Experiences from the ground probing in the Gotthard-Base tunnel

Davide Fabbri, dipl. eng. ETH/SIA
Lombardi Engineering Ltd. - Switzerland
1 INTRODUCTION

1.1 Abstract

The Gotthard-Base Tunnel will be the world’s longest traffic tunnel, with a length of 57 km. The tunnel is part of the New Alpine Transverse in Switzerland. The dual purpose of this project is to provide a high speed link for passengers between Germany in the North of Europe and Italy in the South of Europe and to transfer freight traffic from roads to rail. It makes an essential step to actively protect the Alps and to get an important contribution to preserve the environment in general. At the present time the construction works are proceeding ahead at both portals and at the three intermediate accesses. 66 km or more than 43% of the total length of tunnels and the galleries are excavated. Some difficult parts of the tunnel have been completed successfully, some others with over 2,000 m of overburden and poor rock mass properties are under excavation right now.

The following paper deals with the probing campaigns at the Gotthard-Base tunnel, picking out the relevant information and presenting the guidelines for the procedures and for the interpretation of the results from the ongoing site activities. Although the importance of probing in the Gotthard tunnel is focused on the traditional headings, by obvious reasons, where the rather poor rock qualities are expected, the TBM headings, which cover nearly 90% of the total excavated length of the tunnel, are as well excavated under systematic, but generally simplified probing ahead of the front.

1.2 General information about the client and the project

The transalpine rail routes through Switzerland are more than a hundred years old. As they no longer meet the requirements of ever-increasing rail-traffic between north and south they are now being rebuilt. The actual Gotthard-Rail route is in fact a mountain railway: the northern and the southern access ramps – with a maximum speed of 80 km/h and with a maximum decline of up to 2.2% climbs up to about 1,100 m a.s.l., where the old Gotthard-Rail tunnel is located, approximately 900 m higher as the city of Milan.

The Swiss government has decided to create these new alpine Transverse with two rail lines. The Swiss population did confirm this decision and with his vote gave the required authorization to deliberate the money for this important investment.

The Swiss federal railways together with the Lötschberg railways were commissioned for the realization and the management of the two New Alpine Transverse, Gotthard and Lötschberg. The AlpTransit Gotthard Ltd., founded by Swiss federal railways – with headquarters in the heart of Switzerland in Lucerne – were charged to manage the design and the construction works of the Gotthard-Route until the beginning of the regular service of the new flat railway.

The transalpine rail route “Gotthard” will rely the city of Zurich with the city of Milan (see Figure 1), interesting a catchment’s area of over 20 millions people in Germany, Switzerland and Italy. Shorter travelling times – an hour less between Zurich and Milan, for example – will mean that rail travel across the Alps will be able to compete with flying (a better modal split for the rail) and to permit to optimise connections. The realization of three important tunnels is required: the Ceneri-Base Tunnel in the southern part (15 km long), the Zimmerberg-Base Tunnel in the northern section (total length 20 km) and the Gotthard-Base Tunnel in the heart of the project (57 km).
The most impressive part of the new traffic route through the Alps is the Base tunnel under the Gotthard, which is planned to handle mixed traffic, that is high speed passenger trains (up to 250 km/h) as well as slower freight trains (up to 160 km/h). Once complete and operating, the Gotthard-Base tunnel will be the longest tunnel in the world. It will run through the Alps at approx. 500-550 meters above sea level. Its highest overburden will be approx. 2'300 m. With a minimum Radius in curves of 5,000 m and with a maximum slope of 0.70% the Gotthard-Base tunnel will be the first flat railway trough the Alps (see Figure 2).

2 GOTTHARD BASE TUNNEL: DESIGN UPDATE AND STATE OF THE WORKS

2.1 Design update

The base tunnel stretches from Erstfeld in the north to Bodio in the south (see Figure 3). It consists of two parallel single-track tubes with a diameter varying from 8.8 up to 9.5, which are linked by 178 cross-passages approximately every 300 meters. At two positions, one-third and two-thirds along the base tunnel, are located multifunction stations for the diversion of trains via the crossovers to the other tube, for the installation of electro-mechanical installations, and for the stop of trains and the evacuation of passengers in an emergency case.
Detailed and sophisticated evaluation demonstrated that this tunnel system was the most suitable for long alpine tunnels. To shorten construction time and for ventilation purposes, the tunnel will be driven from several sites simultaneously. To this end, the tunnel has been divided into five sections. Excavation will take place from the portals as well as from three intermediate attacks in Amsteg, Sedrun and Faido (see Figure 4).
From north to south, the 57 km long Gotthard-Base Tunnel passes through mostly crystalline rock, the massifs which are broken by narrow sedimentary zones, the tectonic zones. The 3 crystalline rock sections are the Aar-massif in the north, the Gotthard-massif in the middle and the Pennine gneiss zone in the south (see Figure 5). These zones are unlikely to cause any major technical difficulties during construction and they are quite favourable for tunnelling. These units consist mainly of very strong igneous and metamorphic rock with high strength. More than 90% of the total tunnel length consists of this type of rock. The main danger is the risk of rock burst caused by the high overburden, the instability of rock wedges and water inflow.

Major sections of the tunnel will have a very high overburden: more than 1,000 m for roughly 30 km, more than 1,500 m over 20 km and it can even be more than 2,000 m for approx. 5 km, the maximum is about 2,300 m. This has been taken into consideration in deciding the heading concept and rock support design.

Figure 5: Geology of the Gotthard Base Tunnel.
2.2 State of the works

Work on the Gotthard-Base tunnel has been proceeding for many years, e.g. in Sedrun work has been in progress since 1996. All construction sites (portals and intermediate attacks) the base tunnel is under construction.

The accessory works like external works, construction sites and access tunnels and shafts have been carried out since 1999. With the exception of Erstfeld at the northern portal, where the first milestone has been set in July 2004, they are finished all over. What the two multifunctional stations are concerned, excavation works proceed at various fronts, up to six fronts at each station. The excavation of the Sedrun station, situated at the bottom of the twin vertical shaft, is practically finished. Insulation and concrete lining works will start next. In Faido however, where initially good rock conditions have been expected, an intensively disturbed and unexpected fault area has been met in summer 2002. Unfortunately the critical faults passed right there, where the large caverns have been foreseen, and at a very acute and unfavourable angle. An intensive investigation program was carried out to define the best place for the huge cross-over caverns, with cross sections up to 230 m². The result was an adaptation of the layout of the whole scheme. The excavation works are actually still going on under quite difficult conditions and should be finished by the end of 2006.

The running tubes are currently advanced by TBM in Bodio and in Amsteg. At the end of March 2005, one can say that the two parallel running tubes have got over the half way at each sector concerned: over 8 km in Bodio and over 6 km in Amsteg.

Up to the present, about 66 km of tunnels and galleries or 43% of the entire project (153.4 km) have been excavated. These are shown in red and green on the 3-dimensional picture in Figure 6.

According to the progress made in the different sections, the actual overall time schedule shows that the excavation works of the tunnels will be finished in March 2010 and the first train will run through the Gotthard-Base Tunnel in May 2015.

![Figure 6: State of works, March 2005.](image-url)
3 GOTTHARD BASE TUNNEL: EXPLORATION CONCEPT

3.1 Exploration concept, investigations before construction started, from the surface

Starting from the preliminary studies during the late eighties, up to the final design in 1996, the project has been accompanied by numerous geological and hydrological investigation programs, running parallel to the progressively refinement of the design.

The geological forecast and the estimation of water inflow has been set up step by step, with growing forecast accuracy. In fact the underground of the Gotthard-region is quite well known since a long time from a great number of existing, for some cases even historical underground works, however not at the desired depths. Already in the late seventies two deep boreholes, with interesting, but just partially satisfying results, have been driven, to explore both the Tavetsch-massif in Sedrun and the Piora-zone in the Lucomagno-area.

Apart from the local investigation campaigns near the portals, the Piora-basin and the Tavetsch-massif drew the major attention. Whereas the uncertainty at the Piora has been subject of general feasibility considerations for the whole tunnel for a long time, the ongoing deep drillings in the Tavetsch-area and the subsequent on site and laboratory tests revealed extremely bad rock conditions, with a very poor elasticity modulus.

The related feedback on the project layout, the heading methods and the support quantities was very incisive and the project engineer (Engineering J.V. Gotthard-Base Tunnel South, composed by Lombardi Engineering Ltd, Amberg Engineering Ltd. and Electrowatt Infra Ltd.) reiteratedly had to integrate the latest findings in order to provide the most reliable update about project configuration, construction times and investment costs to the client, Alptransit Gotthard Ltd., who himself was not seldom subjected to critical political and public opinion.

4 GOTTHARD BASE TUNNEL: PROBINGS DURING THE WORKS

4.1 Concept of probing in advance of the headings

Drillings and systematic probing in advance of the headings have been and are applied in various sectors of the project. The procedure in the portal zone of Bodio, where more than 400 m of loose and instable blockfall material had to be crossed by the close together twin tubes, by means of umbrella forepolings and intensive grouting, was decisive for the successful realization, but bears no further interest for this presentation. Neither do the numerous investigation drillings, which became necessary in consequence of the unforeseen geological situation in the Faido multifunctional station and which allowed to fit the layout of the station better to the geological situation.

The probing systems which are applied in the longer and regular running headings and bear useful information for further understanding and application, are the following:
- The Piora investigation system, realized during 1993 and 1997
- The systematic probing from the actual TBM drives in Bodio
- The systematic probing, ahead of the fronts, in Sedrun
Each system has its particular scope and particular application conditions, which can be summarized by the following scheme (see Figure 7):

![Figure 7: Gotthard-Base tunnel south – Advanced probing in the different sectors.](image)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sedrun</th>
<th>Piora</th>
<th>Bodio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel element</td>
<td>runnig tubes, 4 headings</td>
<td>exploration gallery</td>
<td>running tubes, 2 headings</td>
</tr>
<tr>
<td>Method</td>
<td>Drill &amp; Blast</td>
<td>TBM</td>
<td>TBM</td>
</tr>
<tr>
<td>Cross profile</td>
<td>circular/horse shoe, variable size</td>
<td>Ø 5.00 m</td>
<td>Ø 8.83 m - 9.03 m</td>
</tr>
<tr>
<td>Main scope</td>
<td>controlled approach of instable faults, prevention of uncontrolled water inflow from near-by reservoirs</td>
<td>safe approach, investigation and crossing of undrained dolomite, with 150 bar of water pressure</td>
<td>detection of fractured fault zones, prevention of TBM blockade by loose rock parts</td>
</tr>
<tr>
<td>Schedules</td>
<td>works started in 2004</td>
<td>works finished 1997</td>
<td>works actually ongoing</td>
</tr>
</tbody>
</table>

In all cases, the solution has been approached by a concept, based on the result of a specific risk analysis. Focusing on the scenario with water in-break, the experience of the Piora investigation is by far the most interesting.

### 4.2 Piora exploration

As one recalls, the Piora exploration project did not consist in one single activity; it has been a system, composed by an exploration gallery, 5.5 km in length (see Figure 8), driven in fairly good rock with a 5 m diameter TBM, by extended accessory works at the end of the gallery, by a series of long and deep investigation bores and related tests, as well by an optional vertical shaft, 350 m deep, with all the necessary accessory works and the following exploration activities on the future tunnel level. According to the possible outcome of the investigation procedure, one has even prepared the design and the procedure of the base-tunnel sector through the Piora syncline, out of the Piora gallery, prior to the arrival of the normal running tunnel headings at that point.
The critical and most interesting working phase has been the approach to the Piora basin, formed by sugar-grained dolomite, mixed with water at a pressure of up to 150 bar. The concept of the approach aimed to avoid an uncontrolled encounter with the basin, especially while driving with the TBM. Among the different prediction methods, several geophysical and occasional radar measurements have been carried out, but the relevant decisions had to be based on bore results. A first campaign of advance bores from the TBM has been started at 1 km of distance from the supposed limit of the Basin. The final approach some 300 m before the predicted interface with the Piora basin has been carried out with advance bores from the machine, of 80÷120 m of length, overlapping for 10÷20 m (see Figure 9).
Alternatively the TBM has been driven ahead, so that a security rock pillar of at least 20 m remained. The drilling installation, mounted on the TBM, was equipped with a sophisticated preventer system, composed by a “Blow Out Preventer”, used in the oil prospection techniques, and a “Total and Rod Preventer”. The equipment has been fit to a water pressure up to 150 bar, whereas regular hydro-geological tests showed real ground water pressures between 70 and 100 bar.

The bores have been put just above the TBM-crown (see Figure 10), with variable inclination between 2 and 5 degrees. For each bore a stand pipe of 20 m length and a diameter of 146 mm has been set and tested.

During the driving of the 5th borehole in advance, at station 5,553 m, the sugar-grained, porridge-like dolomites of the Piora-basin have been met. The dolomite-water mixture poured into the tunnel through the 42 m long borehole, with 98 mm diameter, at high pressure, initially with more than 90 bar.

To illustrate how the encounter occurred in reality, it is interesting to call back to the diary of the geologist on the site:

“The preliminary rotative bore with core extraction and the setting and testing of the standpipe has been 18 m long. The test of the pipe has been made with 200 bar water pressure. The drilling continued with a diameter of 106 mm until 27 m of depth, then, after 9 days from the start of the bore, it has been changed to the counter flush procedure, with a diameter of 101 mm and the mounting of a rotating preventer. One day later, 37 m have been reached, with no particular problems. The cutter head passed already through 2 m of white and hard quartzite of the base of the Piora syncline and had to be exchanged twice. During the next night the boring arrived at 42 m, 7 m of it consisting of mixed material, quartzite, sericite, phyllite and pieces of gneiss. The water inflow rose and went up constantly to 1.5 l/sec.

During the following mounting of the drilling rods, pressure jets out of the borehole occurred, with ejection of pieces of rock, at intervals of 1÷2 minutes. The rod has been continuously moved with the purpose to keep the drilling hole open. Occasionally the drilling equipment has been violently pushed back on the sledge.
After a while the water flow increased up to about 100 l/sec and the first dolomite rock pieces (gravel sized) have been blown out (see Figure 11), this time at intervals of 10÷15 seconds, followed, half an hour later, by the outbreak of a sugar-grained dolomite-water suspension. The jet has been thrown against the TBM command cabin, which was 10 m behind, some pieces have been thrown up to 30 m.

The jet, driven by a borehole pressure of estimated 90 bar, increased more and reached a maximum outflow of 400÷500 l/sec, and this during 2÷3 hours. The granulometric composition of the material corresponded to a fine to middle grained sand.

Since it was, at that stage, impossible to get close to the boring equipment, the crew left the tunnel. During the whole event there has been no danger for the persons”.

The temporary inflow could occur because the so called Kelly blow-out preventer did not operate effectively during the replacement of the cutter head and the re-installing of the bore rod. The frequent replacements of the cutter head have been required because of the extremely abrasive dolomite rock mass.

After the flow of water and sugar-grained dolomite had stopped, the crew could return to the front and get the situation under control. During the following days, the final front of the gallery has been secured by an armed and anchored 8 m thick concrete tap.

In the next step, the TBM has been retreated and further bores from the end of the gallery, along the axis, have been undertaken, followed by long and deep bores from expressly excavated chambers. These preventer-protected inclined exploratory bores were undertaken, up to more than 1,000 m length, in order to explore the Piora-basin at the level and below the future main tunnel. As one knows, the results of this campaign was quite pleasing for the construction of the Gotthard-Base tunnel: at the level of the tunnel stable dolomite marble has been found, not affected by water and therefore without water pressure. The four long bores, reaching as far as the Gotthard-massif in the north, circumcised the corridor in which the future twin tunnel will be situated.

The following illustrations (Figures 12, 13, 14 and 15) show the layout and the methodology of these long range bores.
Figure 12: long bores, loop gallery with caverns for tests. General layout.

Figure 13: Long range drillings with final geological profile.

Figure 14: Security installation, details
Except for the drillings into the fluidified dolomite mass, the wire line boring system, with core recuperation, has been used (see Figure 16).

In the sugar grained dolomite, closed cutter heads have been used by security reasons, with no core extraction.
The lateral gallery loop with its accessory works has been excavated in preview of the eventual necessity to carry out various tests in the Piora formation and to sink the vertical shaft down to the tunnel level, for further investigation and preparing the crossing with the main tubes (see Figure 17).

4.3 Probing in the Tavetsch zone

As already mentioned above, the mechanical probing ahead of the fronts in the Sedrun sector pursue two main scopes:

a) Exploration of the rock conditions, in order to define in advance the excavation profile, with the type and amount of the rock support. In consideration of the expected bad rock conditions, the extreme initial stress state due to the high overburden and the consequently expected important convergence deformations, this prospectional scope is essential for the safety at the front. In the same time it allows an adequate project management, adapting the support measures and enabling an adequate timing of the works. In Sedrun, with its complex and long logistic line, this is especially important.

b) The presence of various water reservoirs in the influence zone of the tunnel (see Figure 18) bears the risk, that the surface ground deformations due to water drainage into the tunnel, that means due to lowering of the natural ground water table, can damage the sensible concrete arch dams. Water inflow to the tunnel has therefore to be reduced to an amount, which causes no unacceptable deformations of the ground surface. For this reason specific hydrological information should allow to decide about eventual measures (grouting) that have to be realized in advance of the tunnel front.
The hydro-geological conditions in Sedrun (see Figure 19) are very severe: the ground water head is variable from 900 m up to 1,500 m, but has several fixed potentials related to the water levels of the reservoirs. Tunnelling (up to 6 simultaneous headings) takes place more than 800 m lower than the access gallery to the surface and a gigantic pumping plant, with a capacity of 1 m$^3$/s has to be constantly ready for a potential flood emergency.

The water inflow scenarios into the tunnel space are defined in 3 different patterns:
- Inflow from the normal rock matrix, quantified in l/sec*km
- Local inflow from faults and weak zones, characterized with high permeability
- Karstic phenomena are not likely to occur, but cannot be excluded.
In the present case, the water drainage from the singular faults are by far predominant for the expected total water inflow; the matrix permeability normally having little effect. Furthermore one has to distinguish between initial water flow and the stationary flow over a long time. In the mountain tunnels, probably in contrast to undersea tunnels, the initial water inflow peaks usually decrease quite quickly and have a generally diminishing long-term behaviour.

Based on a detailed risk analysis, a clear probing concept with execution guidelines have been elaborated. On one hand these specifications have to fix all the decision steps, the responsibilities of the different parties involved and the precise documentation of the decisions and the results. On the other hand the working instrument has to allow the necessary flexibility and adaptability to the real situation and conditions on site.

Basically the advance probing are done for all the headings, also in both of the parallel tubes. In the geologically favourable zones, the findings in the advanced heading of the parallel tubes can be used to reduce the extent of the probing in the following second tube.

Drillings with up to 200 m in length are done from the current tunnel section, because the excavation and installation in lateral chambers do not bring any advantage in time, nor in cost.

Three types of security devices are adopted:
1. 200 bar preventer for simple roto-percussion drillings (consists of a spherical tap and a rotating preventer)
2. 150 bar preventer for core drillings (consists of several elements similar to the bores at the Piora, inclusive a lock for the wire and core extraction, see Figure 20)
3. 200 bar preventer, idem like the formerly described.

![Figure 20: Drilling with the type 2 preventer.](image)
The procedures, how the relevant decisions are made, and how the responsibilities are assigned are defined according to a preset flow-chart. Each boring is defined by the following steps:

1. Definition of the overlapping length in accordance to the geological forecast (faults, rock behaviour, water). Analysis, if a stand pipe is necessary and with what length. This is a very important factor. Usually there is a minimum length for the pipe, in the present case 10 m, but the final decision has to be done considering the allowable pressure gradient in the rock mass. In fairly good geological conditions, it is assumed with 12 bar/m’. Similar criteria have to be adopted to define the overlapping of the bores. Facing the rather critical risk situation in Sedrun, the overlapping length has been prudentially defined with 30 m.
2. Definition of the type of bore: Roto-percussion drilling or cased core drilling, type of equipment, type of preventer.
3. Definition of bore length. Apart from the minimal length (36 m) and the maximum length (400 m), the forecast length has to be determined according to the scope of the drilling. The real length may be different, applying the predefined “break up” or “go on” criteria.

All these considerations are put clearly down on a form for documentation.

If a stand pipe has to be installed, a detailed test procedure has to be carried out, to ensure full stability and the guarantee that the leak water flow at maximum pressure is within the defined limit.

During the drilling, various criteria are constantly observed and registered. Obviously the report about water inflow is one of the most important. The criteria for complementary measures, when encountering drainage water, are defined by means of a specific data sheet, where not only the initial and the water flow after a certain time (24 hrs.) are considered, but also the hydro-geological rock characteristics (faults, voids), the water temperature and the hydraulic transmissivity.

The complementary exploration measures normally consist in supplementary bores and tests on site.

In case of excessive water inflow, one will proceed to ground treatment by grouting, by different steps, before the tunnel will be driven through the potentially permeable zone.

In the boreholes and with the extracted cores regular tests are undertaken and interpreted for comparison with the initial design data.

4.4 Probing ahead of the TBM in Bodio

The situation in Bodio, where the two open TBM drives of the main tubes run northbound in generally fairly good rock conditions, is less complex. Nevertheless, after a first phase based on tests with seismic explorations, completed with selected roto-percussion drillings, it was considered advisable to cover the whole length with advanced mechanical probing, in order to be prepared for the several forecasted but locally unknown faults, or groups of faults of modest to medium geotechnical importance.
The encounter with an unpredicted fault zone (see Figure 21), shortly after the start of the TBM drive, reinforced the decision to apply systematic mechanical probing; this allowed to renounce to further seismic explorations.

The use of core drillings will occur exceptionally, where the geologist needs more information about the characteristics and the composition of the rock. The probing in Bodio are done without preventers.

The drilling equipment is mounted on the TBM and the bore hole is set in the crown just behind the short finger shield, usually with 5° slope (see Figure 22). The cutter head has a diameter of 76 mm.
The length of the probing is decided according to the geological situation; usually it is 80÷100 m, which fits to a weekly advancement rate. The drillings can be carried out during the maintenance shift and do not cause any delay for the construction programme.

The interpretation and the use of the findings is done according to a prefixed rule. The main criteria being the behaviour of the drilling resistance, followed by the quantity, the pressure and the turbidity of the inflowing water. Depending on the results, eventual supplementary explorations are adopted and the eventual reinforcement of the normal rock support measures can be decided and prepared.

In face of eventual flat lying faults, complementary 16 m-long radial bores approximately every 50 m are carried out by means of the normal anchor drilling equipment.

The investigation program in the following (western) tube is reduced to the zones, where the advanced (eastern) tube has met geological disturbances.

5 CONCLUSIONS AND FINAL REMARKS

5.1 Conclusions and useful experiences

The foregoing presentation can lead us to a discussion about the adequate measures to undertake:

1. Concept of mechanical probing in combination with other exploration methods, like geophysical probing, going along with the tunnel headings

   Based on the forecast from earlier investigations; division of the tunnel in “homogeneous” sectors, in consideration of geology, depth, water inflow forecast, as it is already laid out in the present project documentation, the general program can be set up, starting off with geophysical investigations, then focusing on drillings of variable length and variable safety standards. The project corridor and the surrounding extension of the probed area have to be defined on the base of a risk analysis.

2. General type of mechanical probing (see Figure 23):

   - Short, but more numerous probing from the front (carried out with the normal drilling equipment, as for the bolts), roto-percussion, length up to 20÷30 m, normally outside the tunnel profile, carried out every one or few days.
   - Medium long bores with a special boring equipment, mounted on the TBM, length around 80÷120 m, carried out 1÷2 times a week, roto-percussion destructive or core drillings, with or without preventers. TBM advancing by alternate steps.
   - Long bores, executed from especially excavated side-caverns; length from 500 m, up to 1,500 m; results allow to adapt the tunnel route to a certain extent. TBM can go on while boring.

Setting up realistic risk scenarios, in order to define the preferential type of borings.
3. Influence of probing on the configuration of the pilot gallery and the site infrastructure in general:

- Diameter: 5 m risks to be insufficient (max. length of drive 14 km or more, ventilation duct, refrigeration ducts, transport of muck and segments, safety side walk, emergency pumping station, with ducts); in addition to the usual equipment in the TBM head zone, there must be space for the drilling equipment and all its accessory parts. It requires considerable space (stocking of various material, like drilling rods, cores a.s.o.); in case of construction of lateral caverns, supplementary equipment (D&B) is required. Recommended TBM diameter: 6 m, or better 7 m.
- Slope: 2.5 % and more sets limitations for transportation capacity. Inclination needs increase in pumping power for the evacuation of inflowing water.
- Specific and general safety features: e.g. water tight locks at regular distances, separate side walk for escape, sophisticated communication and person-tracking systems.

4. Guidelines for probing, in conformity of the concept.

E.g. starting with regular preliminary seismic screening, going to next step with roto-percussion destructive drillings; according interpretation of results completed by cased core bores. Definition of preventing safety devices, stand pipe and overlapping length. Guidelines must be clear, but shall leave the flexibility to adapt the procedure to the effective behaviour of the rock and the encountered water inflow. Detailed criteria and limit values (e.g. water inflow volume, turbidity, temperature, conductivity a.s.o.) have to be established, as well as the break-up and repetition criteria, to be used on site.

Probing results don’t have to be stocked in an drawer, but immediately distributed among the concerned persons, who can do the appropriate decisions (example Gotthard-Base tunnel: all relevant tunnel data and exploration results are daily provided to a defined circle of persons, client, general and local supervisor, engineer, by a sophisticated and efficient data and communication system).
5. Safety prescriptions:

In contrast to the project related guidelines, safety prescriptions have to be considered by law. In order to avoid later surprises it is advised to take care of them from the early planning stage. They may have an important impact on the project configuration (tunnel diameter, rescue and pumping stations, shelters, provision of power), the times (tests at various stages of the works, before subsequent works can go on, repetition of unsuccessful tests) and the costs. It is advised not to underestimate the increasing general safety consciousness and the current set-up of new safety prescriptions in all fields (tunnel fires).

6. Tests:

Define procedures for tests and make proper description of tests. Unsuccessful or only partially successful tests have to be repeated.

Tests in boreholes and in laboratories: carry out tests, which give useful results. Test results must allow to establish specifications and execution times of following ground treatment.

Check the reliance of the borehole surveys.

7. Time factors:

The time demand for special borings cannot be established by means of simple experience values for site installation, drilling speed and final clearing, but depends on numerous supplementary activities, most of them hardly foreseeable. One has to consider that every step and mounted equipment has to be tested before operated. Special attention belongs to the safety devices (preventers) and to the stand-pipe. Where the boring equipment with all its accessory parts is installed within a couple of days, it may take more than a week to set and to test the start-pipe, especially – which is not seldom – when the pipe has to be cemented and tested several times. The experience at the Piora showed, that the initial works, before the drilling production started, took more time than a borehole through 120 m of fine grained saturated dolomite. Furthermore in a lot of situations the initial borehole has to be overbored in a subsequent phase.

Apart from the technical time factors there are procedural times, used for interpretation, meetings and decision making. This factor is especially important with complex project organizations, including a lot of involved parties.

8. Organization factors:

- Define responsibilities among operators.
  Highly specialized works, like complex drillings, carried out by sub- and subcontractors, bear the risk of faded responsibilities, with respect to safety, to project success, to project cost. Among the participants (client, designer, supervisor, experts, contractor, specialist subcontractors, suppliers) one has to establish clear interfaces, with criteria and competences for decisions. That is for the kind of safety devices, stopping probing or going on.
  Scope and concept must be known by all participants especially also by the operating crew.
- Tracking of decisions and interpretations:
  All decision steps have to be written down for later understanding and documentation.
- Unobjectionable documentation:
  Extended documentation must be available for further planning and execution. The use of modern data bases, documentation and management tools is recommended (i.e. the SISO-tool, used for some larger tunnel projects: Gotthard-Base tunnel, Lötschberg-Base tunnel, Fréjus safety gallery, a.s.o.).
5.2 Final remarks

For the probing realistic, but prudential evaluation of times and cost has to be taken into account. It is usual to set reserves, but these reserves have to be declared openly. When necessary, reserves have to be used for their proper scope, and not, like it occurs from time to time, for further project extensions.

Experiences show, that complex and difficult works in unknown environment bear ingredients for:
- Delays
- Cost excess

6 REFERENCES

6.1 Former Papers


6.2 Pictures & Tables

Engineering J.V. Gotthard-Base Tunnel South, 1993-2005