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.

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
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