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

Shaojun Li
State Key Laboratory of Geomechanics and Geotechnical Engineering
Institute of Rock and Soil Mechanics, Chinese Academy of Sciences
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 openings: Example of Jinping I underground caverns

- Large deformation
- Big fractures

- No excavation
- Excavation halted for more than 6 months
Rockbursts in deep openings are also related to fracture evolution.

- **Sidewall rockburst**
  - South side wall with hard structure surface
  - North side wall blast, blast depth of about 2.0m

- **Steel mesh destroyed**
  - South side wall steel mesh tore

- **Tunnel floor Fractured**
  - Width: 10 cm, depth: 1.0m

**Tunnels of Jinping II hydroelectric project**
Sit investigations were conducted to understand the correlation between fracture and tunnel stability and hazards.

Fracture distribution abundant boreholes around surrounding rock mass.
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
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

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

Excavated in marble by D&B
Baihetan hydropower station

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

The current biggest one, main power house, dimension: 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 $C$
- $3.0 \times 2.2$ m
- EDZ: 2.35 m

Test tunnel $F$
- $7.5 \times 8.0$ m
- EDZ: 4.25 m

Test tunnel $B$
- $5.0 \times 5.0$ m
- EDZ: 5.2 m

No.3 headrace tunnel
- $\varphi 12.4$ m
- EDZ: 2.7 m

More than 80 boreholes were pre-drilled before excavation
Statistics of EDZ under different tunnel sizes of CJPL-1

<table>
<thead>
<tr>
<th>Tunnel No.</th>
<th>Width of EDZ/EdZ (m)</th>
<th>Tunnel section (m)</th>
<th>Relationship with tunnel geometry</th>
<th>Excavation method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EDZ (ew)</td>
<td>EdZ (dw)</td>
<td>Width (w)</td>
<td>Height (h)</td>
</tr>
<tr>
<td>Test tunnel $B$</td>
<td>5.2</td>
<td>6.8</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Test tunnel $C$</td>
<td>2.35</td>
<td>6.35</td>
<td>3.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Test tunnel $F$</td>
<td>4.25</td>
<td>6.5</td>
<td>7.5</td>
<td>8.0</td>
</tr>
<tr>
<td>No.3 headrace tunnel</td>
<td>2.7</td>
<td>6.3</td>
<td>$\Phi$12.4</td>
<td></td>
</tr>
</tbody>
</table>

\[ R_{ew} = \frac{ew}{w} \quad R_{eh} = \frac{ew}{h} \]

- $R_{ew}$ 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

**Flattered image of borehole wall**
Intersection angle between crack strike and tunnel axis:

- Tunnel tunnel C
  - $1^\circ - 5^\circ$

- Tunnel tunnel B
  - $16^\circ - 40^\circ$
Tunnel advancing direction

New cracks

Perpendicular to tunnel axis

ED08  ED06

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

Northern sidewall

Southern sidewall

Test tunnel F

No.3 headrace tunnel

Tunnel advancing direction

New cracks

Borehole SZ1-1

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

TBM face

Different direction of fracture can be found in D&B tunnels

Fractures in TBM tunnel are almost parallel to axis
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.
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

Horizontal distance originated from the entrance of tunnel $F (m)$

**Vault**

- Southern side wall
- Northern side wall

- Stress relaxed zone
- Corrosion fissure with the width of 2 to 10mm

- Rock burst zone
- Zone of monitoring facilities

**Unfolded geological sketching of tunnel F in CJPL-1 project**

Rockburst occurred on January 09, 2010, with the volume about 6.3 m³
Crack initiation and evolution

0.8m to the tunnel sidewall

(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

Rockburst occurred on Jan 09

Color change of crack tip

Rockburst occurred on Jan 09

Color change of crack tip

Rockburst occurred on Jan 09

Color change of crack tip
Evolution of cracks before rockburst

Rockburst occurred on Jan 09

(a) Oct. 13, 2009, Pre-existing 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

This borehole segment collapsed due to excavation

New cracks occurred, crack propagation and closure
The change of elastic wave of rock mass between monitoring boreholes M2-EW01 and M2-EW02 measured by cross-hole method.

The decrease magnitude of elastic wave is up to 4%.
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!