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

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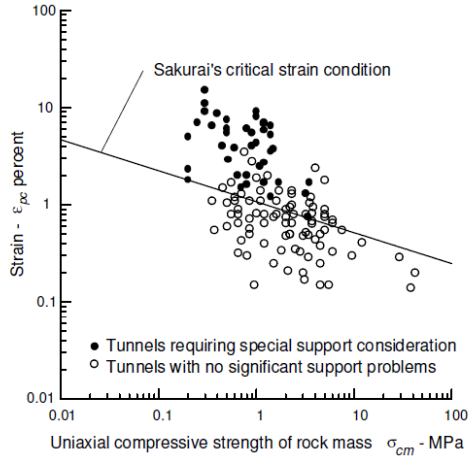
1. Introduction

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

1.Sakurai（1997）

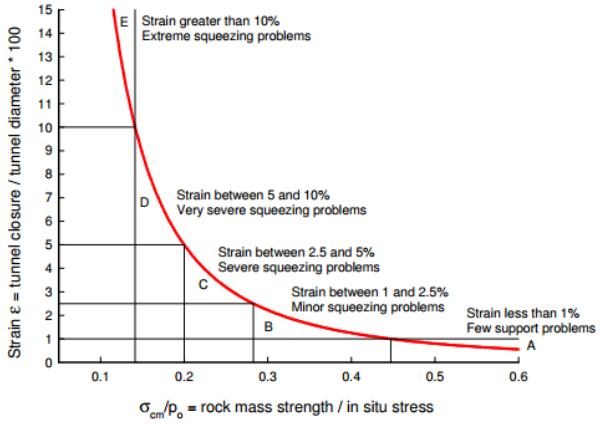
$$\varepsilon_{ci} = \frac{\sigma_{ci}}{E_i}(percent)$$

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

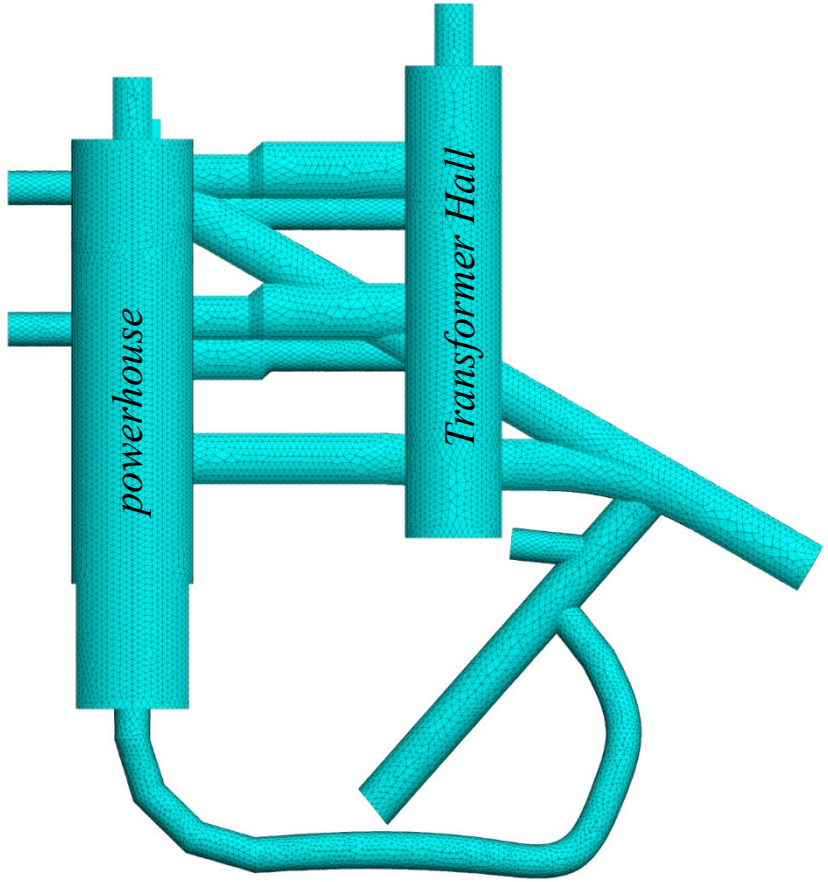


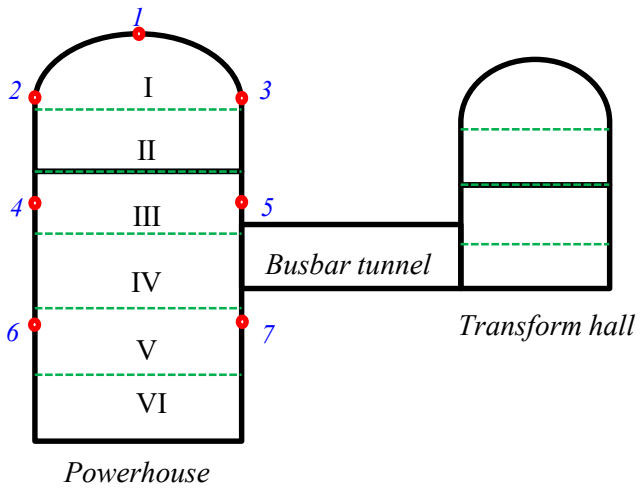
2.Hoek（2000）

$$\varepsilon_{cr} = 1.073\sigma_{cr}^{-0.318}$$



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.

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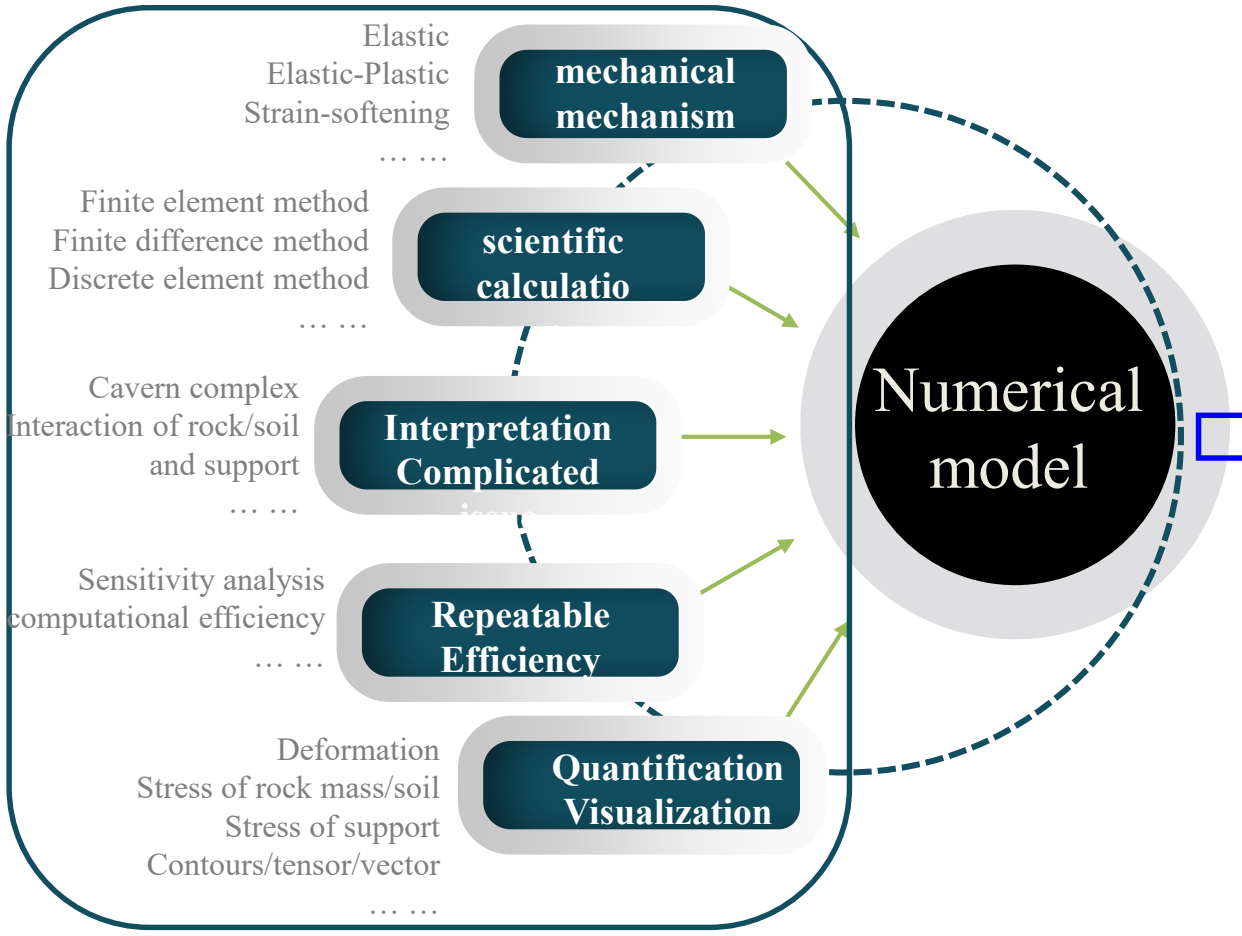
Numerical model

2. Method to determination grade deformation alert value



Hoek Brown

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a$$

GSI ***σ_{ci}*** ***mi***

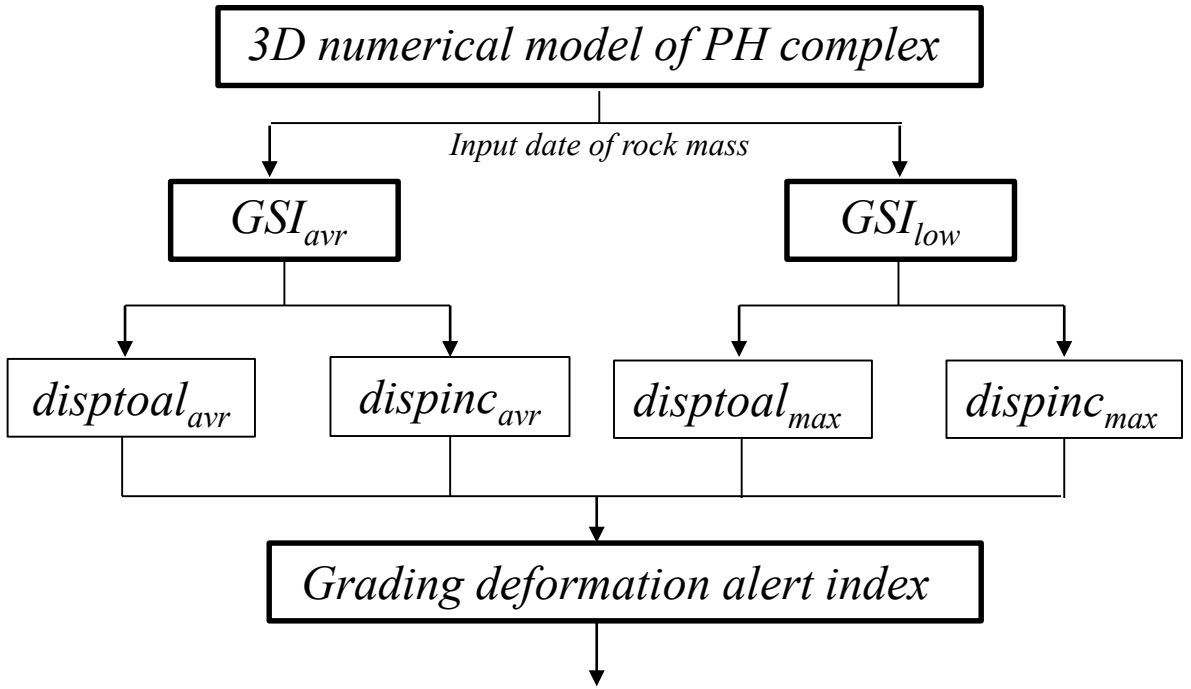
$$E_m(GPa) = \left(1 - \frac{D}{2}\right)\sqrt{\frac{\sigma_{ci}}{100}} \cdot 10^{((GSI-10)/40)}$$

$$m_b = m_i \exp\left(\frac{GSI-100}{28-14D}\right)$$

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

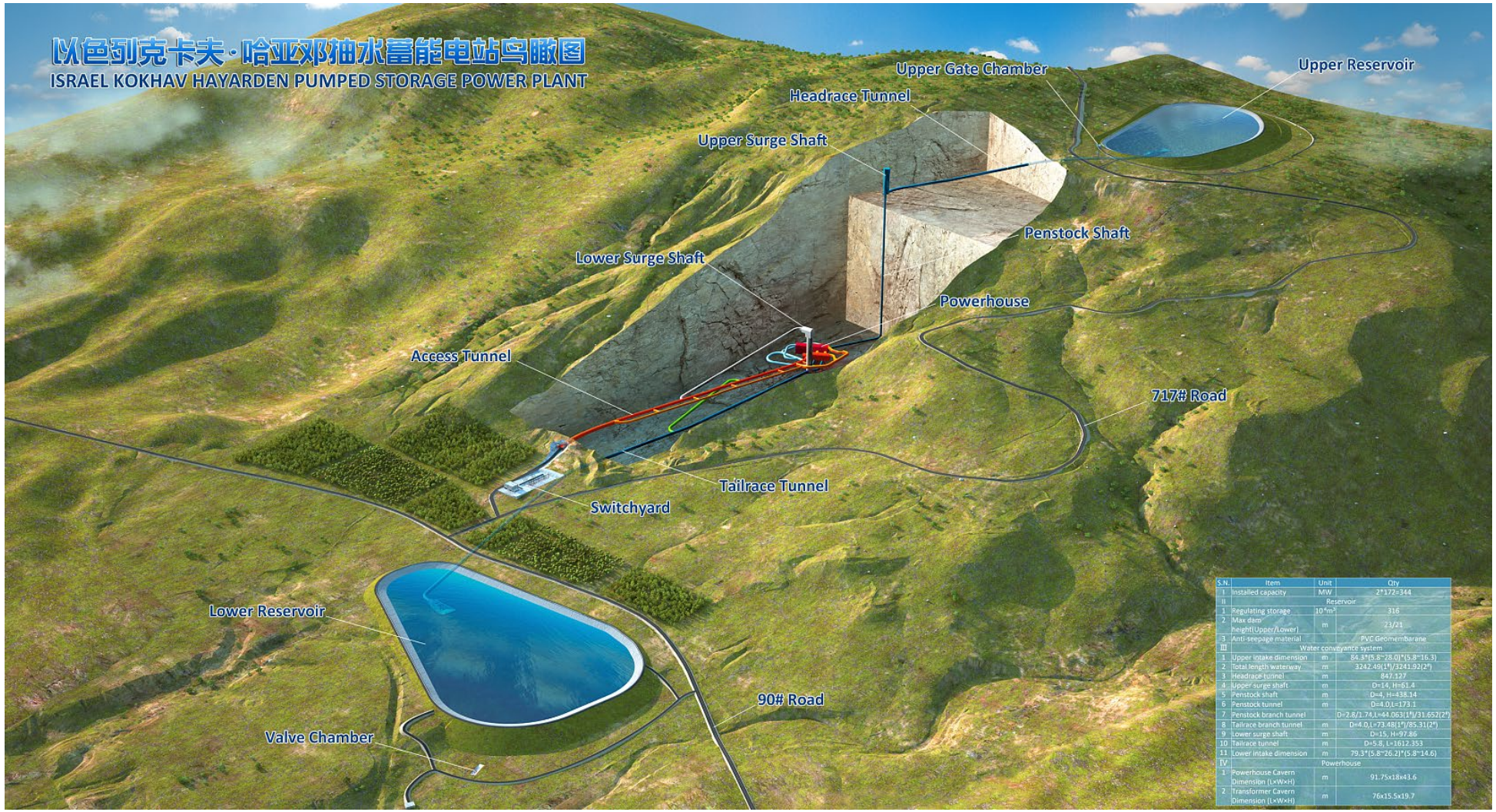
$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right)$$

2. Method to determination grade deformation alert value



	Safety level	Alert level 1	Alert level 2
The monitor device pre-installed before excavation, the monitoring results is obtained the total displacement	$disp_{mon}^{*} < disptoal_{avr}$	$disptoal_{avr} < disp_{mon} < disptoal_{max}$	$disp_{mon} > disptoal_{max}$
The monitor device installed delayed, the monitoring results is obtained the displacement increment	$disp_{mon} < dispinc_{avr}$	$dispinc_{avr} < disp_{mon} < dispinc_{max}$	$disp_{mon} > dispinc_{max}$
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



S.N.	Item	Unit	Qty
I	Installed capacity	MW	2*172=344
II	Reservoir		
1	Regulating storage	10^4m^3	316
2	Max dam height(Upper/Lower)	m	23/21
3	Anti-seepage material		PVC Geomembarane
III	Water conveyance system		
1	Upper intake dimension	m	84.3*(5.8~28.0)*(5.8~16.3)
2	Total length waterway	m	3242.49(1#)/3241.92(2#)
3	Headrace tunnel	m	847.127
4	Upper surge shaft	m	D=14, H=61.4
5	Penstock shaft	m	D=4, H=438.14
6	Penstock tunnel	m	D=4.0,L=173.1
7	Penstock branch tunnel		D=2.8/1.74,L=64.063(1#)/31.652(2#)
8	Tailrace branch tunnel	m	D=4.0,L=73.48(1#)/85.31(2#)
9	Lower surge shaft	m	D=15, H=97.86
10	Tailrace tunnel	m	D=5.8, L=1612.353
11	Lower intake dimension	m	79.3*(5.8~26.2)*(5.8~14.6)
IV	Powerhouse		
1	Powerhouse Cavern Dimension (L×W×H)	m	91.75x18x43.6
2	Transformer Cavern Dimension (L×W×H)	m	76x15.5x19.7

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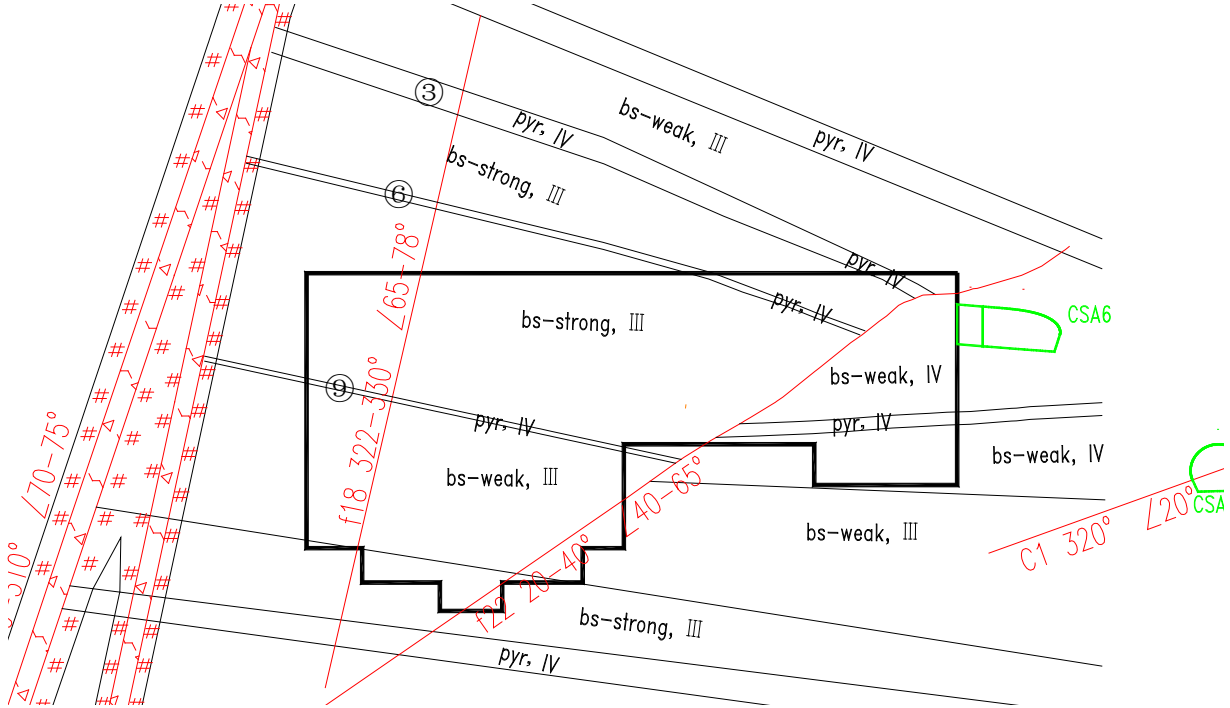
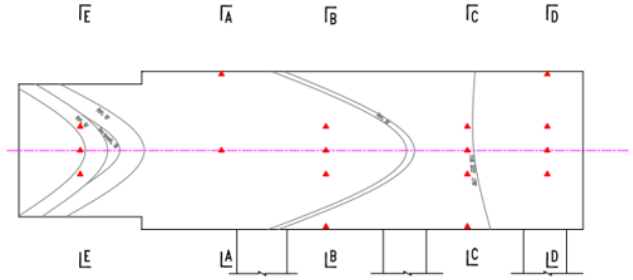
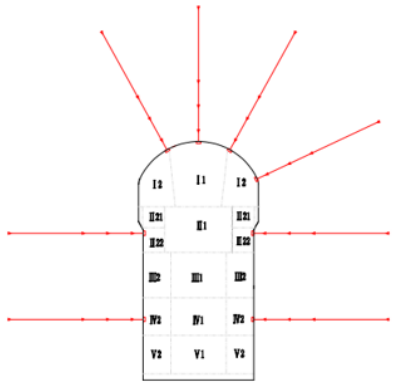




a. Layout of monitor of powerhouse



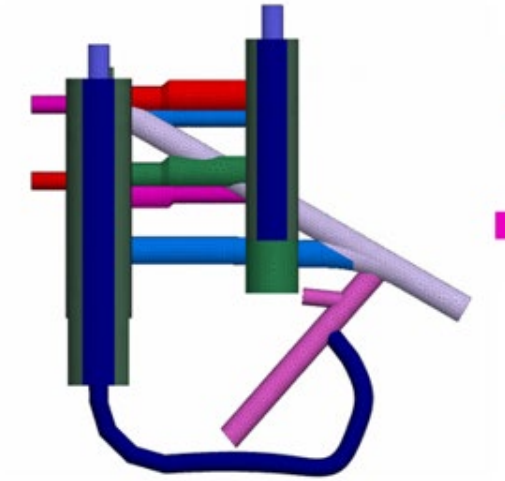
b. Extensometer of typical section B-B

Rock lithology: Basalt, pyroclastic, etc.

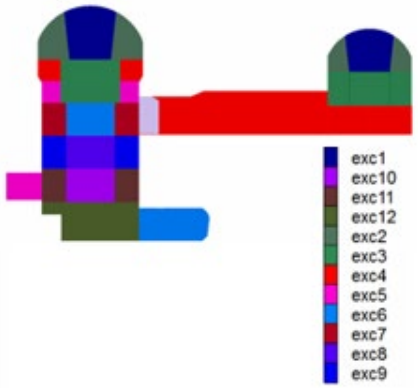
Rock mass quality: Class III,IV.

In-situ stress: $S_{Hmax}>S_v>S_h$, S_{Hmax} =1.5Sv (with a angle of 19° of the axial of PH)

3. Application in Pumped Storage Project in Israel



Excavation parts of PH complex(top view)



12 excavation substeps of PH

Lithology	Rock classification	$\sigma_{ci(MPa)}$	m_i	average value of GSI	minimum value of GSI
bs-strong	III	101.3	12	55	50
bs-weak	III	50.81	12	50	45
	IV	33.90	9	40	35
pyroclastic	IV	8.80	12	35	30
	V	5.30	3	20	15

Take monitor point A for an example. For all the 11 lithology in the left figure:

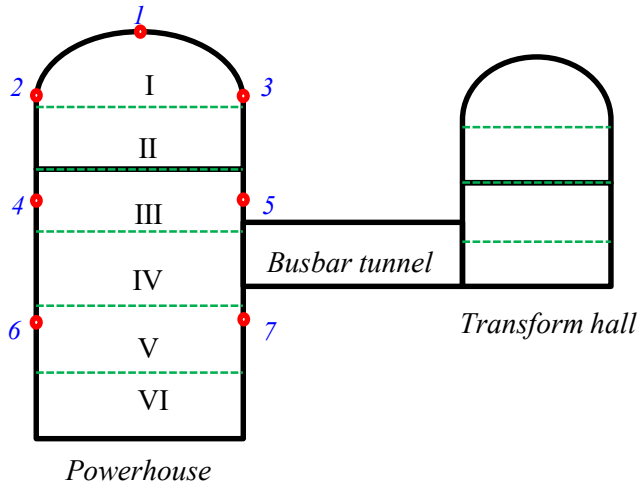
1. *take the average value of GSI in above table, $dispinc_{avr}$ can be obtained, which is means the upper limit value of alert level 1 for each sub-excavation stage;*
2. *take the minimum value of GSI in above table, $dispinc_{max}$ can be obtained, which is means the lower limit value of alert level 2 for each sub-excavation stage.*

- 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_{avr} and GSI_{min}

3. Application in Pumped Storage Project in Israel

Exaction stage	deformation increment δ in the crown of section B-B(unit/mm)		
	Safety level	**Alert level 1**	**Alert level 2**
I	δ≤14	14<δ<18	≥18
II	δ≤20	20<δ<26	≥26
III	δ≤25	25<δ<32	≥32
IV	δ≤26	26<δ<33	≥33
V	δ≤27	27<δ<34	≥34
VI	δ≤28	28<δ<36	≥36
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.

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!

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