AlpTransit

In 1994 the Swiss voted an alpine protection article into their constitution, forbidding the expansion of road capacity in alpine regions. This forced the government to shift heavy goods traffic from road to rail.

To accommodate this, voters approved the "Alptransit" project to build new tunnels through the Gotthard and the Lötschberg.
**Reasons for the Base Tunnels**

**Increasing Population Demands & Commercial Traffic**
- The Gotthard Road Tunnel is the main north-south route through the Alps, between Switzerland and Italy.
- 18,000 vehicles/day pass through the Gotthard Road Tunnel.

**Safety**
Gotthard Road Tunnel Fire (2001) - 11 people killed

**Pollution**
Drivers going through the Gotthard Road Tunnel inhale as many pollutants as if they smoked up to eight cigarettes.

---

**AlpTransit Base Tunnels**

- **Future passenger trains**
  - Euronity (TGV, ICE, trin trains)
  - Minimum speed: 220-250 km/h
  - Seating capacity: 700-800
  - Maximum length: 400 m

- **Rolling road**
  - Maximum speed: 120 km/h
  - Maximum loaded tonnage: 2000-4000 tons
  - Maximum length: 350-1500 m

---

**New Line vs Current Line**

<table>
<thead>
<tr>
<th>Current Line</th>
<th>New Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abtswil/Brig (km):</td>
<td>96</td>
</tr>
<tr>
<td>Main tunnel (km):</td>
<td>15</td>
</tr>
<tr>
<td>Culmination point (m):</td>
<td>1151</td>
</tr>
<tr>
<td>Gradient (°):</td>
<td>26</td>
</tr>
<tr>
<td>Goods (trains/day):</td>
<td>120</td>
</tr>
<tr>
<td>Goods (10³ tons/year):</td>
<td>20</td>
</tr>
<tr>
<td>IC Zürich-Milano:</td>
<td>48,10</td>
</tr>
</tbody>
</table>
Tunnelling & Geology – The Swiss Base Tunnels

World’s Longest Transportation Tunnels

<table>
<thead>
<tr>
<th>Tunnel</th>
<th>Length (km)</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gotthard Base (CH)</td>
<td>57.1</td>
<td>2018*</td>
</tr>
<tr>
<td>Brenner Base (AU)</td>
<td>55.4</td>
<td>2025</td>
</tr>
<tr>
<td>Seikkan (Japan)</td>
<td>53.9</td>
<td>1988</td>
</tr>
<tr>
<td>Chunnel (ENG-FR)</td>
<td>50.5</td>
<td>1994</td>
</tr>
<tr>
<td>Loetschberg (CH)</td>
<td>34.6</td>
<td>2007</td>
</tr>
</tbody>
</table>

#30 Mount MacDonald (CAN) @ 14.6 km
#43 New Cascade (USA) @ 12.5 km
Gotthard Road Tunnel (CH) = 16.9 km

Canada = 5 rail tunnels > 2 km
USA = 4 rail tunnels > 2 km
Switzerland = 42 rail tunnels > 2 km

Tunnel Length

<table>
<thead>
<tr>
<th>Tunnel</th>
<th>Length (km)</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gotthard Base (CH)</td>
<td>57.1</td>
<td>2017*</td>
</tr>
<tr>
<td>Brenner Base (AU)</td>
<td>55.4</td>
<td>2025</td>
</tr>
<tr>
<td>Seikkan (Japan)</td>
<td>53.9</td>
<td>1988</td>
</tr>
<tr>
<td>Chunnel (ENG-FR)</td>
<td>50.5</td>
<td>1994</td>
</tr>
<tr>
<td>Loetschberg (CH)</td>
<td>34.6</td>
<td>2007</td>
</tr>
</tbody>
</table>

World’s Longest Transportation Tunnels

Financing:
- 10% Oil Tax
- 15% Loans
- 55% Heavy Vehicle Tax
- 20% 1% increase in VAT

COST:
- 1998: $7.2 Billion
- 2007: $12.3 Billion
- 1998: $3.2 Billion
- 2007: $4.3 Billion

2017

2020

$23 Billion for entire project
Lötschberg Base Tunnel

- Length = 34.6 km
- Total tunnel system = 88.1 km
- Excavated material = 16 million tonnes

Geological Challenges: Lötschberg Base Tunnel

- **Buried Valleys**: burial is the consequence of glacial down cutting and alluvial deposition. Buried valleys are a major concern in tunnelling as they are often deep (!!), with unknown thicknesses, and filled with water saturated sediments under high water pressures.

  The path of the Lötschberg passed under the Gästern Valley, 200 m below the valley floor. It was estimated that the alluvial sediments extended 100 m below surface leaving 100 m of strong limestone to form the roof of the tunnel.

  In actuality, the buried valley reached depths of more than 185 m. By July 24, 1908, the tunnel had advanced such that only a thin wall of rock divided the working-face from the buried valley. Within seconds of that morning’s blast, 40,000m³ of water saturated sediments swept into the tunnel killing 25 men and filling the tunnel for a distance 1.25 km.
Geological Challenges: Lötschberg Base Tunnel

Karst:
Given the porous nature of karst, large volumes of water and a high risk of water ingress was expected over a section about 3 km long. It was constantly necessary to carry out preliminary boring in order to discover whether any large, water-filled karst sink-holes might endanger the tunnel driving operations.
Gotthard Base Tunnel

- Length: 57 km
- Sedrun shaft: 800 m
- Pillar: 40 m width
- Excavated material: 24 M tonnes
The first Gotthard rail tunnel was constructed between 1872-1882, and cut the travel time from Zurich to Milan from 27 to 5.5 hours. However, 310 men died and 877 were incapacitated during construction of the 14.9 km tunnel. Numerable challenges and harsh conditions were encountered, many of which were augmented by the equally harsh contract signed by the tunnel designer Louis Favre.
Geotechnical Challenges: Known Knowns

Brittle Fault Zones

Zangerl et al. (2006)

Brittle Fault Zones - Water Inflows

Loew et al. (2000)

Fault zones may form highly permeable conduits for groundwater, leading to tunnel inflows. Encountering large quantities of water may lead to flooding of the excavation, especially if there is no outlet for the water to drain to.
Brittle Fault Zones - Weak Ground

Granitic Fault Rocks Aar Massif \( (\sigma_3=5\text{MPa}) \)

Brittle Fault Zones - Ground Support
**Amsteg (June 2005) - West TBM**

West TBM crosses hydrothermally altered rock adjacent to fault zone, encounters flows of 2-3 l/s that flushes loose material into the cutter head.

5 month delay, $10 million cost.

**Geotechnical Challenges: Known Knowns**

Squeezing Ground - Tavetsch Massif

Squeezing ground refers to weak, plastic rock material which displaces into the tunnel excavation under the action of gravity and induced stresses. This squeezing action may result in damage/failure to the ground support system, or require the costly re-excavation of the tunnel section.
Geotechnical Challenges: Squeezing Ground

Ehrbar & Pfenninger (1999)

Squeezing Ground Support

Fabbri (2004)
Geotechnical Challenges: Known Unknowns

Where ground possesses the ability to flow freely (i.e. "running ground"), for example with water-saturated cohesionless materials, then special support and control difficulties can arise.

Sugar-grained dolomites (granular & cohesionless).

Geotechnical Challenges: Running Ground

Sugar-grained dolomites (granular & cohesionless).
**Geotechnical Challenges: Running Ground**

The tunnel will cross the Triassic Piora Zone, a highly weathered and fractured aquifer under high hydraulic pressure. Based on exploratory drilling, it was found that the tunnel will pass ~250 meters below the base of the aquifer through unweathered and unfractured dolomite/anhydrite-sequences.

Considered the greatest geological risk to the feasibility and success of the tunnel project, in Nov. 2008 the TBM passed safely through the Piora.

**Geotechnical Challenges: Known Unknowns**

Rockbursts involve sudden releases of stored strain energy through the failure of strong rock. They manifest themselves through the sudden ejection of rock into the excavation. Rockbursting potential is of special concern in cases of deep tunnelling where high stress concentrations form due to overburden loads or tectonic activity.
Stress-Controlled Failure & Stress Path

- Stress Concentration
- Unstable
- Stable
- In-Situ Stress
- Stress Path
- Relaxation
- Wedge

Kaiser et al. (2000)

High Overburden - Spalling & Rock Bursting

- High Overburden - Spalling & Rock Bursting
- 2.4 M≤ - Mar. 25, 2006
- 1.6 M≤ - Nov. 6, 2006

Boer et al. (2007)
Geotechnical Challenges - Unknown Unknowns

Subhorizontal Faults

Faido-Bodio: "Unexpected" Faults

Faido-Bodio: "Unexpected" Faults

Vorschau der Störzone Trim 3221, 11.09.2003
Störzone, unterer und oberer Horizont
Stand der Arbeiten 29.09.2003, 06:00

Benzonigo, (2007)
The total delay for passing through these faults along this section: ... one year.

Similar ground conditions (i.e., unexpected faults) at the Faido multipurpose cross-over station were responsible for a further 2-year delay and was over budget by more than 200%.
Faido-Bodio: “Unexpected” Faults

“Unexpected” Subsidence in Crystalline Rock

Sure... when cows fly!
"Unexpected" Subsidence in Crystalline Rock

Zangerl et al. (2008)

800 m
1.5 km
"Unexpected" Subsidence in Crystalline Rock

Fluid pressure change

Effective normal stress

Fracture normal deformation

Hydraulic aperture

Fracture fluid flow

\[ \Delta \sigma_n' = \Delta \sigma_n - \alpha_n \Delta p \]

- Normal deformation (i.e. closure)
- Dilation due to shear
- "Poisson ratio" effect

\( \sigma_n \) is a constant

Zangerl et al. (2008)

"Unexpected" Subsidence in Crystalline Rock

Vertical displacement (m)

Regions of increased shear displacement

Discontinuity pattern

Maximum subsidence

Shear displacement in the discontinuity pattern between 1 and 2 km

Zangerl et al. (2008)
“Unexpected” Subsidence in Crystalline Rock

Grouting of fault zone with 13 l/s inflow, near Nalps Dam.

Hodder test site. Pressure records from precise scientific gauges.
More than 13 million m³ of waste rock will be generated, leading to environmental issues as to where to put it. At the same time, the extraction of gravel resources for concrete in the Swiss midlands is becoming more difficult. The solution, therefore, was to specially break, sort & wash the waste rock so that it could be used for concrete aggregate.

Given that tunnel overburden will exceed 2000m, temperatures as high as 45°C are projected. In addition, silicosis, an incurable disease of the lungs, caused by the unprotected respiration of quartz dust presents a potential hazard to workers. Ventilation designs must account for both factors to ensure worker safety.
Lecture References


