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Application of Temporal and Spatial Characteristics of Shotcrete Mechanics in Middle East Pumping Storage Project

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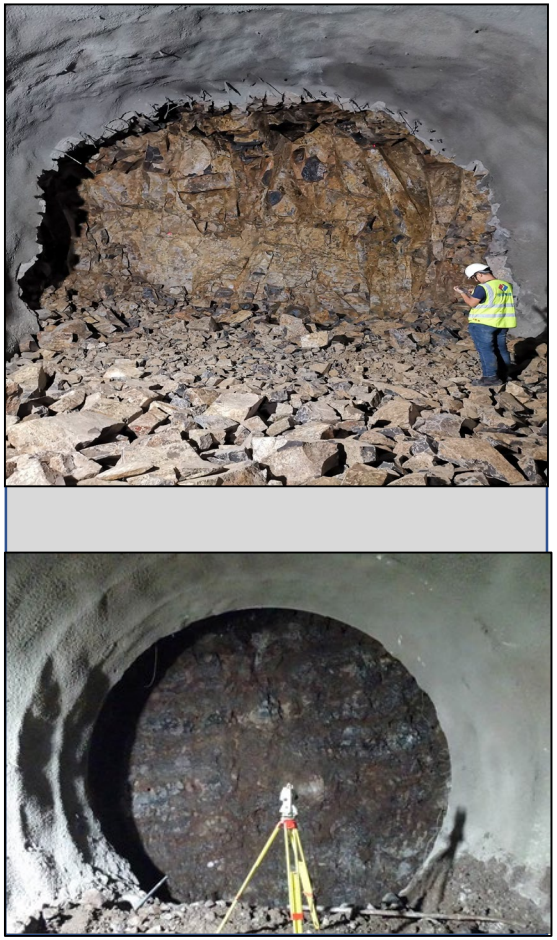
content



1 Introduction

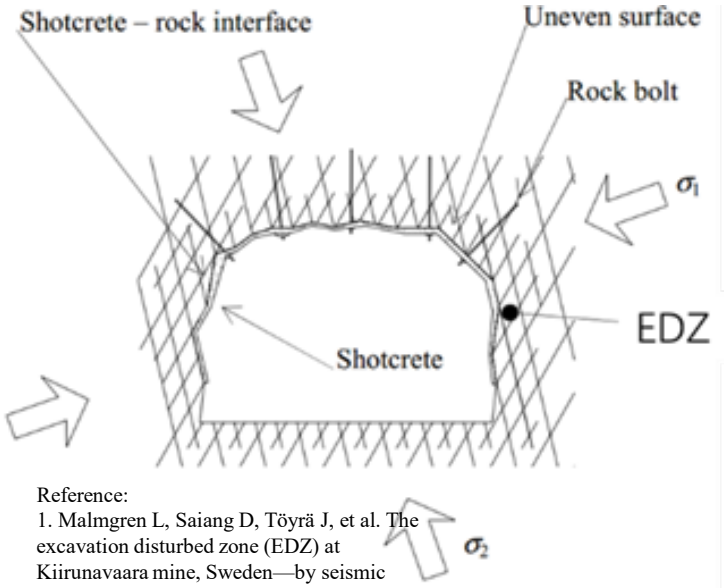
2 Design and Analysis of shotcrete

3 The evaluation of the internal force of shotcrete

4 The engineering application

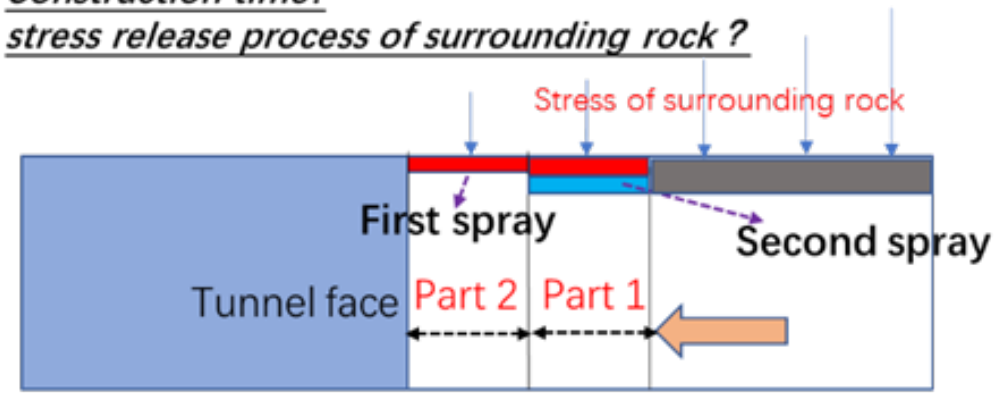
5 Discussion

1. Intruduction



Reference:
1. Malmgren L, Saiang D, Töyrä J, et al. The excavation disturbed zone (EDZ) at Kiirunavaara mine, Sweden—by seismic measurements[J]. Translated World Seismology, 2007, 61(1):1-15.

Concrete raising time ?
Construction time?
stress release process of surrounding rock ?



The stress adjustment of the shotcrete during construction has very complicated time and space effect:

- Concrete raising time
- Construction time
- Stress release process of surrounding rock

… so on

How to design the shotcrete?

2. Design and Analysis of Shotcrete

Common design methods:

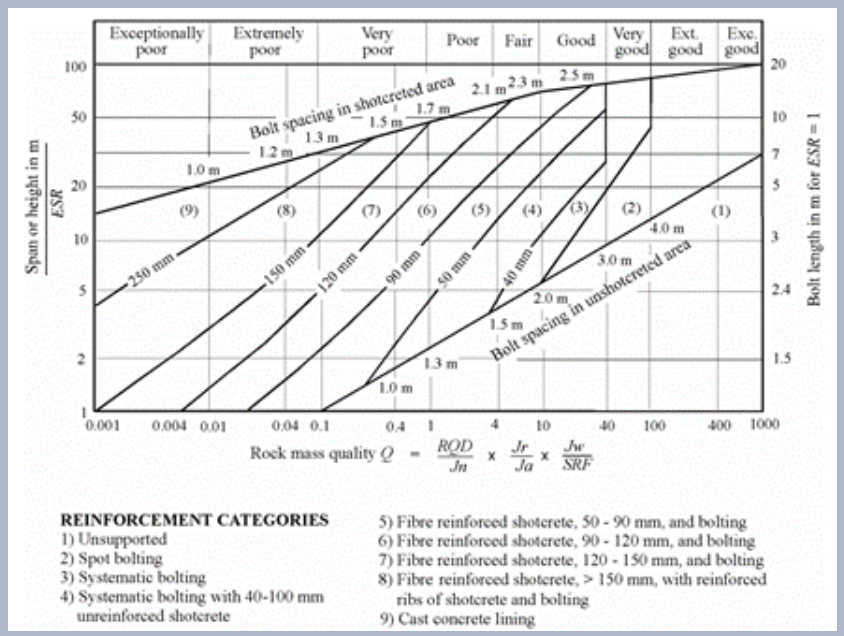
- Engineering analogy method;
- empirical design method;
- numerical calculation method.

Can consider many factors

- ✓ EDZ
- ✓ Construct time
- ✓ Concrete raise time
- ✓ Shotcrete parameters
- ✓ Complex shape of tunnel

…so on

Common empirical design method: **Q system**



Reference:
2. Hoek E, Kaiser P K, Bawden W F. Support of underground excavations in hard rock[M]. CRC Press, 2000

2. Design and Analysis of Shotcrete

Main Problems in Numerical calculation:

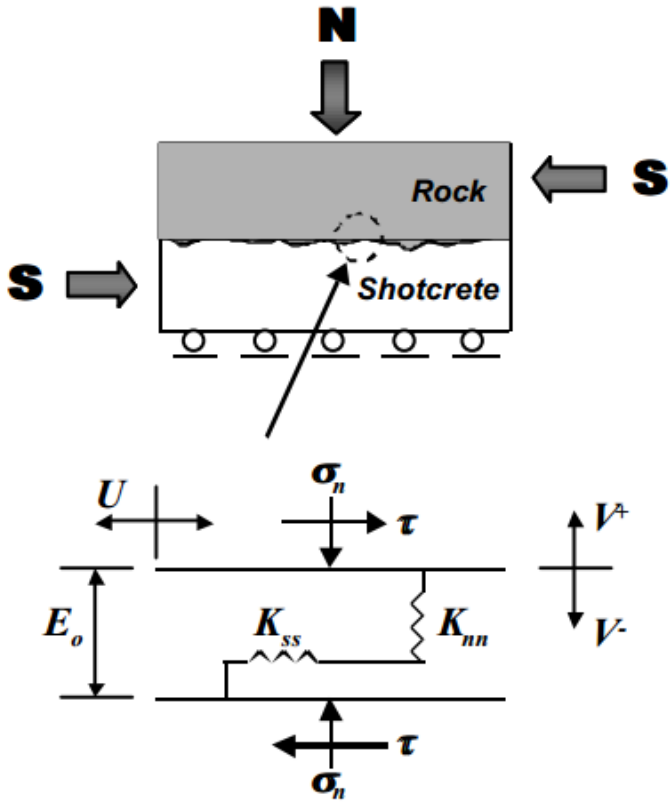
- How to determine Mechanical parameters of shotcrete ?
- How to evaluate the internal force of shotcrete ?
- How to determine the parameters of rock ?
- How to determine the range of EDZ ?
- How to determine the in-situ stress ?
- .. So on.

Highlights of this article

2. Design and Analysis of Shotcrete

Main Problems in Numerical calculation:

- How to determine Mechanical parameters of shotcrete ?



Schematic diagram

$$M_{shot,t} = M_{shot,0} \cdot (1 - e^{-\alpha t})$$

Gyu-jin Base (2004) has done a lot of experiments on the parameters of the contact between the shotcrete and the surrounding rock and got the correlation between the mechanical parameters of the shotcrete itself (elastic modulus E and uniaxial compressive strength σ_c) and the mechanical parameters of the contact between the surrounding rock and the shotcrete (K_n, K_s, c, f) and time-effect.

Reference:

3. Bae G J , Chang S H , Lee S W , et al. Evaluation of interfacial properties between rock mass and shotcrete[J]. International Journal of Rock Mechanics & Mining Sciences, 2004, 41(3):106-112.

2. Design and Analysis of Shotcrete

Main Problems in Numerical calculation:

- How to determine Mechanical parameters of shotcrete ?

$$M_{shot,t} = M_{shot,0} \cdot (1 - e^{-\alpha t})$$

D. Saiang (2005) [4]

Table 1 Laboratory test results of mechanical parameters of the contact surface between shotcrete and surrounding rock

parameters	JRC=1-3	JRC=9-13
f_{inter}	Peak value: 40°; residual value35°	Peak value: 47°; residual value 39°
c_{inter}	0.56MPa	/
$K_{s,inter}$	251MPa/mm	/
$K_{n,inter}$	0.94MPa/mm	1.3MPa/mm

note: JRC is roughness grade divided according to Barton (1997).

Reference:
[4] Saiang D , Malmgren L , Nordlund E . Laboratory Tests on Shotcrete-Rock Joints in Direct Shear, Tension and Compression[J]. Rock Mechanics and Rock Engineering, 2005, 38(4):275-297

3. The evaluation of the internal force of shotcrete

Main Problems in Numerical calculation:

- How to evaluate the internal force of shotcrete ?

The force analysis of shotcrete mainly need to consider two cases:

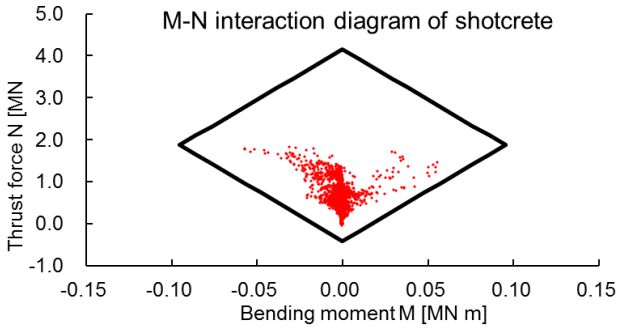
shotcrete and rock dowels support;

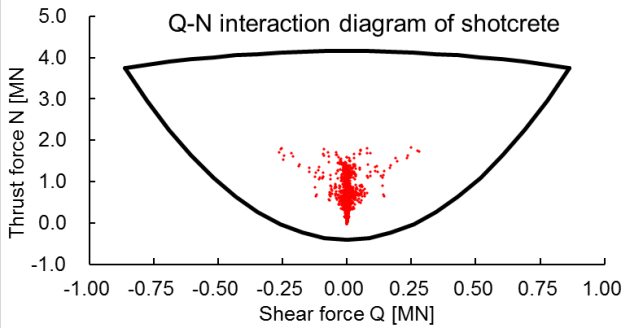
combined support of shotcrete, rock dowels and steel arch.

Want to get

Strength envelope for compression, tension and shear

And displacement plastic zone rock dowels stress and so on.





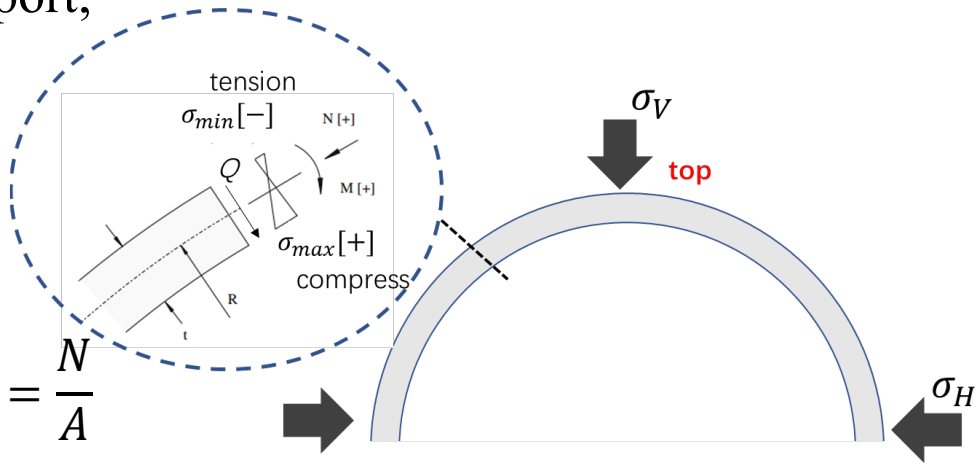
3. The evaluation of the internal force of shotcrete

Main Problems in Numerical calculation:

- How to evaluate the internal force of shotcrete ? [5]

shotcrete and rock dowels support;

$$\begin{cases} \sigma_c^t = \dfrac{N}{A} \pm \dfrac{M}{I} t/2 \\ \tau_{max} = \dfrac{3}{2}\dfrac{Q}{A} \\ \sigma_c^t = \dfrac{\sigma_{max}}{2} \pm \sqrt{\left(\dfrac{\sigma_{max}}{2}\right)^2 + \tau_{max}^2} \end{cases} ; \sigma_{max} = \frac{N}{A}$$



$$\begin{cases} N_c = -\dfrac{|M|At}{2I} + \sigma_c A \\ N_t = -\dfrac{|M|At}{2I} + \sigma_t A \end{cases} \Rightarrow \begin{cases} N_c = -\dfrac{9}{4}\dfrac{Q^2}{\sigma_c A} + \sigma_c A \\ N_t = -\dfrac{9}{4}\dfrac{Q^2}{\sigma_t A} + \sigma_t A \end{cases}$$

Reference:

5。 Carranza-Torres C , Diederichs M . Mechanical analysis of circular liners with particular reference to composite supports. For example, liners consisting of shotcrete and steel sets[J]. Tunneling and Underground Space Technology, 2009, 24(5):506-532.

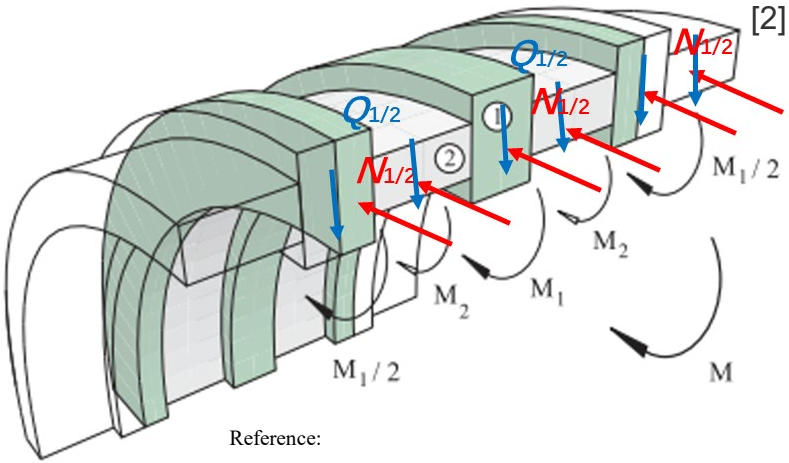
3. The evaluation of the internal force of shotcrete

Main Problems in Numerical calculation:

- How to evaluate the internal force of shotcrete ? [5]

combined support of shotcrete, rock dowels and steel arch.

$$\begin{cases} M_1 = \dfrac{MK_1}{n(K_1+K_2)} \\ M_2 = \dfrac{MK_2}{n(K_1+K_2)} \end{cases} \qquad \begin{cases} Q_1 = \dfrac{QK_1}{n(K_1+K_2)} \\ Q_2 = \dfrac{QK_2}{n(K_1+K_2)} \end{cases}$$



[2]

$$\begin{cases} N_1 = \dfrac{N}{n}\dfrac{D_1}{(D_1+D_2)} + \dfrac{M}{nR}\dfrac{D_2K_1 - D_1K_2}{(D_1+D_2)(K_1+K_2)} \\ N_2 = \dfrac{N}{n}\dfrac{D_2}{(D_1+D_2)} - \dfrac{M}{nR}\dfrac{D_2K_1 - D_1K_2}{(D_1+D_2)(K_1+K_2)} \end{cases}$$

Reference:

4。 Carranza-Torres C , Diederichs M . Mechanical analysis of circular liners with particular reference to composite supports. For example, liners consisting of shotcrete and steel sets[J]. Tunneling and Underground Space Technology, 2009, 24(5):506-532.

Note: "1" and "2" represent the shotcrete and the steel arch respectively

4. The engineering application

Rock layer:

① bs-strong III rock mass (Dense basalt);
② bs-weak III/IV rock mass (stomatal, almond-shaped basalt);
③ pyr III/ IV rock mass (breccia);
④ clay V rock mass;

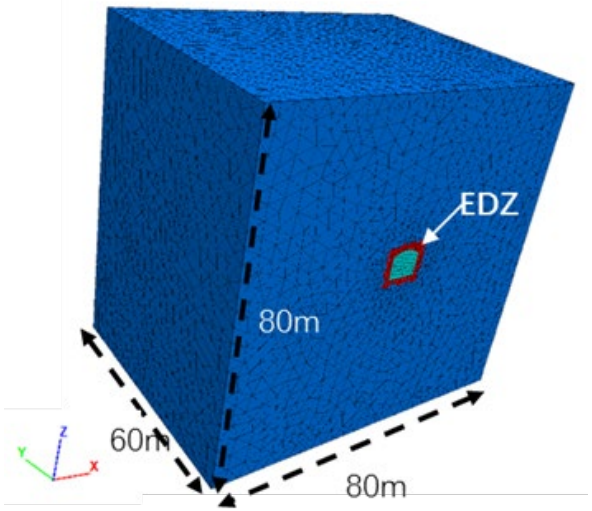
Mechanical parameters of rock mass in engineering area

Rock layer	Rock mass	Density/kN·m³	σ_{ci} /MPa	GSI	mi	u
bs-weak	Ⅲ	2.60	50	50.81	12	0.26
bs-weak	Ⅳ	2.35	40	31.34	9	0.285
Rock layer	**Rock mass**	**Density/kN·m³**	***E*/MPa**	***F***	**C/MPa**	**u**
clay	Ⅴ	1.9	300	0.25	0.03	0.33

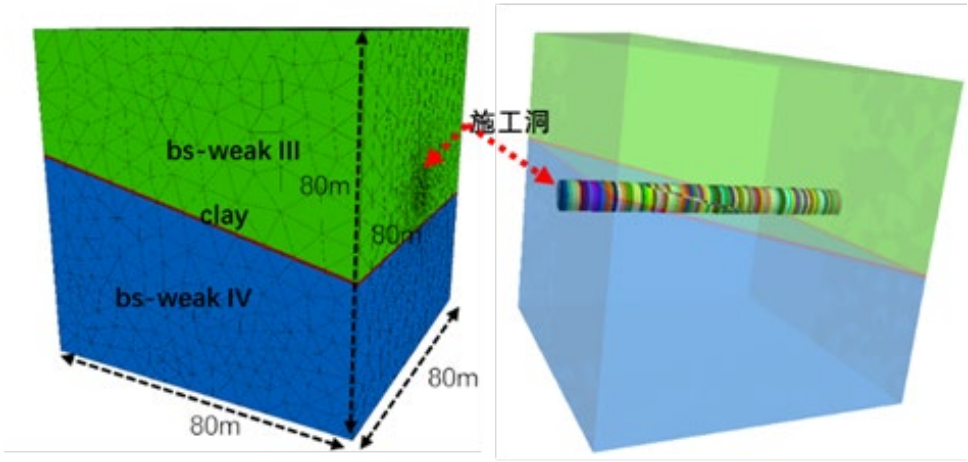
4. The engineering application

Support design parameters

Rock layer	Rock mass	Thickness of shotcrete (B40+steel fiber) /cm	Rock dowels	Steel arch
bs-weak	III	15	Ø25@1.5m×1.5m L=3.0m	/
bs-weak	IV	25	Ø25@1.2m×1.2m L=4.5m	/
clay	V	25	Ø25@1.0m×1.0m L=4.5m	I18@100cm



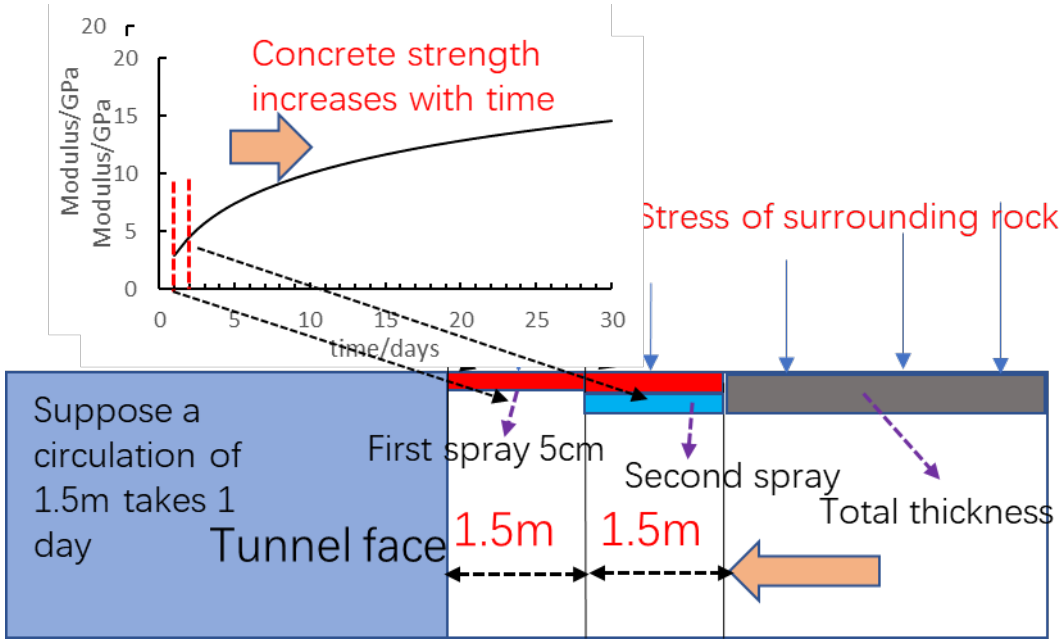
Calculation models for shotcrete design III.IV rock mass



Calculation models for shotcrete design in clay class V rock mass

4. The engineering application

- **Calculated assuming:**



Considered:

- ✓ **EDZ**
- ✓ **Construct time**
- ✓ **Concrete raise time**
- ✓ **Shotcrete parameters**

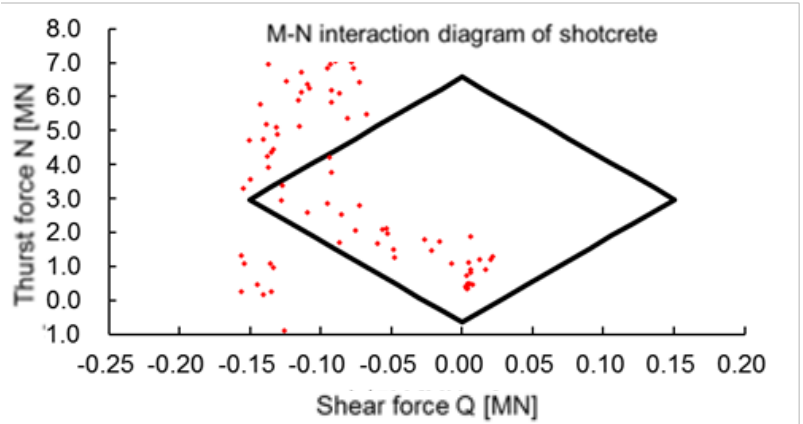
...so on

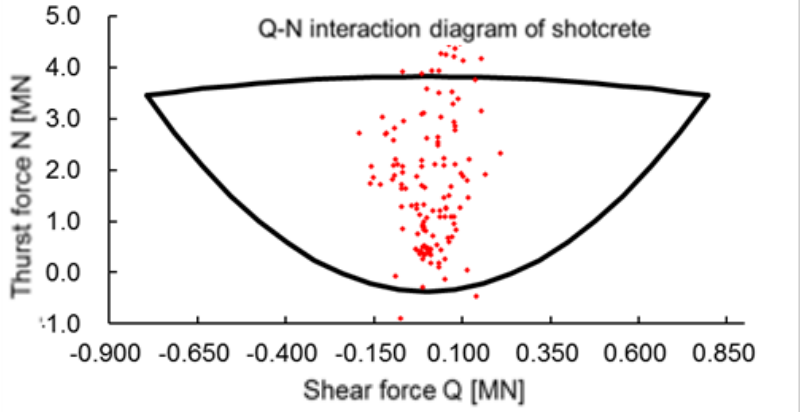
Note: the numerical results of bs-weak IV rock mass and clay V rock mass will be list.

4. The engineering application

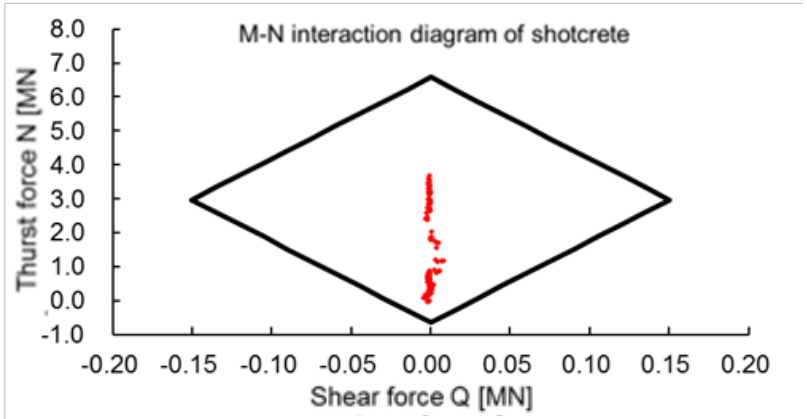
- **Numerical result ----bs weak IV rock mass**

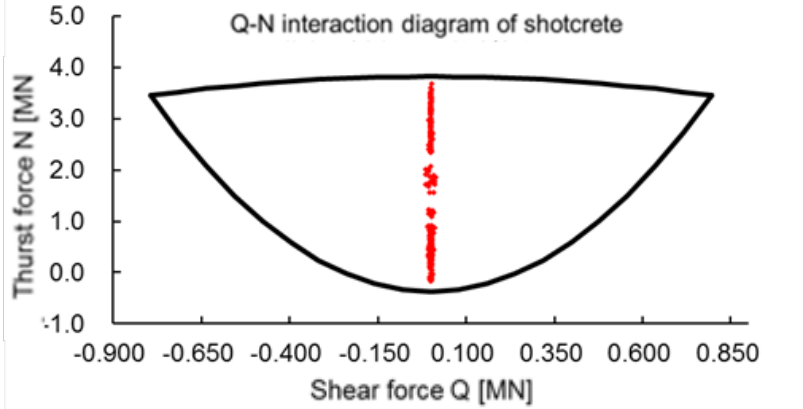
don't considered the time and space effect





considered the time and space effect

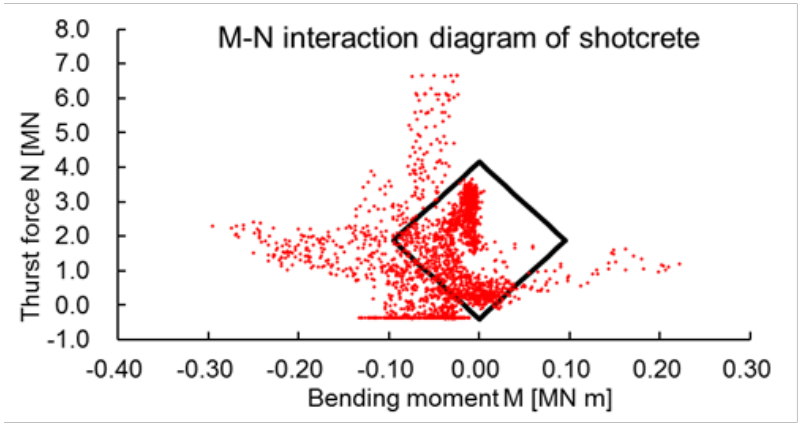


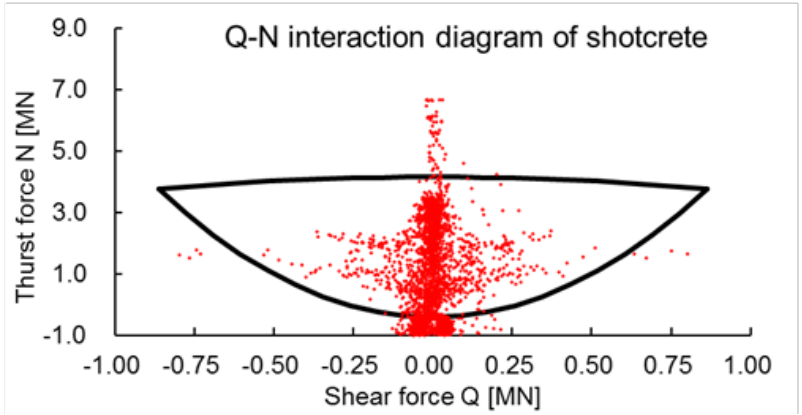


4. The engineering application

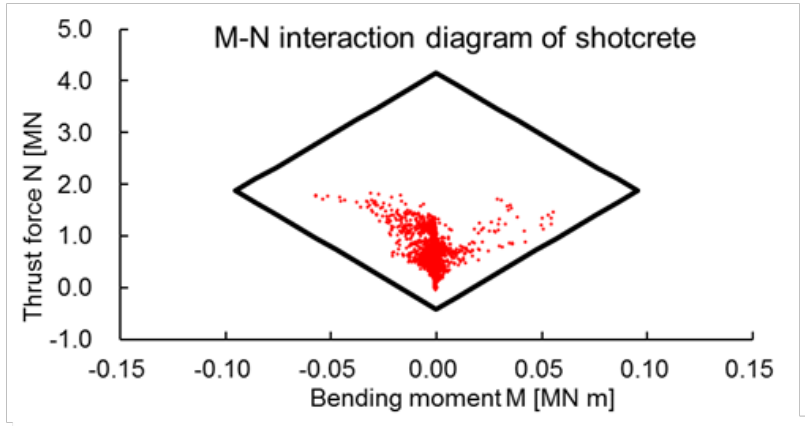
- **Numerical result—clay V rock mass**

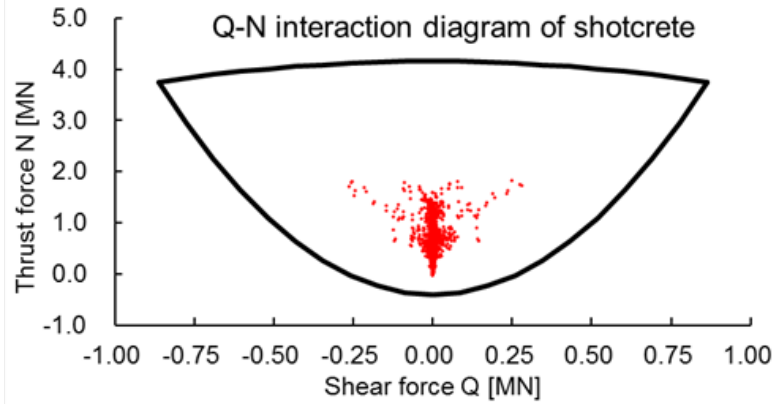
don't considered the time and space effect





considered the time and space effect





5. Discussion

1. As an important supporting type in underground caverns, the shotcrete has complex time and space effects in the process of construction, such as the mechanical properties of the shotcrete itself and the mechanical properties of the contact between the surrounding rock and the spray layer.

2. It is necessary to consider the time and space effect imposed by the shotcrete in the support design and calculation, otherwise, the load borne by the shotcrete will be overestimated by 3-5 times;

3. The practice of the tunnel support design of the Kokhav Hayarden pumping water storage power station in Israel indicates the rationality of the design calculation method considering the time and space effect imposed by the shotcrete.

4. However, the time and space effects of the mechanical parameters of the contact surface between the surrounding rock and the shotcrete have not been taken into account in this study, which will be further explored in subsequent studies.

THANKS