Study on Risk Analysis and Control Technology of Coal Bump *

Xufeng Pang, Yaodong Jiang, Yixin Zhao and Jie Zhu

Abstract

According to the characteristics of coal mine, this paper proposes the definition and function expression of risk. The accident-cause model of coal bump risk is established on the theory of risk management and the analysis of natural and human risk factors. Besides, this paper presents the prevention and control measures of coal bump risk.

1. Introduction

Because of the complicated causes, many affected factors, burstiness and great destructiveness, coal bump is now one of the most serious risks in coal mine, which has many uncertainties and unknowabilities. So there is great risk in deep mining. As our country gradually steps into the deep mining, plenty of coal bumps have great economic loss and bad effect on our country and coal mine enterprises. What is the cause and process of coal bump risk? How can we forecast and reduce the possibility and loss of coal bump risk? In a word, all these problems are risk management problems which can be solved by study and application of risk management. Therefore, according to the characteristics of coal mine, this paper studies the definition of risk, the mechanism and control measures of coal bump risk in order to apply the theory of risk management into the deep mining for improving the safety conditions in coal mine.

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2. The definition of risk

The risk is objective, it can be avoided, controlled and transferred but can’t be fundamentally eliminated. The essence and heart of the risk is uncertainty. The occurrence and the consequence of the risk are uncertain. American scholars Yates and Stone prompted three-factor model of the risk construction. They thought there were three factors determining the risk, i.e. potential loss, the level of the loss and the uncertainty of the potential loss. The model was the fundamental frame of modern risk theories which has indicated the basic connotation of the risk [1].

Because of the different research purpose and concerns in application, the understanding of the risk is different. In this paper, according to the characteristics of coal mine production and previous research, risk is defined as the combination of the accident probability that an objective or an activity result in accident and the accident losses in the safety production of coal mine. The factors that cause risk accident or increasing the occurrence probability and losses are called risk factors. They are the potential or indirect causes of risk events and losses. They are generally divided into objective factors and subjective factors [2]. Objective factors are the visible material conditions which can directly lead the risk, while subjective factors are the invisible human conditions which are connected with human behavior and awareness. The risk losses mainly include economic losses, casualties, construction time losses and environment influence, et al.

According to the above definition, this paper uses P (Probability) to express the probability of the risk which is the function of \( m \) risk factors, the coefficient \( K \) is the influence of each factor on the whole risk [3], as equation (1) follows. The sequence severity C (Criticality) delineates the level of losses which is the function of \( n \) losses, as equation (2) follows. R (Risk Rate) delineates the level of the risk which is the function of risk probability P and sequence severity C, as equation (3) follows.

\[
P = \frac{\sum P_i K_i}{m}
\]

(1)

\[
C = \sum C_i
\]

(2)

\[
R = P \cdot C = \frac{\sum P_i K_i}{m} \cdot \sum C_i
\]

(3)

The definition indicates two aspects of the risk, one is the source of risk (risk factors), and another is the result (risk losses). The treatment measures of risk are to control sources and reduce losses. It is necessary to recognize, analyze and control the risk factors and to liquidate, avoid and transfer the risk losses.

3. Risk analysis of coal bump

Coal seam and surrounding rock of roof and floor is a stable balanced-system which is destroyed by human mining, that is to say the involvement of human factors changes the original status of material factors and makes them have the probability of the risk.

The occurrence of coal bump is the result under comprehensive function of various factors. The research on the occurrence mechanism of coal bump risk plays an important role for safety production in coal mine. According to the relationship between coal bump and coal mining, the risk factors causing coal
bump are divided into natural risk and human risk factors. According to the accident-causing model of track-cross theory, the paper establishes the accident-causing model of coal bump risk in coal mine, as fig.1 shows. On the basis of previous studies, the natural risks are divided into mining depth, geological structure and coal petrology characteristics, while human risks are divided into mining technology and organizational management. These tracks of the above two risks are cross in a space-time node. If we took reasonable measures in the node, the risk would be avoided. But if there were induction factors to cause risk or the control measures were invalid, coal bump would be happen.

![Fig.1 the Accident-causing Model of Coal Bump Risk](image)

### 3.1. Natural Risk Factors

Natural risk factors are the inherent risk in coal mine which are the nature and premise of risk accidents. They are objective that can be controlled but can’t be eliminated.

1. **Mining Depth**
   
   With the increase of mining depth, the geostatic stress of coal-rock mass and the accumulative flexibility increase and the probability of coal bump risk increase[^4].

2. **Geological Structure**
   
   Complicated and specific geological structure influences the distribution of original rock stress and increases the risk of coal bump[^5]. The main geological structure factors of coal bump risk are folds, faults, partial transformation zones of coal seam pitch and height and tectonic stress zones, especially the synclinal axis.

3. **Coal Petrology Characteristics**
   
   The characteristics of coal seam and surrounding rock of roof and floor are also the main risk factors. The roof that is solid, thick, strong integrity and uneasily collapses is easy to form coal bump. If coal is stronger, thicker, bigger elastic modulus, lower water content, higher metamorphic grade and larger proportion of durian, the bursting liability will be stronger[^6].

### 3.2. Human Risk Factors

Human risk factors are dynamitic risks in coal mine which can be pre-controlled. One or some of human risk factors may become induction factors. The energy of induction factors may be very small but...
may become the fuse of the accident. However, if we take some control measures in advance, the accident may be avoided or delayed. These control measures are aimed at coal petrology characteristics, mining technology and organizational management, as Fig. 1 shows.

(1) Mining Technology

Mining technology determines the production and schedule in coal mine and also determines the safety condition. Unreasonable mining technology may cause stress concentration and increase coal bump risk. The risks of mining technology mainly involve mining designs, mining methods, working face layout, coal pillars and so on. The main mining technology factors are as follows. Such as unreasonable mining procedure, incomplete mining and unreasonable alternate distance between two adjacent seams when mining multiple coal seams; roadway and working face promote counter, working face promote to goaf or fault zones; when taking short-wall mining methods, there are many roadways, crosses and remained coal pillars; the shape of working face is curve or irregular; the unreasonable mining layout forms isolated coal pillars [4].

Plenty of domestic and international practices show that coal bump usually happen following by some small production process. The partial stress of the coal mass can be changed when blasting, drilling or mining, which may become the triggers of the coal bump.

(2) Organizational Management

The organizational management factors mainly involve personnel organizations, technical equipments, protection methods and emergency measures. The higher the level of the concentration of production, the more easily coal bump happens. The investment and support technology and equipments being not in place, three illegal behaviors of staff, unreliable monitoring and forecasting and unreasonable emergency measures will all indirectly increase coal bump risk and cause heavy casualties and losses.

4. Control strategies of coal bump risk

Table 1 Control Strategies of Coal Bump Risk

<table>
<thead>
<tr>
<th>Risk classification</th>
<th>Main risk factors</th>
<th>Risk control strategies</th>
<th>Risk control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural risk</td>
<td>Mining depth</td>
<td>Risk avoiding</td>
<td>No-mining</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk self-retention</td>
<td>Risk taking and avoid disasters</td>
</tr>
<tr>
<td></td>
<td>Geological structure</td>
<td>Risk avoiding</td>
<td>No-mining</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk self-retention</td>
<td>Risk taking and avoid disasters</td>
</tr>
<tr>
<td></td>
<td>Coal petrology characteristics</td>
<td>Risk prevention</td>
<td>Blasting distressing</td>
</tr>
<tr>
<td></td>
<td>Mining technology</td>
<td>Risk avoiding</td>
<td>Scientific mining</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk prevention</td>
<td>Optimal layout</td>
</tr>
<tr>
<td></td>
<td>Organization management</td>
<td>Risk prevention</td>
<td>Reasonable support</td>
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<tr>
<td></td>
<td></td>
<td>Risk transferring</td>
<td>Monitoring and prediction</td>
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<td></td>
<td></td>
<td>Risk reserve</td>
<td>Introducing insurance</td>
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<td></td>
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<td></td>
<td>Individual protection</td>
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</tbody>
</table>

According to the former analysis and Fig. 1, the risk of coal mining is objective. The cross of natural and human risk factors is the premise of accident occurrence. Natural risk factors are inherent, human risks are controllable, triggers are stochastic, control measures are necessary. From the perspective of accident prevention, to avoid accident occurrence is to avoid the cross of the natural and human risk factors and to pre-control every risk factor. With regard to stochastic triggers, we should take monitor-dangerbreak-work methods to decrease the risk. When selecting risk control measures, we should consider eliminate the risk factors firstly, then control the factors in terms of sources. When it can’t still
decrease the risk, we should take individual protective measures [2]. Common control strategies of the risk include risk prevention, risk avoiding, risk transferring, risk self-retention and risk reserve. Concrete strategies of coal bump risk are as table 1 follows.

4.1. Control Strategies of Natural Risk Factors

Mining depth and geological structure are caused by original geological movements and can’t be changed by human. The control strategies are risk avoiding or risk self-retention, i.e. to avoid dangerous mining depth or special geological structure to product coal, or undertake the risks of mining depth or special geological structure and avoid disasters taking some measures. For example, we can take mining methods from the axial part of fold zones and from the fault part of fault zones.

The coal petrology characteristics are also inherent natural risk factors, but they can be changed by human methods to decrease the risk. The corresponding control strategy is risk prevention. That is to say, we can take some technology to decrease the partial stress concentration, energy accumulation and the bursting liability. For example, we can take blasting distressing or water-infusion softening to change the physical and mechanical properties of the coal mass and decrease the bursting liability and prevent coal bump risk.

4.2. Control Strategies of Human Risk Factors

Because of different mining methods and roadway layouts of mining technology, the underground pressures and regularities of distribution are different. But these human risk factors can be eliminated, the corresponding strategies are risk avoiding or risk prevention. We can take scientific and reasonable technology to avoid some human risk factors in advance, or make good prevention for unavoidable risks. For example, when mining the coal seam with the bursting liability, we can take long-wall mining that don’t leave coal pillar and manage the roof by carving methods. The mining line must be as possible as straight lines and regularly promoted. When mining heavy coal seams, we should firstly mine coal seams that are weaker bursting liability and can be pressure released.

The organizational management is the backup measures and the last key step to prevent coal bump and reduce accident loss. The corresponding control strategies are risk prevention, risk transferring and risk reserve. We can reduce the losses by monitoring and prediction, education and training, emergency rescuing. For example, we can enhance monitor and forecast by comprehensive index method, micro-seismic method, acoustic emission technique and electromagnetic radiation method. We take retractable supports with integrity and protection capability. We should enhance education and training and institutional constraint to avoid three-violate action. Then we enhance the investment in disaster prevention and individual protection, and make the emergency plan. we also can introduce the insurance into safety production to transfer the risk in coal mine.

5. Analysis of coal bump cases

On the basis of investigation on Zhaogezhuang Coal Mine in Kailuan and Laohutai Coal Mine in Fushun [7]. This paper analyzes some typical coal bump cases using the above methods and control strategies, as table 2 shows.
Table 2  Risk Analysis and Control Strategies of Typical Coal Bump Cases

<table>
<thead>
<tr>
<th>Names of Coal Mine</th>
<th>Description of Typical Cases</th>
<th>Mining Depth</th>
<th>Geological Structure</th>
<th>Coal Petrology Characteristics</th>
<th>Mining Technology</th>
<th>Organization Management</th>
<th>Trigger Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhaogezhuang Coal Mine</td>
<td>2337# working face, loud noise, floor heave, wall systolic, support destroyed</td>
<td>-980m</td>
<td>Located near the synclinal axis</td>
<td>Strong bursting liability coal seam</td>
<td>Around the working face mining irregular and upper coal mining incomplete</td>
<td>Low intensity of support, the lack of real-time monitoring</td>
<td>Blasting, earthquake activity</td>
</tr>
<tr>
<td>Laohutai Coal Mine</td>
<td>83001# north crossheading working face, coal outburst 470t</td>
<td>-830m</td>
<td>Located near the fault</td>
<td>Thick and hard roof, thick and moderate bursting liability coal seam</td>
<td>Goaf influence</td>
<td>Low intensity of support, roof management unreasonable</td>
<td>Blasting</td>
</tr>
</tbody>
</table>

Control Strategies of Risk

| Risk taking and avoid disasters | Risk taking and avoid disasters, monitoring and prediction | Blasting distressing, water-infusion softening | Optimal layout, reasonable support | Increase investment, monitoring and prediction | Optimal technology, monitoring and prediction |

6. Conclusion

Coal bump is one of the major disasters in coal mine, which can be analyzed and controlled with the theory of risk management in order to provide technical guidance for safety production. According to the characteristics of coal mine, this paper has proposed the definition and function expression of risk. In the paper, the risk factors of coal bump are divided into natural risk and human risk factors. Natural risk factors include mining depth, geological structure and coal petrology characteristics, while human risk factors contain mining technology and organizational management. Coal bump is broken out on the time-space cross of natural and human risk factors, and triggered with induction factors. The risk of coal bump is preventable and controllable, it should take the corresponding strategies and technical measures for every risk factor in order to prevent the accidents and reduce losses.

References