

# **ITA/AITES REPORT 2006 on**

## **Shotcrete for rock support**

### **A summary report on state-of-the-art**

**presented by ITA Working Group N°12 "Shotcrete Use"**

## **PART A – REPORT FROM THE WORKING GROUP**

February 2006



## 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

## ITA REPORT - WG12 : SHOTCRETE FOR ROCK SUPPORT

Austrian Guidelines and will mostly meet the J<sub>2</sub> 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 O<sub>2</sub> "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<sup>3</sup> 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<sup>3</sup> 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.

#### 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<sup>3</sup>/h to 20 m<sup>3</sup>/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
- 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<sup>3</sup> 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.

## ITA REPORT - WG12 : SHOTCRETE FOR ROCK SUPPORT

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.

### 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

## ITA REPORT - WG12 : SHOTCRETE FOR ROCK SUPPORT

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.

In Italy about 30 % of the shotcrete produced contains fibre reinforcement (out of 115'000 m<sup>3</sup> 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<sup>3</sup> of shotcrete per year. About 2.4% or 50'000 m<sup>3</sup> 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

## ITA REPORT - WG12 : SHOTCRETE FOR ROCK SUPPORT

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.

### 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 m<sup>2</sup> 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.

## 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.

The French tunnel association, AFTES, through its working no. 20 on shotcrete has prepared a recommendation for the design of “Sprayed Concrete for Underground Support”. Their report presents the recommendations prepared by the local working group for the design of sprayed concrete used in tunnels and underground openings. Version 1 of the document was approved by the Technical Committee of AFTES on November 9<sup>th</sup> in 2000. The French working group was lead by Eric Leca as Chairman,