Method of determining grading deformation alert index of underground cavern complex and its application

Presented by: Jiayao (Michael) Wu
Finished by: Jiayao Wu, Quan Xu, Aiwu Cao, Weijiang Chu, Jiajin Liu.

Hydro-China Itasca R&D Center

Feb 19, 2020
OUTLINE

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1. Introduction

The judgment of the stability for caverns in rock mass can be estimated by critical strain $\varepsilon_{cr}$:

1. Sakurai (1997)

$$\varepsilon_{ci} = \frac{\sigma_{ci}}{E_i} \text{ (percent)}$$

$$\varepsilon_{cr} = \frac{\sigma_{cr}}{E_r} = \left(\frac{m}{n}\right)\varepsilon_{ci}$$


$$\varepsilon_{cr} = 1.073\sigma_{cr}^{-0.318}$$
2. Method to determination grade deformation alert value

- Underground cavern complex
  - Rock mass are not homogenous
  - Geology structure intersected
  - Influence to adjacent tunnels

How to determine the alert value for different monitor devices?
- different location, excavation stages
- extensometers, prisms, etc.

Numerical model
2. Method to determination grade deformation alert value

**Numerical model**

- Elastic
- Elastic-Plastic
- Strain-softening
- Finite element method
- Finite difference method
- Discrete element method
- Cavern complex interaction of rock/soil and support
- Sensitivity analysis computational efficiency
- Deformation Stress of rock mass/soil Stress of support
- Contours/tensor/vector

**Mechanical mechanism**

- Interpretation
- Complicated
- Repeatability
- Efficiency
- Quantification
- Visualization

**Hoek Brown**

\[ \sigma'_i = \sigma_3 + \sigma_{ci} \left( \frac{m_b}{\sigma_{ci}} + s \right) \]

**GSI** \( \sigma_{ci} \) \( m_b \)

\[ E_m (GPa) = \left( \frac{1 - D}{2} \right) \frac{\sigma_{ci}}{100} \cdot 10^{((GSI-10)/40)} \]

\[ m_b = m_t \exp \left( \frac{GSI-100}{28-14D} \right) \]

\[ s = \exp \left( \frac{GSI-100}{9-3D} \right) \]

\[ a = \frac{1}{2} + \frac{1}{6} \left( e^{-GSI/15} - e^{-20/3} \right) \]
2. Method to determine grade deformation alert value

3D numerical model of PH complex

\[ GSI_{\text{avr}} \quad \text{or} \quad GSI_{\text{low}} \]

- \( \text{disptoal}_{\text{avr}} \)
- \( \text{dispinc}_{\text{avr}} \)
- \( \text{disptoal}_{\text{max}} \)
- \( \text{dispinc}_{\text{max}} \)

Grading deformation alert index

<table>
<thead>
<tr>
<th>Safety level</th>
<th>Alert level 1</th>
<th>Alert level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>The monitor device pre-installed before excavation, the monitoring results is obtained the total displacement</td>
<td>( \text{disp}<em>{\text{mon}}^* &lt; \text{disptoal}</em>{\text{avr}} )</td>
<td>( \text{disptoal}<em>{\text{avr}} &lt; \text{disp}</em>{\text{mon}} &lt; \text{disptoal}_{\text{max}} )</td>
</tr>
<tr>
<td>The monitor device installed delayed, the monitoring results is obtained the displacement increment</td>
<td>( \text{disp}<em>{\text{mon}} &lt; \text{dispinc}</em>{\text{avr}} )</td>
<td>( \text{dispinc}<em>{\text{avr}} &lt; \text{disp}</em>{\text{mon}} &lt; \text{dispinc}_{\text{max}} )</td>
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<td>the cavern deformation meets expectations, and surrounding rock is stable</td>
<td>should be paid attention to the deformation of the cavern. It also needs to carry out denser monitoring and analyze the reason, study the additional support</td>
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Stability judgment of rock mass and the engineering countermeasures:
- the cavern deformation meets expectations, and surrounding rock is stable
- should be paid attention to the deformation of the cavern. It also needs to carry out denser monitoring and analyze the reason, study the additional support
- the deformation of the cavern is too large, and the additional reinforcement should be performed in time.
3. Application in Pumped Storage Project in Israel
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Rock lithology: Basalt, pyroclastic, etc.
Rock mass quality: Class III, IV.
In-situ stress: $S_{H_{\text{max}}}>S_{v}>S_{h}$, $S_{H_{\text{max}}}=1.5S_{v}$ (with a angle of 19° of the axial of PH)
3. Application in Pumped Storage Project in Israel

- In-situ stress condition;
- Rock mass constitutive (MC);
- Rock mass parameters (laboratory tests, geology mapping);
- Excavation sequence (sub-excavation steps);
- Support installing (cables, rock dowels and shotcrete)

Two separate models with $GSI_{\text{avr}}$ and $GSI_{\text{min}}$
### 3. Application in Pumped Storage Project in Israel

<table>
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<tr>
<th>Exaction stage</th>
<th>deformation increment $\delta$ in the crown of section B-B (unit/mm)</th>
<th>Safety level</th>
<th>Alert level 1</th>
<th>Alert level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$\delta \leq 14$</td>
<td>$14 &lt; \delta &lt; 18$</td>
<td>$\geq 18$</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>$\delta \leq 20$</td>
<td>$20 &lt; \delta &lt; 26$</td>
<td>$\geq 26$</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>$\delta \leq 25$</td>
<td>$25 &lt; \delta &lt; 32$</td>
<td>$\geq 32$</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>$\delta \leq 26$</td>
<td>$26 &lt; \delta &lt; 33$</td>
<td>$\geq 33$</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>$\delta \leq 27$</td>
<td>$27 &lt; \delta &lt; 34$</td>
<td>$\geq 34$</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>$\delta \leq 28$</td>
<td>$28 &lt; \delta &lt; 36$</td>
<td>$\geq 36$</td>
<td></td>
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#### Stability judgment of rock mass and the engineering countermeasures

- The cavern deformation meets expectations, and surrounding rock is stable.
- Should be paid attention to the deformation of the cavern. It also needs to carry out denser monitoring and analyze the reason, study the additional support.
- The deformation of the cavern is too large, and the additional reinforcement should be performed in time.

- The alert value could be estimate for each monitor point;
- Dynamic adjust according to the new information of geology exposed and back analyzed results.

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4. Discussion and Conclusion

I. Cavern group effect, excavation support scheme, etc., can be reflected with this method.

II. Besides the deformation alert value, support force (load of tendons) also could be established.

III. The stability characteristic of caverns should be determined the safety margin of support, the EDZ depth comprehensively.

IV. Due to variation of the lithological and the existing of the faults, in-situ stress may have abnormal features locally, therefore, the application of deformation alert index needs to consider the impact of this factor according to specific conditions.
Thank you for your attention!

Email: jwu@itasca.cc