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

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Feb 18，2020

OUTLINE

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3. Tunnel face stability analysis
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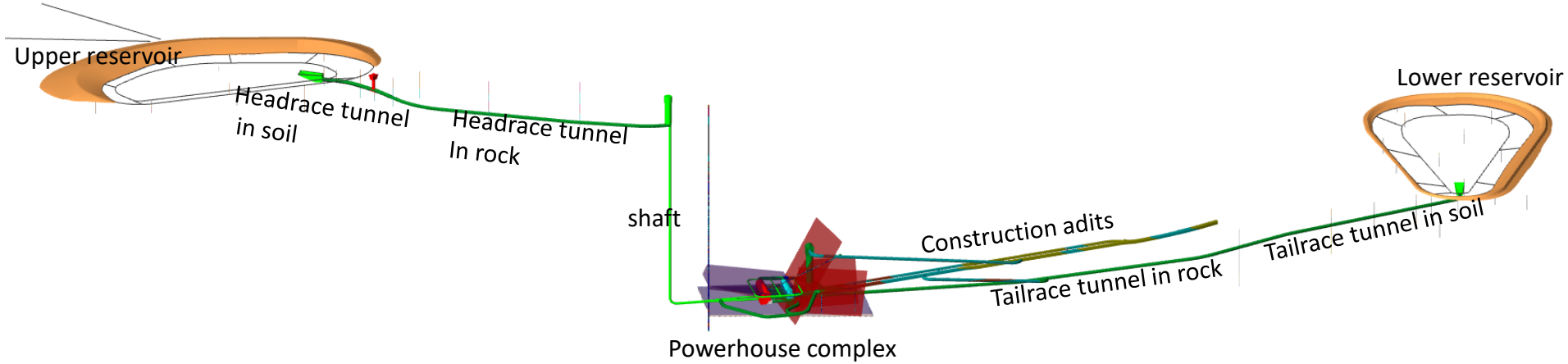
1. General situation

Layout of Israel K pumped storage power station



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

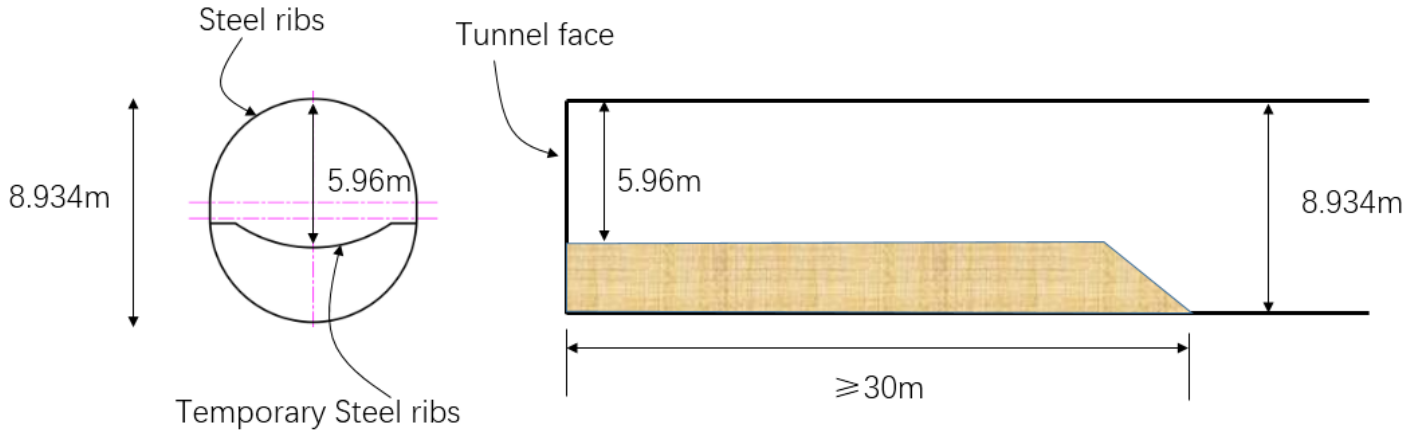
Tailrace tunnel: the last 500 m is in Clay with gravels and Marl layers, below underground water level

1. General situation

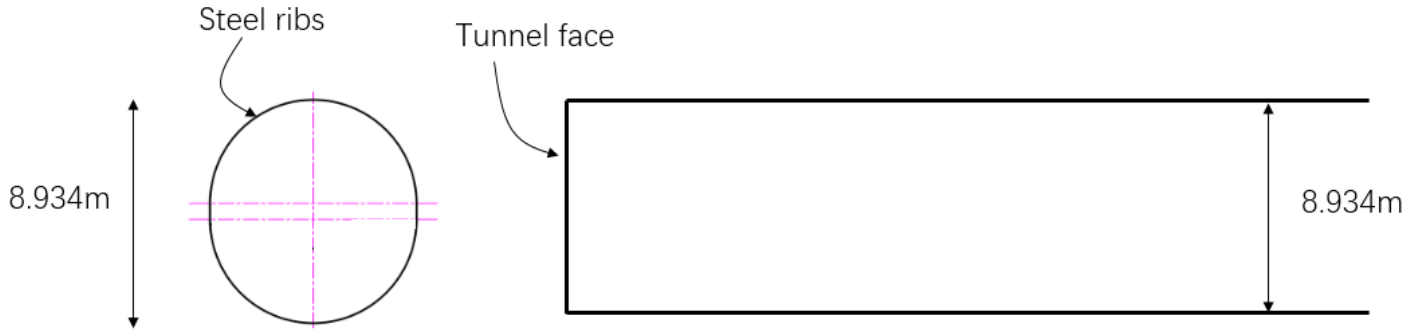
Headrace tunnel: Bench excavation method.

Tailrace tunnel: Full face and Bench excavation method.

Bench excavation



Full-face excavation



Maximum cross section

1. General situation

a) Bench excavation in headrace tunnel in clay with gravels

b) Full face excavation in tailrace tunnel in marl

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

Fig. 2. Photographs showing the face of a few selected tunnels excavated full-face by using the "heavy method" (Lunardi and Barla, 2014).

Tunnels with ADECO-RS in poor condition

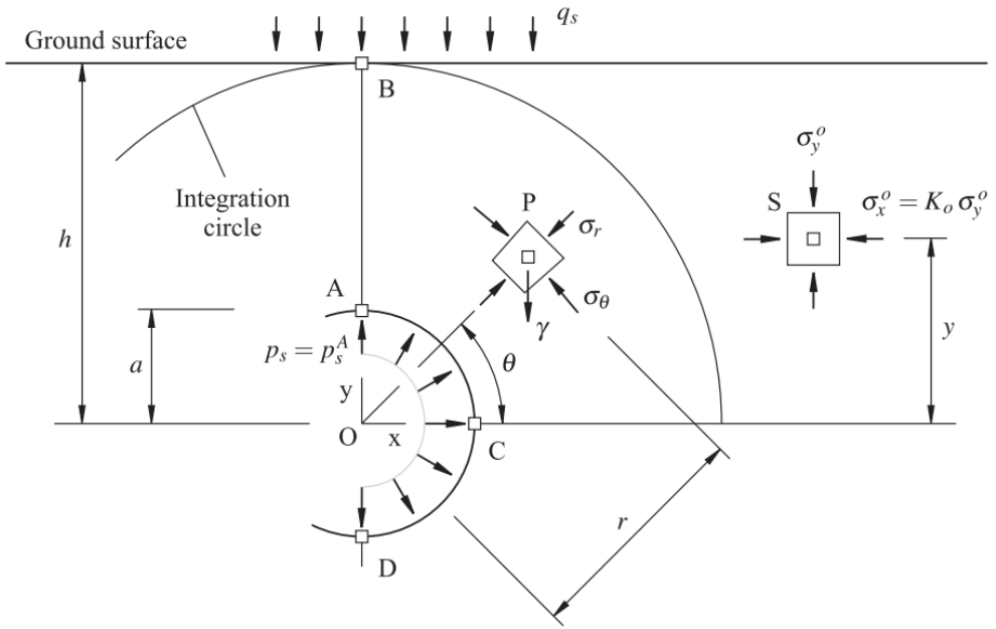
3. Tunnel face stability analysis

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

Carlos Carranza-Torres integrated method of (After Caqout-Kerisel, 1956).

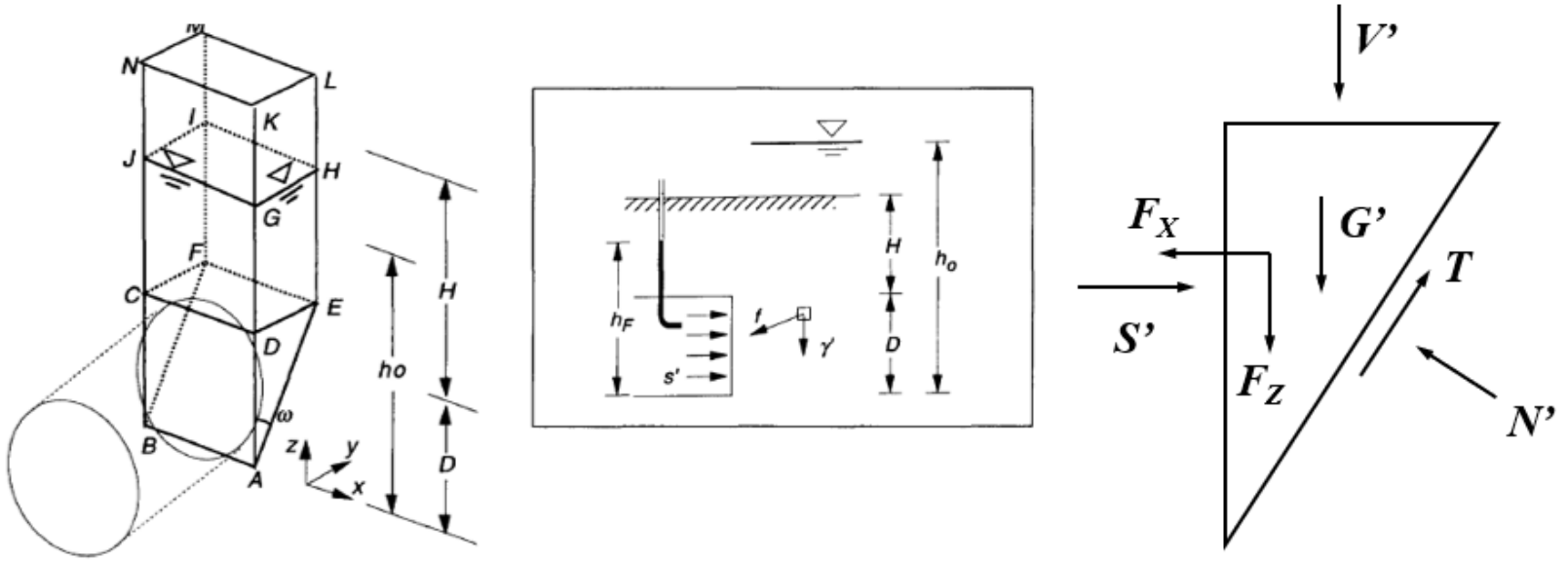


Face support pressure:

$$\frac{p_s}{\gamma a} = \left(\frac{q_s}{\gamma a} + \frac{c}{\gamma a} \cdot \frac{1}{tan\varphi}\right) \cdot \left(\frac{h}{a}\right)^{-k\left(N_\varphi^{FS}-1\right)} - \frac{1}{k\left(N_\varphi^{FS}-1\right)-1}\left[\left(\frac{h}{a}\right)^{1-k\left(N_\varphi^{FS}-1\right)} - 1\right] - \frac{c}{\gamma a} \cdot \frac{1}{tan\varphi}$$

3. Tunnel face stability analysis

Anagnostou & Kovari (1996) :



Face support pressure: $s' = F_0\gamma' D - F_1 \mathrm{c} + F_2\gamma'\Delta h - F_3 c\frac{\Delta h}{D}$

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

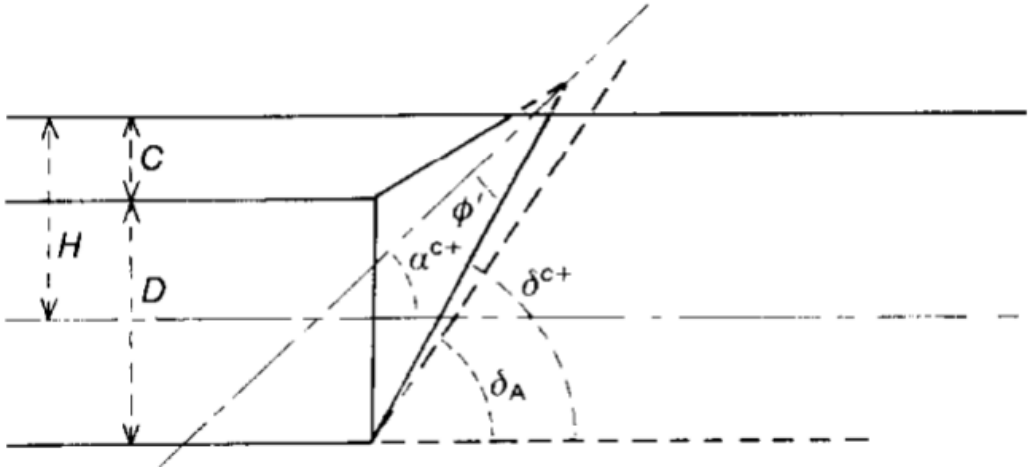
The design of tunnel face reinforcement includes two important issues:

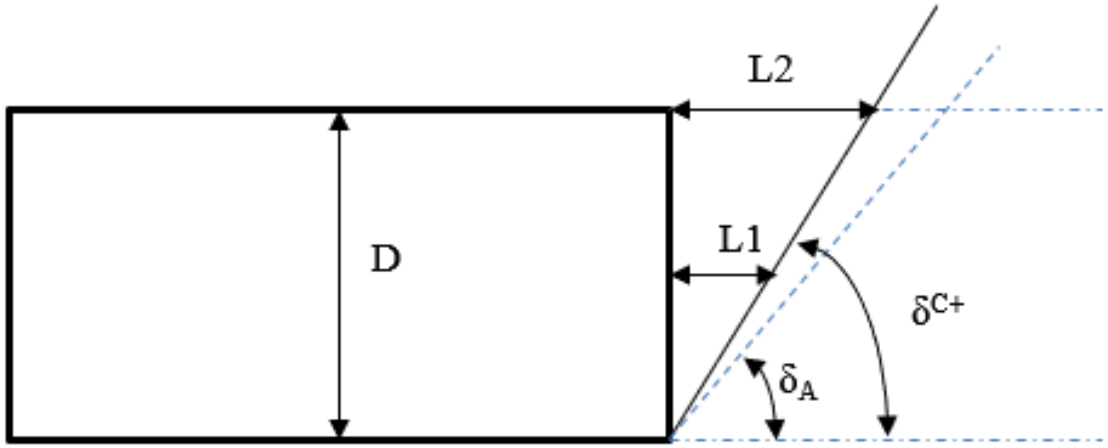
- **Design overlap length of fiberglass anchors**, and ;
- **Required numbers of fiberglass anchors**.

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:

$$\delta_{c+} = 49° + \emptyset'/2$$





4. Reinforcement of Tunnel face

Support pressure
Overlap length
} Numbers of fiberglass anchors

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

(Bustamante & Doix, 1975)

$$p = \min\left\{\frac{N \cdot A \cdot \sigma_b}{S}; \frac{N \cdot s_l \cdot Cg}{S}\right\}$$

Bolt damage

Grout damage

p—— support pressure;

N ——numbers of bolts;

A ——cross-sectional area of the bolt; Bolt property

σ_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

Cg ——maximum shear stress along the soil/bolt interface; Bond strength

5. Examples and Application

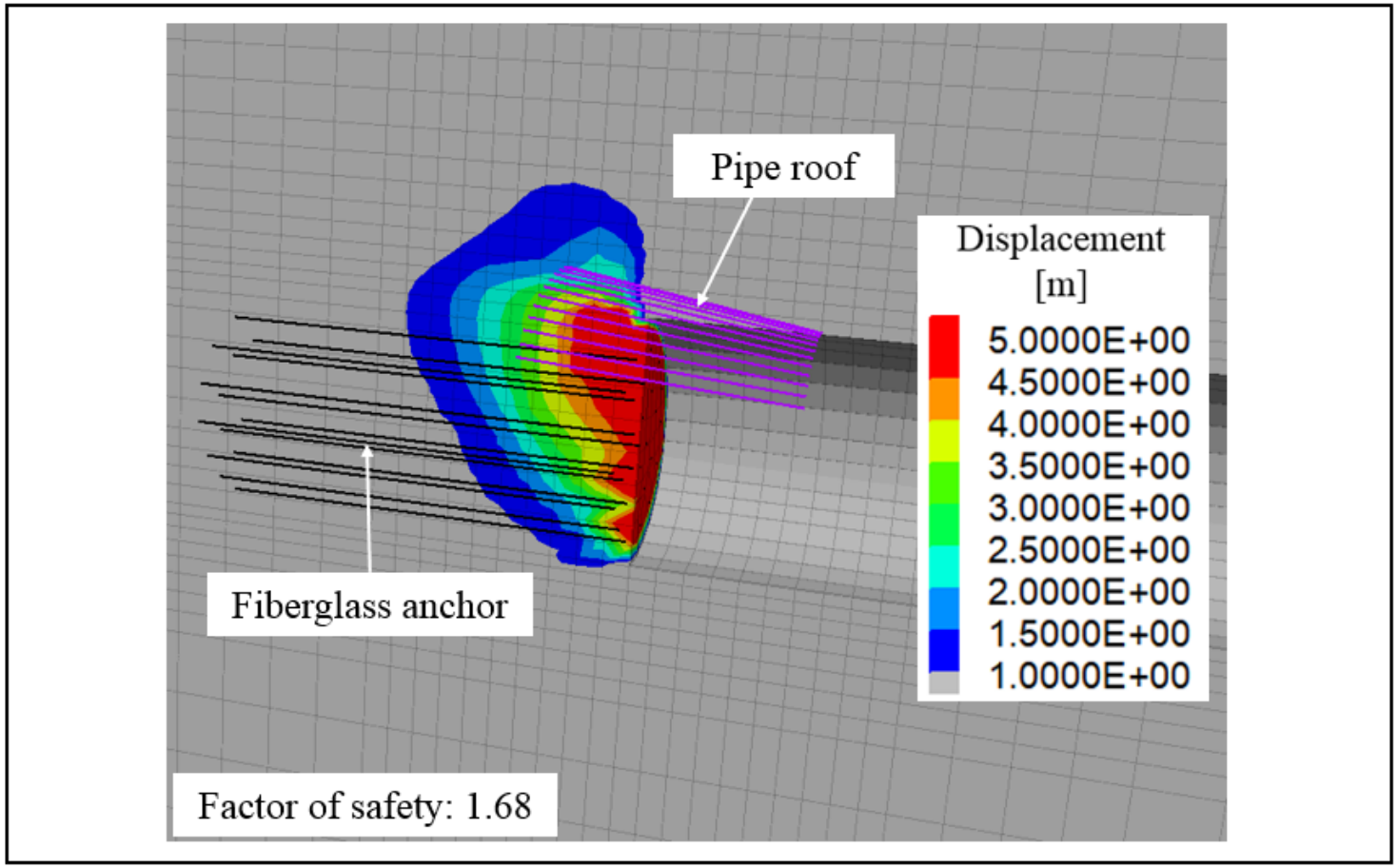
For the tailrace tunnel with full face excavation method, the results are shown in the following:

Table 1. Results of tailrace tunnel face reinforced with fiberglass anchors.

Condition	Cover depth	Numerical Calculation results				Analytical Calculation results		
		Fiberglass anchors		FoS	Density	Required support pressure	Fiberglass anchors*	FoS
Drainage condition	(m)	Length (m)	Number		b/m^2	kPa	Number	
	marl							
	40	15	31	1.7	0.52	67.96	/	1.5
		7		1.5			13*	
	clay with gravels							
	45	15	31	1.8	0.52	192.17	/	1.5
		7		1.5			37*	

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

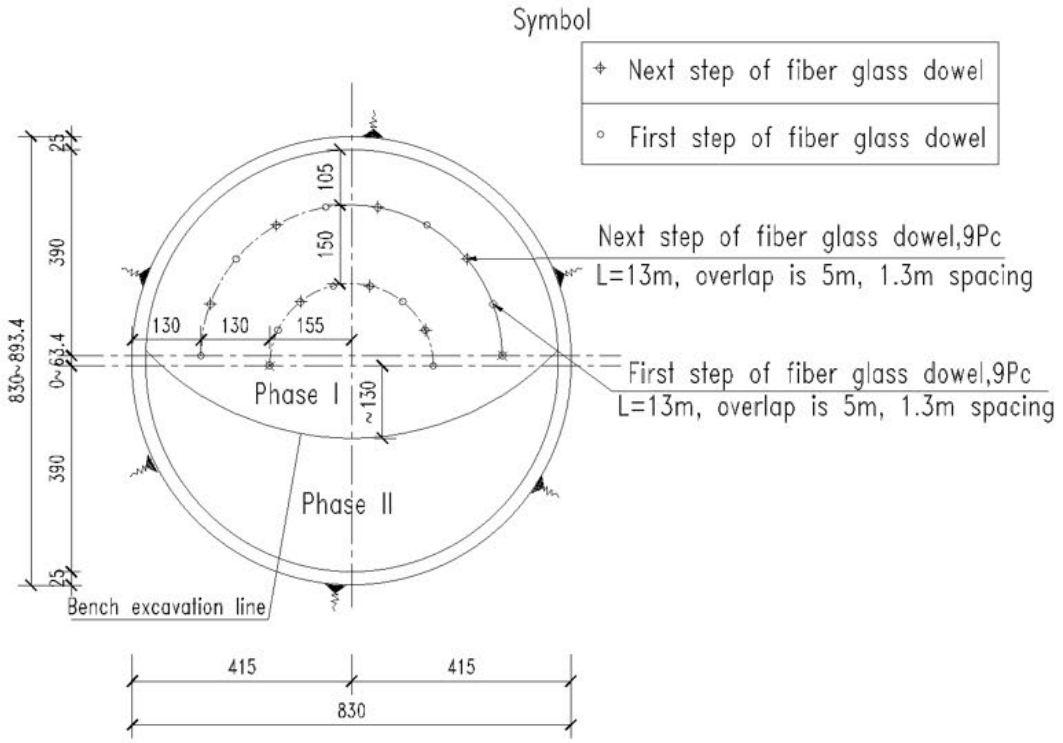
5. Examples and Application



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 supprt 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!