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Fibre reinforced shotcrete lining at the Covanca Tunnel[1]

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Abstract

This paper presents a case history of successful use of steel fibre reinforced shotcrete (SFRS) to a road tunnel lining in Rio de Janeiro. The use of SFRC to replace the steel mesh enabled the works to be completed ahead of time. The fibre type was selected as a function of its length to diameter ratio, or shape factor, which is directed related to fibre performance. A testing programme consisting of beam and French slab tests were carried out and its results were used in the SFRS lining design.

Introduction

The Covanca Tunnel is a 2.2 km long twin-tunnel in Rio de Janeiro, Brazil, excavated in sound and fractured gneisses. The tunnel is a part of the 22 km long Yellow Line project, a high speed motorway, linking the Galeao Airport to South Rio de Janeiro (Figure 1).

The designed cross-section is presented in Figure 2 and has an area of 96 m^2 for two traffic lanes and hard shoulders. This large area also accommodated the horizontal ventilation system, which avoided ventilation shafts.

The initial tunnel lining design employed shotcrete and a steel mesh, as has been the conventional practice in Brazil. However, just before the excavation started a more recent technology was proposed for the reinforced lining: to replace the steel mesh by steel fibres.

Since this method has never been used before in Brazil, a testing programme was conducted to evaluate the application of steel fibre reinforced shotcrete (SFRS).

This paper presents summary of the tunnel design method and give emphasis to the lining design with SFRS commenting its advantages and limitations.

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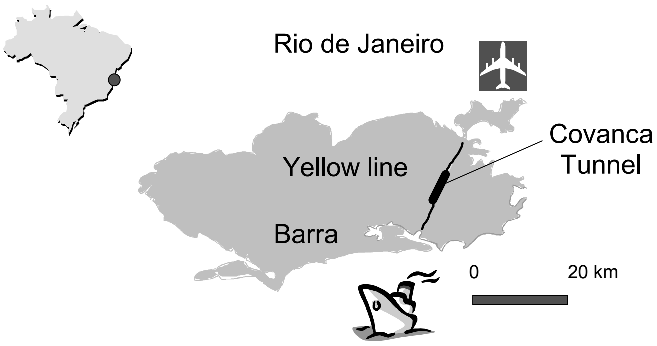


Figure 1 Location

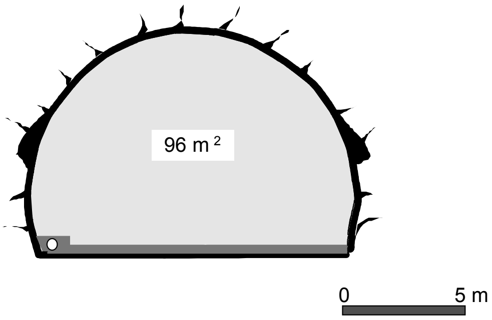


Figure 2 Tunnel section

Geology and site conditions

The tunnel excavation took place at the Pretos Forros Mountain, which presents two main geological units: the kinzigites and the augen gneisses. The first type is biotite-plagioclase gneiss, presenting dark colour and occupying the Southern slope of the mountain. Its schistocity dips 25 to 50 degrees to NE or NW direction. Another characteristic of this formation is the thick saprolite layer on the bedrock, reaching 25 m of thickness. The saprolites are toppled by colluvium layers of relatively small thickness, seldom reaching 10 m.

The augen gneisses are present in the North part of the mountain, its schistocity dips in the same direction of the kinzigites. At the North tunnel portal the rock is sound and dry.

A summary of the geological conditions is shown in Figure 3. The number and extend of the site investigation and boreholes for the tunnel design was particularly poor. This is a result of the depth of the tunnel, reaching 300 m, which led to a very high cost for a comprehensive site investigation.

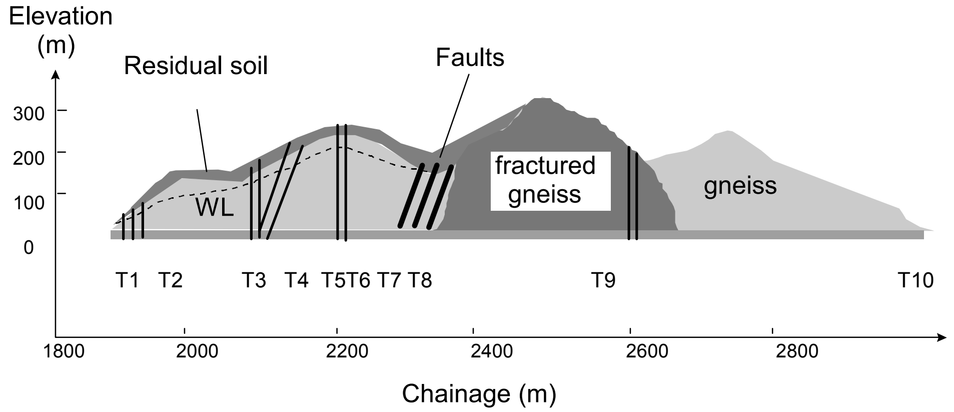


Figure 3 Tunnel geology

Rock classification

The rock mass classification according to the *Q* system (Barton, 1988) is presented in Figure 4. For the design of the support system the tunnel was divided into four different rock categories, leading to design sections *A* to *D*. The support system consisted of a layer of shotcrete and rock bolts, which will be referred later in this paper

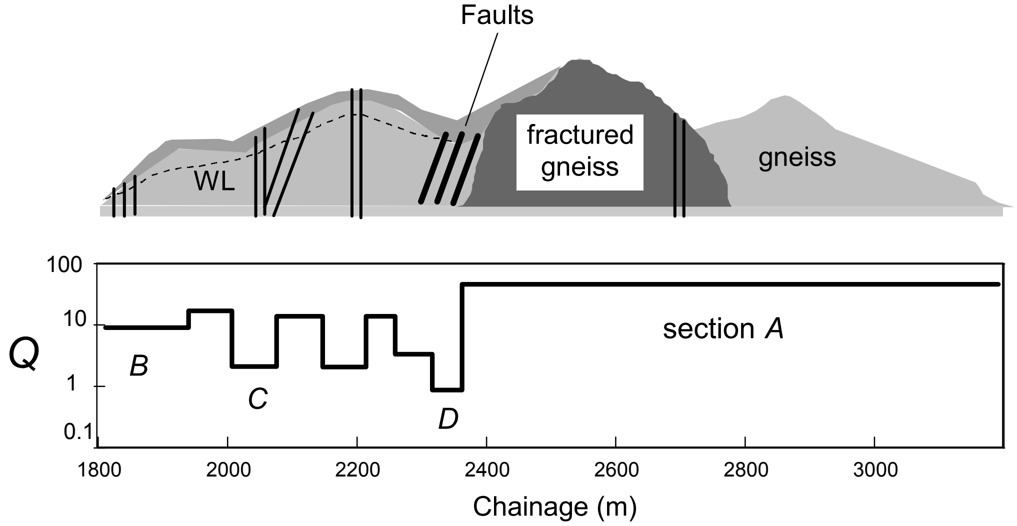


Figure 4 *Q* rock classification

Shotcrete

The dry-mix shotcrete for the tunnel lining had a characteristic strength of 25 MPa (corresponding to test cylinders), 400 kg/m^3 of cement type CPV ARI-PLUS, conforming with the Brazilian standard ABNT NBR 5733,and a maximum diameter of aggregates of 9.5 mm. Two different types of steel meshes were considered: Q 138 and Q 283, corresponding to a steel area of 138 mm^2/m and 283 mm^2/m, respectively.

Steel fibre reinforced shotcrete

Steel fibre reinforced shotcrete (SFRS) was proposed to replace the steel mesh and, although it has been used in other countries (Vandewalle, 1993) it was a new technology for Brazilian engineers. The effect of the fibre reinforced is to give ductility to the sprayed concrete, leading to a homogeneous material with increased flexure strength and ductility.

The main advantage for application to a tunnel lining is the savings of time and labour costs. On the top of that there are the following additional advantages: no shadow effect that occurs with steel mesh and increased corrosion and crack resistance.

The design flexural strength of SFRS is obtained according to the Japanese standard (JCI Japanese Concrete Institute, standard SF-4) from 600 mm x 150 mm x 150 mm beam tests. The *equivalent flexural strength* (f_e) is obtained from:

$$f_e = \frac{T_b}{\delta\, l_b} \frac{l}{b\, h^2}$$

where: b and h are the dimensions of the cross-section of the test beam, l is the span, T_b is the area under the test curve (Figure 5) and $\delta\ l_b$ is the deflection corresponding to 1/150 of the span width which is equal to 2 mm for the standard span width of 300 mm.

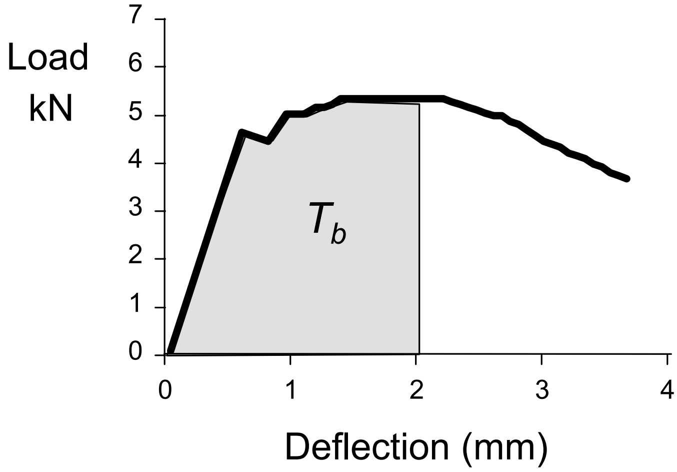


Figure 5 Typical load deflection curve from a test beam

The equivalent flexural strength (f_e) is related to the flexural strength of the unreinforced concrete (f_0) through the *toughness index* R_e:

$$R_e = \frac{f_e}{f_0}$$

Fibre types and performance

Steel fibres for shotcrete applications differ in shape, length, cross-section, and tensile strength. They all have different performance in SFRS. Banthia et al (1992 and 1994) evaluated the performance of different commercially available fibres and a summary of their work in dry-mix is presented in Figure 6. These results were re-plotted in Figure 7 as a function of the shape factor, or length to diameter ratio (*L/D*) which has been considered (Vandewalle, 1993) an important parameter for rating fibre performance in SFRS.

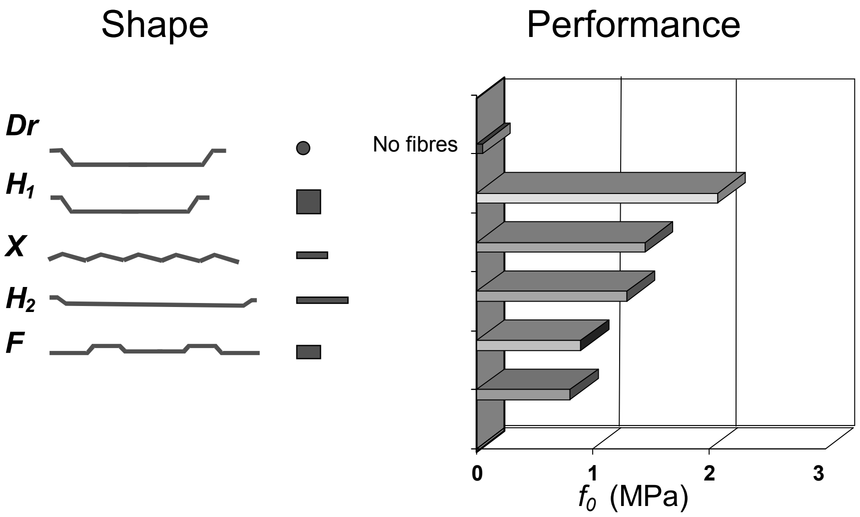


Figure 6 Performance of different fibre types (data from Banthia et al, 1992 and 1994)

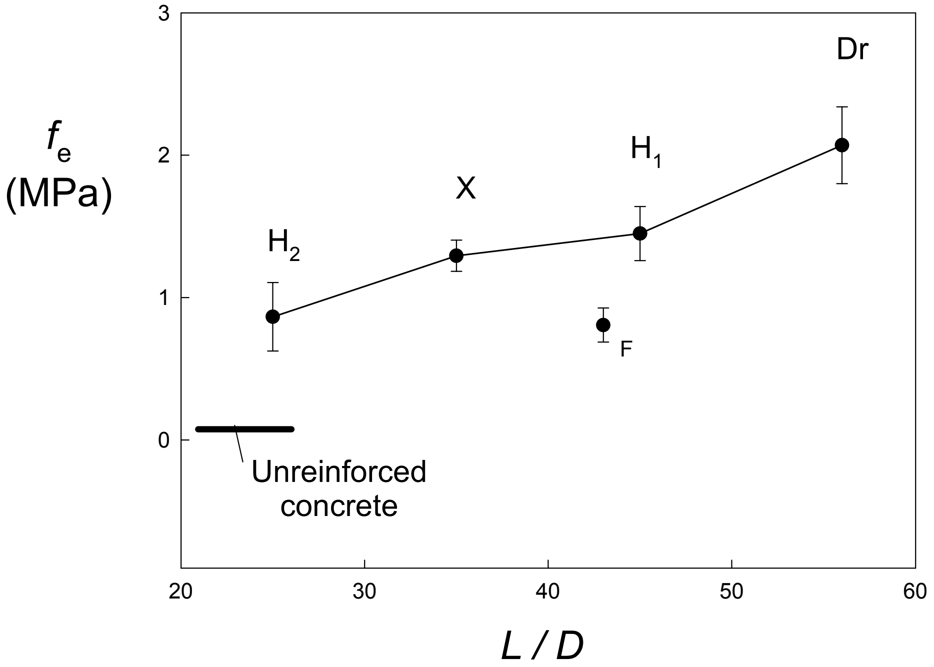


Figure 7 Equivalent strength f_e versus shape factor *L/D*

The results in Figure 7 indicate that best results are obtained with a high shape factor.

Two fibre types commercially available in Brazil were considered for the Covanca Tunnel. They were selected because of their high shape factor and high steel tensile strength, exceeding 1.2 GPa. The fibres were Dramix ZP30/50 and ZL30/65. The first one has a shape factor of 60 and is produced in glued clusters. The latter has a shape factor of 46, but the fibres are loose. The advantage of the glued clusters is that they delay the mix in concrete and, as a consequence, lead to a better random distribution of the fibres in the concrete mass.

Testing programme

A total of 41 shotcreted panels with dimensions 600 mm x 600 mm x 100 mm were obtained for laboratory testing. The shotcreting mixer and pump was Este T10 type operated under air pressure of 600 kPa. The concrete was pumped through a hose 30 m long and 80 mm in diameter fitted with a nozzle with 60 mm in diameter.

The characteristics of the testing panels are given in Table 1.

Table 1 Characteristics of the testing panels

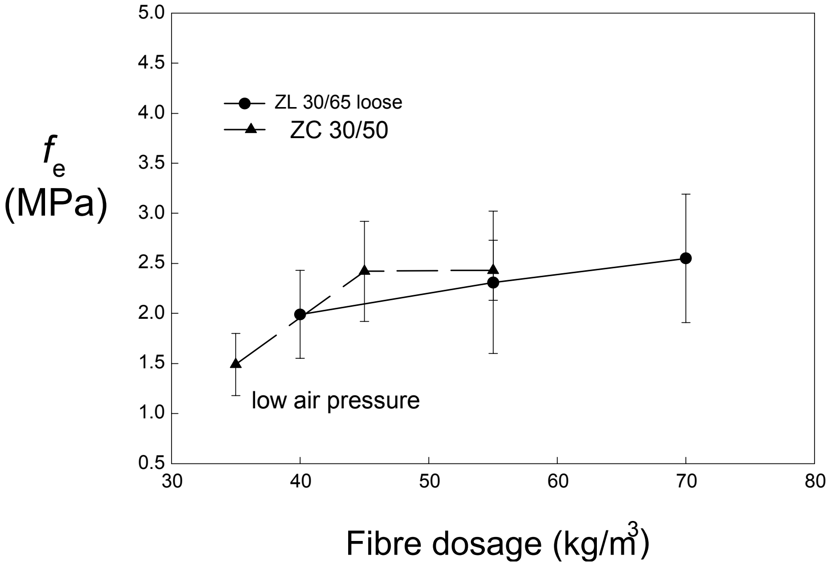
Fibre type	Fibre content	Mesh type	Number of panels
	kg/m^3		
No reinforcement	0		5
ZL 30/65	40		5
ZL 30/65	55		5
ZL 30/65	70		5
ZC 30/50	35		5
ZC 30/50	45		5
ZC 30/50	55		5
No fibres		Q138	3
No fibres		Q283	3

The testing programme consisted of water content, fibre and concrete rebound, axial compression tests in cylinders moulds, beam and slab tests. The beam tests were carried out through the standard JCI SF4 and the slab tests, according to the French slab tests method (AFTES, 1994). The testing machine was a fully automated MTS Sintech 30G type and the force and displacements were measured through electrical transducers connected with a data acquisition system.

Test results

Figure 8(a) presents equivalent flexural strength data versus fibre dosage and Figure 8(b) the fibre rebound at each fibre content. The results indicated that the glued fibre type has a better performance, as a function also of its higher shape factor, but the fibre rebound increases considerably for higher dosages.

During the casting of the test panels, a drop in the air pressure supply was observed. This affected the test results, as noted in Figure 8.



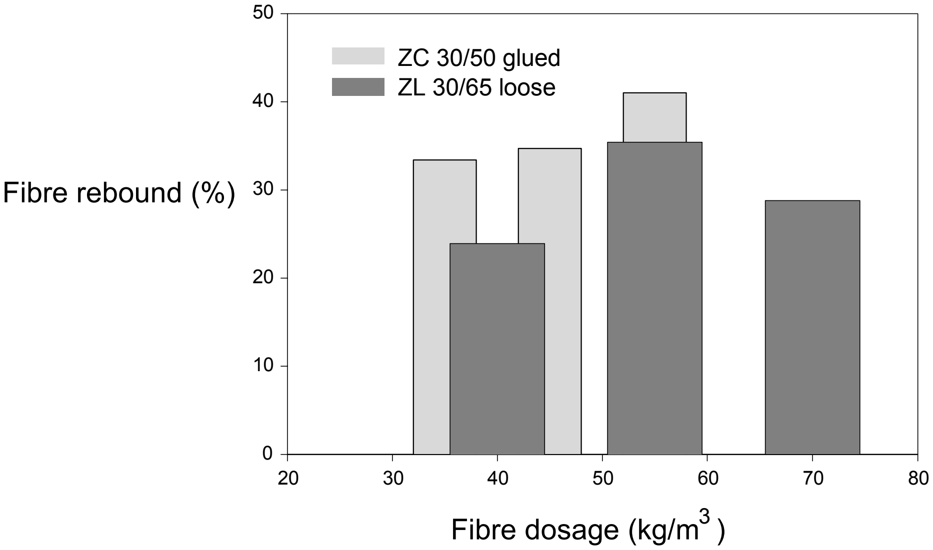


Figure 8 (a) top: equivalent stregth fe versus fibre dosage; (b) bottom: fibre rebound

The mean value of the toughness indices are indicated in Figure 9. Again, the low air pressure influenced the results for the glued fibre type for the 35 kg/m^3 dosage.

The deformation energy measured from French slab tests at a deflection of 25 mm is summarised in Figure 10. These results indicate that a dosage of 55 and 45 kg/m^3 for the loose and glued fibre are necessary to reach the minimum energy of 500 J, as required by the French standard (AFTES, 1994).

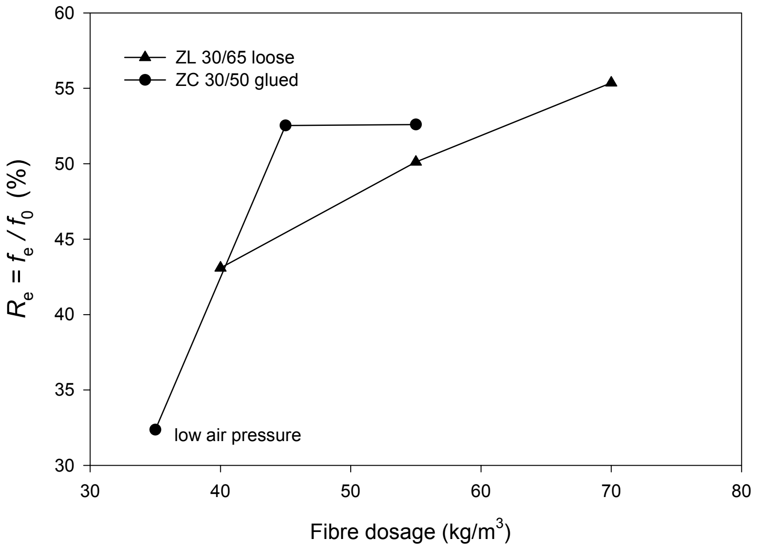


Figure 9 Toughness index R_e versus fibre dosage

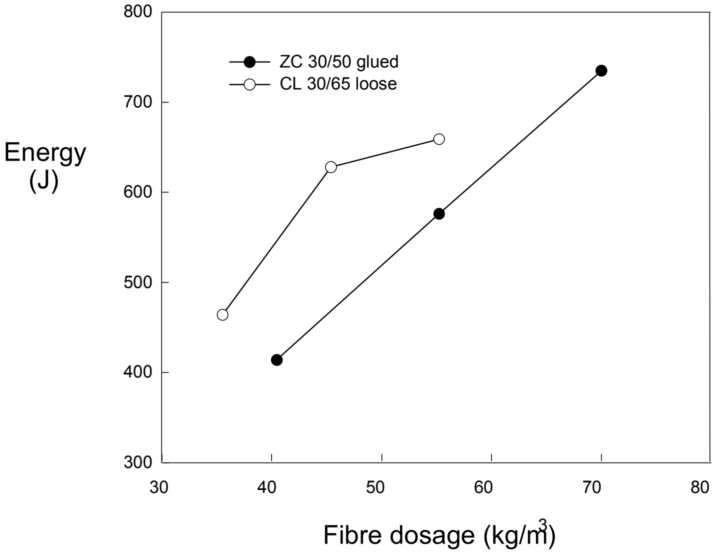


Figure 10 Deformation energy measured in French slab tests

SFRS lining design

SFRS tunnel lining is designed as a homogeneous material with a maximum strength equal to the equivalent SFRS strength. Vandewalle (1993) summarised the design formulae. The stress (f) in a homogeneous section is calculated through:

$$f = \frac{6\,M}{b\,h^2}$$

where M is the maximum moment in the section, b is the section breadth and h its height or, in case of tunnels, the thickness of the shotcreted lining.

As an example, the lining design of section B in Covanca Tunnel is calculated in Table 2.

Table 2 Example of section design

Original shotcrete thickness with mess	**150 mm**
Number and type of mesh	1 mesh Q283, 283 mm^2/ m
Required moment (*M*)	6.69 kNm/m
Required equivalent flexural strength (f_e)	1.8 MPa
Flexural strength of the unreinforced shotcrete (f_0)	4.6 MPa
Required toughness ratio $R_e = f_e / f_0$	38.6 %
$\therefore$ the necessary dosage (from charts such as Figure 9) is	40 kg/m^3
Increasing the dosage to 45 kg/m^3, one gets:	
required f_e	2.4 MPa
required lining thickness *h*	130 mm

Details of the lining design for the tunnel are given in Table 3 and in Figure 11 to Figure 13.

Table 3 Characteristics of the lining design with mesh and with SFRS

Section	B	C	D
Shotcrete thickness(mm)	150	200	250
Mesh quantity and type	Q283	Q283	2 Q283
SFRS thickness (mm)	130	150	200
Dosage ZP 30/50 (kg/m^3)	45	45	40
Dosage ZL 30/65 (kg/m^3)			55

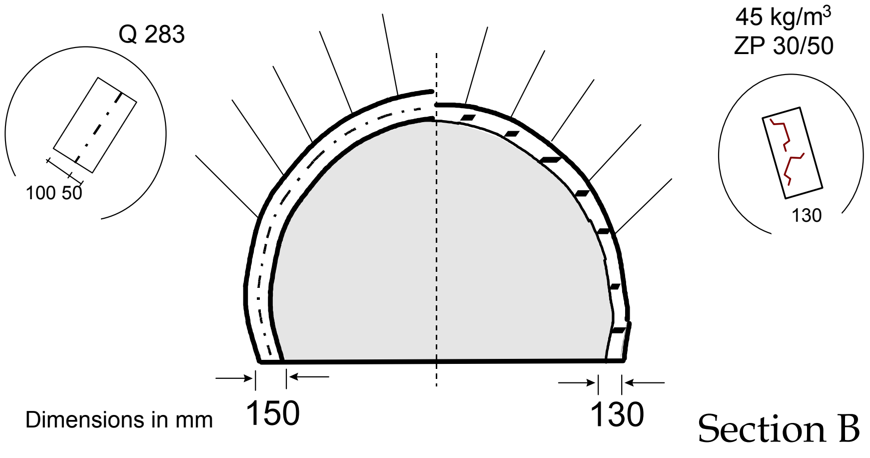


Figure 11 SFRS lining for section type B with one mesh

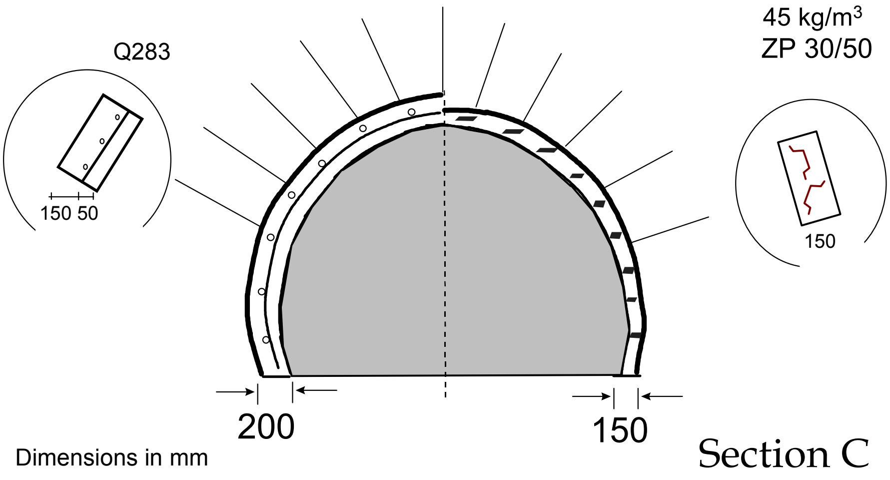


Figure 12 SFRS lining for section type C with one mesh

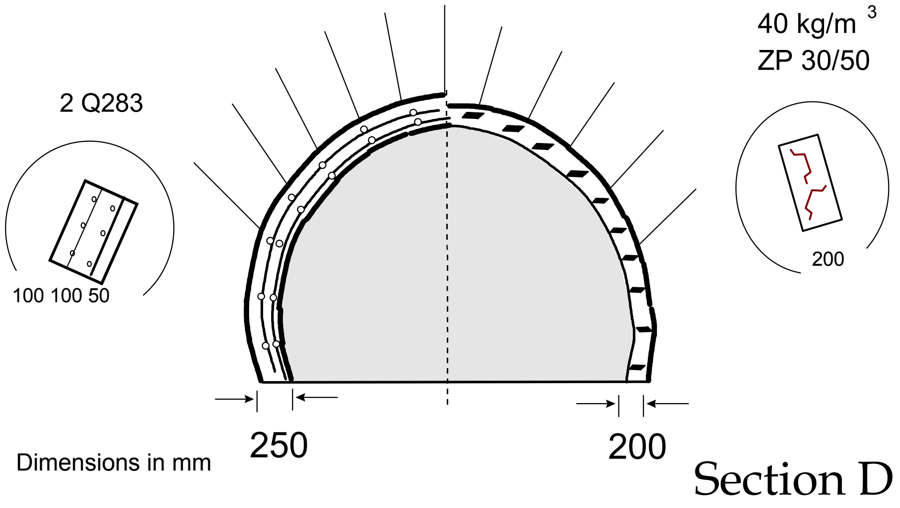


Figure 13 SFRS lining for section type D with two meshes

Savings of time

The biggest advantage of the application of SFRS at the Covanca Tunnel was the economy of time in comparison with the use of a steel mesh shotcrete.

For a complete excavation cycle the approximate require time in each operation is given in Table 4. The use of SFRS saved 3 hours in each excavation time and enabled the completion of the tunnel works ahead of schedule.

Table 4 Time required in each excavation operation

Operation	***Time***	
Drilling	2:00	2:00
Loading	2:00	2:00
Blasting & vent	0:30	0:30
Mucking	3:00	3:00
Bolting	0:30	0:30
Shotcrete 1st layer	1:00	1:00
Steel mesh	3:00	0:00
Shotcrete 2nd layer	1:00	1:00
Total cycle time	**13:00**	**10:00**

Conclusions

The Covanca Tunnel in Rio de Janeiro was the first application of SFRS technology for a tunnel lining in Brazil to replace the steel mesh. The main advantage was the considerable saving in excavation and support time, which enabled the tunnel works to completed ahead of time.

Additional advantages of SFRS are: homogeneous and ductile material with flexural strength, increase in corrosion and crack resistance.

This application of SFRS was backed-up by a comprehensive laboratory testing test programme which demonstrated that the fibre performance is related to the shape factor, dosage and steel tensile strength. The fibre type selection should be referred to the shape factor.

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