

NOVEMBER 2010

# tunnels & tunnelling GOTTHARD

- East bore is 57.104km long
- West bore is 57.017km long
- Diameter ranges from 8.8m to 9.5m
- Maximum overburden is 2.5km
- Deepest shaft is 800m
- 26,500,000t of rock excavated
- Planned completion 2017
- Total cost to date CHF 9.83bn (USD 10.22bn)

[WWW.TUNNELSONLINE.INFO](http://WWW.TUNNELSONLINE.INFO)

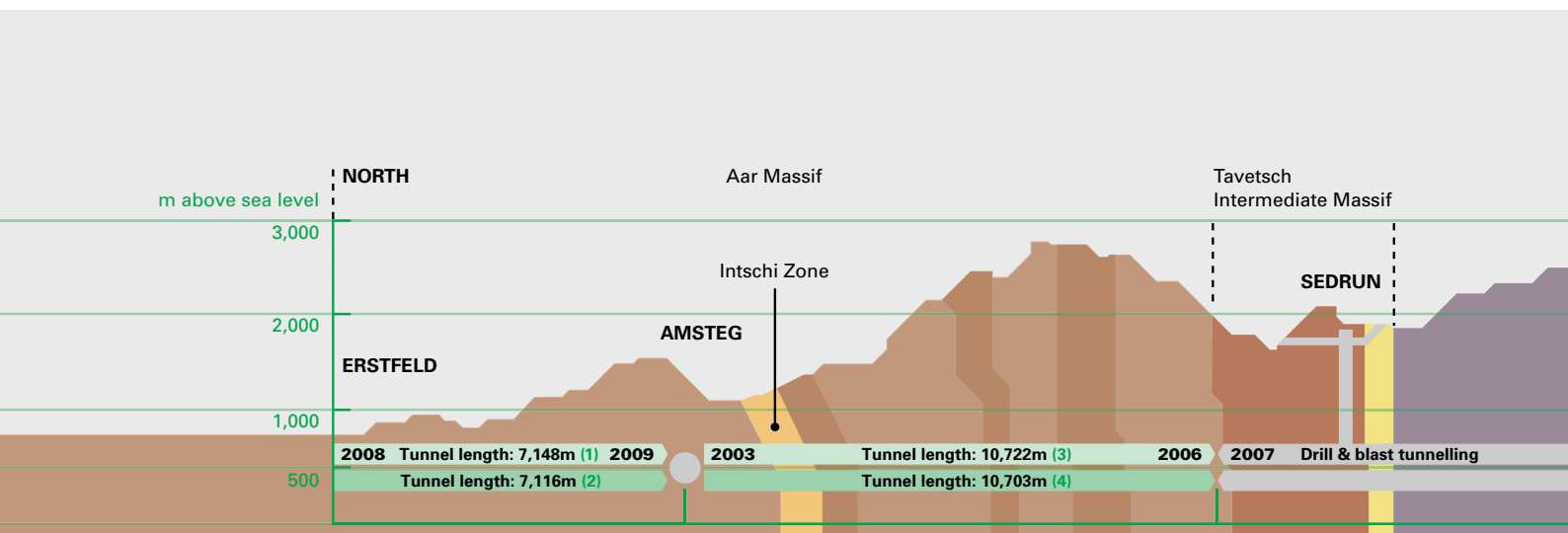
## Digging in to the world's longest transport tunnel



# WORLD RECORD

## CONGRATULATIONS ON THE FINAL BREAKTHROUGH

The breakthrough at the Gotthard Base Tunnel on October 15, 2010 marks the most significant milestone on the way to completing the longest railway tunnel in the world. Europe salutes Switzerland's achievement in creating this 2 times 57 kilometer long epoch-making project to connect northern and southern Europe by rail through the Alps. Our thanks go to the client AlpTransit and our customers for allowing us to be part of this spectacular feat and historic undertaking with our tunnelling technology.



### ERSTFELD/AMSTEG

### AMSTEG/SEDRUN

AGN Consortium: STRABAG AG Tunnelbau Schweiz (CH) / STRABAG AG (A),  
Project Manager of the AGN – Gotthard Base Tunnel North Consortium: Beat Blindenbacher



- (1) Gabi I, Herrenknecht Gripper TBM S-421, Ø 9.58m
- (2) Gabi II, Herrenknecht Gripper TBM S-422, Ø 9.58m

- ▶ **April and May 2008:** Start of regular tunnelling.
- ▶ **July 19, 2009:** 56m of new tunnel are created in just 24 hours. This is deemed to be a world record for a hard rock TBM of such dimensions.
- ▶ **June 16, 2009 and September 16, 2009:** The machines reach their targets after just 18 months – 6 months ahead of schedule. Deviation from the ideal axis measures only 4mm in the horizontal and 8mm in the vertical.
- ▶ **Top tunnelling performances:** 56m/day, 185m/week, 711m/month.

- (3) Gabi I, Herrenknecht Gripper TBM S-229, Ø 9.58m
- (4) Gabi II, Herrenknecht Gripper TBM S-230, Ø 9.58m

- ▶ **October 2003 and January 2004:** Start of regular tunnelling.
- ▶ **2004:** The TBMs pass the Intschi fault zone more quickly than planned.
- ▶ **June 2005:** A mixture of water and fine material entered the cutterhead in the western tube. The TBM must be freed and cannot restart tunnelling until November.
- ▶ **June and October 2006:** The construction site teams successfully complete tunnelling at the end of the lots, 9 and/or 6 months ahead of the schedule.
- ▶ **Top tunnelling performances:** 40m/day, 210m/week, 688m/month.

# AT THE GOTTHARD.

# AT THE NEW GOTTHARD BASE TUNNEL.

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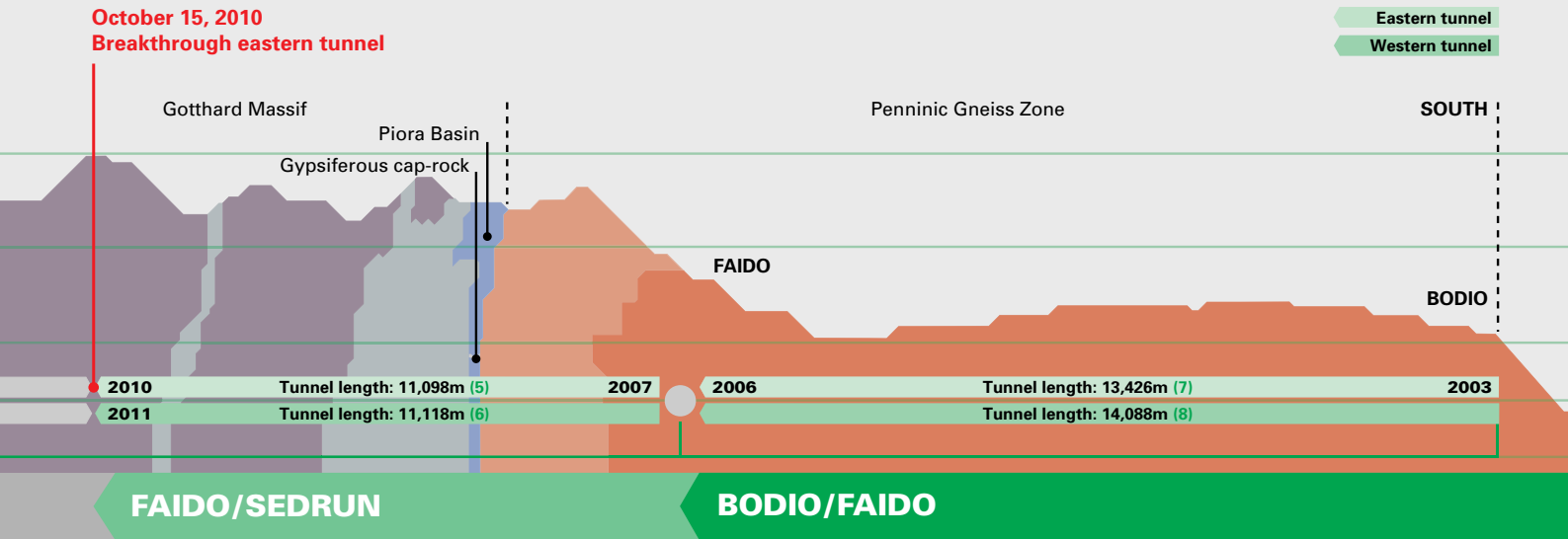


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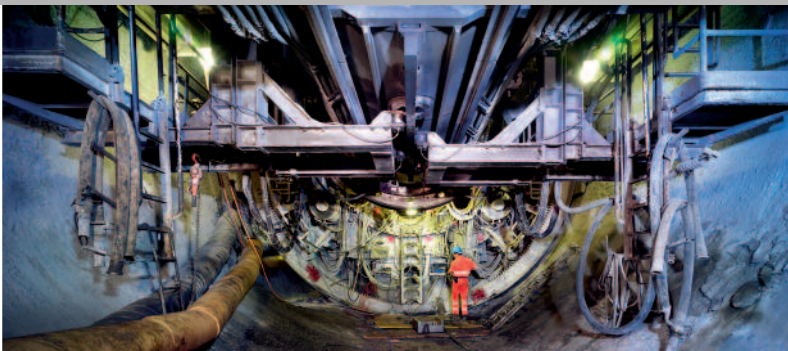
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**October 15, 2010**  
**Breakthrough eastern tunnel**



TAT Consortium: Implenia Industrial Construction, Alpine Bau GmbH, CSC Impresa Costruzioni SA, Hochtief AG, Impregilo SpA,  
overall Project Manager of the TAT Consortium (Tunnel AlpTransit – Ticino): Olivier Böckli



(5) Sissi, Herrenknecht Gripper TBM S-210, Ø 9.43m  
(6) Heidi, Herrenknecht Gripper TBM S-211, Ø 9.43m

- ▶ **July and October 2007:** The TBMs begin tunnelling the second construction phase in the south with new, larger cutterheads (Ø 9.43m).
- ▶ **October 2008 and February 2009:** The 150 meter long Piora Basin is crossed successfully.
- ▶ **March 2010:** A rock fall in the western tube and the subsequent stabilization measures interrupt tunnelling here until July.
- ▶ **October 15, 2010: Breakthrough in the eastern tube. World record.**
- ▶ **Top tunnelling performances:** 36m/day, 179m/week, 705m/month.

(7) Sissi, Herrenknecht Gripper TBM S-210, Ø 8.83m  
(8) Heidi, Herrenknecht Gripper TBM S-211, Ø 8.83m

- ▶ **January and February 2003:** Start of regular tunnelling.
- ▶ **2003:** After just 200 meters the tunnellers unexpectedly encountered unstable kakirites. This slows down tunnelling for 6 months, since every meter of tunnel must be secured in a complex process.
- ▶ **2004 to 2006:** Stable rock alternates with brittle, squeezing rock.
- ▶ **September 6 and October 26, 2006:** Successful breakthroughs at the Faido underground multifunctional station.
- ▶ **Top tunnelling performances:** 38m/day, 190m/week, 619m/month.



## Europe connected for the future: H+E was involved.

The final breakthrough has been made in the Gotthard Base Tunnel. Boring, blasting and digging of the longest rail tunnel in the world has therefore been completed after more than 10 years of construction work. This feat has been made possible in no small part by outstanding engineering work and successful cooperation among colleagues over a number of years. We are proud to have been among the various and companies, teams of engineers, geologists, planners, surveyors and mineworkers who had the privilege of building the Gotthard Base Tunnel.

This project has involved the single-minded pursuit of a goal by thousands of people. We have achieved it together. And with the tunnel breakthrough, we have made our contribution towards reducing traffic congestion and environmental pollution along one of Europe's most important transport routes.

**Congratulations to everyone involved.**



H+E Logistik supplies tunnel conveyor belt systems, back-up conveyors for tunnel boring machines and conveying systems for the mining and construction industries, the ports sector and any companies that have a lot to move. Our tried-and-tested technology and expertise have found successful application in numerous international projects. H+E Logistik is part of the Herrenknecht Group.



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### On the cover

Sliding supports for squeezing ground sections of the main bores in the Faido excavation area. Picture courtesy AlpTransit Gotthard



ALPINE BeMo Tunnelling

# We brake barriers

In order to break records and to bring about visionary projects like the Gotthard Base Tunnel requires the right know-how, a strong team and lots of stamina. ALPINE BeMo Tunnelling is the living proof that we are a competent, flexible and reliable partner for tunnelling projects of any size. This has earned ALPINE an excellent international reputation and has made it into one of Europe's leading construction groups.

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# Making Gotthard happen

From left: Peter Zuber, Renzo Simoni and Peter Zbinden



Breakthrough on the Gotthard base tunnel in mid-October is a major landmark on the world's biggest underground project. It follows a decade of staggering geological, technical, political and workforce challenges, says Adrian Greeman

**P**hysical breakthrough on the deep Gotthard base Tunnel in the Swiss Alps on 15 October completes the basic excavation work for the world's longest tunnel. There is much more to do yet before even the civils work is finished and a five-year programme of rail, signalling, power and communications systems installation has only just begun, with train service not available until 2017.

However, a high summit, as it were, has been reached in this giant Alpine project. As the last cubic metre of spoil was removed, it completed far more than just a world record length twin bore tunnel, it began a whole new generation of tunnel projects.

A 57km length is an immense achievement, yet the even greater significance of Gotthard is that it also represents a breakthrough into tunnel building on an unprecedented scale and facing a new level of technological challenges. This is the first of many deep, very long mountain bores that are set for the 21st century, for rail, road and water projects, in the Alps, in the Andes, in the Chinese mountains, in the Rockies and eventually perhaps in the high Himalayas too.

The CHF 10bn (USD 10bn) Gotthard base tunnel is the second phase of Switzerland's AlpTransit project, creating new high-speed railway links from north to south through the great Alpine mountain range. The first

section was the already finished 34.6km long Lotschberg base tunnel to the west, which also faced some of the new challenges.

The Gotthard tunnel's length is nearly twice that and the scale of the project is much greater, even more so when considered as the complete Gotthard axis. The total length of all tunnels and shafts for the base tunnel is 152km and, as well as the main base tunnel, there are several other tunnels on the route between Zurich and Lugarno. The largest is the 15.6km long Ceneri tunnel to the south, now also under construction.

The challenges that had to be overcome to get to the breakthrough have been huge.

Geological and other physical obstacles go substantially beyond earlier tunnels, demanding the application of logistical and technical methods that have not been used before, especially on any large scale. Surveying technique had to be applied at unprecedented levels of accuracy. In remote deep underground points and under conditions seen only in deep mines; crumbling, squeezing ground was fought with new technology derived from the German coal industry. High rock temperatures 2,300m below the surface meant battling with complex cooling and ventilation systems; the organisation of supply and manpower to workfaces more than 30km inside the mountains demanded sophisticated computer-controlled rail and

conveyor systems; spoil removal and environmental protection needed their own organisation and control. Even the working relations and organisation of a project on this scale were unknown in Switzerland, with contracts lasting not just two to three years but more than a decade.

All of these challenges and risks were part of the huge debate within Switzerland that made up another layer of political, economic and social obstacles to be overcome when the project was first proposed. There were environmental and local community objections that led to delays.

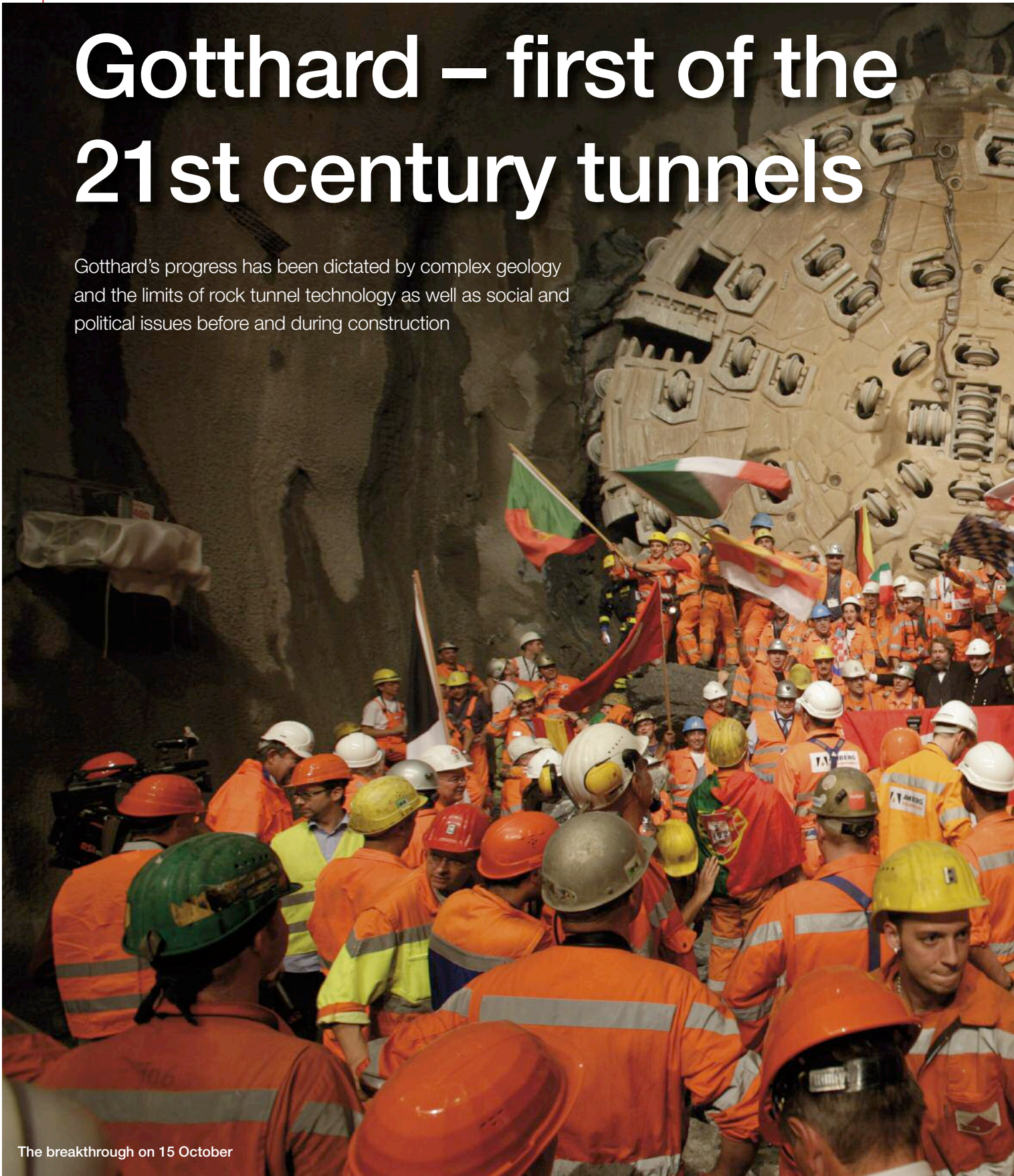
The current Gotthard CEO, Renzo Simoni, says that the battle for his predecessor, Peter Zbinden, who retired in 2007, was as much about overcoming these obstacles and of keeping the project going despite cost increases and delays, as it was about the technical questions.

His own task is no longer one of making sure that the project happens at all, but of bringing it in on time, within the quality and budget targets set, for both Gotthard and the Ceneri tunnels. Much of the attention will be focused now on finishing works and the highly complex five-year fit-out with state-of-the-art rail and signalling technology.

The story of how the Swiss designers and international construction consortiums have met and dealt with these issues to date and the challenges to come are detailed on the following pages. ■

# Gotthard – first of the 21st century tunnels

Gotthard's progress has been dictated by complex geology and the limits of rock tunnel technology as well as social and political issues before and during construction



The breakthrough on 15 October



**B**uilding a long base tunnel for the Gotthard pass was always going to be a challenge. So it has been proved.

The point of the axis is to create a 'flat' link through the Alps, never rising above 550m in altitude and with gradients limited to just 6.7 in 1000. Combined with very large radius limits on the alignment, this will allow high speed passenger trains like Germany's ICE and French TGVs to run at 250km/hour or modern freight at 160km/hour (see box).

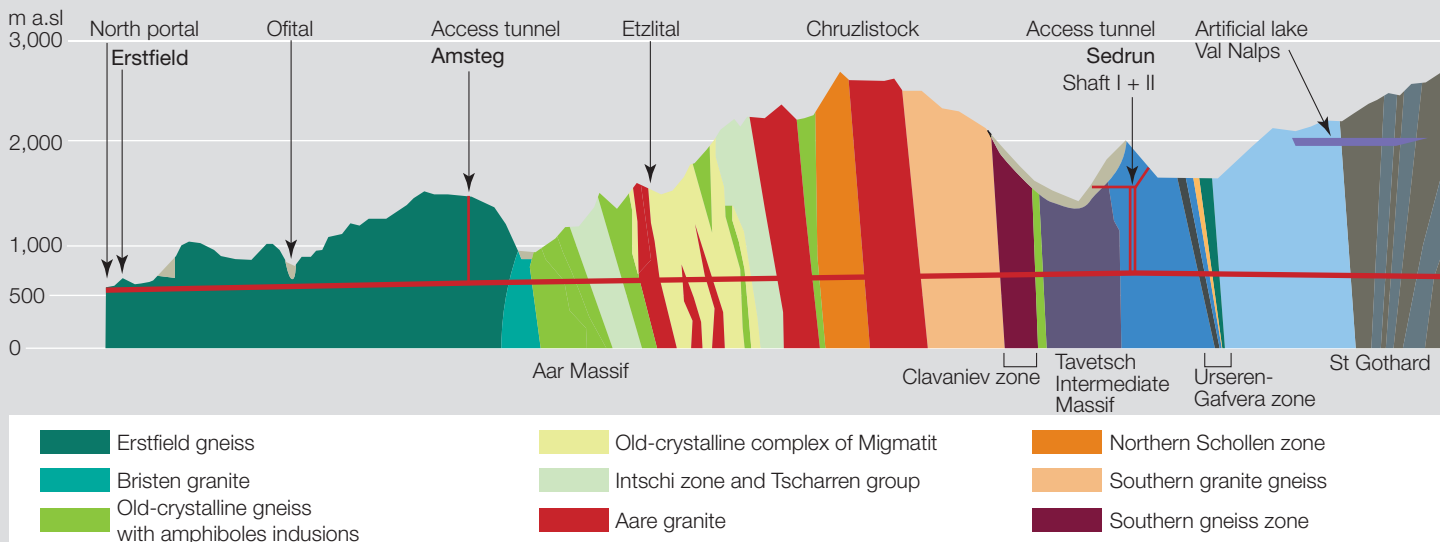
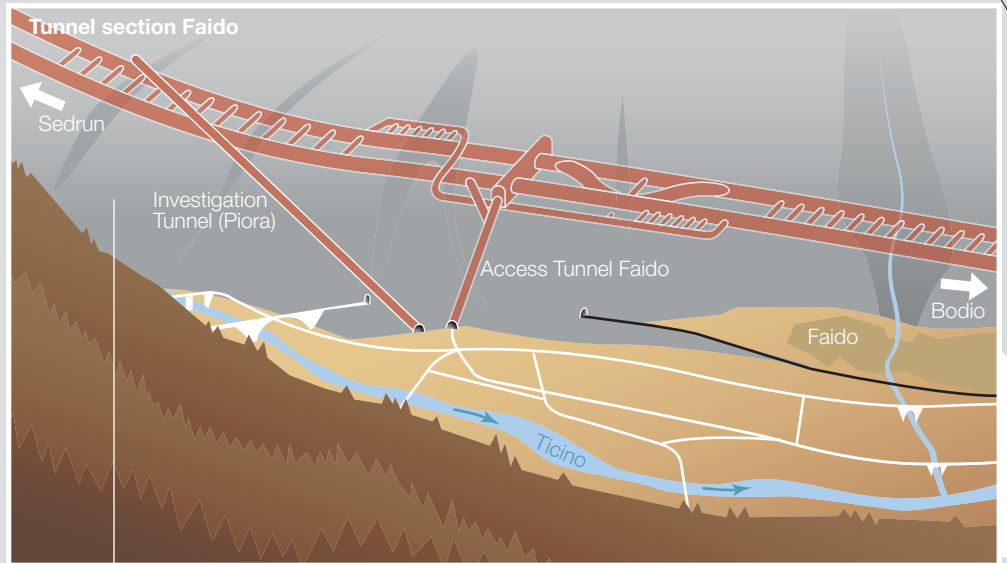
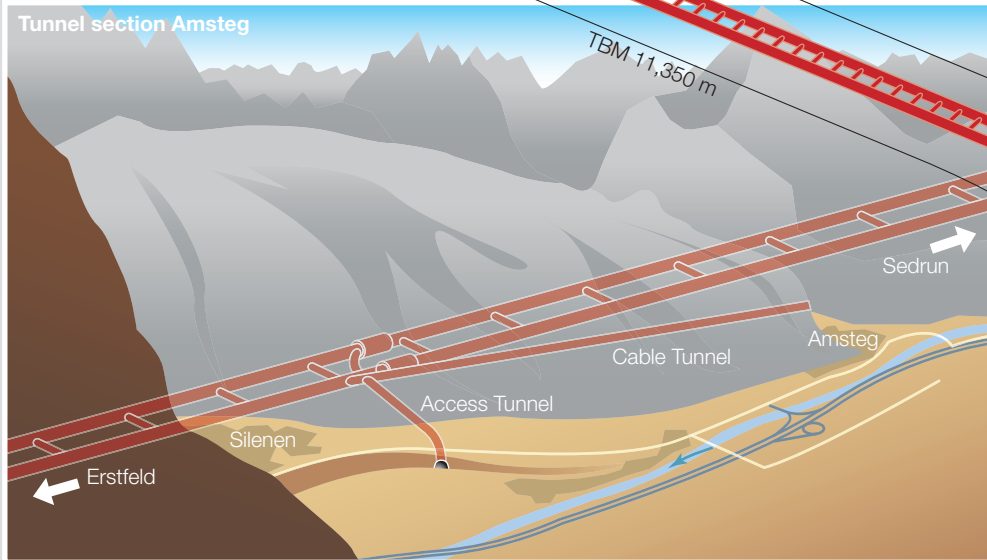
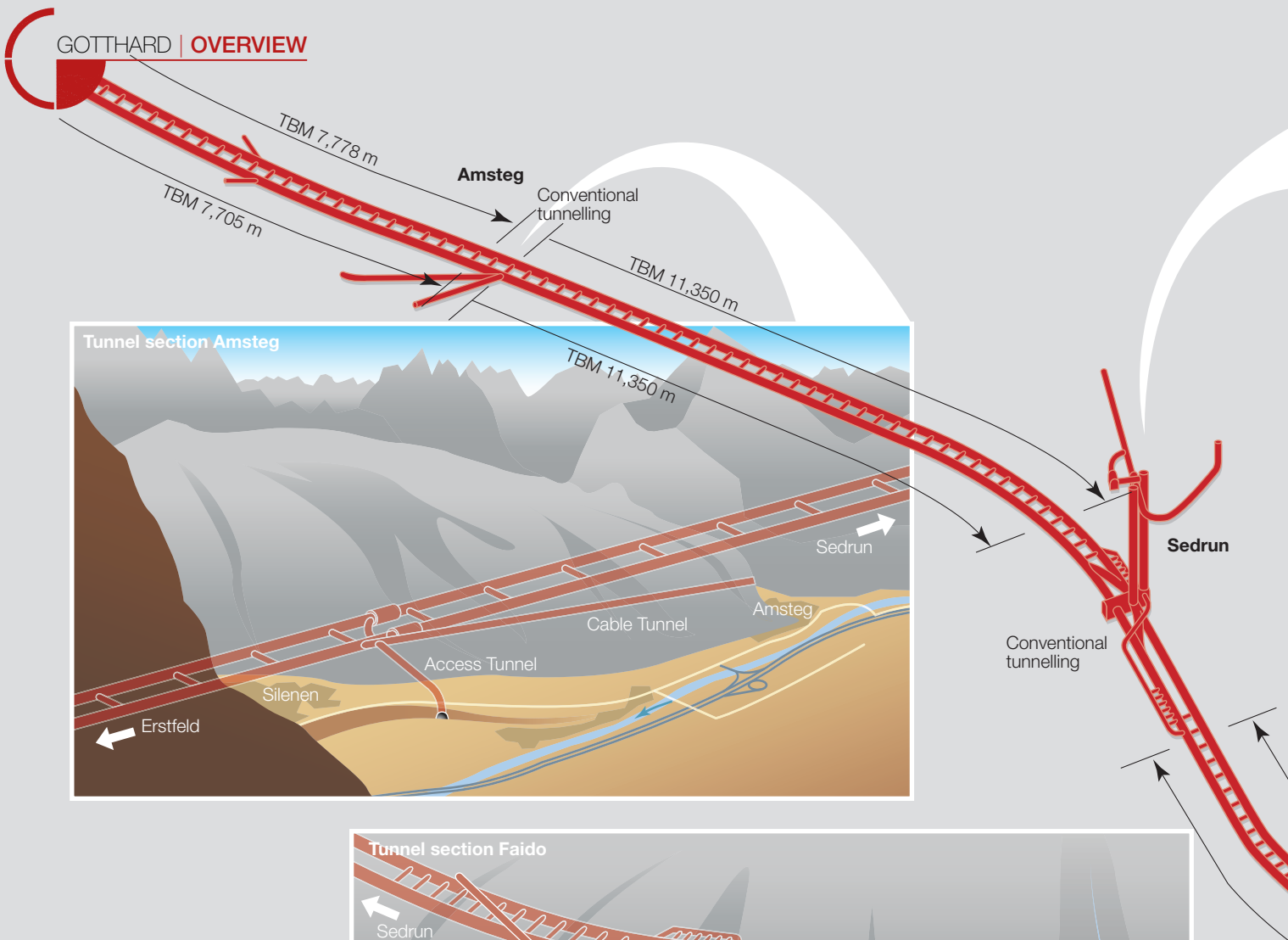
To do that on sensible possible alignments for the tunnel meant staying deep within the mountains, under rock cover that rises as much as 2,300m above the tunnel level.

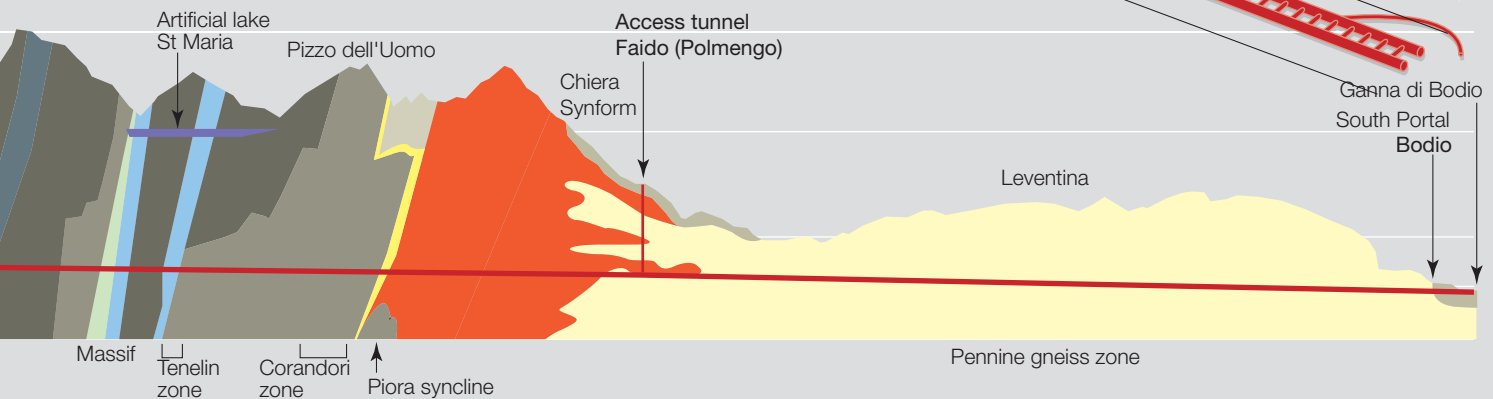
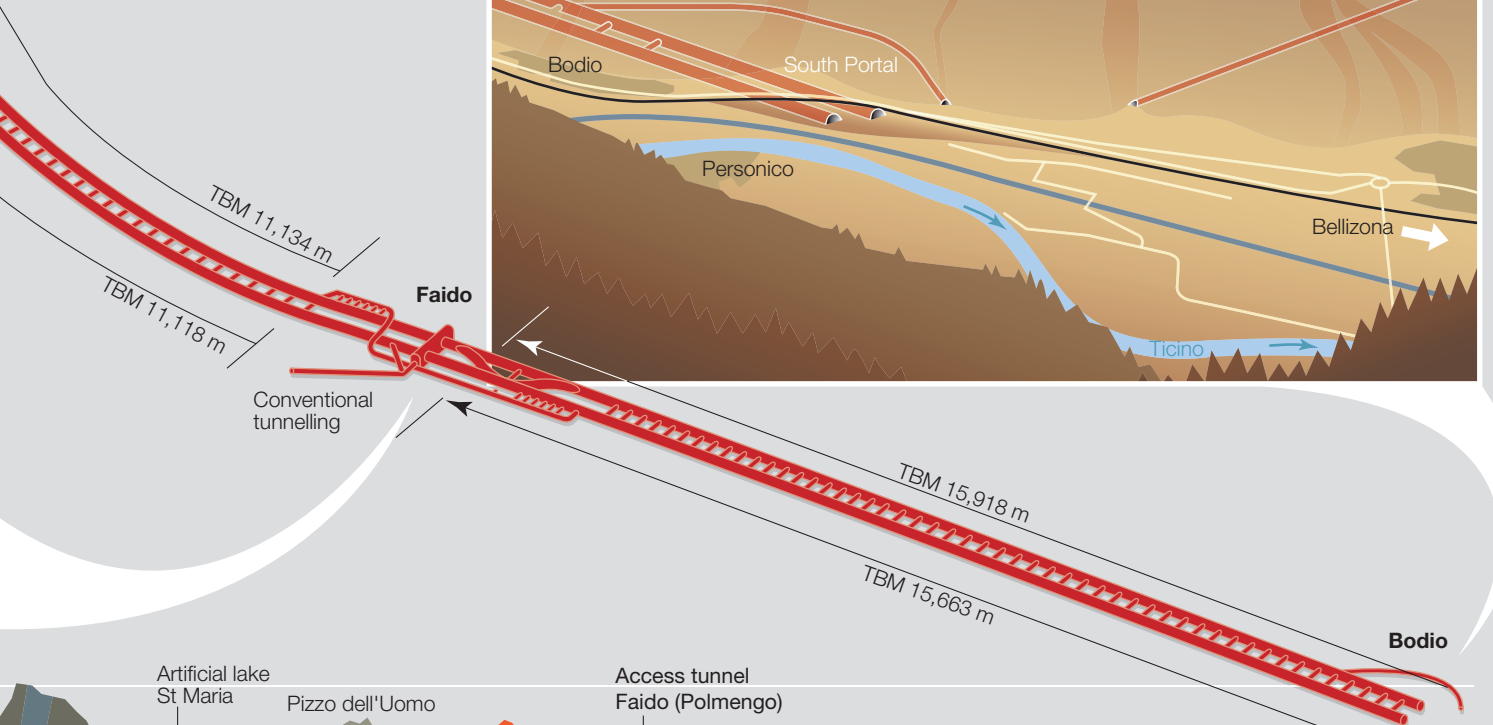
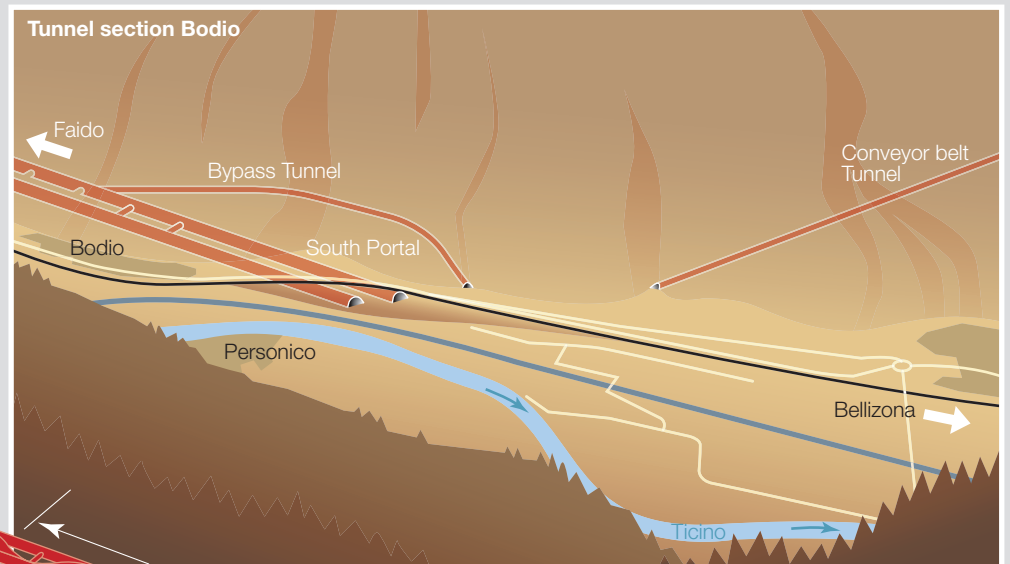
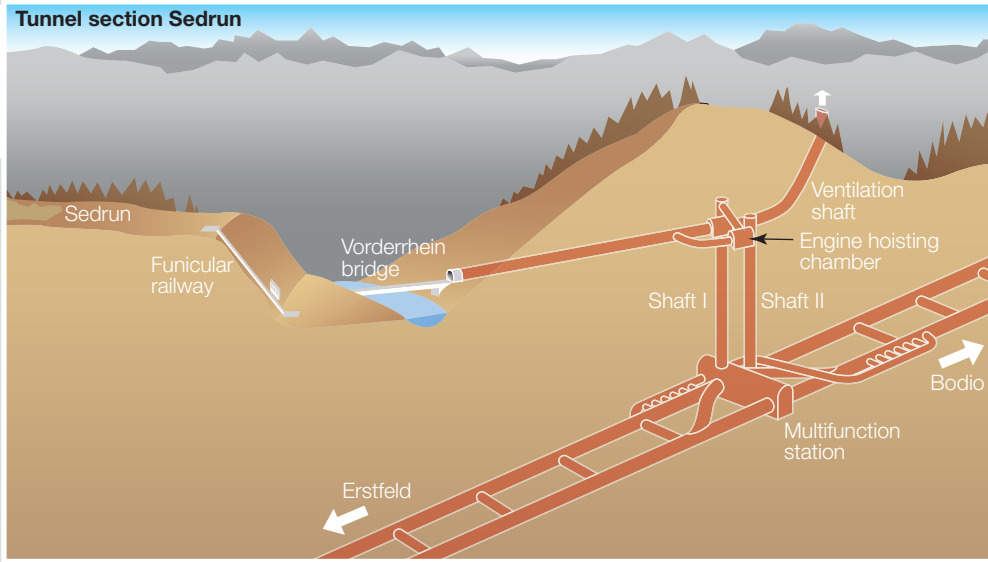
"Restrictive boundary conditions meant the alignment was found quite quickly," says Heinz Ehrbar, AlpTransit Gotthard's chief engineer. "The aim was to avoid high rock cover because of initial stresses and high temperatures, and at the same time to find the shortest way through the difficult zones. We also needed to find intermediate access points that would minimise the whole length of the tunnel system."

The presence of concrete arch dam reservoirs above was a final constraint, with the route avoiding them as much as it could.

High rock cover posed the major difficulties, partly because of the stresses imposed on the rock by such high cover and because of the other dangers of tunnelling at such depth like the very high water

**GOTTHARD | OVERVIEW**





- |                                       |  |                       |                  |
|---------------------------------------|--|-----------------------|------------------|
| Northern Tavetsch Intermediate massif | Heterogeneous gneiss/streaky orthogneiss | Saccharoidal dolomite | Leventina gneiss |
| Southern Tavetsch Intermediate massif | Piz Fuorcia zone                         | Dolomitic marble      |                  |
| Paradise gneiss                       | Medel granite                            | Lucomagno gneiss      |                  |

pressures that could be expected. Inflow to the tunnels would be high and the depth would equally pose problems for safely evacuating the miners.

Most of all, the mass of rock above would trap the heat of the earth's core, making working conditions highly unpleasant, if not impossible. Even past projects, such as the much higher level Simplon tunnel, had been obliged to use ice brought in by wagons but the new depth was unprecedented. No one quite knew how much heat would be contained there or how it would be handled, even with modern cooling technology.

As Ehrbar says, "no one had any experience of the great massifs at these levels."

But at least there was some experience in the world to be drawn on, such as even deeper gold mines in South Africa and deep coal seams in Germany. For the geology however, the deep structure of the Alpine Massifs was unknown. The early studies for the project carried out after its initial go ahead in 1992 focused on this aspect particularly.

It was known that the tectonically tumbled and tortured masses of the great Alpine ranges present a mixed and complex geology with at least two zones that could

prove on the edge of even modern engineering capacities.

One of the key challenges had been debated for decades, particularly since first proposals for a deep base tunnel had been mooted for the Gotthard Pass in 1947. It was the Piora Mulde syncline, a valley in between the great Gotthard Massif, which is the southernmost of the two huge igneous, mainly granite rock blocs that form the 'backbone of the Alps' and the lower mountains of the Leventina Pennine gneiss area on the Italian side of the Alps.

The basin was filled with a soft, whitish, sand-like, weathered dolomite—often described as 'sugar rock', with almost no coherence and which can run like the sand in an hourglass. Part of the valley followed the almost vertical rock bedding downwards and so it was suspected there would be a zone of this soft calcareous material up to 300m across that would need to be crossed on the tunnel alignment. If the valley aquifer extended this far down too, the water/sand mixture could prove not just a problem but perhaps a "killer feature" for the project.

"I think it might have meant stopping the scheme completely," says Charly Simmen, a field engineer for AlpTransit Gotthard who oversaw much of the spoil disposal for the tunnel. "Some technical methods were available to deal with it, such as ground freezing or grouting, but at such depths against enormous pressures—remember there would be up to 1,800m head of water—it would have been either impossible or extremely expensive."

A second major problem was a section between the Gotthard Massif and its counterpart northern bloc, the Aar Massif. Trapped between these two layers, like corn between two Gargantuan millstones, were layers of mainly gneiss and slates that had been ground and battered over millions of

years. In particular, the area of the Tavetch Intermediate Massif was likely to be difficult, its softer and highly fractured rock causing significant ground squeezing.

"For the engineers in the feasibility and design stages the task was to assess and measure the risks," says Erhard, who at that time was on one of the teams of consultants working on the design with the Zurich firm of Electrowatt. "Together they did an excellent job of risk management."

Design work for the project was carried out primarily by two major groups of consultants. On the northern section of the base tunnel this was Gahler & Partners, Gruner, Rothpletz Lienhard and CES. For the southern part it was Amberg Engineering, Lombardi and Electrowatt Engineering (which has since become part of Poyry).

Part of the design involved some extraordinary and extended ground investigation for the Tavetch area and to some extent for another zone near it the Urseren-Garvera. "Though this was already known from the Gotthard road tunnel," says Ehrbar.

Deep borehole investigations were carried out using directional drilling techniques borrowed from the oil industry to sample rock on the tunnel line. These bores were exceptionally long, with one measuring 1,750m, another 1,715m and others of 700-800m.

Ehrbar recalls that the squeezing ground began to show its challenges even at this stage because the drill core bits became stuck several times. The work, by ground investigation firm Foralith, was almost halted "but we tried one more time and it worked," he says.

Sections from the warehouse full of cores were analysed at the famous ETH technical university in Zurich, which specially developed a new kind of triaxial test cell for the work. It could simulate the pressures and groundwater content to be expected at the more than 1,000m tunnel depth at this point, Ehrbar explains, "and with this we got good results for the ground parameters like cohesion, friction angle and so forth."

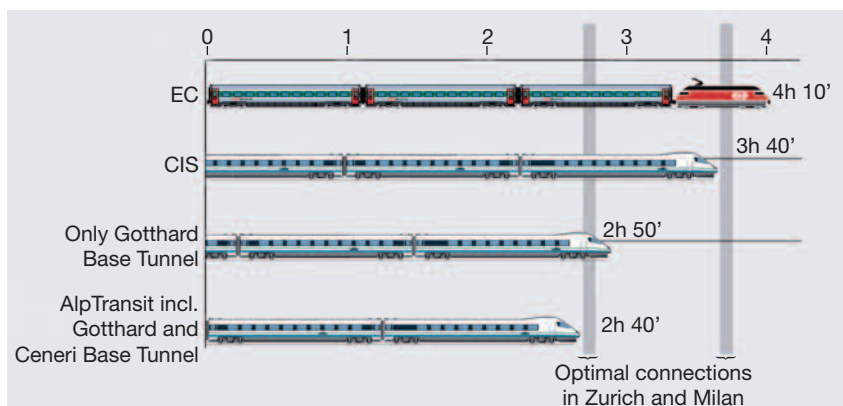
With these data the designers could explore possible solutions to the anticipated ground squeezing. Technology from German coal mines, which are up to 1km deep, could be adapted it was thought. This used multiple section steel arches that have sliding friction joints to allow them to "give" initially to otherwise irresistible ground pressure, and only slowly build-up resistance to stabilise the rock.

For the Piora zone an even more extensive investigation programme was



**Left:** Heinz Ehrbar, AlpTransit Gotthard's chief engineer

**Below:** High-speed journey times



commissioned with a 5.5km long exploratory tunnel begun in 1993 by joint venture Alpi, comprising Zschokke and Locher (now together as Implenia), Mancini and Marti and Murer. Probe drilling was done by a joint venture of Italy's Rodio and Candian firm Morisette, part of Boart Longyear. The tunnel was excavated in as far as the main tunnel line from a site at near the town of Faido, the same location for one of the later construction access points. The horizontal tunnel was 350m above the level of the base tunnel line and ended in a chamber from which boreholes could be driven.

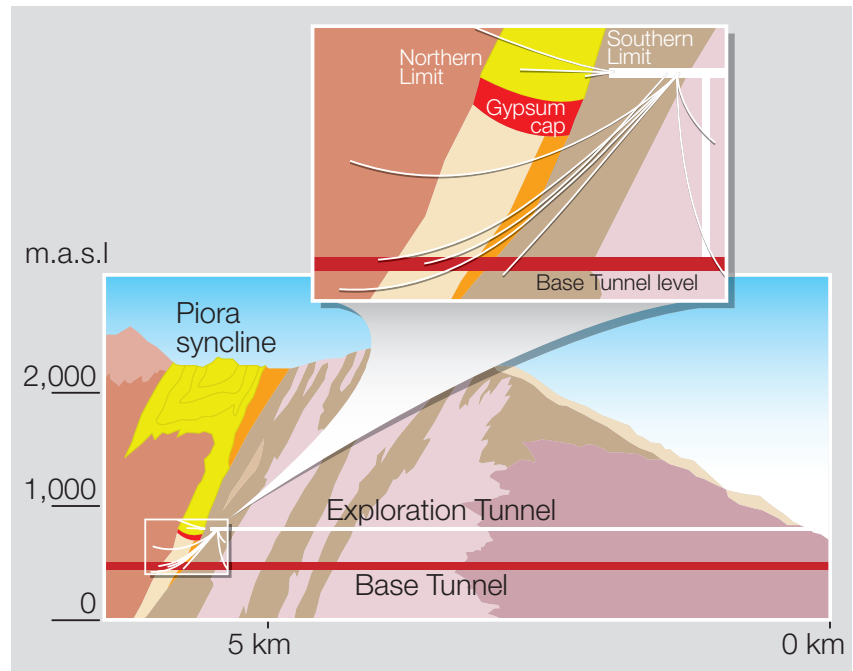
This project produced what could have been a disastrous early result. After driving most of the tunnel, an early forward probe in 1996 hit the Piora material, which proved every bit as bad as thought. Not only that but the failure of an emergency stop valve on the drill bit meant pressurised sand and water blasted into the tunnel, rapidly filling it two-thirds deep with a 'beach' as one engineer recalls. At one point the material was coming in so fast that it began to spill across a local highway near the tunnel portal and evacuation of nearby houses was being considered.

"It was like drilling a hole in a submarine 1,700m down," says professor Georgios Anagnostou at the Swiss Federal Institute of Technology, one of the experts working on the project at the time. "Fortunately the coarser particles in the material clogged the drill hole after about half an hour and the flow slowed and then stopped."

With the tunnel cleared out and a concrete plug installed at the tunnel end, further investigation could proceed. It did not look good either, with groundwater movements of hundreds of metres daily detected in the aquifer, boding ill for attempted grouting or ground freezing work. Freezing coolant or grout would have faced water pressure of up to 130bar and moving like a river.

If the difficulty extended downwards a width of difficult ground of 230m would have to be crossed at the main tunnel level, which would be either impossible or highly expensive.

But a score of core drillings downwards from the tunnel end and seismic tests began to show better results. As Swiss engineer Felix Amberg, head of one of the major design consultancies on the project, told a meeting of the British Tunnelling Society late in 2000: "Investigation revealed that at base tunnel level, the Piora Basin consists of stable dolomite, marble and dolomite-anhydrite. No sign of high water pressure was found in the boreholes at base



**Above, top:** Testing the piora: a special exploratory drive driven at an angel from Faido was made to a level 300m above the main tunnel line cores were made from the end  
**Above, bottom:** Spoil handling conveyors for the batching plants at the Erstfeld portal site. Picture courtesy of AlpTransit Gotthard

tunnel level.

"The geological model showed the Piora Basin to be solid Trias limestones/dolerites with occasional lenses of anhydrite or gypsum. Rock fissures are filled with gypsum, preventing major inflow of water.

"Between the exploration level and the base tunnel level, geologists have interpreted the existence of a gypsum cap formed through the transformation of anhydrite to gypsum by water percolating from nearby valleys."

This was a major stroke of luck, which gave new confidence that a TBM drive could get through, as the "sugar-rock" is stable when dry.

All these challenges and risks were part

of the huge debate and discussion within Switzerland that made up another layer of political, economic and social obstacles to be overcome when the project was first proposed. The country has a complex system of referenda that have to be passed for all major schemes. There were environmental and local community objections, too, which led to delays and scheduling problems.

Key hurdles overcome were the acceptance in 1992 of proposals for the New Rail Link through the Alps (NRLA), which provided the basis for planning. In 1998 the Swiss people agreed to a new heavy vehicle tax (HVT) and overall proposals for modernisation of the railways.



**Above:** Close spacing of the sliding support circles on the northern drives at Sedrun

The company of AlpTransit Gotthard, was set up as an offshoot of Swiss Federal Railways in the same year, which allowed the construction to begin in 1999 for access tunnels at least. Major work began at the end of 2001.

Other issues which had also been critical included the safety of such deep tunnels once in operation. Part of this was settled in 1995 after long debate on layouts, including twin-track tunnels, additional service tunnels and other configurations, with two single parallel bores to be built connected by cross passages every 325m—allowing for the opposite bore to be the rescue tunnel in the event of disaster, most likely from train fire. Cross links would be sealed by high pressure doors to keep the two tunnels separate for a complex ventilation system that would handle smoke and fumes.

Two major intermediate emergency

stations would be included at tunnel level at approximately the one-third points, which would have passenger escape tunnels at 86m intervals from the train tunnel into separate additional parallel emergency tunnels, linked via a pedestrian route to the opposite side.

These so-called multi-function stations (MFS) also allowed for later maintenance work and access, and as key locations for housing important permanent tunnel equipment (most of all the powerful ventilation systems that would be used for both maintenance work and emergencies).

In the same location were to be crossover tunnels for the main train bores allowing trains to switch to the other side, though rock conditions on the southern MFS meant that this was eventually constructed at a separate point (see diagrams on page 10).

The large diameter chambers also

provided critical spaces for the construction work and its separation into phases. To make its great length possible, the tunnel excavation was planned in five sections. One drive each would begin from south and north portals, and the other three from intermediate access points. First of these is an adit to the main tunnel at Faido, close to the Piora investigation tunnel entrance down to the main tunnel. Access here would allow advance construction of the multi-function station, the big excavation initially serving as a start chamber for a TBM drive northwards and later to receive the machines on the southernmost drive.

At Sedrun, a village high in the mountains, a shaft would descend to the tunnel line to excavate the second MFS. From this space the difficult squeezing ground could be tackled. A short tunnel of 1.1km was needed at the top to reach the shaft head.

A final drive was to begin near the village of Amsteg where a short horizontal adit, just 1.2m long was built to access the tunnel line from the narrow valley which forms the beginning of the Gotthard Pass.

The five main sections were of varying lengths, according to the anticipated difficulties for construction, with the longest at 16.5km from the southern portal at the little village of Bodio, through highly competent gneiss, and the shortest at Sedrun where the big MFS had to be built and where the squeezing ground would limit progress.

“The obvious aim was to synchronise the various parts for completion at approximately the same time,” says Charly Simmen, project manager with AlpTransit.

But the best laid plans of mice and men ‘oft gang astray’, especially when the holes they are gnawing are on such a giant scale.

As the work began the challenges and difficulties were increased. Areas of rock assumed to be sound and relatively simple to drive through proved to have some of the worst conditions of all, particularly on the southern end of the project where streamlined TBMs designed “like Formula One cars” for fast progress were stalled by the need for heavy support installation.

Meanwhile rock unexpectedly proved much more difficult for the big MFS cavern excavation to the south, which took twice as long to excavate as estimated. Squeezing ground was the culprit. Part of this section had to be redesigned, with rail track crossovers moved 600m away into sounder rock. It cost time and money.

The more difficult rock in the south, with more faulting than thought and frequent rock bursting, slowed the TBMs and

eventually led to a restructuring of overlapping contracts. The contractor on the central Sedrun section of the work, who had found better than expected conditions on the southward drives, albeit still very difficult, was asked to extend these by 2.5km and the Faido drives were shortened.

Some good luck was set against all of this, however. At Sedrun the rock was not so bad as thought and the north was able to make fast progress. Anticipated levels of water in the tunnels never reached anything like the inflows that might have been in the worst case risk analyses.

Flooding in the worst possible case of a 1,000lt/sec inflow would have been most dangerous in the central section of the tunnel, which was accessed only by the 800m deep Sedrun shafts in the first stages. Pumping resources sufficient to buy time for full evacuation were needed, a major undertaking against an 800m head of pressure.

Further complications were caused to the timetabling by political and community issues, most of all on the northern portal which exits at Erstfeld. A section of new line then connects into the existing Gotthard railway link, close to the historic town of Altdorf, capital of the canton of Uri, where the famous rebel William Tell was reputed to have shot the apple from his son's head.

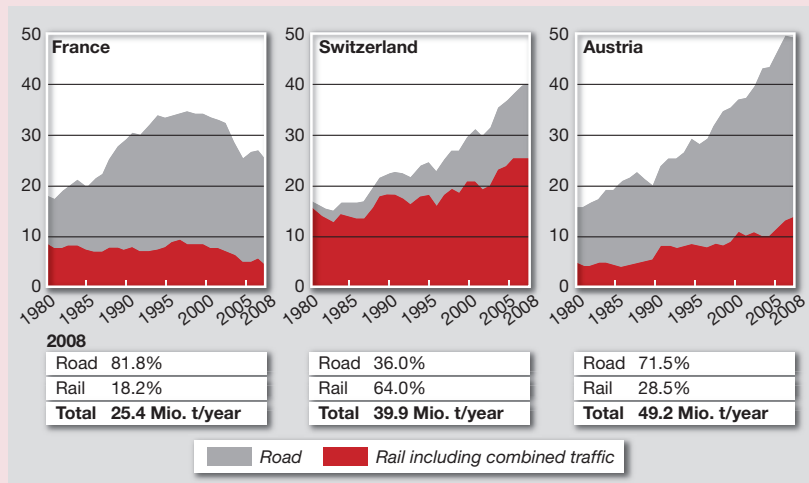
Residents had been pressing for an alternative alignment for the tunnel that would have continued it onwards through the side of the valley for several kilometres. The canton's objections held up the start of works for the northern section until 2003, following an agreement to add a stub tunnel and rail crossover chamber some 3km inside. These will provide a connection point for a possible future extension.

The delay in starting the Erstfeld section might have affected the entire programme but was partly absorbed by fast progress on the preceding Amsteg section and subsequently on the Erstfeld drives as well.

But other factors have caused the timeline to be extended anyway, most of all the very difficult rock conditions at the Faido MFS and in both the Bodio and Faido drives. On top was the impact of re-designing the MFS to get part of it into better ground.

Further design changes were made to both of the multi-function stations as well. These followed discussion with the Swiss Government, which was unhappy with the ventilation arrangements and insisted on the additions of extra vent passages, so that there would be no horizontal movement of smoke in the passenger emergency concourse. ■

## Project purpose



The Gotthard link is the second and larger of two major 'base' tunnels which are part of a CHF 30bn (USD 30.2bn) upgrading of the Swiss railway system agreed in the 1990s. Both the principle and funding from oil tax and heavy vehicle road tax, were agreed in a series of uniquely Swiss referendums.

Its major functions are to integrate Switzerland into the European high-speed network and to reduce the amount of truck borne freight passing between northern Europe's industrial centres and northern Italy and the Mediterranean ports.

Like all of the Alpine countries, Switzerland has seen massive growth in tonnages and is increasingly concerned about the environmental and community impacts, especially on its precious mountain zones. It has long put limits on freight through routes, but is obliged by European treaties to allow trucks up to 42t capacity.

By creating a deep level tunnel with a near flat vertical alignment, rising to only 550m above sea level, the currently saturated rail capacity across the Gotthard pass can be hugely increased. Gradients at only 6.7 per 1000 mean the tunnel will allow speeds of up to 250km/hr for highspeed passenger trains, 160km/hr for capable modern freight trains and 120km/hr for conventional and intermodal trains. Freight trains can also double their capacity to 4,000t and will not require the two locomotives needed for the current 1,150m high pass route.

The Gotthard route axis includes not only the base tunnel but several others. One, the Zimmerberg just outside out of Zurich was completed in 2000, and will be extended by another 11km in a second phase, eventually. A second is the Ceneri, south of Gotthard and now in construction, too. Several other intermediate tunnels are possibilities for the future, putting almost the whole line underground.

It is supplemented by the Lotschberg axis in the west, also a deep tunnel but shorter at 34.6km and awaiting full completion. It opened in 2007; one third of its length is only a single bore.

The main Gotthard base tunnel will shave some 50 minutes from the journey times between Zurich and the major Italian rail hub at Milan when it opens in 2017. This will not quite allow trains to integrate with an hourly framework for the international schedules. But completion of the Ceneri two years later will add the vital extra saving of 10 minutes.

Even so the route, serving an estimated 'local' catchment of 20M people in southern Germany and France, Switzerland and Italy, will be highly competitive with the plane.

Some 50 or so freight trains will use the base tunnel daily, in addition to the 150 on the existing route. But as they are larger this virtually doubles the capacity in tonnage to 40Mt annually.

Two more alpine base tunnels are currently being considered, the Brenner in Austria, where exploration, preparation work and probe tunnelling is well advanced, and the Frejus pass axis between Lyon in France and Turin in Italy. Funding for the Austrian tunnel is to be decided shortly. Both are almost as long as the Gotthard.



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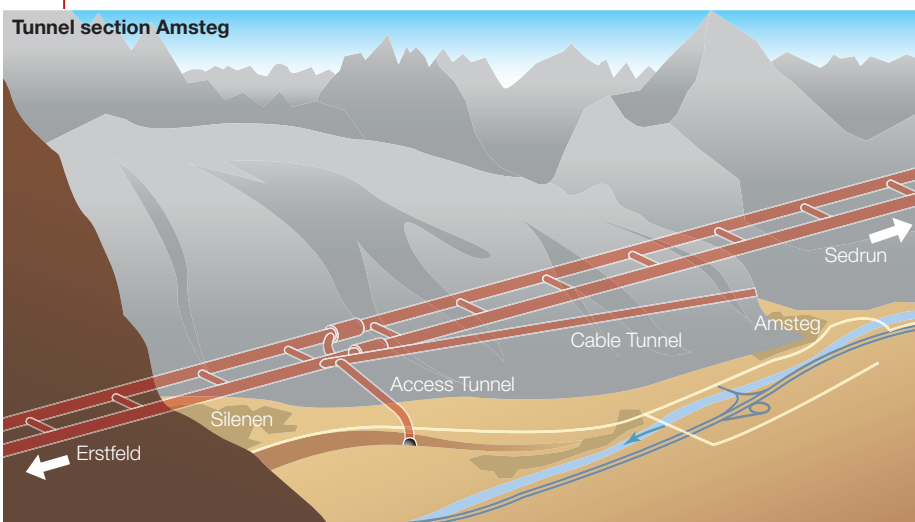
Specialists engaged on a wide range of activities in the construction of the Gotthard Base Tunnel place their trust in the reliability of Leica Geosystems surveying instruments and their solutions from Amberg Technologies. Amberg Technologies is a worldwide leader in tunnel surveying and tunnel scanning, for profile controlling, profile analysis and measurements. Leica Geosystems' high precision total stations in combination with Amberg's TMS Solution improved efficiency and reduced material costs in the longest rail tunnel ever built.

# Record drives at Amsteg and Erstfeld

The two drives for the northern section of Gotthard made the fastest progress including a world record TBM day rate. But they were not without their problems

**T**he two northern sections of the tunnel represent the “bread and butter” design and construction methodology for the base tunnels it could be said. As with 95 per cent of the tunnel length these drives were through relatively sound hard rock, mostly granite. The design specified TBMs made exceptionally fast progress, even achieving on one section a 56m cut in a single day, a possible world record.

That is not to say the drives were easy or even straightforward. The first and more southerly drive, setting out from an underground starting chamber close to the village of Amsteg, passed under some of the highest mountains on its 11.5km route towards the next section at Sedrun, with overburden reaching as much as 2,000m. It was known this would produce both difficulties with rock heat and in places



**Above:** Sections of cut and cover construction 400m long are being completed at the Erstfeld portal to cope with steep mountain slopes above where rockfall risk is high. The TBM drives started at this end point – Picture courtesy of AlpTransit Gotthard

slower progress with flawed and weaker geology, possibly including squeezing ground. A particularly difficult area was the Intschi zone fairly early on in the drive.

Political difficulties too beset the timetable, affecting the northern drives from Erstfeld where the northern portal is just more than 7km away from the end point at the Amsteg cavern.

Local objections held up the start of work for several years. The canton of Uri and its

**Right:** The huge cutter head on the TBM is dismantled at the end of the Amsteg drives in 2006 – Picture AlpTransit Gotthard

**Below, bottom:** The work site and aggregate facility at Amsteg – Picture AlpTransit Gotthard

capital Altdorf wanted an extension to the main base tunnel, which had been a route option, considered in early studies. It would have taken the alignment further through the mountain on the side of the narrow valley, which forms the approach to the Gotthard Pass (see introduction, page 8).

An agreement to build in a stub-tunnel starting point for this option, to go ahead in the future, was eventually made and the drives were started in 2007.

But that came later. While it was under discussion, the work went ahead at Amsteg where the initial 1.8km long access adit was begun in 1999 under an early contract. Local contractor Gebrüder Wuest of Lucerne worked with Ast-Holzmann Baugesellschaft of Austria on the 7.8m high tunnel. An Atlas Copco rig was used for the drill and blast.

Work was extended to include excavation of a 100m long chamber for signalling and electrical equipment, the first cross-passage of the Amsteg section and of the first 100m of tunnel of the eastern and the western tubes.



Outside meanwhile one of the main spoil handling sites was set up with a complex of conveyors and crushers.

A contract for the main drives heading south was let to a joint venture of Swiss firm Murer and Austria's Strabag in late 2001, which ordered two Herrenknecht TBMs for the work.

During the manufacturing of the TBM at Herrenknecht, the contractor built a large chamber 45m long and 20m across for the assembly and various small branch tunnels for conveyors. Another small 1.8km long tunnel to the Amsteg hydroelectric power plant was built by a 3.7m TBM. It was for operational power supplies and could also serve as a second, independent exit during

construction.

Cutting diameter of the TBM was a relatively large 9.55m, because the consultant consortium's design team were anticipating zones of faulted and potentially squeezing rock, which could deform and would eventually require a relatively thick inner lining. The machines, christened Gabi 1 and Gabi 2, were both powered at 3,500kW. They were brought to the start cavern where a large 160t capacity portal crane had been installed for their assembly. Both started out in early 2003.

The machine trains were only partly Herrenknecht, however. Apart from the machine head on hydraulic pads and then a conventional support train running on rails





**Left:** Cleaning the TBM head once it had been rescued from the disaggregated ground on the Amsteg drive – Picture AlpTransit Gotthard

**Below:** The worksite looking north along the Gotthard approach

total 30m of formwork in three 10m sections which were leapfrogged forwards.

“Concreting is usually difficult to keep in synchronisation with the excavation,” explains Wildbolz. “In a normal machine train there is a bridge section to clear the formwork. But there is a limit to how long that can be and if the concreting lags behind the cutterhead, you can run out of space. The whole operation has to slow down.

“But with the overhead chain support the train can move on while the concreting is done, and it can catch up later.”

Other work is also done more easily too, he says, including the general moving to and fro needed in all tunnel work. One important operation needing drill rigs and excavators follows on behind to create the small cross passages, for example.

These 20m<sup>2</sup> section links, every 312.5m, are made from the more advanced of the two parallel main drives, connecting across the 40m spacing between the tunnels. The drives leave a metre or so of rock at the end, which is broken through finally with an excavator-mounted Montabert hydraulic hammer

behind it for the first 150m, which contained rock support drills, shotcreting rigs and other equipment, the joint venture elected to use a hanging platform system, using rock bolts and chains.

“The complete backup train was 440m in total and most of that was supported on a mid-level Rowa platform,” says Adrian Wildbolz, the northern section’s overall supervising engineer for the client, AlpTransit Gotthard. The Swiss firm Rowa has made strong headway in the last decade with its concept on many Alpine contracts especially and increasingly worldwide. It uses the rock-bolted chains to support rails along which the platform can move.

“The hanging support allows the

contractor to keep most of the static equipment, crushers and conveyors in the top half of the tunnel,” explains Wildbolz, “leaving the bottom section of the tunnel free for mobile equipment.”

In the construction sequence used for the Amsteg drives, an important element was formation of a concreted base slab for the tunnel, which was the permanent support for the final railtrack eventually and during construction for temporary twin rail track for Schoma locomotives and Mullhauser wagons to supply the machine. A twin track “station” area ran along behind the machine train with one side for men to arrive and the other for materials.

This concrete base was cast in situ with a



from the second tunnel when it arrives.

"I'm convinced in this geology that it was clever choice of the contractor to use this Rowa system," says Wildbolz, adding that the operational flexibility was an important contributor to some very good progress made on the drives, helping cope with the variation in the cutterhead progress.

According to Herrenknecht this ranged from "good monthly performance of 560m and penetration rates of up to 12mm per revolution, followed by difficult stretches, some with a penetration rate of only 3mm per revolution and an advance of only 140m per month."

Both machines came to the end of their sections early, one with nine months to spare and the other six months. The time gain might have been even greater but for some reorganisation of the tunnels and a significant stoppage on the west drive caused by some unusual loose ground.

Heat caused the initial problem from the rock, which could rise to over 40 degrees centigrade. This was anticipated in all the studies and the contractors had been given warning in their contracts, which set an envelope of expected heat levels, predominantly between 32 and 38 degrees. According to Swiss safety law, which was revised because of Gotthard, working spaces had to be no more than 28 degrees.

Temperatures in the first third of the tunnel were not too problematical, says

Wildbolz, but they began to rise faster than expected once the tunnel cover increased towards 2,000m. "The problem is that no-one has any experience of tunnelling at such depth and the temperature curves were estimates from other situations."

That was initially something for the contractor to sort out, he says, but once it went over the contract-defined limits "it became our problem." A big increase in cooling equipment was needed, especially at the tunnel face where the newly chipped rock contained the most heat, and where the machinery was generating more calories too.

The tunnel spaces were not cooled with ventilation, because airflow heated up on the way to the tunnel face. Instead, industrial tunnel cooler units were used. These absorb the heat into cold water, which had therefore to be carried in and out of the tunnel in large steel pipes. Four of these as well as four return pipes were used eventually for the two drives, which meant some 100km of pipe work.

"You can imagine the pumping capacity needed," says Wildbolz. "The electricity for that alone cost CHF 10,000 (USD 10,000) per day."

Outside there were settlement ponds for water treatment and some cooling and two cooling towers. To cope with the heat the contractor had to add four more bigger cooling towers eventually, says Wildbolz.

The second difficulty was hit about midway into the drive when the two machines ran into some exceptionally difficult rock. "It was a hydrothermally disaggregated material like loose chips for road surfacing," he explains.

The more advanced of the two drives slowed down, he says and by using closely-spaced arch support and mesh, continued to make headway, even though some of the chips would trickle through.

"But just 40m away the other machine had major problems," he says. It had advanced a few metres into the material when suddenly there was an inrush of the material into the cutterhead area. "There was just a little water, perhaps 2lt/s, which seems to have made the difference."

The machine head was jammed and unable to rotate. A small excavation around the side of the head found the material standing, and then it suddenly rushed into the space, he says, "like a waterfall."

The next few days saw a series of boreholes made, which showed another 20m of the worst ground ahead and an unravelled cavity above the tunnel line.

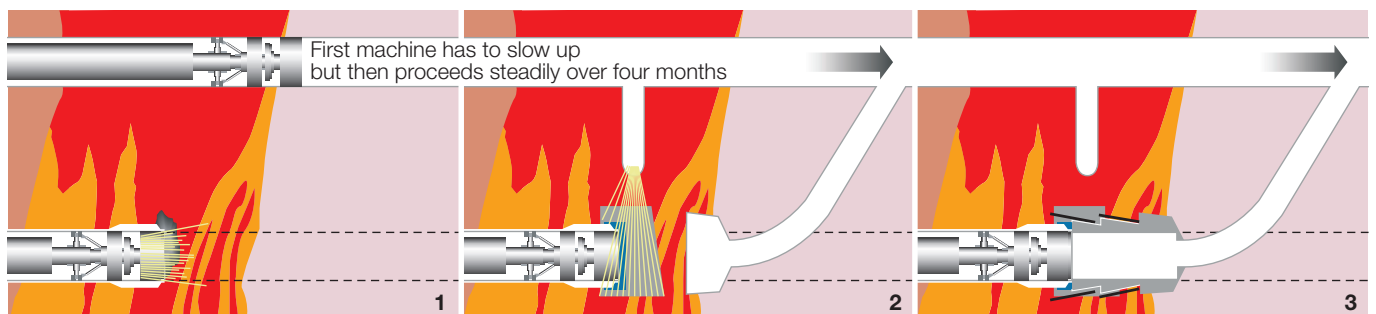
To tackle this it was decided to make a small tunnel from the opposite bore, where the TBM was steadily moving onwards. From here a fan of grouting tubes could inject a gel grout into the loose material forming a plug around the TBM face. Another tunnel from the opposite bore was started further ahead, curving round back to the TBM where it opened out into a chamber in front of the now immobilised, gel-filled ground around the cutterhead.

Forepoling from the opened-out chamber created a grouted umbrella forwards as far as the machine's face, allowing access to clean and free it up. "The contractor took the chance to do some repair and maintenance as well," says Wildbolz.

Some six months progress was lost, he



**Left:** Impermeable membrane being installed for the lining formwork  
**Below:** Rescue sequence for the TBM trapped in disaggregated ground



says, before the machine could move again. Despite the halt, progress for the remainder of the drives was good, the drives finishing six months and nine months ahead of schedule respectively.

Further back in the tunnels, work continued on the permanent lining. The contractor started this while the TBM was still at work, with crews forming kicker sections part way around from the base slab, with their drainage and impermeable liners.

These were completed once the cooling pipes and other service lines could be removed and space made for the full diameter formwork. Lining thickness is a minimum 300mm, varying depending on the rock conditions and the loads that implies. It is assumed that the rock support behind the membrane will corrode and that the inner lining must be capable of sustaining the permanent load alone.

Along with the varied amount of steel and shotcrete that might have been needed, this means the inner diameter of the tunnel also varies from point to point. "There is no fixed size, but a minimum usable diameter," says Wildbolz "the criterion being that the trains require a completely free area of 41m<sup>2</sup> from aerodynamic analysis."

The lining work included installation of unusual precast units for the side walkways that contain most of the ducting for signals and power. The 10m sections were made nearby and allowed much better quality control for the ducting than normal in situ work, thinks Wildbolz.

The second northern drives, which run from the Erstfeld portal to the start chamber at Amsteg, have now been completed by the same contractor, Strabag, which has now bought Murer. It was able to make an offer because the long delay at Erstfeld meant it had finished the other section.

"The bid included some over-excavation because the required diameter was only 9.4m for the Erstfeld section which has lower overburden," says Wildbolz.

The contractor's experience on the first drive and the presence of the existing machines allowed a competitive bid even with the surplus excavation. The set-up used was very similar to the first drives again with conveyor spoil removal

and went equally quickly, finishing last year.

The Amsteg sections were lined, completed and handed over earlier this year and much of the inner lining for the Erstfeld section is now done, completely on the east side and about one third on the west.

Rail track work begins here once the rail teams have completed a first section at Bodio in the south and have transferred their equipment. ■

**Right:** Adrian Wildbolz, Amsteg and Erstfeld section manager for AlpTransit - Picture AlpTransit Gotthard



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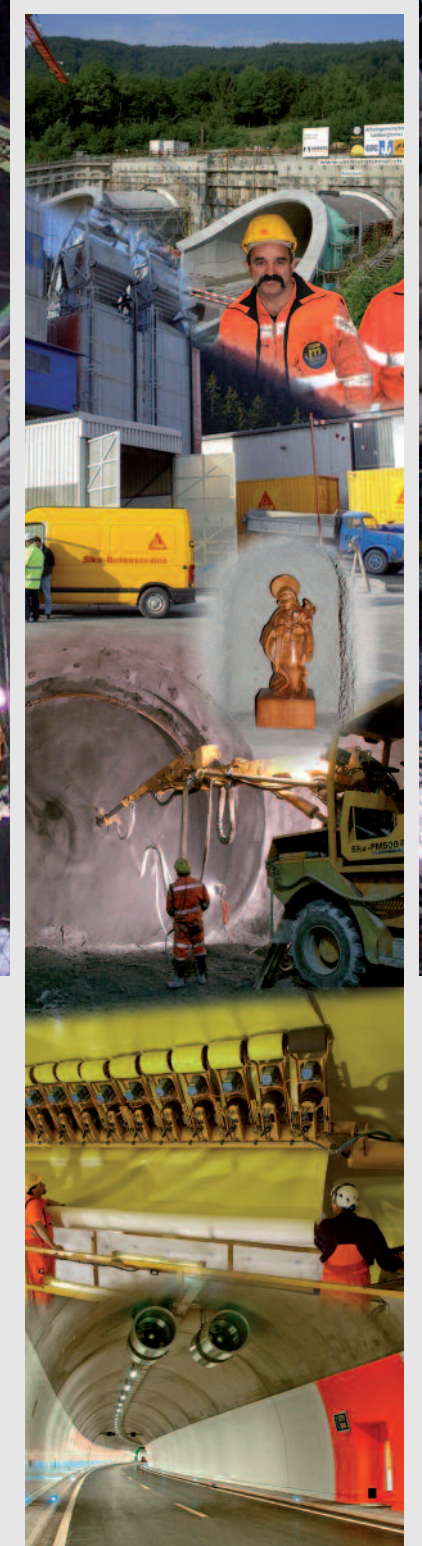
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Gotthard tunnel, Sedrun north section. Using the man baskets from the front of the hanging platform to install mesh on a partial face excavation in squeezing ground. Picture by Maurice Schobinger courtesy of Transco Sedrun



# Deep down and squeezed tight at Sedrun

South African gold mine shafts, German coal seams, World War U-boat construction and Swiss mountain railways all helped on the difficult Sedrun section

**W**hen the Gotthard tunnel was initially divided into construction sections, the shortest length was allocated to Sedrun towards the middle of the project. It would take the greatest effort.

Apart from the Piora problem further south, this was where the really difficult ground was known to exist, with rock so cracked and fragmented it could be pulled from the face by hand. Under more than 1,000m of overburden, at this point it would squeeze and deform.

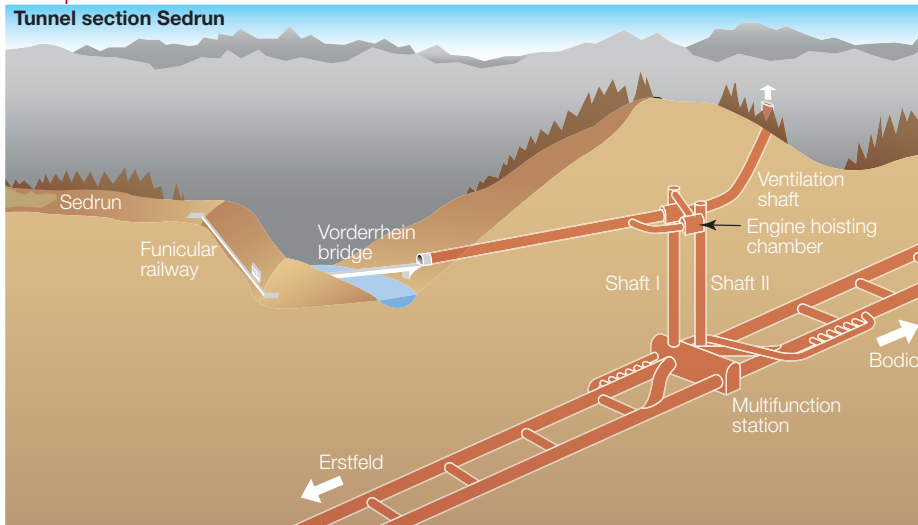
Making a large bore would be hard

going. "If it was possible at all," says Heinz Ehrbar, AlpTransit's chief engineer. "There were some very expert geologists who said the rock would be just 'toothpaste' and it could not be done." Even core drills had become stuck.

Others believed this was exaggerated but "no-one really knew because there was no experience that deep in the massifs," says Ehrbar. There was, however, deep experience in coal mines in Germany, at about 1km down, and also in the famous gold mines of Johannesburg. Technology that might help was there.

The problem was how to handle very big deformations of the rock that would be inevitable under high pressures. That could not be done with conventional anchors, steel arches and shotcrete.

"You just cannot put rigid support close to the excavation front because the forces are so great it will be destroyed immediately, even the strongest of profiles," says Ehrbar. In his office he keeps a piece of steel section from an unexpected area of squeezing ground. It is thicker than the strongest miner's bicep and is almost completely twisted back on itself, proving



**Right:** The Sedrun section of tunnelling near the middle of the project with more than 1,000m of overburden

deformation of the cut.

“They were initially devised for building the hulls of submarines, which face the same difficulties as they dive deeper,” he says. They are made with a very special high strength steel he adds, with particularly low brittleness. “The profile of the sections is also important and you could say that the whole experience of the mining industry is embedded in their form.”

Although they worked in the mines, they had not been used in tunnelling. More importantly they had not been used on the scale required for the train tunnels. “The mine passages are 20m<sup>2</sup> in section and we needed 100m<sup>2</sup>, with a face more than 10m high,” says Ehrbar.

Calculations and tests, including detailed studies on the rock at Zurich’s ETH technical university, and on the telescopic arches, suggested that the system could be made to work. It would mean slow going, perhaps as little as 0.4m a day in places.

Additionally the excavation would have to be much larger in diameter than elsewhere,

the point graphically.

But the tunnel face must be supported or it could collapse.

The way out of the quandary is to let the rock deform to some extent and then gradually start to resist it. At a certain point the diminishing force of the rock and the increasing strength of the support will intersect and “you have a point of equilibrium,” he explains. Stability is achieved and normal rigid support can be added.

“You can describe it as ‘calming down’ the rock,” he says. “You have not to be afraid of

deformation, but know it is under control.”

How to do that was imported from the German coal mines where a system of telescopic, sliding arch supports had been in use for several decades. They used overlapping sections of curved, profiled steel which were connected by specially designed bolted friction joints. These would “give” as pressure increased allowing some

**Below:** The Sedrun workcamp is sited outside the portal for the shaft tunnel in a small valley 150m below the village. A small rack and pinion railway was built to carry materials in and spoil is removed by conveyor. Picture Alptransit Gotthard





up to 13m, to allow both for the squeezing and for the eventual inner concrete lining to the tunnels, which must give the running tunnels long-term stability for the next 100 years. In much of the Gotthard, the lining needed is around 300mm thick but for Sedrun between 600mm and 900mm thickness of concrete was used.

“We even had a design option of 1.2m thickness, though in the event that was not needed,” says Ehrbar.

This extra excavation was somewhat paradoxical since removing more of the ground only added to the effect of the squeezing.

Other complications beset the section. To begin with, there was no easy access from high on the Gotthard pass and that meant the tunnel would have to be reached by a vertical shaft close to the alpine village of Sedrun. By starting inside a mountain, via a 1km long horizontal tunnel, this shaft could be less than the full height of the peaks, though it still needed to go 800m deep.

Like the Faido access tunnel further south, the shaft would have a permanent function as part of the emergency and ventilation facilities for the operating tunnel around a multi-function station. So the contract also included the excavation of the additional caverns, crossover tunnels, side and ventilation tunnels making up the MFS at the shaft base. These were not in the most squeezing ground however, which was in the 2km of rock to the north of the access. Another 5km of excavation, would take the tunnels southwards through some faulted but mostly good ground.

So time-consuming was this work

expected to be in total that the 1km long access tunnel was begun very early, in 1996. A South African company from the goldmines, appropriately called Shaft Sinkers, had the particular experience to win the lead role in the contract for the blind excavation of the 8m diameter shaft down through the rock, begun in 1998. It worked with local contractors Murer, Locher, Marti, Zschokke and CSC, using a platform-mounted Atlas Copco multi-boom jumbo for the drill and blast.

A construction camp with semi-permanent buildings was also set up in a small valley of the Rhine below the village, where the access tunnel portal emerged and a small rack-and-pinion rail link for later spoil disposal.

The shaft was envisaged initially as the main access for the construction and later for the MFS. But one of the bidding groups for the main contract, the Transco-Sedrun consortium of Swiss contractor Implenia leading Frutiger, Germany’s Bilfinger Berger and Italian Pizzarotti, was concerned about the safety and logistical implications of using only one shaft.

“We were convinced the project would have major safety issues that way” says Jakob Lehner, a supervising engineer for the contractor and currently with responsibility for safety and a number of other roles. AlpTransit had added a second shaft to the design during the long tender but it was to be 4.5m.

“We further suggested it should be 7m, at our own cost, because we thought it should have space for an elevator as well as that in the first shaft,” says Lehner. He

**Above, left:** Installing sliding arch supports on the Sedrun squeezing ground section

**Above, right:** Jakob Lehner from, Transco

believes that the suggestion helped put the bid into a good light with the client. A CHF 1.6bn, before VAT, (USD 1.6bn) contract was signed in April 2002.

Early work therefore included the drilling of a second shaft, this time by a raise bore operation subcontracted to Thyssen Schachtbau in JV with Ostu Stettin and Murray & Roberts RUC. Thyssen used a Wirth Vee-Mole for the shaft, which is 35m distant from the first.

For the main excavations the contractor decided on a Rowa suspended platform installation for both drives, north and south.

As for the contracts at Armsteg, the steel frame platform is mounted on rails suspended from ceiling rock bolts and can keep virtually all the static equipment, including rock crushers, water treatment, conveyors and desanding units in the top half of the tunnel, leaving clear space below for drill rigs, loaders, excavators, railway wagons, and other mobile equipment to pass freely.

Most importantly, on front end of the platform was a special handling machine for the movement and installation of the sliding arch units. The 50t unit was developed and made specially for the project by German manufacturer GTA based on smaller “Streckenausbaumaschine” or “seam support handlers” from the coal mines.

“It has arms with pantograph-like extenders which hold up the first sections of

girders,” explains Lehner. “There is another segment manipulator and then there are two man-basket arms as well and from these the installers can put in the intermediate sections and the special clamps.”

The multi-section arches, made by supplier Heinzmann, are bolted to a specific torsion according to the friction needed.

“They slide quite suddenly as the stress is relieved and that can sound like a gunshot,” says Ehrbar. He made sure that the full-scale trials for the system were done in an in situ section at the shaft base early on, with some of the working miners

present “so that they could get used to the noises, because the natural inclination for a miner would be to run.”

Lehner says that the noise is more of a pistol shot than the “cannon fire sound or explosion that you get with rock burst or collapse” and that the miners quickly became accustomed. Though it was thought that squeezing might take up to six months to stop, mostly it was over within the first month, he says.

For the northern drive into the most difficult ground the contractor decided to use a single-track rail for muck out. It

would be laid on a temporary bed built up from spoil.

“The arch support needs a circular excavation. But we did not dare build up the invert with a concrete slab because the amount of convergence to come was not known. In places this could mean re-excavation if it went too far and so the less there was to replace the better,” says Lehner

In the event of re-profiling, just 200m to 300m was needed only on the south section. But the rail track proved difficult as there was some heave and it made the ride on the trucks erratic.

“That makes them slower and causes a lot of track wear,” says Lehner.

The face was cleared with Toro low profile loaders into the rail cars for the northern drives. This was the arrangement used in the south until the harder rock was entered and drill and blast began. At this point the trucks tipped into a crusher on the Rowa platform, feeding a newly installed 600m long conveyor to the back where the railcars were loaded.

“But we realised this was inefficient and finally installed a fixed tunnel conveyor running back to a loading point near the exit,” says Lehner. “That freed the rail for other purposes.”

Full trucks ran to a two-level fast lift in the main shaft, one 12m<sup>3</sup> car per level, making a 50t load. At the shaft top these could run to a muck handling facility outside the portal where they were tipped out with a rotating drum for disposal, which was handled by a separate contractor.

The contractor also moved to cast concrete track bed in the southern tunnels once it was past the first kilometre of potentially difficult rock in the faulted Urseren-Garvera zone.

“After that we were using drill and blast anyway in hard rock,” says Lehner.

In the first, difficult ground excavation was carried out by “pecking” the face with an excavator-mounted hydraulic hammer, as it was for the entire northern drive, which took until 2008 to complete its two crumbled 2km bores.

Here the rock had to be assessed constantly and was “consistent only in its inconsistency,” says Lehner. Progress

**Left, top:** A roadheader is used to re-profile an area of tunnel where convergence has squeezed the diameter at Sedrun. Picture courtesy of AlpTransit Gotthard

**Left, bottom:** Lining work on the multi function station area where tunnels diverge for the cross over



varied from over 1m to just 400mm daily and even on occasion demanded partial face work in 2sqm to 3sqm sections when there was “clayey powdery material,” he explains. Arches varied in spacing from three rings per metre, to one every 1.5m.

The face was reinforced using steel rods. “The contractor had the option of fibre glass,” explains Ehrbar, but since there was no roadheader work, the more quickly installed self-driving steel was better. It was thought some 270 insertions would be needed; the anchors up to 18m long placed in an overlapping sequence of 90 new rods every 6m.

Mostly however the full anticipated reinforcement was not used. “We mainly managed with 12m lengths and only 80 or so rods,” says Ehrbar. A Tamrock T12 was ordered for the face drilling but a smaller T11 proved more nimble and was used more often. The same machine worked on the drill and blast in the south and the cross-passages.

“We might have had more difficulties at the face if there had been a lot of water,” says Lehner, but nothing more than 70lt/sec was encountered and only in the south.

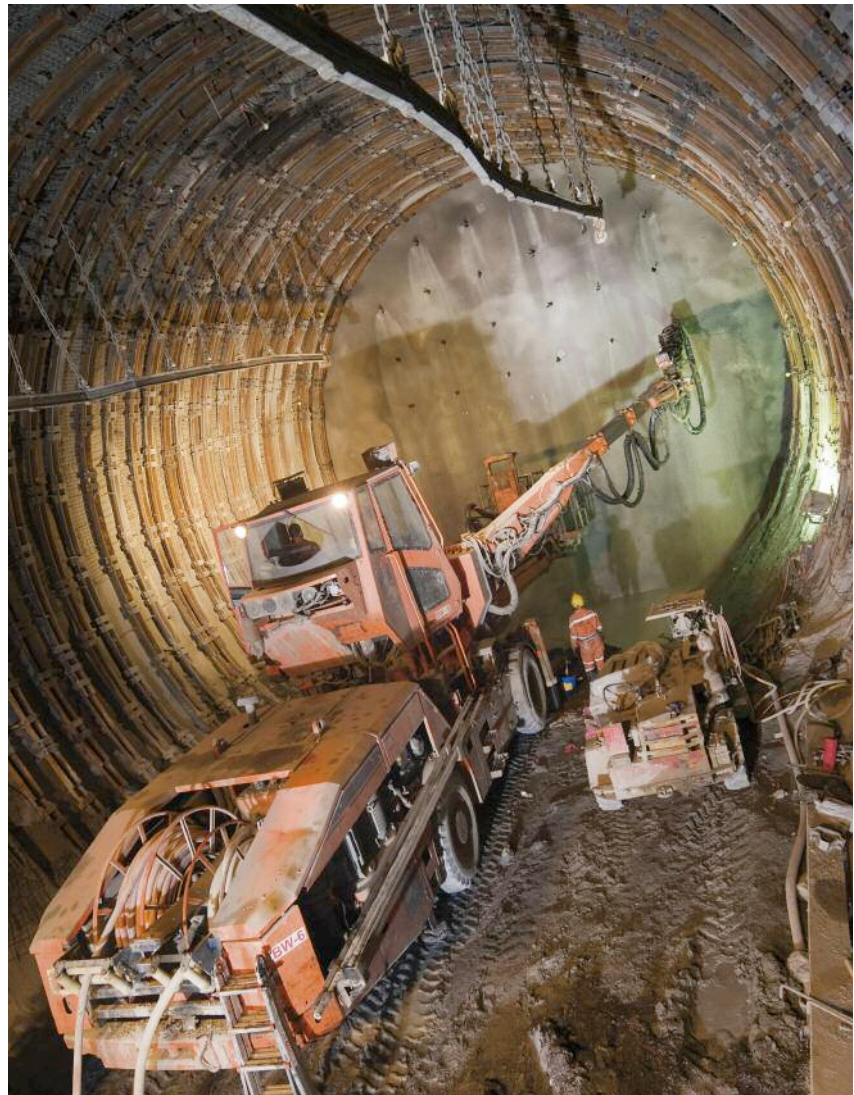
The excavations had to be prepared for up to 1,000litre/sec inflows with corresponding safety arrangements. Particularly until the first breakthroughs were made, and a drainage route was established, this would have flooded the tunnels and it was demanded that shafts could evacuate everyone in one lift.

Huge pumps were necessary at the bottom capable of lifting such volumes through an 800m shaft. Eight Sulzer pumps from ABB were used until breakthrough.

Like the Amsteg tunnels, Sedrun also had to install massive supplies of cold water to service tunnel cooler units. Overburden as much as 2,300m meant rock temperature could be up to 45 degrees centigrade in the excavation area at least.

Once again ventilation could not perform the cooling duties, even during winter when the outside air temperature drops well below zero. “In fact we had to heat the incoming air to prevent the formation of icicles in the shafts,” says Lehner. “If one had broken off and fallen it would have been fatal.”

A complex ventilation system was used, with 250m<sup>3</sup>/sec entering via the main shaft to feed a 200m inner ring of tunnel in the multi-function area. From here fans drew supplies for the various drives. Cross passages are sealed with airlocks to make a circuit along one tunnel and back in the other. Exhaust went out of



**Above:** Installing face anchors for the squeezing ground with a Tamrock T11 at Sedrun. Picture by Maurice Schobinger courtesy of Transco Sedrun

the secondary shaft.

Though the north was not easy, it never proved impossible and was eventually completed nine months ahead of the schedule. The south meanwhile went much better than expected. The first 600m was also anticipated to be relatively difficult rock similar to, if not as bad, as the north. Although there were some faulted sections, progress was very fast.

“With in six months we were a year ahead of schedule,” says Lehner, adding that the contractor had geared up to move at 1m a day and ended up doing 6m. “We actually struggled because we were too prepared.”

Complexities and changes were also met in the multifunction station where additional ventilation tubes were requested by the government for the side passages, to ensure

smoke would be exhausted quickly from the passenger emergency refuges if there was a fire. Organising the spaghetti of tubes and vents was logistically complicated.

Remaining work now includes some re-profiling in the south and much of the lining work. The contractor has a sophisticated, hydraulically-adjusted travelling formwork for this, which can allow a variable internal diameter to be created, ensuring no more concrete is used than is required.

Progress has continued to be good in the harder rock, leading to a contract option for an additional kilometre drive to be activated. Later as difficulties became more apparent on drives from Faido, an option for another 1.5km was added in a contract revision, eventually bringing the original 4km southern Sedrun sections to 6,404m at the final breakthrough in October. ■

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# The unforeseen struggle in the south

Unexpected squeezing, rockbursting and heat made the southern contracts exceptionally difficult testing both human and technical capabilities



**B**odio and Faido, the two southern contracts for the Gotthard tunnel, were thought at the start of the project to be in the best ground and capable of the fastest progress. They were therefore the longest sections, 16.5km heading north from a portal at Bodio, and 13.5km onwards from the intermediate access gallery Faido, to join up with the Sedrun excavation.

Because of schedule revisions these second drives were eventually shortened to 11,134m in the east drive and 11,118m, with the remaining part done by the Sedrun lot which had made better progress than thought.

Faido, the second of the contracts, begun from an adit access at the narrow valley at Faido, included the excavation of all the caverns and side tunnels for the southern multifunction station as well as the running tunnels onwards. Within the 2.5km of the multifunction station some 11km length of tunnels, crosscuts, shafts and caverns were therefore to be done by conventional excavation methods before the drives onwards by TBM.

Neither section turned out to be straightforward with some of the greatest difficulties and rock problems on the whole base tunnel. Particularly the Faido MFS section had unexpected squeezing ground and faulted rock caused major headaches from almost the first days of work. The great 11.8m high cavern with a total volume of 15,000m<sup>3</sup> for the emergency station and ventilation inflows took five and a half years to complete instead of three.

Faulting, rock falls and rock burst also slowed the TBMs on the Bodio drives and

**Left:** The work camp and support facilities at the Bodio portal. Logisitcs control, spoil disposal and concrete batching was done here for the drives to Faido and beyond to Sedrun. Picture courtesy of AlpTransit Gotthard

the rock conditions proved difficult on the Faido TBM drives as well, with more and heavier rock burst and faults. Greater difficulties had been anticipated for this last section however, as it is the deepest, with almost 2,300m of mountain above.

A major redesign was needed for the Faido MFS work eventually, separating the crossover tunnels from the emergency station itself and shifting them 600m southwards into better ground. The final TBM drives from Faido towards the Sedrun section were also slightly shortened, with the additional length added to the Sedrun contracts, to balance out the completion times and bring the overall breakthrough forwards.

“It is the great irony of the project that the most risky and complex sections we planned for should have been less difficult than thought, though not easy, and the easiest had so many problems and challenges,” says Heinz Ehrbar, chief engineer for AlpTransit.

The Sedrun section ended up making faster progress than thought, he says. The “unfeasible” Piora, the syncline full of potentially running “sugar-rock,” which was the great risk in this southern section, was eventually found to be so solid that the drives passed through almost unnoticed.

A big ancient rock slide that covered the mountainside at the Bodio portal with giant “house-sized” boulders and mixed debris, was also dealt with as planned, using steady application of forepoling and grouting to get through its 410m in an early

preparation contract, which also included a further 1,630m of drill and blast for the east bore and 720m for the west. In another preparation contract a temporary bypass tunnel of 1,200m was made around the slide, ending in a cavern, where the TBMs could be assembled to start the main drives without unnecessary delay.

If there were to be challenges on the southern lots, it was supposed these would be focused around the logistics. The concern was how such huge quantities of material and long drives could be supplied and spoil be removed, mostly through the one portal at Bodio, because Faido valley did not have the capacity to handle a huge volume of spoil, a problem made worse by a steep access with a 13 per cent gradient in the 2.7km long adit.

Eventually it was accepted that the only way to tackle it was to combine both contracts, Bodio and Faido, as one overall project with the organisation merged and coordinated.

Doing so allowed a sufficient scale of production to justify a highly sophisticated automated tunnel railway system to be installed, and to create a giant “factory-on-wheels” for all the follow-on tunnel cleaning, drainage installation and lining operations. The so-called “tunnel worm,” 650m long, built by Herrenknecht subsidiary Maschinen und Stahlbau

Dresden (MSD) could run at the same time as the TBMs, speeding up operations.

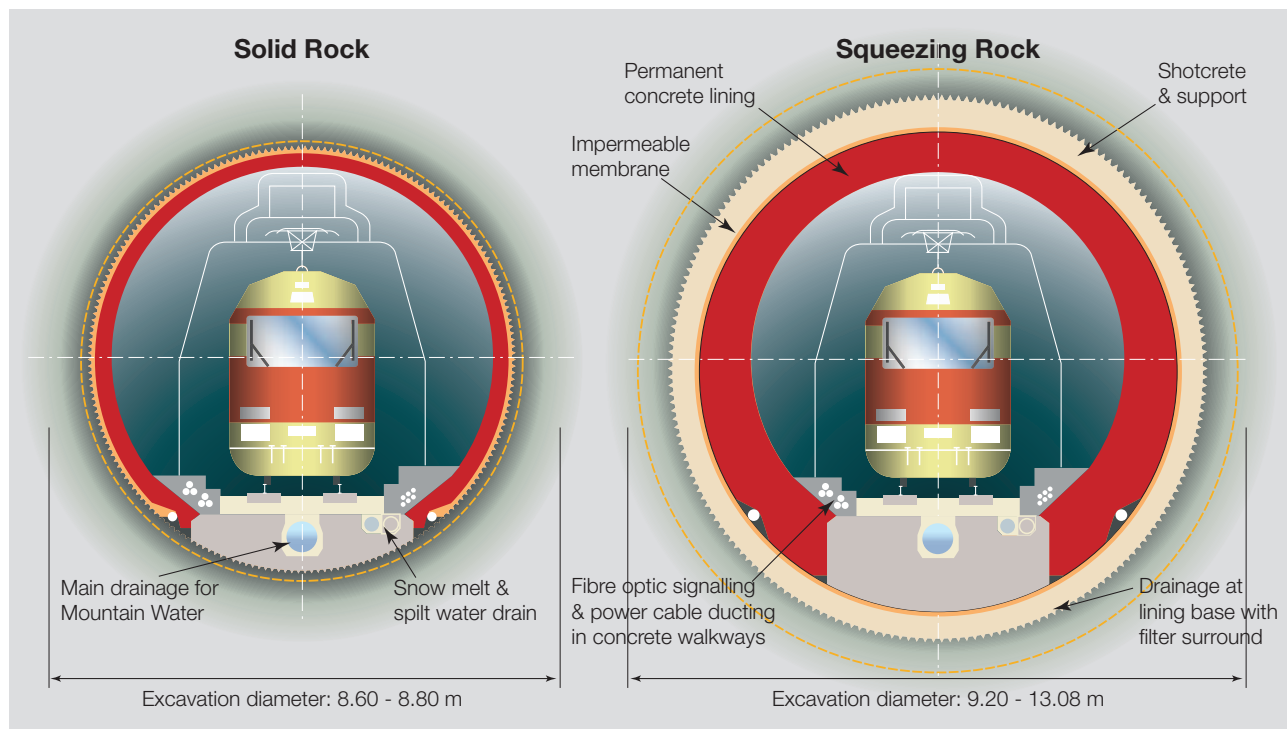
Proposals for this were made by the Tunnel AlpTransit-Ticino (TAT) joint venture, which eventually won the job, a group led by Swiss contractor Implenia Bau (formerly Zschokke-Locher and Bati-Group) with the Austrian Alpine Bau, the Italian firm Impregilo with Swiss subsidiary CSC Impresa Costruzione and Germany’s Hochtief.

Olivier Bockli, the designated director of business unit underground works for Implenia and managing director of the joint venture, says that although TAT submitted four alternative bids treating the sections separately, “the logic of the sites really made no sense unless they were put together.” The group submitted two further bid proposals which merged the works and argued strongly to the client that this was the best way to proceed.

AlpTransit was convinced, even though the scale of the contract would be a new experience for Swiss construction, both in its timescale of over a decade and the cost.

In the accepted bid—worth a very large CHF 1.5bn (USD 1.5bn) and now at least CHF 800M (USD 800M) more, though contract negotiations have some distance to run yet—the plan was to use just two TBMs instead of four proposed in the outline scheme. They would do both the first drives from Bodio and the onwards

**Below:** Linings, cables, and drainage for the southern portions of tunnel, where squeezing rock, among other challenges, was encountered



drives from Faido, being renovated and adjusted after the first section to handle an increase in the cutting diameter. The contractor selected Herrenknecht.

During the first drives from the south, the multi-function station would simultaneously be excavated via a side adit from a worksite in the narrow valley where the little town of Faido is located. The big cavern and tunnels would serve as the initial reception for the machines, where they could be repaired and refitted for the more demanding drives northwards.

These first TBM bores from the Bodio portal northwards, were through the horizontally stratified pennine gneiss of the southern Leventina mountains. While these are fairly high, the cover was not going to exceed 1500m, meaning reasonable rock pressure. The rock was understood to be sound all the way.

In such a relatively problem-free zone and with little squeezing anticipated, the design called for a tight bore diameter of 8.8m to avoid any wasteful overcutting and to reduce spoil disposal. Only a minimum 250mm or 300mm thick inner lining, without reinforcement, would be required.

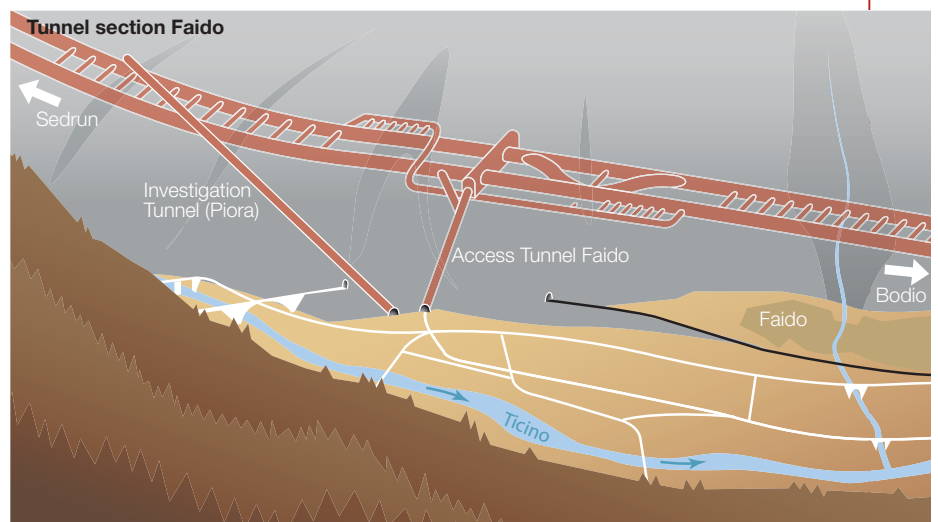
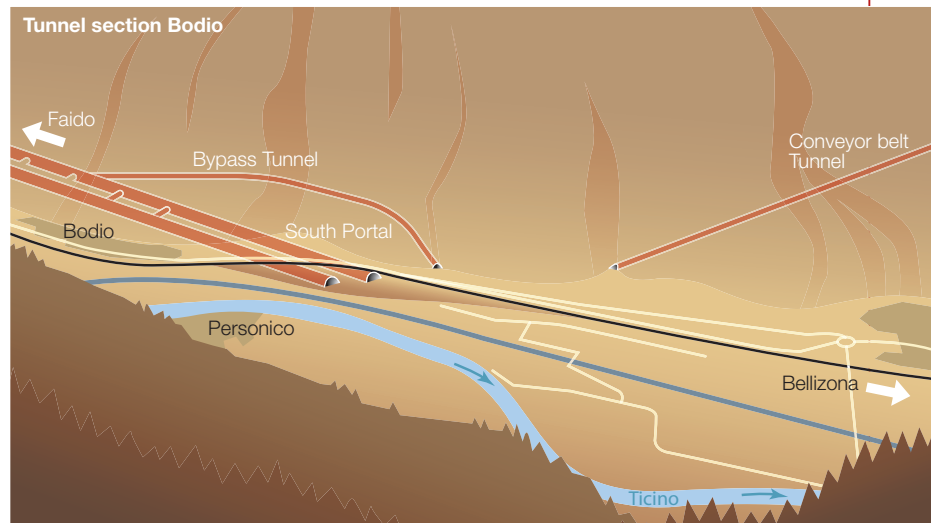
"The TBMs were therefore stripped down like Formula One cars with fairly light rock-support drilling equipment and so forth," says Boeckli. The geology showed this to be a mistake.

"Almost immediately the machines ran into faulted and difficult rock," says Ehrbar shaking his head. "And the luck was bad. There was one fairly small horizontal fault zone for example that just stayed within the tunnel section for 500m on the east side, even though in the west drive it dipped away after only 60m."

The rock continued to be faulted or more difficult than thought. "We quickly realised that we were needing far more rock bolting and support than planned. We had expected 25 per cent bad rock and 75 per cent good. But the ratio was reversed, and for safety there was a much greater need for steel caps with 75 per cent needing," says Boeckli. "After a while it was necessary to modify the machines."

The TBMs were stopped in Christmas 2004 for three weeks and the L1 and L2 area of the machine trains especially were beefed-up by Rowa additions to the otherwise Herrnknecht machine train. More efficient rock drills were added. A new flexible robotised shotcrete system from Sika was added and a new transport and installation system for the ring beams.

The rock also suffered to some extent from rock falls and burst. The gneiss is fairly highly stressed horizontally, says



**Above, top:** The southern portal at Bodio

**Above, bottom:** Faido valley adit

**Right:** Heavy support was needed frequently on the southern sections

Bockli, "because it is on the south, the side of the Alps that the African tectonic plate is pushing."

The machine in the western drive also suffered a jam from rock convergence though this was resolved within 11 days says Bockli. "We devised a technique using hand-held rock drills, small blasts and hand shotcreting to create a small gallery over the TBM shield which took the overburden pressure away." A few areas of the Bodio drives required some re-profiling because of convergence.

A recent 40km loose-rock jam, similar to the one in the north (see northern story, page 17) has since required much greater effort on the Faido drives, with a need to drive rescue tunnels from the other bore and costing three months, almost a repeat



of the northern drive problem.

The difficulties and changes meant that the machines took longer to make their runs than expected, finally arriving after three and a half years at the Faido caverns in autumn 2006, where they were due to be overhauled and modified by the contractor and supplier Herrenknecht.



This later arrival was fortunate. The complex of tunnels and main cavern had been a nightmare to construct and the arrival cavern was finished “just in time” for the first TBM.

The multi-function station was excavated from the end point of a 2.7km long access tunnel that dropped from the Faido valley access above to tunnel level. “It was a very steep gradient, some 13 per cent,” recalls Simon Peggs, an AlpTransit engineer on the site at the time. “I walked up it once but never again.”

No problems had been encountered when this access adit was built in a preparatory contract between 1999 and 2001 and “it went very well,” says Ehrbar. “There were no signs of any difficulty in the rock.”

But within days of the main contractor starting excavation, the crews hit bad ground, he says. “We thought maybe it was lack of experience or a learning curve issue but it became clear that problems would continue.”

At first the contractor and the engineers resorted to heavy support. However, as the work moved on even the strongest steel arches proved to be inadequate.

“It was the beginning of many technical challenges. The ground here suffered significant rock bursts, for example,” says Ehrbar, “which could be very dangerous. It is very sudden and unpredictable. In one incident a piece of rock 20m<sup>3</sup> came away, though such a large piece is an exception.”

Areas of the excavations had to be declared out of bounds for periods. At the excavation fronts an additional waiting period of around four hours was often

needed after blasting, to allow for a period with a high risk of bursts.

In some parts of the excavation there was squeezing ground as difficult as anything on the Sedrun contracts “and with the additional problem that it was unexpected,” says Ehrbar. Early support was bent and destroyed.

The sliding arch system from Sedrun had to be applied, though without the specialised arch handling machines being available to install them. Fortunately the areas requiring the technique were sufficiently small to allow the contractor to work with normal plant to erect the arches.

“Overall the difficulties there affected everyone,” says Boeckli, “starting with the miners who had to fight every centimetre of the way, beginning with enough support to ensure safety. Three-quarters of the time was involved in that and only one-quarter in actual excavation.”

Convergences were sometimes more than a metre and meant that areas of tunnel or cavern had to be reprofiled not just once but in some places as many as four times, with new primary support.

The engineer was also challenged, he says, because eventually it was clear that changing the design was the best solution, so that the big crossover tunnels at least could be built in better rock. They were moved to the south as was the west side passenger escape concourse. The passenger walkway, which takes passengers over the tunnels to the safe side in an emergency, was lengthened.

Separate design changes were also needed to the concourse’s ventilation, as in

the Sedrun MFS, increasing the number of duct passages from one to seven on each side. Vents were required by the government not simply at the end of the concourse, to exhaust any smoke, but between each of the cross passages that connect to the main running tunnel, where any burning train would be standing.

The problems were also a challenge for the client, says Boeckli, because the difficulties raised issues of increased work and costs. Both he and Ehrbar declare however that despite the fraught conditions, it was possible to keep relations going “using a tradition of Swiss compromise and realism.” Ehrbar adds that he is impressed that “not once did the work actually stop.”

Problems were to continue on the second stage of the TBM drives although the TBMs were better able to handle things after their major overhaul and rebuild. Owing to experience from the first section, additional modifications were made to the cutterhead, with more discs added for example. A spiral pattern was adopted rather than eight radial spokes. Wear plates were also strengthened.

Other changes had already been planned because the bores from Faido onwards would include the highest rock cover on the alignment, up to 2,300m. A bigger bore diameter was needed therefore to handle possible convergence and heavier support and so the cutterhead diameter was increased to 9.4m. A capacity to bore to 9.5m diameter if judged necessary was made possible with extensible cutters and changing discs from 17 inches (approx. 43cm) to 18 inches (approx. 46cm) in the



**Above, far left:** Arch and mesh support for faulted ground in the Faido to Sedrun eastern TBM drive. Picture courtesy of AlpTransit Gotthard

**Above, middle:** Renovating and restructuring the cutterhead for the Herrenknecht TBM at Faido before it continued the drive northwards towards the Sedrun section. Picture courtesy AlpTransit

**Above, right:** Rock drills and equipment in the rear of the cutterhead during renovation work on the TBM

calibre range of the cutterhead.

Rock burst continued in these drives, says Boeckli, which at times damaged both the machine faces and follow-on train equipment. Though no injuries were caused, it was necessary to add more rock bolting and mesh to provide protection for the miners. SuperSwellex bolts were a big help.

Due to the delays, there have been various revisions to the project to speed up work, the largest being overlapping the excavation of the two TBM drives and tunnel lining sequences of the multifunction station, originally scheduled to be executed sequentially.

The logistical systems installed at the beginning have proved their worth in coping with the numerous and extensive changes.

First is the rail system itself, which is used both for spoil removal and concrete and other material supply. For the TBM drives, everything comes from the Bodio portal where there is room for a bigger site installation than at Faido. The spoil handling systems, operated under separate contracts are there, as are the contractor's batching plants and other materials.

That means long journey times for the trains, more than an hour in the first

section and during the second drives up two and half hours to cover the 30km to the machines.

There are clearly many trains underway at a time, which meant providing a huge fleet. "There are 70 Schoma locomotives and 380 Muhlhauser wagons," says Boeckli, "with the loading and handling areas at the portal to match, as well as workshops and maintenance." Two tracks in each bore brought the total track length to over 300km.

With multiple trains entering, leaving and passing each other in the tunnel, the normal manual switching and control would have been impossible. Instead TAT turned to the professionals, using a control system based on Tiefenbach technology and the same software as Swiss Federal Railways. A control centre with radio and four computer displays showing train and point positions, with remote switch operation, was run for it by subcontractor VT Verkehrs- und Industrietechnik.

"They coordinated with a team of our own logistics planners who worked out precisely what deliveries were needed, when and where," says Bockli.

Coordination was particularly important because of other works in side the tunnels. Much of this was done by the two "worms," great multipurpose train units following on

the TBMs by some hundreds of metres.

"The unit did every from cleaning and checking the tunnel and track, checking and smoothing the profile, installing waterproof membrane, drainage and ducting and then finally concreting the inner lining with two 12m long shuttering sections and a follow on curing section.

A number of other special units were built later for re-profiling work ahead of the worms as well, in order to accelerate the work and catch up the delays.

The presence of the various machines and building sites added to the logistic complexities and in the later stages of the project a number of obliquely angled cross passages were excavated to allow trains to pass from one tunnel to the other and back.

"But we have managed to keep everything running," says Bockli.

The large number of worksites also demands significant cooling, particularly as the rock temperature under the very high cover was estimated to be capable of reaching 55 degrees C, though to date it has only reached 46 degrees. As on the other contracts, it is technically only possible to cool at the work locations.

A system for cooling began with a possibly optimistic 14MW installation but had to be beefed up to 21MW due to changed rock temperature estimation and overlap of multiple jobsites underground.

Now that drives are finished, the work will continue on finishing the tunnels. This will take until 2014, although one section has already been completed at Bodio and is the first to be fitted with permanent track and signalling. ■

# Fans, pistons and airtight pressure doors

Cooling and ventilation has been critical for the Gotthard construction. It is essential for daily operation in the future and particularly for the safety regime

**L**ike a living organism, the Gotthard tunnel must “breathe” constantly once it is in operation. Airflow is vital for train movements, maintenance and for emergency safety.

People need air of course but the crucial problem is the rock heat of up to 50 degrees C combined with equipment and train generated heat. “In air above 40 degrees C, the trains could have problems operating,” says Simon Peggs, AlpTransit Gotthard project manager for the mechanical systems.

During construction, forced ventilation has been used with large fans pushing in

fresh air through ducts, and used air and pollutants exhausting along the tunnel bores. In later stages the twin bores have helped make air circuits with the cross-passages sealed with temporary airlocks.

Cooling was done by separate cold water systems feeding cooler units but in the operating phase the airflow will remove the heat.

Huge ventilation systems will be sited at the two multifunction stations, each one-third of the way along the tunnel. Fans will have a 200m<sup>3</sup>/sec capacity at each, with a reserve fan giving 100 per cent redundancy.

But these systems will mainly be on standby, with the fans gently idling at around 35m<sup>3</sup>/sec. Trains themselves will create the flows, forcing air along the tunnels by the piston effect as they pass every five minutes. If there is a schedule break, the generated airflow will persist for a short while.

“To achieve this, the main bores must be isolated,” says Peggs. Each of the 178 cross-passages is sealed by massive doors at each end, no easy task given

**Right:** Simon Peggs, AlpTransit Gotthard project manager for the mechanical systems

**Below:** Cross passages require individual fan ventilation from the main tunnel to keep important equipment cooled;

that the high-speed trains generate a 10t pressure wave. “As they pass, the doors must resist a 10t negative pressure too” he says.

But the doors must also glide open quickly in an emergency even for ‘a frail old grandmother’. Developing the right equipment for this has needed ‘quite a bit of engineering development’ with the five manufacturers who tendered for the supply contract.

The multifunction station fans will be triggered if temperatures in the tunnel rise too much. This will be on one side only, venting the last third of the tunnel which is where the gradually heating air may pass a critical 35 degrees C threshold in summer.

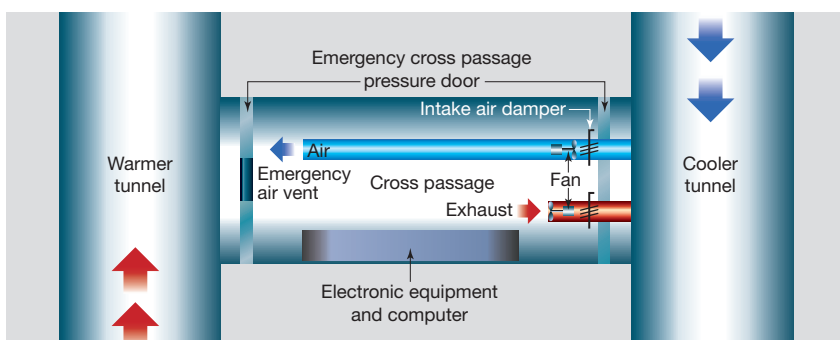
But the fans’ main function is to vent the tunnels during routine maintenance and especially for emergencies.

Maintenance will be done weekly, on Saturdays in one bore and Sundays the other. “The tunnel will be divided into two-thirds and one-third using a large mobile ‘door’ mounted on a locomotive,” explains Peggs. Air from one station will blow into each part, exhausting at the portal.

The division is needed because a maximum 200m<sup>3</sup>/sec flow is possible. “Even that creates a 4m/sec wind for the crews to be working in”. It will be quite a challenge for the federal rail, who will operate the tunnels, to find crews.

For emergencies, the ventilation is linked to several possible scenarios, mostly to deal with fire on a train. If something does happen, the driver will keep the train running a maximum of one third of the tunnel length, to either an exit portal or one of the multi-function stations. Freight trains will be instructed to keep going until exiting the tunnel.

The ventilation system will blow air into the emergency concourses at the multifunction stations to prepare them. The concourses are connected to the main tunnel by lateral passages every 86m (see main diagram) and the air pressure will



**Right, top:** The tunnel will be only fan ventilated during rail track installation and maintenance periods at weekends or in emergencies

**Right, middle and bottom:** Forced ventilation will be used in critical conditions in the last third of the tunnels where there is a chance of the threshold temperature to be exceeded

ensure smoke does not enter the station as passengers evacuate.

Inside the main tunnel, ceiling vents at the station location will extract any smoke from positions between each of the connection passages. The hot gases will be exhausted via a separate duct tunnel to the second shaft at Sedrun and then along an exit vent tunnel to the mountainside above, or along a partitioned vent system at the Faido access tunnel.

Passengers will leave the concourse meanwhile along a connecting passage to the emergency station serving the other, unaffected, tunnel. Here they will be picked up.

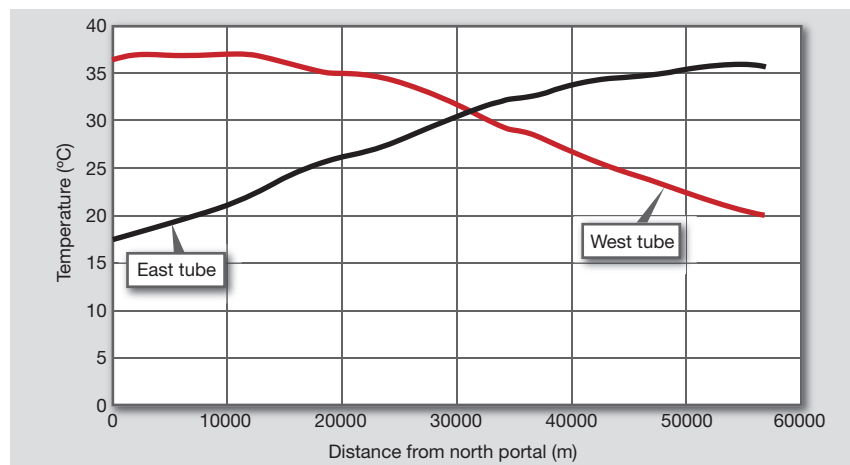
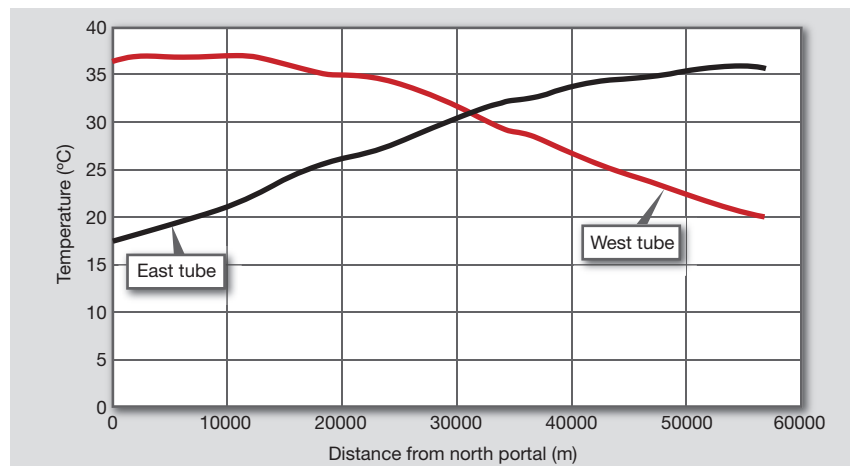
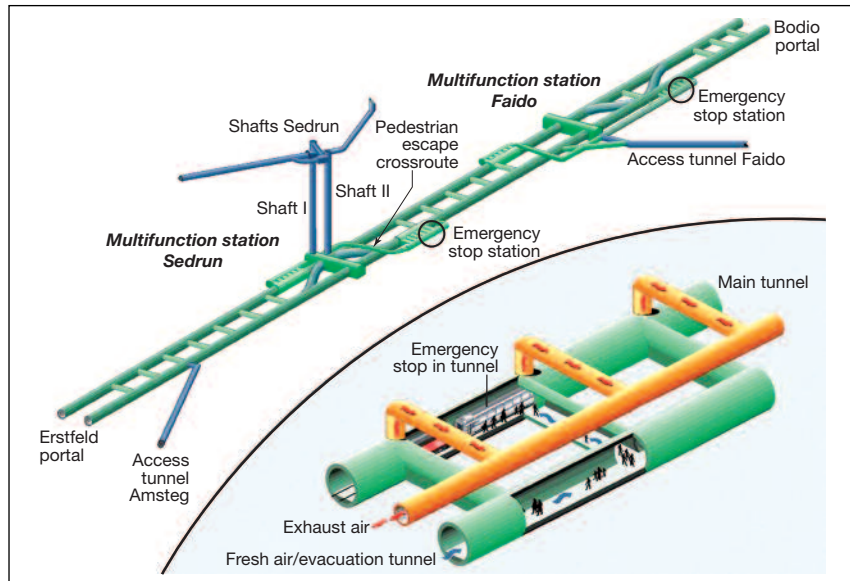
In the event of a disaster preventing the train from reaching the MFS the main cross-passages will provide the escape route. In this case the ventilation will operate differently. "All the air will be blown into the unaffected tunnel to put it into overpressure to blow smoke and air back when an escape route through a cross passage is opened" explains Peggs. "Additional longitudinal fans will operate at the tunnel ends too, to maintain overpressure at the portals."

These scenarios have been kept simple, he says, to avoid confusion in a disaster. "We do not want the danger of a 'Mont Blanc' effect where efforts to blow air in to help people, actually fed the fire."

There is further complication for the ventilation. Each cross-passage must have its own independent ventilation fan systems because the sealing doors prevent airflow in normal operation. There is electronic, signalling and power equipment in every one that has to be kept cooled.

Air will be drawn from one of the main tunnels by small fans to circulate the cross-passage space and then back to an exhaust fan into the same tunnel bore. The air flow inlet will switch sides about half way along the tunnels, according to the direction of the main bore, each of which is cool close to its entrance and hot at the exit.

In an emergency, the cross-passage ventilation must guarantee a 90-minute workability for the equipment inside the passages. A complex scenario operates to open vents on the untouched side of the




cross-passage if the fire is on the usual ventilation inlet side.

Further complications arise if an emergency occurs while maintenance is underway, particularly if the deep shafts at Sedrun are being inspected or worked upon. Special shaft elevator work platforms

with vent gaps have been needed to ensure they are not pistoned down the shaft if the fans should turn on.

"However there is a sequencing procedure to draw out the platform first before the fans turn on," says Peggs "so that should not happen at all." ■



# 52.2 mm

The length of a Monarch caterpillar „Danaus plexippus“ after 10 days and the vertical offset of the laser from the line of site of the theodolite used in VMT’s tunnel guidance systems.



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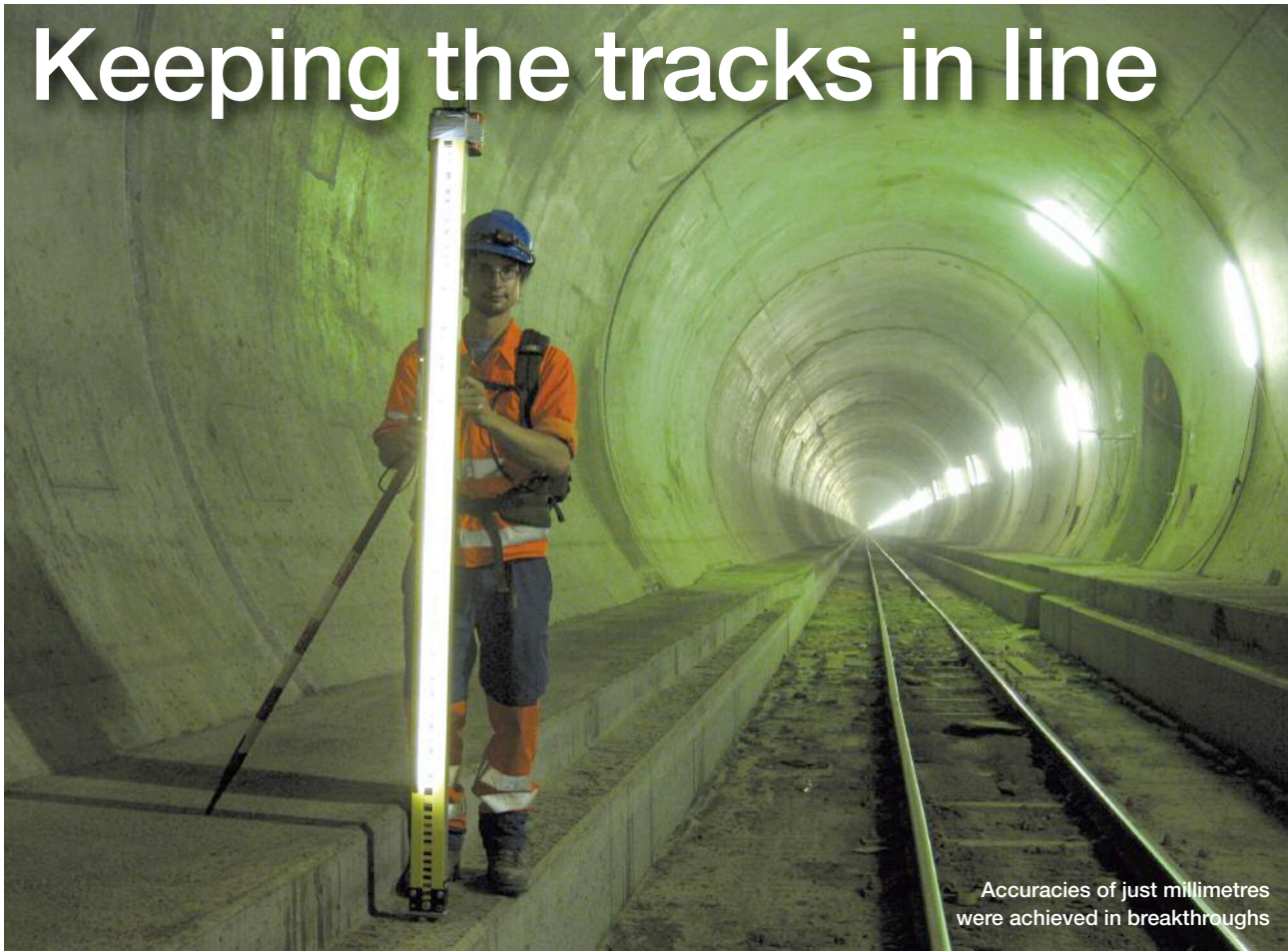
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# Keeping the tracks in line



Accuracies of just millimetres were achieved in breakthroughs

Keeping the AlpTransit tunnels on line has pushed surveying technique to the limit

“I remember standing 800m down at the bottom of the Sedrun shaft when it was first finished,” says Heinz Ehrbar, AlpTransit chief engineer. “I was thinking about how we meet up with the next sections. In this small deep space how do we even know which direction to go in?”

The answer was found of course and with astonishing accuracy. The final breakthrough from Faido to Sedrun on 15 October was just 80mm off horizontally and 10mm vertically. All the previous breakthroughs in the different sections were also well within an allowable maximum error of 250mm horizontally and 125mm vertically. “They did a fantastic job,” says Ehrbar.

Achieving that tested the limits of modern surveying instruments and the teams using them, both those working daily with the contractors and on the TBMs and the AlpTransit Gotthard’s own small oversight team of four. The client worked

with consultants from the VI-GBT, “Konsortium Vermessung Gotthard-Basistunnel” made up from Grunenfelder und Partner, BSF Swissphoto, Studio Meier and Gisi e Bernasconi.

The Sedrun shaft was one of the major challenges for the survey team led by Adrian Ryf, the head of geomatics at AlpTransit Gotthard. It certainly needed something more than a glance at a compass, which would not work there anyway.

“We had three things to do at Sedrun. One was to transfer coordinates down the long shaft accurately. The second was to determine and maintain direction and the other is to measure the height,” says Ryf.

Contradictorily the team first of all turned to a traditional method, the plumbline. But the modern means of doing this, an “optical plumb,” proved difficult at first because there was fog in the shaft caused by the humidity. The tiny red LED light, which is the target below, could not be seen.

So the traditional physical line was used. But it was a plumb on a grand scale, dropping the full depth of the shaft on three steel wires. Steel plates were used at the

bottom, weighing around 370kg, to form a pendulum bob.

“It had to be left overnight to settle down” says Ryf. The base remained swinging very slowly but averaging the end points gave a centre point, theoretically transferring a coordinate from the top which was measured relative to fixed survey points at the end of the short 1km tunnel above.

**Below:** Adrian Ryf was the survey head for AlpTransit Gotthard



But it did not work precisely. The problem is the Alps themselves, which are such a large mass of rock that they exert a gravitational effect, or to state it another way, they make the earth's shape irregular.

The plumb does not hang straight towards the centre of the earth but anything up to 30mm off line, a big error.

Fortunately says Ryf, there is long experience of this issue in Switzerland and a big database of the geophysical characteristics of the mountains. The Swiss Federal Office of Topography even sells a specialist software to allow the correct position to be interpolated. The accuracy achieved on Gotthard has helped confirm the accuracy of that database, too, he says.

Once the physical plumb was complete, it was found that the ventilation could be reversed to achieve clear air in the shaft, allowing the optical method to be used too. "Results were very similar," says Ryf.

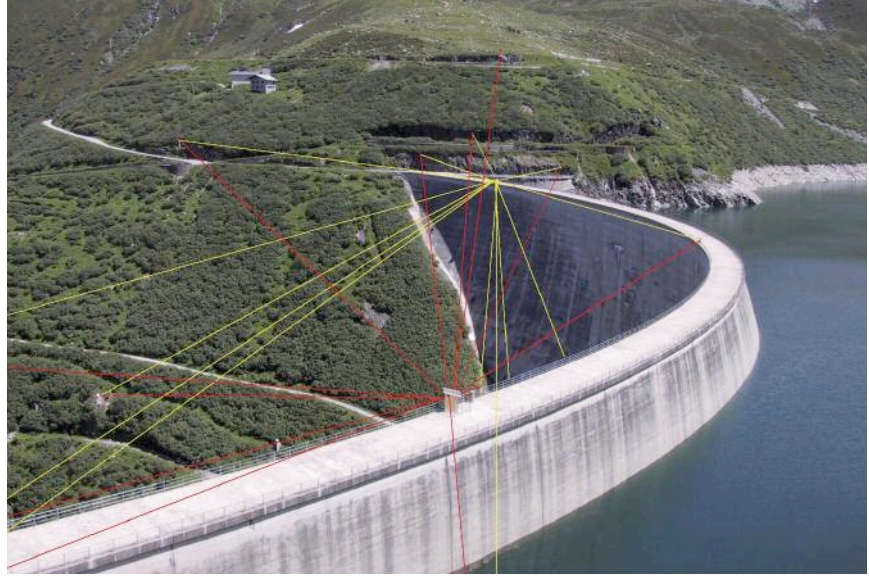
But the optical method also needs the corrections calculated as, just as with any other surveying instrument, work begins by calibrating it against a vertical plumb.

In the second task at the shaft, obtaining the depth, things were a little easier says Ryf, since modern optical distance measurement is highly accurate and it was necessary only to measure vertically.

But then came the question of direction for the tunnels. To find that from plumbline transfers would need a longer distance between two points than the 8m or so at the bottom of the shaft, or even the 35m that became usable once a second shaft had been finished.

Instead the team turned to the latest gyroscopic direction finding instruments. These were first used for checks in the Channel Tunnel but have improved since.

**Below: Readings in the tunnels had to be corrected for gravity effects - Photo Swissphoto**



**Above: These concrete arch dams above the tunnel line were constantly monitored - Photo Swissphoto**

"Inside a vacuum a small gyroscope spins at a very high speed, around 20,000rpm. Its rotation axis will align with that of the earth, which gives you a very accurate direction." Though again, he points out, gravitational corrections must be run.

Such instruments are not much bigger than a total station, he says, though they are expensive at around EUR 120,000 (USD 167,000). Instruments were used that are owned by the ETH Zurich Technical University, where Ryf was a former lecturer, and one at Munich University.

The gyroscopes were also used to correct readings along the tunnel made with total stations, primarily, since this is Switzerland, Leica instruments. An error noted on the Channel Tunnel was that of small refraction effects near the tunnel walls, caused in that case by the colder air layer there and noticeable only on very long distances.

Here the rock was hot but just in case measurements were regularly taken in the centre of the tunnel "when it was clear of activity such as during holidays," says Ryf.

An even newer technology, the Inertial Measurement Unit, was also tried out. "The IMU is a very accurate version of the orientation detector in the latest iPhone. It

detects and measures accelerations and rotations. This was done for the first time to this level of accuracy in civilian application, though the military have used it." It requires some complex calculation, however, he says.

Outside the tunnel a permanent network of reference points set up in 1995, and used for the tunnel survey, was rechecked in 2005 by the client team, using simultaneous GPS measures at 28 separate points. Leica supplied the GPS systems though Trimble is also used.

The exercise was needed not only to apply the latest technology and the better accuracy it could achieve but to see if tectonic movements of the Alps had changed any points. The Alps move around 1mm annually and relative movements between its parts can also have an impact.

Results showed the reference points to be sound and unchanged.

Another task for the survey team outside has been to monitor three significant reservoirs lying close above the route of the tunnel. Settlement effects or rock water loss could endanger the structures, even at the great depths of the tunnel.

"We installed an automated system on the dams and in their valleys with GPS and total stations" says Ryf. Each night the total stations have taken measurements from prisms at the side of the valley to check for any convergence or divergence. A telephone link sends it back to the consultant BSF Swissphoto Regensdorf near Zurich, where the data is processed automatically and sent to AlpTransit, which operates a special website for the monitoring.

"We have collected an enormous amount of data since 2001," he says. Researchers are finding this useful though so far no dangerous movement has been found.

One other task carried out by the surveyors has been to establish a series of accurate survey reference points in the tunnels once they are lined. Set every 50m on both sides of the tunnel and accurate to 1mm, they provide a reference for the trackwork, which is just beginning. ■

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# A mountain of spoil from inside the mountains



The world's longest tunnel has produced a massive quantity of spoil to be disposed in tiny mountain valleys

**T**he Great Pyramid of Cheops could be rebuilt five times over with the quantity of spoil produced from the Gotthard tunnels, the AlpTransit client likes to point out, to indicate the magnitude of its disposal task. Total volume of spoil was 13.3 million cubic metres, which is about 25Mt.

It was the client's task to remove this, rather than leaving it to the main tunnel contractors. Like the tunnel water processing, it was considered too important and sensitive an issue from the beginning to be otherwise.

"You know of 'A' and 'C' tasks?" says Adrian Wildbolz, who supervised the northern tunnel drives for AlpTransit. "The 'A' jobs get high priority. If you give disposal to the main contractor it is a secondary issue for him. If you award it as a special separate contract, it is the only focus for that contractor, his 'A' job."

Disposal had to be an "A" task because it was a sensitive element in the original

political go-ahead for the Gotthard. Minimum environmental and community impact was decreed both because of general growing environmental consciousness and because of the special circumstances of the mountains, with already limited space on narrow valley floors, even for local roads.

A careful combination of rock recycling and landscaping work was used to full effect to minimise the need for disposal. Tunnellers were also instructed to recycle rock to the maximum for concrete needs. Old extraction pits from other projects were located that could be refilled and landscaped.

All of this had to be done without the use of trucks, says Charly Simmen, a project manager with AlpTransit with special responsibility for the disposal. "Only rail, conveyors or boats were possible."

To achieve this required tight logistical control with most spoil handled only at the main portals, particularly Bodio, which took the greatest amount, some 11Mt. The portal at Erstfeld and tunnel exit at Amsteg

handled another 8Mt between them. At the Sedrun shafts another 4Mt came out and 2Mt at Faido.

A first portion was sent back into the tunnels as aggregate in the concrete for linings and shotcrete, some 22 per cent of the excavated volume, he says. This was doubly beneficial, almost eliminating the need for quarried and imported aggregates.

But to use the excavated material for concrete demanded significant processing of the rock and even some new technology.

To begin with the chips had to be broken down from the (up to) 400mm-long pieces that the TBM cutter wheels flake away from the bore face. An initial crushing had to be done by the contractors inside the tunnel; contracts specified no more than 150mm size pieces to be sent to the portal.

There they were handed over to a specialist contractor running a sequence of crushers to produce the various sizes and grades of aggregate needed for the mixes, from sand to large stones. A laboratory



**Main image, opposite page:** Much of the spoil from Bodio passed through a 3km tunnel by conveyor to a disposal site in the Buzza di Biasca, re-filling an area depleted for aggregate during earlier motorway construction

**Above, clockwise from top left:** Uri Lake restoration using spoil disposal to fill in old gravel extraction lake bed depressions; At Amsteg material was crushed for the Erstfeld site as well, returning there by railway to provide concrete aggregate; Spoil conveyor from the Erstfeld portal to storage area. All photos courtesy of AlpTransit Gotthard

constantly analysed the rock quality.

There was still a problem with the rock chips. Although mostly from hard sound rock, they were too generally too angular for good concrete. The acute angles can suffer stresses which reduce strength.

"We pursued a four year research programme with Zurich Technical University to find a way round this," recounts Simmen. The end point was a new machine, christened the "Hurricane," which used a particular arrangement of conical chambers to tumble the crushed stone fragments sufficiently to round them off.

Aggregate plants with the 'hurricanes' were sited at Amsteg in the north, at the worksite outside the Sedrun shaft tunnel and at the Bodio portal. Plant designs were by specialist consultant Ernst Basler in Zurich.

"To save space the spoil from the later Erstfeld contracts was also crushed at Amsteg, sent by train before returning for use in concrete," says Simmen. "We built temporary rail tracks along the valley for that, next to the existing rail line."

Each of the tunnel access points had its own concrete batching plants. But that still

left a lot of material. Various sites were identified for fill and landscaping, the largest at Biasca near the south portal but in the next valley along. An extraction pit was made when the Gotthard motorway was built in the 1980s and was an ideal site, also restoring the valley profile.

To get there without long truck hauls, a short tunnel was made during early preparation, just big enough to house a conveyor and carry the material some 3km through the hillside to the old workings.

Smaller disposal areas were found in the valley at Faido for the early stage of the multi-function station excavation, though later material also went to Bodio. At Sedrun "we were able to use a small side valley near the village, creating a building platform for housing development later," says Simmen. One area had to stay untouched due to important flora and fauna.

In the north about 2.5Mt of the material was dumped by barge into the top end of the Uri lake, which connects into Lake Lucerne. The apparently vandalous act was actually a carefully-tailored restoration of old gravel workings that had removed

natural river aggregates from the Reuss for nearly a century, leaving 50m deep channels and underwater voids.

"That was causing slips and erosion of the upper lake, which led to flooding and dangers to the road," says Simmen. Now embankments and small lake islands have restored it as a pleasant nature reserve.

These disposal sites took 24 per cent of the material. Much of the remaining spoil, more than half, was sent by train separate contractor 'Oeko-Trans' to produce aggregates for use by third parties. A lot has gone to the Zurich area as fill material for embankments on rail and road development projects. Some material has also gone into the brick making industry.

There is a stubborn 1 per cent left which is contaminated from tunnel oil spills and the like, which is sent to landfill sites.

Finally, on each site, separate contracts were also let for treatment of the drainage water from the tunnels. Tight limits were set on disposal into the rivers at only 1.5 degrees above their ambient level. Since the rivers are never much beyond 10 degrees, this was a significant task. ■

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# Safety and sorrows, Gotthard leads to new practices

Tragically the giant Gotthard project has suffered fatalities during a decade of work. But it has also driven significant safety advances in Swiss tunnelling

**W**hen the tunnellers made their breakthrough on 15 October they were carrying photographs of eight men as they climbed through from behind the TBM cutterhead. They were remembering and commemorating those who have lost their lives in the course of the huge Gotthard excavation.

But despite the tragedy of such fatalities for families and work colleagues particularly, the Gotthard and its sister Lotschberg base tunnel projects have also coincided with a significant increase in the tunnelling safety culture in Switzerland. New measures were developed specifically because of the extraordinary challenges of this projects and applied on them for the first time, and others have emerged partly because of the experiences made in the work.

"In the 1980s and 1990s tunnelling was part of the general construction risk sector for our insurance," says Martin Vogel of Suva, a financially independent body dealing with prevention and insurance of accidents and incorporated under public law in Switzerland.

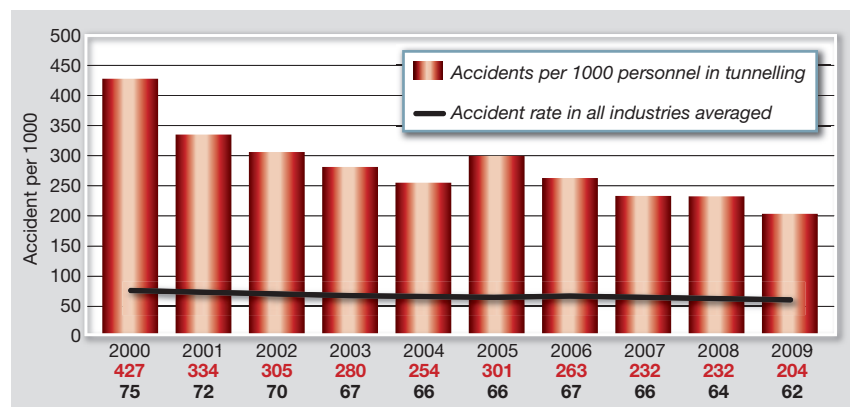
"But the construction industry pressed for separation of the tunnelling risk sector fearing high costs and premiums as the big AlpTransit projects started to gather pace."

This was done, he says, and the figures for the new sector initially reflected the special risks of underground work. The annual accident frequency was running at more than 400 per thousand employees though it must be added that that figure has to be understood in the light of Swiss practice, which is to report every accident such as a minor scratch.

But the accident frequency in tunnelling has been halved in the last 10 years "and is now getting close to the construction industry average," says Vogel.

A large part of the decrease, and a general improvement of health below ground, reflects a new safety culture developed around the AlpTransit works.

Among the most significant safety measures are diesel particulate filters, a ban



**Above:** Tunnelling accidents through the first decade of the 21st century compared to other construction industries

on dry mix shotcrete, mandatory rear cameras on plant for reversing and onboard fire extinguishing systems for locomotives and heavy machinery.

Specifically for the base tunnels, new regulations for work under warm and humid conditions have been introduced for tunnels. A temperature limit of 28 degrees C dry temperature was set, along with limits on allowable humidity, which makes work very exhausting. The limits are part of all the contracts, says Vogel.

Much beyond these temperatures it becomes almost impossible to work. A team of Swiss tunnellers, including Suva, visited South Africa in the 1990s while drawing up the safety concepts to assess conditions in shaft sinking and in gold mines.

"There they allow in certain specialised mine workings a maximum of 30.5 degrees C with very high humidity. But the miners for those areas have to pass stringent medicals. It is only about 10 per cent of the workforce."

The large dimensions of the Swiss tunnel projects and new threshold limits led to an insistence on elimination of diesel particulate exhaust.

"Before, ventilation dilution was used but the air quantities in such long tunnels are not available for this," says Vogel.

But no adequate filters existed.

A special research programme on reduction of diesel-emissions in tunnelling was pursued in the 1990s to develop diesel particulate filters, which was finally successful in the late 1990s. Diesel particulate filters are now mandatory in tunnel construction "and the filters are increasingly common on normal cars and trucks in Europe," says Vogel. They were initially expensive to install, however.

For shotcrete the Swiss industry has traditionally used dry-mix guns that fill the air with cement dust and reduces visibility. The Suva tunnel division drew on Scandinavian experience where wet-mix was introduced earlier. The result is a shift from 90 per cent dry-mix use to 90 per cent wet-mix use not only in Switzerland, but also in Germany and Austria with huge advantages for quality, quantity and health conditions, he says.

Vehicle reversal in tunnels is the greatest source of fatal accidents, he says. Suva introduced mandatory rear cameras on trucks, trains and other machines and he says the incident rate has plunged. Nothing else previously made much impact, he adds. "Audible warnings and beeps get lost in a tunnel where there is a lot of ambient noise and constant sounds from other equipment."

Fires, too, are a critical problem for



**Above:** Miners carried photos of their eight fallen comrades as they made the final breakthrough

tunnels. “Figures from German mining suggested that we had to expect at least one fire from a locomotive every year,” says Vogel. “That is too high and would create a risk we could not tackle.”

It was decided that locomotives be fitted with fire suppression equipment in the engine compartments and the result has been very successful, he says. In the whole time of the project there have only been few fires on the trains and these were contained.

Fire dangers have also seen other measures introduced. In particular there is a hazard from the heat in the tunnels for rescue crews using rebreathers and normal fire protection clothing. The heavy protection worn by firemen becomes a problem precisely because it is an insulator and causes heat retention, which is compounded by the internal heat generated in the lungs by rebreathing apparatus.

Rescue crews needed special training and other lighter equipment is required. At Sedrun there is a special rescue volunteer forces called “Grubenwehr” drawn from the tunnel crews because the local fire service was not available for that purpose.

Other measures for the industry which have been developing include the notion of the “rescue concept.” Rather than imposing specific measures on a contractor for ensuring tunnel miners can be rescued, this insists on a formalised

risk assessment process being undertaken. A fairly long checklist of possible dangers is matched against solutions, with safety measures only having to be taken if a risk is present.

“If a measure is not used this must be declared and a reason given” he says. This flexible method was introduced after examining practice elsewhere he says, such as in Germany “where the rules are strict and detailed but do not give you much scope in finding solutions.”

The major element in rescue provision of rescue chambers in the tunnels with a protected line of air supply and communication to the exterior. They are provisioned with water cooling, emergency air, drinking water and food.

An important issue was that situations should be assessed according to the particular circumstances.

Working on this principle with AlpTransit a number of measures were discussed for example at Sedrun, one of the more difficult project sectors, because it was accessed only by shaft. One issue was the addition of a second access such as a smaller shaft—later enlarged on the contractor’s bid.

“During shaft sinking and excavation of the first cavern safety needed to be able to evacuate the whole shift in one lift in the shaft in the event of flood,” says Vogel.

Suva has also drawn further lessons from incidents on the tunnel, he explains,

particularly analysing the fatalities.

Two of these were early during the shaft sinking in Sedrun, one caused by a drilling rod falling 800m because it has been badly fixed when hauled up and the other by a sudden spoil discharge into a kibble during maintenance work. “An air pressurised cylinder for a shutter holding spoil in a chute was released due to a jam from small stone in the mechanism,” says Vogel.

During later tunnelling at Sedrun an accident with the unloading of muck trucks from the shaft hoisting equipment occurred at the shaft top.

At Amsteg there was an accident due to the use of an improvised system to unwind a cable drum which caused the cable drum to slip sideways.

“There was a bad accident fairly early on with the railway muckout at Bodio,” he says. Here a truck bogie in the middle of a train jumped the switch point during a crossover between two parallel tracks and the rear half of the train continued on the wrong track. “A fully loaded truck with a bogie running on each track was pulled like this along the tunnel and killed two people in the way after the collision with a service train.” He says the cause is not certain yet.

There were no fatal accidents in later years, he says, until 2009 when a staff member was killed while guiding a party of visitors. He was caught at the open door of the personnel transportation car by a steel construction with low clearance.

Vogel hopes all of these experiences will feed into other important projects and the whole tunnelling industry, and that despite the tragedy of their occurrence, will help increase standards in an industry now much improved from the past.

“It is worth remembering that on the first Gotthard high tunnel over 100 years ago, there were 177 deaths in driving a tunnel of 15km,” he says. “Even on the Gotthard road tunnel in the 1970s there 17 fatalities on a similar length of 17km.”

Without understating the tragedy now, he says the figure is on another scale, particularly remembering that the length of tunnels driven is 153km in much deeper conditions.

**The names of the eight men killed are:**

- Andreas Reichardt 23.11.06
- Jacques du Plooy 13.03.01
- Heiko Bujak 03.04.03
- Albert Ginzinger 11.09.03
- Andrea Astorino 21.01.05
- Salvatore Di Benedetto 21.01.05
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# Keeping the timetable on track

Following tunnel breakthrough civils work continues on inner linings and walkways, which complete only in 2014. But focus is already switching to the fit-out of the tunnels

**F**or the last, five-year long phase of the tunnel works the AlpTransit client has decided to put everything into the hands of one consortium, in one huge package contract. It covers signalling, the 16kV train power and normal voltage equipment power supplies, track laying, communications and some other mechanical and electrical work.

"It is the biggest contract we have let at CHF 1.7bn (USD 1.7bn)," says Renzo Simoni, the chief executive officer for AlpTransit since 2007. Equally significant, it is the first essentially turnkey contract on the project, placing all the coordination and organisation of its various parts into the hands of the contractor. The Transtec Gotthard group that won the job against one other major bidder, comprises Alpiq InTec AG, Alcatel-Lucent Schweiz, Thales Rail Signalling Solutions, AlpineBau GmbH, and Balfour Beatty Rail GmbH.

"To manage and synchronise these different elements ourselves would have meant a massive gearing up of staff," says Simoni. "We examined the risk very carefully and concluded this was the right solution."

A major difference to the tunnelling work, adds chief engineer, Heinz Ehrbar, is that there are not the same kind of unknowns as there are with ground formations. Instead the issue will be to keep up with the technology, which in computers, signalling and communications can change very fast. The final operator of the tunnel SBB Swiss Federal Railways, is keen to ensure it has the state-of-the-art when it starts trial runs in 2017.

Currently that means installing the latest ETCS 2 radio-controlled cab display signalling system with its electronic detectors and axle counters and a variety

of radio and telephone systems including GSM-R and GSM-P, thousands of kilometres of cable and fibre optics, computers and the precision catenary wires needed for high speed running.

Transtec began its work with an extended preparation period to plan its methodology and integration. Complete semi-permanent bases have been set up some 5km outside the northern Erstfeld portal and in Biasca in the south, again about 5km from the Bodio portal. Computerised logistic controls are installed in workshops, aggregate and cement stores, and loading bays.

A complex sequence of overlapping operations must cascade through the tunnel, beginning with track laying and with cable installation, communications, overhead catenary work and other

**Below:** The new Biasca worksite and depot for the railway installation. Picture Transtec





**Left, top and bottom:** The multi-wagon concreting train



operations following on behind on the new track. Cross passages must be fitted out with equipment and pressure doors.

The railtrack work illustrates the detailed and disciplined logistical organisation needed to do the work. Transtec has invested in a carefully-designed set of specialised plant and mobile machinery, some completely new, and on a large scale.

Central is a complete concreting train of 24 wagons for pouring the base of the slab track, which is used throughout the tunnel, a total of 115km. Some 39km of ballasted track will be made outside the tunnel.

Aggregate wagons are linked along the train with a conveyor system that brings a carefully tailored mixture of sands, and sized stones, to a concrete batching plant wagon at the forward end of the train. Water wagons and cement wagons also feed their materials into the batcher under computer control using pumps or pneumatic lines. On the most forward wagon finally sits a Putzmeister pump for delivery.

If a batch of concrete is bad when tested, it can be diverted to a waste wagon to prevent disruption of the work. Another wagon has a spare power unit, to ensure work can continue at all times. Only tunnel collapse or other disaster would stop operations.

"We have to be able to work completely self-sufficiently at the end of the track for a 15 hour period," says Thomas Silbermann, the site manager for the trackwork installation group, which is formed from Alpine and Balfour Beatty Rail within the main consortium. He adds that follow-on catenary, signal and other crews from the other companies "would not thank us pushing them back to get out again, breaking their carefully programmed sequences."

Only at night will the train emerge for maintenance and recharging in the depot. However individual tunnel workers from

his team of 85 and his four supervisors will be able to move in and out past the other crews.

The concrete train is needed for a few days at the end of a long tightly timed cycle of works lasting 20 days. "In that time we do a section between 1,680m and 2,160m depending on conditions," says Silbermann.

First day brings a wagon with steel rail sections to the finished track end. Rail lengths of 120m are pulled onto the tunnel floor by a rubber-tyred machine, the Sause, which runs back for more and then butt welds them with a unit on a hydraulic arm. The tracks are supported with temporary fixings and the train runs forwards for a repeat.

On the second day a specially designed wagon arrives with the small sleeper blocks that support the track one on each side. They are made by local firm Tribeton and are fitted with rubber anti-vibration slippers. A fitted crane can pick up 60 blocks at a time and drop them through a slot into the centre of the track.

"Fourteen wagons on the train have all the blocks we need and other materials like shuttering are carried on three more wagons in front," says Silbermann.

Two machines now run in and distribute the blocks. The first lifts the rail to its working level, the second positions the blocks along the rail and then twists them into the correct position for fixing in a 45 second automated sequence. The machine was developed especially for the project. "The blocks are then fixed to the rail, the only part we do by hand," says Silbermann.

A third machine put the rails onto a support frame and positions them to a rough accuracy of 15mm. Adjustments then follow to increase the accuracy. Shuttering is now added for the premade drainage ducts. Crack inducers are installed to ensure even contraction joints in the final rail slab, and their supports are greased to prevent sticking by the concrete, and

protective covers put over the rails.

A third and final measuring stage with a laser surveying tool now performs a final alignment check on the inner edge of the tracks to produce the necessary 0.1mm accuracy. Specialist consultants Grunder from Switzerland and Intermetric from Germany do the measurements.

Three people, the track superintendent, the quality controller and the survey engineer now have to sign off the section against a 50 point checklist. "And then it is out of bounds," says Silbermann.

This whole process has taken six days.

Now the 480m long concrete train arrives for the next 10 days of work, though its 1,700t weight must remain on the previously completed rail section. A small fleet of yet more specialist machines comes into play.

First is a rubber-tyred mobile concrete shuttle-skip which carries 5t loads from the pump to a set of other machines waiting at the end of the precious day's casting. All run on the two walkways along the side to stay clear of the rails heading slowly towards the concrete train.

Here it offloads the concrete into a hopper on the placing machine which pours the concrete around the rails and their sleeper blocks. Three vibrator units work the two sides and the centre.

"The concrete is very controllable because it only flows when you put in energy," explains Silbermann. "We did some expensive experiments for nearly a year to get that mix right."

Behind the placer follows a machine like an ancient rowing galley, with a small set of platforms from each of which a skilled worker trowels a section of the concrete surface to smooth it. Behind that a chemical curing membrane is sprayed on, a particularly important finish in the Gotthard because of the rock temperatures. Ventilation systems create a continuous wind in the tunnels which would quickly dry an unprotected surface.

Curing demands another three days for the slab and its track to bear the loads for the next cycle to go ahead.

This sequencing will continue until the first section is finished, a 16km length of tunnel to Faido. The entire crew and its equipment then moves north to work on the finished sections at Amsteg and Estfeld, and then back and forth as and when the civils contractors hand over their finished lined tunnels.

Test runs begin in 2017. ■



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# Keeping perspective

AlpTransit has meant construction management on a new scale for the Swiss tunnelling sector

**A**s well as stretching technical and logistical capacities, the Gotthard project has also confronted the Swiss tunnelling sector with management and contractual issues on a new scale. Even for a country well used to boring through big mountains, the size and time span of the major works has been unprecedented.

"We are not used to work lasting more than three to four years perhaps. Contracts lasting ten years and more present all kinds of new challenges," says AlpTransit chief engineer Heinz Ehrbar, "because how can you know at the beginning what the conditions will be a decade later?"

Substantial changes have been needed as work got into its stride. Uppermost of course have been the actual conditions of the ground, which are always unexpected in tunnelling. But in the Gotthard these things were written on a very large and sometimes expensive scale. Civils costs have risen from CHF 5.4bn (USD 5.4bn) in 1998 to CHF 7.9bn (USD 7.9bn) now. Timescales have been affected too with an original opening of the tunnel for 2015.

The completely unexpected faulted and squeezing ground at the Faido access and its impact on the excavation of the southern multi-function station was a significant issue that required major changes, including a redesign of the complex crossover tunnels to move them into better ground, and therefore complex changes in the contracts. Long time overruns were one result, offset to some extent by acceleration measures.

Not just the direct contractor for the works was impacted but the consortium building the adjacent tunnel section to the north (Sedrun), where ironically the bad ground had been most anticipated, and progress was in fact far better. South headings there were extended in length to compensate for the delays at Faido. Some provision for this was already included in the contracts but additional sections were eventually negotiated.

Though additional work is a "bonus" it also brings its difficulties on the contractor's side, says Jakob Lehner from the Transco-Sedrun contractor group. "If your machinery

has been selected for a certain capacity it may not be ready for the additional wear and demands of a longer tunnel."

Rock conditions are not the only unknowns however, changes in social and political outlook have their effect too; one with a major impact has been the safety of tunnels in fire, which has become a higher priority after the Mont Blanc and other fire disasters at the turn of the century.

At Gotthard, the Swiss government responded to public concern by imposing new requirements for the ventilation and smoke systems at the emergency stop multi-function stations, requiring design changes and revisions.

Environmental issues and green politics have also grown in significance since the project was first agreed. While these are a large part of its *raison d'être* they also affected discussions on the location of works. Delays at the northern Erstfeld portal were caused by objections of this kind, which also produced design change.

"Such things are not cheap," points out Adrian Wildbolz, the AlpTransit project supervisor for the northern works.

Like most of the AlpTransit engineers he says that a "spirit of Swiss compromise," has prevailed largely in the work. For his own part he says that an attitude of working through problems as they happen and making agreements as far as possible now, "rather than years afterwards when the details are difficult to recall," has kept the northern contracts moving smoothly.

Bigger issues faced the other contracts of course, but Ehrbar says that he is impressed that however difficult things have been for contractors, designers, the client and the workforce, "the work has always continued. That was very excellent behaviour of the contractors, that we could work together and find solutions."

An important element has been the unit price contract system in Switzerland, he believes, with price set by the contractor and a bill of quantities. Contracts also were based on the use of the Swiss codes "almost without modification." A central principle is that the ground "belongs" to the client, who has to take the risk for it or make very clear what risk

is being handed over.

One issue that was confronted, say most of those involved, was the cultural difference between consortium members, with a very different attitude to claims and negotiations apparent sometimes. The Swiss contractors, who took a lead role in each grouping, tend to be more patient before turning to lawyers or accountants, it is agreed.

This was as much an issue within the contractors as it was outside, says Olivier Boeckli and it took a while for the disparate firms from Austria, Germany, Italy and Switzerland to settle in. In the TAT group conscious efforts were made to integrate the workforce particularly, he says, with mixed nationalities in the different work groups. "We even developed our own sub-language on site."

Cultural differences were apparent, says Renzo Simoni, AlpTransit Gotthard CEO, though he says relations with the contractors have generally been good "and always very professional." A series of senior management meetings with contractors are held at six monthly intervals.

Simoni sits at the top 140 staff including local management teams, in particular sector management and the headquarters team in Lucerne. Through this client structure there was an agreed path for escalating any issues, beginning with best efforts to resolve matters at the local level and then upwards via the chief engineer to eventually the CEO.

Civils work continues and particularly on the Sedrun and Bodio/Faido contracts there are still a lot of issues to discuss, says Ehrbar. Meanwhile the latest stage of the work has changed tack. For the huge logistical complexity of the track, communication, electrical and signalling installation, a single huge contract has been let that offsets the risk of integrating the works onto the contractor, says Simoni.

A final element of his team's task will be an 18-month commissioning and test period for the new systems. "A first stage will be on our side and then we will hand over in 2017 to the Swiss Federal Railway for their tests while we collaborate."

Then, he says, the AlpTransit Gotthard will be wound up. Job done. ■

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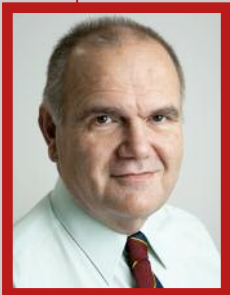
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