BASE TUNNELS IN THE ALPS - HELPFUL EXPERIENCES FOR STRAIT CROSSINGS FROM THE GOTTHARD BASE TUNNEL

Heinz Ehrbar, Heinz Ehrbar Partners llc, 8704 Herrliberg/Switzerland
heinz.ehrbar@heinzehrbarpartners.com

ABSTRACT

Strait crossings with excavated undersea tunnels and the crossing of the Alps with Base Tunnels are different in many aspects. Whereas the vertical alignment of a strait crossing by tunnel consists mainly of falling drives, base tunnels have mainly a rising gradient. The high overburden of the alpine base tunnels creates high initial stresses, rock burst phenomena, squeezing and high initial rock temperatures. For strait crossings with subsea tunnels water inflows to the falling drives are an important challenge for the tunnel engineers and miners. Nevertheless many aspects of tunnelling are similar for strait crossings and for alpine tunnelling. Both type of tunnels have to deal with the uncertainties of the ground conditions and the related remaining risks, the logistic challenges of long tunnel drives, the related safety requirements and the need of the protection of the environment.
This paper will show the experiences and the lessons learned from the Gotthard Base Tunnel:

- *Logistics for long and deep tunnel drives*
- *Concepts for exploratory drillings during the tunnel drive*
- *Experiences with drilling and grouting*
- *Safety aspects for long tunnel drives*
- *Environmental aspects, mainly the reuse of the muck for gravel production*
- *Contract management*

1. ALPINE BASE TUNNELS AND UNDERSEA TUNNEL - SIMILARITIES AND DIFFERENCES

For many people there may be no big difference in constructing a tunnel under a mountain or under the sea. In both cases an underground space has to be excavated in often not well-known ground conditions. Base tunnels and strait crossings normally belong to the category of Mega-Projects [1] with investments often of more than 1'000 € Mio and attracting a lot of public attention. Both types of project have a common catalogue of project requirements, which has to be fulfilled:

- Health and safety requirements
- Environmental requirements
- Project specific requirements on quality, functionality, time and costs
- Requirements on highly professional design and construction processes, project organisation and project management
- The requirements of the public opinion

The differences in the two types of projects are the different boundary conditions. Both types of tunnels can be very long (Channel Tunnel 50 km, Gotthard Base Tunnel 57 km). Whereas Alpine Base Tunnels normally are characterised by high overburden (more than 2'000 metres) subsea tunnels have a comparatively low overburden of around 100 metres of rock overburden and up to a few hundred metres water column (Fig. 1).

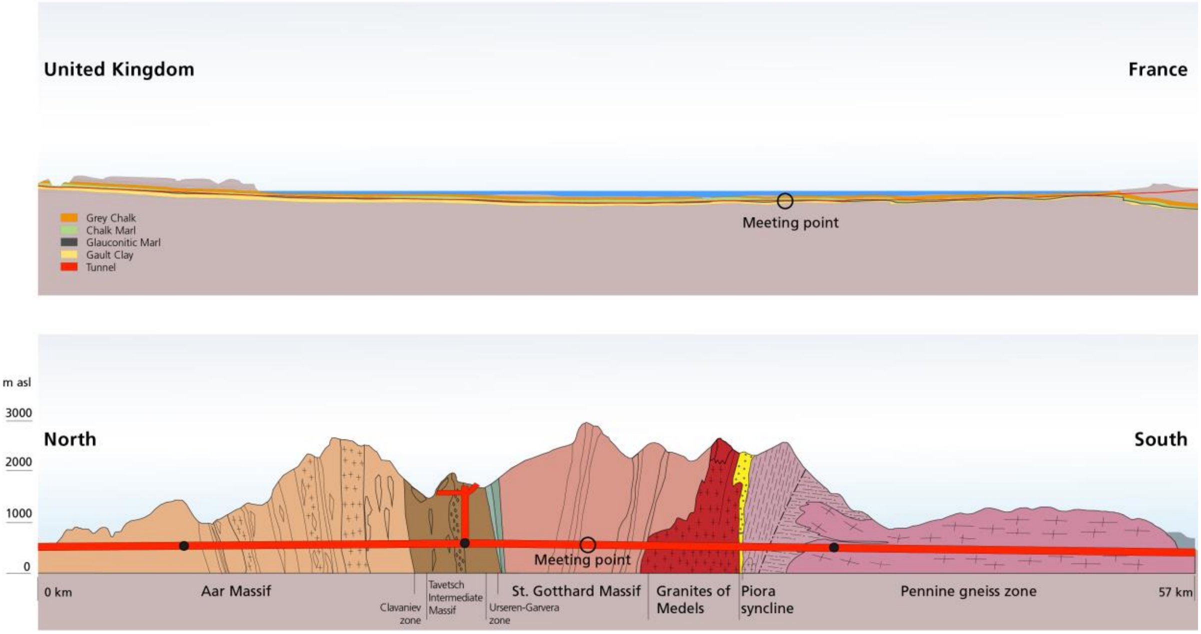

Fig. 1: Comparison of the longitudinal profile of the Channel Tunnel and the Gotthard Base tunnel in the same scale (AlpTransit Gotthard Ltd. (ATG))

The high overburden of Base Tunnels makes a previous systematic probe drilling campaign along the future tunnel axis practically impossible. Pre-investigations before the construction can be carried out only at selected locations of special interest. High overburden is related to high initial ground and water pressures with the typical hazard scenarios like rock burst, squeezing rock and high initial ground and water temperatures. Water inflows can occur under very high pressures.

In subsea tunnels all hazards related to water inflows are dominant. Hazards like squeezing rock or rock burst are generally of lower importance. The initial rock temperatures of subsea tunnels are low. Nevertheless working place temperatures have to be controlled due to machines heat. The completely different topographic situation has a big impact on the design and construction procedures of the tunnels. Undersea tunnels can normally not be subdivided in different construction sections by means of intermediate access tunnels, as it is done for Base Tunnels. Risk management is the key factor to control hazards and to take benefit from chances. The procedures for managing risks are the same for both types of tunnels. The implementation of risk management in the earliest project phases and the continuous maintenance is essential for all underground constructions.

2. EXPERIENCES FROM THE GOTTHARD BASE TUNNEL

2.1 Project description

The Gotthard Base Tunnel (GBT) is part of the Swiss master plan “New Railway Link through the Alps” (NRLA). The 57 kilometres long tunnel will be the centrepiece of the European transit corridor No. 24 between Rotterdam and Genoa (Fig. 2) and will be used in in a mixed mode (passenger trains and freight trains). The maximum speed in the tunnel will be 250 km/h for passenger trains and 160 km/h for freight trains. The tunnel system consists of two separate single-track tunnels with a minimum axial distance of 40 metres, a maximum slope of 6.76 ‰ and a minimum horizontal radius of 5’000 m. The single-track tunnels are linked every 312.5

metres by cross passages. Multifunction stations, containing technical rooms, ventilation systems and emergency stations are constructed in the third points at Sedrun and Faido.

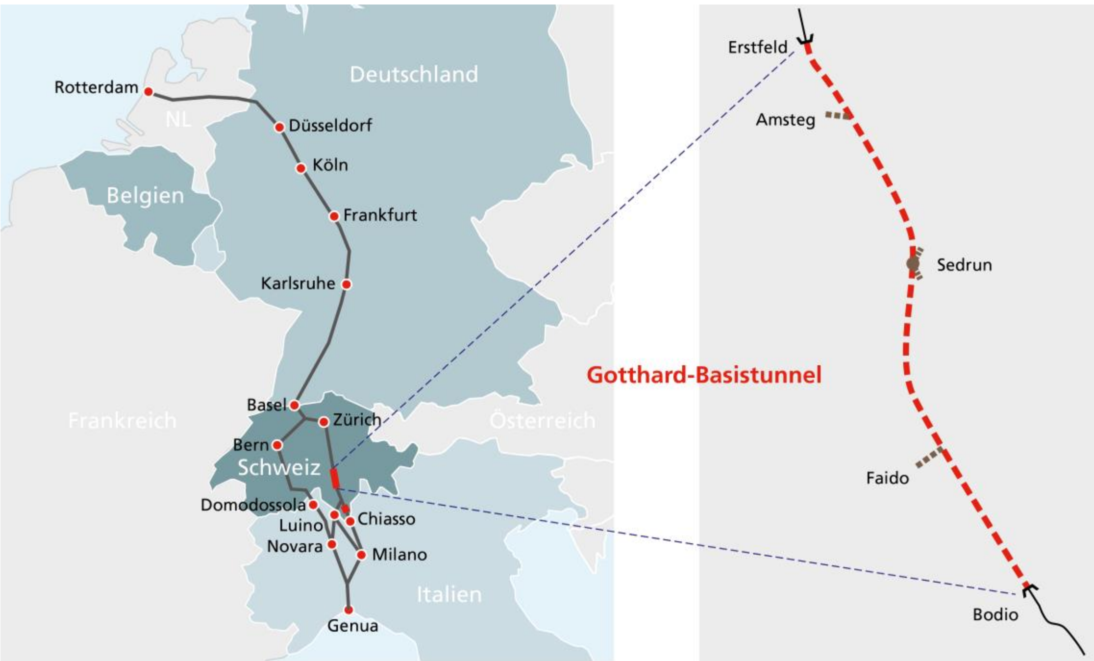

Fig. 2: Gotthard Base Tunnel, centrepiece of the European Transport Corridor 24 (ATG)

The main purpose of the new railway infrastructure is to shift a major part of the heavy transalpine freight traffic through Switzerland from the road to the rail. 220 to 260 freight trains per day will offer higher transport capacities with higher velocities by using the first flat rail link through the Alps (Fig. 1). 50 to 80 passenger trains per day will offer connections linking the economic regions of southern Germany, Switzerland and northern Italy. Faster travel speeds in more comfortable trains will create a real alternative to travelling by car or by airplane.
The project specific standards of the Swiss Federal Office of Transport (FOT) require a lifetime of 100 years for the civil work. No major rehabilitation work with significant operational restrictions (with regard on scope and duration) is allowed during the lifetime.

This requirement can only be achieved with the construction of a double lined tunnel (Fig. 3) with the provisional rock support as outer lining (first lining) and a permanent inner concrete lining (second lining, minimum thickness 30 cm. A drainage system between the two linings reduces permanently the initial water pressures of up to 150 bars. A waterproofing membrane on the entire length of the tunnel (114 kilometres) protects the inner lining against water filtrations. Due to the high initial rock stresses, high water pressures and high initial ground temperatures the development of special design solutions and construction materials was required, in order to fulfil the lifetime requirement.

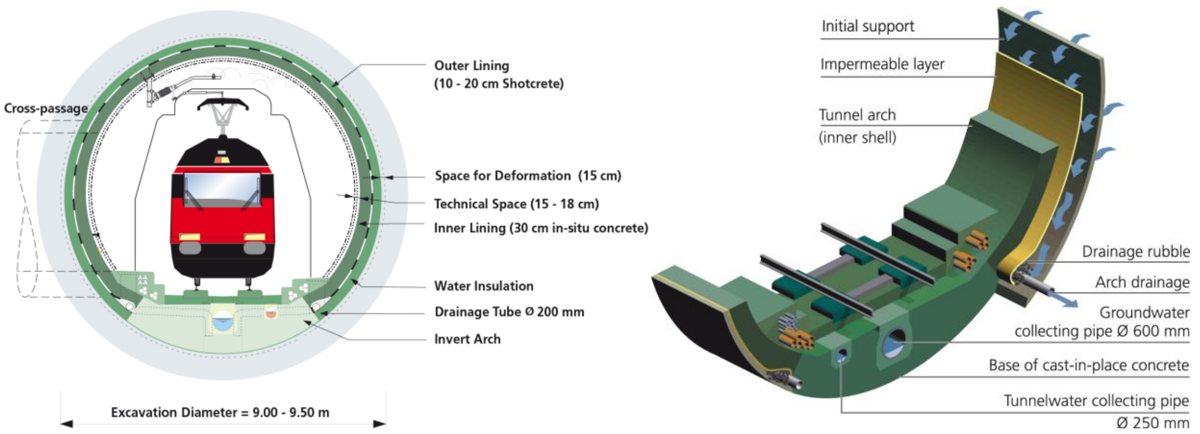

Fig. 3: Standard cross section: 100 year lifetime - double lined tunnel (ATG)

The tunnel was divided into five different construction sections, in order to shorten the total construction time by allowing the parallel work on the five different main sites of Erstfeld, Amsteg, Sedrun, Faido and Bodio (from north to south). 64% of the in total 151.1 kilometres long tunnel system were excavated by 4 Tunnel Boring Machines (TBM).
The civil work of the Gotthard Base Tunnel is practically completed. On approx. 60% of the tunnel length the railway technics is under construction or already completed (Fig. 4). The GBT becomes commercially operable in December 2016.

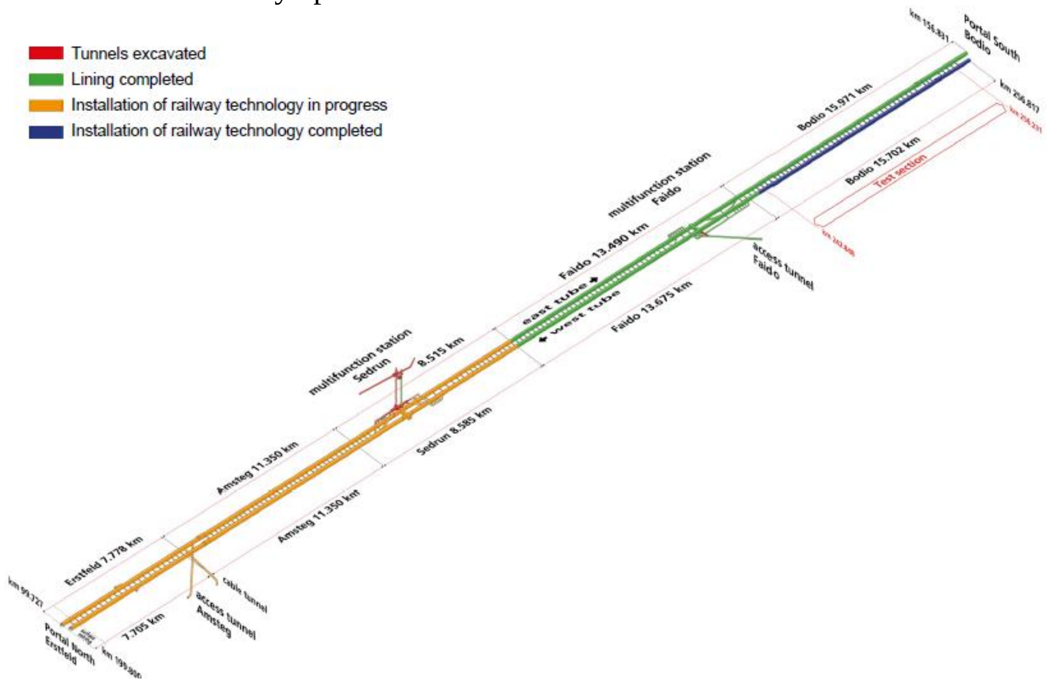

Fig. 4: Gotthard Base Tunnel, state of the work, End of 2012 (ATG)

2.2 Uncertainties of the ground conditions

Underground construction is different from any other type of construction, due to the fact, that the construction material, the ground, is often not well known or may change within a short distance. Additionally the behaviour of the ground is also a result of the interaction with the construction methods applied. Important residual risks are characteristic for large underground projects. The technical measures and the contract models have to take into account these special boundary conditions of underground construction and should allow a fast reaction on changed or unforeseen ground conditions.

At the Gotthard Base Tunnel only the expected most critical areas could be investigated by pre-investigations in the design stage. These investigations helped for a design adapted to the difficult ground conditions (e.g. Tavetsch Intermediate Massif North, Fig. 1) or showed, that the ground conditions would be better than initially assumed (Piora-Syncline, Fig. 1).

Nevertheless, the forecast of the ground conditions for most of the tunnel length had to be done by extrapolation of the information from the surface and from other neighbouring underground structures to the tunnel level. Therefore AlpTransit Gotthard Ltd. (ATG) as the owner and his engineer took the decision, that each meter of tunnel in both tubes (east and west) should be investigated during the excavation phase by well-adapted examination methods. At Amsteg and Faido certain tests with seismic methods were carried out. Due to the heterogeneous crystalline geology, the results were not satisfying for the purpose of a forecast. Finally probe drillings in the axis of the tunnel carried out from the tunnel-face were the main measures for pre-investigations (percussion drillings 80 to 100 metres, core drillings 150 to 300 metres both types with overlapping lengths) (Fig. 5). Preventer protection was carried out in all cases where high water inflows were expected. Short radial probe-drillings have been used only in few special cases.

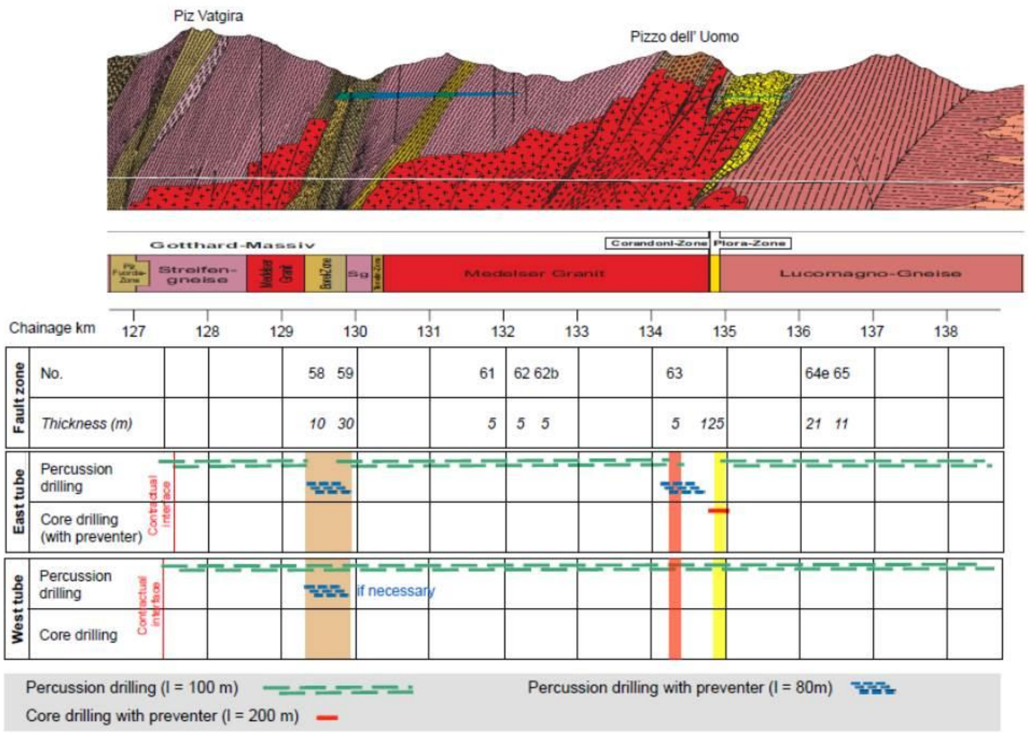

Fig. 5: Gotthard Base Tunnel, Section Faido, concept for probe drillings

The project was delivered by applying the design-bid-build process. All contracts were based on detailed bill of quantities (“unit price contract”) with a well-defined risk sharing policy (based on code SIA 118/198 [2]) and a detailed catalogue of auxiliary construction methods, such as drainage and grouting.

During the construction unexpected bad ground conditions were encountered in the area of the multifunction station Faido. A delay of two years and additional costs of more than 400 Mio € were the result [3]. Nevertheless the unit price contract gave the required flexibility to handle this critical situation.

In three cases (Amsteg, Sedrun and Faido) fault zones were encountered, which required major grouting campaigns for ground improvement (Amsteg, Faido) and impermeabilisation (Sedrun) [4], [5]. It is an important experience that all three cases occurred in the second tube (western tube) in areas where the leading eastern tube had already passed the critical zones without any major difficulties. The fault zones were detected in advance but there was no forecast of the bad behaviour of the ground in none of the three cases.

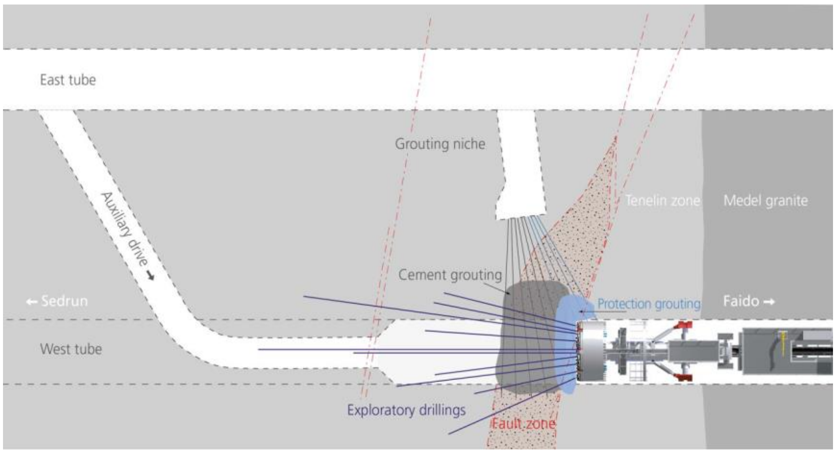

Fig. 6: Gotthard Base Tunnel, Section Faido, grouting of a fault zone in the western tube

A standstill of the excavation of 5 months and additional costs in the range of 10 Mio € were the result in all three cases although there was a comparatively easy access to the fault zone area also from the eastern tube. All three incidents belonged to the category of accepted residual risks and could have been avoided only by means of excessive pre-investigations, which would have hindered the daily advance rates. Such measures were not economical in comparison to the residual risks (ALARP-principle of risk management (as low as reasonable practicable)). The additional construction time could be compensated or was included in the contractual construction time, following the principles of Code SIA 118/198. The fault zones caused therefore no delay in the general construction schedule.

2.3 Construction procedures - logistics

Construction work of the GBT started in 2002 immediately after the signature of three of the four main contracts on the northern side (Amsteg), in the central construction section (Sedrun) and on the southern side (Faido and Bodio) with the goal of a beginning of the commercial operation in December 2014.

For each of the five sections of the Gotthard Base Tunnel large quantities of different categories of material (muck, shotcrete, concrete, rock bolts, wire mesh, steel ribs, impermeabilisation membrane, operating supplies) had to be moved on long distances up to 30 kilometres. In the case of the construction section Sedrun, two 800 metres deep vertical shafts gave the access to the tunnel site (Fig. 7). All the muck, the construction materials and the machinery had to be transported through these shafts by means of a special type of a shaft hoisting installation (Koepe-Machine) known from the mining industry. The supply with electrical energy, water and the ventilation with fresh air, but also the dewatering system and the transport of the exhaust air also used the two shafts.

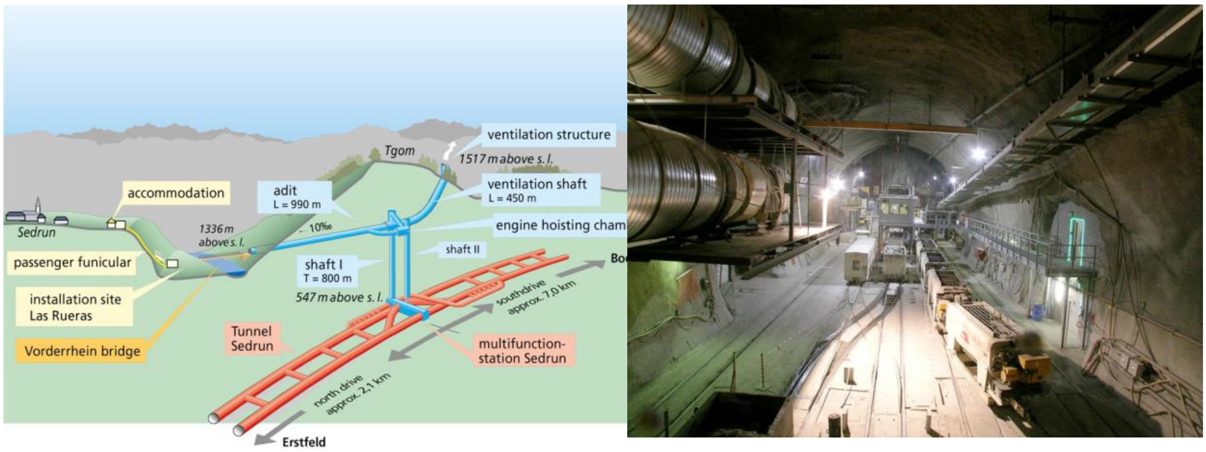

Fig. 7: Section Sedrun of the GBT: access via 800 metres deep shafts and shaft bottom (ATG)

Tunnelling means the just in time production of a long horizontal structure. The limited access to the various construction sites is a big challenge for the contractors. The contractors selected different concepts for the transportation system. In the sections Erstfeld, Amsteg and Sedrun the inner lining was poured after the completion of the excavation. These conditions were favourable to the transportation of the muck by belt conveyer, whereas in Bodio and Faido the inner lining followed the excavation in parallel. Taking these restrictions into account, the contractor took the decision to install a railway system for all transports. In the average every 7 minutes a train circulated from the rig area at the southern portal to the different working places (excavation front, cross passages, water proofing, inner lining, multifunction station, maintenance) (Fig. 8). Experienced railway operators managed the entire traffic from a control centre.

After the construction of additional logistic cross passages, the contractors managed finally their tasks successfully. It is recommended to include a sufficient number of logistic cross passages already in the tender design [6].

Fig. 8: Gotthard Base Tunnel, Section Faido/Bodio, transportation logistics by rail [6]
(CP = cross passage, IL = inner lining)

2.4 Health and Safety

As everywhere, also in the GBT-Project was stipulated, that each worker should leave the job site at the end of his shift as healthy and safe as he started his work.

In the design phase, different types of fires in the tunnel with inclusion of workers in front of the fire were seen as one of the main safety risks. High initial rock and ground water temperatures of more than 50°C were also a big challenge for creation of acceptable working conditions. ATG, as the owner tendered the health and safety installation measures in detail in order to withdraw them from any speculation. Detailed specifications on the health and safety requirements were given in order to be considered by the contractors in their construction processes (e.g. smoke protection containers close to the excavation front connected to a protected compressed air pipe from outside, cross passages to the 2nd tube excavated 1'500 metres behind the first excavation front etc., layout of the ventilation system taking various fire scenarios into account, cooling systems).

Only very few fires occurred below ground during the construction period, mainly caused by engine failures. Thanks to modern extinguishing systems on all major machines (e.g. locomotives) no severe consequences occurred. A big fire of the conveyer belt system at the rig area of Sedrun showed the high importance of the adequate quality of the conveyer belts below ground. The same accident below ground (with the same, but for underground work inadequate belt quality) would have had disastrous consequences.

The accident risk in the AlpTransit project is defined as the number of accidents per full-time employee per year. This number includes any injury (also bagatelle cases). Since 2002 the accident rates were monitored systematically (Fig. 9).

In a common effort ("stop risk" campaign) the contractors, the site supervision and the client tried to bring this specific rate below the predefined target value of 200 accidents per 1000 workers per year. Even if the accident rates could be substantially reduced since the beginning of the main tunnelling work at the GBT, the monitored monthly accident rate never could generally be reduced below the target value [7].

Regrettably 9 workers lost their lives during the construction of the GBT. Eight of these accidents were related to machinery and transportation; one case was related to a rock-fall from the tunnel face. Each fatality is one too much and affects dramatically the live of relatives often for the rest of their lives. The fact, that the specific number of fatalities is comparatively low compared to earlier underground projects, indicates that the industry has reached major improvements in the last decades, but the final goal is not reached yet. A further reduction of accidents is a continuous obligation for all partners on the job site. "Target zero" as it is exercised actually in the Crossrail-Project (UK) must be the future state of mind in all Mega-projects.

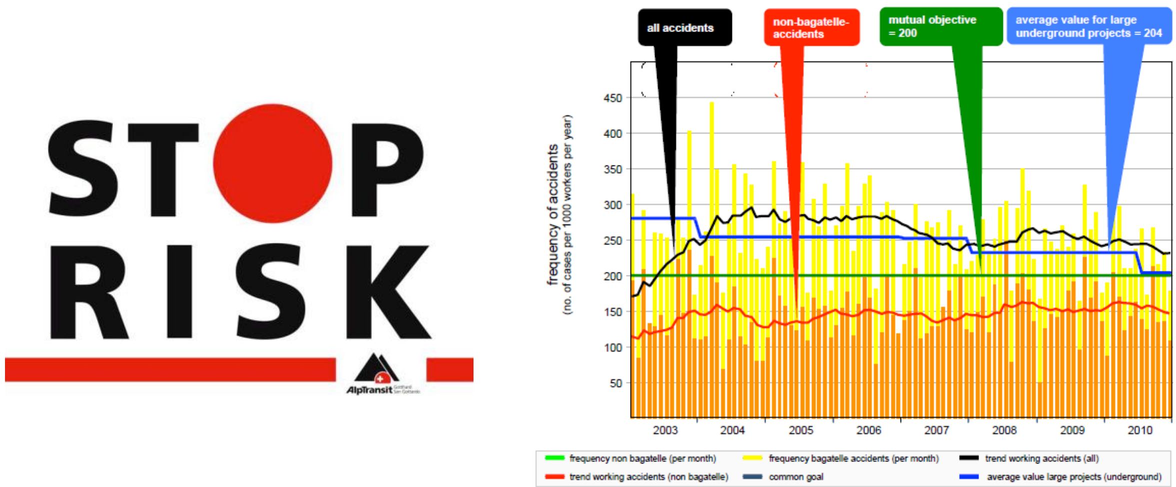

Fig. 9: Stop risk campaign and specific number of accidents (ATG, [5])

2.5 Environmental protection

The main goal of the Gotthard Base Tunnel Project is the improvement of the environmental conditions in the alpine regions by shifting the heavy load trucks from the road to the rail. Air pollution, noise omissions and the risks of accidents should be reduced to a significant lower level in the operational phase. But also in the construction phase dust protection, protection against air pollution, noise protection, water protection, protection of fauna and flora, protecting natural resources by adequate construction methods and the avoidance of damages to third parties properties and rights are also a must during.

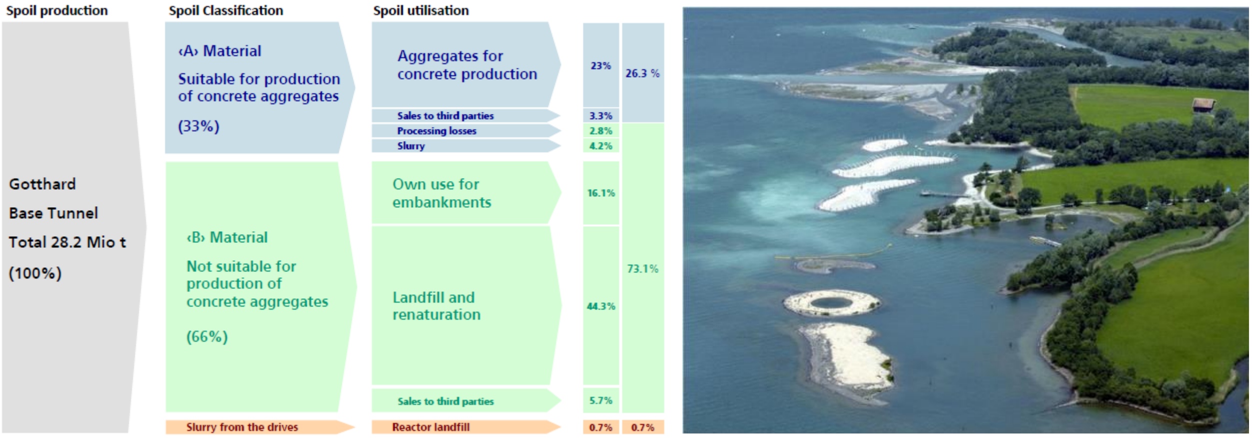

Fig. 10: Flow chart of the excavated material and excellent example of landfill (artificial islands in the lake of Lucerne for bathing and nature reserve)

The following measures were taken to protect the environment, to reduce or to compensate the negative impact of the construction:

- 33% of the spoil was of good quality and could be used for the production of concrete aggregates for the shotcrete (rock support) and the in situ concrete (final lining). 100% of the concrete gravel for the tunnel construction has been produced from excavated rock material with origin from the TBM-drives and the conventional drives! New technologies such as a mica washing process were introduced in order to receive a higher percentage of utilisation.
- All mass goods were transported by rail or by conveyer belts (no road transports).
- Particle filters were required for all Diesel engines above and below ground long before there was a legal obligation.
- Each rig area was equipped with a high tech sewage treatment plant cleaning a broad variety of polluted water.
- High investments were made for the treatment of the various qualities of mud.
- The inevitable interventions to flora and fauna were compensated by predefined mitigation measures. The goal to increase the biodiversity could be reached thanks to a good collaboration with environmental organisations and specialists.

3.8 Management of the underground construction contracts

Contracts for underground structures should take into account the special risk situation of this type of work and should allow a fast reaction on changed or unforeseen ground conditions. Fair risk sharing and partnering are helpful tools to facilitate fast decisions on site. Fair risk sharing between the client and the contractor helps to avoid unnecessary risk surcharges in the contractor’s bid and therefore to reduce the total project costs.

The Swiss Code SIA 118/198 gives a standard solution and follows the widely accepted principle of risk sharing for underground construction work:

1. The ground belongs to the client. Changed ground conditions outside the contractual limits are therefore client's risk.
2. Means and methods applied for ground conditions within the contractual limits belong to the contractor's risk sphere.

This principle works only if the client gives a complete and accurate description of the ground conditions and the expected behaviour according to his project. All relevant data from the ground investigation and all other relevant boundary conditions must be accessible to the contractors.

The selection of means and methods, especially the selection of the excavation method is one of the big risk factors for an underground project. The selected methods should be able to overcome the whole range of the expected ground conditions. Together with a catalogue of auxiliary construction methods, the selected excavation methods should also be able to master unexpected changed ground conditions. If the owner has, based on his risk analysis, compelling reasons to favour one method, he should select the excavation method before tendering. Such reasons can be risks related to the ground conditions, but also environmental or logistic requirements. If the ground conditions allow different methods and mainly the economic requirements become decisive, the contractors should be entitled to select his favourite method. Nevertheless the client has to define fair conditions for the competition (e.g. tendering two methods or allowing contractors alternatives in cases where the client tenders only one method).

Partnering is a key factor for success. Partnering means the definition of mutual objectives, the joint monitoring of the performance benchmarks and the common resolution of problems in the case of divergences. Partnering needs a culture of confidence and open discussions on each level. Big deviations from the cost and time targets at the GBT caused important contractual disputes. Solutions could be found after tough and time-consuming negotiations leaving both partners on an equal level of "unhappiness". The detailed unit price contracts, transparent models for the calculation of the unit prices and of the time dependent costs, a clear definition of the risk sharing and a culture of partnering made this result possible.

Not all disputes could be solved directly between the contractual partners. A Dispute Resolution Boards (DRB) was implemented by contractual agreement in each main construction lot following the Swiss Recommendation on Dispute Resolution (VSS 641'510) [8]. The DRB acts only up to limited amounts in dispute as an arbitration panel. In all other disputes the DRB gives a recommendation, which can be accepted or rejected by the contractual partners. In the case of rejection of the DRB's recommendation by one or both contractual partners the doors are open for a court case. The biggest effect of the DRB was the self-made psychological pressure on the site organisation to find an own solution.

Despite the positive experiences with the contract management of the GBT, a general trend to shift differences quickly to the lawyers and to court decision can be observed also in Switzerland. Experiences show, that court decisions are not faster, not cheaper, not better for the project reputation and are substantially often not better than the compromises taken by the contractual partners directly or based on a DRB recommendation. It's time to think about the actual trend and to change the culture back to partnership where the site management with the help of technical specialists and lawyers find fast and stable compromises.

3. CONCLUSIONS AND RECOMMENDATIONS

Alpine Base Tunnels and subsea tunnels have to fulfil the same project requirements but with different boundary conditions. Looking back on the history of the execution of the civil works for the Gotthard Base Tunnel, the following experiences may be helpful for future strait crossings:

- Professional risk management is the "insurance policy" for the project management and provides the adequate information on the risk situation on time. Risk management has to be introduced in the earliest phases of the project.
- Residual risks are immanent to underground constructions and have to be accepted and communicated by the various stakeholders. The contract should contain a clear and fair risk sharing policy.
- Well-defined mitigation measures such as a concept for probe-drillings and a catalogue of auxiliary construction measures help to reduce the ground risks.
- The design of the tunnel system should take into account all the construction sequences (e.g. logistic cross passages for twin tube systems).
- "Target Zero" must be the future state of mind on health and safety requirements (Crossrail).
- The reuse of the muck for the production of concrete aggregates is technically feasible and is today a must in order to save the natural, alluvial resources.
- The modern tunnelling technique and logistics has proved of value even in the most difficult conditions.
- Unit price contracts with fair risk sharing, partnering and the implementation of a dispute resolution board help to avoid time-consuming court cases.

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