information Day – Final decision

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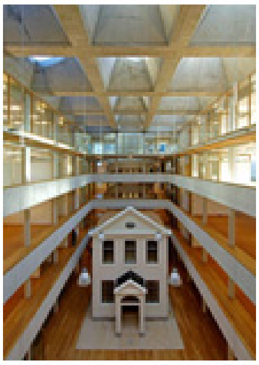
COIN

Attractive Concrete Buildings



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COIN

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- November 2005: Writing the application
- December 1st: Application sent on deadline

SINTEF

COIN

Vision of COIN

Attractive Concrete Buildings!

Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life.

The centre will strive to fulfill this vision by developing advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

SINTEF

COIN

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- October 2005: SINTEF and NTNU Information Day – Final decision
- November 2005: Writing the application in two weeks
- December 1st: Application sent on deadline

- Winter 2006: Promoting COIN in conferences, seminars etc.
- June 16th 2006: COIN announced as SFI

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COIN

15 januar 2007 - Kick-off

Dag Kavlie,
Norwegian Research Council:

"It caused enthusiasms in the international evaluation committee by such a vigorous application from a traditional field like concrete."

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COIN

Lessons learned

- Research must be a long-term strategic investment rooted in the company management
- The research groups must be on the cutting edge of international research
- The companies should cooperate and concentrate their research contributions to SINTEF and NTNU
- SINTEF and NTNU need to demonstrate added value from research

The future:

- The competition in the marked will be even tougher
- The industry need to increase their research efforts in order to be in front

SINTEF

2 Technical performance

December 2nd 2014

Chairman: Tor Arne Martius-Hammer

Crackfree concrete structures

12.30 –	**Introduction**	*Øyvind Bjøntegaard (Norwegian Public Roads Administration)*
	Test rig development	*Anja Estensen Klausen, PhD student (SINTEF/NTNU)*
– 13.15	**Crack TeSt COIN and education of the industry**	*Sverre Smeplass (Skanska)*

Reliable design and prolongation of service life

13.15 –	**Introduction**	*Mette Geiker (NTNU)*
	Alkali-silica reactions	*Terje F. Rønning (Norcem)* *Jan Lindgård (SINTEF)*
– 14.00	**Corrosion**	*Karla Hornbostel, PhD student (NTNU)*

Chairman: Ya Peng

Structural performance

14.15 –	**Ductility of lightweight concrete**	*Jan Arve Øverli (NTNU)*
	Ice abrasion	*Stefan Jacobsen (NTNU)*
– 15.00		

COIN P3.1 Crackfree Concrete Structures

A) Background / Usefulness
Øyvind Bjøntegaard, NPRA

B) Lab equipment (and tests/calculations)
Ph.D. Candidate Anja E. Klausen, NTNU/SINTEF

C) Implemetation and transfer of knowledge
- New program and course
Sverre Smeplass, Skanska Norge AS

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Background
– Earlier projects

- Earlier genuine Norwegian projects on **curing technology / "thermal cracking"**
  - NORCON 1993-1996 (NTNU)
  - NOR-IPACS 1996-2000 (Skanska),
  - NOR-CRACK 2001-2005 (NTNU)

  (supported by the Norw. Res. Council)
- Brite-EuRam project IPACS 1997-2001 (Scancem AB)
  - several Norwegian participants
- **COIN 3.1, 2007-2014 (Sintef Byggforsk)**

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

COIN

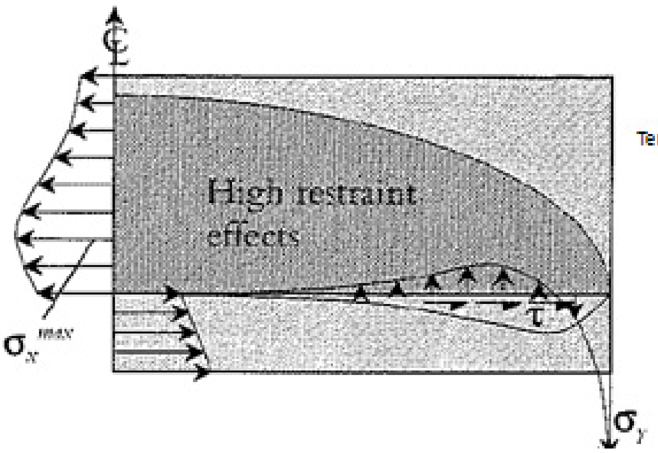
Background
– Norwegian Public Roads Administration (NPRA)

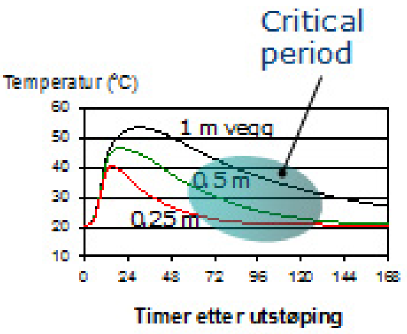
- We have participated in all the listed projects – why?
- We own today about 17.000 bridges, including submerged/underground culvert structures. In addition, supporting wall structures, and numerous other structures..
- Our structures are often massive and the exposure is generally severe (XD3, XS3) - meaning:
  - w/c < 0,40
  - high strength
  - high cement contents
  - significant heat of hydration and **high cracking tendency**

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

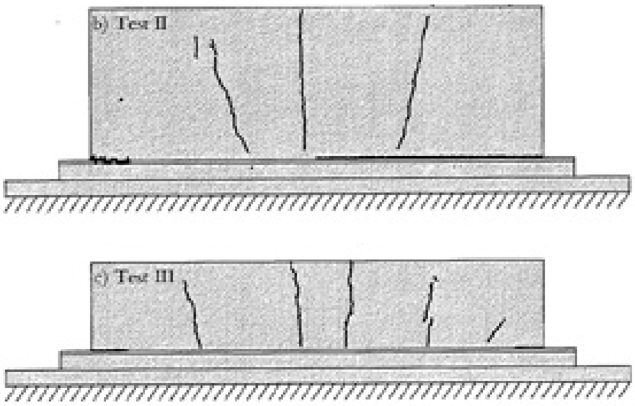
COIN

Background
– Volume changes and stress build-up in the hardening phase





SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures



Example of crack-pattern in walls due to
external restraint *from the bottom slab*

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Background
- what controls stresses and cracking

- **Hydration heat**
- Coefficient of thermal expansion
- Autogenous shrinkage
- E-modulus
- Creep/relaxation
- Tensile strength
- Temperature sensitivity
- Structural case (L/H-ratio, area of structural parts, etc.)

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Background
– Requirements to avoid/minimize thermal cracking

- ΔT

  (Limits on temperature difference between adjoining structures)

<u>For special cases</u>

- ΔT + Low-heat (LH) concrete
  - The definition of LH set by NPRA in an upcoming revision of Prosesskode-2 is directly taken from work in COIN 3.1
- Full crack-risk evaluation with advanced curing technology

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Active participants COIN 3.1 (2014)

- K O Kjellsen - NORCEM AS (manager sub-project 3.1)
- E Heimdal - Veidekke
- A Klausen - NTNU/SINTEF
- T Kanstad - NTNU
- G Kjellmark - SINTEF
- S Smeplass - Skanska
- Ø Sæther - Unicon
- N Al-Manasir - Mapei
- Ø Bjøntegaard - NPRA

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Reports

- Autogenous deformation and relative humidity – Concrete with Aalborg Portland cement and fly ash.
  - Kjellmark G, COIN report 24 - 2010.
- Basis for and practical approaches to stress calculations and crack risk estimation in hardening concrete structures, state-of-the-art report.
  - Bjøntegaard Ø., COIN report 31 – 2011
- Property development and cracking tendency in hardening concrete: Effect of cement type and fly ash content.
  - Bjøntegaard Ø. and Kjellsen K.O., COIN report 40 – 2012
- Temperature development in on-site curing boxes.
  - Klausen, A.B.E. and Bjøntegaard Ø., COIN report 2014 (In press)
- Crack-risk evaluated with Crack-TeSt COIN
  - Smeplass S., Berget O. ..., COIN-report 2014 (close to press)
- Mechanical properties and calculation of model parameters for concrete with variable fly ash content.
  - Kjellmark G., Klausen A., COIN-report 2014 (close to press)

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Conference papers

- **Updated Temperature-Stress Testing Machine (TSTM): Introductory tests, calculations and verification.** *Proceedings of XXII Nordic Concrete Research Symposium, Iceland 2014*
  Klausen, Anja Birgitta Estensen; Kanstad, Terje; Bjøntegaard, Øyvind.

- **Structural Analysis and Crack Assessment of Restrained Concrete Walls - 3D FEM-Simulation and Crack Assessment.** *Proceedings of Concrete Innovation Conference 2014 - CIC 2014, Oslo Norway.*
  Dirk Schlicke, Nguyen Viet Tue, Anja Klausen, Terje Kanstad, Øyvind Bjøntegaard.

- **On materials testing and crack risk evaluation of hardening concrete structures.** *Workshop Proceedings "Understanding the Fundamental Properties of Concrete" Celebrating Professor Erik J. Sellevold on his 75th birthday, 25th-26th April 2013, Trondheim, Norway.*
  Bjøntegaard, Øyvind; Klausen, Anja Birgitta Estensen; Kanstad, Terje.

- **Updated Temperature-Stress Testing Machine (TSTM): Introductory test results and determination of material properties development.** *Proceedings of XXI Nordic Concrete Research Symposium, Finland 2011.*
  Kanstad, Terje; Kjellmark, Gunrid; Klausen, Anja Birgitta Estensen; Bjøntegaard, Øyvind.

Memos

- **User-manual for the TSTM-system**
  Klausen, A B E (2014)

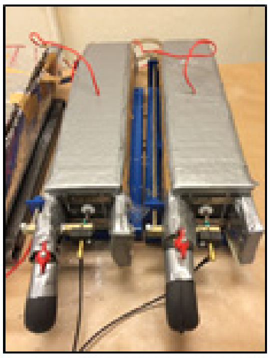
- **Autogenous shrinkage measured during different test series and projects 1996-2006**
  Bjøntegaard, Ø (2013)

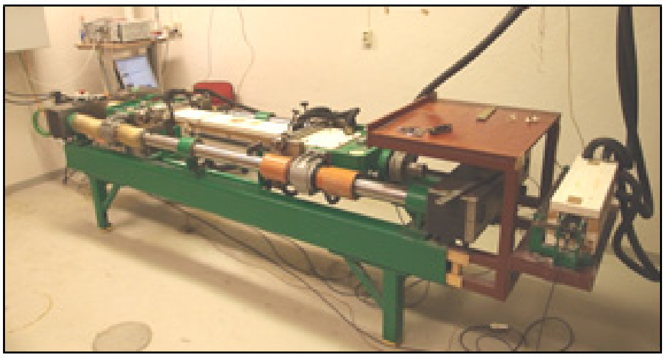
- **TSTM: Description of mode of action and algorithm for the new control system**
  Bjøntegaard, Ø (2009)

COIN

COIN P3.1 Crackfree Concrete Structures – Lab Equipment

The Free Deformation System
The Temperature-Stress Testing Machine





Ph.D. Candidate Anja E. Klausen, NTNU/SINTEF

Supervisor: Terje Kanstad, NTNU

Co-Supervisor: Øyvind Bjøntegaard, NPRA

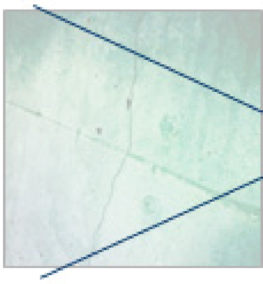
COIN

Content

- Background
- Lab Equipment
  - Free Deformation (FD) - System
  - Temperature-Stress Testing Machine (TSTM) - System
- Performed Tests and Calculation Approaches
- Results
- Conclusion

Background

- Early age concrete
  - Volum changes → Crack development



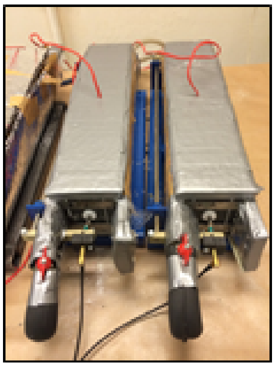
Problems;
- Functionality
- Durability
- Aesthetics
- Economical

How can we control/reduce crack development?:

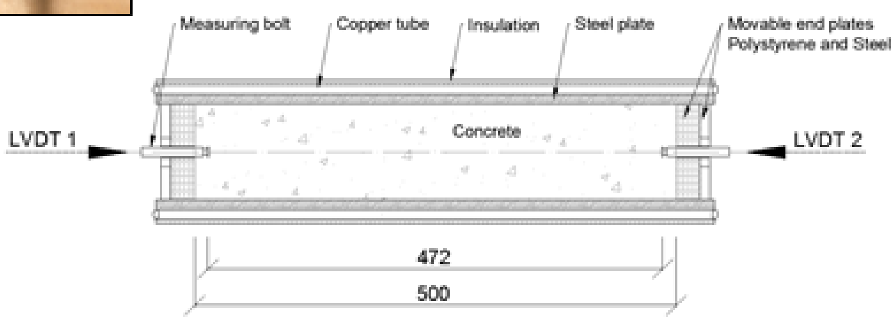
= Material properties + Pre-calculations

SINTEF COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

The Free Deformation System (FD-System)

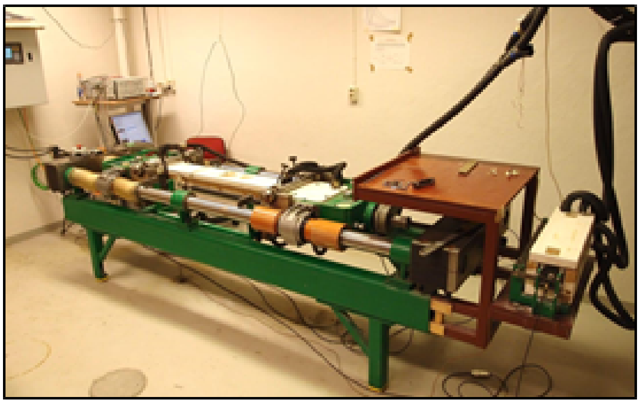


- Measures free deformation
  - Thermal dilation
  - Autogenous deformation
- 7 Rigs
- Temperature controlled



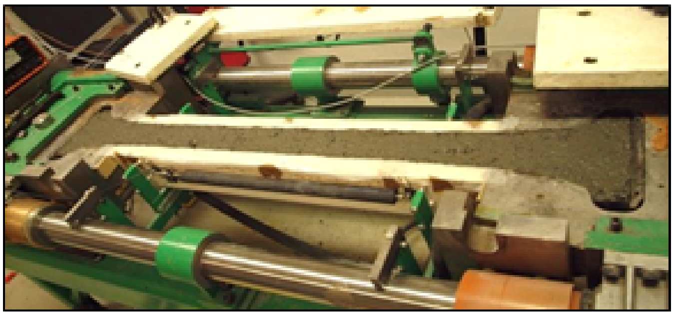
COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

The Temperature-Stress Testing Machine (TSTM) - System



Dilation Rig

Built in 1995, updated in 2009 - 2013



Temperature-Stress Testing Machine (TSTM)

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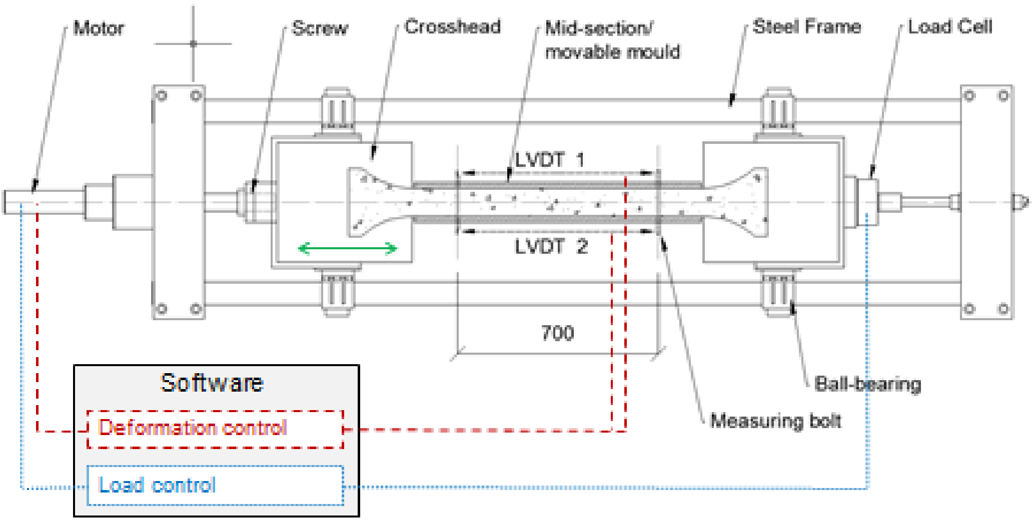
The TSTM



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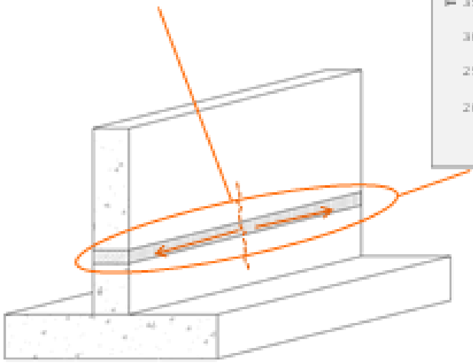
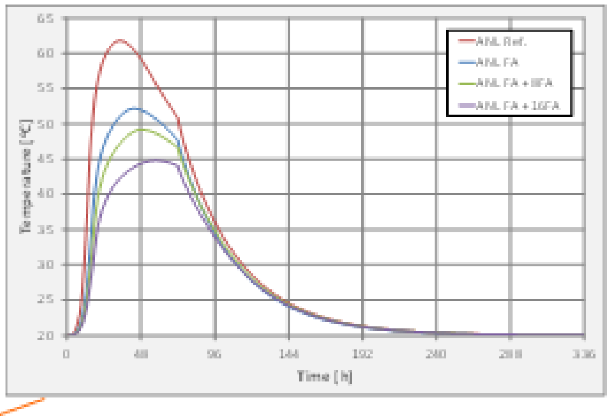
Temperature development

Degree of restraint, R





Performed Tests and Calculation Approaches

- Isothermal 20 °C, R = 100 %
- Realistic temperature development, R = 50 %
- Concrete:
  - Portland Cement
  - Water-to-binder (w/b) ratio 0.4
  - Varying amount of fly ash
- Calculations
  - Excel
  - CrackTeSt COIN
  - DIANA

COIN

Results

- Measured free deformation – Dilation Rig
- Measured stress development – TSTM
- Calculated stress development

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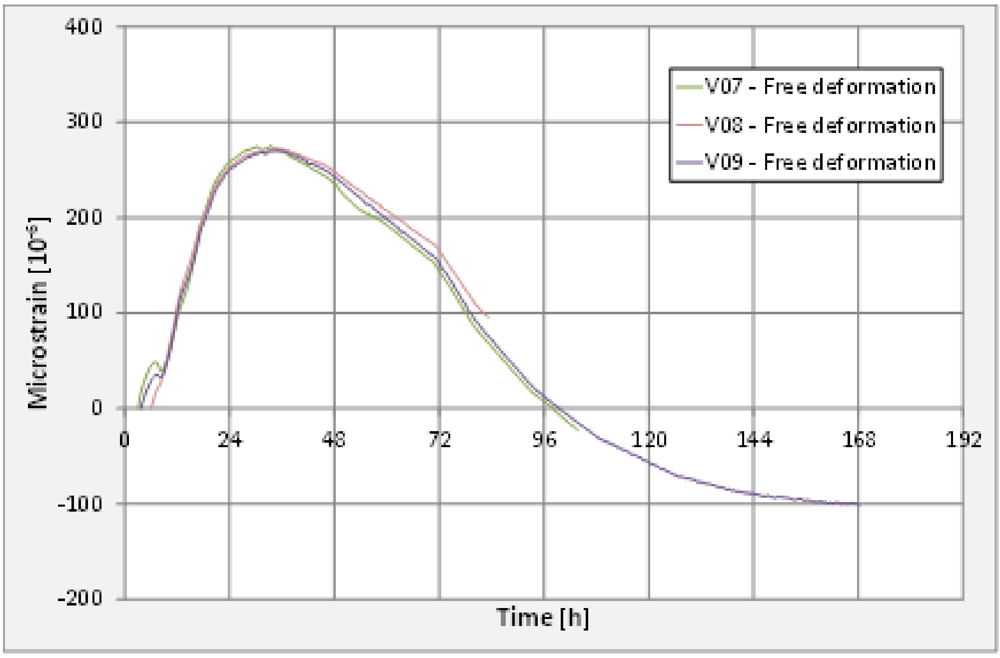
Measured free deformation

Realistic temperature development



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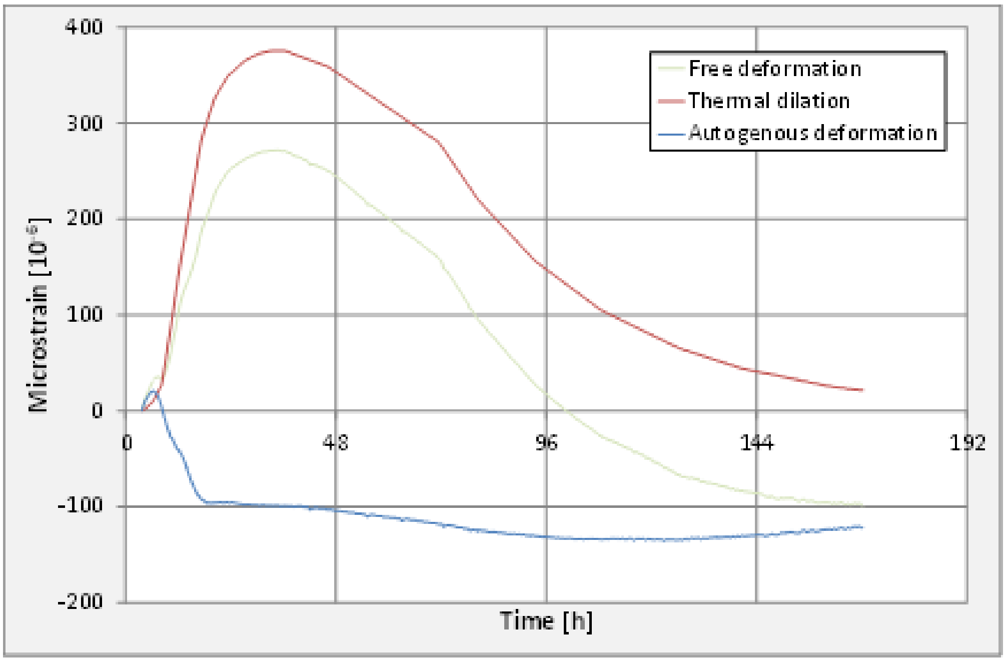
Measured free deformation

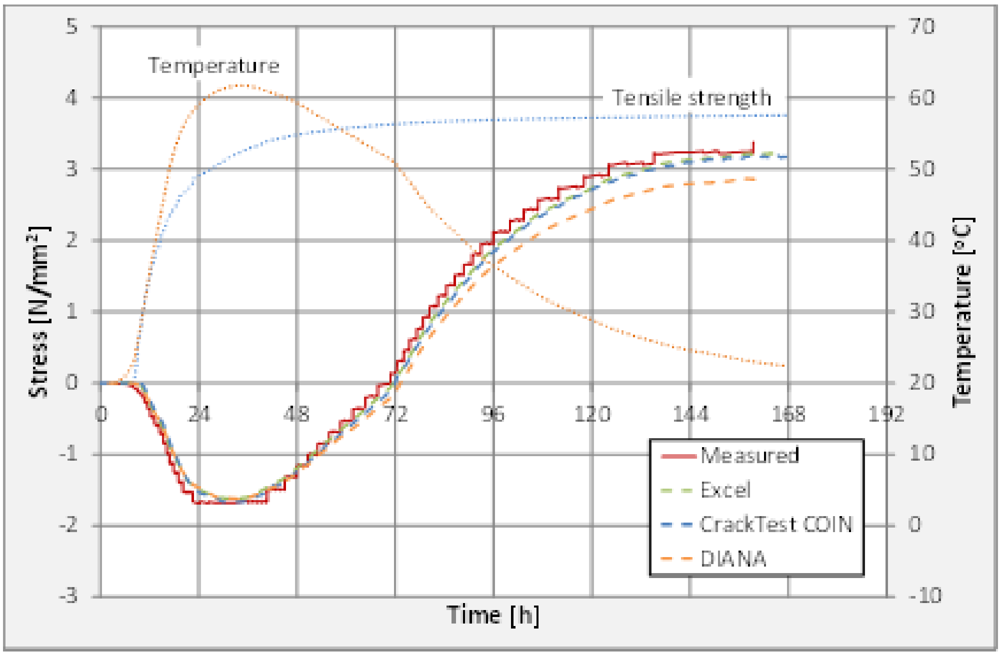
Realistic temperature development



COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Measured stress development, R = 50 %

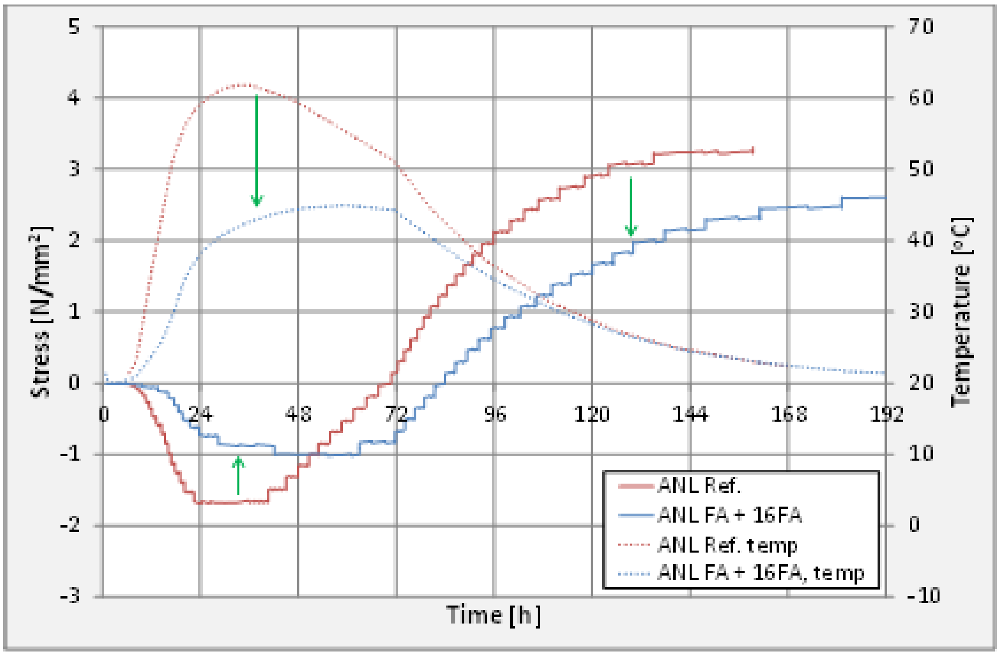
Realistic temperature development



COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Measured stress development, R = 50 %

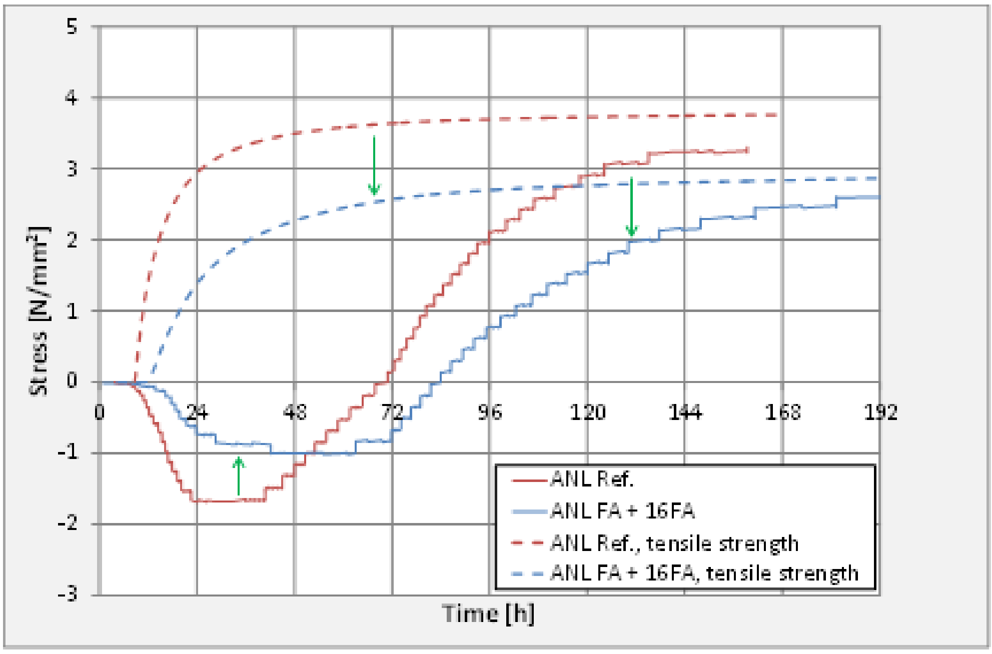
Effect of fly ash



COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

Measured stress development, R = 50 %

Effect of fly ash



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COIN

Conclusion

- The TSTM-System shows good reproducibility
- Measured stress development in the TSTM offer good agreement with corresponding calculated stress development
- Solid material knowledge based on materials testing in the laboratory, combined with reliable calculations (CrackTeSt COIN) makes us able to predict, and thus control, the crack risk in concrete structures caused by early age volume changes.

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COIN SKANSKA

One of the deliveries of COIN FA 3.1:

Crack TeSt COIN

2D tool for assessment of crack risk in massive structures subject to thermal restraint

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COIN

SKANSKA

SINTEF

COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

sfi

COIN

SKANSKA

SINTEF

COIN Seminar, December 2014: P3.1 Crackfree Concrete Structures

sfi

COIN SKANSKA

Crack TeSt COIN can be used to:

1. Improve structural design to avoid or limit thermal restraint effects
2. Detail contract specifications in order to avoid harmful cracking
3. Select the most suitable concrete mix design
4. Plan and select curing and protection measures, including insulation, heating and cooling
5. Documentation of obtained crack risk

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COIN SKANSKA

Implementation and transfer of knowledge?
-The Crack Test COIN course!

Target group for the CrackTeSt COIN course

1. Consulting engineers
2. Developers / Clients
3. Contractors
4. Material suppliers

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SKANSKA

Contents – CrackTeSt COIN course

1. Basic curing technology
   - Maturity principle
   - Material models
   - Thermal and autogenous restraint
   - Recognition of restraint cases
2. Introduction to software and data base
3. Training through case study – individual analysis and report
4. Discussion of results

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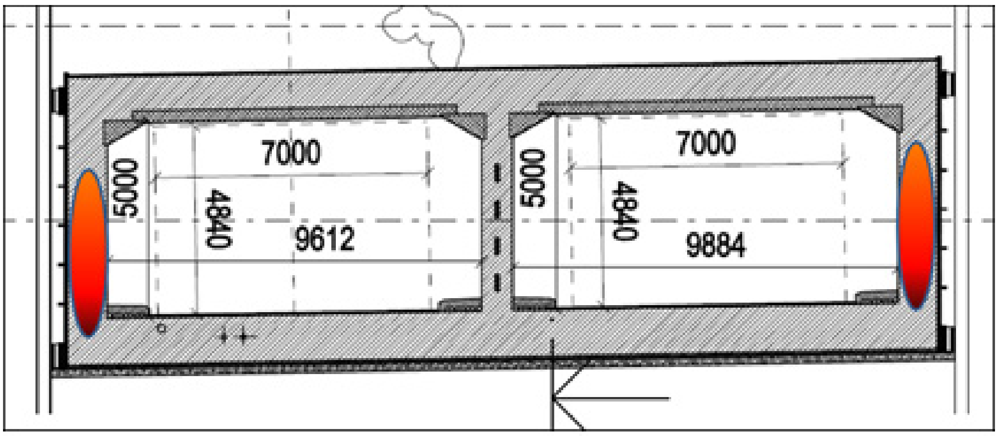
SKANSKA

CrackTeSt COIN course – case: *The Møllenberg tunnel (Trondheim)*



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COIN

SKANSKA

Status

- 1 course conducted, 2014 (Multiconsult and Veidekke)
- 1-2 courses planned, winter/spring 2015

Course committee:
Sverre Smeplass, Skanska
Terje Kanstad, NTNU
Øyvind Bjøntegaard, SVV/NPRA

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Further development

- More material data should be provided
- Mandatory use in SVV / NPRA projects?
- Other types of massive structures?
  - Railroad structures
  - Concrete dams
  - Harbour structures

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COIN Seminar

2nd and 3rd December 2014

Focus area 3.2
Reliable design and prolongation of service life (of concrete structures)

Mette R. Geiker
NTNU

COIN Final Seminar 2 and 3 December 2014 1

Focus Area 3.2
Activities

1. Modelling (see also 7)
2. Critical chloride content
3. Electrical resistivity
4. Alkali-silica reaction – Performance testing
5. Preventive measures
6. Residual Service life
7. Improved service life modelling of reinforced concrete structures
8. Impact of corrosion on structural performance

COIN Final Seminar 2 and 3 December 2014

COIN FA 3.2 – Activities

	Topics	PhD / Post Doc	Main partners	Visitors
1	Modelling		SKANSKA, SINTEF, DTU, Stanford	Alexander Michel Madeleine Flint
2	Critical chloride content	Ueli Angst	ETH	
3	Electrical resistivity	Karla Hornbostel	SVV, ETH	
4	Alkali-silica reaction – Performance testing	Jan Lindgård	NORCEM New Brunswick	
5	Preventive measures		SINTEF	
6	Residual Service life		SKANSKA SINTEF	
7	Improved service life modelling of reinforced concrete structures	Klaartje De Weerdt	SVV, DTU, DTI	Denisa Orsakova Arnaud Müller Ulla H. Jakobsen
8	Impact of corrosion on structural performance	Mahdi Kioumarsi		

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COIN FA 3.2
Publications and presentations

		Journal	Conference	Reports	Others
1	Modelling & general	6	6	4	4
2	Critical chloride content	9	6	0	6
3	Electrical resistivity	1	3	0	3
4	Alkali-silica reaction – Performance testing	5	4	2	11
5	Preventive measures	0	0	1	0
6	Residual Service life	1	0	1	0
7	Improved service life modelling of reinforced concrete structures	4	8	0	3
8	Impact of corrosion on structural performance	1	2	0	0
	Total	27	29	8	27

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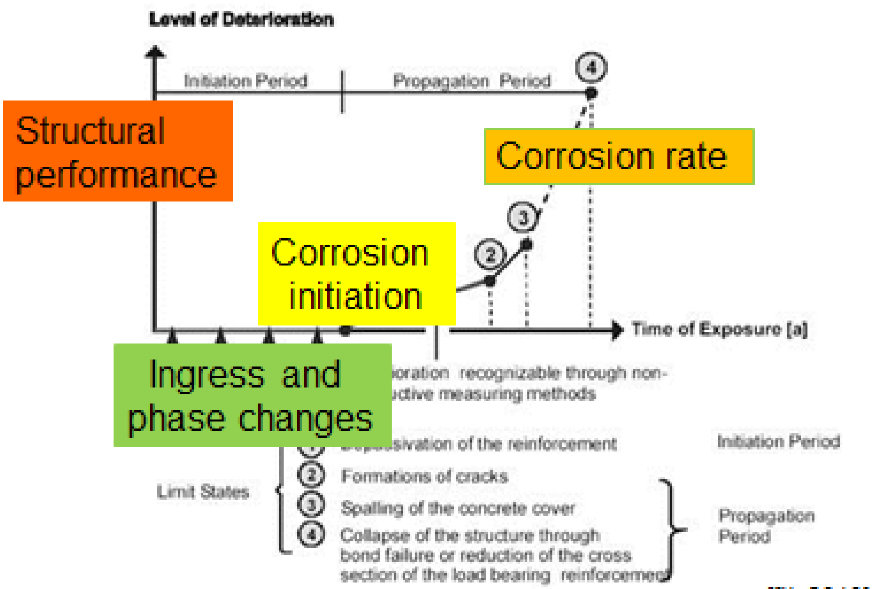
Research on reinforcement corrosion within COIN FA 3.2



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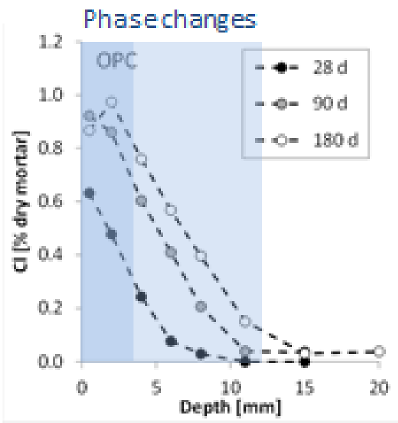
Chloride ingress and phase changes

Post Doc Project

Klaartje De Weerdt



Summary

- Phase changes affect chloride binding and are part of the explanation for D(t) and Cs(t)
- Pore solution chemistry should be considered when quantifying the impact of binder composition on chloride ingress

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Initiation of chloride induced reinforcement corrosion

PhD Project

Ueli Angst

Supervisors

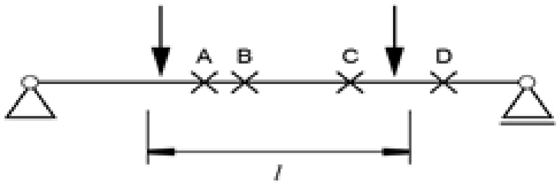
Øystein Vennesland

Claus K. Larsen, SVV/NTNU

Bernhard Elsener, ETH

Summary

The **"characteristic structural length"** should be taken into account when determining the critical chloride content for a given structural element



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Impact of concrete resistivity on corrosion rate

PHD Project

Karla Hornbostel

Supervisors

Mette R. Geiker

Claus K. Larsen, SVV/NTNU

Bernhard Elsener, ETH

Ueli Angst, ETH

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Impact of corrosion on structural performance

PHD Project

Mahdi Kioumarsi

Nerlandsøybrua, Photo by Larsivi
http://commons.wikimedia.org

Supervisors

Mette R. Geiker

Max Hendriks

Terje Kanstad

Summary

- A 3D numerical model was established to investigate the possible impact on carrying capacity of localized corrosion on adjacent rebars
- Interference of localised corrosion within a critical distance

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Alkali-silica reaction (ASR) – Performance testing

PhD Project

Jan Lindgård

"Alkali-silica worms" (ASR gel) escaping from a test sample.....

Supervisors

Harald Justnes, NTNU

Erik J. Sellevold, NTNU

Michael D.A. Thomas, UNB, Canada

Summary

- The test procedure (i.e. specimen "pre-treatment", "exposure conditions" and prism cross-section) dramatically influences the outcome of an ASR performance test
- Alkali leaching is the main source of error during accelerated ASR performance testing

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Presentations - Selected findings

Alkali silica reactions

Terje Rønning (NORCEM)
Jan Lindgård (SINTEF)

Reinforcement corrosion

Karla Hornbostel (NTNU)
Claus Larsen (SVV)

COIN Final Seminar 2 and 3 December 2014

Acknowledgements

Funding

- COIN
- SVV
- NRC
- NTNU

Collaboration

- Colleagues in COIN
- Colleagues at DTU, ETH, New Brunswick University and Stanford University

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ASR vs. Heidelberg Cement NE innovation

What & How

December 2nd 2014, Terje F. Rønning & Jan Lindgård

SINTEF

HEIDELBERGCEMENT

List of content

- Specification vs. Performance based requirements
  - and industrial needs
- Role of NB 21
- Role of RILEM TC
- Spin-offs to other markets
- DRAFT CONCEPT
- TEST RESULTS EXTRACT
  - Overview of research activities
    - PhD study
    - Follow-up study
  - Main results and conclusions
  - Main recommendations - future research

Slide 2 – ASR HC NE innovation

HEIDELBERGCEMENT

ASR Specifications vs. Performance Approach

How they differ ….

- Specs :
  - Normative
  - Simple (normally)
  - Sometimes "copied" from abroad
  - Non-transparent w r t risk / safety margins
  - Often discriminate certain construction materials, i.e.;
  - Do not provide equal playing field leverage
  - Prohibits product and marketing development, i.e.;
  - Prevent innovation

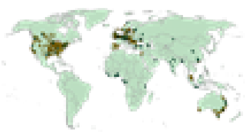
Slide 3 – ASR: HC NE Innovation

HEIDELBERGCEMENT

ASR Specifications vs. Performance Approach

How they differ ….

- Performance approach
  - Must be NORMATIVE
  - May be combined with Specs …
  - Allow assessment of construction products in combination, i.e.;
  - Address functional properties & inter-dependency
  - Provides product value leverage
  - Sometimes disturbs established market shares …
  - i.e. Provides FLEXIBILITY
  - Requires assessment criteria
  - Assumes lab/field alignment
  - Need mtrl. (constituent) characterisation & Concrete Performance Testing
  - Representative Accelerated Testing
  - Penetration assumes intl. accepted principles



Slide 4 – ASR: HC NE Innovation

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HC NE – ASR Targets & Tasks Differentiation

NOR & Stakeholders

- Basic research /support for sustainable concepts & concept development
- International state-of-the-art alignment & Key thresholds addressing
- CEN & Rilem interface
- HTC co-ordination / alignment
- National stakeholder
- NB 21 regulations dialogue

SWE Business development

- Boundary conditions investigations
- Organisational environment development
- National regulations subject to differential approach
- Aggregate marketing development potential
- CEM II marketing concept potential

Baltic market development

- Stakeholder liaison development
- National stakeholder education
- National regulations design (dialogue / up-date)

National & cross boarder market access / development

Slide 5 – ASR HC NE Innovation

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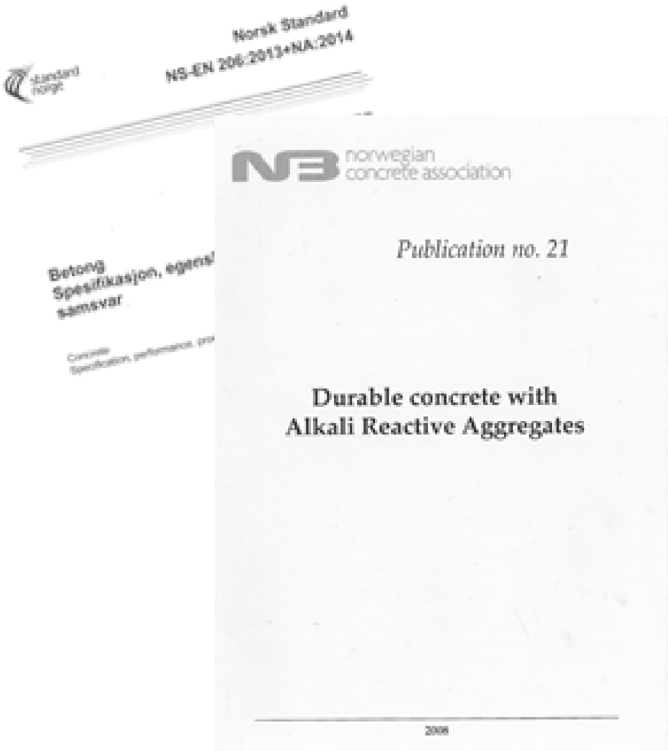

NB 21

- Spec with «Performance extension»
- PT used for product application rules
- Fits product declaration needs
- Norw. CPT amongst «the best» but test application rules & formal interface in need of up-date
- Technical issues (probably;) due for update, following RILEM & new KPN project

Slide 6 – ASR HC NE Innovation

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- Petrography
- Chem/AMBT
- (+A. release?)

RILEM Draft procedure

Concrete prism testing					
Aggregate fraction(s)			Performance testing : Combinations of binder(s) and aggregate(s)		
Potential reactivity	Alkali threshold level	Aggregate combinations with pessimum	Specific aggregate(s) characterisation	Specific binder/ cement characterisation	Job mix combinations characterisation
Potential objectives : • Detection of reactive or potentially reactive aggregates, following initial characterisation by petrography and possibly other tests, including ; • Re-examination and –classification of aggregates based on pre-stage screening testing methods • Assessment of combination of aggregates including fractions exhibiting alkali pessimum behaviour • "Aggregate performance declaration" • Input to guidelines / NAD[1)]'s of aggregates classification and application			Potential objectives : • Characterisation of specific aggregate(s) product combined with specific/general cement/binder, including modified alkali threshold level with such binder ("Aggregate performance declaration II") • Characterisation of specific cement/binder product combined with (reference;) regionally reactive aggregate type ("Cement/binder performance declaration") • Characterisation/tuning of combinations of concrete constituents for a particular construction project, but at a fixed w/c-ratio to avoid artefacts, and formal handling of constituents' quality variations • Input to guidelines / NAD[1)]'s of aggregates, cement/binder		

[1)] National Application Document, i.e. regulations valid in place of use

Slide 7 – ASR HC NE Innovation

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TC AAR Subject matter

Develop/promote performance based testing concept for preventing ASR

- Finalize and validate testing methods (Alkali boosting, Pessimum, Binder/Aggregate kinetics (T), RRT & Lab/Field)
- Potential aggregate alkalis release assessment and alkali household implications (Finalizing testing method and developing application procedure, Alkali "re-cycling"?)
- Flow chart proposal ....
- Standardisation input NO, SE, CAN, ASTM, Balt, CEN

Slide 8 – ASR HC NE Innovation

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Previous "WP 1 related" Deliveries

- "Information mapping" lab/field studies (no success)
- Attempt to quickly address key issues and proceed with draft procedure (failed;) – Need to step back and;
- Prepared comprehensive STAR on various influencing parameters on lab/field relation. Formal report & CCR Publication. Work intensive, substantial individ.contrib.
- Identified critical issues & Research issues
  - Leaching/Threshold ; Substantial support from JL PhD
  - Substantial general research information exchange
  - Boosting of alkalis (draft programme & sampling) / Limitations ; Boosting trial procedure developed. Weimar-HC-Sintef issue. Test samples for trial.
  - Improved focus on lab/field relation investigations
  - Pre-curing (C-type) ; JL, F(C/Aggr)? < Coin WP2
  - Remaining issues must be solved by "convention" / "lack of precision"

Slide 9 – ASR HC NE Innovation

HEIDELBERGCEMENT

Draft procedure

- Petrography
- Chem/AMBT
- (+ A. release?)

Concrete prism testing					
Aggregate fraction(s)			Performance testing : Combinations of binder(s) and aggregate(s)		
Potential reactivity	Alkali threshold level	Aggregate combinations with pessimum	Specific aggregate(s) characterisation	Specific binder/ cement characterisation	Job mix *combinations* characterisation
Potential objectives : • Detection of reactive or potentially reactive aggregates, following initial characterisation by petrography and possibly other tests, including ; ... Aggregate performance declaration • Input to guidelines / NAD[1)]'s of aggregates classification and application			Potential objectives : • Characterisation of specific aggregate(s) product combined with specific/general cement/binder, including modified alkali threshold level with such binder ("Aggregate performance declaration II") • Characterisation of specific cement/binder product combined with (reference;) ... concrete constituents for a particular construction project, but at a fixed w/c-ratio to avoid artefacts, and formal handling of constituents' quality variations • Input to guidelines / NAD[1)]'s of aggregates, cement/binder		

[1)] National Application Document, i.e. regulations valid in place of use

- Characterisation ≠ Performance
- Testing method ≠ Assessment
- Assessment = Char. + Performance T. + T. Criteria (locally or mineral dependant testing limits)

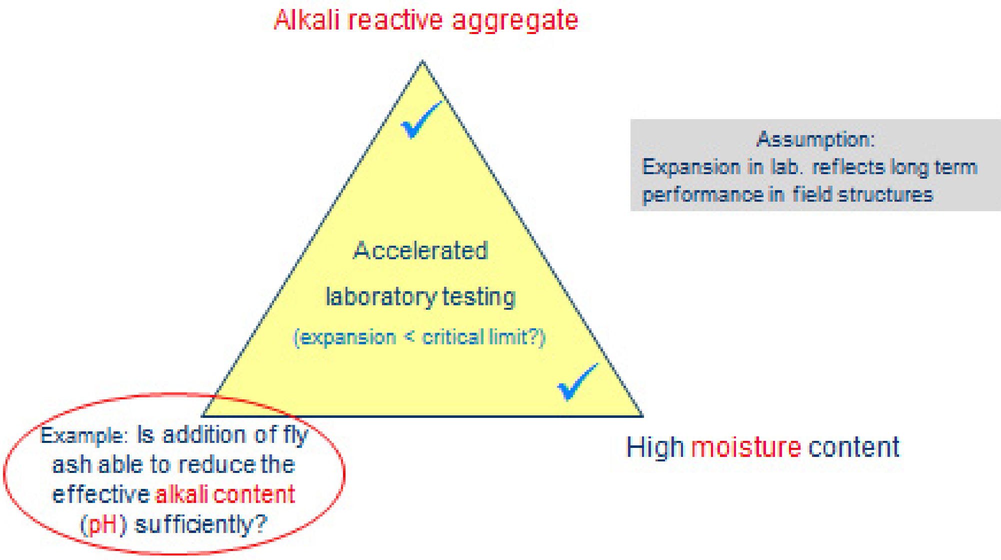
ASR - Performance testing

Extract from research within COIN

Jan Lindgård

SINTEF

ASR performance testing (principle)



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Overview of research activities

- **PhD study** (WP1)
  - Main question:
    - ✓ Are national and international ASR test methods developed for assessment of alkali-silica reactivity of aggregates suitable for general ASR performance testing of concrete?
  - Extensive lab. program
    - ✓ Modified various test procedures – detect any sources of errors
  - Recommendations for performance testing
    - ✓ Papers in journals and at conferences
    - ✓ Input to RILEM TC 219-ACS on ASR

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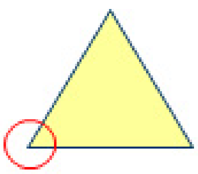
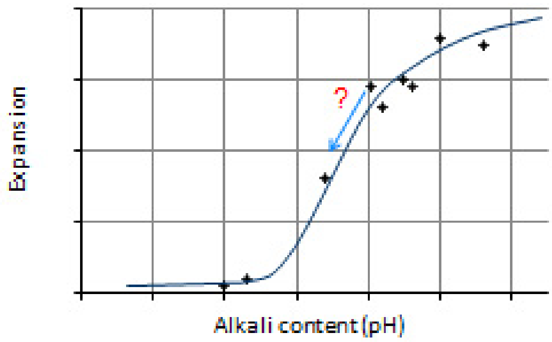
COIN

Important technical questions



1. Are the alkalis kept in the system? (pH?)



Principle illustration of the relation between alkali content (pH) and expansion due to ASR

Questions:

1a. Rate and extent of alkali leaching for various test procedures? ("no" alkali leaching in field)

1b. Influence on the ASR expansion?

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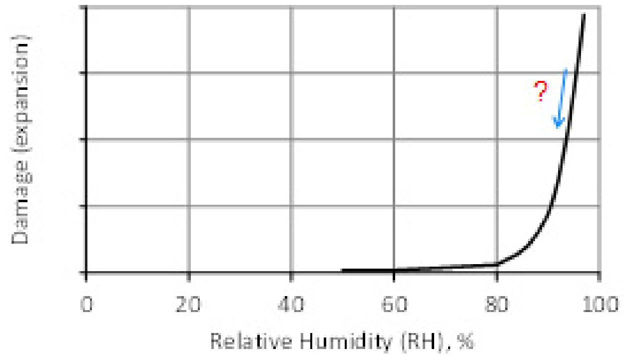
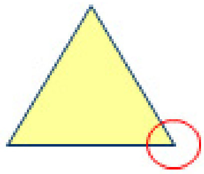
2. Sufficient moisture?





Principle illustration of the relation between RH and damage due to ASR

Questions:

2a. Internal RH when testing concrete with low w/cm?

2b. Internal RH when adding Supplementary Cementing Materials (SCMs)?

2c. Influence on the ASR expansion?

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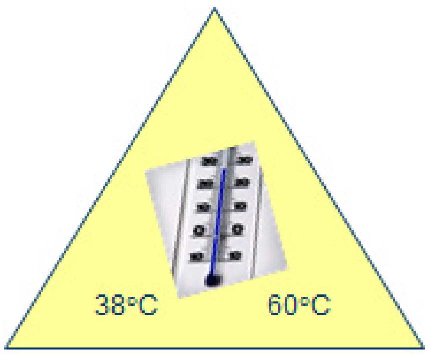
3. Any influence of the exposure temperature?



Questions:

3a. Influence on rate and extent of alkali leaching?

3b. Influence on internal moisture state?

3c. Influence on the ASR expansion?

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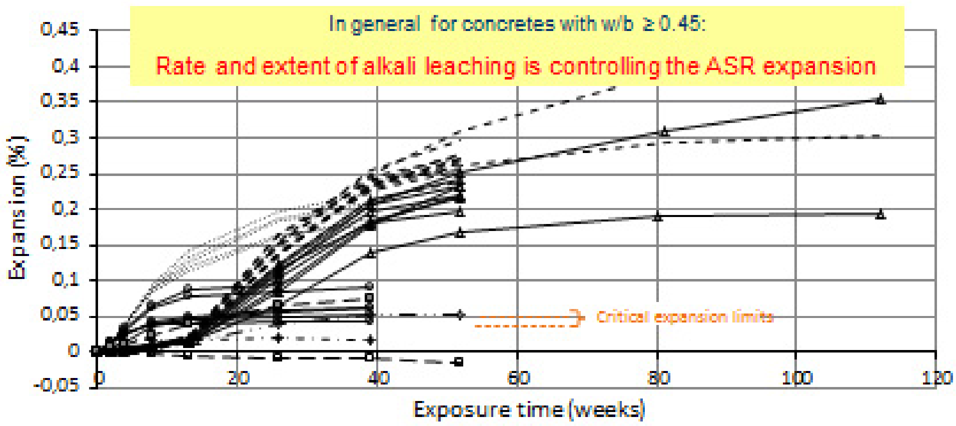
Overview of research activities

- **Follow-up study** (WP2, 2010-2014)
  - Focus on the lab./field correlation
  - Extensive test program
    - ✓ Selection of the most promising test procedures from WP1
    - ✓ Selected aggregate/binder combinations (115 test series)
    - ✓ Two field exposure sites established

SINTEF

Main results

- Summary results for different concrete recipes?
  - NO!
- WP1: <u>Identical</u> concrete composition (CEM I, w/c 0.45). Result of modifying:
  - Prism size (70 or 100 mm)
  - Specimen "pre-treatment" (incl. pre-curing)
  - "ASR storage conditions" (38/60°C, wrapping or not, ...)



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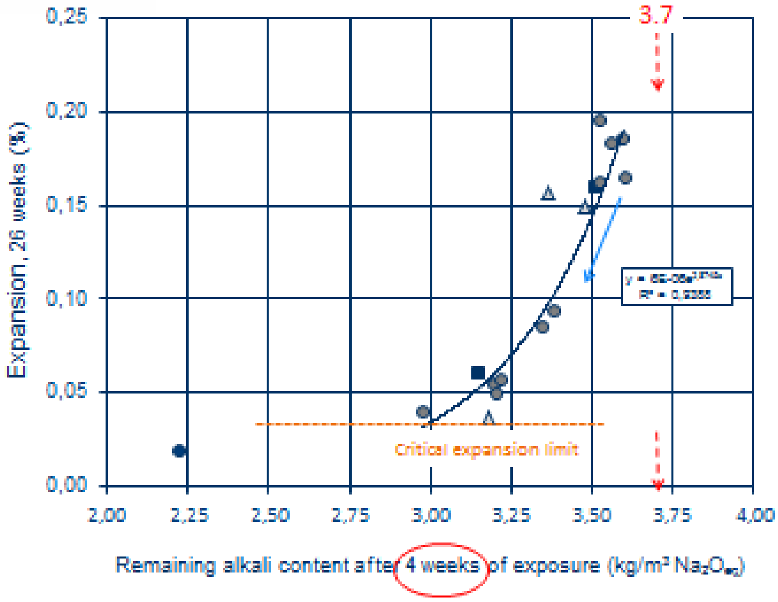
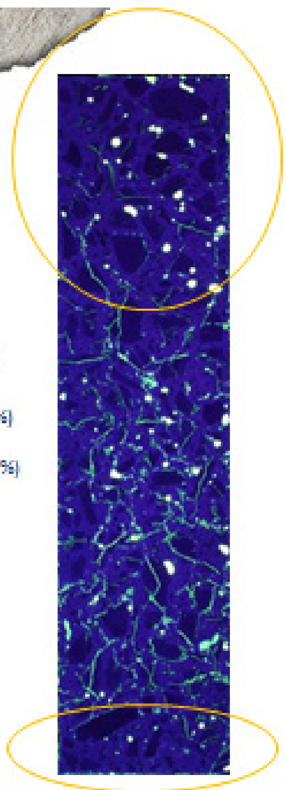
WP1: Effect of alkali leaching on expansion (60°C)

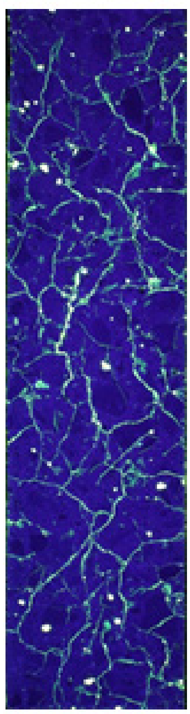


SINTEF 19



High extent of alkali leaching (37 %)

(Expansion 0.18 %)



Lower extent of alkali leaching (12 %)

(Expansion 0.35 %)

SINTEF 20

COIN

Main conclusions

- Specimen "pre-treatment", "exposure conditions" and prism cross-section dramatically influences the outcome of an ASR performance test
- Alkali leaching the most important source of "error"
  - Early age alkali leaching of particular importance - totally controls expansion at 60°C
  - Urgent: Limit, compensate for, or preferably eliminate alkali leaching
- Internal moisture state becomes of importance for more dense binders (low w/b)

SINTEF 21

COIN

Main recommendations to RILEM

- Remove the wrapping procedure from the RILEM ASR aggregate test methods
  - Wrapping leads to high extent of alkali leaching in the early age
  - Immediately adopted by RILEM TC 219-ACS (two of the three RILEM test procedures withdrawn in 2010)
- Adopt the "Norwegian concept" for performance testing (NB21)
  - Several applications (reactivity of aggregates, alkali threshold for aggregates, doc. of "safe binders", ...)
  - Focus on testing at 38°C (lack of correlation lab/field for 60°C testing)
  - Increase the prism cross section (reduces the extent of alkali leaching)
  - Adopted in the draft RILEM performance test procedure (2012)
- Avoid testing of low w/b concretes
  - Must secure access to sufficient water supply during testing (avoid "false negative" test results)
  - Adopted in the draft RILEM performance test procedure (2012)

....

- New RILEM TC "AAA" on ASR (2014-2019)
  - Norway have taken the leadership (chair, secretary, leader of performance task group, ...)

SINTEF 22

Future research on ASR (based on COIN)

- ASR – Reliable concept for performance testing (BIA/KPN, 2014-2019, 18.5 MNOK)
  - Focus on the lab./field correlation (structures, field exposure sites)
  - Lead by SINTEF
  - Partners: Norcem, NTNU, owners, aggregates producers, international collaborators
  - Input to future regulations (NB21, RILEM TC "AAA")
  - Also basis for research on repair actions

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Summary

- **ASR based innovation is feasible**
- **Norwegian (COIN+) based research is well reputed and contributes to the development of a sustainable performance concept on international level**
- **Research needs still exist, but we believe that;**
  - **Threshold items have been identified and are adequately dealt with / are in the pipeline**
  - **NB 21 main principles are sound (but modifications due)**

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COIN Seminar

2nd and 3rd December 2014

Focus area 3.2

Reliable design and prolongation of service life

Impact of concrete resistivity on corrosion rate

Karla Hornbostel

NTNU

COIN Final Seminar 2 and 3 December 2014 1

PhD project Participants

Supervisors

Mette Geiker (NTNU - main)

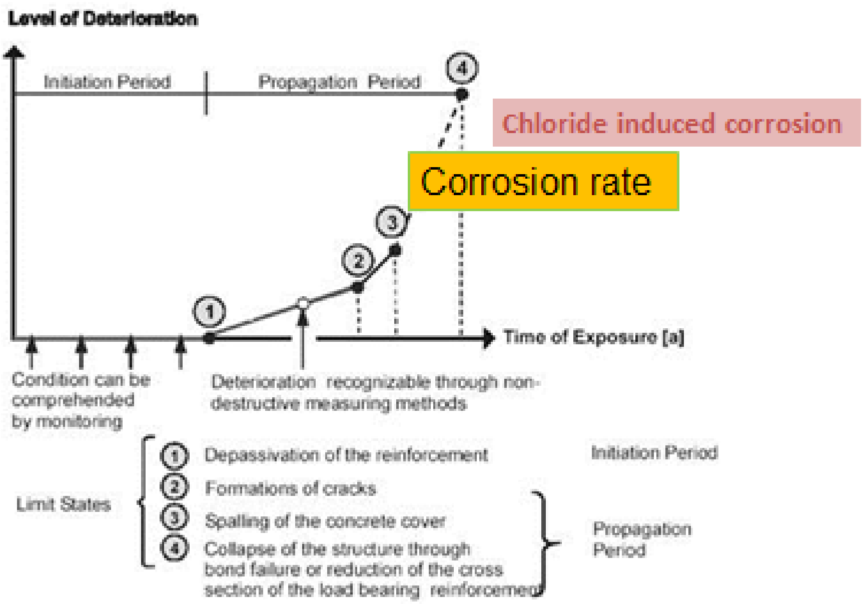
Claus K. Larsen (SVV)

Bernhard Elsener (ETH)

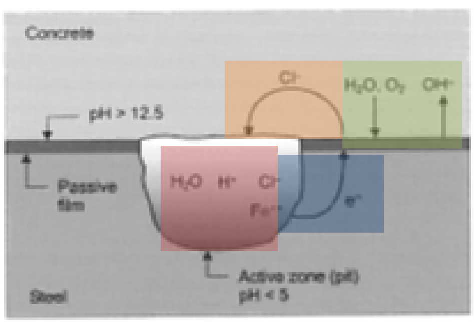
Ueli Angst (ETH)

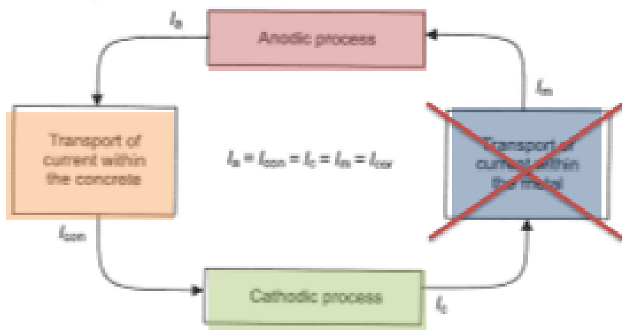
COIN Final Seminar 2 and 3 December 2014

PhD project
Background



PhD project
Background





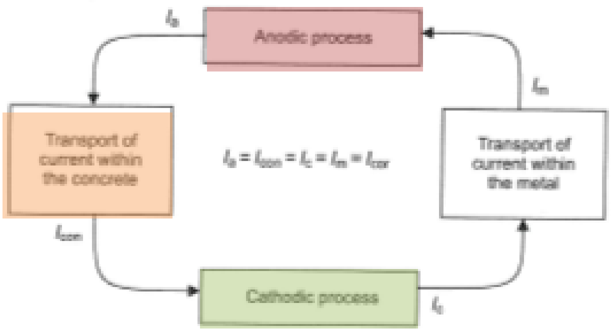
Bertolini, L., B. Elsener, et al. (2004). Corrosion of steel in concrete. Weinheim, WILEY VCH

COIN Final Seminar 2 and 3 December 2014

PhD project
Background

Electrical resistivity

... characterizes ion transport in concrete



COIN Final Seminar 2 and 3 December 2014

PhD project
Objectives and approach

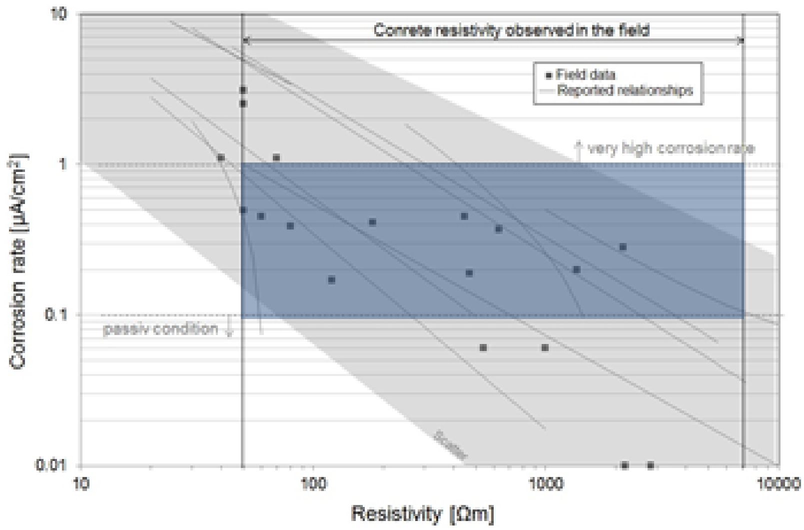
Identify and quantify parameters affecting the relationship between corrosion rate and concrete resistivity

Approach

- Literature review ⟶ hypotheses
- Laboratory testing
- Conclusions

COIN Final Seminar 2 and 3 December 2014

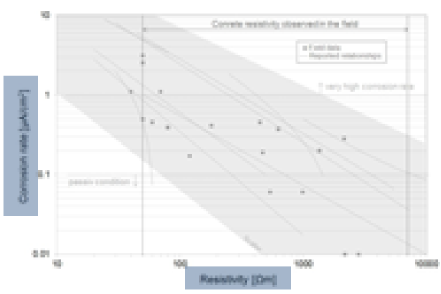
Literature Review

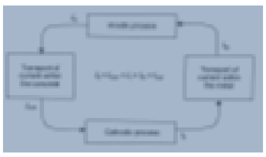


[K. Hornbostel, C.K. Larsen, M.R. Geiker, Relationship between concrete resistivity and corrosion rate - A literature review, Cement Concrete Comp, 39 (2013) 60-72]

COIN Final Seminar 2 and 3 December 2014

Hypotheses





Improved parameter determination

- Corrosion rate
- Electrical resistivity

Improved understanding

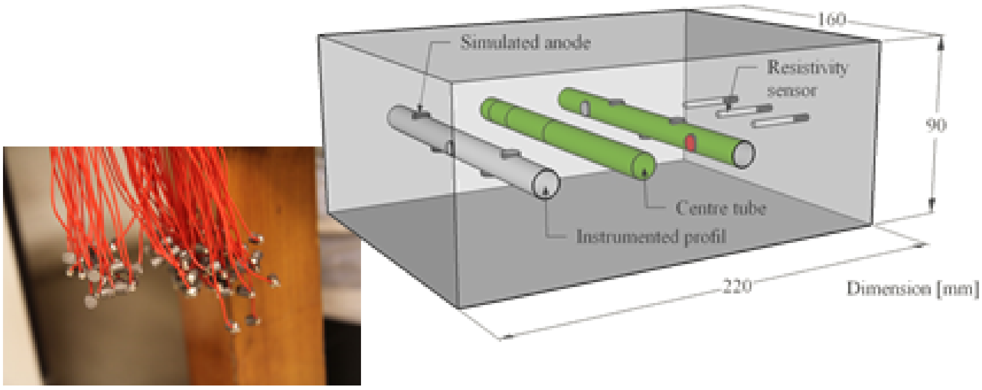
- Rate limiting step

COIN Final Seminar 2 and 3 December 2014

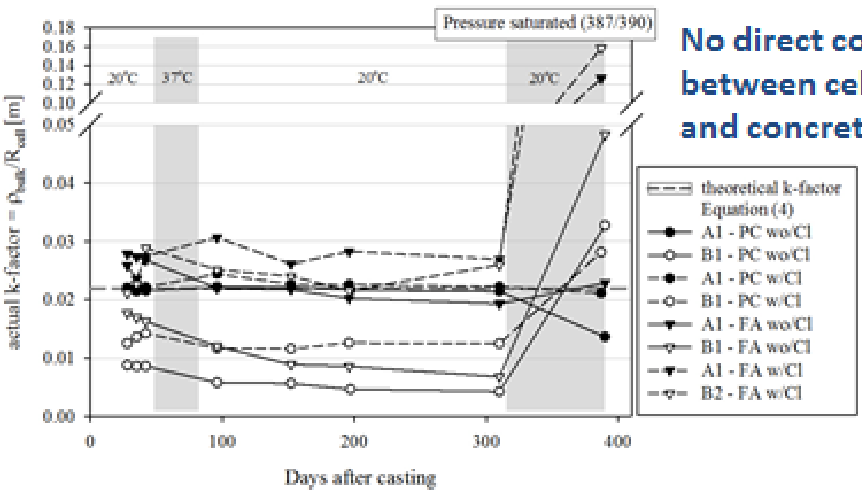
Experimental setup

Simulating macrocell corrosion

Artificial anodes in a large network of cathodes



Results 1



No direct correlation between cell resistance and concrete resistivity

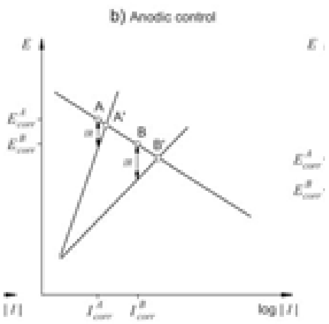
[K. Hornbostel, U. Angst, B. Elsener, C.K. Larsen, M.R. Geiker (in preparation)]

Results 1

COIN Final Seminar 2 and 3 December 2014

Results 2 + 3

Corrosion process not under resistance control



Corrosion process is under anodic control

[U. Angst, B. Elsener, C.K. Larsen, Ø. Vennesland, Chloride induced reinforcement corrosion: Rate limiting step of early pitting corrosion, Electrochim. Acta, 56 (2011) 5877-5889.]

COIN Final Seminar 2 and 3 December 2014

Preliminary conclusion

Chloride induced reinforcement corrosion is under anodic control

Corrosion rate not only dependent on bulk resistivity

... Improves Service Life prediction

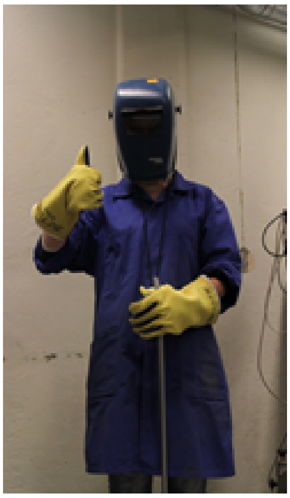
Acknowledgements

Funding

- COIN
- SVV
- NTNU

Collaboration

- Colleagues in ETH, COIN



COIN Final Seminar 2 and 3 December 2014 14

Ductility of Lightweight Aggregate Concrete

Confinement Effects of Fibres

Jan Arve Øverli
Norwegian University of Science and Technology

SINTEF NTNU

FA 3 Technical performance

FA 3.3 Structural Performance

- High performance LWAC
- Ice abrasion
- Hybrid structures
- Ductility of LWAC structures
  - A project initiated and in cooperation with KVÆRNER

SINTEF NTNU

COIN

People:

- Tore Myrland Jensen, SINTEF
- Helge Brå, SINTEF
- Gunrid Kjellmark, SINTEF
- Tore Arne Martius-Hammer, SINTEF
- Knut Lervik, SINTEF
- Jan Arve Øverli, NTNU
- Ove Loraas, NTNU
- Steinar Seehuus, NTNU
- Gøran Loraas, NTNU

SINTEF NTNU

COIN

Lightweight aggregate concrete

- Advantages
  - Reduced dead load
  - Reduced inertia forces
  - Easier handling and transportation
  - Improved durability properties and fire resistance
  - Low thermal conductivity
- Disadvantages
  - Brittleness in compression
  - Price

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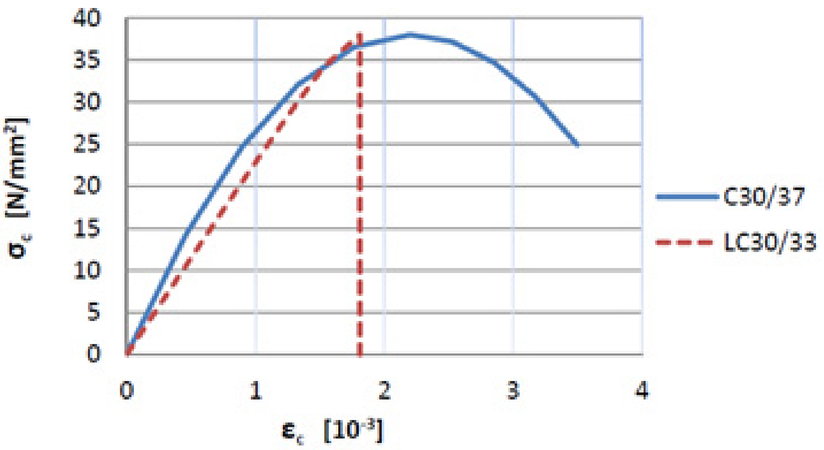
Lightweight aggregate concrete



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Construction of GBS

Photos: Norsk Oljemuseum

SINTEF NTNU

Construction of GBS

Photos: Norsk Oljemuseum

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Construction of GBS

Photos: Norsk Oljemuseum

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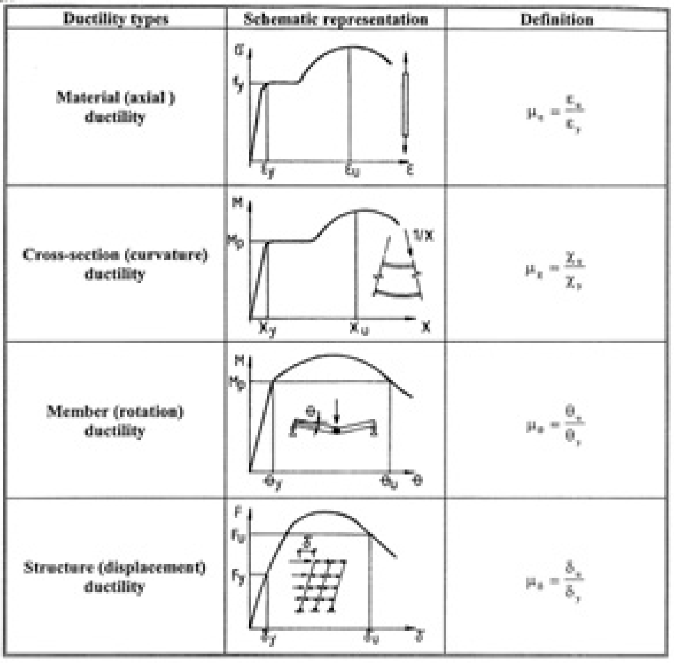
Construction of GBS

Photos: Norsk Oljemuseum

Ductility

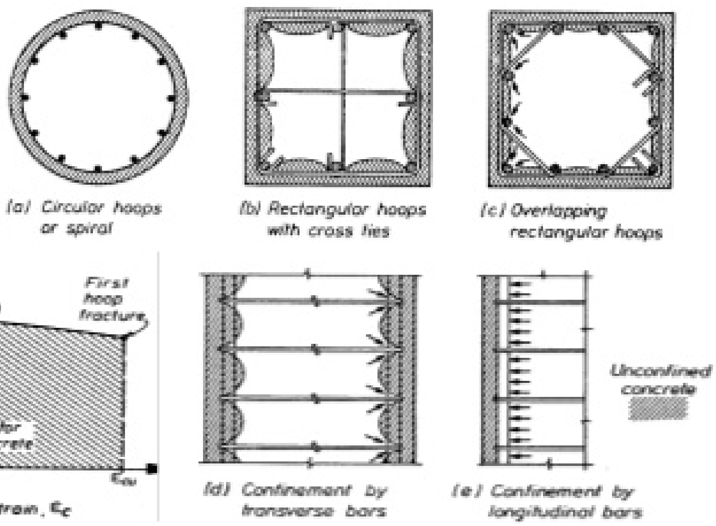
- Ductility is defined as individual structural members or entire structures ability to sustain significant inelastic deformations after peak load without a significant loss in the capacity prior to failure.
- Of great importance in redistribution of forces and a major consideration in design of structures subjected to dynamic loading.

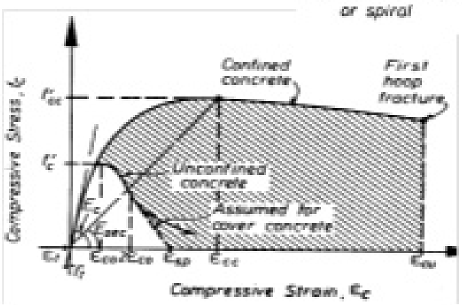


Ductility types	Schematic representation	Definition
Material (axial) ductility		$\mu_\varepsilon = \frac{\varepsilon_u}{\varepsilon_y}$
Cross-section (curvature) ductility		$\mu_\chi = \frac{\chi_u}{\chi_y}$
Member (rotation) ductility		$\mu_\theta = \frac{\theta_u}{\theta_y}$
Structure (displacement) ductility		$\mu_\delta = \frac{\delta_u}{\delta_y}$

Gioncu, 2000

Confinement





Mander et.al, 1998

Dowrick, 2003

Motivation for project

- Increase ductility in lightweight aggregate structures
- Focus on large structures, GBS offshore structures, LNG terminals
- Flexural ductility in heavily reinforced cross-sections
- Effect of fibres and stirrups on the ductility

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Experimental program

- Four point bending of beams
- Configurations of confinement, two beams each

Test series 1

- Only LWAC
- Steel fibre
- Stirrups with spacing 100mm
- Stirrups + steel fibre

Test series 2

- Only LWAC
- Steel fibre 60mm
- Steel fibre 35mm
- Basaltic fibre

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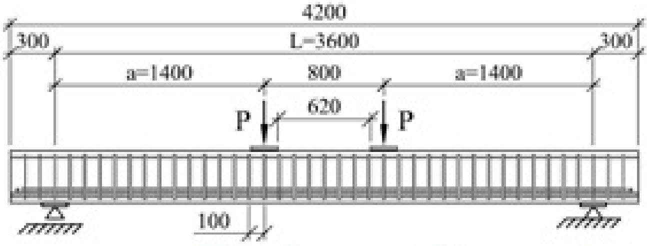
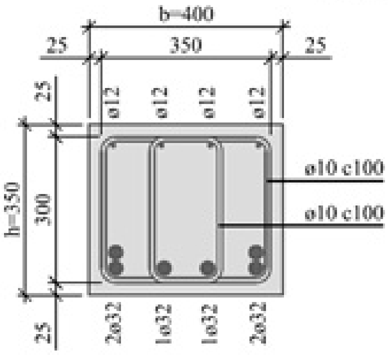
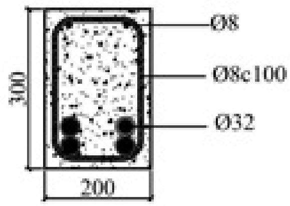
Test set-up



With shear reinforcement



Program 1



Program 2

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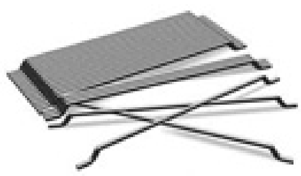
Fibre-Reinforced Lightweight Concrete

- Density ~1800 kg/m^3
- Maximum size of lightweight aggregate 8mm (LECA)
- Compressive strength 30-40 MPa
- 1% fibre



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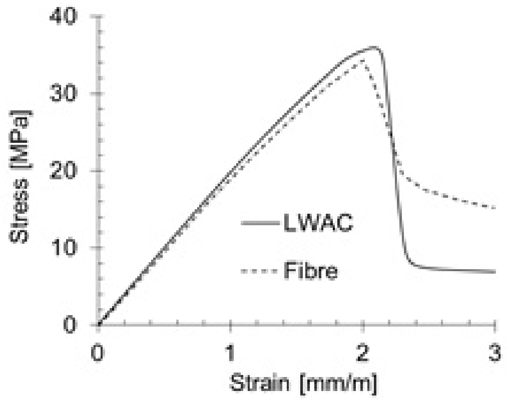
COIN

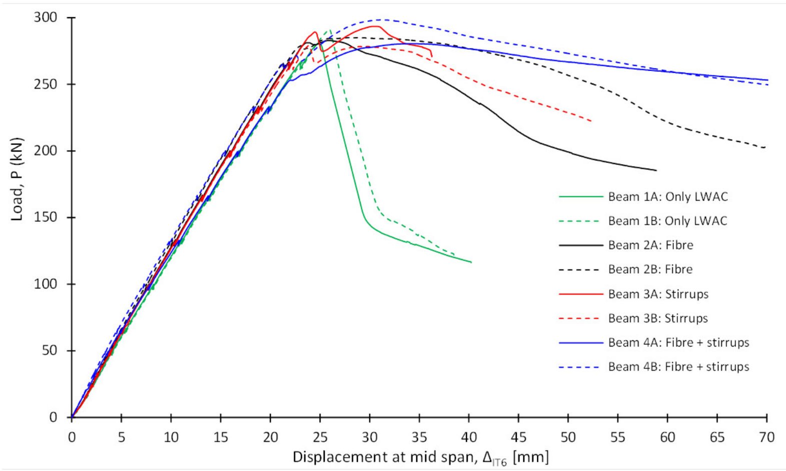
Fibre-Reinforced Lightweight Concrete



SINTEF NTNU sfi

COIN

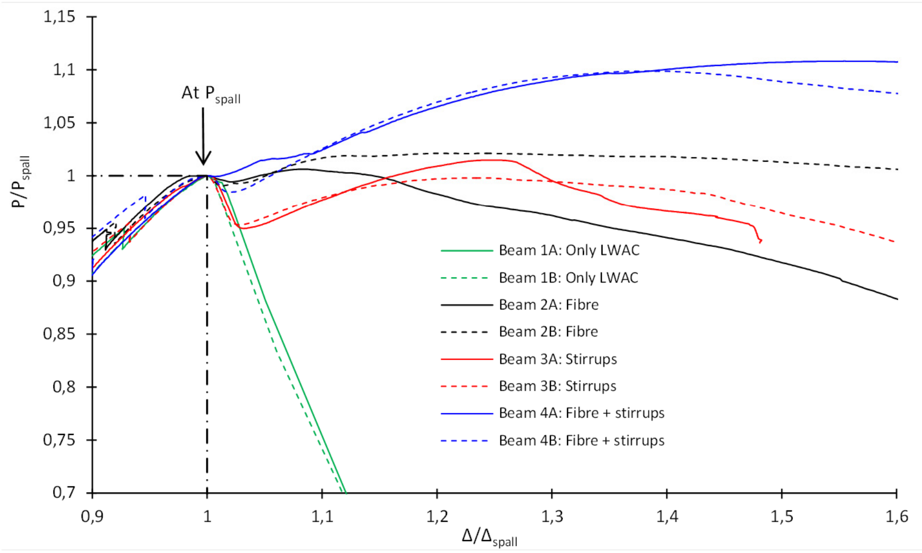
Load-displacement, program 1



SINTEF NTNU sfi

COIN

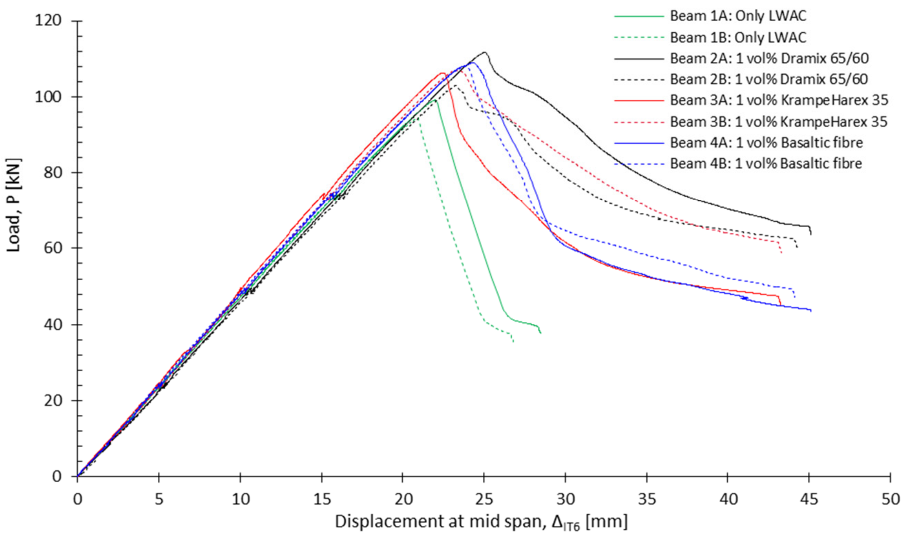
Load-displacement, program 1



SINTEF NTNU sfi Senter for forskningsdrevet innovasjon

COIN

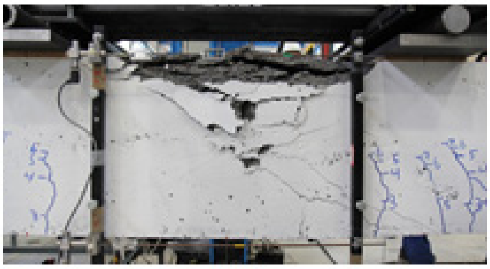
Load-displacement, program 2



SINTEF NTNU sfi Senter for forskningsdrevet innovasjon

Failure mode

LWAC only

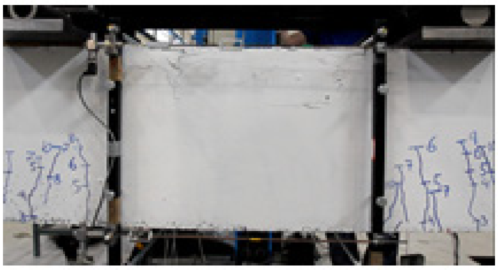


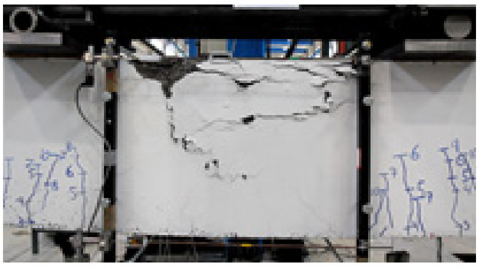
At peak load

At end of loading

Failure mode

Steel-fibre



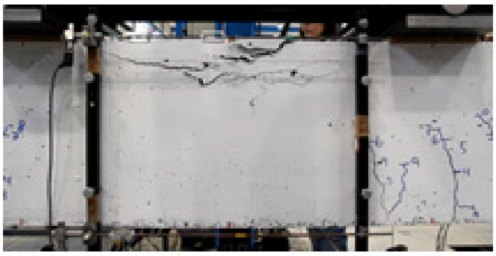


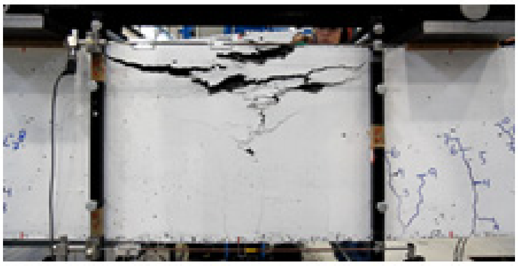
At peak load

At 90% of spalling load

Failure mode

Stirrups





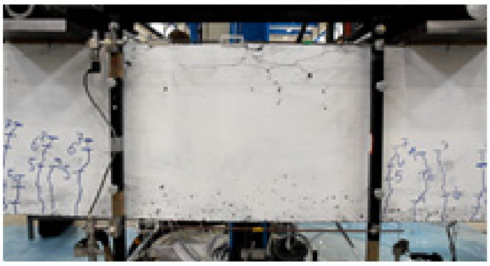
At peak load

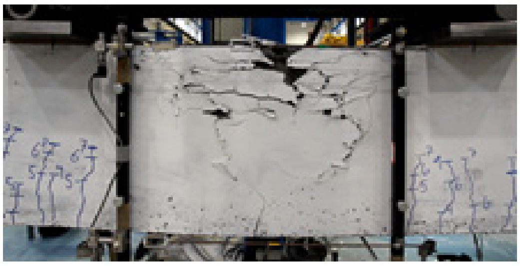
At 90% of spalling load

SINTEF NTNU sfi

Failure mode

Steel fibre+Stirrups



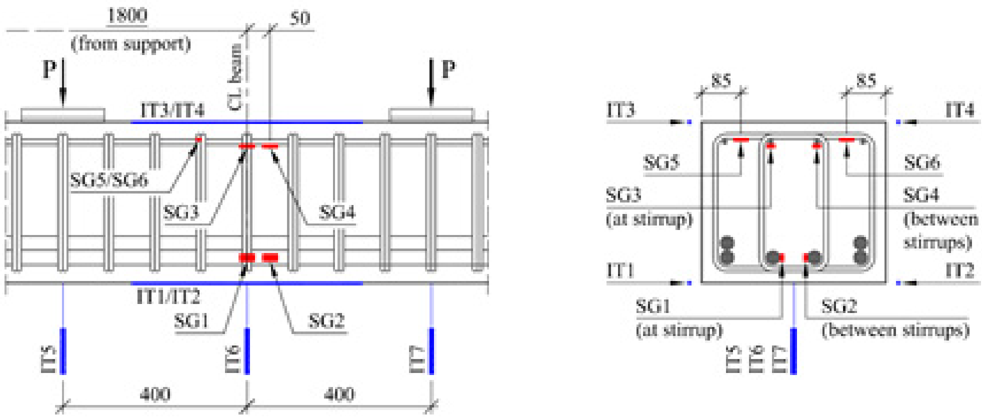


At peak load

At 90% of spalling load

SINTEF NTNU sfi

Strain measurements



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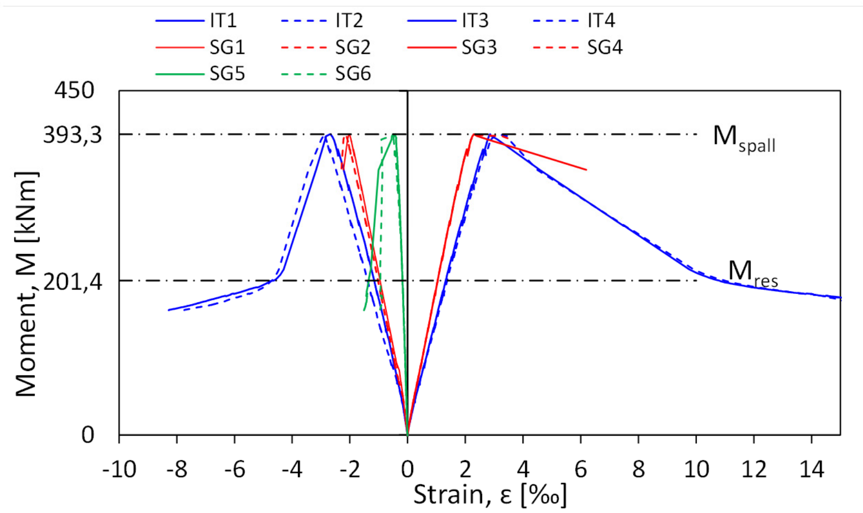
Strain distribution



LWAC only

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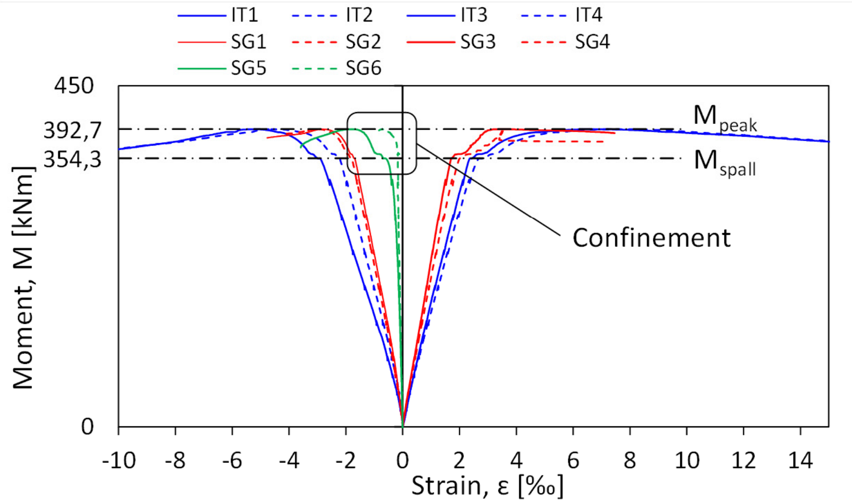
Strain distribution



Fibre + stirrup

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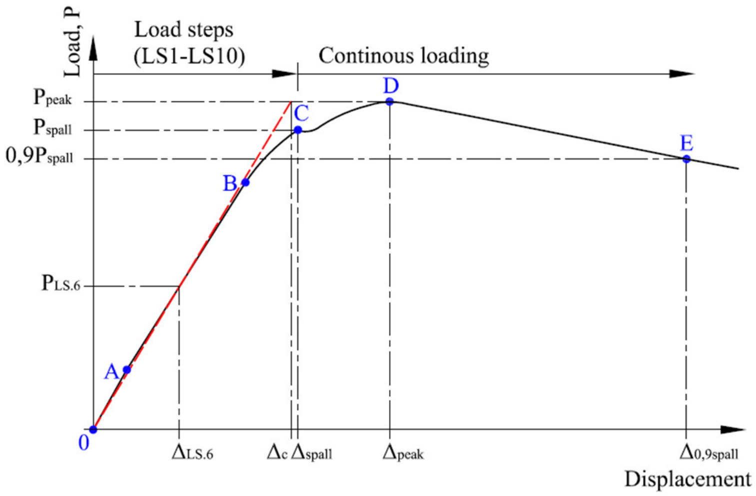
Ductility



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Ductility

Beam: Configuration	f_c (MPa)	Δ_{spall} (mm)	Δ_{peak} (mm)	$\Delta_{0.9,spall}$ (mm)	$\Delta_{0.9,spall}/\Delta_{spall}$
1A: Only LWAC	36.9	24.8	-	-	-
1B: Only LWAC	39.7	25.9	-	-	-
2A: Steel fibre	34.9	23.9	30.5	37.2	1.55
2B: Steel fibre	39.6	23.1	29.5	52.1	2.25
3A: Shear links	34.5	24.5	26.0	36.3	1.48
3B: Shear links	33.5	23.9	28.8	39.5	1.66
4A: Shear links + steel fibre	27.7	22.0	34.2	100.7	4.57
4B: Shear links + steel fibre	40.4	22.6	31.4	79.9	3.54

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Conclusions

- Considerably increased flexural ductility of the beams when applying steel fibres and/or confinement reinforcement. Especially the combination of fibre and confinement reinforcement experienced a continuous response and the beams were able to maintain a high load level after reaching the maximum load
- No significant influence of the different confinement configurations on the response before initiation of spalling.
- The fibres introduce a softer transformation at spalling. There is no drop in the load response.

SINTEF NTNU

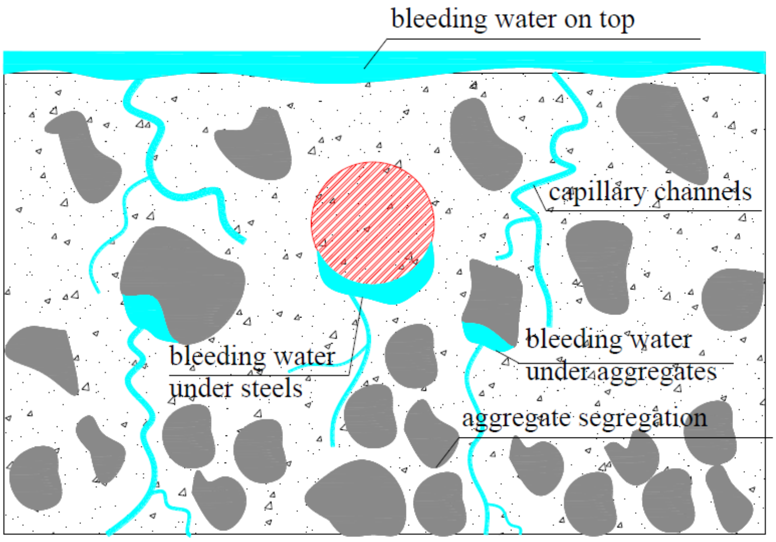
Research with COIN & new initiatives 2015 onwards:

- Fresh concrete
  - PhD 2014:89 -Ya Peng on Stability
  - PhD ongoing - Rolands Cepuritis on Crushed aggregates and rheology
- Concrete exposed to ice and frost
  - Review, Kværner in Russia's Far East/Sea of Okhotsk
  - NTNU concrete ice abrasion lab
- New project proposals sent Research Council of Norway
  - Kværner et al BIA Innovation DaCS – Durable advanced Concrete Solutions (stage 2 sent 15oct14)
  - NTNU et al BIA Kompetanse FLOC – FLOwing stable and sustainable Concrete (stage 1 sent 19nov14)

NTNU

2

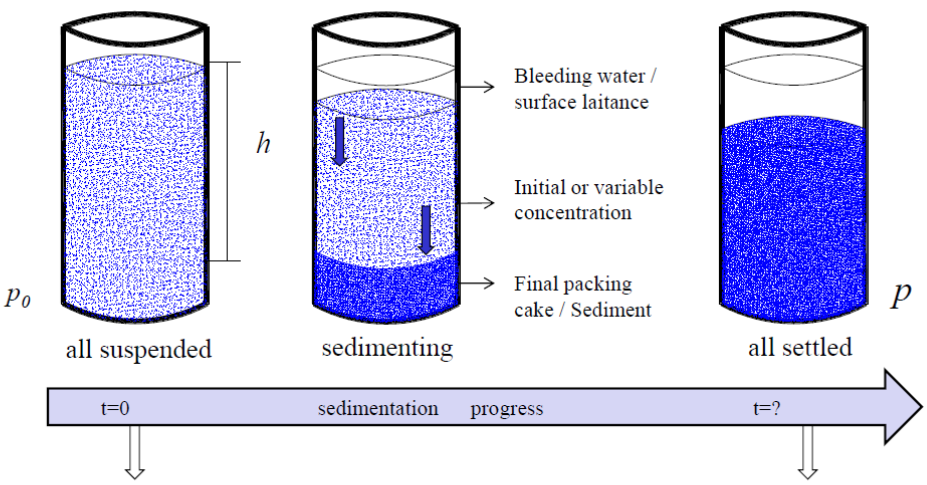
Stability: the ability to retain a uniform distribution



By Peng Y., Jan. 2014

3

Hydrostatic Pressure Measurements to study Sedimentation of cement paste



$$p_0 = \rho_{susp} g h = \{\rho_p \cdot \Phi + \rho_l (1 - \Phi)\} \cdot gh \qquad p = \rho_l g h$$

Particles supported by liquid at terminal velocity: ρ=p/gh ⇔ m/A = p/g. So at a depth h with pressure p(t), initial **particle flow J ($kg/m^2 \cdot s$) =** d/dt (m/A) = **1/g (dp/dt)** and in sediment $p = \rho_l g h$ (hydrostatic pressure of water)

4

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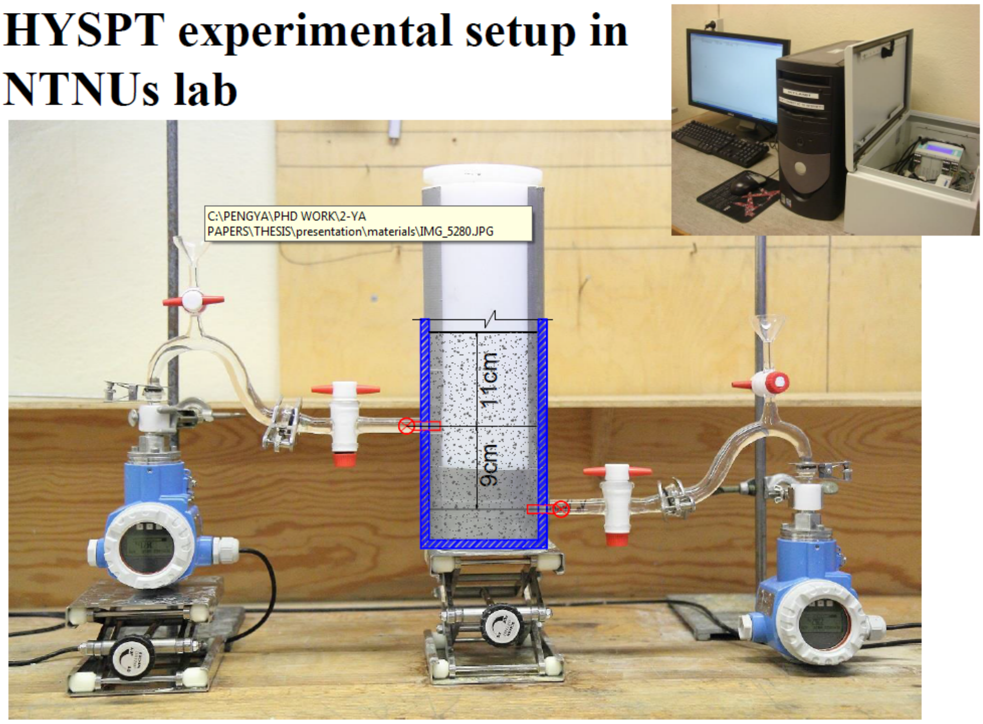
HYSPT experimental setup in NTNUs lab



5

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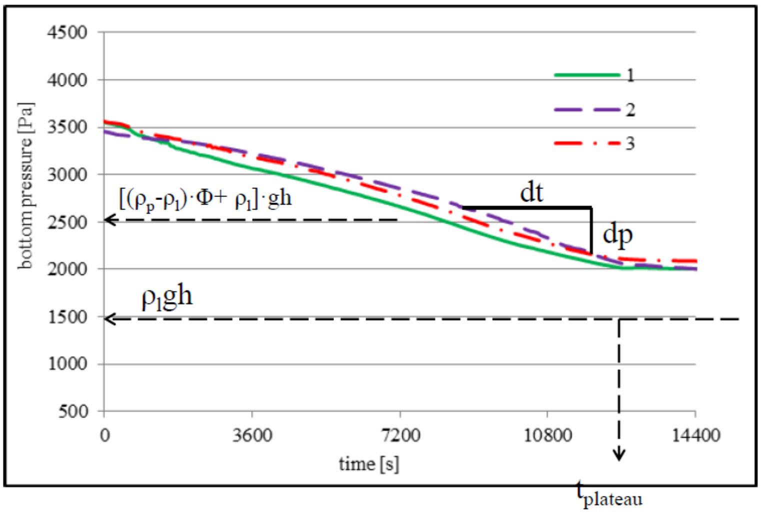
Hydrostatic Pressure measurement: dp/dt and $t_{plateau}$



PhD by YP: sedimentation in various powder/admixture combinations

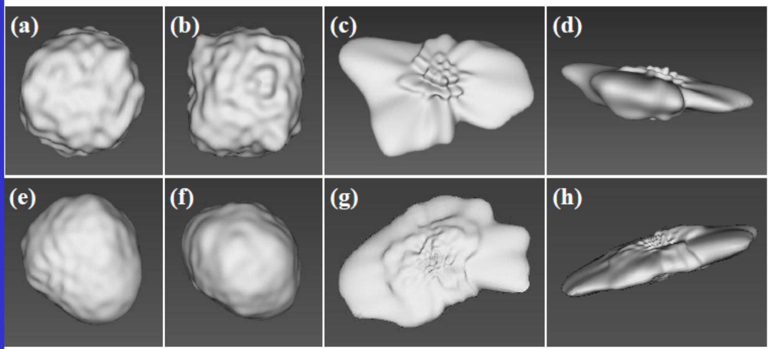
Ongoing YP: further development of method by studies of:

- bleeding (combined with light scanning in turbid media)
- aggregate particles sinking – higher plateau pressure than that of water detected

6

Rolands Cepuritis PhD characterizing fine crushed aggregate particles and their relation to rheology of fresh concrete:

- «ground truth» vs industrial application of controlled particle size distributions, specific surface, shape, mineralogy etc in crushed fines
- a little «pre-taste» of his work at NIST on µCT:



(a), (b) VESD=7.24 µm, SA/ VESD SA=1.083;

(c), (d) VESD=3.80 µm , SA/ VESD SA=1.592;

(e), (f) VESD=131.48 µm, SA/ VESD SA=1.034;

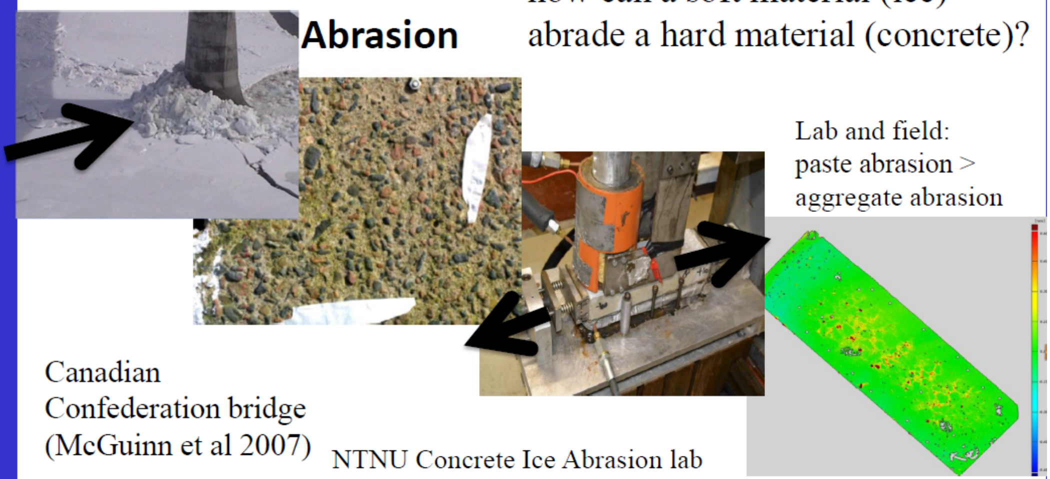
(g), (h) VESD=131.89, SA/ VESD SA=1.625.

Figure 9: 3-D VRML images of selected crushed fine particles of basalt studied with µCT scanning and spherical harmonic analysis

7

DaCS DP3 Concrete-Ice Abrasion

how can a soft material (ice) abrade a hard material (concrete)?

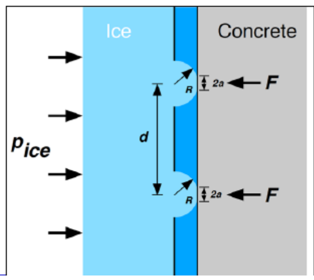


Lab and field: paste abrasion > aggregate abrasion

Canadian Confederation bridge (McGuinn et al 2007)

NTNU Concrete Ice Abrasion lab (Kirkhaug 2013, Greaker 2014 etc)

Concrete-Ice Abrasion Mechanics (Jacobsen, Scherer, Schulson 2014)



8

NTNU

DaCS DP3 Concrete Ice Abrasion

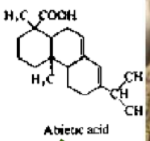
No.	Main activity, objectives and deliverables	Participating partners
3	Main activity: Concrete ice abrasion resistance Objectives/deliverables: To develop a test and calculation model for the wear of concrete due to abrading ice, investigate the effect of basic parameters (material, exposure, roughness etc), combined effect of abrasion and freeze/thaw damage and the effect of repair systems on new and damaged concrete.	Kværner, Mapei, NTNU, Sintef

9

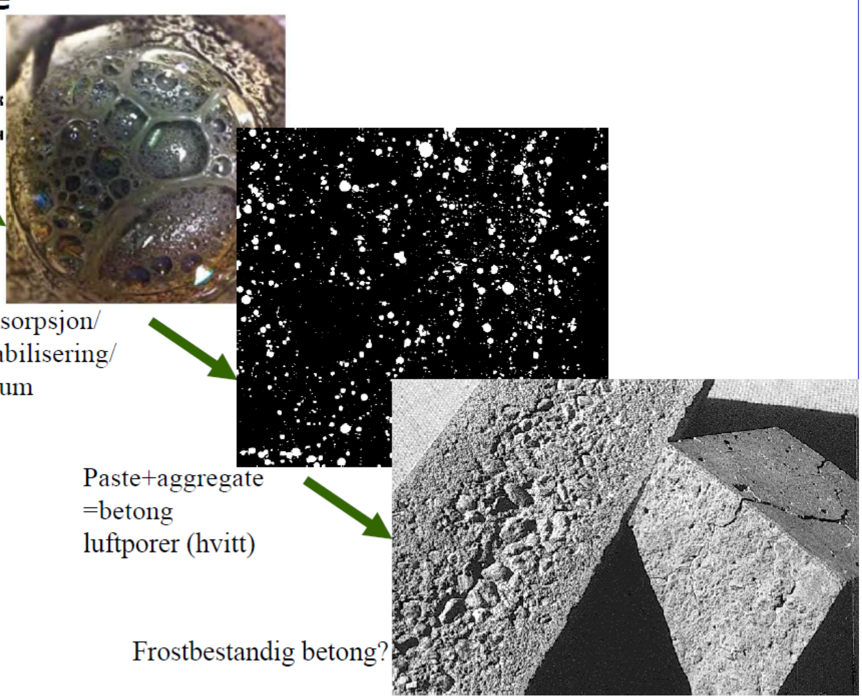
NTNU

DaCS DP2 Air entrained sustainable concrete

From AEA to foam to protective air voids



L-stoff
+ SP
+vann
+ pulver



adsorpsjon/
stabilisering/
skum

Paste+aggregate
=betong
luftporer (hvitt)

Frostbestandig betong?

10

NTNU

DP No.	Main activity, objectives and deliverables	Participating partners
2	Main activity: Frost resistant concrete for various purposes Objectives/deliverables: Identify requirements for frost durability for various purposes including air entrainment mechanisms and the reciprocal effects of cracking and scaling in freeze/thaw performance testing	Kvaerner Norbetong, Mapei, Statens Vegvesen, NTNU, SINTEF

11

NTNU

New BIA KMB proposal – FLOC – 3p stage 1 sent BIA-RCN 19nov14

NB! Please note that the outline may only be uploaded and submitted once.

Outline for Knowledge-building Project for Industry (the BIA programme)

Working title of project	FLOwing stable and sustainable Concrete (FLOC)
Applicant institution	NTNU
Website of applicant institution	www.ntnu.no
Contact person for applicant institution	Stefan Jacobsen
Email address of contact person	stefan.jacobsen@ntnu.no
Telephone number of contact person	97666987

1. Is the project of relevance for Research Council programmes other than the BIA programme?

□X We have looked for other relevant programmes, but did not find any.

□ We are uncertain whether the BIA programme is the correct programme and would like an assessment. Relevant programme(s) may be:……

2. Have you submitted an outline to the BIA programme previously?

□ Yes, with BIA outline number:

□X No

□ Don't know

3. What is the objective of the Knowledge-building Project for Industry and what new expertise is the project expected to lead to within Norwegian research groups? How will the project be incorporated into the strategic plans of the applicant institution?

The goal of this project is to increase knowledge and competence in the fields of particle packing and chemical admixtures to control the stability and rheology of fresh cement-based materials, such as Self-Compacting Concrete (SCC) and Fiber Reinforced Self-Compacting Concrete (FRSCC). The research aims to solve the scientific problems of optimizing particle size distribution, dispersion, stability and rheology, with the goal of avoiding the quality problems which are often encountered with SCC. This will fulfill the needs of Norwegian concrete industry and society by allowing industrial use of SCC made with sustainable manufactured mineral powders and non-spherical (or irregularly shaped) particles, such as crushed aggregate and steel fibers. Use of crushed aggregate and fibers in concrete production will also conserve natural sand and gravel resources and reduce cost of a significant part of the reinforcement work. SCC is one of the most innovative developments of the concrete industry due to its potential to reduce construction costs, facilitate placement, improve working environment and enhance surface quality. However, the amount of SCC cast in-situ in Norway has stagnated at a very low market share due to factors such

12

3 Competitive constructions

December 2nd 2014

Chairman: Ya Peng

Robust and highly flowable concrete with controlled surface quality

15.00 –	**Introduction**	*Klaartje De Weerdt (SINTEF/NTNU)*
	Surface classification tool	*Tone Østnor (SINTEF)*
– 15.45	**Assessment of SCC stability – lab and field**	*Tor Arne Martius-Hammer (SINTEF) Sverre Smeplass (Skanska)*

Chairman: Gunrid Kjellmark

Ductile high tensile strength fibre reinforced concrete

16.00 – 16.45	**Fibre concrete guideline** **"Pros and cons" and possibilities with fibre reinforcement**	*Terje Kanstad (NTNU)*

High quality manufactured sand for concrete

16.45 –	**Introduction**	*Børge J. Wigum (Norcem)*
	Utilisation of Local Low Grade Manufactured Sand	*Sverre Smeplass (Skanska)*
	Crushed sand, Manufactured sand and "Engineered sand"	*Rolands Cepuritis, PhD student (Norcem/ NTNU)*
– 17.30	**Tranportation and Sustainability**	*Svein Willy Danielsen (SINTEF)*

COIN

COIN FA 2.1

Robust and highly flowable concrete with controlled surface quality

Klaartje De Weerdt, NTNU/SINTEF

SINTEF De Weerdt - COIN Closure Seminar - 2 & 3 Dec 2014

COIN

Members of COIN FA 2.1

SINTEF
- Tone Østnor
- Tor Arne Martius-Hammer
- Kari Aarstad
- Kristin Kaspersen
- Klaartje De Weerdt
- Knut Lervik
- Stig
- Erik
- Roger
- Chris
- Hedda Vikan
- Mari Bøhnsdale Eide

Mapei
- Espen Rudberg

NTNU
- Stefan Jacobsen
- Ya Peng
- Ove Loraas
- Albertas Klovas

Norbetong
- Britt Marstander
- Ernst Mørtsell

Norcem
- Knut Kjellsen
- Rolands Cepuritis

Skanska
- Sverre Smeplass

Veidekke
- Lise Bathen

Statens Vegvesen
- Eva Rodum

ICI
- Jon Wallevik

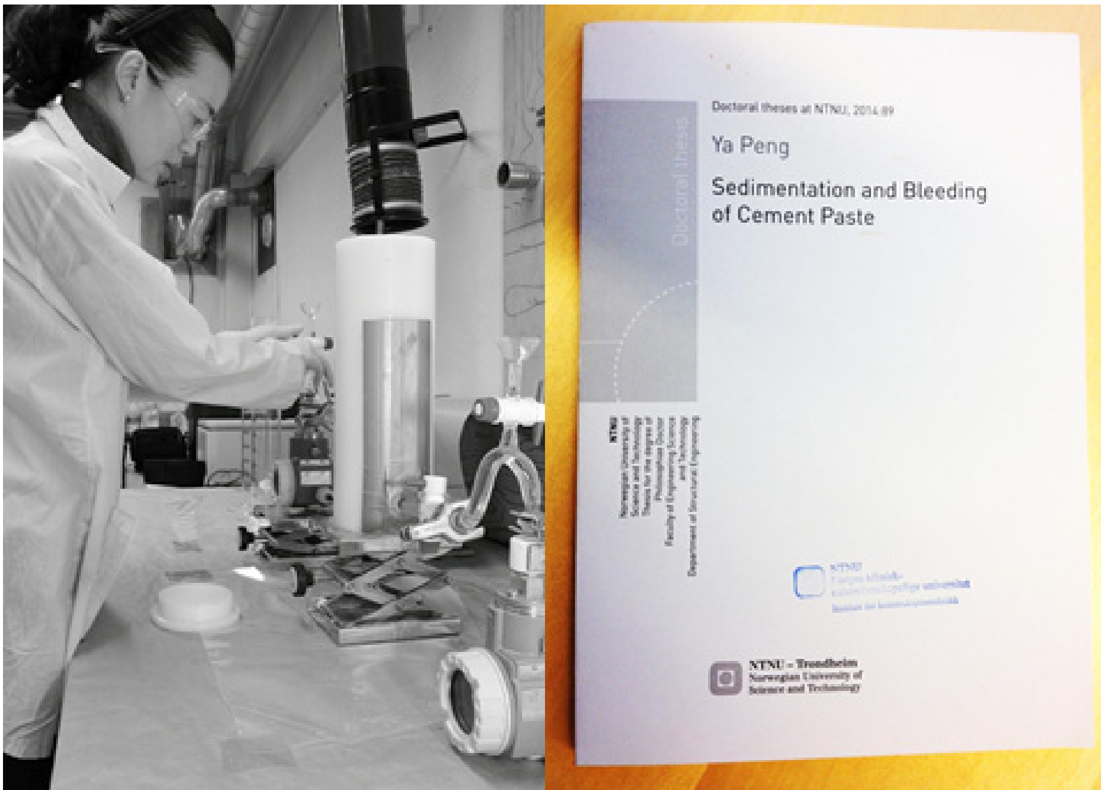
External advisor
- Olafur Wallevik

SINTEF De Weerdt - COIN Closure Seminar - 2 & 3 Dec 2014

Content

1. Surface classification tool
   Tone Østnor
2. Assessment of SCC stability – lab and field
   Tor Arne Martius Hammer and Sverre Smeplass

SINTEF De Weerdt - COIN Closure Seminar - 2 & 3 Dec 2014



SINTEF De Weerdt - COIN Closure Seminar - 2 & 3 Dec 2014


Ya Peng
SINTEF
De Weerdt - COIN Closure Seminar - 2 & 3 Dec 2014

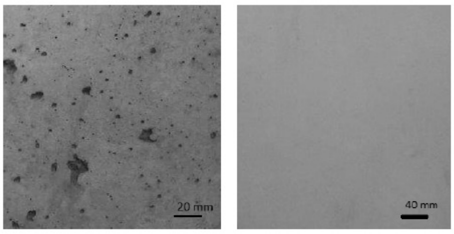
Classification of Exposed Concrete Surfaces

Kari Aarstad
Kristin Kaspersen*
Klaartje De Weerdt
Tone Østnor

SINTEF Building and Infrastructure
*SINTEF Information and Communication Technology

SINTEF

Motivation



What happens if you end up with a concrete surface with an unacceptable number and size of pores?

- Result in extra finishing costs and man hours
- Result in disagreements between the various parties
  - Who is responsible? Ready-mix concrete producer? Contractor? Architect?
- In the worst case: Start all over again

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COIN

Bygg Uten Grenser

- Their main focus is description of concrete surfaces and how to obtain them
- Our aim is to supplement this work by offering an objective classification tool and system.

SINTEF sfi Senter for forskningsdrevet innovasjon

COIN

The need for a classification tool

- Be able to coordinate expectations on concrete surfaces in advance
  - A tool both for architects and contractors
- Get an objective measure of the amount and size of pores
  - Be an help in discussions between contractors, ready-mixed concrete producers, architects and building owners
- In future, make it easier to study how parameters affect the in-situ cast concrete surface

SINTEF sfi Senter for forskningsdrevet innovasjon

Proposed classification system*

Pore diameter [mm]	Class A	Class B	Class C	Class D	Class E	Class 0
	Max. amount of pores per m²					
1-5	250	800	2500	5000	Project specific	No require-ments
5-10	5	20	50	100		
10-15	1	5	10	20		

*Eide Bøhnsdalen, M. and Hegseth, I.: Klassifiseringsverktøy for forskalte betongflater, master thesis 2009.

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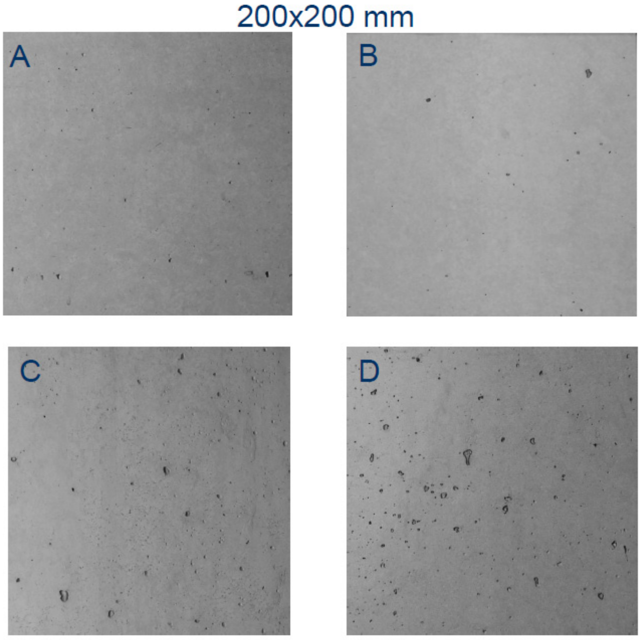
Examples of classified surfaces

200x200 mm



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BetongGUI

- Objective and quantitative tool
- Image analysis programme based on Matlab for analysing smooth concrete surfaces with regards to pores
- For the photographic procedure normal commercially available photo equipment is used
- The test area is about 60 x 60 cm and the scale is set with a ruler
- User friendly

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Set up

- Images are taken with flash from left and right angle (approx. 45°)
- The images are combined by choosing the darkest pixel for each position. This highlights the pores and evens out the background lighting.

Image example

Flash from the left | Flash from the right | Combined image

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Pore analysis example

Combined image | Combined image with pores marked manually | Pores found by BetongGUI

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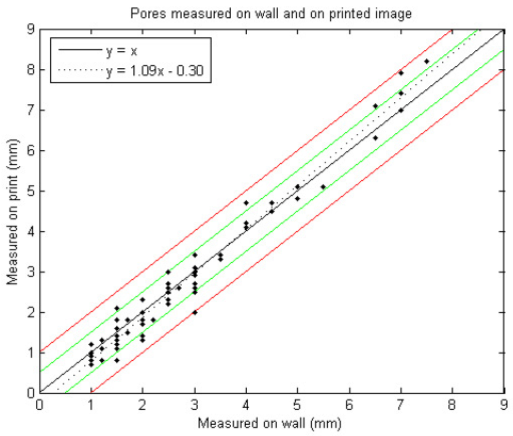
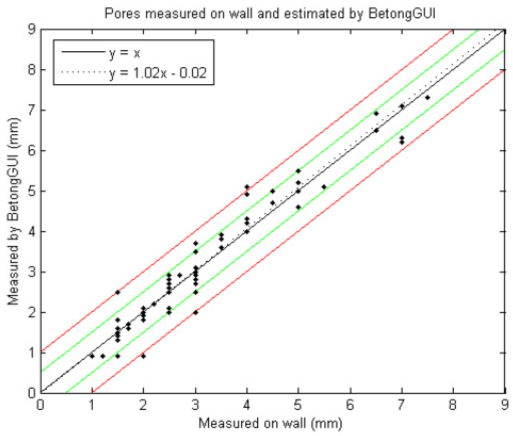
Comparison of results





- Compared manual measurement on wall, manual measurement on paper and results from BetongGUI
- Overall good correspondence between all three measurement methods

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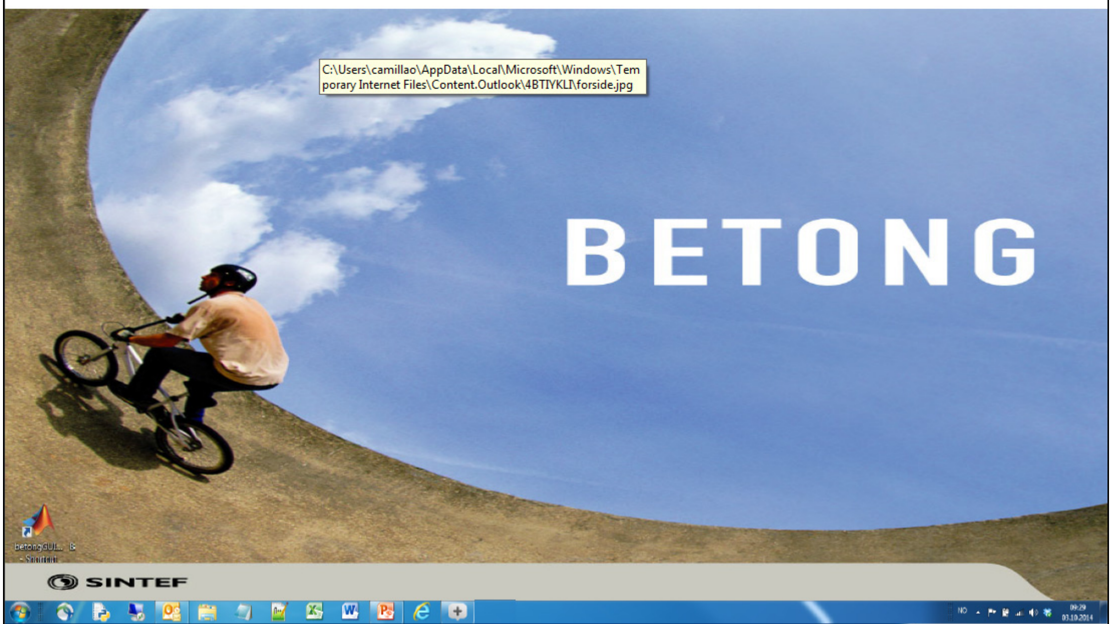
Demo of BetongGUI



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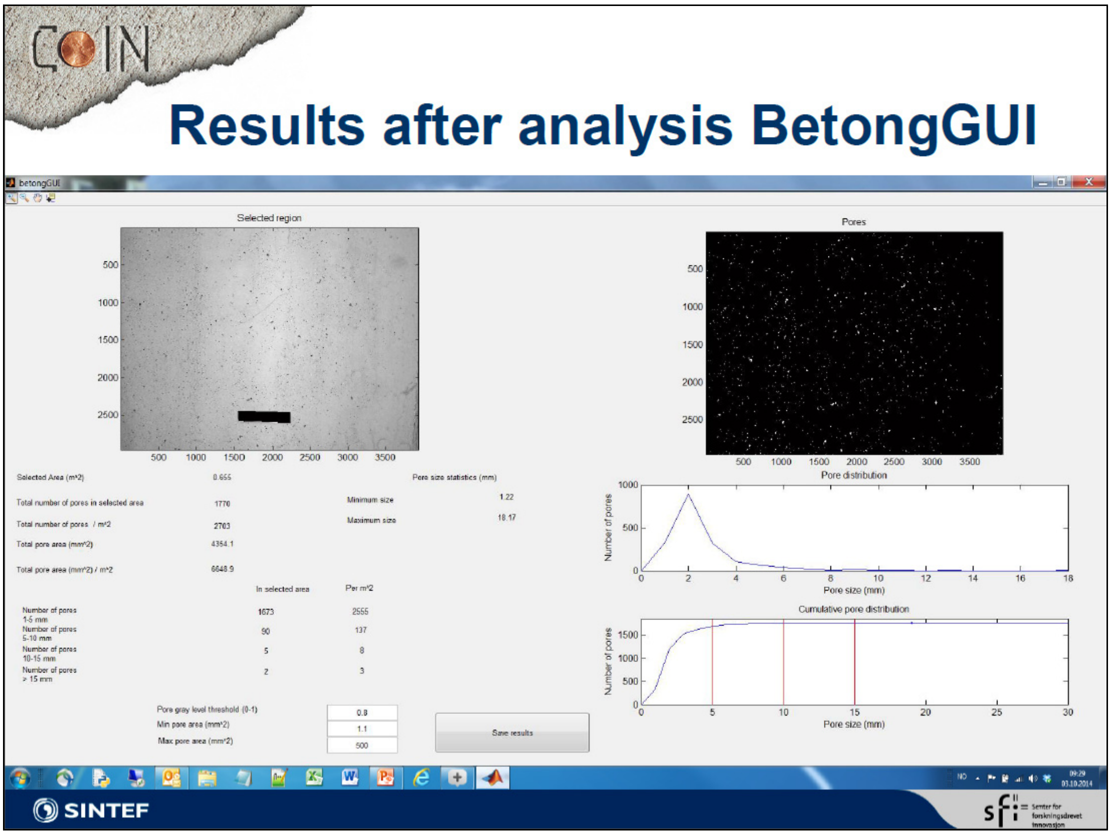
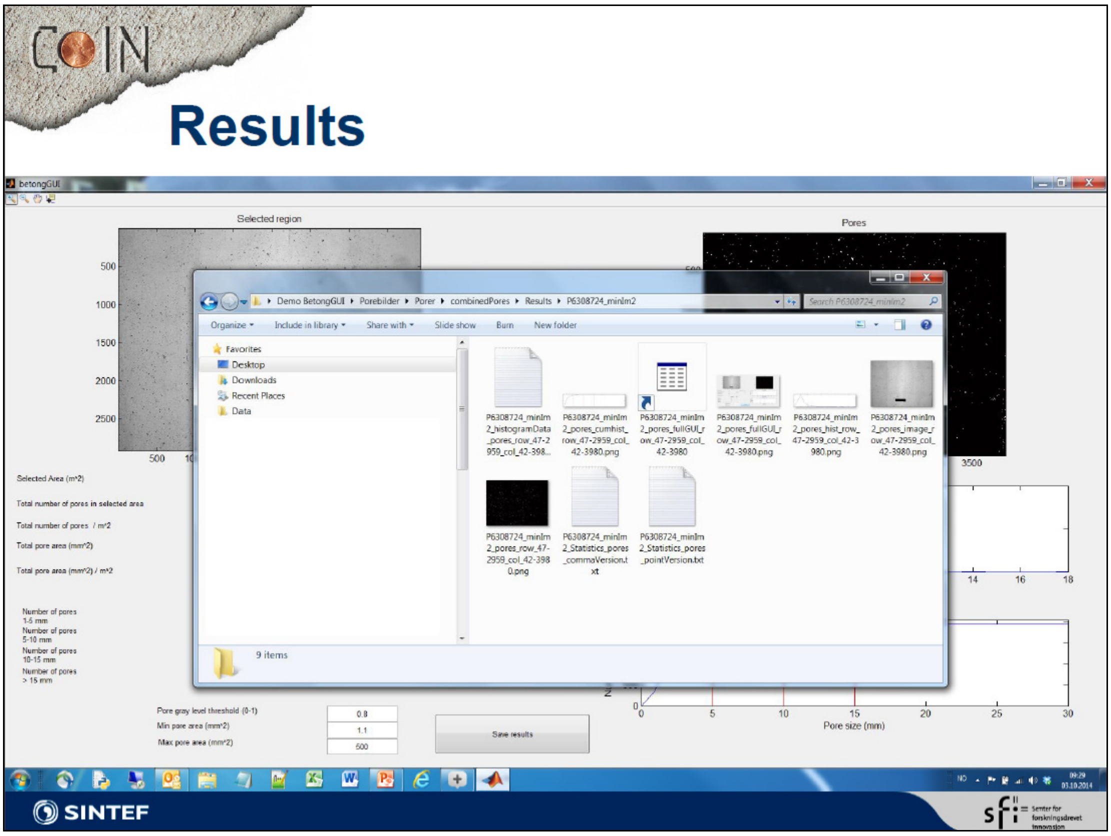

COIN
Results after analysis BetongGUI
betongGUI
Selected region
Pores
Selected Area (m^2) 0.655
Total number of pores in selected area 1770
Total number of pores / m^2 2703
Total pore area (mm^2) 4354.1
Total pore area (mm^2) / m^2 6648.9
Pore size statistics (mm)
Minimum size 1.22
Maximum size 18.17
In selected area
Per m^2
Number of pores 1-5 mm 1673 2555
Number of pores 5-10 mm 90 137
Number of pores 10-15 mm 5 8
Number of pores > 15 mm 2 3
Pore distribution
Number of pores
Pore size (mm)
Cumulative pore distribution
Pore gray level threshold (0-1) 0.8
Min pore area (mm^2) 1.1
Max pore area (mm^2) 500
Save results
SINTEF


COIN
Results
betongGUI
Selected region
Pores
Demo BetongGUI ▸ Porebilder ▸ Porer ▸ combinedPores ▸ Results ▸ P6308724_minIm2
Organize
Include in library
Share with
Slide show
Burn
New folder
Favorites
Desktop
Downloads
Recent Places
Data
9 items
Selected Area (m^2)
Total number of pores in selected area
Total number of pores / m^2
Total pore area (mm^2)
Total pore area (mm^2) / m^2
Pore gray level threshold (0-1) 0.8
Min pore area (mm^2) 1.1
Max pore area (mm^2) 500
Save results
Pore size (mm)
SINTEF

Future

We now have a tool which allows objective quantification of pores on the concrete surfaces

- It gives a basis to establish the classification system
- It can be used in the description and evaluation of surfaces

We depend on you!

- A beta-version of BetongGUI is available on request
- We wish to test BetongGUI on a wider range of concrete surface qualities.

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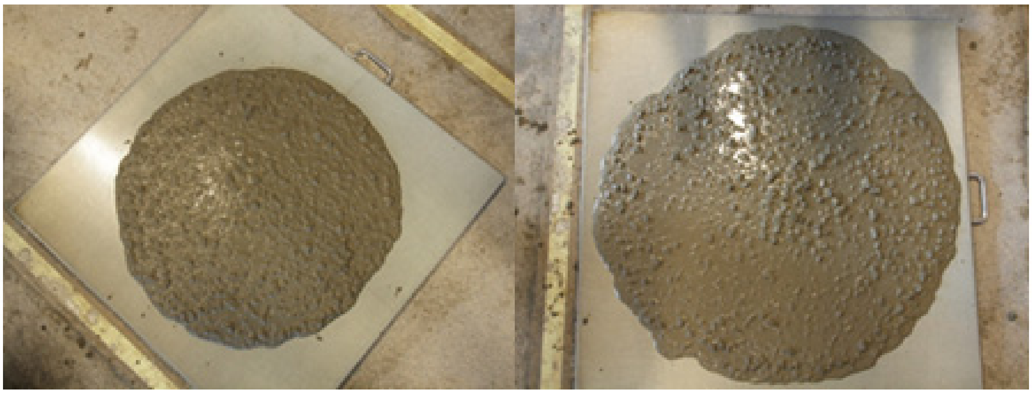
SCC – Stability assessment



Goal: To find a method to assess stability of SCC which is practical, reliable and representative for in situ stability problems

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SCC – Stability assessment

1. Requirements
2. Survey of test methods to find those with potential to fit the requirements
3. Gain experience with them in lab
4. Test them against stability assessed in situ:
   - *Stone content along a 10 m long wall, at the top and bottom*
   - *One "stable" concrete; SF = 700 mm and one "unstable" concrete, SF = 740 mm*

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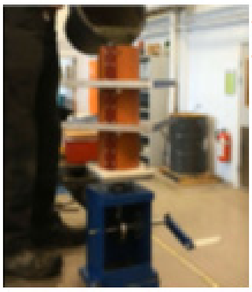
COIN

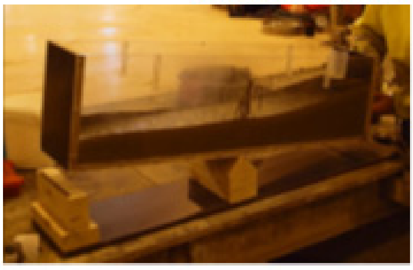
The methods

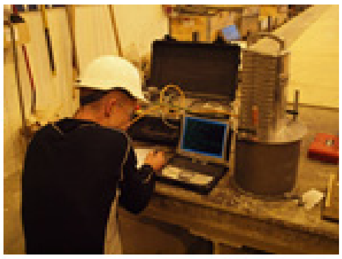
0 / 0.1	Stable and homogenous concrete. Aggregates and paste flow towards the rim of the sample.
0.2 / 0.3	Stable and homogeneous concrete that flows well, but has become a shiny surface with possible black spots
0.4 / 0.5	Has additionally a hint of a paste rim at the outer edge of the spread, but the aggregates follow the flow towards the edge. Still stable.
0.6 / 0.7	Clear rim of paste at the outer edge of the spread. Coarse aggregates tend not to flow towards the edge of the spread (are left in the middle of the spread).
0.8 / 0.9	Additional separation of water/paste at the outer rim of the spread.
1	Complete separation



Settlement Pipe Segregation, SPSI

Rheological Segregation, RSI





T-Box - penetration index, PDI, and volumetric index, VI

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COIN

In field

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In field

SINTEF

In field

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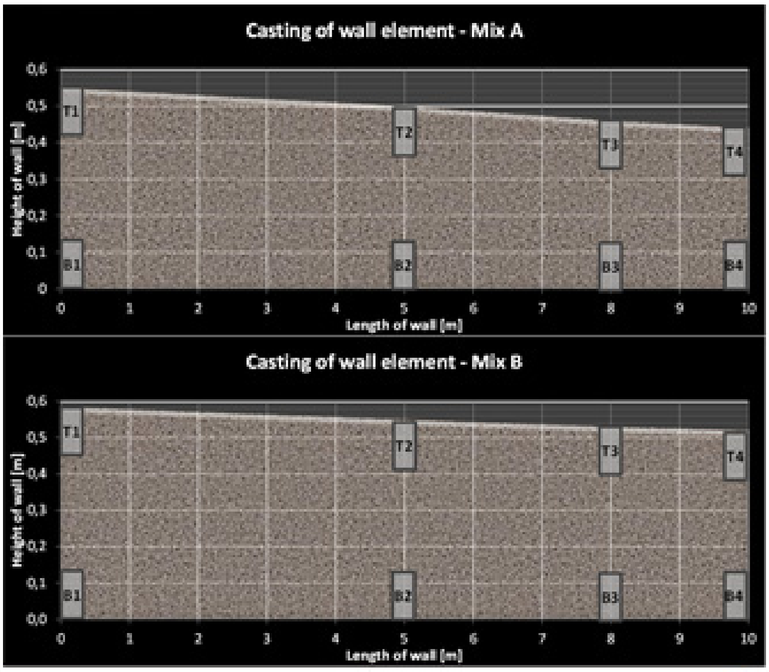
Results



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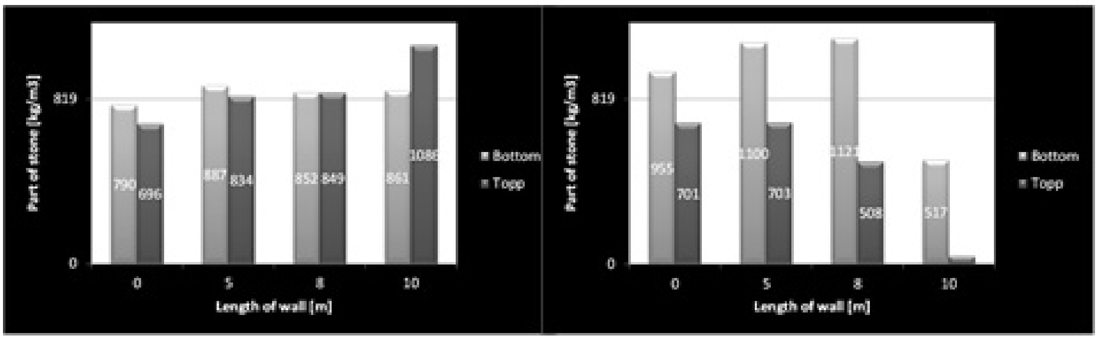
Results



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Results

Concrete	VSI[b]	RSI	SPSI	T-Box	
				PDI	VI
	≤ 0.6	≤ 0.5	≥ 0.88*	≤ 6 mm	≤ 25 %
A, SU=700, t_{500} = 0.8	0.5/0.6	0.5	0.88	4.5 mm	4.7 %
B, SU=740, t_{500} = 0.4	0.7/0.8	0.9	0.68	-6 mm	1.4 %

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Conclusion

Three methods seem to reflect segregation in a wall in a good way

The **VSI-test** is obviously the easiest and fastest one, also because slumpflow is measured in most cases anyway. Person dependency?

The **RSI-test** is relatively easy and fast, but power supply is needed and data has to be processed in a separate computer

The **SPSI-test** is the slowest and less easy one of the three, also because it includes flushing, drying and weighing of the coarse aggregates. But, fairly directly to the point; the difference in coarse aggregate content

Note: Limited investigation; more concretes (with higher viscosity?) must be tested

Nevertheless, the results show that these methods may be used to specify and control stability, and thus form a basis for revision of NB29

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COIN FA 2.2: Ductile high tensile strength fibre reinforced concrete

Terje Kanstad - Department of structural engineering, NTNU

Fibre concrete guideline - "Pros and cons" and possibilities with fibre reinforcement

+Project overview:

(1) Fibres and concrete qualities with high tensile stress after cracking
(2) Development of regulations for design and execution of FRC
(3) Tests of load carrying structural elements within or related to COIN

Overall objective: To do R&D work which stimulates and makes use of fibres possible in load carrying structures.

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Project Overview

- **Industrial partners:**
- Veidekke, Unicon, Mapei, Norwegian public roads admin, Reforcetech
- Outside COIN: Spenncon/Consolis, Thilt AS and Bekaert
- FA 3.3: Kværner and Weber St Gobain
- **NTNU researchers:** Giedrius Zirgulis, Elena Vidal Sarmiento, Håvard Nedrelid, Mette Geiker, Stefan Jacobsen, Max Hendriks, Jan Arve Øverli and Terje Kanstad
- **Lab-engineers:** Ove Lorås, Steinar Seehuus and Gøran Lorås
- **Sintef researchers:** Gunrid Kjellmark, Tor Arne Hammer, Helge Brå
- **Ex Sintef-researchers:** Sindre Sandbakk, Hedda Vikan, Bjørn Erik Jakobsen
- + 6 MSc students this spring (typical number for all years)
- Thanks to all who have contibuted, **and to those who funded the project**

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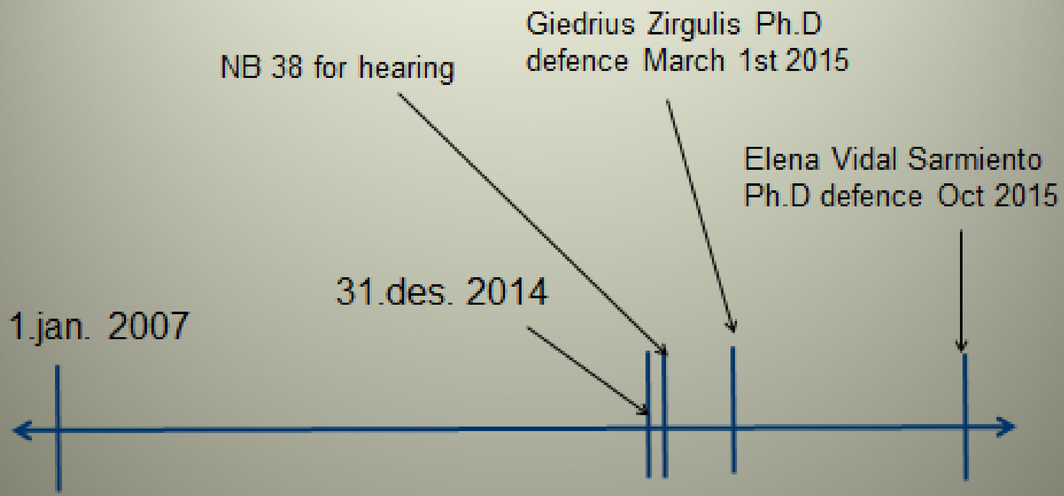
Time schedule COIN FA 2.2:

- It's not over until it's over !!



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Ongoing PhD-studies: Giedrius Zirgulis

Main topics

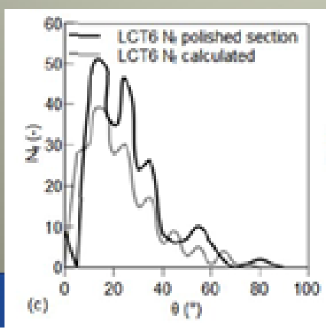
-Quantification of fibre orientation in structural elements by CT and image analysis of sawn and polished sections.

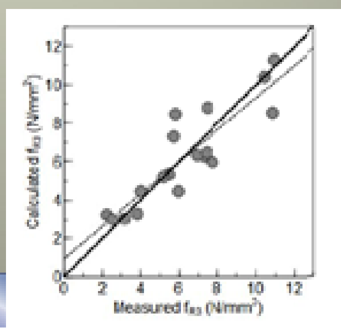
-Influence of geometry, casting method, mould surface structure, and reinforcement on fibre orientation

-Investigation of relations between fibre orientation and post-cracking tensile strength

Main contribution

Basis for avoiding the most unfavourable situation and utilizing the favourable effects of fibre orientation in practice





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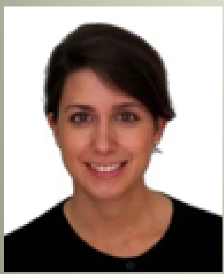
Ongoing PhD-studies: Elena Vidal Sarmiento



Main Topics

-Quantification of fibre orientation and fibre volume variations

-Structural analysis (Nonlinear finite element analysis) including the effects of fibre orientation and fibre volume variations due to flow and segregation.

-Further utilization of the 15MPa concrete

-Uniaxial tensile strength testing

Main contribution

-Will contribute a more thorough basis for design of structures made of flowable FRC

The fibre efficiency parameter: $\mu = w_1(cos\theta) + w_2\left(\frac{v_f}{\bar{v}_f}\right)$

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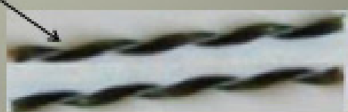
Fibre types:

- Steel fibres with hooked ends, ordinary / high strength quality – L=35-60mm several suppliers
- Alternative steelfibres
  - Alternative geometry
  - Alternative steelquality
  - Short fibres
- Polymer-fibres (typically Barchip)
- Basalt-fibres (=Reforcetech's Minibars)



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Traditional fibre concrete for slabs on grade and sprayed concrete:

- Until 40kg steelfibres per m³ concrete (0,5 volum%)*
- Until 10kg polymerfibres per m³ concrete (1,0 volum%)*
- Until 12 kg Minibars per m³ concrete (0,6 volum%)*

- Concrete composition as for ordinary concrete
- Suitable for floors, sprayed concrete for rock stabilization and for solutions combined with traditional longitudinal reinforcement

- *Based on the speakers personal experience and overview

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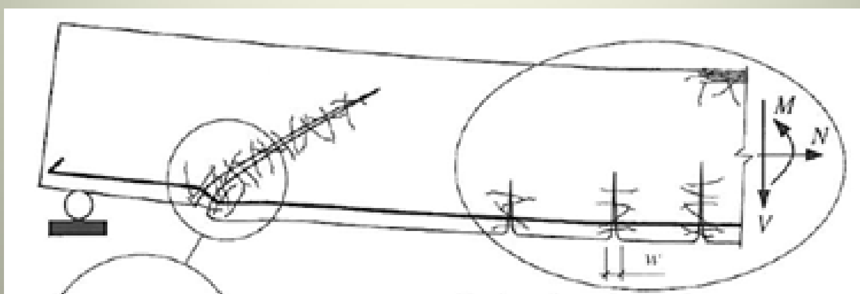
What is fibre concrete and how does the fibres work?



Together with longitudinal reinforcement can fibres contribute to:

Closer crack spacing and smaller crackwidths (invisible)
Less deformations (increased stiffness)
Increased moment and shear capasity

Traditional reinforcement can therefore partly be replaced by fibres

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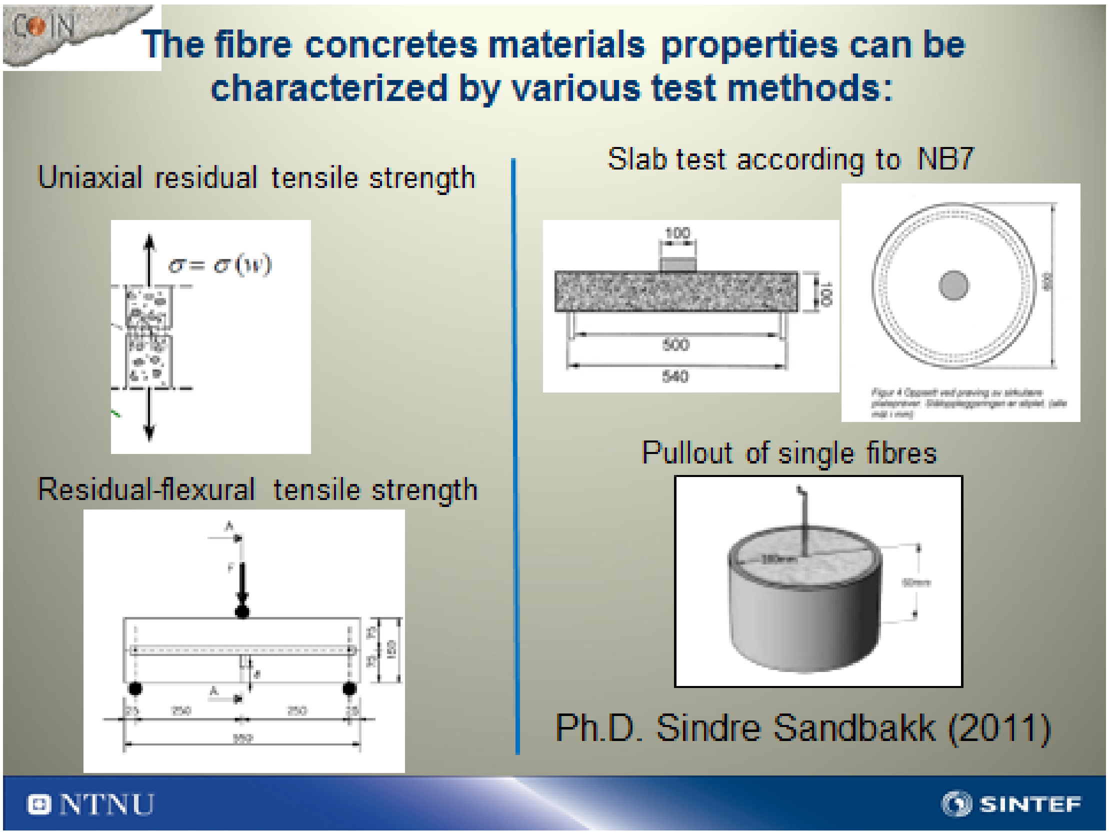
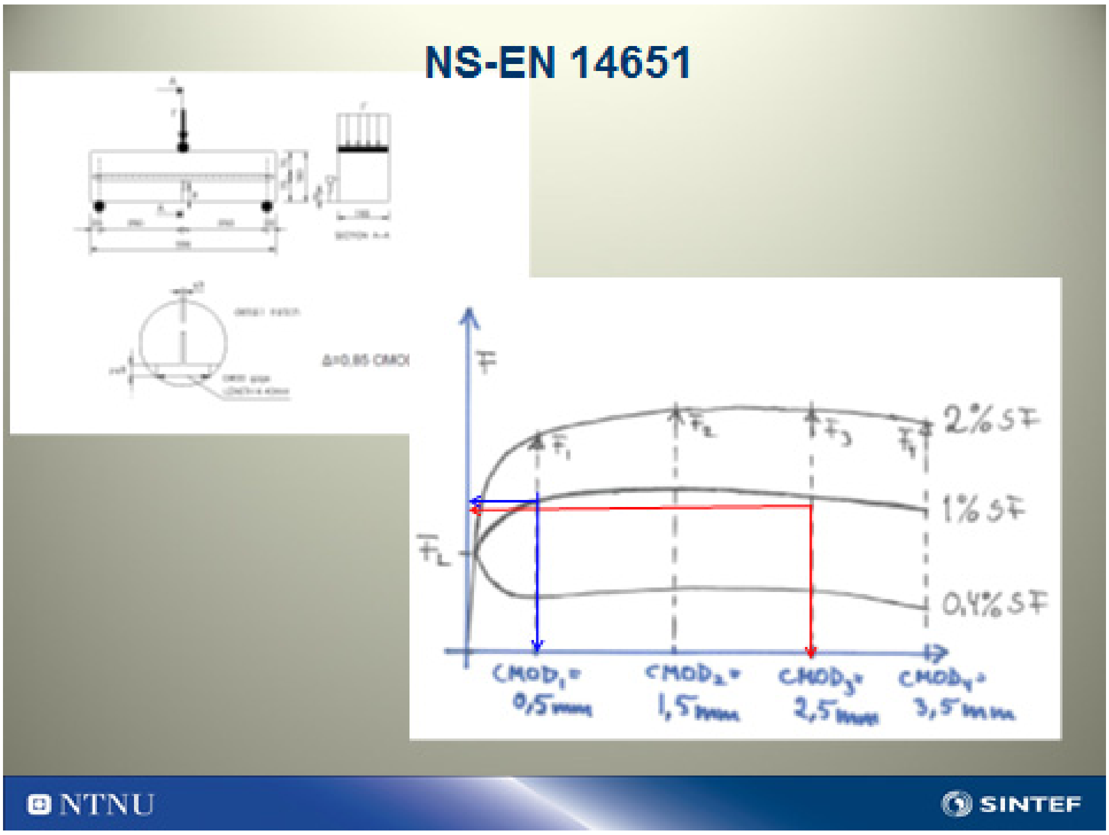

The fibre concretes materials properties can be characterized by various test methods:
Uniaxial residual tensile strength
$\sigma = \sigma(w)$
Residual-flexural tensile strength
Slab test according to NB7
100
500
540
Pullout of single fibres
Ph.D. Sindre Sandbakk (2011)
NTNU
SINTEF


NS-EN 14651
F
F1
F2
F3
F4
FL
2% SF
1% SF
0,4% SF
CMOD1 = 0,5 mm
CMOD2 = 1,5 mm
CMOD3 = 2,5 mm
CMOD4 = 3,5 mm
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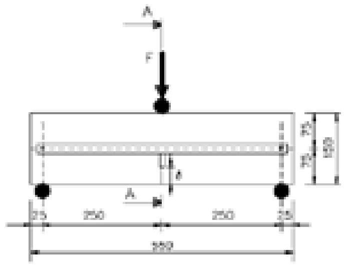
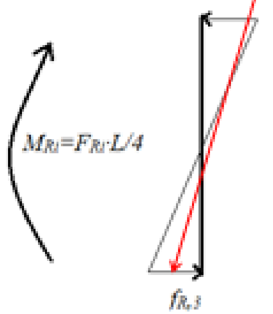
The design-parametres are taken from the beam test



Restbøyestrekkfasthet ved 2,5mm rissvidde: $f_{R3} = \frac{3PL}{2bh^2}$



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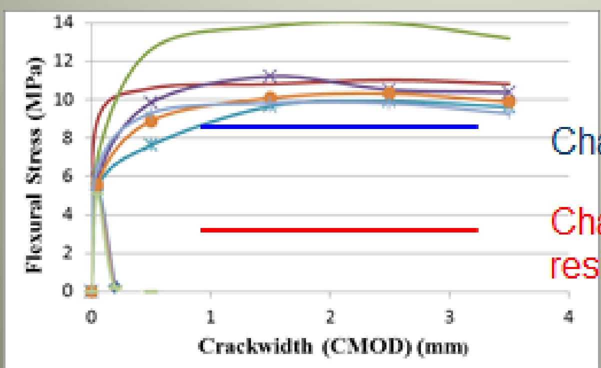
One step towards the vision of a 15MPa tensile strength concrete

- Concrete delivered by Unicon with 1 vol% 60mm steelfibres (80kg/m^3) The concrete recipe is modified by removing parts of the course aggregate (økt finstoffmengde) (PhD-candidate Giedrius Zirgulis)



Characteristic value

Characteristic uni-axial residual tensile strength

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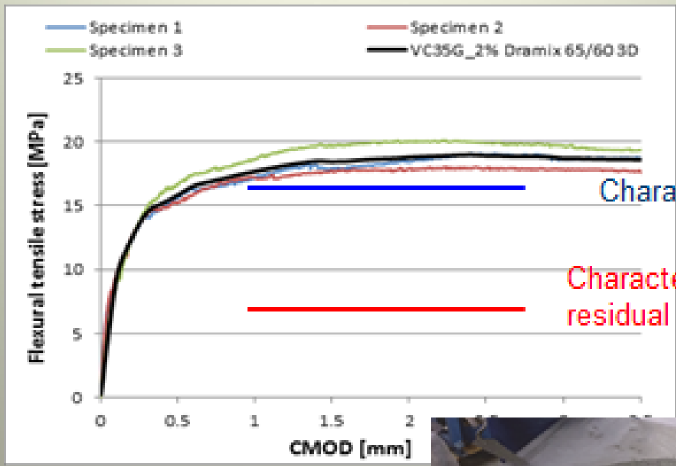
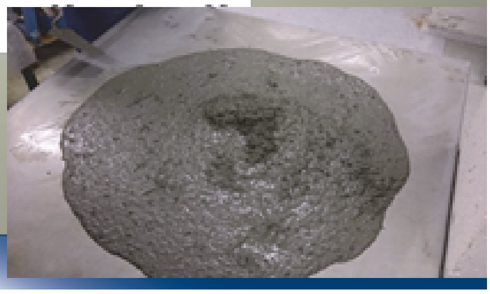
Best so far …. w/b=0,35, 2vol% Steel fibres

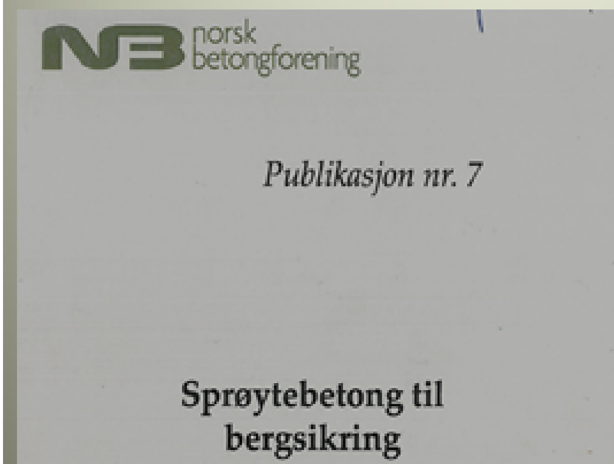




NTNU

Development of national and international regulations

Norsk betongforeningspublikasjoner relatert til fiberarmert betong:



- **NB 15 Betonggulv, gulv på grunn og påstøp** (ferdig i løpet av 2014)
- **NB 38 Use of fibre reinforcement in load carrying concrete structures: Guidelines for design, execution and control** (høringsversjon ferdig i løpet av 2014)

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NB 38 Use of fibre reinforcement in load carrying concrete structures: Guidelines for design, execution and control

Committee :

Øivind Bjøntegaard, Statens Vegvesen, Vegdirektoratet
Alf Egil Mathisen, Jernbaneverket (tidl Veidekke)
Arne Vatnar, Skanska (tidl Unicon)
Åse Lyslo Døssland, Multiconsult, Bergen
Nils Leirud, Bekaert
Dan Arve Juvik, Mapei
Thor Sandaker, Norconsult
Jorun-Marie Hisdal, Sintef
Helge Brå, Sintef
Terje Kanstad NTNU

Steinar Leivestad (NB representant og "godfather" for the commitee)

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Overview over standardizaton work

Norwegian arena	International arena
COIN-rapporten Forslag til retningslinjer for dimensjonering, utførelse og kontroll av fiberarmerte betongkonstruksjoner ble gitt ut og oversendt Norsk Betongforening i 2011.	Fib Model Code ble ferdigstilt i 2011. Endelig trykt utgave i 2013,.
Komite for Norsk betongforenings-publikasjon etablert i 2012 Rapporten planlegges ferdigstilt i 2014	Etablering av Eurocode 2 komite CEN/TC 250/SC 2 TG 2 "Fibre reinforced concrete" høsten 2012 (Norsk initiativ)
Praktisk erfaring med retningslinjene og videre verifikasjon og utvikling Flere referanseprosjekt er ønsket !!!	Tysk regelverk iht EC2: Steel fibre reinforced concrete. «Komplett» iht EN 206 og 13670. 2013: Forslag til Svensk Standard, SS 812310 Dimensionering av Fiberbetongkonstruktioner 2014: Forslag til Dansk regelverk (DTI), Spesielt tilpasset SCC

Nytt annex til EC2 om Fiberbetong planlegges ferdig i 2015, og endelig utgave i 2020.

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Committee work organized within NB

- Based on a COIN-report (2011) but is rewritten to be similar to NB's sprayed concrete publication (NB7)
  - Specification (Spesifikasjon)
  - Test methods (Prøvingsmetoder)
  - Calculation methods (Dimensjoneringsregler)
  - Guidelines (Veiledning)
- To be finished in 2014
- Today:
  - Validity range (Gyldighetsområde)
  - Design-parameters & strength-classes
  - Test program for concrete producers
  - Control and documentation of execution

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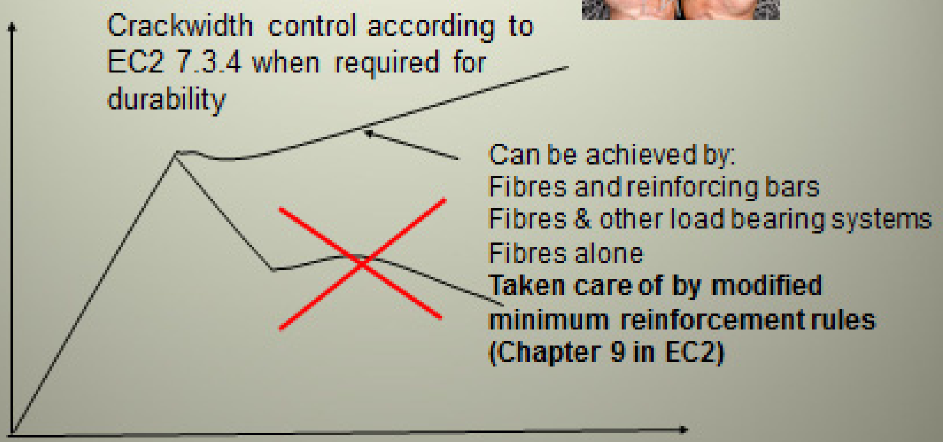
Validity range: Structures with hardening ..



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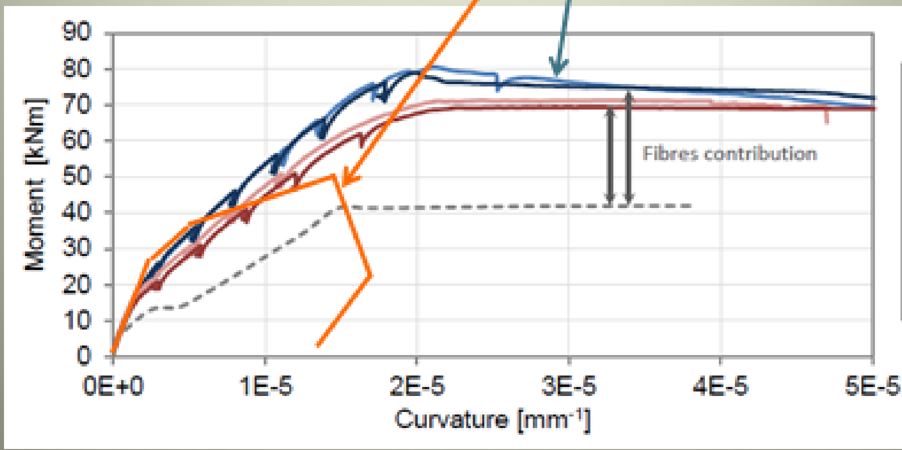
Experience with structural elements

- Moment capacity of beams with fibres+bars
- Moment capacity, beamswith only fibres



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Minimum reinforcement (Chap 9 i EC2)

Bjelker skal ha en minste armeringsmengde på strekksiden :

$$A_{s,min} = 0.26 \cdot \frac{f_{ctm} - f_{Ftsm}}{f_{yk}} \cdot b_t d \geq 0.0013 \cdot (1 - \frac{f_{Ftsm}}{f_{ctm}}) \cdot b_t d$$

For armerte betongbjelker er kravet til minimum skjærarmering [mm^2/mm^2] :

$$\rho_{w,min} = (0.1\sqrt{f_{ck}} - 0.2 f_{Fstm}) / f_{yk}$$

About 0,7 volume % (50kg/m3) elliminates the need for minimum reinforcement according to these formulas

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Minimum reinforcement (Chapter 9 i EC2)

Minimumsarmeringkravet for plater er i prinsippet de samme som for bjelker, men gjelder begge retningene. Hovedarmeringen og en gjennomgående minimumsarmering på tvers av denne skal derfor begge ha et tverrsnittsareal som svarer til:

$$A_{s,min} = 0.26 \cdot \frac{f_{ctm} - f_{Ftsm}}{f_{yk}} \cdot A_c \geq 0.0013 \cdot (1 - \frac{f_{Ftsm}}{f_{ctm}}) \cdot A_c$$

About 0,7 volume % (50kg/m3) elliminates the need for minimum reinforcement according to this formula

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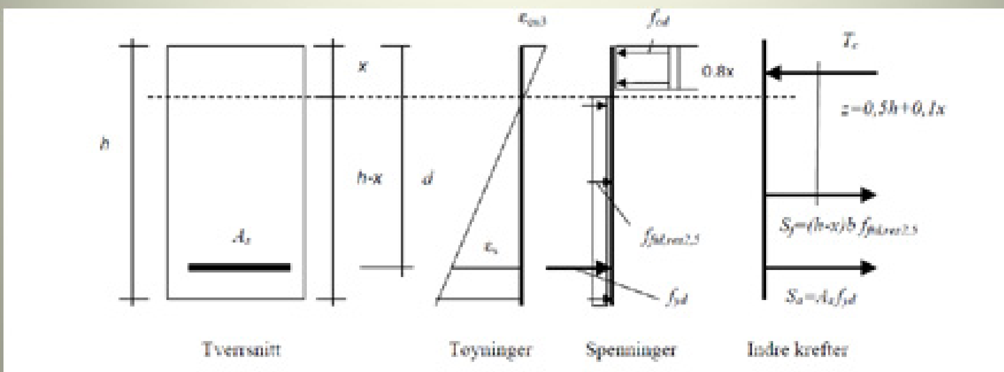
Moment capacity



Figur 6.2: Spennings- og tøyningsfordeling for rektangulært tverrsnitt av armert fiberbetong utsatt for ren bøyning. Betongens bruddtøyning for trykk, ε_{cu3}, er gitt i tabell 3.1 i Eurocode 2.

$$M_{Rd} = S_f(0,5h+0,1x) + S_a(d-0,4x)$$

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Addition rule for bending and axial forces:

For structural members exposed to moments and/or axial forces where a structural collapse can lead to loss of human life, or is of major social or economic importance

shall it in addition be verified that bending moments and the axial tensile forces can be carried by the cross section without contribution from the fibre reinforcement.

In this control all load and material coefficients shall be set equal to 1,0, and the combination factors $\psi_{0,i}$ (Table A1.1 EN 1990) be used for the accompanying variable actions.

From the specification part:

The specification to the concrete producer **shall** at least include:

- Strength class (Fasthetsklasse)
- Durability class (Bestandighetsklasse)
- Residual strength class (Reststrekkfasthetsklasse)
- Max aggregate class (Maksimal tilslagsstørrelse) D_{max}

The fibres shall be declared according to the following materials standards:

– NS-EN 14889 – 1 Fiber for betong Del 1: Stålfibere. Definisjonskrav, krav og samsvar, eller
– NS-EN 14889 – 2 Fiber for Betong Del 2: Polymerfibere. Definisjoner, krav og samsvar.
– Teknisk Godkjenning/ ETA (European technical approval)

Longtime-load and temperature stability

Uncertianty due to polymer fibers properties under longtime load and high temperatures

For situations where this might be critical, these properties must be particularly verified

Pre-documentation of the residual flexural strength

In additon to ordinary testing, the concrete producer shall document the residual flexural tensile strength (restbøyestrekkfastheten) using standard beams cast with the current concrete, mixing and transport equipment, and fibre addition method.

If the fibres are added directly in the automixer shall the mixing volume be at least 50% of the automixers total volume. Requirements for amount of fibres and distribution(minus- and plustolerances) shall also be controlled for the same volume.

Scope and procedures are described

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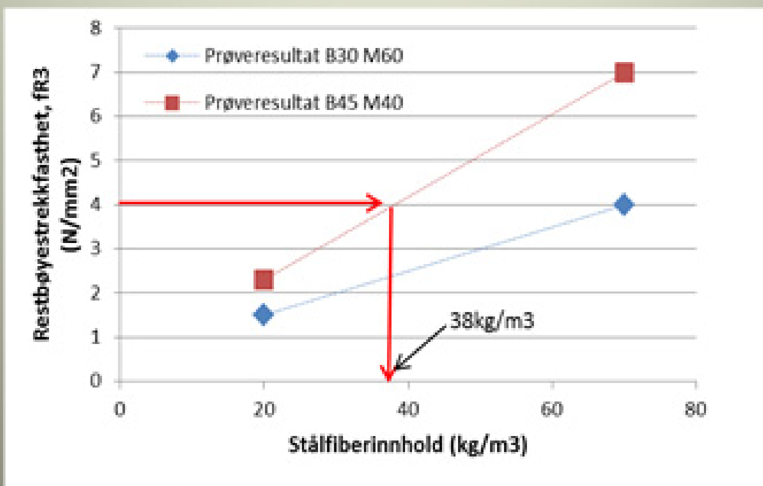
Test program for concrete producers

- The concrete producers shall verifify the residual flexural tensile strength. Scope and procedures are proposed:



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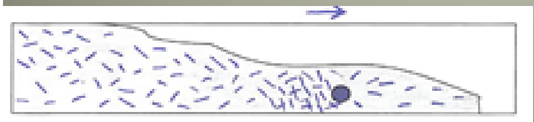
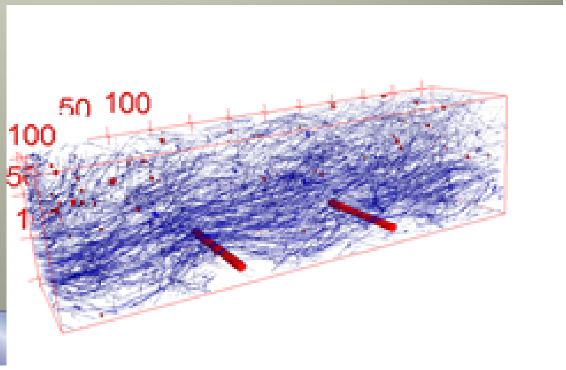
Control and dokumentation of execution:

- A risik evaluation regarding stability for the concrete deliveries and the casting works shall be carried out by the contarctor.
- It is for safety reasons extremely important that fibre-continuity between different casting batches is secured.
- Casting breaks which might give (separate) layers shall not occur. This is the contractors responsibility.
- It is very important that hindrances do not create weakness zones with low amounts of fibres.





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Design-parameters & methods

Uniaxial residual tensile strength=0,37xResidual flexural strength

$$f_{fik,res,2,5} = 0,37\, f_{R,3}$$

Expressions for moment capacity
Moment and axial force
Shear force capacity
Torsion
Crackwidth calculations
Minimum reinforcement rules

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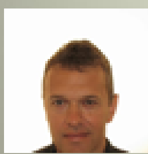
Typical applications:

- Foundations
- Walls
- Beams
- Load carrying slabs and ground slabs on piles
- Pipes and culverts
- Design for concentrated loads on slabs on grade and design of sprayed concrete in special cases
- Others? For sure

Design, testing and evaluation of a fullscale post-tensioned steelfibre reinforced flat slab

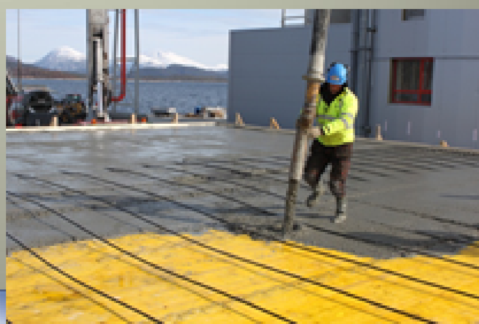
Ordinary reinforcement replaced by steel fibres (0,4% /30kg/m3)



Dr. Steinar Trygstad
THiLT Engineering AS,
Ålesund

Prof. Terje Kanstad
Department of
structural engineering,
NTNU

Funded by Spennteknikk construction AS, Betong Øst, Dyrøy betong, Mapei, Innovation Norway, NTNU mfl)



Objectives

- Stimulate use of fibres in load carrying structures
- Verify Norwegian proposal for fibre concrete guidelines
- Moment capacity
- Moment (re)distribution – Elastic analysis vs yield line analyses
- Shear capacity around central column
- EN14651 strength vs in-situ residual strength
- Ductility & robustness as input to future Eurocode 2 annex for steel fibres

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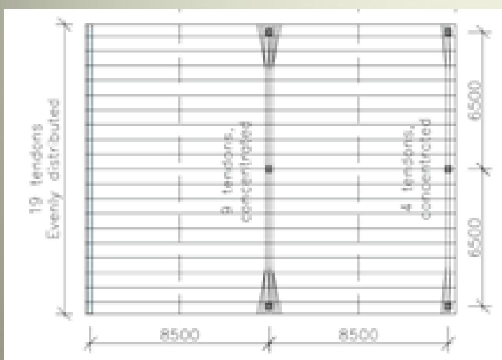
Tendon layout and slab geometry

150 mm² tendons



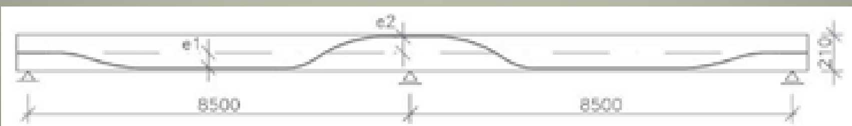


Figure 50: Tendon layout in x-direction.

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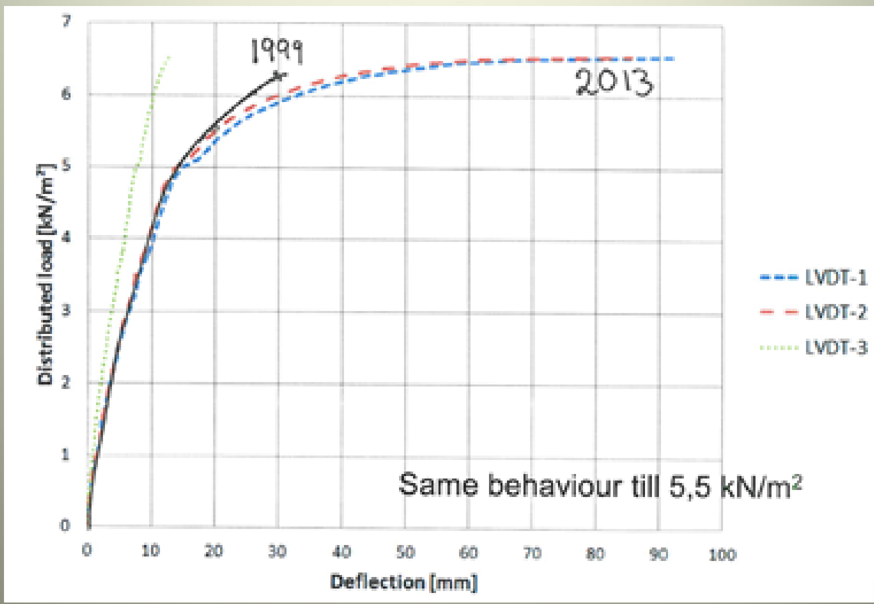
Test results: Deflections in both slabs



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Summary and conclusions

- The results are considerably at the safe side if characteristic strength values and elastic theory for calculation of moment and shear forces are used – This holds independently of which guidelines are used
- If yield line analysis and redistribution of forces is accounted for – nice agreement between theory and experiment is achieved
- The ductility seems to be sufficient
- The current approach with a relatively low degree of prestressing and low amount of fibres can be recommended for further use in practice
- A reference projects has been carried out (Munkvold – Trondheim)
- A technical approval is in progress at Sintef

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Structural fibre-reinforced concrete - Tests and design methods for RC beams with dapped ends and RC beams with openings Carried out in cooperation with Spenncon

Also:
I-shaped cross sections
Post-tensioned beams
LWAC beams
Anchorage of steel details
Post-tensioned flat slab

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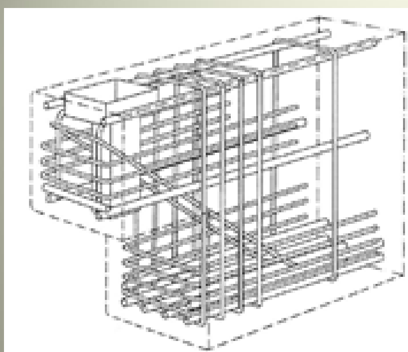
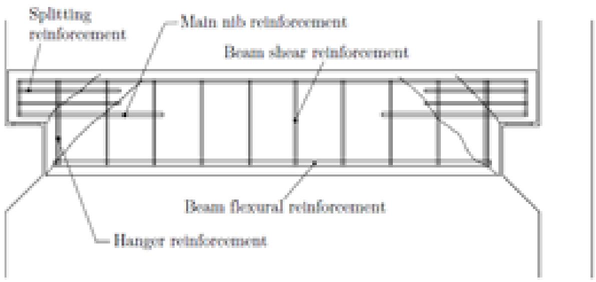
Dapped end beams (





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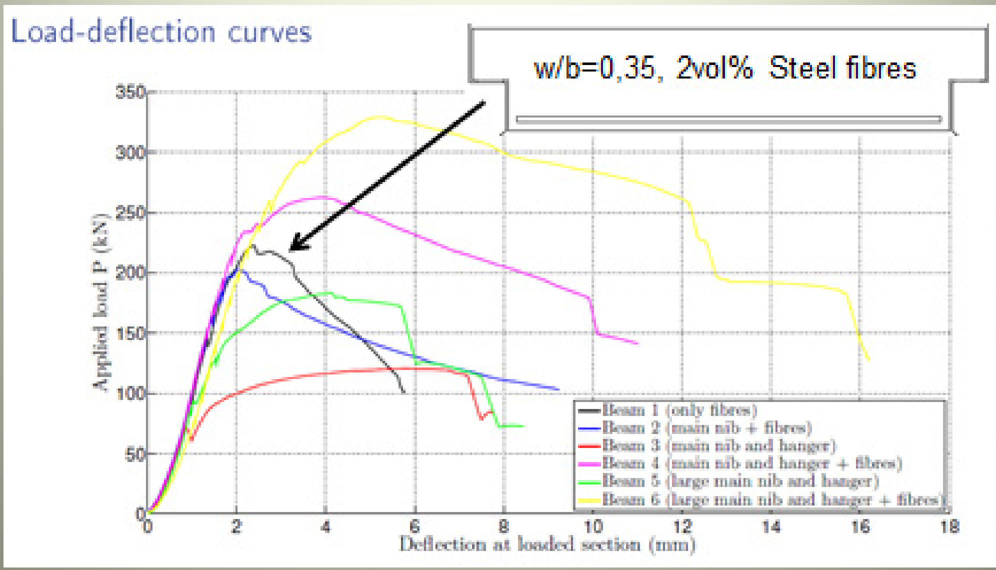

Conclusions

- The proposed calculation model agrees well with experimenteal behaviour
- Dapped end beam reinforcement can be considerably reduced if fibres are used
- Only main tensile bars is possible, but not recommended

One hanger should be included for practical and economical reasons
And nib tensile reinforcement for robustness and uptake of horizontal forces

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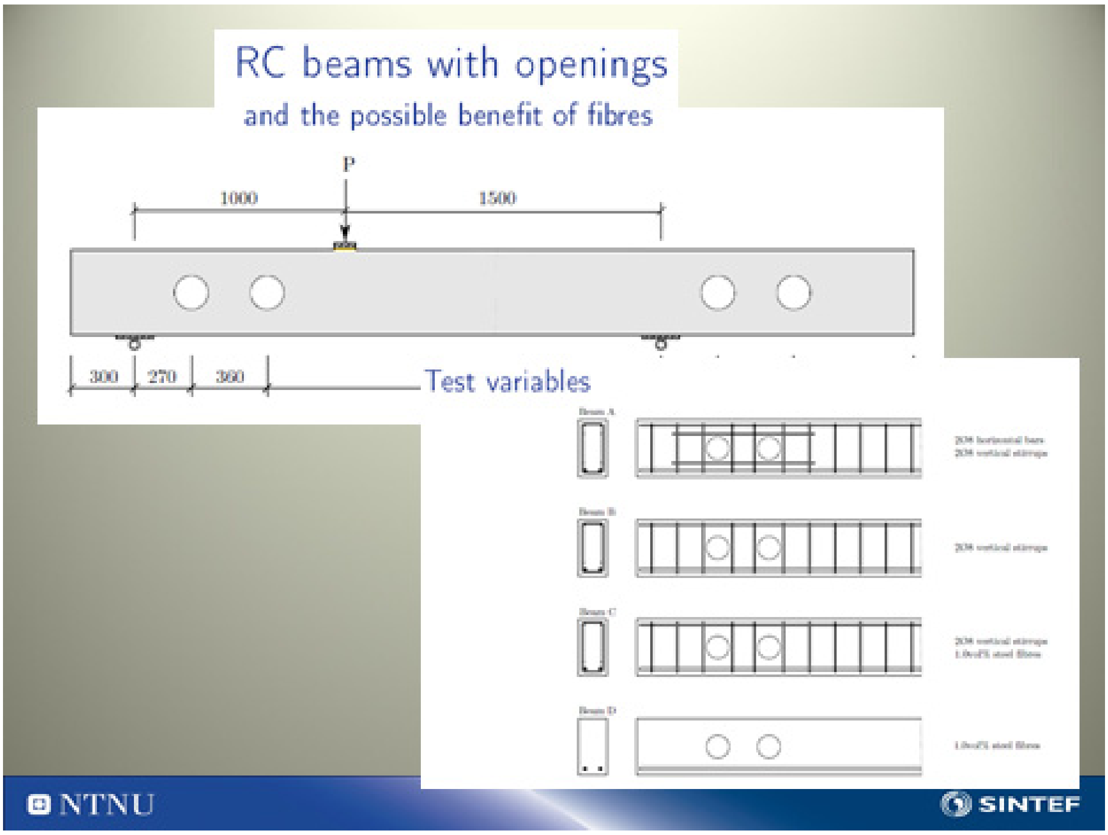

Summary beams with openings

– It has been shown that the shear reinforcement in the region of the openings can be replaced by 1.0 vol% hooked-end steel fibres
– Simple shear design formulas for RC beams with openings based on the EC2 expressions for solid beams have been proposed

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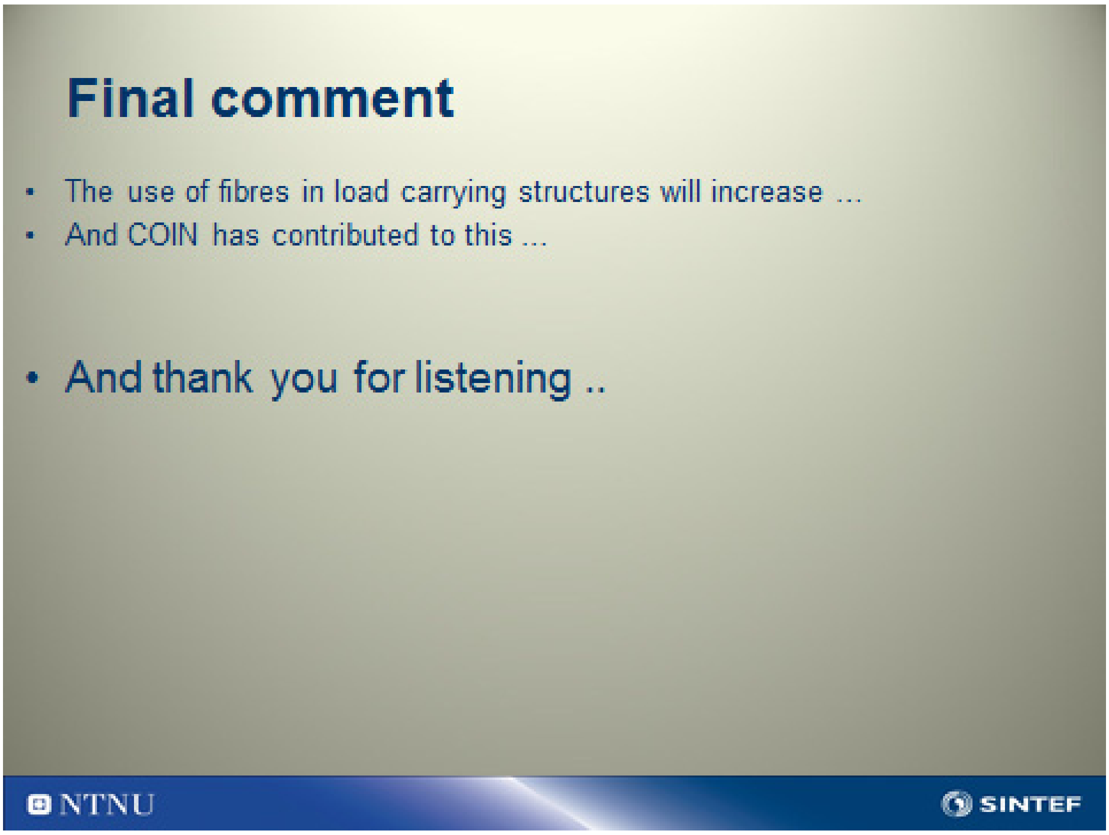
Final comment
The use of fibres in load carrying structures will increase ...
And COIN has contributed to this ...
And thank you for listening ..
NTNU
SINTEF

COIN – Concrete Innovation Center

Concrete innovation in Norway 2007- 2014

December 2nd & 3rd, 2014
Realfagsbygget, Auditorium R9, NTNU Høgskoleringen 5, Trondheim

COIN FA 2.3

High quality manufactured sand for concrete

Børge J Wigum – Norcem/NTNU

NORCEM
HEIDELBERGCEMENT Group

The outcome; 2008 - 2014

COIN FA 2.3

High quality manufactured sand for concrete:

New ***aggregate processing methods*** *(crushing and classification) - along with new sophisticated ways of* ***concrete mix design*** *- have enabled the production of various types of concrete containing 100% crushed aggregates.*

These ***innovative*** *new processes and products provide a better utilization of natural resources; reducing transportation and environmental impacts, and lead to improved sustainability in the building sector.*

NORCEM
HEIDELBERGCEMENT Group

Why manufactured sand ?

Natural resources are depleting

Transportation of aggregates in Norway (2012); 110.000 tonn CO_2

- 1.1% of all transport
- 10% of cement

Increased transportation

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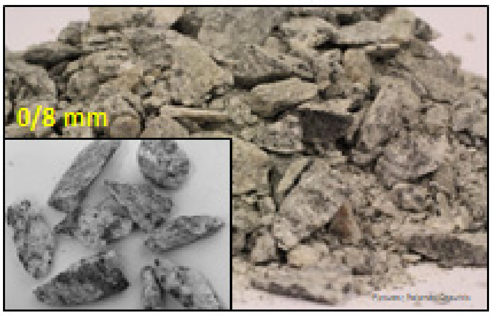
Manufactured sand

Utilisation and Innovation – both by low- and high quality



NORCEM
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This session

16:45 – 17:00 **Introduction & Background** - *Børge Johannes Wigum*

17:00 – 17:10 **Utilisation of Local Low Grade Manufactured Sand** - *Sverre Smeplass*

17:10 – 17:20 **Crushed sand, Manufactured sand & «Engineered sand»** - Rolands Cepuritis

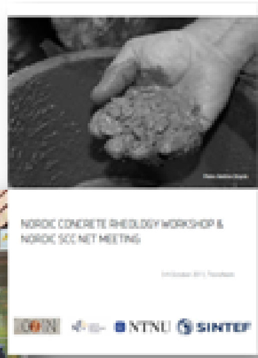
17:20 – 17:30 **Transportation and Sustainability** - Svein Willy Danielsen

Workshops

Manufactured sand – Workshop; Stavanger, Norway, October 30th and 31st 2008

Workshops

Nordic Concrete Rheology Workshop & Nordic SCC Net Meeting, 3-4 October 2011, Trondheim



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Workshops

Manufactured sand – Seminar, Stavanger, Norway, October 20th and 21st 2014

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STAR Reports
Production and Utilisation of Manufactured Sand
State of the art Report
COIN Project report 12 - 2009
Review report on dry and wet classification of filler materials for concrete
State of the art
COIN Project report 52 - 2014
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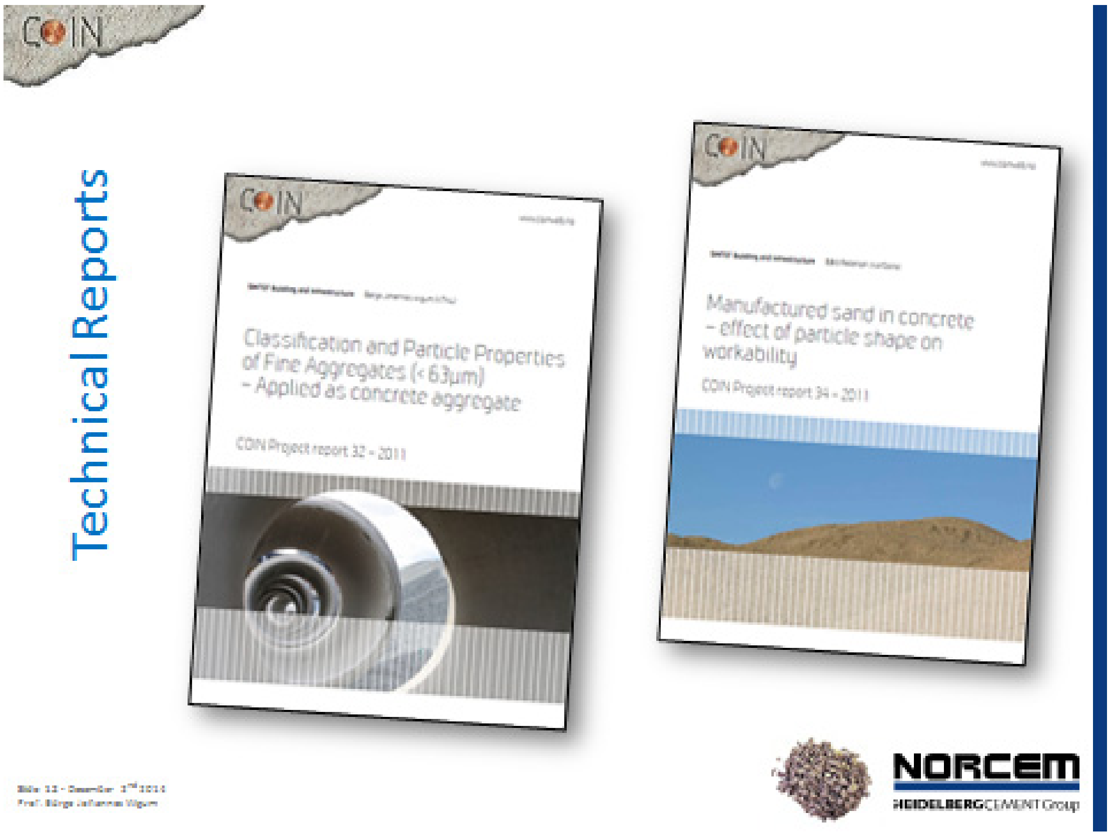
Technical Reports
Classification and Particle Properties of Fine Aggregates (< 63µm) – Applied as concrete aggregate
COIN Project report 32 - 2011
Manufactured sand in concrete – effect of particle shape on workability
COIN Project report 34 - 2011
NORCEM
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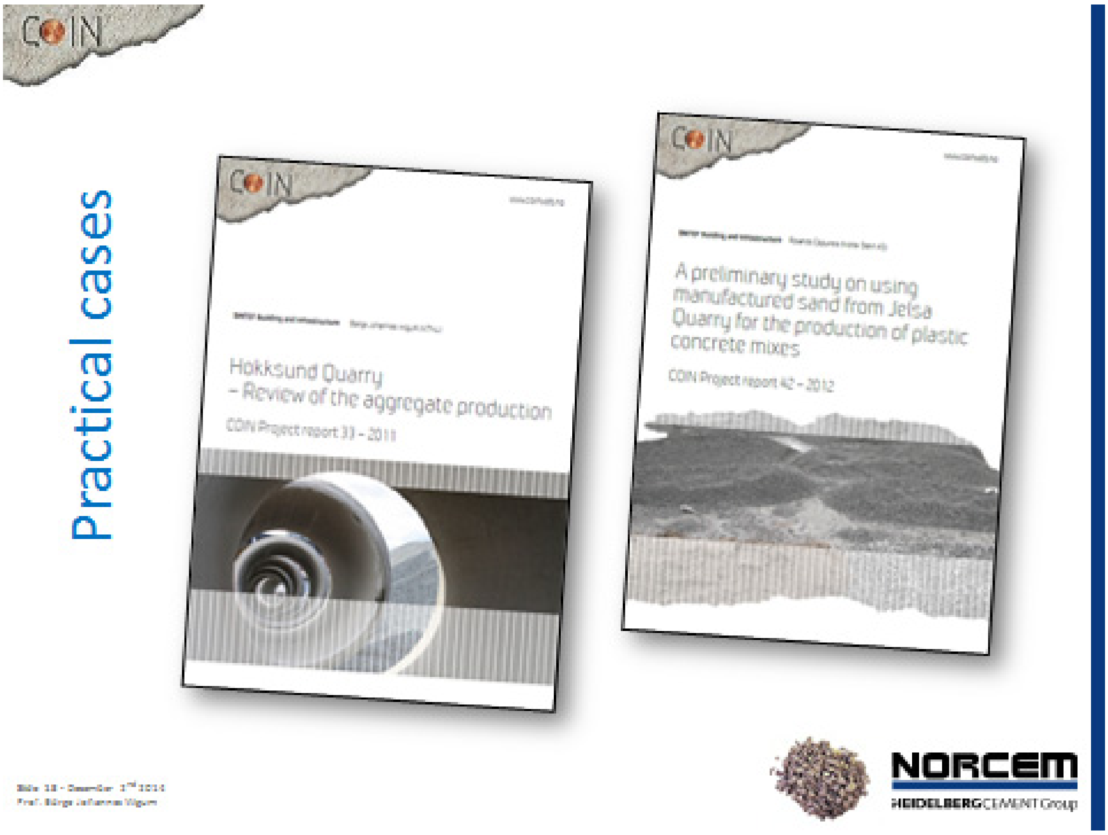
Practical cases
Hokksund Quarry
– Review of the aggregate production
COIN Project report 33 – 2011
A preliminary study on using manufactured sand from Jelsa Quarry for the production of plastic concrete mixes
COIN Project report 42 – 2012
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Scientific Articles
Cement & Concrete Composites
Filler from crushed aggregate for concrete: Pore structure, specific surface, particle shape and size distribution
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COIN
Trade journals - newspapers
New type of crushed sand to replace natural sand in concrete production
Kortreist stein løser knipe
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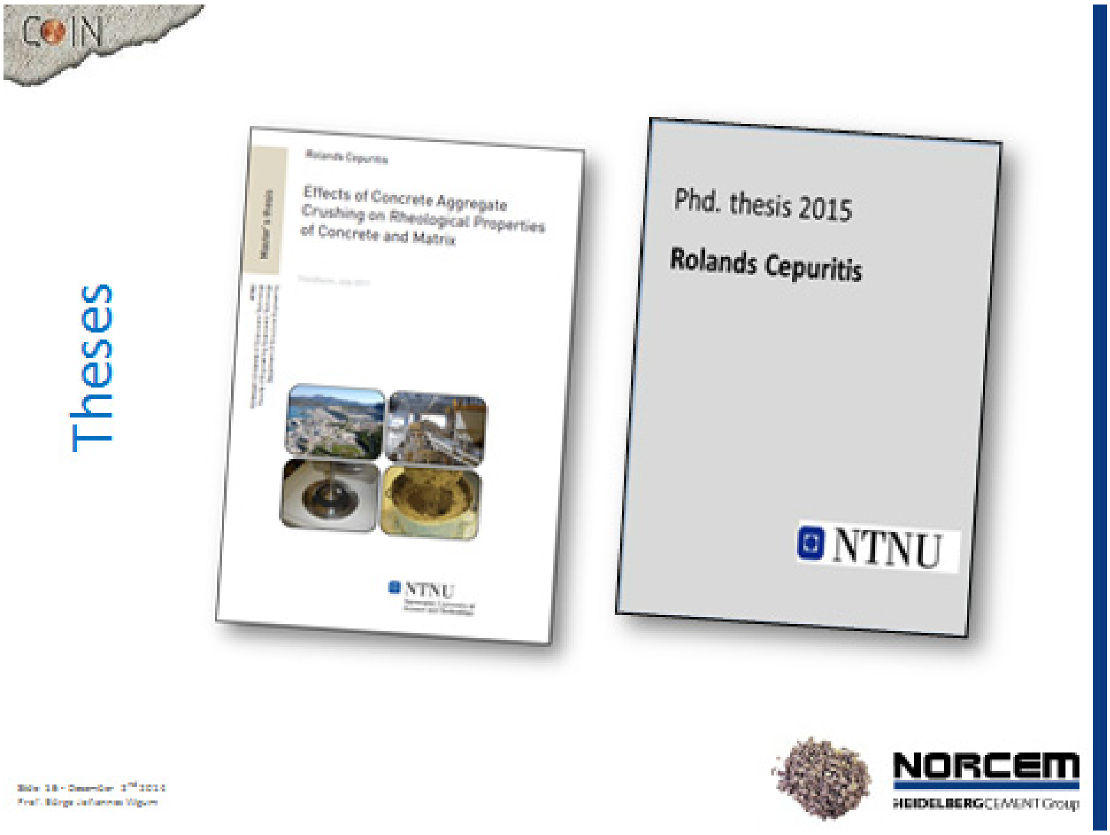
COIN
Theses
Rolands Cepuritis
Effects of Concrete Aggregate Crushing on Rheological Properties of Concrete and Matrix
NTNU
Phd. thesis 2015
Rolands Cepuritis
NTNU
NORCEM
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Manufactured Sand in Concrete
Sustainable & Durable Structures for the Future !

COIN

Værnes Airport Commuter Terminal concrete slabs:

The use of low grade manufactured sand

SINTEF

sfi

COIN

SKANSKA

Værnes Airport Commuter Terminal - concrete slabs

- 28800 m^2 slabs, 350 mm thick
- 10000 m^3 concrete
- Non-reactive aggregates
- Low-alkali binder or CEM II/A-V
- High flexural strength requirement
- Frost resistance

Problem: local crushed rock and local natural sand are both alkali reactive!

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COIN

SKANSKA

Solution developed in cooperation between Skanska and Norbetong

- Non- reactive crushed rock from Nord-Fosen
- Combined sand
  - 60 % non-reactive manufactured sand from Nord-Fosen
  - 40 % reactive local natural sand
- CEM II/A-V binder
- "Normal" binder content
- Relatively high dosage of SP
  - Slightly retarded concrete
- Prolonged mixing time

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sfi

COIN

SKANSKA

Manufactured sand from Nord-Fosen

- Low grade – no processing after crushing
- High content of fines, 11% < 0,125 mm

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Slab production

- Bidwell paver
- Slump measure 220 mm
- Placing of concrete in front of paver by concrete pump
- Brushed finish
- Extensive use of curing membrane

Challenge: Very viscous concrete. Normal slump for this production process is approx. 140 mm

COIN

SKANSKA

Results and conclusion

- High quality slabs
  - No separation or segregation
  - Superb wear properties
- High flexural strength
- Acceptable variation in fresh and hardened concrete properties

- ***Low grade manufactured sand can be used successfully for special purposes***
- ***Production must be adapted to "deviating" concrete properties***

SINTEF

sfi

COIN www.coinweb.no

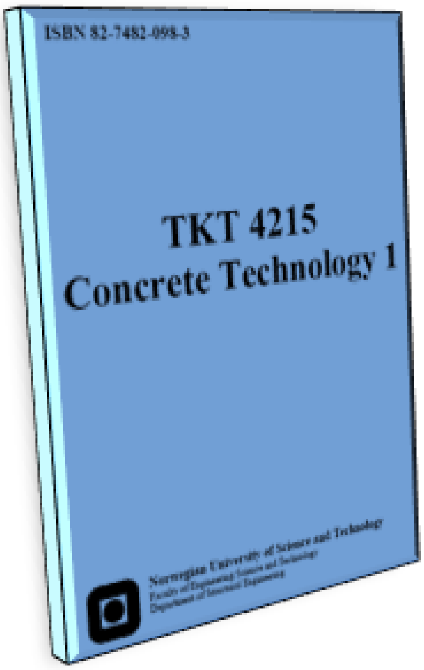
NTNU Norwegian University of Science and Technology www.ntnu.no

Crushed sand, Manufactured sand & "Engineered sand"

www.norcem.no NORCEM HEIDELBERGCEMENT Group

COIN – Concrete Innovation Center, Concrete Innovation in Norway 2007- 2014, Trondheim, Norway, December 2nd and 3rd, Rolands Cepuritis

Chapter 9 – Concrete aggregates



- Both in the PAST and TODAY it is MOST COMMON to use sand aggregates from NATURAL gravel deposits […]
- In more recent years, it has also become common with partial mix of sand produced from CRUSHED ROCKS (the so so-called "CRUSHED SAND/ MACHINE SAND" […]

Slide 2 – 02.12.2014
Rolands Cepuritis

NORCEM HEIDELBERGCEMENT Group

Using “crushed sand” …

… without a “PRESCRIPTION” from a DOCTOR:

Slide 3 - 02.12.2014
Rolands Cepuritis

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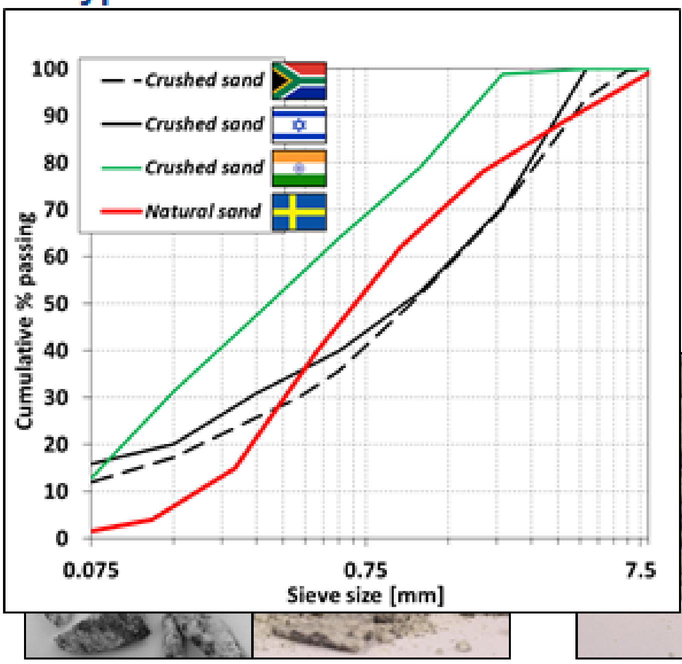
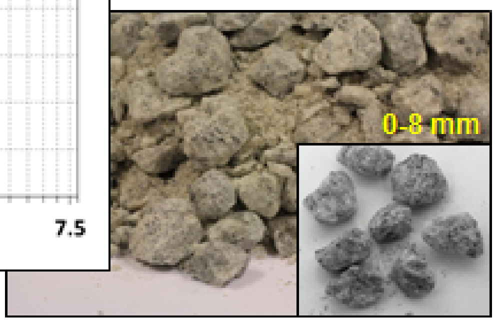
Types of "crush sand"



80-100 NOK/t



Slide 4 - 01.12.2014
Rolands Cepuritis

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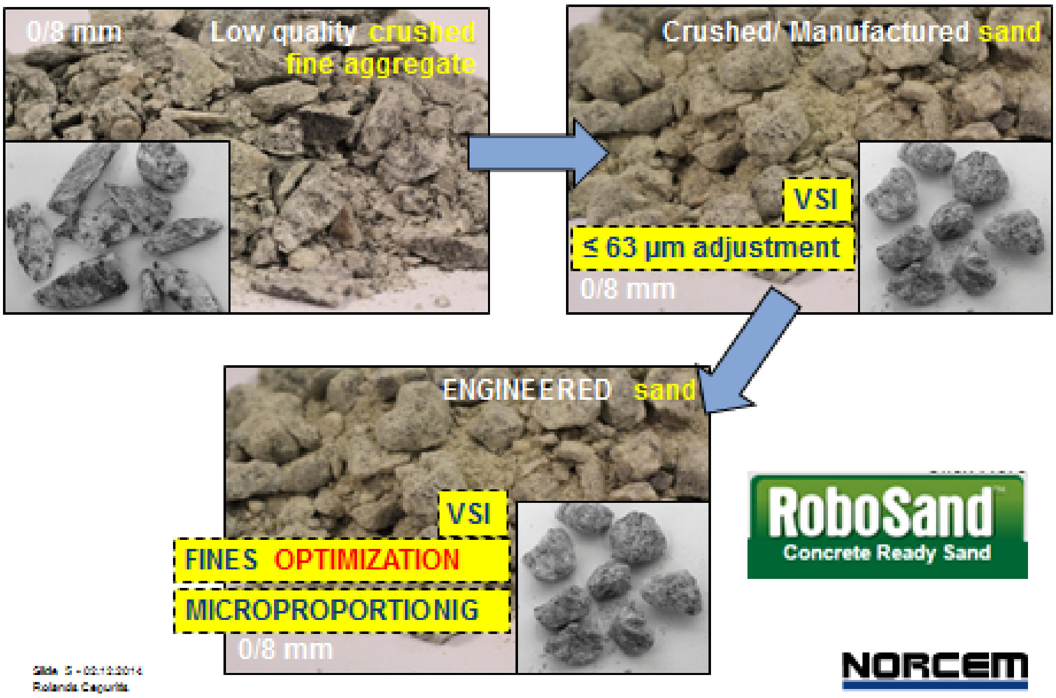
Types of "crush sand"



Slide 5 - 02.12.2014
Rolands Cepuritis

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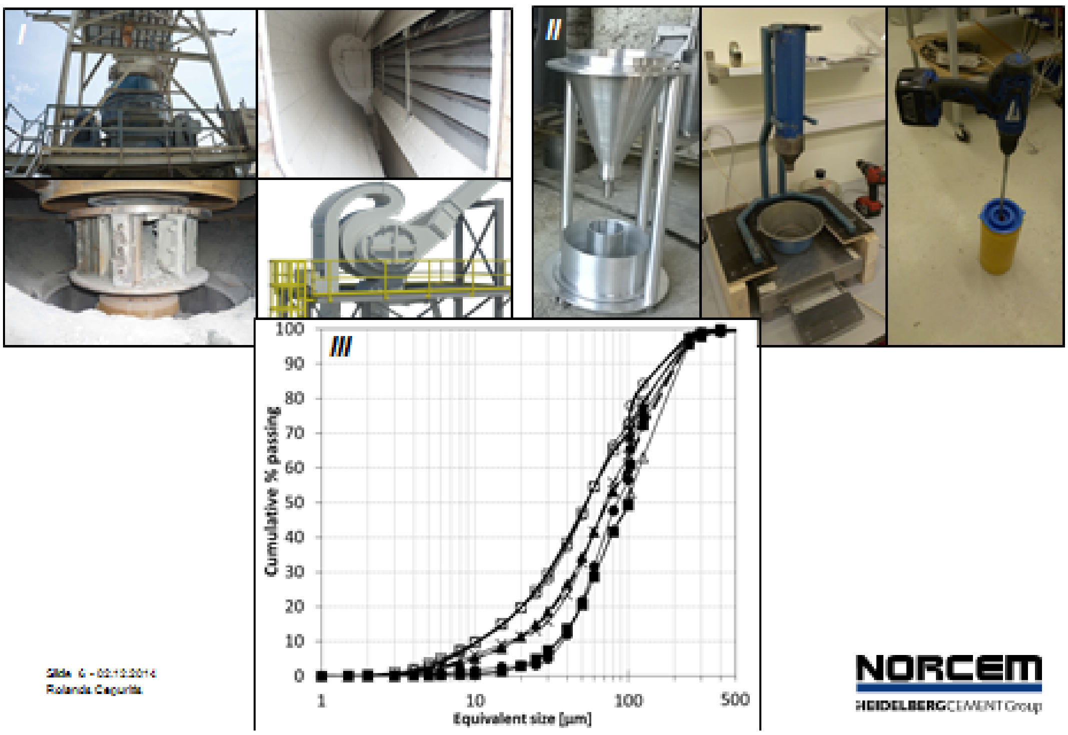
ENGINEERED SAND - TOOLBOX



Slide 6 - 02.12.2014
Rolands Cepuritis

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ENGINEERED SAND – HOW TO

Slide 7 - 02.12.2014
Rolands Cepuritis

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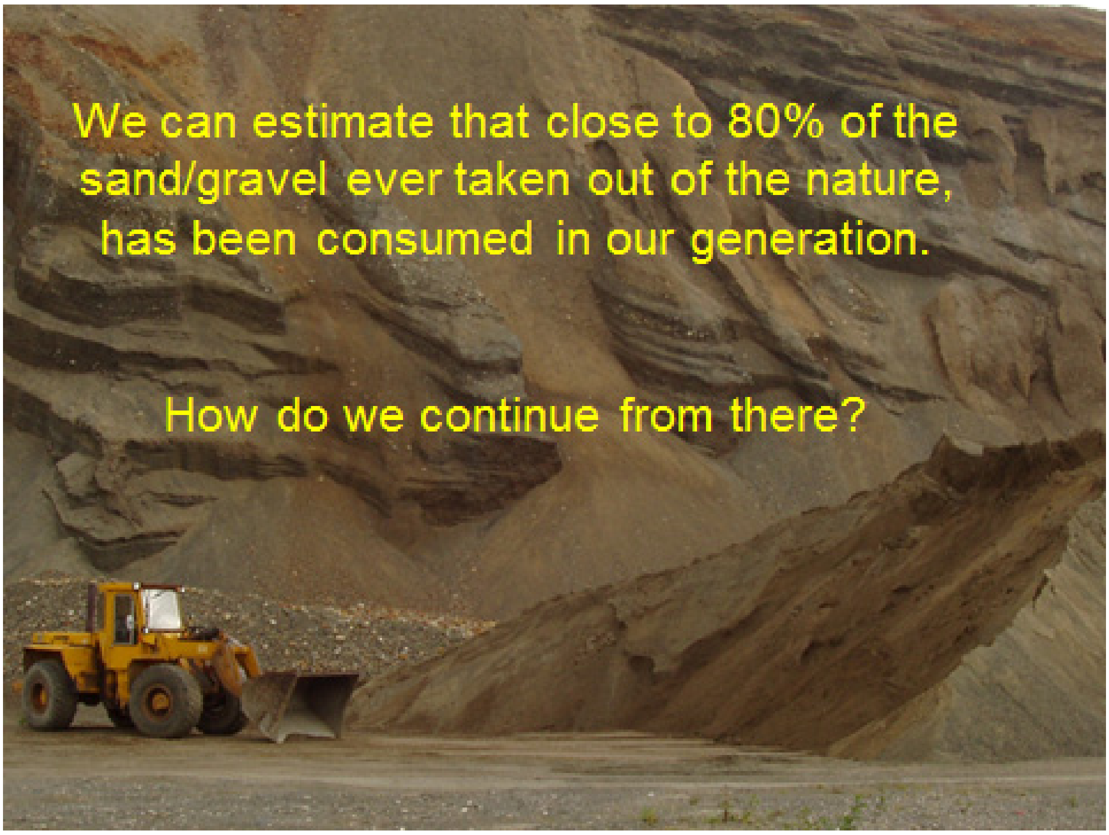
COIN – Concrete Innovation Center

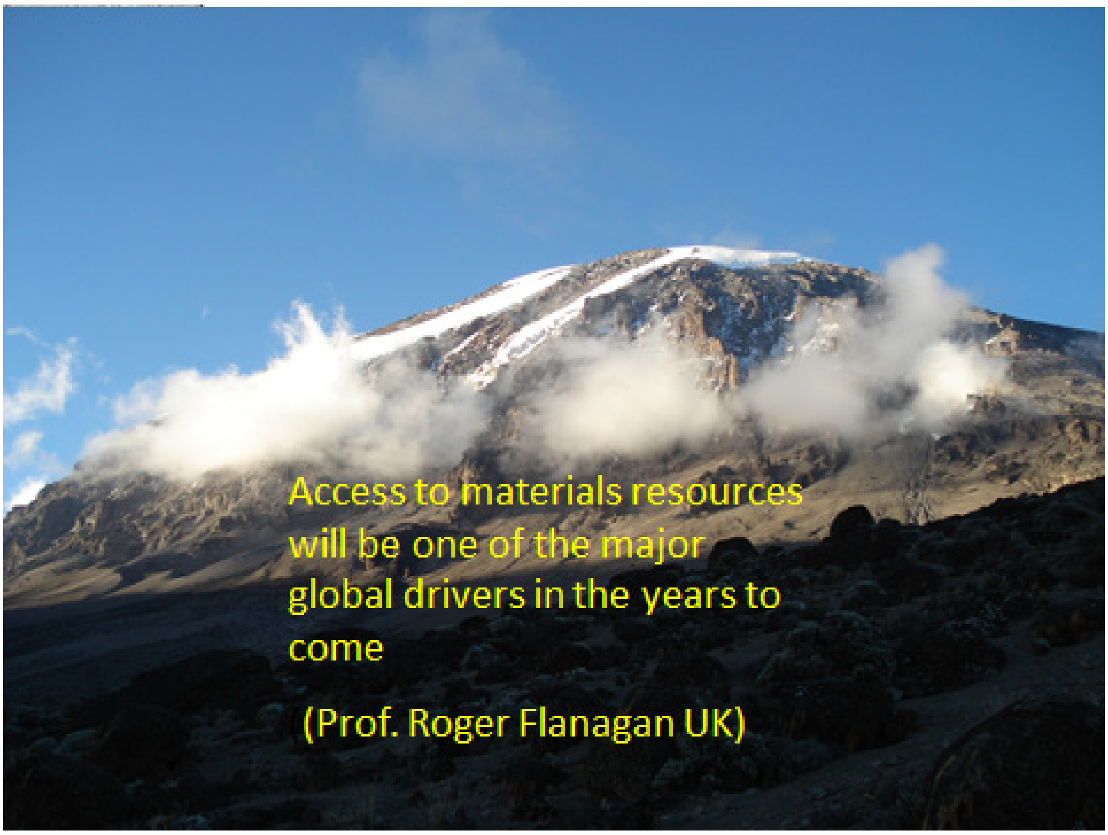
COIN FA 2.3

High quality manufactured sand for concrete

Transportation and sustainability

Svein Willy Danielsen
SINTEF



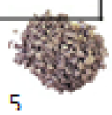


Some international key figures

- Global demand for aggregates is some 15 billion tons/year
- Expected to increase to 22 billion, where China alone will account for some 6 billion
- European aggregate industry produced >3 billion tons in 2005, at a value of >40 billion €
  - 47 % sand/gravel, 45 % crushed hard rock
  - The remaining part was recycled and artificial materials
  - Production took place in 28.000 quarries
- European concrete production is almost 600 mill m3, and uses approx 1,2 billion tons of aggregates per year

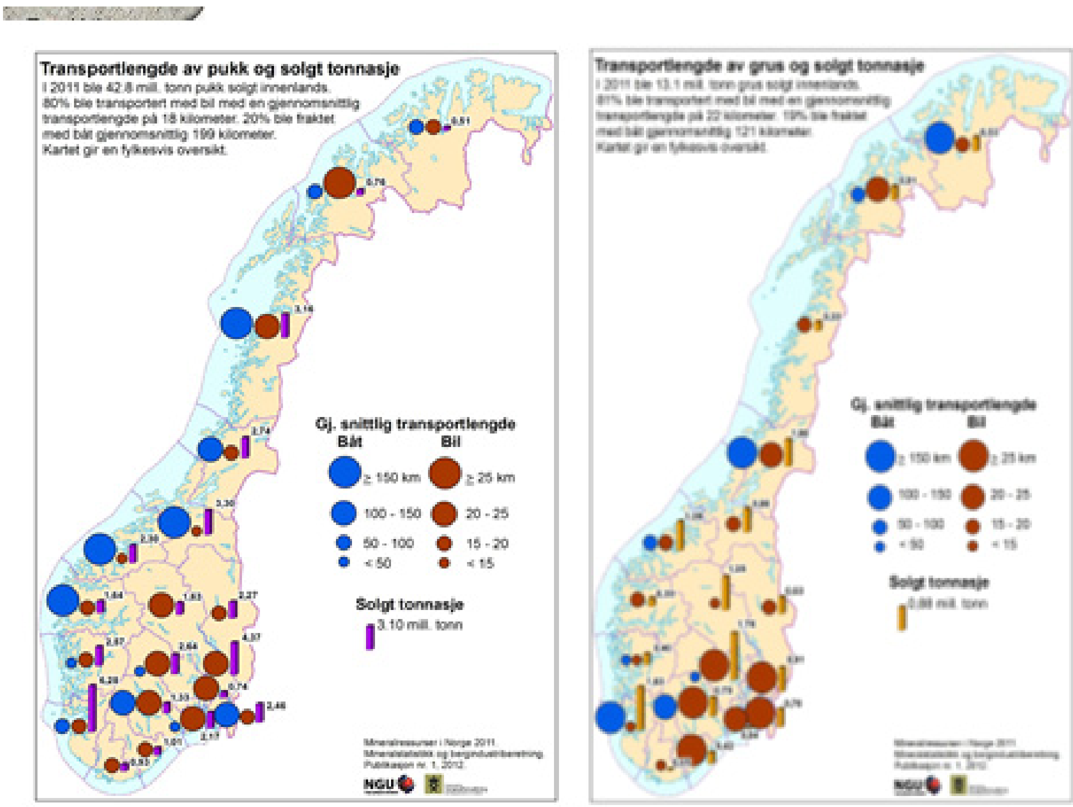
% distribution for some countries

%	Crushed	Recycled	Of European total prod.	Of Eur. no. of quarries
Norway	83	<1	3,2	16
Sweden	77	10	3,1	6,5
Netherlands	0	42	1,6	0,7
Germany	48	9	20	11
UK	62	20	6,8	4,6
France	57	2,5	15	9,5
Spain	71	<1	7,5	6,8



5


But the aggregates have to be used where society needs them
And that is not necessarily the same place


Transportlengde av pukk og solgt tonnasje
I 2011 ble 42.8 mill. tonn pukk solgt innenlands.
80% ble transportert med bil med en gjennomsnittlig transportlengde på 18 kilometer. 20% ble fraktet med båt gjennomsnittlig 199 kilometer.
Kartet gir en fylkesvis oversikt.
Gj. snittlig transportlengde
Båt
Bil
≥ 150 km
100 - 150
50 - 100
< 50
≥ 25 km
20 - 25
15 - 20
< 15
Solgt tonnasje
3.10 mill. tonn
Transportlengde av grus og solgt tonnasje
Gj. snittlig transportlengde
Båt
Bil
Solgt tonnasje

Transport and emissions – Norway

Transport	Domestic market, million tonnes	Million tonne - km	Ktonn CO2
Car, crushed rock	34	616	80
Car, sand/gravel	11	233	30
Ship, domestic	11	2000	30
TOTAL, domestic	**56**	**2850**	**140**

In addition: 22 million tonnes for export and off-shore

Sources: NGU and Odd Hotvedt

NORWEGIAN AGGREGATE EXPORTED IN 2011

Total production export 21 mill. tonnes aggregate, armour-
stone, sand and gravel, plus 1.4 mill. tonnes aggregate for offshore use.
Exportproduction values for 2010 in parentheses .


Sustainability:
Resource management is the key
– access to resources the main challenge.
Any encroach upon nature should be justified by increased values for the society, both relating to the products made and to the area left for later use.


COIN
Overskuddsmasser skal bli kortreist stein
STEIN i VEI 2015
Kortreist stein løser knipe

Local production – less transport – less emissions

Tunnels

Sub-surface quarrying

MASS BALANCE

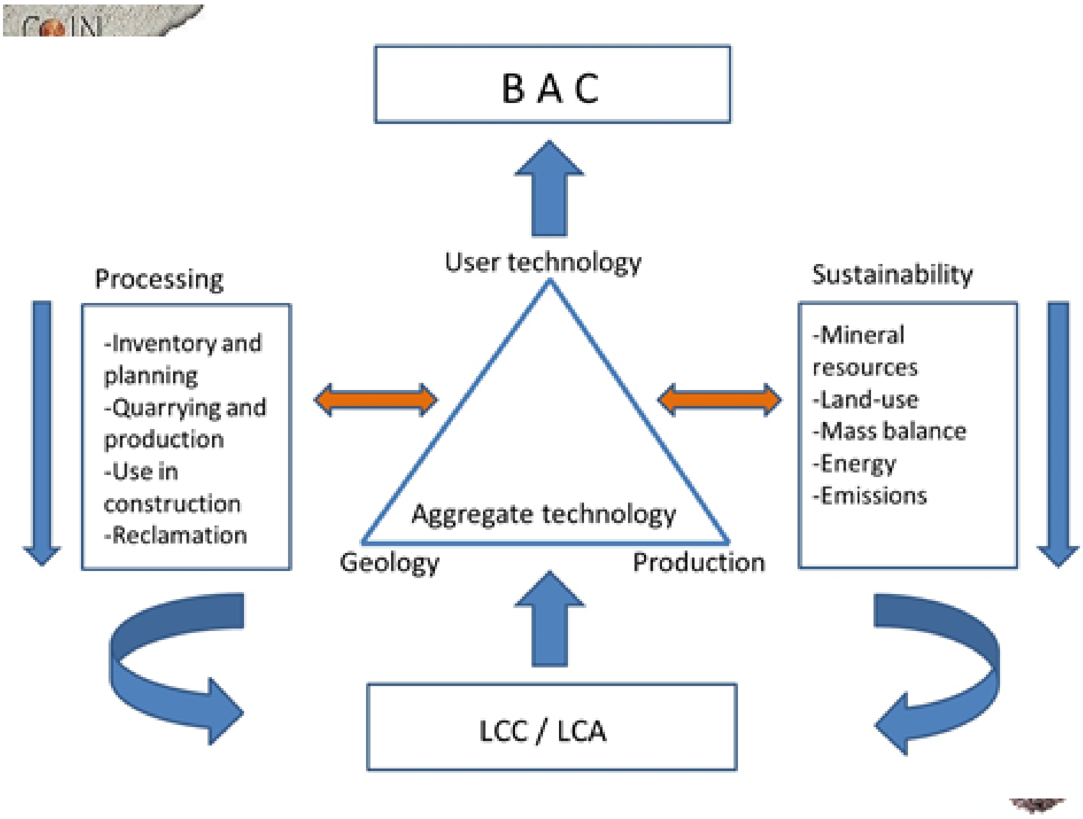
Excavations

Less predictable rock properties

Sustainability concept

Requirements

VELDE


B A C
User technology
Processing
-Inventory and planning
-Quarrying and production
-Use in construction
-Reclamation
Sustainability
-Mineral resources
-Land-use
-Mass balance
-Energy
-Emissions
Aggregate technology
Geology
Production
LCC / LCA

4 Environmental friendly concrete structures

December 3nd 2014

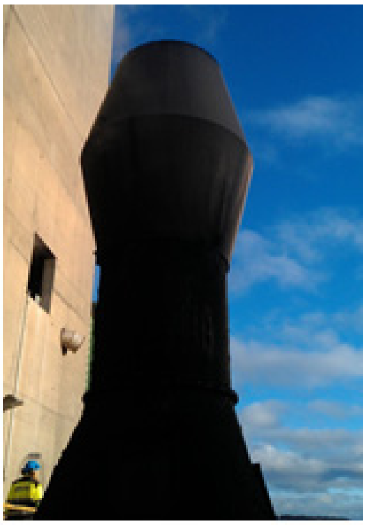
Chairman: Serina Ng

Binders with low emission and reduced resource consumption

09.10 –	**Fly ash-limestone synergy**	*Klaartje De Weerdt (SINTEF/NTNU)* *Knut O. Kjellsen (Norcem)*
	Accelerators for fly ash cement	*Klaartje De Weerdt (SINTEF/NTNU)* *Espen Rudberg (Mapei)*
	Calcined clay	*Klaartje De Weerdt (SINTEF/NTNU)*
	Calcined marl	*Klaartje De Weerdt (SINTEF/NTNU)* *Geir Norden (Saint-Gobain Weber)*
– 09.55	**Plasticizers for SCMs**	*Klaartje De Weerdt (SINTEF/NTNU)*

Utilisation of concrete in low energy building concepts

09.55 –	**Concrete and Passive House**	*Olafur Wallevik (SINTEF)*
	ZEB-concrete and LCA	*Kristin Holthe (Byggutengrenser)*
–10.35	**Insulating concrete**	*Olafur Wallevik (SINTEF)*



COIN FA 1.1

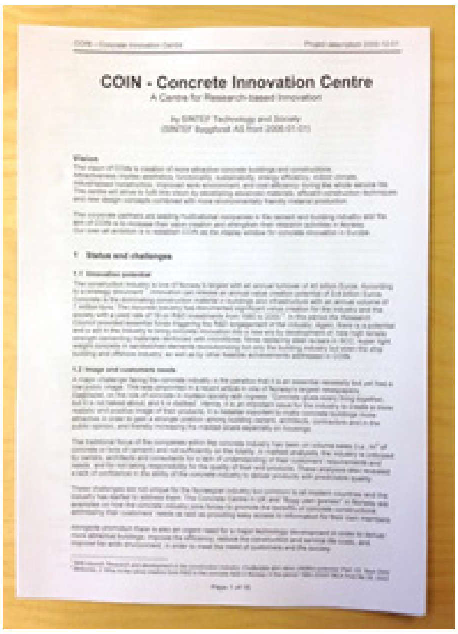
Binders with low emission and reduced resource consumption

Klaartje De Weerdt, NTNU/SINTEF

SINTEF — De Weerdt - COIN Closure Seminar - 2 & 3 Dec 2014 — sfi

COIN proposal

1. Reduced CO_2 emissions
2. High tensile strength
3. High flowability and stability
4. Low permeability



COIN - Concrete Innovation Centre
A Centre for Research-based Innovation

SINTEF — De Weerdt - COIN Closure Seminar - 2 & 3 Dec 2014 — sfi

FA 1.1 objective (COIN application)

- **The overall goal:**
  To identify and document general purpose cementing materials that will decrease CO_2-emissions by at least 30% compared to an average Portland cement clinker (about 900 kg CO_2 per ton).

- **A sublime idea from the project leader:**
  Combining fly ash or blast furnace slag (aluminate rich) with limestone filler to form a ternary blend.
  This would lead to a larger fraction of the limestone reacting to calcium carboaluminate hydrate, $Ca_3Al_2O_6 \cdot CaCO_3 \cdot 11H_2O$, which might result in a strength increase.

SINTEF De Weerdt - COIN Closure Seminar - 2 & 3 Dec 2014

Content

1. Fly ash–limestone synergy (PhD Klaartje De Weerdt)
   → Knut O. Kjellsen, Norcem
2. Accelerators for fly ash cement (PhD Kien Dinh Hoang)
   + further work (Harald Justnes)
   → Espen Rudberg, Mapei
3. Calcined clay (PhD Tobias Danner)
4. Calcined marl (Tone Østnor)
   → Geir Norden, Saint Gobain Weber
5. Plasticizers for SCMs (Serina Ng)

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COIN

Fly ash – limestone synergy

«Blended Cement with Reduced CO_2 Emission – Utilizing the Fly Ash-Limestone Synergy“

- Higher strength for cement with fly ash+limestone than clinker replacement with fly ash alone.
- Fly ash contributes with more aluminates when combined with limestone:

→ calcium carboaluminate hydrates ↑ (proposal)

→ stabilizes ettringite (voluminous) ↑

→ lower porosity ↓

→ higher strength ↑

Dr. Klaartje De Weerdt
NTNU thesis 2011:32

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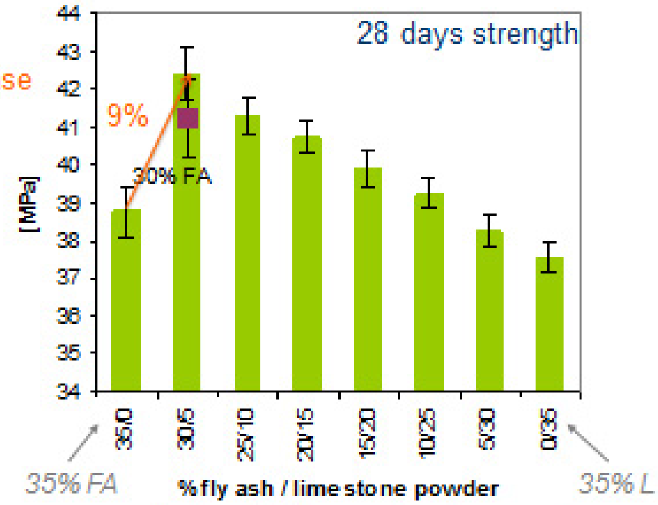
Fly ash – limestone synergy

strength increase
replacing
5% FA with L



all mixes 35% cement replacement

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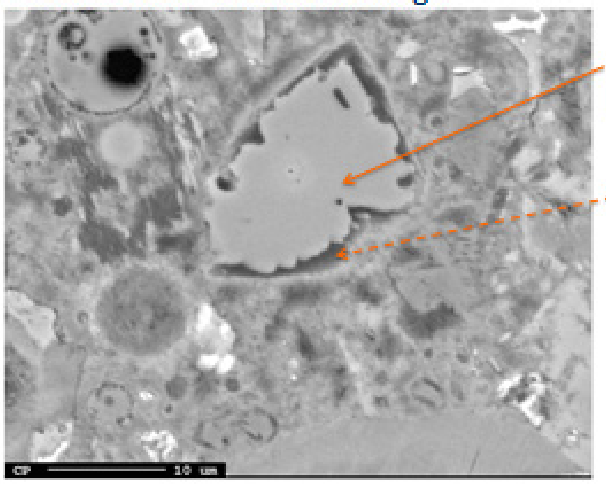
Fly ash – limestone synergy

Backscatter electron image



Limestone particle

Reaction rim

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Fly ash – limestone synergy

Norcem experience

Knut O. Kjellsen, R&D Manager, Norcem

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Fly ash – limestone synergy

- Hypothesis by Harald Justnes (SINTEF):
  Fly-ash + limestone => chemical reaction

- The 'fly ash – limestone synergy' activity was very successful:
  - Scientific idea
  - Excellent researchers
  - Scientific work within the frame of the Cement Standard

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Fly ash – limestone synergy

- Norcem product development project
  - 'Fly ash - limestone synergy effect' forms an important technical basis for a new cement product

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COIN

Accelerators for fly ash cement

"Hardening Accelerator for Fly Ash Blended Cement"

- Fly ash is much slower reacting than cement → finding a good hardening accelerator
- Kien found a ternary hardening accelerator for cement with 30% fly ash

fulfilling EN 934-2:

- >120% compr. strength at 24 h and 20°C
- >130% compr. strength compared 48 h and 5°C
- strength >90% at 28 d for both

Dr. Kien Dinh Hoang
NTNU thesis 2012:366

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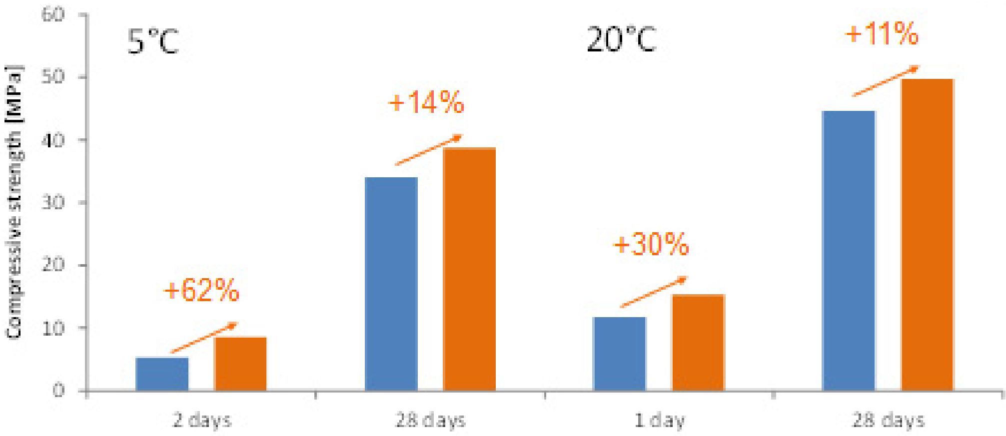
COIN

Accelerators for fly ash cement

!!! XYZ-accelerator was patented by MAPEI !!!



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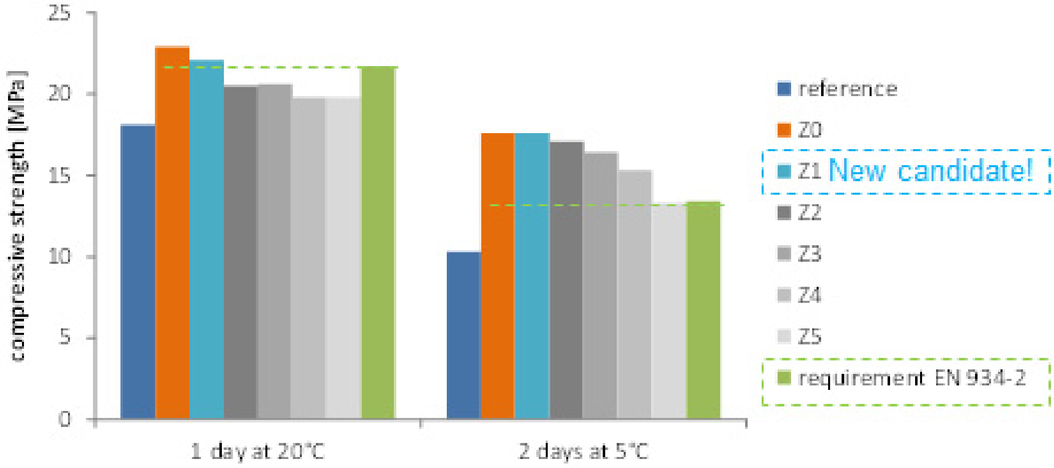
Further accelerator development

MAPEI wished to replace the «Z» in the XYZ-formulation

ref. COIN report nov 2014



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Accelerators for fly ash cement

Mapei experience

Espen Rudberg

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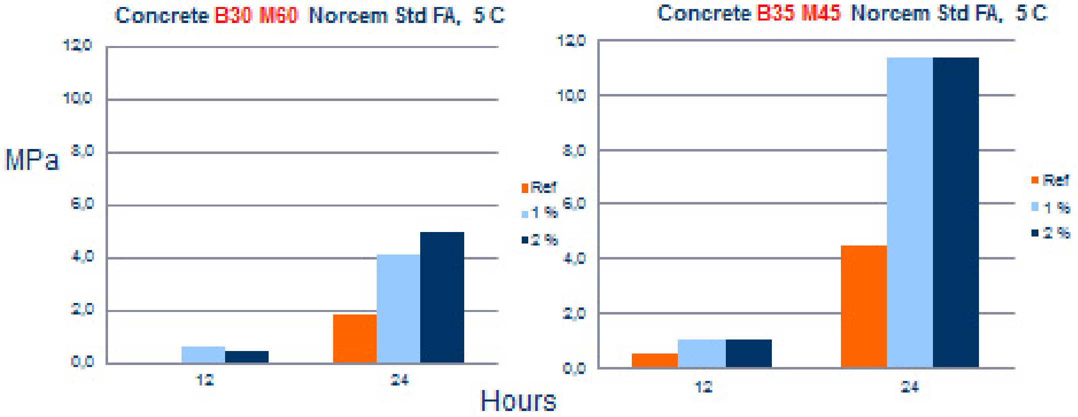
Product development at Mapei

- New accelerator tested in M45 and M60 concrete at low temperature and room temperature (also for other cements)
- This work has given ideas for new products (also in other business areas)



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Calcined clay as SCM

"Reactivity of Calcined Clays"

- Fly ash is slowly reacting
  Need to look for alternative supplementary cementing materials (SCMs)
- A COIN State-of-the-Art report concluded that calcined clays could be promising
- Initial tests of calcined "ordinary blue clay" dug out of the ground were so interesting that partner Saint Gobain Weber financed a separate PhD study

Dr. Tobias Danner
NTNU thesis 2013:218

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Calcined marl (CM) as SCM

- Marl is a clay containing some calcium carbonate making it unsuitable for expanded clay products
- Large and unexploited resource

Tone A. Østnor done sufficient work on marl to warrant a PhD..

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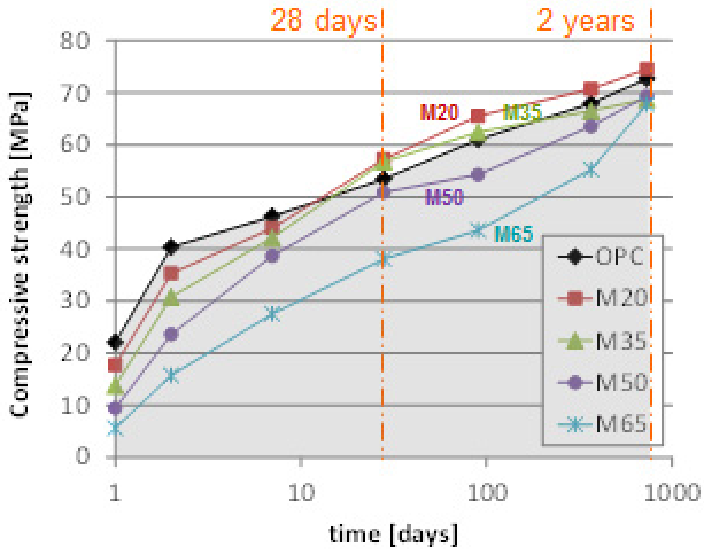
Calcined marl (CM) as SCM



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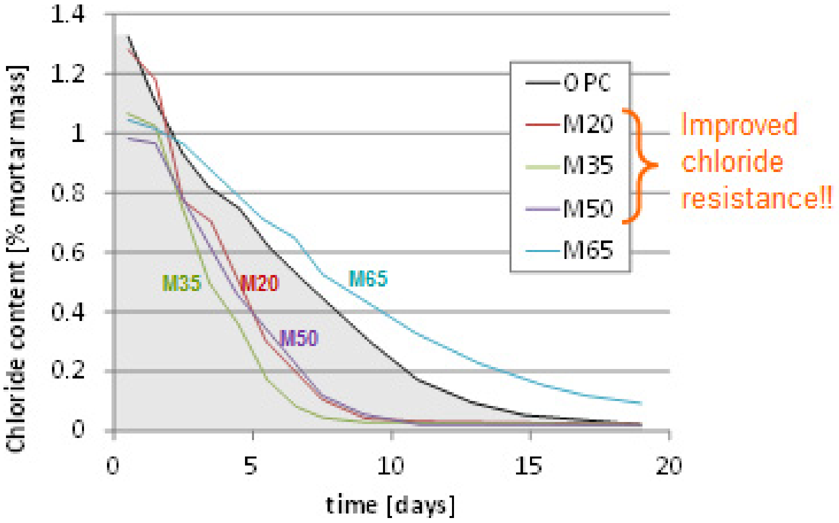
Calcined marl (CM) as SCM



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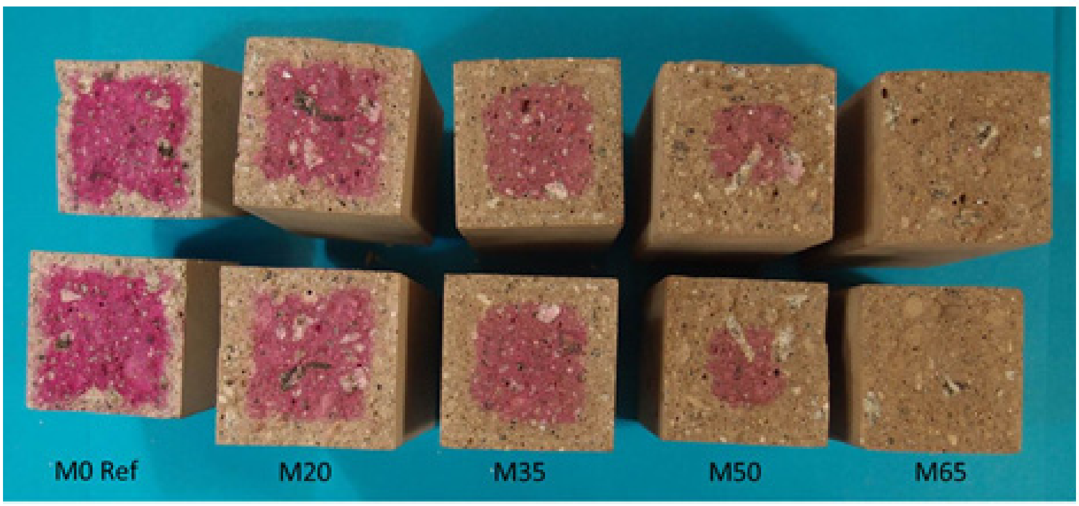
Calcined marl (CM) as SCM



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Calcined marl (CM) as SCM

Conclusion: Calcined marl is an effective pozzolan

+ Good compressive strength at both 1 and 28 days, even for 50 % cement replacement; Strength continues to increase to 2 year
+ Chloride ingress significantly decreased up to 50% marl

− Carbonation rate increase with increased cement replacement as for most blended cements.

Calcined clay and marl as SCM

Saint Gobain Weber experience

Geir Norden

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Plasticizers for SCMs

- SCMs will affect the workability of mortar and paste
- The activity focused on finding the best plasticizer for mortar with SCM such as fly ash (FA) and calcined marl (CM) as two extremes in terms of water demand
- A range of plasticizers were tested: lignosulphonate and naphthalene based plasticizers were compared with 3 modern polycarboxylate super-plasticizers

Dr. Serina Ng employed SINTEF since Jan 2013

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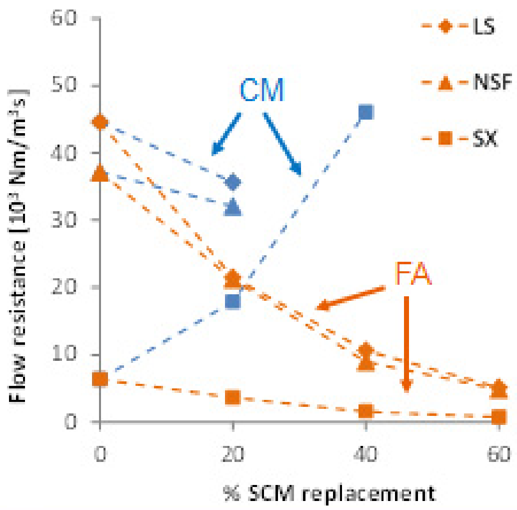
Cement replaced by FA and CM



Different SPs (LS, NSF, SX) 0.2% for different FA and CM replacement

→ More FA - lower flow resistance

→ More CM – higher flow resistance
SPs could not plasticize >40%CM

Hypothesis:

- FA interacts little with SP
- CM interacts strongly with SP

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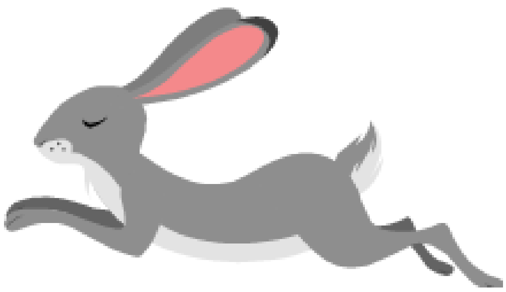
..but where is the FA1.1 leader?

Harald Justnes

"Nobody knows where the rabbit jumps" as we say in Norway, without further comparison.... ☺



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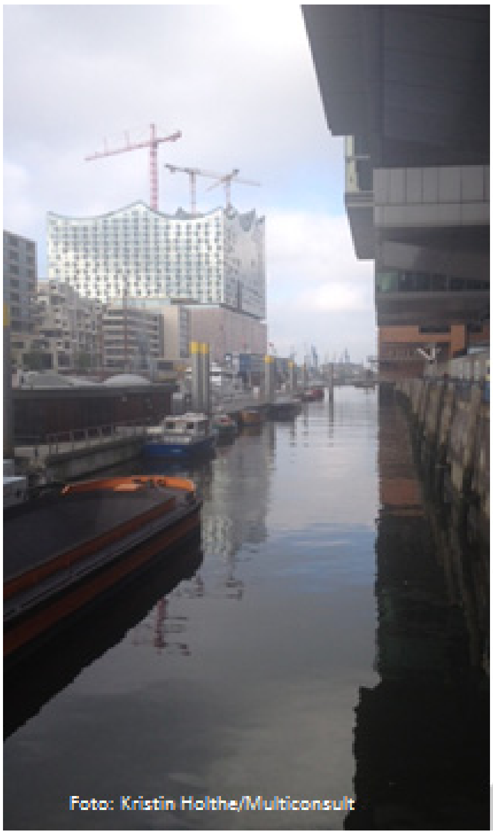
Utilisation of concrete in low energy building concepts – Industry initiatives and perspectives

Concrete innovation in Norway 2007- 2014
December 3, 2014 in Trondheim
Kristin Holthe, Multiconsult / Coordinator CEAP



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Low energy / Zero Emission Buildings challenge the materials

- GHG emissions of production
- GHG emissions over the whole life cycle: **Production – Building use phase – End of life**
- Environmental documentation
- **The concrete industry** is working on several areas

2

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Low carbon cement

environmental cement

low carbon concrete

environmental concrete

green concrete

4

Environmental documentation of concrete

- EPD-generator: 3. parts verified environmental documentation according to international agreed standards
- The industry itself may develop EPDs for own products

Source: www.EPD-Norge.no

Østfoldforskning

FABEKO

Betongelementforeningen

Concrete in buildings - Use phase

- Potential for **CO_2 uptake** in concrete constructions, both during use and concrete recycling
- **Thermal mass** in buildings and its potential for contributing to reduction in energy use, and thus GHG emissions.
- Solutions that combine **sound absorption and energy storage/use of thermal mass** in buildings

Betongelementforeningen

Thermal mass

- T-BOX concept - increased knowledge of usage of thermal mass in concrete structures

- Developed by the Norwegian Precast Concrete Federation in cooperation with their members prior to CEAP
- Under the CEAP, the concept was further developed to meet future regulatory requirements for energy performance

7

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Energy efficiency of buildings | Storage of thermal mass

8

Link to COIN

- The cooperation between Concrete Innovation Centre (COIN) and the CEAP started in late 2013:
- Thermal mass:
  - Collate current results from pilot buildings and assess the need for further work
- Life cycle assessments:
  - Collate experiences from LCA and greenhouse gas assessments of pilot buildings and identify methodological challenges for future work
- The cooperation has resulted in e.g. a **workshop in 2013** which involved both themes, where state-of-the art solutions on both themes were given and resulting in spin-off ideas for further R&D projects.

9

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Thermal Mass | Future needs for R&D

- Some results exits, on use of thermal mass / use of concrete (pilot buildings)
- **Future needs** regarding thermal mass:
  - Bring forward **more** lessons learned from pilot projects and use of energy calculation tools
    - Calculations results on kWh, GHG emissions, costs for different design solutions
  - Establish **simplified models and tools** for how to further exploit thermal mass
  - Establish **guidelines** for design for optimal use of thermal mass / also based on pilot experiences

10

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The Concrete Environmental Action Plan (CEAP) 2012-2015

- **Why and who**
  - Create a **new arena** for cooperative approach to common challenges
  - Main organizations with **long traditions in developing new knowledge about concrete** for a large number of members

CEAP interacts and coordinates with several all ready ongoing projects

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Goal/vision of the CEAP

- **Agreed goals, priorities and actions will give the concrete industry a high awareness of the environmental performance of its final products and of the production phase of these.**
- By promoting existing initiatives and projects, as well as establishing a specific amount of new research and development projects (R&D projects), CEAP's goal are to be achieved through:
  - **Building on existing knowledge**
  - **Contribute to new knowledge**
  - **Implement plans and results**

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Financing organizations and industry own efforts

The CEAP is financed by three organizations:

- The Norwegian Ready Mixed Concrete organization
- The Norwegian Concrete Association, NCA
- The Norwegian Precast Concrete Federation

FABEKO

norsk betongforening

Betongelementforeningen

Secretary

- Brilliant Building

byggutengrenser.no
MUR- OG BETONGBRANSJEN I NORGE

weber
SAINT-GOBAIN

Financing

- Allows a **project coordinator** to contribute to overview and create arenas for synergies and initiate and conduct projects
- **Important - industry own effort** (hours) and financing own specific projects and activities under the CEAP (in addition)

Information to be found here: www.miplan.no

5 The road towards new concrete research and innovation

10.50 – 11.50 **Panel debate – concrete innovation and dissemination**
Kjell Skjeggerud (Norcem), Jan Eldegard (Byggutengrenser), Elisabeth Schjølberg (Multiconsult), Anders Sjaastad (Yngres Betongnettverk) and Tor Arne Martius-Hammer, introducer (SINTEF)

Moderator: Lisbeth Alnæs, SINTEF

11.50 – 12.00 **Summary and concluding remarks**
Terje F. Rønning

Innovation

RCN's success factor concerning innovation:

"Created opportunities for innovation and increased competitiveness among user partners and expectations of social impacts".

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Innovation

is

a new product,
a new service,
a new production process, application or organisation

that is launched in the market or used in production to create economic values. A new idea or invention is not an innovation until it has come to practical application and creates value.

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COIN innovations

Products:
Cement(s)
Hardening accelerator
Calcined clay

Services:
CrackTestCoin
FRC guideline

Production processes/applications:
Fibre reinforced walls
Artic sea structures without abrasion casing
Manufactured sand

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COIN innovation opportunities

Products:
Calcined marl
Admixtures
Low thermal conductivity structural concrete
Technology for production of advanced LWA

Services:
Surface quality classification system
Guidelines
Utilization of thermal mass
Performance based spec./test. (e.g. ASR)

Production processes/applications:
FRLWAC
Hybrid concrete
SCC?

SINTEF

For debate

- How can we contribute to that what is created in COIN becomes innovations?
- How can we, as an industry, in the future ensure that ideas and research results become innovations?
    - *How to get research inst. and industry together to develop research topics with sufficient innovation and implementation potential?*
    - *Dissemination and implementation of R & D results in general*
    - *Organizing of R & D projects where innovations are the target*

SINTEF

COIN Seminar
Concluding remarks

COIN December 3rd 2014 – Terje F. Rønning

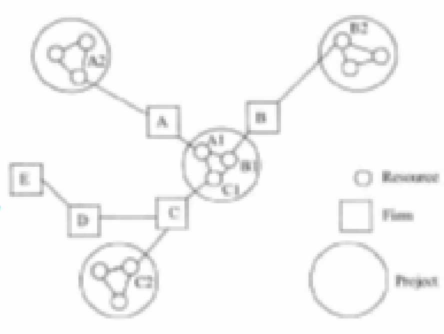
HEIDELBERGCEMENT

What did we learn in school today .....

- ....
- BUT we had great fun !

HEIDELBERGCEMENT

- **Construction industry**
  - Often considered as assembling of standard components
- **But**
  - Frequently we need tailor made solutions
- **And, generally**
  - The only way to improve value creation for a construction project is to interact



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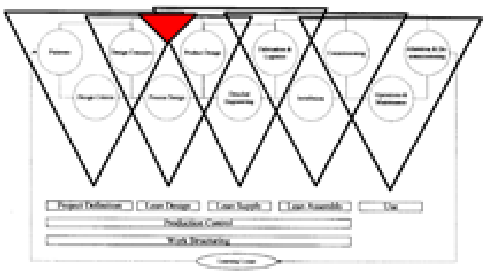

- **IF**
  - We want to innovate
  - We want to learn
- **THEN**
  - We must do so outside the normal tendering process of the construction sector
  - We must create an organisational environment
  - We must involve the Sector and Academia
  - Everybody needs a strategy of its own *and* one of interaction
  - Influence the RCN & EU (funding;) Calls!
  - JOINT TARGETING & CREATIVE PROCESSES

HEIDELBERGCEMENT

POST COIN

Thank you !

&

Welcome back at some occasion …?

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SINTEF Building and Infrastructure is the third largest building research institute in Europe. Our objective is to promote environmentally friendly, cost-effective products and solutions within the built environment. SINTEF Building and Infrastructure is Norway's leading provider of research-based knowledge to the construction sector. Through our activity in research and development, we have established a unique platform for disseminating knowledge throughout a large part of the construction industry.

COIN – Concrete Innovation Center is a Center for Research based Innovation (CRI) initiated by the Research Council of Norway. The vision of COIN is creation of more attractive concrete buildings and constructions. The primary goal is to fulfill this vision by bringing the development a major leap forward by long-term research in close alliances with the industry regarding advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.