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Simulation Study on Risk Warning and Control Mechanism and Transmission Path of Major Disasters and Accidents in Coal Mine Based on Method of Structural Equation

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Abstract: *The frequent occurrence of coal mine accidents seriously jeopardizes people's lives and national public property. Early warning of coal mine disaster accidents can provide rescue programs for the occurrence of coal mine disaster accidents to reduce losses. This paper analyzes the current situation of coal mine major disaster accidents in China, conducts a study of coal mine major disaster accident risk early warning by means of questionnaires, analyzes the association of risk factors affecting coal mine major disaster accidents with risk early warning by warning by means of questionnaires, analyzes the association of risk factors affecting coal mine major disaster accidents with risk early warning by constructing structural equation models, and finally proposes corresponding measures to make a comprehensive evaluation and early warning of coal mine major disaster events.Initially, the theories relating to the risk warning of coal mine production safety are analyzed and summarized. Then, the characteristics and causal factors of major disaster accidents in coal mines are thoroughly examined, leading to the compilation of major disaster risk warning indicators. By developing a structural equation model to warn against major disasters in coal mines, a study evaluating safety measures was conducted. The results can significantly reduce the threat of major accidents to coal mine operations. Based on the findings, countermeasures addressing production challenges were proposed for safety management and technology. These countermeasures aim to provide guidance and reference for coal mines related to safety work.*

Keywords: *Major coal mine disasters; Risk Warning; Structural Equation Model; SPSS; AMO*

1. Introduction

Coal safety has been the focus of extensive social concern worldwide and a prominent issue in China. Coal has always been the first energy source in China[1]. Under the influence of natural environment and geography, coal in China is mostly suitable for underground mining. From ancient times to the present, there have been dozens of unavoidable disasters in the process of coal mine production and operation, which threaten the stability of people's living space at any time. Among them, major coal mine disasters are the result of the intersection between human, machine, environment and management factors[2]. In this paper, by constructing a structural equation model, we analyze the risk factors that exist in major disaster accidents in coal mines, find out the most influential factors that affect major disaster accidents in coal mines and get the risk factors that are more closely related to risk warning, and finally come up with relevant measures to prevent the occurrence of major disasters. The characteristics of the coal mining industry determine the importance of safety management, especially the frequent occurrence of coal mine accidents, which often bring great blows to coal mining enterprises. In China, the coal industry, due to its special production conditions, has been one of the high-risk industries in our society, with casualties occurring almost every year[3]. Although the national government has formulated relevant laws and regulations, introduced a large number of institutional measures regarding safety inspection, and increased the supervision and inspection of enterprises in the process of safety production, etc., the results received are not very good, and accidents of all sizes still occur frequently[4]. Starting from the various aspects that affect major disaster accidents in coal mines, structural equation modeling is used to explore the factors that have the deepest influence on the early warning of major disaster accidents in coal mines and to quantify the correlation between them.

2. Purpose of the study

The purpose of this paper is to study the risk warning of major coal mine disaster accidents, combine the existing relevant theoretical research, design the investigation of major coal mine accidents and their influencing factors on the risk warning, investigate and analyze the effect on the risk warning of major coal mine disaster accidents from four dimensions: human factors, physical factors, environmental factors, and management factors, respectively, and propose targeted countermeasure suggestions from these dimensions, respectively, to reduce the the probability of major disaster accidents in coal mines .

3. Questionnaire design

3.1 Variable design

There are four aspects involved in the generation of major disaster accidents in coal mines, and we design relevant variables from these four aspects in order to measure the accuracy of their early warning. One is the human factor, the other is the physical factor, the third is the environmental factor, and the fourth is the management factor. In order to study the risk warning of major coal mine disasters and accidents, this study designs five first-order latent variables, which belong to four categories of second-order latent variables: human factors, physical factors, environmental factors, and management factors. The five first-order latent variables are coal mine fire aspect, coal mine flood aspect, coal mine gas explosion aspect, coal mine dust explosion aspect, and coal mine impact ground pressure aspect.

3.2 Questionnaire design

The core question studied in this paper is the influence of causal factors of major coal mine disaster accidents on the risk warning of major coal mine disaster accidents[5]. Through literature analysis and expert interviews, the content dimensions of the questionnaire for major coal mine disaster accident risk warning were divided. There were 41 questions in the questionnaire, mainly divided into two categories[6]: quantitative and non-quantitative. The non-quantitative questions were the basic information of the respondents, and 30 questions were retained after analysis and screening. Four to five evaluation indicators were designed as observed variables for each of the four latent variables: human factors, physical factors, environmental factors, and management factors. The human unsafe behavior dimension contains 5 questions, the machine work performance dimension contains 4 questions, the machine prevention performance dimension contains 2 questions, the natural environment dimension contains 7 questions, the human activities change the environment dimension contains 4 questions, and the management factor dimension contains 5 questions, forming a total of 30 test questions as the observed variables. The questionnaire was prepared according to a 4-point scale, and the respondents' responses were assigned a score of 1 to 4 from "great influence" to "no influence". 105 questionnaires were distributed, and 105 valid questionnaires were returned, with a 100% return rate.

3.3 Sample information

Table 1 Basic information of the sample

	Classification	Number of samples	Percentage
Gender	Male	55	52.38%
	Female	50	47.62%
Academic qualifications	High School and below	8	7.61%
	Specialty	13	12.38%
	Undergraduate	80	76.19%
	Graduate student and above	4	3.81%
Level of knowledge of major coal mine disasters and accidents	Very knowledgeable and understanding	51	48.57%
	General Understanding	36	34.29%
	Don't really know	18	17.14%
	Specialty	13	12.38%
	Students	178	52.66%
	Other	3	0.89%

As can be seen from Table 1, because this test was mainly concentrated in colleges and universities, most of those surveyed were undergraduates, accounting for 76.19%, followed by college staff specialists, accounting for 12.38%, so the education level was generally at undergraduate level and above. In the survey on the degree of knowledge of major coal mine disasters, the number of people who know and understand very well accounted for 48.57%, followed by the general understanding, accounting for 34.29%.

4. SPSS initial model testing and analysis

4.1 Confidence analysis

Reliability is the degree of consistency and stability of measurement results[7]. The SPSS 27.0 statistical software was used to analyze the sample data for internal consistency reliability. It is generally accepted that the reliability of the scale is good if the Alpha (Cronbach) coefficient is above 0.8. The Alpha (Cronbach) coefficient in this study was 0.940, which indicates that the reliability of the questionnaire is good and the data results are reliable, and the results are shown in Table 2 below.

Table 2 Reliability statistics

Cronbach Alpha	Number of items
.940	27

4.2 Validity analysis

Validity analysis is to analyze the validity of the sample data, the level of validity reflects the extent to which the questionnaire reflects the theoretical assumptions, the larger the value, the greater the extent to which the theory reflects the actual situation, and the smaller is the opposite[8]. Risk factors were analyzed using SPSS with Bartlett's test of sphericity and KMO test are presented in Table 3 below. The KMO value reached 0.898 and the significance of Bartlett's spherical test was 0.000, which is less than 0.05, indicating a high correlation and good degree of validity between the variables.

Table 3 KMO and Bartlett's test

KMO Sampling suitability number.		.898
Bartlett's sphericity test	Approximate cardinality	1424.737
	Degree of freedom	351
	Significance	.000
a. Relevance-based		

4.3 Descriptive statistical analysis of the questionnaire

Descriptive statistical analysis of the risk factors is shown in Table 4 below.

Table 4 Description Statistics

	N	Minimum value	Maximum value	Average value	Standard deviation	Variance
1. What do you think is the degree of influence of employee safety awareness on major coal mine disasters and accidents	105	1	4	2.01	.753	.567
2. What do you think is the extent of the impact of illegal operation of employees on major disaster accidents in coal mines	105	1	4	1.88	.730	.533
3. How do you think the psychological and mental state of the employees affects the degree of major disaster accidents in coal mines	105	1	4	2.15	.794	.630
4. How much do you think the professional knowledge and skills of the employees affect the major disaster accidents in coal mines?	105	1	4	1.88	.756	.571
5. How do you think employees violate the principle of water exploration and release for the degree of impact of flooding accidents in coal mines	105	1	4	1.85	.731	.534

6. What do you think is the degree of impact of roof collapse on coal mine gas explosion accident?	105	1	4	1.92	.768	.590
7. Do you think the use of non-coal mine explosives and electric detonators for coal mine gas explosion accident impact degree how	105	1	4	1.85	.782	.611
8. How do you think the use of non-coal mine small power blower for coal mine gas explosion accident impact degree	105	1	4	1.98	.796	.634
9. Do you think the drainage system (equipment drainage, water detection and release equipment, etc.) for the degree of impact of flooding accidents in coal mines	105	1	4	1.79	.716	.513
10. What do you think is the degree of influence of equipment fire prevention and dustproof capability on coal mine fire accidents?	105	1	4	1.79	.703	.494
11. How do you think the hazardous equipment that can produce combustible materials, combustion materials and ignition sources affects the degree of coal mine fire accidents?	105	1	4	1.77	.823	.678
12. How do you think geological conditions affect the extent of flooding accidents in coal mines?	105	1	4	1.89	.725	.525
13. What do you think is the degree of influence of ventilation capacity on coal mine fire accidents?	105	1	4	1.97	.700	.490
14. Do you think that the coal is easy to spontaneous combustion for the coal mine fire accident impact degree how	105	1	4	1.90	.759	.575
15. How do you think the natural ventilation conditions affect the degree of dust explosion accidents in coal mines	105	1	4	2.00	.760	.577
16, you think the detonation heat source and explosion environment for the coal mine dust explosion accident impact degree how	105	1	4	1.91	.748	.560
17. How do you think the geological conditions affect the degree of coal mine gas explosion accidents?	105	1	4	1.85	.731	.534
18. How do you think the physical and mechanical properties of coal rocks affect the impact ground pressure accidents in coal mines?	105	1	4	2.05	.739	.546
19. How do you think the dust concentration and toxicity for coal mine dust explosion accident impact degree	105	1	4	1.81	.681	.463
20. What do you think is the degree of influence of dust particle size on coal mine dust explosion accidents	105	1	4	2.02	.720	.519
21. What do you think is the degree of influence of mutual disturbance between mining areas on coal mine impact ground pressure accidents?	105	1	4	2.01	.753	.567
22. How do you think the mining depth affects the impact pressure accident in coal mines?	105	1	4	1.94	.718	.516
23. What do you think is the degree of influence of hidden danger investigation and management on major coal mine disaster accidents	105	1	4	1.84	.735	.541
24. What do you think is the degree of influence of safety management regulations and supervision on major disaster accidents in coal mines	105	1	4	1.78	.759	.577

25. What do you think is the degree of influence of managers' ability on the major disaster accidents in coal mines	105	1	3	2.07	.737	.544
26. How do you think the safety engineering technology and management staffing affect the degree of major disaster accidents in coal mines?	105	1	3	1.91	.709	.502
27. What do you think is the degree of influence of safety input on major disaster accidents in coal mines	105	1	4	1.99	.727	.529

It seems from the sub-means that the vast majority of people think that the factor of things is high, where the factor of instruments with the characteristics of each major accident has the highest mean value, indicating that the majority of people think that instruments have a high impact on the major disaster risk warning in coal mines, where controlling the state of different instruments and using the specifications can have a significant impact on the major disaster accident warning.

5. Structural equation model construction

5.1 Introduction to the structural equation model

Structural Equation Modeling (SEM) is a social science research method based on matrix analysis techniques for analyzing complex multivariate problems[9]. Structural Equation Modelling (SEM) is favoured by many research scholars due to its capacity to indicate causal relationships between variables, its strong processing abilities and numerous applications in project management and economic development studies.

5.2 Composition of the structural equation model

5.2.1 Basic variables[10]

Latent variables cannot be measured directly, but must be observed through the data information of the reflected variable[11]. On the other hand, an observed variable can be directly measured and observed.

5.2.2 Basic model

Measurement model

The measurement model is composed of latent and observed variables and reflects the relationship between the observed and latent variables[12].

The formula is as follows

$$\begin{aligned} x &= \Lambda_x \xi + \delta \\ y &= \Lambda_y \eta + \varepsilon \end{aligned} \tag{1}$$

Eq:

y - endogenous observation variable; x - exogenous observation vector;

Λ_x -factor loadings of the variables; Λ_y -factor loadings of the variables;

η -endogenous latent variables; ξ -exogenous latent variables;

δ -measurement error of the variable; ε -measurement error of the variable y.

② Structural Model

The structural model is a model of the correlation between latent variables with the following equation[13]:

$$\eta = B_{\eta} + \Gamma \xi + \varsigma \tag{2}$$

Eq:

B- reflects the relationship between endogenous latent variables; Γ - the degree of influence of ξ on η ;

ζ -Errors in the structural equations.

5.3 Structural equation modeling

The modeling process of structural equation model is divided into 5 steps: model construction, model identification, model fitting, model evaluation, and model correction. The details are shown in the figure 1.

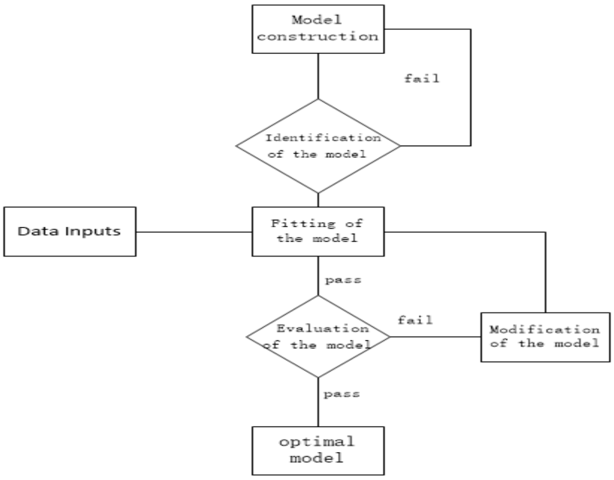

Figure 1 Step-by-step diagram for structural equation modeling analysis

5.3.1 Model construction

Model construction refers to the establishment of measurement and structural models and the formulation of research hypotheses based on a specific research object, using mathematical equations or path diagrams based on relevant theoretical research results.

5.3.2 Identification of the model

Theoretical model testing may occur when the model is not identified, so firstly, model identification is required, which is the estimation of the unknown parameters in the model[14]. Firstly, the number of exogenous observed variables and endogenous observed variables in the model are estimated, and secondly, the degrees of freedom of the parameters to be estimated in the model are calculated, and the magnitude of both is related to whether the model has a solution or not. According to Bollen's model identification rating rule ($t-rule$) model identification results in three outcomes: over-identification, just-identification, and under-identification, as detailed in Table5.

The model satisfies the conditions for identification as follows[15]:

$$t \leq \frac{1}{2}(p+q)(p+q+1) \quad (3)$$

In the formula:

p - number of exogenous observed variables; q - number of endogenous observed variables;

t-Number of free parameters.

Table 5 Law judgment result

Serial number	Judgment Conditions	Model Identification Results	Explanation
1	$t<\frac{1}{2}(p+q)(p+q+1)$	Over-identification	SEM models can be fit tested
2	$t=\frac{1}{2}(p+q)(p+q+1)$	Just the right identification	SEM model suitability cannot be tested
3	$t>\frac{1}{2}(p+q)(p+q+1)$	Low recognition	SEM model estimation cannot obtain a unique solution

5.3.3 Fitting of the model

Model fitting is the process of inputting the data from the research into a structural equation model and fitting the data with the help of software such as AMOS using the likelihood function method to verify the correlation between the structural equation model and the actual situation.

5.3.4 Evaluation of the model

Model evaluation is to analyze the fit of the theoretically constructed structural equation model with the research data by comparing the parameter estimates with the reference index values after obtaining the model output, so as to evaluate whether the model is the same as the real situation and whether the optimal model is obtained. To perform model evaluation, we generally test whether the output of the structural equation model meets the requirements and whether the fit of the structural equation model to the sample data meets the requirements. If all the above tests meet the requirements, the theoretical hypothesis is accepted; if there is a test that does not meet the requirements, the original hypothesis is rejected. If there are parameters that do not meet the requirements when the model is evaluated, the model can be revised and processed, and then the model can be optimized.

5.3.5 Modification of the model

Model revision is a process that requires optimization of the structural equation model if the parameter estimates or model fitness are not in a reasonable range. The steps to revise the model are to add or delete restructuring variables or release restrictions according to the model fit results, and then to check whether the basic parameters and fit indicators meet the requirements. The process of modifying the model is the process of continuously improving the model fitness, and the actual operation may require several corrections to obtain the optimal model.

5.4 Initial structural equation model

Based on the research hypothesis, a preliminary model of the full path structural equation affecting the risk warning of major disaster accidents in coal mines was constructed. As shown in Figure 2.

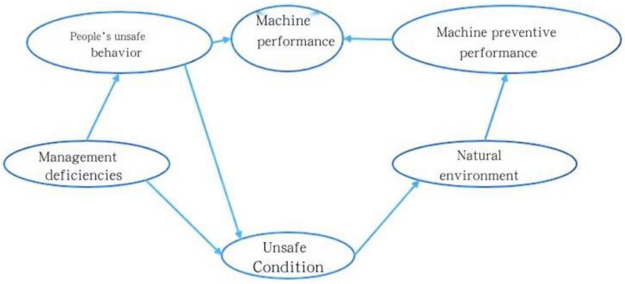

Figure 2 A preliminary model of the full path structure for risk warning of major disaster accidents in coal mines

6. Data and Model Analysis

The regression path diagram is generated after the model is built and data is imported through AMOS

As shown in Figure 3.

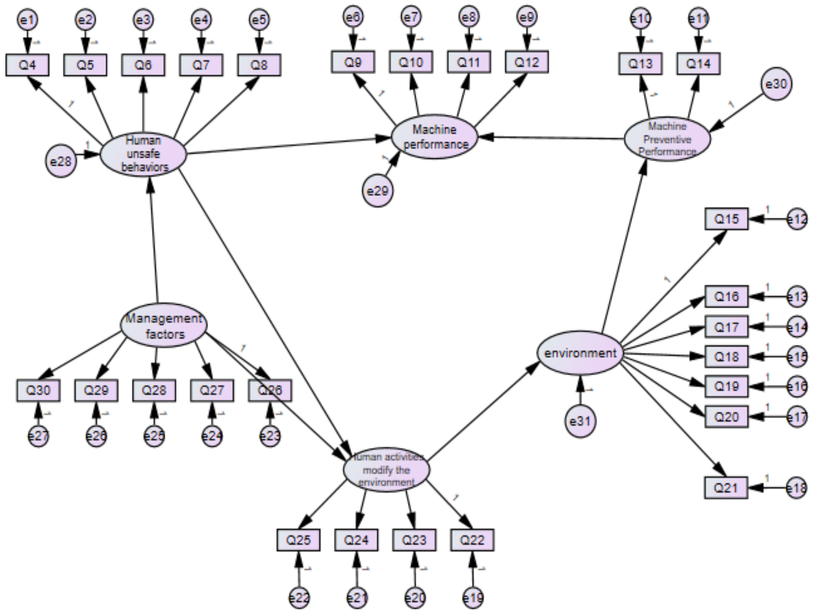

Figure 3 Regression path diagram

For "human unsafe behaviors", it can be seen that all the significant variables are positively correlated with the latent variables and the correlations are relatively large. The standardized regression coefficients between employee safety awareness, employee illegal operation, employee psychological and mental state, employee expertise, and violation of water exploration and discharge principles (mine flooding) and human unsafe behavior were 0.69, 0.74, 0.75, 0.79, and 0.78, respectively, and the majority of the surveyed sample group believed that employee expertise was more influential and more likely to contribute to the occurrence of coal mine disasters. Among them, violations of water exploration and release principles are also more likely to lead to coal mine flooding.

For "machine performance", it can be seen that all the significant variables are positively related to the latent variables. The standardized regression coefficients between roof fall (coal mine gas), use of non-coal mine explosives (coal mine gas), use of non-coal mine low-powered blowers (coal mine gas), and drainage system (coal mine flood) and machine performance are 0.74, 0.70, 0.60, and 0.54, respectively. Mutual impact and friction release energy to produce high temperature on the rock surface to cause gas disaster accident. From this and the model, it is clear that the impact of roof collapse on the occurrence of gas explosion is very large.

For "machine prevention performance", it can be seen that all the significant variables are positively correlated with the latent variables. Among them, the standardized regression coefficients between the fire and dust resistance of equipment (coal mine fire and dust explosion) and hazardous equipment that can produce combustible materials, combustion materials and ignition sources (coal mine fire) and machine prevention performance are 0.76 and 0.60, respectively. It can be seen that improving the fire and dust resistance of equipment is very important to prevent fire and dust explosion.

For the "natural environment" can be seen, each significant variable is positively related to the latent variables. The standardized regression coefficients between geological conditions (coal mine floods), ventilation (coal mine fires), ease of spontaneous combustion of coal (coal mine fires), natural ventilation (dust explosions), detonation heat source and explosive environment (dust explosions), and geological conditions (gas explosions) and the natural environment affecting coal mine hazards are 0.53, 0.61, 0.73, 0.64, 0.64, 0.48, and 0.67, respectively, Ventilation is crucial for both fire, dust explosion and gas explosion.

For the "anthropogenic activities to change the environment", it can be seen that all the significant variables are positively correlated with the latent variables. The standardized regression coefficients between dust concentration and toxicity (dust explosion), dust particle size (dust explosion), inter-take disturbance (impact ground pressure), and mining depth (impact ground pressure) and anthropogenic modification of the natural environment and thus coal mine hazards are 0.65, 0.41, 0.65, and 0.64, respectively.

For the "management factors", it can be seen that all the significant variables are positively correlated with the latent variables. Among them, the standardized regression coefficients of 0.65, 0.53, 0.25, 0.61, and 0.66 were found between hidden danger investigation and management, safety management procedures and supervision, managerial ability, safety technical engineering and management staffing, and safety investment and management factors, respectively.

As can be seen from the plotted structural equation model path diagrams, the correlations between machine performance and between environments are relatively large.

7. Conclusion

Coal mine flooding. According to the above model and analysis, we can learn that violation of water exploration and release principles, drainage system, geological conditions, etc. can affect the possibility of coal mine flooding. The sixteen principles of water exploration and discharge are: if there is doubt, explore, explore before digging, explore before mining. We need to strengthen the supervision and management of the staff's water exploration and release behavior, and operate strictly according to the water exploration and release principles, so as to reduce the possibility of coal mine flooding; improve the drainage system and drainage equipment, and send special personnel to regularly check the performance and maintenance; observe the geological conditions, and pay attention to the gushing of groundwater and the timely removal of other water sources.

Coal mine fires. According to the above model and analysis, it can be seen that equipment fire prevention capability, dangerous equipment that can produce combustible materials, combustion materials, ignition sources, ventilation capability, and whether coal is easy to natural, etc. can affect the possibility of coal mine fires. Using equipment with higher fire prevention capability and other fire prevention measures, particularly for hazardous equipment, such as safety switches, judicious use of electrical equipment, regular equipment maintenance, etc., along with an analysis of the coal seam's nature and isolation protection, can decrease the incidence of coal mine fires. Moreover, fire reduction in the vicinity of hazardous equipment and coal seams, and the implementation of fire analysis per regulations can serve as ways to reduce the possibility of coal mine fires.

Coal mine gas explosion. According to the above model and analysis can be seen, the roof collapse, the use of non-coal mine permitted explosives, the use of non-coal mine small power blower, geological conditions can affect the possibility of coal mine gas explosion. Gas explosion is essentially a violent combustion reaction, the process of such reaction is very complex, the chain reaction of free base is the essence of combustion reaction. After the gas absorbs enough heat, the chain of gas molecules will immediately break and dissociate into multiple free radicals. Free radicals are very active, and when the conditions are suitable, the free radicals can continue to decompose and form several free radicals again. The reaction will continue to generate increasing numbers of free radicals, resulting in an acceleration of the reaction rate that leads to an eventual explosion, improve the ventilation system using the recommended blower to ensure proper working face ventilation and prevent gas build-up, avoid any non-working ignition sources to eliminate the risk of explosions, install rock powder, water sheds, explosion-proof doors and other facilities to reduce the impact of roof collapse after an explosion and take heed of changes in geological conditions, particularly with heightened construction and mining depths, as gas emissions will inevitably increase. The intrusion of magma into the coal seam and groundwater flow will also contribute to an uptick in emissions, adopt moderate mining practices and avoid risky operations to lessen the probability of a coal mine gas explosion.

Coal mine dust explosion. According to the above model and analysis can be seen, equipment dust control capacity, natural ventilation conditions, detonation heat source and explosion environment, dust concentration and toxicity, dust particle size can affect the possibility of coal mine dust explosion. Dust explosion can take the following preventive measures, such as: explosion, explosion isolation, explosion suppression, etc.; to prevent mechanical sparks and friction, the use of dust explosion-proof electrical equipment, to prevent spontaneous combustion of substances in the environment, to prevent open flames, etc. From the point of view of industrial hygiene, various kinds of dusts should be protected from mechanical sparks and friction. From the point of view of industrial hygiene, all kinds of dust is harmful to the human body, the chemical composition of dust and its concentration in the air directly determines the degree of harm to the human body, the higher the amount of free silica in the dust, the more serious the harm. The higher the amount of free silica in the dust, the more serious the hazard. Special measures should be taken to increase air circulation, reduce dust accumulation by using various types of dust collectors, dust spraying, coal seam water injection, etc., especially for dust that is toxic to humans. In this way, the possibility of coal mine dust explosions can be reduced.

Impact ground pressure. According to the above model and analysis, it can be seen that the mutual disturbance between mining areas and mining depth can affect the possibility of impact ground pressure. With the reduction of shallow resources and subsequent articulation to deep mining succession, the load ground stress in the coal body increases, and the long-term load high ground stress, under the repeated strong disturbance of mining activities, the equilibrium stress state of the original coal-body-perimeter rock system is broken, and the impact energy accumulated in the coal body is released. The impact energy accumulated in the coal body is also released. The greater the mining depth is, the greater the possibility of impact pressure occurs, so it is necessary to optimize the anti-influence measures and mining sequence between mining areas and mine reasonably, in order to reduce the possibility of impact pressure.

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