Saint Martin squeeze

G Barla, Politecnico di Torino, M Rettighieri and Fournier, of LTF, A Fava, of Alpina, and J Triclot, of Egis, describe the current status of the Saint Martin Access Adit and the related research studies on squeezing rock being undertaken

Above: View in the background of the support system initially adopted which underwent convergences up to 2m and later needed to be re-profiled

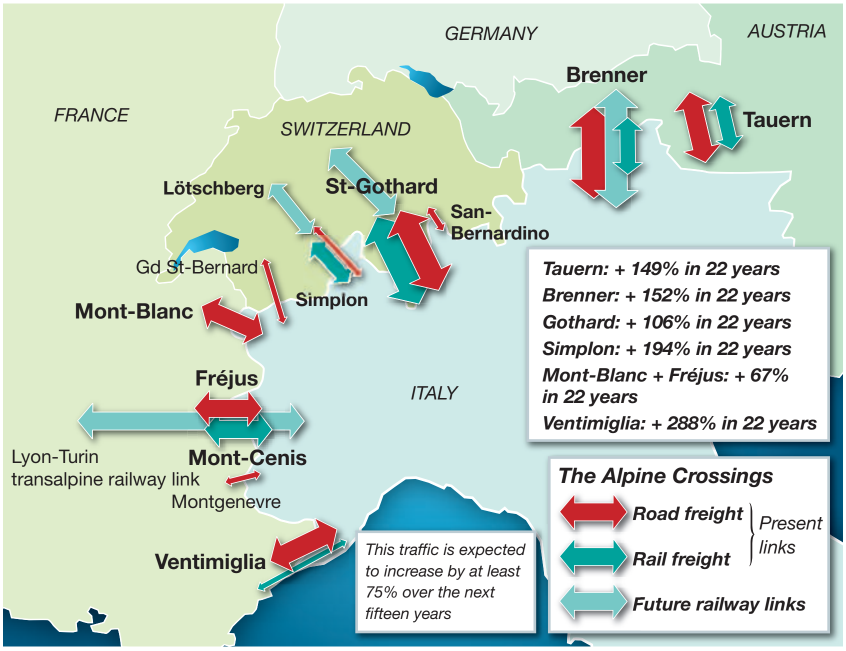
The Saint Martin La Porte access adit is a vital part of the early works for the US$11.7bn, 53km long Lyon-Turin Base Tunnel. It is currently being successfully excavated using a novel method through ground that at times exhibits extremely severe squeezing conditions[1]. An essential feature of this method is a two-stage excavation sequence with the installation, in the second stage, of a shotcrete lining which incorporates steel ribs with sliding connections and yielding concrete elements in longitudinal slots.

This method proved successful in permitting excavation, with construction proceeding slowly, where the cross section and stabilisation methods previously adopted failed so dramatically that it brought face advance almost to a standstill.

Lyon-Turin high-speed rail link

The Lyon-Turin high-speed rail link is at the centre of the axes linking the North and South, and East and West Europe (figure 1).

The 53km long, parallel tube Base Tunnel is to be excavated between the portals in Italy and France (figure 2). At present two access adits (La Praz and Saint Martin La Porte) are being excavated and one adit (Modane) is complete. They are essential for understanding the geological, geomechanical and hydro-geological conditions along the alignment and for the selection of the excavation method to be used for the Base Tunnel. They will also provide multiple faces for construction, and be used for ventilation access for maintenance and rescue teams if necessary.

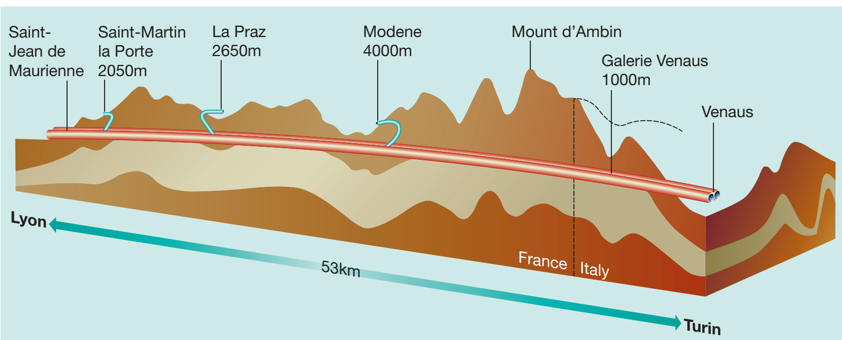


Above: Fig 1 - The Lyon-Turin high-speed railway link responds to the increasing traffic through the Alpine crossings

Saint Martin La Porte access adit

The Saint Martin La Porte access adit is being excavated in the Carboniferous Formation, "Zone Houillère Briançonnaise-Unité des Encombres" which is composed of black schists (45-55%), sandstones (40-50%), coal (5%), clay-like shales and cataclastic rocks. A characteristic feature of the ground observed at the face is the highly heterogeneous, disrupted and fractured conditions of the rock mass that exhibits severe squeezing problems. The formation is often affected by faulting resulting in a degradation of the rock mass conditions.

The overburden along the tunnel ranges from 300-600m although excavation takes place in essentially dry conditions. In order to assess the rock mass quality during excavation, detailed mapping of the geological conditions at the face was undertaken. This provides information to evaluate the percent distribution of "strong" (sandstones and schists) and "weak" (coal and clay-like shales) rocks at the face. It has been found that the "weak" rocks are the main cause of the squeezing problems associated with the Carboniferous zone, having an estimated length of more than 600m.



Above: Fig 2 - The Base Tunnel between Saint-Jean de Maurienne and Venaus including the three access adits

Above left: **Installation of the highly deformable concrete elements in stage 2**
Above right: **Excavation of the invert and placement of steel ribs in stage 2**

Excavation support system

Several support systems were used in the Carboniferous zone. It soon became apparent that stiff support would not work in the squeezing conditions. The design concept finally chosen allowed the support to yield while using full-face excavation with systematic face reinforcement by fibre-glass dowels. The support system initially implemented consisted of yielding steel ribs with sliding joints (TH, Toussaint-Heintzmann type), anchors and a thin shotcrete layer in a horseshoe profile (P7.3). These sections of the tunnel underwent very large deformations with convergences up to 2m and later needed to be re-profiled.

To improve the working conditions and to control deformations, a novel support system was implemented with a near circular cross section (DSM) (figure 3).

Stage 0: face pre-reinforcement, including a ring of grouted fibre-glass dowels around the opening perimeter, designed to reinforce the rock mass over a 2-3m thickness.

Stage 1: mechanical excavation carried out in 1m steps, with installation of 8m long un-tensioned rock anchors along the perimeter, yielding steel ribs with sliding joints (TH type), and 100mm of shotcrete. The tunnel is opened in the upper cross section to allow for a 600mm convergence.

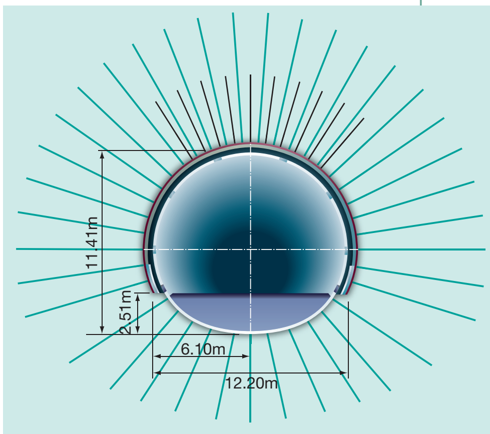
Stage 2: the tunnel is opened to the full circular section 15-25m from the face, with 200mm shotcrete lining applied, and yielding steel ribs with sliding joints (TH type) with 9 longitudinal slots (one in the invert) fitted with highly deformable concrete elements. The tunnel is allowed to deform so as to develop a maximum convergence that should not exceed 400mm.

Stage 3: installation of a coffered concrete ring 80m from the face.

The deformable elements are installed in slots in the shotcrete lining between TH type steel ribs[2] allowing controlled deformations to take place. At Saint Martin each deformable element has a beam shape (height 400mm, length 800mm, and thickness 200mm) designed to yield at approximately 40% strain, with a yield stress chosen to be 8.5MPa. It is composed of cement, steel fibres and hollow glass particles. The glass particles increase the void fraction of the mixture and collapse at a predetermined compressive stress. The yielding strength depends on the composition of the mixture.

FACT FILE

Saint Martin La Porte Adit Fact File
Client – LTF (Lyon Turin Ferroviaire SAS)
Contractor – Razel/Pizzarotti/Bilfinger Berger/Granulats Rhone-Alpes
Contractor's Consultant – Terrasol
Engineer – Egis Tunnels/Alpina/Antea
Engineer's Consultant - G Barla, Politecnico di Torino
Adit Cost - US$231M
Adit length – 2280m
Adit section – 100m^2 (approx)
Construction method – 780m D&B, then pick hammer
Construction start – July 2003
Construction finish – Mid 2009
Current Progress (May 2008) – 1839m

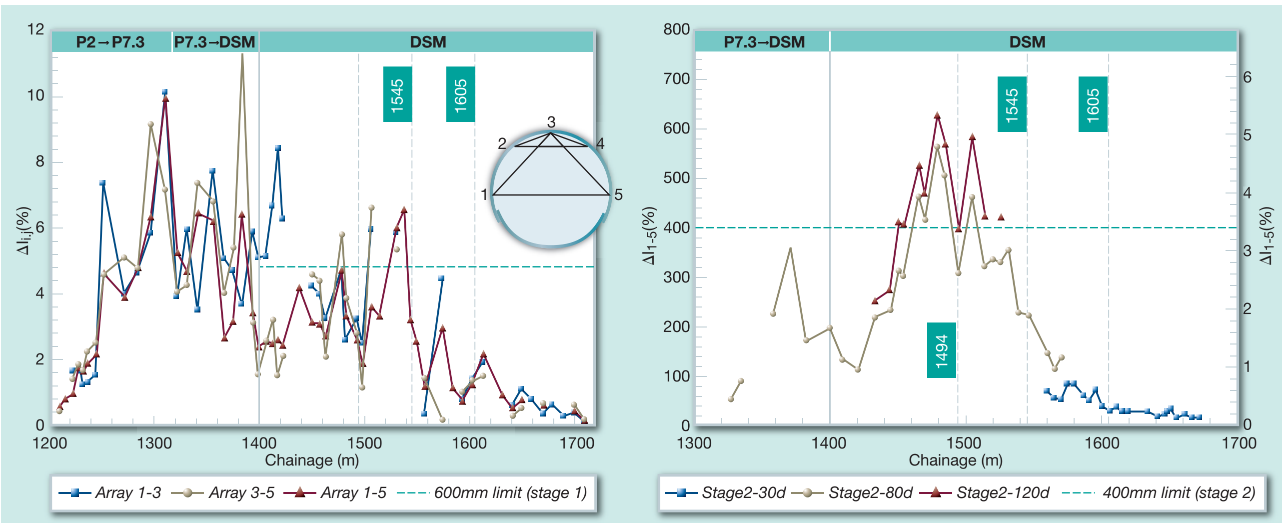


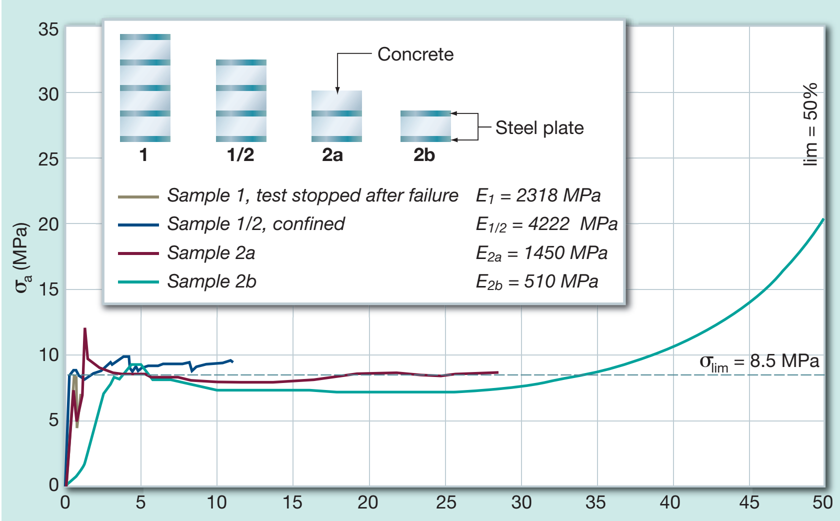
Above: **Fig 3 - Tunnel cross section showing the new excavation support system (DSM) adopted between chainages 1325 and 1700m**

Controlled response

Systematic monitoring of convergence is underway along the tunnel where the support system described is being adopted systematically. Convergences are measured by means of optical targets placed along the tunnel perimeter. A number of special sections have been equipped with multi-position borehole extensometers and strain meters located across the deformable elements. Extrusometer monitoring has been used to measure the longitudinal displacement ahead of the tunnel face. In addition, the strain level in the primary lining

Below: **Fig 4a (left) - Deformations along arrays 1-3, 3-5 and 1-5 at 15m from the face in stage 1. Fig 4b (right) - Convergences at 30, 80 and 120 days after excavation with stage 2 installed**





Above: **Fig 5 - The characteristic curve obtained under uniaxial loading of the deformable element in the laboratory.**

has been monitored.

To understand the tunnel response, consider figure 4a, which shows the convergences measured along arrays 1-3, 3-5 and 1-5 (Δl_{i-j}) between chainage 1200m and 1700m, with the tunnel face being 15m ahead of the monitoring section. Up to chainage 1400m, the tunnel has been excavated using the P7.3 system; thereafter, the new DSM system, as described in figure 3, has been used systematically. Also illustrated in figure 4b, the tunnel "deformation" (i.e. convergence divided by the length of each array measured at the time of installation of the optical targets) that has occurred along the same tunnel length. It is relevant to point out that three stops of face advance shown in the same figure took place as follows: at chainage 1494m, for 18 days due to the 2006 Christmas holidays; at chainage 1545m, for 28 days, in relation to the tendering procedure that took place between April and May 2007; at chainage 1605m, for 14 days, for the excavation of a side drift at chainage 1488m.

Additional observations can be made:

1) Large deformations are associated with cross section P7.3 between chainages 1200 and 1400m; with cross section DSM the convergences in phase 1 are mostly smaller with tunnel strain never exceeding 6-7%

2) The 600mm allowed convergence with cross section DSM has been exceeded locally (e.g., between chainages 1525 and 1550m where the rock mass quality was very poor) and required re-profiling of the tunnel cross section before installing the composite lining adopted in phase 2

3) The tunnel deformation associated with cross section P7.3 appears to be rather different in one section with respect to the neighbouring one, which generally is not the case for cross section DSM.

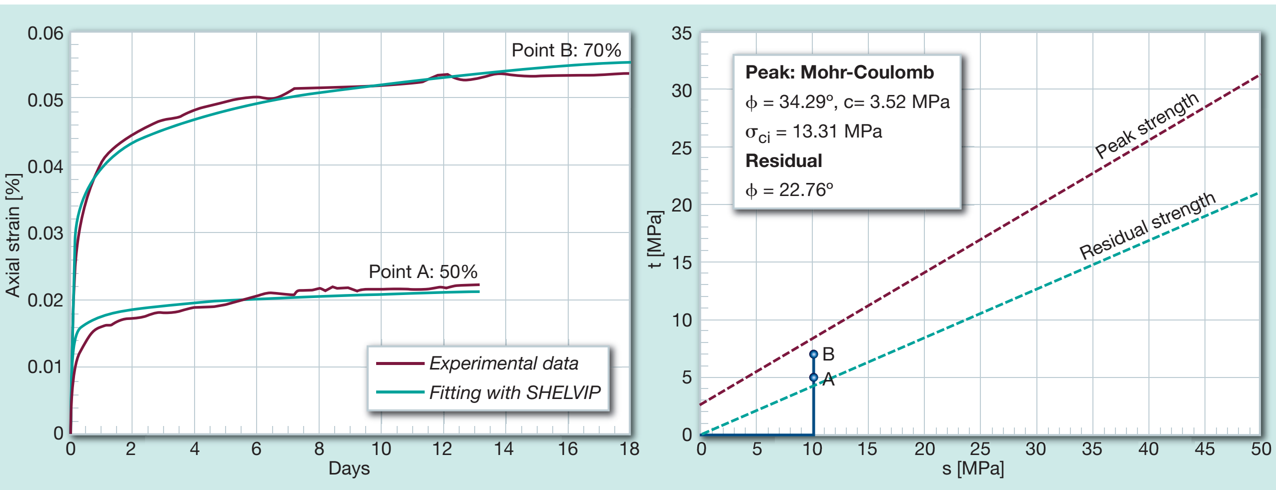
It is also important to consider the tunnel convergence versus time in stage 2 depicted in figure 4b. This behaviour occurs at a significant distance from the advancing face and when the yielding support has been active for a certain time duration and the final concrete lining has not yet been installed. The diagram is for 80 and 120 days following excavation of the monitored section. It is noted that between chainage 1450 and 1525m, the tunnel cross section experienced deformations along array 1-5 in excess of that theoretically allowed (400mm). In such a case the yielding elements on the right wall (looking at the tunnel face) attained the allowed 40% limit strain (figure 5) so that visible overstressing occurred in them, which did not seem to be an issue because no difficulty was encountered before installing the final lining.

Innovative developments

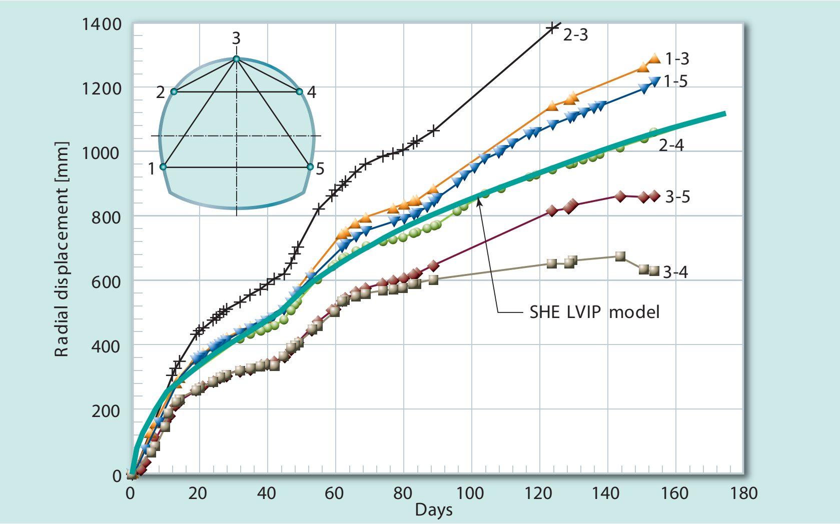
The use of the deformable element with the DSM excavation-support system went through a learning process, which resulted in its careful installation having no adverse impact on the overall advance cycle. To underline the role of such an element incorporated within the primary lining, it is of interest to show in Figure 5 the characteristic curve of the deformable element obtained in the laboratory. It is clear that as the yield stress is reached the element becomes plastic and the stress in it remains equal to 8.5MPa. Actually, the element incorporated in the lining is capable of shortening under a nearly constant tangential stress, while it applies to the surrounding rock, which is squeezing, a non-zero radial stress. It is this radial stress that is important in controlling the rate of deformation in the tunnel.

Squeezing is time dependent. Thus, under the most severe squeezing in the Saint Martin access adit, an appropriate representation of the tunnel response can only be obtained by using a behavioural model that may account for time dependence. This originates from the fact that time dependent deformations are observed whenever face advancement is stopped and these are likely to take place during excavation, when it is difficult to distinguish "face effect" from "time effect".

Based on triaxial creep tests performed in the laboratory on coal samples taken from the tunnel face and from borehole drilling, a Stress Hardening ELastic VIscous Plastic model (SHELVIP) has been derived. According to such a model, the time-independent plastic strains develop only



Above: **Fig 6 - Comparison of predicted (SHELVIP model) and measured behaviour in laboratory creep tests on coal samples**



Above: Fig 7 - Comparison of predicted (SHELVIP model) and observed behaviour in the Saint Martin access adit during face advance. Monitoring section at chainage 1311m, with the old excavation-support system adopted (P7.3)

when the stress point reaches the plastic yield surface. The viscoplastic strain rates develop only if the effective stress state exceeds a given viscoplastic yield surface. The SHELVIP model is shown to describe well the results of creep tests of coal samples in the laboratory (figure 6). The same model can also reproduce the time dependent response of the tunnel during excavation[3, 4] (figure 7). Note that the results presented are for the tunnel cross section at chainage 1311m (P7.3), which experienced very large deformations when the excavation-support system adopted was that used prior to the one finally adopted.

Conclusions

Tunnelling in squeezing conditions is very demanding due to the difficulty in making reliable predictions at the design stage.

The system adopted in the Saint Martin La Porte access adit proved effective in coping with this. A number of factors have been essential: teamwork; attention to the understanding the geological and geomechanical conditions to the readiness in adapting the excavation-support system to such conditions; the attention posed to observation and monitoring during face advance; and the conviction that the observed performance may allow, through a reliable model of behaviour for the rock, reliable predictions of tunnel response. T&T

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