# Refurbishment in Squeezing Ground on Large Scale: Lesson Learned from the Southern Section of the Gotthard Base Tunnel

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ABSTRACT: During the excavation of the southern section of the Gotthard Base Tunnel, the rock mass response to tunneling activities induced by two open, gripper TBMs described unusual magnitudes of displacements in the near-field domains of the heading without evidence of major failures of the surrounding medium. The sedimentary rock mass encountered along the whole tunnel belongs to two typical gneiss-families, which are well known to geologists and engineers since many underground facilities have been mined out in this region starting by the late 40s; nevertheless, the behavior of the opening turned to the unexpected as soon as the chainage 13'500 has been reached, where the mechanical excavation was carried out in a biotite-rich gneiss with sub horizontal weakness planes with relatively low shear strength of the surfaces compared to that of the intact rock and a overburden slightly exceeding the km mark at the same location. Following the usual notions of engineering mechanics, prevention of displacements is accompanied by increase in the state of stress in and around the support units preserved to control near-field rock deformation, which turned out to be a major issue by managing the whole contract of the southern section of the Gotthard Base Tunnel. In fact, the result of such a ductile rock mass was to overstress the steel ribs supporting the 9.0 m circular excavation and finally to shrink the drifts so much, that the requested cross section were not more assured. The increase of the deformations took place with an unforeseen delay with respect to the mining of the tunnel in so far as the concrete invert was totally damaged by shifting up to 20 cm. As a result, securing and replacing of this final lining work caused a time and cost expensive intervention for the last 3 km of tunnel for widening the opening according to the contractual specifications.

## 1 INTRODUCTION

### 1.1 *The new Gotthard Base Tunnel Project*

By constructing the New Rail Link through the Alps, Switzerland is integrating itself into the growing European high-speed network. AlpTransit Gotthard Ltd. – a completely state owned subsidiary of Swiss Federal Railways charged with the overall planning and supervision of the construction works of the New Rail Link on the Gotthard axis – is creating a flat rail link for future travel through the Alps.

At the heart of the new transalpine rail route is the world's longest tunnel – the 57 km Gotthard Base Tunnel – whose highest elevation at 550 meters above sea level is much lower than the highest point of the existing route through the mountains at 1'150 meters, so that gradients will be no steeper accordingly to those of a modern high performance rail link making freight transportation more productive, while passenger traffic benefits from massively shorter journey times.

In 1995, after intensive political, financial and technical studies of several options the Swiss Federal Council approved the plan for the Gotthard Base Tunnel and spoke in favor of a tunnel system with two single-track tunnels. The two rail tunnels are about 40 meters apart and joined approximately every 312,5 meters by connecting galleries. Two double crossovers allow trains to change from one tunnel to the other – which may be necessary to allow maintenance work if an accident occurs. Trains can switch tunnels in the multifunction stations which also house ventilation and technical equipment, safety and signaling systems, as well as two emergency stop stations which are directly linked by separate access tunnels.

Other then the two portals, intermediate headings provide additional accesses to the tunnel from above (shafts) and from the sides (adits), shortening also the construction time and dividing the tunnel into five sections: this paper focuses on the southern section of Bodio.

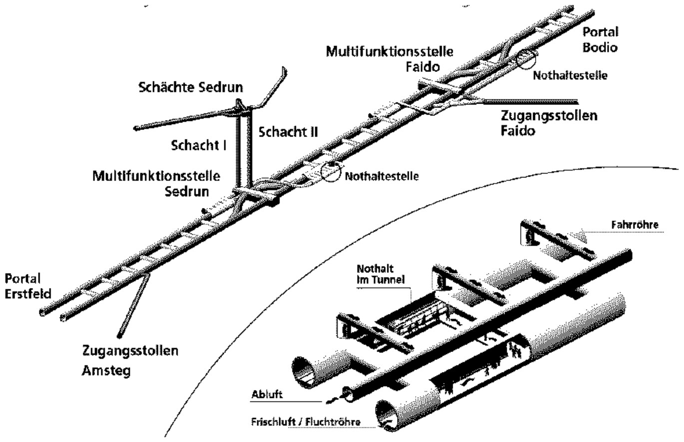


Figure 1. Gotthard Base Tunnel. Tunnel systems with shafts and adits.

### 1.2 *Site description*

The section of Bodio is located in Southern Switzerland (Ticino) at the southern portal of the tunnel. This section is the longest one of the Gotthard Base Tunnel. To allow faster construction of the underground assembly caverns for the TBM, a bypass tunnel was driven out round the site of the portal. From the assembly caverns, two 400 m long – complete driving unit with backup train – open gripper TBMs with a diameter of 8.9 m started driving north towards the next section of Faido in 2003: the breakthroughs took place on by the end of 2006 in the "multifunction station" about 16 km from portal.

While the invert was steadily poured in the rear section of the TBM to allow transportation by rail so close as possible to the excavation site, the 25 cm thick concrete lining were put in place some 2 km afterwards: in between, rock mass reinforcement was performed as usual by the means of wire meshes, shotcrete, steel ribs and rock bolts according to the local conditions.

Continuous surveying of the cross section was also carried out both electronically and mechanically.

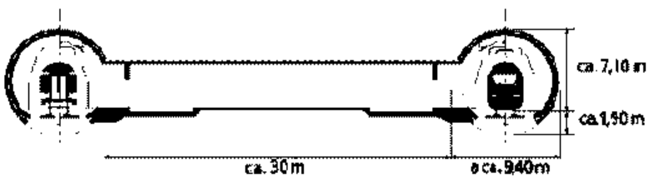


Figure 2. Typical cross section of the two twin tube tunnel in the section of Bodio.

### 1.3 *Unexpected convergences starting from Ch. 13'474*

The sensitivity of the planned excavation diameter to overall convergences in adverse rock mass conditions has been a major issue since the very beginning of the design and tendering stages of the Gotthard Base Project; in view of the crossing of some 100 m of zones allocated to the poorest excavation classes accordingly to the contract specifications, the owner even commissioned TBMs with reaming equipment by pull-out cutters fitting the driven diameter up to 30 cm over the standard one. Expectation of plastic convergences along large section of the tunnel was very little. The sensitivity of the tunnel diameter by those convergences was particularly well highlighted by the event started at ch. 13'474, where unusual large displacements without evidence of major failure of the surrounding rock mass endangered the completion of the 25 cm thick final lining.

Based on a case study, this paper describes how a year long delay and economic bad performance have been managed as well as appropriate design and contractual approach are critical in assuring efficient deep tunneling in hardrock under adverse conditions..

## 2 GEOLOGY AND POTENTIAL MODES OF OPENING BOUNDARY FAILURE

### 2.1 *General geological and geomechanical data*

The section of Bodio lies in the hard rock formations of the Penninique gneiss, which are typical of southern Switzerland. The geological longitudinal section shows at the location mentioned in 1.3 a biotite rich gneiss with prominent sub-horizontal weakness planes with relatively low shear strength compared to that of the intact rock; the overburden at the same location slightly exceeds the km mark.

Average geotechnical parameters of intact rock were determined by a large series of triaxial compressive tests carried out by the lab of the Federal Institute of Technology in Zurich on core samples recovered in the near field of the jammed West TBM: Young's modulus ranging around 10 GPa, uniaxial strength ranging from 5 MPa to 35 MPa. The mechanical properties of the weakness planes of the intact rock were also assumed on the basis of the same lab tests, i.e. cohesion C' = 1'200 kN/m2 and friction angle $\varphi'$ = 32°.

### 2.2 *Potential modes of rock mass failure*

Following the two main factors mentioned in the abstract for designing the rock supports, particular attention has been given to ensure that large, uncontrolled displacements of excavation peripheral rock couldn't occur in order to satisfy the tunnel duty requirements, such as minimum dimensions required both for excavating equipment as well as for the minimum clearance of the mined section. The first main factor – major boundary failure – could be neglected due to the fact, that starting from chainage 13’474 almost no one was reported; nevertheless, the effect of any major discontinuities which will transgress the excavation has been examined by consideration of both the general effect of the structural features on boundary stresses and local stability problems in the vicinity of the discontinuity / boundary intersection. These considerations educed support design adjustments to achieve simultaneous satisfaction of local and general stability conditions.

The potential mode of boundary failure is depicted in Figure 3, where the banding (i.e. $K_s$) running with sub-horizontal banding is showed. Local phenomena of minor parting or slabbing couldn’t be excluded if two or more families of joints (i.e. $K_I$ to $K_V$) come to intersect each other.

The mapping of the tunnel sets forth the bent of that geological unit to large displacements; this feature has been then confirmed by monitoring the behavior of the rock mass surrounding the tunnel.

| Volumen [m$^3$] | <0.001 |
|---|---|
| Höhe [m] | <0.5 |
| Gewicht [to] | |
| KS | 225-057 /0-85 |
| K I+ II | 150(320) /89 |
| K IV | 045-070 /80-85 |
| K III + V | 220-230(050) /80-85 |

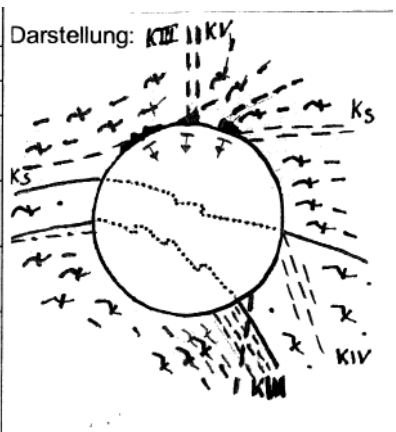


Figure 3. Tunnel mapping and potential modes of boundary failure reported for the western tube from ch. 13’569 to ch. 13’743.

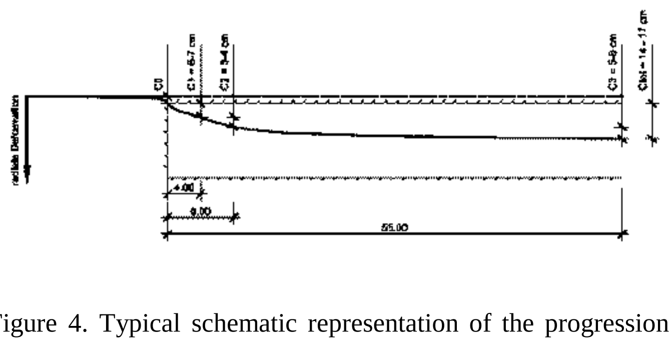

Figure 4. Typical schematic representation of the progression and extension of the roof displacements between.

## 2.3 *Rock support*

The adverse performance of the opening boundaries in the post-excavation stress field illustrated in the previous chapter were mainly caused by slipping on the pervasive weakness planes while a few sloughing due to induced tensile stress exceeding the strength of the rock occurred.

The opening reinforcement was defined in the attempt to reach as soon as possible a stable equilibrium between the rock mass and rock supports by placing the reinforcement close to the TBM short shield soon after excavation. Heavy rock support consisting of blocked steel sets (TH 29 each meter, all around) combined with a wire mesh and two layers of shotcrete (first layer of 9 cm, second layer of 5 cm, both sprayed on 260°) were installed for a maximum stiffness of the reinforcement.

Although heavy rock supports were installed, evidence of suffering from the disadvantage of a poor stiffness by the blocking points of the steel arches, where overlapping of two neighboring elements often happened, as well as from failure by sideways buckling were reported.

# 3 TUNNEL REFURBISHMENT

## 3.1 *Working progress and first records*

On February 2006 excavation of both tubes of the tunnel was reported to be around chainage 13’700, works on the concrete lining having reached chainage 9’900 on the west site respectively chainage 8’900 on the east site when firstly improper convergences where reported about 3’600 m ahead (ch. 13’474 of the eastern tube).

In fact, large deformation of the roof and on both side walls were recorded along with evidence of structural collapse of the provisional rock support as well as unusual cracks, which opened across some section of the massive concrete slabs of the invert, and shifting of the same concrete slabs by the joints.

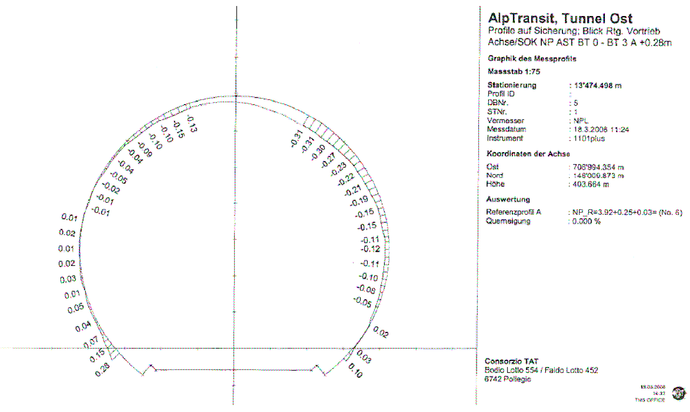


Figure 5. Convergences at chainage 13’474, eastern tube.

Figure 6. Local shifting by the joint between two concrete slabs of the invert, chainage 13’480, eastern tube.

Due to the amplitude of the displacements in the vault, the typical cross section of the tunnel couldn’t no more ensured to make further the necessary 25 cm concrete lining impossible.

### 3.2 *Implementing the refurbishment*

Accordingly to an accurate survey campaign of the tunnels starting from the spot of the first event and carried out until the completion of the final lining, local displacements have been steadily monitored and analyzed.

Unexpected, it was find out, that an extended portion of both tunnels has been subjected to anomalous, erratic deformations (Figure 8).

As a result, the Contractor was requested to present a proposal for a remedial action, i.e. local refurbishment, based upon design and specifications given by the Engineer. In particular, such action has not to affect the TBM operations and should assure rail transportation on both track through the site.

The Contractor submitted for both technical and economical approval two installations - one for each tunnel.

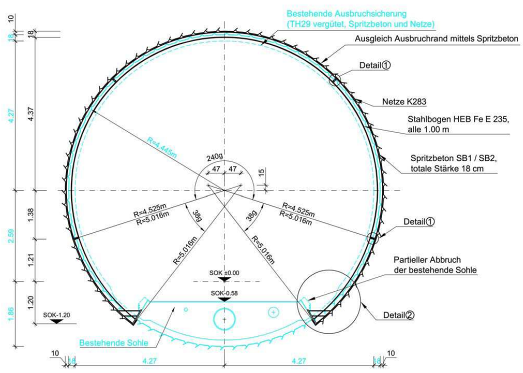


Figure 7. Typical design of the remedial action

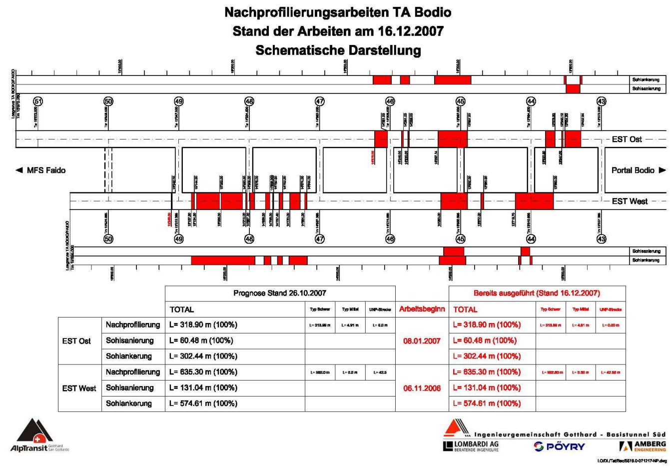


Figure 8. Erratic distribution of the anomalous deformations in both tunnels .

consisting in a sort of short back-ups equipped with a full range of devices for appropriate mechanization of the working cycle. In fact, the planned overhauling tasks on site range from the dismantling of the existing provisional rock support by heavy sledgehammer to the restoring of the new one by positioning of renewed steel arch, wire mesh and shotcrete.

On November 2006 the Contractor began with the operations in the western tube. Contractor, Designer and the site Engineer agreed to set out a time table to the Owner reaching daily advance rates between 1.5 to 2.5 m depending on the reconditioning class designed. In order to get the most industrialized process, class I to III were designed to fit any kind of intervention.

### 3.3 *Uplift of the invert*

Although several measures were taken to ensure the stability of the opening, the refurbishment caused seemingly a further stress displacement, so that uplift of the invert has been continuously reported short ahead of the operations.

To contrast the extent of the upwards movements 6 m long rock anchors were put in place with a pattern of 2 x 2 m. This procedure was usual successful in the zone with little deformed cavity but not if the extent of the zone was important or in presence of discontinuities.

In fact, some of the invert slabs experienced so dramatic uplifts – mostly accompanied by a rotation of the slab – that a refurbishment of the invert become also a necessity.

By the end of the refurbishment 19 invert slabs have been replaced summing up 191.5 m of renewed concrete invert.

Uplift of the invert considerably contributed to the total delay on the working schedule.

Due to the replacing of the invert, any operation in the concerned tunnel had to be cancelled and operations in the other tunnel consequently delayed: priority was given to the supply of the many sites in front of the refurbishment area such TBM-operations as well as to the logistics and safety.

Figure 9. Back-up for the refurbishment operating

### 3.4 *Impact on the contract*

The contract suffered from this unexpected, large event because - of course - of the extra-charges but mainly due to the important setback of the working schedule. Additional allowance with time extension amounts to 14 months out of some 40 months expected.

The impact of the events, which have to be faced staggered within a long time, made things difficult to manage by requiring many amendments to the contract instead of unique one.

Total costs of the refurbishment summed up to around 10% of the contract sum referred to the Bodio section of the Gotthard Base Tunnel.

## 4 DISCUSSION

### 4.1 *The importance of the contract*

The contract governing the project is a fixed price one, ruled also accordingly to Swiss construction standards such SIA 118 and 198.

The contractor accepted with its tender the risks for stipulated sum or rates nominated in its bid. However, provisions for adjustments have been included; in particular, the risk of a diverting, unexpected geology and delays caused by the owner are compensated to the contractor.

Provisional items, which also are a part of the contract, allow to cover works for which complete details were not know at the time of tendering without creating new ones. Time related costs are covered by separated items offered by the contractor with its bid, so that unexpected variations of order could easily, upon agreement, be integrated in the contract.

That's to say, the unexpected additional works caused by the refurbishment of the above depicted sections of the tunnel has been well managed by the existing contract in consequence of the agreement on the liabilities.

To notice that agreement on claims arisen from this event has been reached by short term immediate decision, which the parties accepted as final without transfer of the judicial function to a separate, independent arbitration committee.

## 5 CONCLUSION

The refurbishment on large scale on the longest section of the Gotthard Base Tunnel caused delay and extra costs due to remedial actions undertaken and the compulsory stop of other operations in progress at the same time.

The main aim of the paper is to incentive the curiousness about the contractual approach given by the Swiss Standards mentioned in the above chapter.

The authors are firmly convinced on this way for managing TBM operations in deep, long tunnels and showed the benefits from the experiences learned on the Bodio site.

## 6 ACKNOWLEDGMENT

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