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KEY TECHNOLOGIES AND APPLICATIONS OF SHAFT EQUIPMENT FOR PUMPED STORAGE POWER STATIONS

With the continuous expansion of pumped storage power station construction in China and abroad, the demand for constructing large-diameter shafts has been increasing significantly. Traditional large-diameter shaft construction still relies on manual drilling and blasting, which suffers from low efficiency, poor safety and significant environmental impact. Therefore, based on the construction of large-diameter shafts in pumped storage power stations, this paper focuses on the development of three core equipment for shaft construction, namely, the full face shaft boring machine, the reaming-type shaft boring machine and the large-diameter raise boring machine, and systematically analyzes their key technologies and engineering applications.

Firstly, it summarizes the structural characteristics of shafts in existing pumped storage power stations and the problems associated with current construction methods. Secondly, from the perspectives of full face excavation, forward reaming and reverse reaming, it sorts out the key challenges that the three shaft construction methods must address, and introduces the working principles of the three equipment along with targeted solutions to their respective challenges.

Finally, it summarizes the engineering application cases of the three equipment to analyze their suitability for different engineering scenarios and potential directions for optimization. The research results provide valuable technical references and practical examples for shaft construction in pumped storage power stations and similar underground engineering projects both in China and abroad.

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Key Technologies and Applications of Shaft Equipment for Pumped Storage Stations

Juan Berjillos Gonzalez

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1 Structural Characteristics of Pumped Storage Power Stations

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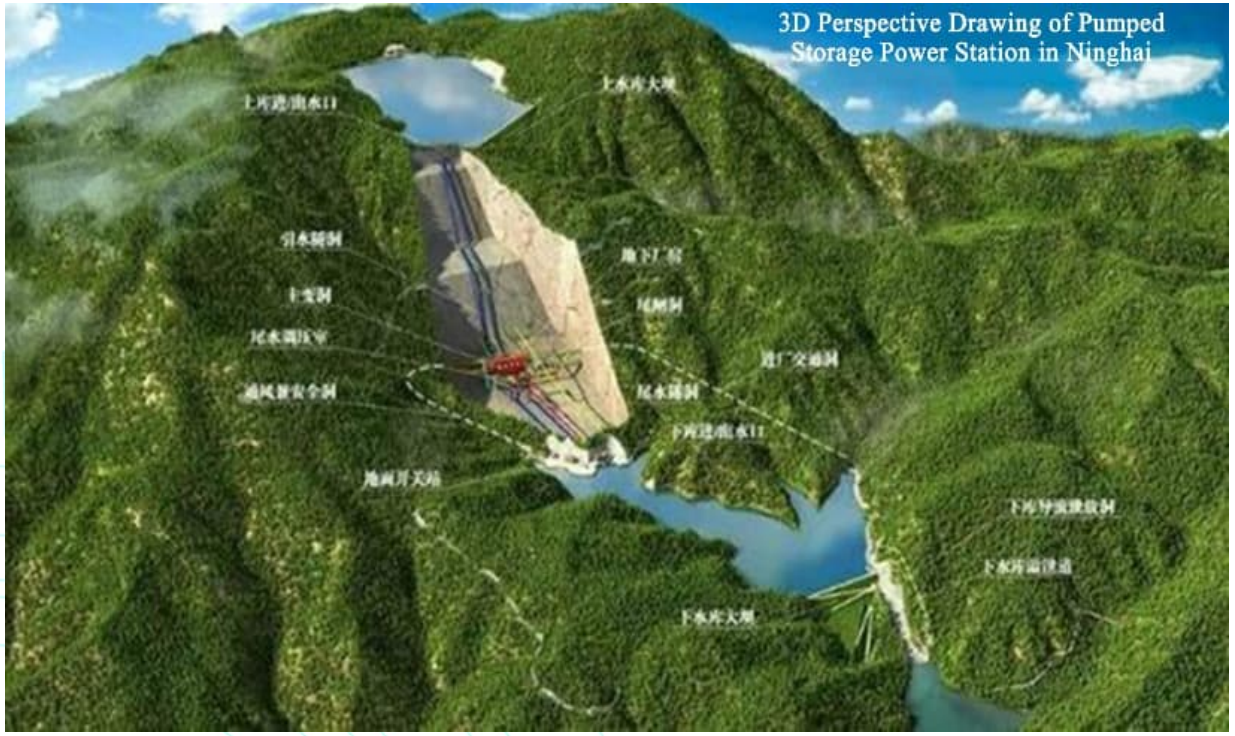
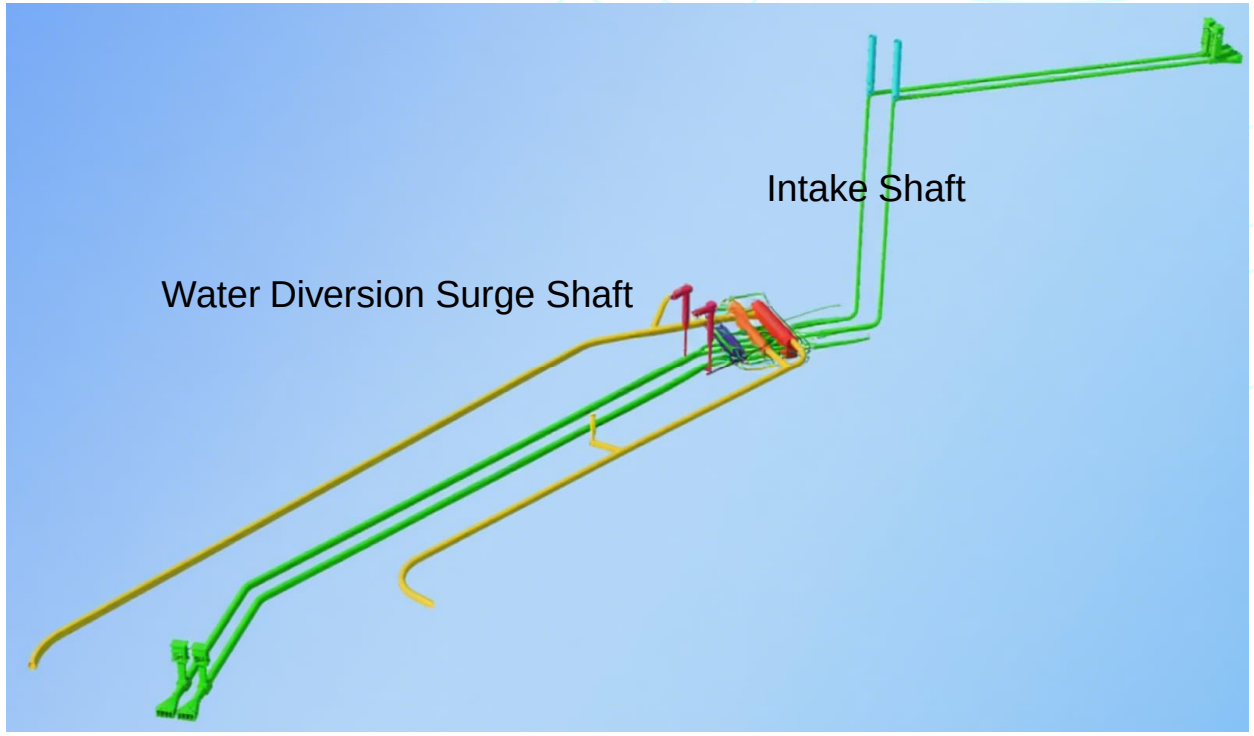
1 Structural Characteristics of Pumped Storage Power Stations

The pumped storage power stations are core facilities for peak shaving, valley filling and energy storage in current electrical power system. They generate electricity by utilizing the potential energy difference of water. This height difference depends critically on shafts that are used as water diversion channels.





Shaft boring machines are becoming popular due to the low efficiency, poor construction environment, and poor quality associated with traditional construction methods.

1 Shaft Boring Machine Types

			
Type	Full Face Shaft Boring Machine (SBM)	Reaming-type Shaft Boring Machine (EBM)	Raise Boring Machine (RBM)
Max. depth	1000m	1000m	500m
Excavation range	φ5m- φ15m	φ5m- φ15m	φ5m- φ7m
Support Type	Initial	Initial	/
Advance speed	≥4m/d	≥8m/d	≥5m/d

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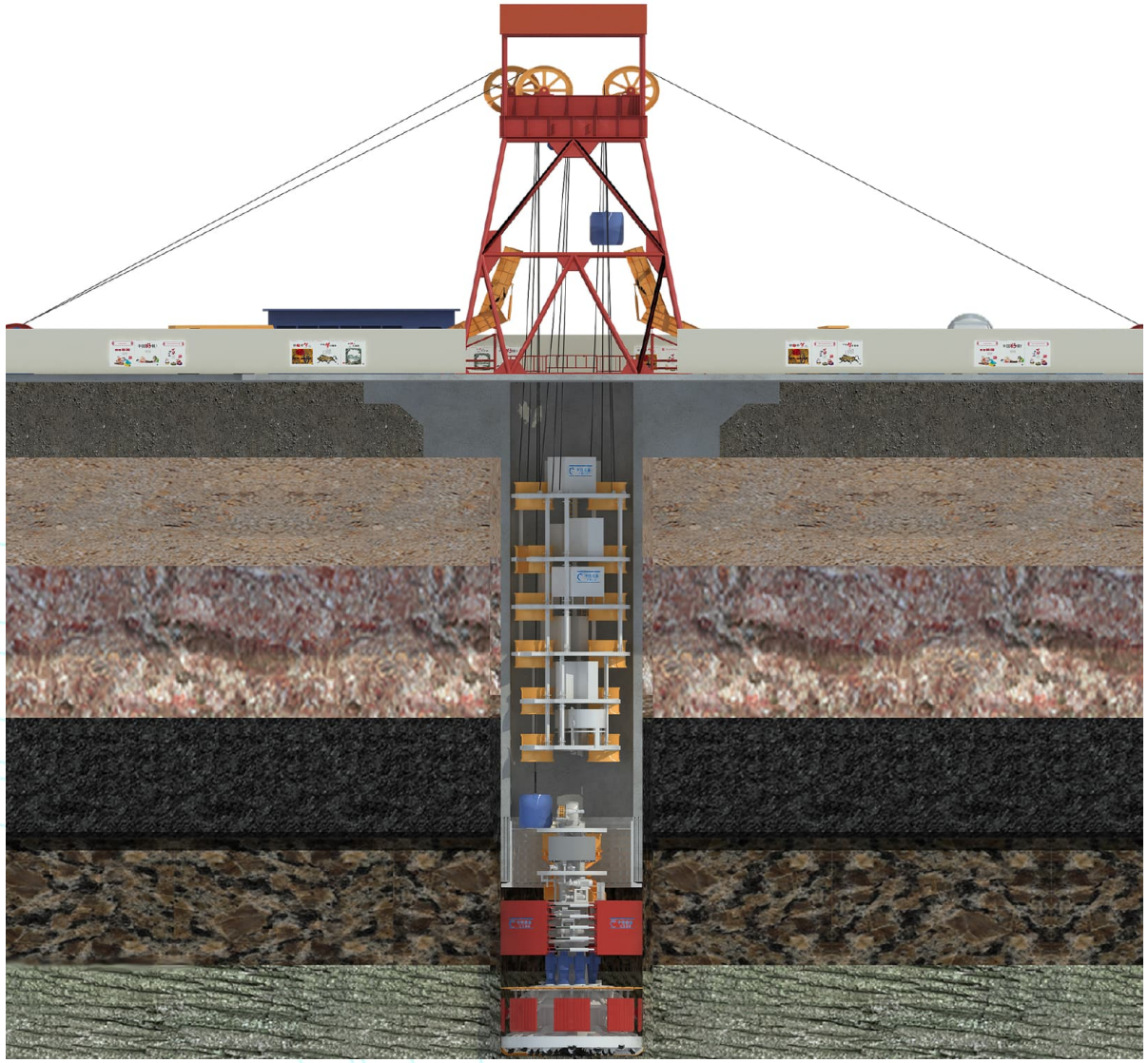
2 Working Principles and Key Technologies

Full Face Shaft Boring Machine (SBM)



Equipment Parameters

- Shaft diameter:φ5m- φ15m
- Designed boring depth: 1000m
- Economic boring depth: >400m
- Overall construction efficiency: ≥4m/d
- Suitable hydrologic condition: no water/ waterless formation, or with special water treatment

Applicable Shaft Type

- Ventilation shaft of pumped storage power station
- Working/ventilation shaft of big diameter tunnel
- Underground minerals shaft

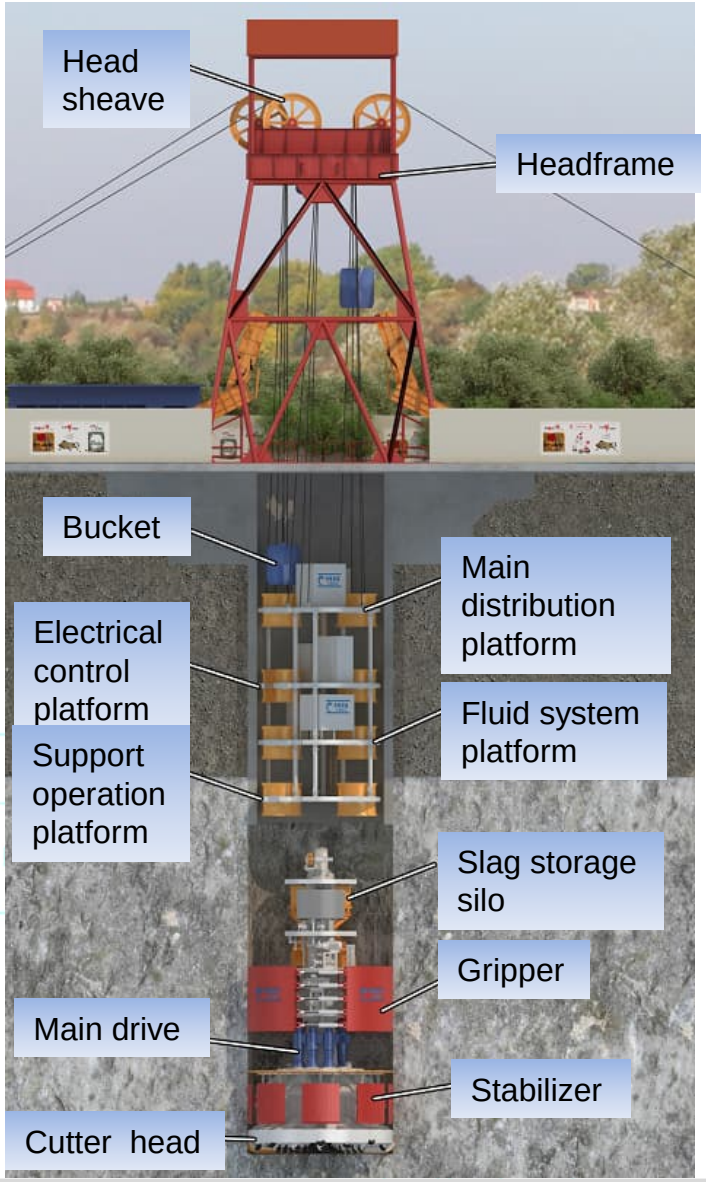
Typical Reference Project

China Ninghai Ventilation shaft of pumped storage power station

- Diameter: φ7.8m
- Depth:200m

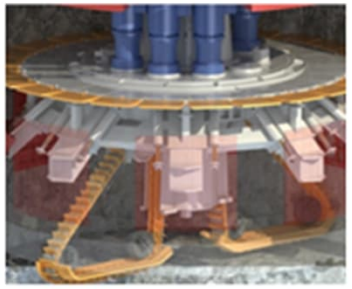
2 Working Principles and Key Technologies

Full Face Shaft Boring Machine (SBM)

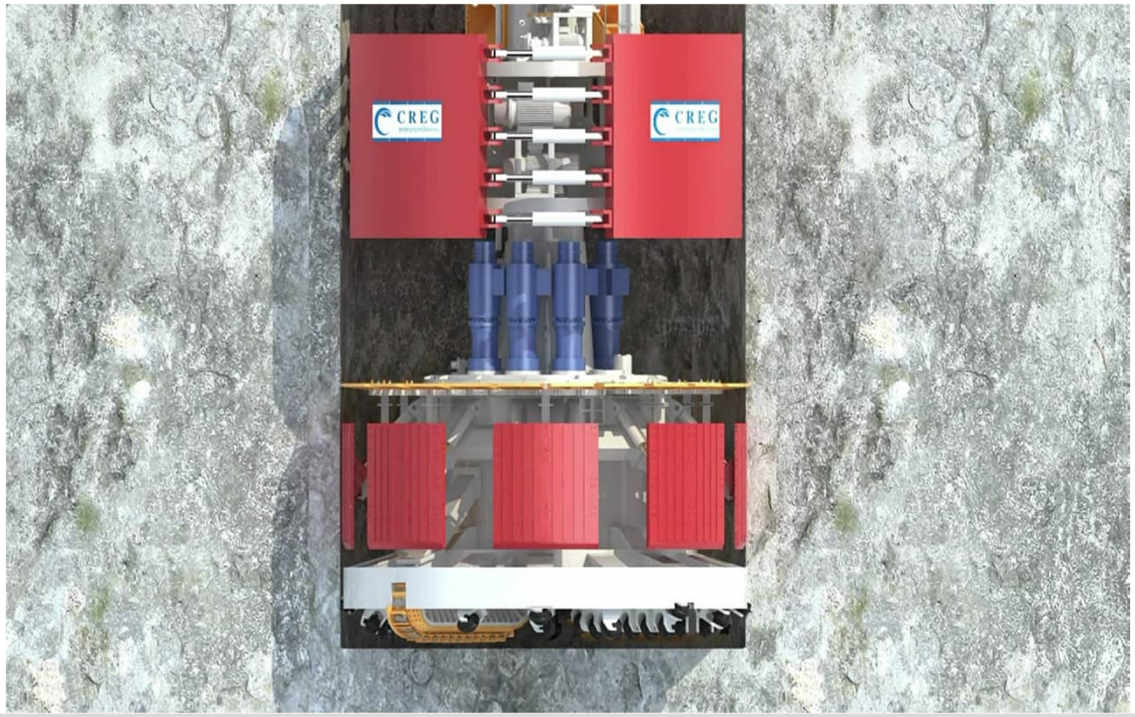


Top slag discharge type

Slag cleaning of the shaft bottom → Slag transport with the bucket elevator → Slag storage in the silo → Slag discharge with a bucket



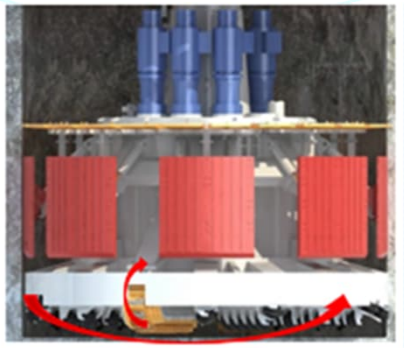




Multifunctional Full-face Cutter Head

Disc cutter

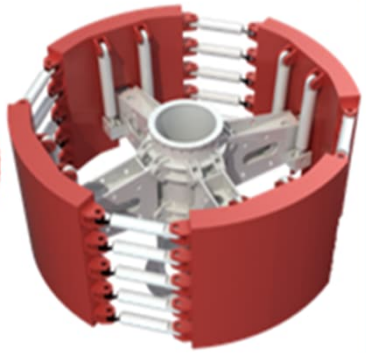
Simultaneous excavation & mucking

Dual-support, low specific pressure, high thrust

Annular stabilizer

Annular gripper

2 Working Principles and Key Technologies

Raise Boring Machine (RBM)

Equipment Parameters

- Shaft diameter:φ5m- φ7m
- Designed boring depth: 500m
- Rod pulling force: ≥12,000 kN
- Overall construction efficiency: ≥5m/d
- Suitable hydrologic condition: unlimited
- Suitable geologic condition: stable hard rock formation

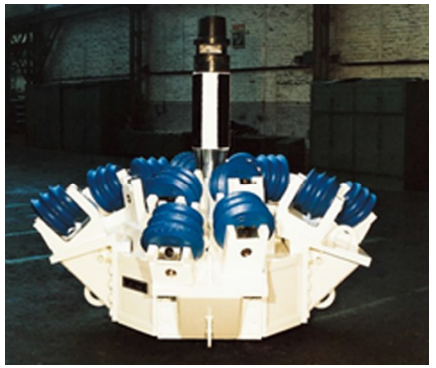
Applicable Shaft Type

- Ventilation shaft of pumped storage power station
- Working/ventilation shaft of big diameter tunnel
- Underground minerals shaft

Typical Reference Project

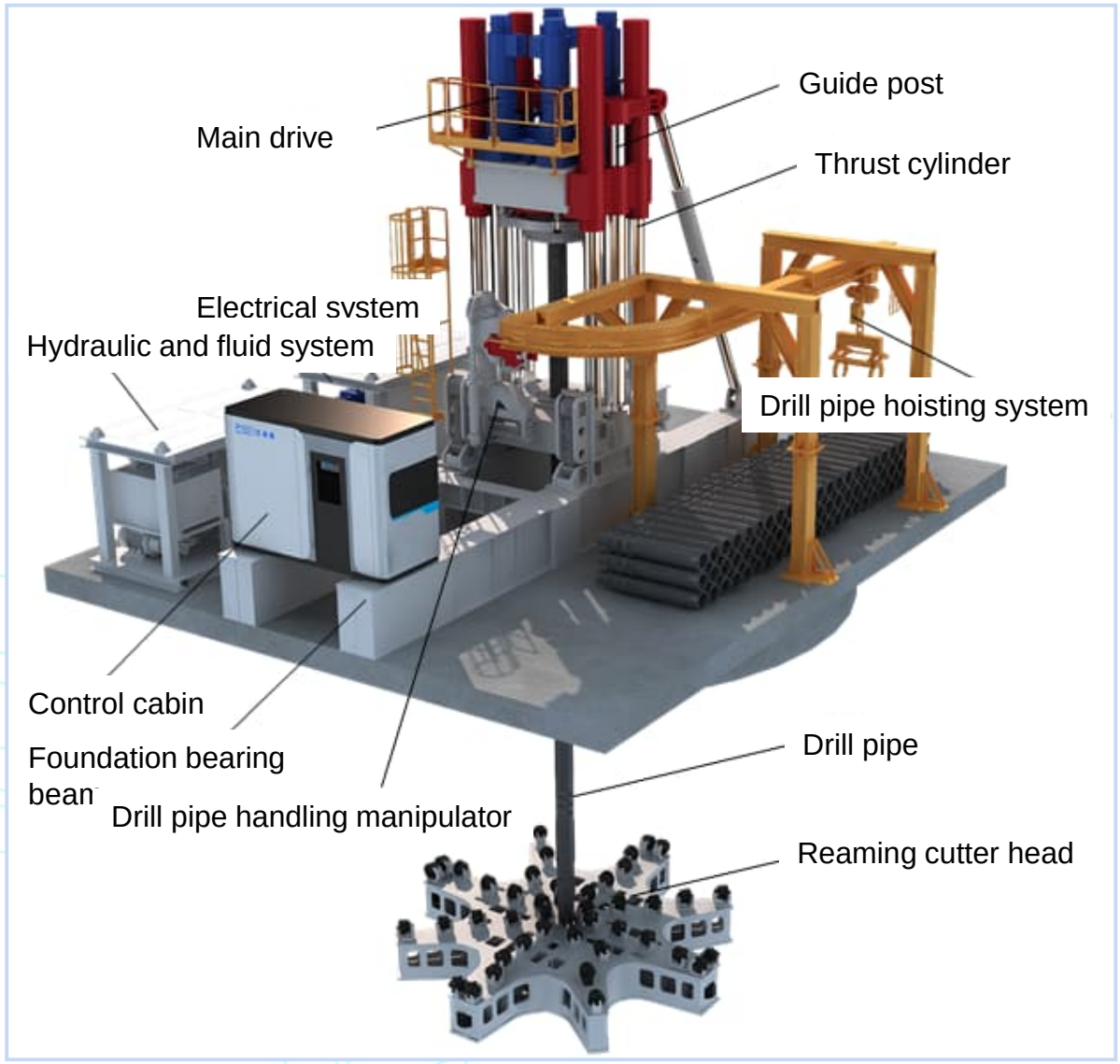
China Jiaohe ventilation shaft of pumped storage power station

- Diameter: φ7m
- Depth:320m
- Geology: Class II and III rock formation



2 Working Principles and Key Technologies

Raise Boring Machine (RBM)



Characteristics

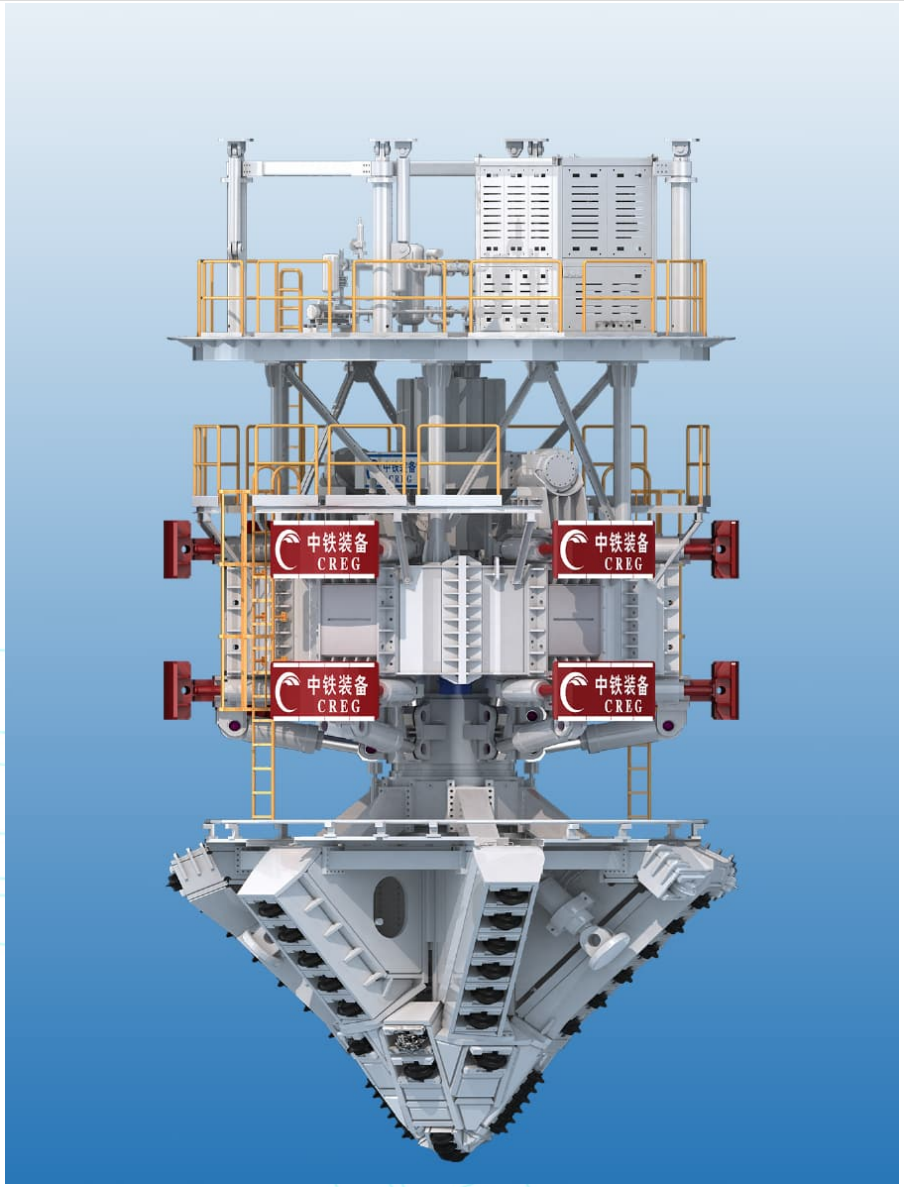
- Applicable to **stable rock strata without fracture zones or strata that underwent geological improvement;**
- Suitable for shaft projects with diameters of **5–8m** and depths of no less than **500m;**
- Mechanized construction with low labor intensity;
- Advantages include **small footprint, low cost, high efficiency and ease of relocation.**

Applicability

- Mining projects: main shafts, auxiliary shafts and ventilation shafts in mining areas;
- Long and large shafts: equipment maintenance shafts, ventilation shafts and working shafts;
- Hydropower projects: surge shafts, ventilation shafts and vertical pressure shafts.

2 Working Principles and Key Technologies

Reaming-type Shaft Boring Machine (EBM)



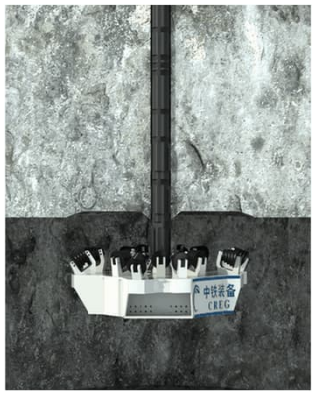
Equipment Parameters

- Shaft diameter:φ5m- φ15m
- Designed boring depth: 1000m
- Overall construction efficiency: ≥8m/d
- Suitable geologic condition: hard rock formation

Applicable Shaft Type

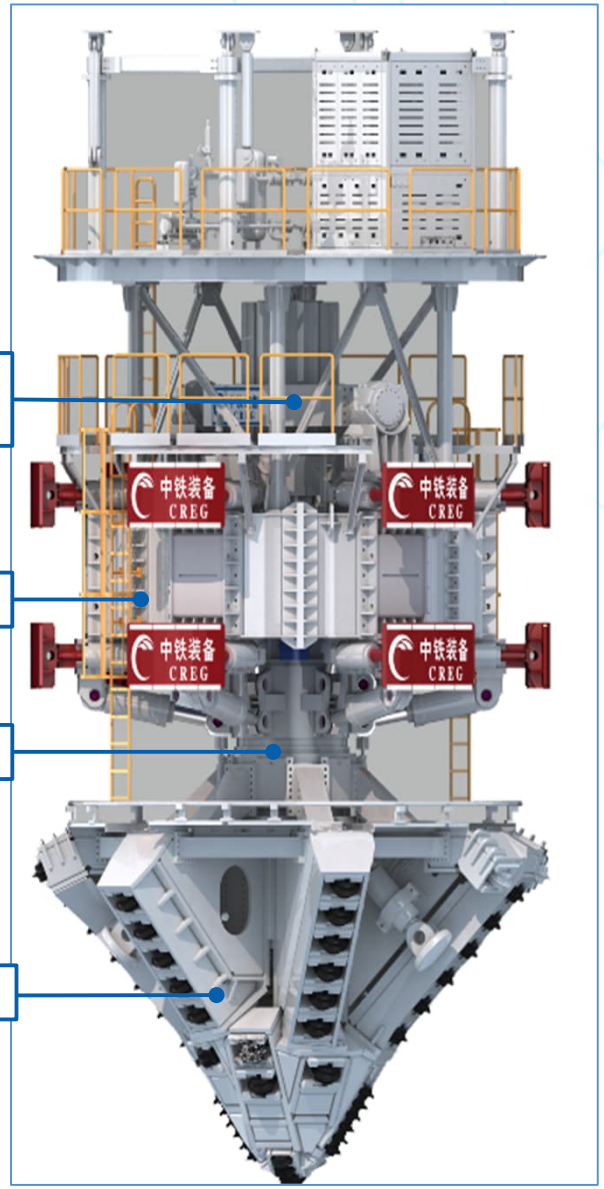
- Ventilation shaft or pressurized shaft of pumped storage power station
- Working/ventilation shaft of big diameter tunnel
- Underground minerals shaft

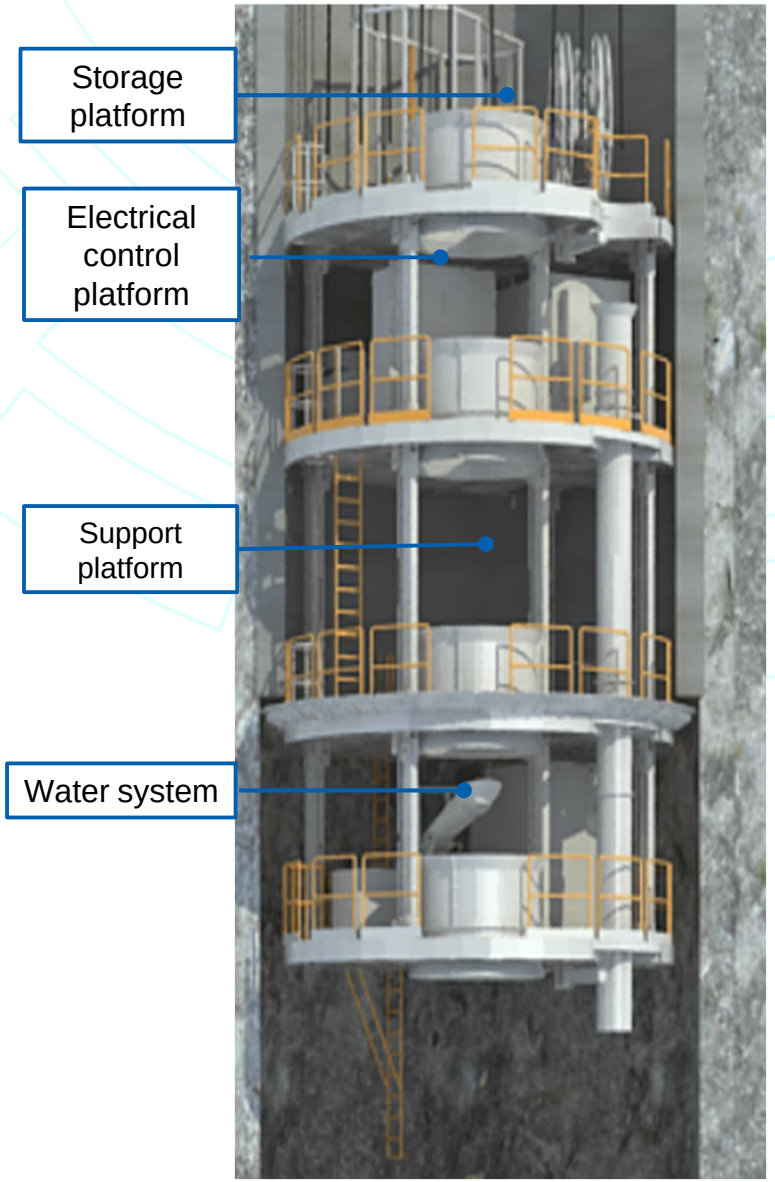
Pilot hole drilling → **Raise reaming** → **RBM boring** → **EBM**



2 Working Principles and Key Technologies

Reaming-type Shaft Boring Machine (EBM)





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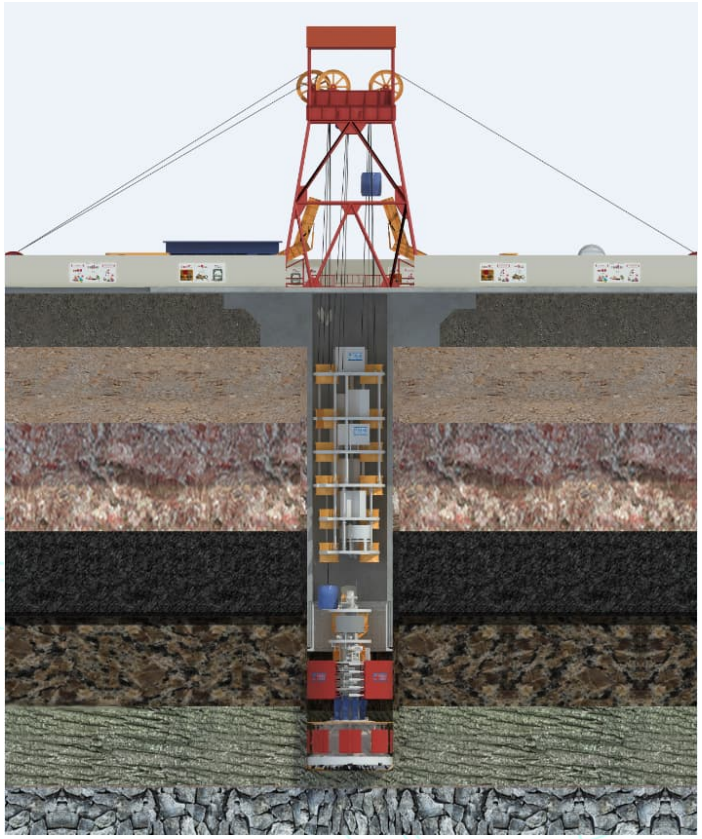
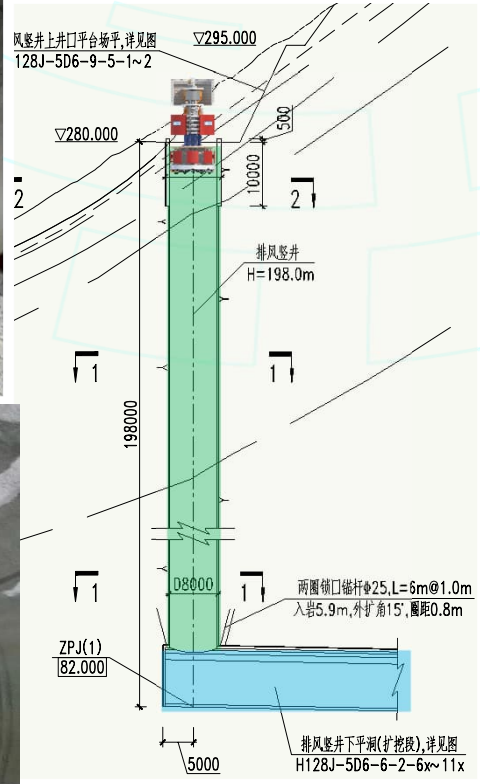
3 Application Cases

Full Face Shaft Boring Machine (SBM)

The Ninghai Ventilation shaft of pumped storage power station was constructed by using a Φ7.8m shaft boring machine (SBM). The SBM had a main machine height of about 16m and a hanging platform height of about 13m, giving an overall machine height of 29m. The SBM officially commenced underground excavation on April 6, 2021, and broke through on December 28, 2021, successfully completing the 198m ventilation shaft excavation. The maximum daily advance rate reached 5m.

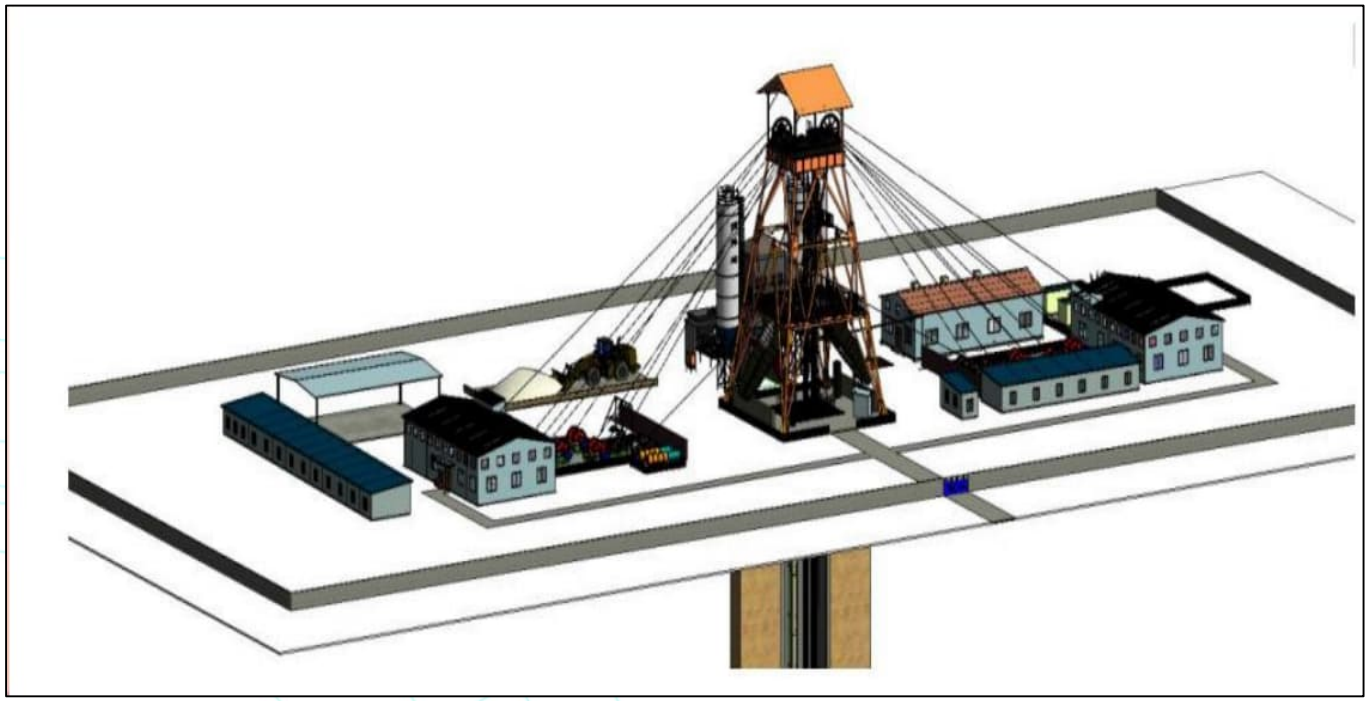




3 Application Cases

Full Face Shaft Boring Machine (SBM)

The ground supporting system mainly consists of a headframe, hoisting winch, stabilizing winch, head sheave, hook assembly, muck bucket, concrete mixing plant, air compressor station, ventilation fan, water storage tank, waste water tank and other facilities. These systems enable the suspension of the hanging platform and associated pipelines. **The ground facilities are already experienced equipment commonly used in mining drill-and-blast methods.**



3 Application Cases

Full Face Shaft Boring Machine (SBM)

On-site assembly and muck discharge

3 Application Cases

Full Face Shaft Boring Machine (SBM)

Ventilation shaft of the pumped storage power station

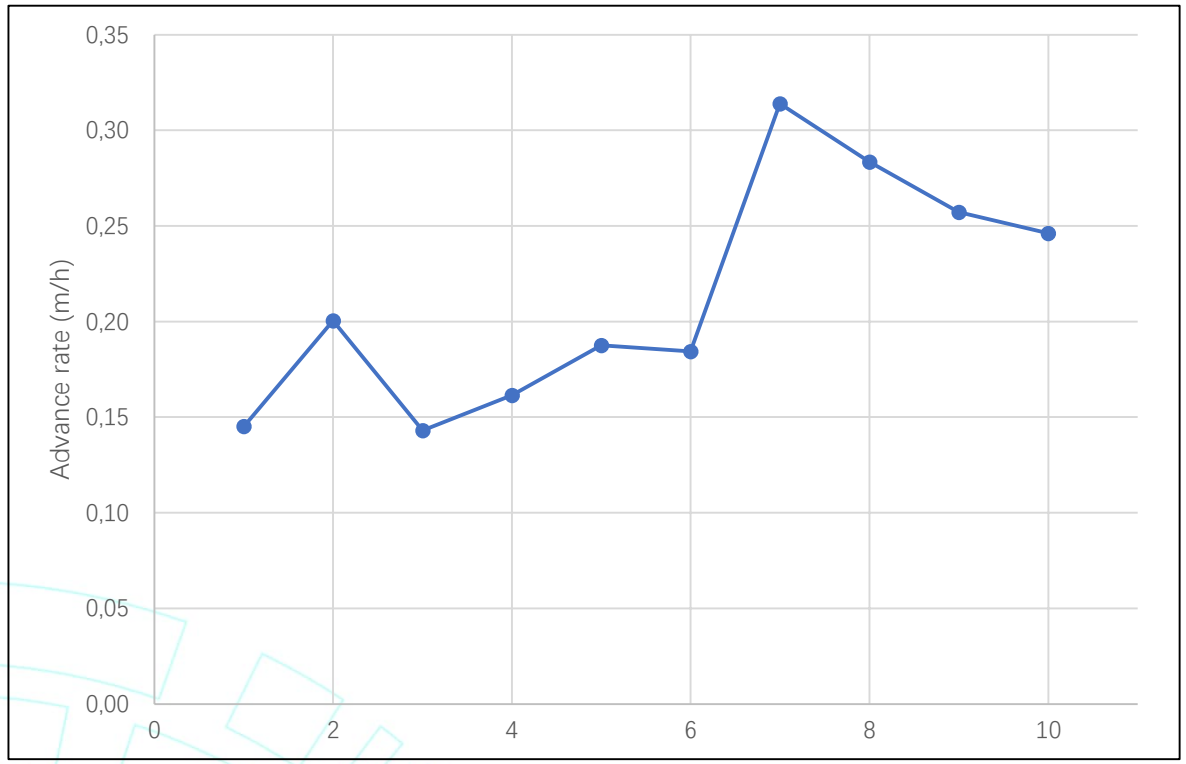
Depth: 198m-deep exhaust shaft

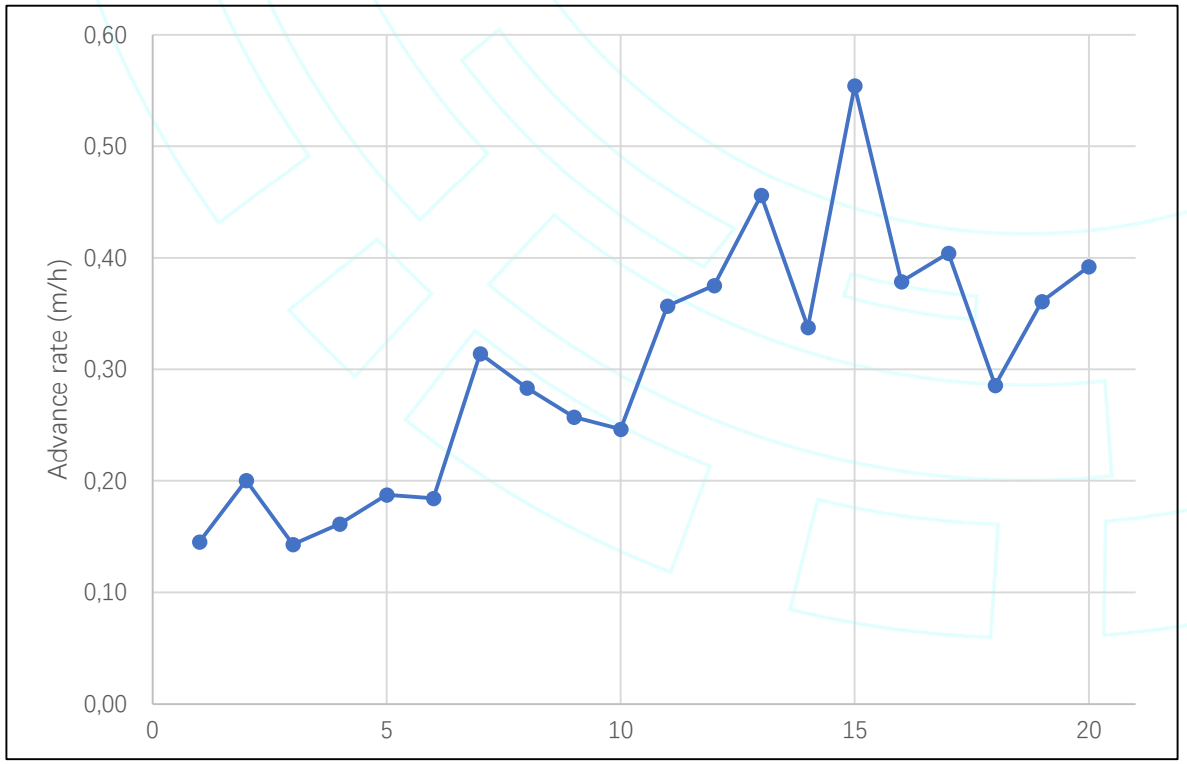
Excavation diameter: Φ7830mm

Geological conditions: The shaft collar (0-5m) is composed of strongly weathered class Ⅴ surrounding rock; the depth from 5m to 25m is weakly weathered class Ⅳ–Ⅲ surrounding rock with relatively broken rock mass; below 25m depth is class Ⅲ–Ⅱ slightly weathered to fresh rock, mainly with poor to relatively complete rock mass integrity and good tunnelling conditions. The entire exhaust shaft passes through sedimentary rocks with a strength of 80-120MPa, locally reaching 140MPa.

3 Application Cases

Full Face Shaft Boring Machine (SBM)



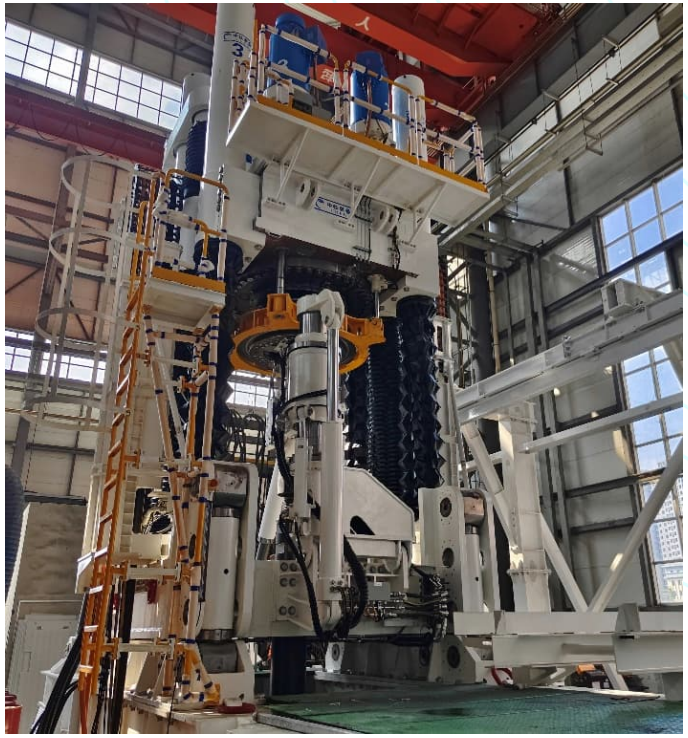


During the first 10m of SBM commissioning, the average advance rate was 0.2m/h. The advance rate of the SBM commissioning section is shown in the above figure.

After the commissioning was completed, the SBM excavated 10.56m in 1644 minutes, and it entered the normal tunnelling state with an average advance rate of 0.39m/h.

3 Application Cases

Raise Boring Machine (RBM)



Project: Zhejiang Jingning Pumped Storage Power Station Ventilation Shaft Project
Depth: 321m-deep ventilation shaft
Excavation diameter: Φ7000mm
Geological conditions: granite, with an **average uniaxial compressive strength of 70–80 MPa, and up to 100 MPa in some areas**
Surrounding rock classification: mainly class II–III surrounding rock; local fault fracture zones fall into class IV. Overall, the ground conditions and surrounding rock stability are relatively favorable for tunnel construction

3 Application Cases

Raise Boring Machine (RBM)

Large-diameter Raise Boring Machine — Zhejiang Jingning Pumped Storage Power Station Ventilation Shaft Project

Pilot hole breakthrough

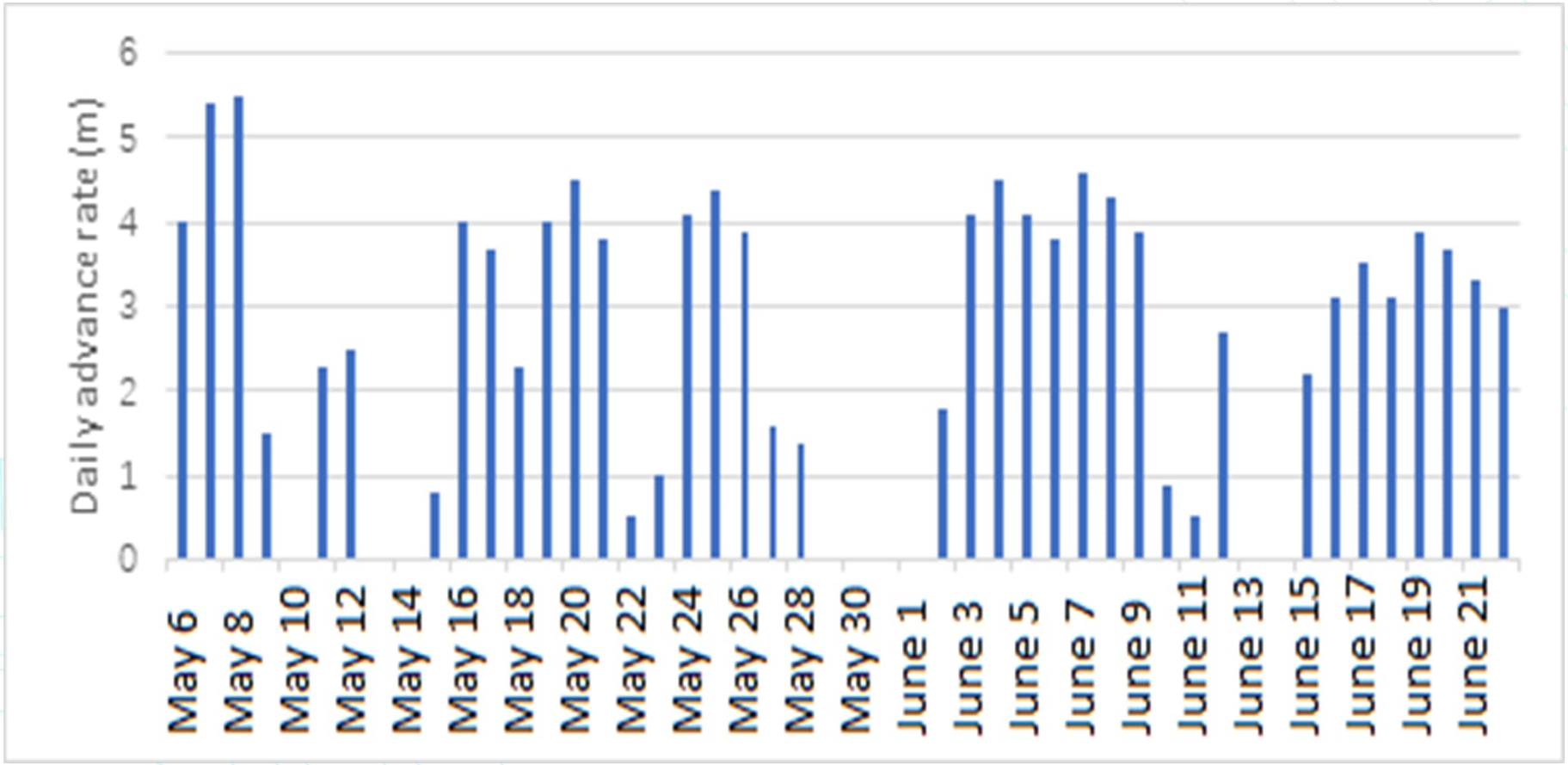
7m cutter head

Rock breaking

➢ **Progress:** Breakthrough completed, with an average daily advance rate of 5.2m.

3 Application Cases

Raise Boring Machine (RBM)



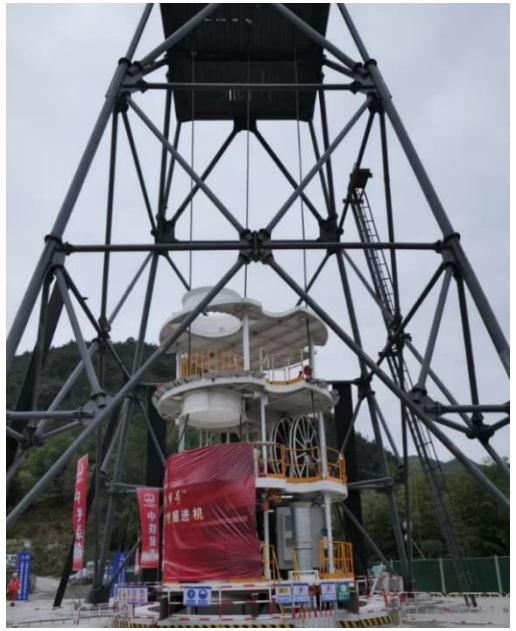
As of June 22 of 2025, 121.2m had been excavated since tunnelling began on May 6, 2025, with an average daily advance rate of 2.55m.

3 Application Cases

Reaming-type Shaft Boring Machine (EBM)

Ready for the project

Launch



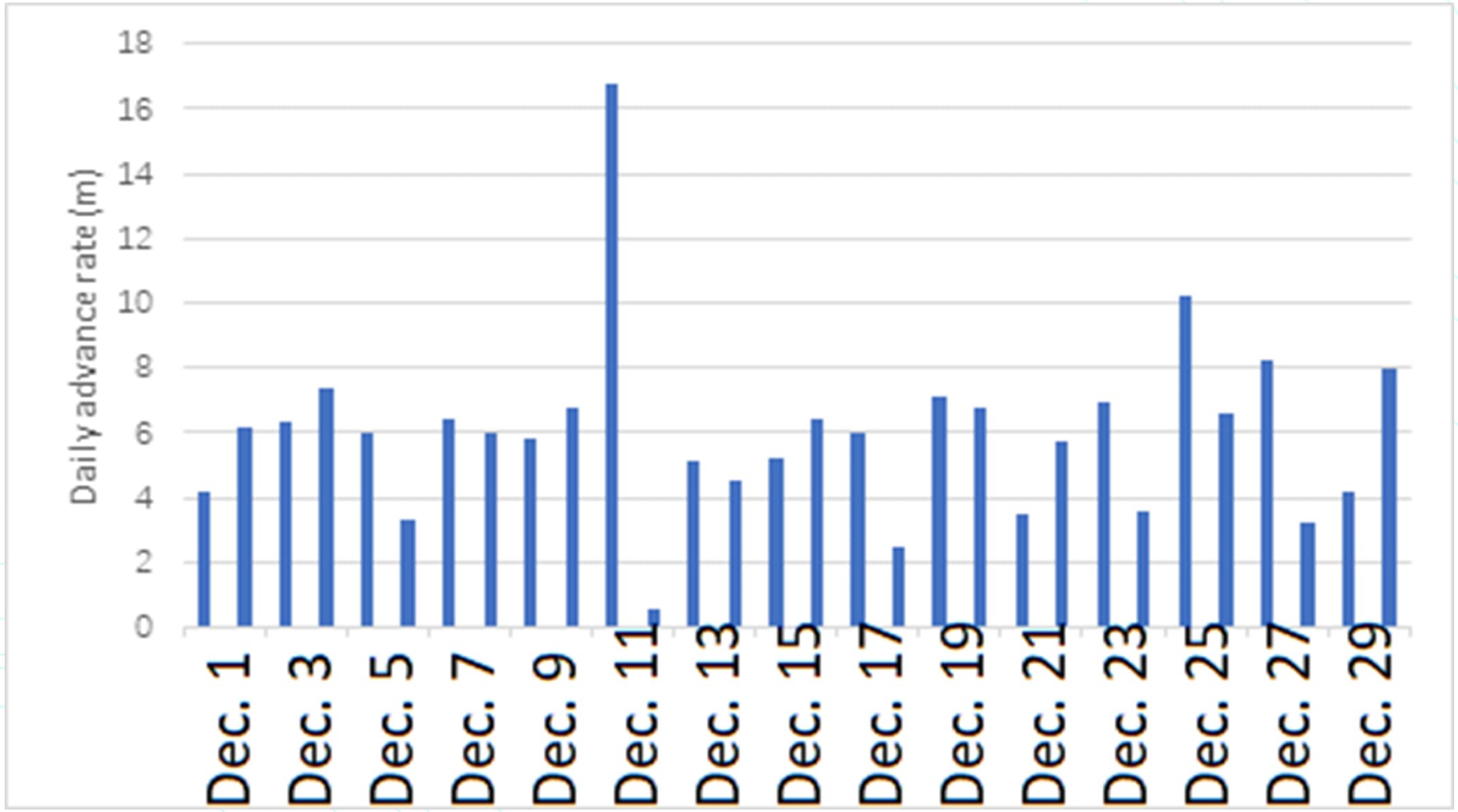
Excavation

Muck discharge from bottom

- **Application project:** Yongjia Pumped Storage Power Station Ventilation Shaft and Water Diversion Shaft Construction
- **Excavation depth:** Ventilation shaft 358m; water diversion shafts 2 × 488m (including 100m surge shaft)
- **Excavation diameter:** Φ7230 mm
- **Geological conditions:** Lithology consists of crystal tuff and spherulitic rhyolite, with an average uniaxial compressive strength of 119–190MPa, reaching up to 223 MPa locally.
- **Progress:** Maximum daily advance rate of 23m; average monthly advance rate of 200m; maximum monthly advance rate of 331m.

3 Application Cases

Reaming-type Shaft Boring Machine (EBM)

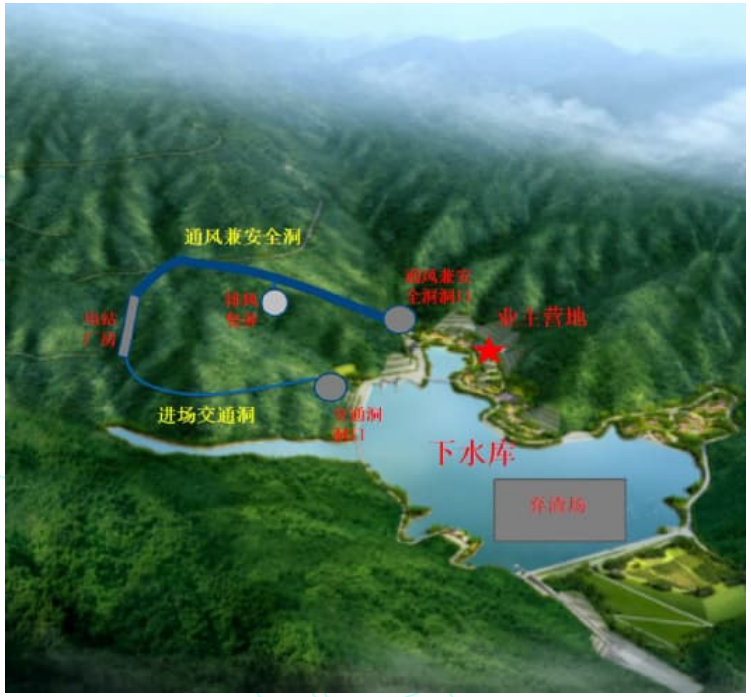


Taking the advance rate in December as an example, the monthly advance rate was 179.4m, with an average daily advance rate of 6m and an average monthly advance rate of 150m.

3 Application Cases

Reaming-type Shaft Boring Machine (EBM)

Anhui Ningguo pumped storage power station exhaust shaft project: The total height of the exhaust shaft is **211.6m**, including 179.1m of Class II–III surrounding rock sections and 32.5m of Class IV–V surrounding rock sections. The net diameter is 6.7m, and the excavation diameter is **Φ7030mm**. The lower end of the shaft is connected to the lower horizontal tunnel of the exhaust shaft. The lithology is the pebbly **tuff** of the Leigongwu Formation (Z1l). The rock mass is in a weakly weathered to slightly weathered state, mainly consisting **of relatively hard rock**. Joints and fractures are relatively developed, and the rock mass is from relatively intact to relatively fractured. The surrounding rock classification is approximately 60% Class III and 40% Class IV.



3 Application Cases

Reaming-type Shaft Boring Machine (EBM)

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4 Summary and Discussion

SBM

The adaptability to strata needs to be improved. During full face excavation, water inflow affects the slag discharge efficiency. If the slag at the bottom of the shaft is not discharged in time, the rock breaking effect of the cutters is poor, and the cutters are worn quickly.

EBM

The EBM equipment is equipped with an automatic slag loading device. Although the EBM has a fast excavation speed and smooth slag flow, the slow slag loading speed of the bottom loader affects the construction speed of the shaft.

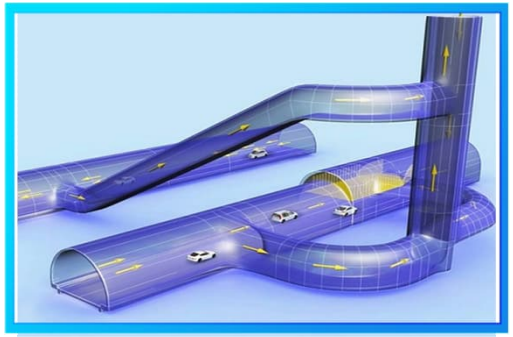
RBM

The RBM has poor adaptability to broken strata. In geological fragmentation, the pilot hole construction is prone to deflection. In the process of upward reaming, excessive pulling force and torque may occur, affecting the construction efficiency of the shaft. In severe cases, it may lead to project failure.

SBM & EBM

SBM and EBM require mechanized support systems. Although the equipment's excavation and slag discharge functions meet construction requirements, and the slag discharge speed has been significantly improved, the shaft forming speed is restricted by the manual support speed.

- Mine shaft

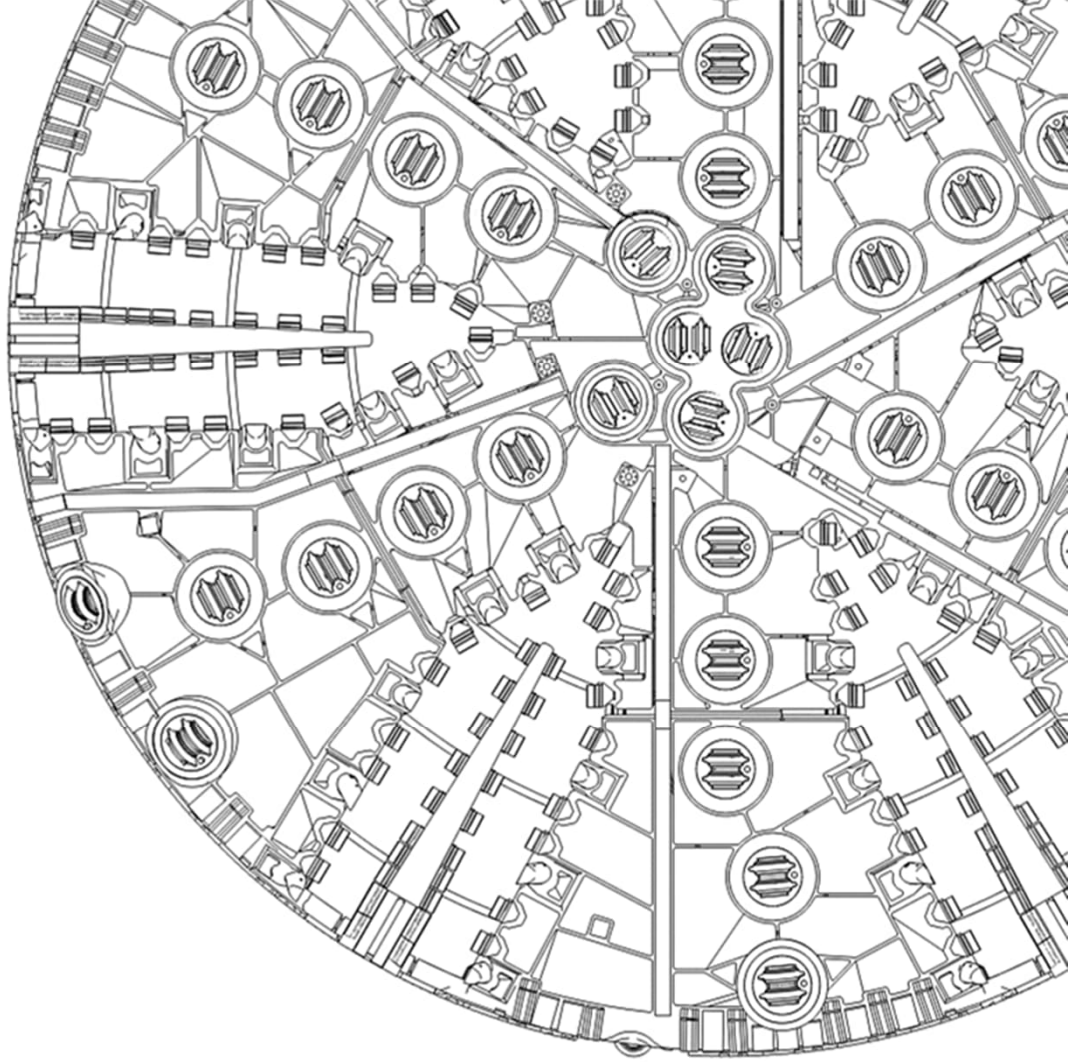


- Ventilation shaft

- Water conservancy shaft

- Municipal utility shaft

Thank you



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