Gotthard Base Tunnel
Risk Management for the World's Longest Railway Tunnel: Lessons Learnt

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Extended Abstract

1. Introduction

When breakthrough of the Gotthard Base Tunnel took place on October 15, 2010, one of the most important milestones was reached for scheduled train services in the 57-kilometres-long world's longest railway tunnel to start in 2016.

The Gotthard Base Tunnel consists of two parallel single-track tubes with an excavated diameter that varies between 8.8 and 9.5 metres. Approximately every 312 metres, the tubes are linked by cross-passages. Two multifunction stations (MFS) are located in the Sedrun and Faido sections, one-third and two-thirds along the length of the tunnel respectively. These will be used for the diversion of trains to the other tube via crossovers, to house technical infrastructure and equipment, and as emergency stopping stations for the evacuation of passengers. To shorten construction time, the tunnel has been divided into five sections, and is being excavated from several sites simultaneously. Excavation is taking place from the portals at Erstfeld in the north and Bodio in the south, as well as at three intermediate attack points: through access tunnels at Amsteg and Faido, and through two vertical shafts at Sedrun. Preparatory work began in 1996 with the excavation of access adits. Work on excavating the two parallel single-track tunnels started in 2002. As of end of March 2011, all of 151.8 km of access tunnels, shafts and main tunnels have been excavated. Reason enough to review what has been achieved, and to present the experiences and findings from the risk management perspective.

2. Principles of risk management at ATG

Even after 15 years of the project, the central questions in risk management for the Gotthard Base Tunnel remained unchanged:

- What could hinder, or even prevent, accomplishment of the goal?
  In other words, what are the risks that we must be able to master?
- What could further, or assist, accomplishment of the goal?
  In other words, what are the opportunities that we must exploit?

These questions also underlie the overall process of risk management, comprising risk identification, risk assessment and classification, application of the action strategy, planning and monitoring of measures.

Before the individual risks can be dealt with, boundaries must be defined for the system. In doing so, the scope of observation is defined, and determines which external influences will not be considered (e.g. meterorite impact). Risk identification is concerned with promptly recognising and describing the risks and opportunities. At ATG, when elaborating and periodically updating the risk lists, to ensure as much expert knowledge as possible, not only employees of ATG but also others involved in the project are included. In the next step, based on their probability of occurrence as well as on the consequences of their occurrence for costs, time schedule, functionality and work safety, the risks are systematically assigned scores in the range 1 to 3 and classified according to their relevance. For the classification, a weighted score is calculated for each risk or opportunity as the product of the score for the expected extent of the damage or benefit and the score for the probability of its occurrence. This system was introduced at the start of the project, and takes account of the characteristics of the project. A finer differentiation is deliberately not undertaken because of the lack of statistical relevance.

With the management strategy, the general parameters for the planning of measures are defined, and the following basic management options are always being evaluated:

- **Avoidance of a risk,** for example by not performing an activity
- **Reduction of a risk**, by suitable additional measures
- **Transfer of a risk**, partly or completely, to third parties, e.g. by means of insurance
- **Acceptance of a risk** as a residual risk.

ATG has adopted the following strategic approach for the planning of measures:

- For risk scores of 6 to 9 (above the acceptance threshold), additional measures must always be implemented, with the objective of obtaining for the residual risk a lower risk score of 1 to 4 (below the acceptance threshold).
- For risk scores of 2 to 4, additional measures must be evaluated.
- Risks with a low probability of occurrence (1) but a high level of damage (3) are rare major incidents for which corresponding emergency plans must always be defined.
- Opportunities above the action threshold must be actively exploited.

Measures planning consists of defining those additional measures that make risk mastering possible and result in an acceptable residual risk. Consideration must always be given to the material, personnel, and organisational aspects. When doing so, it is particularly important to include everyone involved in the project in the considerations, to avoid omissions or duplication in the planned measures. In the risk controlling process, the effectiveness of the strategy that is applied, and the planned measures, are reviewed in the risk discussions and modified where necessary. At the beginning of the project, these steps were repeated as many times as necessary using simple tables. Updating currently takes place quarterly, and is supported by an Internet-based database with a special Excel interface.

3. Geology as central risk

As in all major underground projects, the geological risks must be precisely analysed and localised. In the case of the GBT, this mainly referred to unknown geological and hydrological conditions at depths of up to 2,500 metres below the earth's surface. Based on the geological investigations, two zones were identified that threatened the feasibility of the project: in the Faido section the Piora syncline; and in the area of the Sedrun intermediate heading, the Tavetsch intermediate massif as well as the adjoining Clavaniev zone to the north, and the Urseren-Gavera zone to the south. By reference to these two examples, it is shown how the corresponding risk-reduction measures were successfully planned. Highly elaborate explorations of the geology were a major success factor.

The GBT demonstrated that even with extensive advance explorations, the geological risk cannot be ruled out entirely. Several times during the excavations the experience was made that in the one tube no driving difficulties occurred, but in the other tube, which was excavated at an axis distance of 40 metres, rockfalls occurred which caused months-long interruptions. On the other hand, constructionally more favourable conditions than were forecast also created opportunities. These were, and are being, actively exploited, as the repeated relocation of the lot boundary between Sedrun and Faido illustrates.

4. Conclusions

To date, the risk management system has proved itself. Where risks were identified, the necessary measures were initiated promptly. Despite extensive advance investigations and exploratory work, until the drives have been completely excavated they are subject to major risks associated with the geology. As far as possible and practicable, the measures required to master these risks should be included in the work contracts. In the overall time schedule, it is advantageous to work with ranges.

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Summary

The risk management system that is described in this article has, with amendments, been in use for the Gotthard Base Tunnel for 15 years. It is tailored to the needs of this unique construction and includes everyone involved in the project.

The geological risk is of central importance. By reference to specific examples, it is shown how the consistent planning of measures for the mastery of risks and exploitation of opportunities allows major successes to be achieved. Substantial residual risks nevertheless remain, for whose mastery the principles must already be included at the planning stage.

Keywords:

Tunnel construction, Tunneling, risk management, geology

1. Introduction

When breakthrough of the Gotthard Base Tunnel took place on October 15, 2010, one of the most important milestones was reached for scheduled train services to start in 2016 in what will then be the world's longest railway tunnel. Reason enough to review what has been achieved to date, and to present the experiences and findings from the risk management perspective.

2. The project

On several occasions, the Swiss electorate voted to construct a new high-speed rail link through the Alps. Switzerland's New Rail Link through the Alps (NRLA) will provide a faster and more reliable rail link between northern and southern Europe. It will enable much of the freight traffic to be transferred from road to rail. There are two NRLA routes: the Lötschberg axis in the west (in operation since 2007), and the Gotthard axis in central Switzerland (to be completed by 2019). The 57-kilometres-long Gotthard Base Tunnel is the main structure of the Gotthard axis.

Preliminary work for the Gotthard Base Tunnel started in 1996, with excavation of access tunnels and shafts. The main construction work began in 2002, and will be completed in 2014 [1]. After completion of the railway installations and commissioning, the Gotthard Base Tunnel will be ready to start commercial operation at the end of 2016.

To shorten construction time, the tunnel has been divided into five sections, and is being excavated from several sites simultaneously. Excavation is taking place from the portals at Erstfeld in the north and Bodio in the south, as well as at three intermediate attack points: through access tunnels at Amsteg and Faido, and through two vertical shafts at Sedrun (Fig. 1).

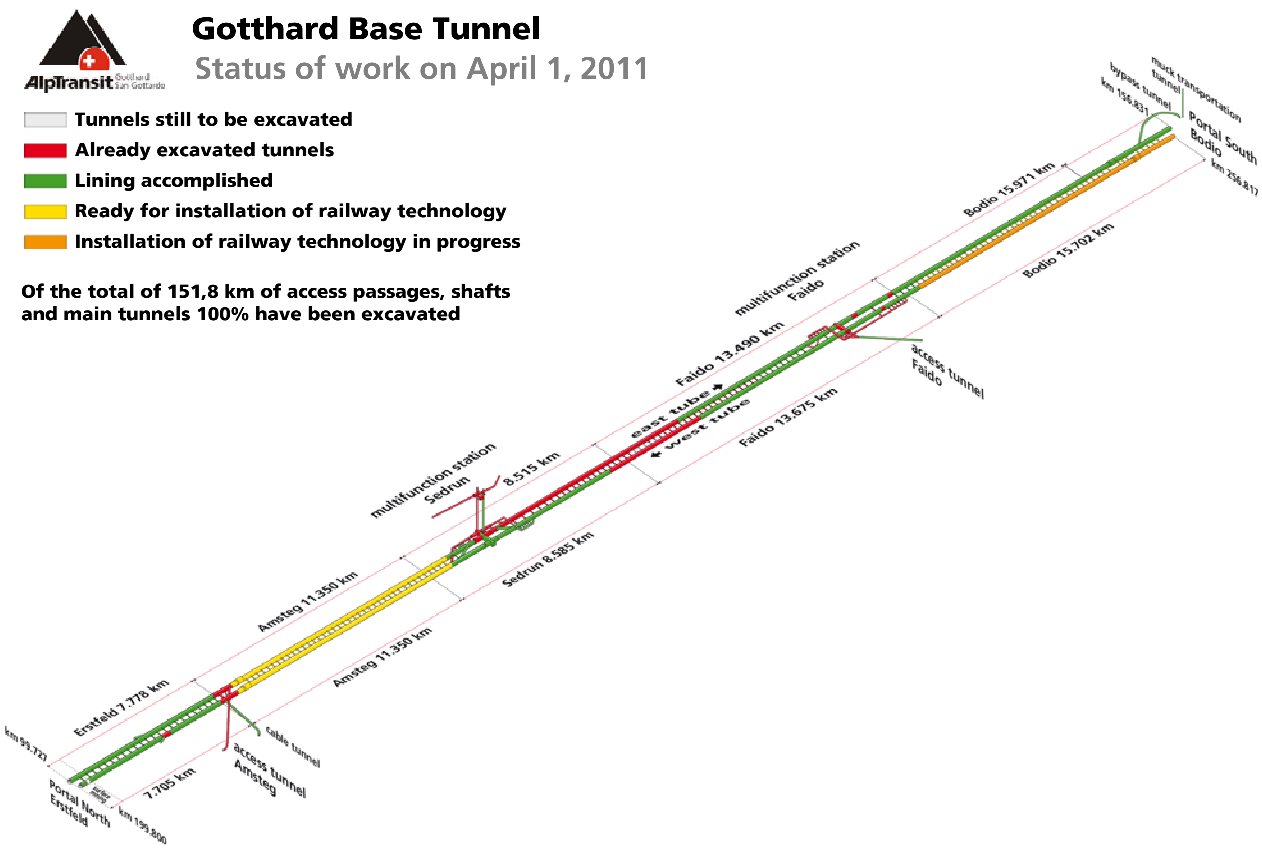

Fig. 1: Status of work on April 1, 2011

The Gotthard Base Tunnel consists of two parallel single-track tubes with an excavated diameter that varies between 8.8 and 9.5 metres. The tubes are linked by cross-passages at intervals of approximately 312 metres. Two multifunction stations (MFS) are located in the Sedrun and Faido sections, one-third and two-thirds along the length of the tunnel respectively. These will be used for the diversion of trains to the other tube via crossovers, to house technical infrastructure and equipment, and as emergency stopping stations for the evacuation of passengers.

Most of the tunnel will have a very high overburden: more than 1,000 m overburden over approximately 30 km of the tunnel, more than 1,500 m over 20 km, and more than 2,000 m over approximately 5 km. The maximum overburden is about 2,500 metres.

As of end of March 2011, all of 151.8 km of access tunnels, shafts and main tunnels have been excavated. Around 65% of the entire tunnel system is being excavated by tunnel boring machine (TBM). Around 35% of the total length, mainly the access tunnels, the main tunnels in the central construction section of Sedrun, and the multifunction station at Faido, is being driven by the conventional tunnelling method.

3. Principles of risk management at ATG

Like every management system, in the already more than 15 years duration of the project, the risk management system for the Gotthard Base Tunnel (GBT) has developed further. The key questions have nevertheless remained unchanged:

- What could hinder, or even prevent, accomplishment of the goal?
  In other words, what are the risks that we must be able to master?
- What could further, or assist, accomplishment of the goal?
  In other words, what are the opportunities that we must exploit?

These questions also underlie the overall process of risk management, comprising risk identification, risk evaluation and classification, application of the action strategy, planning and monitoring of contingency measures (Fig. 2).

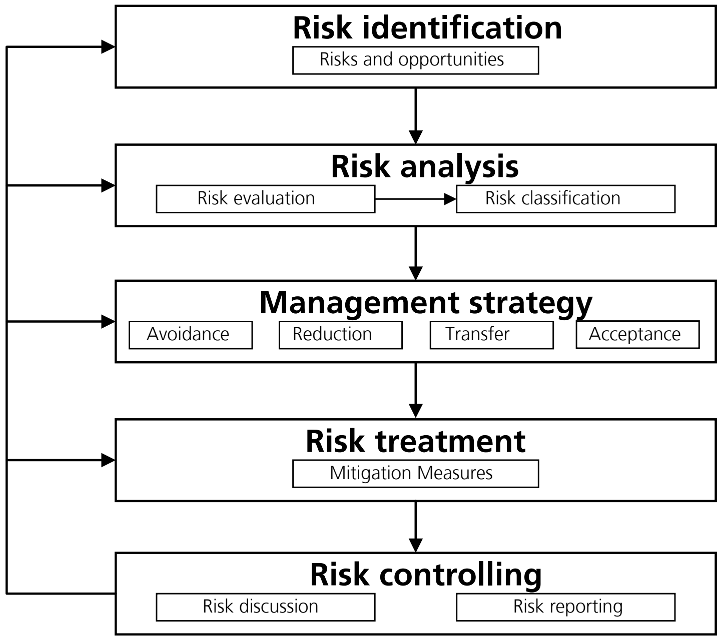

Fig. 2: General process of risk management [2]

Before individual risks can be considered, boundaries must be defined for the system. When doing so, the scope of observation is defined, and determines which external influences will not be considered (e.g. meteorite impact). The following must be defined:

- The object of consideration: e.g. for which part of the project should the statements apply?
- The point in time of the consideration: what status of knowledge is available?
- The duration of the consideration: which phase of the project should be handled?
- The perspective of the consideration: e.g. the perspective of the owner or the contractor?

Risk identification is concerned with promptly recognising and describing the risks and opportunities. At ATG, when elaborating and periodically updating the risk lists, in addition to employees of ATG, the project engineers and geologists, construction managers, external specialists and, depending on the phase of the project, also the contractors of the major tunnel lots are involved. This ensures that the greatest possible amount of expert knowledge is used.

In the next step, the risks are evaluated and classified according to their relevance. The evaluation is based on a weighted score for each risk or opportunity. The weighted score is the product of the score for the expected extent of the damage or benefit and the score for the probability of its occurrence.

ATG uses a system in which the probability of occurrence and the extent of the damage or benefit are each scored on a scale of 1 to 3 (Fig. 3). This system was introduced at the start of the project and takes account of the characteristics of the NRLA project. A finer differentiation is deliberately not undertaken due to the lack of statistical relevance.

W: Probability of occurrence	**1** Low	**2** Medium	**3** High
Definition	Based on experience unlikely to occur	Cannot be ruled out during construction	Occurrence must be expected

A: Extent of damage/benefit	**1** Low	**2** Medium	**3** High
Costs	Less than CHF 1 million	CHF 1 to 10 million	More than CHF 10 million
Time schedule	Less than 2 months	2 to 6 months	More than 6 months
Work safety	No permanent impairment	Permanent health impairment	Severe permanent health impairment or death
Quality / functionality	Insignificant impairment	Some impairment	Severe impairment

Fig. 3: Risk evaluation table

The risk classification serves to determine the planned measures, and at ATG comprises the risk classes shown in Fig. 4.

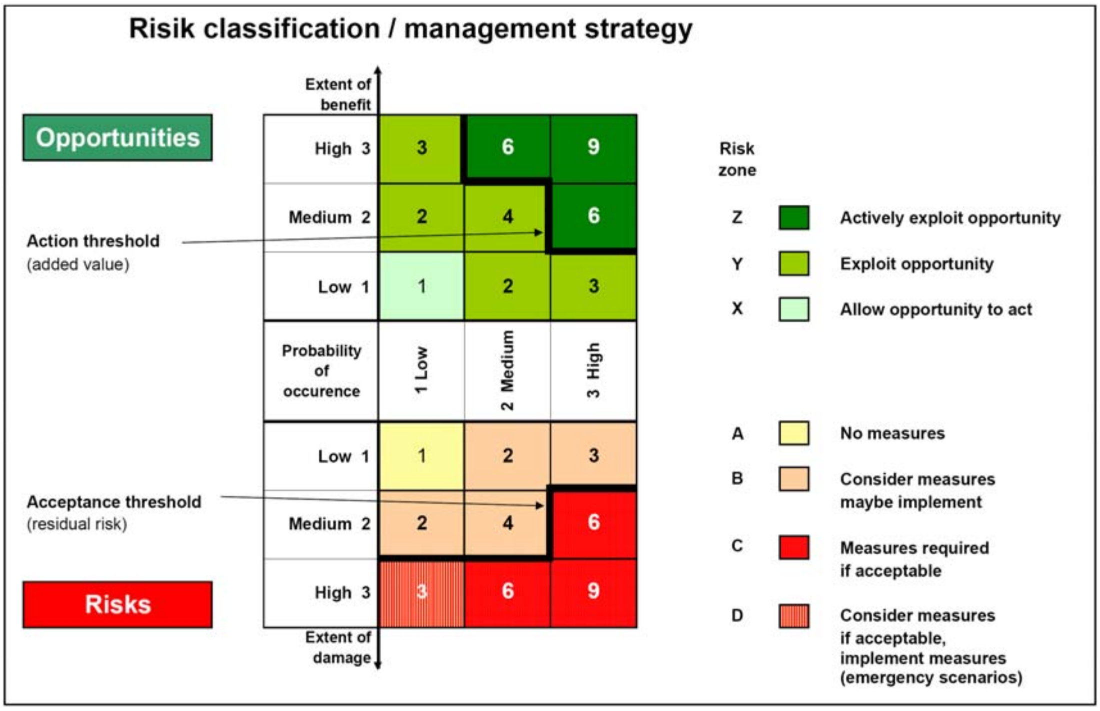

Fig. 4: Risk classification and management strategy

With the management strategy, the general parameters for the planning of measures are defined, and the following basic management options are always being evaluated:

- **Avoidance of a risk,** e.g. by not performing an activity
- **Reduction of a risk**, by suitable additional measures
- **Transfer of a risk**, partly or completely, to third parties, e.g. by taking out insurance
- **Acceptance of a risk** as a residual risk.

ATG has adopted the following strategic approach to the planning of measures:

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- Risks with a low probability of occurrence (1) but a high level of damage (3) are rare major incidents for which corresponding emergency plans must always be elaborated.
- Opportunities above the action threshold must by actively exploited.

Measures planning consists of defining those additional measures that make risk treatment possible and result in an acceptable residual risk. Consideration must always be given to the material, personnel, and organisational aspects. When doing so, it is particularly important to include everyone involved in the project in the considerations, to avoid omissions or duplication in the planned measures. For this reason, at least twice a year the risk analyses and contingency measures of ATG must be bilaterally agreed with the project engineers, the local construction management, and the main contractors.

In the risk controlling process, the effectiveness of the strategy that is applied, and the planned measures, are reviewed in the risk discussions and modified where necessary.

At the beginning of the project, these steps were repeated as many times as necessary using simple tables. Updating currently takes place quarterly, and is supported by an Internet-based database with a special Excel interface.

Equally decisive for successful risk management is seamlessness of the system from the individual construction lot via the tunnel section, the complete tunnel, and the different project phases, to the contract with the Swiss Confederation.

4. Geology as central risk

In the early project phases, four questions had to be answered which are not independent of each other:

- What must be constructed?
- What safety aspects must be taken into consideration for construction and operation?
- Can we construct it?
- How long will it take, how much will it cost, and can its construction be financed?

To answer these questions, the first step was to analyse the geological risks and define them more precisely. In the case of the GBT, this mainly referred to unknown geological and hydrological conditions at depths of up to 2,500 metres below the earth's surface.

Based on the geological investigations, two zones were identified that threatened the feasibility of the project: in the Faido section the Piora syncline; and in the area of the Sedrun intermediate heading, the Tavetsch intermediate massif as well as the adjoining Clavaniev zone to the north, and the Urseren-Gavera zone to the south [3]. By reference to these two examples, it will now be shown how the corresponding risk-reduction measures were planned.

4.1 Piora syncline

For decades, there was controversy among geological and engineering experts about the form that the Piora syncline would take at the level of the base tunnel. While the pessimists held the view that cutting through the syncline would be virtually impossible, the optimists were of the opinion that this formation would not be present at the level of the tunnel, or could be mastered without noteworthy hindrance. To evaluate and define the risk, in the years 1993 to 1996 elaborate exploratory work, costing around CHF 100 million, was performed [4]. These showed that neither the pessimists nor the optimists were totally wrong in their convictions.

A tunnel boring machine was used to cut an approximately 5.5-kilometres-long exploratory bore about 350 metres above the level of the future tunnel to the area where the syncline was believed to be situated. In March 1996, a core bore in this area encountered the syncline, consisting of sugary dolomite under very high water pressure. Because of a faulty manipulation of the preventer system, water and sugary dolomite flowed into the tunnel and within a few hours flooded the main road in front of the tunnel.

After this situation had been mastered, a total of 19 bores, with a total length of 7,000 metres, were performed from the exploration adit. These showed that, in the area of the future tunnel, solid dolomite anhydride was present, but no water. These findings were taken into account in the further project, the invitations to tender, and the contract documents. However, despite the now positive findings, special measures were planned for the approach to the Piora syncline. In addition, in autumn 2008, before starting cutting with the TBM, an almost 300-metres-long core bore was made from the east tube of the base tunnel, which confirmed the findings of the exploratory bore system. This confirmation was pleasing, since it could have been otherwise. Indeed, during the excavations, ATG had several times made the experience that in the one tube, no driving difficulties occurred, but in the other tube, which had to be excavated at an axis distance of 40 metres, there were rockfalls that caused months-long interruptions.

In October 2008, the Piora syncline was traversed without problem by the east TBM, and in January 2009 by the west machine.

4.2 Tavetsch intermediate massif and Urseren-Gavera zone

The intermediate heading at Sedrun presented a special challenge not only because access to the base tunnel required two 800-metres-deep shafts to be sunk, but also because a multifunction station had to be constructed between two constructionally very unfavourable rock formations. At the time when the exploratory bores for the Piora syncline began, the feasibility of the tunnel in the northern section of the Tavetsch intermediate massif (TZM North) and in the Urseren-Gavera zone (UGZ) was regarded equally critically. This was mainly because of the intense pressure effects that were expected [5].

Such huge plastic deformations in the UGZ were already known from the Gotthard road tunnel, which was constructed in the nineteen-seventies about 500 metres higher but 15 kilometres further west. The TZM North was expected to present similar, if not even greater, constructional difficulties. It was between these two formations that the MFS, consisting of several tunnels and galleries at various levels, should be constructed. Because of this, also here an elaborate campaign of exploratory bores was performed with several diagonal bores, some of them to the level of the tunnel. The results can be summarised as follows: construction of the MFS in the planned position would be possible, since the UGZ could not be bored and the MFS would therefore only be affected in the southernmost area. North of the MFS, in the TZM North with a length of around 1,200 metres, kakiritic rocks would be encountered. Triaxial tests indicated these rocks to be highly ductile, and to increase greatly in volume when fractured. With an overburden of 800 metres and more, in these rocks two tubes with a final internal diameter of approximately 8 metres, and an axial separation of 60 metres, should be constructed.

To master these conditions, a new construction concept was developed by the project engineers in collaboration with the Construction Engineering work group of ATG. The new concept combined two known methods: the use of steel inserts in the form of deformable (sliding) steel rings, which was known from the mining industry, in conjunction with the Italian practice of full face excavation with systematic strong support of the face. Neither of these methods had previously been used under the prevailing conditions.

The deformable steel insert is based on the displacement principle, which means that as the amount of deformation increases, the resistance that is required to maintain equilibrium decreases. Convergences of the excavation support are therefore deliberately allowed, for which additional excavation must be foreseen. Static calculations for the GBT indicated a required excavation diameter of up to around 13 metres (approximately 133 m2), with expected radial convergences of up to 70 cm and a maximum thickness of the final concrete inner lining of 120 cm. Experience with such dimensions in the mining industry did not exist.

Since the deformable steel rings require full face excavation, support of the driving face takes on a central significance. In combination with rigid, and therefore non-deformable support, there was experience in the range of 100 to 120 m2, but with much lower overburdens, mostly of 200 to 300 metres.

Since the constructional principle was technically groundbreaking and associated with corresponding risks, those responsible for the project decided to perform trials on a scale of 1:1. Because the installations for a full excavation with a diameter of 13 metres presented a challenge, to obtain the maximum possible benefit for everyone involved in the project, these trials were included in the work contract of the tunnel construction contractor. It was originally intended to perform the trials in a hall. In fact, the trials were performed on the construction site at Sedrun in a side tunnel only a few hundred metres from the actual point of application, and by those workers who would later put the method to daily use. The rock pressure was simulated with water-filled cushions, and the collapsing behaviour of the double steel rings was determined in relation to various parameters. An important finding of the trials was that the theoretical load-bearing behaviour was not obtainable in practice, so for the most extreme cases additional solutions had to be sought. In case the deformations should result in an undersized cross section despite the oversized excavation, the necessary repair and reprofiling measures were already included in the work contract. During the trials phase, a work group was set up comprising representatives of the project engineers (including geologist), the construction managers, the contractors, ATG, and external experts. This group not only guided the driving work until its successful conclusion, but also prepared the fallback levels required for mastering squeezing rock conditions of exceptional severity.

Driving in the TZM North began in summer 2004 and was completed in mid-November 2007. After a further 20 metres in compact rock, breakthrough to the adjacent Amsteg section in the west tube was celebrated on October 17, 2007. Breakthrough in the east tube took place on November 29, 2007, more than half a year earlier than originally planned.

According to the forecast, the UGZ should start in the southernmost area of the MFS. Its length was forecast to be somewhat more than 500 metres (510 m). To master the expected intensely squeezing rock conditions, the use of deformable steel inserts in conjunction with intensive systematic cutting-face support, as in the TZM North, was foreseen. Based on the average advance rate of 1.1 metres per working day that had been agreed with the contractor in the work contract, a duration of 15.5 months was calculated for excavation of this zone.

In fact, the UGZ was encountered 465 metres further south than expected [6]. Consequently, no squeezing rock conditions had to be mastered in the MFS, which favourably affected the time schedule and construction costs. In addition, no pressure effects at all occurred, and the actual length of the UGZ at tunnel level was only 305 metres, or 60% of the forecast length. The actual average advance rate including exploratory bores and interruptions was 1.9 metres per working day in the east tube and 1.8 metres per working day in the west tube. Within less than half a year, an enormous advance on the construction schedule was thus achieved: a great opportunity.

5. Relocation of the section boundary between Sedrun and Faido

In contrast to Sedrun, driving work in the southern sections from Bodio and Faido was not progressing at all satisfactorily. The main reason was that the geological conditions did not correspond to the forecasts. Unexpected pressure effects brought the TBM drives at Bodio to a virtual standstill and made reprofiling and repair work necessary which lasted for more than a year. The geological and constructional problems that arose in the MFS Faido shortly after excavation started have already been described several times, and resulted in repositioning of the MFS.

In May 2005, when the drives from Sedrun had traversed the UGZ and reached the Gotthard massif, the situation was as follows: while Sedrun was 10 months ahead of the construction schedule, the drives from the south were already 22 months behind schedule and falling further behind all the time. Even if the delays did not become longer after the middle of 2005, the TBMs would only reach the Faido/Sedrun lot boundary around three years after the blast drive from Sedrun. It was already clear that the date of breakthrough between Faido and Sedrun would be crucial for completion of the work, and therefore also for commissioning on time.

Already before mid-2005, ATG in collaboration with the project engineers started to initiate the necessary measures to optimise the construction programme, working on two aspects in parallel: firstly, preparing to initiate the options that were foreseen in the work contracts for lengthening or shortening construction lots; and secondly, a further relocation of the Sedrun/Faido lot boundary towards Faido.

To reduce the deadline risk, already in the construction project options were foreseen of lengthening or shortening the Sedrun lot at the boundaries to the Amsteg section in the north and the Faido section in the south. These options were also included in the work contracts of the tunnel construction lots at Amsteg, Sedrun and Faido. While it was not necessary to implement these options for the Amsteg/Sedrun boundary, in view of the situation described above, the Board of Directors of ATG decided on December 7, 2005, to implement the option of lengthening both of the southward drives from Sedrun by 1,000 metres.

Since, in view of the project development, these additional 1,000 metres of southward drive from Sedrun did not provide sufficient safety for a stable time schedule, work was begun on concepts for a further southward relocation of the lot boundary. For such a relocation of the lot boundary to be possible, among other things it was necessary to develop a new concept for spoil processing at Sedrun [7].

In October 1995, planning permission was issued for the surface systems at Sedrun. These also included the temporary storage sites and landfills for the excavated rock. To take account of the known project risks, the calculations for the spoil processing were based on wide ranges, and the landfill requirement dimensioned accordingly. Relative to the scenario that was probable at that time, even without relocation of the lot boundary the quantity of excavated rock increased by around 900,000 tonnes. This was mainly because of the large number of additional or modified excavations. Examples are construction of the second shaft, modifications to the air exhaust system, changes to the lot boundaries, and changes to the distances between the transverse passages between the preliminary project and the construction project. Although the ATG concept of recycling the excavated rock to manufacture aggregate for the concrete and shotcrete required for construction of the tunnel meant that not all of the increased quantity had to be deposited, the range was nonetheless exceeded. Relocation of a lot boundary results in substantial additional quantities of excavated rock. Since transportation by train or road vehicle was not possible in sufficient quantities, additional storage possibilities had to be found close to the construction site.

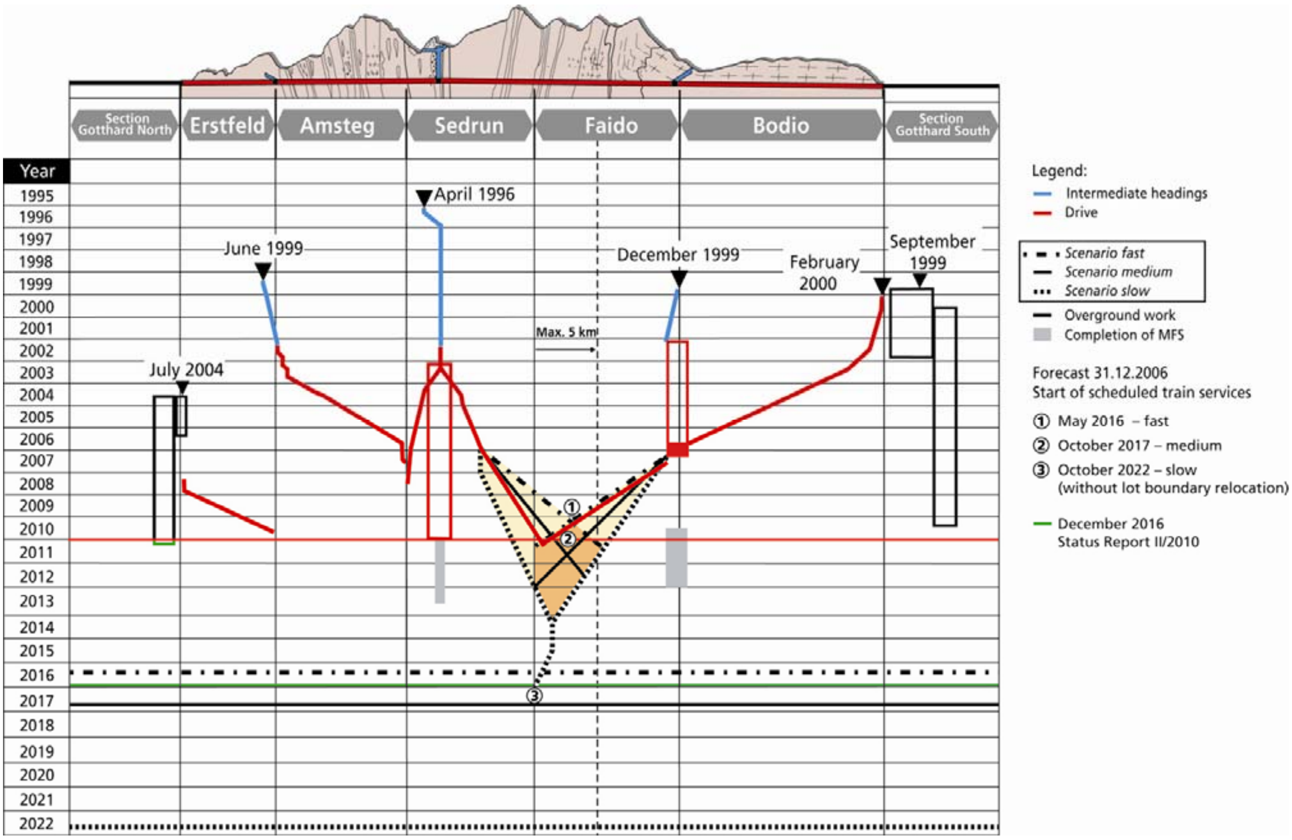

Fig. 5: Comparison of range forecast on 31.12.2006 with the actual status on 31.12.2010

By involving all the interested partners who were affected – municipality, region, canton, residents, environmental organisations and approval authorities – solutions capable of being approved could be found and realised. This was an essential prerequisite for implementing the relocation of the lot boundary.

To estimate the time and cost risks of the entire project with and without lot-boundary relocation, this aspect was analysed in depth in a joint study by the project engineers and ATG in 2006 [8]. Since this study was described in detail at WTC 2010, it will not be discussed further here. As a result, in the first half of 2008, a further relocation of the Sedrun/Faido lot boundary of around 1.5 km towards the south (Faido) was initiated.
Since the study was performed, several important unexpected events with substantial effects on the construction time have occurred. Examples are the squeezing rock conditions in the TBM drives north of the MFS Faido, and the more than 150-metres-long fault zone 50/50b, instead of the 5 metres that were forecast, in the Sedrun section. On the other hand, not all of the unfavourable assumptions that were made have occurred to the full extent. The ranges that were calculated in 2006 have proved to be sufficient to cope with these unforeseeable situations. In the relocated boundary until the date of breakthrough, 763 metres were excavated in the east tube, and for the west tube it is 1,282 metres. Relative to the forecast made in autumn 2006, the breakthroughs took place around 1.5 km further north, and half a year earlier, than planned.

Since the favourable development in the overall time schedule had already been apparent for some time, in February 2009 ATG initiated a project with the goal of bringing the opening of the tunnel with scheduled train services forward by one year from 2017 to 2016. Once the measures for assuring the technical feasibility had been decided, negotiations were also held with the contractors. At the end of October 2010, the proposals for implementation were approved by the Board of Directors of ATG. At the moment the SBB (Swiss Federal Railways) as the future owner is checking whether this one year can fully be used for commercial operation.

6. Conclusions

To date, the risk management system has proved itself. Where risks were identified, the necessary measures were initiated promptly. Fig. 6 shows the effects of the implemented measures for the Piora syncline and the TZM North as examples. Despite extensive advance investigations and exploratory work, until the drives have been completely excavated they are subject to major risks associated with the geology. As far as possible and practicable, the measures required to master these risks should be included in the work contracts. In the overall time schedule, it is advantageous to work with ranges, and, wherever possible, to allow corresponding options for relocating lot boundaries.

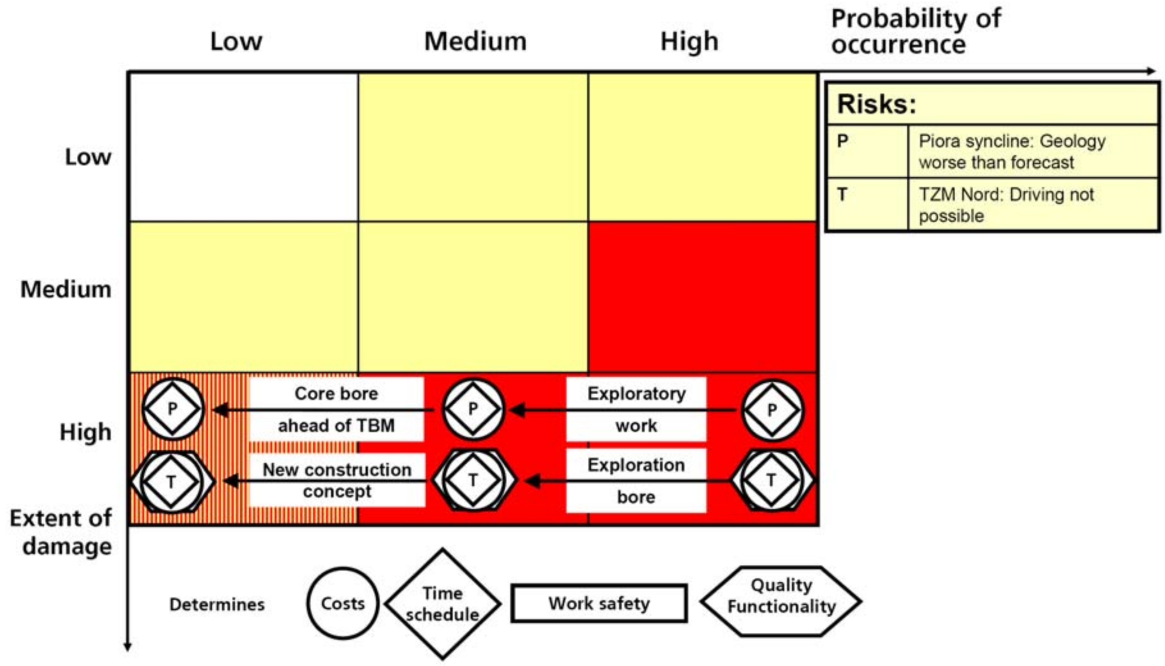

Fig. 6: Example of reduction of major risks by additional measures

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