Session 2: Mechanical Probing

EXPERIENCES FROM THE GROUND PROBING IN THE GOTTTHARD-BASE TUNNEL AND THEIR APPLICABILITY IN THE GIBRALTAR STRAIT CROSSING

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Introduction

The ground probing campaigns carried out at the Gotthard-Base tunnel project in Switzerland, the world’s longest railway tunnel, call for useful experiences for the Gibraltar Strait crossing. In spite of the completely different surroundings, the two projects are in many aspects comparable, i.e. what the length of the headings, the difficulties and limitations of preliminary explorations from the surface and the unpredictability and the consequences of the water inflow is concerned.

The following presentation 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 probings ahead of the front. Many critical features of probings in view of a water inflow scenario can be considered equivalent for D&B and TBM headings.

Overview of Gotthard-Base Tunnel, design and general geological situation

The Gotthard-Base Tunnel, together with the other Swiss Transalpine flat highspeed rail tunnel, the Lütschberg Base Tunnel, belongs to the actually biggest tunnelling works going on worldwide. It is the main tunnel of the AlpTransit line, which runs north-south through Switzerland and will link the new European high speed rail system.
The whole tunnel of 57 km consists of five sections, with a variable length between 7 km and 16.6 km. It is a system with two parallel single-track tubes with an excavated diameter varying from 8.8 m up to 9.5 m. There is no parallel safety gallery, but 180 cross passages, with approximately 300 m of distance between one and another, link the two tubes. Considering all accessory works like access tunnels, shafts, multifunctional stations and by-passes, the whole length of excavation sums up to 153 km. 41% of it has been excavated by the end of the year 2004.

To shorten construction time and for ventilation purposes, the tunnel is driven from several sites simultaneously. Excavation in the five sections takes place from the two portals as well as from three intermediate attacks in

- Sedrun, by means of an access gallery and a twin vertical shaft of 835 m of depth,
- Faido by means of an inclined access gallery of 2.7 km of length,
- Amsteg by a horizontal access gallery of 1 km.

At two positions, one third and two thirds along the tunnel, are located multifunctional stations for the following main purposes:

- Construction from several sites simultaneously

- Sedrun, by means of an access gallery and a twin vertical shaft of 835 m of depth,
- Faido by means of an inclined access gallery of 2.7 km of length,
- Amsteg by a horizontal access gallery of 1 km.

At two positions, one third and two thirds along the tunnel, are located multifunctional stations for the following main purposes:
For diversion of trains via the cross-overs to the other tube
For the installation of electro-mechanical equipment
And for the stop of trains and the evacuation of passengers in an emergency case.

For the excavation of the tunnel, different methods are adopted:
- TBM drive for the accessory transportation tunnel at the southern portal, as well as for the largely major part of the running tubes in the sections Bodio, Amsteg, Erstfeld and Faido. As mentioned above this method is applied by far for the most part of the total tunnel length.
- Drill & Blast for the by-pass tunnel in the section Bodio, for the access tunnels in Amsteg and Faido, the entire section Sedrun, the multifunctional station in Faido and all the cross passages.
- Cut & Cover at the two portals in Bodio and Erstfeld.

The geological/geotechnical background, which is of interest when talking about probing, can be shortly presented as follows:

The geology of the central Alpine zone, where the tunnel is situated, consists of three major gneiss zones: the Aar massif in the north, the Gotthard massif in the middle and the Pennine gneiss zone in the south. These units consist mainly of very strong igneous and metamorphic rock with a high initial strength. In general these zones should not cause major geotechnical difficulties during construction, but bear nevertheless some dangers and risks due to:

- Local instabilities of kakiritic and broken rock wedges; there are some dozens of fault zones of variable length over the whole tunnel, defined from the geological forecast,
- Uncontrolled water inflow, which is especially critical when the heading is lower than the tunnel portal,
- Rock burst caused by high overburden.

It must be recalled, that the overburden is very high for long tunnel sections, for 5 km it is higher than 2000 m and reaches up to 2300 m. This was an important factor to consider in deciding the heading concept and the rock support design.

In between the gneiss massifs we find two important intermediate sub-massifs, where difficult geotechnical conditions have been foreseen:
- The Tavetsch intermediate massif in Sedrun
- The Piora syncline, located in the section Faido.

Fig. 4: geological profile
These two critical sections have been in the headlines from the initial planning, out of various points of view: First they have been the object of intense investigation, their supposed position has been determinant for the tunnel alignment, since the tunnel should cross the weak zones at their narrowest points and avoiding maximum overburden. Finally, in the interest of the whole project, one had to assure, that the tunnel construction in these difficult circumstances would be technically feasible.

**Actual state of the works**

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 square meters. 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 the year 2004, one can say that the two parallel running tubes have reached about half way at each sector concerned: 8 km in Bodio and 6 km in Amsteg.

**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 in situ 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 and ElectroWatt Infra) 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 Ltd., who himself was not seldom subjected to critical political and public opinion.

**Explorations during construction**

**Concept of probing in advance of the headings**

Drillings and systematic probings 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 probings, ahead of the fronts, in Sedrun
Each system has its particular scope and particular application conditions, which can be summarized by the following scheme.

**Fig 6: Advanced probings in the different sectors**

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, which stands in the foreground of the present session, the experience of the Piora investigation is by far the most interesting. It can be presented as follows:

**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, 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.
Fig 7: Piora exploration gallery, vertical section

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 -120m of length, overlapping for 10 – 20m.

Fig. 8: steps approach to the Piora syncline by steps

Alternatively the TBM has been driven ahead, so that a security rock pillar of at least 20m 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 bars, whereas regular hydrogeological tests showed real ground water pressures between 70 and 100 bars.

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

During the driving of the 5th borehole in advance, at station 5553 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 bars.

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 stand-pipe 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 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, 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 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 1000 m length, in order to explore the Pióra 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 show the layout and the methodology of these long range bores.
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.

**Fig. 12**: Proposed steps for crossing the sugar grained dolomite formation with the main tubes

**Fig. 13**: Security installation, details
Except for the drillings into the fluidified dolomite mass, the wire line boring system, with core recuperation, has been used.

Fig 14: working mode with wire line

In the sugar grained dolomite, closed cutter heads have been used by security reasons, with no core extraction.

Fig. 15: View of installation at the end of the gallery
Fig. 16: long range drillings with final geological profile

Probings in the Tavetsch zone

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

1. 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.

2. The presence of various water reservoirs in the influence zone of the tunnel 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 hydrogeological conditions in Sedrun are very severe: the ground water head is variable from 900 m up to 1500 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 mc/sec has to be constantly ready for a potential flood emergency.

Fig. 18: Geological profile sector Sedrun

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 probings 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 probings 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:

- 200 bar preventer for simple roto-percussion drillings (consists of a spheric tap and a rotating preventer)
- 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)
- 200 bar preventer, idem like the formerly described.

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 hydrogeological rock characteristics (faults, voids), the water temperature and the hydraulic transmissivity. The complementary exploration measures normally consist in supplementary bores and tests in situ.

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.

**Probings 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 roto-percussion drillings, it was considered advisable to cover the whole length with advanced mechanical probings, in order to be prepared for the several forecasted but locally unknown faults, or groups of faults of modest to medium geotechnical importance.

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*Fig. 20: Tunnel Bodio; unexpected fault zone*
The encounter with an unpredicted fault zone, shortly after the start of the TBM drive, reinforced the decision to apply systematic mechanical probings; 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 probings 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. The cutter head has a diameter of 76 mm.

**Fig. 21: Drilling equipment on the TBM**

The length of the probings 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 radial bores 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.
Conclusions and useful experiences

The foregoing presentation can lead us to a discussion about the adequate measures to undertake in the Gibraltar Strait crossing undersea tunnel. Tentative recommendations can be set up for the following main topics in mechanical probings:

1. **Concept** of mechanical probings in combination with other exploration methods, like geophysical probings, 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 probings

   ![Fig. 22: types of advanced borings from TBM](image)

   - Short, but more numerous probings 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 1500 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 probings on the configuration of the pilot gallery and the site infrastructure in general
   - Diameter: 5m 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. Dislevel 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 probings, 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 b 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 GBT: 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 performant 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 re-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 subsubcontractors, 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. I.e. for the kind of safety devices, stopping probings 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.).

**Final remarks**

For the probings 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.

It is good to recall the proverb, expressed by the Greek philosoph Heraklith, 550 ante Christum,

**“Panta rei”**

which says that everything is flowing. This is not only true for our natural physical environment, but also for our projects, the times and the costs. Beside our effort for careful design preparation, clear decisions and the right actions, we always have to be prepared to react to changes that occur on the way going.