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Study on the mechanism of rock burst in shaft coal pillar under thick conglomerate

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Abstract: *The shaft protection coal pillar is in a high static load environment for a long time, the impact mechanism is different from the mining area, and the prevention and control is more hidden and sudden. Aiming at the impact problem without mining disturbance, this study reveals the static instability mechanism : as a deep isolated bearing structure, coal pillar forms static load concentration under overlying strata and tectonic stress ; long-term high stress leads to rheology and strength degradation of coal and rock mass, decrease of bearing capacity and accumulation of elastic energy. The essence of this kind of impact is the instability of coal pillar caused by the coupling of high static load and time effect. The critical criterion is related to load, coal pillar strength and time. Based on this, an active pressure relief method based on long-term monitoring and stress transfer is proposed to provide support for the safety of key facilities in the mine.*

Keywords: *huge thick conglomerate; shaft coal pillar; rock burst; prevention*

1. Introduction

In the process of coal mining, rock burst is a serious safety hazard. It not only threatens the safe and efficient recovery of coal resources, but also poses a major risk to the life safety of miners. According to statistics, since 1998, there have been 48 rock burst events with roadway damage in Qianqiu Coal Mine, and three rock burst accidents have caused dozens of casualties and huge economic losses. China 's coal mining is gradually shifting to the central and western regions. Qianqiu Coal Mine is rich in resources, but most of the coal seams have the characteristics of large inclination, multi-layer clamping, and complex structure. The geological factors of rock burst in Qianqiu Coal Mine mainly include the thick conglomerate overlying the coal seam, the north-south extrusion of the F16 thrust fault, the thickness and change of the coal seam, the stratum structure of ' two hard and one soft ', the mining depth and so on. The occurrence of rock burst is the result of the combined effect of geological factors and mining factors. With the continuous progress of mining technology and the increase of mining depth, the problem of rock burst is more complex and difficult to predict. It is of great significance to study the impact mechanism under complex conditions for the safe mining of mines.

In view of the mechanism and prevention and control of rock burst, many scholars have carried out a lot of research. Zhu Guang 'an et al. [1] used FLAC3 d to study the mechanism of fault island working face, and adopted the law of inducing fault slip instability. The island working face is easy to cause mine earthquake ; aiming at the problem of rock burst and instability in deep coal mines with high three-dimensional stress difference, Liu Guolei et al. [2] revealed the mechanism of rock burst instability in deep coal mines with high three-dimensional stress difference by theoretical analysis, numerical simulation and engineering case analysis. The improved Burgers constitutive model was introduced by FLAC3 [3]Dnumerical simulation software, and the time node of accelerated creep under the condition of real ground stress was obtained by simulation calculation, which provided guidance for the subsequent pressure relief timing..

Gao Jiuguo[4] studied the fracture height and vertical stress and displacement distribution characteristics of overburden strata in filling working face through theoretical calculation, numerical simulation and field monitoring methods, optimized pressure relief measures and tested the pressure relief effect by microseismic monitoring. Based on the residual mining face in Yangyang [5] mining area,

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the stress distribution characteristics and the zoning control system of roadway layout under the boundary conditions of three types of goaf are studied by numerical simulation method. Based on the geological conditions of large mining height mining in coal seams such as Xu Xuhui [6], the theoretical analysis and numerical calculation method are used to study the rock burst mechanism and reasonable layout position of floor roadway in large mining height working face under the disturbance of remaining coal pillars. Taking Dong Wenzhuo [7] and other island working faces as the background, the mechanism and effect of controlling stress and preventing rock burst by constructing weak structure under the condition of overlying irregular coal pillar are studied by numerical simulation and field practice. Zhang Xiang et al. [8] used theoretical analysis, numerical simulation and field measurement methods to study the instability mechanism and control system of thick and hard rock-coal pillar structure based on the working face of the mining area.

2. Overview of coal pillar and rock burst in super thick conglomerate shaft

2.1 General situation of shaft coal pillar

The shaft coal pillar of Qianqiu Coal Mine is located in the middle of the mine, with a length of 546 m in the north and south, 792 m in the east and west, and an area of about 434824 m2. The buried depth of coal seam in the coal pillar area of the shaft is 448 ~ 574 m, the thickness is 5 ~ 13 m, and the average is 8 m. The uniaxial compressive strength of coal is 13.48 MPa, which has weak impact tendency. The mining situation around the coal pillar of the shaft is shown in Figure 1 : the eastern part is 21011, 21012, 21031, 21051, 21052 goaf, the width of the goaf is 538 ~ 783m ; the southern part is the goaf formed by large-scale mining of 21101, 21102, 21121, 21141, 21091, 21092, 21111, 21112, 21131 and other working faces. The north-south width of the goaf is 388 ~ 1932 m ; in the west, there are 18041, 18042, 18061 and 18220 goafs, with a width of 474 ~ 516 m. The northern part is a large area of goaf formed by the mining of 18151, 18152, 18131, 18132 and other working face areas. The north-south width of the goaf is 591 m.

The distribution of rock strata to the surface revealed by the 7 boreholes near the coal pillar of the shaft is shown in table 1. It can be seen from the table that 38.6m, 60.37m, 76.43m, 142.15m, 154.42m, 173.2m and 202m above the coal seam are 17.12m thick sandy conglomerate, 16.06m sandy conglomerate, 53.49m sandstone, 12.27m gray sandy conglomerate, 11.22m purple sandy conglomerate, 17.13m purple sandstone and 238.37m conglomerate. Among them, the thickness of 238.37 m conglomerate is the largest, which is the main stress source of coal pillar rock burst.

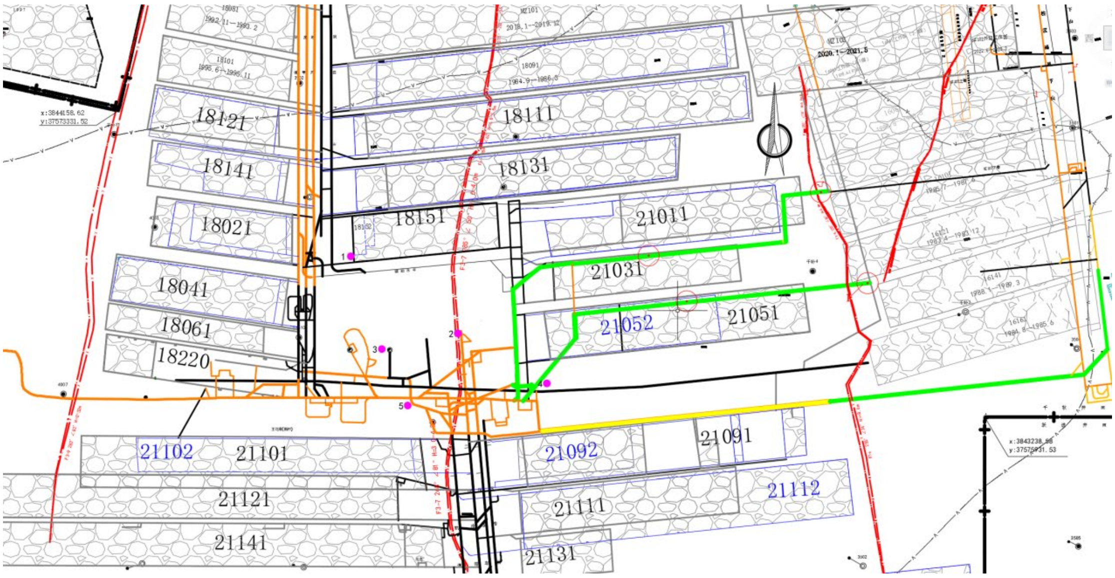

Figure 1 Shaft coal pillar impact diagram

Table 1 The distribution of overlying strata revealed by the supplementary 7 boreholes

Rockstrata No.	lithologic characters	Thickness / m	Rock strata No.	lithologic characters	Thickly/m
R19	loess	5.44	R8	mudstone	4.65
R18	conglomerate	238.37	R7	sandy conglomerates	17.12
R17	sandstone	9.46	R6	fine sandstone	3.62
R16	conglomerate	2.21	R5	sandy conglomerates	5.15
R15	purple soil	17.13	R4	fine sandstone	1.64
R14	Grey glutenite	7.56	R3	siltstone	2.34
R13	Purplered sandy conglomerate	11.22	R2	mudstone	25.4
R12	Grey glutenite	12.27	R1	medium sandstone	0.45
R11	Purplered sandstone mudstone	12.23	0	Second coal	6.27
R10	sandstone	53.49	F1	carbon mudstone	1.28
R9	sandy conglomerates	16.06	F2	conglomerate	2.94

2.2 Occurrence of rock burst in shaft coal pillar

During the period from 1998 to 2023, many rock burst events occurred in the shaft coal pillars of Qianqiu Coal Mine, which caused huge losses to the mine.

(1) Rock burst event 1

On September 3, 1998, the lower roadway of 18152 working face, which is close to the coal pillar of the shaft, was impacted during the excavation along the roof. The roadway was damaged to varying degrees from 20 m to 100 m at the entrance of the roadway. The roof sank, the two sides protruded, the floor heaved, and the I-steel trapezoidal shed used for support fell, as shown in *Figure 2*.

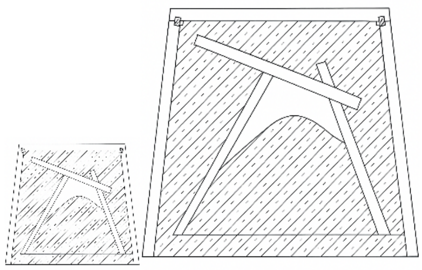

Figure 2 ' 9.3 ' rock burst site roadway damage situation

(2) Rock burst event 2

On March 27, 2014, a 1.1 × 107J (ARAMIS), magnitude : 1.9 (KZ-301) (Coordinates : X : 3500 Y : 4195 Z : 214) impact event occurred on the 21032 return air uphill. The impact event occurred in the roof. When the impact event occurs, 21032 return air uphill is excavated to 85 m above the return air roadway, 20 m away from the occurrence position, 21032 lower roadway yard is excavated to 45 m, 88 m away from the occurrence position, 21032 return air uphill section 15m2, spray anchor cable + 5154 type 36U steel shed + 36U reinforced point column, coal seam roof mudstone, floor conglomerate, 21032 return air uphill excavation along the bottom. When the rock burst occurs, the roadway is excavated 85 m above the return air contact roadway, and the roadway is damaged to varying degrees above 20 m from the lower slope change point. The roadway is seriously damaged at 50 m from the lower slope change point, and the roadway is basically closed. There is about 0.8 m space in the lower side of the roadway, and most of the 36 U holding columns in the roadway are bent. The two air doors in the lower yard are damaged by the shock wave, and the gas concentration is as high as 9 %. The 763 belt inclined roadway, the strong belt head chamber and the three-meter winch room in 21 area are deformed to varying degrees.Figure 3 is the damage of rock burst roadway.

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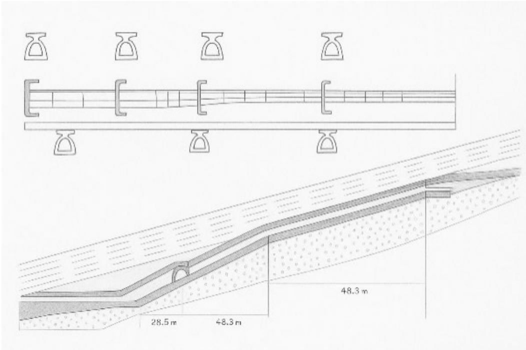


Figure 3 ' 3.27 ' rock burst site roadway damage

3. Force source analysis of shaft coal pillar impact under thick conglomerate

In order to verify the rationality and operability of the ' grey correlation degree-GM (1,1) grey prediction-pile settlement reliability ' and ' grey correlation degree-GM (1,1) grey prediction-pile settlement reliability ' models, this paper takes the pile foundation project of a high-rise building in a campus of Zhengzhou Airport as an example. The pile length is 16 m, the pile diameter is 800 mm, the design allowable settlement is 30 mm, and the monitoring period is 12 months.

3.1 Numerical simulation of overlying rock structure and stress field evolution in the formation of coal pillar in super thick conglomerate shaft

Based on the actual geological occurrence conditions of shaft coal pillars in Qianqiu Coal Mine, a UDEC numerical calculation model was established. In the simulation process, the goaf is formed by excavating the coal seams on both sides of the wellbore to reproduce the isolated bearing state of the wellbore coal pillar. The shaft protection coal pillar is set in the middle of the model. The average thickness of the coal seam is 130 m above the 7m coal seam, and the thickness of the conglomerate is 212 m. The self-weight of the rock layer from the top of the model to the surface is equivalent to the uniform load. The surrounding and bottom of the model are set as the displacement boundary conditions. The overall model size is 1400 m × 400 m × 374 m as shown in *Figure 4*

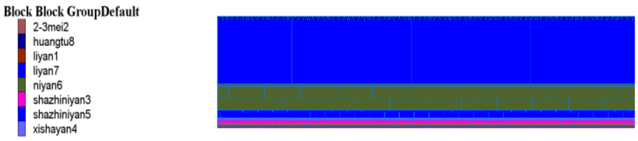
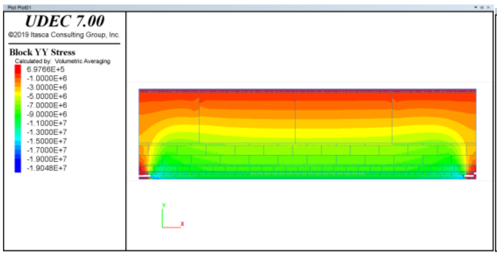
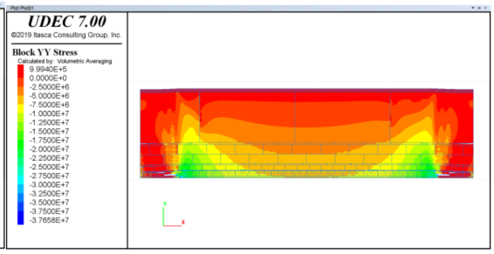
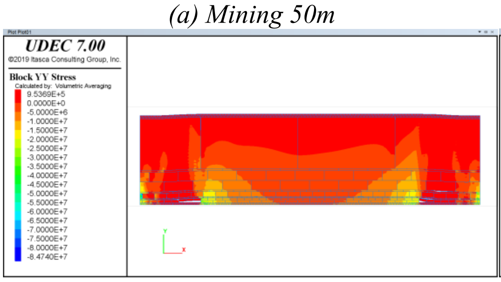


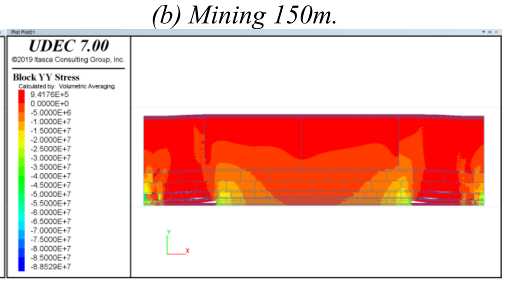
Figure 4 Numerical calculation model of wellbore coal pillar





(a) Mining 50m *(b) Mining 150m.*





(c) Mining 250m *(d) 300 m mining*

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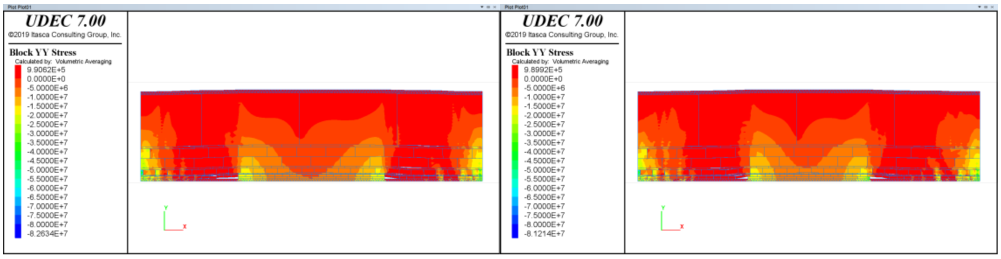

(e) Mining 400m *(f) Mining 450m*

Figure 5 Vertical stress cloud diagram of shaft coal pillar at different mining distances

It can be seen from the stress cloud diagram of different mining distances of shaft coal pillars in *Figure 5* that the vertical stress field of coal pillars at the initial stage of mining (50 m) shows significant layered distribution characteristics. The lower low stress area is dominated by self-weight stress and is evenly distributed. The overall performance of coal pillars is the mechanical characteristics of uniform stress distribution, and there is no obvious stress concentration and disturbance. When the mining distance increases to 150 m, 250 m and 300 m, the stress field of the coal pillar shows a gradual evolution trend. There is no displacement mutation in the upper high stress area, and there is no significant mechanical response of the coal pillar. The degree of stress activation is at a low level.

When the coal pillar is pushed to 400 m, the normal stress cloud map in the Y direction at the bottom of the coal pillar presents a typical stress concentration distribution mode. Affected by the expansion of the mining space, a large-scale stress concentration area is formed at the bottom of the coal pillar, which indicates that the coal pillar enters the mechanical activation stage, the elastic energy begins to accumulate continuously, and there is a risk of stress sudden release in the later stage. When the mining distance reaches 450 m, the stress cloud map extends to the top of the coal pillar in a columnar shape, and the stress at the bottom of the coal pillar changes abruptly after a large area of accumulation. The coal pillar shows a mechanical instability trend and induces mine pressure appearance. At this time, the coal pillar is in a critical state of high stress.

3.2 Mechanical analysis of coal pillar impact force source in ultra-thick conglomerate shaft

In order to simplify the calculation, the shaft coal pillar is regarded as a circle, and the shaft coal pillar load model is established as shown in Figure 6.

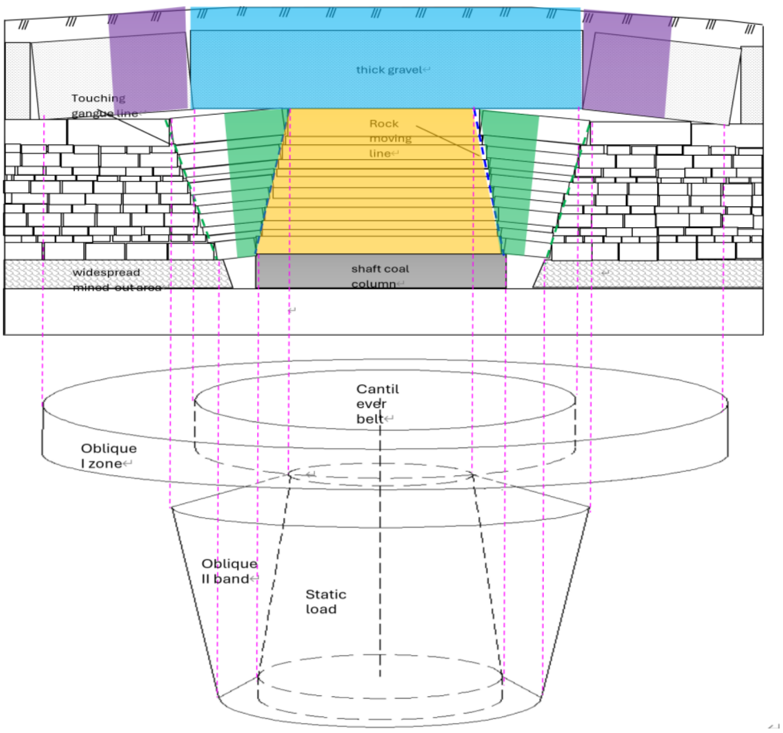

Figure 6 Shaft coal pillar bearing load mechanical model

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The load of the coal pillar in the shaft can be divided into four parts, which are the static load (QJZD), the cantilever load (QXBD), the half of the inclined I belt load (QXYI) and the half of the inclined II belt load (QXYII). That is :

$$Q = Q_{JZD} + Q_{XBD} + 2 \times \frac{Q_{XYI} + Q_{XY\text{II}}}{2} \tag{1}$$

From *Figure 6*, it can be seen that the static load band is a truncated cone, then the expression of QJZD is :

$$Q_{JZD} = \frac{\pi h\left(r^2 + R^2 + rR\right)\gamma}{3} \tag{2}$$

In the formula, h is the height of the cone ; r is the radius of the circle on the cone ; r is the radius of the circle under the frustum ; γ is the bulk density of overburden rock.

It can be seen from *Figure 6* that the cantilever band is a disk, and the expression of QXBD is :

$$Q_{XBD} = \pi a^2 m\gamma \tag{3}$$

In the formula, a is the radius of the disk ; m is the thickness of the disk.

It can be seen from *Figure 6* that the oblique I band is the inner hollow truncated cone, and the expression of QXYI is :

$$Q_{XYI} = \frac{2\left(3ab\cos\alpha + 2b^2\cos^2\alpha\right)\pi m\gamma}{3} \tag{4}$$

In the formula, b is the length of the inclined I-zone rock beam, and α is the angle between the inclined I-zone rock beam and the horizontal direction.

From *Figure 6*, it can be seen that the oblique II zone is a hollow inner truncated cone, and the expression of QXYII is :

$$Q_{XY\text{II}} = \frac{2\pi h\gamma}{3}\left[2\left(c^2 + d^2 + cd\right)\cos^2\theta + \left(2cr + 2dR + rd + cR\right)\cos\theta\right] \tag{5}$$

In the formula, c is the fracture length of the rock beam in the upper part of the II belt ; d is the fracture length of the rock beam at the lower part of the II belt ; θ is the angle between the inclined II-belt rock beam and the horizontal direction.

The load on the shaft coal pillar obtained by the simultaneous (1) ~ (5) is as follows :

$$\begin{aligned} Q = {} & \frac{\pi h\left(r^2 + R^2 + rR\right)\gamma}{3} + \pi a^2 m\gamma + \frac{2\left(3ab\cos\alpha + 2b^2\cos^2\alpha\right)\pi m\gamma}{3} \\ & + \frac{2\pi h\gamma}{3}\left[2\left(c^2 + d^2 + cd\right)\cos^2\theta + \left(2cr + 2dR + rd + cR\right)\cos\theta\right] \end{aligned} \tag{6}$$

In fact, whether the wellbore coal pillar is impacted is also related to the size of its bearing area. When the wellbore coal pillar area is large, the load per unit area on it is small, that is, the stress concentration is low, and the wellbore coal pillar is not easy to impact. When the area of the wellbore coal pillar is small, the load acting on the unit area is large, that is, the stress concentration is high, and the wellbore coal pillar is prone to impact. The stress concentration in the unit area of the wellbore coal pillar is σ. Assuming that the bearing stress of the wellbore coal pillar is uniform, then :.

$$\sigma = \frac{1}{R^2}\left\{\begin{aligned} & \frac{h\left(r^2 + R^2 + rR\right)\gamma}{3} + a^2 m\gamma + \frac{2\left(3ab\cos\alpha + 2b^2\cos^2\alpha\right)m\gamma}{3} \\ & + \frac{2h\gamma}{3}\left[2\left(c^2 + d^2 + cd\right)\cos^2\theta + \left(2cr + 2dR + rd + cR\right)\cos\theta\right] \end{aligned}\right\} \tag{7}$$

4. Prevention and Control of Rock Burst in Shaft Coal Pillar under Extremely Thick Conglomerate

4.1 Prevention measures

During the excavation of roadway and exploration roadway, if the bottom coal is left due to the

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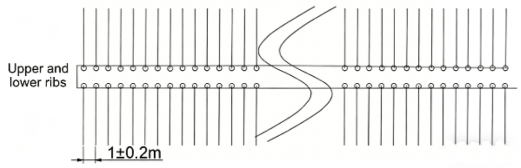
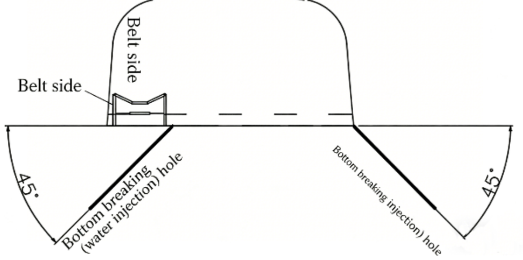
change of coal thickness and slope, roadway wear layer and other reasons, the floor pressure relief measures must be taken [9], and the lag head distance of the bottom hole is less than or equal to 15 m.

(1) When the thickness of bottom coal (containing coal gangue interbedded) on any side of the roadway is greater than 1m, the floor pressure relief measures are taken.

(2) When the thickness of the roadway bottom coal (containing coal gangue interbedded) is greater than 1m, the floor pressure relief hole is implemented at the two sides of the roadway, the azimuth is vertical to the roadway side, the dip angle is 45 ° ± 5 °, the aperture is 75mm, the hole spacing is 1m ± 0.2m, and the final hole contacts the floor rock layer, and the borehole is softened by water injection [10].*Figure 7* is a schematic diagram of the layout of broken bottom (water injection) holes in roadways and exploration roadways.



(a) working face bottom hole plane schematic diagram



(b) Bottom drilling layout section diagram

Figure 7 Roadway and exploration roadway broken bottom (water injection) hole layout diagram

4.2 Special regional prevention and control scheme

For the affected area of the goaf in the overlying working face, the prevention and control principle of ' monitoring first, dynamic pressure relief, and gradual strengthening ' is adhered to. During the excavation, the joint early warning of drilling cuttings method and stress on-line monitoring should be strengthened. Once the signs of impact danger are monitored, targeted pressure relief measures should be implemented immediately. The diameter of the pressure relief borehole is not less than 120 mm, and the depth of the borehole is 5 m deeper than that of the conventional pressure relief borehole. The borehole spacing follows the principle of ' from sparse to dense and gradually dense '. The initial construction is carried out at a distance of 1 m. If the danger is not eliminated after the first round of pressure relief, the second round of construction is carried out by drilling holes between the original boreholes ; when the impact danger is still not relieved after three rounds and above drilling pressure relief, the coal pressure relief blasting is used to strengthen and relieve the danger to ensure the full release of stress.

5. Conclusion

Based on the engineering background of Yima Coalfield in Henan Province, the prevention and control of rock burst in wellbore under thick conglomerate is studied. The main conclusions are as follows :

(1) The full circumferential three-dimensional bearing capacity model of coal pillar in island wellbore and the two-dimensional bearing capacity model of coal pillar section in long strip roadway are constructed. The bearing load of coal body is decomposed into four parts : static load zone, cantilever zone and oblique I / II zone. The quantitative calculation formula of total load and stress concentration degree of coal pillar is deduced, and the negative correlation between coal pillar size and stress concentration level is revealed.

(2) The UDEC system was used to carry out the rock burst risk analysis of the driving roadway under the multi-goaf of the coal pillar adjacent to the wellbore, and the movement and breaking law of the thick

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hard rock layer during the advancing process of the working face was revealed. The critical distance of the initial breaking of the hard rock layer was determined to be 450 m. When the hard rock layer was pushed to the critical distance, the broken block of the hard rock layer rotated and sank, and the energy was suddenly released, which was the core inducing factor of the rock burst instability.

(3) The study area as a whole has a moderate risk of rock burst. Based on this, the fine classification of the impact danger zone is completed, and a comprehensive anti-impact technology system integrating hierarchical differential pressure relief management, full-process anti-impact management, multi-dimensional safety protection and standardized emergency response is constructed.

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