Research and Application of Active Support and Pressure Relief Protection in Deep Mines

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Research and Application of Active Support and Pressure Relief Protection in Deep Mines

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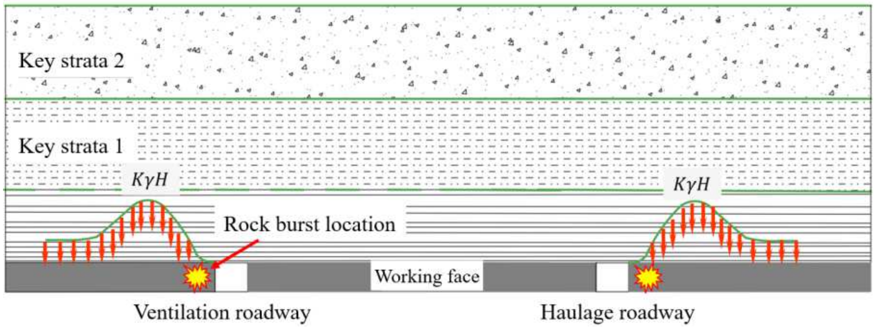
Abstract. In recent years, with the extension of the coal mine at depth, rock bursts are more and more frequent. Therefore, the research of roadway support and pressure relief has become the key to prevent rock burst. In this paper, the primary high strength support and hydraulic fracturing pressure relief measures of roadway are studied and analysed. The primary high strength support emphasizes the matching characteristics of support materials, strengthen the protection of the active support to the roadway, and realize an integrated support system. Considering strong burst-prone area, the hydraulic fracturing is used to achieve pressure relief of surrounding rock mass, which can release and transfer the energy within the range of pressure relief. When there is energy release outside the range of protection system, the pressure relief region can absorb the energy so as to achieve the purpose of protecting the roadway. A field engineering case is applicated, the results shown that the stress of roadway surrounding rock and micro seismic energy significantly decreases, reducing the possibility of rock bursts.
Keywords: Active support; Hydraulic fracturing; Pressure relief; Rock bursts

1. Introduction

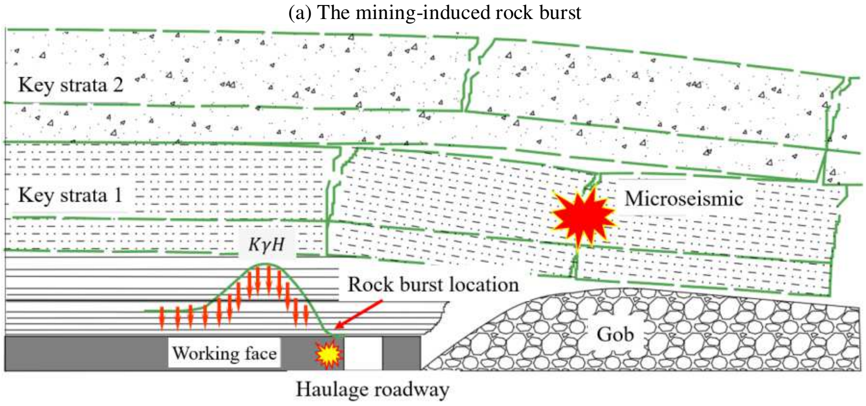
In recent years, rock burst accidents occur frequently, causing serious equipment damage and casualties (Dou Linming et al. 2003; Kaiser P K et al. 1996). The typical characteristic of rock burst is that the stored elastic energy in rock mass is released in the form of kinetic energy, throwing rock mass into roadway or stope. Therefore, taking an effective support and pressure relief protection system are particularly important for the rock burst prevention and control. Many researchers have conducted tremendous studies about the mechanism and damage types of rock burst (Qi Qingxin et al. 2014; Pan Yishan et al. 2014; Wang Guifeng et al. 2016; Zhang Yan et al. 2010; Li Yuewen et al. 2019; Tan Zhi et al.2015; Jiang Fuxing et al. 2015). Jiang Yaodong et al. summarized the characteristics of rock burst disasters in China's coal mines, studied the occurrence mechanism of rock burst, classified rock burst types, and established the prevention and control strategies of rock bursts (Jiang Yaodong et al.2014). Qi(2019) proposed the roadway support technologies based on classification criterion. Rock burst types includes the mining-induced rock burst and dynamic-induced rock burst, as shown in Fig.1. At the same time, many experts and scholars have done lots of research on deep hole blasting pressure relief technology (Zhang Shengli et al.2017; Liu Yang et al. 2015; Liu Jian et al.2014; Gao Kui et al. 2013; Tian Peng et al. 2013). Gao(2019) put forward the surrounding rock control technology by directional tension blasting pressure relief in deep and high-stress roadway. Under the condition of not damaging the stability of the roof, this technology can actively control the collapse position of overburden structure and effectively optimize the stress environment of the roadway. Hao(2016) believe that the effect of simply improving the strength of passive support based on traditional support theory is not significant. Lan(2005) think that the combination of energy absorption support and pressure relief measures can effectively prevent and control rock burst.

At present, there are still some problems in the prevention and control of rock burst. Most mines do not have rational support strategies according to its geological conditions. The surrounding rock conditions of each mine are different, especially whether the overlying strata have hard and thick key strata, and the corresponding support measures are also different. What's more, the key point of rational support is to strengthen the primary active support strength, because the active support can fully use the support capacity of surrounding rock and make the support become a whole. At the same time, pressure relief measures are critical to reduce the stress concentration of roadway surrounding rock.

In this paper, a deep research is carried out on increasing the integrity of surrounding rock mass by primary high strength support and reduce the stress concentration by hydraulic fracturing pressure relief. According to that, Guotun coal mine that is thick coal seam are analysed and studied in china. The primary high strength support is used to form the support shell structure to improve the stability of surrounding rock. The hydraulic fracturing pressure relief is used for releasing stress and achieving the effect of roadway protection.



(a) The mining-induced rock burst



(b) The dynamic-induced rock burst

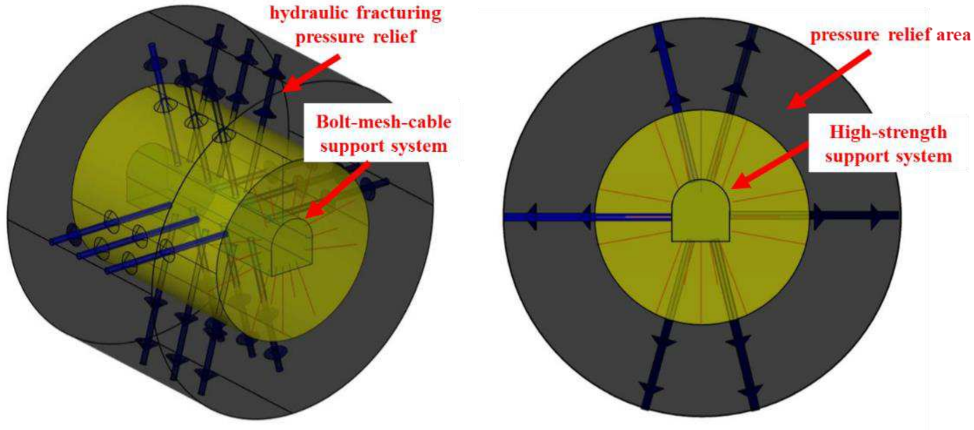
Figure 1. *Schematic diagram of roadway rock burst*

2. The technologies of high strength support and hydraulic fracturing pressure relief

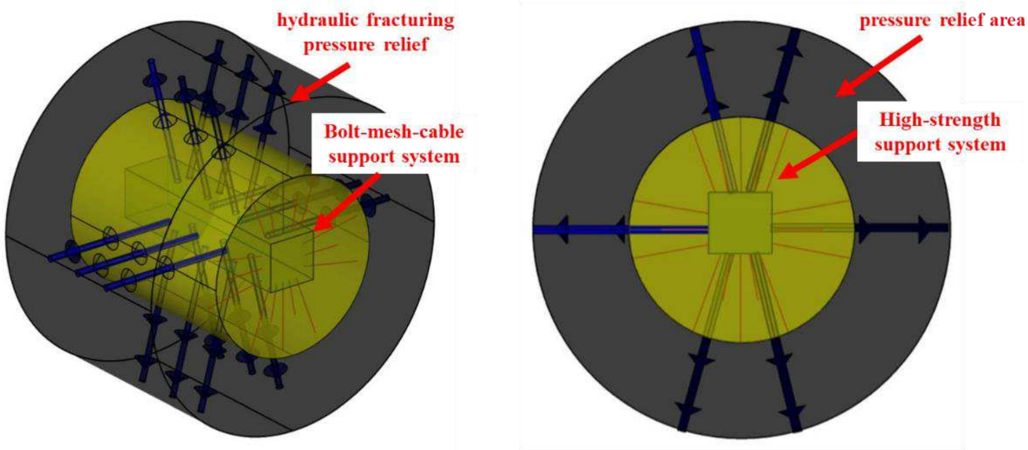
By the study of the current support and pressure relief theories, the technologies of high strength support and hydraulic fracturing pressure relief is put forward, which can be applied in arched roadway and rectangular roadway, as shown in Fig.2.

According to the stress distribution characteristics of roadway surrounding rock, the supporting capacity of roadway surrounding rock can be fully used by strengthening primary supporting strength and the matching characteristics of supporting materials, so as to realize high-strength support system. By strengthening the reasonable matching of the integrity function, the supporting system of roadway always presents a complete structure. Under the mining disturbance, the supporting system can realize the overall shrinkage and yield pressure, keeping the roadway stable.

At the same time, in the strong burst-prone area, the pressure relief measures should be carried out in advance. In this paper, a high-pressure hydraulic fracturing drill is used for cutting roof to release the internal stress of rock mass in advance and form a protective cylinder of 2-5 times roadway width or height, which can ensure that there is less burst-prone risk within the range of pressure relief and can absorb the impact energy well and make the roadway not damaged, improving the anti-impact ability of the roadway.



(a) Application in arched roadway



(b) Application in rectangular roadway

***Figure 2**. The technologies of high strength support and hydraulic fracturing pressure relief*

3. The design parameters of key technology

The design parameters of key technology are designed in advance, including the design of primary high-strength support and the design of hydraulic fracturing pressure relief in burst-prone area. Taking Guotun coal mine as an example, the mine field is located in Yuncheng County, Heze City, Shandong Province.

3.1. The design of primary high-strength support

The main coal seam of the mine is 3# coal. The thickness of coal seam in 3301 mining face is 6 m, the immediate roof is 4.58 m siltstone, the basic roof is 2.93 m fine sandstone, the immediate floor is 1.34 m mudstone, and the basic floor is 7.03 m siltstone. The intake and return air roadway of the roadway adopts rectangular section, with width of 4.4 m and height of 3.8 m.

Section diagram of primary support for supporting top coal roadway in thick coal seam is shown in Fig.3. At the roof, the ribbed steel bolt with diameter of 22×2400 mm is selected, the yield strength is greater than 552 MPa, and the row-column spacing is 900×900 mm. In the side, the full threaded steel bolt with diameter of 20×2400 mm is selected, the yield strength is greater than 335 MPa, and the row-column spacing is 900×900 mm. The anchor cable is made of Φ22×8000 mm left-handed prestressed steel strand with yield strength is greater than 1770 MPa and row-column spacing of 1800×900 mm. The size of anchor tray is 150×150×12 mm, and the strength of anchor tray is greater than 165 kN. The size of cable tray is 300×300×12 mm, and the strength of cable tray is greater than 400 kN.

3.1.1 The matching calculation of support strength

(1) Plastic zone radius in limit equilibrium region

$$R_s = R_o\left[\frac{(1-\sin\phi)\times(\mathrm{K}\gamma H + C\times ctg\phi)}{C\times ctg\phi}\right]^{\frac{1-\sin\phi}{2\sin\varphi}} \quad (1)$$

Rs is the radius of roadway plastic zone, m. R_0 is the exterior radius of roadway, 3.01 m based on the geometric algorithm. γ is the average unit weight of overlying rock. According to the production geological report of Guotun coal mine, γ is 25.15 kN/m^3. H is the buried depth of roadway, and the maximum buried depth is 690 m. C is the cohesive force of surrounding rock. According to the production geological report of Guotun coal mine, the shear strength τ is 20.65 MPa. According to the formula τ=6C, the cohesive force C is 3.44 MPa. φ is the internal friction angle of surrounding rock. According to the production geological report of Guotun coal mine, the internal friction angle is about 30°.

Substitute the parameters into the formula and the result is

$$R_s = 3.01\left[\frac{(1-\sin 30°)\times(3\gamma H + C\times ctg30)}{C\times ctg30}\right]^{\frac{1-\sin 30}{2\sin 30}} \quad (2)$$

(2) The support force needed to keep the rock from falling

The thickness of the top rock load is: h_d = Rs - h/2; R_S is the radius of plastic zone of roadway, m. h is the roadway height and the roadway height is 4.3 m, h_d=4.85 m.

In order to keep the rock from falling in the limit equilibrium zone, the minimum support force required is as follows: `

$$\mathrm{P} = \sum \lambda_i h_i = 5.3\times 27.1\mathrm{kN/m^3} = 143.63\mathrm{kN/m^3}$$

(3) The supporting resistance provided by anchor cable

$$P_s = n\frac{q_s}{B\times D} \quad (3)$$

q_s is the breaking force of anchor cable. According to the anchor cable tension test report, the steel strand of 22 mm diameter is taken as q_s = 510 kN. B is the width of the roadway, 4.4 m. D is anchor cable row spacing, 0.9 m. n is the number of anchor cables in each row and the minimum value is 2. The supporting resistance provided by anchor cable is 257.58 kN/m^2.

(4) The support resistance provided by bolt

The support resistance provided by the uniform compression belt after the anchor reinforcement is as follows:

$$\mathrm{P}_m = \eta q_m / D_m^2 \quad (4)$$

q_m is the anchoring force of the bolt, 100 kN. D_m^2 is the row spacing and column spacing of the bolt, 0.9× 0.9m^2. η is the bolt support coefficient, 0.35. The support resistance provided by anchor is P_m=43.21 kN/m^2.

(5) Total support resistance

$$\mathrm{P} = \mathrm{P_s} + \mathrm{P_m} = 257.58 + 43.21 = 300.79\ \mathrm{kN/m^2} \quad (5)$$

(6) Support safety factor

$$K = 300.79/143.63 = 2.1 > 1.5 \quad (6)$$

The safety factor is not less than 1.5, which meets the engineering requirements.

The anchor cable and bolt support in strong impact area are all changed from end anchorage to full-length anchorage. Supporting system adopts the active high-strength composite support mode of bolt-mesh-cable-beam and large diameter tray, high-strength steel belt, steel mesh and other strong deformation resistance and surface protection ability materials in strong impact risk area and thick coal seam. Maintain the primary support strength and make the roadway become a whole matching high-strength and energy absorbing support system structure, giving full play to the characteristics of balanced yield pressure.

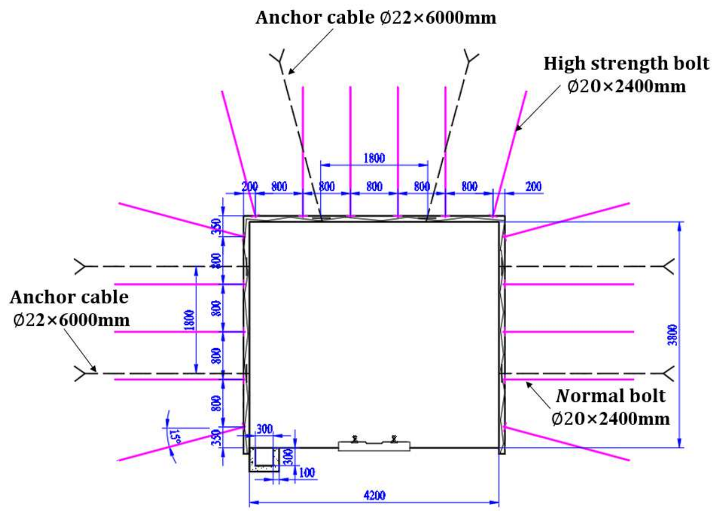


Figure 3. *Section diagram of primary support for supporting top coal roadway in thick coal seam*

3.2. The design of hydraulic fracturing pressure relief

According to the principle of "stress three-way transfer", within 200 m ahead of the working face, in addition to the large diameter borehole pressure relief of 150 mm in diameter, 20 m in depth and 1 m in spacing at the coal body, the top coal and roof are relieved by hydraulic fracturing pressure relief or blasting presplitting， as shown in Fig.4. Through the implementation of pressure relief measures, the surrounding rock at a certain depth of the roadway is structurally damaged, forming a weakening zone, which causes the high stress in the surrounding rock around the roadway to transfer to the deeper (Fig.5), so that the surrounding rock near the roadway is in the low stress area. When the rock burst occurs, the pressure relief space can absorb the energy to prevent the coal from rushing out to a certain extent.

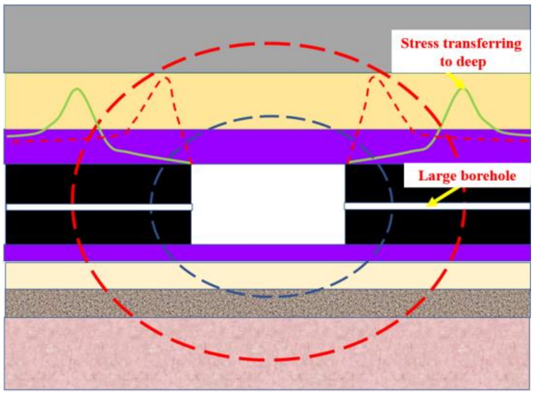


Figure 4*. Schematic diagram of stress transfer*

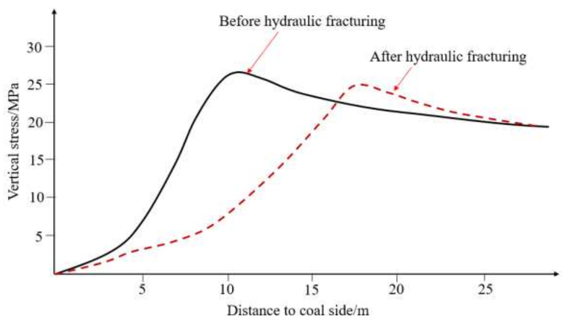


Figure 5*. The pressure relief effect of hydraulic fracturing*

4. Numerical simulation analysis

4.1. The establishment of the Numerical model

In order to obtain the optimal design parameters and verify the correctness of theoretical analysis, according to the application practice in 3301 mining face of Guotun coal mine, a numerical model is established by FLAC3D. The size of model is 50 m × 50 m × 60 m, the roadway size is 4.2 m × 3.8 m, the Mohr Coulomb constitutive model was used. The geological background of this simulation is 3301 fully mechanized working face. The radius of hydraulic drilling is 12 cm. In order to more intuitively calculate the deformation of the roadway, we arrange displacement monitoring and stress monitoring points on the roof and floor of the roadway, the specific layout and model are shown in Fig.6. This numerical analysis is divided into three different cases. The first is that the roadway does not adopt any support and pressure relief measures. The second is that the roadway adopts bolt-mesh-cable support, as shown in Fig.7. The third is that hydraulic fracturing pressure relief and anchor-mesh-cable high strength support are combined for analysis, as shown in Fig.8.

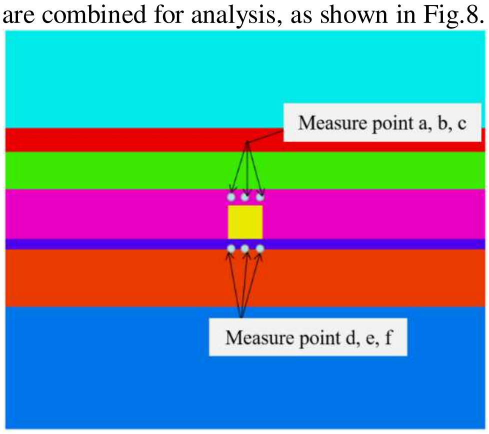


Figure 6. *Numerical simulation diagram*

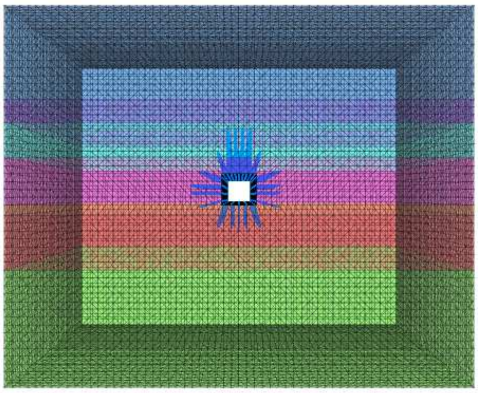


Figure 7. *Numerical model of bolt-mesh-cable support*

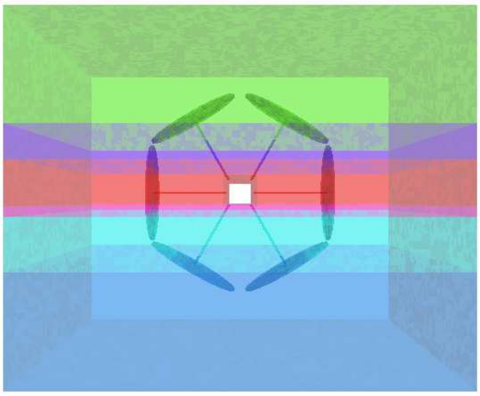
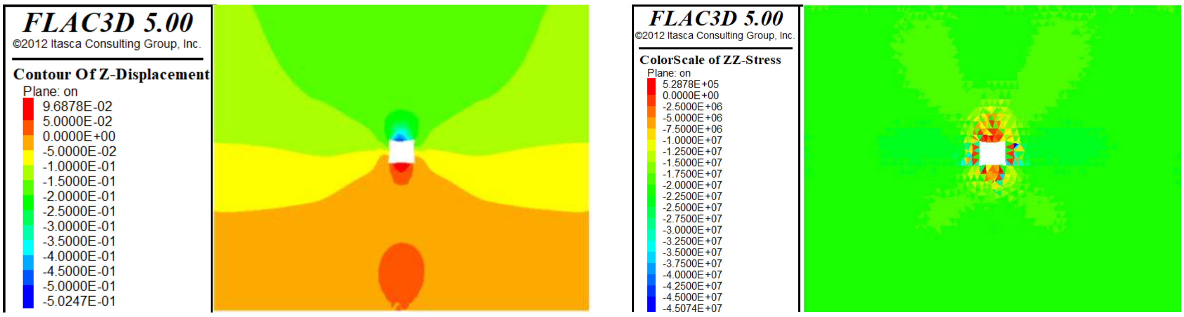


Figure 8. *Numerical model of hydraulic fracturing*

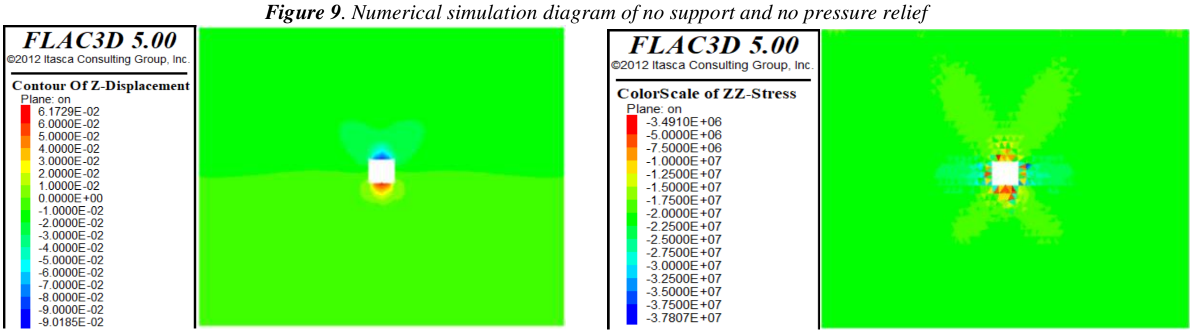
4.2. Simulation results

The numerical simulation results of no support and pressure relief measures, bolt-mesh-cable support and hydraulic fracturing are shown in Fig.9 to Fig.11, respectively. Through the analysis, it can be found that the displacement of roof and floor of hydraulic fracturing is much less than that of the other two cases, the stress of surrounding rock of roadway is also less than that of the other two cases. The stress is transferred to the depth of surrounding rock mass. Therefore, the application of bolt-mesh-cable support and pressure relief technology can not only reduce the stress of roadway confining pressure, but also reduce the deformation of roadway.



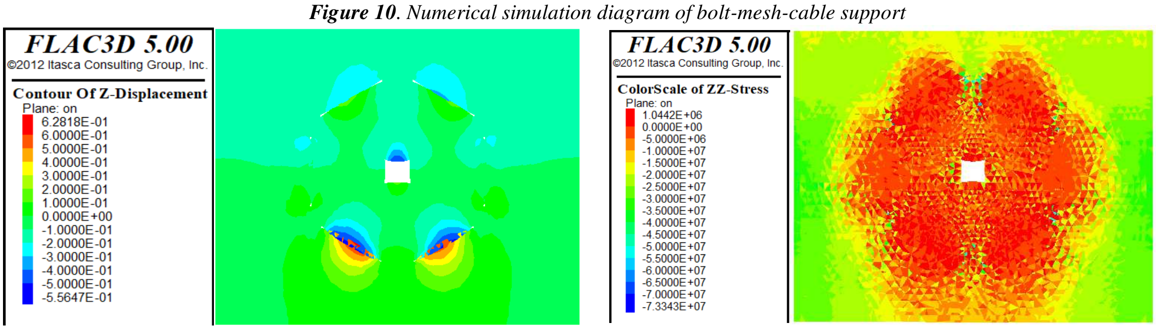
(a) Displacement nephogram (b) Stress nephogram

***Figure 9**. Numerical simulation diagram of no support and no pressure relief*



(a) Displacement nephogram (b) Stress nephogram

***Figure 10**. Numerical simulation diagram of bolt-mesh-cable support*



(a) Displacement nephogram (b) Stress nephogram

***Figure 11**. Numerical simulation diagram of hydraulic fracturing*

5. Field application

5.1. Stress data analysis of roadway

According to the roadway layout system of 3301 working face, the pressure sensors are arranged in both sides of the roadway from the working face to the outside, one group every 20~30 m, two sensors in each group. The depth of borehole stress gauge is 8 m and 14 m respectively. The distance between two measuring points in each group is 0.5~1.0 m. The drilling was carried out with a 42 mm drill. The distance between the borehole and the coal seam floor is 1.0~1.5 m, which is perpendicular to the coal body and parallel to the coal seam. The initial pressure value of the pressure sensor is 4~5 MPa, the yellow warning value is generally 10~12 MPa, and the red warning value is generally 13~15 MPa.

According to the advanced stress data of mining face, the data is normal below the warning value by the stress online system. As shown in Fig.13, the stress concentration is eliminated or the stress concentration area is transferred to the deep part of the coal body.

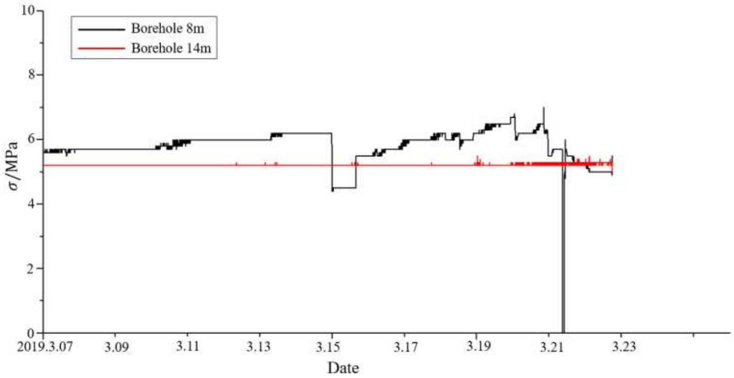


Figure 12. *The monitoring data of stress sensor in mining face cutting*

5.2. The microseismic data analysis

Before working face mining, the 24 channel Aramis M / E regional micro seismic monitoring system is used to set up a group of monitoring probes in the working face channel, and two groups of seismic detectors are installed in the centralized track Lane near the working face, so as to make full use of the four monitoring points to accurately monitor the micro seismic events in the working face.

According to the distribution range of micro seismic events, by using the technologies of high strength support and hydraulic fracturing pressure relief, the micro seismic events of working face all occur 150 m away from the mining position of working face and the maximum value of micro seismic energy is 3.8E+04J, which is below warning value 1.5E+05J, as shown in Fig.13. It fully shows that this technology can effectively reduce the stress accumulation in the working face, and can well absorb the stored elastic energy of surrounding rock mass.

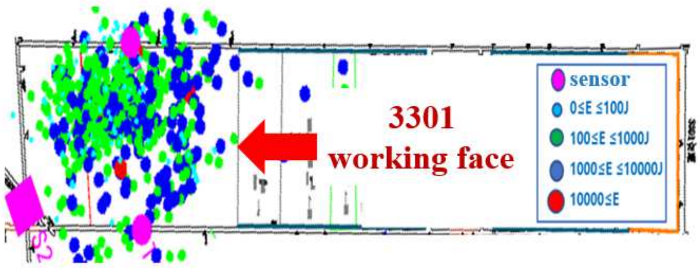


Figure 13. *Distribution map of micro seismic events of 3301working face*

6. Conclusion

(1) This paper study the technologies of high strength support and hydraulic fracturing pressure relief. The supporting capacity of roadway surrounding rock can be fully used by strengthening primary supporting strength and the matching characteristics of supporting materials, so as to realize high-strength support system. In this paper, a high-pressure hydraulic fracturing drill is used for cutting roof to release the internal stress of rock mass in advance and form a protective cylinder of 2-5 times roadway width or height, which can ensure that there is less burst-prone risk within the range of pressure relief.

(2) Through FLAC3D numerical simulation, the vertical stress distribution under the state of no support, no pressure relief, bolt-mesh-cable support and hydraulic fracturing is compared. It is proved that the technologies of high strength support and hydraulic fracturing pressure relief can effectively reduce the stress concentration of surrounding rock and form a plastic pressure relief protection zone.

(3) The field monitoring data of Guotun coal mine show that the stress concentration degree around the roadway significant decreases and the number of micro seismic events in the protection area of pressure relief is small, which reduces the energy concentration degree. The research in this paper lays a theoretical and practical foundation for the application of the technologies of high strength support and hydraulic fracturing pressure relief.

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Figures

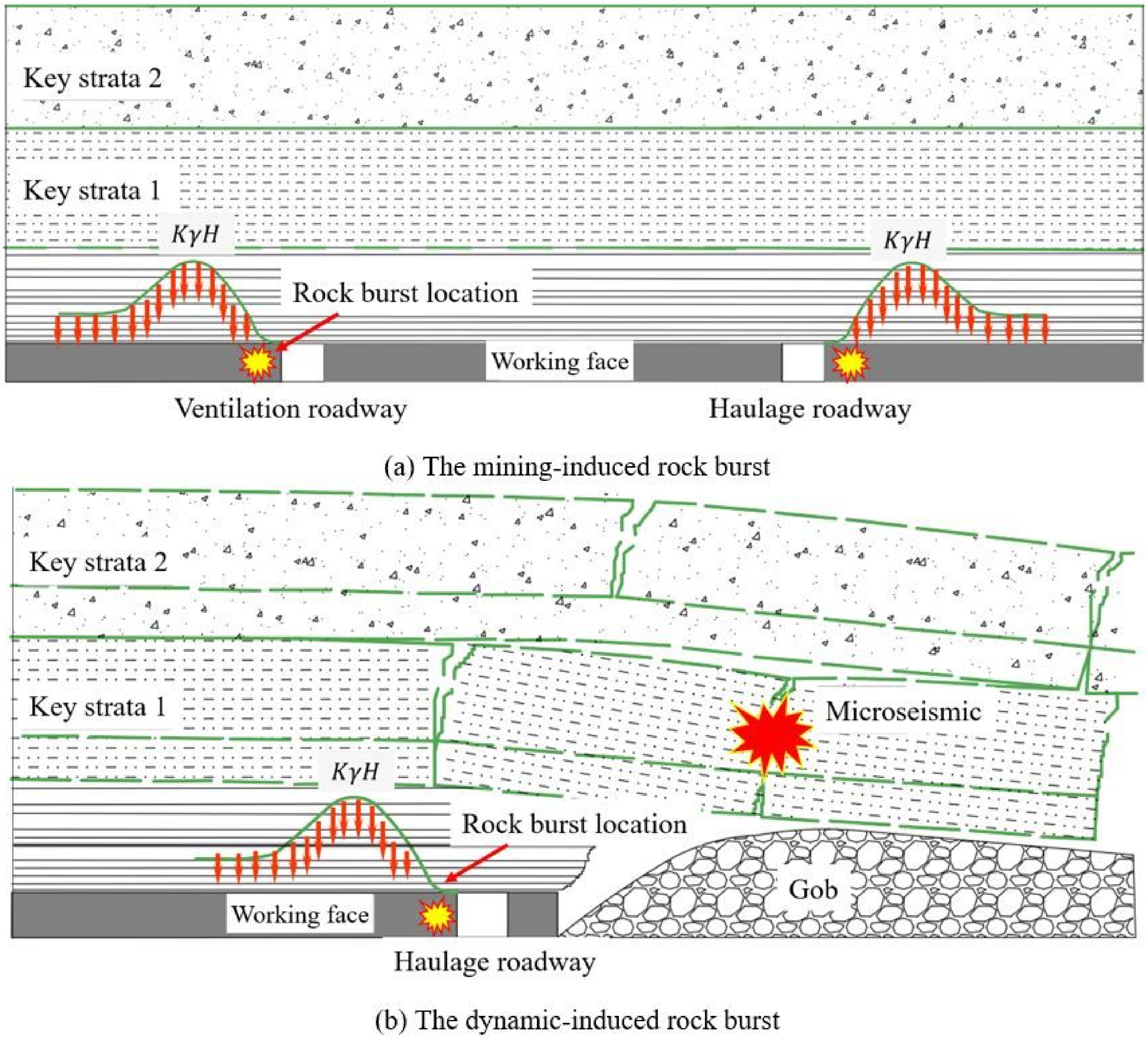


Figure 1

Schematic diagram of roadway rock burst

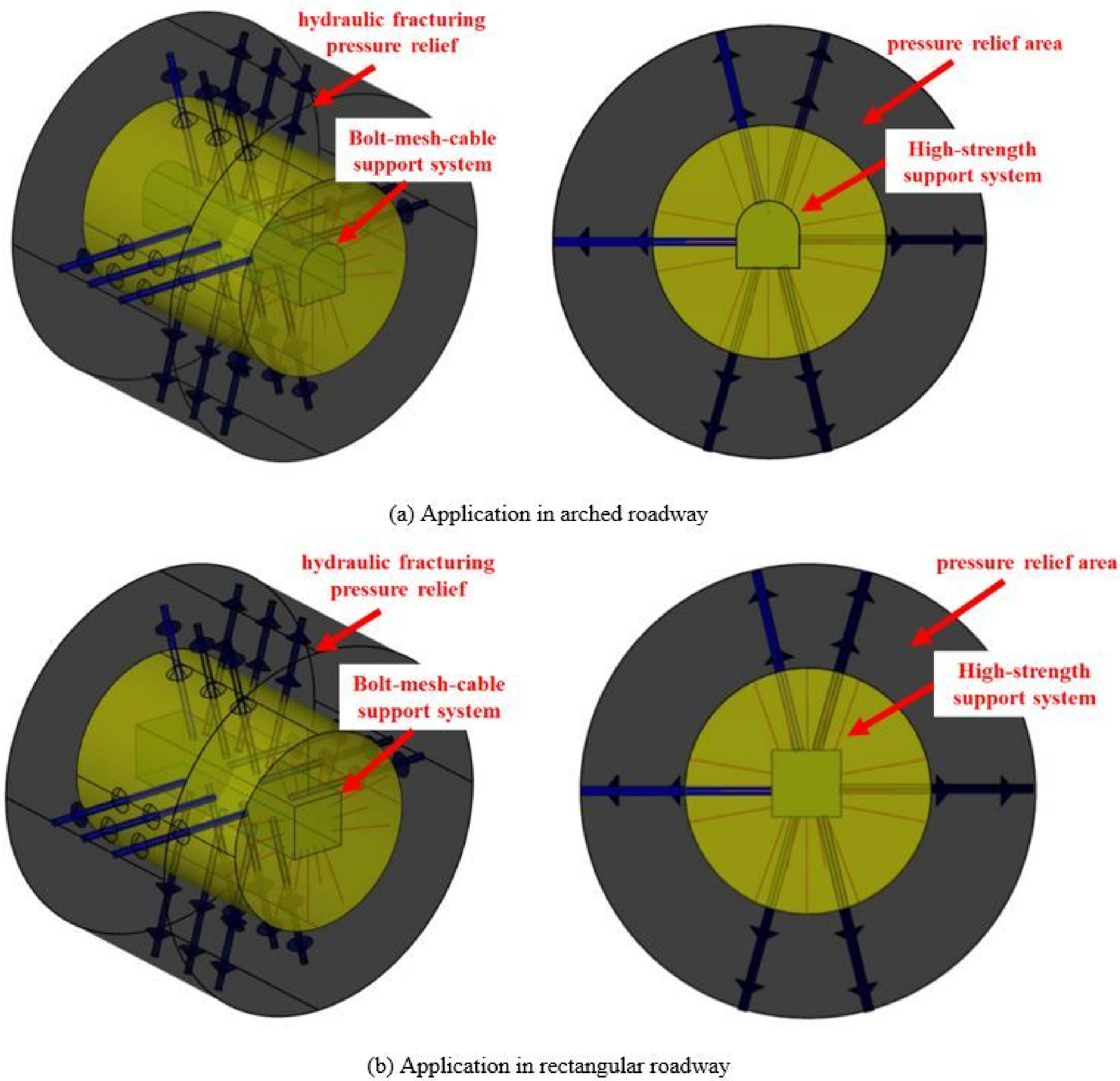


Figure 2

The technologies of high strength support and hydraulic fracturing pressure relief

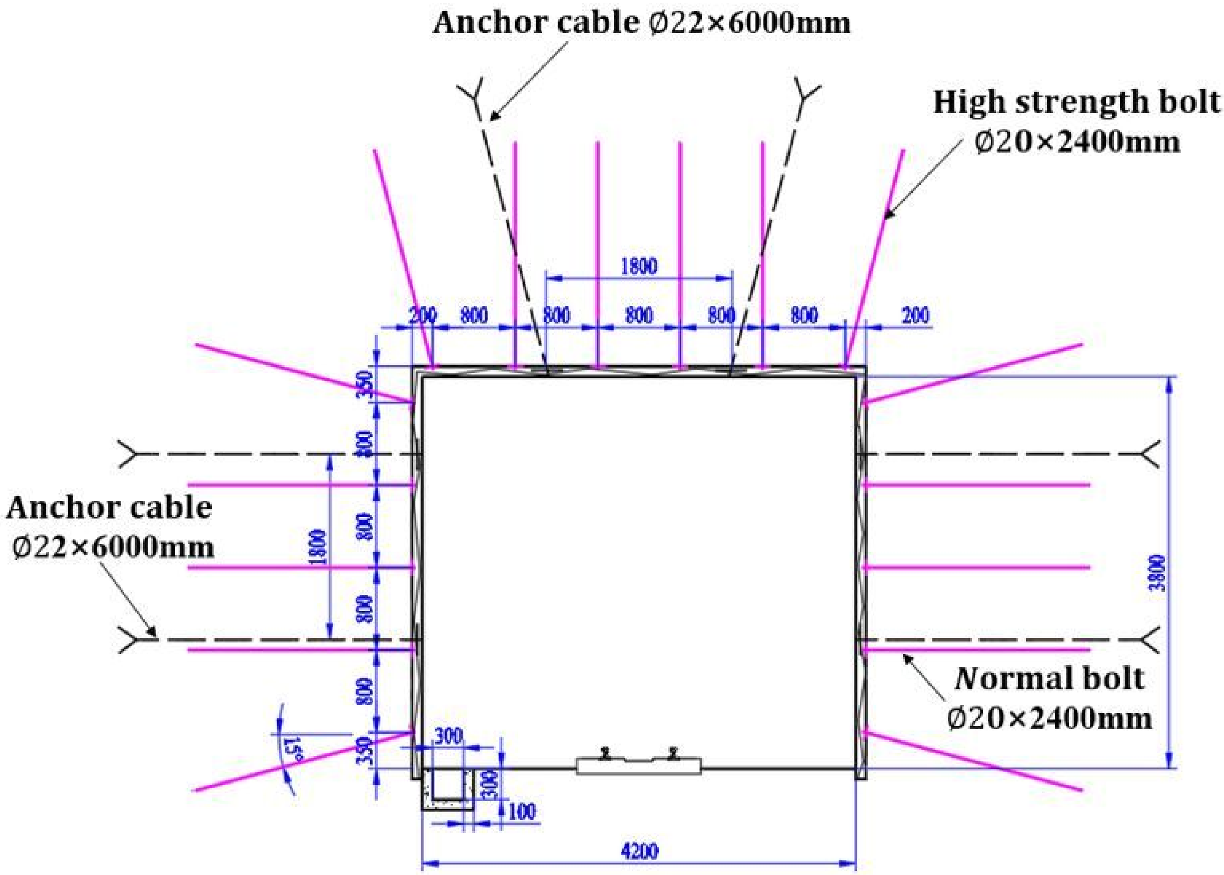


Figure 3

Section diagram of primary support for supporting top coal roadway in thick coal seam

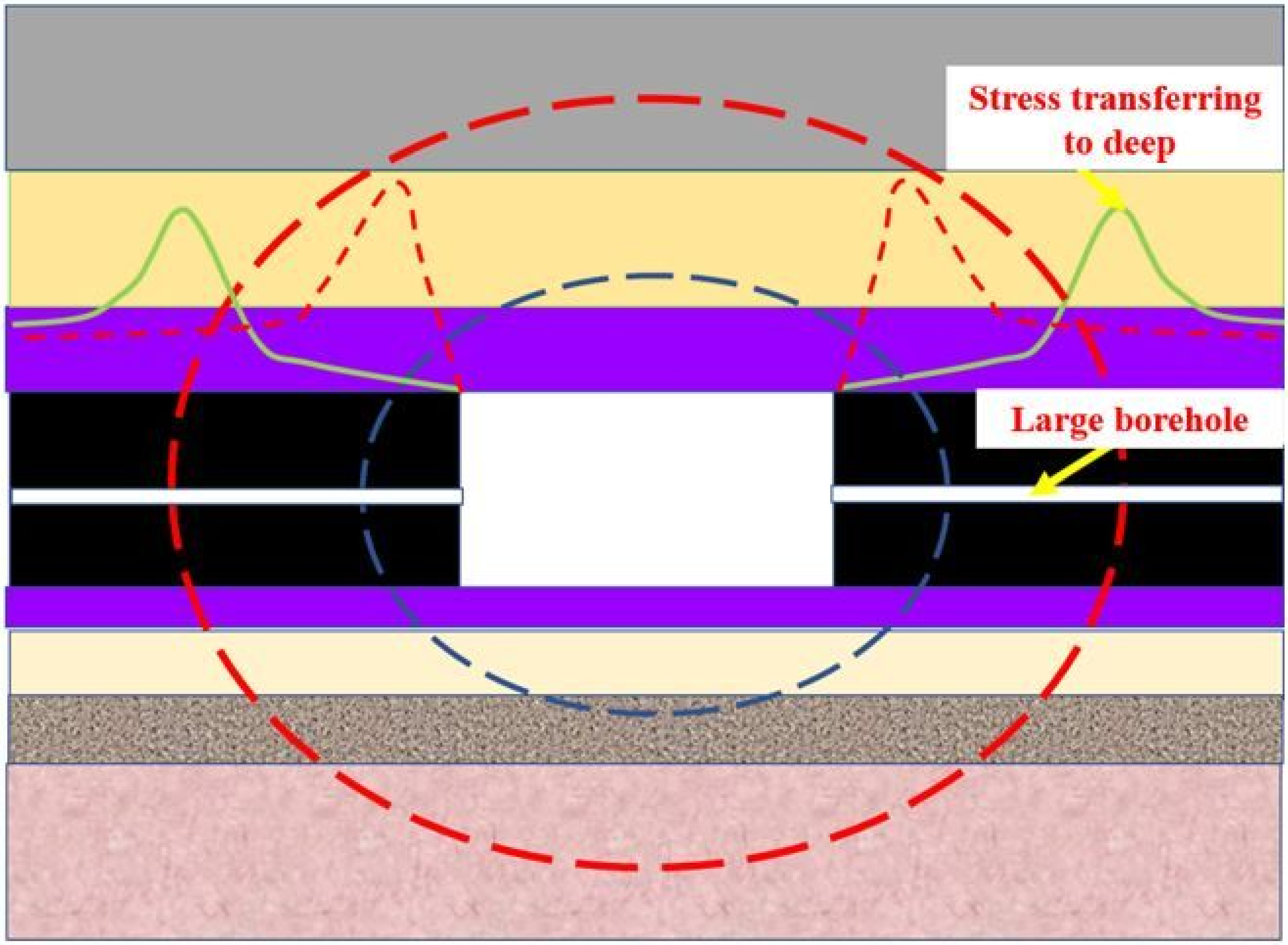


Figure 4

Schematic diagram of stress transfer

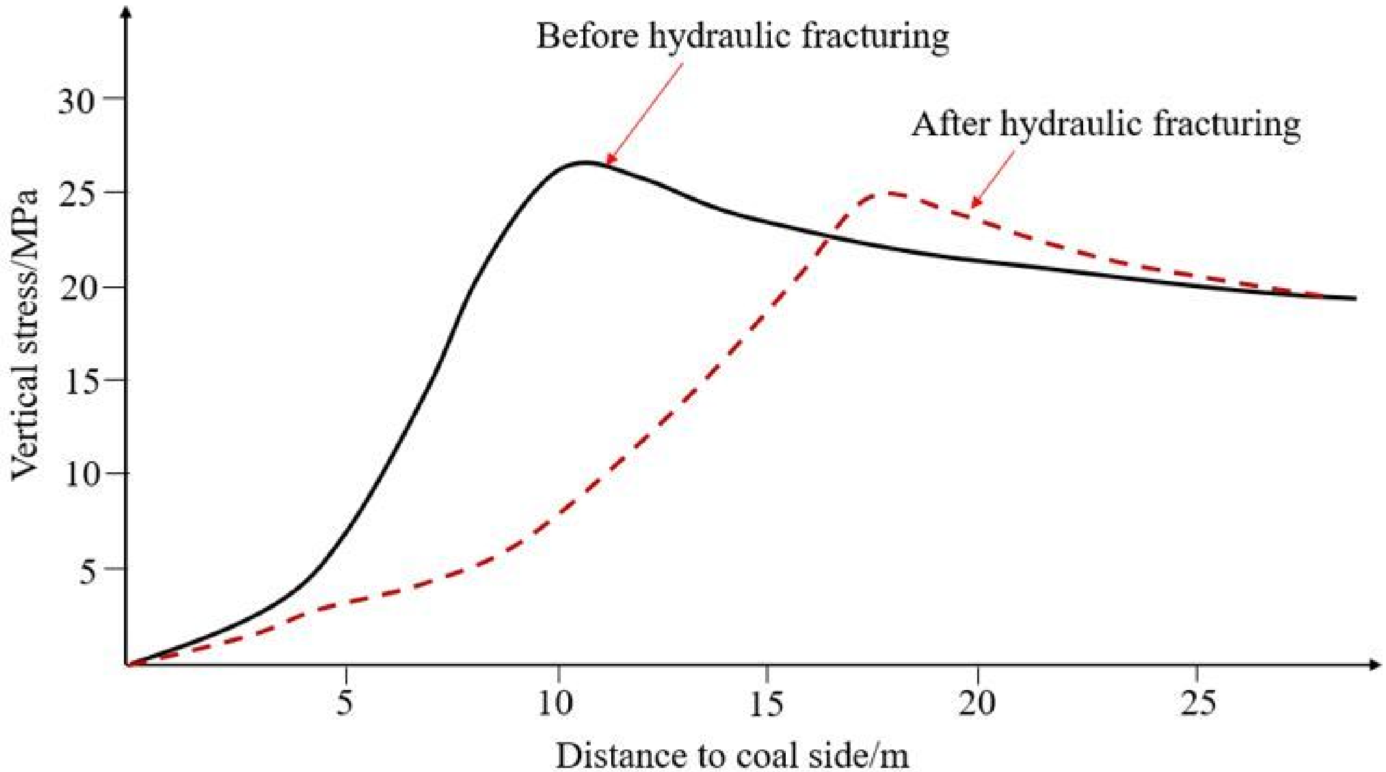


Figure 5

The pressure relief effect of hydraulic fracturing

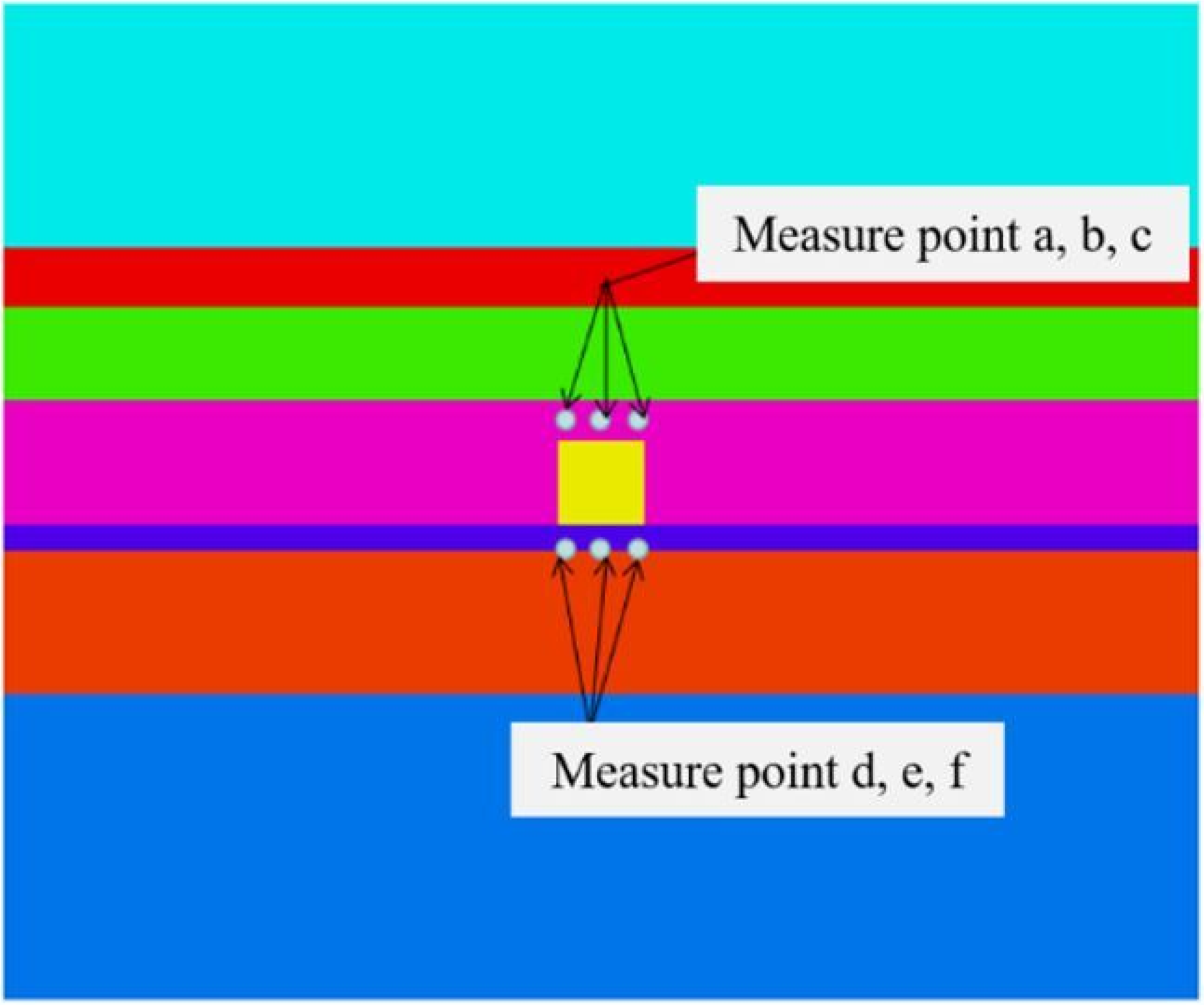


Figure 6

Numerical simulation diagram

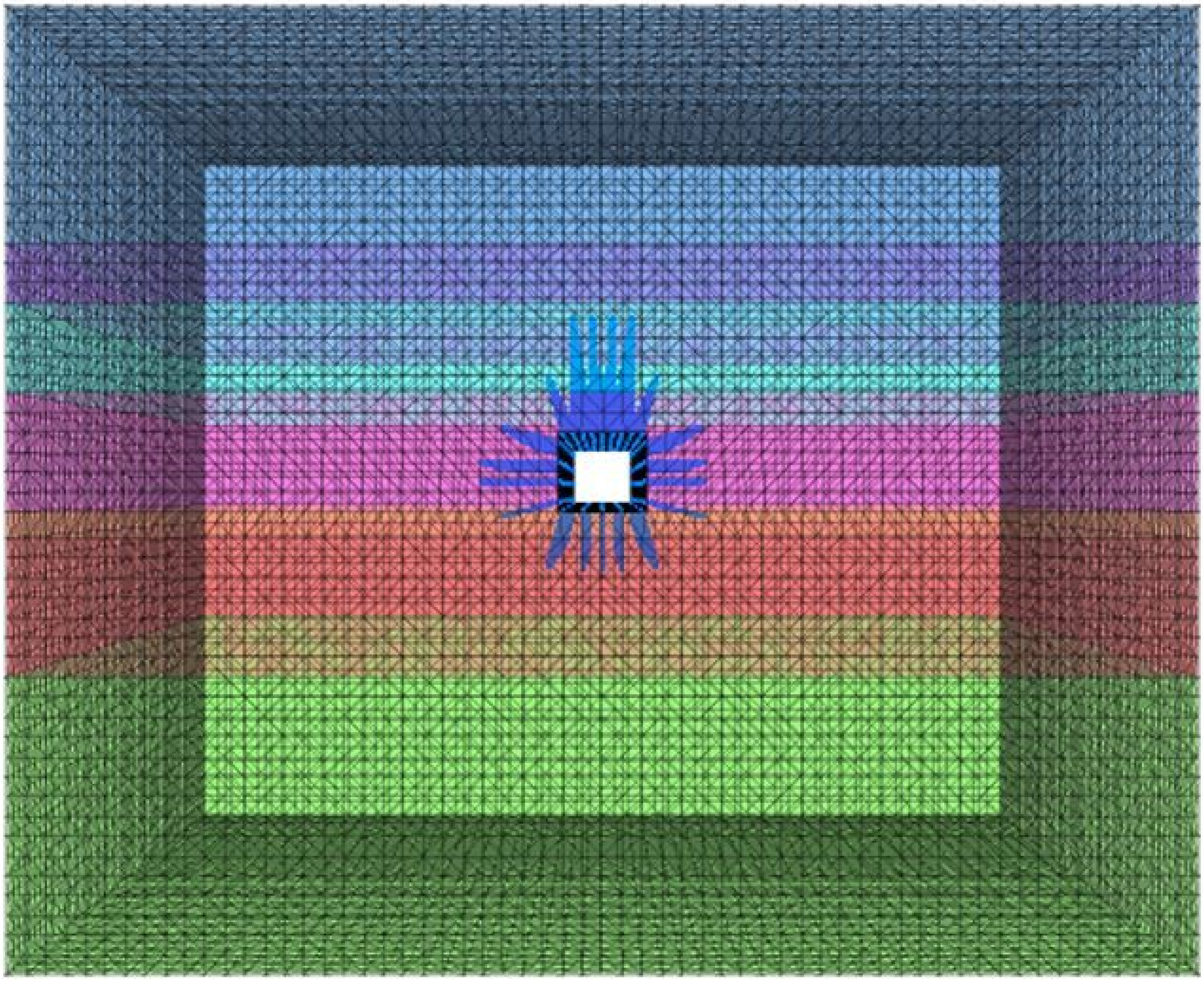


Figure 7

Numerical model of bolt-mesh-cable support

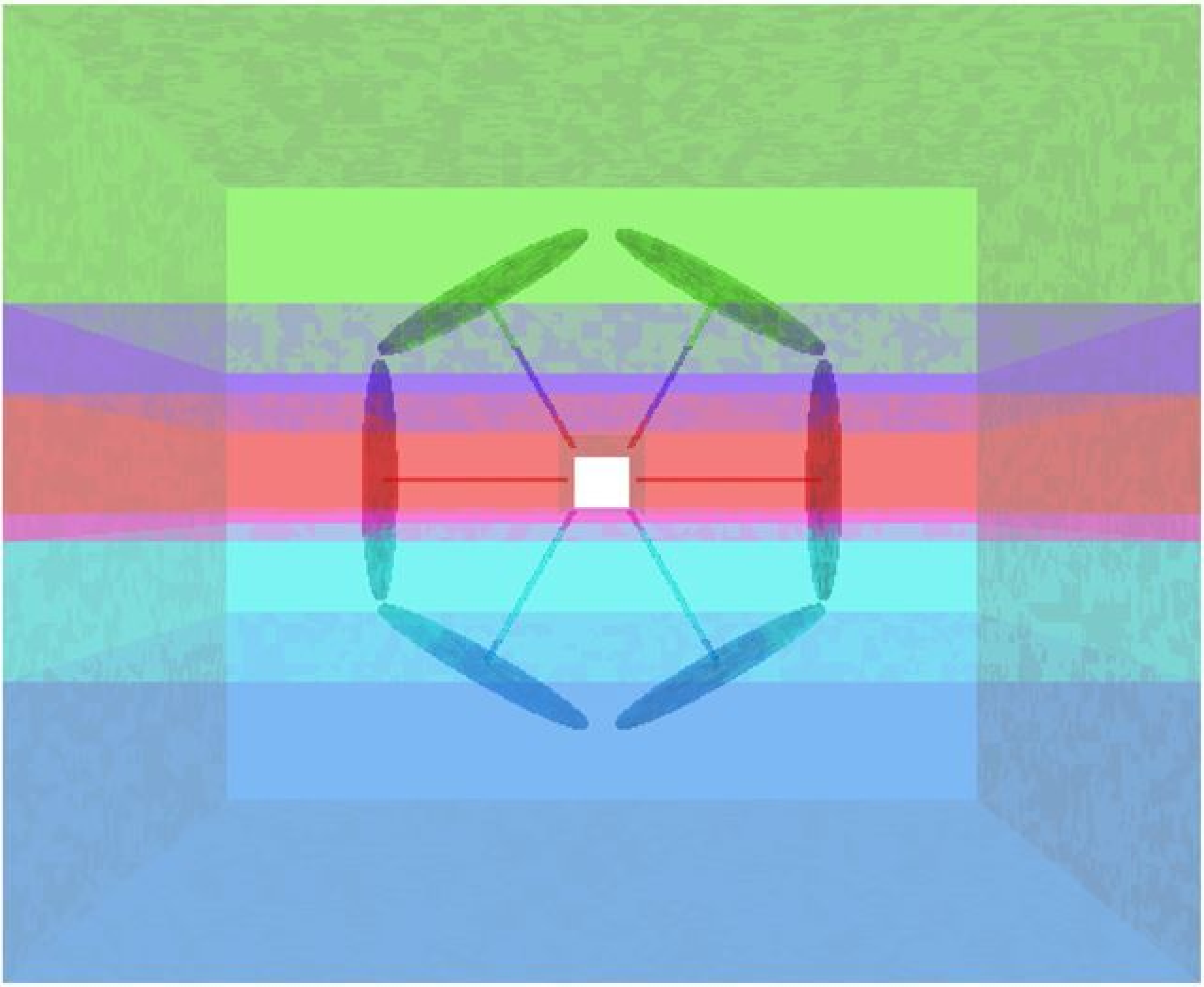
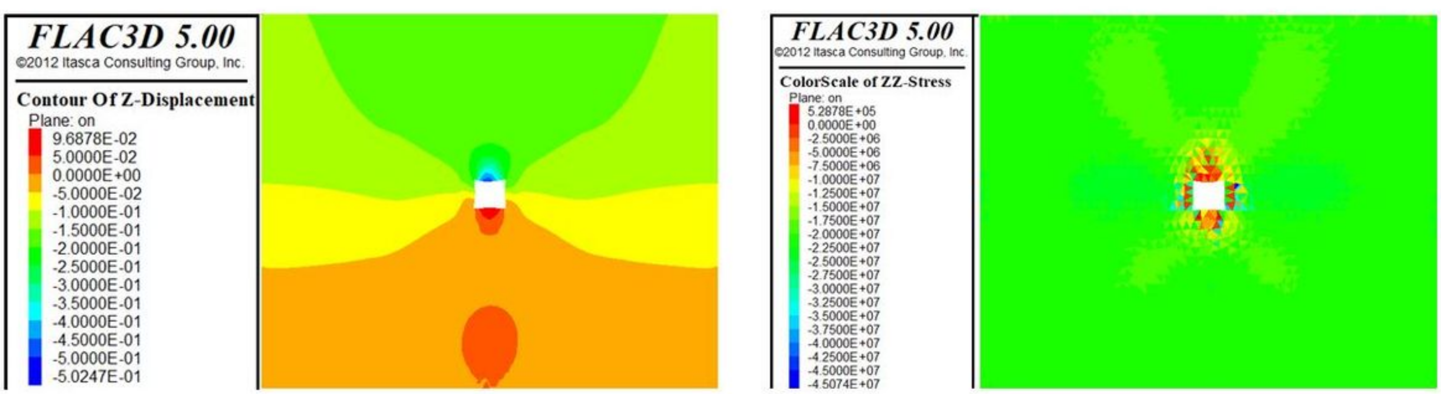


Figure 8

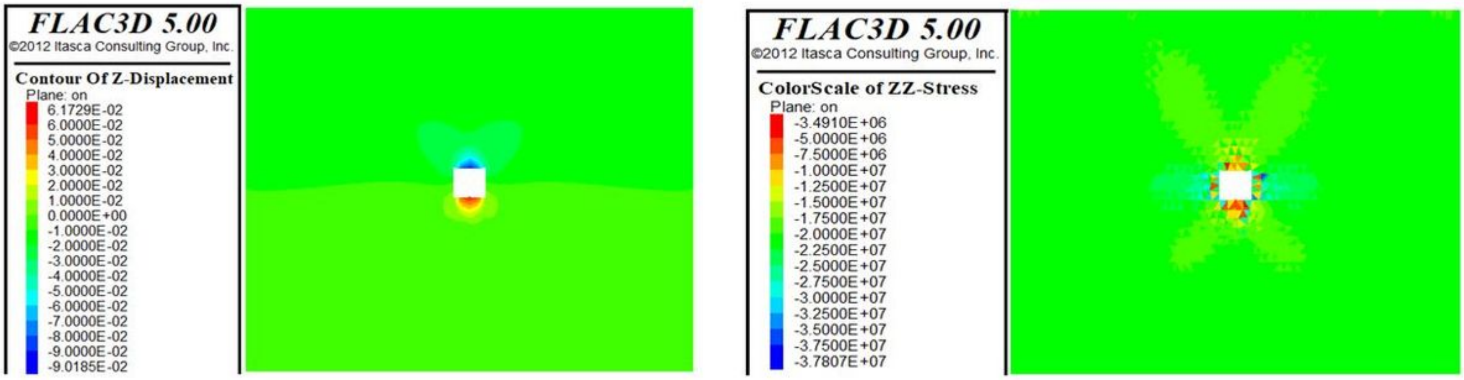
Numerical model of hydraulic fracturing



(a) Displacement nephogram (b) Stress nephogram

Figure 9

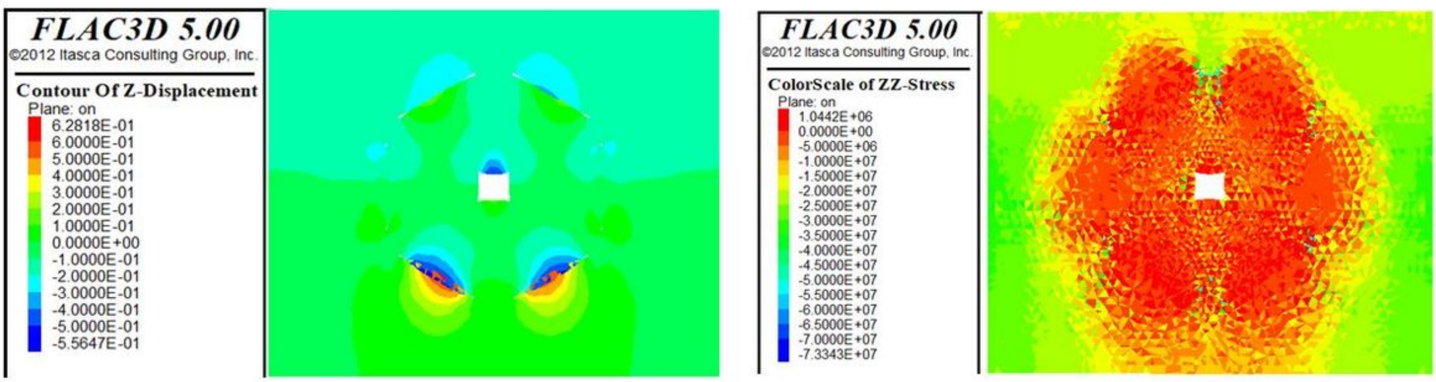
Numerical simulation diagram of no support and no pressure relief



(a) Displacement nephogram (b) Stress nephogram

Figure 10

Numerical simulation diagram of bolt-mesh-cable support



(a) Displacement nephogram (b) Stress nephogram

Figure 11

Numerical simulation diagram of hydraulic fracturing

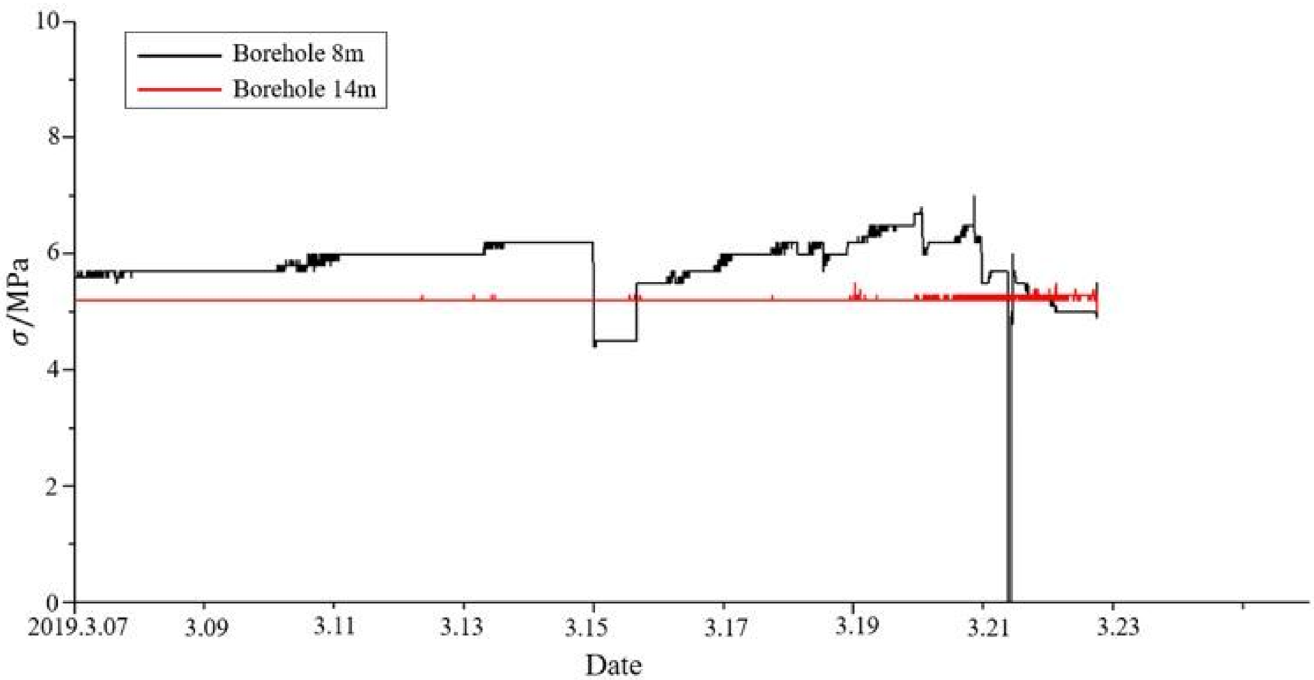


Figure 12

The monitoring data of stress sensor in mining face cutting

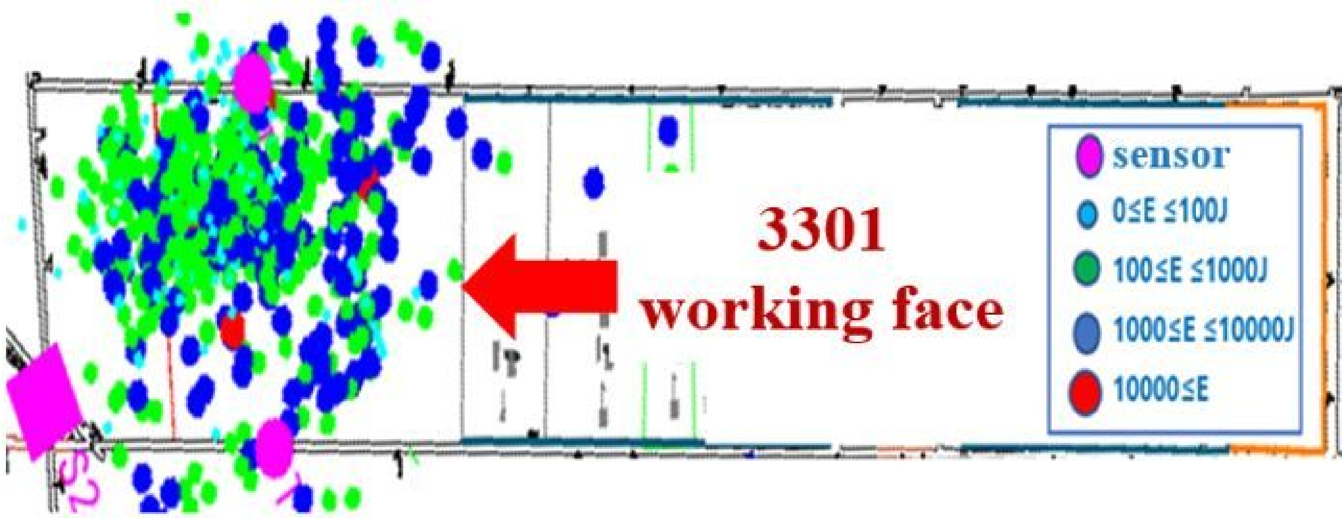


Figure 13

Distribution map of micro seismic events of 3301working face