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Gotthard Base Tunnel Sedrun section mastering squeezing rock zones

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ABSTRACT: Since more than three years the main tunnel of the Gotthard Base Tunnel is under construction. In the central section of Sedrun large zones with squeezing rock are predicted. The project takes the high forces and the necessary deformations into account. For the rock support steel ribs are the main elements. Special on site tests were carried out to check the effectiveness of the chosen rock support.

1 FUNDAMENTAL CONSIDERATIONS REGARDING PLANNING AND IMPLEMENTATION

Since the route of the Gotthard Base Tunnel (GBT) was decided, it has been known that in the Sedrun section two constructional difficult zones – the Tavetsch Intermediate Massif (TIM) (North) and the Urseren Garvera Zone (UGZ) – must be cut through. In both zones, squeezing rock conditions are expected to be encountered.
The main questions during design and construction are:

1. With what type of ground conditions are we confronted?
2. What phenomena could hinder the successful construction of a tunnel?
3. What are the constructional measures to overcome these phenomena, so that a tunnel can be constructed safely at an acceptable cost?

In each phase of the project, answers to these questions have been, and are, found by application of the procedure shown simplified in Fig. 2.

The main project steps are:

- Geological exploration
- Description of the rock mass based on the geological exploration
- Assessment of the rock mass with regard to excavation of the underground cavity
- Determination of the cross section
- Determination of the rock support
- Determination of the method of excavation
- Determination of the requirement for constructional aids
- Definition of the radial and longitudinal procedures (construction sequence)

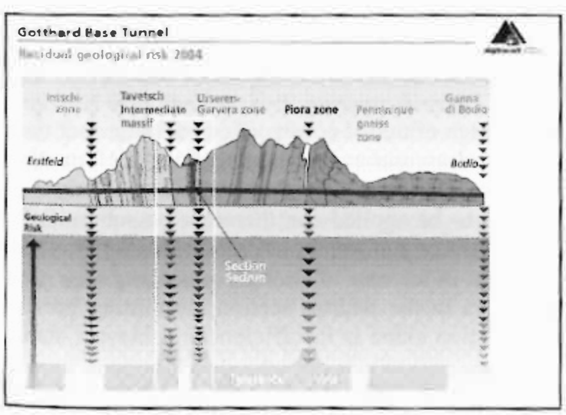


Figure 1. Gotthard Base Tunnel, geological risk zones.

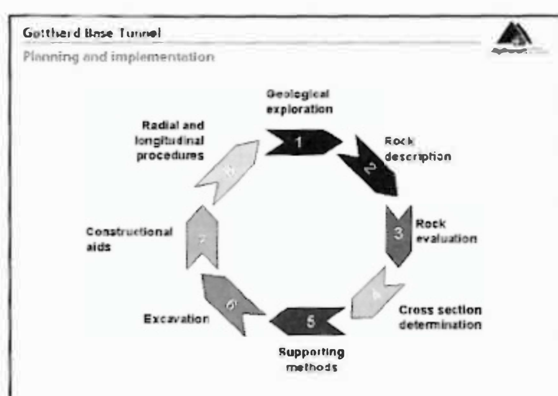


Figure 2. General planning procedure.

2 CONSTRUCTIONAL FOUNDATION

2.1 *Geological exploration*

The owner AlpTransit Gotthard Ltd. (ATG) already decided at an early stage to explore the geologically difficult zones with extensive test-bore campaigns and other investigations. The following test-bore campaigns were conducted:

1991:	Diagonal bore SB 1	L = 838 m
1991:	Diagonal bore SB 2	L = 543 m
1993:	Diagonal bore SB 3.1	L = 780 m
1997:	Diagonal bore SB 4.1	L = 1750 m
1997/98:	Diagonal bore SB 3.2	L = 1716 m

The Urseren Garvera zone was not explored with test bores. However, since this tectonic unit had been traversed during construction of the headrace tunnel for the Vorderrhein hydropower scheme, and when building the Gotthard road tunnel, sufficient knowledge and experience was available.

During the construction phase, horizontal test bores are made in both of the single-track tunnels, to the north as well as to the south. Depending on the rock conditions, the test bores are either percussion or core bores. The length of the bores varies between 36 m for the percussion bores and from 150 m up to 400 m (in the region of the Nalps dam) fore the core bores. Depending on the evaluation of the potential hazard of water ingress, the test bores are protected with preventers.

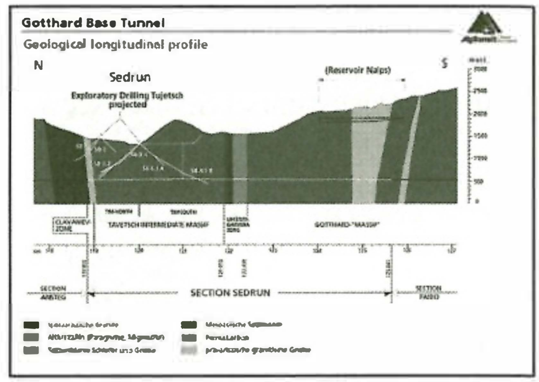


Figure 3. Sedrun section, longitudinal geological profile.

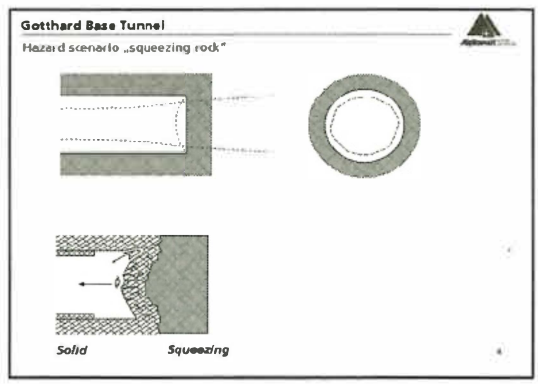


Figure 4. Hazard scenario "squeezing rock".

2.2 *Description of the rock situation*

The test bores to the north have indicated that the 1.1 km long Tavetsch Intermediate Massif North consists to approximately 70% of soft, kakiritic rocks displaying ductile fracture behaviour. Approximately 30% of the rock is hard and displays brittle facture behavior. Hard and soft rocks alternate in narrow vertical layers. Where the material resembles loose rock, it is saturated with water.

2.3 *Assessment of the rock mass*

The assessment of the rock serves to forecast the composition and behavior of the rock which will be encountered when constructing the underground cavity. This evaluation, as well as an evaluation of the rock in relation to water and gas, was made project-specifically based on known hazard scenarios.

In the Tavetsch Intermediate Massif (North) as well as in the Urseren Garvera zone, the predominant hazard is the phenomenon of squeezing rock.

In view of the high overburden of 900 m and more, as well as the fact that the rock is saturated with water, the squeezing conditions are classified as extreme. The phenomenon of squeezing rock will manifest itself both radially as well as at the work-face as a tendency of the excavated cavity to converge. In the longitudinal direction, given the expected alternation of different vertical layers of rock, the phenomenon will be accentuated as potential instabilities at the workface.

3 CONSTRUCTIONAL MEASURES

Experience of tunnel construction indicates that rock pressure decreases as the amount of rock deformation increases. The amount of constructional resistance needing to be applied can therefore be substantially reduced if a certain amount of deformation is permitted. However, in the case of strongly squeezing rock such as occurs in the Sedrun section, permitting greater deformation alone is insufficient to achieve a stable situation.

Despite permitting deformations of the order of several decimeters, extremely massive supporting forces must be applied to keep the excavated cavity

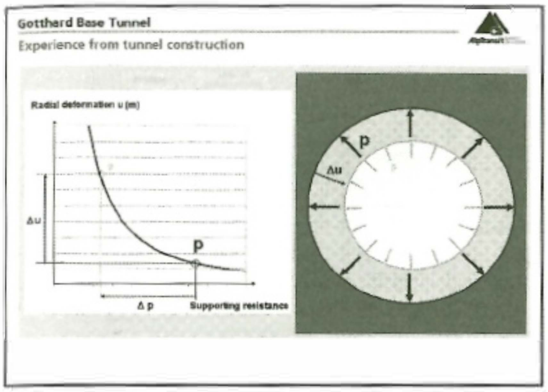


Figure 5. Experience of tunnelling in squeezing rock.

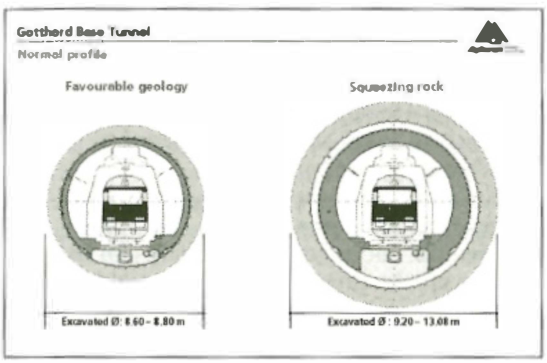


Figure 6. Normal profiles.

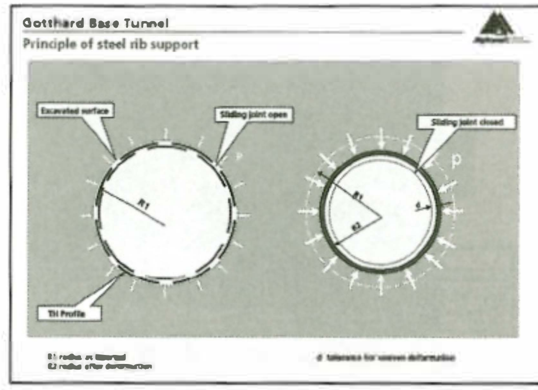


Figure 7. Principle of steel rib support.

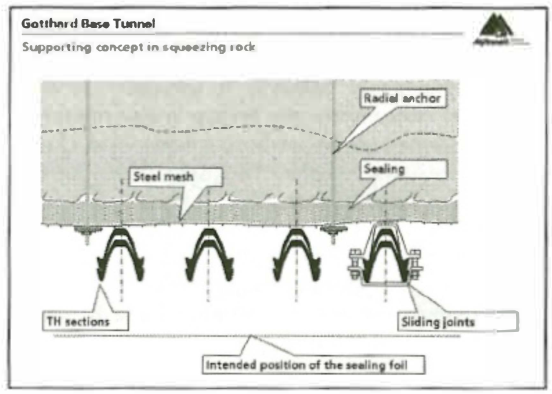


Figure 8. Supporting concept in squeezing rock.

open. Without permitting deformations, it would be technically practically impossible to create the forces needed to keep the excavated cross section open.

3.1 *Design of the cross section*

The specifications for the high-speed railway line in the GBT stipulate a minimum free air cross section Fair of 41.0 m^2. The high forces on the construction expected from the true rock pressure demand a structurally optimal form. For this reason, through-out the entire Sedrun section, the only cross section which can be used for the single-track tunnel is a circle, whereas in sections with favorable geological conditions the base of the tunnel is made flat to assist construction operations.

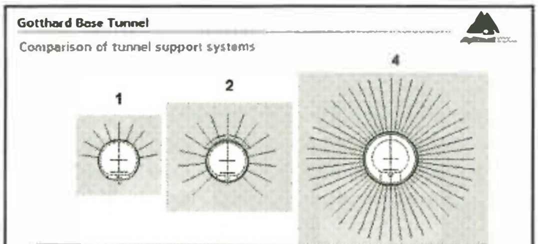
3.2 *Mining engineering methods of support*

Considerations based on the principles of rock mechanics resulted in a concept being sought which would fulfill the conditions specific to the Sedrun situation, i.e. a concept which would allow a high degree of deformation but also provide a high level of outward resistance when completed.

In their search, both owner and project engineers endeavored to find a solution based on proven technology. The technique applied in German coal mines of using deformable steel inserts with Toussaint-Heintzmann (TH) sections fulfilled the specified requirements.

After excavation of the cavity, two steel ring inserts each consisting of eight segments are assembled to form two concentric rings. The joins can slide over each other to a predefined limited extent, which allows the overall system to deform radially. When fully compressed, the system attains a maximum load-bearing pressure of approx. 1.8 MPa.

The insertion process is shown idealized and symmetrical in Fig. 5. However, this idealized situation will rarely be achieved in practice. The GBT project allows a degree of tolerance for uneven deformation, which in the mining industry leads to the term 'swimming inserts'.



	1	2	4
X-section area	approx 70 m2	approx 80 m2	≤135 m2
Extra width for deformation	-	≤ 20 cm	≤ 75 cm
Steel inserts	-	≤ 1,5 t/Tm	≤ 10 t/Tm
Radial anchors	≤ 20 m'/Tm	≤ 20 m'/Tm	≤ 250 m'/Tm
Face anchors	-	≤ 20 m'/Tm	≤ 210 m'/Tm

Figure 9. Comparison of tunnel support system.

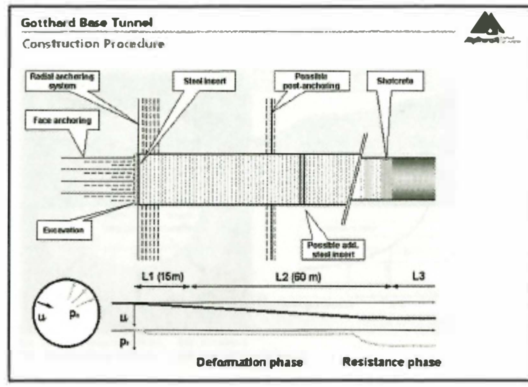


Figure 10. Construction procedure.

In the most extreme case, the steel rings are inserted practically 'shoulder to shoulder'. In addition to the steel inserts, the system is also reinforced with a systematic radial anchoring using up to 25 m of anchor per tunnel meter. The tunnel face is also anchored to a similar extent.

After the steel rings have been inserted, they are permanently concreted into place with shotcrete.

The overall supporting concept in the Sedrun section is modular, so as to allow optimal deployment of the associated machinery.

3.3 *Constructional aids*

Constructional aids are measures which enable driving under exceptional conditions by improving the rock (increased strength, rigidity, reduced permeability, etc.) and assuring the stability of the tunnel face.

In the main contract for the construction of the Sedrun Section, the following measures are foreseen:

- long advance drainage;
- grouting (individual grouting, grouting shields, grouting bodies);
- reinforcement of tunnel-face anchors and lances;
- re-profiling if necessary.

3.4 *Construction procedure*

The procedures for creating the profile are based on the following considerations:

The exploratory bores which have been made in the TIM (North), and the associated laboratory tests, indicate that in the TIM (North) an extreme amount of squeezing must be expected. Quick closure of the ring is therefore essential to keep the cross section open. For this reason, in the Sedrun section full-face excavation will always be used followed by immediate ring closure. The procedure for closing the ring will be as follows:

- After each advance, the steel rings are inserted (2 × TH 44, minimum distance 33 cm).
- 12 m long radial anchors are inserted to form an anchoring system.
- 18 m long tunnel-face anchors are inserted after every 6 m of advance.
- When the full length of the sliding join has been taken up, the circular force in the steel insert and with it the risk of buckling, increases. For perfect embedment, and to ensure the full load-bearing capacity, the steel rings are then completely shotcreted in. In the project, it is assumed that the insertion phase is completed 75 m behind the tunnel face.
- Within this distance of 75 m it is stipulated that over the entire cross section additional supporting measures must be possible, namely
  - insertion of additional steel rings
  - re-anchoring during the deformation process
  - application of a shotcrete lining after the deformation process is complete.

For this construction procedure to be possible, some major logistical challenges have to be mastered. The driving equipment must be capable of coping with enormously different dimensions (e.g. tunnel faces from 65 m^2 to 135 m^2). Also, the limited amount of space in the temporary base of the tunnel restricts the extent to which machines can pass each other. Because of this, large parts of the installations are placed on a following hanging plat-form.

For installation of the steel rings, as well as for various tasks at the tunnel face, so-called tunnellining machines are being used for the first time in railway tunnel construction. These machines allow insertion of steel inserts using two working platforms and a manipulator arm; application of the tunnel-face sealing

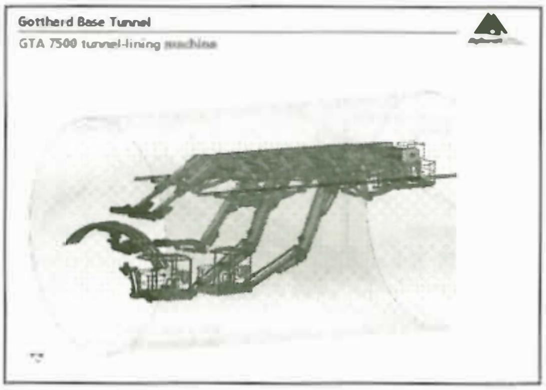


Figure 11. GTA 7500 Tunnel lining machine.

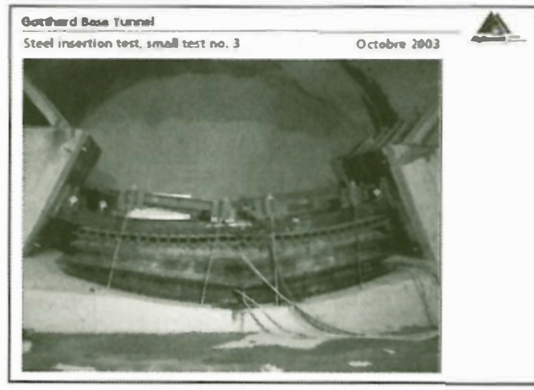


Figure 12. Steel rib tests, small test.

from the work platform by means of spray nozzles; cutting the tunnel-face anchors to length with hydraulic pincers.

Such installations for insertion of steel supports are used in mining, but not with the dimensions required on the Sedrun section where a weight of 50 tones has to be suspended from overhead rails.

The tunnel-lining machine is augmented with a backup suspension platform from the ROWA Company.

4 INNOVATIVE IN SITU TESTS FOR STEEL RIB SUPPORT

The concept described above is, as stated, based on already known technology. However, in the Sedrun section, tunnel cross sections of up to 13 m diameter must be excavated. Since experience with such large dimensions is lacking, critical questioning of important assumptions such as, for example, the insertion procedure and the assumed load-bearing capacity of the steel ring inserts was necessary before implementation.

The owner, AlpTransit Gotthard Ltd., therefore decided to contractually re-quire the contractor to perform a suitability evaluation of the proposed system. In consequence, tests ordered by ATG were performed on the construction site at a scale of 1:1.

The principle used in the tests is for the rock pressure to be simulated by means of inflatable rubber cushions. Such cushions are known in lifting technology for lifting heavy weights.

To gain greater familiarity with the system, a large number of small tests were performed on a single ring segment. This allowed the participants to test the necessary adaptations to the system with low outlay.

The tests began in the autumn of 2003 and were completed in spring 2004.

The results of the tests confirmed the theoretical calculations with the predicted accuracy. The selected

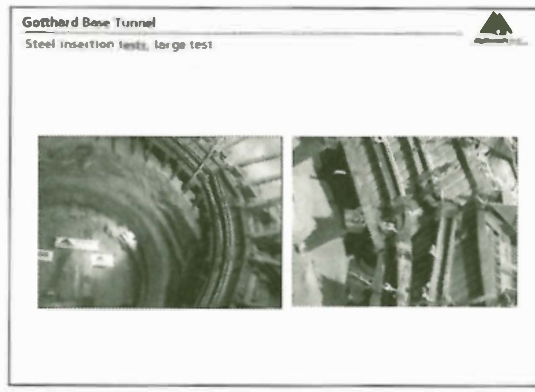


Figure 13. Steel rib tests, large test.

concept can therefore be judged to be suitable. However, the tests also showed potential limitations of the system.

In a subsequent large test, two complete steel rings with a diameter of 13 m were loaded to failure. With a closing distance of 60 cm, the knowledge regarding compression behavior and load-bearing capacity which was gained in the small test was confirmed.

At the same time, a certain margin for unexpected conditions, and potential for possible optimization, was also identified. It became evident that the direction of insertion of the shape of the steel-profile is of only minimal significance. In practice, the focus will be mainly on optimizing the system of single rings with smaller distances between the rings, since the additional load-bearing capacity of a double ring is not significantly greater than that of a single ring. Everyone involved in the project is aware that, despite the utmost care in preparation, further optimization will have to be achieved. For this purpose, a permanent working group with representation of the construction contractors, the project engineers, the local construction management, and the owner has been set up so as to be able to respond swiftly when required.

It was certainly right to perform the tests on the construction site rather than in the laboratory. This gave the driving team the opportunity to experience for the first time the techniques which will have to be used and the immense forces which will be encountered. This aspect must not under any circumstances be underestimated, since compression of the steel inserts is accompanied by loud noises which are not usual in tunnel construction.

5 CONSTRUCTION STATUS AND OUTLOOK

Since the contract was signed in April 2002, an enormous amount of work has been completed by the Transco Sedrun consortium. First, extensive installation works had to be done both above and below ground to make systematic construction work at all possible. At the same time, Shaft 2 was sunk, and lined with fireproof shotcrete, thereby becoming the first underground structure to be completed in the Sedrun section.

Since November 2003, driving at up to nine workplaces at tunnel level has proceeded practically unhindered by installation activities. Between 400 m and 700 m of tunnel system were constructed each month at a depth of more than 1.5 km under the mountain of Tgom.

In mid-May 2004, the transition zone to the area of squeezing rock was reached in the northward drive. Until autumn 2004 even in zones of bad rock quality no phenomena of squeezing rock occurred at Sedrun. In December 2004 rock masses with a high potential of squeezing were detected in the exploratory drillings. From the beginning of the year 2005 the construction procedure will follow the before mentioned method in the northern drive.

It is self-evident that under conditions with highly squeezing rock only greatly reduced rates of advance are possible. Whereas in favorable geology advance rates of more than 7 m of excavated tunnel per working day are possible, in squeezing-rock zones the advance rates fall to less than 1.0 m per working day.

Figure 14. Status of work, September 2004.

The facts as described lead to the following key dates for the construction schedule of Lot 360:

– Start of construction	April 2002
– Shaft II sunk	End-May 2003
– Start driving north	July 1, 2003
– Start driving south	August 1, 2003
– Start driving in squeezing-rock zones	Summer 2004
– Breakthrough at north	July 2008
– Breakthrough at south	October 2008

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