THE USE OF STEEL FIBERS AS REINFORCEMENT FOR UNDERGROUND CONCRETE STRUCTURES

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1. The underground offers the space which mostly is not anymore available on surface.

   Urban traffic is saturated and rapid mass transport is only possible with a good underground metro network.

   Service facilities require a dense network of pipes to bring fresh water into the cities and a dense network of sewers to evacuate the waste water to the water treatment stations.

   Communication, being the main characteristic of our present world community, needs an extensive network of cables and service stations.

   The required space is only available under surface level.

   Cities can be linked through air connections but saturated air space, overcrowded airports and lack of comfort in most of the aircrafts do not offer the business people the possibilities of a useful use of their travelling time.

   The construction and the extension of the high speed railway network in Europe and Japan proves to be successful and will be connecting soon most of the European main cities even faster than air travel can do.

   Also heavy traffic is being taken off the road mainly in mountaineous areas where winter conditions are prohibitive for fast transport during part of the year. The two most spectacular examples are the two long Alp Transit tunnels in Switzerland: Gothard (57 km) and Lötschberg (39 km). Also Lyon – Torino is expected to be realized soon and includes a 52 km long railway tunnel.

   The use of natural ressources such as hydropower and the excavation of minerals from the mines require the construction of impressive underground constructions.

The modern industrial principles do not only need a fast data communication system but also an efficient transport to get the goods on the right time on the right place. There still is a lot to be built and to upgrade in order to realize an efficient infrastructure.

2. The use of the underground used to be a very expensive solution but has proven in the last 25 years to become the most efficient way of solving problems.

Development of modern tunnelling techniques, construction materials and skilled mining people have highly influenced the attractiveness of the underground building technology.

One of the main breakthroughs was the change in mentality when designing a tunnel. Observational methods, such as N.A.T.M. (New Austrian Tunnelling Method) and N.T.M. (Norwegian Tunnelling Method), are strengthening the underground to become self supporting instead of supporting the rock mass above the tunnel opening.

This of course made it possible to build underground constructions in a much more economical way and much faster than what was done in the past. This, however, made it necessary to develop new tunnelling equipment and adapted building materials. And of course trained people to build the tunnels. This human factor, still today, sometimes remains a critical issue.

3. Depending on underground conditions, rock quality, overburden, tunnel diameter and length, ground water level, a tunnelling method has to be selected using or manual or mechanised excavation.

Manual excavation includes drill and blast and/or the use of a roadheader. Depending on the tunnel parameters the tunnel cross section will be excavated in one operation or in different steps. In the last case, more temporary linings will be required to stabilise the underground at any moment.

Mechanised tunnelling, however, is cutting the full cross section in one operation. Important and spectacular progresses have been made in the field of Tunnel Boring Machines (T.B.M.) being used in a wide variety of ground and rock conditions and for very large diameters.

Up to now the record is held by the 4th Elbe Tunnel in Hamburg having a diameter of 14,56 m using a Herrenknecht mixed shield TBM. But larger tunnels are coming up soon and it can be expected that the race between East and West for the largest tunnel diameter is going on for quite some time.

The main parameters, however, driving the tunnelling method selection are speed and safety, resulting mostly in the economically most attractive solution.

4. Tunnelling methods using the manual excavation technique are still being used to build most of the underground constructions. This method offers a high degree of flexibility both in easy and also in difficult ground conditions. This of course is a major advantage in a heterogeneous underground where ground conditions may change even within short distances.

Tunnelling experience and understanding of the ground conditions allow to apply the correct support system in each point depending on local parameters. Constant monitoring is an essential part of modern tunnelling and indicates if the underground has been stabilised after applying the selected support system.

Modern tunnelling mostly uses rock bolting, reinforced shotcrete and steel arches, or a combination of two or three of these techniques, in order to create inside the rock surrounding the excavated tunnel opening a new equilibrium forming a self supporting arch.

The cycle comprises blasting or roadheader excavation, mucking and stabilisation of the rock. It is important to stabilise the rock as soon as possible after it has been disturbed by building the tunnel opening. Safety of the whole operation can be strongly enhanced by applying a reinforced shotcrete layer before sending mining people inside the newly built opening.

Shotcrete has become a standard technique and is used as a major tool to stabilise the rock in the early stage of the tunnel construction.

Shotcrete has a double effect: it glues the loose pieces of rock together forming a continuous outer shell and it develops strength in order to control and support the rock in it's early movements. Both effects contribute to create a new equilibrium and to help the rock to become again self supporting.

It is important that this shotcrete layer can be applied before someone of the tunnelling crew members has to enter the new opening as loose pieces of rock still can fall down. The use of a remote controlled robot allows to apply the shotcrete layer in safe conditions from outside the dangerous area of falling blocks and not exposed to the rebound of the shotcrete material.

Plain shotcrete like also concrete does, however, is a very brittle material which can hardly absorb any deformation. It needs to be reinforced in order to cope with tensile and flexural stresses. In fact the shotcrete layer has to be able to control the underground movement which actually has to result in a new equilibrium where the rock again is self supporting. Hence not the shotcrete strength, to <u>support</u> the soil, is the most important materials's characteristic but it's ductility in order to make the rock <u>self supporting</u>.

Shotcrete is brittle and has to be properly reinforced in order to become ductile and tough.

Steel still is the most common and most reliable and durable material to strengthen concrete. The effiency and compatibilty of the composite concrete and steel have been proven in reinforced and prestressed concrete.

Traditional wire mesh is difficult to fix to the irregular substrate of the blasted or excavated cross section. Also this meshing operation takes a lot of time. Job data have shown that installing the mesh lasts 3 times more than shotcreting the same surface. The continuously changing position of the reinforcement within the shotcrete lining doesnot guarantee at all a uniform bearing capacity.

Even more than the lack of an efficient technical performance is the risk for accidents when installing the mesh on the freshly exposed rock surface. Mining people has to work in very difficult and unprotected conditions.

Steel fibers have proven to be a more modern and technically better solution. Steel fibers are added as one more aggregate to the shotcrete mix, both wet and dry, and mixed together with the other shotcrete constituant materials. Steel fiber reinforced shotcrete is applied using standard equipment and when using a robot a reinforced lining will be in place before any miner has to enter the new opening, which has a major impact on the safety of the tunnel job.

Steel fiber reinforced shotcrete's main technical advantage, however, is it's high degree of ductility. Being able to absorb important movements without loosing it's bearing capacity it helps the underground to stabilise in a controlled way.

Ductility, however, is not a common characteristic for a usually brittle concrete. An appropriate test method to determine steel fiber reinforced shotcrete's ductility has been developed and proposed by SNCF / Alpes Essais (France). This test method has been approved by EFNARC and will also be included in the new European Standard on Sprayed Concrete, which is expected to be published in 2001.

Based on this test usually three steel fiber reinforced shotcrete classes are being defined:

500 Joules	for sound ground conditions
700 Joules	for medium ground conditions
1000 Joules	for difficult ground conditions.

Steel fiber reinforced shotcrete is the standard for primary linings as it allows to build a ductile support in safe working conditions quite immediately after excavation.

5. Tunnels still mostly are built using the double shell concept: a primary stabilising lining of steel fiber reinforced shotcrete and a final lining mostly of plain cast concrete. In between a waterproof membrane is built in to avoid water leakages through the tunnel lining.

Steel fibers sometimes are used as a reinforcement for this final lining in order to have a better crack resistance of the concrete which has a positive influence on the durability of the concrete structure.

Also when future tunnelling in the neighbourhood of the tunnel is expected steel fibers enhance the ductile behaviour of the concrete lining and give it a better resistance against changing stress conditions.

Improved shotcrete technology, a wide range of admixtures keeping the shotcrete characteristics within the required workability limits and skilled and certified nozzlemen allow to produce nowadays high quality and durable steel fiber reinforced shotcrete linings.

In the single shell method the full lining, including the primary and final layers, is built using only shotcrete. The total lining consists of different shotcrete layers which form a single shell. There is a need for a tough quality control of the total shotcrete lining as bond strength between the different layers is the key issue in order to guarantee the "one shell" behaviour.

As no waterproof membrane can be used in this single shell concept, as it should act as a bond breaker between the different layers, shotcrete durability and impermeability need special attention. It is strongly recommended to use silica fume and PFA in adequate dosages in order to improve the density of the applied shotcrete material.

Steel fibers are being used both in the first and the final shotcrete layer, be it for different purposes. Ductility is required in the first stabilising layer, while in the final layer crack control improves the durability of the lining.

The single shell method offers the advantage of being able to apply the final layer shortly after the first layer. This allows to shorten drastically the total construction time. In the double shell method very often the final cast lining only can be applied after the breakthrough as the mould obstruct the normal traffic in the tunnel.

6. More recently mechanised tunnelling largely has increased it's application field. Improved technology makes it possible to use a TBM (tunnel boring machine) in a wide variety of ground conditions and for large to very large diameters.

Although the investment of a TBM still is quite high, in some cases a tunnel length of 2,2 km already can justify economically the application of the mechanised tunnelling process.

This method of course offers the advantage of constructing a constant tunnel cross section, avoiding expensive overbreak which is the case in drill and blast. Particularly in urban areas the use of a TBM proves to be very interesting as it provides a continuous support, even at a small overburden. The tunnel opening also is lined immediately behind the TBM using precast concrete segments. This of course reduces the risk for settlement of buildings in the neighbourhood of the tunnel.

The segments are precast or at the job site or are brought in from a remote specialised precast concrete plant. The lining consists of concrete rings which are formed by putting several single pieces together. The ring is closed or by bolting the segments or by using a keystone which gives an expanded lining.

In most ground conditions the segments forming a closed ring only have to resist normal compressive forces in their final position. However, these segments are subjected to different loading conditions before they get into their final place. The precast segments have to resist bending moments and flexural stresses when being demoulded and transported to the storage facilities located outside the precast building. They have to resist tensile thermal stresses due to temperature changes at the storage area. The heaviest loading, however, takes place when the segments are being installed and have to resist the very high jack loads of the TBM when moving forward.

Cracking and spalling is the main problem of reinforced concrete segments.

The heavy jack loads are being applied at the outer unreinforced concrete skin of the segments. When spalling occurs the segment has to be repaired or even replaced for obvious reasons of durability concern. This however delays the tunnel construction progress and is a very expensive operation.

The very complex tensile stress pattern induced by the jack loads requires a quite complicated steel reinforcing cage, what makes it heavy and expensive.

Steel fibers are a technical valuable alternative for the traditional mesh and rebar reinforcement. The homogeneous fiber distribution makes it possible to absorb tensile stresses in any point and any direction of the concrete segment. Cracking and spalling resistance are considerably improved.

Various reference projects have proven that tunnels with a diameter up to 7 – 8 m can be lined with steel fiber reinforced concrete segments without the need for any other additional reinforcement. For higher diameters it is recommended to use a mixed reinforcement of mesh and steel fibers.

Some heavy fires that recently happened in some of the main European transport tunnels have focused the need for an improved fire resistance of the tunnel lining.

Extensive research, especialy under U.K. initiative, has shown the positive result of a blend of steel fibers and polypropylene fibers.

7. There is a still growing use of the underground for infrastructure and utility projects.

   Modern tunnelling methods are ruled by concerns on safety and speed.

   Steel fibers which can be added as another component to the concrete and shotcrete mix allow to increase the tunnelling speed under safer working conditions and provide concrete and shotcrete with a high degree of ductility in order to allow a controlled movement of the underground in a process of becoming again self supporting.

   Steel fibers do control concrete cracking much better and justify for durability reasons it's use in final cast or sprayed concrete layers.

   Mechanised tunnelling becomes more popular and economically more attractive. Substantial savings are possible when using steel fiber reinforced concrete for segment manufacturing.