# TBM Drives at the Gotthard Base Tunnel

## Challenges in the Faido section

Thomas Jesel, MSc, Amberg Engineering AG



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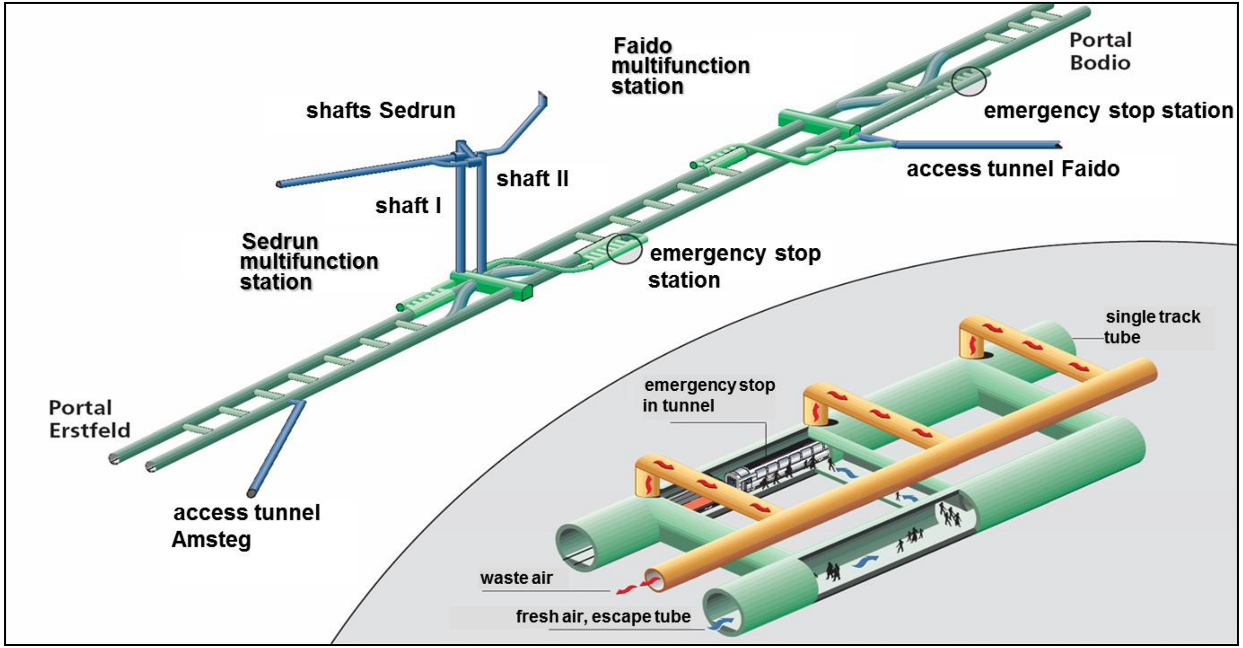
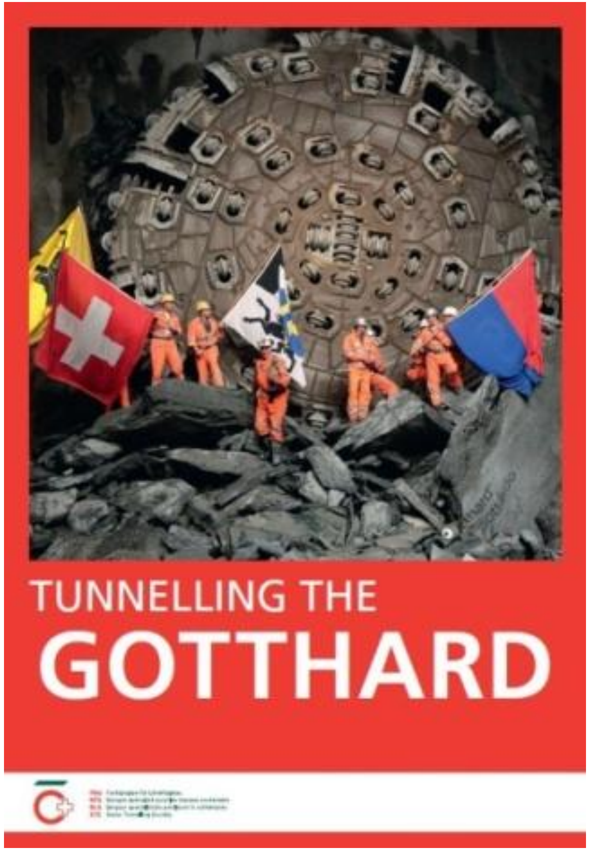
| Project Main Information | |
|---|---|
| **Client** | Alp Transit AG (ATG) |
| **Location** | Switzerland |
| **Design Level** | All design stages up to detailed design |
| **Design Joint Venture** | JV with Pöyry Infra AG and Lombardi SA under lead of Amberg Engineering AG |
| **Project Phases & Design Schedule** | Design 1990-2016<br>Construction 1993-2016<br>Commissioning 2017 |
| **Design Costs** | 485 Mio. CHF (part of AE: 165 Mio. CHF) |
| **Total Project Costs** | 12.2 billion CHF |

| Design Responsibilities | |
|---|---|
| **Preliminary Design** | Amberg within JV, responsible for the whole tunnel itself |
| **Basic Design** | Amberg within JV, responsible for the whole tunnel itself |
| **Detailed Design** | Amberg within JV, responsible for the Faido section |
| **Tender Design** | Amberg within JV, responsible for the Faido section |
| **Assistance on Site** | Amberg within JV, responsible for Bodio, Faido and partially Sedrun |
| **Site Supervision** | Amberg within JV, mainly Faido but also Bodio and Sedrun |

## Gotthard Base Tunnel, www.alptransit.ch



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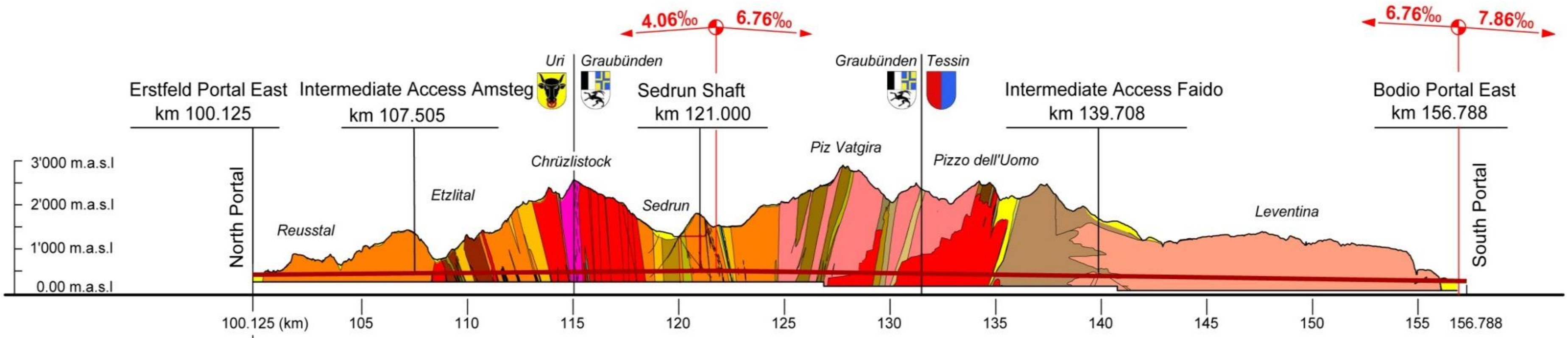
# Excavation method




| **Section length** (east tunnel) | **Erstfeld** 7.778 km | **Amsteg** 11.330 km | **Sedrun** 8.569 km | **Faido** 13.456 km | **Bodio** 15.971 km |
|---|---|---|---|---|---|
| **Direction of advance** | TBM | TBM | conventional tunnelling | TBM | TBM main drives |



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# TBM

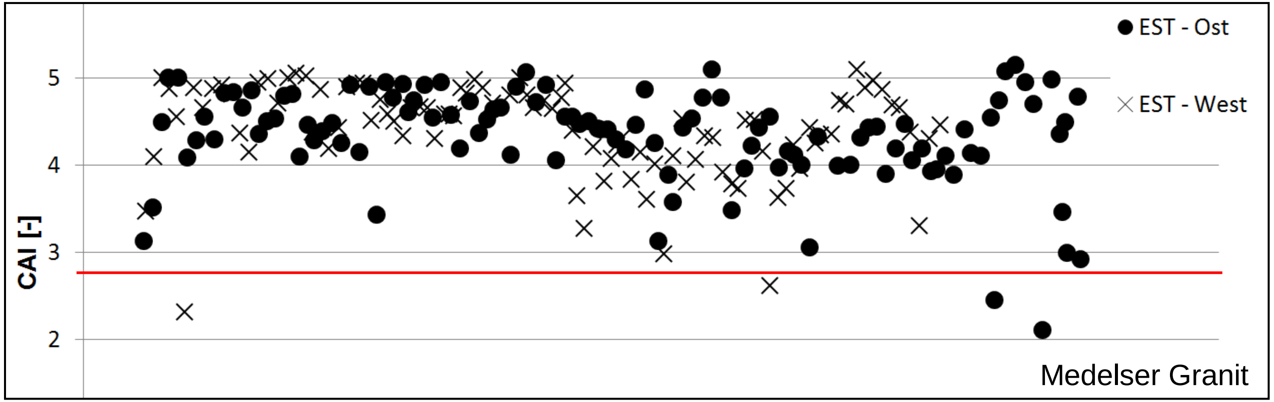
- 4 Herrenknecht TBM
- Open gripper shield
- Length
  TBM: 26 m
  Back-up: 450 m
- Cutter head
  Diameter: 9.43 m
  Shifted, max: 9.53 m
  Weight: 240 t
- Discs:
  Number: 66
  Diameter: 17”

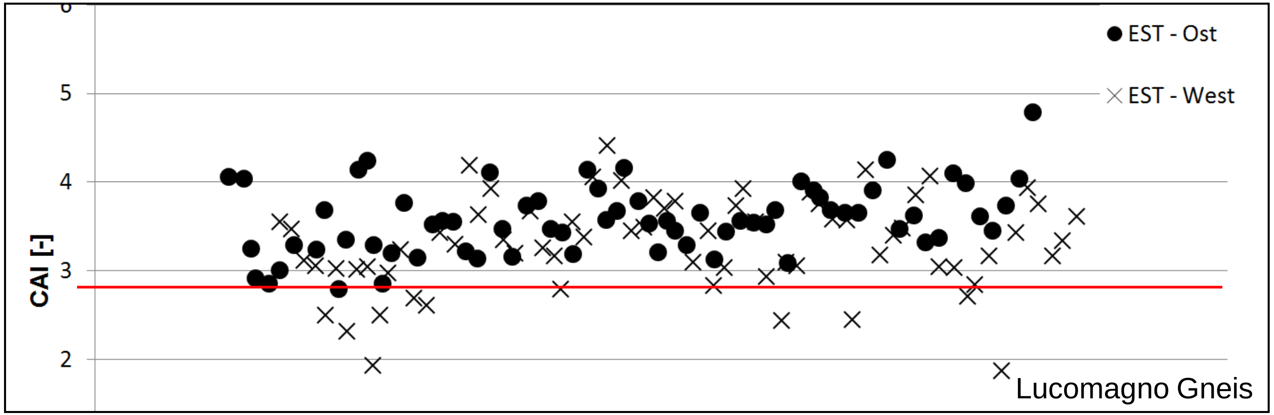
## Experience Faido

- 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



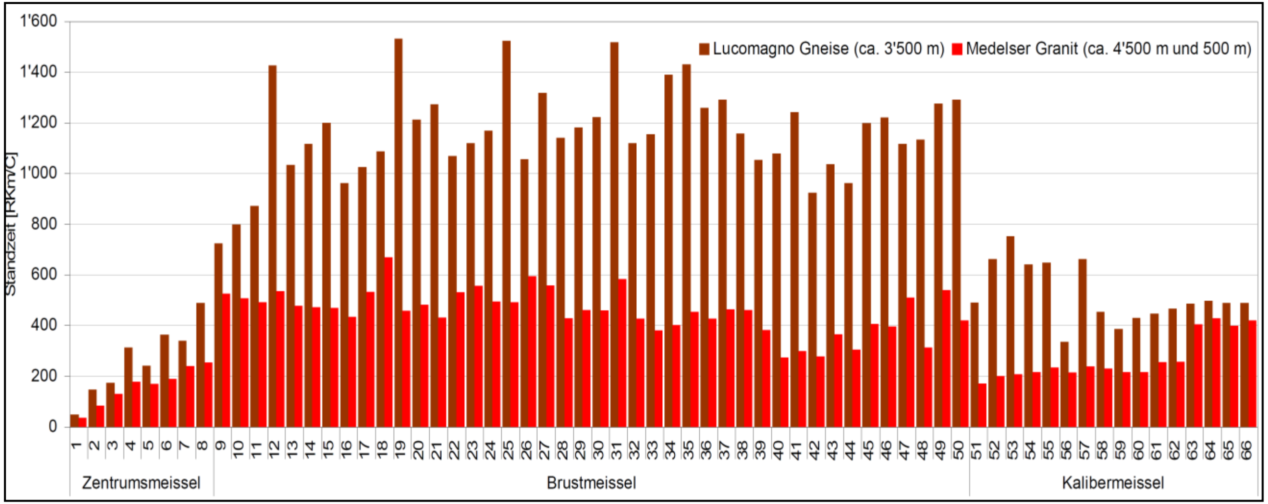
# Cutter head wear II

- 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





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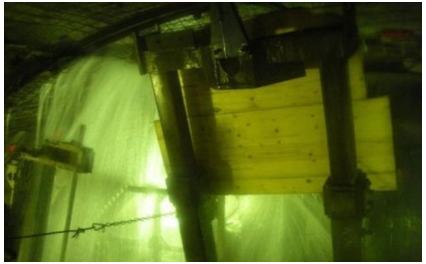
## Water inflow I

- 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







# 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





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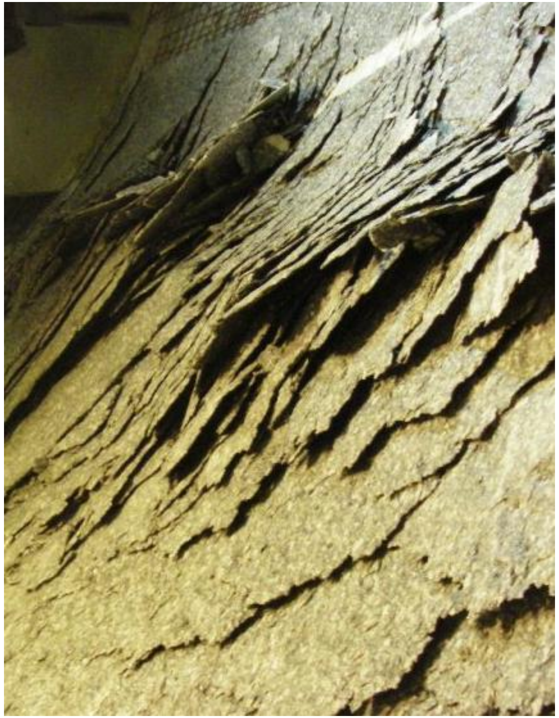
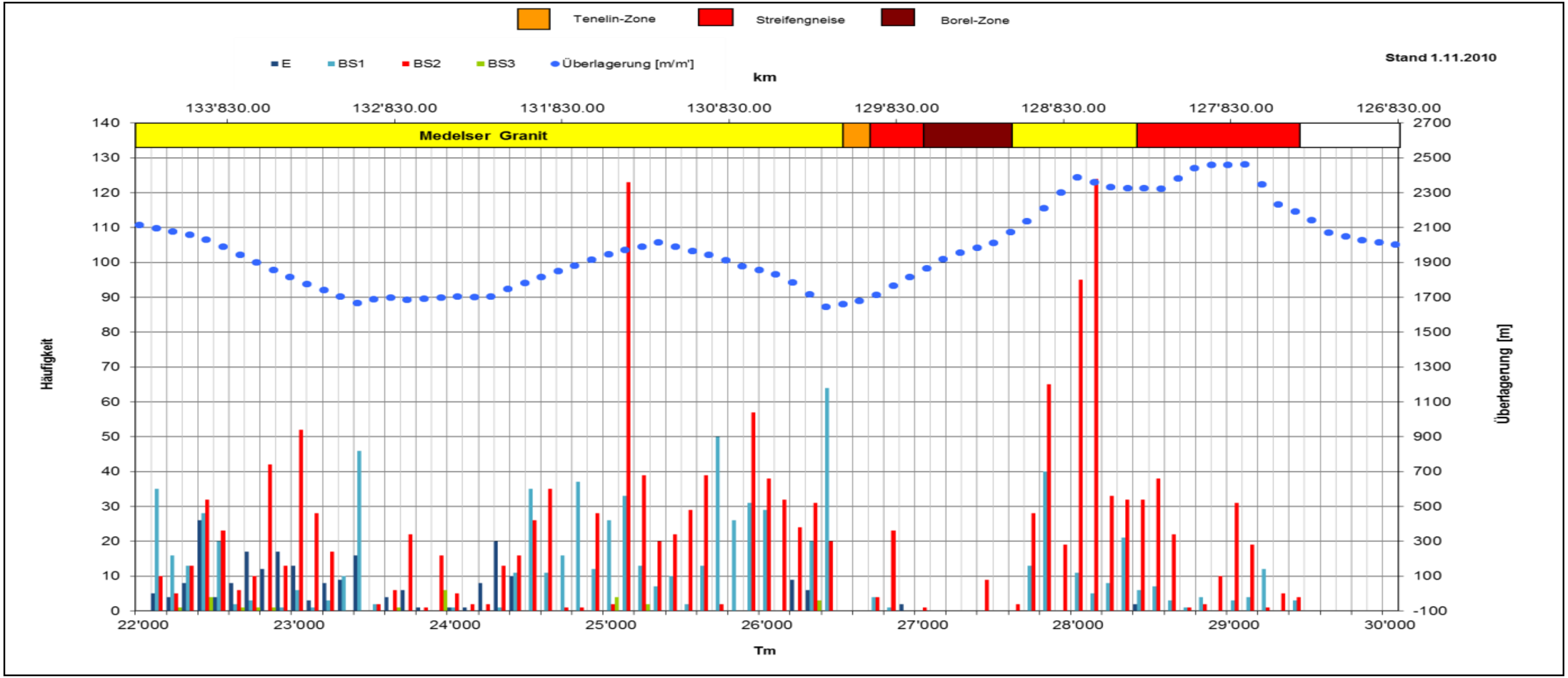
# Rock burst I



# 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

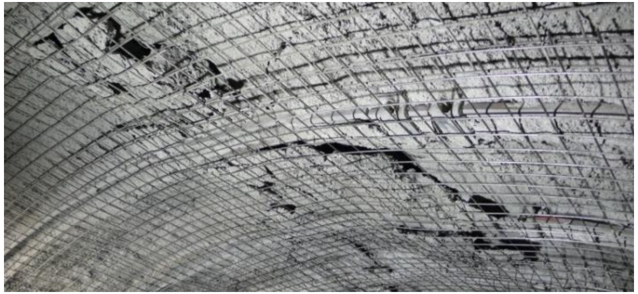
| Begriff (Ereignis) | Beobachtete Phänomene | Massnahmen |
|---|---|---|
| E<br>Entlastung | Geräuschvolle Entlastung, leichtes Abbröckeln: Knistern, Schläge und Knackgeräusche im Gebirge | - Schichtführer und Vortriebsbauleiter informieren.<br>- Sicherung konsequent zum Fingerschild nachziehen<br>- Beobachtungen dokumentieren auf Tagesrapport TAT und SISOBL |
| BS1<br>Leichter Bergschlag | Spannungsbedingtes Abblättern ohne Gesteinsablösung: Gestein zerbricht mit einem Schlag, Schuppenbildung bis 5 cm Stärke, Bildung von Staubwolken | Zusätzlich zu E:<br>- Überprüfen der Verankerung (Typ, Länge, Anzahl, Raster, Ankerplatte) sowie Einsatz und Abstand der Teilbogen.<br>- Prüfen Einsatz nachgiebiges Ankersystem (Freispiel-Swellex).<br>- Prüfen oder Anpassen der Hublänge |
| BS2<br>Mittlerer Bergschlag | Spannungsbedingte Ablösung oder Niederbruch an Tunnelleibung oder Brust im ungesicherten Bereich: Gestein zerbricht grob und geräuschvoll. Ev. Brustablösungen vor dem Bohrkopf mit möglicher Störung des Vorschubes. | Zusätzlich zu B1:<br>Verstärken der Ausbruchsicherung<br>- Einbau nachgiebiges Ankersystem<br>- Einbau super Swellex<br>- Einbau Netze auf ganzem Umfang<br>- Einsatz von Spritzbeton im L1*<br>- Einsatz Stahlbogen TH |
| BS 3<br>Starker Bergschlag | Starker Knall mit Felsabsprengung: Gesteinssplitter oder –platten werden plötzlich in radiale Richtung mit lautem Knall ab der Tunnelleibung geschleudert (im gesicherten und ungesicherten Bereich).<br>Die Sicherung wird möglicherweise beschädigt (Spritzbeton gerissen, abgerissene Anker, verformte Bögen). | Zusätzlich zu B2:<br>- Anpassung Hublänge<br>- Einbau TH-Bogen im Abstand 1 m in Kombination mit Ankern<br>- Prüfen von Entspannungsbohrungen |



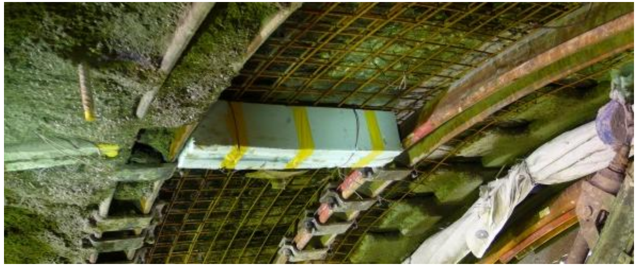
Tenelin-Zone
Streifengneise
Borel-Zone
E
BS1
BS2
BS3
Überlagerung [m/m']
Stand 1.11.2010
km
133'830.00
132'830.00
131'830.00
130'830.00
129'830.00
128'830.00
127'830.00
126'830.00
Medelser Granit
Häufigkeit
Überlagerung [m]
Tm
22'000
23'000
24'000
25'000
26'000
27'000
28'000
29'000
30'000

## Squeezing rock I

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



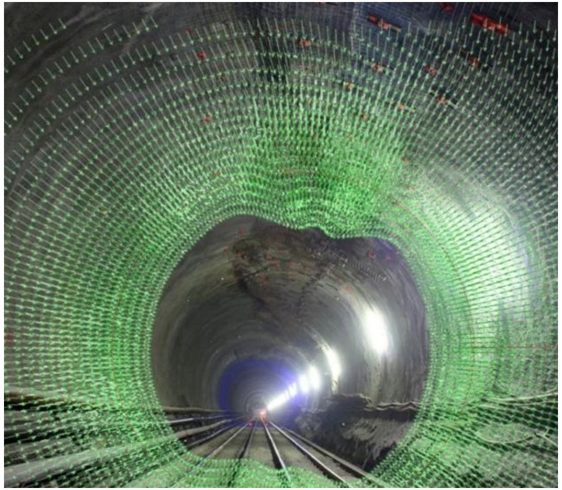



# Squeezing rock II

- 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

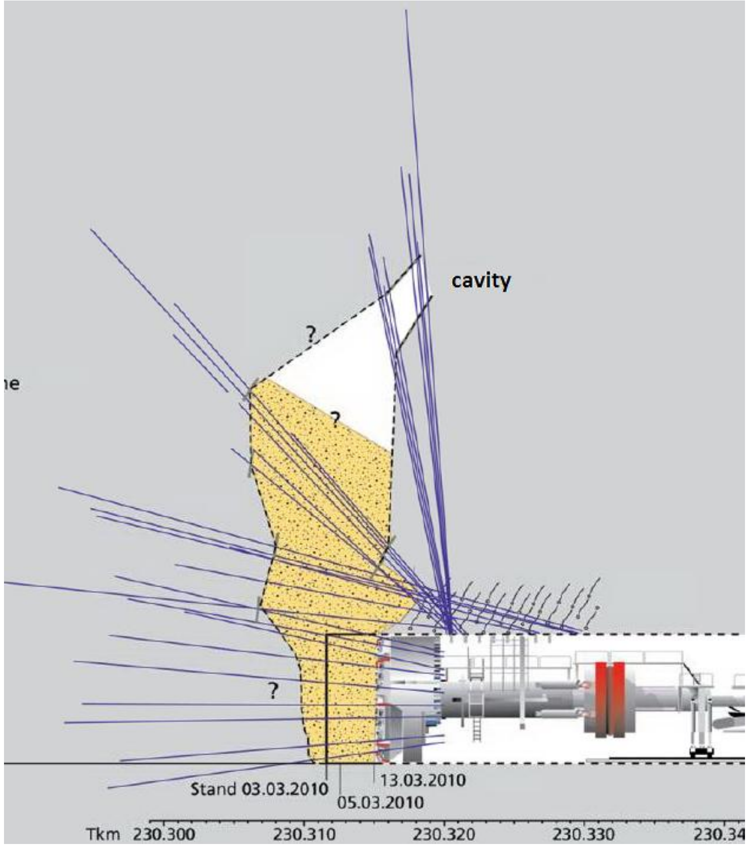
# Blocked TBM I

- 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

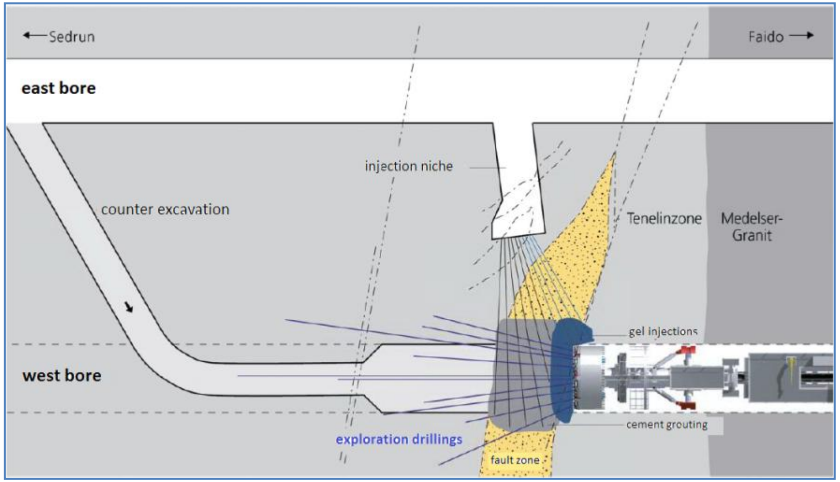
- Still not successful
- A lot of material was taken out without any progress
- ➢ Massive cavern above  tunnel
- Extensive probe drilling



# Blocked TBM III

- Stabilize loos material
- Grouting campaign from a niche, east tunnel
- Counter heading to secure the time schedule

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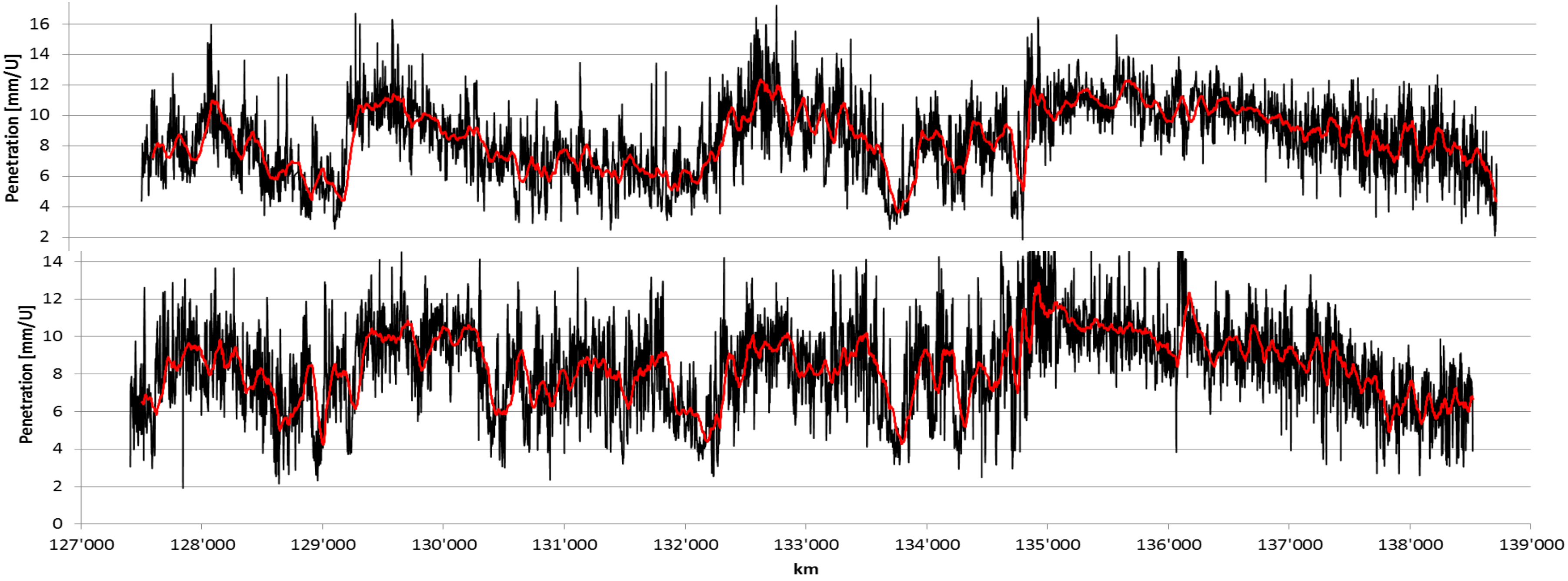
# Blocked TBM IV

- 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

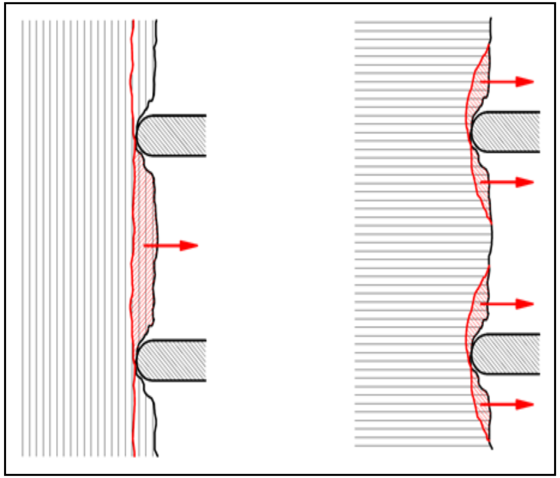
- Design: 2.33 m/h

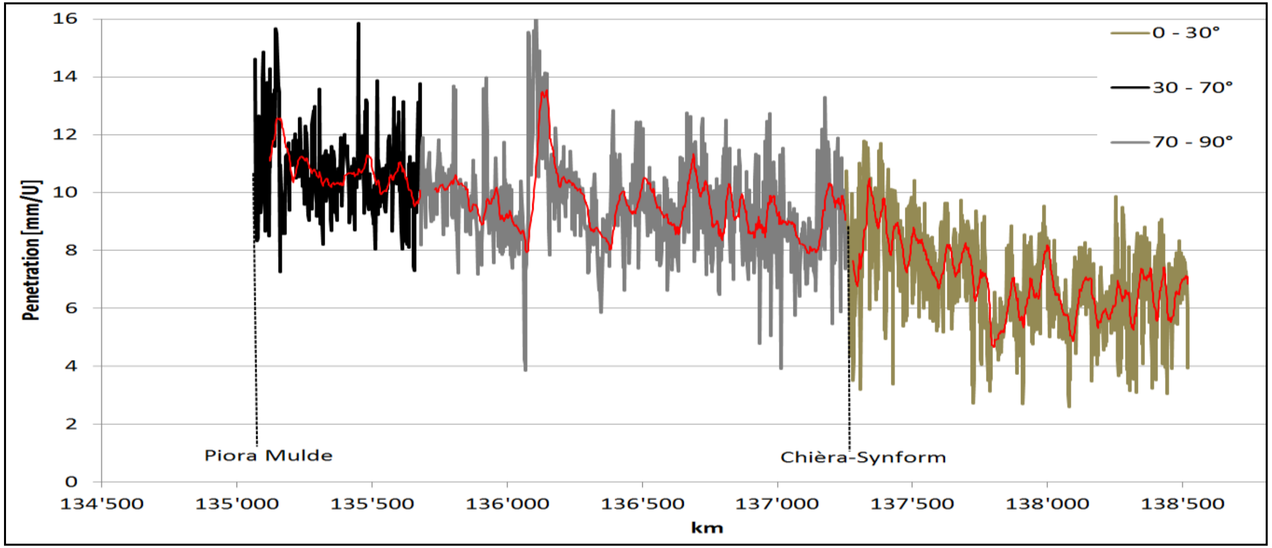
| | | Ost | West |
|---|---|---|---|
| Penetration | mm/U | 8.28 | 8.46 |
| Netto advance rate | m/h | 2.51 | 2.64 |



# Advance rates II

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



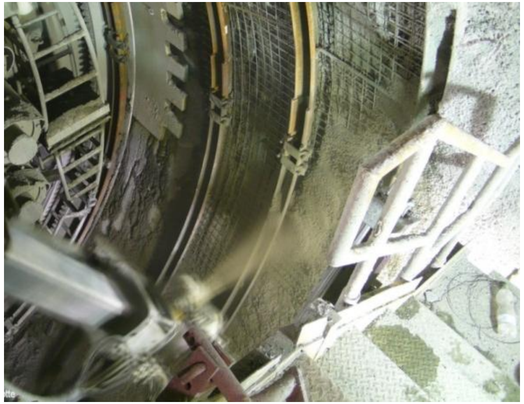



# Advance rates III

| Teilabschnitt *Section* | Röhre *Tunnel* | Länge *Length* [m] | Beginn *Start* | Ende *Finish* | Vortriebs-tage *Driving days* | Stillstandstage *Standstill days* | Ausführung / *Site* [m/VT] *[m/DD]* | Ausführung / *Site* [m/KT] *[m/D]* | Planung / *Design* [m/KT] *[m/D]* | Planung / *Design* Vergleich *Comparison* |
|---|---|---|---|---|---|---|---|---|---|---|
| Erstfeld | Ost | 7150 | 04.12.2007 | 16.06.2009 | 392 | 168 | 18.24 | 12.77 | 10.85 | 118 % |
| | West | 7116 | 16.03.2008 | 16.09.2009 | 400 | 149 | 17.79 | 12.96 | | 119 % |
| Amsteg | Ost | 10.723 | 22.05.2003 | 05.06.2006 | 749 | 361 | 14.32 | 9.66 | 7.44 | 130 % |
| | West | 10.703 | 08.08.2003 | 09.10.2006 | 676 | 482 | 15.83 | 9.24 | | 124 % |
| Faido | Ost | 11.134 | 07.07.2007 | 15.10.2010 | 910 | 286 | 12.24 | 9.31 | 8.89 | 105 % |
| | West | 11.088 | 15.10.2007 | 23.03.2011 | 894 | 361 | 12.40 | 8.84 | | 99 % |
| Bodio | Ost | 13.450 | 01.11.2002 | 06.09.2006 | 1149 | 256 | 11.71 | 9.57 | 12.21 | 78 % |
| | West | 14.113 | 01.02.2003 | 26.10.2006 | 1114 | 249 | 12.67 | 10.35 | | 85 % |

# 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





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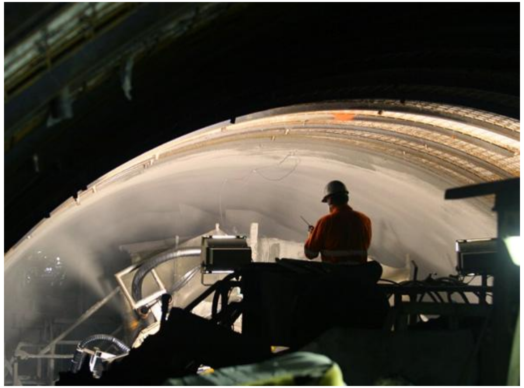
## Lessons learned II

- 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!

tjesel@amberg.ch

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