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Monitoring, preventing and controlling rock burst in deep coal mines

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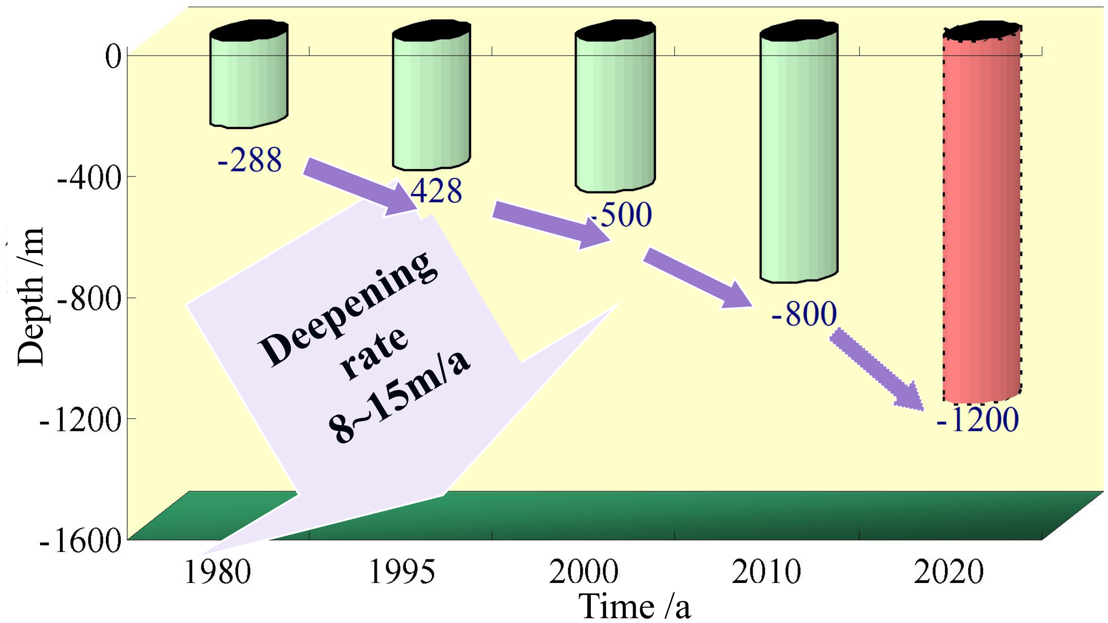
Content

- Introduction
- Main investigations
  - Risk estimation
  - Monitoring and early warning
  - Risk relief
- Conclusions

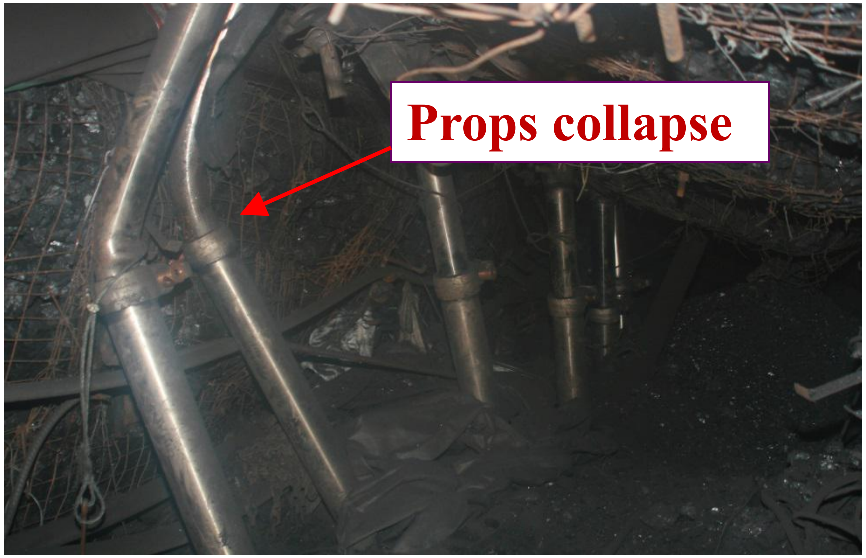
Introduction



- **As mining immigrates to depth, rock burst or coal bump risk gets higher and higher.**
- **The buried depth of 177 coalmines reaches more than 800 m in China, and rock burst is one of the worst disasters in deep coalmines.**

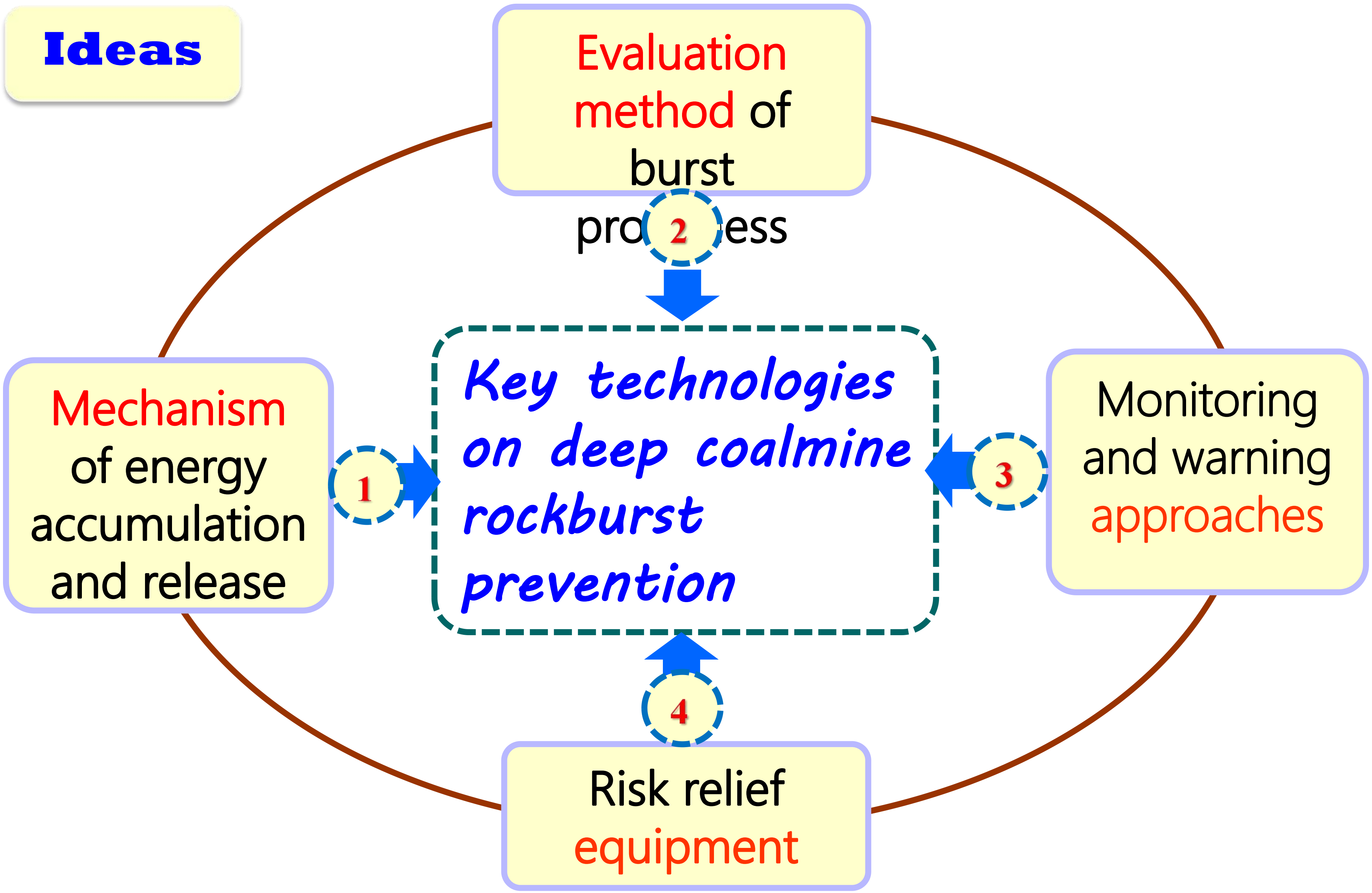
Introduction

- **Rock burst disaster is strongly disruptive, and it may bring out roadway destroyed.**



Risk evaluating, monitoring and controlling of deep rock burst is a long term task in coal mining engineering.

Introduction

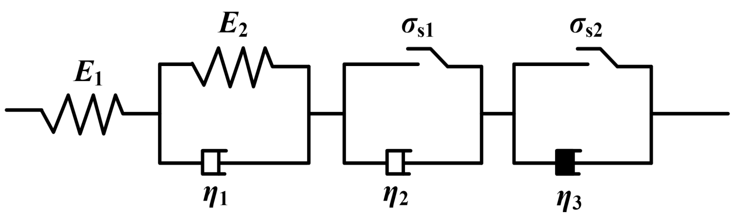


Content

- Introduction
- **Main investigations**
  - ✓ Risk evaluation
  - ✓ Monitoring and early warning
  - ✓ Risk elimination
- **Conclusions**

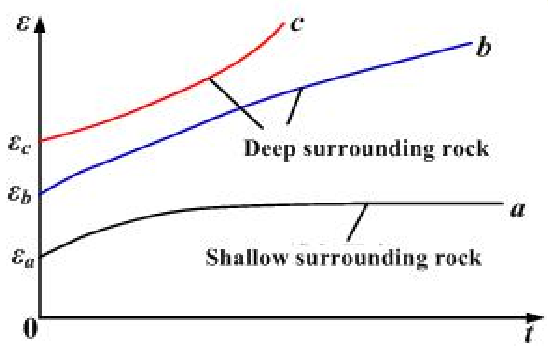
Risk evaluation

Viscoelastic nonlinear mechanism of energy accumulation and release of deep surrounding rock



Curve b $\varepsilon(t)=[\frac{1}{E_1}+\frac{1}{E_2}(1-e^{-\frac{E_2}{\eta_1}t})]\sigma_0+\frac{\sigma_0-\sigma_{s1}}{\eta_2}t, \sigma_{s1}\le\sigma_0\le\sigma_{s2}$

Curve c $\varepsilon(t)=[\frac{1}{E_1}+\frac{1}{E_2}(1-e^{-\frac{E_2}{\eta_1}t})]\sigma_0+\frac{\sigma_0-\sigma_{s1}}{\eta_2}t+\frac{\sigma_0-\sigma_{s2}}{\eta_3}t^n, \sigma_0\ge\sigma_{s2}$



Mining disturbance

Deep surrounding rock → **Stress redistribution** (Nonlinear energy accumulation > release+dissipation)

↓ $U_E > U_0$

Surrounding rock failure (energy accumulation > release+dissipation) → **Energy re-accumulation**

↓ $U_E > U_0$

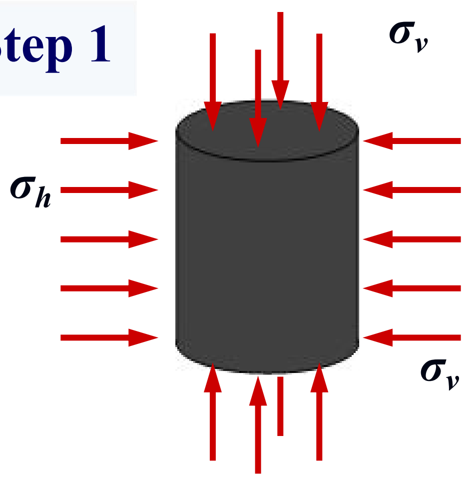
Energy release, surrounding rock failure → ……

Time effect of energy accumulation and release

Risk evaluation

Unloading impact energy rate index

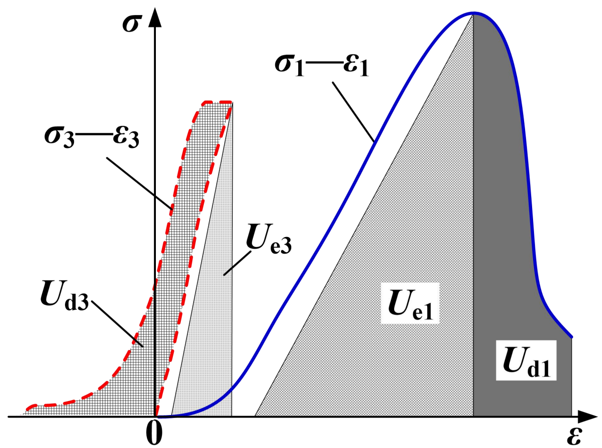
Step 1



Coal sample

- **Getting the triaxial compressive strength, σ_c, at the confining pressure of σ_h.**
- **Unloading confining pressure when the axial pressure is about 85% σ_c.**

Step 2



Loading-unloading curve

Step 3

$$W_{ST} = \frac{U_{e1} + 2U_{e3}}{\left(U_{d1} + 2U_{d3}\right) \cdot D_T}$$

- $U_{e1} + 2U_{e3}$: **Strain energy accumulated before unloading**
- $U_{d1} + 2U_{d3}$: **Energy consumed after peak stress**
- D_T: **Duration of dynamic fracture**

When W_{ST} <3, no rockburst risk;

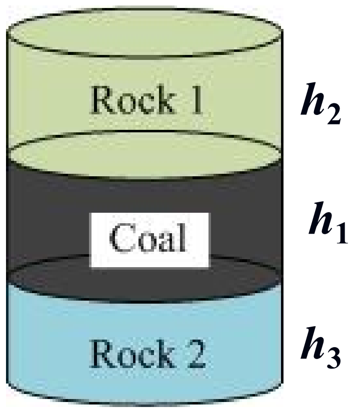
When 3≤ W_{ST} <100, weak rockburst risk;

When W_{ST} ≥100, strong rockburst risk.

Risk evaluation

Impact energy rate index of combined coal-rock

Step 1



$$h_1 = \frac{0.1H_1}{H_1 + H_2 + H_3}$$

$$h_2 = \frac{0.1H_2}{H_1 + H_2 + H_3}$$

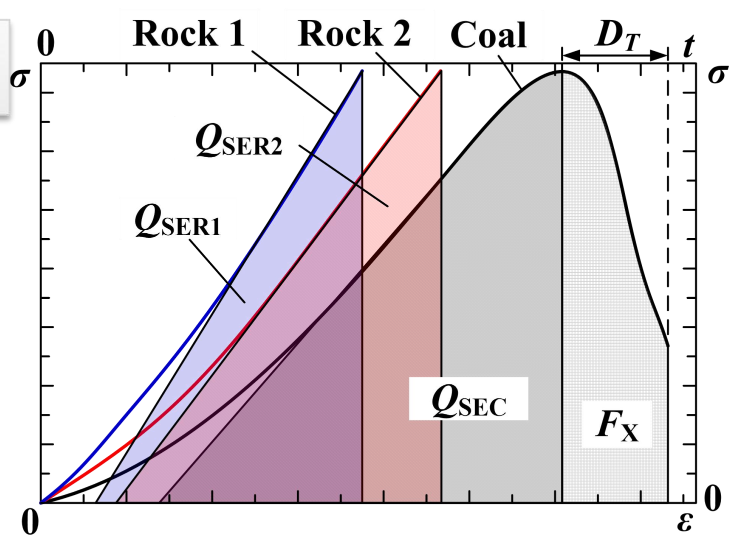
$$h_3 = \frac{0.1H_3}{H_1 + H_2 + H_3}$$

H_1—the height of coal seam;

H_2—the hard roof height;

H_3—the hard floor height.

Step 2



Loading results of the coal-rock combined sample

Step 3

$$W_{ZT} = \frac{h_2 Q_{SER1} + h_3 Q_{SER2} + h_1 Q_{SEC}}{h_1 F_X \cdot D_T}$$

Strain energy accumulated before peak-stress

Energy consumed after peak stress

Duration of dynamic fracture

Risk evaluation

The new evaluation index system of rock burst risk of deep coal seam

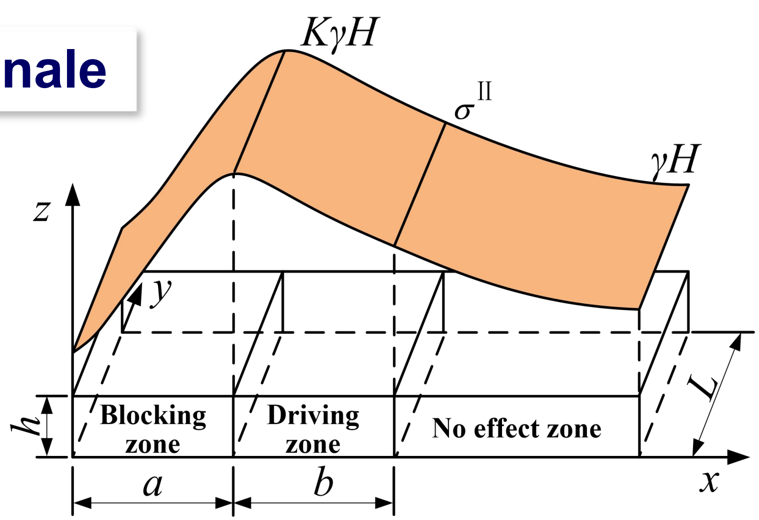
Indices	No rock burst risk	Low rock burst risk	High rock burst risk	Note
Duration of dynamic fracture	$D_T > 500$	$50 < D_T \le 500$	$D_T \le 50$	China standard
Elastic strain energy index	$W_{ET} < 2$	$2 \le W_{ET} < 5$	$W_{ET} \ge 5$	
Bursting energy index	$K_E < 1.5$	$1.5 \le K_E < 5$	$K_E \ge 5$	
Uniaxial compressive strength	$R_C < 7$	$7 \le R_C < 14$	$R_C \ge 14$	
Unloading impact energy rate index	$W_{ZT} < 6$	$6 \le W_{ZT} < 180$	$W_{ZT} \ge 180$	New
Combined coal-rock impact energy rate index	$W_{ZT} < 3$	$3 \le W_{ZT} < 100$	$W_{ZT} \ge 100$	New

Risk evaluation

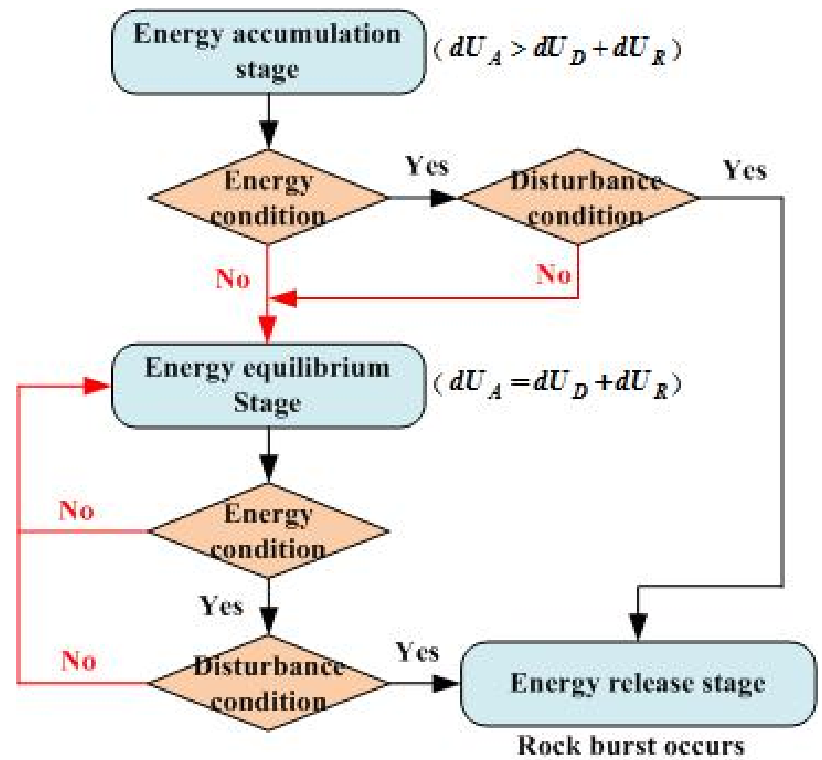
■ Evaluation approach

Strain-mode rock burst

Rationale



Abutment pressure distribution



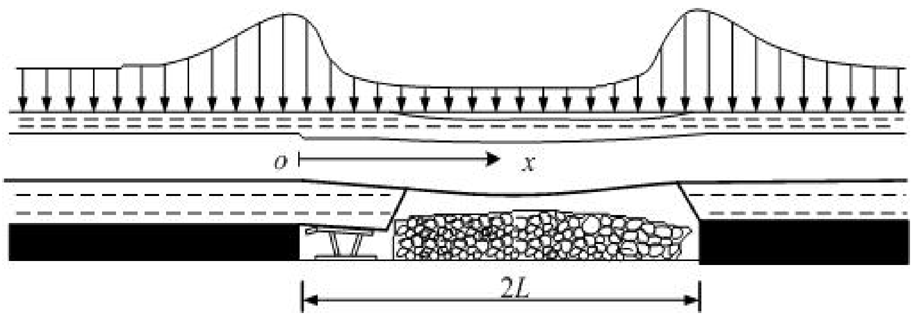
Judgement flow chart

Index choice

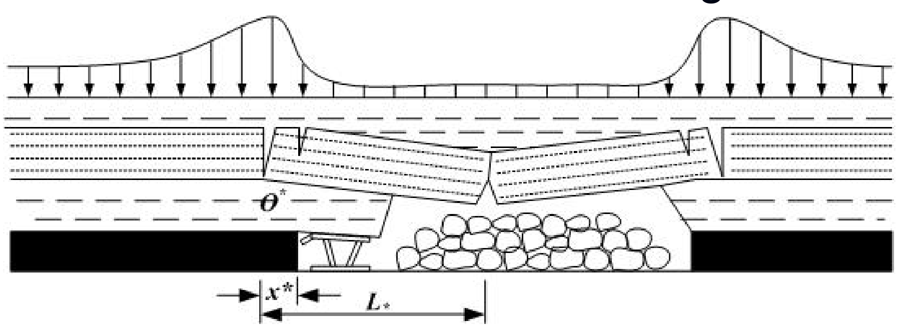
China standard				Added index
Duration of dynamic fracture	Elastic strain energy index	Bursting energy index	Uniaxial compressive strength	Unloading impact energy rate index

Risk evaluation

➢ *Hard roof weighting aroused rock burst*



Before main roof breaking



After main roof breaking

Rationale

Strength criterion:

$$\sigma / [R_t] > 1$$

Energy criterion of system instability:

$$-\Delta E - \Delta G > 0\ ;$$

$$\delta^2 U \leq 0$$

Necessary condition

Coal thrown criterion:

$$F_{xt} - F_{zt} > 0$$

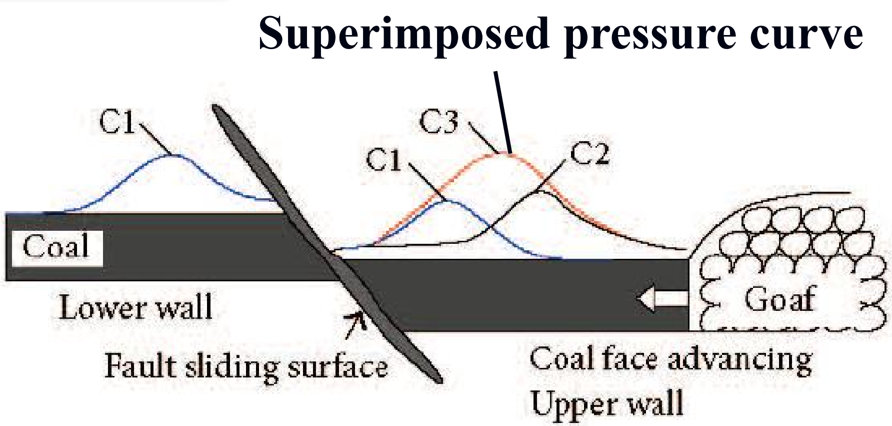
Sufficient condition

Index choice	China standard				Added index
	Duration of dynamic fracture	Elastic strain energy index	Bursting energy index	Uniaxial compressive strength	Combined coal-rock impact energy rate index

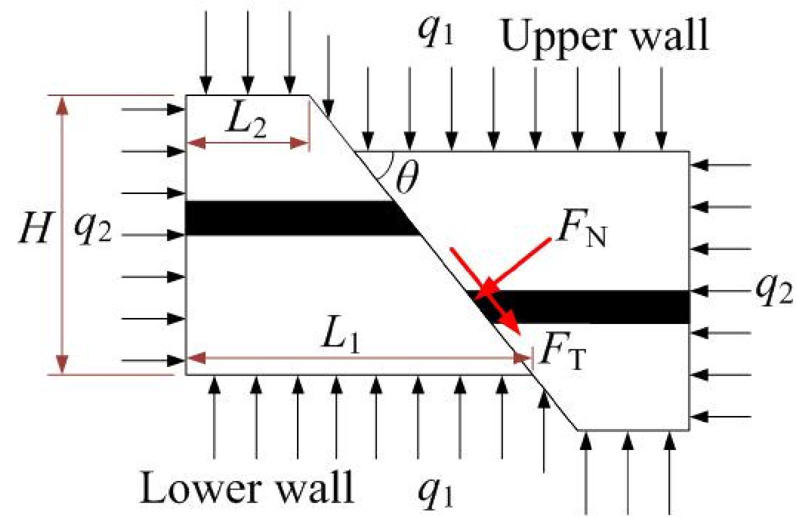
Risk evaluation

➢ *Fault aroused rock burst*

Rationale



Stress distribution around the fault



Mechanical model

Index choice

	China standard				Added index
Fault slip	Duration of dynamic fracture	Elastic strain energy index	Bursting energy index	Uniaxial compressive strength	Unloading impact energy rate index
No fault slip	Duration of dynamic fracture	Elastic strain energy index	Bursting energy index	Uniaxial compressive strength	Combined coal-rock impact energy rate index

Risk evaluation

The new evaluation index system of rock burst risk of deep coal seam

Indices	No rock burst risk	Low rock burst risk	High rock burst risk	Note
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Risk evaluation

➢ *Optimal fuzzy assessment model*

Membership matrix of the indices:

$$S_{5\times 3}=\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \\ S_{41} & S_{42} & S_{43} \\ S_{51} & S_{52} & S_{53} \end{bmatrix}$$

Generalized Euclidean distance weighted by u_j :

$$\bar{D}_j = u_j \left\{ \sum_{i=1}^{5} \left[W_i \left(r_i - S_{ij} \right) \right]^2 \right\}^{\frac{1}{2}}$$

$\vec{r}$ **is membership matrix after normalization;**

$\vec{u}$ **is membership matrix to each type;**

$\vec{W}$ **is weight vector of the indices.**

Objective function: $\min\left\{F\left(u_j\right)\right\} = \min \sum_{j=a_1}^{a_2} \left\{ u_j^2 \sum_{i=1}^{n} \left[W_i \left(r_i - S_{ij} \right) \right]^2 \right\}$

Constraint condition: $\sum_{j=a_1}^{a_2} u_j = 1$

Optimal fuzzy assesment is by

$$u_j = \left[D_j^2 \sum_{j=a_1}^{a_2} D_j^{-2} \right]^{-1}$$

Risk evaluation

Example: No. 10 coal seam of Da'anshan Coal Mine is located in the axial of syncline, and strain rock burst occurs easily. Its related burst indexes are as follows:

D_T=432ms (Weak), W_{ET}=5.332 (Strong), K_E=2.632 (Weak), R_C=27.28MPa (Strong), W_{ST}=132ms^{-1} (Strong).

According to optimal fuzzy identification model, their membership degrees are as follows: u_1=0.01, u_2=0.37, u_3=0.61, No. 10 coal seam had ***strong burst proneness.***

Monitoring and early warning

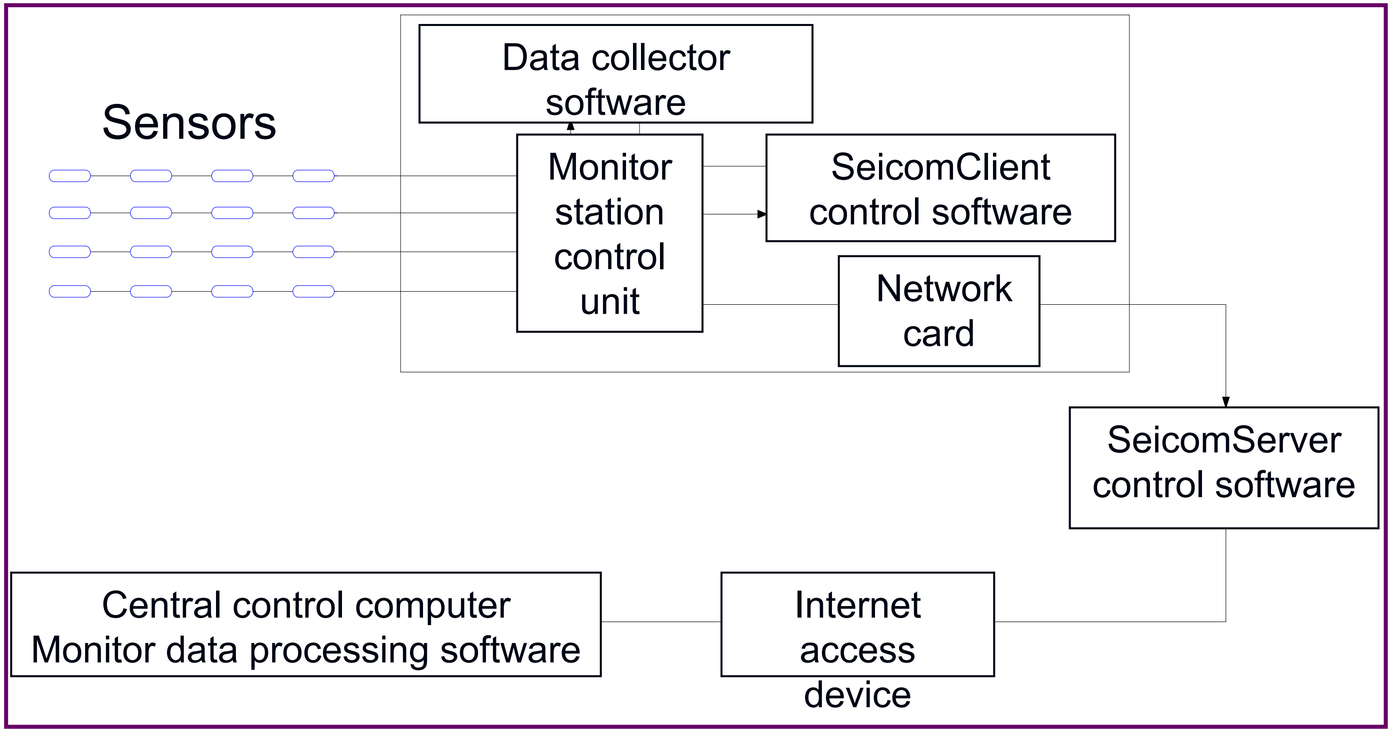
➢ *Precursory features and monitoring approaches*

Types	Precursory features	Monitoring methods
Strain-mode rock burst	1. A long stress rising period, the intensity and pulse number of electromagnetic radiation increase continuously. 2. A energy accumulation period exists, where both the frequency and energy of microseismic event are small.	Microseismic, electromagnetic radiation, online stress and drilling.
Hard roof weighting aroused rock burst	1. The static stress changes sharply. 2. Micro cracks induced by roof sinking increase. Both the energy and frequency of AE event increase.	Online stress, AE, microseismic and drilling.
Fault-slip type rock burst	1. Continuous sliding-mutation: the energy grows exponentially. 2. Sliding-stable-mutation: the energy experiences multiple peaks.	Microseismic, online stress and drilling.

Monitoring and early warning

➢ *Development of monitoring equipment*

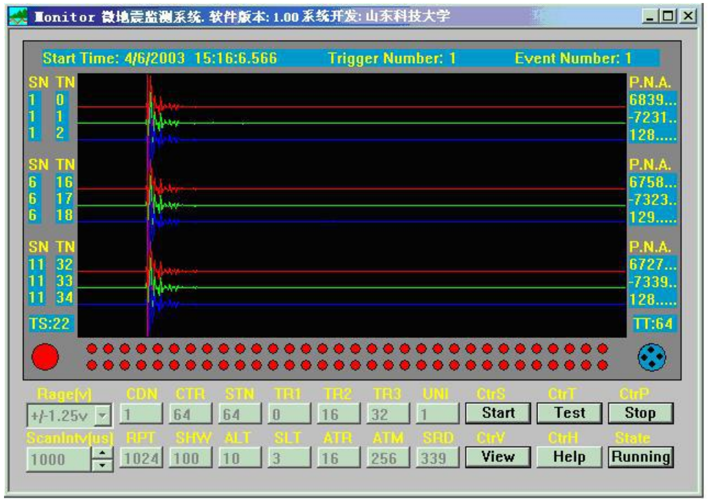
Microseismic system



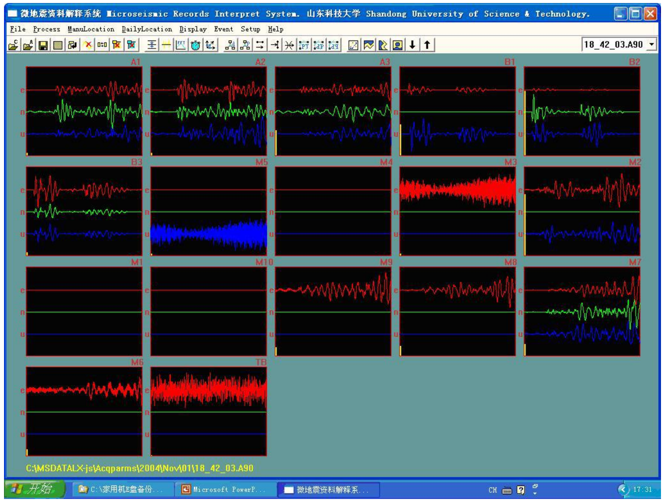
Hardware construction

Monitoring and early warning

Software construction



Monitor data collecting software



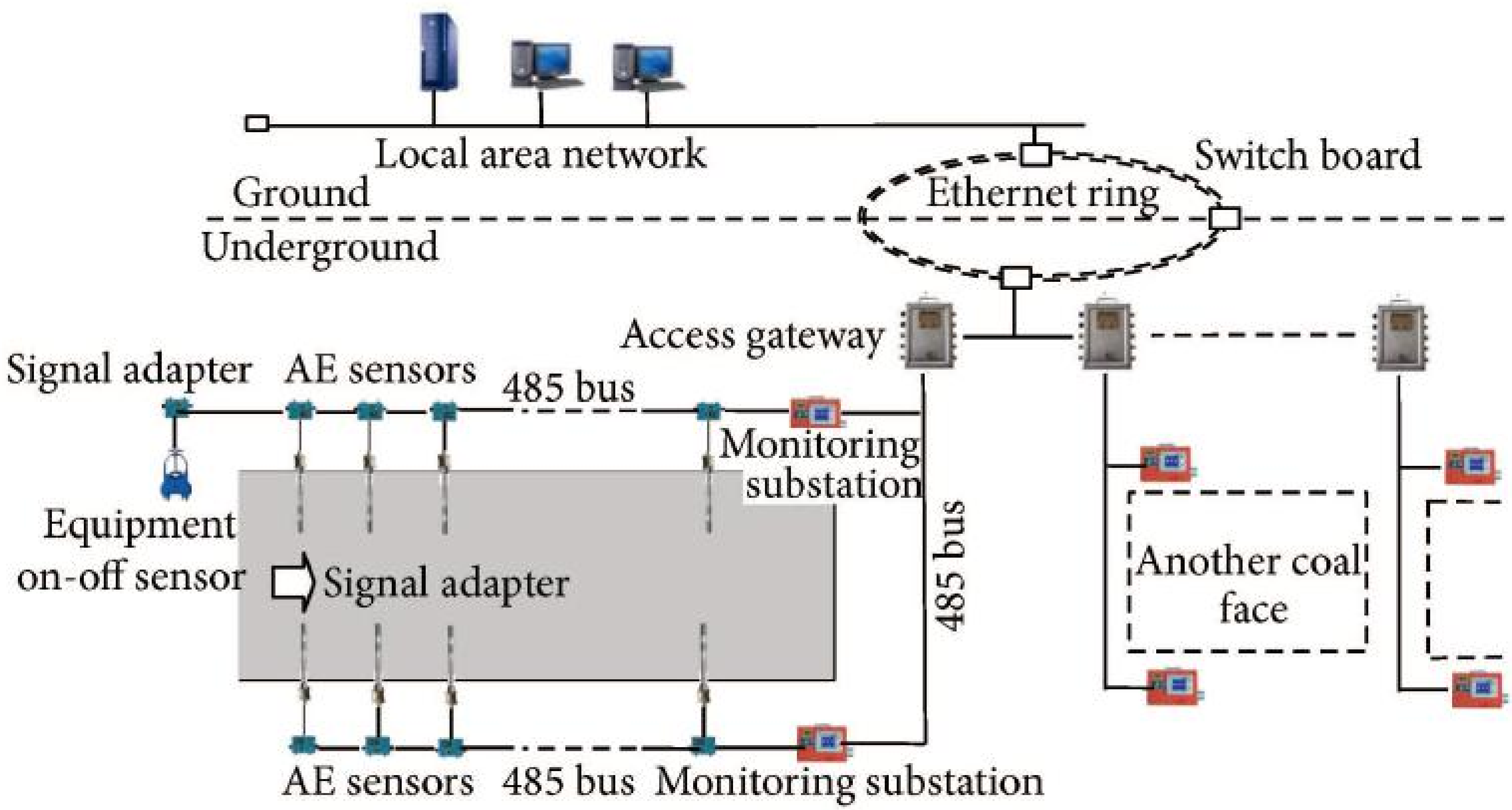
Locator data collecting software

Advantages:

- ✓ **Remote Intelligent Control of microseismic monitoring is achieved, by building the remote network monitoring stations.**
- ✓ **'Relay' connection mode and 'Parallel' communication mode are applied to expand the monitoring scope, and the cost is saved.**

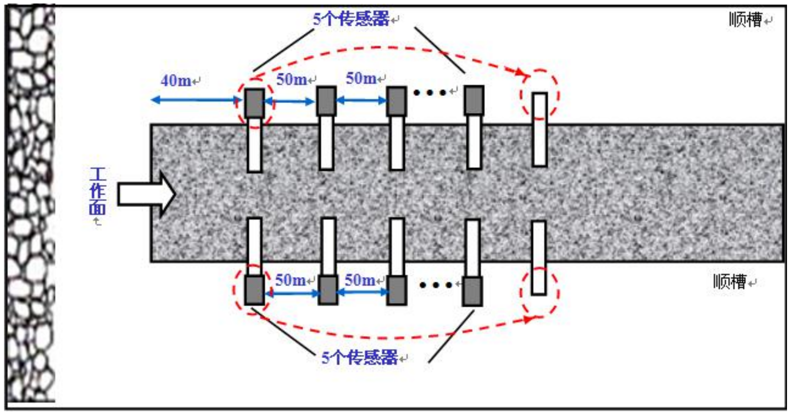
Monitoring and early warning

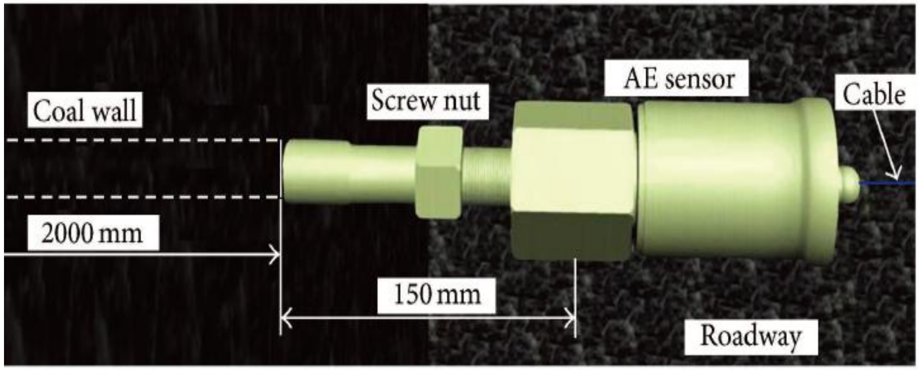
KJ623 AE system



RS458 bus and Ethernet ring structure, are composed by switch board, access gateway, monitoring substations, AE sensors, etc.

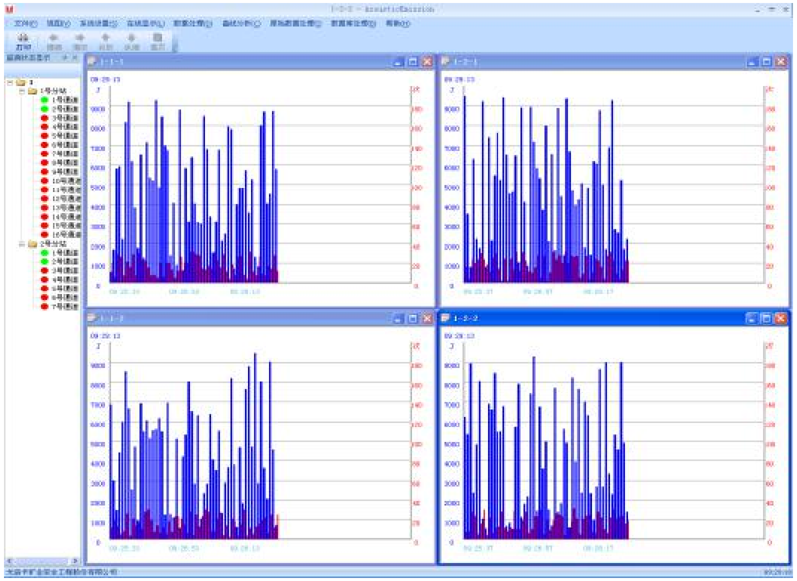
Monitoring and early warning

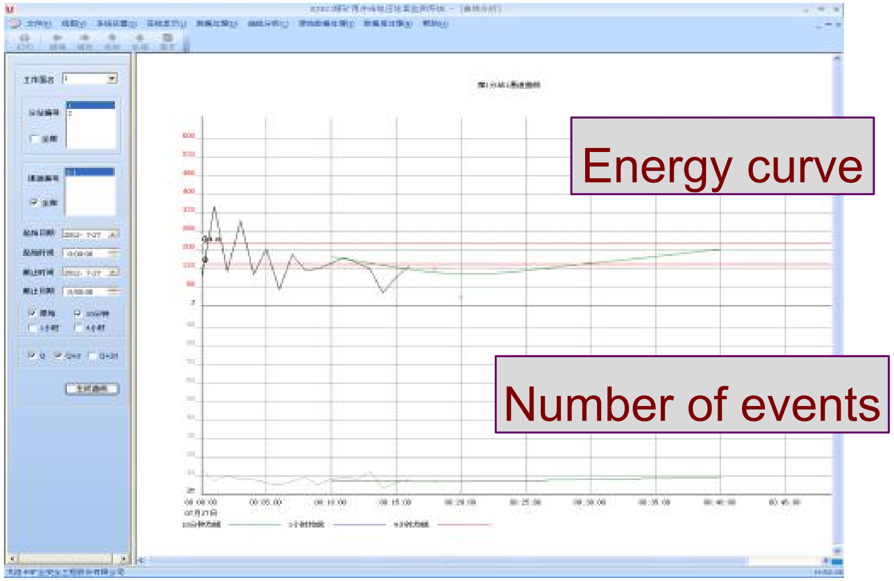




Layout of AE sensors

Installation of AE sensor

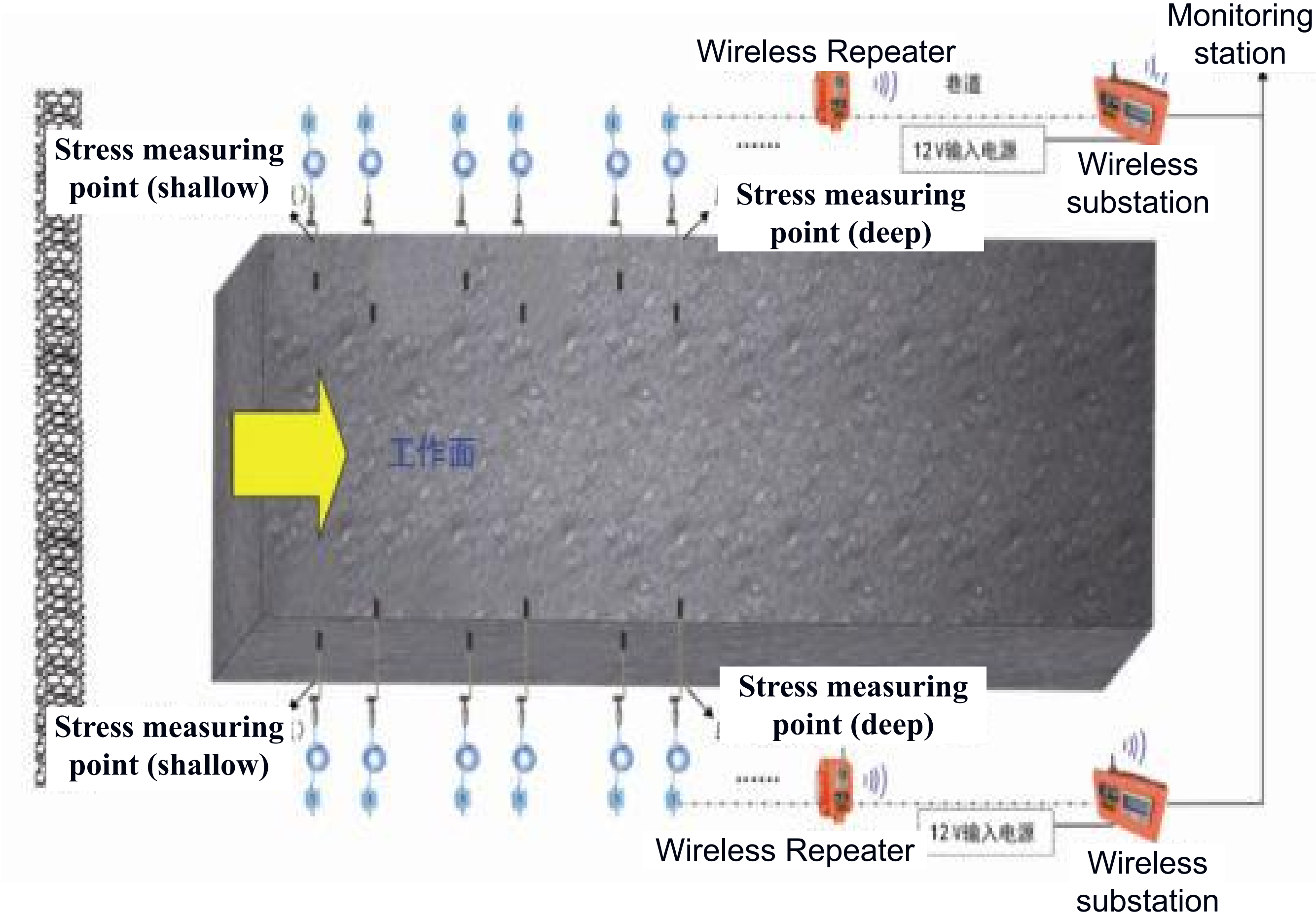




AE monitoring datas

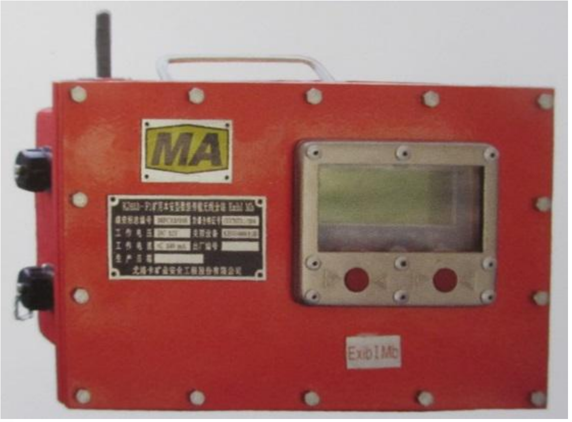
Monitoring and early warning

KJ743 online stress monitoring system



Stress sensor

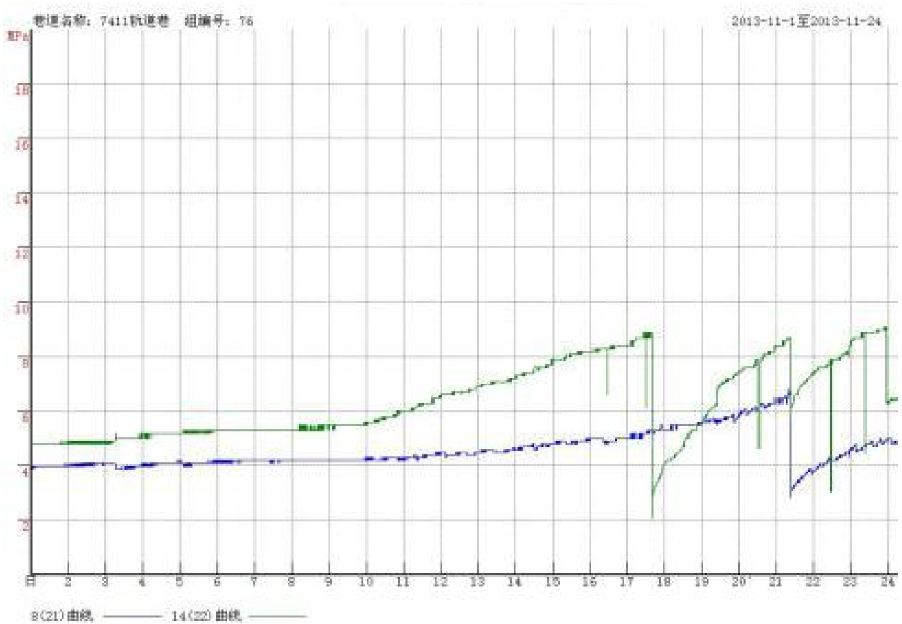
Drilling dynamometer



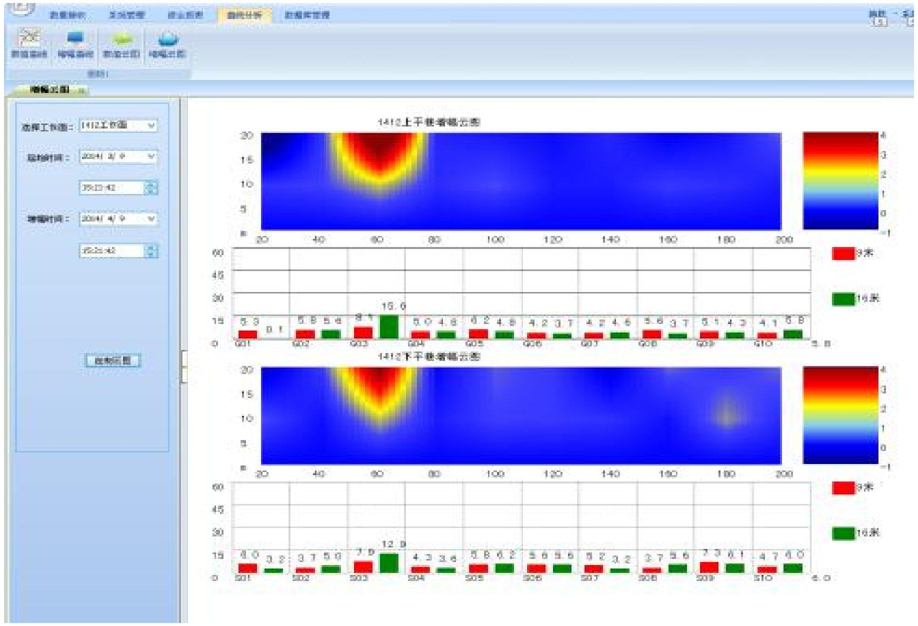
Wireless monitoring station

Monitoring arrangement and hardware

Monitoring and early warning



Mining pressure



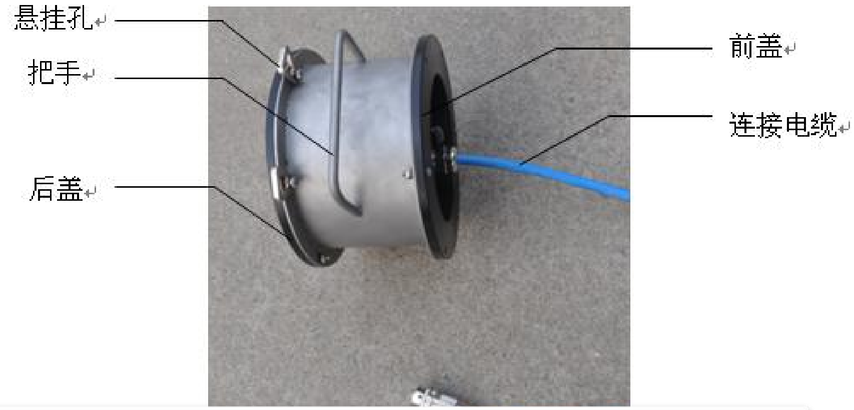
Increase of mining pressure

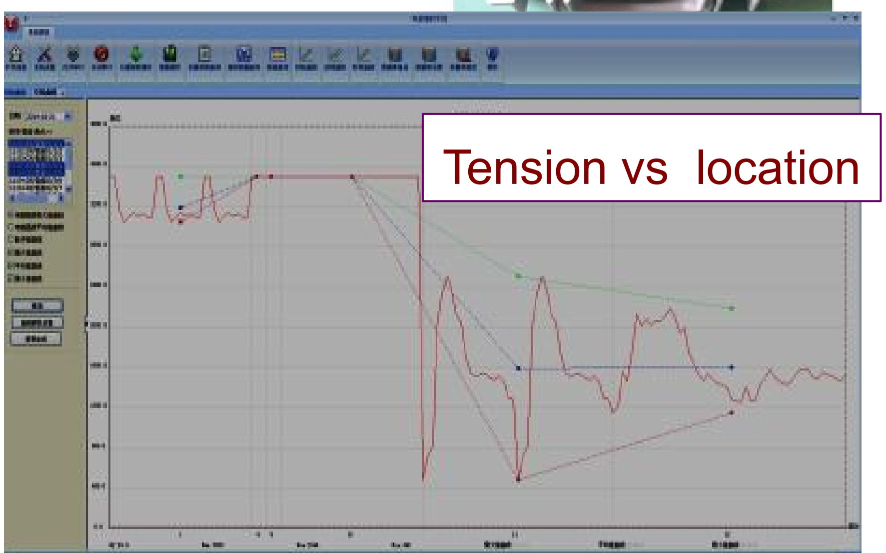
- ✓ **Real-time wireless monitoring of mining pressure variation was achieved.**
- ✓ **The early warning of rock burst can be done by analyzing the variation of mining pressure.**

Monitoring and early warning

YHC7.2-Z electromagnetic radiation system

Hardware construction





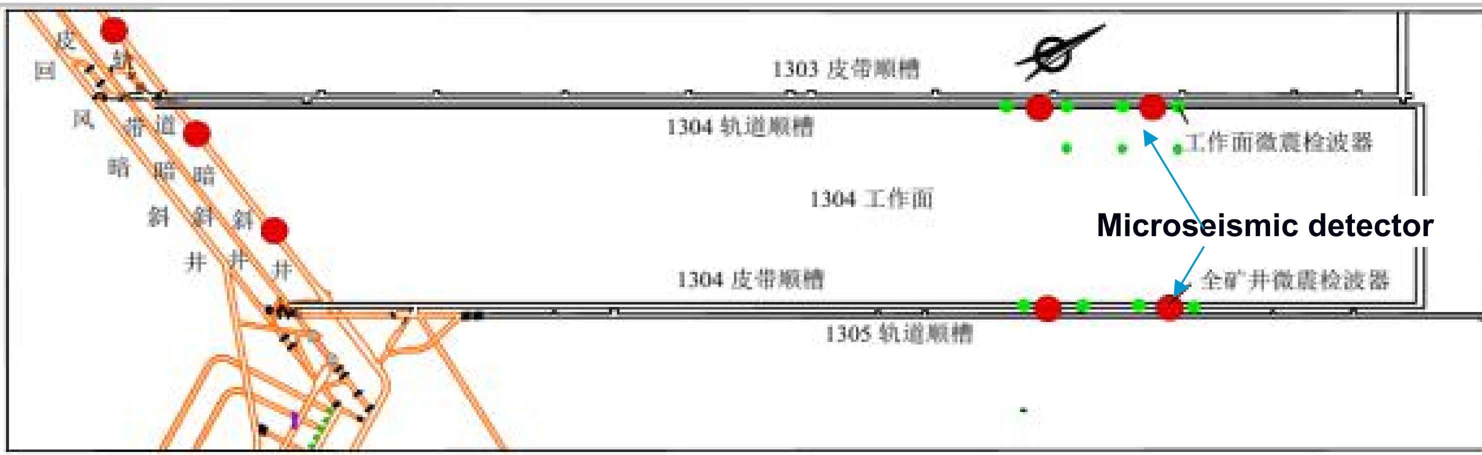
Monitoring results

Monitoring and early warning

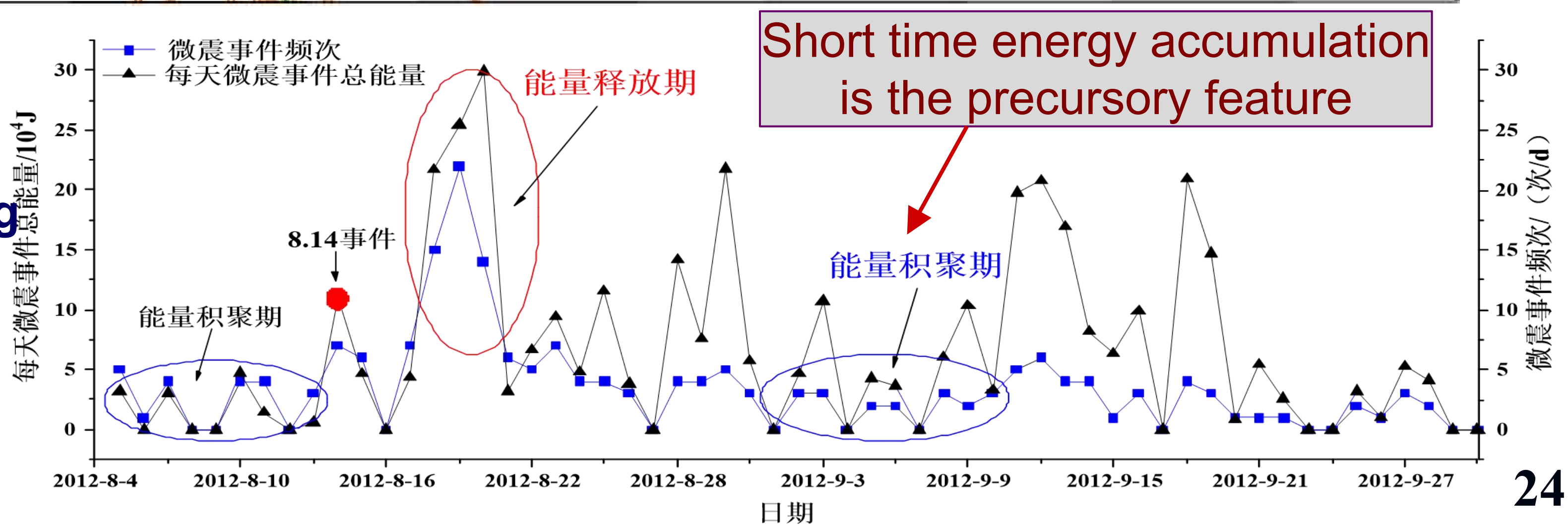
➢ *Case studies*

Strain-mode rock burst—No. 1304 face in Yangcheng Mine

Station layout



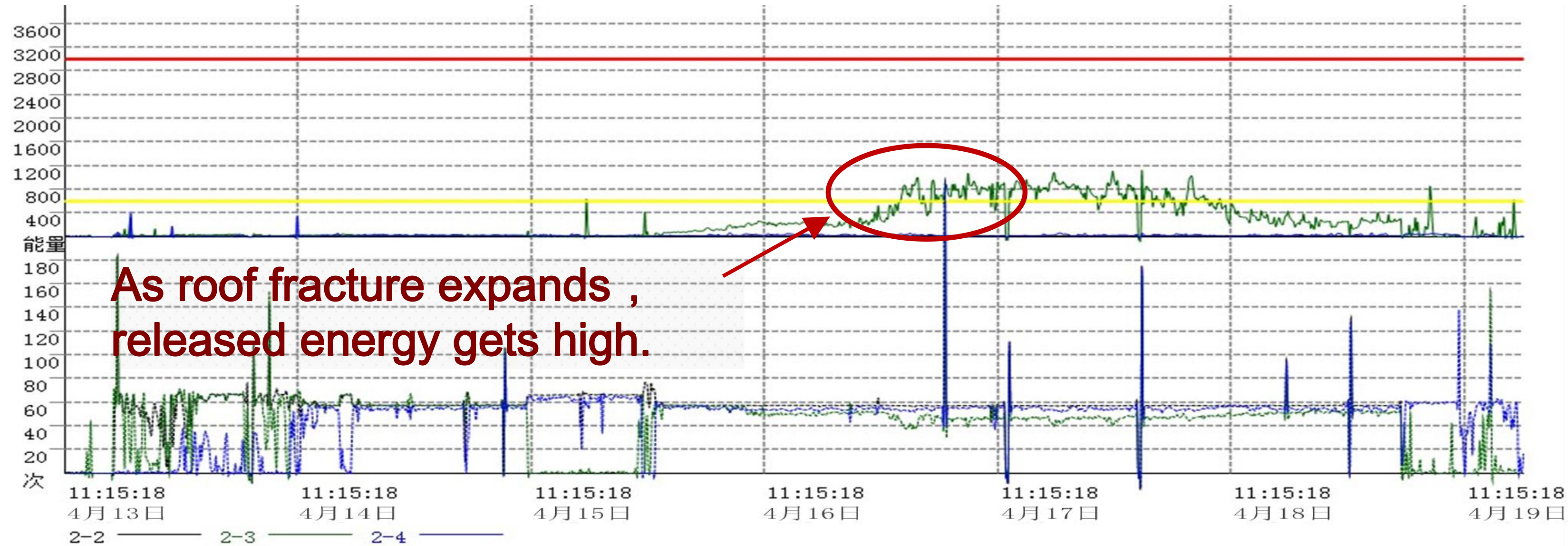
Monitoring results



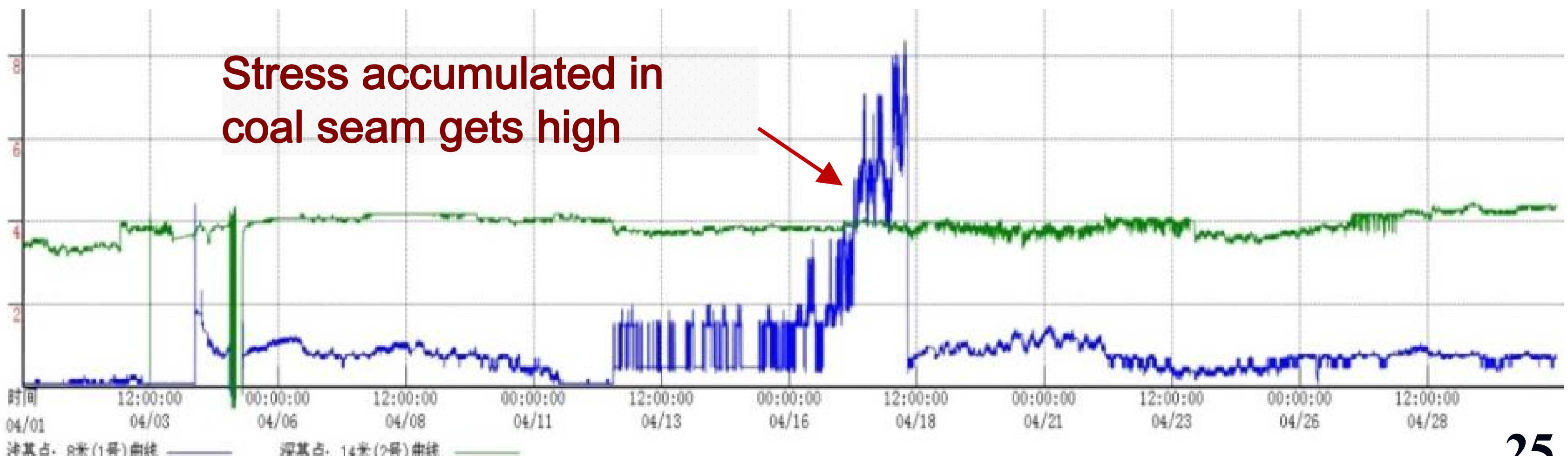
Monitoring and early warning

Hard roof weighting aroused rock burst—No. 1411 face in Huafeng Mine

AE



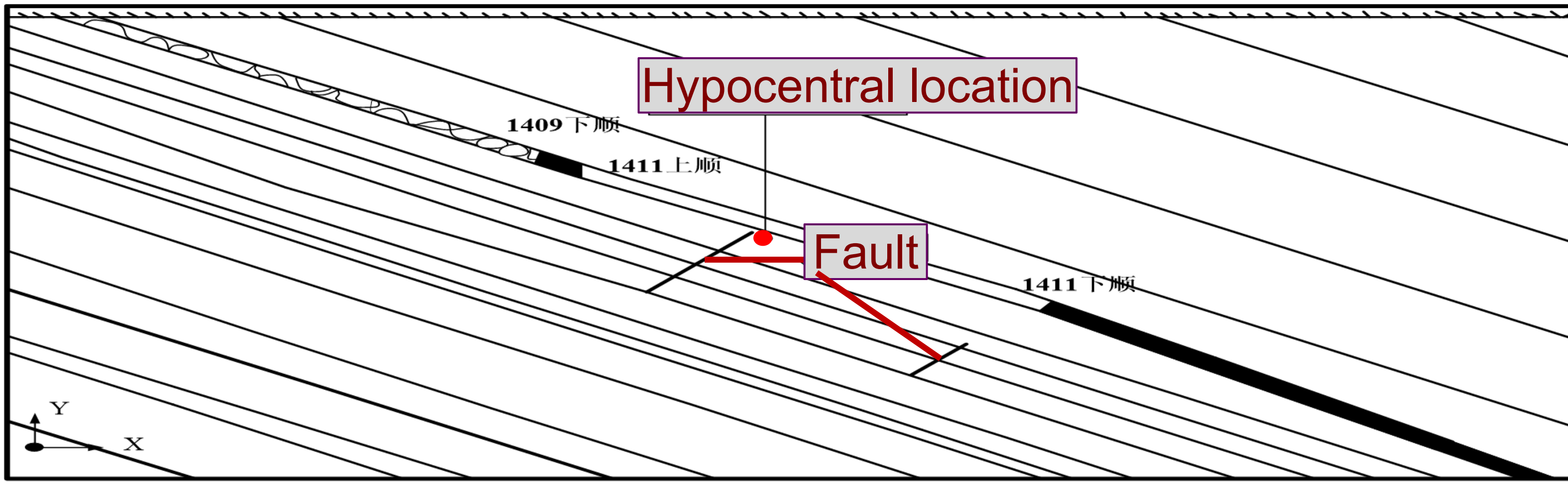
Stress variation

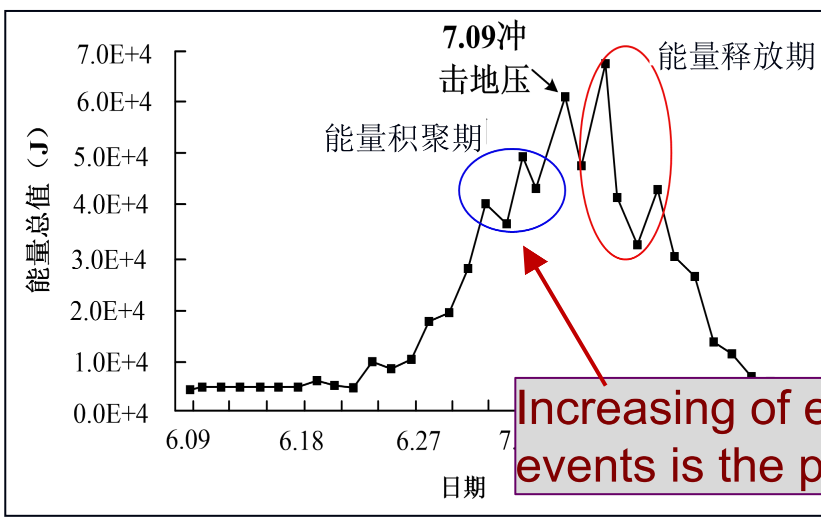


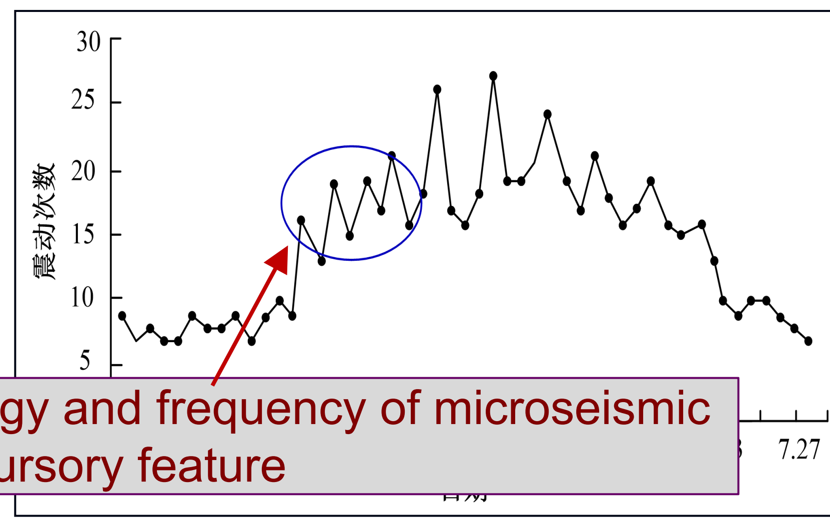
Monitoring and early warning

Fault-slip aroused rock burst—No. 1411 face in Suncun Mine

Location of fault and hypo-central



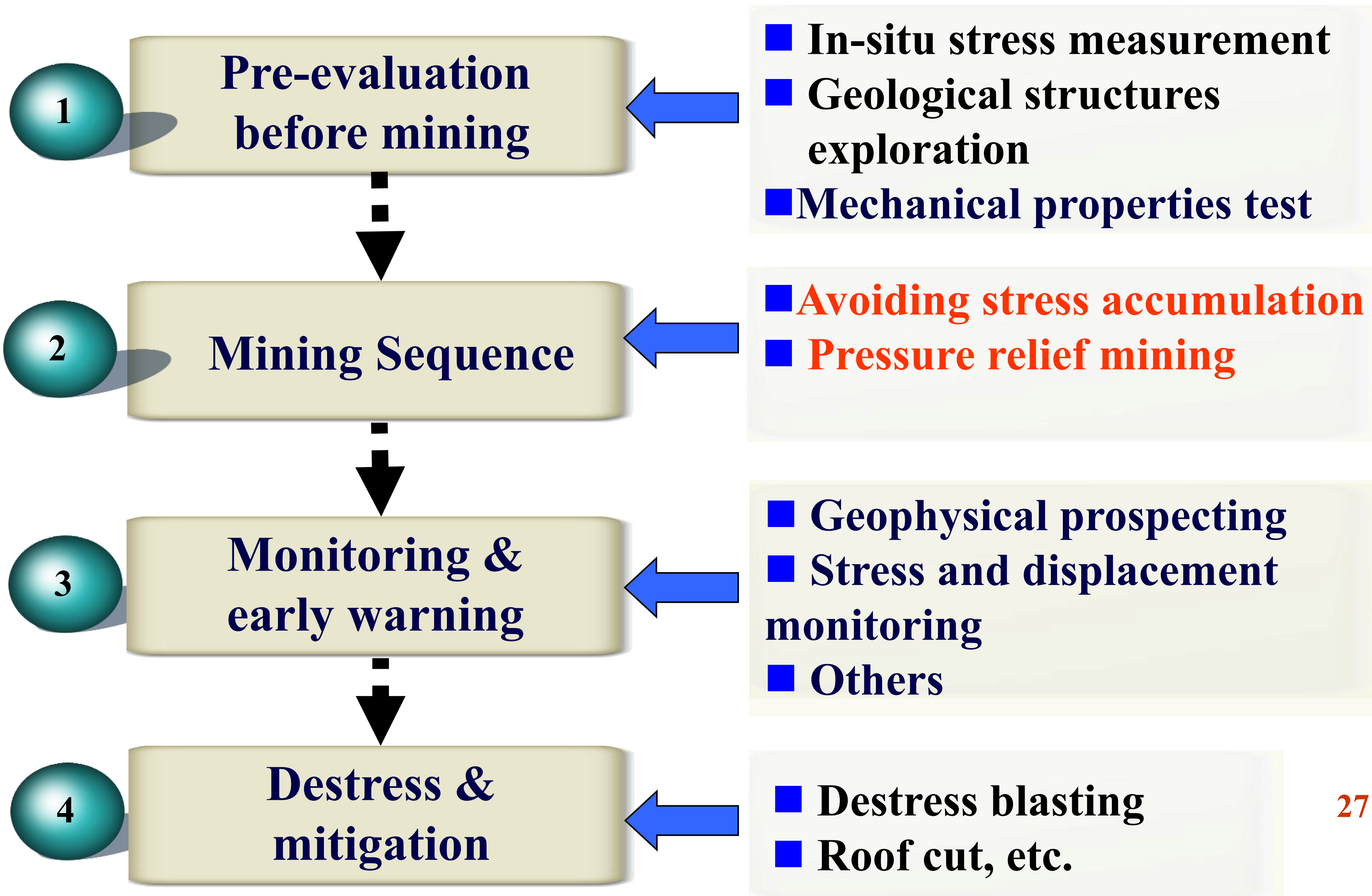




Increasing of energy and frequency of microseismic events is the precursory feature

Monitoring results

General destress flowchart



Ascending mining

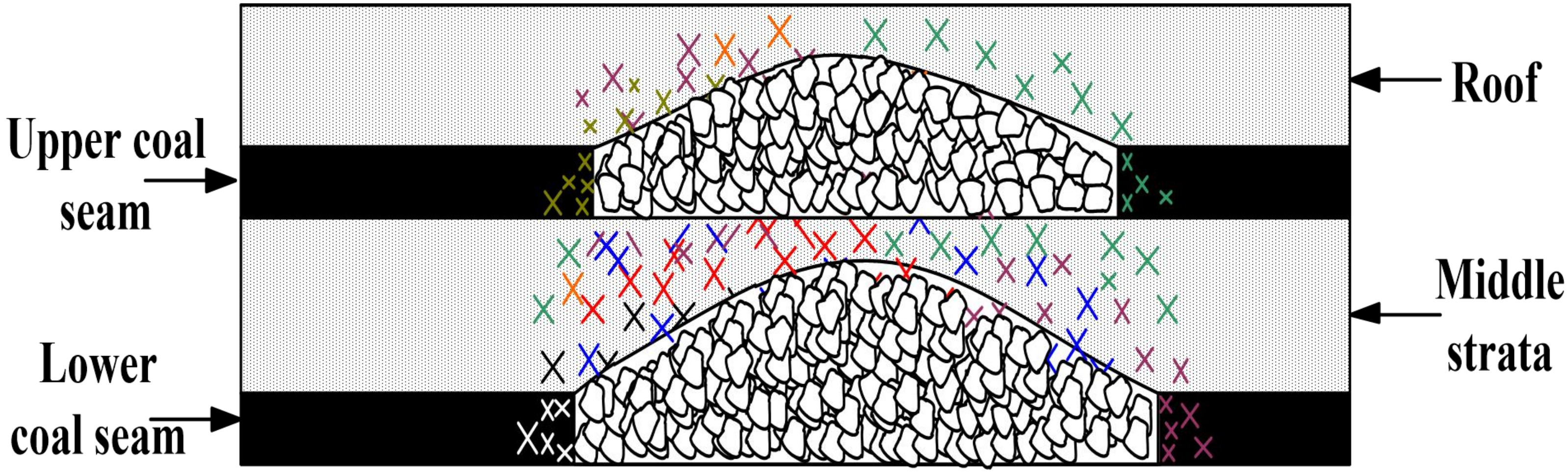
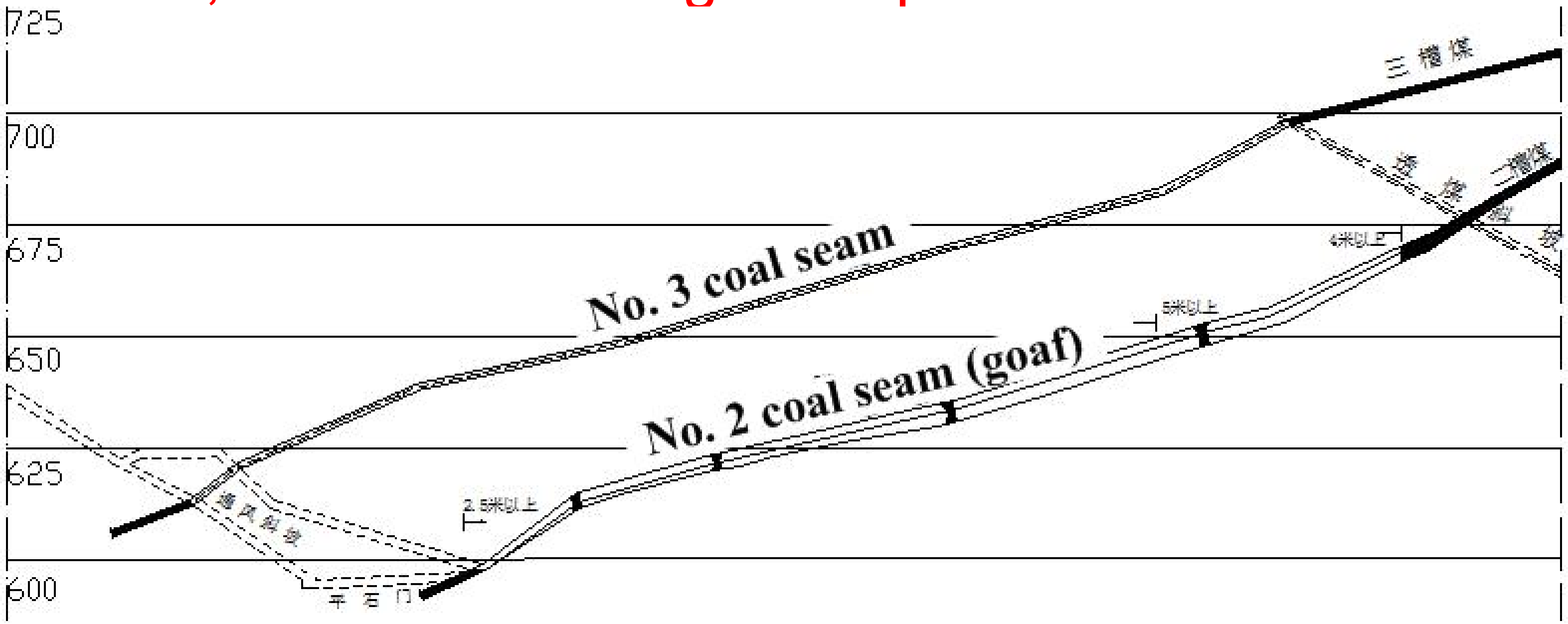


Fig. 3 Sketch of strata fracture for ascending mining

Ascending mining

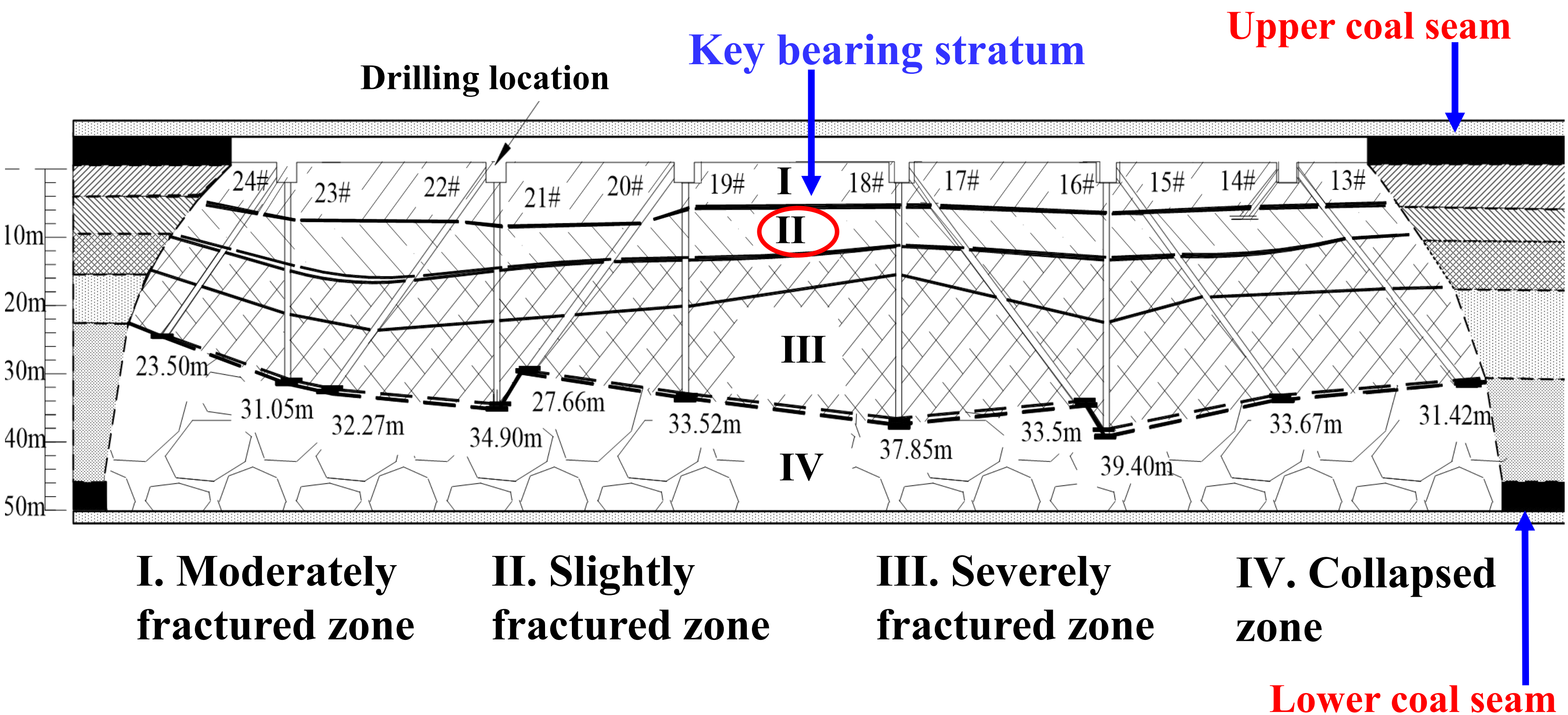
Case study: No. 2 coal seam (2-6 m thickness) below No.3 coal seam was first exploited in the +570 Level of Muchengjian Coal Mine. Distance between two coal seams varied from 30.3 to 37.5 m. Rock bursts occurred in No. 3 coal seam, which has strong burst proneness.



Cross-section of No. 2 and No. 3 coal seams in Muchengjian Coal Mine

Ascending mining

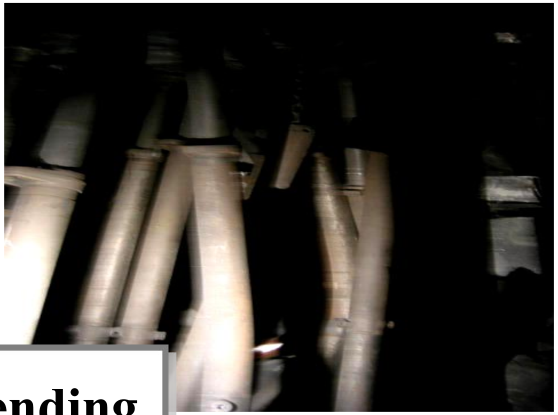
Exploration results



Roof fracture distribution of No.3 coal seam

Ascending mining

Ascending mining can effectively reduce the risk of rock burst

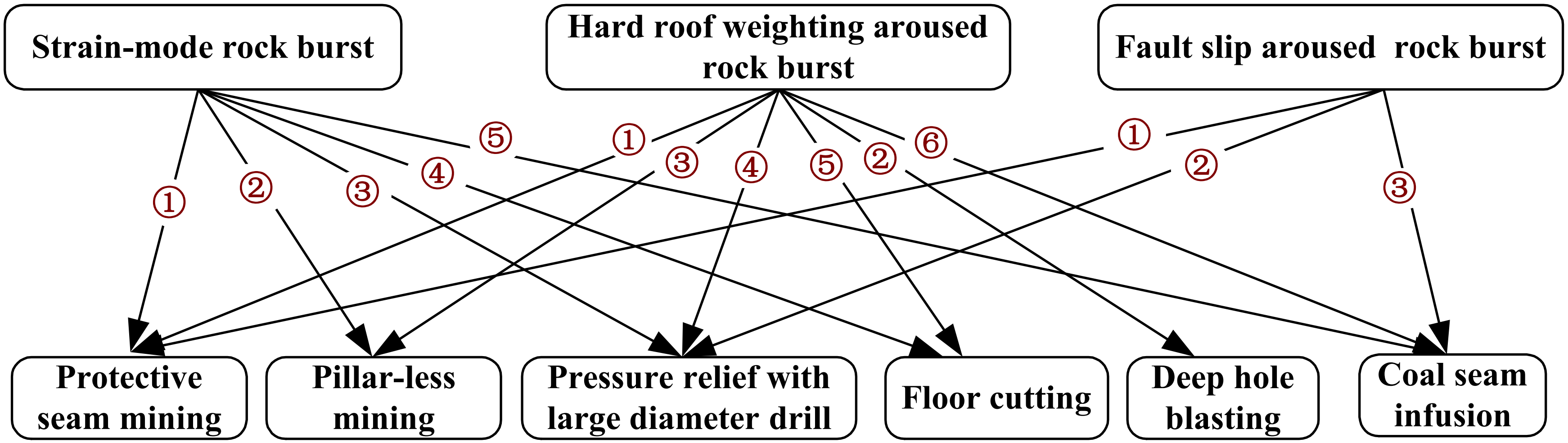


Before ascending mining approach was adopted

After ascending mining approach was adopted

Risk relief in mining

➢ *Risk relief approaches*



- ✓ **Strain-mode rock burst:** **protective seam mining, pressure relief with large diameter drill, floor cutting and coal seam infusion.**
- ✓ **Hard roof weighting aroused rock burst:** **protective seam mining, deep hole blasting, pressure relief with large diameter drill, floor cutting and coal seam infusion.**
- ✓ **Fault-slip aroused rock burst:** **protective seam mining, pressure relief with large diameter drill and coal seam infusion.**

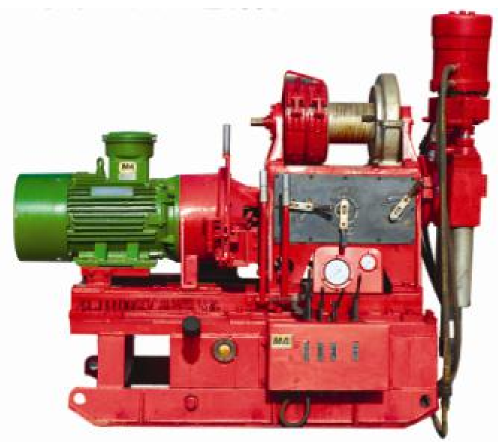
Risk relief in mining

➢ *Development of risk relieving equipment*

Drilling rigs

ZDY4200L

CMQS1-400/5.2S



ZLJ1100

ZDY4000S

Risk relief in mining

Drilling bits

Drilling pipes

- ✓ **The diameters of drilling bits range from 25 to 153 mm, with the torque of 150~250 N.m, the weld shear strength larger than 160 MPa and the yield strength larger than 392 MPa.**
- ✓ **The diameters of drilling pipes are 20~110 mm, with the bending strength larger than 500 MPa and the tension strength larger than 630 MPa.**

Risk relief in mining

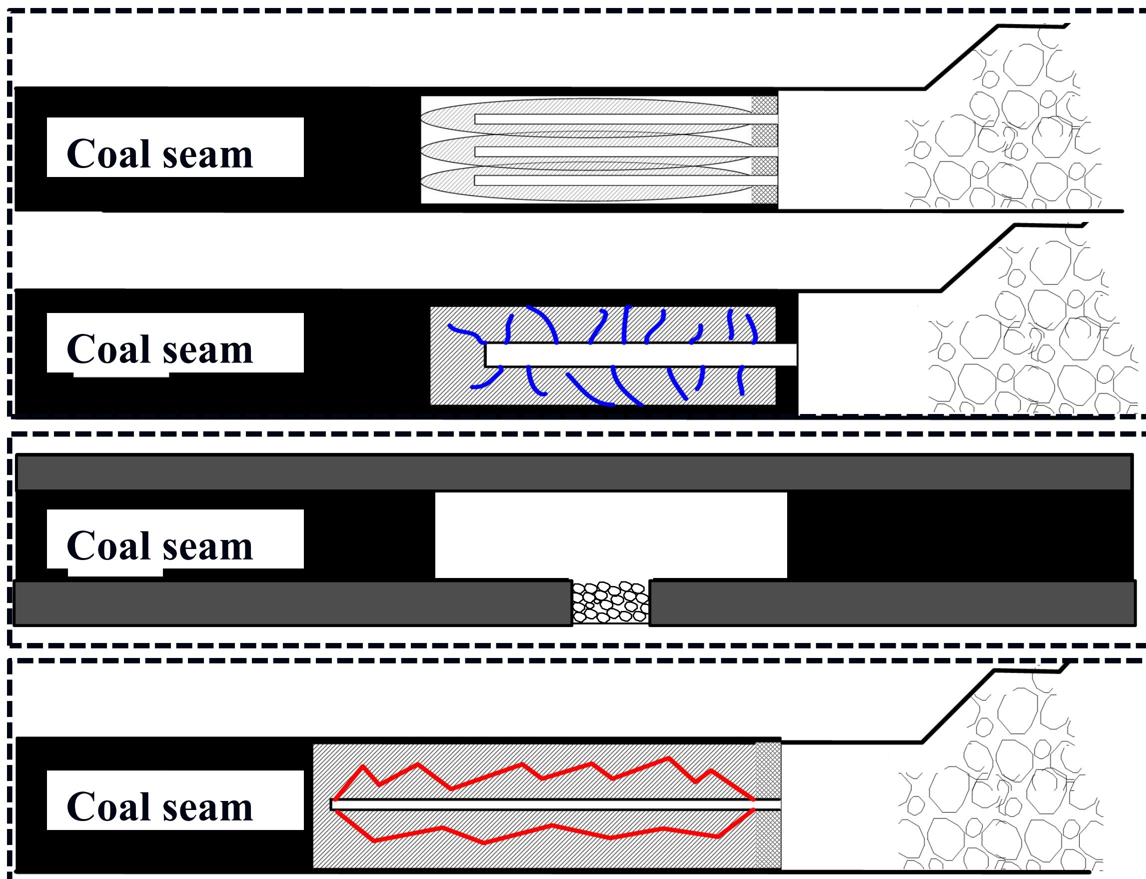
➢ *Combined relief technologies*

Using large diameter drilling as a main measure, water injecting, floor cutting and borehole blasting as supplementary measures.

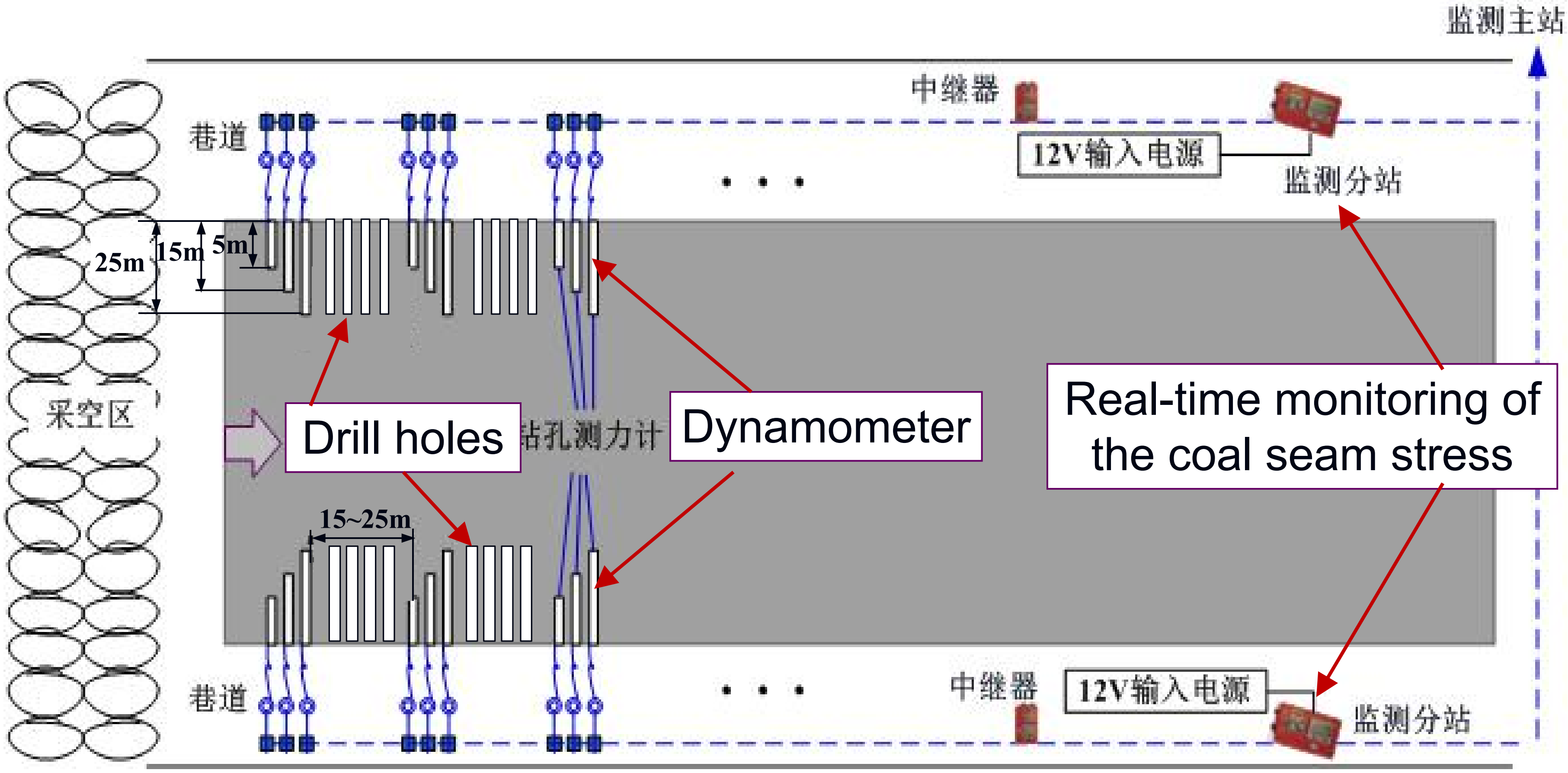
Ⅰ - Drilling of water injecting

Ⅱ -Floor cutting

Ⅲ-Borehole blasting



Risk relief in mining



✓ **The real-time monitoring of coal seam stress and early warning during the pressure relief can be achieved.**

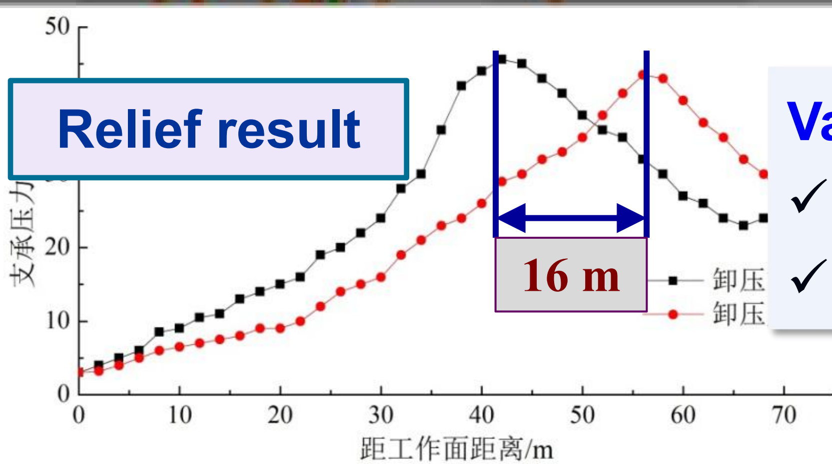
Risk relief in mining

➢ *Case studies*

Strain-mode rock burst—No. 1304 face in Yangcheng Mine

Large diameter drilling

- ✓ **Diameter: 113 mm**
- ✓ **Spacing: 2 m**
- ✓ **Depth: 25 m**

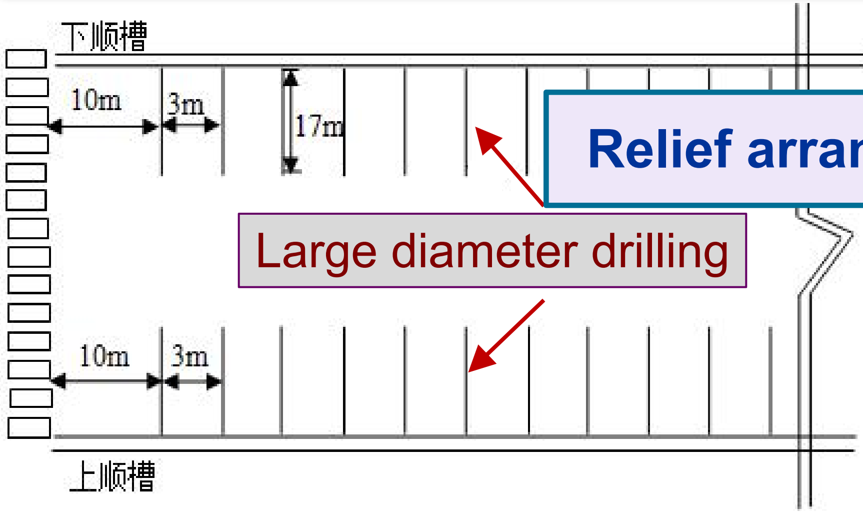


Variation of front abutment pressure:

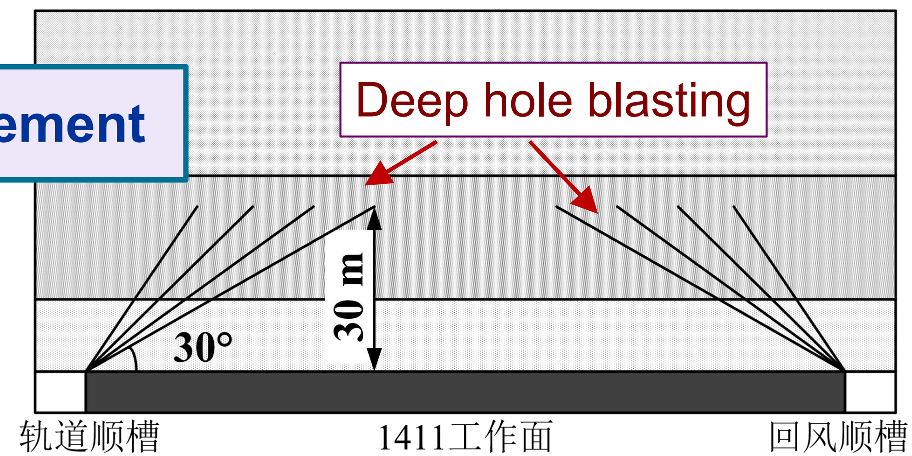
- ✓ The peak position is 16 m far away
- ✓ The peak stress is 2 MPa less than origin

Risk relief in mining

Hard roof weighting aroused rock burst-- No. 1411 face in Huafeng Mine



Layout



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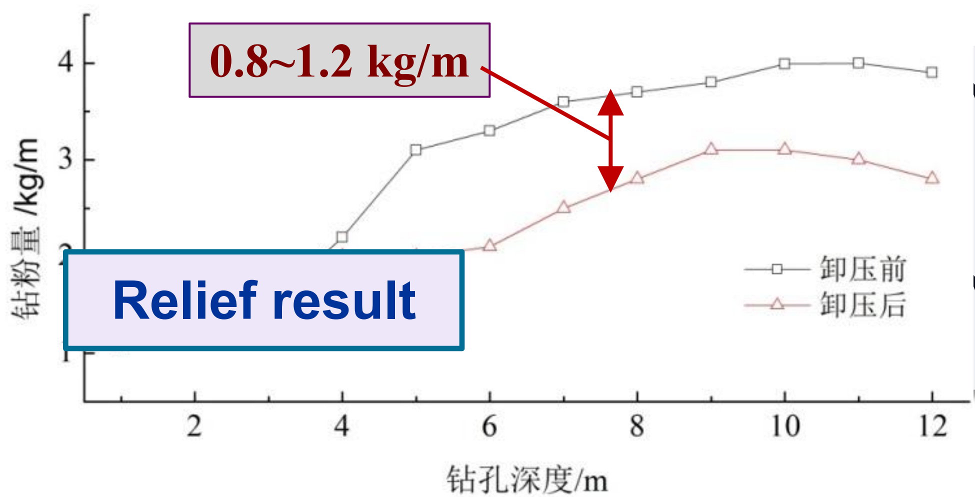
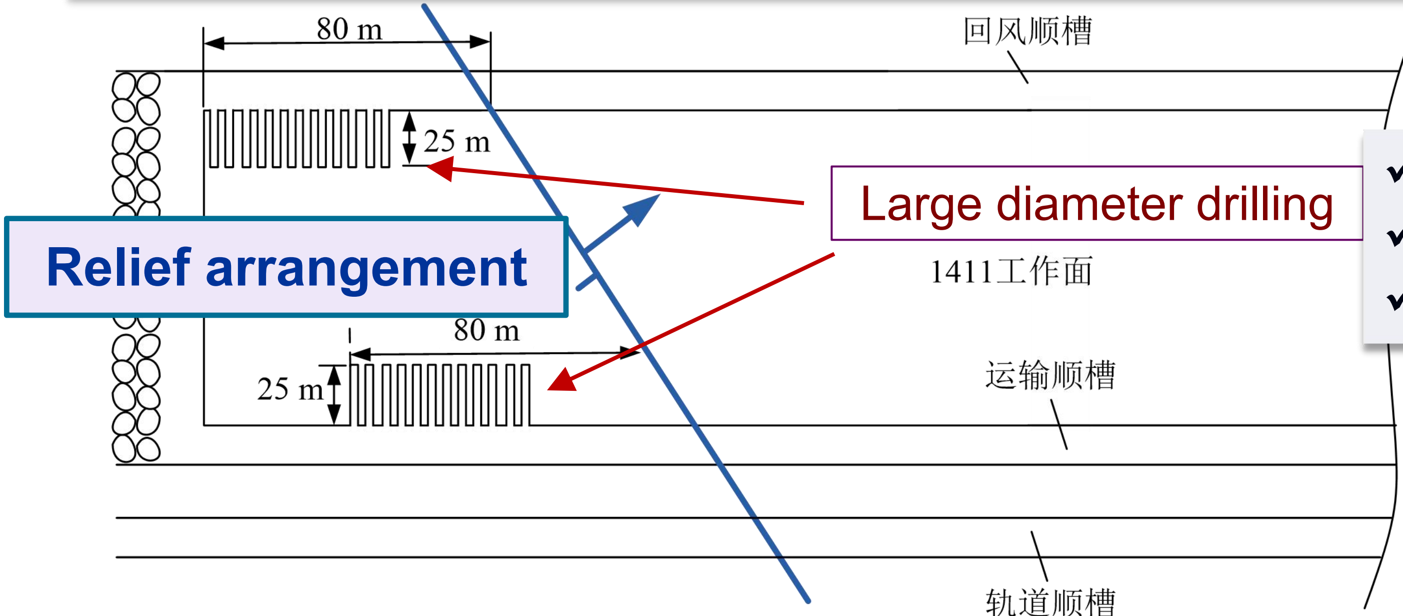


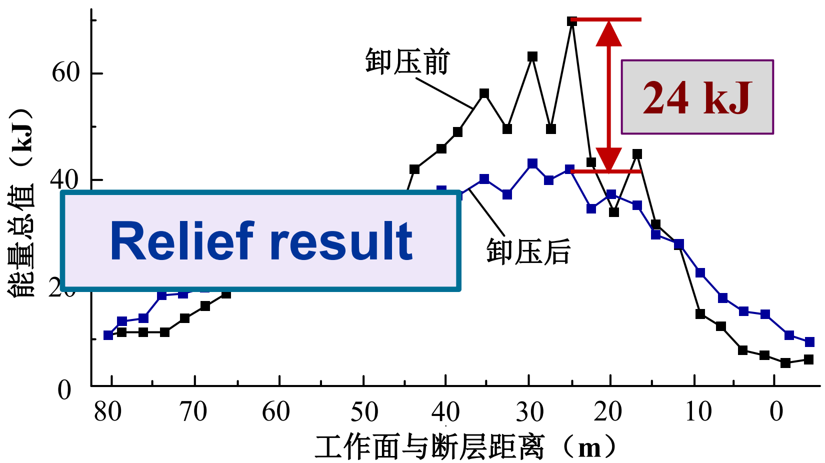
- ✓ **Before stress relief, the maximum drilling weight is 4.1 kg/m.**
- ✓ **After stress relief, the maximum drilling weight is 3.1 kg/m.**

Risk relief in mining

Fault-slip aroused rock burst—No. 1411 face in Suncun Mine



- ✓ Diameter:118 mm.
- ✓ Spacing: 3 m.
- ✓ Depth: 25 m.



- ✓ Before stress relief, the largest microseismic energy is 65 kJ.
- ✓ After stress relief, the largest energy reduced to 41 kJ.

Content

- Introduction
- Main investigations
  - ✓ Risk estimation
  - ✓ Monitoring and early warning
  - ✓ Risk relief
- **Conclusions**

Conclusions

- ✓ Unloading impact energy rate index and combined coal-rock impact energy rate index, are proposed to perfect the risk evaluation index-system of deep rock burst, which enhances the risk evaluating reliability.
- ✓ Each type rock burst has some specific precursory features, so some suitable monitoring approaches should be utilized for different rock burst.
- ✓ The pressure relieving and deep rock burst, should be combined both by ascending mining in large region, and by different relief approaches locally.

Thank you for your attentions