ITA TUNNELLING AWARDS 2018

An Innovative Hard-rock TBM-mounted System for Geological Forward-prospecting

Presented by : Prof. Shucai Li, **Dr. Yong Li**

Shandong University, China

ITA TUNNELLING AWARDS 2018

Stakeholders

Prof. Shucai Li

Prof. Bin Liu

Dr. Lichao Nie

Dr. Yong Li

Dr. Xinji Xu

Dr. Zhengyu Liu

Lei Chen & Yuxiao Ren

SHANDONG UNIVERSITY

ITA TUNNELLING AWARDS 2018

Contents

1. Background & Challenges

2. Main achievements

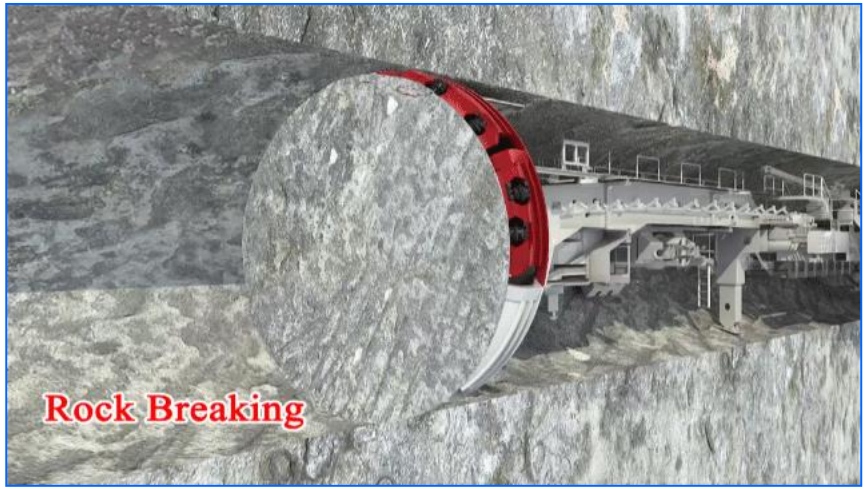
3. Applications & benefits

ITA TUNNELLING AWARDS 2018

More and more hard-rock TBMs are applied in engineering projects

- 18 hard-rock TBMs were applied in a water diversion project in Xinjiang Province, China.
- The Sichuan-Tibet Railway in China intends to use about 30 hard-rock TBMs.

The TBM for the Xikang Qinling Tunnel



Illustrations of TBM tunnelling

Water and mud inrush
Parbati Hydroelectric Project in India

Water inrush
A TBM project in Switzerland

TBM tunnelling has poor adaptability for adverse geology, which often causes serious disasters: water inrush and collapses……

TBM blockage
A water diversion tunnel in China

Serious Consequences

-- TBM blocked or damaged
-- heavy economic loss
-- casualties

ITA TUNNELLING AWARDS 2018

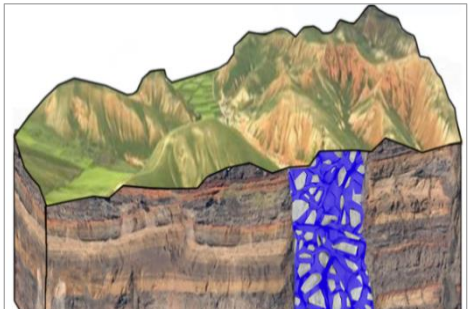
TECHNICAL PRODUCT/EQUIPMENT INNOVATION - OF THE YEAR -

Two main adverse geology: water body and fault fractured zone

Water body-karst cave

Water body-karst cave

Water body-karst cave



Fault

Fault

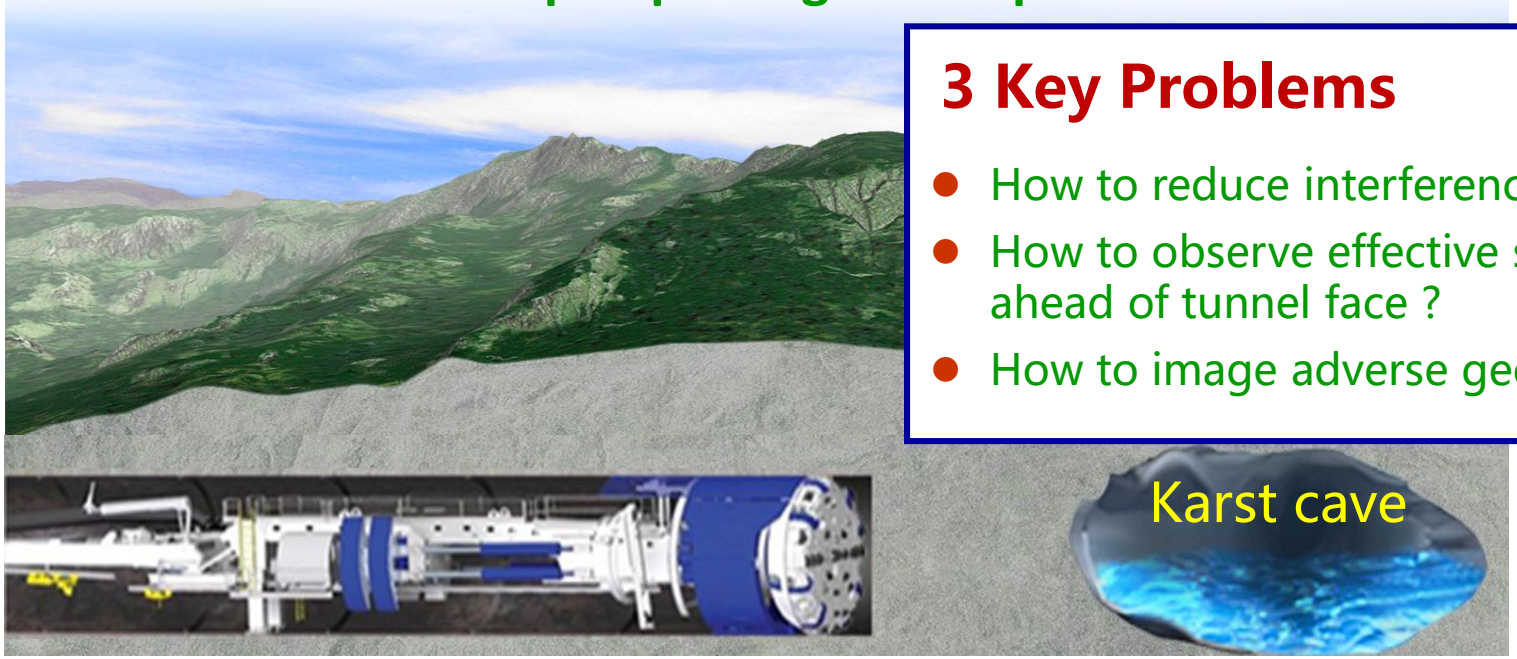
Fractured zone

Prospecting geological conditions ahead of tunnel face is of crucial importance

Challenges of forward-prospecting in TBMs

- Severe electromagnetic interferences can overwhelm the effective signals.
- TBM occupies most of tunnel space, little room available for prospecting.

Few effective forward-prospecting techniques suitable for TBM



3 Key Problems

- How to reduce interference ?
- How to observe effective signals ahead of tunnel face ?
- How to image adverse geology ?

Contents

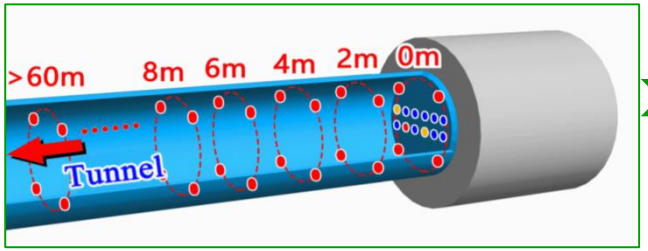
1. Background & Challenges

2. Main achievements

3. Applications & benefits

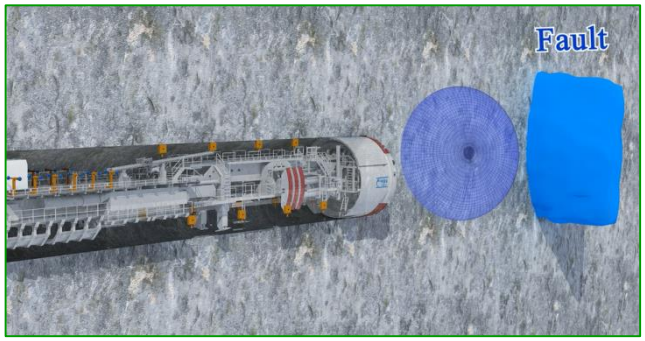
ITA TUNNELLING AWARDS 2018

Solution: TBM-mounted forward-prospecting instruments



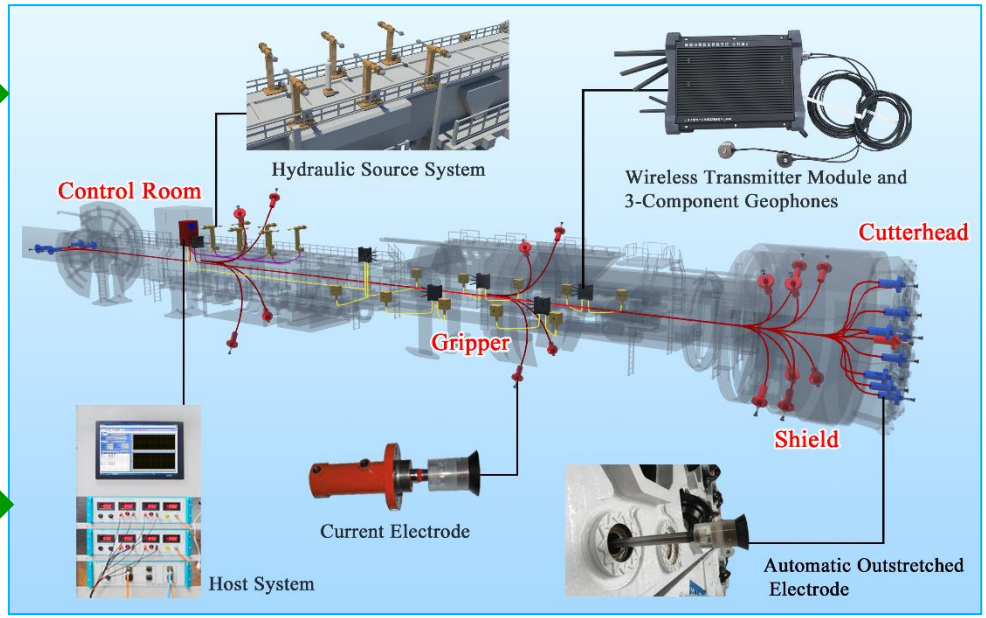
Water body → TIP

Tunnel Induced Polarization



Fault fractured zone → SFP

Seismic Forward-prospecting



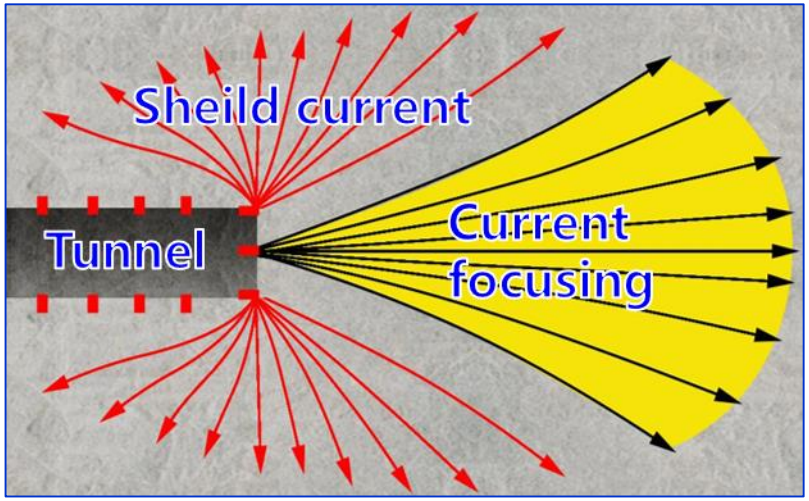
TBM-mounted forward-prospecting instruments

Three Innovations

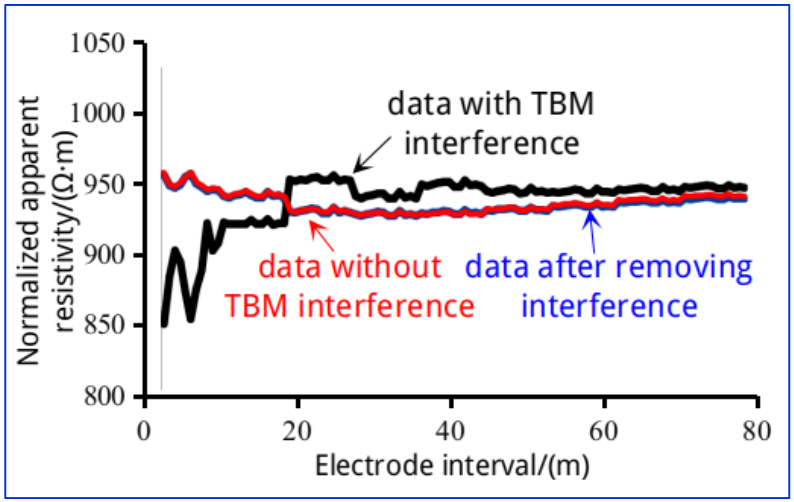
ITA TUNNELLING AWARDS 2018

Innvation1: Tunnel Induced Polarization technique for water bodies

- Interference removal method



Mutually exclusive of the same polarity current → **P**roduce a focusing effect → **R**educe TBM's interference



Proportional noise reducing algorithm

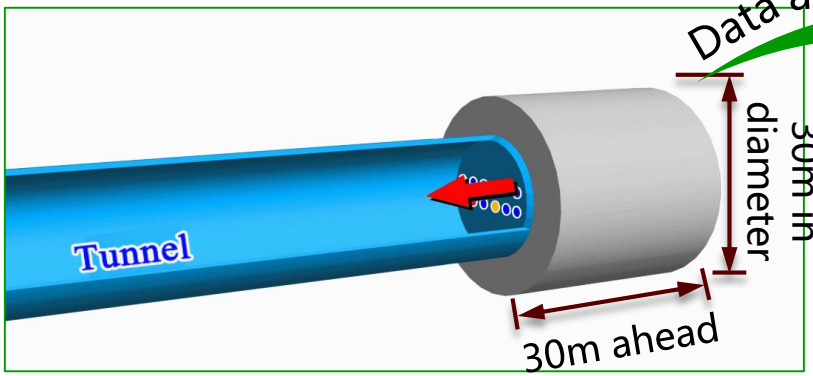
Critical breakthrough

TBM interference is reduced from over 30% to 1%

ITA TUNNELLING AWARDS 2018

Innvation1: Tunnel Induced Polarization technique for water bodies

- New observation mode & Constrained inversion method



Data acquisition

over 2000 data collected

$$\left[(W_d A)^T W_d A + \lambda C^T \Lambda C\right]\Delta m = (W_d A)^T W_d \Delta d$$

Incorporating known information into inversion equation

Image water body

By current electrodes moving, detection range reaches 30m ahead.

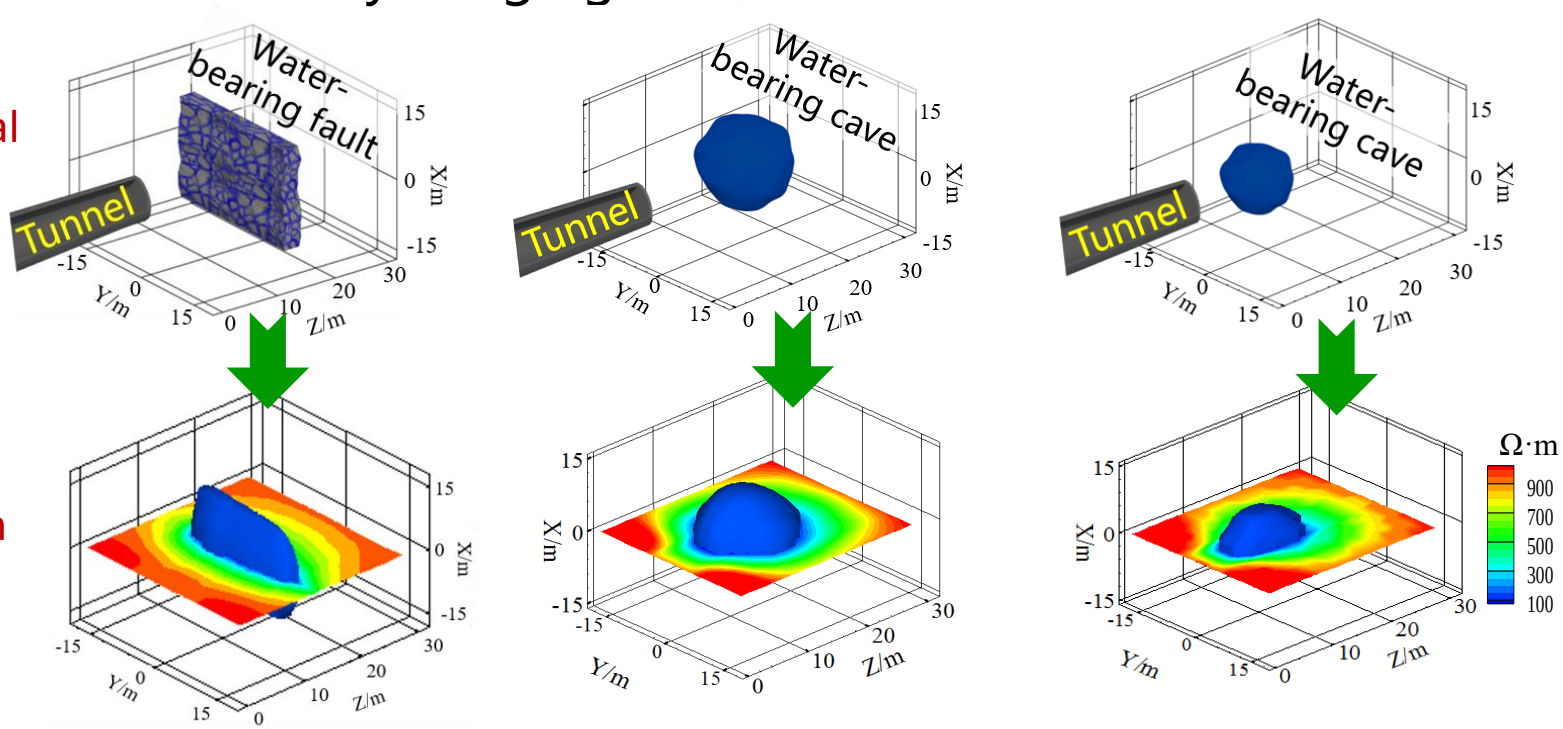
ITA TUNNELLING AWARDS 2018

Innvation1: Tunnel Induced Polarization technique for water bodies

- Typical water-body imaging cases

Geological models

Inversion results



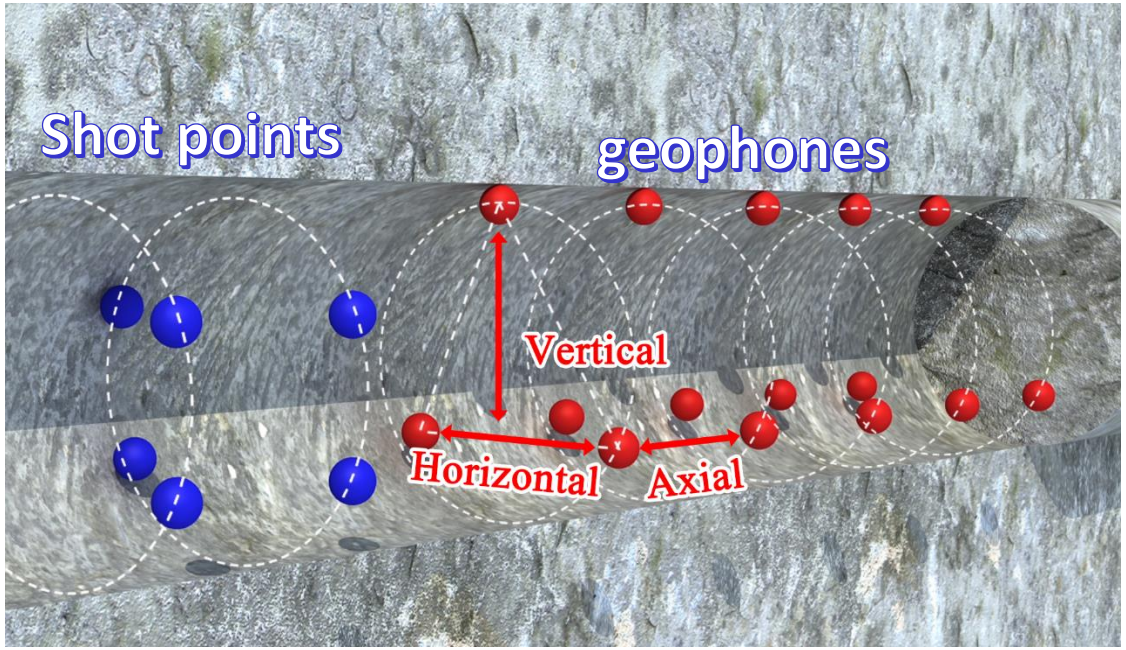
Low-resistivity area represents water body

ITA TUNNELLING AWARDS 2018

TECHNICAL PRODUCT/EQUIPMENT INNOVATION - OF THE YEAR -

Innvation2: Seismic Forward-Prospecting technique for faults

- New observation mode with three directional offsets



Collect a wealth of seismic wavefield information

ITA TUNNELLING AWARDS 2018

Innvation2: Seismic Forward-Prospecting technique for faults

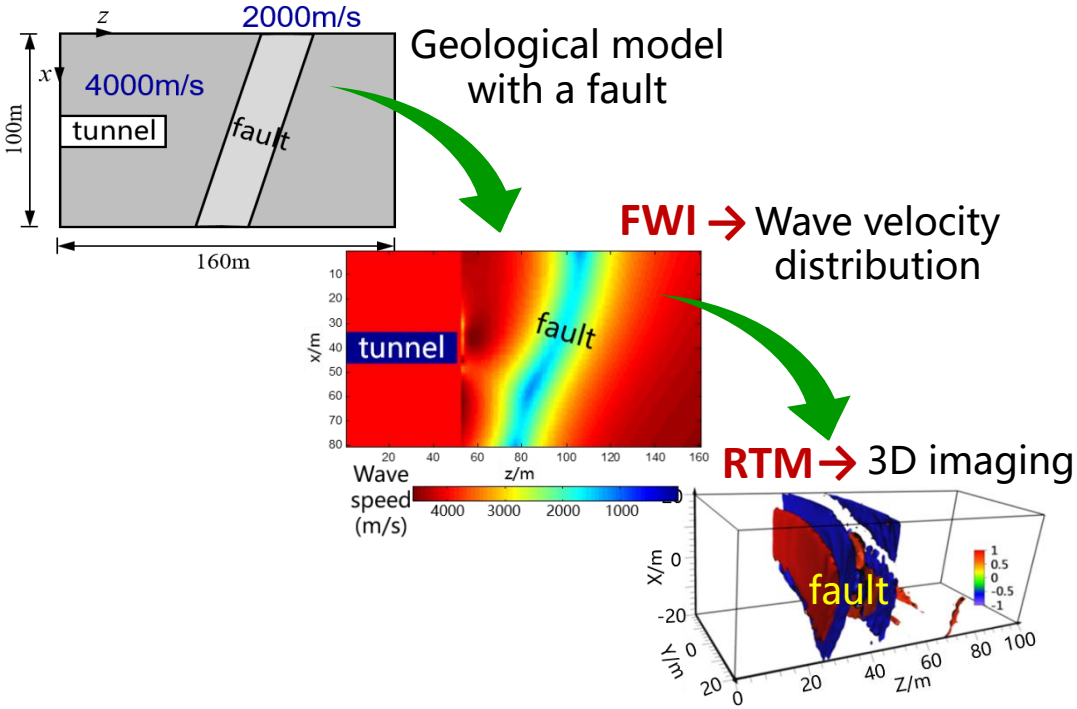
- Full waveform inversion(FWI) & migration

Innovation

- Inversion of all information including geological constraints, time, amplitude, phase.
- Accurate velocity distribution
- By reverse time migration (RTM), positioning error <5%

$$S'(\lambda,\mu)=\left(\frac{1}{2}\sum_{s}\sum_{d}\sum_{\tau}\left[V(\lambda,\mu)-V_{obs}\right]_{d,\tau}^{T}\cdot\left[V(\lambda,\mu)-V_{obs}\right]_{d,\tau}\right)\cdot\left(\begin{array}{l}1+\alpha_1\sum_{x}\left[\max(\lambda-\lambda_{\max},0)-\min(\lambda-\lambda_{\min},0)\right]\\+\alpha_2\sum_{x}\left[\max(\mu-\mu_{\max},0)-\min(\mu-\mu_{\min},0)\right]\end{array}\right)$$

Equation of FWI

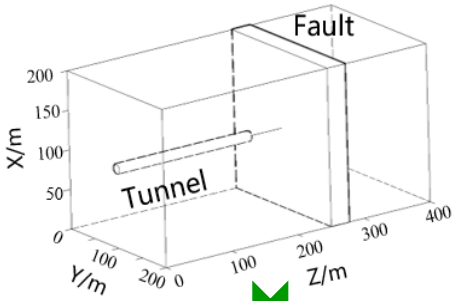


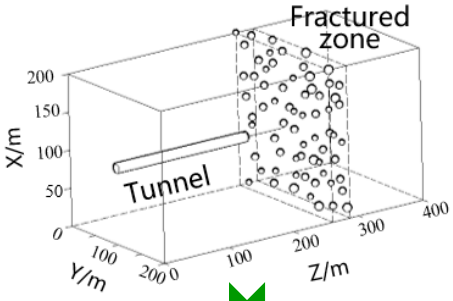
ITA TUNNELLING AWARDS 2018

Innvation2: Seismic Forward-Prospecting technique for faults

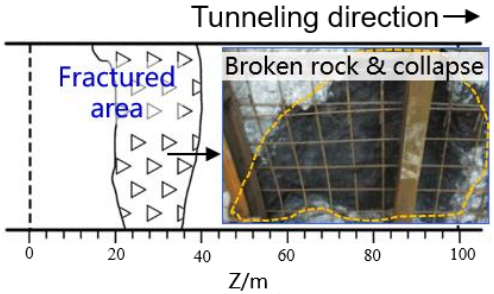
- Imaging cases of typical adverse geology

Geological models

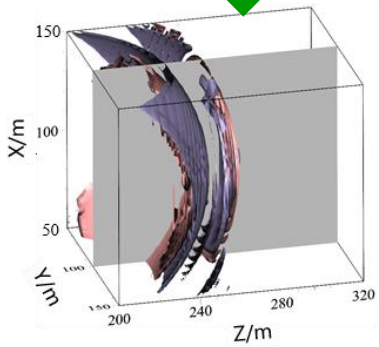


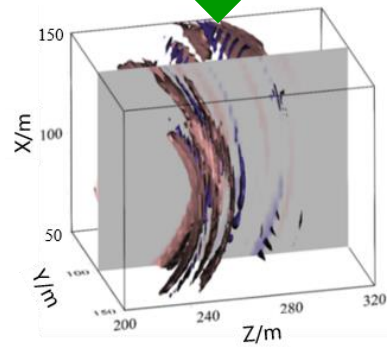


Field case

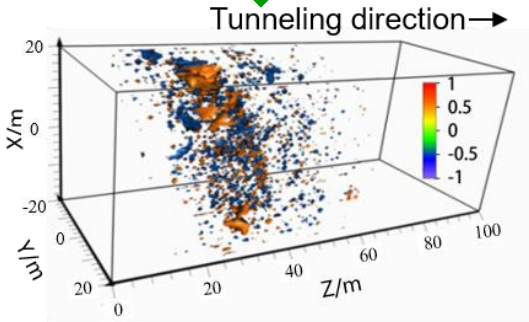


Imaging results





Imaging results



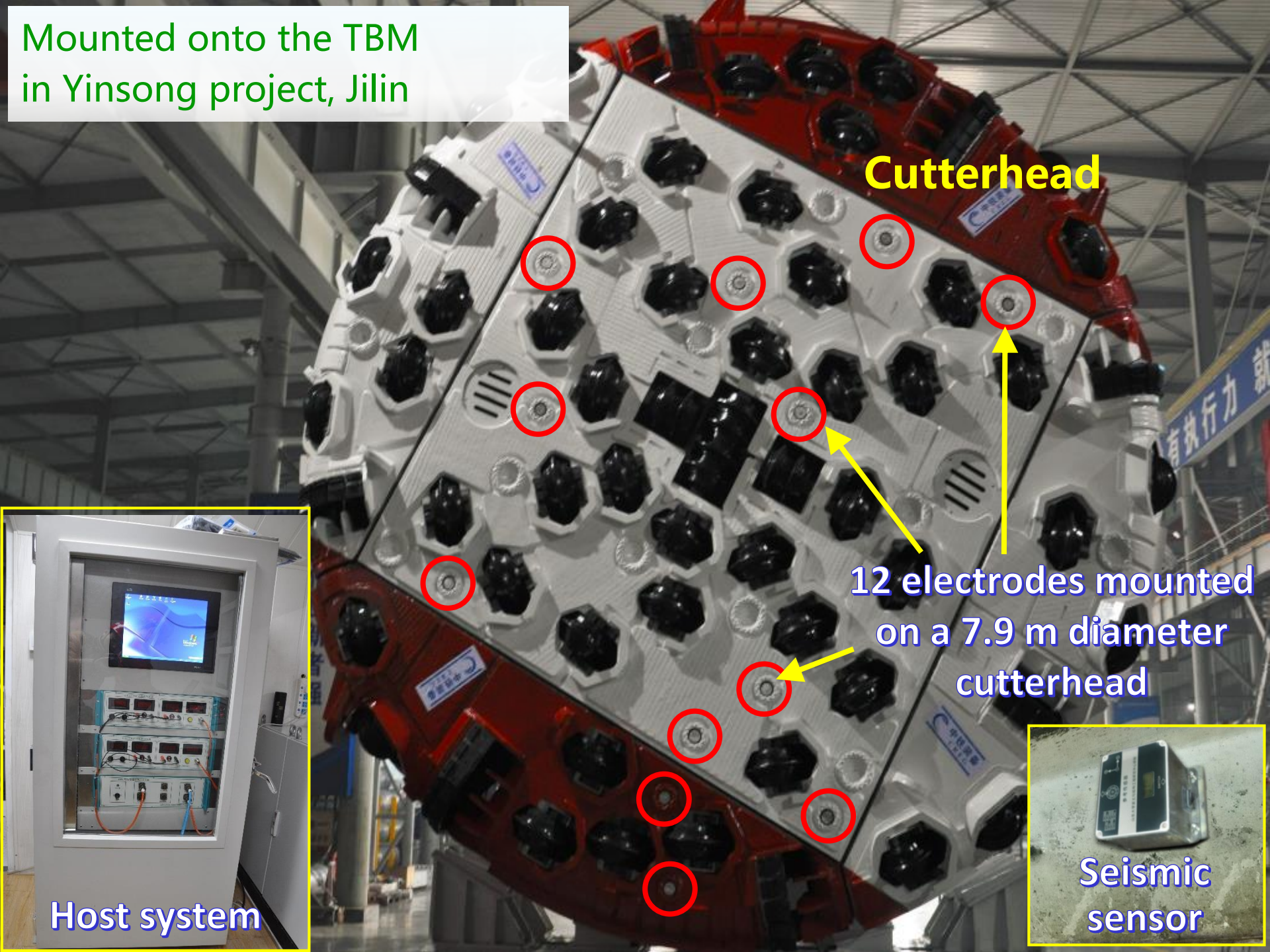
Strong reflection represents geological interface

ITA TUNNELLING AWARDS 2018

Based on the above theoretical achievements

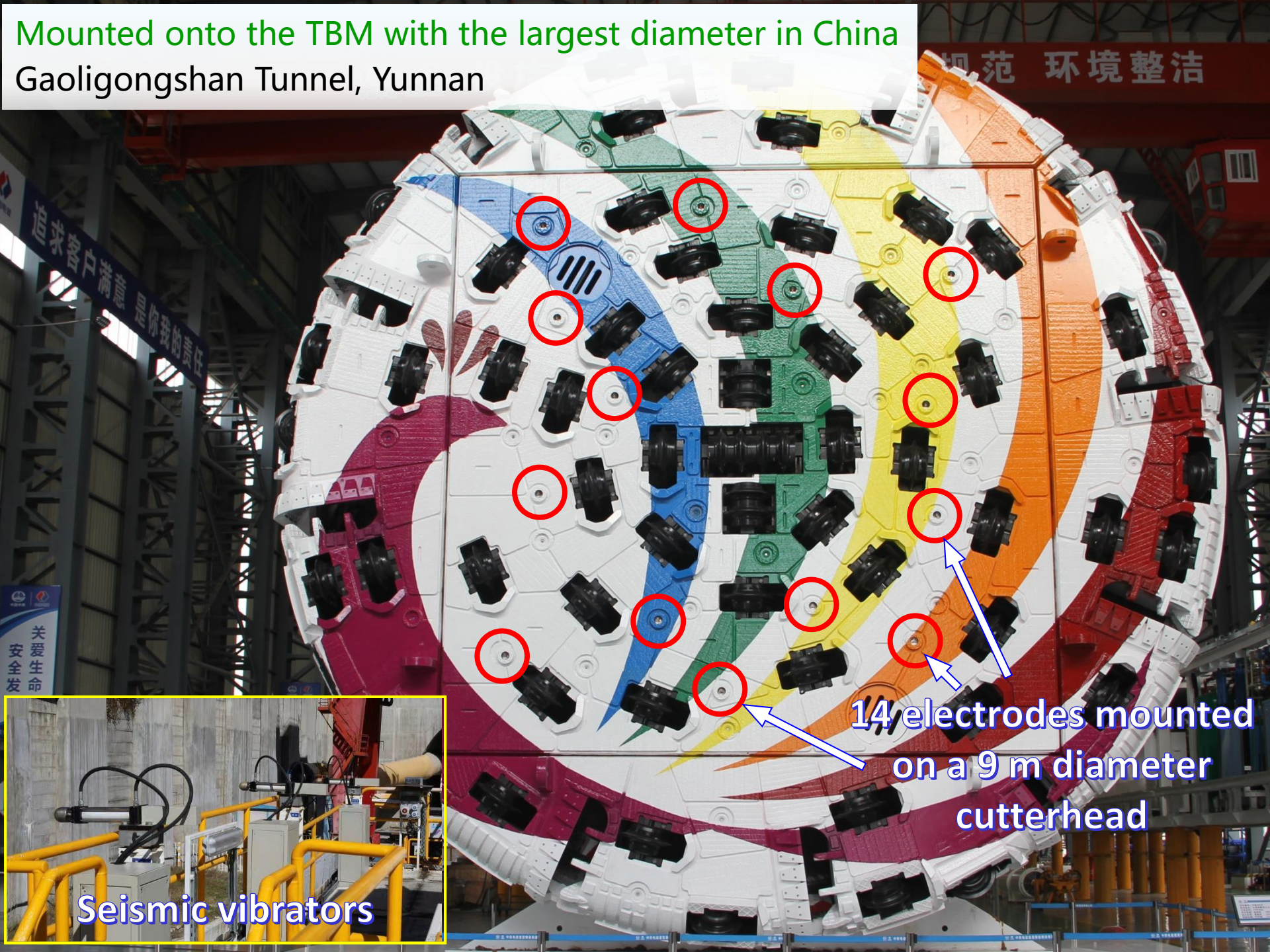
Innvation3: TBM-mounted prospecting instruments

Video


Mounted onto the TBM
in Yinsong project, Jilin
Cutterhead
12 electrodes mounted
on a 7.9 m diameter
cutterhead
Host system
Seismic
sensor

Mounted onto the TBM with the largest diameter in China

Gaoligongshan Tunnel, Yunnan



Contents

1. Background & Challenges

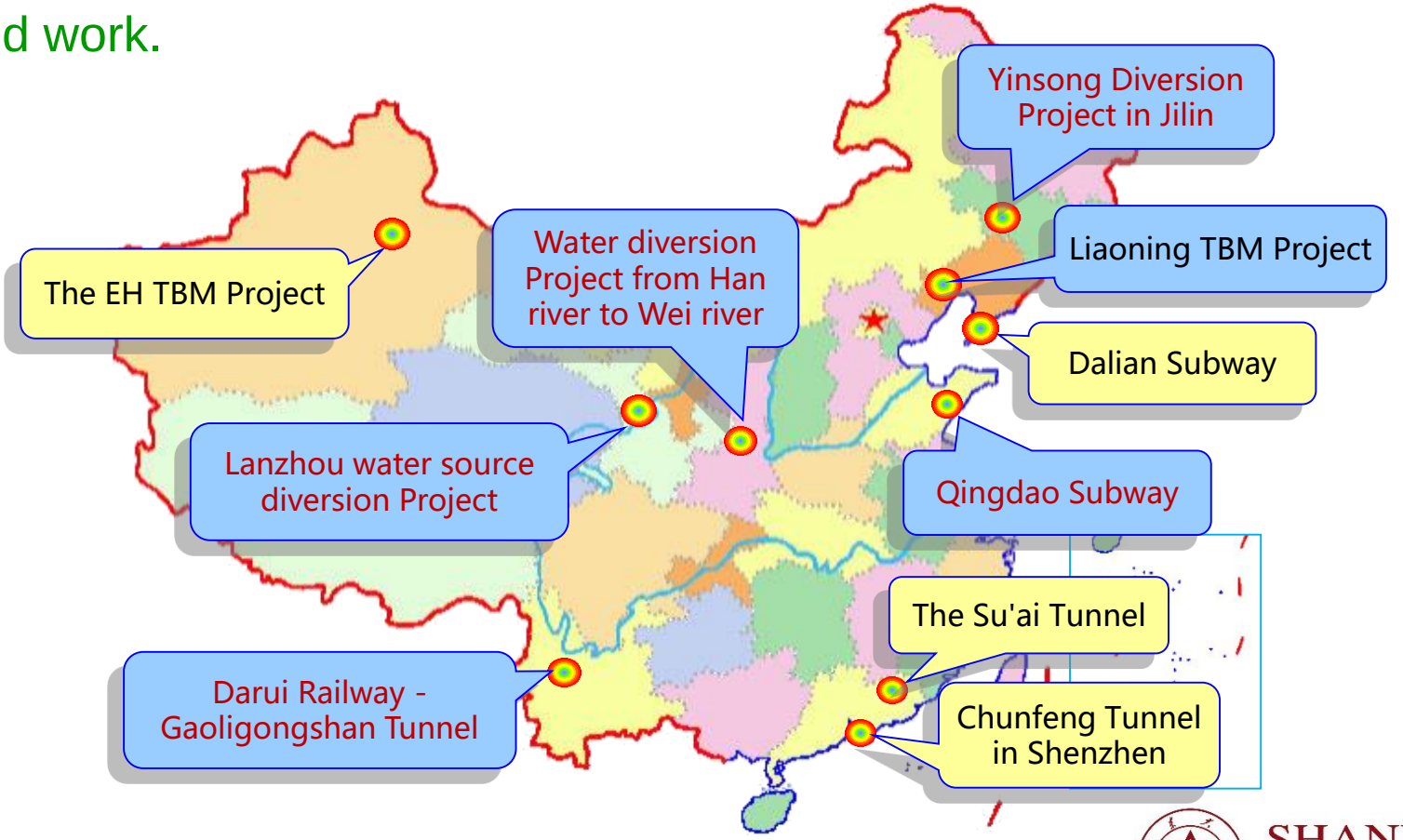
2. Main achievements

3. Applications & benefits

ITA TUNNELLING AWARDS 2018

18 projects, 638 times

No significant geo-hazard-causing geological bodies were missed in our field work.



ITA TUNNELLING AWARDS 2018

TECHNICAL PRODUCT/EQUIPMENT INNOVATION - OF THE YEAR -

Case1: 4th section of Yinsong water supply project in Jilin Province

- TBM tunnelling through a 7 km limestone stratum
- High risk of water inrush
- 138 detections
- 61 major water inrush sources

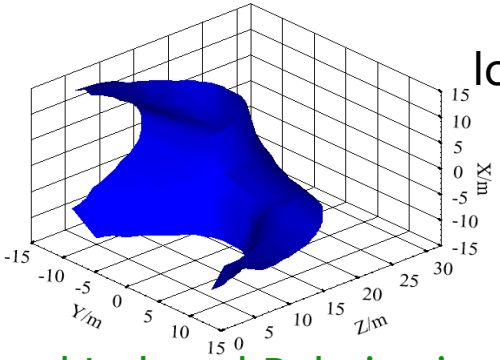
Safeguarded this project to be completed 9 months ahead of schedule.

ITA TUNNELLING AWARDS 2018

TECHNICAL PRODUCT/EQUIPMENT INNOVATION - OF THE YEAR -

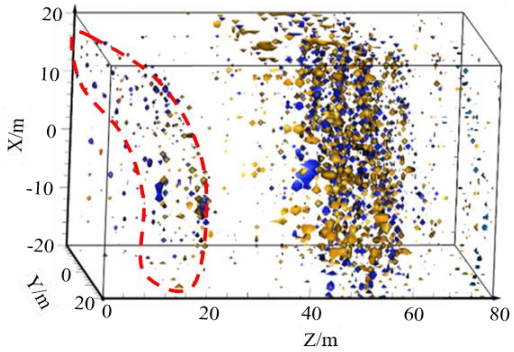
Case1: 4th section of Yinsong water supply project in Jilin Province

Typical detection case



Tunnel Induced Polarization result

low resistivity area



Seismic result

Strong reflection

a large-scale water body with a 2500m^3/h water inrush was accurately detected

TBM safely pass through this high risk region

ITA TUNNELLING AWARDS 2018

TECHNICAL PRODUCT/EQUIPMENT INNOVATION - OF THE YEAR -

Case2: 3rd section of Yinsong water supply project in Jilin Province

In the beginning, forward-prospecting technique was not employed, resulting in TBM blockage for 135 days.

↓

Since then, we have been entrusted to perform prospecting (151 detections).

↓

16.7 km tunnel safely breakthrough without any accident .

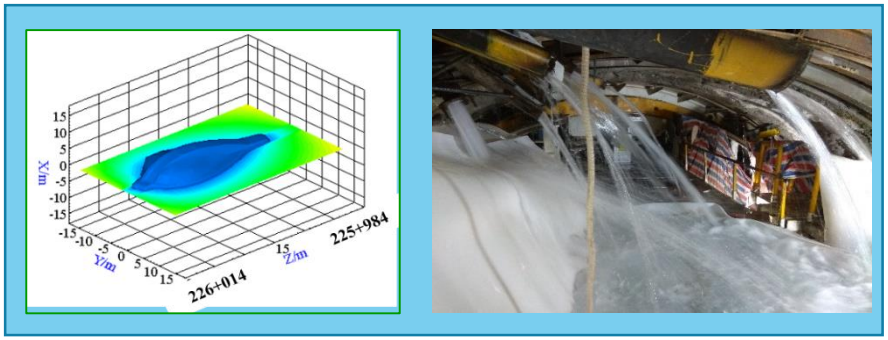
This formed a sharp contrast !

Tunnel breakthrough in May 2018

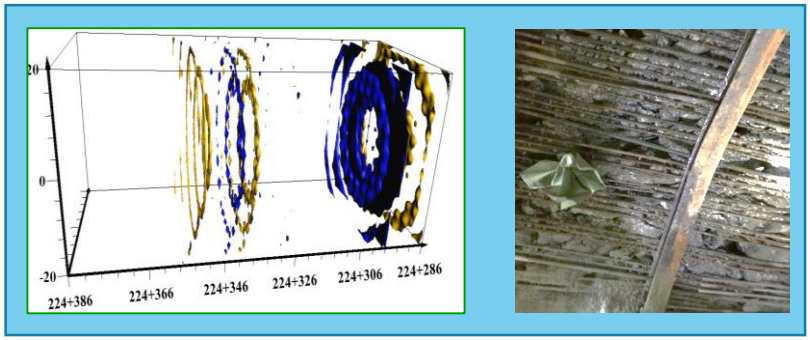
ITA TUNNELLING AWARDS 2018

Case3: the Gaoligongshan tunnel in Yunan Province, China

- The most difficult tunnel in China
- A total of 25 detections so far
- Identifying a water inrush area and a severely fractured zone



Detected a water inrush area (about 240m^3/h)



Detected a severely fractured zone

Benefits

Safe

- **Ensure** safe TBM tunnelling
- **Avoid** casualties

Intelligent

- **"Transparent"** geological information
- **Intelligent** decision of TBM tunnelling parameters

Innovative

- Solve the problem of prospecting adverse geology
- An association standard of Chinese Geophysical Society

Benefits

Friendly

- **Reduce** labor intensity
- Identify and seal groundwater in advance
- **Protect** water resources and ecosystem

Summary

- This system has been proven to be an effective equipment for detecting water bodies and faults in TBM.
- There is no significant geo-hazard-causing geological bodies were missed.
- We hope it can be employed worldwide to safeguard TBM tunnelling in the future.

Thank You!