Auxiliary measures applied in the tunnel construction of the Jonica motorway

Kolloquium
Bauhilfsmassnahmen im Tunnelbau
ETH Zürich

Outline

Project overview
Tunnel construction problems and design changes
Conclusions
Project overview

Jonica motorway (490 km)

Completed Sections

Launches

Assigned and not launched

In design

New motorway

Old motorway
Project overview

“Strada extraurbana principale – Cat. B (D.M. 5 novembre 2001) ”

Two-lane dual carriageway (lane width 3.75 m)

Velocity: 70 - 120 km/h

Total length 11.3 km
Project overview

Costs of the project = 354 Ml €

Two-tube tunnels
n° 5; \( l = 2.6 \) km

Two-tube cut-and-cover tunnels
n° 7; \( l = 1.1 \) km

Viaducts
n° 7; \( l = 2.5 \) km

Project overview

<table>
<thead>
<tr>
<th>35%</th>
<th>35%</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H &gt; 2B )</td>
<td>( 2B &gt; H &gt; B )</td>
<td>( H &lt; B )</td>
</tr>
</tbody>
</table>

Total length of the tunnels (\( L = 5.2 \) km)

Ground surface: \( H = 4.5 \) m – 75 m

Water table: \( I = 30-35 \) m

\[ 9.4 \text{ m} \]

\[ 11.9 \text{ m} \]

\[ B \]
Monte Narbone formation (gravelly sand)

Trubi formation (silty clay, clayey silt)

Trubi formation (clayey sandy silt)

Quaternary deposits (superficial deposits)

z [m]

5%  20%  75%

total length of the tunnels ($L = 5.2$ km)

Project overview

Tunnel construction problems and design changes

Conclusions
Tunnel construction problems and design changes

Limbia Tunnel Carr. Nord
$L = 385$ m

PL (gravelly sand)

considered section

Tunnel construction problems and design changes

**PI**: Monte Narbone formation (gravelly sand)

Granulometry

0% 50% 100%

- Blue: Gravel
- Red: Sand

Relative density $D_r = 40 - 80$

- $\sigma'_v$ vs. $N_{SPT}$
  - $D_r [\%] = 100$
  - $D_r [\%] = 80$
  - $D_r [\%] = 60$
  - $D_r [\%] = 40$

Friction angle $\phi' = 30° - 45°$

- $N_{SPT}$ vs. $\sigma'_v$
  - $\phi' = 45$
  - $\phi' = 40$
  - $\phi' = 35$
  - $\phi' = 30$

Cohesion $c' = 0$
Tunnel construction problems and design changes

In situ jet grouting tests

<table>
<thead>
<tr>
<th>Column</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design diameter [m]</td>
<td>0.8</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grout pressure [MPa]</td>
<td>40</td>
<td>40</td>
<td>35</td>
<td>35</td>
<td>40</td>
<td>40</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Number of nozzles [-]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Nozzle Diameter [mm]</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>W-C ratio by weight [-]</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Grout flow rate per nozzle [l/min]</td>
<td>57</td>
<td>57</td>
<td>53</td>
<td>53</td>
<td>143</td>
<td>119</td>
<td>155</td>
<td>133</td>
</tr>
<tr>
<td>Injected grout volume per unit length [l/m]</td>
<td>380</td>
<td>333</td>
<td>442</td>
<td>398</td>
<td>108</td>
<td>90</td>
<td>117</td>
<td>100</td>
</tr>
<tr>
<td>Average lifting speed of the monitor [mm/s]</td>
<td>5</td>
<td>5.7</td>
<td>4</td>
<td>4.5</td>
<td>13.3</td>
<td>16.0</td>
<td>11.5</td>
<td>13.3</td>
</tr>
<tr>
<td>Observed diameter [m]</td>
<td>0.75 - 0.85</td>
<td>0.85 - 0.95</td>
<td>0.44 - 0.5</td>
<td>0.39 - 0.48</td>
<td>0.62 - 0.71</td>
<td>0.55 - 0.65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tunnel construction problems and design changes

- Tunnel dimensions shown in meters:
  - 9 m
  - 10.3 m

- Images of tunnel construction site and detailed sketches illustrating design changes and problems.
Tunnel construction problems and design changes

**Limbia Tunnel Carr. Nord**

- **$L = 385\,\text{m}$**

**PI (gravelly sand)**

**new design**

**advance rate = 0.25\,\text{m/day}**

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[Graph showing advance rate vs. costs for original and new designs]
Tunnel construction problems and design changes

jet grouting columns

drainage

shotcrete and steel ribs

10 m

12 m

1.2

15-35 m

1.25

1.2

1.2 m

1 m

0.9 m

14.3
### In situ jet grouting tests

#### Mono fluid system

<table>
<thead>
<tr>
<th>Grout pressure</th>
<th>40 MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nozzles</td>
<td>2</td>
</tr>
<tr>
<td>Nozzle Diameter</td>
<td>4 mm</td>
</tr>
<tr>
<td>W-C ratio by weight</td>
<td>1</td>
</tr>
<tr>
<td>Grout flow rate par nozzle</td>
<td>160 l/min</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Injected grout volume per unit length</th>
<th>733 l/m</th>
<th>800 l/m</th>
<th>933 l/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average lifting speed of the monitor</td>
<td>7.3 mm/s</td>
<td>6.7 mm/s</td>
<td>5.7 mm/s</td>
</tr>
</tbody>
</table>

#### Design values

- $D_t = 1.2$ m, $L_t = 2.1$ m
- $D_m = 1.25$ m, $L_m = 2.15$ m

#### Observed values

- $D_m = 1.04$ m, $L_m = 2.03$ m
- $D_m = 1.06$ m, $L_m = 2.07$ m

### Tunnel construction problems and design changes
Tunnel construction problems and design changes

Trigoni Tunnel Carr. Sud
$L = 880$ m

$Ap$ (silty clay)

considered section

Tunnel construction problems and design changes

$Ap$  Trubi formation (silty clay, clayey silt)

granulometry

<table>
<thead>
<tr>
<th></th>
<th>0%</th>
<th>50%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

limit liquid (%) vs. plasticity index (%)

$c' \text{ [kPa]}$

$\phi' \text{ [°]}$
Tunnel construction problems and design changes

**Surface Fractures Induced by the Excavation**

- **60-110 fiberglass bolts** (density 0.5 - 0.9 bolts/m²)
- **48 steel forepolings** (spacing 0.4 m)

**Shotcrete and Steel Ribs**

**Concrete Invert**

- Length of round = 0.75 m

**Installation Every 12 m of Advance**

**Re-profiling of the Tunnel Section** in order to guarantee the minimum clearance profile

**Monitoring Stations in a Distance of 24 m from the Tunnel Face**
Tunnel construction problems and design changes

Trigoni Tunnel Carr. Sud
$L = 880$ m

$A_p$ (silty clay)

new design

advance rate $= 0.3$ m/day
Tunnel construction problems and design changes

- Concrete invert
- Length of round = 1 m
- Shotcrete and steel ribs
- 24 m offset from tunnel face
- Monitoring stations in a distance of 24 m from the tunnel face

Tunnel convergences strongly reduced

New design

Bored piles of lean concrete

Bottom of the bored piles
Tunnel construction problems and design changes

Gerace Tunnel Carr. Nord
$L = 553 \text{ m}$

$Sp$ (clayey sandy silt) $H = 4 - 6 \text{ m}$ $Ap$ (clayey silt)

considered sections
Tunnel construction problems and design changes

**Ap**  Trubi formation (clayey silt)

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**Sp**  Trubi formation (clayey sandy silt)

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- **c’ [kPa]**
- **φ’ [°]**

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**Tunnel construction problems and design changes**

- **A-A**  60-110 fiberglass bolts (density 0.5 - 0.9 bolts/m²)
- **B-B (after exc.)**  48 steel forepolings (spacing 0.2-0.4 m)

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- **Grouted steel forepolings**
- **Fiberglass bolts**
- **Concrete invert**
- **Shotcrete and steel ribs**
- **Installation every 12 m of advance**
- **Length of round = 0.75 m**

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**Dimensions:**
- 12
- 16
- 18 m
- 9.8 m
- 1.25
Tunnel construction problems and design changes

Face instability

0.0
0.5
1.0
1.5
2.0

0 5'000 10'000 15'000 20'000 25'000

advance rate [m/day]

costs [€/m]

original design
Tunnel construction problems and design changes

Gerace Tunnel Carr. Nord
$L = 553$ m

$Sp$ (clayey sandy silt)

$H = 4 – 6$ m

$Ap$ (clayey silt)

new design

advance rate $= 0.25$ m/day

Tunnel construction problems and design changes

lean concrete

concrete invert

length of round $= 1$ m

shotcrete and steel ribs

ground surface
Tunnel construction problems and design changes

![Graph showing advance rate vs. costs with new and original designs marked.

- Carr. Sud
- Carr. Nord

- Costs [€/m]
- Advance rate [m/day]

- New design
- Original design

- Graph legend: new design and original design

- Dimensioned graph with cost values: 0, 5,000, 10,000, 15,000, 20,000, 25,000
Conclusions

Contractual obligations (construction time and costs) &
uncertainties in the design phase

flexibility in the execution phase