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Characteristics on Rock Fractures Induced by Different Excavation Methods of Deep tunnels

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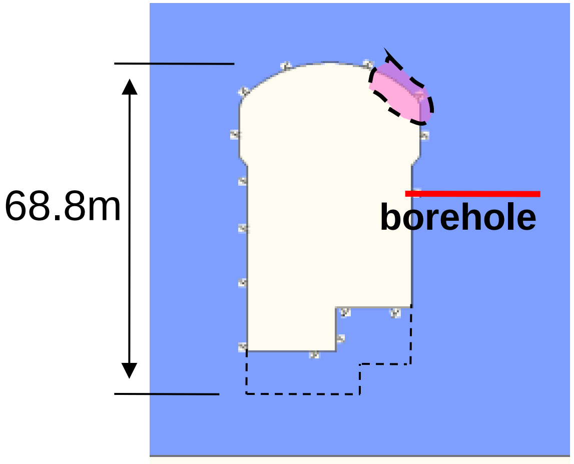
Outline

- Motivations
- Method of rock fracture measurement
- Deep tunnels excavated by different methods
- Characteristics of rock fractures and hazards
- Conclusions

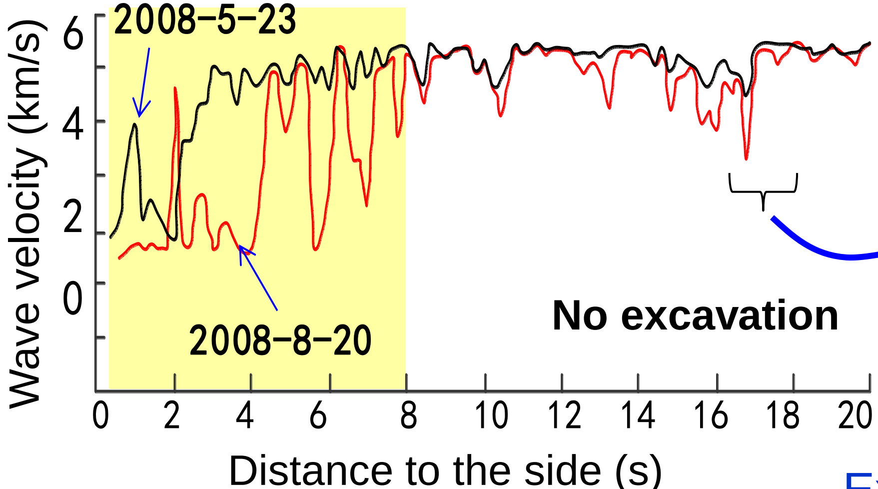
Motivations

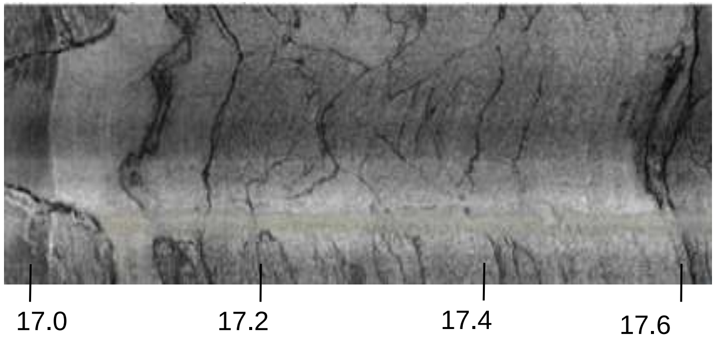
- **Fracture of hard rock induced serious instability of deep opennings : Example of Jinping I underground caverns**



- Large deformation
- Big fractures

Fall of sprayed concrete



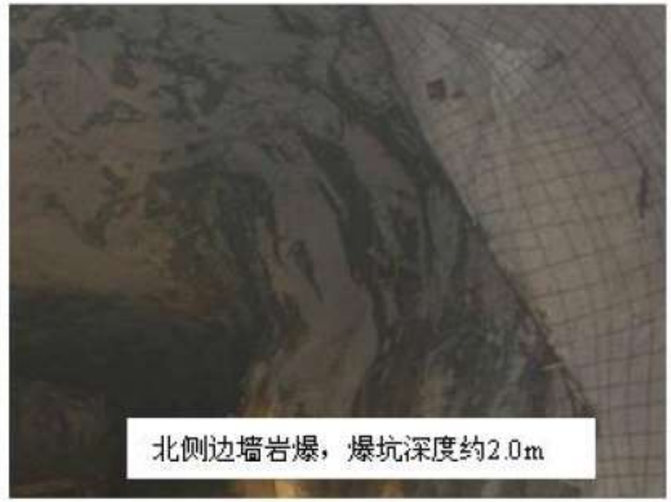


Fractured marble

Excavation halted for more than 6 months

Rockbursts in deep openings are also related to fracture evolution

Sidewall rockburst

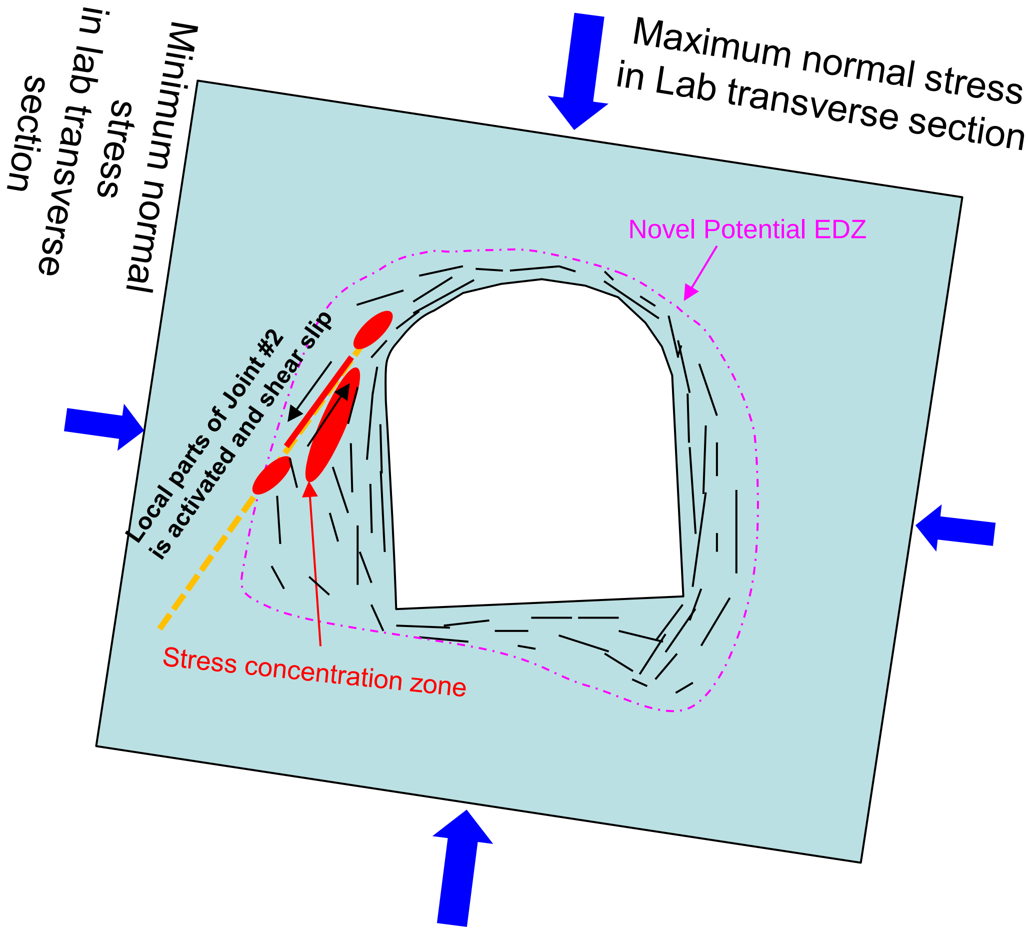


Notch left. depth : 2.0m

Steel mesh destroyed

Tunnel floor Fractured

Tunnels of Jinping II hydroelectric project



Fracture distribution abundant boreholes around surrounding rock mass

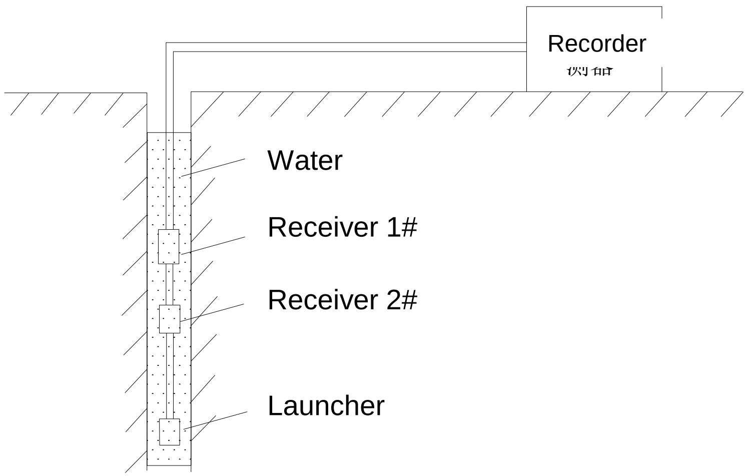
Sit investigations were conducted to understand the correlation between fracture and tunnel stability and hazards

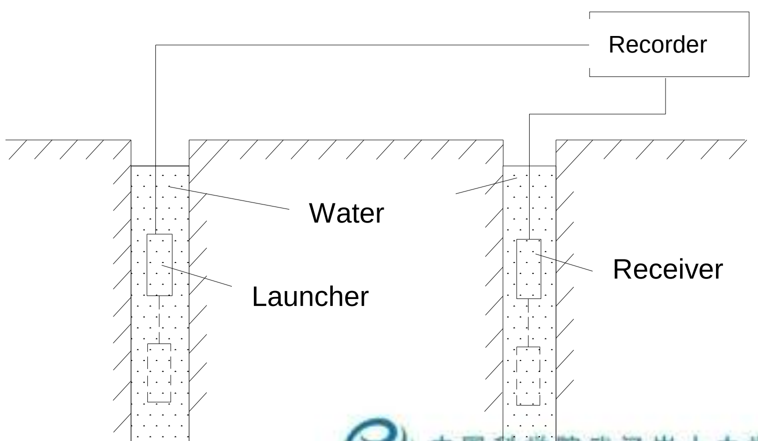
Method of rock fracture measurement

Comprehensive measurement by acoustic wave velocity and digital borehole televiewer

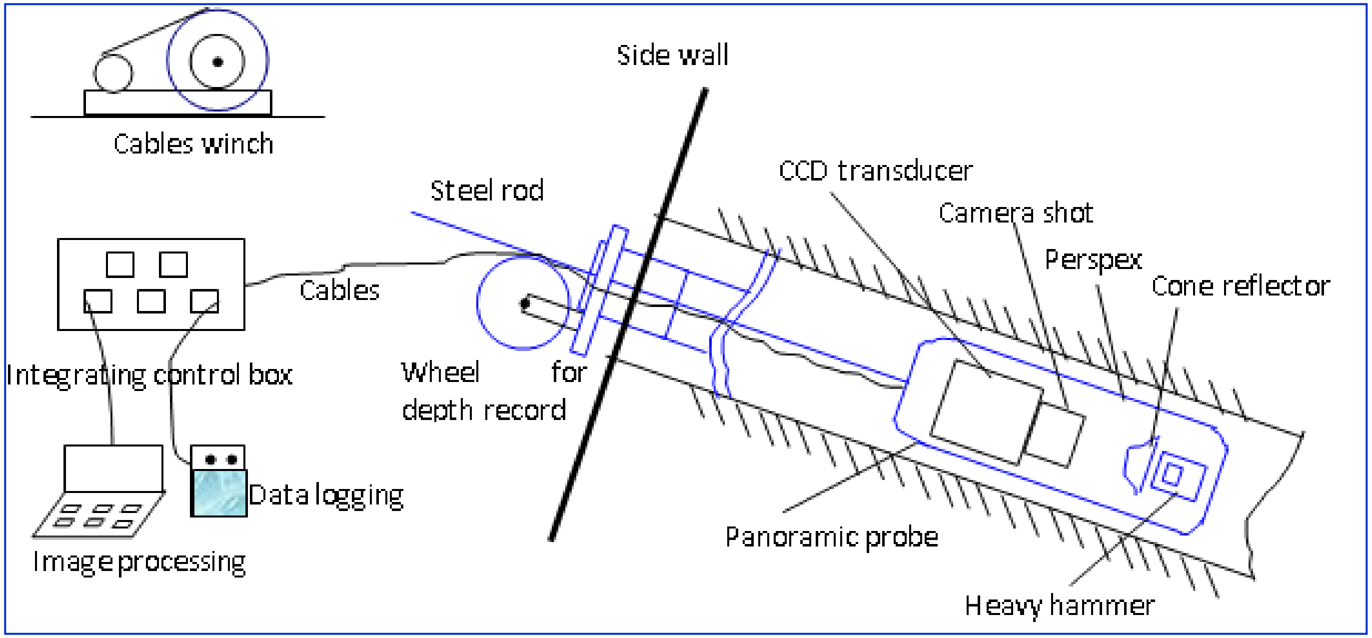
Acoustic wave apparatus

(single or cross-hole method)





Digital borehole televiewer system



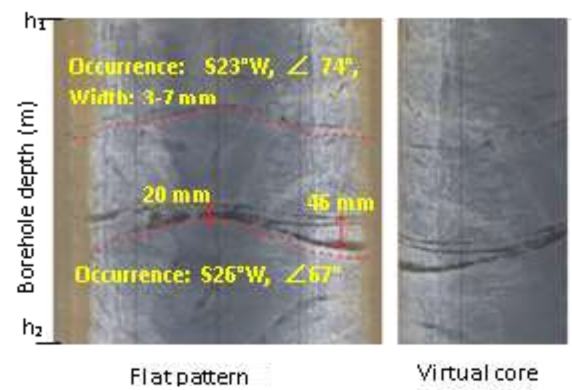
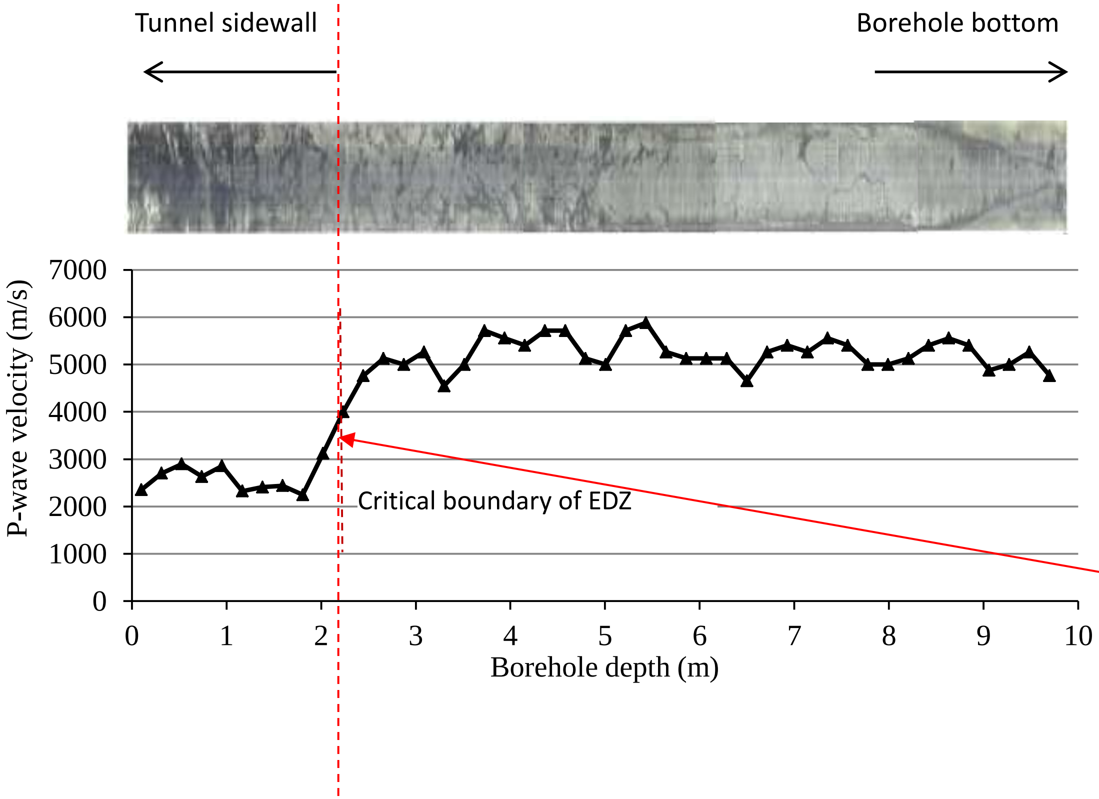
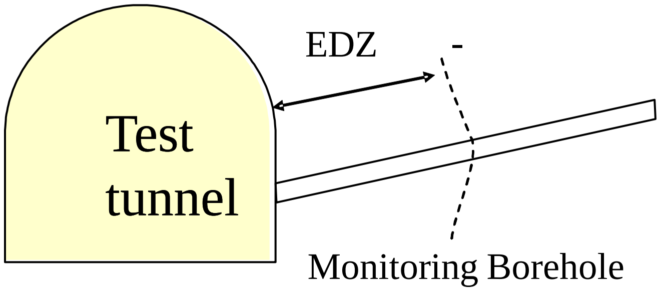


Image of borehole wall and fractures

■Comprehensive recognition of excavation damaged zone (EDZ)

new fractures observed by digital borehole camera and P wave velocity, >0.2mm



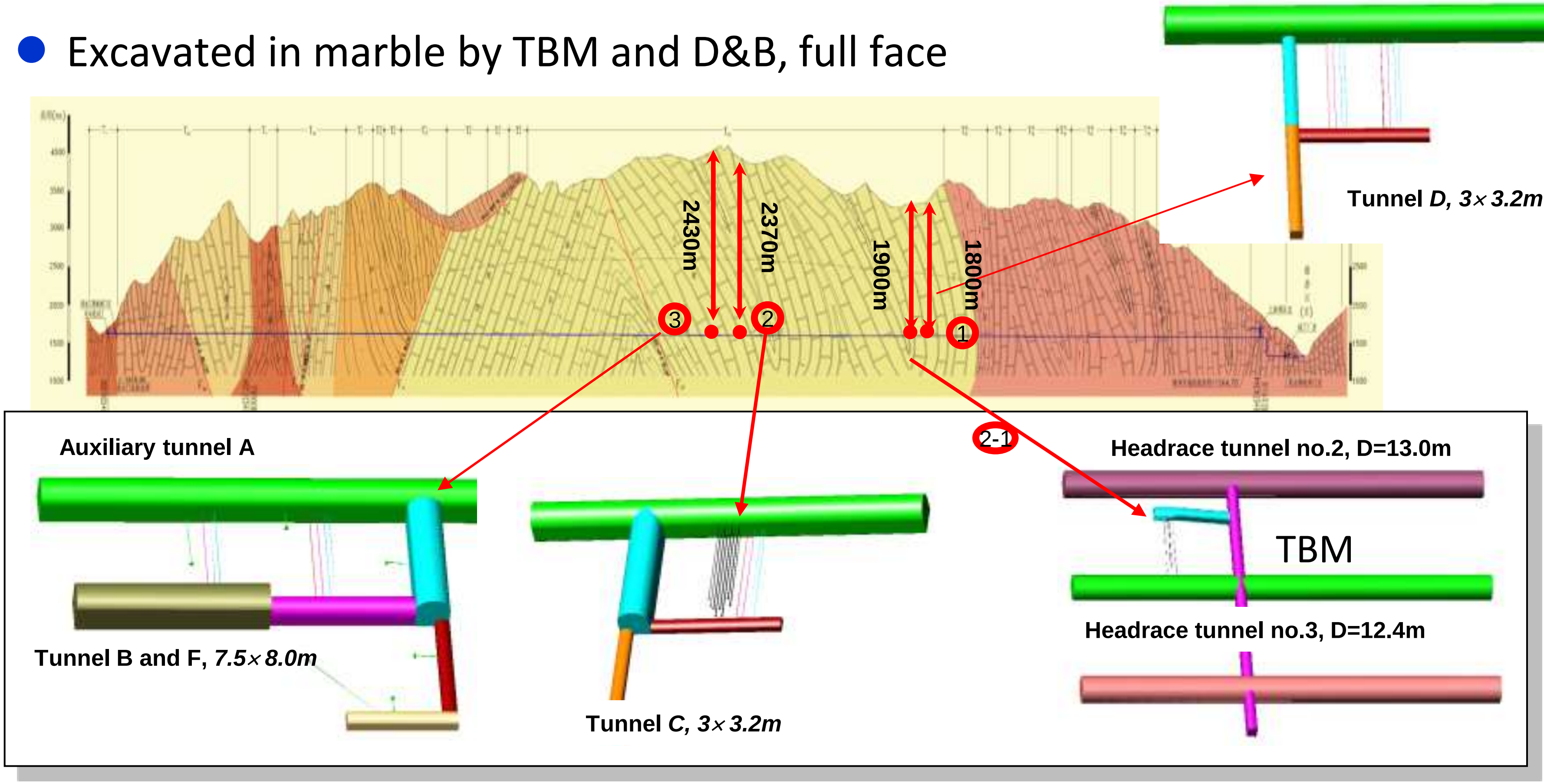


Lower than 30% of average velocity of original rockmass

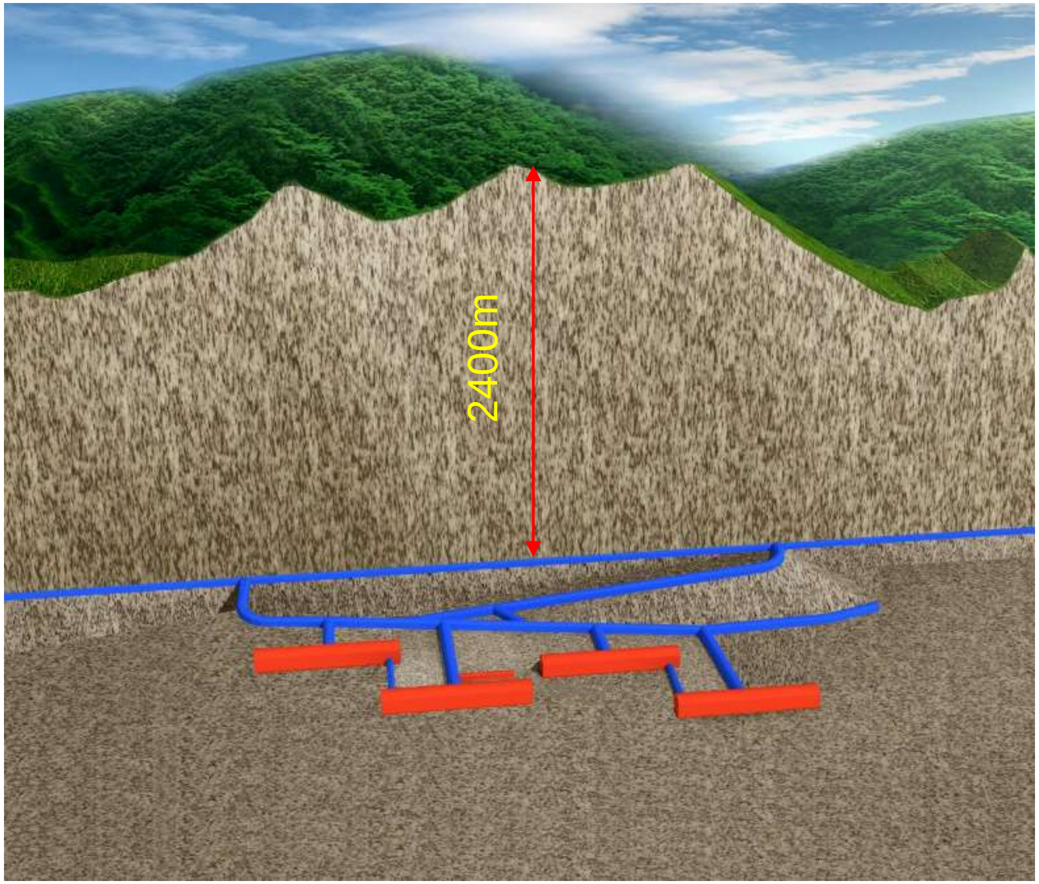
Deep tunnels excavated by different method

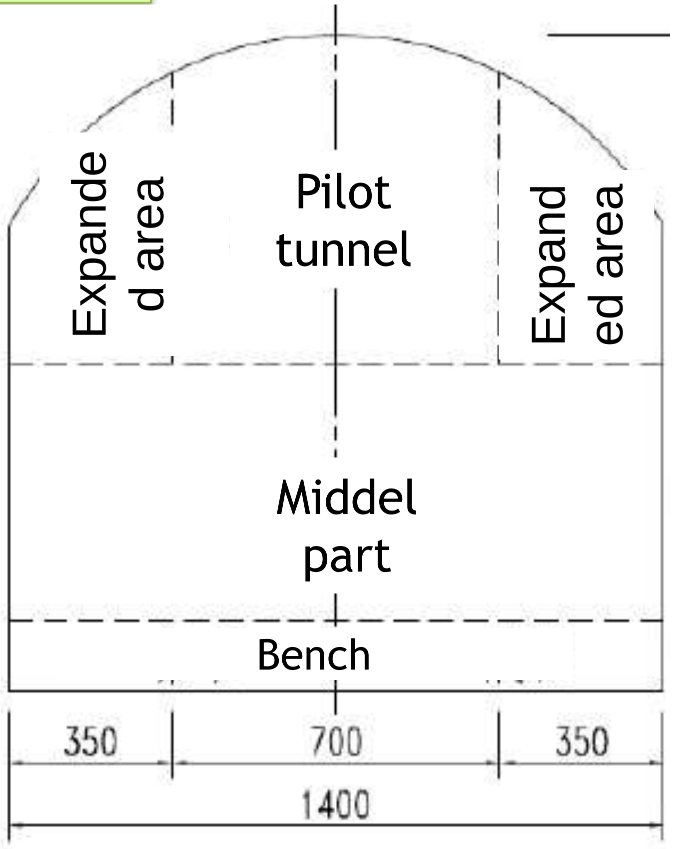
CJPL-1: China Jinping underground laboratory

- Excavated in marble by TBM and D&B, full face



CJPL-II: China Jinping underground laboratory



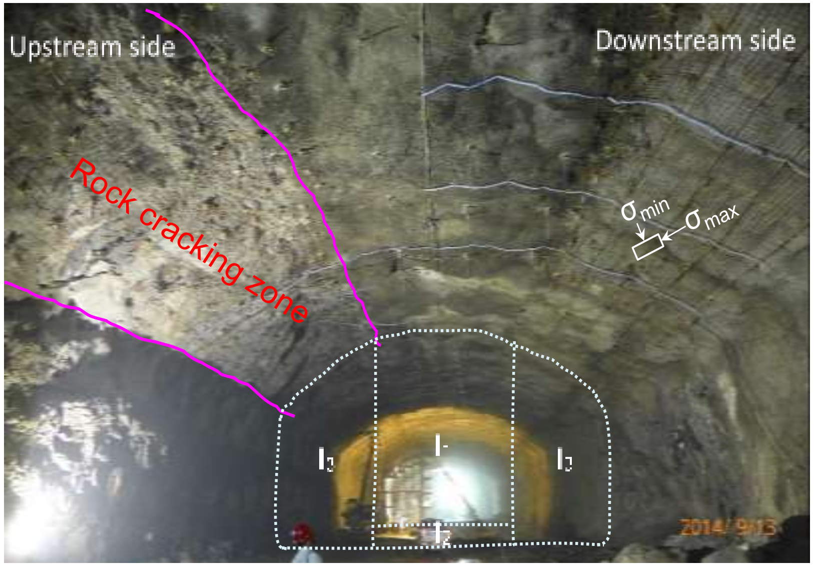


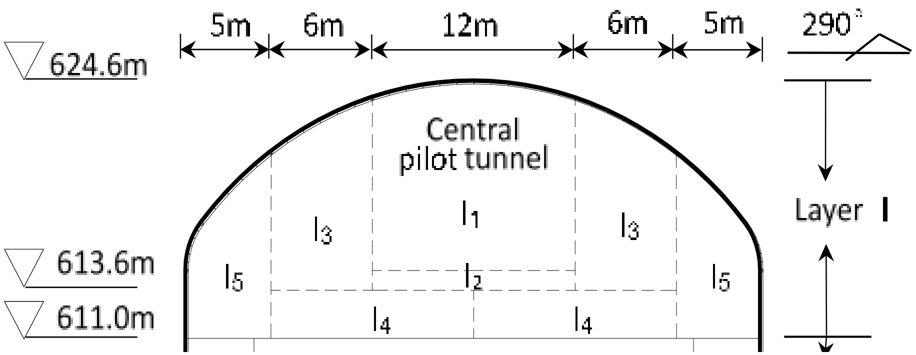
- Excavated in marble by D&B

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

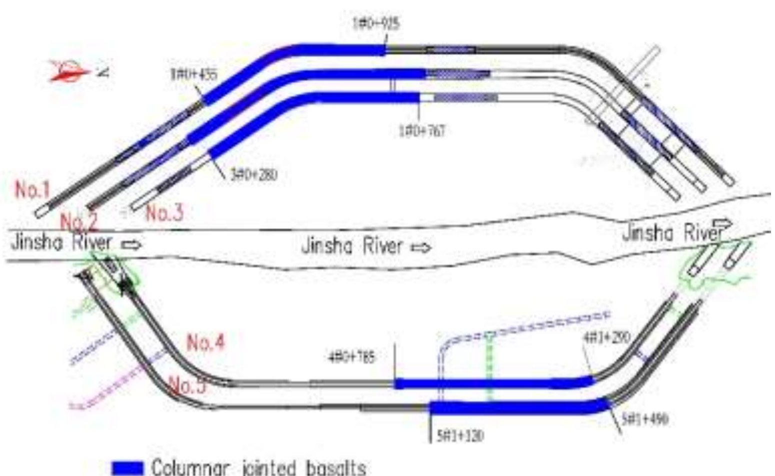
Baihetan hydropower station

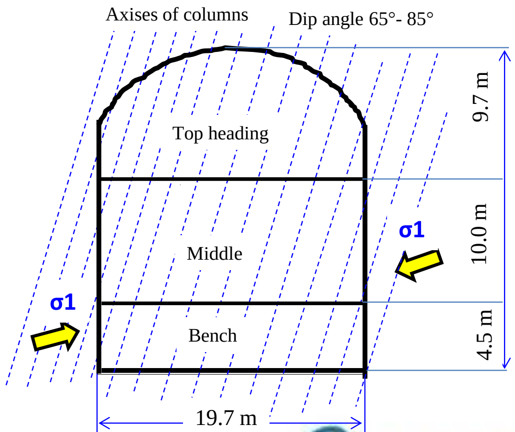
- Excavated at different layers in basalt
- Drillng and blasting method





The current biggest one, main power house, dimision:434×34(31)×86.7 m (L×W×H)

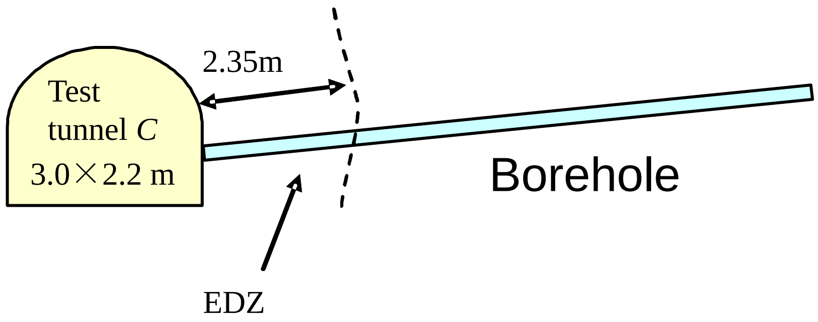




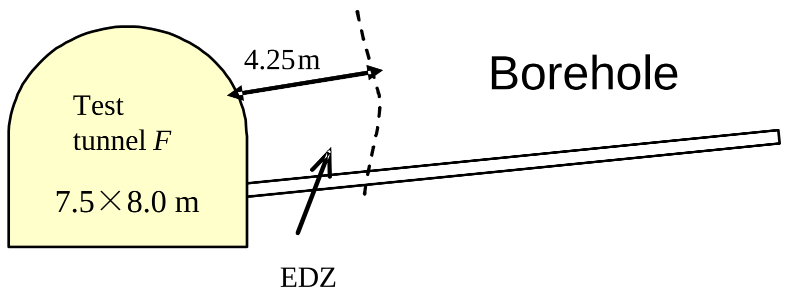
5 diversion tunnels

Characteristics of rock fractures and hazards

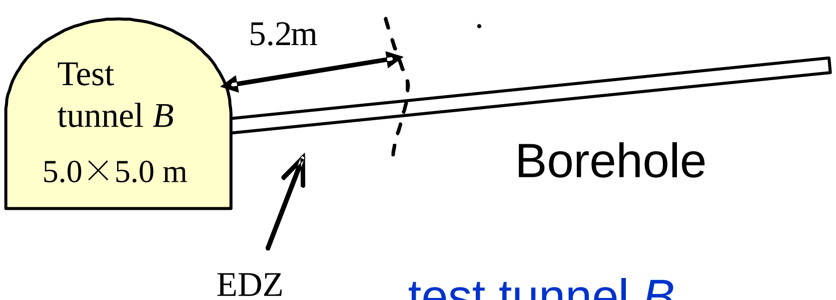
Change of Excavation damaged zone



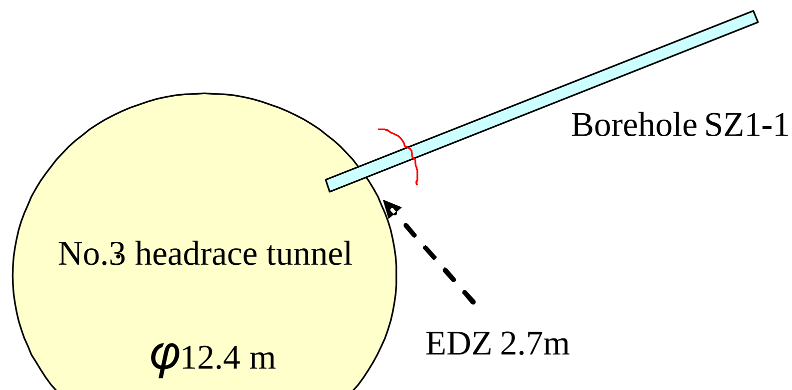
test tunnel *C*



Test tunnel *F*



test tunnel *B*



Headrace tunnel

More than 80 boreholes were pre-drilled before excavation

Statistics of EDZ under different tunnel sizes of CJPL-1

Tunnel No.	Width of EDZ/EdZ (m)		Tunnel section (m)		Relationship with tunnel geometry		Excavation method
	EDZ (*ew*)	EdZ (*dw*)	Width (*w*)	Height (*h*)	R_{ew}	R_{eh}	
Test tunnel *B*	5.2	6.8	5.0	5.0	1.1	1.1	D & B) （Full-face）
Test tunnel *C*	2.35	6.35	3.0	2.2	0.78	1.1	D & B （Full-face）
Test tunnel *F*	4.25	6.5	7.5	8.0	0.57	0.53	D & B (two benches)
No.3 headrace tunnel	2.7	6.3	ϕ12.4		0.22		TBM （Full-face）

$$R_{ew} = ew / w \qquad R_{eh} = ew / h$$

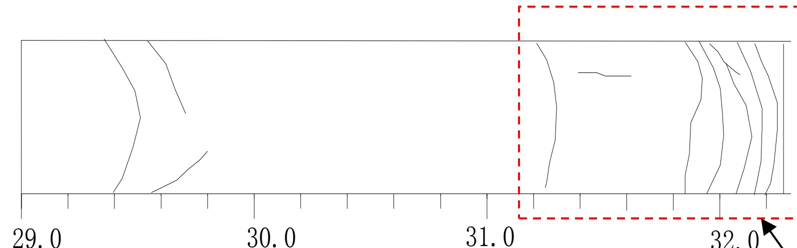
R_{ew} and R_{eh} are 0.78-1.1 times of tunnel width and height (For D&B and full-face excavation method)

R_{ew} and R_{eh} are 0.55 times of tunnel width and height (For D&B excavation with two benches)

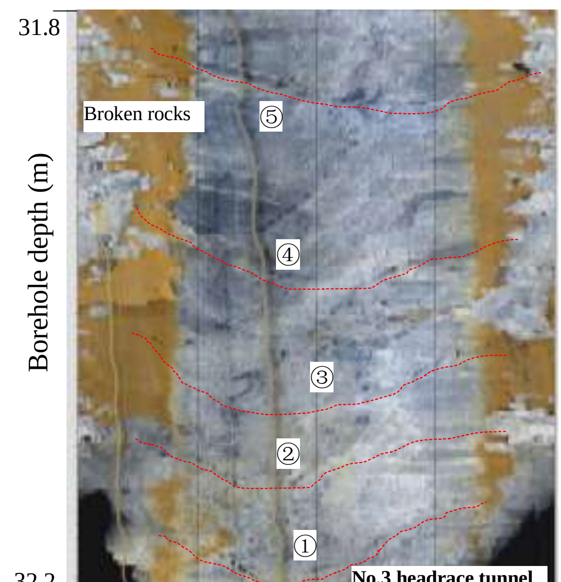
R_{ew} and R_{eh} are 0.22 times of tunnel diameter (For TBM excavation)

Property of rock fracture induced by excavation

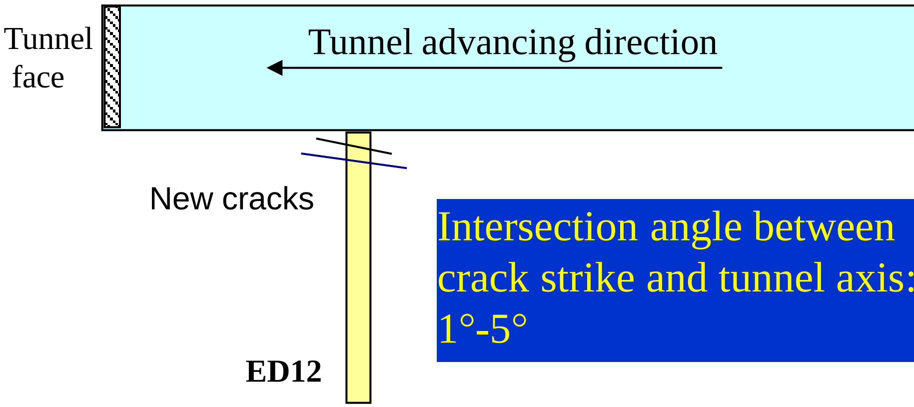
- *In situ* observation on tunnel sidewalls
- Rock spalling occurred but fractures can also be found in deep rock mass



Fractures

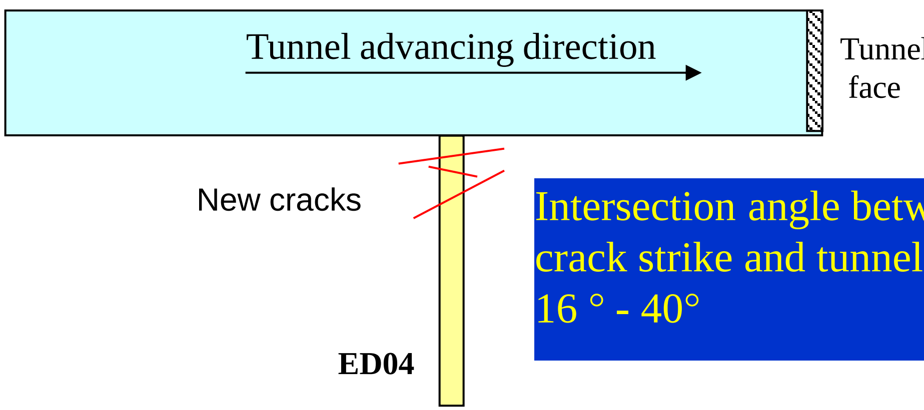


Flattered image of borehole wall



Intersection angle between crack strike and tunnel axis: 1°-5°

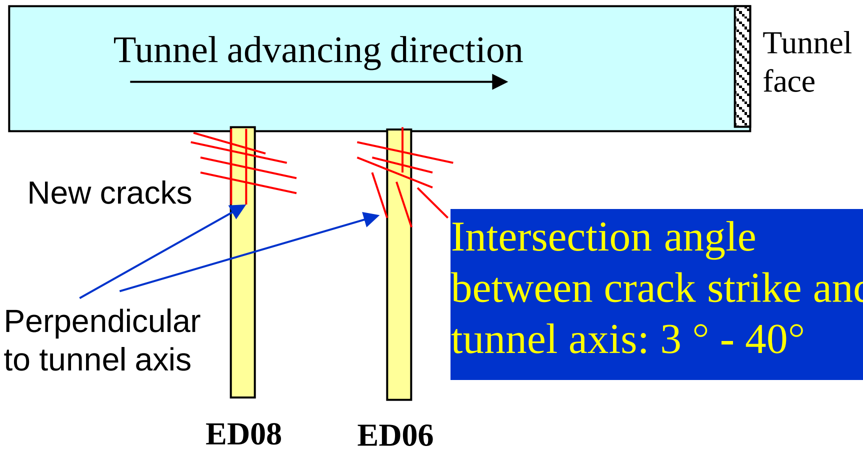
Test tunnel *C*



Intersection angle between crack strike and tunnel axis: 16 ° - 40°

Test tunnel *B*

Test tunnel *F*

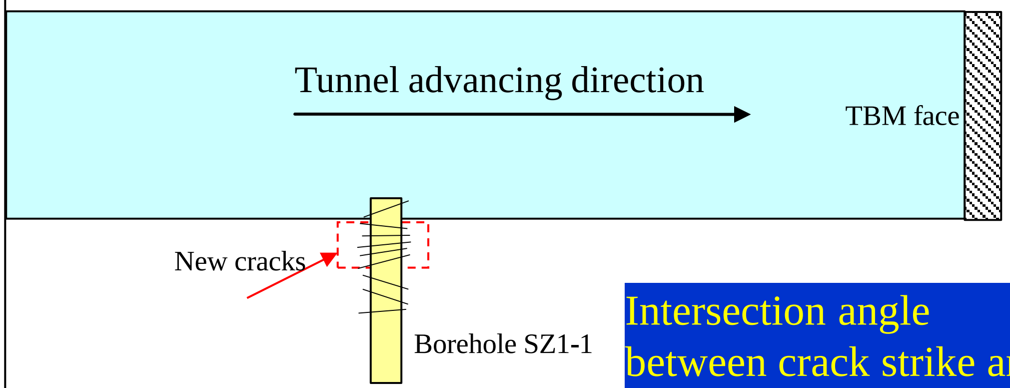


Intersection angle between crack strike and tunnel axis: 3 ° - 40°

Northern sidewall

Southern sidewall

No.3 headrace tunnel



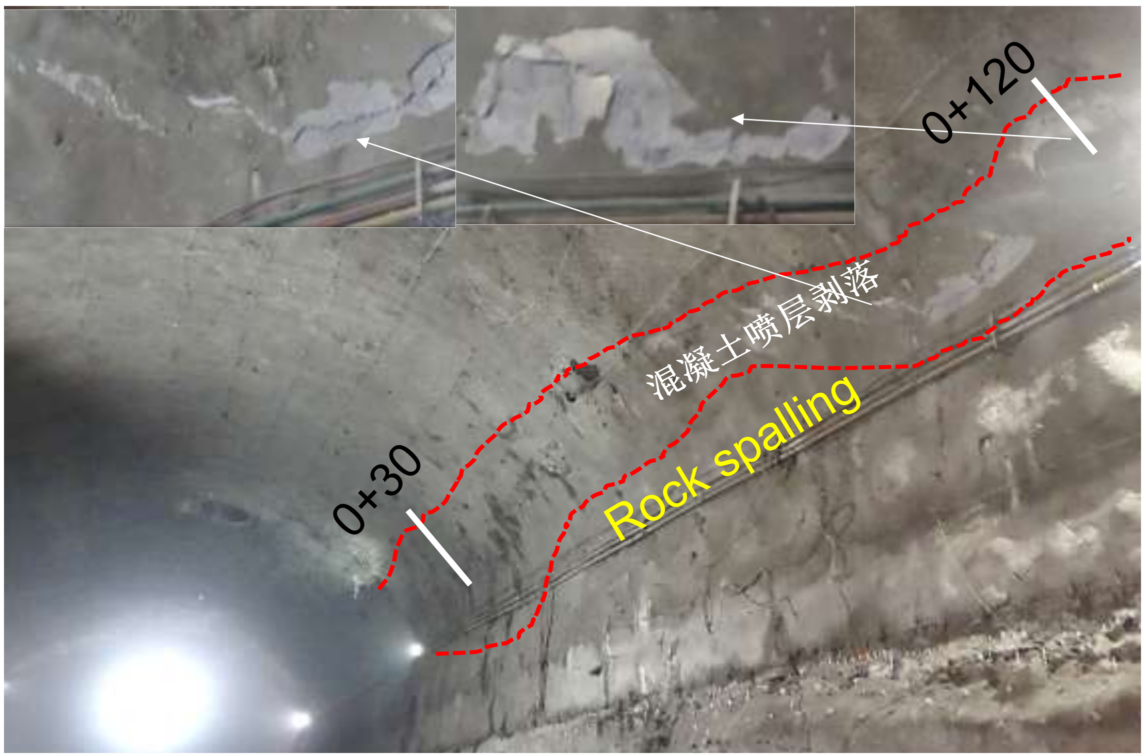
Intersection angle between crack strike and tunnel axis: 1 ° - 20°

- Different direction of fracture can be found in D&B tunnels
- Fractures in TBM tunnel are almost parallel to axis

Fracture evolution and spalling

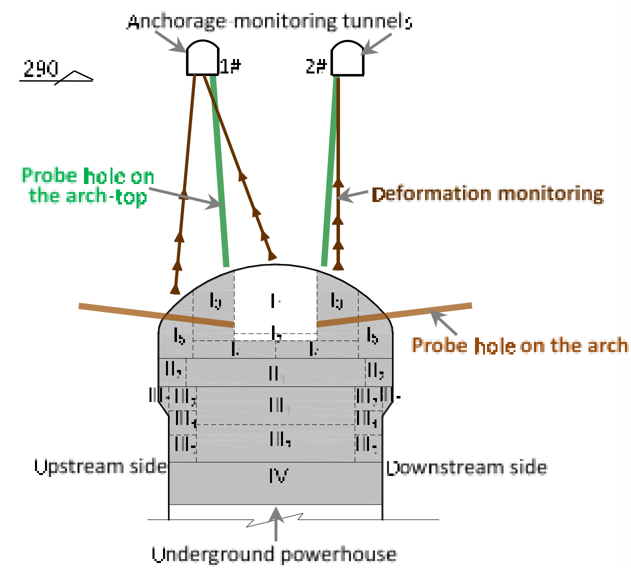
Observation and calculation during the excavation layer 3

- 2015.9.27, the workers heard a big sound, spalling happened inside the rock mass
- Following detail check found that there were many cracks along 0+30 - 0+133 at the crown.



Main power house of Baihetan

River side

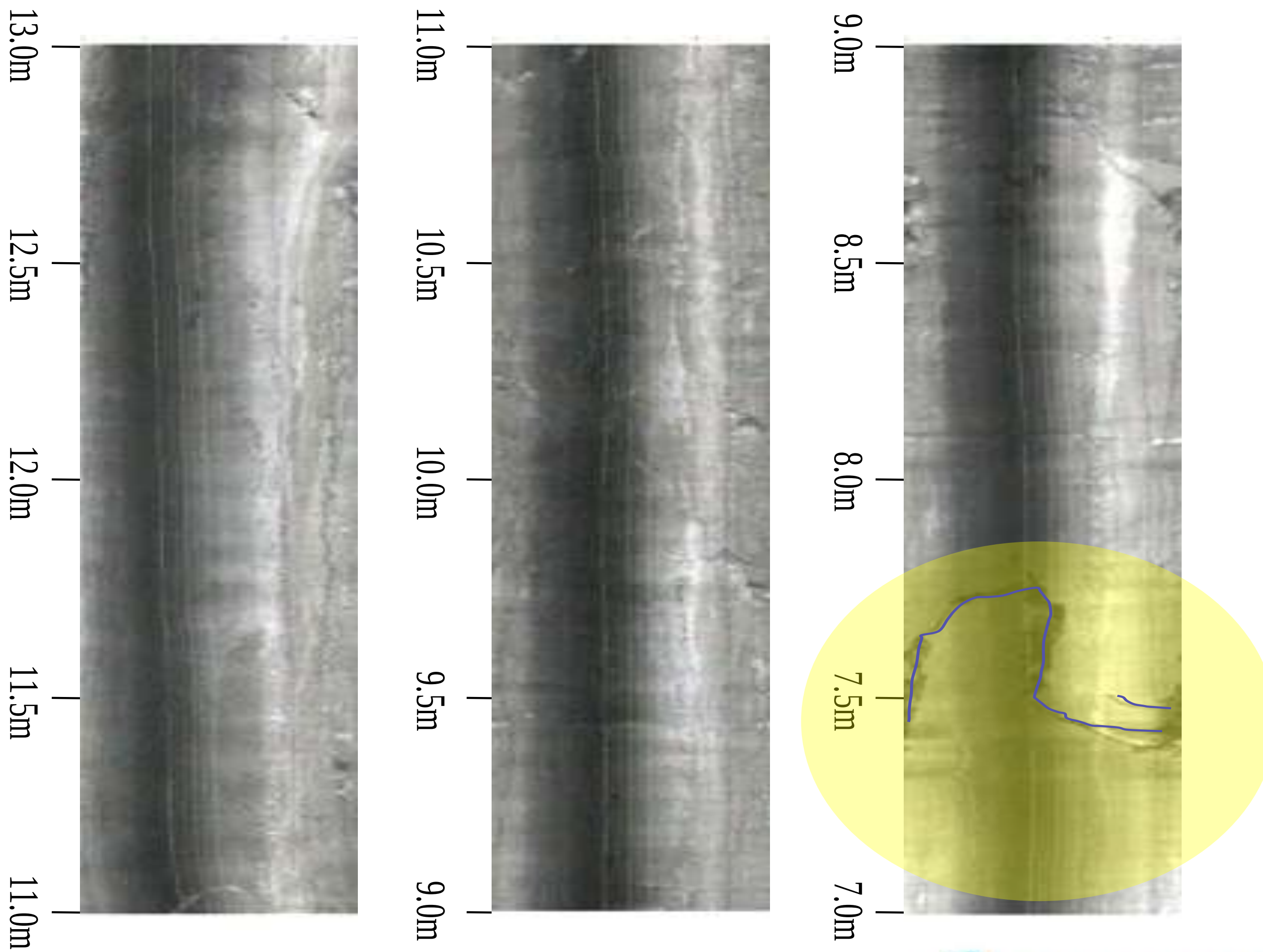


Two borehole preinstalled

Observation and calculation during the excavation layer 3

✓Observation in the boreholes at 0+72

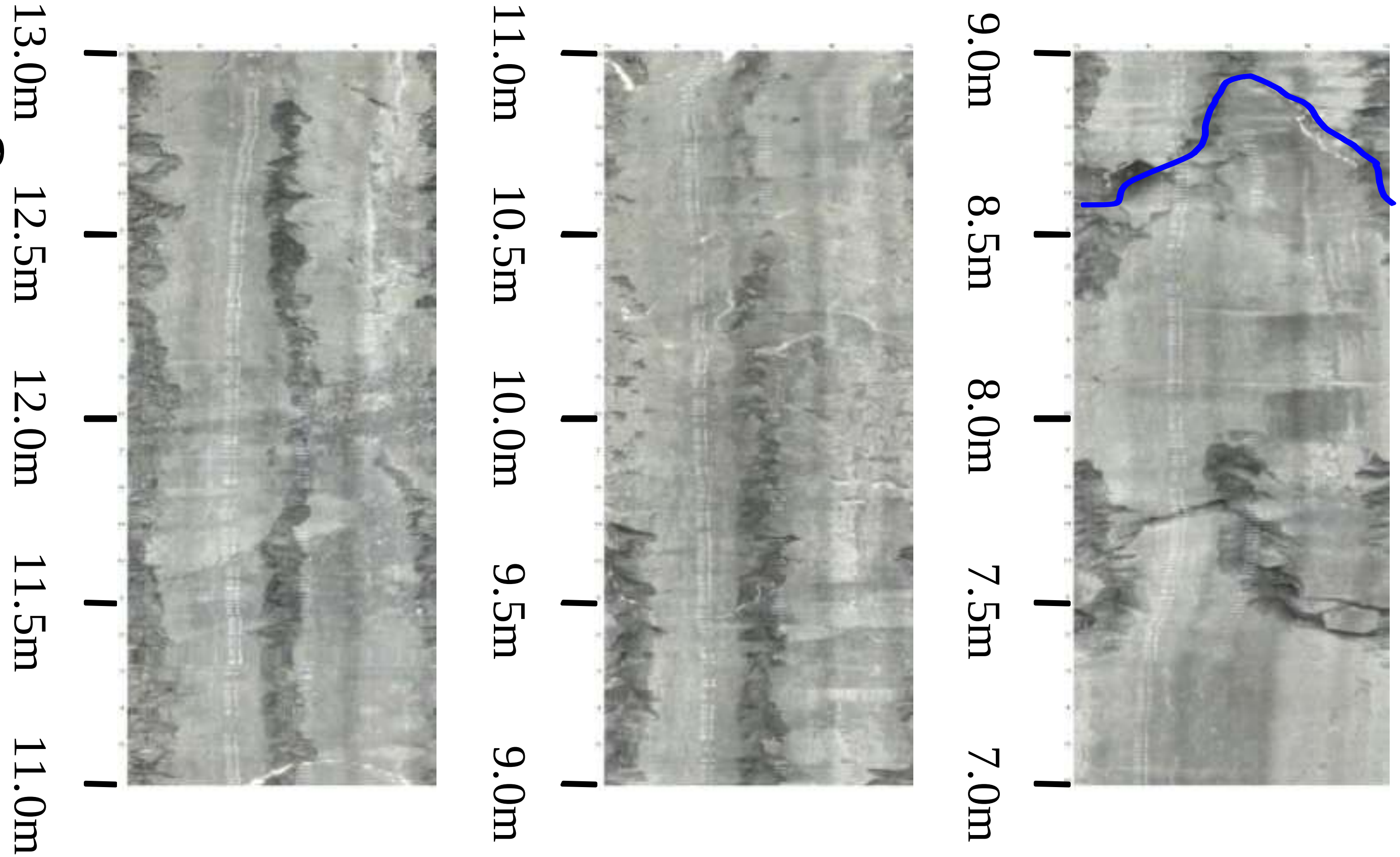
Date:
2015-9-27



Observation and calculation during the excavation layer 3

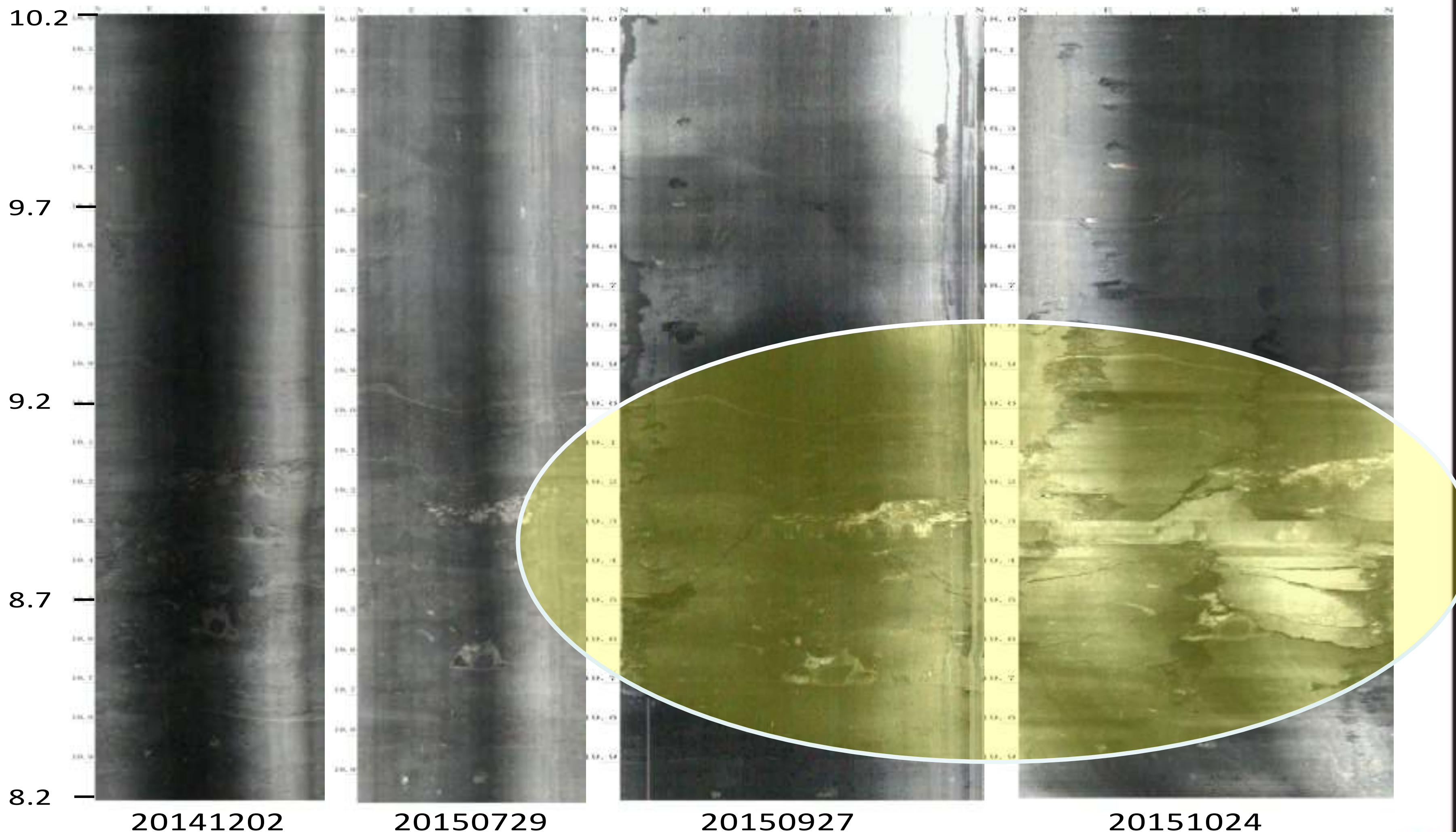
✓Observation in the boreholes at 0+72

Date:
2015-11-29

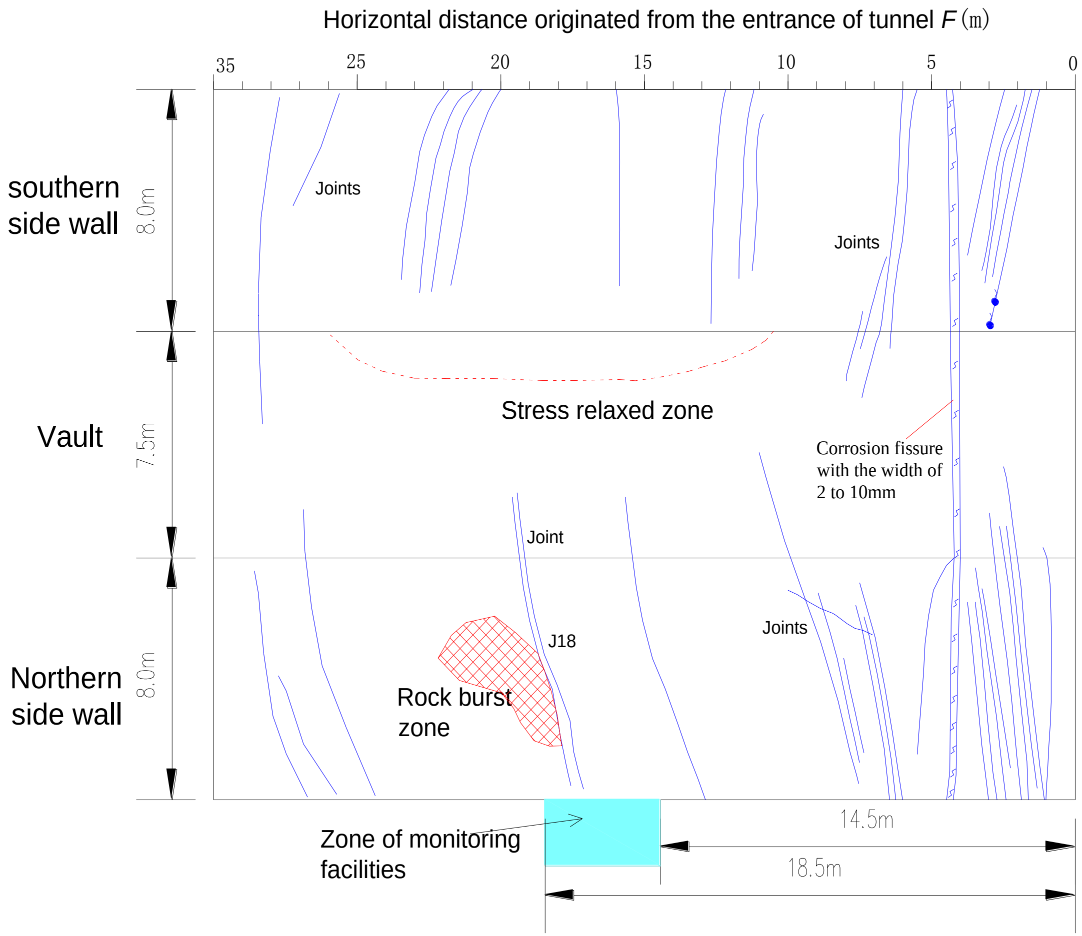


Observation and calculation during the excavation layer 3

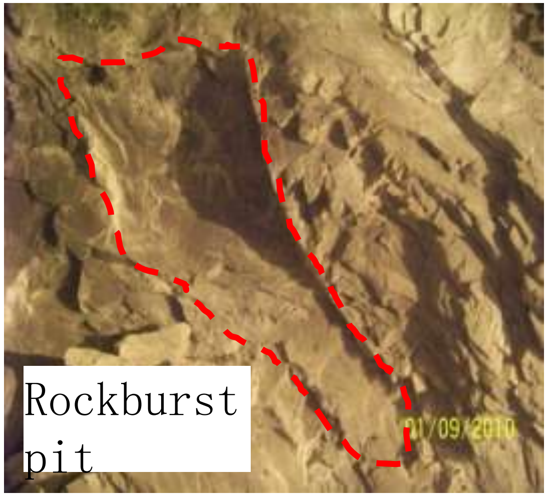
✓Observation in the boreholes at PB2: 0+90



Fracture evolution and rockburst

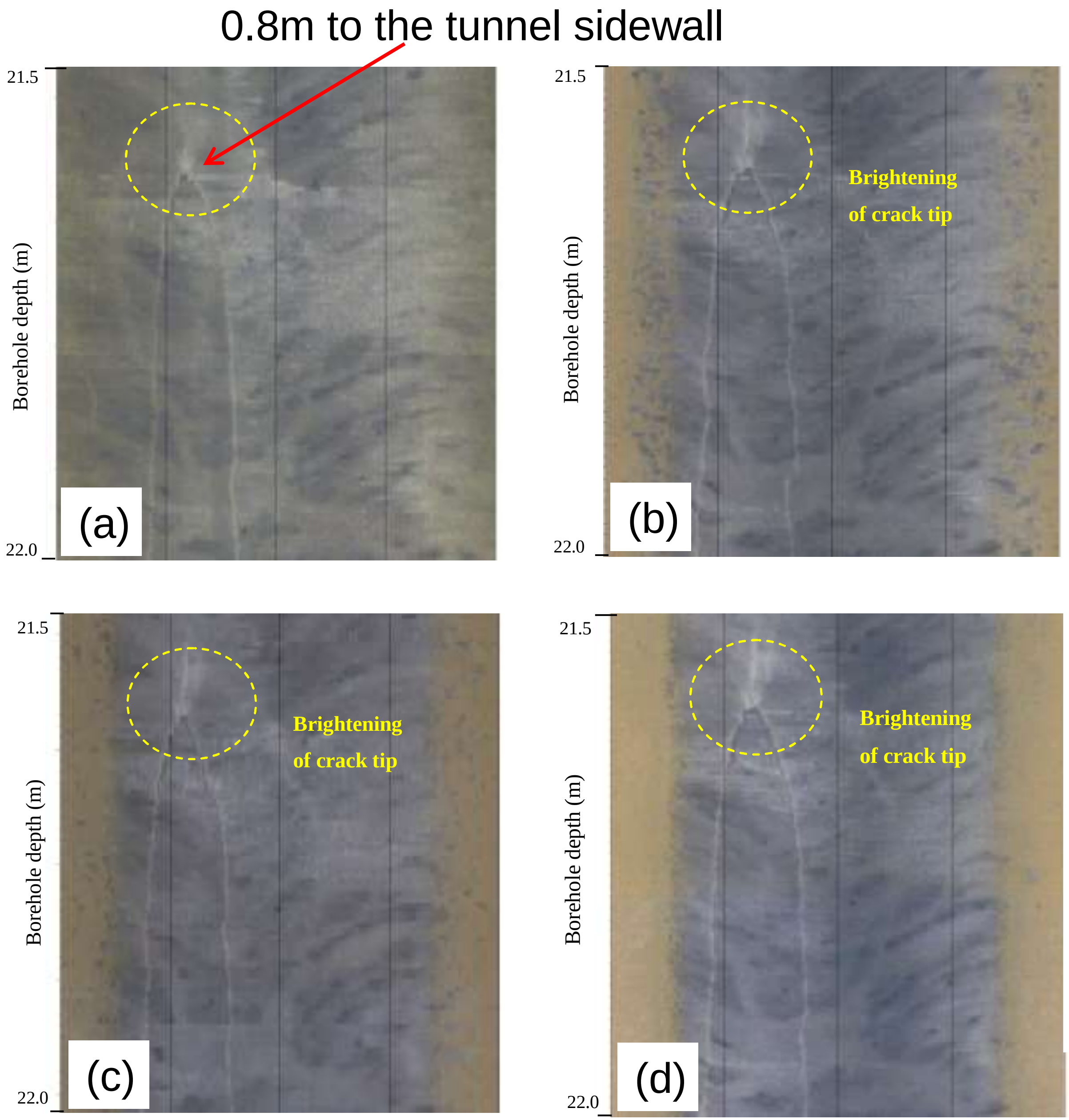


Unfolded geological sketching of tunnel F in CJPL-1 project

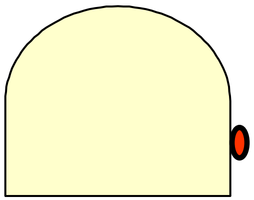


Rockburst occurred on January 09, 2010， with the volume about 6.3 m^3

Crack initiation and evolution



Rockburst occurred on Jan 09



Color change of crack tip

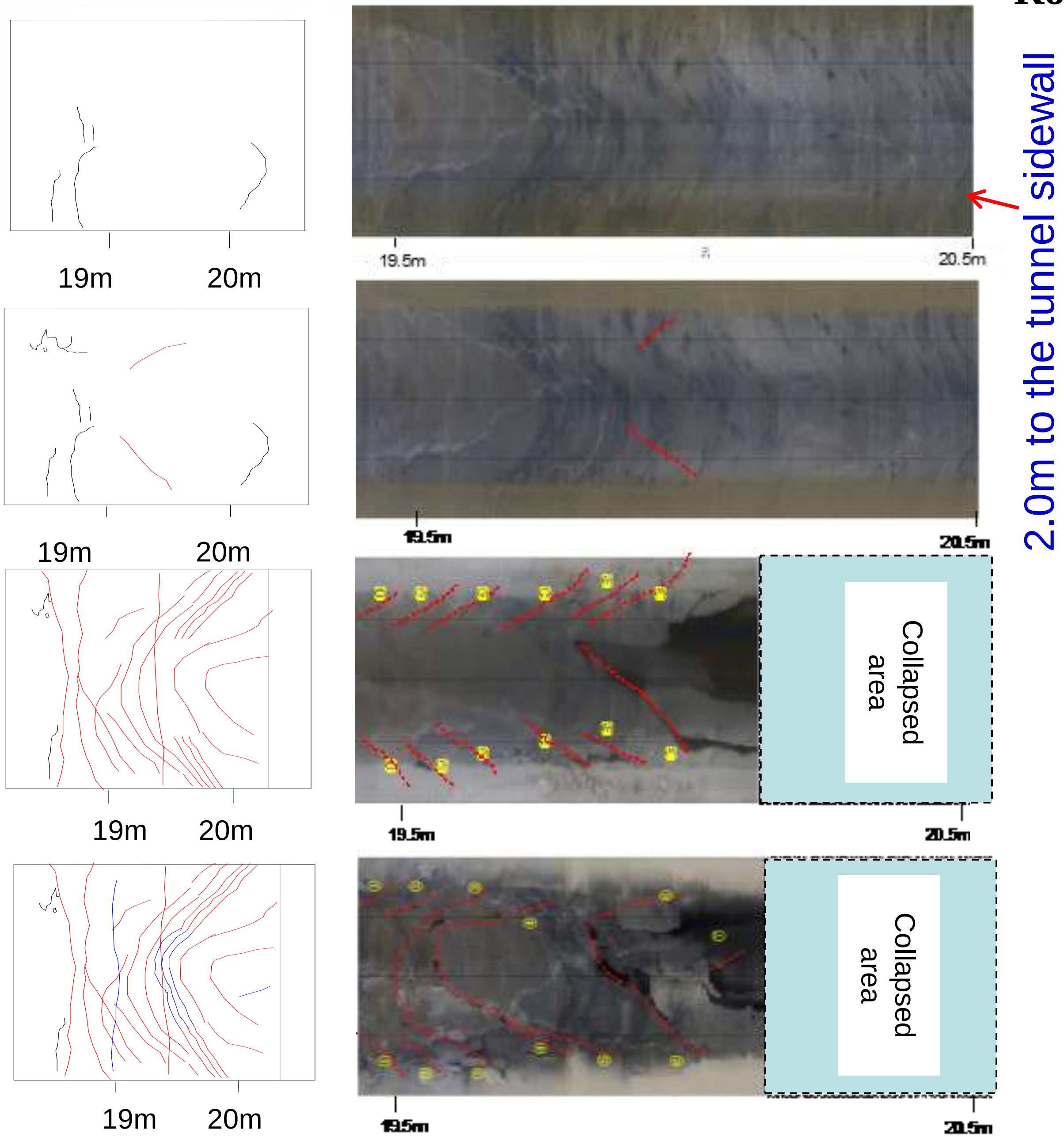
(a)Oct. 13, 2009, before excavation

(b)Dec. 22, 2009, 19.3 m excavated at the top heading of test tunnel *F*

(c)Dec. 28, 2009, 33.1 m excavated at the top heading of test tunnel *F*

(d)Jan. 03, 2010, the excavation was finished at the top heading of test tunnel *F*

Evolution of cracks before rockburst



Rockburst occurred on Jan 09

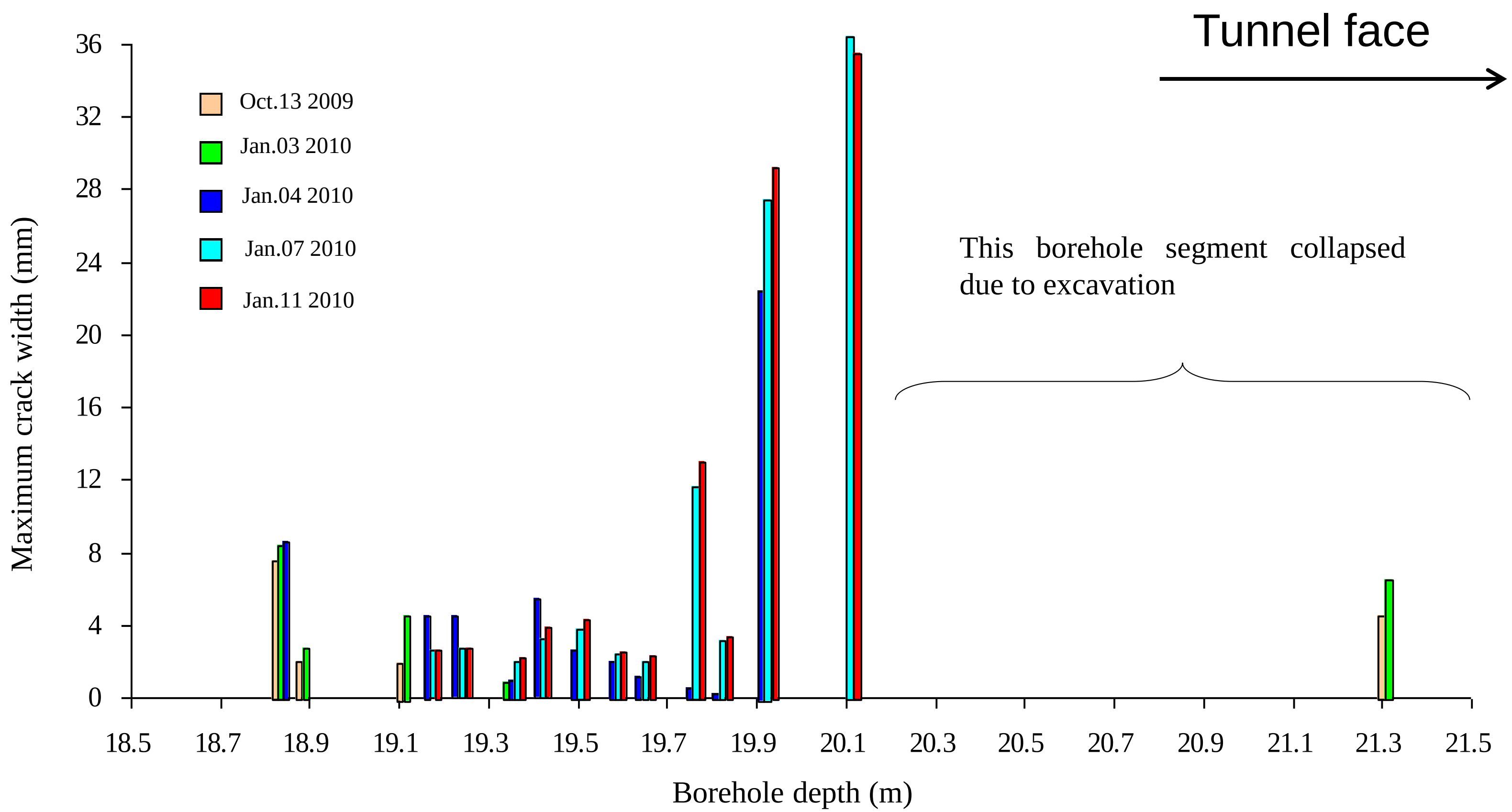
(a)Oct. 13, 2009, Pre-existed cracks before excavation

(b)Jan. 03, 2010, New cracks appeared in red line, the upper layer excavation finished

(c) Jan. 04, 2010, Abundant of new cracks appeared, 10.0 m excavated at the bottom layer

(d) Jan. 07, 2010, cracks run through, 21.0 m excavated at the bottom layer

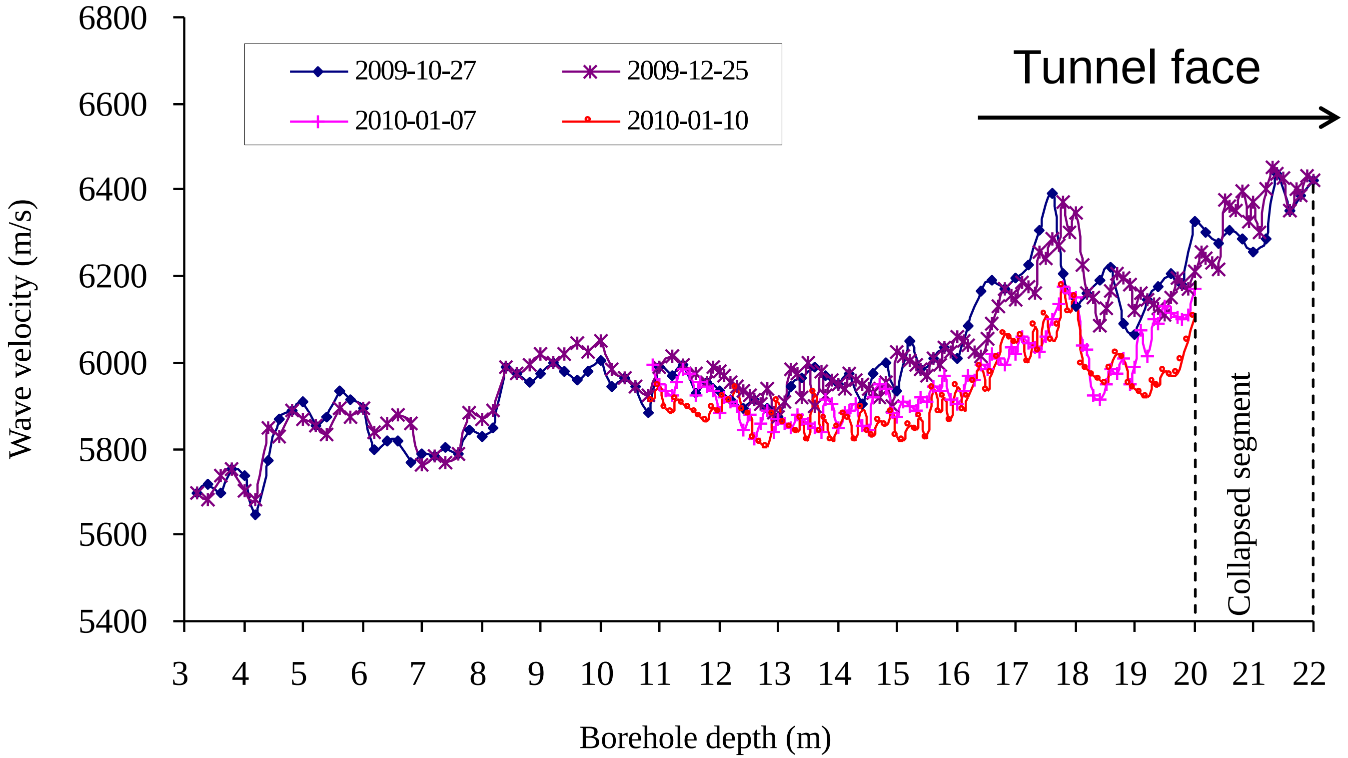
Change of macro cracks' width in borehole M2-DB01 at different borehole depth



New cracks occurred, crack propagation and closure

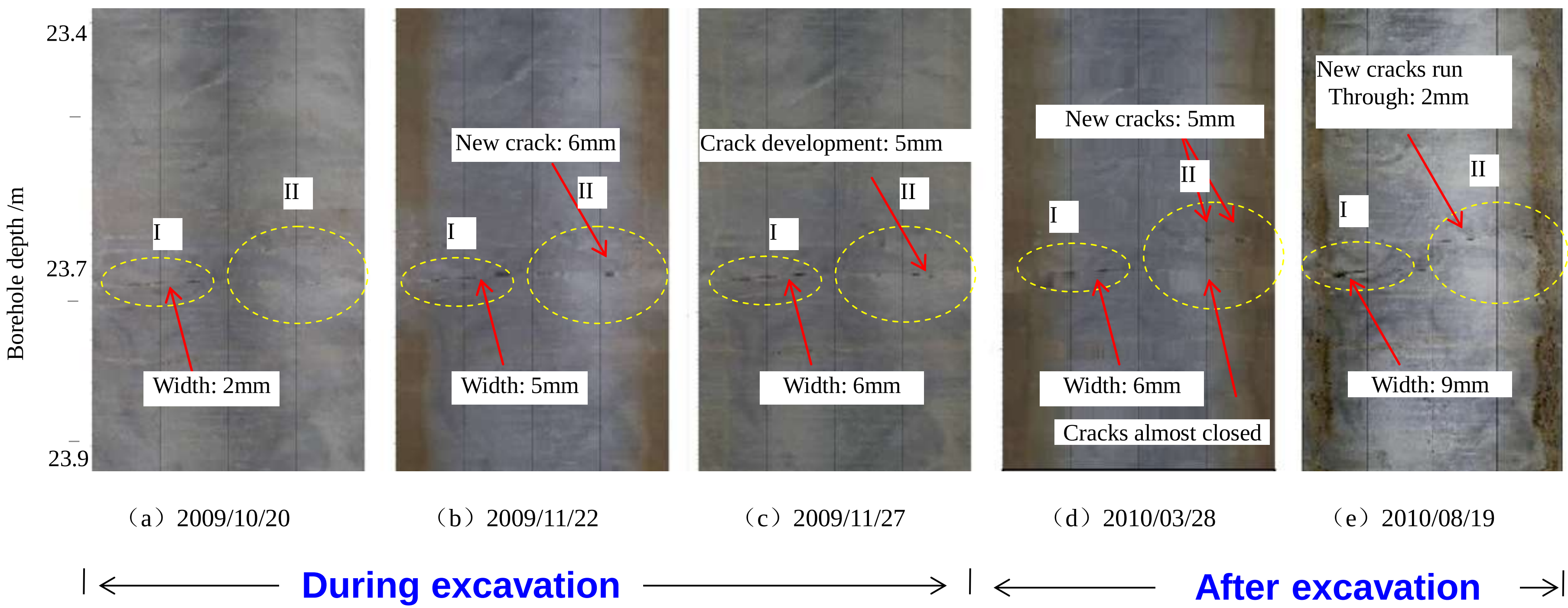
Change of elastic wave velocity

The decrease magnitude of elastic wave is up to 4%



The change of elastic wave of rock mass between monitoring boreholes M2-EW01 and M2-EW02 measured by cross-hole method

Time depended evolution of fracture in hard rock



- **8 months after excavation**
- **New cracks occurred and existed joint propagation and closure**

Conclusions

Important role of fracture *in situ* measurement for

- ✓ Formation and evolution process of excavation damaged
- ✓ Rock spalling process
- ✓ Rockburst evolution and prewarning
- ✓ Mechanism of stability of underground openings under deep environment and high stress condition

Thanks for your attention!