TBM Drives at the Gotthard Base Tunnel

Challenges in the Faido section

Thomas Jesel, MSc, Amberg Engineering AG
<table>
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<tr>
<th><strong>Project Main Information</strong></th>
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<tr>
<td><strong>Client</strong></td>
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<tr>
<td><strong>Location</strong></td>
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<td><strong>Design Level</strong></td>
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<tr>
<td><strong>Design Joint Venture</strong></td>
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</tbody>
</table>
| **Project Phases & Design Schedule** | Design 1990-2016  
Construction 1993-2016  
Commissioning 2017 |
<p>| <strong>Design Costs</strong>            | 485 Mio. CHF (part of AE: 165 Mio. CHF) |
| <strong>Total Project Costs</strong>     | 12.2 billion CHF              |</p>
<table>
<thead>
<tr>
<th>Design Responsibilities</th>
<th>Details</th>
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<tr>
<td>Preliminary Design</td>
<td>Amberg within JV, responsible for the whole tunnel itself</td>
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<td>Basic Design</td>
<td>Amberg within JV, responsible for the whole tunnel itself</td>
</tr>
<tr>
<td>Detailed Design</td>
<td>Amberg within JV, responsible for the Faido section</td>
</tr>
<tr>
<td>Tender Design</td>
<td>Amberg within JV, responsible for the Faido section</td>
</tr>
<tr>
<td>Assistance on Site</td>
<td>Amberg within JV, responsible for Bodio, Faido and partially Sedrun</td>
</tr>
<tr>
<td>Site Supervision</td>
<td>Amberg within JV, mainly Faido but also Bodio and Sedrun</td>
</tr>
</tbody>
</table>
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Gotthard Base Tunnel, www.alptransit.ch

TBM Drives at the Gotthard Base Tunnel

29.8.2017
Excavation method
TBM

- 4 Herrenknecht TBM
- Open gripper shield

Length
- TBM: 26 m
- Back-up: 450 m

Cutter head
- Diameter: 9.43 m
- Shifted, max: 9.53 m
- Weight: 240 t

Discs:
- Number: 66
- Diameter: 17”
Experience Faido

- Cutter head wear
- Water inflow
- Rock burst
- Squeezing rock
- Blocked TBM
- Excavation rates
Cutter head wear I

- Abrasivity with Cherchar index
- Tender design: CAI 2.8
- Medelser Granite: CAI 4.4
- Lucomagno Gneiss: CAI 3.4

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TBM Drives at the Gotthard Base Tunnel

29.8.2017
Cutter head wear II

- Instable face
- Not all discs at face
- Reduced face pressure
- Reduced cutting speed
- Blocks at the face
- Cutter head as crusher
- Rolling blocks hits the disks
Cutter head wear III

- CAI much higher than prognosis
- Damaged Disks due to blocks
- Often longer maintenance shifts
- Reduced pressure due to instable face

➢ Determinating for advance rate
Water inflow I

- Water pressure up to 200 bar
- Probe drillings require preventer (in sensitive areas)
- Needs specification in tender docs
- 1:1 tests on site recommended before start
- Works well for both percussion and core drillings
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**Water inflow II**

- Water inflow initial max 100 l/s
- Ascending tunnel
- 600 mm drainage pipe
  - No problem
- But 48°C!
- Cooling system limited
- Reduced working hours
- Frequent pauses required
  - Reduced advance rate
Rock burst I
Rock burst II

- Difficult to predict
- Without warning – suddenly!
- Rock support cannot prevent rock burst
- But must protect staff
- TBM helps!
- Absorb kinetic energy
- Not easy to classify, subjective
- Code of classification
- Potential measures

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<table>
<thead>
<tr>
<th>Begriff (Ereignis)</th>
<th>Beobachtete Phänomene</th>
<th>Massnahmen</th>
</tr>
</thead>
</table>
| E Entlastung        | Geräuschvolle Entlastung, leichte Abbröckeln, Kratzen, Schläge und Knackgeräusche im Gelände | - Schichtführer und Vortriebsabwärts informieren.  
- Sicherung konsequent zum Fingerschild nachziehen  
- Beobachtungen dokumentieren auf Tagesreport TAT und S100L |
| B31 Leichter Bergschlag | Spannungsbedingtes Ablösen ohne Bruchablauf. Gestein zerbricht mit einem Schlag, Schuppenbildung bis 5 cm Stärke, Bildung von Staubwolken | Zusätzlich zu E:  
- Überprüfen der Verankerung (Typ, Länge, Anzahl, Raster, Ankerabstand) sowie Einsatz und Abstand der Teiltüten.  
- Prüfen des Einsatz nachgiebiger Ankersystem (Beispiel: Swellex).  
- Prüfen oder Anpassen der Hublänge |
- Verstärken der Ausbruchssicherung  
- Einbau nachgiebiger Ankersystem  
- Einbau Swellex  
- Einbau Netze auf ganzem Umfang  
- Einsatz von Spritzbeton in L1+  
- Einsatz Stahloben TH |
| B33 Starker Bergschlag | Starker Knall mit Felsabsprengung. Gesteinsstolper oder  -platten werden plötzlich in radiale Richtung mit lauten Knall ab der Tunnelübung geschleudert im gesicherten und ungesicherten Bereich. Die Sicherung wird möglicherweise beschädigt (Spritzbeton gerissen, abgerissene Anker, verformte Bögen). | Zusätzlich zu B2:  
- Anpassung Hublänge  
- Einbau TH-Bögen im Abstand 1 min Kombination Anker  
- Prüfen von Entspannungsnahgrauen |
Squeezing rock I

- Started with Steel arches and rock bolts and shotcrete
- Soon deformations (30 cm)
- Shotcrete destroyed
- Steel arches plastified
Squeezing rock II

- Second TBM even worse
- Back up was squeezed in
- Heave in the invert
- Reconstruction of the invert still under the TBM
Squeezing rock III

- TBM got through – at the end
- Intensive back calculations
- New loads, new design
- Tunnel redone on 400 m
Squeezing rock IV

- D&B in this area had less problems
- Rock support can be installed direct at the front, with TBM not possible
- Distance between face and installed rock support is important
  - Shield must be as short as possible
- Styrofoam elements worked well to protect young shotcrete
- Inclined cross passages allowed to redo the tunnels without interrupting the TBM
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Blocked TBM I

- First machine passed
- Some over brake
- Second machine got stocked
- Several attempts with backing and restart were not successful
- 1’100 m spiles installed
- Voids filled up with 48 m$^3$ concrete and 47 m$^3$ grout
Blocked TBM II

- Still not successful
- A lot of material was taken out without any progress
- Massive cavern above tunnel
- Extensive probe drilling
Blocked TBM III

- Stabilize loose material
- Grouting campaign from a niche, east tunnel
- Counter heading to secure the time schedule
Blocked TBM IV

- Action plan was very helpful, reduced reaction time significantly
- Expert panel was important
- Close collaboration and clear communication was crucial
- Decision need to be taken fast, immediately at the face
- Willingness to solve the problem compulsory
Advance rates I

- Design: 2.33 m/h

<table>
<thead>
<tr>
<th></th>
<th>Ost</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration mm/U</td>
<td>8.28</td>
<td>8.46</td>
</tr>
<tr>
<td>Netto advance rate m/h</td>
<td>2.51</td>
<td>2.64</td>
</tr>
</tbody>
</table>
Advance rates II

- Joint and foliation angle important influence
- Penetration around 10 mm while perpendicular
- Drops down to 70% while flat
## Advance rates III

<table>
<thead>
<tr>
<th>Teilabschnitt</th>
<th>Röhre</th>
<th>Länge [m]</th>
<th>Beginn Start</th>
<th>Ende Finish</th>
<th>Vortriebs- Driving days</th>
<th>Stillstandstage</th>
<th>Ausführung/ Site [m/VT]</th>
<th>Planung/ Design [m/KT]</th>
<th>Vergleich Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Erstfeld</strong></td>
<td>Ost</td>
<td>7150</td>
<td>04.12.2007</td>
<td>16.06.2009</td>
<td>392</td>
<td>168</td>
<td>18.24</td>
<td>10.85</td>
<td>118 %</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>7116</td>
<td>16.03.2008</td>
<td>16.09.2009</td>
<td>400</td>
<td>149</td>
<td>17.79</td>
<td>12.77</td>
<td>119 %</td>
</tr>
<tr>
<td><strong>Arnsteg</strong></td>
<td>Ost</td>
<td>10.723</td>
<td>22.05.2003</td>
<td>05.06.2006</td>
<td>749</td>
<td>361</td>
<td>14.32</td>
<td>7.44</td>
<td>130 %</td>
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<tr>
<td></td>
<td>West</td>
<td>10.703</td>
<td>08.08.2003</td>
<td>09.10.2006</td>
<td>676</td>
<td>482</td>
<td>15.83</td>
<td>9.66</td>
<td>124 %</td>
</tr>
<tr>
<td><strong>Faido</strong></td>
<td>Ost</td>
<td>11.134</td>
<td>07.07.2007</td>
<td>15.10.2010</td>
<td>910</td>
<td>285</td>
<td>12.24</td>
<td>8.89</td>
<td>105 %</td>
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<tr>
<td></td>
<td>West</td>
<td>11.088</td>
<td>15.10.2007</td>
<td>23.03.2011</td>
<td>894</td>
<td>361</td>
<td>12.40</td>
<td>9.31</td>
<td>99 %</td>
</tr>
<tr>
<td><strong>Bodio</strong></td>
<td>Ost</td>
<td>13.450</td>
<td>01.11.2002</td>
<td>06.09.2006</td>
<td>1149</td>
<td>256</td>
<td>11.71</td>
<td>12.21</td>
<td>78 %</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>14.113</td>
<td>01.02.2003</td>
<td>26.10.2006</td>
<td>1114</td>
<td>249</td>
<td>12.67</td>
<td>85 %</td>
<td></td>
</tr>
</tbody>
</table>
Lessons learned I

- Optimize TBM for most probable geology – set right focus
- Make sure, that TBM can handle worst case
- Open gripper TBM was right decision - flexibility was needed
- Shotcrete in L1 was necessary and feasible, main shotcrete in L2
- Rock bolts in L2 were not used. Bolts are needed as close to the face as possible
Lessons learned II

- A continuous probe drilling from the TBM was very useful (low cost, no time)
- In such difficult geology it is inevitable to have competent staff on site (contractor, designer bust also client)
- Decisions need to be taken fast, to keep TBM running
- Logistic is important. Keep other activities as low as possible
- TBM produces a lot of data. Data evaluation needs a clear concept to get significant results
Main challenge: Communication!
Thank you for your attention!

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