

II INTERNATIONAL SYMPOSIUM ON WATERPROOFING FOR UNDERGROUND STRUCTURES

December **01-02, 2015**
São Paulo - Brazil

WORLDWIDE SPRAYED CONCRETE - STATE OF THE ART REPORT

Chief Scientist/Professor Eivind Grøv
SINTEF/NTNU

*Animateur ITA Working Group 12
on Sprayed Concrete Use*

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NEW

Last time Norwegians guests were in Sao Paulo!





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I am fully aware that the Symposium theme is "Waterproofing for Underground Structures" however:



3º CONGRESSO BRASILEIRO DE TÚNEIS E ESTRUTURAS SUBTERRÂNEAS
SEMINÁRIO INTERNACIONAL "SOUTH AMERICAN TUNNELLING - SAT 2012"
20 a 22 de março de 2012 / São Paulo - SP

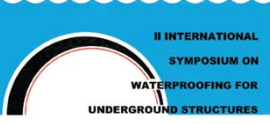
**"Pre-grouting"
Or "Ground Water Control"**

Chief Scientist/Professor Eivind Gray
SINTEF/NTNU

 **SINTEF**  **NTNU**





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NEW

The presentation focused 4 main aspects of "Grouting" or Water Control" were focused:

Adding; no point in repairing the entire ground, dedicated effort




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SEMINÁRIO INTERNACIONAL "SOUTH AMERICAN TUNNELLING - SAT 2012"
20 a 22 de março de 2012 / São Paulo - SP

Pre-grouting

SOME MAIN ASPECTS OF THE PRESENTATION:

- **Tight Enough For Its Purpose!**
- **Water Control - Not Water Proofing!**
- **Pre-excitation Grouting!**
- **Prevent - Not Cure!**



www.tuneis.com.br/3cbt

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NEW

Rock Mass Grouting

Water seepage into rock tunnels constitute non-complying incidents too



How can we control water inflow like these??

And what would the consequences of non-compliance be??

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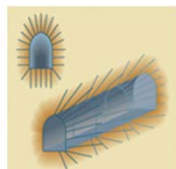
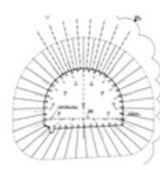
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NEW

Rock Mass Grouting

Aspects of a grouting strategy

- Evaluate the effect of inflow criteria
- Identify conductive zones in rock mass
- Aim at completing grouting after 1 round
- Focus on a limited area around the opening
- Choose grout type, mix design, pressure & grout hole pattern
- Include additives to custom design the properties of the grout
- Monitor inflow, evaluate modifications
- Integrate the grouting in the support system

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Rock Mass Grouting

Monitoring and follow-up

- Pre-construction assessment can be made, working procedures can be established
- Monitoring is needed to document the effect on the ground water regime:
 - at surface before construction
 - at the tunnel face from probe holes
 - of water inflow to the tunnel
 - at surface during construction



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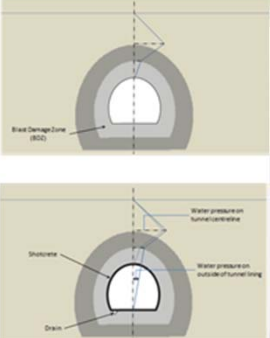
NEW

Rock Mass Grouting


Drained concept/pregrouted:

- Temporarily prior to placing a lining
- Permanently in an unlined concept

Reduction of gradient at tunnel periphery



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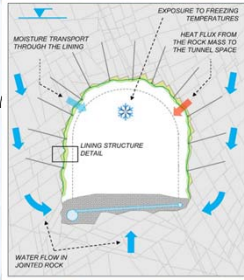
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Sprayed concrete in tunnelling:

- Grouting and water control (waterproofing) is important to achieve appropriate quality of SCL
- There are many reasons to water control,
 - External aspects
 - Internal aspects
 - It is mandatory for a drained concept and SCL
- Thus, SCL and impermeabilization of the rock mass are closely tied together



Ill. by Halter



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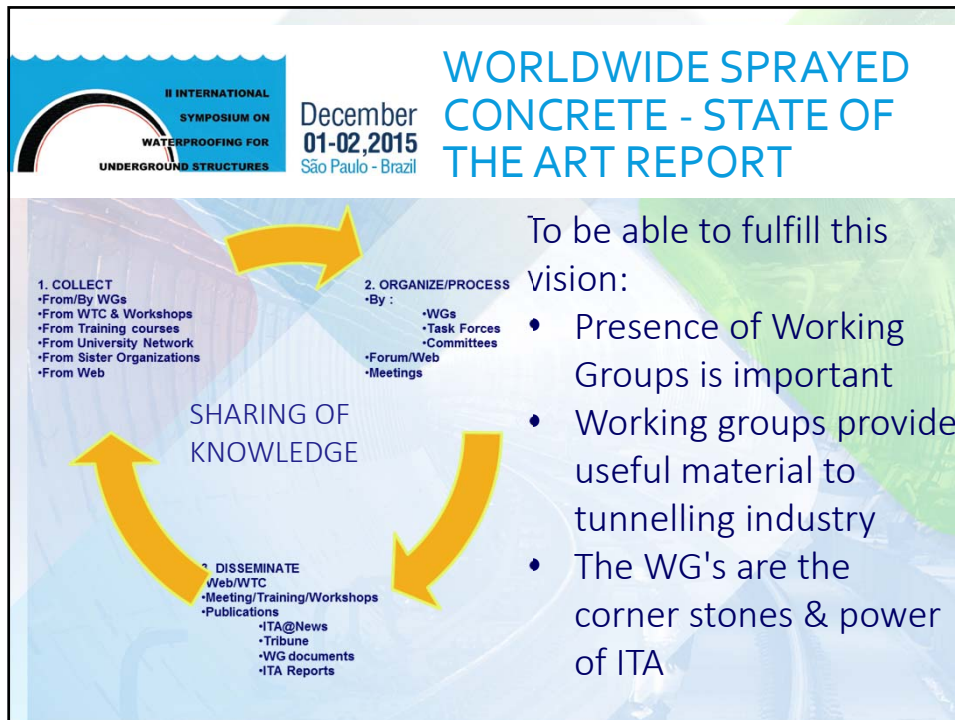
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ITA NEW VISION (Strategy 2014)

« ITA, the leading international organization promoting the use of tunnels and underground space through knowledge sharing and application of technology »





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Established in 1989 (ITA meeting in Toronto)

Animateurs:	Tomas Franzén	(Sweden)	1989 - 2000
	Knut Garshol	(Norway)	2001 - 2004
	Tarcísio Celestino	(Brazil)	2005 - 2010
	Atsumu Ishida	(Japan)	2010 - 2013
	Eivind Grøv	(Norway)	2013 -
Tutors:	Jindra Hess	(Czech Rep.)	2000 - 2003
	Eivind Grøv	(Norway)	2004 - 2010
	Felix Amberg	(Switzerland)	2010 - 2013
Current Team			
Animateur:	Eivind Grøv	(Norway)	2013 -
Vice Animateur:	Stefan Bernard	(Australia)	2013 -
Tutor:	Nikolaos Kazilis	(Greece)	2013 -



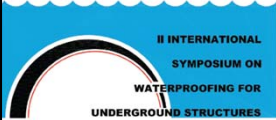
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- Scheduled meetings are annual in conjunction with the World Tunnel Conference (normally 1 meeting, but sometimes also 2)
- Some times ad-hoc meetings in conjunction with relevant technical conferences

In Iguassu Falls in Brasil in May 2014, a total of 27 participants from 17 member nations; Australia, Chile, France, Germany, Italy, Japan, Norway, Russia, South Africa, Switzerland, Thailand, United Kingdom, U.S.A.






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- WG publications highly depend on contributions of Member Nations (MN)
- WG issues and distributes Questionnaires to the MN
- The affiliated mass is huge (> 70 MN)
- Appr. 20 MN contribute to Reports
- The majority of MN are quiet
- The content vary in length/scope,
- Short notes to extensive reports



Permanent sprayed concrete lining at Gautrain RSA

Photo: Andre Assis



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Typical activities of WG 12 are:

- Making best practice documents
- Preparing State-of-the-art reports
- Endorsing Guidelines
- Cooperate with EFNARC
- Coordinate and cooperate with ITATECH activity group on sprayed concrete
- Arena for discussions
- Reach out to less developed countries
- Members suggest reports to be prepared and volunteer to participate



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Subjects of publications released:

- State-of-the-Art Reports
- Guidelines and Recommendations
- Health and Safety
- Shotcrete for Final Lining
- Waterproofing

To mention some





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Reports prepared by WG12


T. Franzén (1992)
“Shotcrete for underground support a state-of-the-art report with focus on steel-fibre reinforcement”
Tunnelling and Underground Space Technology, 7 (4), 383-391.

B. Malmberg (1993a)
“Shotcrete for rock support: Guidelines and recommendations – a compilation”
International Tunnelling Association Working Group on Shotcrete Use, published by the Swedish Rock Engineering Research Foundation

B. Malmberg (1993b)
“Shotcrete for rock support: a summary report on the state of the art in 15 countries”
Tunnelling and Underground Space Technology, 8 (4) 441-470.

K. Ono (1996)
“Health and safety in shotcreting”
Tunnelling and Underground Space Technology, 11(4), 391-409.

T. Franzén, K. F. Garshol, and N. Tomisawa (2001)
“Sprayed concrete for final linings: ITA working group report”
Tunnelling and Underground Space Technology, 16 (4), 295-309.



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Reports prepared by WG12

T. Celestino & T. Franzén (2002)
“Lining of Tunnels under Groundwater Pressure”
ITA2002 Sydney, Congress Proceedings, Vol. 1, pp. 481-487


T. Celestino (2005)
“Shotcrete And Waterproofing For Operational Tunnels”
ITA Workshop on Waterproofing - Sao Paulo

K. Garshol (2002)
“State of the art report WG12”
Proceedings of Fourth International Symposium on Sprayed Concrete, pp. 130-133

C. Larive (2006)
“Sprayable mortars for fire protection”
London, Workshop on Fire protection engineering

C. Hauck (2009)
“ITA Sprayed Concrete Tests at Hagerbach Testgallery Longterm Effect on Fibres in Sprayed Concrete”
5th Symposium on sprayed concrete. Lillehammer

C. Larive (2009)
“Certification of shotcrete nozzlemen around the world”
Shotcrete for South Africa



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K. Garshol et al (2006)


“Shotcrete for rock support – a summary report on the State of the art presented by ITA WG12 on Shotcrete Use”

State of the Art Report was given “go-ahead” at the WTC in Durban 2000

Covers the period 1992 until about 2005

(Under the leadership of Tarcisio Celestino)





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Australia: A two-page presentation given by the Australian Shotcrete Society

Belgium: Three different papers, primarily covering aspects of steel fibre reinforcement in shotcrete

Brasil: A three-page presentation covering temporary and permanent tunnel linings, shotcrete materials, standardization and rock mass – shotcrete interaction.

Canada: The contribution presents shotcrete usage in mining in Western Canada and in the Sudbury Basin. The use of boltless shotcrete in mining is described.

Czech Republic: Delivered a six-page contribution describing general shotcrete usage, following the outline given by the WG12 for Task 1.

Germany: About German tunneling technology over the last 20 years.


Italy: A SIG National Working Group Report with a good coverage of the most important issues of shotcrete usage in Italy.

Japan: A Japan Tunneling Association Shotcrete Working Group contribution containing a comprehensive seventeen-page coverage of the Japanese shotcrete market. The special aspects of shotcrete methodology in Japan are well illustrated. Also the new airless spraying method is presented.

Korea: A three-page contribution was received, giving an overview of the extensive tunneling in South Korea and the development of shotcrete for rock support for this purpose.

Lesotho: A ten-page paper on the Moatsku Diversion tunnel was submitted. The paper gives an in-depth presentation of the use of shotcrete at this 5.6 km tunnel project (part of Lesotho Highlands Water Project).

Mexico: A two-page report about usage of shotcrete in Mexico with a focus on the need to bring more users up-to-date with modern shotcrete technology.



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North America: "Guide Specification for Shotcrete for Underground Support" under preparation by the ACI 506 Shotcrete for Underground Support Committee. This is a comprehensive document covering all aspects of shotcrete usage of more than 100 pages in total.

Norway: Contributions were received in three steps. The final document contains seven pages, where the first two are summarizing the current status of shotcrete usage in tunneling and the next 5 pages give highlights about eight different tunnel projects. One of them is about the World's longest road tunnel between Aurland and Laerdal.

S. Africa: The twenty-page document gives a comprehensive presentation of shotcrete in deep level hard rock mining, rounding it off with three selected practical examples. The section about identified support mechanisms of shotcrete deserves special attention and credit, for being highly useful and educational.

Sweden: Submitted two papers on the Southern Link road tunnel project and the main document contains eight pages primarily about rock support and shotcrete. There is also a section about blast vibration effects on shotcrete and research on shotcrete durability and corrosion problems.

Switzerland: A set of five project-description papers were submitted, covering a range of practical shotcrete application examples.

Turkey: A five-page paper describing the Bolu Tunnel project was submitted. The paper compares wet mix shotcrete with two different types of accelerator and the influence on long term Young's modulus and compressive strength.



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The latest version of State-of-the-art report

- ITA Report on state-of-the art of sprayed concrete
- Issued in 2010 and presented in Vancouver WTC
- To be downloaded from www.ita-aites.org
- Under the leadership of Tarcisio Celestino




SHOTCRETE FOR ROCK SUPPORT
A SUMMARY REPORT ON STATE-OF-THE-ART

ITA Working Group N° 12
"Sprayed Concrete Use"

N° ISBN: 978-2-010024-5-0 ITA REPORT N° 005 / MAY 2010

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INTERNATIONALE DES TUNNELIERS
ET DE LA BRANCHE SOLUTIONS
ET DE LA BRANCHE SOLUTIONS
ASSOCIATION AITES
INTERNATIONAL TUNNELLING
AND UNDERGROUND SPACE
ASSOCIATION




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1. Guidelines, specifications, standards

- A variety of local national and also international codes and guidelines are applied world wide
- EFNARC has a good international recognition
- That goes for the Austrian Guidelines also
- ASTM, Norwegian Guidelines and Japanese ones are also used
- Australian Round Determinate Panel test has been recognized




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2. Design

- A common understanding that sprayed concrete entails rock reinforcement rather than rock support
- Rock support design is complicated, this approach is only changing the approach to it
- Observational approach supported by other methods seem to be the way forward



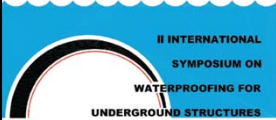


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3. Concrete technology

- Focus on finding alternatives to micro silica
- Create a best possible bond strength
- Durability requirements are specified case by case
- Still "Waterglass" is widely used
- Wet mix and alkali free accelerator required where focus on high end quality
- Extensive pre-construction tests, freeze – thaw properties





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4a. Equipment and application methods

- Some nations report that all wet mix shotcrete is applied by robotic equipment
- Monitor the close rate of accelerator
- A shift towards wet mix and fibre reinforcement
- Control of mixture composition
- High capacity mechanised robotic application to 20m³ per hour with dust and elutes reduction
- Less rebound – high output – less dust



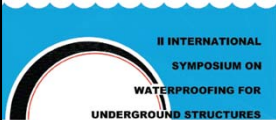


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4b. Equipment and application methods

- Difficult to find nozzlemen who are able to operate dry process,
- In some nations dry operation is dominating
- Dry mix with manual nozzle operation
- And particularly in complicated mine operations
- Other nations report wet mix operations since the 1970's
- Still a wide range of applications in the industry





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5a. Method of reinforcement

- Proper fibre application can replace welded wire mesh
- Fibres are favorable where joints are involved
- Increased use of synthetic fibres, and even high performance structural synthetics fibres have proven effective
- Installation of welded wire mesh is time consuming, takes 3 times longer time
- In general increased use of fibre reinforcement



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5b. Method of reinforcement

- Fibre sees an increased use due to such as:
 - labour and time saving,
 - reduced rebound,
 - reduction of applied thickness
 - Better overall quality
- Improved safety is another issue that is valued by the member nations

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6. Sprayed concrete as permanent lining

- In 1985 SUS V reported: " an increasing use of shotcrete as final lining for transportation tunnels and lining of waterways
- Today; most nations are reporting that shotcrete lining constitute final and permanent lining
- This goes for road tunnels, sub way tunnels, metros etc
- Specifications and thickness are crucial instruments (Norway has a min thickness 8cm)



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7. Health and safety

- There are two main aspects that are dominate on these issues
 - Dust development and workers health
 - How to avoid injury or death from falling rocks
- Another issue is related to the fact that blasting can take place relatively shortly after shotcreting without risk of damage





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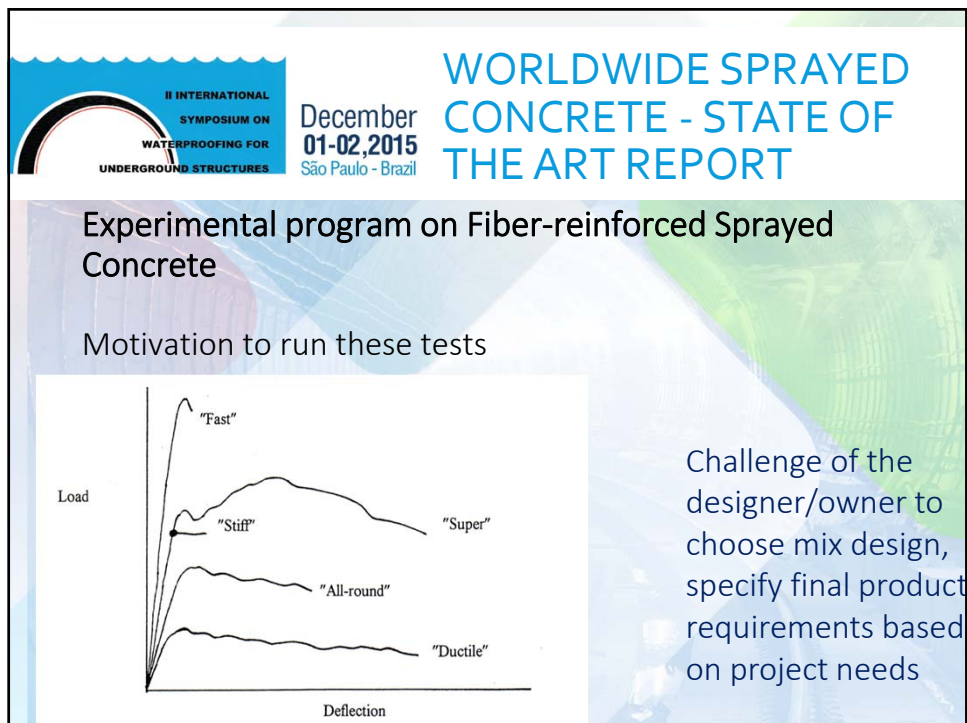
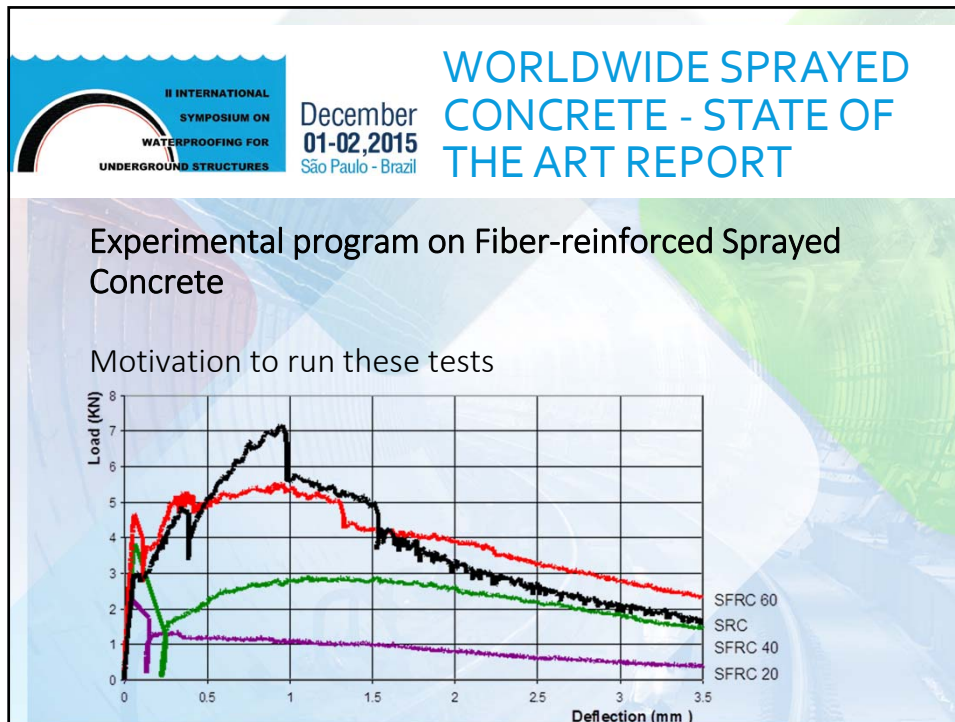
**Experimental program on
Fiber-reinforced Sprayed Concrete**


Commenced in March 2006

Influence on energy absorption of:

- Fiber type (steel, synthetic)
- Fiber content (to reach 1000 J)
- Age (early to 3 years)








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Experimental program on Fiber-reinforced Sprayed Concrete

- Took place at the Hagerbach test facility in Switzerland
- Invited suppliers to participate
- Suppliers provided material and paid the testing
- WG 12 managed and administered the project
- WG 12 to report the results (C. Hauck 09)
- Uniform, common, neutral test series
- Long term test scheme, up to 3 years
- Planned to be restarted with new tests
- The plan is currently put on hold!!





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Performance Comparison, tests performed with


- Same shotcrete (40-50 MPa)
- Same tests


Fresh concrete properties, Compressive strength, Energy Absorption (Circular panels), Fibre content

- Same procedures
- Comparable tests

Different fiber types

- Planned 2 steel fibers and 3 synthetic
- Attracted one of each for a full test series
- Decided to go ahead with a new invitation
- Project is on hold
- Is it worthwhile to try once again?






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Experimental program on Fiber-reinforced Sprayed Concrete

- **Recipe:** Standard Cement which achieve early strength in the range of J2 with AFA (alkali free accelerator), Cement content of 450 kg/m³
- **Fresh concrete characteristics:** w/c ratio 0.45, Slump 200 mm, Open time 3h
- **Harden concrete characteristics:** Early strength range of J2, 28 d compressive strength 40-50 MPa, Energy absorption 1000 J (according to suppliers reported documentation in advance!)



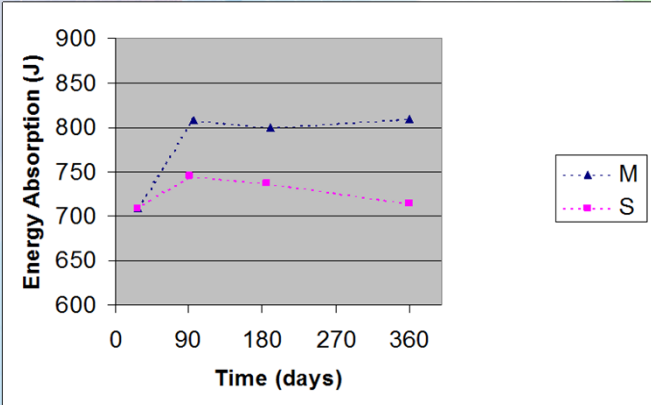


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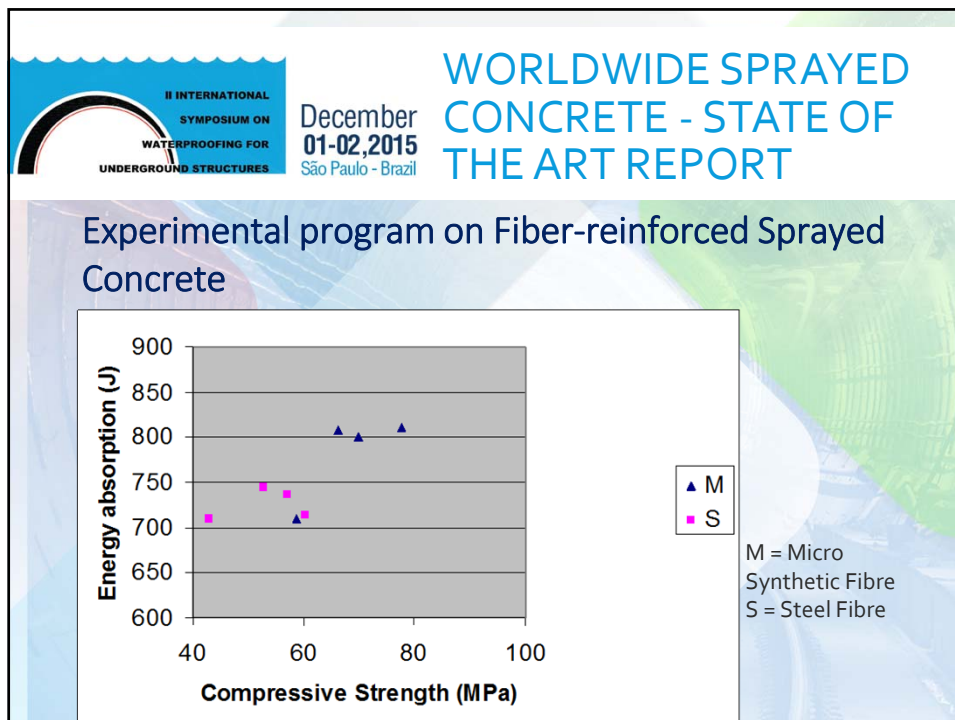
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Experimental program on Fiber-reinforced Sprayed Concrete



Time (days)	Macro Synthetic Fibre (M) [J]	Steel Fibre (S) [J]
0	~700	~700
90	~810	~740
180	~800	~730
360	~810	~710

M = Macro
Synthetic Fibre
S = Steel Fibre




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Current Activities, prioritised by the WG

- Fiber-reinforced sprayed concrete**
A draft report has been prepared, which will be reviewed internally in the WG, to be updated to enable preparation of ITA report;
- Mix design and durability**
A draft paper has been circulated and to be reviewed by the WG
- Quality control**
The initiative came up last year and the WG appointed persons to be dedicated to develop the document
- Permanent sprayed concrete lining**
Updating of report published in 2001, allocated persons to update the report



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1. FIBER-REINFORCED SPRAYED CONCRETE

General: Purpose compile information from Member Nations on information regarding fiber reinforced sprayed concrete

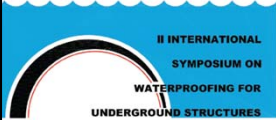
Part I: Compiling specification, recommendation, guideline of fiber reinforced sprayed concrete, from also EN, EFNARC

Part II: Compilation of information from research and investigation, publications of papers from technical journal and conference, research field and classification of papers.

Part III: Test method and energy absorption, design, properties, performance of fiber reinforced sprayed concrete, applications and history, synthetic fibers

Part IV: Research evaluation in Hagerbach test gallery

Task force Atsumu Ishida &
Stefan Bernard +++

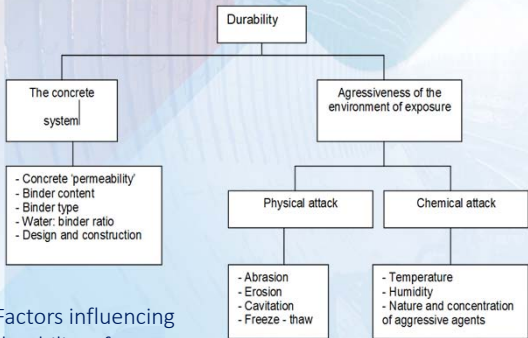


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2. REPORT ON THE TESTING OF SPRAYED CONCRETE FOR DURABILITY



```

graph TD
    Durability --> ConcreteSystem[The concrete system]
    Durability --> Environment[Agressiveness of the environment of exposure]
    ConcreteSystem --> ConcreteSystemList["- Concrete permeability  
- Binder content  
- Binder type  
- Water: binder ratio  
- Design and construction"]
    Environment --> PhysicalAttack[Physical attack]
    Environment --> ChemicalAttack[Chemical attack]
    PhysicalAttack --> PhysicalAttackList["- Abrasion  
- Erosion  
- Cavitation  
- Freeze - thaw"]
    ChemicalAttack --> ChemicalAttackList["- Temperature  
- Humidity  
- Nature and concentration of aggressive agents"]

```

Factors influencing durability of concrete

- Motivation: To produce permanent structural material with design life up to 120(?) years
- Discusses durable shotcrete as uniformly dense and impermeable $10^{-12}m/s$

Task force Chris Viljoen, Alun Thomas & Charles Allen +++



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UNDERGROUND STRUCTURES

December
01-02, 2015
São Paulo - Brazil


WORLDWIDE SPRAYED CONCRETE - STATE OF THE ART REPORT

3. QUALITY CONTROL

- Proposal was made at WG12 meeting in WTC 2013 in Geneva
- Framework, structure of the task, target goal, and time schedule will be decided by the task force



Task force Volker Wetzig, Catherine Larive & Odd-Bjørn Kleven +++



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4. PERMANENT SPRAYED CONCRETE

Issued 2001 by Franzen et.al.

- Has been reviewed by the WG12
- Compilation of project data & requirements, technical data
- Concluded to update recent doc. and fill in gaps in information
- Low priority



Task force Alun Thomas, Charles Allen, Matous Hilar, Tarcisio B. Celestino +++



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Other issues to work with in the WG

- Coordination and liaison with ITATECH
There is a need to strengthen the coordination with ITATECH and its activity groups, this is a responsibility of the A and VA, and will be followed up activity groups leaders;
- Management structure of WG12
A management structure will be prepared by the A and VA to run and operate the WG to enable the desired level of deliverables and production
- Communication architecture
There is a risk that participants in the meetings are not receiving the distributed documents, the A and VA need to establish a architecture that secures comprehensive distribution



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Availability on technology???

- A quote from a project manager in SN Power
- “To plan a project in Nepal is the same as planning for a project on the moon!”
- Availability on High-Tech equipment, state-of-the-art technology may lack!
- There is a wide gap on availability on technology and know-how
- The sprayed concrete industry has an important role to play to disseminate technology
- And understand local limitations





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Technology development

- A collection of state-of-the-art shotcreting jumbos anno 2011
- No doubt that technology development has reached high levels on spraying jumbos
- But elsewhere??



By AMV



By Normet



By Meyco



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Technology development

- Has there been any technology development in sprayed concrete?
- Do we spray the same product with increased capacity?
- In increased thickness?
- Or in small distinct steps, one by one
- Do WE see any 'Moonlanding' in technology development for sprayed concrete?



> 40 years have elapsed since the US landed a man on the moon




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Technology development

- Do we see a future fundamental change in course or just an adjustment?
- Norwegian public roads administration turns to cast-in-place concrete lining as inner lining (water&frost protection)
- Europe seems to experience a trend towards increased application of sprayed concrete SCL
- Where do WE want to go?
- Do WE have ambitions to conquer the tunnelling industry
- Replace cast-in-place by sprayed concrete fully





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Technology development

- Materials & Material technology (same recipe)
- Application of sprayed concrete (new and existing)
- Durability & life cycle considerations (50, 100 yrs!?)
- Additives (improve workability and HSE)
- Fibres (steel and plastic)
- Equipment (jumbos)
- Basic understanding (always something to learn)
- Sustainability, CO2 foot print (a key aspect today)




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Future trends and applications

- Norway is looking at future road tunnels being cast-in-place lined
- Whilst; growing interest of SCL in Europe
- Not necessarily with thin layers of sprayed concrete, actually more often 20-30cm thick layer
- But most important:
- **HIGH QUALITY SPRAYED CONCRETE**
- **AND CAREFULLY DOCUMENTED!**





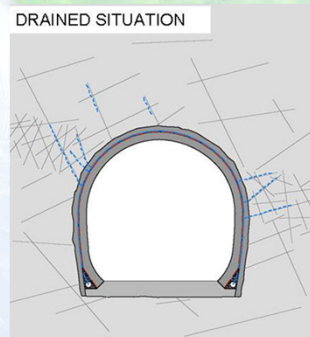
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Understanding of important mechanisms

- Who knows and who can document what takes place behind the sprayed concrete?
- Water pressure build up, or not?
- I think and a lot think they know
- But there is no hard fact, or scientific documentation on this
- It is a serious lack of knowledge if we are not able to document the behaviour



Ill. by Holter



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How to improve OUR competitiveness!

- High technology solutions
- Effective utilization of available resources
- Human resources; skilled and professional
- Equipment and products
- Incite for developments
- Intelligent and practical solutions
- Well defined and expressed specs to life cycle and functional requirements
- Focus on the final product
- Cooperation at site is a must to succeed
- Quality and communication





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Quality and reputation

- No short cuts
- Clients need to know their requirements
- Designers/consultants need to know the aim of sprayed concrete and specify the final product
- Contractors need to know to produce the work
- Suppliers need to know the demands of the industry
- Follow-up need to know how to secure quality
- Communication/dialogue/gatherings/ITA-EFNARC



GETTING THE BEST FROM SPRAYED CONCRETE



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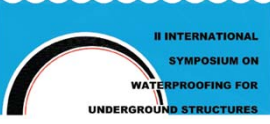
NEW

SCL in Cross-rail, the article reports

- Soft ground conditions
- Largely applied SCL for 14 km of station platform tunnels, cross passages, crossover caverns, Central stations for 5 lines
- Proved that SCL is a viable method in soft ground
- Under a densely populated and developed city without causing undue settlements
- Big step forward in confidence
- It is safe, efficient and reliable and lends itself to architectural curves



Crossrail's
SCL lessons
learned



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NEW

SCL in Cross-rail, the article reports

- The primary lining has been integrated into the permanent works, whereas earlier it was usually a sacrificial part of the permanent works
- It provides load sharing in the long run, based on steel fibre reinforced sprayed concrete
- It meets the design life expectancy of 120 years
- Works completed without any major problems
- Application of sprayed waterproofing membranes has moved on during the project
- What does this tell us? That SCL has become a reliable product, given that quality is assured



Crossrail's
SCL lessons
learned



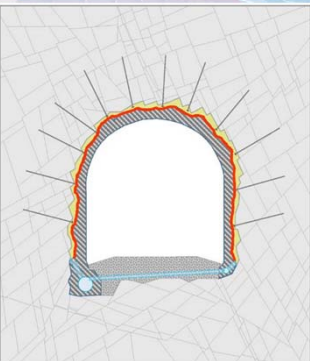
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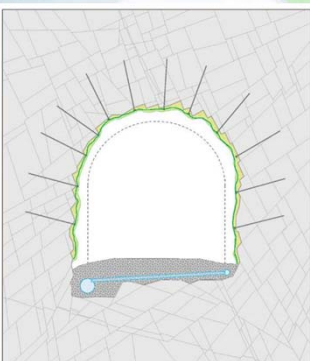
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NEW

Sprayable membranes




V
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S




Cast-in-place concrete lining with drained sheet waterproofing

Rock support lining based on sprayed concrete and rock bolt made permanently waterproof with sprayed membrane

ill. by Holter



The Gevingås rail tunnel (2010-11)
The Holmestrand rail tunnel (2015)




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NEW

Sprayable membranes




Rock mass

Rock support by sprayed concrete

Membrane EVA-based (etyl-vinyl-acetat)

Cover by sprayed concrete

ill. by Holter



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NEW

Sprayable membranes

A PhD-work by Karl G. Holter in Norway suggests that:

- Sprayable membranes work as intended, water tight but allows moist diffusion
- Restricts water flow on cracks and imperfections
- Impossible to exactly define a life time assessment
- Requires improved contour blasting, pre-grouted zone around the tunnel, fiber dosage to reduce cracking
- In the mean time membrane technology develops and new products become commercial
- All in all; decent alternative when circumstances are right



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- Do you have ideas and thoughts that you would like to share with the international tunnelling society on sprayed concrete use?
- Please share these with us, join the WG 12 and if needed contact the following:
 - Stefan Bernard at s.bernard@tse.net.au
 - Nikolaos Kazilis at nka@geodata.it
 - Eivind Grøv at eivind.grov@sintef.no
- OR; contact your local tunnelling society or Eng Cassio Luis Abeid Moura who is appointed CBT contact with WG12



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WG 12: An arena for professionals in the field of sprayed concrete technology

WG 12: Promoting application of sprayed concrete as permanent lining and documentation

Wishing you a successful conference here in Sao Paulo and hoping to see you all again in WTC 2016 USA or elsewhere to learn your experience on sprayed concrete





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THANKS



Geneva meeting
WTC
2013
(all time high participation)

Welcome to join us, in a friendly, international and professional environment sharing technical up-dates



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