THE USE OF STEEL FIBER REINFORCED SHOTCRETE FOR THE SUPPORT OF MINE OPENINGS

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What separates the support of mining openings from the support of similar civil engineering structures is the fact that mine openings have to survive large deformations as a result of changing stress conditions induced by progressive mining.

Steel fibers impart to concrete and shotcrete a high degree of ductility which not only allows the shotcrete and concrete linings to absorb important rock movements but also to increase it's bearing capacity by a redistribution of the loads.

A range of applications will be discussed technically and economically.

1. ROCK SUPPORT DESIGN

1.1. The potential for instability in the rock surrounding mine openings is an ever-present threat to both the safety of men and equipment in the mine.

In addition, because of dilution of the ore due to rock falls, the profitability of the mining operations may be reduced if failures are allowed to develop in the rock surrounding a stope.

1.2. The classical approach used in designing engineering structures is to consider the relationship between the capacity C (strength or resisting force) of the element and the demand D (stress or disturbing force). The factor of safety of the structure is defined as $F = C/D$ and failure is assumed to occur when F is less than 1.

The value of the factor of safety, which is considered acceptable for a design, is usually established from previous experience of successful designs. A factor of safety of 1.3 would generally be considered adequate for a temporary mining opening while a value of 1.5 to 2.0 may be required for a permanent excavation, such as an underground crusher station.

1.3. What separates the support of mining openings from the support of similar civil engineering structures is the fact that mine openings may have to survive large deformations as a result of changing stress conditions induced by progressive way back into the rock mass. In these circumstances, shotcrete provides very effective support and deserves to be much more widely used than is currently the case.

2.2. Rock at depth is subjected to stress resulting from the weight of the overlying strata and from locked in stresses of tectonic origin.

When a mine opening is excavated in this rock, the stress field is locally disrupted and a new set of stresses are induced in the rock surrounding the opening.

One of the major problems in designing underground openings is that of estimating the strength and deformation properties of the in situ rock mass.

2.3. Support Design for Overstressed Rock

2.3.1. The failure of a rock mass around an underground opening depends upon the in situ stress level and upon the characteristics of the rock mass.

Failure around openings in lightly stressed rock masses progresses from brittle spalling and slabbing, in the case of massive rocks with few joints, to a more ductile type of failure for heavily jointed rock masses.

2.3.2. Deformation of rock mass

The plastic behaviour of the rock mass surrounding the tunnels does not necessarily mean that the tunnel collapses. The failed material still has considerable strength and, provided that the thickness of the plastic zone is small compared with the tunnel radius, the only evidence of failure may be a few fresh cracks and a minor amount of ravelling and spalling.

On the other hand, when a large plastic zone is formed and when large inward displacements of the tunnel wall occur, the loosening of the failed rock mass will lead to severe spalling and ravelling and to an eventual collpase of an unsupported tunnel.

The primary function of support is to control the inward displacement of the walls and to prevent the loosening, which can lead to the collapse of the tunnel. The installation of rockbolts, shotcrete lining or steel sets cannot prevent the failure of the rock surrounding a tunnel subjected to significant overstressing.

But these support types do play a major role in controlling tunnel deformation.

2.3.3. Deformation characteristics of support

2.4.2. The spalling progress tends to start very close to the face of the tunnel and, while the full extent of the failure zone may take time to develop, small rockfalls can occur close to the face and can pose a threat to work crews.

The purpose of the support is ti carry the dead weight of the broken rock and to prevent rockfalls close to the working force.

3. Support applications

3.1. The wide variety of orebody shapes and rock mass characteristics which are encountered in underground mining mean that each mine presents a unique design challenge. "Typical" mining methods have to be modified to fit the pecularities of each orebody.

Factors controlling the performance of the support system are abrasion, vibration, secondary blasting damage, stress changes due to stoping.

3.2. Safety - Support Systems

The simpliest form of underground excavation support is that which is installed solely for "safety" reasons.

This support is not called upon to carry very heavy loads due to the large wedge failures or to massive stress induced instability, but its function is to provide an acceptable level of safety for personnel and equipment in the mine.

The decision on when support is required in such tunnels in a very subjective one, since there are very few guidelines and those which do exist vary widely from country to country. Possibly the only consistent guideline is that heavily traficked openings, such as shafts, ramps and haulages, should have rockbolts and/or reinforced shotcrete installed to protect personnel and equipment from rockfalls.

The expense of this support is justified because very little maintenance or rehabilitation would be required for the life of the tunnel. Such rehabilitation can be very expensive and, in the case of a conveyor tunnel or a similar critical route in the mine, the suspension of operations due to rockfalls would be a serious problems.

3.3. Permanent mining excavations

Shafts, shaft stations, underground crusher chambers, underground garages are examples of "permanent" mining excavations.

In recent years the mining industry has become a major user of shotcrete for underground support. The simultaneous working of multiple headings, difficulty of access and unusual loading conditions are some of the problems which are peculiar to underground mining and which require new and innovative applications of shotcrete technology.

An important area of shotcrete application in underground mining is the support of permanent openings such as ramps, haulages, shaft stations and crusher chambers. Rehabilitation of conventional support sytems can be very disruptive and expensive. Increasing numbers of these excavations are being shotcreted immediately after excavation.

The incorporation of steel fibre reinforcement into the shotcrete is an important factor in this escalating use, since it minimises the labour intensive process of mesh installation.

4.2. The design of shotcrete support for underground excavation is a very imprecise process.

The complex interaction between the failing rock mass around an underground opening, and a layer of shotcrete of varying thickness with properties that change as it hardens, defies most attempts at theoretical analysis.

It is also important to recognise that shotcrete is very seldom used alone and its use in combination with rockbolts, cable bolts, lattice girders or steel sets further complicates the problem of analysing its contribution to support.

Current shotcrete support design methodology relies very heavily upon rules of thumb and precedent experience : Grimstad & Barton have publisjed an updated chart relating different support systems, including shotcrete and SFRS

4.3. SFRS can not prevent deformation from taking place, especially in high stress environments. It can, however, assist in controlling deformation, particularly when used in combination with rockbolts, dowels or cables.

SFRS becomes very effective when bolt or cable installations are carried out after an initial shotcrete support application. This allows the face plate loads to be transmitted over a large area to the underlying rock mass.

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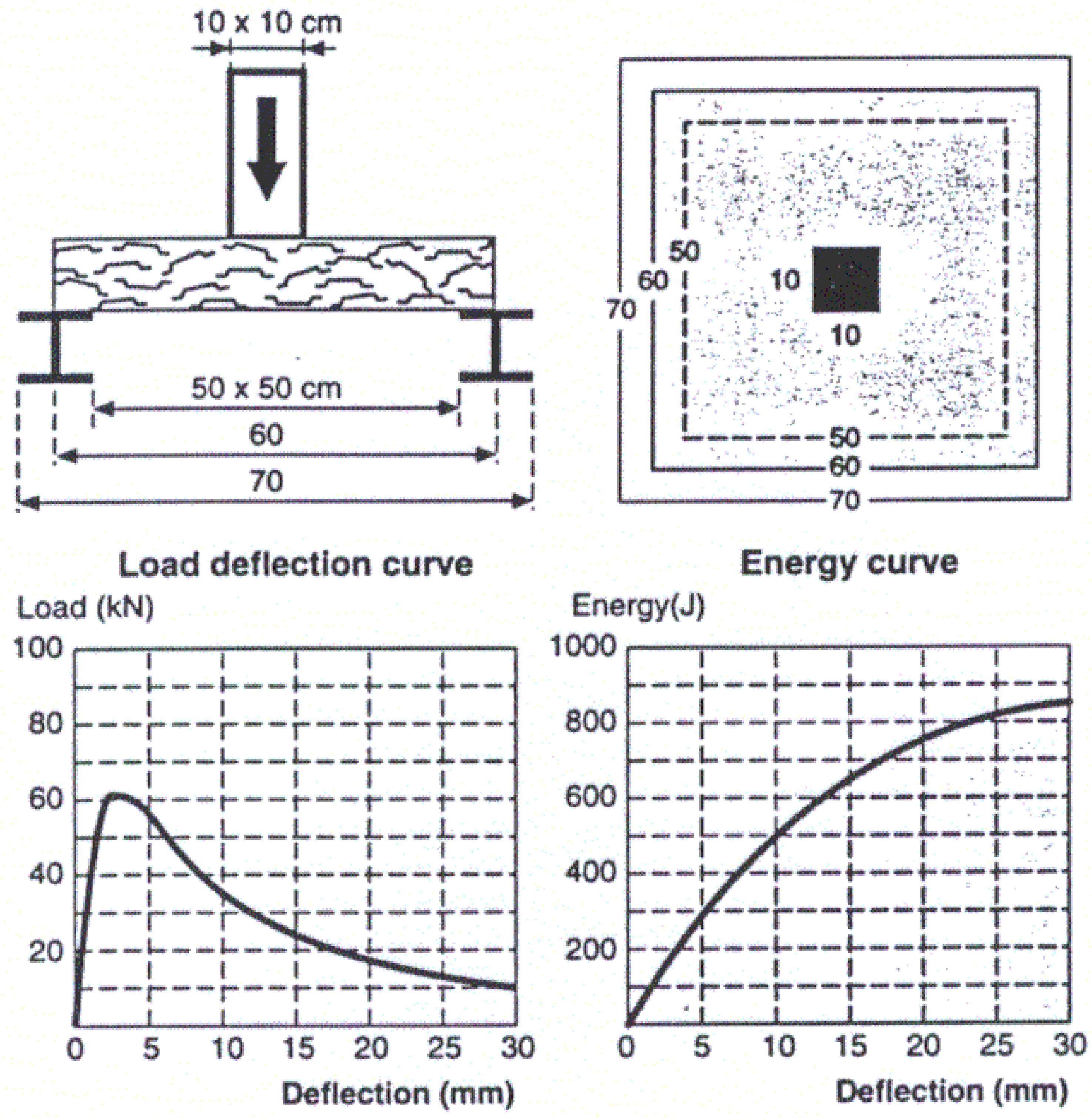
5.1. Definition

curve a second curve is drawn resulting in the absorbed energy as a function of the slab deformation or deflection (Figure 5).



The slab test is more appropriate than the beam test to determine the performance of SFRS lining for the following three reasons:

- A slab test corresponds much better than a beam test with a real tunnel lining; the slab support on the 4 edges simulates the continuity of the shotcrete lining;

- As in reality, steel fibres act in at least two direcions and not just in one direction as in a beam test; the fibre reinforcing effect in a slab is very similar to the real behaviour of a SFRS lining;

- SFRS can be compared very easily with a mesh reinforced shotcrete to be tested in the same way.

For the same concrete matrix, the amount of absorbed energy is significantly influenced by the fibre type (e.g. the aspect ratio length diameter) and fibre dosage. The higher the aspect ratio and fibre content, the better the performance of the SFRS (A Lambrechts, 1996).

5.2.3. Interaction with rock bolts

Comparative tests (J. Holmgren, 1985) have been conducted on bolt anchored shotcrete linings reinforced with steel fibres and mesh by the BeFo (Swedish Rock Engineering Research Foundation) and the FortF (Royal Swedish Fortifications Administration). The tested shotcrete structures were subjected to a punch load from a single block. Support for the shotcrete layer was provided by two rock anchors, one on each side of the punching block. The can be connected to any standard concrete batching or mixing plant. The use of an automatic dosing equipment makes it possible to eliminate the need for additional personnel but makes it also possible to have a clear control of the added fibre dosage.

5.2.5. SFRS versus mesh reinforced shotcrete

One of the factors which makes SFRS particularly appealing to contractors is the ability to do away with the need to install mesh. Fixing mesh to a wall is difficult, time consuming, costly and sometimes hazardous. Another advantage is that SFRS allows the exact contours of the rock, while even on a regular excavated surface, the mesh is pinned mostly at spots that project from the surface. It is pinned back inside large depressions, but it is draped over most small ones (see Figure 8).

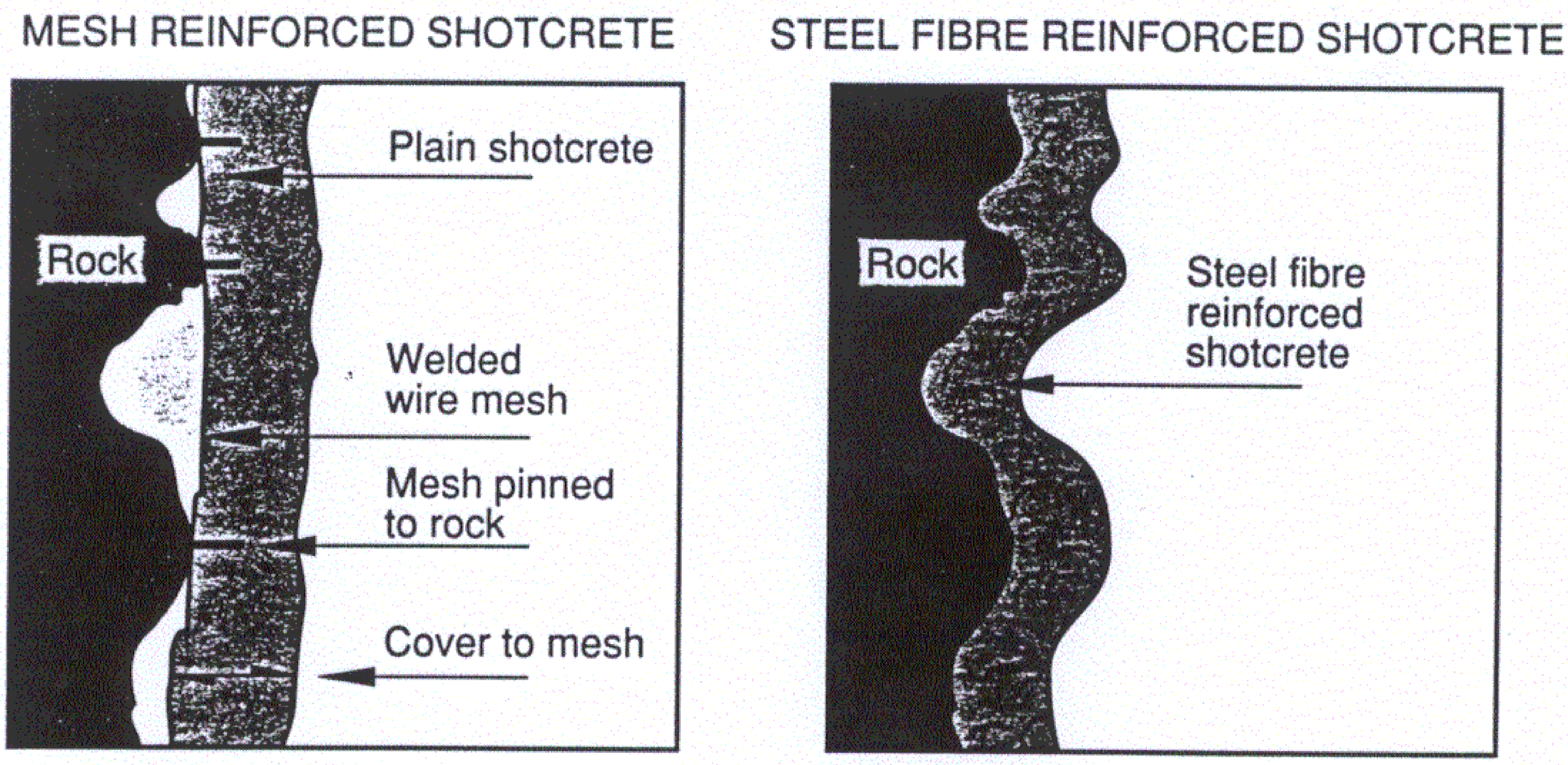


Figure 8

Mesh reinforced shotcrete requires 30 to 50 mm cover as well as filling in all the voids behind the mesh with shotcrete. Filling the voids behind the mesh in draped-over areas takes extra shotcrete, more than what is required by the minimum specified thickness. It may happen even that the mesh remains uncovered. With SFRS, there is no need anymore to thoroughly encapsulate the reinforcing mesh with shotcrete. An improper nozzling technique can be costly too. If the correct pressure is not used or the nozzle is not held at the correct distance from the rock face, shotcrzete can build upo on the face of the mesh, leaving voids and sand pockets behind. Not bonded to the rock, this shotcrete will deteriorate quickly and the reinforcing mesh will rapidly start corroding especially if exposed to groundwater, aggressive atmosphere or freezing conditions.

The wire of the mesh causes a much higher rebound of the bigger aggregates, creating poor quality shotcrete behind the wires and, as such, preferential drains for groundwater. Big size aggregates hitting the wires make the mesh vibrate, the previous paragraph, some practical considerations are given why SFRS is preferred above with mesh reinforced shotcrete.

Thirdly, for rockburst conditions with very large displacements and/or violent ejection, the cracks induced during rockbursts could be too large to keep a sufficient strong bridging effect.

5.3. Specifying SFRS

5.3.1. Introduction

For many years shotcrete has been considered as a second hand material which was only used for temporary linings and preliminary sealing layers. However, a lot has changed in the last 10 years.

Shotcrete equipment has been adapted to job conditions, including mechanized spraying arms, and nozzlemen are trained and certified to use it in the proper way.

Technology and mix design have called for the right basic components. Aggregates need to have a continuous grading. As a result of thorough research in recent years a lot of admixtures have been offered to the market, such as accelerators to reduce rebound and increase early shotcrete strength development, set retarders and activators to increase shotcrete life, silica fume to improve shotcrete characteristics...

Actually shotcrete having the proper mix design and being applied by a certified nozzelman using the right equipment has been upgraded to a high quality material.

Improved characteristics allow to extend the shotcrete applications, including for structural use.

5.3.2. Steel fibres

Steel wire fibres, added as one more component to the shotcrete mix, do allow to guarantee a uniform reinforcement and an end product with homogenous characteristics

Steel fibres do reinforce the whole shotcrete matrix resulting in

- an efficient crack control
- a ductile behaviour

Structural applications however, require a tougher quality control. The proper characteristics have to be checked depending on the application of the steel fibre reinforced shotcrete :

Toughness can be determined based on the results of a flexural beam test.

In many countries local standards and/or recommendations include full description of the test itself, such as beam size, span, rate of loading... but only few numerical date are available as to the values to obtain.

ASTM - testing method (C1018)

Toughness indices are determined based on the ratio of energy absorption between first crack and first crack related deformations.

Accurate measuring of first crack deformation is highly complicated and due to the uncertain behaviour or testing equipment at the cracking stage results may be completely wrong or manipulated.

D. Wood therefore recommended to skip I5 and I10 indices and to us higher toughness indices (I20, I30 and I60).

Toughness factors have been defined as

- R30,10 = 5 (I30 - I10)
- R50,30 = 5 (I50 - I30)

Recommended values for both toughness factors are in the range of 50 - 75

Equivalent flexural strength

The equivalent flexural strength is designed as an average value based on the load bearing capacity of steel fibre reinforced shotcrete considering large deformations.

A larger part of the load-deflection diagram of the beam test is taken into account, giving a better idea of the real ductile behaviour.

The equivalent flexural strength is a material characteristic which has to be applied in the proper design method.

This required however, the right design assumptions as to loading conditions and lining dimensions. This can be done for inner linings having a uniform thickness.

The German DBV Recommendations have published a design method based on the MN-method using the equivalent flexural strength.

Project specifications have to include the required equivalent flexural strength values which were introduced in the lining design.

5.3.5. Recommendations

Due to efforts from several parties involved in shotcrete development shotcrete has been upgraded to a high quality material to be used for structural purposes.

Quality also requires a thorough check of the relevant characteristics related to the material's application.

Specifications have to call for the required numerical values to be obtained from the appropriate testing methods.

Steel fibre reinforced shotcrete properties depend largely on steel fibres specific characteristics. Steel fibre should have a quality label.

The effect of steel fibres on crack control depends on steel fibre dosage and aspect ratio. Specifications have to mention a minimum fibre length and a maximum fibre spacing. Based on this value a minimum dosage can be specified for each fibre type.

Toughness should be specified based on

- The French slab test energy absorption values (Joule) for outer linings
- beam test equivalent flexural strengths (N/mm^2) for designed inner linings.