THE LÖTSCHBERG BASE TUNNEL – LESSONS LEARNED FROM THE CONSTRUCTION OF THE TUNNEL

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Abstract - Construction work for the Lötschberg Base Tunnel in Switzerland is progressing according to schedule. As of the end of 2003 already 90 % of the total tunnel system has been broken out. With the building of the Lötschberg Base Tunnel the future connection of Switzerland with the most modern and fastest rail systems in Europe is assured.

THE SWISS TRANSPORT POLICY

Generalities

The growth of all forms of traffic still seems unending. This puts more and more strain on the infrastructure, and capacity is rapidly becoming exhausted.

The people of Switzerland have expressed their will and clearly spoken out in favour of modernising the railways and switching transit traffic from road to rail. The acceptance of the draft for the New Rail Alpine Routes (NEAT) in 1992 formed the basis for planning. With the performance-related levy on heavy goods traffic (LSVA) and the bill for modernising the railways, the legislature gave the green light in 1998 for Switzerland's greatest ever investment programme.

Modern links for Europe

By building the NEAT, Switzerland is integrating itself in terms of passenger traffic into the successful European high-speed network.

The NEAT system is designed as a network solution, together with the two Lötschberg-Simplon and Gotthard axes. The new rail link through the Alps involves two new rail tunnels, one through the Lötschberg, the Lötschberg Base Tunnel with a length of 34.6 km and the other one through the St. Gotthard, the Gotthard Base Tunnel with a length of 57 km.

Figure 1. The Swiss Rail Network

Financing the project

The Swiss electorate agreed to a fund of more than 30 billion Swiss francs (around 20 billion Euros) for the modernization and development of the railway infrastructure. The projects include the New Rail Link through the Alps with the Gotthard Base Tunnel and the Lötschberg Base Tunnel, the project of Rail 2000 (railway network), the rail network noise reduction project and linking the system to the European high-speed network. The Gotthard Base Tunnel will cost about 10 billion Swiss francs (about 6.7 billion Euros) and the Lötschberg Base Tunnel will be realised for about 3.2 billion Swiss francs (about 2.1 billion Euros). Cash flows into the fund for major rail projects from the Mileage-Related Heavy Vehicles Tax, 0.1 per cent of value-added tax, and revenue from loans and taxes on fuels.

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Generalities

By incorporating the existing Lötschberg line and the modernised Simplon Base tunnel, Switzerland is establishing a high-performance link safeguarding the future through the Alps to extended access routes as far as the economic centres of Germany in the north and Northern Italy in the south. The Lötschberg axis in the west of Switzerland, as the only new transalpine route for some considerable time, will enable the handling of many different forms of combined goods traffic, including heavy goods vehicles with a 4 metre headroom height.

The structure

The Lötschberg Base Tunnel runs from Frutigen in the Kandertal valley to Raron in the Valais. The total length of the tunnel is 34.6 km. To the south it links up with the existing Simplon line. The design speed varies with the type of trains: this is 230 km/h for high-speed passenger trains and 140 km/h for shuttle trains.

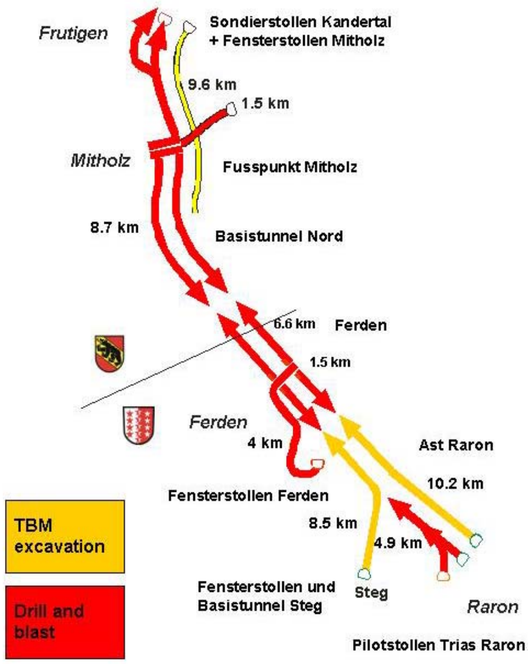

Figure 2. Main construction sections on the Lötschberg Base Tunnel

The Lötschberg Base Tunnel is designed as a tunnel system with two separate single-track tubes. The distance between the two tubes varies from 40 to 60 m, depending on the quality of the massif. Transverse tunnels connect the tubes every 300 m. The so-called transit function requires the European clearance profile EBV4 with 4 m headroom height. The cross-sectional diameter for excavation with a tunnel-boring machine (TBM) is 9.43 m. Excavation with the traditional blasting method yields a surface area between 62 and 78 m^2.

Safety is a very important aspect in the project. Two emergency stations have already been built, one in Mitholz and the other in the vicinity of the village of Ferden, about 700m underneath the ground level of the Lötschental valley. The emergency stations have been designed for rescuing passengers from a train in case of fire by use of the lateral adits, to remove smoke by a ventilation system and to pump fresh air into the rescue galleries.

The northern portal at Tellenfeld near Frutigen is located at a height of 780 m, and the southern portal at Raron, at 660m. The tunnel rises by 0.3 % until it reaches its apex in the mountains between the cantons of Berne and Valais and drops by roughly 1.1 % at its southern end. The tunnel has five major construction sites consisting of the Frutigen and Raron portals and the intermediate points-of-attack at Ferden (portal at Goppenstein Station), Steg (Niedergesteln portal) and Mitholz.

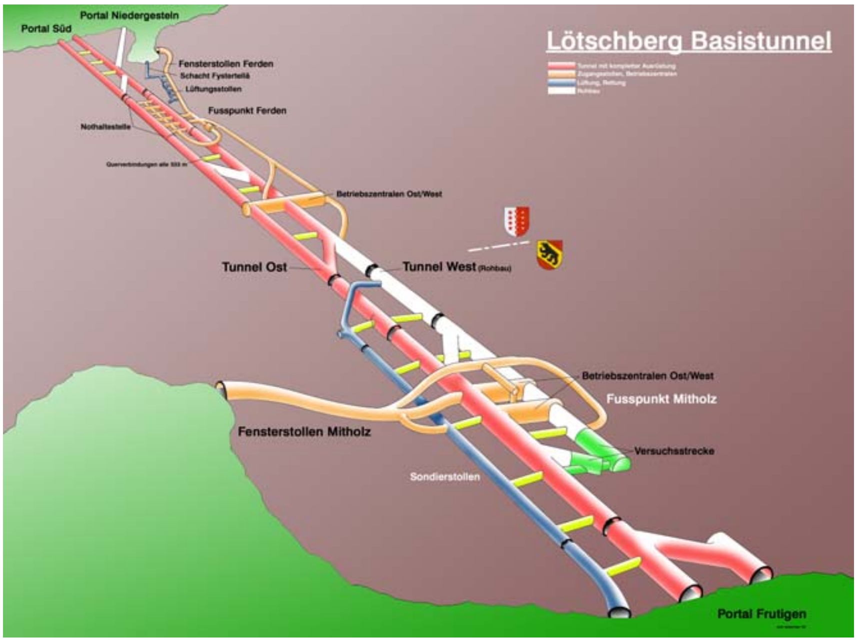

Figure 3. System with the two single-track tubes

The construction concept and programme

The Lötschberg Base Tunnel is split up into sections that can be optimally constructed in technical terms. The Mitholz, Ferden and Steg access tunnels serve as intermediate points-of-attack. From their base points, as well from the portals, the excavation of 11 tunnel sections can be embarked upon. This concept provides for the greatest possible flexibility and means that relatively short tunnel sections of up to a maximum of 10.2 km in length can be created.

From the south, two tunnel-boring machines (TBM's) are carving their way through the rock: for the Steg lateral adit/base tunnel and for the first 10 km of the eastern tube from the south portal at Raron. In all the other sections, the traditional method of blasting is being used.

The entire programme is directed at a short construction period and the Base Tunnel going into service in 2007. According to the overall construction programme, excavation is due to be concluded by the end of 2004 with the last breakthrough between the Mitholz and Ferden sections. Most of the interior finishing will be carried out during 2004 and 2005, with the rail technology being installed in 2005 and 2006.

The geology of the Lötschberg Base Tunnel

Geologically speaking, the Lötschberg Base Tunnel has been thoroughly investigated. This is in no small part due to the 9.4 km long exploratory tunnel in the north, which stretches from Frutigen to the Kandersteg district and was built between 1994 and 1996. The existing Lötschberg apex tunnel, as well as tunnels for power stations, roads and railways and a large number of exploratory boreholes provided invaluable geological information.

The geological profile is given in figure 4.

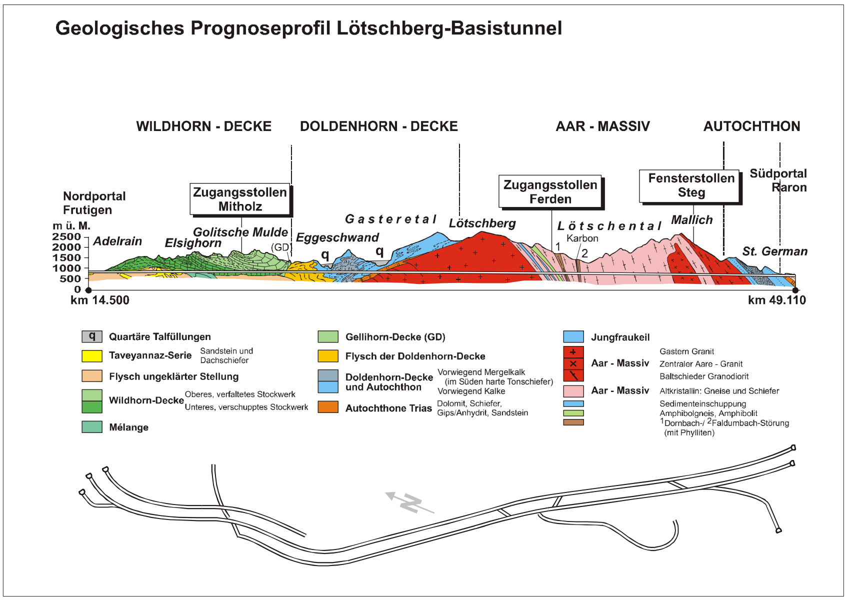

Figure 4. Geological longitudinal profile for the Lötschberg Base Tunnel

The material management for the Lötschberg Base Tunnel

Altogether 16 million tonnes of spoil will be produced during the building of the Lötschberg Base Tunnel. Approximately one third of this excavated material, the so called “class 1 – material”, will be reutilised in form of concrete aggregate for segments, shotcrete and case-in-place concrete. Excavation material of classes 2 and 3 is used for various purposes, for example constructing the avalanche protection tunnel for the cantonal highway at Mitholz. Material transport is mainly carried out via rail. Non-utilised excavated material is carried to dumps by means of conveyer belts or by rail.

The current state of operations

The length of the Base Tunnel is 34.6 km, but in reality, about 88 km of galleries must be excavated all in all. At the end of 2003 already 90 % of the whole system has been excavated. The first breakthrough between two Base Tunnels for the two main sections at Ferden (Drill and Blast) and Steg (TBM) was done the 14th December, 2002; the second one between Frutigen and Mitholz the 14th Mai, 2003 and the third one between Raron and Mitholz the 29th November, 2003. The principal and last one is predicted for the autumn 2004.

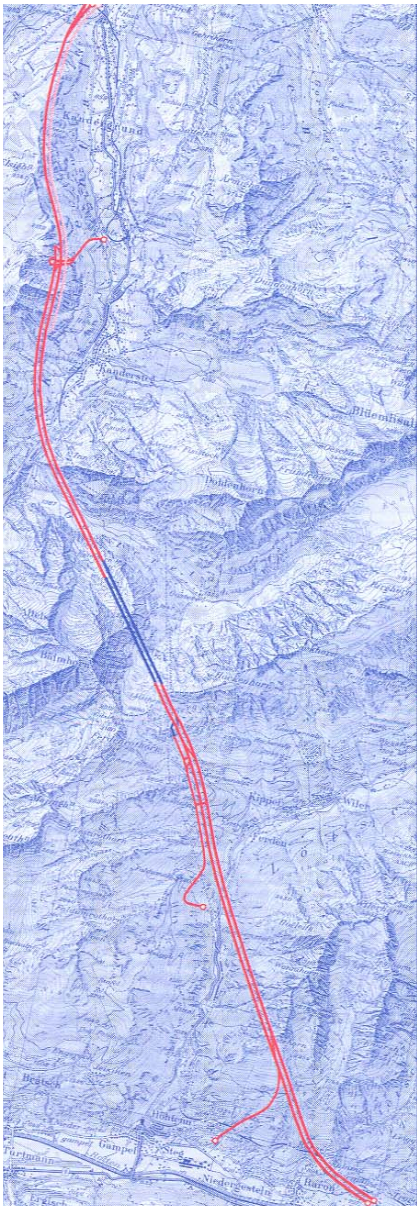

Figure 5. Current state of operations on December 5, 2003

LESSONS LEARNED FROM THE CONSTRUCITON OF THE TUNNEL

Rockburst

The depth of the Aar massif granite and granodiorite rock cover along the Lötschberg Base Tunnel route reaches up to 2000 metres in two places. The depth is greater than 1500 metres for a total of about 9.3 km. The risk of rockburst occurring is therefore relatively high.

Theoretical Studies

For the evaluation of zones with rockburst risk and their location, the Engineering Community IGWS applied the following procedure in the first phase: a) an investigation of the natural geostatic stress state of the rock mass on the basis of a 3D-FE modelling (3-dimensional finite element model). On the assumption that the controlling stress state was determined by the relief and not by the tectonics, only heavy weight phenomena were taken into consideration. The rock mass was modelled on the basis of the Swiss topological maps with 200 m contour lines. The simulation showed that the major stress direction should be vertical and that the intermediate and minor stresses should be horizontal, b) comparison of the results of the modelling with estimated stresses from hydro-fracturing tests in boreholes. From these comparisons the basic data could be fixed as follows: γ = 25 kN/m^3 und ν = 0.3, c) retro-analysis of rockburst phenomena in the existing Lötschberg apex tunnel: calculation of the tangential boundary stresses σ_t in the decompression zones of the apex tunnel and an estimate of the value of the σ_{tmax} / σ_c ratio (σ_c = unconfined compression strength) from which decompression phenomena could have occurred and d) evaluation of the risk zones in the Lötschberg Base Tunnel on the basis of the values determined in the apex tunnel under point c).

From experience with the Lötschberg apex tunnel and from comparisons with other underground constructions with rockburst problems (Mont Blanc tunnel), the following classification was formulated: class A = very high rockburst risk (75-100%) with σ_t > 130 MPa; class B = high rockburst risk (50-75%) with 120 MPa < σ_t < 130 MPa; class C = medium rockburst risk (25-50%) with 110 MPa < σ_t < 120 MPa and class D = low rockburst risk (0-25%) with 100 MPa < σ_t < 110 MPa. On the basis of this classification and the above theoretical considerations, about 4.1 km of the Lötschberg Base Tunnel were classified as class A, about 1.4 km as class B, about 1.4 km as class C and about 300 m as class D.

Rockburst phenomena encountered in the Lötschberg Base Tunnel

For the TBM-excavation two distinct failure phenomena could be identified: a) Block formation in front of the TBM head: The blocks have no particular shape; they are not slab-shaped like fragments typically encountered in spalling and slabbing processes. When these instabilities appear, instead of showing a flat aspect with clear marks from the cutters, the tunnel face is quite irregular. The marks from the cutters are then only visible in a smaller area of the face. In some cases this block-formation seems to be assisted by the presence of weak failure planes filled with chlorite. The blocks reduce the TBM utilisation time and penetration rate. b) Onion-skinning initiated at the level of the TBM shield: About 0 to 4 m behind the tunnel face, scales of low thickness peel off the walls in the excavation. When high overburden depth is encountered, deep notches up to about 1 m may appear, typically in a symmetrical pattern. In some cases, the notches prevented the grippers from making good contact with the rock mass, which caused significant output losses. The project geologist believes the difficulties encountered in this particular case are to a large part attributable to the increased fracturing of the rock. Most often, these phenomena were noticed in zones of strong massive rocks. Some strong acoustic phenomena have also been reported, but almost no violent projections of blocks have so far been observed. Apparently, most energy releases occur within 4 meters from the face within the TBM shield. There is no evidence that the TBM cannot handle the minor energy releases so far experienced.

Only sporadic strong acoustic phenomena have been observed up to now with tunnel blasting in the Lötschberg region. The excavation is not yet finished in this zone but till now the granite encountered is fairly jagged.

Rock-mass sealing of a high-pressure water-conducting zone for environmental reasons

After the entry adit at Ferden in Lötschental had already been excavated in September 2000, the work on both of the tunnel tubes of the major Lötschberg Base Tunnel lot 46.23.010 “Base Tunnel Ferden – BE” could be started. During the preliminary drilling north of the foot at Ferden, a water-conducting sedimentary slice was investigated. This lies prior to the intrusion zone of the Jungfrau Wedge. The planning and execution for the pre-treatment of this sedimentary slice lay in the conflict area of such factors as deadlines, costs, safety and certain environmental requirements in the planning authorisation regulations.

Geology

The two “sedimentary slice” and “Jungfrau Wedge” intrusion zones were investigated starting from the foot at Ferden in a northerly direction using a total of 5 preliminary core boreholes protected with preventers. These zones had to be crossed by the following three tunnels: a) the western Base Tunnel in the northern direction, with an excavation area of about 65 m^2, b) the eastern Base Tunnel in the northern direction and c) the entry/ventilation adit, with an excavation area of about 40 m^2.

The sedimentary slices consist of a sequence of TRIAS with anhydrite, LIAS/DOGGER with limestone and sandstone, SHALE with clay and limestone shales and again LIAS/DOGGER and have a total thickness between 80 and 90 metres. In the LIAS/DOGGER sequence a water-conducting zone was encountered with a thickness of about 8 metres. There the water pressure measured reaches up to 110 bars. The rock in the water-conducting area is of good quality. The Jungfrau Wedge appears as a sequence of TRIAS with quartz sandstone, bulky dolomite with anhydrite and JURA with limestone, clay and limestone shales and has a total thickness of between 40 and 45 metres. No significant water influx was encountered.

The challenges

During the surface-drilling probes made in the preliminary stages of the construction work, mountain water in the Jungfrau Wedge was encountered that showed the same chemical composition as the water in the thermal springs at Leukerbad. Thus it could not be excluded that the Jungfrau Wedge was a part of the catchment area for the thermal springs in Leukerbad. The possibility of affecting this thermal spring by the work on the Lötschberg Base Tunnel had to be excluded. Thus in the planning authorisation regulations, the requirement was defined that the maximum drainage per Base Tunnel tube in the region of the Jungfrau Wedge must be reduced to 1 l/s. The quantity of 1 l/s per tube was defined as a function of the water quantity flowing into the main thermal spring in Leukerbad.

The mountain water in the intrusion zones had a temperature up to 39.5°C and a fairly high sulphate content, up to 2 g/l. This placed certain requirements on the injection material used and on the protection extension of the tunnels.

The solution

Taking the deadlines and costs into consideration, the following procedure was laid down as a basic principle: only that which was absolutely necessary would be carried out with the absolute minimum of material, but upgradeable in order to subsequently attain the required results. This meant that the drilling was designed and executed so that at the same time it could be used for checking, drainage and injection drilling. In the case of the injection this was a sealing injection. The target was therefore to make a leak-proof ring at some distance from the tunnel.

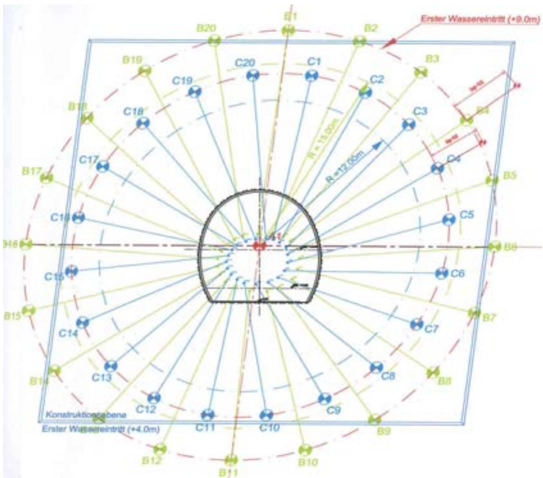

Figure 6. Drilling pattern

After drilling a borehole A in the middle of the tunnel for checking water pressure and quantity for the whole duration of treatment, generally two different drilling and injection rings, B and C, each with about 20 boreholes, were planned around the tunnel. The second ring C was only implemented in its entirety if the desired results were not achieved after injecting the previous ring B. The possibility of arranging a third ring D was available. By exacting monitoring the water influx in the preliminary reconnaissance drilling and the A drilling, a planned construction plane could be defined which reflected the spatial alignment of the general bedding. This plane lay in the centre of the first and last water influx and due to the safety margin was about 30 metres distant from the heading face. On this construction plane the defined radii of the rings were applied. The kinematics of the utilised drilling machines (height of the rotation point, distance from the heading face, etc.) had to be taken into consideration. By optimising the drill diameter and the method of drilling, a drilling operation relatively free of deviation could be guaranteed at the heading face.

The distance between the individual boreholes of the outermost B ring was between 5 and 6 metres for the Base Tunnel. Ring B was aligned at the construction plane at a distance of between 15 and 20 metres from the middle of the tunnel. Due to the offset borehole alignment in the various rings and the relative proximity of the individual rings to each other (distance about 3 metres), a continual sealing of the injection net could be achieved. The length of the boreholes varied according to the situation between 30 and 60 metres.

The following general applicable procedure was employed for pre-treatment and traversing the section: a) The tunnel is excavated to about 40-50 metres before the start of the predicted intrusion zone. b) With a core probe drill and preventer, the exact commencement, the geological sequence and the initial influx of water are determined. c) The tunnel is then excavated to within 30 metres of the first influx of water. d) From the tunnel header face the first boreholes of the B ring with preventer and stand pipes are carried out. Here the individual appearances of water are meticulously registered with location, quantity and pressure. e) Then follow the rest of the drillings of the B ring, which are generally carried out without preventer. f) Subsequently run-out tests, water injection tests and to some extent borehole photographs are made, which give an indication concerning the suitable injection material and the order for the injection procedure. g) After the choice of the suitable injection material follows the injecting into the B ring boreholes. Preliminary suitability tests and a detailed compilation of the controlling parameters are carried out each time. After the injection a certain hardening time has to be allowed. h) The efficiency of the first injections of the B ring can be checked on the basis of the water influx in the boreholes of the second ring C. The zones can thus be determined where the injection ring has to be improved. Here too run-out and water injection tests take place. i) Certain zones are subsequently injected via the C boreholes,

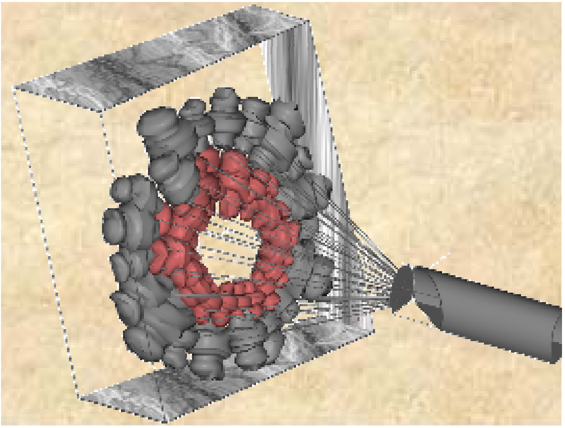

Figure 7. Injection of the B and C boreholes

j) Four relief boreholes in the face, which go out over the intrusion zone, test on one hand the efficiency of the C ring injection and on the other hand the risk of a water leakage at the front is reduced, k) tunnelling is carried out to within about 10-15 metres from the first water influx, l) an approximately 20 m long drainage screen is erected up front, m) tunnelling is carried out through the pre-treated intrusion zone with radial drainage drilling n) a second drainage screen up front is erected with a certain overlap with the first screen, o) A further traversing stage follows with radial drainage drilling, p) with the above-explained principle the whole pre-treated intrusion zone is crossed.

In close collaboration with the injection company and the injection specialist, various recipes were defined for small fissure openings that are not normally injected. These were tested in preliminary trials and optimised for their suitability. Finally the three following recipes were employed: “Rheosil grossier”, “Rheosil fin” and “Silisol”. The product Silisol, developed by the firm Soletanche, is a liquefied silicate with a similar viscosity to water. After hardening a sort of gel is formed, which although having no great resistance against pressure, is insoluble in water and possesses a good long-term stability. The stability of the extremely liquid injection materials in the fissures was evaluated as being satisfactory. Thus the various fissure widths or total porosities for each borehole could be specifically treated. Particularly the results of the water injection tests served as a criterion for deciding the choice of injection material.

The execution

In all 172 holes were drilled for both intrusion zones in a total length of 7.7 km and 233 m^3 of material were injected. Due to the very low water influx in the Jungfrau Wedge, injecting was dispensed with. Tunnelling of the access/ventilation adit has not yet reached the Jungfrau Wedge.

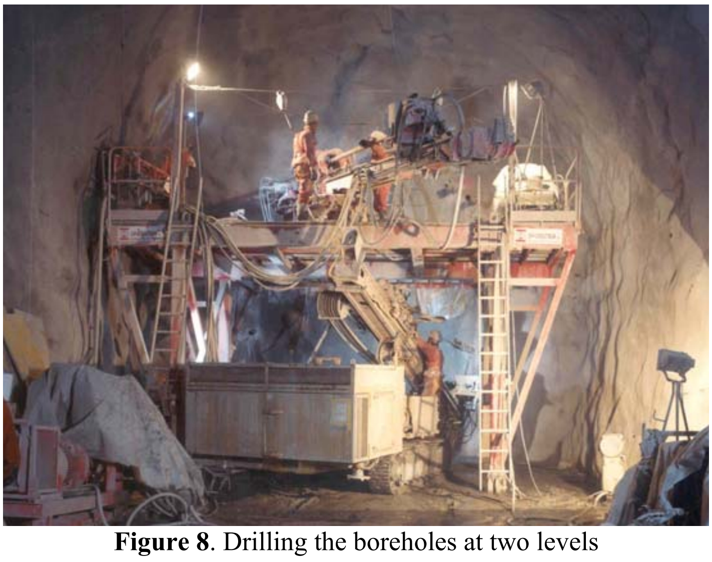

Figure 8. Drilling the boreholes at two levels

The costs for the pre-treatment, i.e. drilling and injecting in the sedimentary slice, amount to approx. 6.2 million SFr. for the three tunnel headers. Together with the special measures taken for the safe traverse with drainage screens and radial drainage drilling, which cost 0.6 milion SFr., the total costs amounted to 6.8 million SFr. The total costs for the Jungfrau Wedge for two tunnel headers and without injection are 1.6 million SFr. If one analyses the costs for the sedimentary slice, it can be seen that the boreholes contribute approx. 54% of the total costs. The installations cost about 19%, followed by material supplies with 13%, 10% for injecting and 4% for direction costs.

The pre-treatment of the sedimentary slice for the tunnelling of the Base Tunnel West with the core reconnaissance drilling and the approach tunnelling took 3.9 months. The pre-treatment of the sedimentary slice, i.e. drilling and injecting of the two rings, took 2.5 months. The crossing of the approximately 80 m long pre-treated sedimentary slice with the up-front drainage screens and the radial drainage drilling took about 50 days. The pre-treatment of the Jungfrau Wedge without injecting could be completed in a month and the crossing of the approx. 40 m long Jungfrau Wedge was managed in 25 days. The pre-treatment and crossing with the Base Tunnel East was effected in about the same time frame as the Base Tunnel West.

Prior to the injection work a water influx of up to 8 l/s was measured. The water influx after the completed pre-treatment and crossing with the three tunnel headers levelled off in all to about 3.3 l /s for the sedimentary slice and 0.2 l/s for the Jungfrau Wedge, so that at the moment the total drainage quantity for both intrusion zones is measured at 3.5 l/s. The water influx in the tunnels will now be observed over a longer period and then, if necessary, further reduced in the working phase by additional injections.

The pre-treatment measures carried out in the sedimentary slice and the Jungfrau Wedge can be considered to be successful and there should be no further hindrance for tunnelling to the north until the breakthrough point is reached with the miners in Mitholz.

FURTHER LESSONS

Further interesting lessons learned from the excavation of the Lötschberg base tunnel will be developed at the conference, such as :

- reuse of excavation material as shotcrete aggregate
- mastering of the temperature into the tunnel during construction phase
- mechanical characteristics of the rocks effectively encountered compared to previsions
- hydrogeological conditions effectively encountered in comparison with previsions

The general assessment of the project and of the construction of the Lötschberg base tunnel will also be given in the conclusion of the conference.

REFERENCES

[1] Teuscher, P. & Zbinden, P., 2002. Die AlpTransit-Projekte am Lötschberg und Gotthard. Betonbau in der Schweiz, First fib-Congress Osaka

[2] Teuscher, P. & Hufschmied, P., 2000. Lötschberg-Basistunnel: Beginn der Bauarbeiten. Tunnel 4/2000.

[3] Rojat, F. & Labiouse, V. & Descoeudres, F. & Kaiser, P.K., 2002. Project R487 Brittle rock failure at the Loetschberg, Steg sector. Laboratoire de Mécanique des Roches, Faculté ENAC – EPFL, Lausanne

[4] Hedley, D.G.F., 1992, Rockburst handbook for Ontario hardrock mines. CANMET special report SP92-1E, 305p

[5] Aeschbach, M., 2002. Lötschberg-Basistunnel: Gebirgsabdichtung einer wasserführenden Zone mit hohem Wasserdruck aus Umweltschutzgründen. IGWS. FGU-Fachtagung Thun

[6] Vuilleumier, F., Hufschmied, P., Seingre G., 2001. Travaux du Tunnel de base du Lötschberg. PATRON EDITORE World Tunnel Congress Volume I.