THE GOTTHARD BASE TUNNEL: PROJECT OVERVIEW

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Abstract:

The Gotthard-Base Tunnel will be the world’s longest traffic tunnel, with a length of 57 km. The tunnel is part of the New Alpine Transverse in Switzerland. The dual purpose of this project is to provide a highspeed link for passengers between Germany in the North of Europe and Italy in the South of Europe and to transfer freight traffic from roads to rail. It makes an essential step to actively protect the Alps and to get an important contribution to preserve the environment in general. At the present time the construction works are proceeding ahead at both portals and at the three intermediate accesses. Over 33% of the total length of tunnels and the galleries are excavated. Some difficult parts of the tunnel have been completed successfully, some others with over 2,000 m of overburden and poor rock mass properties have to be excavated next.

Introduction:

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

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

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

General aspects of the new Gotthard route:

The transalpine rail route “Gotthard” will rely the city of Zurich with the city of Milan (see Fig. 1), interesting a catchment’s area of over 20 millions people in Germany, Switzerland and Italy.

Shorter travelling times – an hour less between Zurich and Milan, for example – will mean that rail travel across the Alps will be able to compete with flying (a better modal split for the rail) and to permit to optimise connections.

The realisation of three important tunnels is required: the Ceneri Base Tunnel in the southern part (15 km long), the Zimmerberg Base Tunnel in the northern section (total length 20 km) and the Gotthard Base Tunnel in the heart of the project (57 km).

Fig. 1: New transalpine rail routes through Switzerland.
The most impressive part of the new traffic route through the Alps is the Base tunnel under the Gotthard, which is planned to handle mixed traffic, that is high speed passenger trains (up to 250 km/h) as well as slower freight trains (up to 160 km/h). Once complete and operating, the Gotthard base tunnel will be the longest tunnel in the world. It will run through the Alps at approx. 500-550 meters above sea level. It’s highest overburden will be approx. 2'300 m. With a minimum Radius in curves of 5,000 m and with a maximum slope of 0.70% the Gotthard base tunnel will be the first flat railway trough the Alps.

Overview of the Tunnel Design:

The base tunnel stretches from Erstfeld in the north to Bodio in the south (see Fig. 2). It consists of two parallel single-track tubes with a diameter varying from 9.0 up to 9.5, which are linked by cross-passages every 300 meters. At two positions, one-third and two-thirds along the base tunnel, are located multifunction stations for the diversion of trains via the crossovers to the other tube, for the installation of electro-mechanical installations, and for the stop of trains and the evacuation of passengers in an emergency case.

Detailed and sophisticated evaluation demonstrated that this tunnel system was the most suitable for long alpine tunnels. To shorten construction time and for ventilation purposes, the tunnel will be driven from several sites simultaneously. To this end, the tunnel has been divided into five sections. Excavation will take place from the portals as well as from three intermediate attacks in Amsteg, Sedrun and Faido.

The Geology / Geological Conditions:

From north to south, the 57 km long Gotthard Base Tunnel passes through mostly crystalline rock, the massifs which are broken by narrow sedimentary zones, the tectonic zones. The 3 crystalline rock sections are the Aar-massif in the north, the Gotthard massif in the middle and the Pennine gneiss zone in the south (see Fig. 3). These zones are unlikely to cause any major technical difficulties during construction and they are quite favourable for tunnelling. These units consist mainly of very strong igneous and metamorphic rock with high strength. More than 90% of the total tunnel length consists of this type of rock. The main danger is the risk of rock burst caused by the high overburden, the instability of rock wedges and water inflow.
Major sections of the tunnel will have a very high overburden: more than 1,000 m for roughly 30 km, more than 1,500 m over 20 km and it can even be more than 2,000 m for approx. 5 km, the maximum is about 2,300 m. This has been taken into consideration in deciding the heading concept and rock support design.

Fig. 4:
Investigations in the Sedrun section.

Fig. 5:
Forecast rock temperatures at base tunnel level.
The most difficult section facing the new tunnel is the so called (old crystalline) Tavetsch intermediate sub-massif in the Sedrun section. Located between the Aar-massif and the Gotthard-massif, it is one of the about 90 different isolated short fault zones along the 57 km. It consists of a steeply-inclined, sandwich-like sequence of soft and hard rock. Exploratory drilling in the early nineties indicated extremely difficult rock conditions for about 1,100 m of the tunnel (see Fig. 4). As well as compact gneiss, there are also intensively overlapping strata of schistose rock and phyllite.

In the Faido section the Piora syncline has been deeply investigated in the second part of the nineties.

The initial planning phases concentrated on cutting through the different fractured zones at their narrowest points wherever possible.

The high mountain overburden of up to 2,300 m means that operating temperatures in the tunnel can reach 35-40°C (see Fig. 5). In order to maintain the required air conditions in the different working areas, a continuous cooling system is required.

Current state of Construction works:

Work on the Gotthard Base tunnel has been proceeding for many years, e.g. in Sedrun work has been in progress since 1996. On July 19th 2004 the first milestone at the northern portal Erstfeld, the starting point of the last section, has been set and in the next months preparations will proceed for the main work on the tunnel. Now in all construction sites (portals and intermediate attacks) the base tunnel is under construction. Up to the present, about 50.4 km of tunnels and galleries or 33% of the entire project (153.3 km) have been excavated. These are shown in red and green on the 3-dimensional picture in Fig. 6.

Fig. 6: Gotthard base tunnel, state of works on July 14th 2004.

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

In Amsteg, the heading of the 2 km long horizontal adit to the axis of the Base Tunnel began in December 1999, as did construction of the processing plant and all the conveyor belt equipment for the removal of the muck.

In autumn last year the two TBMs in the Amsteg section with a diameter of 9.58 meters each, were installed in underground installation chambers. More than 3.2 km in the west and 3.7 km in the eastern single track tube have been driven thus far. In April this year the first predicted geological difficult zone (the Intschi-zone) was penetrated successfully and without the suspected time delays.

![Fig. 7: Tunnel Amsteg, east tube, TBM cutter-head TBM.](image)

The TBMs (see Fig. 7) still have more than 7 km each to go. The best performances up to July 31st 2004 are 40.10 m within a single day and 664.50 m within a single month; at the present time the daily average heading rate is of about 9.62 m (TBM west) respective to 9.06 m (TBM east).

The debris is transported with conveyor belts from the back-up of the TBMs to the material processing plant on the construction site, where a part of it is recycled to produce concrete aggregates. Tunnel trains only provide transportation of rock support materials, concrete, miners and staff members, and sometimes visitors. The rest of the debris of the Amsteg and Erstfeld sections will be transported by rail and boat to the nearby Reuss river mouth, where it will be used for restoration of the natural conditions of the river delta.

**Sedrun Section:**

This section is the most complicated of the base tunnel, for logistical and geological reasons. The adit (1 km), the inclined ventilation shaft (450 m), the cavern at the top of the first shaft and the 835 m-deep vertical access shaft have been completed in several preparatory construction lots. The entire logistic supply for the heading of a total tunnel length of 2 x 6.8 km (4 simultaneous tunnel drives, together with others minor drives) has to be done through the access tunnel and the double shaft system. Up to 6,000 tonnes of excavated material have to be handled every day. Shaft drives were installed for a double floor hoisting cage with a 5 MW rating, providing 60 km/h hoisting speed for an 80 t load.

Shaft 1, with a diameter of 7.90 m has been excavated in full section from the cavern at the shaft top by drilling and blasting. To sink shaft 2 -two extra caverns have been first excavated at the top and bottom level - in the phase 1 a pilot bore with a drilling bit of 43 cm has been realised from shaft top (daily heading rate 11.07 m). In second phase the pilot bore has been enlarged with a raise-boring machine to a diameter of 1.80 m (daily heading rate 25.83 m). In the third and last phase shaft 2 has been enlarged to the final diameter of 7.0 m with a shaft top down boring machine (daily heading rate 5.05 m). Phases: see Fig. 8.
The headings are still going on in quite favourable geological conditions (better as the geological prediction, without radial deformations and dry water conditions). To the present, about 5.3 km of tunnels and galleries have been excavated. However in autumn this year they will reach the phyllits and shales of the Tavetsch intermediate massive. In these very bad rock conditions, in consideration of over 2,000 m of overburden, it is expected to deal with radial deformations of up to 70 cm and a daily heading rate of about 80 cm. Intensive support with steel arches, anchoring and face support will be necessary. To check the ultimate resistance of yielding lining, tests in real scale with a double steel ring TH44 – with simulation of rock mass pressures of about 0.75 MPa – have been undertaken (see Fig. 9). With a minimum distance between each double steel ring of only 0.33 m, the ultimate expected resistance of the support of the strongest cross section (including rock bolts) will be under a rock mass pressure of about 1.80 MPa. The cross section of the single tubes increases from about 80 square meters up to more than 130 square meters (see Fig. 10).
Faido Section:

In Faido the Base Tunnel is opened up via an inclined 2.7 km long access adit (decline of 12.7%). The construction of this gallery began in December 1999 and has been constructed by conventional drilling and blasting. Close to the adit portal, extensive processing plants – for recycling of a part of the muck and for the production of concrete aggregates – and conveyor belt systems for the transportation of debris have been constructed. A 5 km long conveyor belt takes part of the surplus debris to be deposited finally in an old quarry.

The contract for the main lot in combination with the southern Bodio section has been awarded at a sum of 1.1 billion US$. The Multifunctional station was planned according to the geological prediction in favourable rock conditions. The different types of galleries, tunnels and caverns are excavated by drilling and blasting.

Totally unexpected, in summer 2002 an intensive fault zone has been met. It passes through the large caverns of the multifunctional station at a very acute angle. An intensive investigation program was carried out to define the best place for the huge cross over caverns with cross sections up to 260 square meters – mind that with an overburden of nearly 1,500 m. The picture in Fig. 11 gives an impression of the test drillings, investigation headings as well as the location and dimension of the fault zone (shown in red). As a result of these investigations it was possible to adapt the layout of the multifunctional station with the aim of placing the large caverns in good rock conditions in the southern part of the multifunctional station. To the present, about 6.7 km of tunnels and galleries and two cross over caverns have been successfully excavated.
The northern headings in the single track tubes are still within the fault zone and still need very intensive rock support. The yielding steel support (see Fig. 12) has proved to be a good system in these rock conditions with more than 40 cm of radial deformations.

Fig. 12: Tunnel Faido, yielding lining.

**Bodio Section:**

Extensive constructions work were taking place at the southern Portal in Bodio before Autumn 2002, in preparation for the heading of the main tunnel lot. These were:

1. A bypass-adit – headed with conventional drilling and blasting, with a total length of 1,200 m – to bypass the very delicate and time-consuming loose rock zone at the portal of the base Tunnel. The bypass was excavated in good rock conditions. The two 15 km tunnel tubes in Bodio, leading north in the direction of Faido started in the cavern at the end of the bypass.
2. The 3.2 km long mucking tunnel, which will serve as a conveyer belt tunnel. The conveyor belt system (3.7 km long) will transport 6 million tons of debris to the neighbouring Blenio valley. The mucking tunnel was excavated by means of a 5m-diameter TBM. The work was finished in April 2001.
3. The opencast constructed Tunnel (380 m long), including the portal (see Fig. 14). The construction works has been completed successfully in July 2003.
4. The tunnel section in the loose rock material that follows the open cast construction, which is also close to 410 m long. This tunnel section was excavated through very delicate rock fall and loose rock material (see Fig. 13). To drive the heading through this zone, auxiliary measures have been taken such as putting a pipe screen umbrella in place and undertaking a large amount of grouting. The heading of this section has been completed successfully in June 2003, on time and in full respect of the expected costs.
5. Finally all the processing plants that recycle the debris into concrete aggregates, or the conveyer belt systems that will transport the surplus debris through the mucking tunnel to the Buzza of Biasca stone quarry or to the construction site of the open air part of the new railway route.
In January respective in February of the last year the two TBM s in the Bodio section with a diameter of 8.80 meters each, installed in underground installation chambers, started their journey. More than 4.0 km in the west and 5.1 km in the eastern single track tube have been driven thus far. The TBM s (see Fig. 15) still have about 9 km each to go. The best performances up to July 31st 2004 are 35.00 m within a single day and 512.00 m within a single month; at the present time the daily average heading rate is of about 10.21 m (TBM west) respective to 7.13 m (TBM east).
During the “learning” phase, shortly after the start of the TBMs, also in Bodio the TBM headings met a unpredicted fault zone. The flat lying zone followed the tunnel tubes for some 500 m in the eastern and nearly 60 m in the western tube (see Fig. 16). In autumn last year this fault zone was successfully penetrated. The average heading rate in the fault zone was approximately 2.45 m per day. After that the average heading rate increased to 13.13 m (TBM west) respective to 12.21 m (TBM east) per day this year.

In April 2004 the concreting of the lining support and of the lining itself has been started in the west tube. About 500 m of final lining have been executed using the especially designed formworks with variable geometry installed on the so-called “worm” (see Fig. 16).
Environmental considerations:

The Swiss population is in general very sensible for environmental problems and the Swiss government did and does set high priority on the preservation of the territory and of the water resources. Several federal laws prescript measures to protect persons and the nature from contamination, pollution, noise and different kinds of waste. An important recycling quote has to be attempted. To respect all these incisive dispositions, different concepts and technical solutions have been adopted in this project in order to reduce as far as possible temporary and permanent effects caused by the construction works and by the final deposit of the muck.

The volume of the excavation of the complete Gotthard base tunnel (including galleries and multifunctional stations) is estimated in about 13.3 millions of cubic meters; with the entire produced volume of muck it would be possible to build five new pyramids with the same size of those of Cheops (see Fig. 17). On all construction sites material processing plants have been realized in order to recycle the muck and to produce concrete aggregates. Depending from the petrography and the properties of the excavated material, according to the predicted geology, about 28% of entire muck will be processed; the expected recycling rate is around 85% (concrete aggregate production about 22% of entire muck). A part of it is used as filling material and the rest is transported to final deposits or to an inert landfill (see Fig. 18).

The contamination of the muck – cause of loss of oil from the machines (especially the TMBs), waste products from the use of explosives, chemicals and heavy metals from rebounded shotcrete – not ever permit to store this material in a “conventional” inert landfill. The requirements for “non contaminated” muck are very high and at the present time about 1% of the excavated material of the section Bodio has been transported to a special reactor landfill. This is related to intensive costs, caused by the extremely high level of the deposit and treatment prices. To reduce noise and pollution, muck is transported with conveyor belt systems above ground and it is sprayed with water to avoid dust production.

Fig. 17: Gotthard base tunnel, volume of excavated material.

Fig. 18: Gotthard base tunnel, recycling of excavated material.

Wastewater from the tunnel and from several technical installations outside the tunnel is treated to reduce the acidity (pH), to neutralise chemicals, to separate oils and particles in suspension. After the treatment, if necessary, the temperature of the cleaned water has to be reduced prior to the introduction in a river or before being recycled for industrial use or as liquid for the cooling system in the tunnel (see Fig. 19, treatment of maximum 200 l/s, recycling of about 5÷10 l/s). The mud cake resulting from the treatment of wastewater is pressed to reduce water content and is handled with the same criteria for the muck. In general the quality of the cake is “contaminated”, especially because of the concentration of oils.
To reduce the impact of noise from the construction sites on the nearby living populations the required standard of some installations, like tunnel train wagons, have been set very high. Concrete production plant, material processing plant and conveyors belt systems have been encapsulated (see Fig. 19). Temporary dams and absorbent walls have been extra erected to avoid the propagation of very noisily activities.

**Conclusions:**

The construction works of the Gotthard-Base Tunnel are proceeding at all fronts ahead. Up to now, some parts with bad geologically conditions did delay the excavation-schedule of the Faido and Bodio sections. But two of the seven predicted geological difficult zones, the Intschi-zone in the Amsteg section and the tunnel section in the loose rock material of Bodio, have been completed successfully.

Rail technical equipments for the Gotthard-Base Tunnel are scheduled to be published in the Swiss official trade gazette in Summer 2005 by the AlpTransit Gotthard Ltd.

The Gotthard-Base Tunnel will be a milestone for the realisation of the New Alpine Transverse in Switzerland. A total investment of about 30 billions Swiss francs (33 billions AUD) is going to be realized to ensure a future with sufficient transport capacity for the ever-increasing rail-traffic between north and south of Europe. A tunnel with an elevated standard of safety and technology, with several “new land” and “world-première” solutions. An important contribution to the preservation of the Alps.
Original articles written on the subject:

1. D. Fabbri - "Concetto di ricognizione per l'avanzamento fresato nella tratta di Bodio", Pubblicazione della Società Svizzera di Meccanica del Suolo e delle Rocce, N°144, Riunione di primavera 19.04.2003 a Bodio


References on the internet:

AlpTransit Gotthard Ltd., Homepage: www.alptransit.ch