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Stability Analysis and Reinforcement of the Existing Karst Cave Passing through Yujingshan Tunnel

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STABILITY ANALYSIS AND REINFORCEMENT OF THE EXISTING KARST CAVE PASSING THROUGH YUJINGSHAN TUNNEL

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Tuesday, November 19, 2019 · PATTAYA, THAILAND

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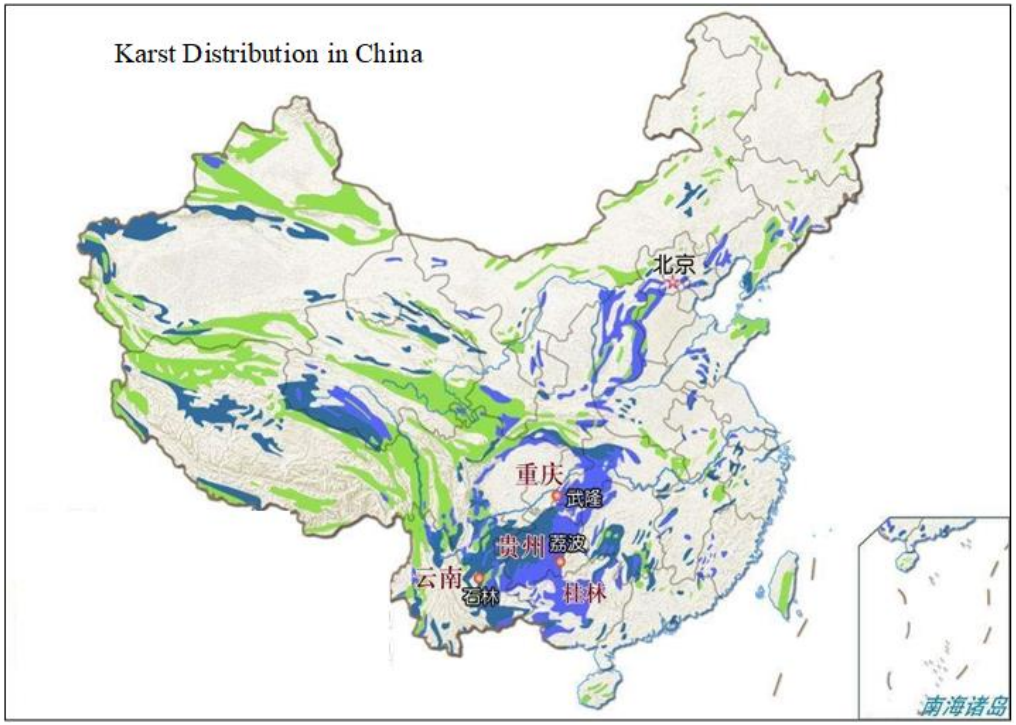
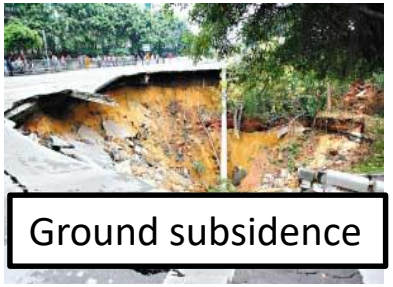
1.1 A SUMMARY OF KARST STUDY



- The country with the largest karst distribution in the world
- A variety of karst types from the tropical to the frigid zone
- Wide distribution in Guangxi, Yunnan, Guizhou and Guangdong province

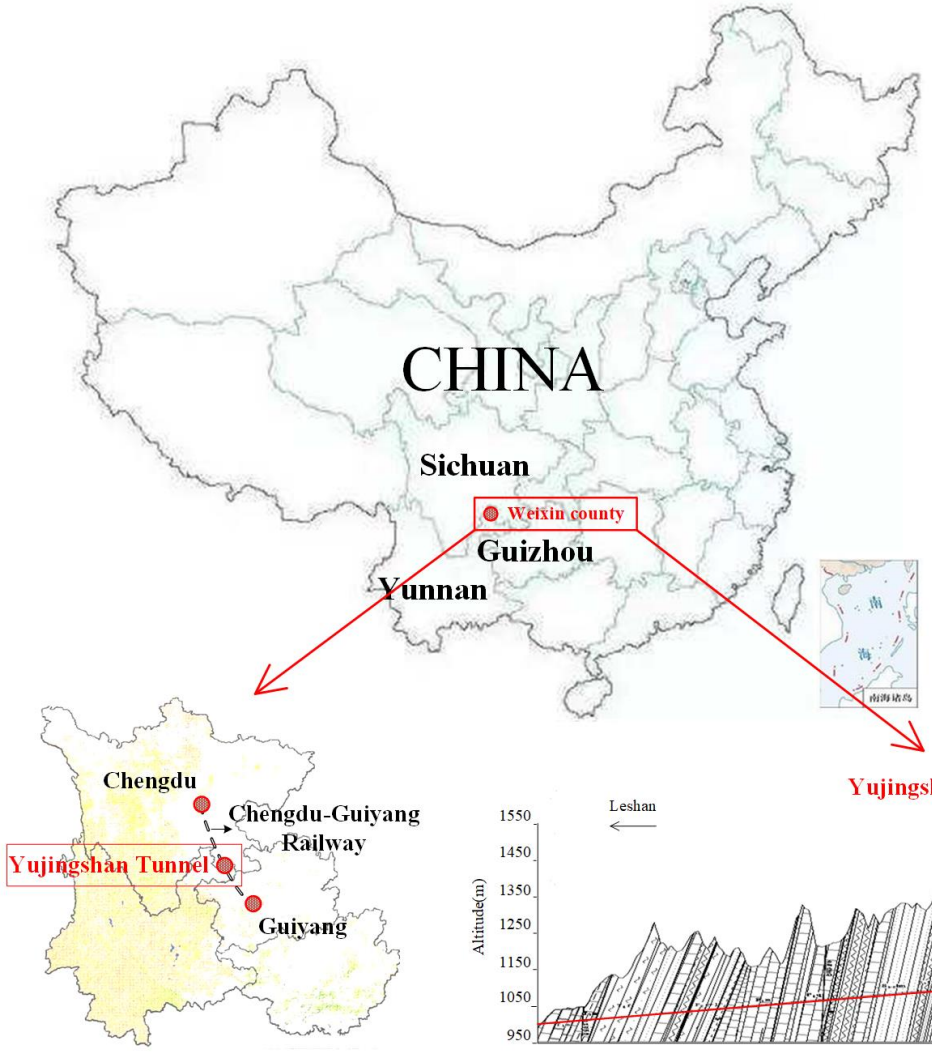
Geological Hazards

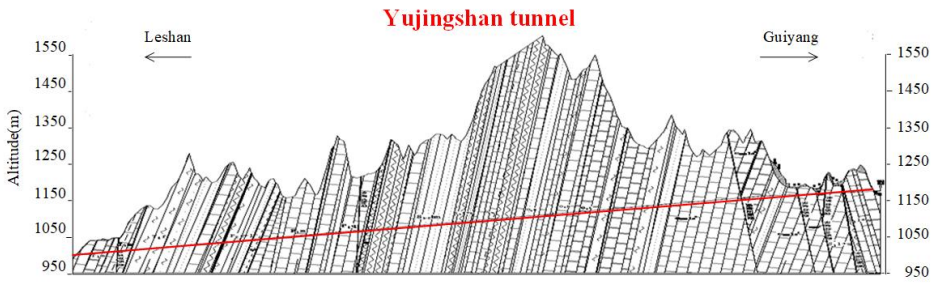

Ground subsidence


Water leakage & inrush


Underground collapse

2.1 ENGINEERING SITUATION





- Yujingshan tunnel is located along the newly-built chengdu-guiyang railway
- Length: 6306m;
  Slope: 30‰ single side;
  depth: 350m
- The tunnel is located in a karst-prone area with large elevation difference and staggered valleys, soluble rock formations account for 65% of the total tunnel length.

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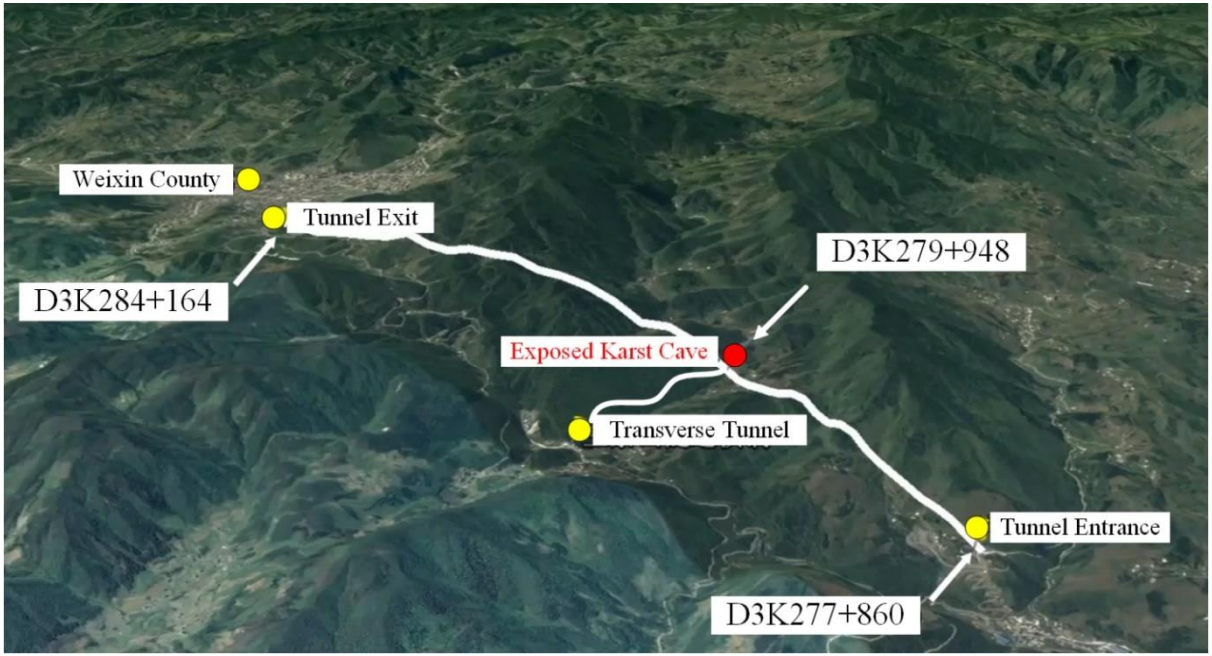
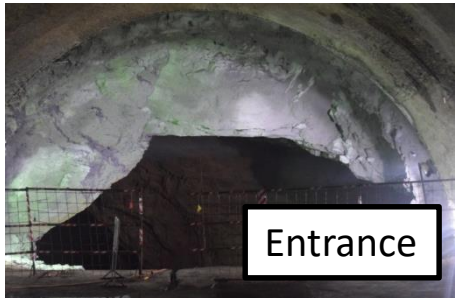
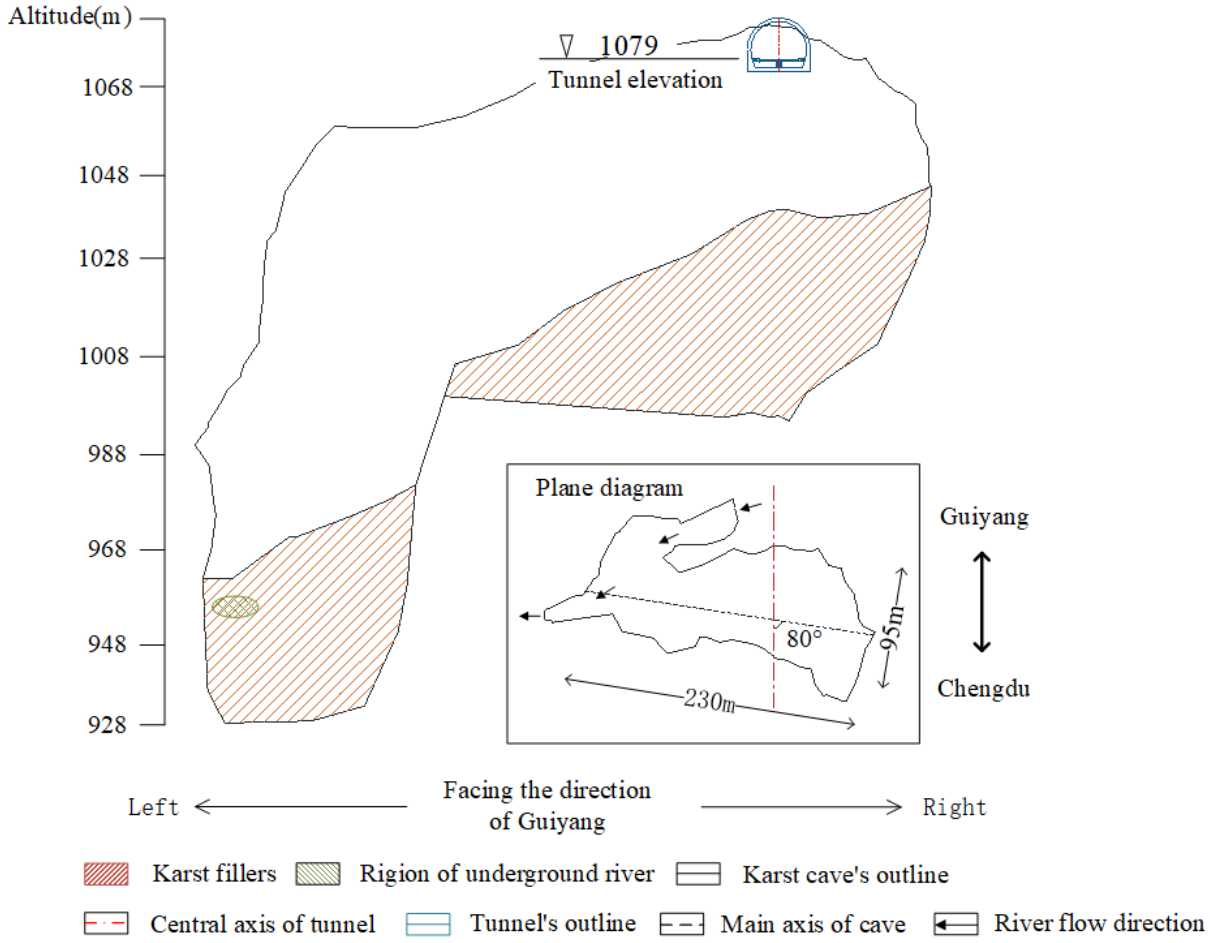
2.1 REVEAL OF KARST CAVE





- The karst cave was exposed when tunnel was excavated to position D3K279+948;
- A underground river was also found at the bottom of the cave during the subsequent investigation.

2.2 GEOLOGICAL CONDITION OF THE KARST SYSTEM



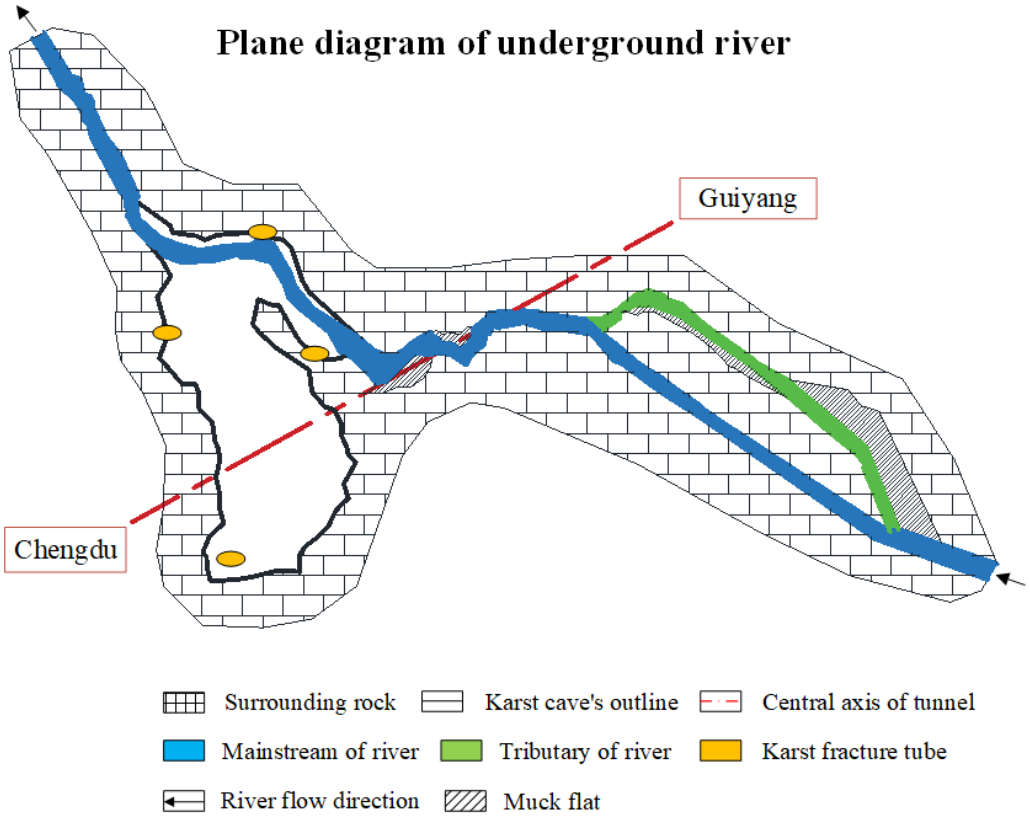
TUNNEL:

- Passes through the cave hall from D3K279+855 to +960;
- is located in the upper part of the cave;
- intersects the cave at an angle of 80 degrees

KARST CAVE:

- About 95m long along the line and 230m perpendicular to the line;
- The bottom fillers is about 30～90m thick, developing downwards with a slope;
- Underground river passes through the left side of the bottom

2.2 GEOLOGICAL CONDITION OF THE KARST SYSTEM

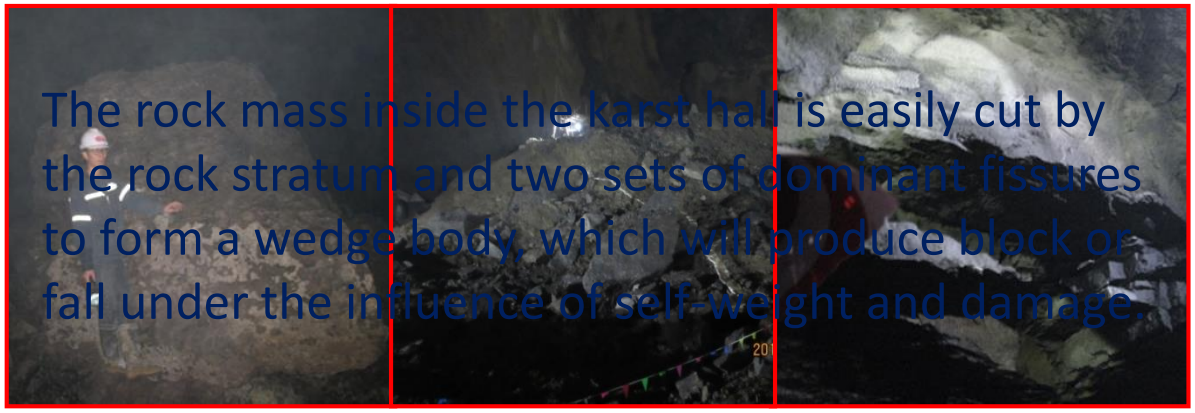


Underground river:

- Total length of the main river is about 740m and width is about 5～15m;
- is located 100m below the base of tunnel, intersecting the line at an angle of 70 degrees;
- Total flow is predicted to be 70m3/s, the hydraulic gradient is 1.8%, and the total catchment area is about 85km2;
- Multiple karst fracture tube develope along the river region with a maximum flow of 4L/s.

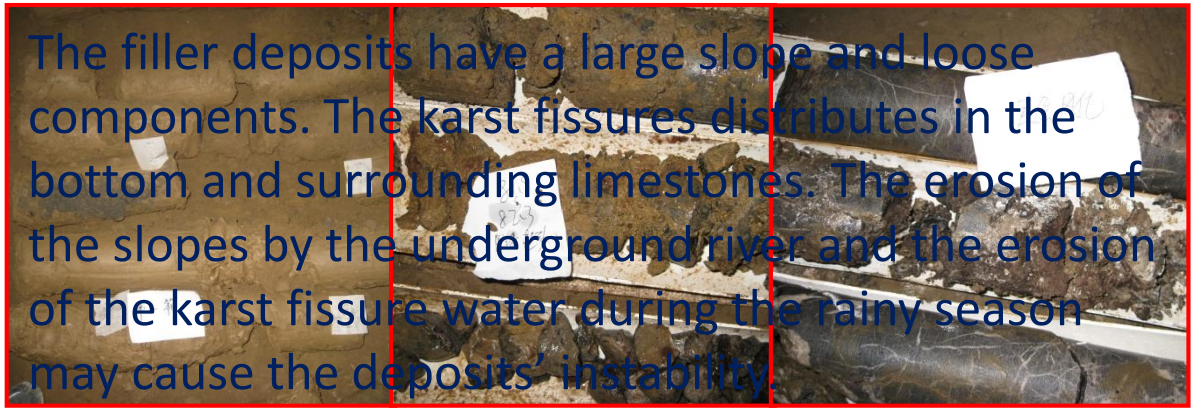
2.3 STABILITY EVALUATION

Stability of cave wall



- Multiple rockfall deposits;
- Overhanging surface in vault;
- Seasonal fissure water;
- Steep rock stratum dip with sets of fracture planes;

Stability of bottom fillers



- soft plastic clay with a thickness of 0 to 15 m;
- Gravel soil, coarse sand, round gravel;
- Bottom contact fracture zone

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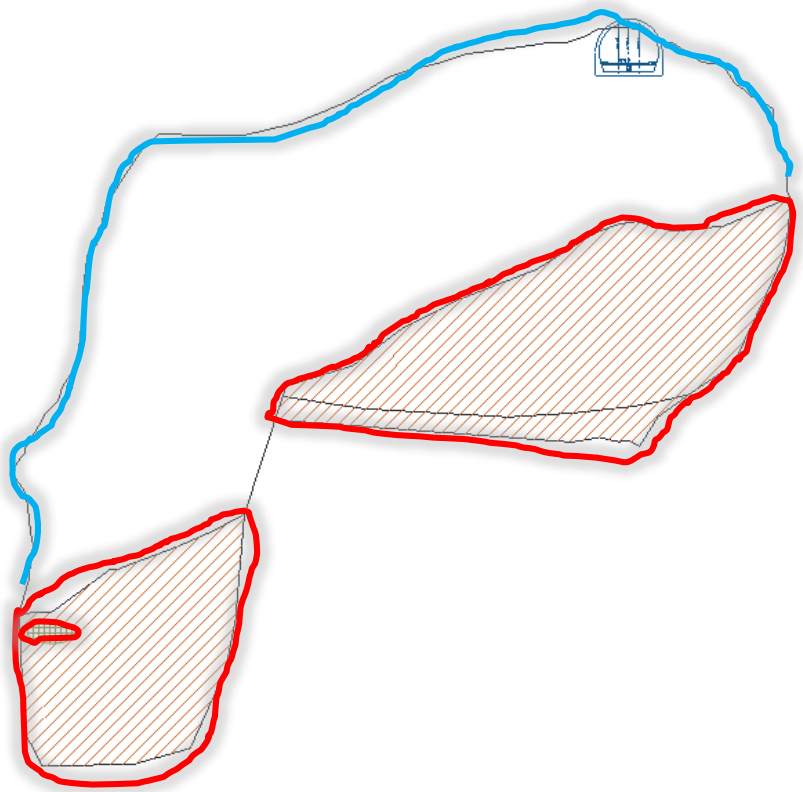
3.1 OVERVIEW OF TREATMENT SCHEME



Instability of bottom fillers & karst water

Underground river treatment

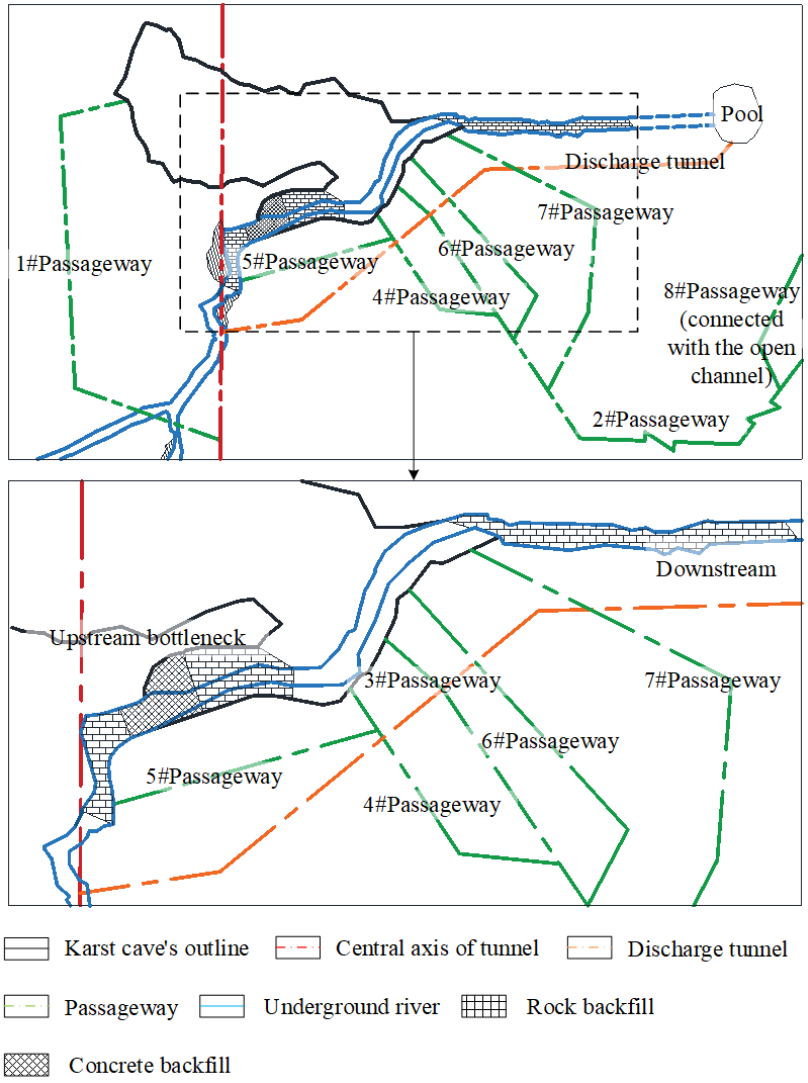
Karst hall backfill

Instability of cave wall

Bolting-net-spray support to surrounding rocks

Anchor cable protection in vault

3.2 UNDERGROUND RIVER TREATMENT



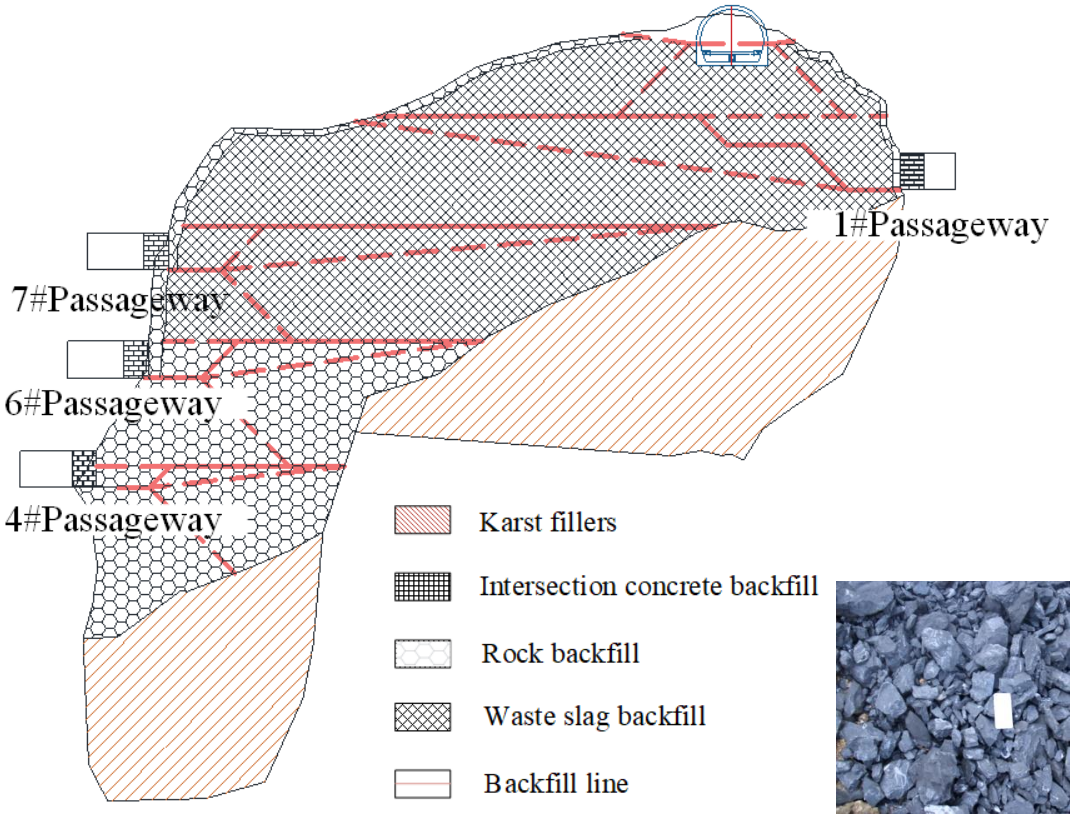
Discharge tunnel

2#～8# construction passageway

Upstream bottleneck plugging

Downstream pool plugging

3.3 KARST HALL BACKFILL



- The height of each backfill layer is 20m, and the slope of each layer is 10%;
- Intersection should be plugged by concrete after each layer's backfill;
- In order to ensure the smooth discharge of fissure water, the block with a diameter of not less than 30cm is used for backfilling within 3m of the cave wall.

3.4 REINFORCEMENT OF CAVE WALL

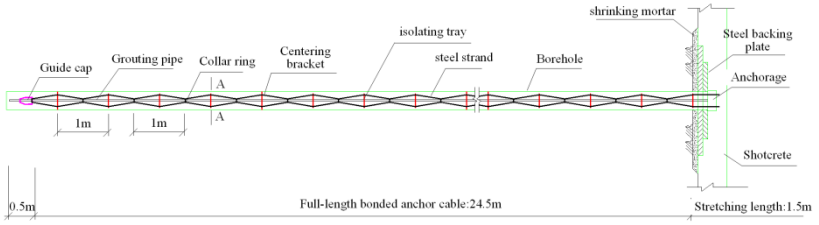
C35 steel fiber shotcrete:

Designation	Dosage(kg/m3)								Slump(mm)	Initial setting time	Final setting time	Cubic compressive strength(MPa)		
	Cement	Fly ash	Sand	Gravel	Water	Water reducing agent	Accelerator	Steel fiber				1d	7d	28d
1#	538	95	819	754	190	6.96	31.6	30	181	3min15s	8min7s	15.4	36.4	45.5
2#	505	89	838	771	190	6.53	29.7	30	175	4min17s	9min12s	12.4	35.0	43.7
3#	475	84	854	786	190	6.15	27.9	30	160	5min11s	9min15s	10.4	31.8	40.0
4#	505	89	838	771	190	6.53	29.7	25	164	4min15s	9min17s	8.2	29.1	35.9
5#	505	89	838	771	190	6.53	29.7	35	157	4min10s	9min11s	13.2	35.7	45.1

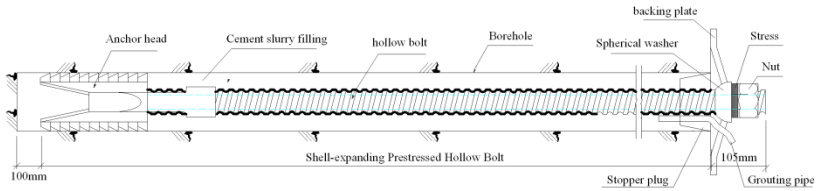
Items	Retults	Limit value
Initial setting time	4min29s	5min
Final setting time	9min36s	10min
Rebound rate	7.6%	10%
Bond strength（28d）	1.8MPa	1.0MPa
Core compressive strength（48d）	45.8MPa	35MPa

3.4 REINFORCEMENT OF CAVE WALL

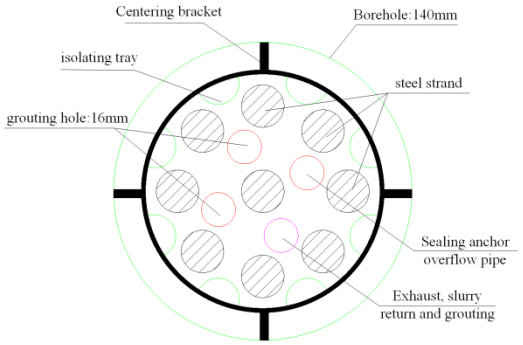
Anchor bolt & cable protection



Longitudinal Profile of Anchor Cable Structure

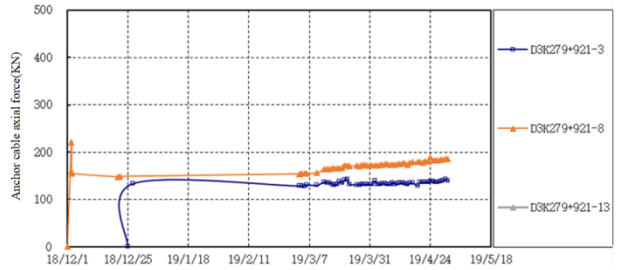


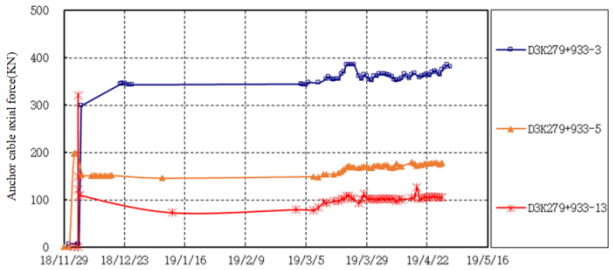
Structural sketch of shell-expanding prestressing hollow bolt

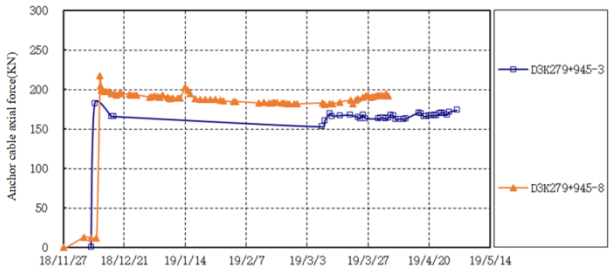


A-A section

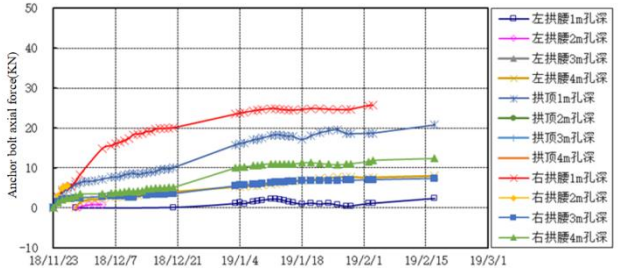
3.4 EFFECT OF REINFORCEMENT

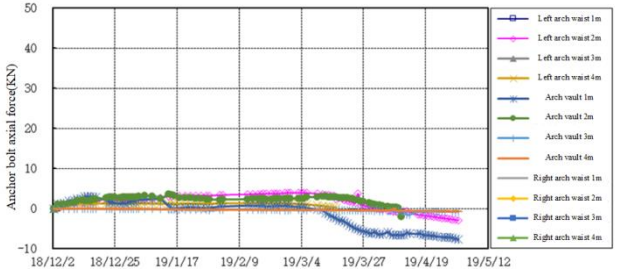


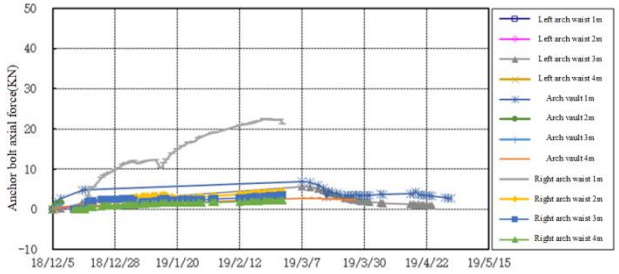




Before March 15th, 2019, the axial force of the anchor cable did not change significantly, and some of them showed a slow growth. From March 16 to April 20, 2019, the tunnel spanned the construction process. The axial force of the anchors in each of the measuring points has increased significantly. After April 20, the axial force changes of most measuring points tend to be stable.

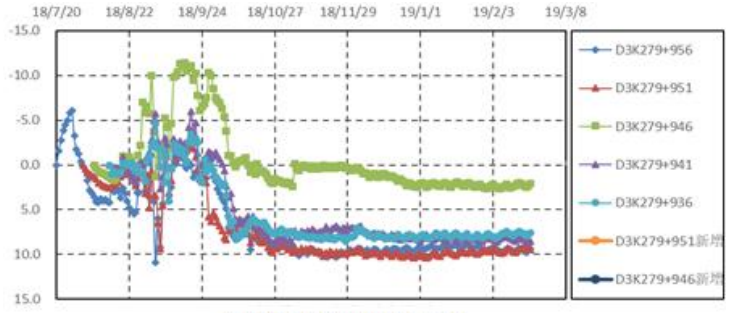




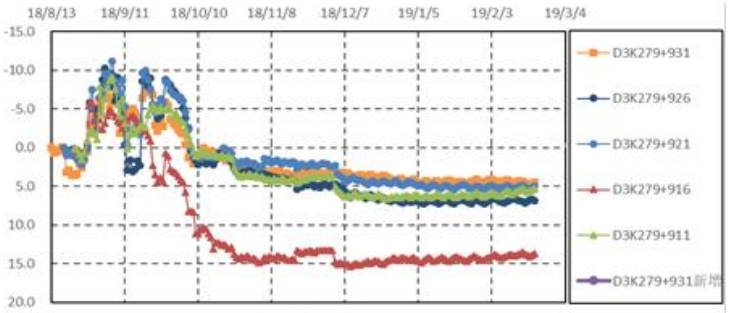


The internal forces of the D3K279+879, 891, and 951 sections are mainly tensile forces. The anchors of the D3K279+915, 927, and 939 sections are mainly subjected to pressure. During the tunnel spanning construction from March 16 to April 20, 2019, the tensile strength of the tensioned anchor tends to be gentle, and the tension of some anchors decreases or showing the pressure change trend. the internal force of the compressed anchors increases during the period. the internal force changes of each measuring point tend to be stable after construction.

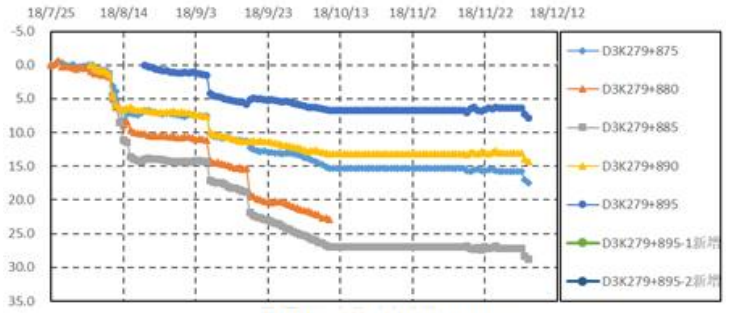
3.4 EFFECT OF REINFORCEMENT



Vault settlement curve



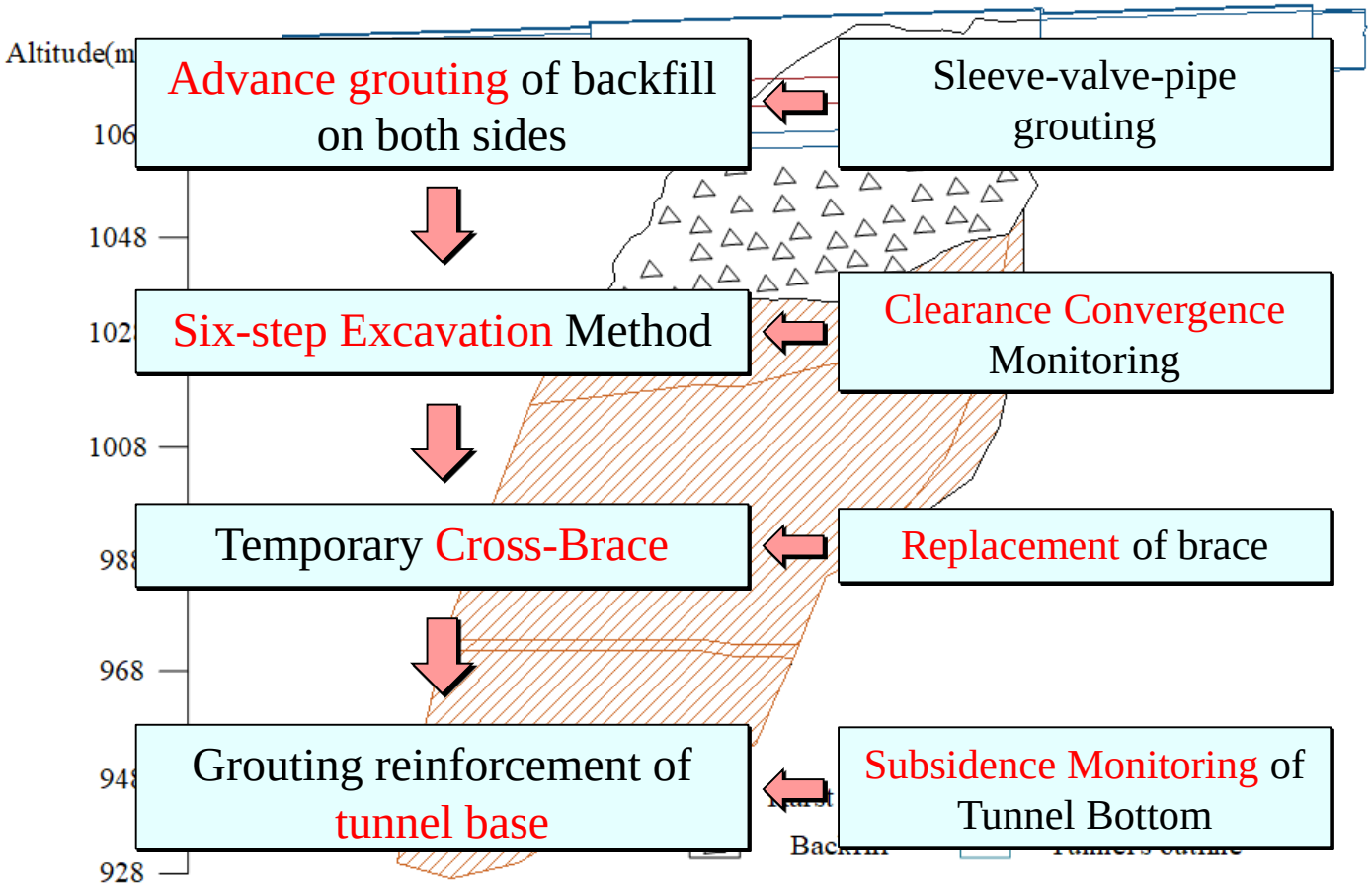
Vault settlement curve



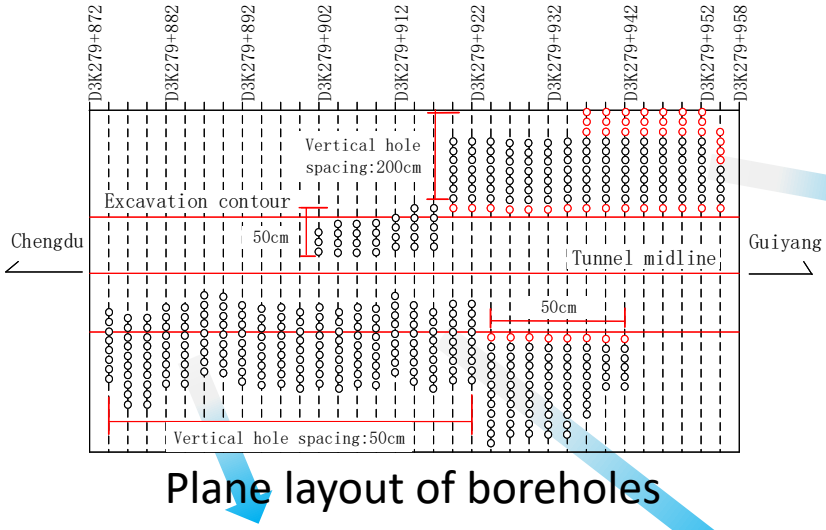
Vault settlement curve

The monitoring results show that the maximum settlement of the karst hall vault occurs at D3K279+885, and the maximum settlement value is 28.6mm. The karst hall dome has obvious growth and fluctuation during the expansion stage of the tunnel. The settlement growth rate accounts for 82%-91% of the total settlement value of the dome; November 13 From the day of December to December 4, after the completion of the anchor cable and anchor, the settlement of the dome tends to be stable, and the anchor cable and anchor have a good control effect on the settlement deformation of the dome of the karst hall.

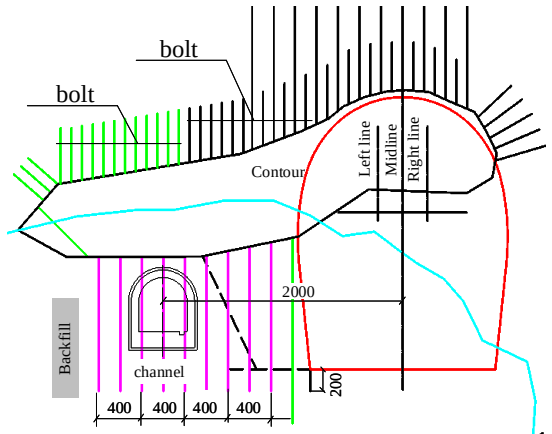
- Overall construction process



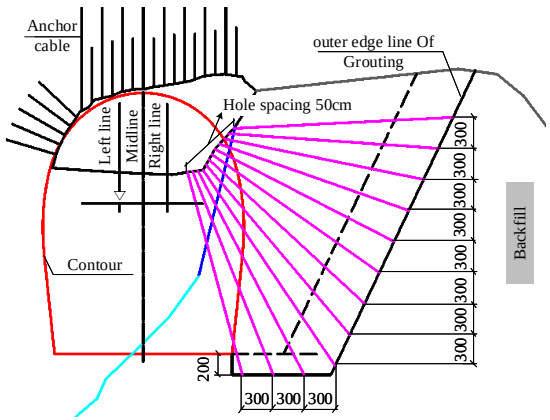
- Pre-reinforcement of backfill at both sides of tunnel



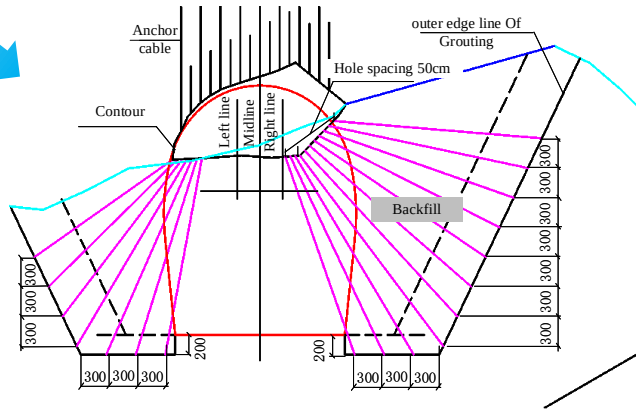
Plane layout of boreholes



Borehole layout_D3K279+938

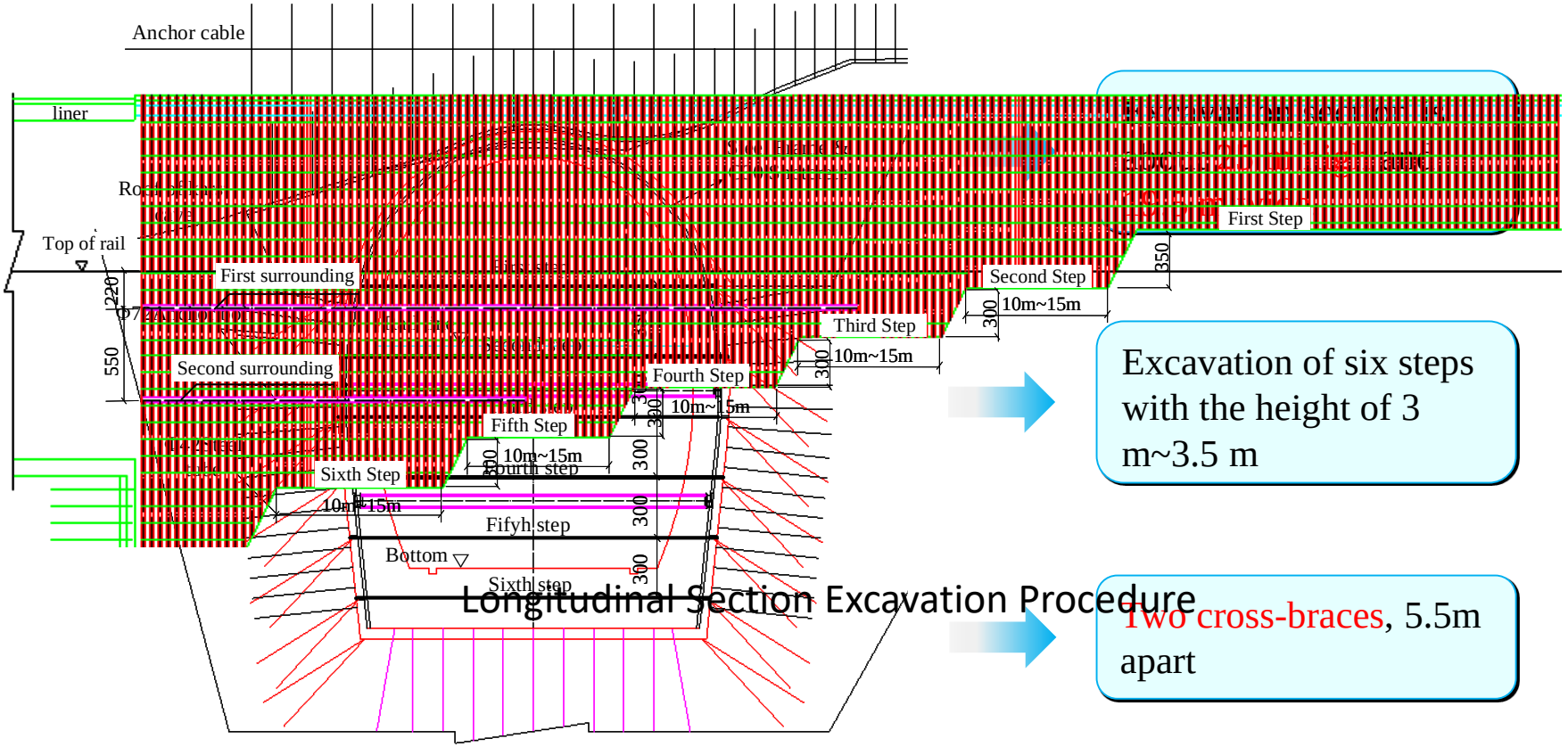


Borehole layout_ D3K279+888



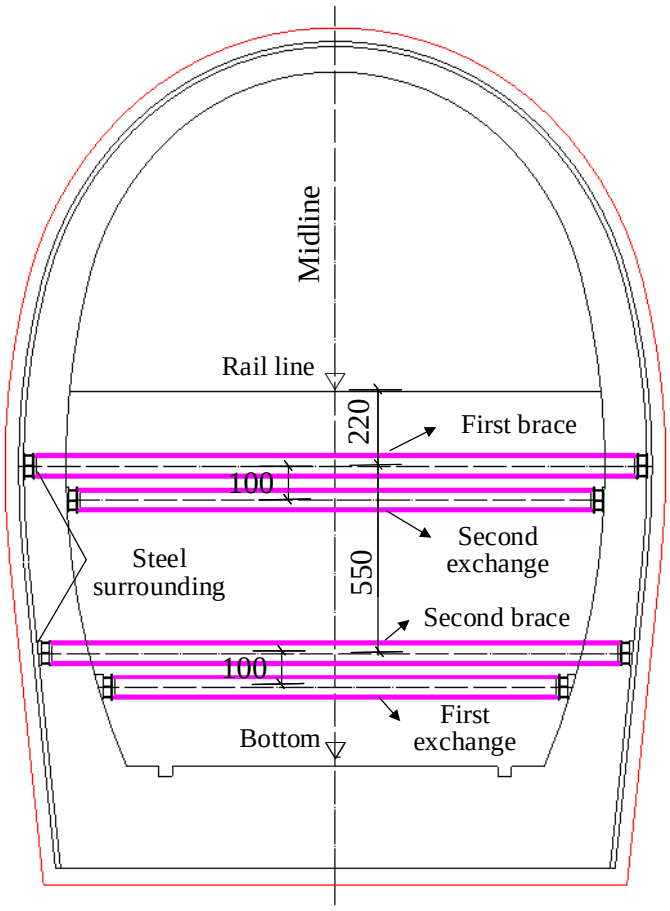
Borehole layout_ D3K279+913

- Tunnel excavation procedure

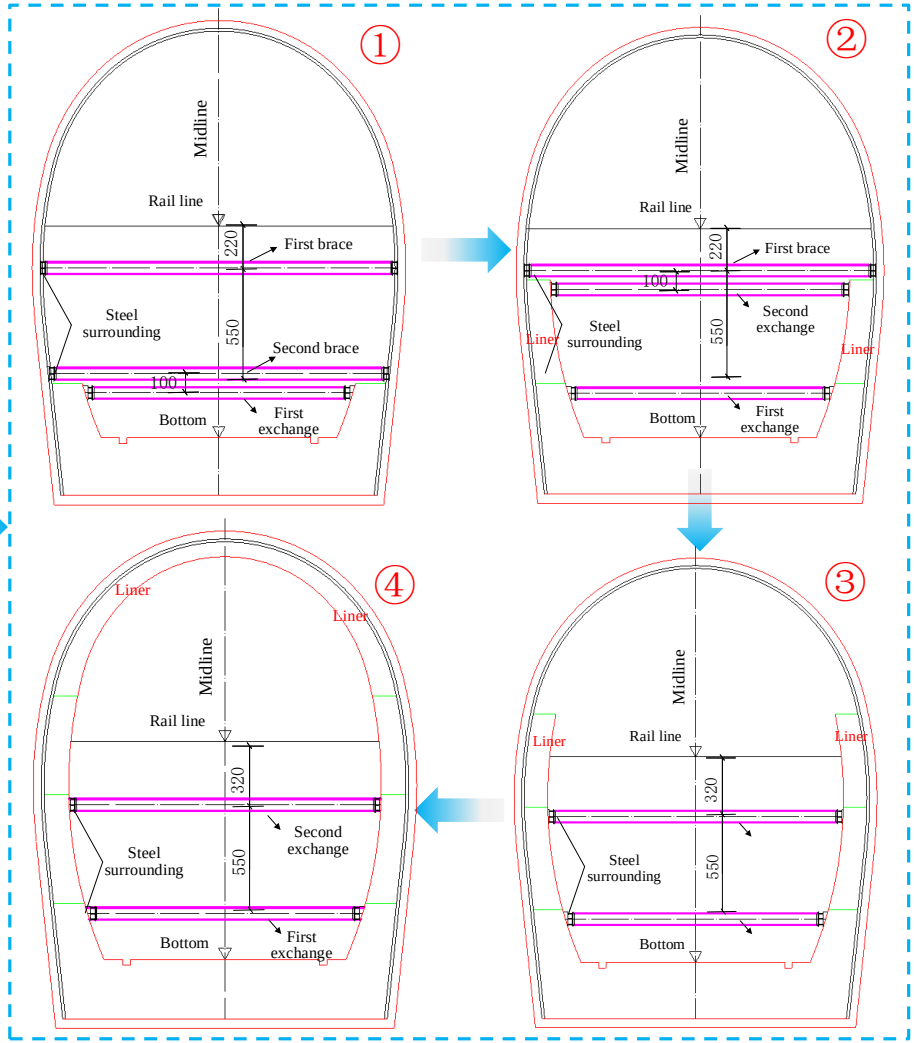


3.5 CONSTRUCTION TEC OF BACKFILL TUNNEL

Temporary Cross-Brace

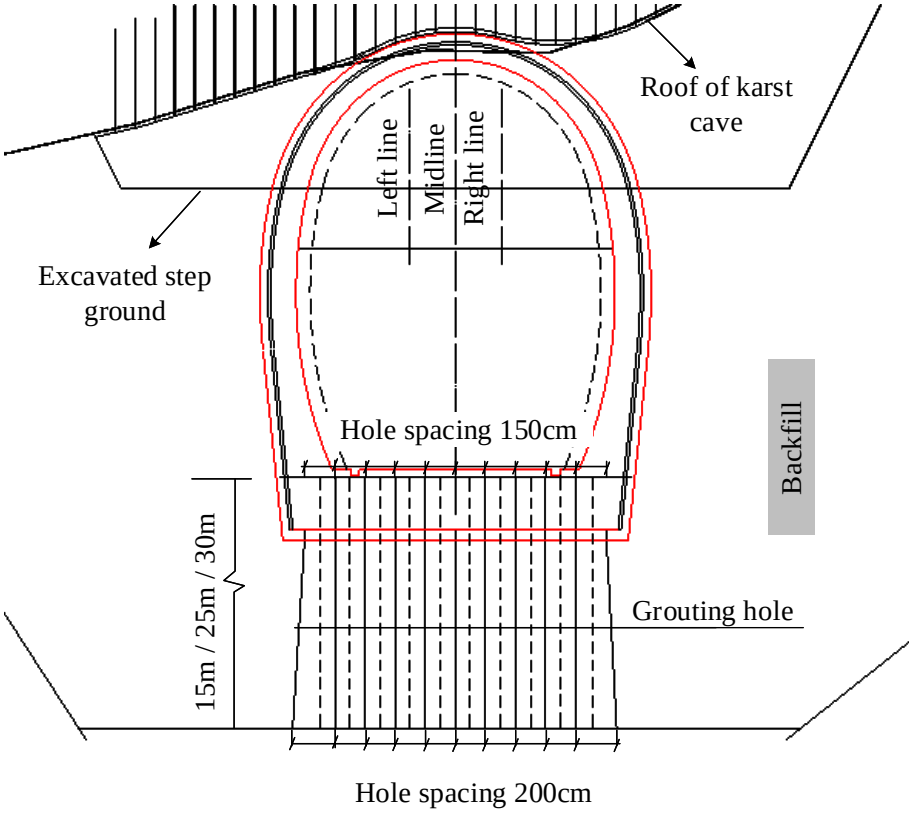


Layout section of steel cross brace



Replacement process

Grouting reinforcement of tunnel base



Base Grouting-Reinforcement Section

- sleeve-valve-pipe grouting
- 86m Strengthened length along line direction
- Grouting holes: transverse spacing 1.5m, final spacing 2.0m and longitudinal spacing 2.0m
- Reinforcement Depth: 30m / 25m / 15m

3.5 CONSTRUCTION TEC OF BACKFILL TUNNEL

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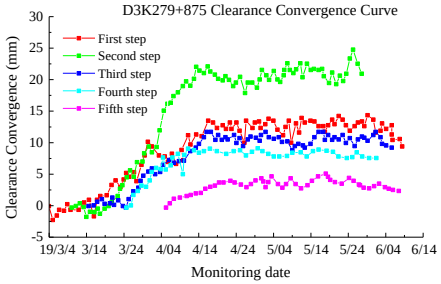
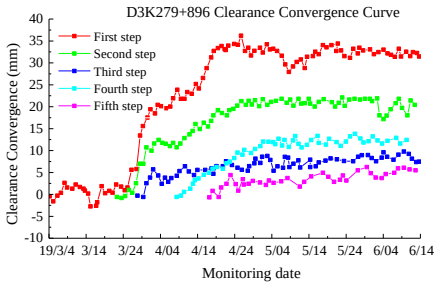
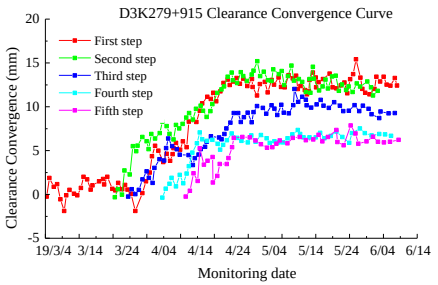
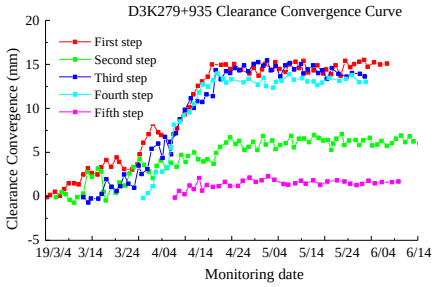
- Analysis of field monitoring

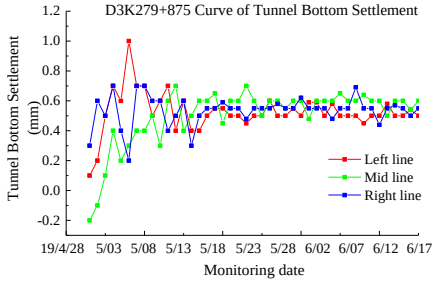


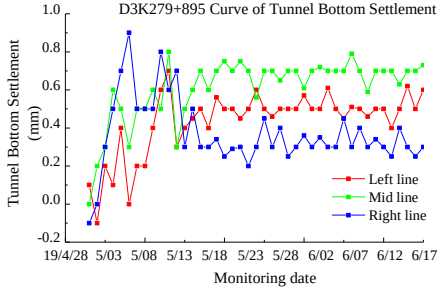


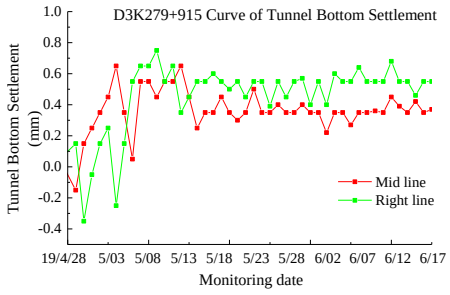


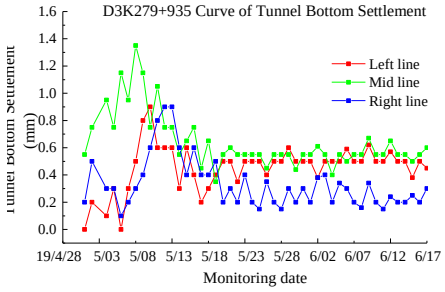


Clearance Convergence Monitoring of Typical sections









Subsidence Monitoring of Tunnel Bottom of Typical sections

CONTENTS

4.1 CONCLUSION

- The giant karst caves in the Yujingshan tunnel have complex developmental forms. The underground river passes through the karst hall and develops several tributary pipelines. The overall stability of the cave wall and the fillers is greatly affected by the rock strata, fissures and karst water. According to its geological characteristics and stability, the series of schemes of “karst river remediation – karst backfilling – cave wall protection” was adopted to carry out the karst remediation of the dark river, which provided a guarantee for the construction and operation of the subsequent tunnel crossing karst.

- As the stability monitoring of the karst hall during the rectification and subsequent tunnel crossing construction shows, the monitoring value of the internal force of the anchor bolt and cable is less than the design limit, the increase of the tunnel spanning during construction is obvious, and the internal force changes tend to be stable after the construction After the construction was completed, the internal force of the bolt was not significant. The change of the dome is mainly caused by the expansion of the stepped arch of the tunnel. The protection measures of the cave wall have a good control effect on the settlement deformation of the dome of the karst hall.

THANKS FOR LISTENING!

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