Nordic SCCNet
Nordic network for RTD on Self Compacting Concrete

- Benefits, costs and challenges
- A Nordic Network with the objective to exchange results and knowledge in order to establish an improved basis for use of Self Compacting Concrete
- More information at www.nordicscc.net

Author: Tor Arne Hammer, SINTEF Building and Infrastructure
### Participants:

#### Denmark
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Title: Nordic Network for RTD on Self Compacted Concrete (Nordic SCCNet)

Nordic Innovation Centre (NICe) project number: 03037

Author: Tor Arne Hammer

Institution: SINTEF Building and Infrastructure

Abstract:
Self Compacting Concrete (SCC) is a collective term for concrete with very high flowability, and which may be placed without addition of compacting energy, e.g. by poker vibrators. Thus, use of SCC contributes potentially to increased productivity (e.g. faster casting operation and with less workers) and improved working environment (no use of heavy, vibrating and noisy compacting tools). Some studies claim also better durability and surfaces. The potential has been demonstrated in a number of studies in several countries. Still, the market share of SCC is generally very low.

The project is a network with the aim to exchange results and knowledge in order to establish an improved basis for use of Self Compacting Concrete (SCC). It includes identification of obstacles, and procurement and spread of knowledge about how to overcome them. The work has achieved this aim by bi-annual assemblies with the 18 participants covering the national R&D projects on SCC, as well as the actors in the building and construction market; owners, consultants, material suppliers, contractors and research institutes/universities discussing specific topics of interest.

The new information and knowledge gained through the assemblies were spread by:
- The participants bringing new knowledge, research approaches and the like, back to the national R&D projects in order to strengthen the R&D in the projects
- WEB-site
- Liaisons established with national and international committees
- Presentations at National and Nordic concrete days
- The workshop ”SCC – Vision and Reality” at Kastrup 19 June 2006, with nearly 100 participants from the Nordic building industry

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Executive summary

The purpose of the project was to:
- Exchange results and knowledge in order to establish an improved basis for use of Self Compacting Concrete (SCC)
- Identify obstacles and provide and spread knowledge about how to overcome them

The work has achieved this aim by:
Bi-annual assemblies with the 18 participants covering the national R&D projects on SCC, as well as the actors in the building and construction market; owners, consultants, material suppliers, contractors and research institutes/universities discussing specific topics of interest.

The new information and knowledge gained through the assemblies were spread by:
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Method
Self Compacting Concrete (SCC) is a collective term for concrete with very high flowability, and which may be placed without addition of compacting energy, e.g. by poker vibrators. Thus, use of SCC contributes potentially to increased productivity (e.g. faster casting operation and with less workers) and improved working environment (no use of heavy, vibrating and noisy compacting tools). Some studies claim also better durability and surfaces. The potential has been demonstrated in a number of studies in several countries. Still, the market share of SCC is generally very low.

- Therefore, the project started with a study in order to find the main reasons for this and identify the obstacles to overcome. This was done by the use of a questionnaire among the participants, requesting for their opinion about reasons and obstacles.
- Then, the most important reasons and obstacles were discussed in the bi-annual assemblies, and actions to overcome obstacles were presented and made accessible in an internet based project base
- As one obstacle was related to lack of guidelines and norms, liaisons were established with relevant international committees working with guidelines and standardisation, both in order to influence their work and to make information accessible to the participants. Key persons in such committees were invited to assemblies (if not SCCNet member)
- Main results and examples how to overcome obstacles were presented at the workshop "SCC – Vision and Reality” at Kastrup 19 June 2006, with nearly 100 participants from the Nordic building industry

Main results, conclusions and need of further work
- Use of SCC improves potentially productivity and working environment
- SCC has a potential to replace the major part of common vibrated concrete
- Main obstacles for increased market share of SCC is related to higher material cost, mix design/robustness regarding workability and segregation and lack of guidelines
• Since the major volume of concrete is used in buildings with less demanding performance requirements, and thus with relatively low price, it is necessary to develop compliant SCC with acceptable material cost. This has shown to be a challenging task, first of all because of the cost of means needed to achieve sufficient stability against segregation of SCC, but also because the technology for production of such “cheap” SCC is young and not sufficiently spread. However, mix design guidelines for such SCC is now available, but more RTD work seems necessary in order to improve the robustness of such concretes.

• The acceptable material cost of SCC is strongly influenced by the economical benefits of using SCC. It has been demonstrated that savings related to e.g. less repair, faster casting and less labour may be higher than the additional material cost. More studies are however needed.

• A number of the Nordic SCCNet members have been directly or indirectly active in international committees working with guidelines and standards for SCC. This has contributed to reflect Nordic attitude which make the Nordic countries even better prepared for such standards.

• In general, the network contributed to make contacts between participants which may be utilised in future projects. The participants decided to continue Nordic SCCNet, financed by own money.
1. BACKGROUND

2. OBSTACLES FOR SCC OBTAINING AN INCREASED MARKET SHARE
   2.1 Cost – benefit
   2.2 Lack of robustness and confidence
   2.3 Lack of guidelines and norms

3. INTERNATIONAL STANDARDISATION WORK

4. MAIN RESULTS

APPENDICES:

Presentations at the workshop “SCC – Vision and Reality”

- Introduction and status of use and R&D in the Nordic countries
- Guidelines / Quality Control
- Mix Design
- Economy / Benefits / Environment
- Production / Execution
1. BACKGROUND

Self Compacting Concrete (SCC) is a collective term for concrete with very high flowability, and which may be placed without addition of compacting energy (e.g. by poker vibrators). Thus, use of SCC contributes potentially to increased productivity (e.g. faster casting operations and with less workers) and improved working environment (no use of heavy, vibrating and noisy compacting tools). Some studies claim also better durability and surfaces. The potential has been demonstrated in a number of studies in several countries. Still, the market share of SCC is generally very low.

Therefore, the main task of the project was to find the main reasons for the low market share. It includes identification of the obstacles, and to procure and spread knowledge about how to overcome them, in order to establish an improved basis for use of SCC.

Obstacles were identified by the use of a questionnaire among the 18 participants of the project, requesting for their opinion about reasons and obstacles. Then, the most important reasons and obstacles were discussed in bi-annual assemblies. The participants covered the Nordic R&D projects on SCC, as well as the actors in the building and construction market; owners, consultants, material suppliers, contractors and research institutes/universities.

As one obstacle was related to lack of guidelines and norms, liaisons were established with relevant international committees working with guidelines and standardisation, both in order to influence their work and to make information accessible to the participants. Key persons in such committees were invited to assemblies (if not SCCNet member).

Main results of the work and examples how to overcome obstacles were presented at the workshop, organised by Nordic SCCNet, ”SCC – Vision and Reality” at Kastrup 19 June 2006, with nearly 100 participants from the Nordic building industry.

Other tools to procure and spread knowledge were:

- The participants bringing new knowledge, research approaches and the like, back to the national R&D projects in order to strengthen the R&D in the projects
- WEB-site: www.nordicscc.net
- Presentations at National and Nordic concrete days
2. OBSTACLES FOR SCC OBTAINING AN INCREASED MARKET SHARE

Possible obstacles were discussed among the participants and in other forums of SCC. A questionnaire among the participants was also used. The questions were: What do you think are the main obstacles for an increased market share of SCC, and how do you think they can be forced?

In general, the discussions revealed that mix design of SCC varied between the countries, as result of different part materials, but also different mix design approaches. For instance, Swedish SCC tends to contain more fines than Danish and Norwegian SCC. The discussions revealed also differences in the definition of SCC between countries, but also related to application: In Denmark SCC is all concrete cast without use of compaction tools, the main application being slabs. Slabs are cast without compaction tools in other countries also, but the flow of the concrete is still below the defined minimum values for SCC (e.g. minimum slumpflow of 600 mm). Accordingly, the difference in definition contributes also to the difference in market share between the countries.

The results of the discussions may be divided in three groups:

2.1 Cost – benefit

SCC costs more than the “competing” NCC, and it has not been sufficiently documented that savings in less workers, faster casting, less repair, etc., as well as improved working environment is more than the additional cost. The acceptable additional cost of SCC is strongly influenced by the economical benefits of using SCC.

The additional cost has two factors:

1. Cost of means needed to achieve sufficient stability against segregation of SCC. It may include investments in e.g. extra silos for fine sands and or fines
2. Riskiness for the concrete producer. Concrete producers experience higher risk of return batches and more following up work

Also, it was not clear which actor in the value chain that profits the most, and thus, should be the target for marketing SCC

2.2 Lack of robustness and confidence

The experience reveals that the flowability and segregation resistance of SCC as used, are sensitive to natural variations in the composition of the SCC (e.g. moisture
content and grading of aggregates), as well as to common variations in transportation
an casting procedures (temperature, time, delayed admixture addition, etc.). This
appears to be both an economical and technical question. Economical, because the
concrete producers like to use part materials on silo intended for NSC, which not
necessarily are suitable for SCC. Technical, because of lack of knowledge about the
influence of part materials and admixtures on the production properties.
The major volume of concrete is used in buildings with less demanding performance
requirements, which means that concrete with relatively low price is used.
Consequently, it is necessary to develop compliant SCC with acceptable additional
cost. This has shown to be a challenging task, first of all because of the cost of
means needed to achieve sufficient stability against segregation of SCC (see above),
but also because the technology for production of such “cheap” SCC is young and
not sufficiently spread.

2.3 Lack of guidelines and norms

Lack of guides for proportioning of “cheap” SCC was another obstacle mentioned,
and also lack of consistent test procedures for compliance control, as well as casting
procedures for various applications. Regarding the latter, it seems sensible to look at
the relationship between type of object/application, casting technique and fresh SCC
properties. Work is being performed with the aim to simulate flow numerically,
based on the rheological properties of the concrete and the boundary conditions. This
will be a valuable contribution to the work in preparing a guideline for production.

Testing of the fresh SCC and casting of specimens are not standardised, and SCC is
not mentioned in any CEN-standard to day. This constitutes a potential formal
conflict because the existing standards require compaction, which shall not be used
on SCC. A proposal for such SCC test methods was prepared within the NICe
project “Test methods for SCC”. The SCCNet acted as reference group and agreed
with the proposal, except for the proposed test for segregation resistance.

A commonly accepted segregation test is still lacking. This is particularly
unfortunate since resistance to segregation is as important as flowability, and thus, an
important factor in the compliance control, also. At present, segregation resistance is
often evaluated visually, which may lead to dispute between concrete producer and
contractor on site.

Furthermore, the contractual situation of the trade between the concrete producer and
the contractor is not clear: The new aspect using SCC is that the potential conflict in
that the concrete producer is basically responsible for the compaction of the
concrete, while the contractor is responsible for the quality of the final product.
3. INTERNATIONAL STANDARDISATION WORK

There are a number of international committees world wide dealing with SCC. A list is given in www.nordicscc.net. One or more SCCNet members participate in the committees.

The CEN-standards shall be used in Europe. As previously mentioned, SCC is not mentioned in any CEN-standard to day. A CEN-committee (CEN TC 104/SC1) is being established with participants from Nordic SCCNet also, in order to evaluate test methods for SCC.

The question is if SCC has properties that are in conformity with the design assumptions in the CEN-design standard (Eurocode 2). This regards particularly cases where SCC is produced without coarse aggregate.

Another important point is that the standards should regulate the trade between concrete producer and contractor. This is suggested in the on-going revision work of prEN 13670. Also, this standard will have an “Informative annex” describing placing and finishing of SCC. SCCNet communicates with the convener of this committee (Steinar Helland, Skanska).

“The Europe Guidelines for SCC” was prepared in 2005 by a group of European concrete organisations with participants from SCCNet. The document is considered as European consensus report on SCC, and basis for the future work on standardisation. The document can be downloaded from www.nordicscc.net.

4. MAIN RESULTS

Main results of the work and examples how to overcome obstacles were presented at the workshop ”SCC – Vision and Reality” at Kastrup 19 June 2006, with nearly 100 participants from the Nordic building industry. There were 13 presentations on the five topics:

1. Status in the Nordic countries
2. Guidelines
3. Mix design
4. Benefits and
5. Production

The presentations are given in APPENDIX 1. The presentations were followed by four parallel workshop sessions where the technical topics were discussed more in detail, and conclusions reported in plenum.
The market share of SCC has increased in the last couple of years in Denmark and Sweden. The Danes claim approximately 25% market share (but note definition differences as previously discussed), in prefabrication and ready mixed concrete in slabs, mainly. This is partly results of the still running joint industry project “SCC Konsortium”. The Swedes claim approximately 10%, in prefabrication and in ready mixed concrete for housing, mainly. There are no major joint industry projects on SCC at the moment, but several smaller and local projects. The market share in the other countries is still below 2-3%, and without optimistic prospects in the near future. Except that the Norwegians seem optimistic in that they started two joint industry projects a year ago, one with the ambiguous objective to increase the market share up to nearly 50% in 5 years.

The presentations certainly confirm the potential of using SCC, both in savings due to less labour input and improved working environment. Moreover, calculations show that the savings may easily exceed the additional price of SCC. Used in floor, for instance, net savings of up to EUR 18/m² was shown. Also, there appears to be potentially further savings by utilizing the relationship between tailored concrete properties and new/improved production techniques.

Thus, since sufficient guidelines exist also (see e.g. www.nordicscc.net), the main remaining obstacle is the lack of robustness, and the challenge is how it can be forced without resulting in an unacceptable additional charge. This should be in focus in the further RTD-work on SCC.

It seems that the contractors are the main profiteers of using SCC. They may save money as result of less labour input and faster production, and their workers experience less health problems. It was also claimed that SCC sometimes is specified by the architect/building owner/consultant because of request for good surfaces and good working environment (note, however, that good surfaces can be obtained with NCC, too).
APPENDICIES

Presentations at the workshop “SCC – Vision and Reality”
Introduction and status of use and R&D in the Nordic countries
Nordic SCCNet

The workshop is a part of the delivery from SCCNet

Intention of the workshop is to:

- exchange knowledge and experience in the Nordic countries
- inform about possibilities and benefits
- discuss obstacles and how to overcome
- inform were to find guides and solutions

Many thanks to
Jeanette von Mehren and Lars Nyholm Thrane, DTI, for taking care of the practical part of the organising!
SCCNet - time and budget

- Pre-project in fall 2002
- Summer 2003 - summer 2006
- Total budget is NOK 5 mill, 2.5 mill from NICe
Background

SCC contributes potentially to increased productivity and improved working environment. Some studies claim also improved strength, durability and surfaces.

The potential has been demonstrated in a number of studies in several countries. Still, the market share of SCC was generally very low. Why?

There was little co-operation and co-ordination within the Nordic countries, and activities were therefore partly overlapping and partly complementary.

This was demonstrated in a pre-project showing that focus varies between the countries, ranging from fundamental approaches on mix design and material models to applications and execution, but also that the topics are of common interest.
Objective and method

To exchange results and knowledge in order to establish an improved basis for use of SCC.

It includes identification of obstacles, and procurement and spread of knowledge about how to overcome them.

The work has achieved this aim by bi-annual assemblies with the 18 participants discussing specific topics of interest.

The participants cover the national R&D projects on SCC, as well as the actors in the building and construction market; owners, consultants, material suppliers, contractors and research institutes/universities.
The new information and knowledge gained through the assemblies were spread by:

- The participants bringing new knowledge, research approaches and the like, back to the national R&D projects in order to strengthen the R&D in the projects

- WEB-site: [www.nordicscc.net](http://www.nordicscc.net)

- Liaisons established with national and international committees

- Presentations at National and Nordic concrete days

- The present workshop “SCC – Vision and Reality”
Method cont.

Questionnaire about obstacles was basis for identification of topics to be discussed.

The most important topics were found within:

- **Cost – benefit**
  - Higher concrete price than the “competing NCC
  - Savings in less workers, faster casting, less repair

- **Lack of guidelines and norms**
  - Mix design
  - Production and compliance control
  - Casting procedures

- **Robustness**
  - Mix design to achieve acceptable properties
  - Production – relationship between type of object, casting technique and fresh SCC properties
Economy / Benefits / Environment

Benefits of use of SCC in common buildings/structures could be:

- economical,
- work environmental,
- technical and
- aesthetical.

Within these four groups some benefits are directly decisive for the choice of SCC, while others are “nice to have”.

In addition, SCC is a “problem solver” offering easier casting of “complicated” structures or parts of structure.”

Who are we going to convince?
Economy / Benefits / Environment

Economical benefits

Placement (faster casting and with less workers and tools as well as less workers reported sick)

Finishing (faster and with less workers and tools, as well as less need of self-leveling toppings)

Repair of casting defects (need of repair is eliminated or at least significantly reduced)

Also, as there in many regions are lack of workers and bad recruiting, SCC may be the way out.

Less sickness absence
Economy / Benefits / Environment

Work environmental benefits

Eliminated impact of lifting and carrying of compaction tools, on arms, shoulders and backs.

Less noise

Improved ergonomic and occupational safety makes the building industry more attractive regarding recruiting of workers.
Economy / Benefits / Environment

Technical benefits

Some studies show that strength and durability of the building/structure is better than equivalent NCC. This has been explained as result of less defects, better homogeneity (e.g. improved paste/aggregate phase and more even degree of compaction) and better paste/rebar bond. However, all are of the “nice to have” kind and can hardly be used as main attraction for the choice of SCC?

May be more important: SCC is a “problem solver” offering easier casting of “complicated” structures or parts of structure.”
**Aesthetical benefits**

There is no doubt that SCC gives potentially better surfaces than NCC. In most cases, this is a “nice to have benefit”, but it can be used in a specification for special surfaces (note however that SCC is not a must to achieve special surfaces).
Nordic SCC Network Workshop

Marketing of SCC in Norway

Inge R. Eeg
Norcem AS

June 2006
Goal

• To increase the application of SCC in Norway from today's approx. 60 m³/year to 1000 m³/year

• Prefabricated elements: +/- 50% of all concrete except dry concrete (hollow core etc.)

• RMC: only project related
Aims:

• To establish confidence in successful concrete work with less flaws and improved durability.

• To obtain more aesthetic structures in terms of both surface quality and shape by means of slimmer and more densely reinforced concrete.
Aims:

• To demonstrate a better overall economy for specific projects
• To demonstrate improvements in HES related questions
• To create acceptance among customers for improved product precision and quality
How?

• Demonstration of the SCC advantages for the dominating volume of "ordinary" structures (flooring, slabs, walls) and "common" concrete in selected projects
• Documentation of the profit by utilising SCC in selected projects
How?

• Establish a SCC marketing campaign;
  → Web site
  → Brochures / guidelines
  → Demonstrations / reference project
  → Documentation (HES, quality, profit)
  → Presentations / workshop
Web site
(Selvkomprimerendebetong.no)
Project organisation

1. All participants (approx. 20 companies)
2. Steering committee (Norcem, Skanska, Veidekke, Unicon, Spenncon and The Norwegian Road Dept)
3. Project leader (Sintef)
4. Part project leaders / groups
Time frame and cost

• 2006 – 2009
• Approx 0.5 mill NOK / year
• Work contribution hours/yr (?)
• Material contribution m3/yr (?)
Facts about the Consortium

- SCC-Consortium
  - Established in 2003
  - 3½ year innovation project.
  - 17 companies and knowledge centres are participating
  - Representing every stage of the value chain
  - Activities continue until 2007
  - The overall budget represents approx. DKK 20 million
  - DKK 7,7 million contributed by the Danish Ministry of Science, Technology and Innovation
The Main Partners

- MT Højgaard a/s (Head of Steering Committee)
- Danish Technological Institute (Project manager)
- 4K Beton
- Aalborg Portland A/S
- Videometer A/S
- Betonelement A/S
- Informatics and Mathematical Modelling of the Technical University of Denmark
The Scope

- SCC the most used type of concrete in Denmark before 2008
- Improvement of the working environment
- Increased productivity
- A technology jump to the Danish Concrete Industry
## Activities and Projects in the Consortium

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SCC-Consortium

SELF-COMPACTING CONCRETE
SCC stands for Self Compacting Concrete. SCC was created in Japan in the early 1990s. Today, Denmark is the largest user of SCC relative to the total domestic consumption of concrete. SCC has excellent flow properties and can therefore be cast without the use of vibration or other mechanical influences. Less effort is therefore required, and the amount of noise produced is greatly reduced.

SCC's advantages include a better working environment, better concrete quality, improved productivity, minimum need for levelling equipment, lighter work, less time consumption and a better overall economy. The flow properties are achieved by means of chemical admixtures and good mix design. SCC can be used both for casting in situ and for the production of precast concrete elements.

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For further information go to www.scc-konsortiet.dk

PARTICIPANTS

INDUSTRY
4K Béton A/S one of Denmark's largest manufacturers of ready-mix concrete, producing more than 500,000 cubic metres a year.
MT Højgaard a/s Denmark's leading industrial contractor, with 5,100 employees and an annual turnover of just under DKK 8 billion.
Aalborg Portland A/S Denmark's only cement manufacturer and the world's leading manufacturer and exporter of white cement.

RESEARCH
Vidensmotor A/S manufacturer of advanced vision systems for measuring and quality control in the industry.
Betonelement A/S one of Denmark's leading manufacturers of precast concrete elements with eight production centres in Denmark.
Other participants include NGC Bastøfjord, Dragfjorden Beton ApS, Emmelud A/S, Elum Materials (Norway) and the Danish Road Directorate.

KNOWLEDGE CENTRES
The Danish Technological Institute, Concrete Denmark’s independent technological service institute. The institute serves as project coordinator for the SCC Consortium. Also associated with the SCC Consortium is the Danish Working Environment Centre for Construction.

SELF-COMPACTING CONCRETE
SCC CONSORTIUM
WWW.SCC-KONSORTIET.DK
SCC-Consortium

THE CONCRETE

SCC, or Self-Compacting Concrete, is the concrete of the future - a material that will bring great advantages to the construction industry and society as a whole.

SCC is not only capable of increasing productivity in the building industry, its use can also dramatically improve the working environment. What's more, SCC provides architects with new possibilities for the design of beautiful concrete structures. The resulting structures will be of a better quality and live longer than those made using traditional concrete.

SCOPE

The SCC Consortium brings together research, development and innovation. Its goal is to improve the working environment in the building industry and to enhance productivity by increasing the use of SCC. SCC differs from traditional concrete in a number of ways, and new expertise is therefore required to exploit the huge potential offered by this material. The SCC Consortium will generate knowledge about SCC and the construction of concrete structures with SCC.

The primary aim of the SCC Consortium is to make SCC the most used type of concrete in Denmark before 2008. In addition, the Consortium is to give the Danish concrete industry a technology jump, making it a worldwide leader in the design and construction of concrete structures with SCC.

SCC or Self-Compacting Concrete

OF THE FUTURE

• STRONG COLLABORATION
The SCC Consortium brings together large and small companies, as well as knowledge centres and leading European research institutions. Close collaboration between suppliers, contractors, building owners and researchers is one of the main strengths of the SCC Consortium, which draws on frontline research as well as practical knowledge from the building trade.

• EFFORTS
The Consortium's efforts focus primarily on the three areas where SCC offers the greatest potential: namely, floors, prefabricated elements and civil engineering. More specifically, the Consortium's activities focus on material development, the construction of concrete structures with SCC and the production of SCC. These activities are carried out under a number of sub-projects which focus on the examination of polymers at the nano-level, the correlation between constituent materials and concrete properties, determination of concrete properties, specification of requirements, the efficient production of SCC using on-line monitoring, and placing SCC.

• UNIQUE DOCUMENTATION
The SCC Consortium's research will be the first to scientifically document the use of SCC in terms of productivity and the working environment. It will do so with assistance from the Benchmark Centre for the Danish Construction Sector and the Working Environment Centre for Construction.

THE SCC-CONSORTIUM

The SCC Consortium is the abbreviated name for The Innovation Consortium for Self-Compacting Concrete - a technology jump for productivity and working environment in the building industry. The members of the SCC Consortium represent every stage of the value chain, from knowledge centres and research institutions, through the suppliers of raw materials and measuring equipment, to manufacturers, contractors and building owners. The SCC Consortium was established in 2005, and activities are due to continue until 2008. The overall budget represents approximately DKK 20 million, of which DKK 7.4 million are being contributed by the Danish Ministry of Science, Technology and Innovation.

The Benchmark Centre for the Danish Construction Sector will document productivity by means of the key figures generally used to measure construction productivity. The Working Environment Centre for Construction will document both improvements of the working environment as well as new challenges involving SCC.

• COMMUNICATION
The results of the project will be disseminated by the SCC Consortium via the construction of a bridge for the Danish Road Directorate. The Consortium's findings will also be published in a number of publications, guidelines and handbooks that convey new knowledge about SCC and the construction of SCC structures to, among others, concrete suppliers, contractors and consultants.
Unique Documentation

- The Benchmark Centre of the Danish Construction Sector
- The Working Environment Centre for Construction
Communication

- Construction of a bridge for the Danish Road Directorate
- Publications
  “CtO Beton-Teknik, Selvkompakterende Beton – SCC”
  Issued January 2005
- Guidelines
- Handbooks
- Website: www.scc-konsortiet.dk
- Newsletter no. 2 issued January 2005
- Newsletter no. 3 issued August 2005
Nyhedsbrev nr. 2 fra SCC-Konsortiet

Januar 2005

Model til beskrivelse af SCCs flydende skaber

En af de dilemmaer, der er meget langt i løbet af den senaste år, er projektet ved at genbruge en materialet for SCC.

Modellen er et fyldestgørende modell, som kan tilpases til stenens størrelse og stenens størrelse og stenens størrelse og stenens størrelse og stenens størrelse og stenens størrelse.

Modelen er et fyldestgørende modell, som kan tilpases til stenens størrelse og stenens størrelse og stenens størrelse og stenens størrelse og stenens størrelse.

En model, der er fyldestgørende modell, som kan tilpases til stenens størrelse og stenens størrelse og stenens størrelse og stenens størrelse og stenens størrelse.

De to modeller beskriver også forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskellige forskelig
SCC-konsortiet

SCC-Konsortiet

SCC-konsortiet

Beggrunden for dannelsen af SCC-Konsortiet er, at dansk byggebranche, herunder også betonbranchen, står overfor store udfordringer. Produktivitet, arbejdsmiljø, kvalitet og æstetik er noglebegreber for at imødekomme fremtidens stadig skærpede krav i den internationale konkurrence. Det er blandt grundene til, at selvkompakterende beton, i daglig tale SCC (fra engelsk: Self Compacting Concrete), er udnævnt som fremtidens betontype.

Beton er verdens vigtigste konstruktionsmateriale. I Danmark produceres årligt ca. 8 mio. tons beton, færdigblandedt og til elementer, svarende til 1,5 tons per indbygger. Anvendelse af SCC giver mulighed for markant at forbedre produktivitet, arbejdsmiljø og kvalitet samtidig med, at der åbnes op for konstruktioner med arkitektonisk mere avanceret design.

På trods af, at SCC i dag finder stigende anvendelse i Danmark, er der mange udløste problemer, og i flere lande er anvendelsen af SCC stagnet. Det er derfor nødvendigt at tilføre betonbranchen det teknologiløb, der skal sikre, at SCC kan leve og til forventningerne om fremtidens betontype.

Næste side »
Webside: www.VoSCC.dk

Viden om selvkompakterende beton

[Images of construction sites and workers]
MT Højgaard won the contract for the concrete works at Segment 3 of the DR-Byen

DR-Byen as building owner is positively disposed to carry out different tests at the construction site

The full scale testing began at the end of 2004

5 plan inner walls and a core in the cellar has been cast with SCC
Full scale testing in DR-Byen, Copenhagen

Ready for casting the three first walls of the basement in DR-Byen, Segment 3.
SCC used on Fields, Copenhagen
SCC used on Spinderiet, Valby
Further information

- Lars Gredsted – MT Højgaard
  Chairman of the Steering Committee
  Phone: 22709816
  lag@mthojgaard.dk

- Mette Glavind – Teknologisk Institut, Beton
  Projectmanager
  Phone: 72202220
  mette.glavind@teknologisk.dk
Guidelines / Quality Control
Guidelines and Quality Control

Chairman: Kai Westphal
• First SCC in Japan around 1988
• First SCC in Europe around
• 1999 first International SCC Symposium
• 2001 SCC Symposium Tokyo
• 2003 SCC Symposium Reykjavik
• 2005 SCC Symposium Chicago
• Development all over the world
• Conventional test methods not suitable
• New test methods
• Development of guidelines
• Standards need modifications
• Comparison of Guidelines for SCC
  By Kai Westphal

• How is SCC handled in EN Standards
  By Steinar Helland
Nordic SCC-Net Workshop
19.06.06 Copenhagen
Comparison of Guidelines for SCC
Kai Westphal, Dipl.-Ing.
Mest ehf
Iceland
Guidelines

- EFNARC “The European Guidelines for SCC” May 2005
- Norsk Betonforening “Guidelines for production and use of self-compacting concrete” 2002
- Svenska Betonföreningen “Self-compacting concrete Recommendations for use” 2002
- DAfStb-Richtlinie “Selbstverdichtender Beton” Dec 2004
Content

- Definitions
- Engineering Properties
- Specifications of self-compacting-concrete
- Requirements of constituent materials
- Mix composition
- Producing ready mixed SCC
- Site requirements
- Placing and finishing on site
- Precast concrete products
- Appearance and surface finish
- Checklist
- Test methods
Norway

Content

- Background / Why is self-compacting concrete different (matrix models and properties, workability)
- Selection of constituents and proportioning
- Mixing of concrete, operation of mixing plant (control of water content, mixing equipment, quality control)
- Transport (general, after dosage of admixtures, stop in casting operations)
- Treatment and casting (testing at site, casting method and equipment, formwork)
- Guidance notes, finishing)
- Hardening concrete (setting, heat development, cracking)
- Curing
- Test methods
- Specifications
Sweden

Content

- Terminology of SCC, constituents, rheological terms and test methods
- Material technology in fresh and hardened stage
- Design aspects and applications
- Recommendations for choice and handling of constituent materials
- Recommendations for production, transport and deliverance
- Recommendations for pumping, casting and finishing (testing at site, casting method and equipment)
- Working environmental effects of SCC
- Comments on existing regulations
- Quality assurance
- Research and development needs
- Test methods
Germany

Content

- General, Definition of SCC
- Personnel and equipment of plants and sites
- Constituents
- Concrete (consistency, content of fines)
- Quality assurance of the constituents and the SCC (sample taking, subjects of testing, initial testing)
- Quality monitoring on site and of precast elements
- Production of the concrete and Transportation (dosing, mixing)
- Conveyance, casting and curing
- Formwork
- Shrinkage and creeping
Slump Flow

- **EFNARC**
  - SF1 550 to 650 mm for e.g. un- or slightly reinforced structures
  - SF2 660 to 750 mm for normal applications
  - SF3 760 to 850 mm for vertical applications, very congested structures

- **Norway**
  - 600 to 750 mm for columns or walls
  - 500 to 650 mm for slabs

- **Sweden**
  - no specifications

- **Germany**
  - ≥700 mm
T\textsubscript{50} Slump Flow

- **EFNARC**
  - VS1 \( \leq \) 2 sec
  - VS2 > 2 sec

- **Norway**
  - 2 to 12 sec for columns or walls
  - 2 to 10 sec for slabs

- **Sweden**
  - *no specifications*

- **Germany**
  - *no specifications*
Slump Flow with J-Ring

- **EFNARC**
  - *no specifications*

- **Norway**
  - *580 to 730 mm for columns or walls*
  - *480 to 630 mm for slabs*

- **Sweden**
  - *no specifications*

- **Germany**
  - ≥650 mm
$T_{50}$ Slump Flow with J-Ring

- EFNARC
  
  *no specification*

- Norway
  
  3 to 15 sec for columns or walls
  3 to 12 sec for slabs

- Sweden
  
  *no specifications*

- Germany
  
  *no specifications*
J-Ring Height Difference

- EFNARC
  no specifications

- Norway
  no specifications

- Sweden
  no specifications

- Germany
  no specifications
Difference between Slump Flow with and without J-Ring

- EFNARC
  no specifications

- Norway
  not mentioned

- Sweden
  not mentioned

- Germany
  $\leq 50 \text{ mm}$
V-Funnel Test

- **EFNARC**
  - $VF1 \leq 8$ sec
  - $VF2 \ 9 \text{ to } 25$ sec

- **Norway**
  - *not mentioned*

- **Sweden**
  - *no specifications*

- **Germany**
  - *not mentioned*
L-Box Test

- EFNARC
  - \( PA1 \frac{h_2}{h_1} = 0.8 \text{ to } 1 \) with 2 rebars
  - \( PA2 \frac{h_2}{h_1} = 0.8 \text{ to } 1 \) with 3 rebars

- Norway
  - depending on the structure

- Sweden
  - \((0.6)\) 0.8 to 0.85

- Germany
  - not mentioned
U-Box Test

- EFNARC
  *no specifications*

- Norway
  *not mentioned*

- Sweden
  *not mentioned*

- Germany
  *not mentioned*
Kajima-Box Test

- EFNARC
  - no specifications
- Norway
  - not mentioned
- Sweden
  - not mentioned
- Germany
  - not mentioned
GTM-Stability Test
(Sieve Segregation Test)

- EFNARC
  - SR1 $\leq 20\%$
  - SR2 $\leq 15\%$

- Norway
  - *not mentioned*

- Sweden
  - *no specifications*

- Germany
  - *not mentioned*
Orimet Test

- EFNARC
  - no specifications
- Norway
  - not mentioned
- Sweden
  - not mentioned
- Germany
  - not mentioned
Grooving Test

- **EFNARC**
  - *not mentioned*

- **Norway**
  - *not mentioned*

- **Sweden**
  - *< 10 sec, otherwise countermeasures*

- **Germany**
  - *not mentioned*
Sedimentation Behaviour Test

- EFNARC
  no specifications
- Norway
  not mentioned
- Sweden
  not mentioned
- Germany
  no specifications
<table>
<thead>
<tr>
<th>Test</th>
<th>EFNARC</th>
<th>Norway</th>
<th>Sweden</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>column/walls</td>
<td>slabs</td>
<td></td>
</tr>
<tr>
<td>Slumpflow</td>
<td>mm</td>
<td>550 – 850</td>
<td>600-750</td>
<td>500-650</td>
</tr>
<tr>
<td>T&lt;sub&gt;50cm&lt;/sub&gt;slumpflow</td>
<td>Sec</td>
<td>VS1≤2 or VS2&gt;2</td>
<td>2-12</td>
<td>2-10</td>
</tr>
<tr>
<td>Slumpflow with J-Ring</td>
<td>mm</td>
<td>no specification</td>
<td>580-730</td>
<td>480-630</td>
</tr>
<tr>
<td>T&lt;sub&gt;50cm&lt;/sub&gt;slumpflow with J-Ring</td>
<td>mm</td>
<td>no specification</td>
<td>3-15</td>
<td>3-12</td>
</tr>
<tr>
<td>J-Ring</td>
<td>mm</td>
<td>no specification</td>
<td>3-15</td>
<td>3-12</td>
</tr>
<tr>
<td>Slumpflow - Slumpflow with J-Ring</td>
<td>mm</td>
<td>not mentioned</td>
<td>not mentioned</td>
<td>not mentioned</td>
</tr>
<tr>
<td>V-funnel</td>
<td>sec</td>
<td>VF1≤8 or VF2 9-25</td>
<td>not mentioned</td>
<td>no specification</td>
</tr>
<tr>
<td>L-box</td>
<td>(h&lt;sub&gt;2&lt;/sub&gt;/h&lt;sub&gt;1&lt;/sub&gt;)</td>
<td>PA1≤0.8 2 rebars PA2≤0.8 3 rebars</td>
<td>depending on structure</td>
<td>(0.6) 0.8 to 0.85</td>
</tr>
<tr>
<td>U-box</td>
<td>(h&lt;sub&gt;2&lt;/sub&gt;-h&lt;sub&gt;1&lt;/sub&gt;)</td>
<td>no specifications</td>
<td>not mentioned</td>
<td>not mentioned</td>
</tr>
<tr>
<td>Fill-box</td>
<td>%</td>
<td>no specifications</td>
<td>not mentioned</td>
<td>not mentioned</td>
</tr>
<tr>
<td>GTM Screen stability test</td>
<td>%</td>
<td>SR1 ≤ 20 %</td>
<td>not mentioned</td>
<td>no specification</td>
</tr>
<tr>
<td>Orimet</td>
<td>sec</td>
<td>no specifications</td>
<td>not mentioned</td>
<td>not mentioned</td>
</tr>
<tr>
<td>Flow Cyl.</td>
<td>I&lt;sub&gt;Q&lt;/sub&gt;</td>
<td>not mentioned</td>
<td>0.55-0.75</td>
<td>not mentioned</td>
</tr>
<tr>
<td>Grooving</td>
<td>sec</td>
<td>not mentioned</td>
<td>not mentioned</td>
<td>not mentioned</td>
</tr>
<tr>
<td>Tixometer</td>
<td>Nm</td>
<td>not mentioned</td>
<td>not mentioned</td>
<td>no specification</td>
</tr>
<tr>
<td>Sedimentation Behaviour</td>
<td>no specifications</td>
<td>not mentioned</td>
<td>not mentioned</td>
<td>not mentioned</td>
</tr>
</tbody>
</table>
Content of Fines ($\leq 0.125$ mm)

- EFNARC
  
  $380 \text{ kg/m}^3 \leq \text{Fines} \leq 600 \text{ kg/m}^3$

- Norway
  
  no requirements

- Sweden
  
  no requirements

- Germany
  
  $450 \text{ kg/m}^3 \leq \text{Fines} \leq 650 \text{ kg/m}^3$
Water/Powder - Ratio

- **EFNARC**
  - *w/p ratio by volume 0.85 to 1.10*

- **Norway**
  - *without stabilizer 0.30 to 0.45, otherwise stabilizer is recommended*

- **Sweden**
  - *powder type, powder+stabilizer type and stabilizer type SCC mentioned, higher w/p-ratio’s demand finer powder*

- **Germany**
  - *no requirements*
Water/Cement - Ratio

- **EFNARC**
  
  *based on requirements in EN 206*

- **Norway**
  
  *no requirements*

- **Sweden**
  
  *no requirements*

- **Germany**
  
  *no requirements*
Watercontent

- **EFNARC**
  - *typically 150 - 210 l/m³*

- **Norway**
  - *no requirements*

- **Sweden**
  - *no requirements*

- **Germany**
  - *no requirements*
Maximum Grainsize

- EFNARC
  usually 12 - 20 mm

- Norway
  ≤ 16 mm as a recommendation

- Sweden
  ≤ 16 mm as a recommendation

- Germany
  ≤ 16 mm
Personal Evaluation

EFNARC

- Most specific regarding ranges of test results
- No background informations
- Practical help how to produce, transport and place SCC on site and in precast production
- Tips for trouble shooting
- Good description of the test methods
- Best practical guideline for concrete producers
Personal Evaluation

Norway

- Practise orientated guideline
- Theoretical background and explanation why SCC is different
- Background for mix-design approach, but not very specific
- Test result requirements for field testing
- Different requirement for different structures
Personal Evaluation

Sweden

- Main focus on the use of SCC
- Good explanation of the terminology regarding SCC
- Promotion of SCC / advantages and risks
- Nearly no test result requirements
Personal Evaluation

Germany

- Requirements for field and laboratory testing (fresh and hardened concrete)
- Not usable as a stand alone guideline
- Very theoretical, without background informations
- Stiff with little space for new developments
Conclusions

- SCC must become a standard concrete
- Specifications are necessary
- Defined quality control methods
- Assurance for a high quality concrete for the future
SCC
European standardisation
Nordic Workshop on SCC
Steinar Helland

Copenhagen 19th June 2006
Present European regulations concerning structural use of concrete

EU's Construction Products Directive
+ National legislation

2005

Eurocode - 0
Basis of structural design

2007

Eurocode - 2
Design of concrete structures

prEN 13670
Execution of concrete structures

EN 206-1
Concrete

Product and testing standards

prEN 10138 or ETA
Tendons & PT kits

Product and testing standards

prEN 10080
reinforcement

Product and testing standards

EN 13369 - xx or ETA
Prefabricated elements

Product and testing standards

2000
The objectives of including SCC in CEN standards

1. Does SCC have properties that are in conformity with the design assumptions in Eurocode 2?

2. To regulate the trade between ready-mix producer and contractor
Present state-of-affairs I

- Default models and mechanical properties in EC-2 is based on empirical experience with traditional concrete.

- EC-2 and EN 206-1 defines concrete as a mix of water, cement, fine and coarse aggregate etc.

- EN 12620 has later defined ”coarse aggregate” as $\geq 4$ mm.

- Such ”concrete” does not support the design assumptions of EC-2 concerning ”aggregate interlock”, shrinkage, creep, ”rotation capacity” etc.
Present state-of-affairs II

- SCC is per today not mentioned once in any CEN standard
- What is SCC?
- Can it be used within the standards?
- How to order it from a ready-mix plant?
- Is it the contractor or the ready-mix producer that guarantee the self compactability?
Present state-of-affairs III

CEN TC 250/SC2 (Eurocode-2 / prof. Guiseppe Mancini) has been asked by me (TC 104/SC2) to sort out the data base for the present default models and mech. properties in EC-2

SCC was on the agenda for TC 104/SC1 (EN 206-1) at its meeting on Cyprus last November.
Present state-of-affairs IV

- CEN TC 104/SC1 initiated the standardisation of 5 test methods for the characterization of the fresh properties of
  - L-box
  - Slumpspread
  - V-funnel test
  - Sieve segregation resistance test
  - J-ring test
Present state-of-affairs V

Resolution 336 (Larnaca 2005-11-02)
CEN/TC 104/SC 1 establishes a new task group 16 "Provisions for SCC" and requests the task group to prepare a report on the different provisions regarding the requirements for SCC (testing, product requirements and the relationship with the execution requirements) in the CEN-member countries within the next 18 months. The report should be drafted in a way, that the relevant parts may be introduced in the future EN 206. Members of the new TG 16 are: **L. Meyer** (Convenor), FR (Mr Delort will announce), DK (Mr Bager will announce), SE (Mr Sandahl will announce), NL (Mr Cornelissen will announce), UK (Mr Harrison will announce), Mr Biasioli, Mr Marino, Mr Cussigh (on behalf of SC 2).

Tor Arne Hammer is Norwegian expert in the TG

TG 16 will report in Stockholm in June 2007
Europe is exhausted by the implementation of EN 206-1 and EC-2

None of these will be subject to any revision in this decade

The only main module in the hierarchy still under production is the execution standard, prEN 13670
Present European regulations concerning structural use of concrete

- EU's Construction Products Directive + National legislation
- Eurocode - 0: Basis of structural design
- Eurocode - 2: Design of concrete structures
- prEN 13670: Execution of concrete structures

- EN 206-1: Concrete
- prEN 10138 or ETA: Tendons & PT kits
- prEN 10080: reinforcement
- EN 13369 - xx or ETA: Prefabricated elements

2000

2005

2007
prEN 13670 plan to give a requirement to the contractor that the designer has to be contacted if the concrete mix planned to be used is outside some given criteria ($D_{\text{max}}$ and / or paste content)

The EC-2 committee is asked to give us guidance for the criteria
prEN 13670 § 8.5 Self Compacting Concrete

(1) By the use of concrete described as Self Compacting Concrete (SCC), the needed compaction of the fluid concrete is achieved due to the effect of gravity. Working procedures, for the actual cast, that shall ensure that the required compaction will be obtained shall be established based on the constructors experience and/or pretesting. Additional requirements to those given in EN 206-1 to the fresh concrete properties and its conformity criteria shall be agreed with the producer.
F.8.4.2 Placing and compaction – Self compacting concrete

(1) SCC mix design should comply with specific requirements in the fresh state depending on the type of application, and especially on:

- confinement conditions related to the concrete element geometry and the quantity, type and location of reinforcement, inserts and recesses;
- placing equipment (pump, truck-mixer, skip);
- placing methods (number of delivery points);
- finishing method.

Those requirements might be expressed and justified in terms of:

- flowability and filling ability;
- viscosity (measure of the speed of flow);
- passing ability, (flow without blocking);
- segregation stability.
(2) The required consistence retention time depends on the transportation and placing time. This should be determined and specified.

(3) Self-compacting concrete should, as much as possible, be placed in one continuous pour so delivery rates should be matched to placing rate. Maximum allowed period of time between successive concrete layers should be declared and kept under control.

(4) Free-fall of SCC should be limited in order to avoid any adverse effect on concrete quality and homogeneity.

(5) Horizontal flow of SCC should be limited in order to avoid any adverse effect on concrete quality and homogeneity.
(6) Vibration of SCC should generally be avoided as it is likely to result in significant segregation of the coarse aggregate. A carefully controlled and light vibration can be used if it is demonstrated that there is no adverse effect on concrete quality and homogeneity.

NOTE 1 At the time of publishing the standard, CEN has not completed its work to standardize test methods characterizing the properties of SCC nor additional provisions for its specification in EN 206. Till such CEN-provisions are available, the constructor and the concrete producer might find guidance in national and European guidelines published by other bodies.

NOTE 2 Guidance regarding limitation of free-fall and horizontal flow can be found in published guidelines (e.g. RILEM SCC Technical Committee report).
Conclusion

- SCC is still controversial in parts of Europe
- The challenge is to identify "extreme mix-composition"
- The minor challenge is to sort out the communication between ready-mix producer and contractor
"SCC"
"SCC"
Example of successfully use of SCC.

Tjennvoll church,
Rogaland - Norway
Holmenkollen - 100 km/h - 5 meters above the ground

Prepare yourself before taking new technology into use !!!

Photo:
Steinar Helland
2005
Mix Design
Material Models in SCC Mix Design

Claus Pade, SCC-seminar in Copenhagen, 19 June, 2006
Role of Model in Mix Design

- Estimate/predict the rheological behavior of concrete

(1) Newtonian liquid (water)
(2) Bingham-material (concrete)

\[ \tau_0 = \text{distance of flow} \]
\[ \eta_{pl} = \text{speed of flow} \]
Types of Model

- **Emperic**
  - Too simplistic
  - It works but you don’t know why

- **Analytic**
  - Too complicated
  - It works and you know why
Danish SCC-Consortium Model

Originally proposed by Oh et al.:

\[ \eta_{\text{concrete}} = \eta_{\text{paste}} \left( A_\eta \cdot \Gamma^{-B_\eta} + 1 \right) \]
\[ \tau_{0,\text{concrete}} = \tau_{0,\text{paste}} \left( A_\tau \cdot \Gamma^{-B_\tau} + 1 \right) \]

\( \eta_{\text{concrete}} \), is the plastic viscosity of the concrete
\( \eta_{\text{paste}} \), is the plastic viscosity of the paste
\( \tau_{0,\text{concrete}} \), is the yield stress of the concrete
\( \tau_{0,\text{paste}} \), is the yield stress of the paste
\( A_\eta, A_\tau, B_\eta, B_\tau \), are constants
\( \Gamma \), is the relative thickness of excess paste

\[ \Gamma = \frac{1 - \varphi/\varphi^*}{f/k \cdot \varphi} \]

\( \varphi \), is the volume fraction of the aggregate
\( \varphi^* \), is the max volume fraction of the aggregate

\( f/k \), is a shape factor – related to the ratio between surface and volume of a particle with characteristic dimension 1

\( f/k \) (sphere) = 6
\( f/k > 6 \) for all other shapes
Elements of the Model

The excess of paste is found around each aggregate particle with $\Gamma = R/D$ constant for all aggregate particles.

$\Gamma = R/D$ is the same for either particle.
Experimental Program

\[ \tau_{0,\text{concrete}} = \tau_{0,\text{paste}} \left( A_t \cdot \Gamma^{-B_t} + 1 \right) \quad \Gamma = \frac{1 - \varphi/\varphi^*}{f/k \cdot \varphi} \]

\begin{align*}
\tau_{0,\text{paste}} & \quad \text{EMPA Zürich - Estimated from plate-plate rheological measurements} \\
\eta_{\text{paste}} & \\
\tau_{0,\text{concrete}} & \quad \text{DTI - Estimated using 4C Auto Slump Flow equipment} \\
\eta_{\text{concrete}} & \\
\varphi^* & \quad \text{DTI - Estimated using the 4C Packing software} \\
\varphi/\varphi^* & \\
f/k & \\
A & \quad \text{Fit-parameters in regression analysis} \\
B & \\
\end{align*}
## Materials and Composition

### Mix 1

<table>
<thead>
<tr>
<th></th>
<th>0/2</th>
<th>4/8</th>
<th>8/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural pit</td>
<td>Natural pit</td>
<td>Sea dredged</td>
<td>Sea dredged</td>
</tr>
<tr>
<td>Max packing</td>
<td>0.808</td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/c</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP-konc</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess paste</td>
<td>110,120,130,140 L</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Mix 2

<table>
<thead>
<tr>
<th></th>
<th>0/2</th>
<th>4/8</th>
<th>8/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass beads</td>
<td>Glass beads</td>
<td>Glass beads</td>
<td>Glass beads</td>
</tr>
<tr>
<td>Max packing</td>
<td>0.848</td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/c</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP-konc</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess paste</td>
<td>100,110,120,130 L</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Mix 3

<table>
<thead>
<tr>
<th></th>
<th>0/4</th>
<th>4/8</th>
<th>8/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural pit</td>
<td>Natural pit</td>
<td>Crushed granite</td>
<td>Crushed granite</td>
</tr>
<tr>
<td>Max packing</td>
<td>0.804</td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/c</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP-konc</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess paste</td>
<td>160,170,180,190 L</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Identical pastes in all three mixtures
4C Packing Diagrams

37, 18, 45, 0.808

37, 18, 45, 0.848

45, 10, 45, 0.804
4C Auto Slump Flow

Yield stress = 26 Pa
Plastic viscosity = 44 Pa × s
Results – Yield Stress

\[ \tau_{0,\text{concrete}} = 4.5 \times 10^{-6} \times \Gamma^{-4.3} \]

\[ \Gamma = \frac{1 - \phi/\phi^*}{\text{shapefactor} \cdot \phi} \]
Results – Yield Stress

- **Crushed**
- **Natural**
- **Glass beads**

**Aggregate volume fraction**

Crushed +100L excess paste
Natural +45L excess paste

Innovation in 100 years
Shapefactor – Image Analysis

Parameter guess
Parameter measurement

Shapefactor

0/2 natural pit
0/4 natural pit
Glass 0/4

Innovation in 100 years
\[ \tau_{0,\text{concrete}} = \tau_{0,\text{paste}} \left( A_\tau \cdot \Gamma^{-B_\tau} + 1 \right) \]

\[ \Gamma = \frac{1 - \varphi / \varphi^*}{f/k \cdot \varphi} \]

For practical purpose:

\[ \tau_{0,\text{concrete}} = A \times \Gamma^B \]

\[ \Gamma = \frac{1 - \varphi / \varphi^*}{\text{shapefactor} \cdot \varphi} \]

- Estimate particle packing parameter - $\varphi^*$ \textbf{OK!}
- Select aggregate proportions – $\varphi$ \textbf{OK!}
- Estimate shapefactor \textbf{?}
- Estimate the constants $A$ and $B$ \textbf{?}
EFFECT OF FORM PRESSURE ON THE AIR VOID STRUCTURE OF SCC

Mikkel V. Jensen
Department of Civil Engineering,
Technical University of Denmark

Marianne T. Hasholt
Concrete Centre,
Danish Technological Institute

Mette R. Geiker
Department of Civil Engineering,
Technical University of Denmark
The air void structure of a hardened concrete has to satisfy two requirements if the concrete is to be approved in Denmark as frost resistant;

- The total air content in paste (including air) should be no less than 10 %
- The spacing factor must be no more than 0.20 mm
Motivation – 2 of 2

The high workability of self-compacting concrete (SCC) invites to high casting rates
The high workability of self-compacting concrete (SCC) invites to high casting rates. Casting at high rate may result in large pressure at the bottom of the form and compression of air voids. [Billberg 2003]
Boyle-Mariottes Law

The pressure related changes of a certain volume of air can be estimated by using Boyle-Mariottes law (constant temperature):

\[ p \cdot V = \text{constant} \]

\( p \) pressure
\( V \) volume
Expected Pressure Related Changes

Total air content, $V$

$$V_{\text{bottom}} = \left( \frac{p_{\text{top}}}{p_{\text{bottom}}} \right) \cdot V_{\text{top}}$$

Radius of air voids, $r$

$$r_{\text{bottom}} = \left( \frac{p_{\text{top}}}{p_{\text{bottom}}} \right)^{\frac{1}{3}} \cdot r_{\text{top}}$$
Expected Pressure Related Changes

Specific surface, $\alpha$

$$\alpha_{bottom} = \left( \frac{p_{\text{top}}}{p_{\text{bottom}}} \right)^{-\frac{1}{3}} \cdot \alpha_{\text{top}}$$

Spacing factor, $\bar{L}$

$$\bar{L} = \frac{3 \cdot (1.4(1 + R)^{1/3} - 1)}{\alpha} \quad R \geq 4,342:$$

$R$ paste / air volume ratio
Expected Pressure Related Changes

- Specific surface
- Spacing factor
- Total air content

Index

Pressure [bar]
Experimental

Laboratory

- 3 concrete batches with approximately 6.5 % air
- 3 concrete batches with approximately 4.5 % air

Full scale wall castings

- Filling from the bottom
- Filling 0.5 m above concrete surface
## Experimental (Laboratory) – Concrete Mixes

<table>
<thead>
<tr>
<th>Constituent material</th>
<th>Unit</th>
<th>“H”</th>
<th>“L”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (CEM I 52.5)</td>
<td>kg/m³</td>
<td>384</td>
<td>393</td>
</tr>
<tr>
<td>Water</td>
<td>kg/m³</td>
<td>135</td>
<td>138</td>
</tr>
<tr>
<td>Sand (0-2 mm)</td>
<td>kg/m³</td>
<td>661</td>
<td>675</td>
</tr>
<tr>
<td>Rounded gravel (4-8 mm)</td>
<td>kg/m³</td>
<td>316</td>
<td>323</td>
</tr>
<tr>
<td>Rounded gravel (8-16 mm)</td>
<td>kg/m³</td>
<td>800</td>
<td>818</td>
</tr>
<tr>
<td>Superplast, Glenium C151</td>
<td>kg/m³</td>
<td>1.91</td>
<td>1.95</td>
</tr>
<tr>
<td>AEA, Conplast 316 AEA1:5</td>
<td>kg/m³</td>
<td>0.96</td>
<td>0.39</td>
</tr>
<tr>
<td>Air content in fresh concrete</td>
<td>%</td>
<td>6.3 ± 0.7</td>
<td>4.7 ± 1.0</td>
</tr>
</tbody>
</table>
Experimental – Testing Laboratory

Pressure: 1, 1.5, 2 and 2.5 bar (0, 2, 4, 6 m concrete)

Duration: 24 hours
Experimental – Testing Laboratory

Air void analysis

(Frost testing)
Air Void Analysis; DS/EN 480-11
(only ¼ of required samples size)

Low paste content  
High paste content
Experimental – Testing
Full Scale

Walls for basement cast December 2004
5-8 % air; $\eta_{pl}=60$ [Pa s]; $\tau_0=20$ [Pa]
Expected Pressure Related Changes

Index vs. Pressure [bar]

- \( \alpha \) (Specific surface)
- \( \bar{L} \) (Spacing factor)
- \( \bar{V} \) (Total air content)
Pressure Related Changes of the Spacing Factor in Laboratory cured concretes

![Graph showing the relationship between pressure and spacing factor for different conditions labeled H-A, H-B, H-C, L-A, L-B, and L-C.](image)
Total Air Content (% of paste + air), Mean of the Laboratory Cured Concretes

\[
V_{\text{bottom}} = \left( \frac{P_{\text{top}}}{P_{\text{bottom}}} \right) \cdot V_{\text{top}}
\]

- H-Measured
- H-Estimated
- L-Measured
- L-Estimated
Measured and Estimated **Air Void Distribution**, Laboratory Cured Concrete, Mix H-B

![Graph showing air void distribution for different bar pressures.](image-url)
Air Void Distribution in **Full-scale Wall** Casting

**Form Filled From Bottom**

![Graph showing cumulative air content vs. void size for different sections of the wall.](image-url)
Air Void Distribution in **Full-scale** Wall Casting Concrete **Poured 0.5 Meter Above Surface**

![Diagram showing cumulative air content vs. void size (micron)]
Summary and Conclusions

Through laboratory castings of six concrete mixes, each hardened at four different pressures, the pressure related changes of the air void structure were examined.

The results indicate that pressures related changes might be estimated by using Boyle-Mariottes law.

Full-scale casting revealed that other factors than the form pressure influence the air void structure, e.g. the method of placement.

SCC Network Workshop; June 19, 2006
References

Acknowledgement

The full-scale wall castings were carried out as part of the work in the Danish SCC Consortium. The authors would like to thank for the access to the results:

www.SCC-konsortiet.dk
ASTM C09.47
Minutes of Meeting June 12, 2006, e.g.

Blocking
• ASTM C 1621/C1621M-06 Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring - Approved
• Development of U-box and L-box methods stopped

Stability
TG for establishment of ASTM test method for dynamic stability established

Others
Proposed terminology to include in existing ASTM test methods to allow their use with SCC
Economy / Benefits / Environment
SCC - economical benefits?

Sverre Smeplass, Skanska Norge AS
Bård Pedersen, NorBetong AS
Why use SCC?

- **Increased productivity?**
  - Reduced manhours, reduced work force
  - Reduced repair costs

- **Increased quality?**
  - Less flaws
  - Smoother surfaces, less pores, improved surface durability

- **Improved working environment?**
  - Reduced noise
  - Reduced back and arm wear
Why use SCC?

- SCC is normally the choice of the contractor:

...is it profitable?
Use of SCC

- Slabs
- High walls
- Restricted access
- High quality surfaces
- Concrete elements
Traditional float plastering
..replaced by a all-in-one procedure?...
Example, slab, 200 mm

- **Traditional procedure**
  - Float plastering: + NOK 100,- /m²
    (alt. troweling: + NOK 70,- /m²)

- **SCC**
  - Increased concrete cost: + NOK 25,- /m²
  - Reduced man hours: - NOK 5,- /m²
  - Grinding: + NOK 20,- /m²

_Potential saving: NOK 60,-/m²_  
(+ reduced production time)
Success criterions (1)

- Robust concrete
  - Sufficient amount of fines / filler
  - Moderate cement content
  - Moisture control
  - Non-sensitive to normal variation in additive dosage

- Formwork
  - No leakages, well adapted details
  - High quality panels for smooth surfaces
  - Correct use of release agents
  - Proper cleaning
Success criterions (2)

■ Well prepared concreting
  ➢ Formwork, sections and joints according to SCC properties
  ➢ Detailed filling plan
  ➢ Well adapted flowability and viscosity
  ➢ Delivery capacity and actual delivery
  ➢ Filling rate vs formwork pressure

■ Communication at site
  ➢ Competence in both ends
  ➢ Detailed specification (according to Euro Guideline)
  ➢ Visual control basis for corrections
..nice surfaces, bad panel sectioning
Altered responsibilities?

- More detailed concrete specification
- Increased risk for both contractor and concrete producer?

> Bad result: Who is to blame?

- New European guidelines: a step towards a “clean cut” between contractor and concrete producer??
Example, major civil structure

Bjørvika Concrete Tunnel
AF Bjørvikatunnelen

- Joint Venture between
  - Skanska Norge AS (60%)
  - Bam Civiel, Holland (20%)
  - Volker Stevin, Holland (20%)

- NOK 1,0 bill contract.
  - (1 av 3 main contracts, total of > NOK 3.0 bill.)

- Approx. 70000 m³ structural concrete

- Completed 2010 / 2011
Bjørvika Concrete Tunnel, typical data

- 6 elements, each 112 m long
- Widths 28-41 m
- Each element consists of 5 sections
- Top and bottom slabs 1.20 - 1.40 m, walls 1.00 m
- Pre-fabrication at Hanøytangen (Bergen), towed to Oslo

.....

- 2 of 6 elements almost completed (June 2006)
Concrete specification (1)

- CEM I
- w/b < 0.45
- “C40”
- 30-65% PFA (by clinker weight), k=0.7
- 4-8% CSF (by clinker weight), k=2.0
- Frost resistance (!)
- Density 2450 kg/m³ (!)
Concrete specification (2)

- Crack index < 0.75 (tensile stress / tensile strength)
- PP-fibers for fire protection in lower 400 mm of tunnel ceiling
- Comprehensive test- and documentation programme
  - General material documentation, data input for FEM stress analysis, and conventional site control
Mix design challenges

- High concrete density
- Locally congested reinforcement in walls
  - Pump hoses must be pre-placed
  - Difficult to lower pokers
  - SCC?
- Minimized heat of hydration
  - Slow strength development
  - Late demoulding - affecting production cycles?
Mix Design Solutions

- PFA ground with HS clinker to CEM II B/V (Norcem)
  - Improved logistics
  - Improved workability / stability
  - Effect on heat of hydration?
- High quality natural sand (Årdal), high fines content (~ 10% < 0.125 mm)
  - Increased viscosity / stability
  - Increased matrix volume; improved flow
- High density crushed rock (Eklogitt ~3120 kg/m³)

Mix design in close cooperation between Skanska and NorBetong
Workability

- **Bottom slab and upper layer of top slab:** SF 500-600 mm (vibrated)
- **Walls:** SU 650-720 mm (SCC)
  - Pre-placed pipes and hoses
  - Approx. 5 meters between pipe outlets
  - Rate 1 m/h (50m³/h)
- **PP-fiber concrete in top slab:** slump 240 mm (vibrated)
SCC - Effect on costs for the concrete tunnel

- Limited additional concrete costs
  - SCC mix design close to ordinary low heat concrete
  - Minor changes in production procedures and production control
- Reduced man hours
  - Saving approx. 0.1h/m³
- Repair almost eliminated
  - Saving approx. 0.05h/m³
- Positive total balance!
Concrete Tunnel - SCC surfaces
Preliminary experience

- Very reliable concrete delivery
  - 1300 m³ continuous pours without critical stops
  - 50-60 m³/h during 30 hours
  - Impressive production statistics

- Extremely stable workability
  - SCC more robust than vibrated concrete
  - Low form pressure
  - No visible layers
SCC - economy, summary

- Additional material cost will normally exceed man hour savings in the concreting process
- A positive balance can be achieved
  - Simplified solutions
  - Reduced repair and surface treatment costs
- A robust, cost optimized technology is crucial
SCC and the Working Environment
- results from the SCC-Consortium

Co-operation between:
- Danish Technological Institute
- Danish Centre for the Working Environment
- MT Højgaard A/S
What are the impacts of SCC on the working environment?

- Vibrations are reduced (most significant on the building site)
- Noise level is reduced (most significant in the precast plant)
- Fewer unhealthy working positions and better ergonomics (most significant on the building site in connection with vertical casts)
- Chemicals and dangerous substances

Background:
- Brite EuRam “Rational Production…SCC”, 1997-2000
- Brite EuRam “TESCOP”, 1997-2000
- Danish investigation of health and safety in the construction industry, DTU, 1979-1981
Concrete workers average occupation

SCC has impact on this part

Taken from Danish project on concrete workers health and safety, DTU, 1979-1981.
Concrete workers do wear down more than the public in general

Introduction

Taken from Danish project on concrete workers health and safety, DTU, 1979-1981.
Vibration impact on hand-arm from poker vibration

- Accelerometer measurements
- Vibrator hanging from scaffold
- Resulting acceleration calculated from x, y and z components
- Wacker declare that acceleration impact is 4 m/s²

Distance from poker - m

Acceleration $a_{hv}$ (m/s²)

- Wacker 58 mm
- Wacker 45 mm

m/sec²
Allowable exposure times

Exposure time - minutes

<table>
<thead>
<tr>
<th>Acceleration [m/s²]</th>
<th>Exposure time [minutes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 m/s²</td>
<td>2 m from the container 4 hours</td>
</tr>
<tr>
<td></td>
<td>1 m from the container 40 minutes</td>
</tr>
<tr>
<td>2 m/s²</td>
<td>1 m from the container 1 hour</td>
</tr>
<tr>
<td>1 m/s²</td>
<td>0.3 m from the container 18 minutes</td>
</tr>
<tr>
<td>0.3 m/s²</td>
<td>At-Vejledning D.6.2</td>
</tr>
<tr>
<td>0.1 m/s²</td>
<td>Wacker 45mm</td>
</tr>
</tbody>
</table>

Vibration
Allowable exposure times

Observation for wall casting: Approx. 2 hours exposure

Taken from Danish project on concrete workers health and safety, DTU, 1979-1981.
Conclusions - 1

- Exposure to vibrations from handheld equipment is a health risk for concrete workers.
- Increased risk of numbness and poor blood circulation in fingers/hands.
- Limit of 3 m/sec² is easily exceeded with poker vibrators.
- However, pistol type poker vibrator with handle (for horizontal castings) are less strenuous.
- Avoiding compaction with vibrators will improve the working environment significantly.
Noise measurements

- External vib. on formwork
- Vibrating table
- 35 mm poker (2 pcs.)
- Operator's ear

Similar to Danish prescast plant
Similar to Danish building site
Background noise

Taken from Brite EuRam SCC project, 1997-2000, Results obtained at University of Paisley.
Conclusions - 2

- In a precast plant form vibrators generate excessive noise throughout the building.
- Level around 95-100 dB(A) under vibration, which means less than one hour daily exposure time allowed.
- Omitting vibration reduces noise level from down to around 70-80 dB(A).
- Only need for ear protection when noisy equipment are used (electric saw, drilling, grinding, etc.)
- Leaving out the noise from vibration improves the working environment significantly in the precast plant.
- However, still a short vibration is sometimes used with SCC.
Conclusions - 3

- At building site the limit of 85 dB(A) is clearly exceeded for all the workers in the vicinity of the casting. Thus, ear protection is mandatory.
- Max allowed exposure time is around 2 hours per day.
- Omitting vibration at the building site reduces noise level from 90-95 dB(A) to around 85 dB(A). 10 dB(A) increase is felt as a doubling of the sound.
- Therefore, avoiding compaction with vibrators will improve the working environment significantly at the building site even though noisy operations are still taking place (heavy machines, pumps, etc.).
Ergonomics

- What are the important issues?
  - heavy lifts of equipment and building materials
  - pushing and pulling (risk of sudden unexpected movements/impacts)
  - many repetitions
  - unhealthy and unpleasant working positions (crouched/hunched)

- Difficult to measure and quantify
- Differs from person to person (not objective)
Lift of equipment and materials

Lifts/hour ≥ 5 kg

Observation for wall casting:
Approx. 86 lifts/hour in connection with vibration

Taken from Danish project on concrete workers health and safety, DTU, 1979-1981.
Lift of equipment and materials

Ergonomics

Sudden impacts per working day

Vibration of floors, where vibrator hose gets stuck.

Taken from Danish project on concrete workers health and safety, DTU, 1979-1981.
Ergonomics for wall castings with traditional vibration

- Many moderately heavy lifts.
- Bending over and lifting at the same time, resulting in torsion of the back.
- Difficult to obtain good and secure base for your feet.
- All in all very stressful working conditions for the human body.
- Plus vibration and noise impact.

Video from MT Højgaard site at DR-byen, Copenhagen, June 2005.

\MVI_0538_pumpe.AVI
\MVI_0540_arb_stillinger.AVI
Conclusions - 4

- Concreting has large and impact on back and joints due to heavy lifts and unhealthy working positions.
- SCC reduces the impact and thereby the increased wearing down of concrete workers by leaving out some of the stressful working positions.
- The SCC effect on the ergonomic working environment is most pronounced for wall castings.
More information

- www.SCC-konsortiet.dk
- www.VoSCC.dk (only in Danish)
- www.NordicSCC.net
- Claus.V.Nielsen@Teknologisk.dk
Copenhagen 19 June 2006.

Cost savings by use of SCC in floors.
It is not possible to give one strait answer for savings using SCC. There is a lot of different combinations in
Surface treatment
Floor thickness
Weather conditions
Specification of surface concerning tolerance of level.
Size of floor area.
Ect.
The following choice has been made.

The economical analyse will be based on.

1000 m² of floor/slab
Thickness vary from 10 cm to 40 cm.
Surface treatment vary from none to smooth grinding.
Weather condition won’t be a part of this paper.
Special surface treatment developed as a part of using SCC to be mentioned.
Risk to be mentioned.
Figure 11.1 Levelling SCC with a skip float

After-treatment such as the use of steel trowel finishing or float-finishing may be carried out as vibrated concrete. However, if the SCC shows thixotropic stiffening, judging the correct time to start this part of the finishing can be difficult.
Concrete price level.

<table>
<thead>
<tr>
<th>Concrete type</th>
<th>Standard Price average</th>
<th>SCC %</th>
<th>SCC Price EUR/m3</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 20 P</td>
<td>85</td>
<td>17,1</td>
<td>99</td>
</tr>
<tr>
<td>C 25 P</td>
<td>87</td>
<td>16,4</td>
<td>102</td>
</tr>
<tr>
<td>C 30 P</td>
<td>91</td>
<td>15,6</td>
<td>105</td>
</tr>
<tr>
<td>C 35 P</td>
<td>95</td>
<td>14,9</td>
<td>109</td>
</tr>
<tr>
<td>C 30 M</td>
<td>103</td>
<td>9,5</td>
<td>113</td>
</tr>
</tbody>
</table>
Figures used.

Concrete as "we know it" without surface treatment.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>unit</td>
<td>Eur/unit</td>
<td>EUR 40 EUR</td>
<td>EUR EUR</td>
</tr>
<tr>
<td>Euro</td>
<td>7,45 DKK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>1000 m²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>10 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>m²</td>
<td>1000</td>
<td>0,05</td>
<td>5</td>
</tr>
<tr>
<td>Formwork along edges</td>
<td>m²</td>
<td>20</td>
<td>5</td>
<td>27</td>
</tr>
<tr>
<td>Reinforcement 2 o/oo</td>
<td>ton</td>
<td>3,04</td>
<td>12</td>
<td>670</td>
</tr>
<tr>
<td>Concrete deliver and casting</td>
<td>m³</td>
<td>100</td>
<td>0,4</td>
<td>85</td>
</tr>
<tr>
<td>Concrete pump</td>
<td>m³</td>
<td>100</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>Vibration eq.</td>
<td>m³</td>
<td>100</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Claye with steel towel</td>
<td>m²</td>
<td>0</td>
<td>0,08</td>
<td></td>
</tr>
<tr>
<td>Hire eq.</td>
<td>m²</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Evaporation protection</td>
<td>m²</td>
<td>1000</td>
<td>0,03</td>
<td>0,5</td>
</tr>
</tbody>
</table>

| Total                           |         |              |                |                          |
|                                 | 256     | 10.259       | 16.577         | 1.500                    |
| Total                           | 28.336  |              |                |                          |
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**Total** 24.143
Concrete floor without surface treatment.

1000 m2

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Savings without surface treatment. 1000 m2

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| Total                         | 886     | 35.437        | 57.007 | 8.000   |                  |

Total: 100.444
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Concrete floor with surface treatment

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cm
EUR
### SCC floor with surface treatment

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**cm**

**EUR**
Savings with surface treatment. 1000 m²

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<td></td>
</tr>
<tr>
<td></td>
<td>2.993</td>
<td>5.063</td>
<td>7.133</td>
<td>9.203</td>
<td>11.273</td>
<td>13.343</td>
<td>15.413</td>
</tr>
<tr>
<td><strong>C 30 M</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Advantage contra disadvantage.
Using SCC in floors.

• **Advantage**
  • Cost saving
  • Noise reduction
  • Faster (less manhour)
  • Ect.

• **Disadvantage.**
  • Overall level more difficult to obtain
  • Surface contains airbubble after grinding.
  • More sensitive if concrete aren’t delivered as planned.
  • Evaporation protection more difficult.
  • Insulation must be ”protected” against oplift
SCC surface without grinding.
Same after grinding one time.
Insulation must be kept in position or it will float.
Quality of concrete delivery and casting.
SCC floor after treatment as mentioned below to be used as final surface

EverCrete® dybdæmprægnering
Diamantslibeprocesser
DBE Microspartel
Micopur W top mat – poreforsegler
Steinfix 50 poreforsegler
Steinfix 60 natursæbe

Price level 34 EUR
Final surface.
Production / Execution
Production and execution of SCC - for Industrial Construction

Mats Emborg
Betongindustri AB,
Luleå University of Technology
Sweden
Insufficient productivity increase ……. 

Productivity increase / year 

<table>
<thead>
<tr>
<th>%</th>
<th>Manufacturing industry</th>
<th>Building industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1993 – 2001
The solution...

Industrial construction

- Assembly line/Conveyor belt
- Standardisation
- Lean Construction
- Mechanization
- Prefabrication
Industrialisation
- with cast in place concrete

- New reinforcement e.g. fibres
- Pumping
- Form technique
- Weather independence
- Fill the form with concrete
  - No compaction
  - Minimum reinforcement work
- Enhanced working environment
- Increased productivity
- Enhanced quality

Emborg (2003)
Reinforcement

- Large share of total construction costs

With prefabrication they are reduced
Reinforcement

The Bamtec system

Enormous decrease of fixing time
More effective utilization of reinforcement
Weather independence
- an important factor for an industrial process
Industrial construction
- as many component as possible are combined

Lattice girder elements filled with SCC
Steel fibre reinforced SCC (X-ray examination)
The future cast in place concrete....

- A highly industrialized process:
  - Effective reinforcement fixing
  - Rational form handling, left forms
  - Weather independence
  - SCC - accurately produced and executed
Disposition

• How to produce and transport SCC
  – Mats Emborg, Betongindustri, Luleå Univ Techn
    First SFR-SCC garage slab in N Europe

• Full Scale SCC Castings, DK
  – Lars Nyholm Thrane, Danish Technological Institute
    First SCC wall – by the computer!

• Executions of Civil Engineering Structures
  – Thomas Österberg, Vägverket
    First SCC bridge, Europe

Workshop sessions
PRODUCTION OF SCC

Mats Emborg

Betongindustri AB, Stockholm
Luleå University of Technology, Luleå
Content

• Concrete constituents
• Mixing
• Transport
• Delivery
Variation of aggregate

During 2 weeks

Quarry: Jehanders, Stockholm

≈ 0 mm

8 mm

Sieve, mm

Passing, %

0 - 8 mm storage 991209
0 - 8 mm storage 991214
0 - 8 mm storage 991215
0 - 8 mm storage 991210
0 - 8 mm storage 991213
0 - 8 mm conveyor 991213
0 - 8 mm conveyor 991214
0 - 8 mm storage 991215
0 - 8 mm storage 991215
0 - 8 mm storage 991216
0 - 8 mm conveyor 991216
0 - 8 mm storage 991217
0 - 8 mm storage 991220
0 - 8 mm storage 991222
0 - 8 mm storage 991223
0 - 8 mm mean

< 0.075 0.075 0.125 0.25 0.5 1 2 4 5.6 8 11.3 16 22.6 32 8 0

During 2 weeks
During 1 day
Variation of aggregate humidity

Delivery for building site no 1

Delivery for building site no 2
How much variations can we accept?
Criteria SCC

Example:
Filling ability / flowability - target value and tolerances

Depends on application and casting method

**Workability:**

![Graph showing slump flow (mm) vs. T50 [sec] with accepted variations for Wall and Slab.]
Rheology:

The "Wallevik area" for SCC

My (Pas) vs. Tau (Pa) graph with annotations for wall and slab.
Example:
Target rheology area - Concrete for housing

Corresponding workability area
Criteria for SCC is now suggested in:

Check them!

Input from the European project Testing – SCC 2001-2004 (coord. Univ of Paisley Scotland)
SCC should fulfil the criteria

Robust SCC:

Admits variations of a number of factors:
- Fluctuations of properties of concrete constituents
- Mixing procedure
- Transport conditions
- Casting conditions
- etc

Project: influence of crushed aggregate
Robustness of SCC - example

Variation of water content - +/- 0.5% of sand humidity
Natural (N), Crushed (K) aggregate, 0 – 8, 8 – 16 mm

Workability

Rheology
Variation of water content - +/- 0.5 % of sand humidity
Crushed aggregate 0 – 16 mm
Increase of cement content

Rheology

Cement
Variation of water content - +/- 0.25, 0.5, 1 % of sand humidity
Natural aggregate
different filler

Workability
Mixing at the plant
Mixing order, mixing time

- **Mixing order:**
  - Start mixing:
    - (W)
  - Activity:
    - A, C, S
    - Sp, W
    - 1/2 Sp, W
    - 1/2 Sp
    - 1/2 A
  - End mixing:
    - (W)

- **Mixing time:**
  - A, C, S
  - Sp, W
  - 90 sec
  - 90 sec
  - x sec
  - 180 sec
  - 120 sec
  - 210 sec
  - 270 sec
  - y sec

- **Activity:**
  - A - aggregate,
  - C - cement,
  - S - filler,
  - Sp - superplasticiser,
  - W - water
Mixing, examples

Paisley, UK
A tilting drum 6 m³
Sa, Co, F, Gg, C
1 min

B tilting drum 6 m³
all
5 min

Norrköp, SW
C tilting drum 6 m³
Co, W+1/2Sp
1/2Sp

Stockholm
D tilting drum 6 m³
all
(varied)

Stockholm
E pan mixer 1 m³
Co, C, W, Sp

Bretonneau, F
F forced mixer 3 m³
Sa, Co, C

Bunol, Spain
W, Sp

C - cement
W - water
W1, W2 - water
F - filler, powder
Sp - superplast
Sa - fine aggr
Co - coarse aggr
Vi - viscosity ag
Air - air entr ag.
Gg - slag.

Paisley, UK
Norrköp, SW
Stockholm
Bretonneau, F
Bunol, Spain

Betongindustri
HEIDELBERGCEMENT Group
Mixer effect and mixing time

Slump flow

Resis.
The Arlanda control tower

> 1000 m³
Transport: 5 – 10 min
Same mix

Here:
49 deliveries
(of 270)
Transport

- influence of truck
  - type of drum
  - volume of drum
  - speed of revolution etc

- influence of length
  - temperature

- influence of concrete
  - superplasticiser
Slump flow

Truck no
Pump length, height, pressure etc

Pump pressure

Cement + fines

SCC
Betongindustri, 2006

- Locally very large share of concrete production – 20 - 35 %
- Mainly housing concrete
- Prerequisites (conditions) at plants vary
- Limestone filler, crushed aggregate, superplasticiser
- Both larger contractors and smaller ones
Betongindustri, 2006

- Mixing order – all materials at once (some 10 sec between aggregate, cement, superplasticiser and water)
- Mixing times – not longer than for vibrated concrete
  - 60 – 90 sec – concrete for housing,
  - 90 – 120 (180) sec – civil eng concrete
- Careful check of resistance meter – mix, experienced based value for finalizing the mixing
- Diluting water at end often used – some 2 -3 l/m3
- Target plant SF-value depends on known effect of transport (increase or decrease of slump flow – concrete quality, superplasticies, filler etc and truck type)
Conclusions:

Production

- Production can be performed without any particular problems
- Standard type of mixing equipment can be used
- Higher degree of control at concrete plant is needed:
  - Include variation of material in mix design
  - Control of aggregate humidity variations
  - Mixing must be checked carefully prior to full scale production. (Mixing order, mixing time)
Transport/pumping

- Transport of SCC can be performed without any particular problems
- Normal types of trucks (with rotating drum) can be used. Transport time up to 1 h is possible
- Pumping of SCC can be performed without any particular problems with existing equipment
- Higher degree of site control is needed
Experiences from Vertical Full Scale Castings with SCC

Lars Nyholm Thrane
Danish Technological Institute, Concrete Centre
Overall objective:
To improve the productivity and the working environment of the concrete industry
Outline

Introduction

Test setup

Results
- Form filling
- Segregation/Blocking
- Form pressure
- Surface finish
- Frost resistance
- Air void structure

Fresh state

Hardened state

Nordic Concrete Day
2005
Introduction

The use of SCC in vertical castings is still much lower than the use of SCC use in horizontal castings such as floors.

The aim of the full scale wall castings is to obtain experience on i.e.

- the relation between the fresh concrete workability, casting technique and the form filling behavior
- form pressure
- surface finish
- air void structure and frost resistance
## Test Setup

<table>
<thead>
<tr>
<th>Wall ID</th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V4</th>
<th>V5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>H * W * L = 4m * 0.5m * 5m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Type</td>
<td>A35</td>
<td>A35</td>
<td>A35</td>
<td>M30</td>
<td>M30</td>
</tr>
</tbody>
</table>

Nordic Concrete Day
2005
Test Setup

- Inlet
- V1 and V4
- V2 and V5
- V3
- Concrete surface
Test Setup

![Diagram showing test setup with labels for height and length in meters. The diagram includes numbers indicating specific measurements at various points along the height and length axes.]
Test Setup
## Test Setup

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump Flow, Annex U i DS 2426</td>
<td>Compressive strength</td>
</tr>
<tr>
<td>Slump Flow, 4C Auto-slump</td>
<td>Heat development</td>
</tr>
<tr>
<td>J-ring</td>
<td>Finish</td>
</tr>
<tr>
<td>Air content</td>
<td>Macro analysis</td>
</tr>
<tr>
<td>Air void distribution: Air-Void-meter</td>
<td>Air void structure: EN 480-11</td>
</tr>
<tr>
<td>Form pressure</td>
<td>Frost Resistance: SS 13 72 44</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
</tr>
</tbody>
</table>
4C Automatic Slump Flow

B/W Video camera

Lifting device – Ball screw ensures accurate lifting speed of 7 cm/s

Base plate in hardened sand blasted glass on adjustable rubber feet

Everything mounted on "rollers"

Monitor – one click and the analysis will proceed automatically

Upright Abrams slump cone with weight ring

PC

Nordic Concrete Day
2005
4C Automatic Slump Flow

Concept:

- Field of view 232 x 172mm – 640 x 480 pixels
- Spread as a function of time is determined – 30 images per second
- Raw image
- Binary image – only black and white pixels

Nordic Concrete Day 2005
4C Automatic Slump Flow

Concept:

Field of view 232 x 172 mm – 640 x 480 pixels
Binary image – only black and white pixels

Spread as a function of time is determined – 30 images per second

Yield stress: \( \tau_0 = 45 \text{ Pa} \)

Plastic viscosity: \( \eta_{\text{pl}} = 30 \text{ Pa s} \)
## Results

<table>
<thead>
<tr>
<th></th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V4</th>
<th>V5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air [%]</td>
<td>5</td>
<td>6.6</td>
<td>5.1</td>
<td>8.5</td>
<td>7.1</td>
</tr>
<tr>
<td>SF [mm]</td>
<td>640</td>
<td>660</td>
<td>670</td>
<td>550</td>
<td>570</td>
</tr>
<tr>
<td>$\tau_0$ [Pa]</td>
<td>20</td>
<td></td>
<td>60</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>$\eta_{pl}$ [Pa·s]</td>
<td>60</td>
<td>34</td>
<td>34</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results

Complete form filling was obtained. Depending on the rheological properties it was necessary to move the inlet to level the concrete surface.

Form geometry and reinforcement configuration do not prevent high casting rates of up to 25 m/hour. However, may have to lower due to e.g. finish and form pressure.
Results

V1 (~ 2 cm)

V4 (~ 10 cm)
Results

Blocking was not observed during form filling.

Nordic Concrete Day
2005
Dynamic segregation very dependent on the casting technique and the rheological properties.
Results

Dynamic segregation very dependent on the casting technique and the rheological properties.
Dynamic segregation very dependent on the casting technique and the rheological properties.
Results

Hydrostatic pressure is obtained (> 18 m/hour)
Results

2 types of form oil:

- Bricon Unislip 9-12, mineral oil
- Emulfix LL, vegetable formololie

Visuel inspection showed no difference in surface finish.
Results

Finish is evaluated by counting pores according to:


For each wall four sections are chosen of 1x1 m². The sections represent
Results

4 m

5 m

Nordic Concrete Day
2005
Results

The surface finish is very dependent on the casting technique and the rheological properties.
Results

According to annex F in DS 2426 concrete in exposure class XF2, XF3 og XF4 (A, A and E in DS 481), which is exposed to a combination of salt and frost should obtain:

- Air void content in hardened concrete (DS/EN 480-11) > 3,5%
- Spacing factor is < 0.20.

It is observed that all the tested samples fulfil these requirements except for the three core samples in the bottom of V1 where the total air void content is 3.4%.
Results

According to annex F in DS 2426 concrete in exposure class XF2, XF3 and XF4 (A, A and E in DS 481), should obtain the result good in a frost/thaw test (SS 13 72 44).

The results show that a satisfactory frost resistance is obtained.
Experiences of Civil Engineering

Projects Involving SCC

2000 – 2006

Thomas Österberg

Swedish National Board of Roads
Business Unit Production and Maintenance (SNRA,P&M)
Present situation (Civil Engineering)

- 7 years of experiences using SCC in civil engineering projects has not led to a wide use (only a few percent today)

- Why this sparse use of SCC in Sweden?
  - Problems with variations in consistency
  - Lack of practical experience at site
  - Too expensive!
  - Problems with homogenity in hardened state
  - Seldom available outside urban areas

........
Constructions where SCC has successfully been used by SNRA, P&M

- Retaining walls
- Concrete arches
- Entrance arches to tunnels
- Concrete walls and arches in rock tunnels
- Repair jobs, thin topping layers
- Closed formwork, dense reinforced structures
  (often a part of 2, 3 and 4)
Concrete arch, Kallhäll - Kungsängen

Figur 8.1 Tvärsektion av tunnel med valyform.
Mälarbanan, Kallhäll - Kungsängen
Mälarbanan, Kallhäll - Kungsängen

Finished 90 m concrete arch
Bridge B 1931, Nynäshamn

High demand of aesthetics, negative inclination
SL 25 Värmdöleden, concrete arch at tunnel entrance

Dense reinforcement, high demands of aesthetics
SL 25 Värmdöleden, tunnel entrance

Detail, surface cast against Plywood
SL 01 Tpl Huddingevägen, rock lining

Dense reinforcement, closed formwork
SL 01 Tpl Huddingevägen, concrete arch & rock lining
SL 20 Årsta, retention walls

Nice surfaces despite the negative inclination and structural elements
SL 04 Nobelberget, walls in emergency evacuation tunnels

The walls were cast with SCC pumped through valves into a closed formwork, in order to obtain tightness to the rock surface.
Götaleden, maintenance tunnel entrance at Stora Badhusgatan, Göteborg

7*5 meters. Cast with valves. Casting time 2 hours!
Stora Badhusgatan, Göteborg

Close up!
Bridge Z 799, Lillån Jämtland

Repair of ice damaged supports, concrete topping 8-10 cm
Bro Z 799, Lillån

Finished job
Bridge N 844 at Falkenberg, Sweden

Heavy fire damaged concrete on a length of appr. 40 m
Bridge N 844 at Falkenberg, Sweden

A thin (4-6 cm) layer of SCC was cast on fire damaged and water jetted parts of the under side.
Bridge N 844 at Falkenberg, Sweden

Finished bottom of beam
Bridge N 844 at Falkenberg, Sweden

Part of east console and beam
Why was SCC chosen by SNRA P&M in this project?

- It was not possible to compact the concrete by the use of pokers or vibratos (closed formwork).
- High amount of reinforcement. Not possible to survey the compation process (conventional).
- A way to achieve better surfaces (especially at structures with negative inclinations).
- Less colour variations, less pores and potholes.
- The combination of self compactability and high strength has in some cases turned out to be an attractive alternative to conventional compacted normal strength concrete.

Conclusion: Our experiences using SCC in a number of different projects, 2000 - 2006 are generally positive, used at selected structures and cast with a close monitoring of delivered concrete!
Nordic Innovation Centre

The Nordic Innovation Centre initiates and finances activities that enhance innovation collaboration and develop and maintain a smoothly functioning market in the Nordic region.

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