Graitery Tunnel

Use of ZSoil for complex excavations

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Graitery Tunnel

Tunnel: L = 2'462 m

South portal: L = 18 m
South portal excavation

Cut and cover tunnel
L = 18m

Tunnel face

Axis N16

PC9
PC10
PC11
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South portal - initial project - Front excavation wall

Strand anchors

Bar anchors

Axe N16

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History of excavation:

Mid 2007: Beginning of the excavation of the south portal of the Graitery Tunnel

October 2007: Movements of the front excavation wall
Increase in the tensile forces of the anchors
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Novembre 2007: Reinforcement of front wall (more anchors are added)
Excavation continues

The wall movements and the increase in anchor forces are not hindered
Geodesic measurements – Horizontal displacements

Embankment displacements

Front wall displacement (top)

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Tensile forces in strand anchors

$P_{\text{initial}} = 500 \, \text{kN}$
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16th November 2007
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Mid-novembre 2007: Partial filling of the excavation to prevent an instability
January - April 2008: Complementary investigations (6 additional borings)
More precise geological model

Important laboratory tests campagne carried out by the EPFL

Retrofit Stability analysis using ZSoil performed by GVH

Constant interaction between the geological model, the stability analysis and the scope of the laboratory testing.
**Geology – Vertical section**
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Retain structure front and lateral walls:
- strand anchors AVT 5T13, \( P_{\text{initiate}} = 500 \text{ kN} \)
- bar anchors GFK D25mm
- bar anchors GEWI D25mm
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Ground water
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Pretressed strand anchors

Front wall

Lateral wall

Level A:
1/2 AA15, AA14, AA13, AA12, AA11 et AA10

Level C:
CA1, CA2, CA3 et CA4

Level C:
CA12, 1/2 CA11 et CA10

Level D:
DA 10
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Bar anchors

Front wall

Lateral wall

Level A: 2 GEWI

Level B: 3 GEWI

Level B: 3 clous GEWI + 3 GFK

Level C: 3.5 GFK

Level D: 4 clous GFK

Level E: 3.5 clous GFK

Level D: 5GEWI

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Displacements for $c_{\text{molasse marneuse}} = 20 \text{ kN/m}^2$
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Displacements for $C_{	ext{molasse marneuse}} = 20 \text{ kN/m}^2$
Tensile forces in prestressed anchors

\[ C_{\text{molasse marneuse}} = 20 \text{ kN/m}^2 \]
**Adjustment of cohesion using measured tensile forces in anchors**

<table>
<thead>
<tr>
<th>Cohesion</th>
<th>AA10 (AA20)</th>
<th>AA11 (AA19)</th>
<th>AA12 (AA18)</th>
<th>AA13 (AA17)</th>
<th>AA14 (AA16)</th>
<th>AA15</th>
<th>CA10 (CA20)</th>
<th>CA11 (-)</th>
<th>CA12 (CA19)</th>
<th>DA10 (DA19)</th>
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<tbody>
<tr>
<td>30 kN/m²</td>
<td>493</td>
<td>510</td>
<td>524</td>
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<td>485</td>
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<td>523</td>
<td>530</td>
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<td>525</td>
</tr>
<tr>
<td>20 kN/m²</td>
<td>484</td>
<td>502</td>
<td>525</td>
<td>531</td>
<td>532</td>
<td>534</td>
<td>536</td>
<td>550</td>
<td>578</td>
<td>583</td>
<td>536</td>
</tr>
<tr>
<td>18.5 kN/m²</td>
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<td>504</td>
<td>528</td>
<td>535</td>
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<td>555</td>
<td>570</td>
<td>602</td>
<td>809</td>
<td>546</td>
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<td>16 kN/m²</td>
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<td>523</td>
<td>552</td>
<td>558</td>
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<td>641</td>
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<td>695</td>
<td>717</td>
<td>506</td>
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<td>Mesures 29.11.07</td>
<td>547</td>
<td>576</td>
<td></td>
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<td></td>
<td></td>
<td>532</td>
<td>602</td>
<td>*</td>
<td>554</td>
</tr>
</tbody>
</table>

$\phi' = 16^\circ$

* : La force de précontrainte du tirant de contrôle DA10 n'a pas pu être mesurée à la date du 29.11.07. Elle est donc évaluée en multipliant la force de précontrainte initiale par un facteur. Ce facteur multiplicatif correspond à la moyenne des ratios entre la force de précontrainte initiale et la force de précontrainte mesurée le 29.11.07 des autres tirants de contrôle.

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Redesign of the south portal retaining structure

Front wall:
- Anchored pile wall
- Fireglass reinforcement for piles within the tunnel build

Lateral walls:
- Secant anchored pile walls

Embankment above tunnel:
- Permanent prestressed anchors
Models for the design of the retaining structures:

2D models for design of piles

2D model for stability of lateral walls

2.5D model for stability of front wall

3D model for acknowledgement of previous results
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ZSoil 3D Model

- Excavation for permanent anchors
- Horizontal beam
- Investigation gallery
- Sheet-pile walls
- Sandstone molasse
- Compact molasse compacte
- Limestone
- Colluvions
- Fractured marny molasse
Retaining structures

- Permanent anchors
- Superior horizontal beam
- Pile walls
- Tunnel face support
  Fiberglass bolts (GFK)
1. Initial state

Excavation filling modelized by triangular shaped horizontal forces

Existing retaining structure (constructed before filling)
2. Construction of the pile walls

Front and lateral pile walls
3. Permanent anchors in embankment
4. Step by step excavation

Anchors activated step by step
6. Demolition of piles in front of the tunnel crown
   Construction of the umbrella vault
8. Excavation of the tunnel upper half and activation of the initial support

Vue de la excavation du tunnel
Bending moments in piles and top beam

Horizontal cross section in beam

Vertical cross section in pile wall
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Tensile forces in bar anchors on the tunnel face

Tunnel face – GFK bolts
Tunnel in marly molasse
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Tunnel cross section

First drift (upper half)
Arch support
Steel ribs HEB 240 and concrete filling

Umbrella vault
Longitudinal steel tubes

Support of the invert
Steel ribs HEB 240 and concrete filling

Support of the core
Rock bolts

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ZSoil 2D Model

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Initial state
Step 2

2a Activation of umbrella vault
2b Excavation of upper half
2c Arch and invert support
Step 3

3a Transfer of the efforts from the umbrella vault to the arch support
3b Activation of rock bolts for core support
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Step 4

4a  Removal of first invert support
4b  Excavation of lower half
4c  Activation of core and final invert support

Core and invert support
Beam modelling the steel ribs and concrete filling
5a Activation of tunnel lining
5b Transfer of efforts from initial support to lining
Problems with 2D model:

Unconfinement rate of upper half: well documented -> assumptions made in 2D ok

Unconfinement rate of core: not well documented - > specific 3D model

Stability of tunnel face - > specific 3D model
Excavation of the core and invert by steps 2m long starting from the south portal going north.
Support systems

- **Core and invert supports**
  - Shell modelizing steel ribs and concrete filling

- **Base of arch support**
  - Volumetric elements

- **Arch support**
  - Shell modelizing the steel ribs and concrete filling

- **Rock bolts**
  - Constructed from the first invert
Excavation steps

1. Excavation of upper half in one step
2. Activation of rock bolts
3. Removal of first invert and excavation of lower half by 2m long steps
4. Activation of core and invert support following the excavation
5. End of excavation and activation of inner lining
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ZSoil 3D Model

Tunnel face stability

Variable 4 m – 18 m

Marny Molasse

Umbrella vault
ROR steel tubes

Face support
Rock bolts

Arch and invert support
Shell modelizing steel ribs and concrete filling

3 models:
27.5 m, 34.5 m
et 41.5 m

30 m

3x2+10x1+4x2 = 24 m

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Excavation steps

1. Initial state
2. Activation of the umbrella vault
3. Activation of face support
4. Step by step excavation and support of the upper half over the first 6 meters
5. Face stability (decrementation of $c_{\text{molasse}}$ from $C_k$ to $C_d$)
Displacements
Tensile forces in tunnel face rock bolts
Friction along tunnel face rock bolts
Conclusion:

• Use of several models adapted to specific problems
  ➢ Faster model generation
  ➢ Refined mesh around studied area
  ➢ Faster calculation allows for more case studies

• Start with basic model (elastic, no contact, single phase) then add complexity

• Start with small model, then extend to get correct boundary conditions

• Complex models can confirm results of specific models

• For retrofit analysis, complex models cannot be spared
  ➢ but when results correspond well to in-situ measurements, the reward is worth the effort