Experience Gained in Mechanical and Conventional Excavations in the Gotthard Base Tunnel, Switzerland

Presented by:
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1. Gotthard Base Tunnel, Introduction

2. Hazard scenarios

3. Construction Section Faido

   3.1 Multifunctional Station (MFS) Faido

   3.2 TBM Heading in the Single-Track Tunnels

   3.3 TBM Heading Piora Basin

4. Problems encountered during TBM heading

5. Interaction between two tubes
Gotthard Base Tunnel (GBT),
Geological Longitudinal Profile
GBT, Alignment and Tunnel Lots

- Total length: 57 km
- Three intermediate points of attack
- Five construction sections
- Excavation and lining accomplished

- Already excavated tunnels

- Tunnels still to be excavated

Of the total of 153.5 km access passages, shafts and main tunnels 131 km or 85.42% have already been excavated.
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Hazard scenarios

Loosening of the ground

Detaching of wedges
Hazard scenarios

Brittle failure, rock burst related phenomena

Rock burst
Hazard scenarios

- Plastic deformation
- Fault zones
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Multifunctional Station (MFS) Faido, Cross Cavern, Unexpected Downfall April 2002
MFS Faido, Encountered Geology
Deformation of Steel Support
Deformation of Invert, Destroyed Steel Support
Flexible Lining Concept

- Flexible steel arches
- Horizontal slits
Characteristic Line Method

- Yielding Principle
- Resistance Principle
- Equilibrium
- Character line support
- Character line rock mass

\[ \sigma_1 = \sigma_2 \]

Support Pressure \( P_i \)
Radial displacement \( d \)
Example: applied method for Drill & Blast
Example: applied method for Drill & Blast
Time dependent deformation behaviour
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TBM Heading in the Single-Track Tubes, TBM Data

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

TBM Cutter Head
- Diameter: 9.43 m
- Shifted: max. 9.53 m
- Weight: 240 t

Discs
- Number: 66
- Diameter: 43 cm
Section Faido, Start of the TBM in Northern Direction

- TBM East Tube: July 2007
- TBM West Tube: October 2007
Tunnel Faido: Geology, Support Elements

Start East TBM: July 2007
Start West TBM: October 2007

Encountered geology:
- subhorizontal layers of Lucomagno Gneiss

A yielding support system
- Shotcrete with slits
- Yielding steel arches
- Rock bolts

is installed
Rock Support Concept

- Deformation
- Support pressure
- Yielding principle
- Resistance Principle

Engineering Joint Venture Gotthard Base Tunnel South
Yielding Steel Arches
Tunnel Faido, Rock Support Concept

- Rock support measures behind cutter head required
- Second possibility only 65 m behind the face

East tube

- 8-16 rock bolts
- Steel arches @ 1m
- 15 cm shotcrete
- Low advance rate of approx 6.5 m/day
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## Piora Basin

- **Piora Basin**: Triassic deposit of Dolomite in the Gotthard Massif, inserted between Lucomagno Gneiss and Medelser Granite

- Extension approx. 150m
- Overburden approx. 1'800m

- Extensive investigations to explore geological conditions
- Four exploratory drillings showed solid Dolomite-Anhydrite-formations and no water pressure

- Additional measures: preventer protected core drillings up to 250 m
Piora Basin
Piora Basin, Preventer

Preventer:
- Shear Preventer
- Pipe Ram
- Roto Pac
AFTES Conférence "Mécanique des Roches et Tunneliers", Paris le 11 Juin 2009

Piora Basin
Exploration - decision tree
Exploration - decision tree

**Systematic exploration**
- Measure of temperature
- Tunnel Seismic prediction
- Percussion drilling
- Protected with preventer

**Depending on the results**

**Additional exploration**
- Borlog scanning
- additional percussion drilling
- Core drilling
- Protected with preventer
Exploration – approach of Piora Basin

500 m / 450 m / 400 m / 350 m to Piora
- Intensify measurements of temperature
Exploration – approach of Piora Basin

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500 m / 450 m / 400 m / 350 m to Piora
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Exploration – approach of Piora Basin

500 m / 450 m / 400 m / 350 m to Piora
- Intensify measurements of temperature

300 m to Piora
- Additional measurement of temperature
- Tunnel seismic prediction
Exploration – approach of Piora Basin

250 m / 200 m / 150 m / 100 m to Piora
- Additional measurement of temperature
- At 200 m: - tunnel seismic prediction
- At 150 m: - overlapping percussion drilling: 50 m
- At 100 m: - drillings with Preventer
  - tunnel seismic prediction
**Exploration – approach of Piora Basin**

**250 m / 200 m / 150 m / 100 m to Piora**
- Additional measurement of temperature
- At 200 m: tunnel seismic prediction
- At 150 m: overlapping percussion drilling: 50 m
- At 100 m: drillings with Preventer
  - tunnel seismic prediction
Exploration – approach of Piora Basin

250 m / 200 m / 150 m / 100 m to Piora
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Exploration – approach of Piora Basin

250 m / 200 m / 150 m / 100 m to Piora
- Additional measurement of temperature
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  - tunnel seismic prediction
50 m to Piora (Tkm 135.019)
- Additional measurements of temperature
- Intended stop
- Core drilling through Piora
Piora – possible hazards

Local decomposition into sand
Piora – possible hazards

**Action plan**

(E6) Collapse
- Backfill cavity
Piora – possible hazards

Action plan

(E6) Collapse
- Backfill cavity
- forepoling (M3)
Piora – possible hazards

Action plan

(E6) Collapse
- Backfill cavity
- forepoling (M3)
- Grouting (M1, M2)
- Grouting gallery (U1, U2)
Piora – possible hazards

Action plan

(E6) Collapse
- Backfill cavity
- Forepoling (M3)
- Grouting (M1, M2)
- Grouting gallery (U1, U2)
Piora Basin, Excavation
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Damages at Crown and Invert
Problems TBM Heading

Shotcrete cracks (support includes 6m SN M33, TH 36, 40 cm SC2)
Problems TBM Heading
Shotcrete cracking invert
Deformed steel arches
Problems TBM Heading
Section L1 to operators stand

Bereich Tm 18435 – 18450, Tkm 238’375 – 238’360

07.01.2008

08.01.2008
Problems TBM Heading
Section L1 to operators stand
Problems TBM Heading
Section L2: Drilling rig
Problems TBM Heading
Section L2: Shotcrete robot
Problems TBM Heading

Intact rock bolts SN M33 L=4m
Problems TBM Heading

Damages Invert
Problems TBM Heading at the invert

Problem with the clearance profile up to 70 cm
Failure Mechanisms, Load of Rock Support

- Loosening
- Buckling
- Brittle failure (shear off)
- Lateral Pressure
The diagram illustrates the relationship between support pressure (in MPa) and radial displacement (in cm) for various tunnel support conditions. Key features include:

- **Failure of support pressure**: The point where support pressure fails.
- **Residual resistance**: The remaining resistance after support failure.
- **Flexible support type with slots**: Represented by a green dashed line.
- **Rigid support type**: Represented by an orange dotted line.
- **Failure of support system**: Represented by a red dotted line.
- **Restoration**: Represented by a green dotted line.

The graph shows the following data points:

- **Roof (2. tube)**
- **Side wall (2. tube)**
- **Roof (1. tube)**
- **Side wall (1. tube)**

The data points are marked with red triangles for the roof (2. tube) and blue squares for the side wall (2. tube). The roof (1. tube) and side wall (1. tube) are represented by red and blue triangles, respectively.
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Heading interaction

**JOB TITLE:** Fels E pi=0: Ausbruch Weströhre, Vertikalspannungen

**FLAC (Version 5.00)**

**LEGEND**
- 10-Jan-08 14:14
- step 11517
- -6.752E+01 < x < 6.494E+01
- -6.366E+01 < y < 6.880E+01

**Boundary plot**
- 10-Jan-08 14:14
- step 11517
- -6.752E+01 < x < 6.494E+01
- -6.366E+01 < y < 6.880E+01

**YY-stress contours**
- -7.00E+07
- -6.00E+07
- -5.00E+07
- -4.00E+07
- -3.00E+07
- -2.00E+07
- -1.00E+07
- 0.00E+00

**Contour interval:** 1.00E+07

Amberg Engineering Ltd.
Zuerich, Switzerland
Increasing displacements in first tube due to excavation of 2nd tube

Def. West > Ost
JOB TITLE: Fels E pi=0: Ausbruch Weströhre, plastische Zonen

FLAC (Version 5.00)

LEGEND

10-Jan-08 14:14
step 11517
-5.692E+01 < x < 5.330E+01
-5.366E+01 < y < 5.655E+01

Boundary plot

Plasticity Indicator
* at yield in shear or vol.
X elastic, at yield in past
o at yield in tension

Amberg Engineering Ltd.
Zuerich, Switzerland

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Heading interaction

**JOB TITLE**: Fels D pi=0: plastische Zonen

**FLAC (Version 5.00)**

**LEGEND**

- 9-Jan-08 14:48
- step 11573
- \(-3.687E+01 < x < 3.573E+01\)
- \(-3.751E+01 < y < 3.509E+01\)

- **Boundary plot**
  - \(0 \leq 2E \leq 1\)

- **Plasticity Indicator**
  - * at yield in shear or vol.
  - X elastic, at yield in past

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Zuerich, Switzerland
Heading interaction

Convergence Measurements

Firstisochronen

TBM-Ost Tunnelmeter

Stand TBM-West in Tm-Ost: Tm 18505

Einfluss aus Vorbeifahrt TBM-West

nullmessung 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Vorfahrt TBM-West

Nullmessung

Folgemessung 1

Folgemessung 2

Folgemessung 3

Folgemessung 4

Folgemessung 5

Folgemessung 6

Folgemessung 7

Folgemessung 8

Folgemessung 9

Folgemessung 10

Folgemessung 11

Folgemessung 12

Folgemessung 13

Folgemessung 14

Maximum am Steuerstand

NL Folgemessung 1

NL Folgemessung 2

NL Folgemessung 3

NL Folgemessung 4

NL Folgemessung 5

NL gesamt

West Folgemessung 1

West Folgemessung 2

West Folgemessung 3

West Folgemessung 4

West gesamt

Engineering Joint Venture Gotthard Base Tunnel South
Merci beaucoup pour votre attention!