Rock Mass Behaviour during Excavation of China Jinping Underground Laboratories (CJPL-II) with Overburden of 2400 m

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2016.12.15

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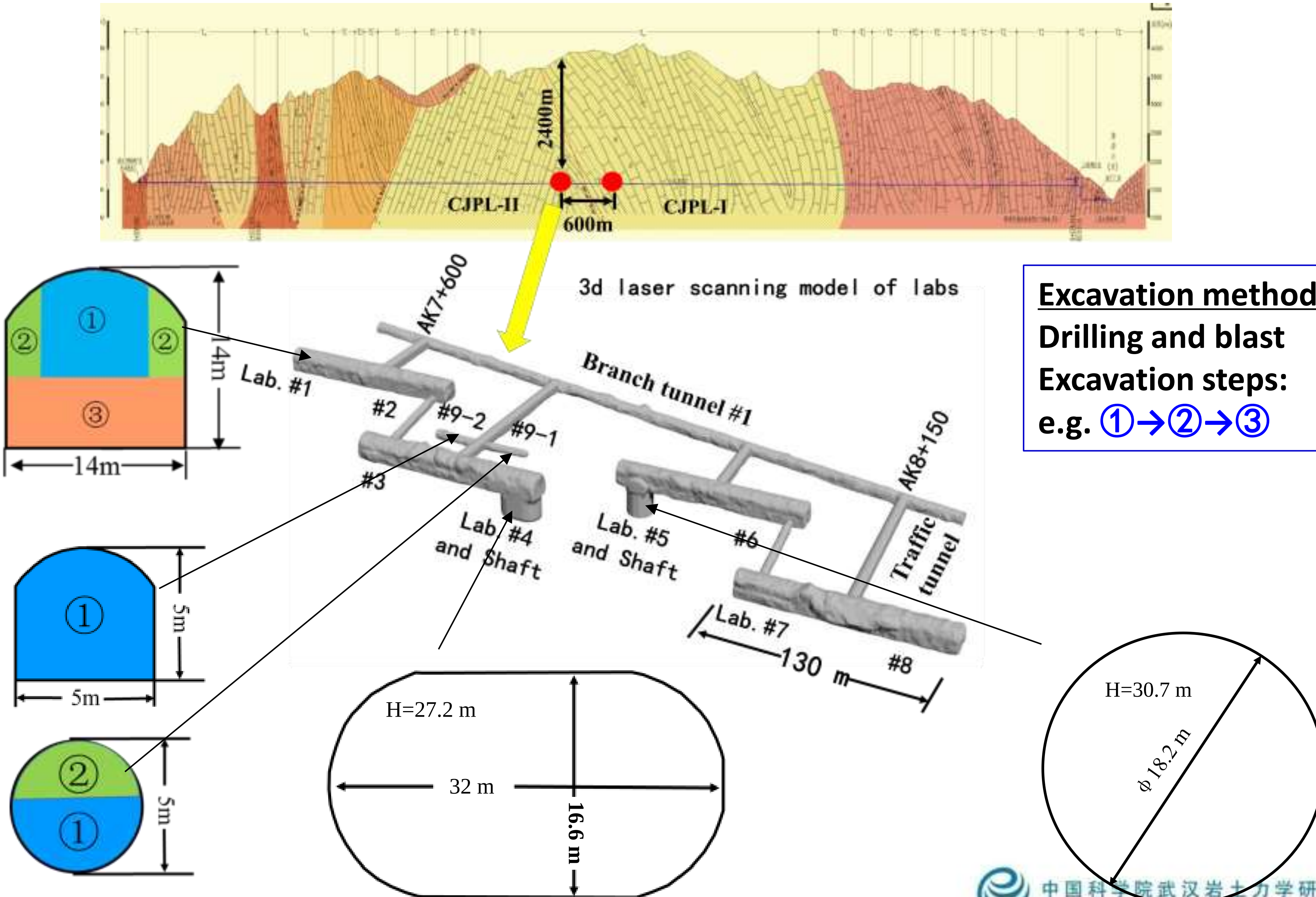
1. Introduction of CJPL-II

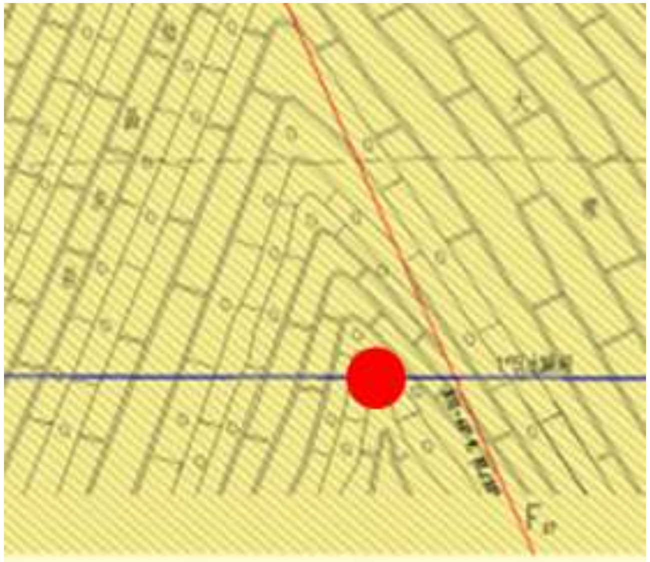
- Xichang City, Sichuan Province
- Middle of Jinping traffic tunnel A
- Marble
- Overburden 2400m
- Stress up to 70MPa

1.1 Project layout of CJPL-II



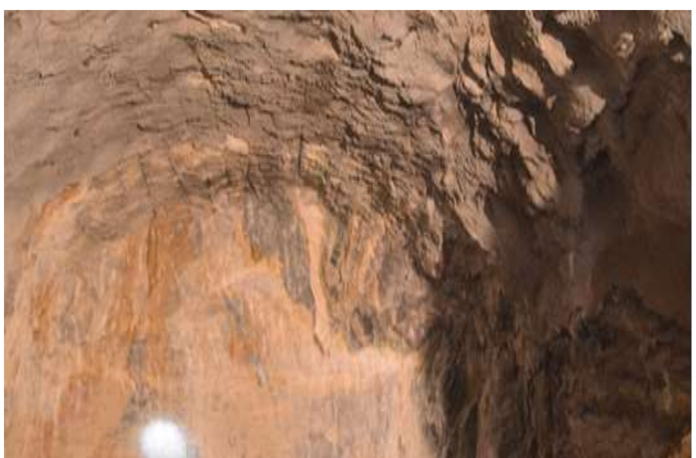
Excavation method:
Drilling and blast
Excavation steps:
e.g. ①→②→③

1.2 Geological setting of CJPL-II



Location in the middle of an anticline structure

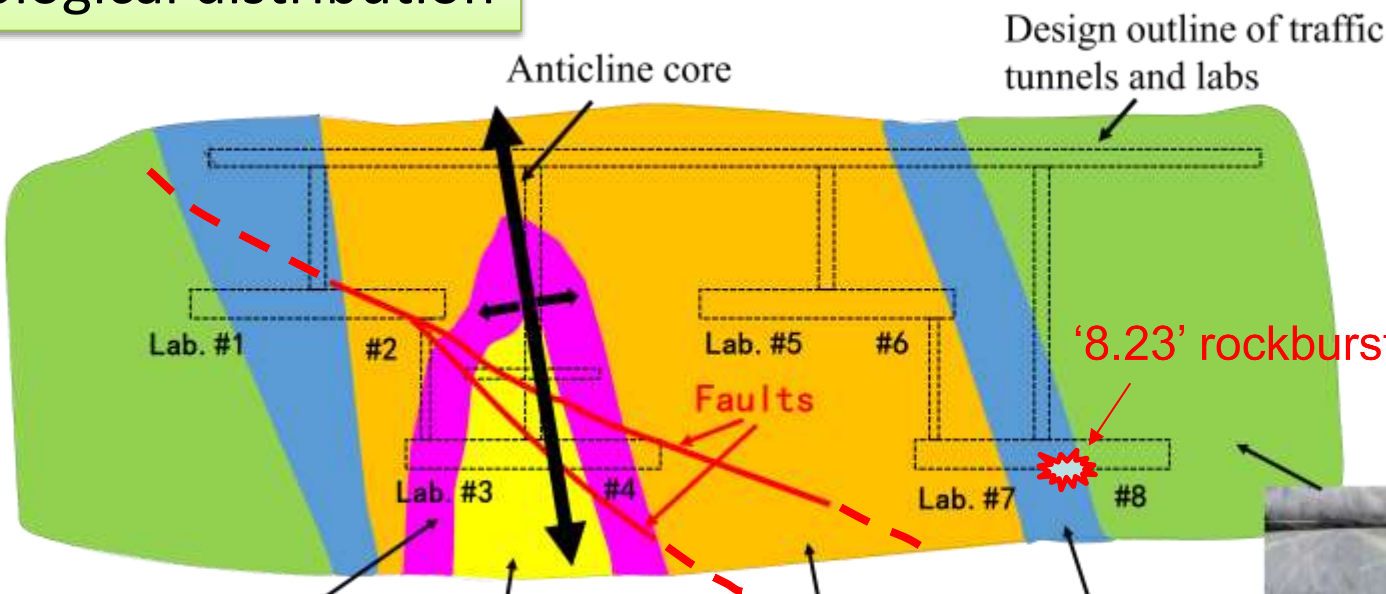
- Hard intact — original rock mass
- Alteration fractured — original rock mass
- Change of rock mass structure occurred due to cavern excavation (High stress released or redistributed)



Alteration fractured zone in 2# access tunnel

Rock altered into mud

Lithological distribution



Black-grey infilled white Calcite belts fine grain marble UCS:150-170 MPa

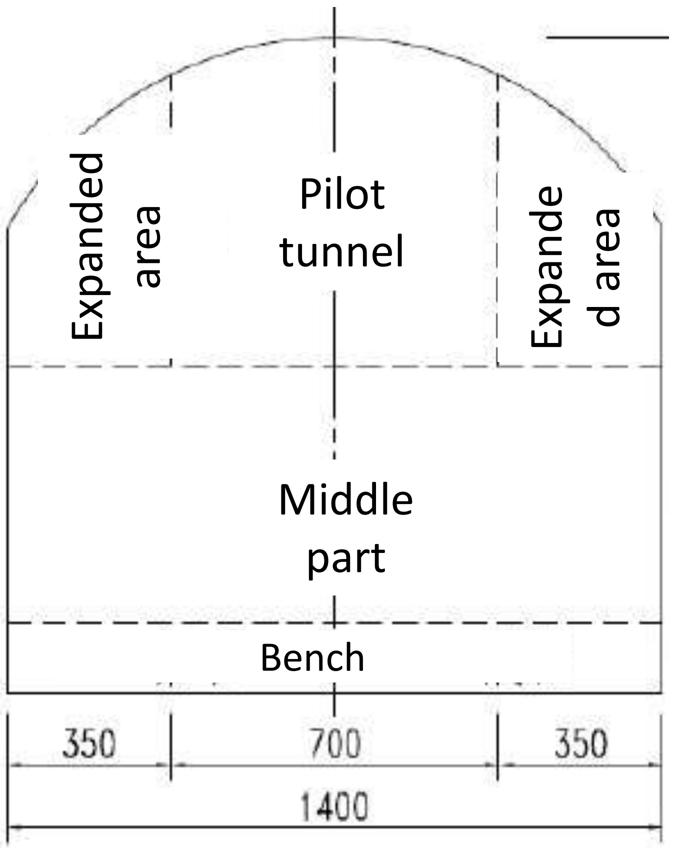
Black-grey with meat red fine grain marble UCS: 80-100 MPa

Multiple-Color fine grain marble UCS:60-120 MPa

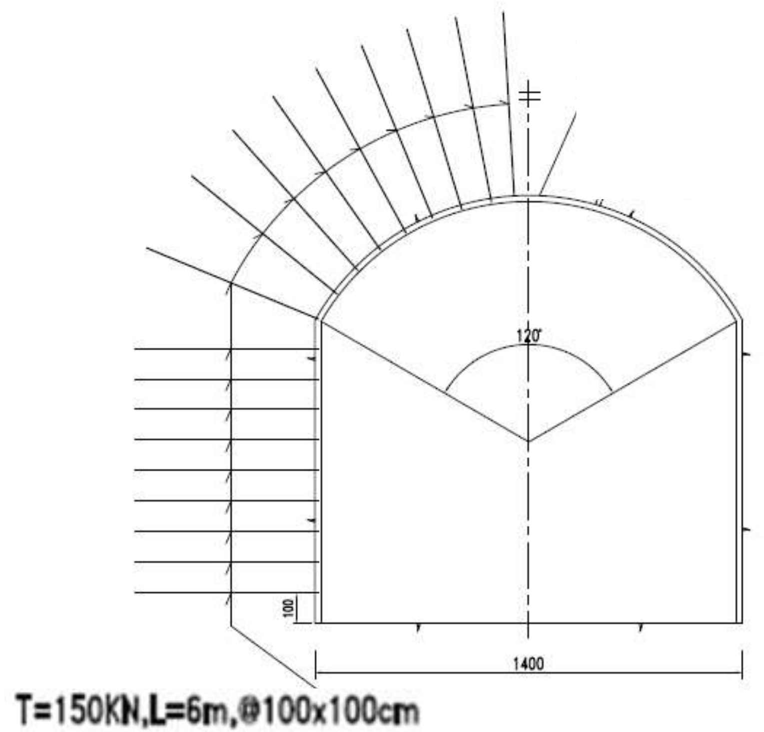
Grey-white fine grain marble UCS: 80-120 MPa

Black-grey with white belts or stripes fine grain marble UCS:180-190 MPa

1.3 Excavation and support



- Excavated in marble by D&B



Excavation scheme:

Three layers, top heading (8.5m) with pilot tunnel, middle of 4.5m, bench with 1.0 m

Support scheme:

- Rock bolt Anchored
- Shotcreted (20 cm thick)
- Lining is unexpected

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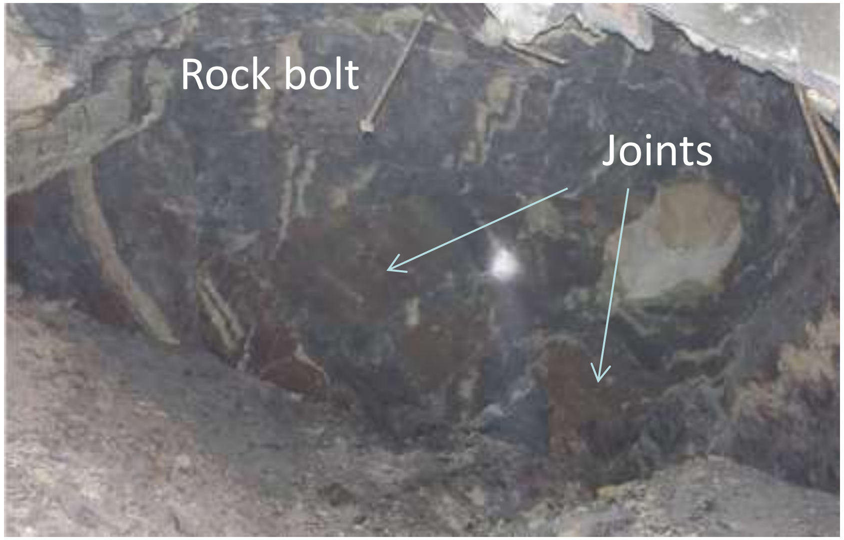
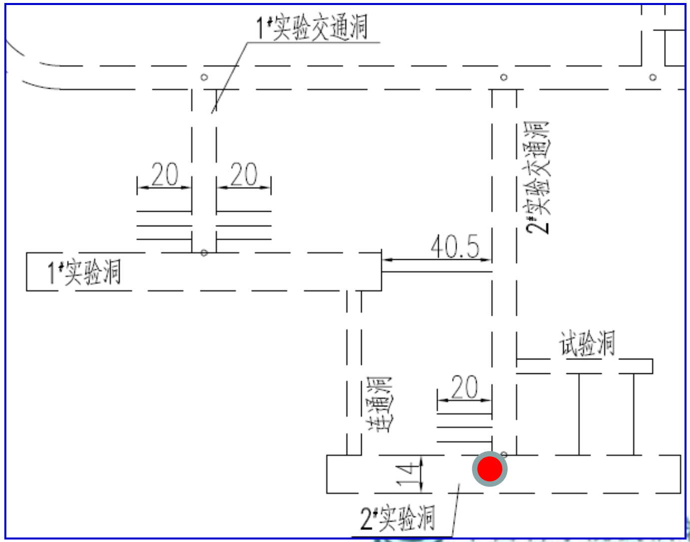
Different hazards at different chambers under the same overburden and excavation method

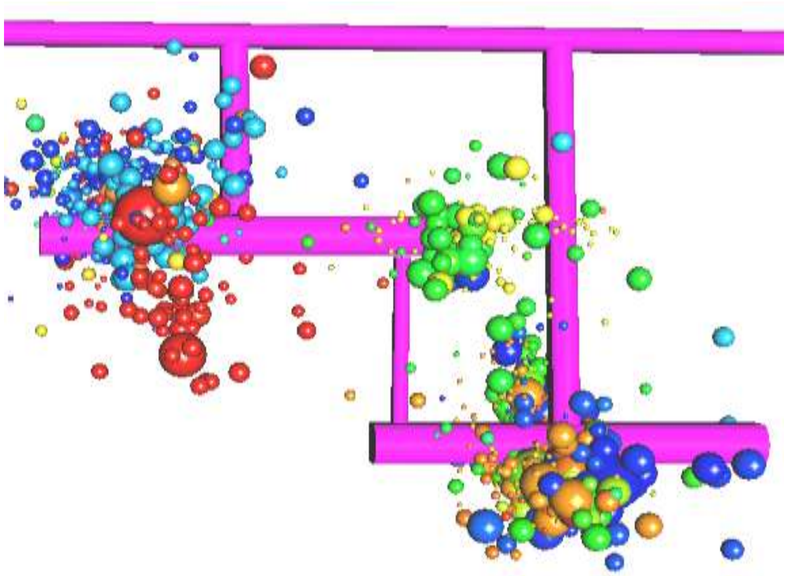


(1) Large scale collapse at roof in 3# Lab, 13 April, 2015,volume: 1000m^3

Recollapsed on 09 May,2015 after support



(2) Extremely intensive rockburst in 5# Lab, 23 April 2015



Micro seismic events

Two zones with length of 19 m and 10 m, depth of notch is 2-3m

(3) Frequent rock spalling in 7# chamber

Tunnel face

Flakelike rocks

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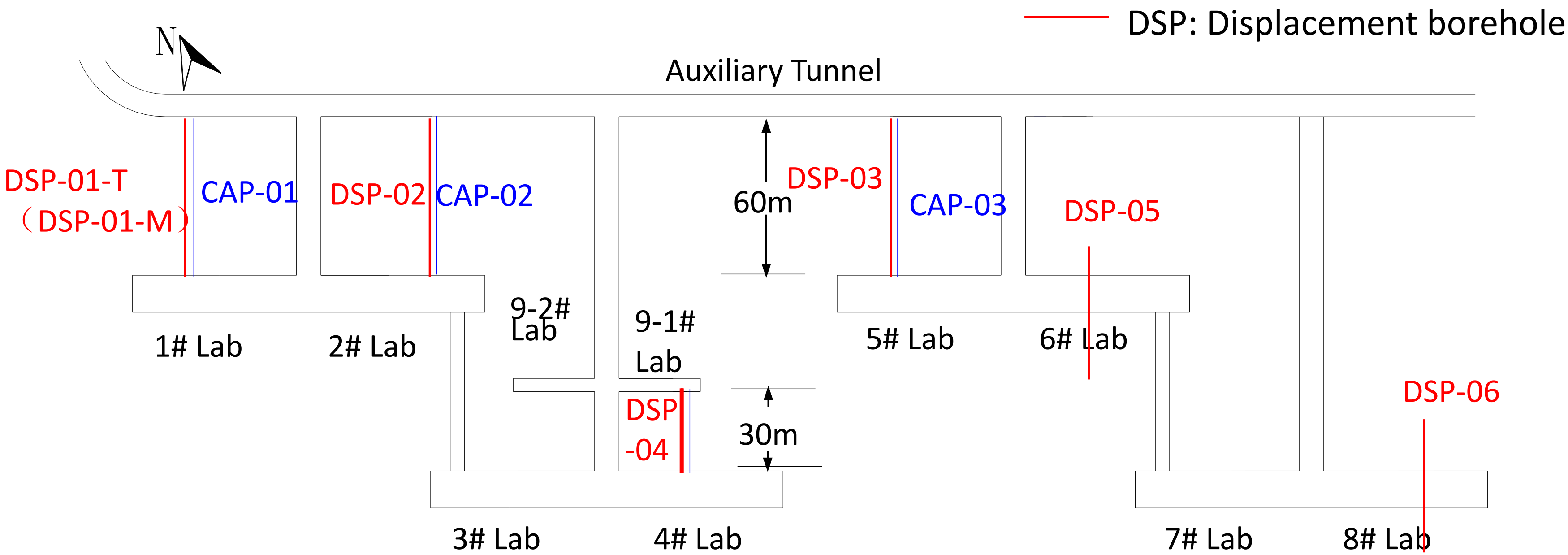
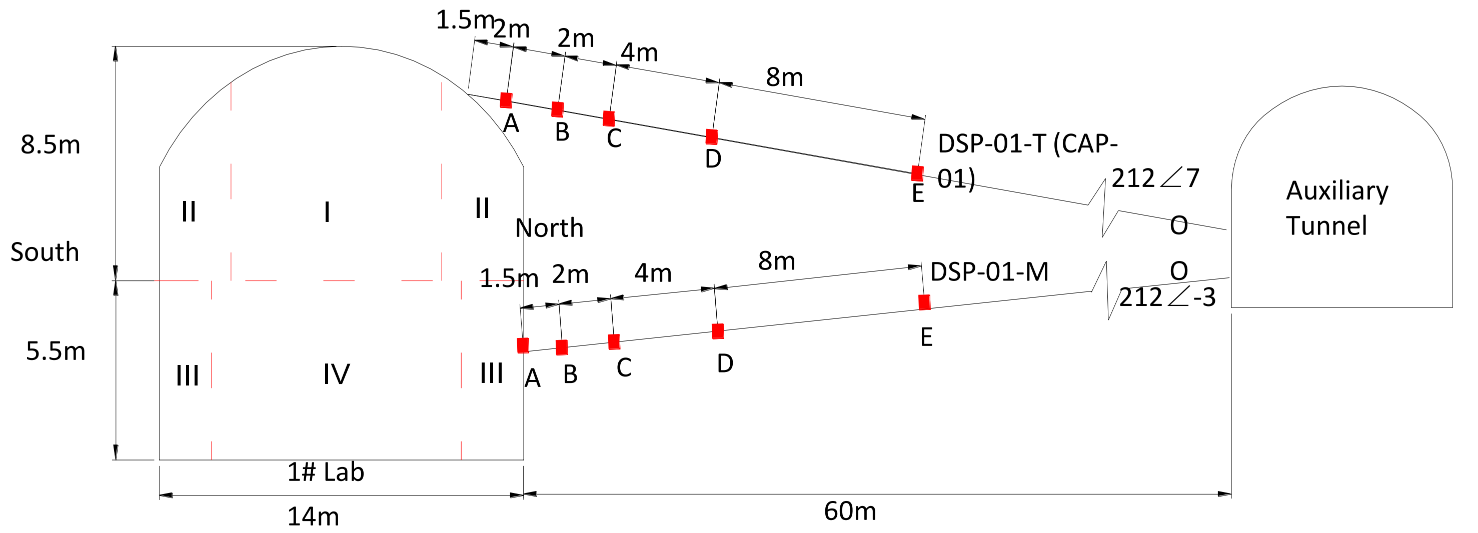
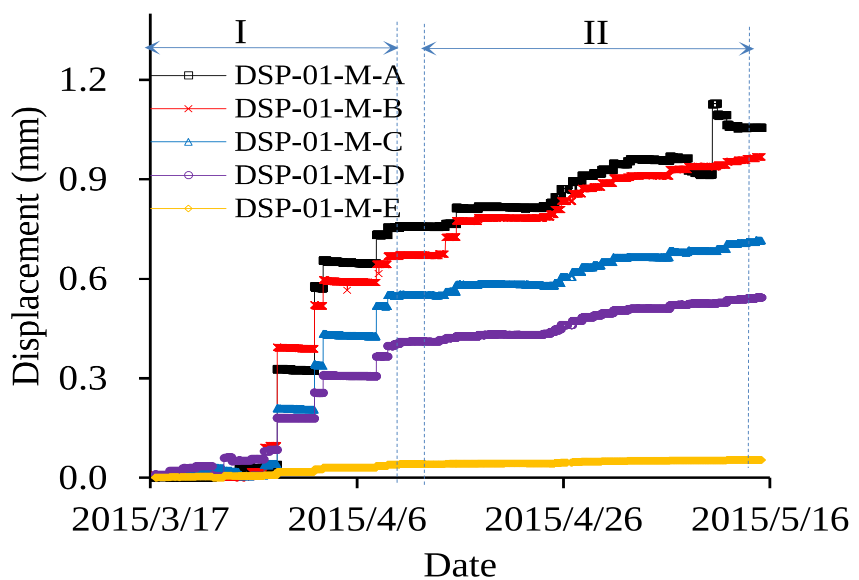
2. Displacement at Jinping Underground Laboratory

Borehole layout of multi-point extensometer



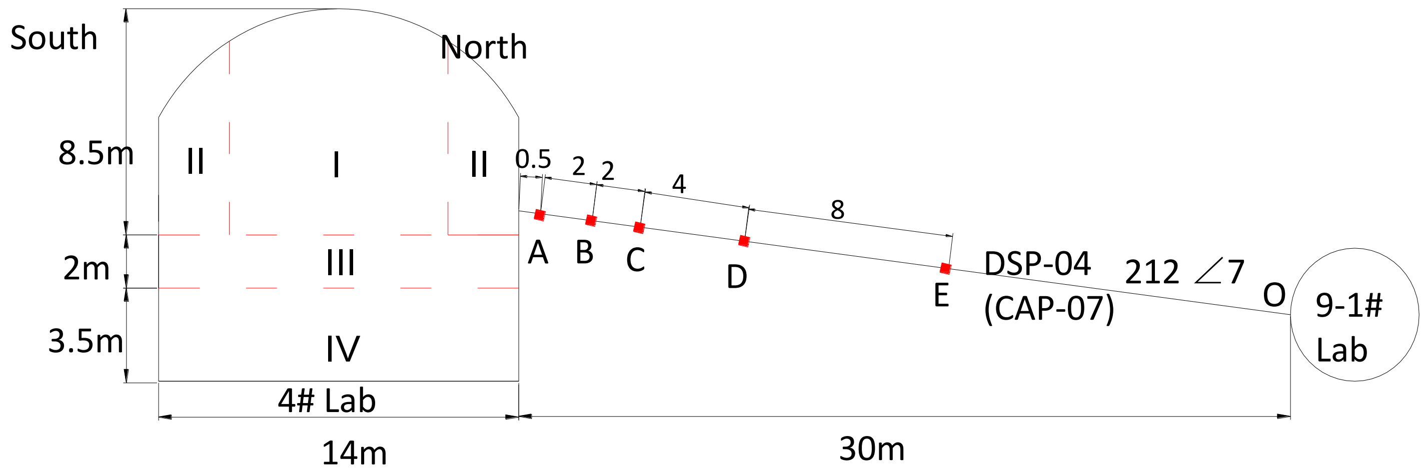
Displacement of the excavation of upper layer

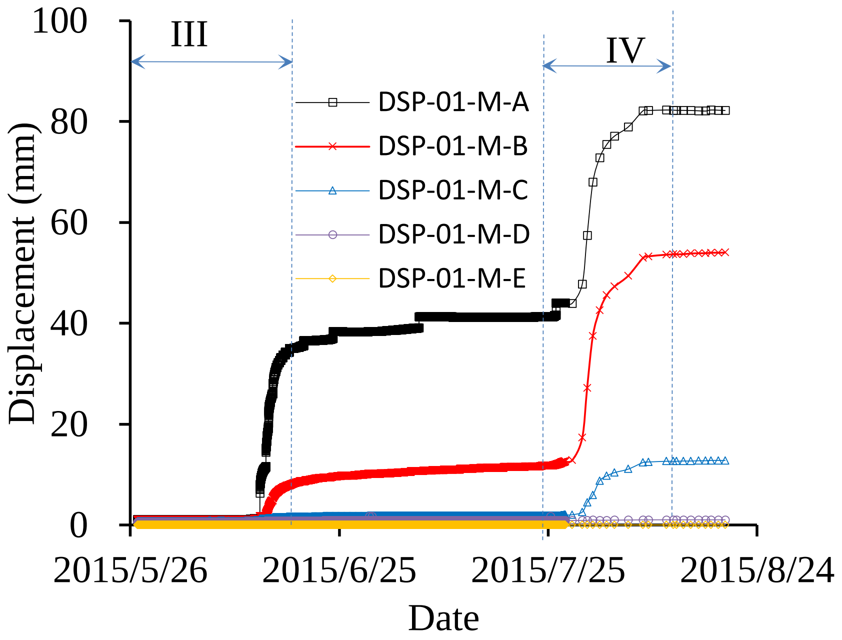




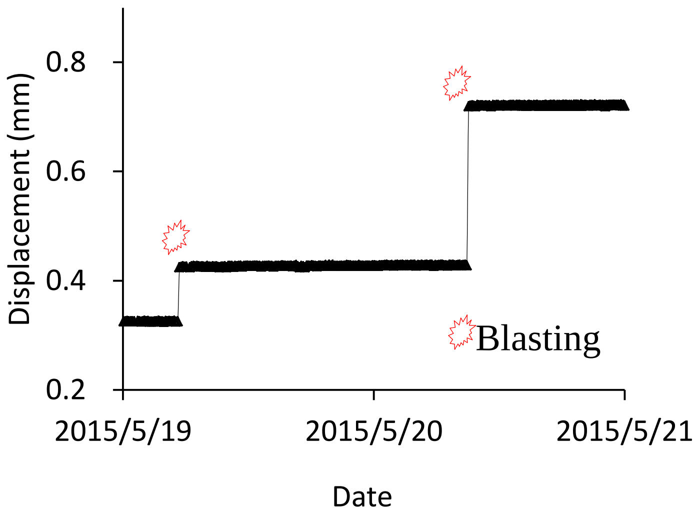
The displacement of DSP-01-M

Displacement of the excavation of lower layer

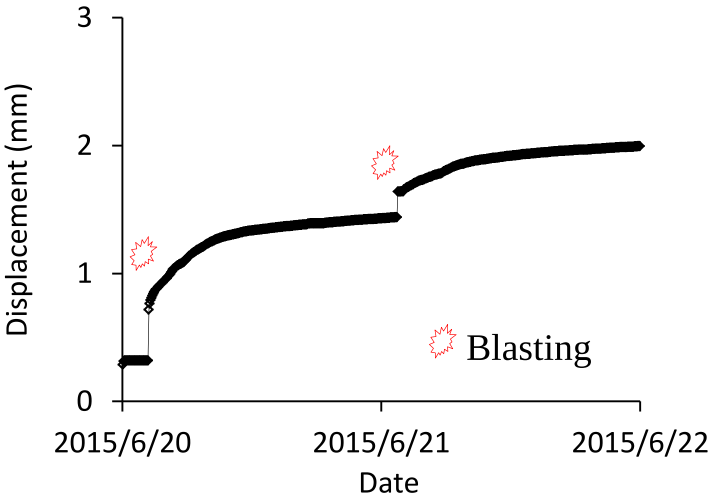




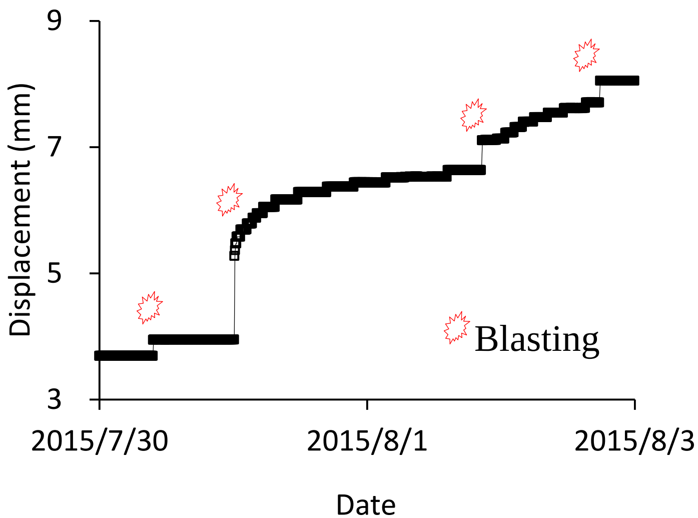
Time-dependent evolution characteristics



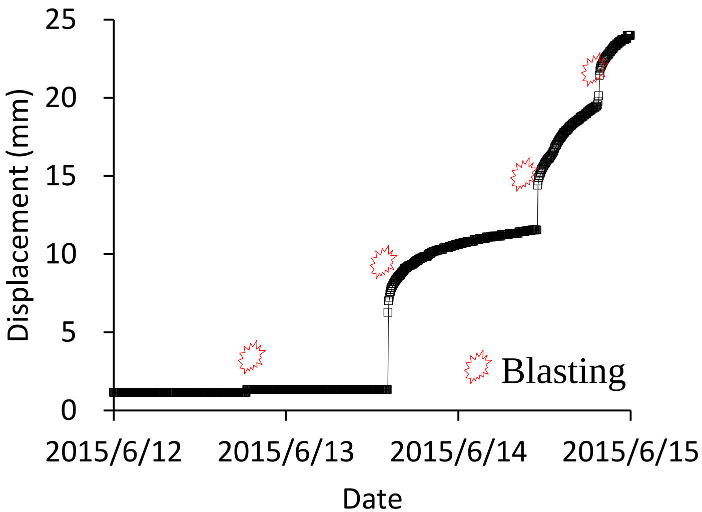
(a) 'S' type



(b) 'C' type



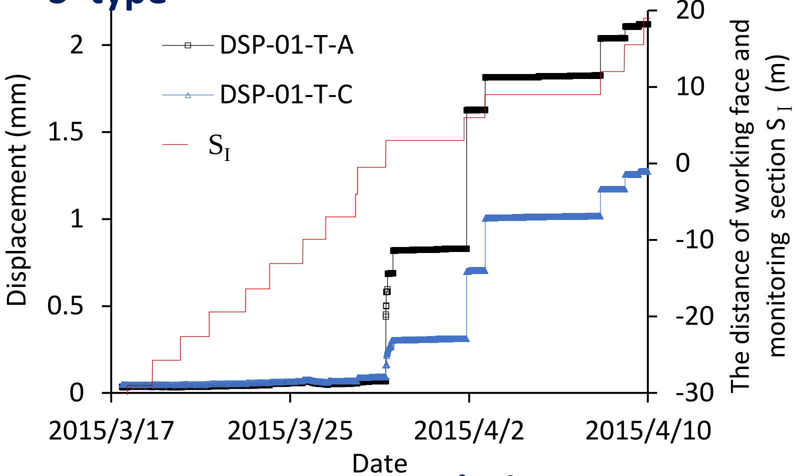
(c) 'S-C-S' type



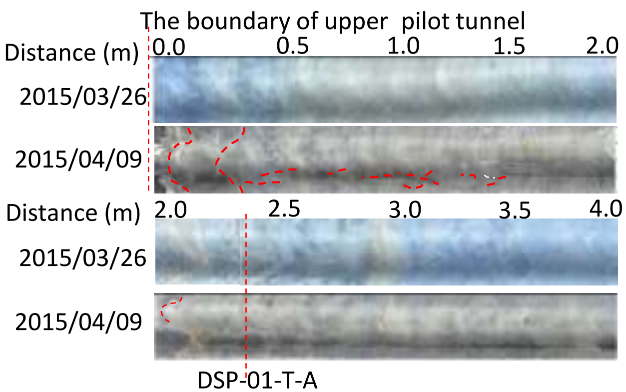
(d) 'S-C' type

The types of displacement evolution characteristics

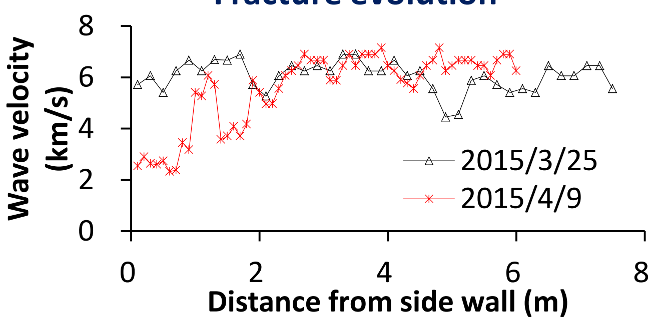
‘S’ type



Displacement evolution

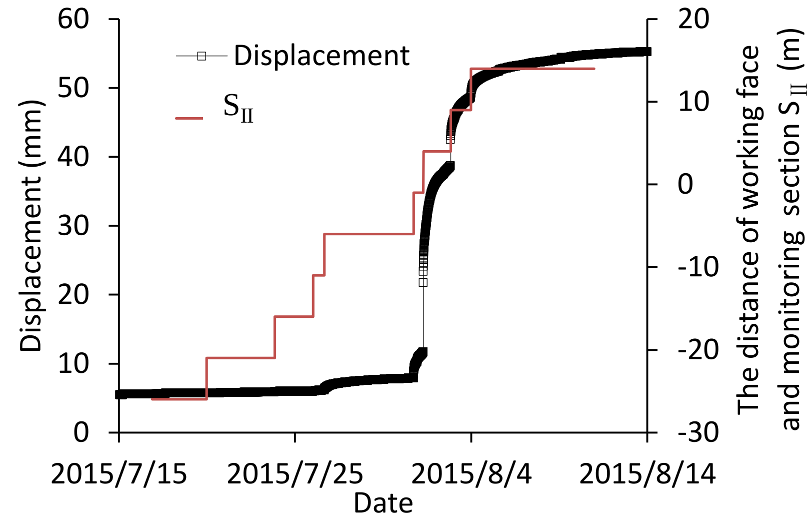


Fracture evolution

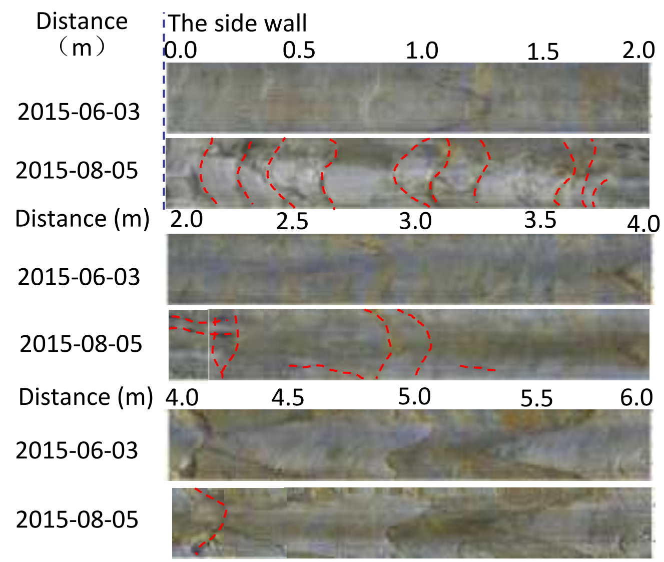


Changes of elastic wave velocity

‘C’ type

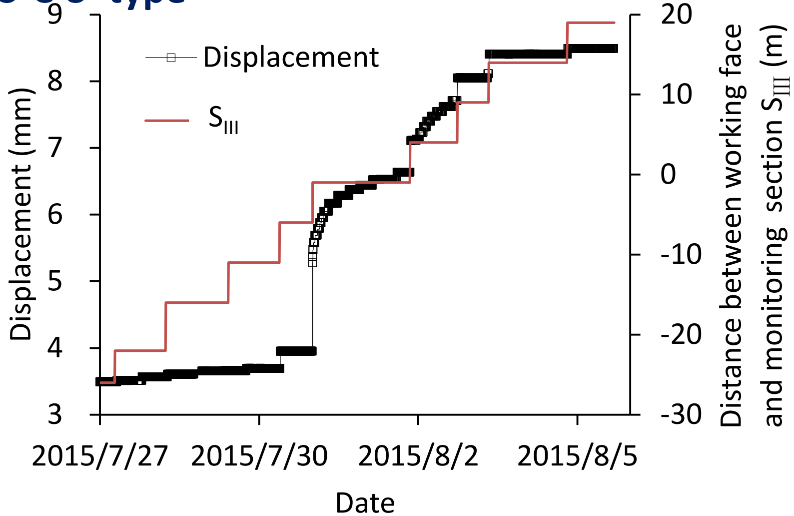


Displacement evolution

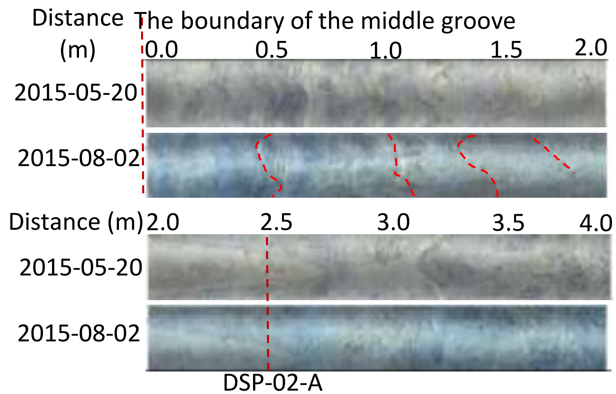


Fracture evolution

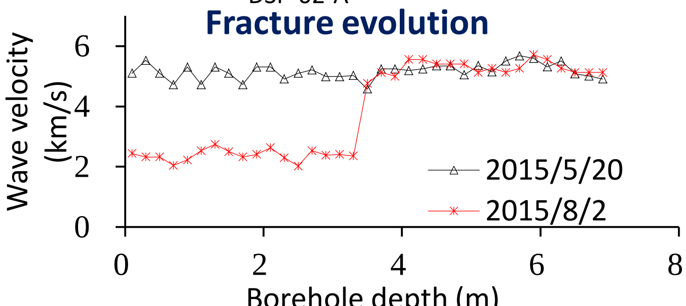
'S-C-S' type



Displacement evolution

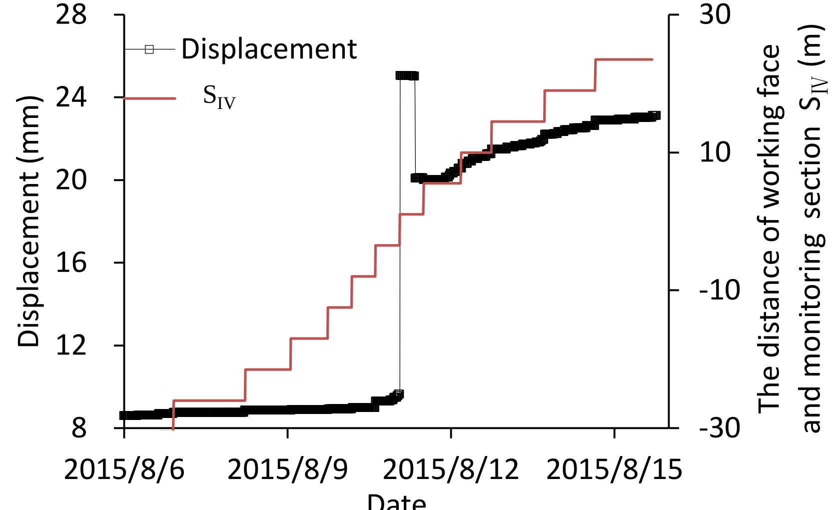


Fracture evolution

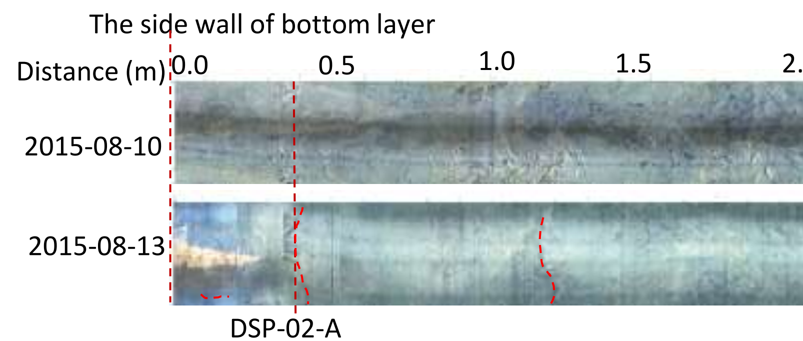


Changes of elastic wave velocity

'S-C' type

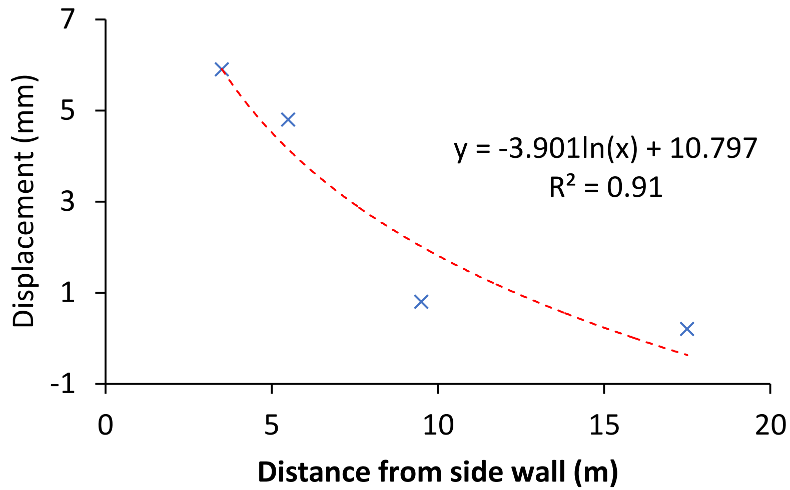


Displacement evolution

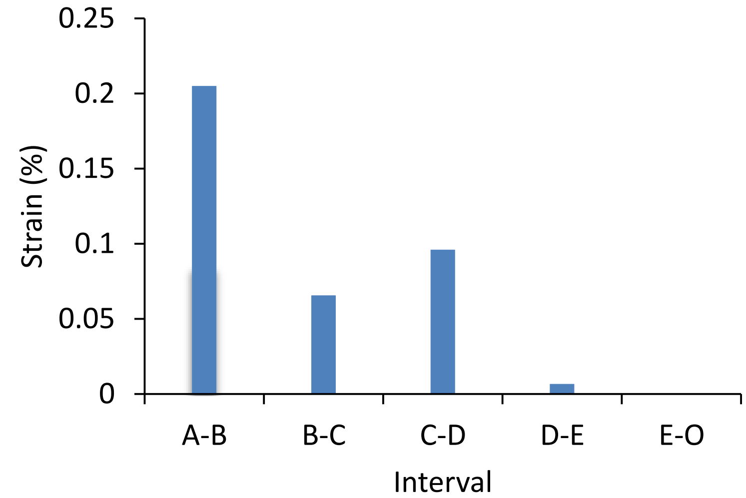


Fracture evolution

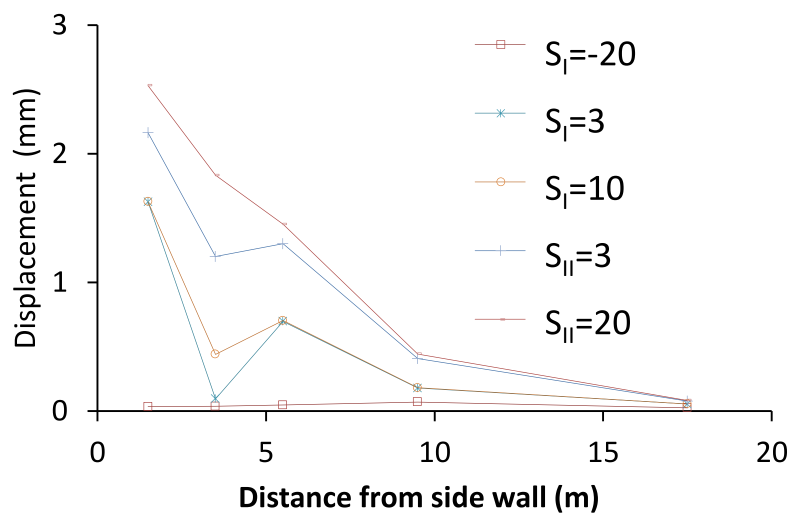
Spatial distribution characteristics (DSP-01-T)



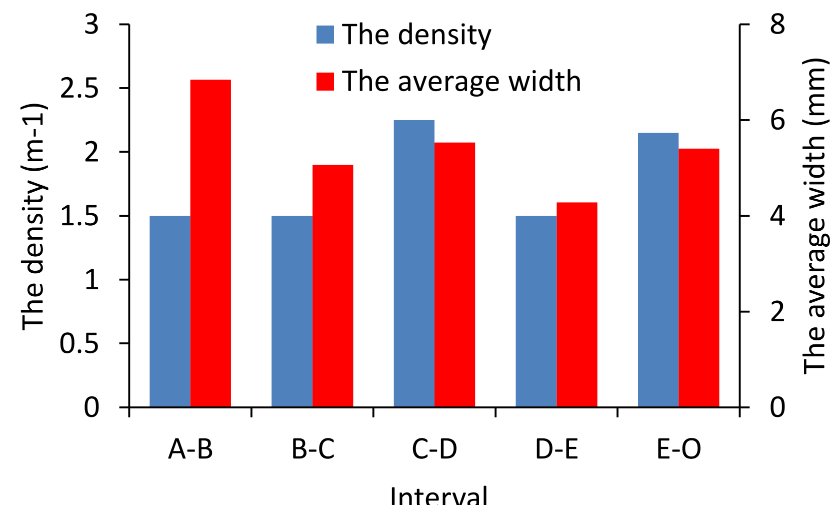
Final displacement



Final Strain

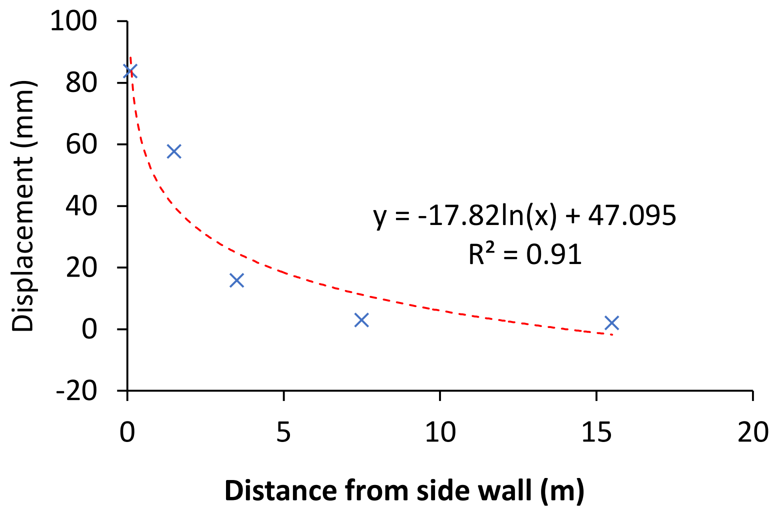


The multimodality distribution characteristic of the displacement

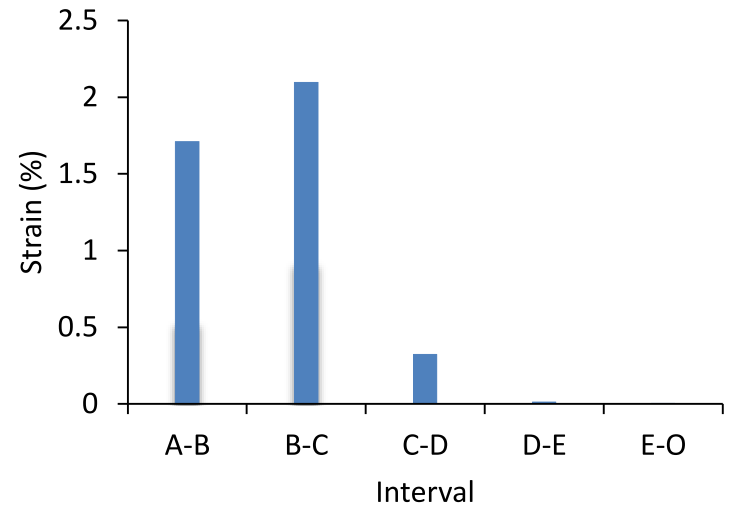


The densities and average widths of the pre-existing cracks

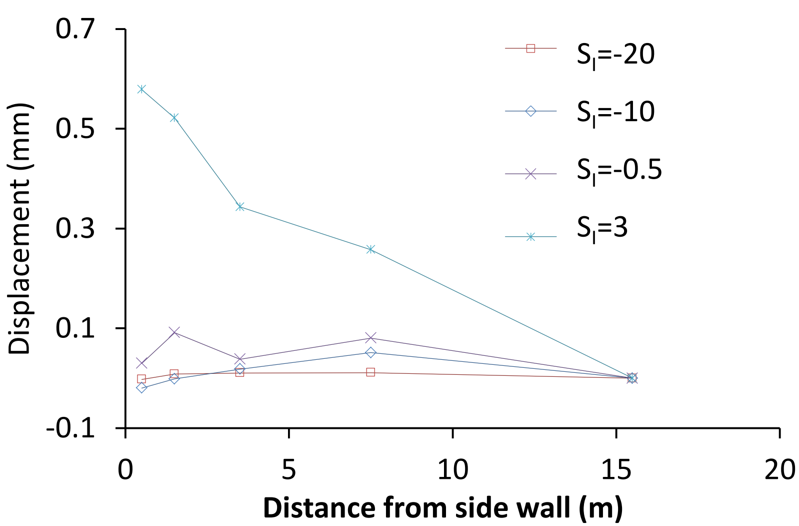
Spatial distribution characteristics (DSP-01-M)



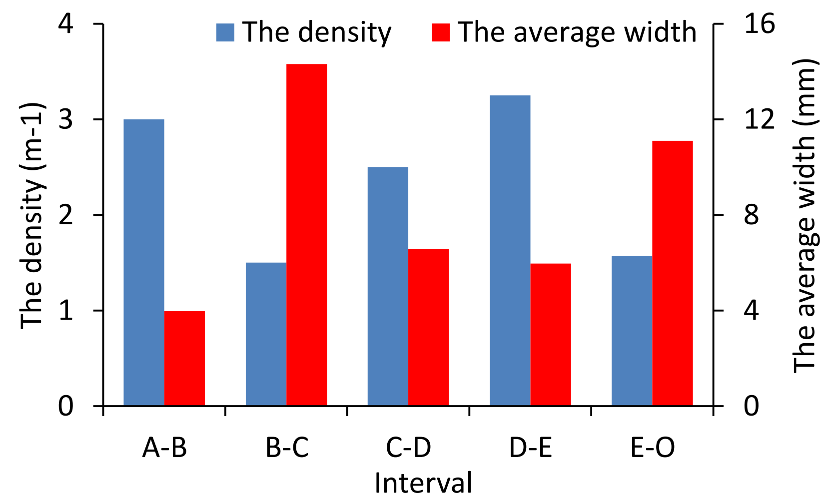
Final displacement



Final Strain



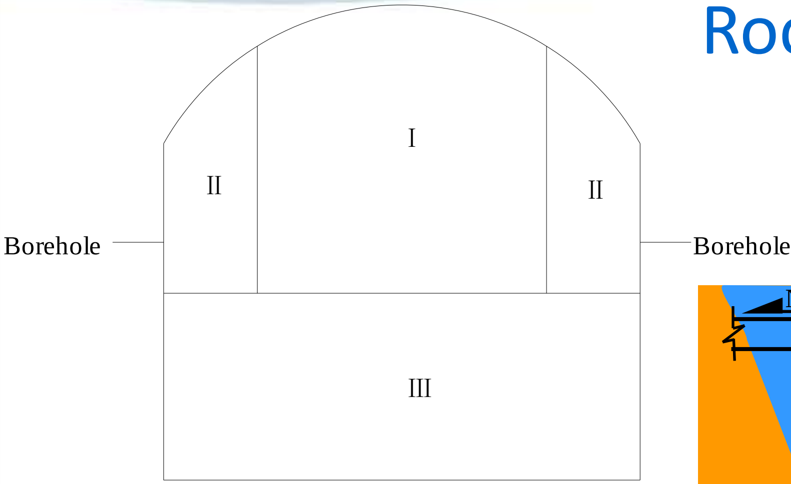
The The multimodality distribution characteristic of the displacement

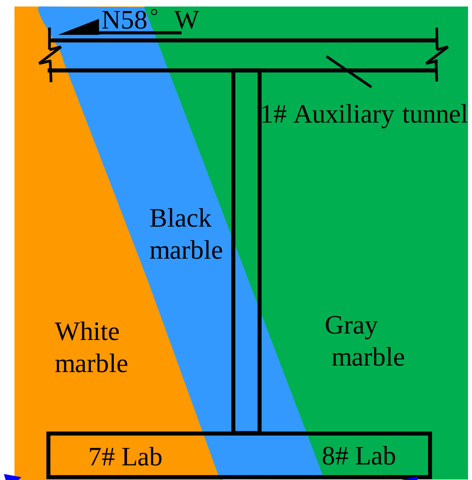


The densities and average widths of the pre-existing cracks

Content

Rock slabbing





T8-2 of southwestern side walls at chainage 0+45 of the 8# Lab

7# and 8# Labs in CJPL-II laboratory and the excavation sequence and borehole layout

Rock slabbing after the slashing excavation of side walls of the 7# Lab



Southwest sidewall


Northeast sidewall

Flowchart for measuring quantitative slabbing information using photogrammetric method

Slabbing quantitative information photogrammetric method

↓

Step 1: Positioning

- Artificial marks or feature points in the rock surface
- ↓
- Total station testing

↓

Step 2: Measurement

- Stereo Camera or Single lens reflex testing

↓

Step 3: Data processing

- Thickness identification
- Orientation identification
- Depth identification, etc

↓

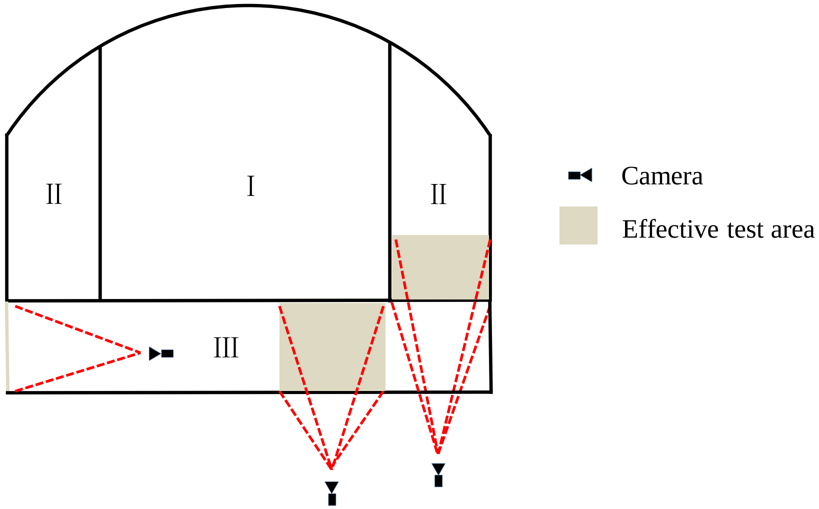
Slabbing characteristic

Test tools

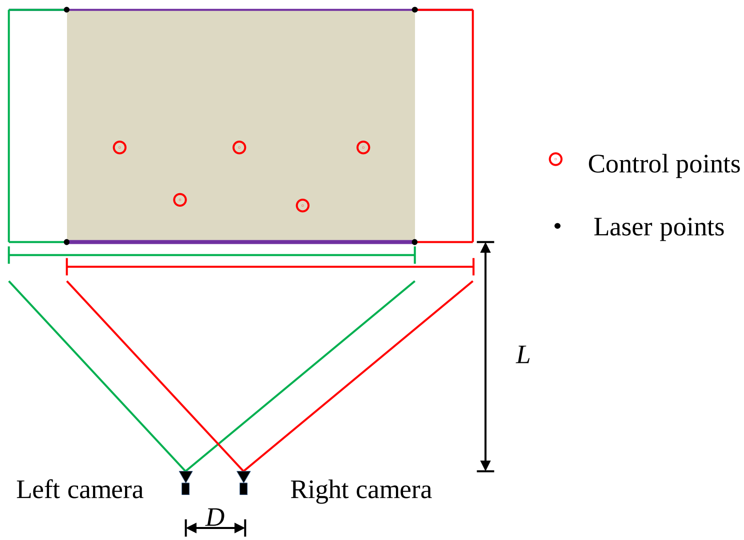
Single lens reflex

Stereo Camera

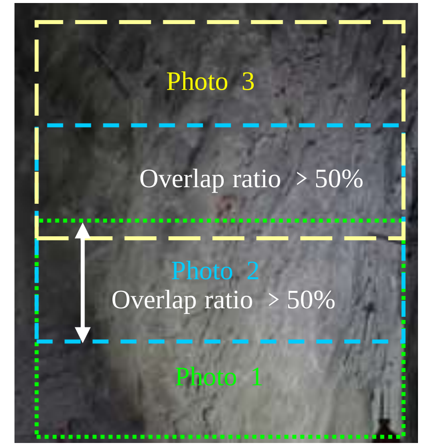
(a)



(b)

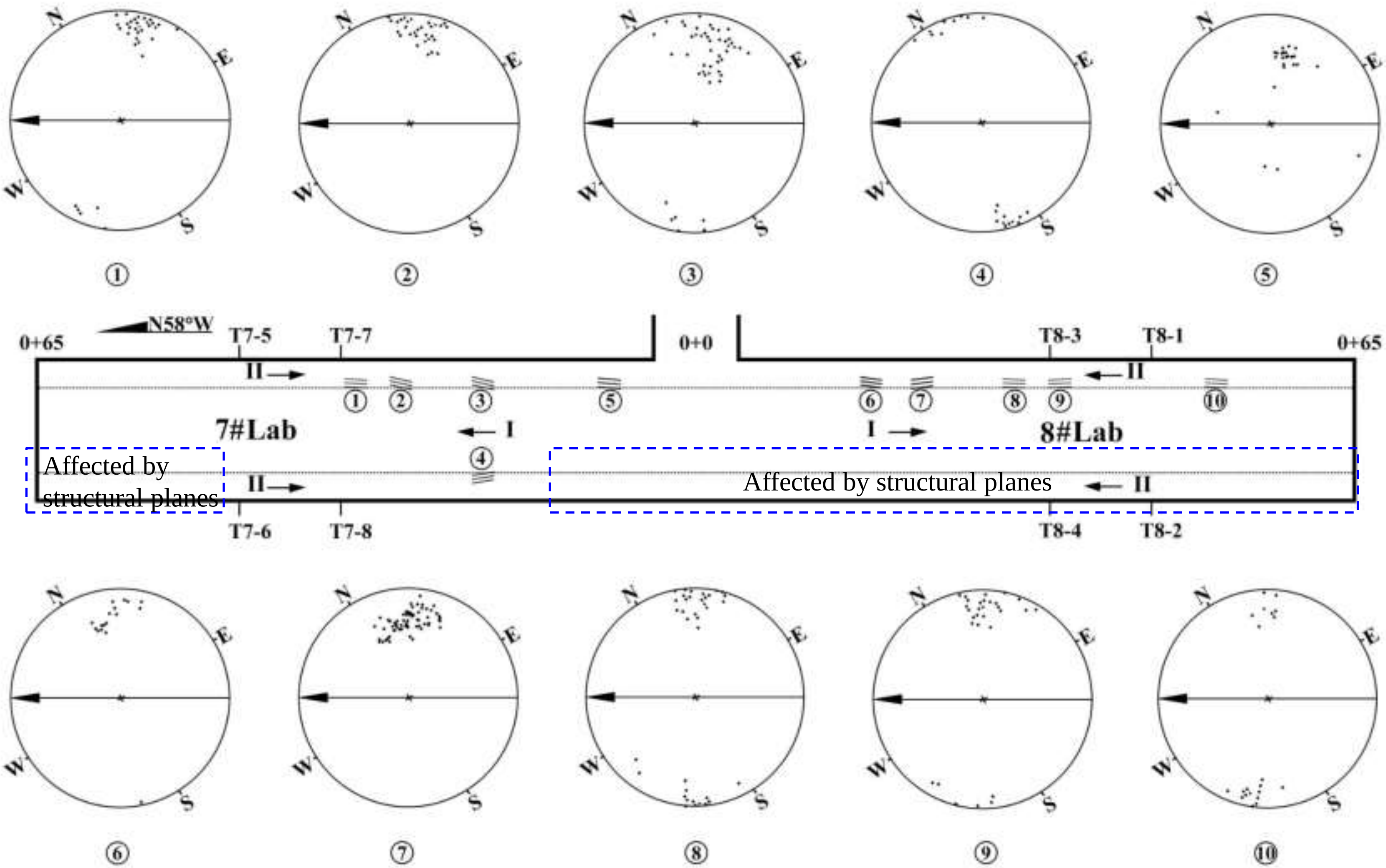


Photogrammetry measurement of slabbing. (a) Measured area at working face of slashing excavation and sidewall of tunnel. (b) Measurement of two cameras. *L* represents the distance from the camera to measured rock surfaces, and *D* denotes the distance between two cameras in the stereo camera, fixing at 45 cm.



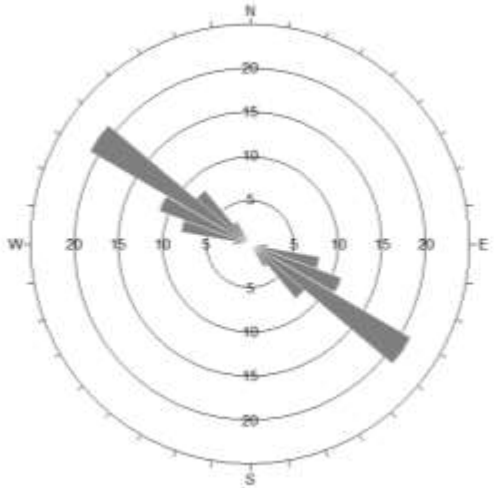
Test of non-contact measurement technology

3D images of rock surfaces after identifying slabbing characteristics

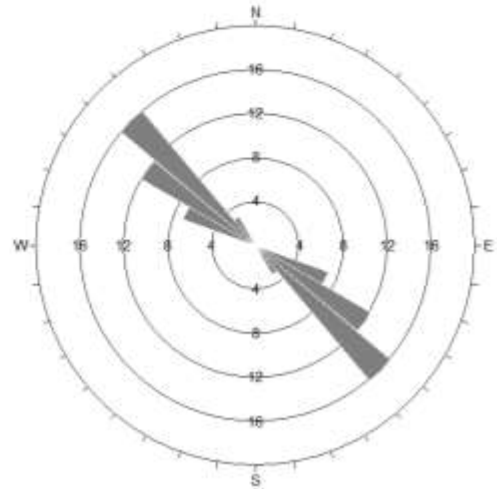


Distribution of slabbing orientations at typical sections after slashing excavation. These don't include zones affected by structural planes at the southwestern side wall of the 7#Lab chainage 0+20 at 7# Lab to chainage 0+65 at 8# Lab and chainage 0+45 to 0+65 at 7# Lab. T8-1, T8-2, T8-3, T8-4, T7-5, T7-6, T77, T7-8 are nos. of boreholes used for test of the digital borehole camera. Arrow at stereographic project is axis of Labs tested.

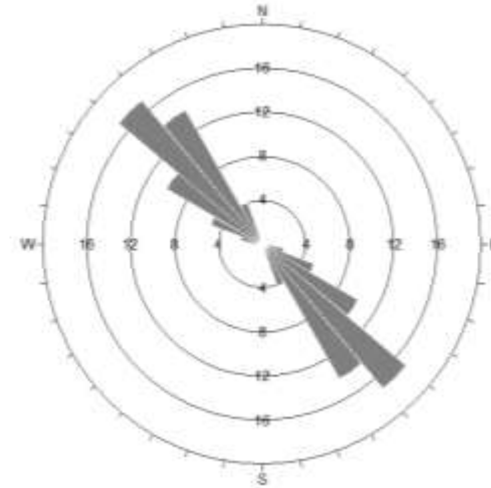
Rose diagrams of slabbing orientation at typical test sections



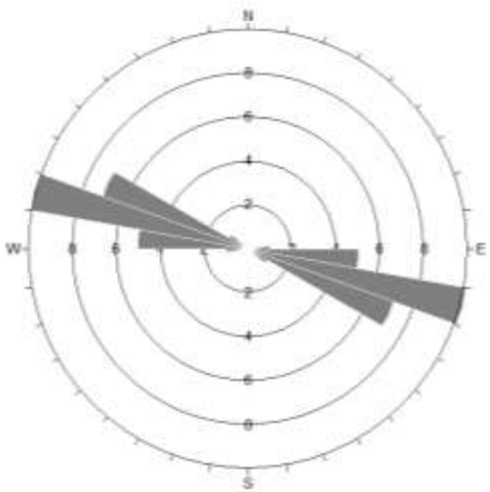
(a) Test section ①



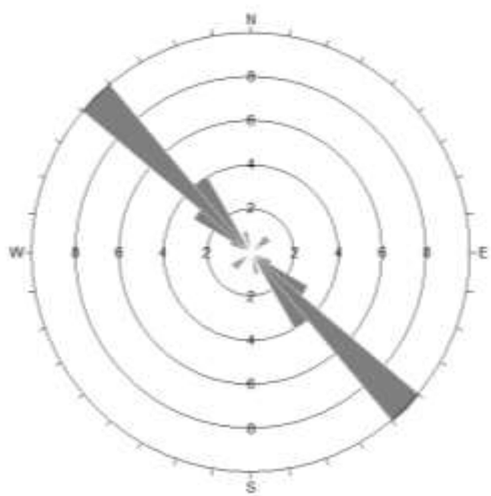
(b) Test section ②



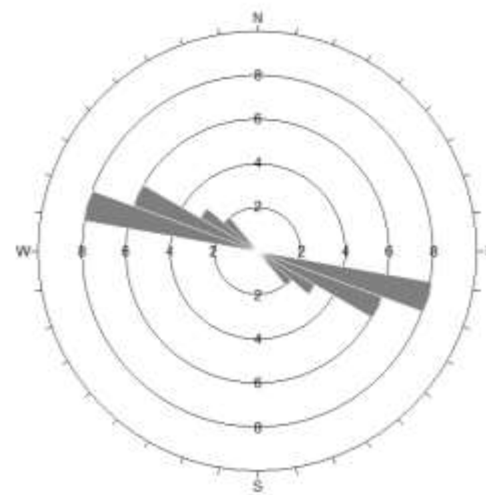
(c) Test section ③



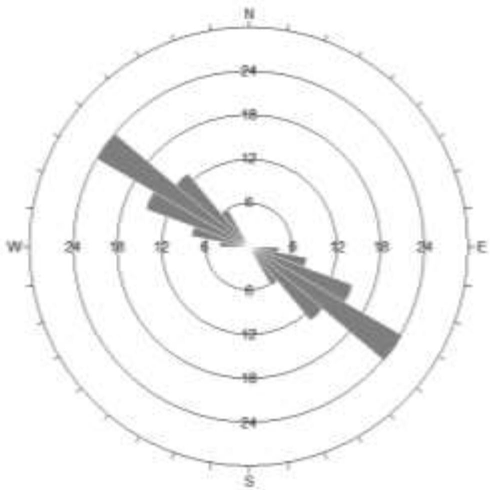
(d) Test section ④



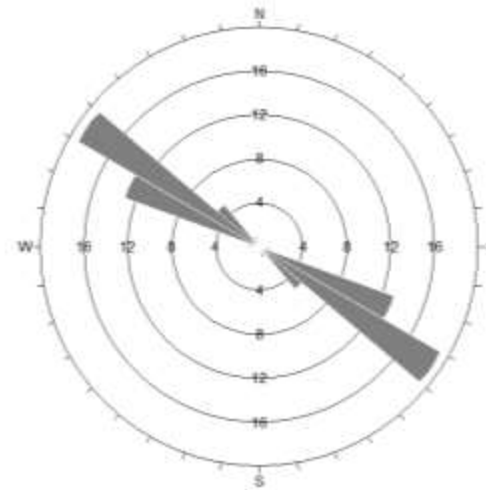
(e) Test section ⑤



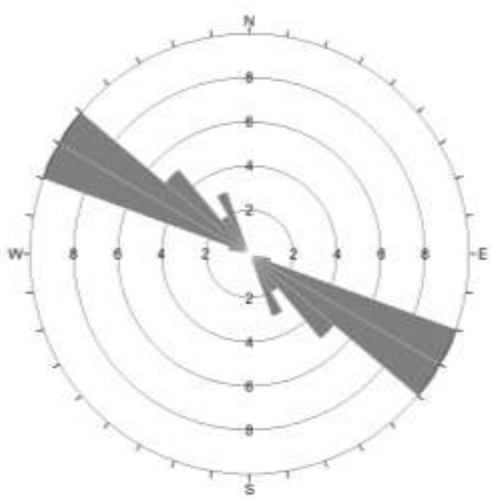
(f) Test section ⑥



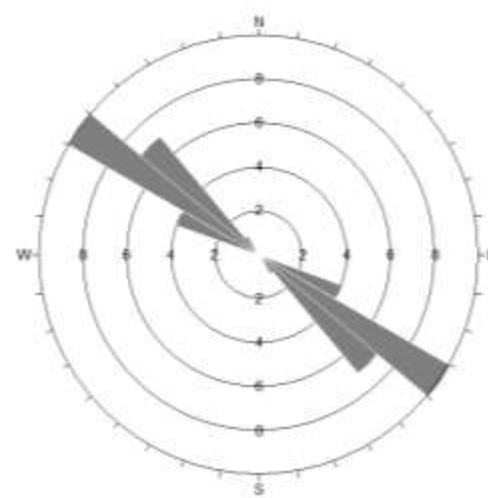
(g) Test section ⑦



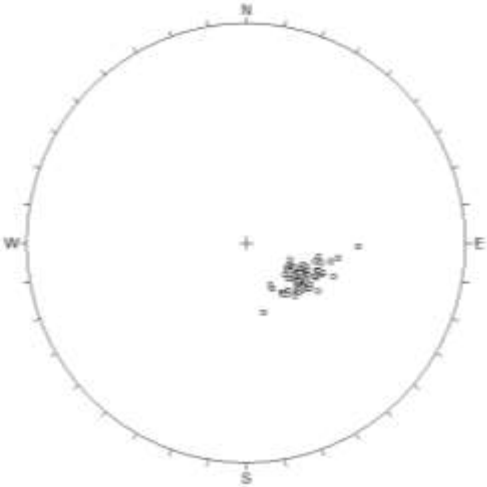
(h) Test section ⑧



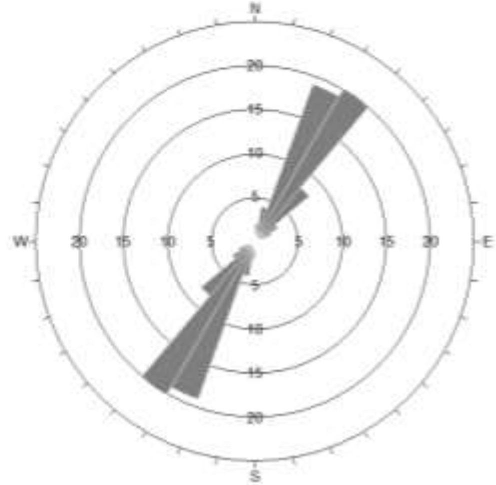
(i) Test section ⑨



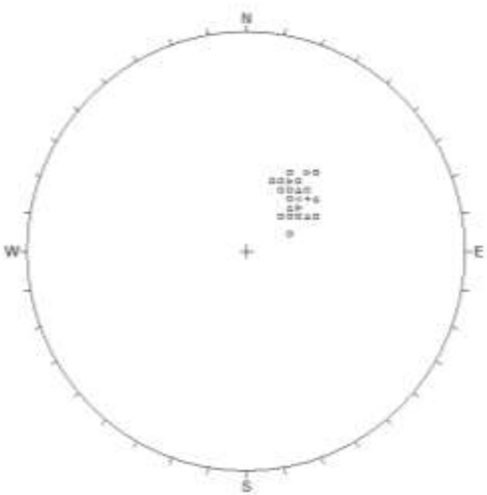
(j) Test section ⑩



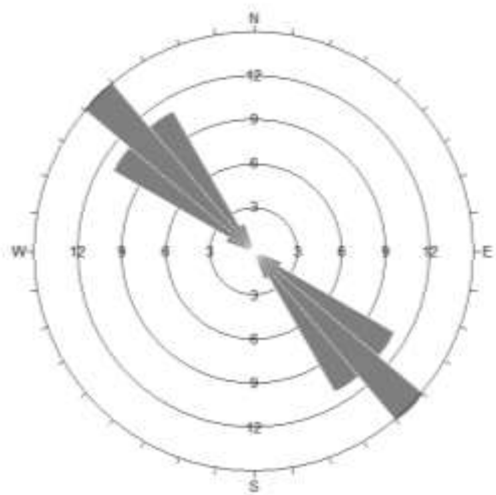
(a) Pole diagram



(b) Rose diagram



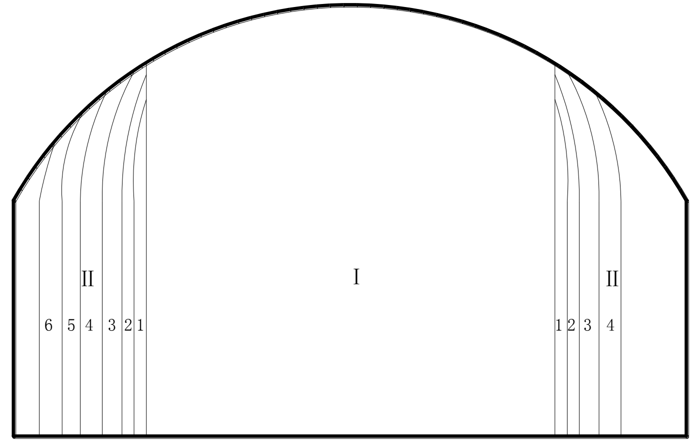
(a) Pole diagram



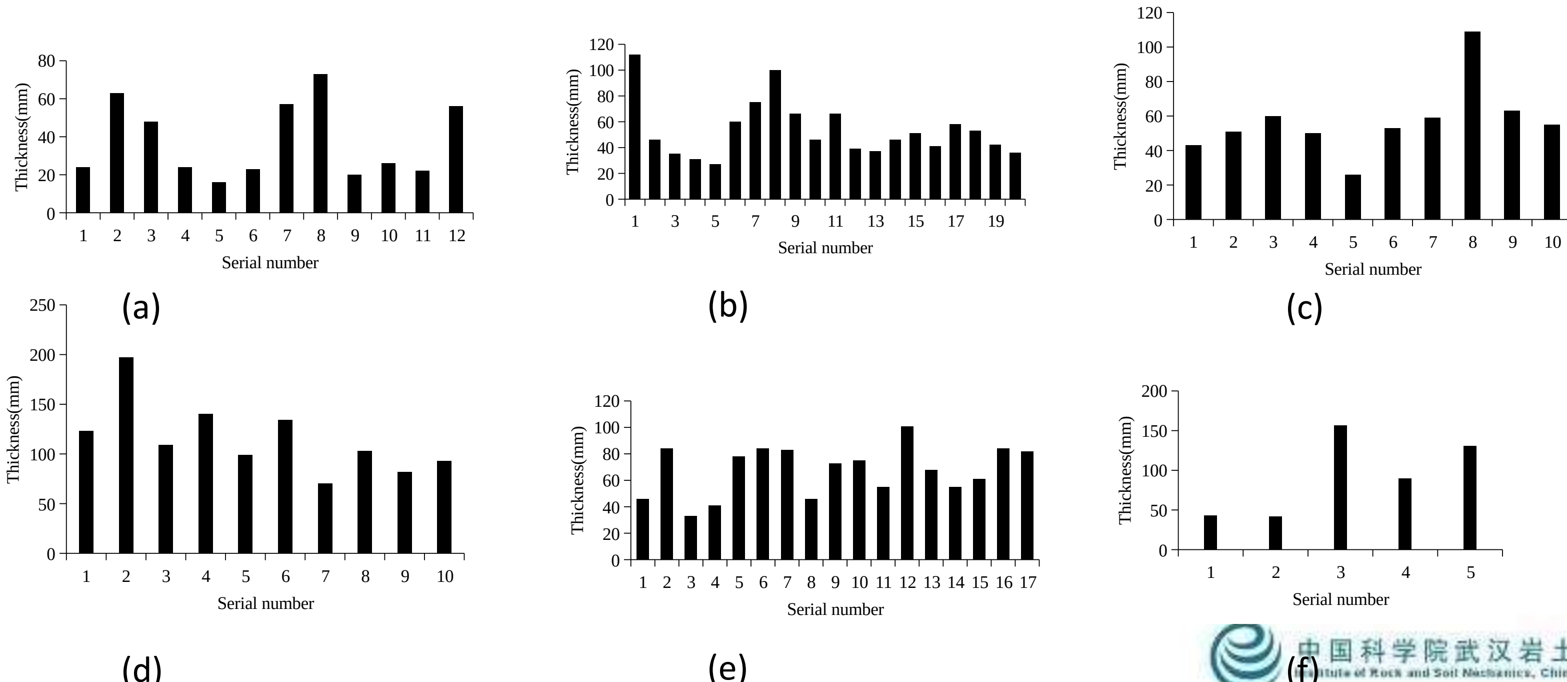
(b) Rose diagram

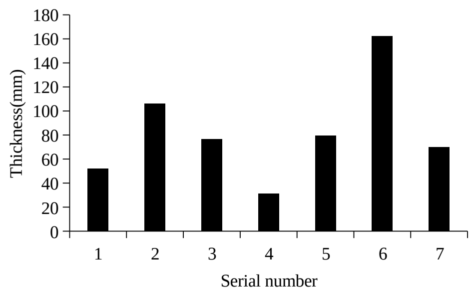
Orientation of slabbed surfaces at the northeastern sidewall of the bottom layer at (a) and (b) chainage 0+37, 8# Lab and (c) and (d) chainage 0+26, 7# Lab

Slabbing of sidewalls after the slashing excavation. Numbers denote the numbers of rock plates from the sidewall to the interior of surrounding rocks

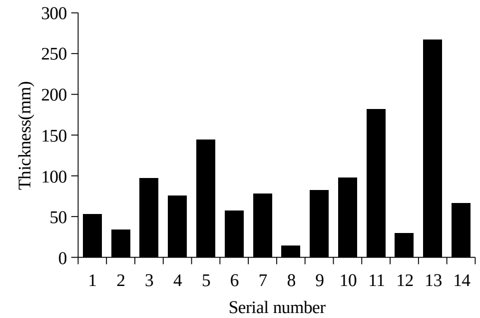


Thickness distribution of slabbing plates on different test sections (a) ①, (b) ②, (c) ④, (d) ⑤, (e) ⑥, and (f) ⑩

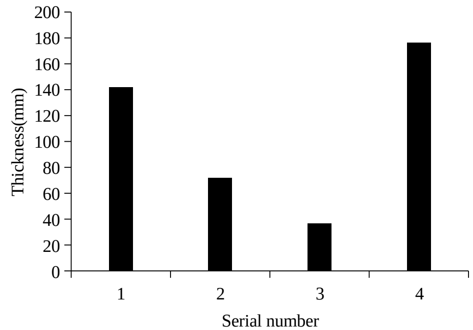




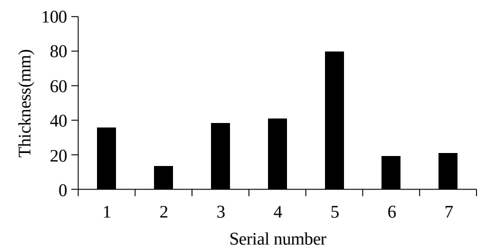
(a)



(b)



(c)



(d)

Characteristics of plate thickness at typical test sections by using borehole camera. (a) T7-6 borehole at southwestern sidewall at chainage 0+45 of 7# Lab. (b) T8-1 borehole at northeastern sidewall at chainage 0+45 of 8# Lab. (c) T8-2 borehole at southwestern sidewall at chaiange 0+45 of 7# Lab. (d) T8-3 borehole at northeastern sidewall at chainage 0+35 of 8# Lab.

It can be seen that the slabbing in the side walls of slashing excavation occurred parallel to the cavern axis. Moreover, the plates were alternatively thick and thin and gradually thickened to the interior of surrounding rocks. Such feature was similar with that of non-contact measurement technology.

Content

1. Introduction of CJPL-II
2. Hazards during tunnel excavation
3. Displacement at Jinping Underground Laboratory
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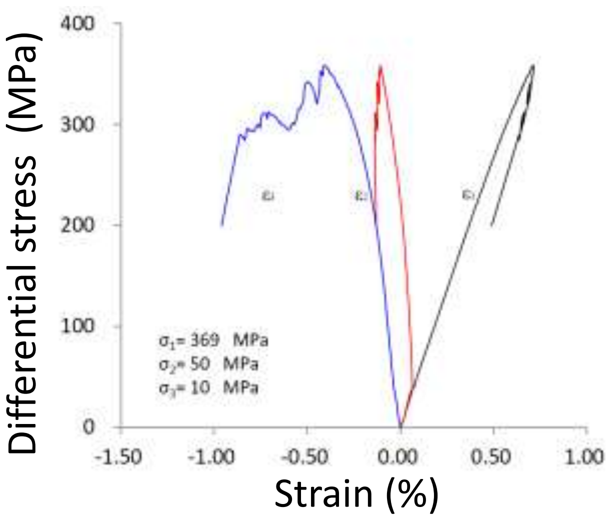
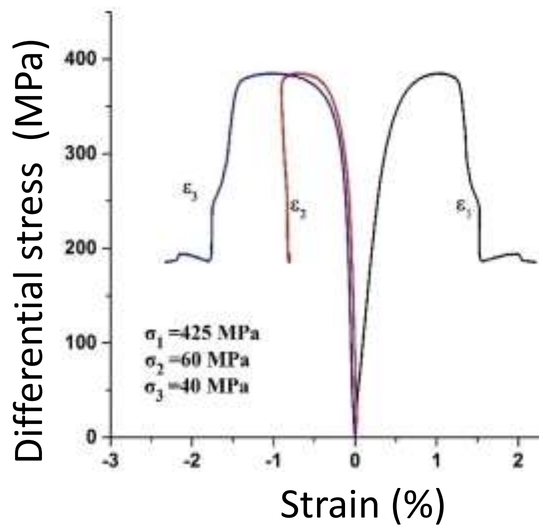
5. True triaxial compressive test
6. Conclusions

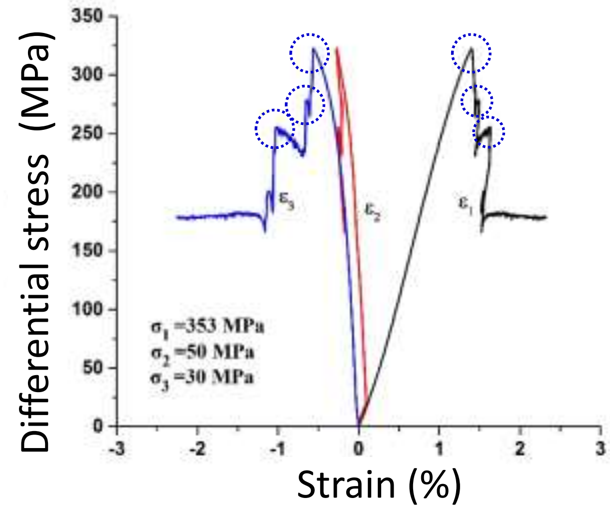
Different type of post-peak behavior related to stress level on hard rock



Class II mode



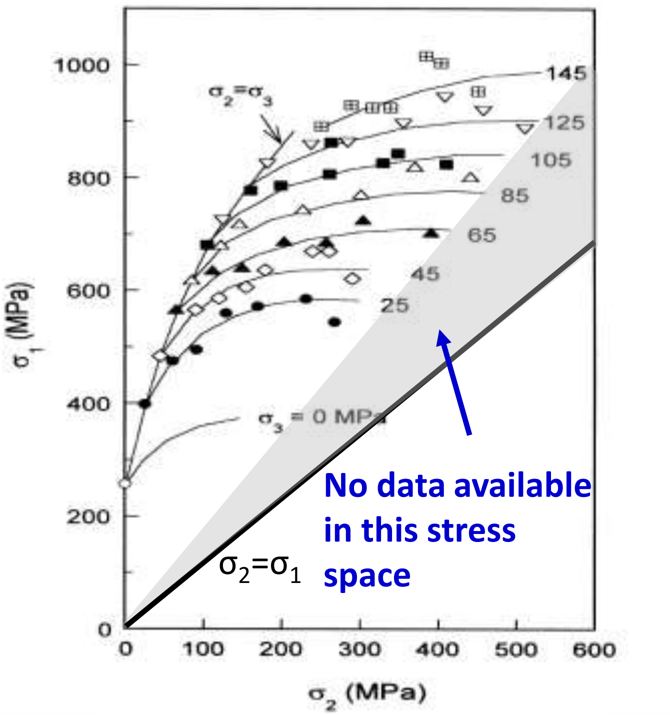
Brittle-ductile transition



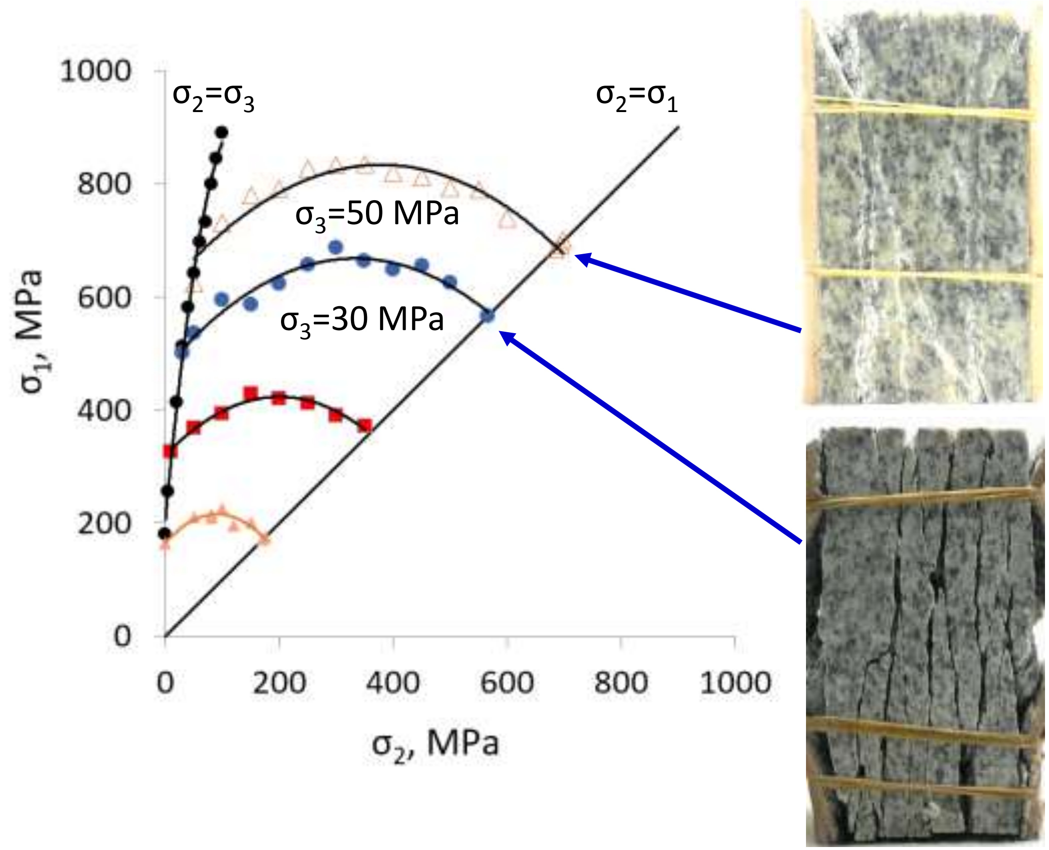
Progressive failure with multi stress drop

- **Finding： Apparent energy suddenly release, fracture with time-dependence, multi-stage fracture**
- **To design the supporting in terms of the different fracture characterization, to prevent geological disaster in deep rock mass engineering**

The parallel extension fraction mode when the intermediate principal stress equals to the maximum principal stress



(Haimson & Chang, 2000)

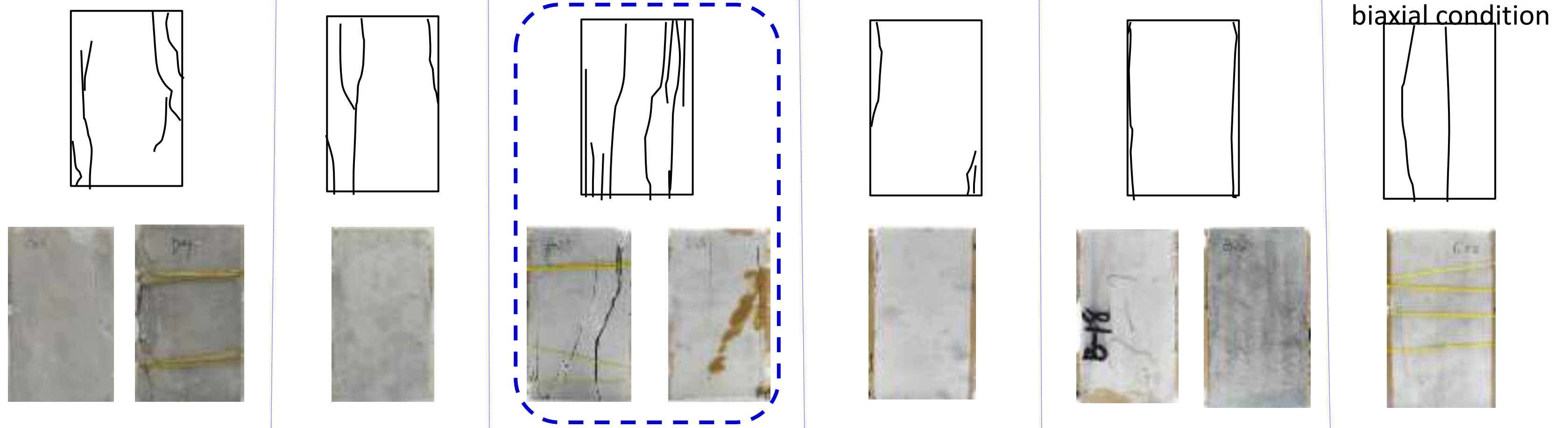


To reduce the intermediate principal stress to decrease the risk of engineering disaster

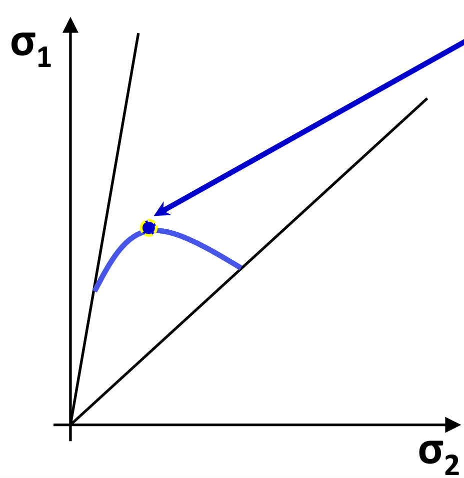
The intermediate principal stress control the transition of extension fracture in the surrounding rock

Fracture under biaxial condition

σ_3=0MPa



σ_2= 0 MPa	σ_2= 25 MPa	σ_2= 50 MPa	σ_2= 75 MPa	σ_2= 100 MPa	σ_2= 150 MPa
local fracture in the surface →	go deeper →	Strong deep fracturing →	Shallow fracturing →	fracture in the surface →	Extensional fracture



- ☐ Brittle fracture feature on the surface of the tunnel
- ☐ Existing a sensitivity range of the $\sigma_2 \Rightarrow$ to avoid it in the excavation by means of optimal design

Conclusions

- Typical displacement characteristics of hard rock masses during excavation
- Rock slabbing occurred frequently in the side walls of slashing excavation, almost parallel to cavern axis
- Influence of intermediate principal stress and stiff struction on fracturing of hard rock
- Long term behavior of deep rock mass has been further monitored