Application and research of soil tunnel face stability and reinforcement in Israel K project

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1. General situation

Headrace tunnel: the first 200 m is in Clay with gravels, above underground water level

Tailrace tunnel: the last 500 m is in Clay with gravels and Marl layers, below underground water level
1. General situation

Headrace tunnel: Bench excavation method.
Tailrace tunnel: Full face and Bench excavation method.

**Bench excavation**

**Full-face excavation**

Maximum cross section
1. General situation

Soil section of headrace tunnel had been completed on time, and the tailrace tunnel is left about 100 m until the Jan, 2020. The soil tunnels are designed with Analysis of Controlled Deformations in Rock and Soils method.
2. ADECO-RS

Tunnel face stability is very important for the tunnel stability.

Fiberglass anchor

Tunnels with ADECO-RS in poor condition
Analytical and numerical methods are mostly used to evaluate the tunnel face stability.

Design factor of safety (FoS) of the tunnel face: 1.5
3. Tunnel face stability analysis


Face support pressure:

\[
\frac{p_s}{\gamma a} = \left(\frac{q_s}{\gamma a} + \frac{c}{\gamma a} \cdot \frac{1}{\tan \phi}\right) \cdot \left(\frac{h}{a}\right)^{\frac{k(N_{p}^{FS}-1)}{k(N_{p}^{FS}-1)-1}} - \frac{1}{k(N_{p}^{FS}-1)-1} \left[\left(\frac{h}{a}\right)^{1-k(N_{p}^{FS}-1)} - 1\right] - \frac{c}{\gamma a} \cdot \frac{1}{\tan \phi}
\]
Anagnostou & Kovari (1996):

Face support pressure:

\[
s' = F_0 \gamma' D - F_1 c + F_2 \gamma' \Delta h - F_3 c \frac{\Delta h}{D}
\]
3. Tunnel face stability analysis

Several numerical methods used in tunnel face stability analysis:

- **Strength reduction method**
- **Load reduction method**
4. Reinforcement of Tunnel face

The design of tunnel face reinforcement includes two important issues:

- Design overlap length of fiberglass anchors, and;
- Required numbers of fiberglass anchors.
4. Reinforcement of Tunnel face

According to E. Leca and L. Dormieux (1990), the collapse mechanism of tunnel face in cohesionless soil (without considered the function of cohesion). The angle of critical failure surface to the horizontal:

\[ \delta_{c+} = 49^\circ + \phi' / 2 \]
4. Reinforcement of Tunnel face

The bond strength between the soil and grout of fiberglass anchors ($C_g$) is a key factor to estimate the numbers of tunnel face.

\[ p = \min \left\{ \frac{N \cdot A \cdot \sigma_b}{S}; \frac{N \cdot s_l \cdot C_g}{S} \right\} \]

- $p$ — support pressure;
- $N$ — numbers of bolts;
- $A$ — cross-sectional area of the bolt; *Bolt property*
- $\sigma_b$ — yielding strength of the bolt material; *Bolt property*
- $S$ — tunnel face surface; *Tunnel property*
- $s_l$ — contact surface area of the bolt with soil; *Overlap length*
- $C_g$ — maximum shear stress along the soil/bolt interface; *Bond strength*
5. Examples and Application

For the tailrace tunnel with full face excavation method, the results are shown in the following:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Cover depth (m)</th>
<th>Length (m)</th>
<th>Number</th>
<th>Fiberglass anchors</th>
<th>FoS</th>
<th>Density (b/m²)</th>
<th>Required support pressure (kPa)</th>
<th>Fiberglass anchors*</th>
<th>FoS</th>
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<tbody>
<tr>
<td>Drainage</td>
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</table>

*Analytical methods only show the results with the overlap length of 7 meters of fiberglass anchor.
5. Examples and Application

FoS of reinforced tunnel face in tailrace tunnel with cover depth of 40 m, 31 fiberglass anchors and overall length of 15 m.
5. Examples and Application

a) Geotechnical mapping of HRT0+115.2

b) Design of tunnel face support of HRT0+115.2
6. Conclusion

- With the analytical and numerical method, tunnel face stability is evaluated and the required face support is obtained.

- A quantitative method to determine the required number of fiberglass anchors for the soil tunnel with different excavation method can be used in the design.

- There are some difference between the analytical and numerical method. More researches can be done to find out the collapse mechanism of tunnel face.

- Monitoring is also very important for examining the reinforcement and making optimization of the design.
Thank you for your attention!