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Experimental Study on the Pattern of Surrounding Rocks' Movement under Excavation Activities and Impact Prevention Technologies in Island Mining Face

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Abstract: Based on the structural feature of island mining face's 'T' shape overburden and by using analog material and numerical simulation to analyze the rules of overburden movement and stress distribution, and yield failure characteristics during stoping in island mining face, this paper studies the variation rules of roadway stress, acceleration, displacement and deformation velocity when island mining face's overburden breaks， producing strong dynamic impact load. The result shows: In the beginning stage of stoping, plastic failure in the surrounding rocks mainly appears in the roof, while in later times, plastic failure in the overburden will gradually move up towards the overlying strata, appearing in symmetrical arcuate; under the dynamic load of mine earthquakes, the left and right ribs suffer slighter deformation than the roof and the floor; the right rib and the roof changes faster than other places; the roof sinks the most; and the vertical stress on the left and right ribs are bigger than that on the roof and the floor. The rules of overburden movement and impact failure in island mining face stated in this paper provide theories for impact prevention in high impact-risk island mining face, impact prevention parameters design and impact prevention measure-making as well as help engineering practice so as to guarantee stoping safety in high impact-risk island mining face.

1. Introduction

After stoping in island mining face, strata behaviors are determined by overburden movement failure characteristics, so studies on the rules of overburden movement in island mining face cast a great significance on monitoring and early-warning as well as prevention of rock bursts in island mining face[1-5]. The special structural features of the overburden and the rules of its movement in island mining face increase support pressure on coal rocks[6-8]. Therefore, dynamic load produced during overburden breaks becomes a serious factor that may cause rock bursts [9-13]. Many experts[14-16] pointed out that mass elastic strain energy in coal rocks is only necessary but not sufficient in causing bursts, but excavation activity is also needed to cause rock bursts. During stoping activities, external factors including mine earthquake shock waves, mechanical shock and blasts are all possible reasons of rock bursts, among which dynamic load produced during overburden breaks has a rather serious influence. With the special structural feature of island mining face's 'T' shape overburden, areas under high stress are easily prone to rock bursts together with strong dynamic load.

As a result, researches on the rules of overburden failure characteristics and its movement in island mining face cast a great significance on monitoring and early-warning as well as prevention of rock bursts in island mining face.

2. Engineering Facts

163_{lower}02C working face in a certain mine means the island mining face in the 3_{lower}coal seam of No. 16 mining area. The structure of this working face is simple with average seam thickness being 3.3m and average angle of inclination 3°. The average ground level is +33.68m. The working face level is -604.2~-651.4m averaging at -622.2m. The east part is 163_{lower}02 gob and the west 163_{lower}03 gob. 163_{lower}02C working face's hard roof consists of medium and fine sandstone. Its immediate roof consists of siltstone. Its immediate floor and hard floor consist of aluminum mudstone and interlaying siltstone respectively. The excavation activities in 163_{lower}02C working face are faced with serious rock burst risk.

Drilling method monitoring of the gateway excavation in 163_{lower} 02C working face shows excessive drilling cuttings and dynamic disasters such as blocked drilling, sticking and borehole burst.

When 10m to the front of the working face, the drill was blocked after 7m of drilling, coal bursting, and coal dust particle grew. When 6m to the front of the working face, the drill was blocked after 4m of drilling, coal bursting, and coal dust particle grew. When 9m to the front of the working face, the drill was blocked after 7m of drilling and the rod was stuck after 8m of drilling. When 4m to the front of the working face, the drill was blocked after 7.4m of drilling with frequent small-scale coal bursts and the rod was stuck after 8m of drilling. The monitoring results of the quantity of drilling cuttings show that during excavation of the gateways, under the influence of support pressure and roof overhang in the two flanking gobs, a large area has been detected abnormal coal dust quantity as well as obvious signs of dynamic disasters during drilling, which put the working face in high impact risk. Therefore, before and during excavation, researches on the rules of overburden movement and the variation pattern of stress field must be carried out in order to effectively prevent and control rock bursts.

3. Features of Pressure on and Failure of Surrounding Rocks during Excavation in Island mining face

3.1. Establishing FLAC^{3D} Numerical Simulation Model

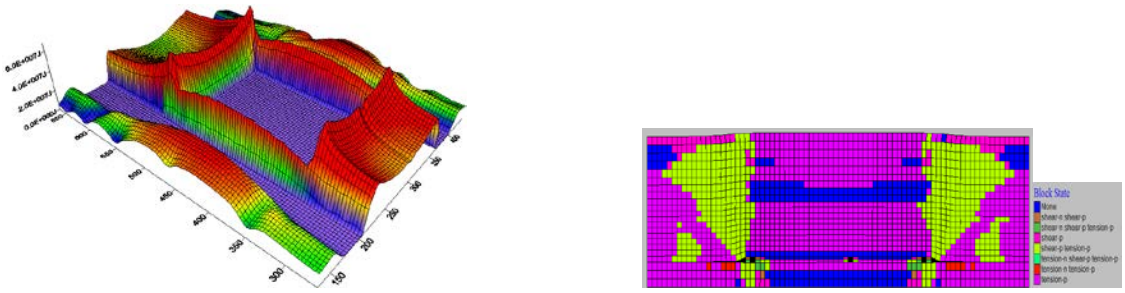
At present, most studies on the rules of overburden movement in island mining face are built upon that of working faces other than island mining face. This kind of studies lack system and pertinence and are not sufficient to serve as directions for impact prevention in island mining face. In order to systematically study the rules of overburden failure and stress distribution, we established FLAC^{3D} Numerical Simulation Model based on above-mentioned geological conditions of island mining face. The horizontal length of this model is 578m and vertical 82m. Coal seam's mining depth is 650m and its thickness 4m. The distance to the floor is 18m. The first layer of the roof is 28m-thick medium sandstone and the second layer 12m-thick siltstone. According to Mohr-Column strength criterion, boundary conditions of model should be like: zero horizontal movement and velocity in left and right ribs; fixed vertical movement and velocity of the floor; 13.7MPa vertical stress on the upper border; and acceleration of gravity being 9.8m/s^2.

3.2. Features of Pressure on and Failure of Surrounding Rocks Before Excavation in Island mining face

We use simulation to study variation pattern of stress and features of yield failure in overburden before and after stoping in island mining face. We also analyze the rules of overburden movement and variation pattern of support pressure on the ribs by loading dynamic load.vertical stress on the floor and roof of coal seam is bigger than other parts. Stress is relatively focused on coal rocks flanking the gob. The stress distribution pattern resembles a saddle and vertical stresses on both sides are symmetrical with the maximum at 34.3MPa.

3.3. Features of Pressure on and Failure of Surrounding Rocks After Excavation in Island mining face

Stress distribution on coal seam and surrounding rocks after stoping in island mining face is shown in Figure 1.



(a) Distribution of support pressure on coal seam in island mining face

(b) Distribution of vertical stress on surrounding rocks in island mining face

Figure 1. Stress distribution on coal seam and surrounding rocks after stoping in island mining face

As shown in Figure 1, after stoping in the working face, shearing stress and tensile stress will cause damage to the roof. At the same time, plastic failure in the roof is arcuate and extends gradually to top-left and top-right. The roof will break entirely and cause dynamic mine earthquake load. At this time, vertical stress on coal seam will reach 64MPa. As a result, it is safe to say that the roof is very easily prone to breaking and produce strong mine earthquake and cause impact when excavation activities drive near the stop line.

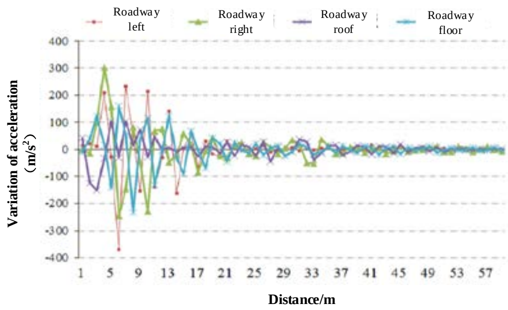
4. Influences of Dynamic Mine Earthquake load on Impact Failure

Sudden breaking in island mining face's overburden will release mass of elastic energy, part of which will spread out by shock waves, causing mine earthquake. When shock waves reach coal seam, its dynamic load on the seam will interact with high support pressure on coal rocks, thus causing damage and impact to roadway and working face. This paper analyzes impact failure effect on roadways caused by mine earthquake by the method of simulation.

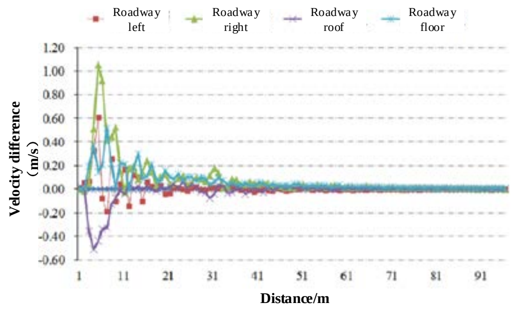
4.1. Impact Failure Caused by the Breaking of Overburden in Island mining face

The stress on roadway's roof and floor, deformation velocity and degree of sinking (i.e. impact failure in roadways caused by sudden breaking of overburden in island mining face) when a mine earthquake takes place are shown in Figure 2.

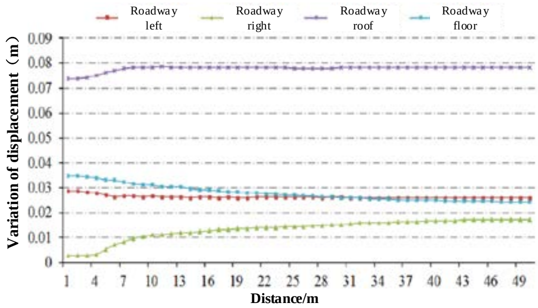
We can see from Figure 2 that when shock waves produced in a mine earthquake spread nearby the roadways, a surge in stress will instantly appear and vertical stress there will gradually increase. At the same time, area of plastic yield failure in surrounding rocks will enlarge and mechanical strength decrease. The instant surge of stress in roadways mainly appears in the form of horizontal stress in the roof and vertical stress in left and right ribs. Vertical stress in the roof reaches 20MPa; vertical stresses in the left and right ribs instantly reaches 48MPa and 37MPa respectively under the disturbance of dynamic load, while vertical stress in the floor is relatively small, being 20MPa. Deformation of the left and right ribs is slighter than that of the roof and the floor with maximum deformation of the left rib being 35mm and that of the roof reaching 80mm. Obviously, deformation of the roof is mostly severe. The right rib and the roof suffer from bigger deformation velocity at 1m/s and 0.6m/s respectively, while that of the left and the floor is smaller.



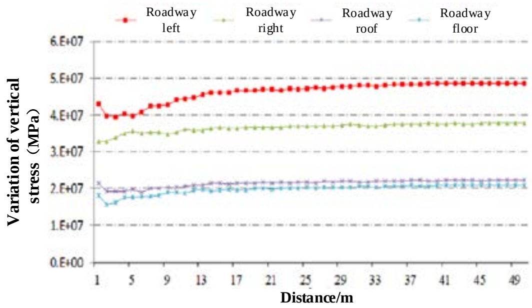
(a) Acceleration



(b) Velocity



(c) Displacement



(d) Vertical stress

Figure 2. Impact failure in roadways caused by the breaking of overburden in island mining face

All in all, in island mining face, a strong mine earthquake induced by the breaking of the overburden may cause severe damage to roadways, particularly to the rib close to gob. In case of a hard roof in island mining face, the floor there is under a strong concentration of stress, so during stoping, stronger measures to release pressure from coal pillars adjacent to gob should be applied and roadway support should also be strengthened so as to form a strong-weak-strong structure, thus resisting mine earthquake's shock waves. Other pressure-releasing measures such as blasting on the floor should also be considered if necessary.

5. Impact Prevention and Monitoring Technology in 163_{lower}02C Working Face

5.1. Impact Prevention and Monitoring Plan in 163_{lower}02C Working Face

The source of impact risk in 163_{lower}02C working face comes from fracturing destabilization of the arms of the 'T' structure and the O-X breaking of the roof. Therefore, using long-hole blasting to sever the arms and the overhanging roof will reduce static load in coal rocks caused by the overburden and dynamic impact load caused by fracturing destabilization.

5.1.1. Calculating the Depth of the Hole According to the theory of long-hole blasting, the blasting depth should reach over half of the hard roof rocks. According to the bar chart of the drilling holes in No. 16 mining area, the thickness of the sandstone roof above coal rocks is around 30m, so the blasting depth should be around 20m. The elevation of the drilling hole is 75 º, so its depth should be 25m.

5.1.2. Blasting Spacing After calculation, the radius of the crack area after blasting is 1436mm, but considering the damage and shock caused by stress waves outside the crack area may also weaken the integrity and strength of the roof, so the actual number should be 1.5 times of the calculation, that is 2154mm. Therefore, the influencing area of a single-hole blasting (radius of the crack area) should be around 5m. In field practice, in order to both control the deformation on roadway's surface and eliminate impact risk, the space between drilling holes while using long-hole blasting to release pressure from the roof should be 5~6m.

5.1.3. Explosive Load Explosive should fill 0.52m per meter of a blast hole. With the depth of a blast hole being around 25m, the loaded length should be near 13m.

5.1.4. Blasting Plan Based on the above calculations, we can get the design and technical parameters of long-hole blasting on the roof in $163_{lower}02C$ working face as follow.

Drill deep holes every 6m in secondary gateway, conveyor gateway and the middle roadway. In the two gateways, drill holes symmetrically in the flanking ribs, while in the roadway, drill holes alternately in both sides. Parameter including depth of drilling holes: 25m, loaded depth: 13m, sealing depth: 12m, inclination: 75°, radius of drilling holes: 55mm, and cartridge diameter of water-gel explosive for coal mines: 50mm. Explosive charging method is protective reverse charging through plastic flexible tube. Place 3 millisecond delay electric detonator at an equal distance in every drilling hole. The circuit inside every hole should be parallel and between holes should be connected in series. 1~2 blast holes should be detonated at every time. Drilling holes are set as shown in Figure 3.

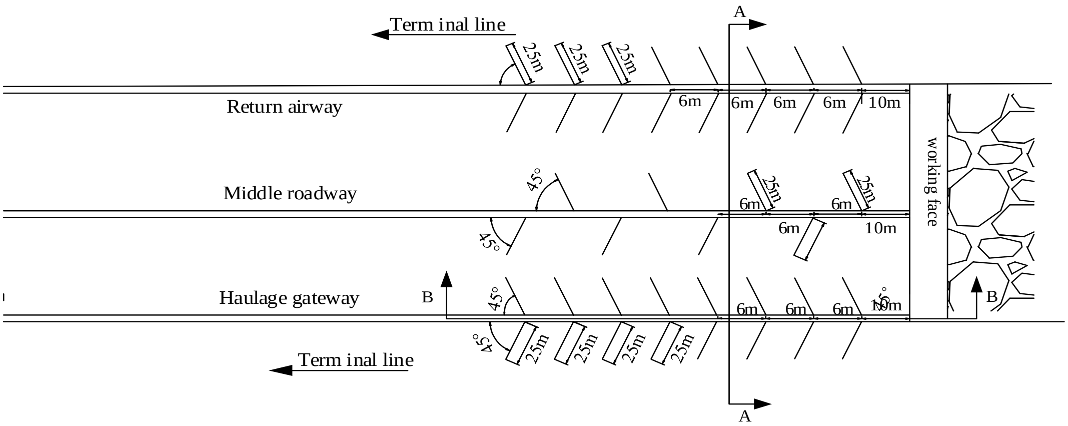


Figure 3. Long-hole blasting design on the roof in $163_{lower}02C$ working face

5.2. Results of Impact Prevention in $163_{lower}02C$ Working Face

During stoping in $163_{lower}02C$ working face, use micro seismic monitoring system to conduct continuous real-time surveillance not only can evaluate and predict impact risk but can also test the results of rock bursts monitoring.

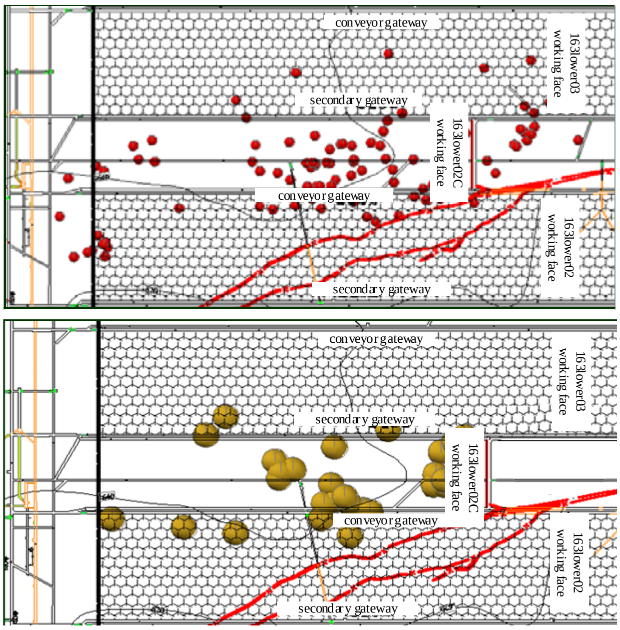
During the period of nearly 6 months of stoping in $163_{lower}02C$ working face, 6496 micro seismic events were detected and located nearby the working face. Up to August 31, 2010, stoping activity in this working face is finished. The monthly classification statistics of micro seismic events and monthly footage are shown in Table 1, from which we can see that shocks caused by excavation are mainly events with small energy release at 10^2~10^4 J; mine earthquakes releasing energy over 10^4 J are relatively fewer. Monthly earthquake frequency is closely related to monthly footage in this working face. If the monthly footage is large, the monthly earthquake frequency will increase. Table 2 shows the proportion of events at different energy level. After effective treatment, the shock energy of $163_{lower}02C$ working face which was once under high impact risk decreased and its energy release was stabilized.

Table 1. Monthly classification statistics of micro seismic events and monthly footage

Date	Shock Energy /J				Footage /m
	10^2～10^3	10^3～10^4	>10^4	Number of Earthquakes	
2010.03	23	14	0	37	34
2010.04	387	158	4	549	111
2010.05	369	83	1	453	153
2010.06	570	81	0	651	183
2010.07	332	188	8	528	135
2010.08	306	90	0	396	123

Table 2. Statistics of mine earthquakes in 163_{lower}02C working face

Energy Released by Mine Earthquakes E /J	$\leq 10^3$	$10^3 \sim 10^4$	$10^4 \sim 10^5$	合计
Energy Level	10^2 J	10^3 J	10^4 J	
Earthquake Frequency /times	5300	1155	41	6496
Proportion	81%	18%	1%	100%



(a) 5×10^3 J <E< 10^4 J (b) 10^4 J <E< 10^5 J

Figure 4. Distribution of Micro Seismic Events with an Energy Level Above 5×10^3 J

Figure 4 shows the distribution of mine earthquakes taking place every half-month during excavation, from which we can tell that:

In most part of this working face, there are few earthquakes in gobs, especially large-scale ones. This indicates that long-hole blasting on the roof before stoping is quite effective, severing the arms of the ‘T’ structure. As a result, 163_{lower}02C working face would mainly be influenced by the breaking and collapse of the roof.

Earthquakes mainly take place in the conveyor gateway while fewer happen in the secondary gateway. This means that the roof of the gob nearby the secondary gateway collapse more sufficiently and the structure of the roof becomes more stable. Overburden movement in the gob on the side of conveyor gateway is not sufficient, so its structure is at a relatively stable state, but if disturbed by excavation activities, this structure will once again undergo movement and destabilization, thus producing many earthquakes. At the same time, while being cut by fault SF187, the roof of the gob may break along the fault. As a result, since the overhanging roof close to the fault is long, as the working face moves forward, the roof over this area will break and destabilize, resulting in frequent earthquakes in this area. Under the influence of the fault, the roof is much easily prone to sliding and destabilization.

Figure 4 shows the distribution of Micro Seismic Events with an Energy Level Above 5×103 J, from which we can clearly see there are very few high-energy-level seismic events, indicating well effects of impact prevention measures in this working face. In general, high-energy-level seismic events happen in two areas: i) During first weighting, its distance on the roof is long, thus coal pillars suffer greater support pressure. At the same time, the breaking will release high level of energy, so coal rocks, the roof and the floor will suffer relatively more shocks; ii) When fault SF187 is cutting the roof, since this fault is a normal fault, 163_{lower}02C being the upper part and 163_{lower}02 the lower, and the inclination being 55º, when the stoping moves to fault SF187 part of the roof will fracture along the fault and a stable “bond beam” structure will be difficult to form. As a result, a long overhanging roof will be left, which will break and destabilize if disturbed by excavation in 163_{lower}02C working face. These together with the sliding of the upper and lower rocks lead to frequent earthquakes. In later stage of excavation, there are very few severe earthquakes.

Stoping in 163_{lower}02C working face ran from March 22 to August 31, 2010, during which not one rock burst accident took place. According to micro seismic monitoring results, seismic events above a certain standard in this working face add up to 6496, with the maximum energy reaching 1.7×10^5 J (the only one excessing 10^5 J) and averaging at 3.3×10^3 J. Energy releasing during the stoping is stable, which owes credit to scientific analysis of risks and appropriate impact prevention plan.

6. Conclusions

Excavation in island mining face exerts a rather significant influence on its neighboring not-fully excavated gobs. In this way, the long arms of the ‘T’ shaped structure are more active, which will result in greater dynamic synergy. When there is an abscission layer in inferior key strata, this abscission layer will run all the way through gobs, thus forming a larger structure across two working faces. Since this structure extends a large area, overburden fracture in island mining face develops in a faster speed.

In the beginning stage of stoping, plastic failure mainly appears in the lower roof, while in later times, plastic failure in the overburden will gradually move up forwards. Coal seam then is under huge vertical pressure, so the floor will not easily collapse. In this case, relevant impact prevention measures should be applied correspondingly.

Under the dynamic load of mine earthquakes, the left and right ribs suffer slighter deformation than the roof and the floor; the right rib and the roof changes faster than other places; the roof sinks the most; and the vertical stress on the left and right ribs are bigger than that on the roof and the floor.

In island mining face, a strong mine earthquake induced by the breaking of the overburden may cause severe damage to roadways, particularly to the rib close to gob. In case of a hard roof in island mining face, the floor there is under a strong concentration of stress, so during stoping, stronger measures to release pressure from coal pillars adjacent to gob should be applied and roadway support should also be strengthened so as to form a strong-weak-strong structure, thus resisting mine earthquake’s shock waves. Other pressure-releasing measures such as blasting on the floor should also be considered if necessary.

Analysis on 163_{lower}02C working face with high impact risk is indicative of the reason that lead to frequent earthquakes caused by concentrated stress in coal rocks, and that is the length of the overhanging roof in lower inferior key strata at the arms of the ‘T’ structure is relatively long. In this scenario, breaking and destabilization may happen under the influence of excavation. At the same time, the working face is deep underground, together with high static and dynamic load, so shocks in the roof can easily lead to impact. Micro seismic monitoring results show that by scientific calculation of parameters and using long-hole blasting to sever the overhanging roof before stoping, energy release keeps stable and even with no high-energy-level mine earthquakes and not one rock burst accident, indicating well effects of impact prevention measures in this working face.

Acknowledgments

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