Short presentation of Loetschberg base tunnel

Switzerland is now building two major high-speed railway tunnels through the Alps:
- the Gotthard base tunnel: 57 km
- the Loetschberg base tunnel: 34.7 km (which is connected to the existent Simplon tunnel)

The traffic of freight through the Alps between Italy and Northern Europe is always increasing. The Alpine Valleys are more and more affected by pollution of the road traffic. To stop this unfavourable evolution, government and people of Switzerland have decided to build two new alpine high-speed railway lines.

With the new Loetschberg-Simplon line the travelling time through the Alps (North-South in the direction Basle-Milan) will be reduced by about one hour. By the completion of these two tunnels Switzerland will be integrated into the European high-speed network.

The Loetschberg base tunnel connects Frutigen in the Kander Valley (Canton Bern, altitude: 778 m) to Raron in the upper Rhone Valley (Canton Valais, altitude: 656 m). The apex is situated at 828 m. The overburden reaches up to 2 000 m. The tunnel is designed as a system with two twin single-track tubes.

But for economical and political reasons, only the Southern portion of the tunnel will be fully completed in 2007. In the middle part from Frutigen to Ferden both tubes are excavated but only the eastern tube will be fully furnished. In the Northern portion only one tunnel is excavated while the exploratory gallery will serve as a safety tunnel. It can be implemented in a future stage to create a direct link in direction of the middle Rhone Valley through the Steg lateral adit.

The length of the Loetschberg base tunnel is 34.7 km, but the total length of all the galleries is about 88 km.
The tunnel is designed for the circulation of high-speed passenger trains (200-250 km/h) and for transport of heavy goods vehicles with a 4 metres headroom height (140 km/h).

The area excavated with drill-and-blast traditional method varies between 65 and 70 m$^2$. The normal tunnel profile is a horseshoe shaped cross section. Invert is necessary only on bad rock conditions. The rails are fixed on a concrete slab. Clear water is separated from water from inside the tunnel to avoid pollution in case of accident.

In the section excavated with a TBM, the diameter is 9.43 m. Both twin tunnels are separated by a distance varying from 40 to 60 m. Transverse galleries are built every 333 m.

The paper focuses on the construction of five large caverns at the Loetschen intersection, where the Steg lateral adit meets the main tunnel.

**Geology**

The Northern section of the Loetschberg base tunnel is formed by Flysch (shales, calcareous schists, sandstone) overlain by the Wildhorn nappe (limestone, shales, sandstone). The Doldenhorn nappe is formed of hard limestone to marly limestone. In this nappe the risk of karst with important water inflow was suspected. Before
reaching the massive Gastern a short but difficult autochthonous zone of Triassic rocks (dolomites, shales, gypsum, sandstone) was crossed. But after 500 m in the granite, the Trias reappeared unexpectedly. It was followed by a Carbon zone (schists) which gives very important convergence. Then the granite came back as expected.

![Figure 2: Tunnel geological longitudinal section](image)

South of Ferden the tunnel was excavated as planned in the old crystalline (steeply dipping gneiss and schists) of the Aar massif. In the Aar massif a sedimentary wedge (Jungfrau wedge) with water under high pressure (up to 100 bar), a Carbon trough and two phyllites are intercalated in the gneiss. In the amphibolitic gneiss fractures with asbestos were regularly found of about 4 km. Further South the tunnel crosses the granite of central Aar massif and the Baltschieder granodiorite. On the last three kilometres the tunnel runs through the Southern Autochthon (limestone and sandstone and Trias rocks) with a short old crystalline section for the last 500 m.

**Rockburst in the base tunnel**

Due to the high overburden (up to 2000 m) the risk of spalling and rockbursting was expected in the granite and the granodiorite.

Rockburst and spalling can occur in massive rockmass of brittle rock under high stress level. In the last 10 years the Canadian researchers (P. Kaiser, S. Martin, M. S. Diederichs and al.) have done an important way in the comprehension of brittle failure phenomenon.

The onion-skinning appears at the maximum point of stress. According to Kirsch theory (1898) the maximal tangential stress at the tunnel wall is given by the equation:

$$\sigma_{\text{tan stress}} = 3 \sigma_1 - \sigma_3$$

where $\sigma_1$ and $\sigma_3$ are the natural maximal and minimal stresses.
In the Loetschberg base tunnel the natural principal stress is vertical so that onion-skinning (spalling) appeared symmetrically in the side wall according to theory. The onion-skinning initiated at the level of tunnel shield (4.5 m). The hazard for the tunnel workers was reduced. There is no evidence of strong rock ejection (rockburst) but strong acoustic emission has been heard during TBM stops.

Deep notches up to about 1 m have appeared and that gave problems to seat the TBM grippers on the tunnel walls.

In the first TBM drive of Steg support was provided with 4 m Yielding-Swellex bolt in association with wire mesh (over 220°) directly behind the TBM-shield (5 m behind cutter head). Then in the zone of the back-up trailer 7 to 10 cm shotcrete was applied on the mesh. But severe rockburst was not observed and the Client's engineers decided to use conventional Swellex bolts for the parallel TBM drive of Raron.

The caverns of Loetschen

The adit of Steg can be implemented in a future stage to create a direct link to the middle Valais. For connecting this future railway line with the base tunnel, a giant intersection cavern (L = 340 m, W_max = 23 m) and a crossover between the two main tubes, with two connecting caverns (L = 263 m, W_max = 23 m), have to be built now.

And two other big caverns (L = 60 m, W_max = 21 m) are necessary to install the electro-mechanical equipments.

The caverns of Loetschen are located in the hard and massive granite of the central Aar massif

The tunnel was driven with an open TBM first. Only when the tunnel was completely bored, the contractor began to blast the five large caverns of the Lötschen intersection.

The orientation of the electromechanical caverns is very important. During the execution of some other caverns and small lateral galleries, we had several problems
with all the structure which were perpendicular to the tunnel axe. So we decided to turn the cavern parallel to the tunnel, according to a proposal of Prof. Descoeudres.

A lot of spalling occurred in Loetschen zone during TBM-excavation. So IGWS engineers decided to undertake a 3D-modelling of the caverns before the beginning of the blasting to verify and adapt the previous support especially for the pillar of the intersection and crossover caverns.

**3D-Modelling of crossover cavern**

The model of the crossover cavern is composed of twelve thousand six hundred nodes. Due to the high overburden, the vertical load, 43 Megapascal, is quite uncommon.

This model was developed at IGWS engineers joint-venture office by Mr. Regis Marclay. The computation was always running during the weekend on a standard PC.

One of the goal of the 3D-Modelling was to find the best excavation sequences, which minimizes the plastification of the pillar zone and finally the support cost.

Its not possible to model all the excavation stages of such a large cavern. So the final model is composed of four steps of unloading:

- The zones corresponding to the base tunnel, were discharged first, between time one and time five;
- Then the pillar zone is excavated between time six and time nine;
- After that the crossover gallery is done, between time ten and thirteen;
- Finally the excavation of the cavern itself is modelled between times fourteen and seventeen.

Exactly the same excavation sequence was performed in reality.
Exactly the same excavation sequence was performed in reality.

The computation showed that an eighty-meter long sector between the two tunnels is plasticized. Around the cavern and the tunnel the plastification is very deep, up to five meters. Hundred meters north of the pillar only a small elastic zone remains between the two tunnels.

According to computation the pillar itself is completely plasticized. That is a very unfavourable situation. So before the excavation of the pillar a very large number of grouted anchors were installed to prevent that risk.
Five meters South of the pillar, the depth of plastification is about five meters on the first and eight meters on the invert.

Figure 7: Stress level 5m beyond the pillar of crossover caverns

Prediction of the depth of brittle failure around the caverns

Prof. C. D. Martin and Prof. P. Kaiser have developed a criterion to assess the depth of brittle failure around a circular excavation. They assume that in the brittle failure process peak cohesion and friction are not mobilised together. So the depth of brittle failure can be estimated by using a strength envelope based solely on cohesion. This criterion has been expressed in terms of the Hoek and Brown parameters with the frictional constant \( m \) equal zero and \( s \) equal zero point eleven.

This criterion was verified by Rojat on the base tunnel where deep notches were observed.

Figure 8: Mesh of electromechanical cavern with access gallery
At the beginning the depth of brittle failure was estimated by hand by reading the listing. It was quite long. So IGWS Engineers wrote a small basic software to transfer automatically the results on an Autocad drawing.

The same type of calculation was performed for the two big electromechanical caverns. The main problem of these caverns is the intersection with the access gallery, which is in an unfavourable orientation according to the experiences in the Loetschberg base tunnel.

The transfer was done on a 3D-drawing. This type of drawing was used to define the length of the anchors.

Conclusion

The caverns of Lötschen were blasted without great difficulties. A very large number of four meters-yielding-swelllex-anchors were installed for the first support. Then 1700 eight meters and 4900 six meters long steel rebar were grouted.

Only the access gallery to the large electromechanical caverns gave some problems. We had to reinforce the support at some places due to excessive displacement of the gallery walls.

The unconfined compressive strength of the granite was probably higher than expected and we suppose that the tectonic stress induced a favourable confinement, what has reduced the risk of rockburst.
References
