Shotcrete for rock support
A summary report on state-of-the-art

ITA Working Group N°12
"Sprayed Concrete Use"

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>> PRESENTATION

The International Tunnelling and Underground Space Association (ITA) Working Group 12 on Sprayed Concrete Use decided, in its meeting held in Durban in May 2000, to produce a State-of-the-Art Report about the current states of shotcrete technology in different countries. This report is the result of that task. This is a revised version of the report first published in November 2007.

This printed report is the first part of the full report. It contains the summary prepared by the Working Group itself from the contributions of the ITA Member Nations. These contributions can be found on the ITA web site (www.ita-aites.org).

The report has been produced by compiling information requested to the ITA National Groups under the coordination of Knut Garshol, Animateur of the Working Group 12 during the period when it was produced.

ITA would like to acknowledge all those people who have been participating in the work of Working Group 12 during these years of preparation of the report, including Tutors, Animateurs, Vice-Animateurs, national correspondents and representatives, all have contributed to the materialisation of this report.

>> Foreword

The task of compiling a State-of-the-Art report on shotcrete for rock support, based on contributions from ITA member nations has offered some challenges, especially in terms of extracting clear trends. The task has also been very interesting since a number of excellent papers were submitted. The Report content will speak for itself and even though a number of important shotcrete-using countries have not participated, we still hope some useful information can be found in the Report.

Through working on compilation of the Report and via general professional contact with the subject of shotcrete for rock support, it is possible to reflect on some important aspects of shotcrete use in tunnelling. These thoughts, as presented below, have not been discussed within WG 12 and should be seen as an open contribution aiming at "food for thought" and further discussion among specialists.

The rapid technological development that we have seen during the last 10 years is quite impressive. If asked 10 years ago, few engineers would have expected that alkali free accelerators could take over to the extent we see today. Structural polypropylene fibres, today offering an alternative to steel fibres and steel mesh, was also not expected by many at that time. In addition, we have now set-control products and the last generation of water reducers, allowing much lower water content at high concrete fluidity. A well recognized university academic stated some 10 years ago, that there was no more development potential in the wet mix method. The future belonged to improvement of the dry mix application. Reality has shown how difficult it is to predict the future.

Fibre reinforcement has been proven to offer substantial advantages in comparison to normal steel mesh (typically about 5 to 7 kg/m^2 with mesh openings of 100 to 150 mm), especially when used with the wet mix method. It is possible to outperform the mesh in terms of failure energy and actual load carrying capacity and at the same time avoid compaction problems, corrosion problems and difficult and time consuming handling. With this number of advantages using fibre reinforcement, it is a surprise to still see so much work execution with mesh reinforcement.

It is not the intention to overlook dry mix shotcrete. This method has its own set of advantages that are decisive in selecting it for many practical situations. However, because of the also existing disadvantages, the lion's share of the shotcrete volume for rock support will increasingly be done by wet mix application. There is no need for strong feelings in this regard, since the market decides which way to go, irrespective of individual opinions.

In this context, it should be noted that the principle of thin stream transport (by compressed air) seems to offer some serious disadvantages. The single most important negative aspect is the surplus of compressed air in the concrete jet. This air has to evacuate sideways at the moment of concrete impact on the substrate and the air pulls a lot of fibres out of the mix, along with increased concrete rebound and dust. It increases the cost of placing fibre reinforced shotcrete quite substantially and makes it more difficult to ensure uniform quality. Combination with wet mix concrete does not change these basic problems of the thin stream transport principle.

The acceptance of shotcrete for permanent linings is still today facing obstacles caused by the previous standard approach of using shotcrete exclusively for temporary support. Since shotcrete was defined as temporary, the requirements were lax and quality control had a low priority. It is sometimes claimed that concrete placement by spraying (shotcrete) will produce highly variable and low quality concrete (that is not suitable for permanent structures). Of course, any project will get a low quality variable product if that was actually specified. This is, however, not proof that a better quality cannot be achieved. On the contrary, the technology is available and today high quality and durable shotcrete is the norm and just a matter of decision-making and specification.
The fact that use of permanent shotcrete linings is increasing, does not automatically ensure that everything is in good shape. One of the problems that need more attention is the durability of the structure, in addition to considering the shotcrete material itself.

The designer will frequently decide to supplement the shotcrete shell with other support elements. The typical lattice girders and also steel sets (H-beams) regularly cause poor compaction of the shotcrete along the "shadow" side (seen from the shotcrete nozzle side). When this happens, ground water may infiltrate these channels and strips of humid shotcrete surface can be observed in the position of the arches. In a permanent lining structure, this is not a satisfactory result, as the steel members will corrode with time and eventually the cover shotcrete will spall, further increasing the rate of reinforcement corrosion.

>> Foreword

One possible reason for such poor results is the sometimes very strict requirements on high early strength. When spraying to incorporate lattice girders and steel sets, it is necessary to keep the dosage of accelerator low, to allow concrete workability for some seconds after impact. This will help a lot in improving the compaction. Without proper compaction, the problem is not only corrosion, but also the substantial and not quantifiable reduction of load-carrying capacity.

In many cases the lattice girders or steel sets are not structurally necessary and there are, as mentioned, very good reasons not to use them in the first place. Rock bolts or rock anchors may often quite economically and safely replace the girders and steel sets and the corrosion problems can thus be easily avoided. If arches are used for control of the excavation line, final shotcrete thickness and final surface shape, it must be noted that there are other ways of achieving this.

The Report shows that in many projects worldwide the nozzle operation has been mechanized. There are many good reasons for this and probably the most important ones are health and safety.

In many cases, the health and safety authorities should consider requiring the application of fibre reinforced shotcrete by remote controlled hydraulic manipulator. When excavating split face openings in very poor ground, followed by manual erection of lattice girder or steel set plus mesh reinforcement, people are put at risk. This is frequently done even before any shotcrete application, or after an initial thin layer of handsprayed shotcrete. This approach is typically exposing 4 to 5 persons for 3 to 4 hours to unnecessary risk. Why, when the whole operation can be done much faster without a single person being at risk at any time by simply using a manipulator and fibre reinforced shotcrete.

Another interesting subject is shotcrete sulfate resistance. Under given conditions, the designer may want to ensure a high degree of sulfate resistance for the shotcrete support. The most frequently specified measure is to use low C_3A cement, or so-called sulfate resistant cement.

What is mostly not considered is that such cements are very slow reacting and they are also not very reactive with accelerators. Often ground conditions require shotcrete to reach high early strength and this is not very compatible with low C_3A cements. The result is that safety may suffer due to less than optimal early strength and in addition, the accelerator must be used at high dosage. This will produce poor final quality, high porosity and therefore a low sulfate resistance, in spite of the special cement. Much better overall quality and safety can be achieved with normal cements by ensuring a very low w/c-ratio (< 0.40), low dosage of alkali free accelerator and some micro silica in the mix. Highly sulfate resistant shotcrete has been sprayed this way, without the safety issues and quality problems of low C_3A cement.

The Report is the result of a team effort, where active members of WG12 and the people behind the country report submittals have done the main part of the work. Jindrich Hess has been the WG12 Tutor during the Report work period and he and other members of the Executive Council has provided helpful review of the Draft Report. To avoid the risk of leaving someone out, no further names will be given. It has been a pleasure to work with everyone who contributed in one or the other way, making the final Report possible and the recognition belongs to everybody.

Miami 29 Nov. 2004
Knut F. Garshol
Animateur WG 12

1. GUIDELINES, SPECIFICATIONS, STANDARDS

As could be expected the different countries and regions adopt a variety of local and international codes, standards and guidelines for shotcrete application. The EFNARC specification and also the Austrian Guidelines have a good international recognition, along with parts of ASTM, Norwegian Guidelines and Japanese Guidelines.

One important recent addition is the Australian Round Determinate Panel test for failure energy testing of fibre reinforced shotcrete. The driving force behind this new method is Dr. Stefan Bernard. The method has now been published as ASTM C 1550.

2. DESIGN

Today more than before, the common understanding is that most shotcrete usage entails rock reinforcement rather than rock support. How to design rock support is in any case a very complicated subject and this understanding is not making it easier, only changing the way to approach the problem.

The contributions from different countries illustrate well the widely different views on rock support design. This becomes especially evident when comparing the sometimes over-conservative cast in place concrete linings with what evidently is satisfactory support under similar conditions using shotcrete. There are many examples of thickness reduction from about one meter cast in place down to 10 to 15 cm of shotcrete. The use of empirical systems like Barton's Q-method is one way of approaching the design problem in a structured manner. In any event, it appears that an observational approach, supported by other methods as needed, is the way to go.

It is a matter of system-understanding, where not only shotcrete and rock are involved, but also rock bolts, lattice girders, steel beams and other sorts of reinforcement depending on the actual case.

3. CONCRETE TECHNOLOGY

Australia is reporting that alkali free accelerators have more or less completely taken over the market both in civil construction and in mining. The reasons are health and safety requirements as well as performance results. It is also customary to use set-regulating admixtures and high range water reducing admixtures, since a combination of low w/c-ratio and high fluidity is normally targeted. There is some focus on finding alternatives to micro silica, due to high cost of this additive. The Belgian contribution deals with the concrete mix requirements when using steel fibres. The target is to create a best possible bond between fibres and the concrete matrix and in high quality concrete mixes, this will require a high tensile strength of the steel fibre material.

Czech Republic is reporting on concrete technology for wet mix shotcrete and the approach is very much up to normally applied European practice. Early strength is tested according to the Austrian Guidelines and will mostly meet the J2 requirements. Durability requirements are specified on a case by case basis.

In Italy the wet mix method already covers 98% of all shotcrete applied, like in a few other countries, but the fact that about 95% of the accelerator use is Na Si O2 «waterglass» is a very special situation. The reason has been stated as low cost and availability. However, it can be added that after the time of submittal of the Italian contribution, there has been a strong increase in the use of alkali free accelerators. In addition to investigations about set control and water reducing admixtures, Italy has also been working on special types of cement. The target has been to reduce the dependency on admixtures and expensive additives like micro silica.

The shotcrete market in Japan seems to be strictly regulated and application is either carried out as so-called normal shotcrete (18 MPa 28 day compressive strength) or as high strength shotcrete (36 MPa 28 day compressive strength), the last version may be used with fibre reinforcement. Accelerator is generally in powder form, even though some use of liquid products has been reported. Set control and water reducing admixtures are used on a regular basis.

Lesotho is presenting a detailed account of the requirements and the control system used at the Lesotho project. Wet mix and alkali free accelerator was a requirement and the whole regime as described in detail, reflects the targeted high quality end result.

The Norwegian contribution describes the change from silicate accelerators to alkali free and the effects of high range water reducing admixtures. Investigations showed that the strength gain reached after 3-4 hours with silicates could be achieved immediately (at end of application) by the modern systems. Also, dust exposure was reduced and the ability to cope with wet conditions was improved. Tests with the use of re-circulated aggregate in shotcrete is described and the results are very encouraging, with compressive strength exceeding 45 MPa.

South Africa presents a very advanced stage of wet mix application for a mining shaft. To reach the required 60 MPa strength, 1000 J Efnarc failure energy and 60 year service life, a full set of State-of-the-Art measures were adopted. About 7500 m^3 were successfully applied under very wet conditions.

Sweden presents the concrete technology issues for the Southern Link highway tunnels in Stockholm, where again the requirements were very demanding and strictly controlled. Extensive pre-construction testing was carried out with products from several different suppliers. One of the important parameters to control was the required freeze thaw properties. More than 30'000 m^3 have been applied and more than 200 tests carried out for control purposes. The results have met the strict requirements with only small variations. Turkey is presenting a very interesting comparison of shotcrete mixes based on use of alkali free accelerator and silicate accelerator as used and tested at the Bolu project. The details can be found in the Report, but the highlight is may be that not only is the compressive strength of the silicate accelerated shotcrete seriously lower than when using alkali free, but the quality further deteriorates from 28 days to 1000 days.

Photo 1: Wet mix sprayed concrete for tunnel lining, nozzle in action, in the city of Campinas, Brazil.

Photo 2: Tests for qualification of the sprayed concrete used in the tunnels.

Photo 3: Measurement of early age strength of sprayed concrete.

4. EQUIPMENT AND APPLICATION METHODS

The contributions cover traditional dry mix thin stream shotcreting, as well as thin stream wet mix, dense stream wet mix and wet mix using dense stream the first part of the conveying distance and thin stream the last part. Accelerators are available both in powder and liquid form.

The development away from thin stream to ordinary wet mix dense stream is evident from the contributions received and by comparing with the previous WG12 State of the Art Report.

In Australia, practically all wet shotcrete applied in mines and in civil tunnelling projects is done by robotic shotcrete equipment. Most robotic shotcrete equipment has facilities to monitor the dose rate of accelerator that is being applied.

Shotcrete usage for mining in Canada shows a shift from dry mix materials and shooting methods towards wet mix with many operators using dry mix material supply with wet mix shooting. The development into wet mix fibre reinforced boltless shotcrete, especially within INCO in the Sudbury Basin is part of a rapid increase in the use of robotic shotcrete application and even computer controlled or computer assisted placement of shotcrete in Canada. The majority of the shotcrete is still being placed by dry mix equipment.

In the Czech Republic dry shotcrete is still dominating, but especially for traffic tunnels and other objects requiring high volume shotcrete application, the wet mix is now taking over, using modern equipment like the rest of Europe.

Germany has seen a rapid change from dry mix into mechanized wet mix shotcrete application, specifically is mentioned the output increase from typically 8 m^3/h to 20 m^3/h and the reduction of dust and eluates (which was previously a problem).

In Italy, most of shotcrete (98%) is applied by the wet process. The reasons for this according to the preference given by the Italian building companies and designers are:

- the composition of the mixture can be controlled with certainty
- the wet process produces less rebound
- higher concrete output
- the wet process produces a very small quantity of dust

Photo 4: Robotic shotcrete equipment (©Normet).

Photo 5: Concrete spraying, wet mix method.

• difficult to find nozzlemen who are able to operate the dry process
• the machinery manufactured in Italy for pumping and spraying of shotcrete is exclusively designed for the wet process;
• industrial-safety norms are very strict in Italy, and in the safety plans the use of manipulators is imposed. These manipulators are at present only produced for the wet process. (Emphasis added).

Japan has a special situation on the equipment side. Almost all the huge quantity of more than 2 mio m^3 of shotcrete per year is placed by the wet mix method. What is special, is the extensive use of thin stream concrete conveyance for the last 10 to 15 m up to the nozzle. This technique is frequently combined with the addition of powder accelerator also transported by compressed air. The current Japanese focus and legislation to reduce dust levels may be partly linked to this special situation.
Both Korea and Lesotho are reporting the use of wet mix (Korea since 1995).

In Mexico the dry mix method with manual nozzle operation is still dominating. However, both manual and robotic wet mix is now increasingly being used.

Norway is reporting that wet mix robotic spraying was in use from the beginning of the 1970s. From about 1980 practically all shotcrete has been placed by the wet mix method using robotic equipment of the last generation all the time.

In South Africa the large volumes of shotcrete are linked to deep level mining. Difficult logistics and small openings will have the effect that dry shotcrete, manually applied will continue to have a dominant position. Still, the described examples of wet mix usage show that also this sector is well advanced and some very successful projects have been executed. Some applications are using robotic equipment.

Both Sweden and Switzerland are describing the use of modern integrated robotic equipment for shotcrete application, including dosage systems for accelerator. In both countries this is now the standard approach for larger projects.

Photo 6: Concrete spraying, wet mix method, and arch installation.

Photo 7: Application of the wet mix sprayed concrete in the Komorany road tunnel in the Czech Republic.

5. METHOD OF REINFORCEMENT

It is already clearly documented by research as well as in practical applications and accepted by most shotcrete rock support specialists that proper fibre reinforcement can replace normal welded wire mesh.

One possible problem with fibres is the question mark on [lack of] reinforcement continuity through construction joints. A substantial contribution to remove this question mark was presented at the Fourth International Symposium on Sprayed Concrete in Davos, Switzerland, September 2002 by J-F Trottier [4]. The conclusions are very clearly in favour of fibres where joints are involved, compared to the use of mesh.

In Australia, the rapid increase in usage of structural synthetic fibres compared to steel fibres and mesh has been significant the last 4 years. A widespread adoption of steel fibres developed during the 1990's, especially within the civil construction industry; the rate of acceptance was somewhat slower in the mining industry. However, the emergence of high performance structural synthetic fibres that have proven an effective form of reinforcement for shotcrete at the high levels of deflection typical of mine roadway development has promoted acceptance of this type of fibre within the mining industry. SFRS was used for permanent support at the Eastern Distributor and the M5 East tunnels in Sydney. They were all permanently lined by SFRS.

In Brazil fibre reinforced shotcrete has been widely used recently. This is a new trend, as mesh has been almost the only reinforcing element until recent years.
For the tunnels of a sample of 5 hydroelectric schemes under constructions steel fibre reinforced wet mix shotcrete is being used in 4 (tunnel spans ranging from 15 to 17 m), and mesh is being used in one case (8-m tunnel span).

Belgium highlights that the traditional wire mesh is difficult to fix and it takes a lot of time. Job data have shown that installing the mesh lasts 3 times longer than shotcreting the same surface. The continuously changing position of the reinforcement within the shotcrete lining does not at all guarantee a uniform tensile capacity.

In Canadian mining industry there is a rapid increase in acceptance of steel fibre reinforced shotcrete for mine support. A good illustration of the confidence placed in this technology is the fact that the use of boltless shotcrete support is also increasing (using a shotcrete thickness of typically 60 to 100 mm).

Czech Republic and Denmark are still primarily using mesh reinforcement, but the Czech Republic describes the use of fibres for special cases.

Photo 8: Steel fiber reinforced shotcrete being applied as primary support.

In Italy about 30 % of the shotcrete produced contains fibre reinforcement (out of 115'000 m^3 shotcrete in 2000). The reasons for the increasing use of fibres and the acceptance from designers to introduce the fibre reinforced shotcrete were the following:

- labour saving in comparison to welded mesh
- less rebound
- a reduction of the thickness of the applied shotcrete

Japan produces an amazing about 2'100'000 m^3 of shotcrete per year. About 2.4% or 50'000 m^3 is currently executed as fibre reinforced shotcrete.
Since 1995, in Korea the design of rock support in road tunnels has changed to wet shotcreting with steel fibre using robot application. The contribution from Lesotho is also describing the use of steel fibres.

Mexico is highlighting the problem linked to fibre reinforcement in dry shotcrete caused by high fibre rebound. Because of this, also in Mexico the development now shows increase of wet mix and further increase of fibre reinforcement.

Norway has been using steel fibre reinforcement in shotcrete since the early 1980s. All kinds of steel mesh are practically excluded from shotcrete for rock support. Most tunnel projects use high quality robotically applied steel fibre reinforced shotcrete and corrosion protected rock bolts. Cast concrete linings are not used unless rock conditions are exceptionally poor and concrete is needed locally for stability against squeezing or swelling rock.

South Africa is using shotcrete in deep level mining. With the high loads and rock burst situations encountered in these mines fibre reinforcement has been seriously investigate in research and also used in practical cases under ground. Research on fibre reinforced shotcrete has been executed both for static loading and for the rock burst situation, starting in 1994 and ongoing for more than 5 years.

Extensive testing of fibre reinforced shotcrete, both steel and synthetic fibres and for both static and dynamic loading shows very well that fibres are an adequate alternative also under very demanding conditions. Under repeated dynamic loading the shotcrete support should be combined with wire lacing.

Both Sweden and Switzerland are describing the use of fibres in shotcrete for rock support. The Swiss contribution is highlighting the improved safety of robotic shotcrete application where the reinforcement is mixed into the concrete (no personnel under unsupported ground to fix a mesh). Also a 30% reduction in time for rock support installation was given.

In Turkey the 18 m diameter Bolu highway tunnel used both mesh and steel fibres in the shotcrete rock support.

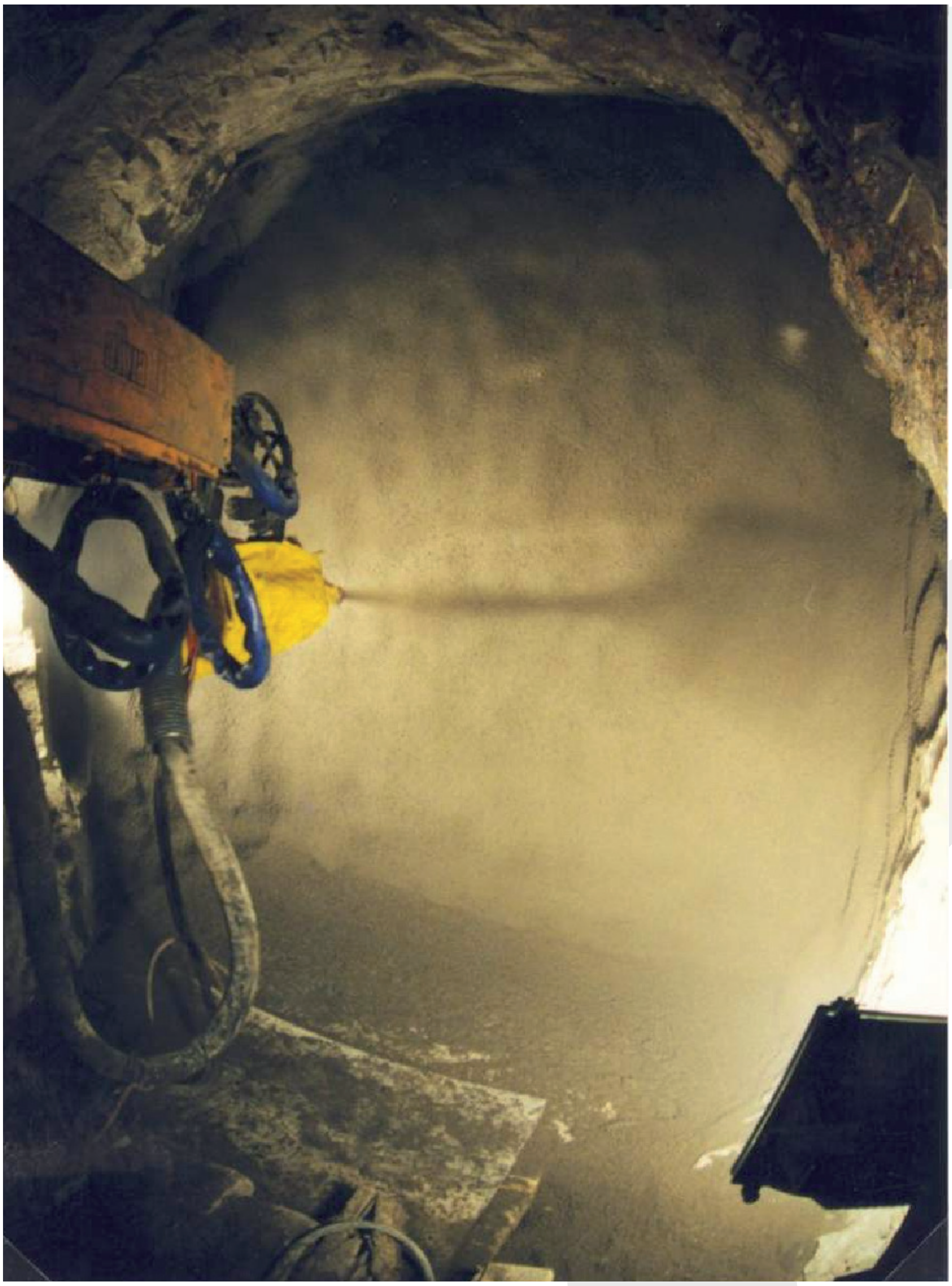

Photo 9: Application of steel fibre reinforces sprayed concrete in the gas reservoir Pribram – Haje in the Czech Republic (photo Vaclav Braun).

6. SHOTCRETE FOR PERMANENT LININGS

The use of permanent shotcrete linings has been increasing rapidly, even though it is not a new solution for tunnel linings. Already in 1985 John Sharp wrote the following in the conference summary note for Shotcrete for Underground Support V – Uppsala, Sweden [1]: "The increasing use of shotcrete as a final lining for machine caverns, transportation tunnels and the lining of waterways, has been emphasized."

Brazil reports from the mid 70´s about substituting the planned 1.5 m thick heavily reinforced cast in place concrete lining of the 26-m span Paulo Afonso IV Underground Powerplant with a shotcrete lining. Substantial savings were achieved when 15-cm shotcrete lining was adopted instead. At the same time railway tunnels were being constructed with 40-cm cast in place concrete lining, some of which with geology similar to that of the powerplant. In the early 80's the first NATM tunnels were constructed for the São Paulo Subway, with shotcrete as permanent lining. Specifications were written at the time with tight criteria for porosity, permeability and electrical resistivity, with the purpose to reach durability. Recent inspections of those tunnels have shown that the shotcrete is in good shape.
The West section of the São Paulo ring road includes 3 twin tunnels with large cross-sections (200 m² for four lanes in each direction). Permanent shotcrete linings were adopted. This decision was taken during construction due to problems of meeting the schedule and budget in case cast concrete had been adopted.

The Czech Republic is already using shotcrete for permanent lining in utility tunnels and also optionally in sections of traffic tunnels.

Lesotho reports about final lining shotcrete for a 5.6 km long raw water transfer tunnel. One of the reasons for this solution was to resolve delay problems.

The Norwegian Public Roads Administration carried out a comprehensive control of shotcrete linings in road tunnels. The investigations clearly conclude that the condition of existing shotcrete is generally good. At some spots with thin layers (less than 30 mm) deterioration and delamination had nevertheless taken place and a minimum of 60 mm thickness is recommended. Even sections of sub-sea road tunnels with permanent salt water ingress and chloride saturation, showed no corrosion problems where steel fibres had been used.

Also Russia gives examples of permanent lining shotcrete for Metro and road tunnelling.

Photo 6: Final lining shotcrete for T-Centralen Station, Stockolm Metro.

7. HEALTH AND SAFETY

There are two main aspects that the contributors point at within this sector:

- Dust development and workers health
- How to avoid injury or death from falling rocks

The three contributions received on this subject are all comments to the above mentioned bullet points.

8. OTHER ITEMS

The subjects covered under this heading range from terminology, ambient temperature conditions, Italian national group activity to the effects of dynamic loads from blasting close to the applied shotcrete.

Especially the last subject deserves special note, since the subject is frequently being discussed with very little factual information. The Swedish contribution is giving some very good information within this aspect of shotcrete application and drill and blast excavation. After 24 hours, shotcrete could resist vibrations up to 500 mm/s. Tests done in the Southern Link tunnel gave vibrations of less than 80 mm/s, as close as 5 m from full blasting rounds at the tunnel face.

9. REFERENCES

[1] "Shotcrete in Tunnelling. Status Report 1991" by International Tunnelling Association Working Group: Shotcrete Use, Animateur T. Franzen, published by Swedish Rock Engineering Research Foundation, 1991.

[2] "Shotcrete for Rock Support. Guidelines and Recommendations – A Compilation" by International Tunnelling Association Working Group: Shotcrete Use, Bo Malmberg, published by Swedish Rock Engineering Research Foundation, 1993.

[3] "Shotcrete for Rock Support: a Summary Report on the State of the Art in 15 Countries" by International Tunnelling Association Working Group: Shotcrete Use, Bo Malmberg, published in Tunnelling and Underground Space Technology, Vol 8, No 4, 1993.

[4] "Influence of Construction Joints on the Flexural Performance of Fibre and Welded Wire Mesh Reinforced Wet mix Shotcrete Panels" by J-F Trottier, D. Forgeron and M. Mahoney, Proceedings of the Fourth International Symposium on Sprayed Concrete, Davos, Switzerland, 22-26 September 2002.

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