Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2017, 4(12):67-72

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Risk Analysis of Spontaneous Combustion of Coal in Combined Mining of Short Distance Coal Seams

Fu Dong

Department of Safety & Science Engineering, Henan Polytechnic University, Henan, Jiaozuo 454000, China

Abstract Through analysis of factors affecting spontaneous combustion in close distance coal seam, the evaluation hierarchy model of coal spontaneous combustion in near distance seams is established by applying the basic principle of analytic hierarchy process (AHP),the speed of working face is the primary factor affecting the coal spontaneous combustion, followed by coal seam spacing, the interlayer pressure difference and geological structure, the active choice for mine coal spontaneous combustion prevention measures.

Keywords spontaneous combustion; combined mining; mine fire; AHP (analytical hierarchy process); evaluation mode

1. Introduction

The spontaneous combustion process of coal and air is spontaneous combustion under certain conditions. The process of spontaneous combustion of coal is a very complex dynamic process, and it is affected by many factors. China is a country with serious spontaneous combustion of coal, according to statistics [1], in China's key coal mines, the spontaneous combustion mine accounts for 51%. All the mines with large dip angle coal seam, thick and extra thick coal seam basically have spontaneous combustion problems. The annual coal fires caused by spontaneous combustion of coal are more than 360 times. Especially in the near distance coal seam, because of the complexity and particularity of mining conditions, the short distance coal seam combined mining goaf left coal spontaneous combustion occurs frequently, it will affect the production, while in the working face is closed, even the gas explosion caused by goaf accumulation, greatly threaten the safety of miners. Therefore, based on the combination of Sunjiagou coal mine coal mining situation closely, using AHP method will influence factors of coal spontaneous combustion from qualitative description to quantitative representation, determine the main factors affecting coal seam spontaneous combustion goaf near distance, for the prevention of spontaneous combustion in goaf has important practical significance.

2. Hierarchical Analysis of Influencing Factors of Coal Spontaneous Combustion in Fully Mechanized Mining Face

2.1. Level Analytic Method

The analytic hierarchy process (AHP) is a simple, flexible and practical multi criteria decision making method of Professor of operational research experts T.L. Saaty proposed in early 1970s, it is a combination of qualitative and quantitative, systematic and hierarchical analysis method, it is a complicated problem is decomposed into several components, and the formation of according to the hierarchical structure of relations of domination, then the comparative method is used to determine the relative importance of decision criteria.

2.2 Survey of Mining Face

The 11# coal seam is located at 5m below L2 limestone, and the average thickness is 2.19m. The 13# coal seam is located below 19m under the L2 limestone, which is about 14m from the 11# coal seam, and the average thickness of the coal seam is 13.05m.

11101 working face in 11# coal seam layout of the intake in 13# coal seam 13307 tailentry above, the layout of the 11101 11# coal seam working face return air lane in 13# coal seam working face intake above 13307.Because the 13307 mining method is fully mechanized coal mining and caving mining at a full height and the height of mining is 3m, the goaf will be connected with the 11101 working face, resulting in the leakage of ventilation on the 13307 working face and the danger of spontaneous combustion of coal in goaf.

2.3. Establishment of Evaluation Hierarchy Structure Model

Based on field investigation of 11# and 13# coal mining face in Sunjia Gou coal mine, we collected and read a lot of related data. Combined with the actual situation of mining face, referring to the principles of index determination and general requirements of system evaluation, we set up a hierarchical structure model of evaluation index.

The meaning of each evaluation factor is as follows [2-4]:

1) Spontaneous combustion characteristics of coal. Refers to the characteristics of coal itself, this characteristic reflects the ability of coal warming oxidation.

2) Production management. Refers to the management personnel to participate in the organization to prevent coal spontaneous combustion key activities, actively carry out the prevention and control of coal spontaneous combustion technical measures, strengthen the prevention and control of coal spontaneous combustion safety concept, take the pressure, pre grouting, plugging and other active measures to control the goaf spontaneous combustion of residual coal.

3) Production layout of mining face. It refers to the layout of the mining area controlled by people. In the early stage of mining design, the coal spontaneous combustion is considered as a whole. During the mining process, the driving speed of the mining face is controlled artificially, so that the oxidized coal has been thrown into the asphyxiation zone and the interpenetration and air leakage have been reduced.

4) Geological condition of coal seam. Refers to the occurrence condition of coal seam itself, because of the complexity of geological structure, coal seam dip angle and other coal seam occurrence conditions, not only affect the advancing speed of the working face, but also easy to cause air leakage and a large number of lost coal, provide conditions for coal spontaneous combustion.

2.4. Construction Judgment Matrix

The construction of judgement matrix is the transformation from structural model to quantitative model. It is a quantitative judgement of the importance of a factor in the same level in relation to two factors in the same level. The results of all comparisons can be expressed in a matrix form, and the concrete construction method is as follows:

$$A = \left(a_{ij}\right)_{n\times n}, a_{ij} > 0, a_{ij} = \frac{1}{a_{ji}}$$

At this point, A is called positive reciprocal matrix.

There are many kinds of scaling methods for judgment matrix. The scientific 1~9 scale method is used in this paper, and its meaning is shown in table 1.

Table 1: Determine the meaning of the scale of the matrix

Scale value	**1**	**3**	**5**	**7**	**9**	**2、4、6、8**
Importance	The same	Slightly important	Obviously important	Strongly important	Extremely important	Between the two

The judgment matrix of each layer is shown in Table 2 to table 6. The importance of each factor in the judgment matrix is determined by the experts and the engineers and technicians of the mine.

Table 2: Judgment Matrix O－B

O	B_1	B_2	B_3	B_4
B_1	1	1/2	1/5	1/8
B_2	2	1	1/2	1/4
B_3	5	2	1	1/2
B_4	8	4	2	1

Table 3: Judgment Matrix **B_1－C**

B_1	C_1	C_2	C_3
C_1	1	1/5	1/4
C_2	5	1	2
C_3	4	1/2	1

Table 4: Judgment Matrix **B_3－C**

B_3	C_8	C_9	C_{10}
C_8	1	1/6	1/4
C_9	6	1	2
C_{10}	4	1/2	1

Table 5: Judgment Matrix **B_2－C**

B_2	C_2	C_4	C_5	C_6	C_7
C_2	1	1/3	1/3	1	3
C_4	3	1	1	4	5
C_5	3	1	1	3	5
C_6	1	1/4	1/3	1	3
C_7	1/3	1/5	1/5	1/3	1

Table 6: Judgment Matrix **B_4－C**

B_4	C_9	C_{11}	C_{12}	C_{13}	C_{14}
C_9	1	1/2	1/2	3	1
C_{11}	2	1	1/3	4	2
C_{12}	2	3	1	5	2
C_{13}	1/3	1/4	1/5	1	1/3
C_{14}	1	1/2	1/2	3	1

2.5. Calculate the weight of the evaluation index

After constructing the judgment matrix, in order to calculate the weight of each factor, the judgment matrix should be quantized. For the judgment matrix B, the eigenvector is computed by the square root method [5].

1) to normalize each column vector of matrix O-B:

$$w_{ij} = B_{ij} \Big/ \sum_{i=1}^{n} B_{ij} \quad i=1,2,3,\ldots,n \qquad (1)$$

In the formula: W_{ij} is the matrix that is obtained after the normalization of the matrix; it is the element to judge the matrix; n is the order of the judgement matrix, n=4.

It can be obtained from (1) formula: $\begin{pmatrix} 0.062 & 0.067 & 0.054 & 0.067 \\ 0.125 & 0.133 & 0.135 & 0.133 \\ 0.313 & 0.267 & 0.270 & 0.267 \\ 0.500 & 0.533 & 0.541 & 0.533 \end{pmatrix}$

2) Summation of W_{ij} by row $Q_{ij} = \begin{pmatrix} 0.250 \\ 0.526 \\ 1.117 \\ 2.107 \end{pmatrix}$ Normalization processing, the eigenvector is obtained $\begin{pmatrix} 0.063 \\ 0.131 \\ 0.279 \\ 0.527 \end{pmatrix}$ $= e$

For the O-B matrix, the eigenvectors obtained are as follows $e=(0.063,0.131,0.279,0.527)^T$。

2.6. Consistency test of evaluation index

The analytic hierarchy process (AHP) is the subjective judgment according to the relative importance of each evaluation index. It is very important to keep the consistency of judgment in the application of analytic hierarchy process (W_{ij}). Therefore, we need to check the consistency of the judgment matrix. The steps of consistency check are as follows:

1) The largest eigenvalue of computing judgement matrix λ_{max}

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Be)i}{e_i} \qquad \text{among them} \quad B\times e=\begin{pmatrix}0.251\\0.528\\1.120\\2.113\end{pmatrix}$$

$$\text{Substitution } \lambda_{max} = \frac{1}{4}\times\left(\frac{0.251}{0.063}+\frac{0.528}{0.131}+\frac{1.120}{0.279}+\frac{2.113}{0.527}\right)=4.010$$

2) The consistency index of the calculation judgment matrix CI :

$$CI = \frac{\lambda_{max}-n}{n-1} = 0.0033$$

3) The proportions of the random consistency of the calculation judgment matrix CR :

$$CR = \frac{CI}{RI} \qquad (2)$$

In the formula: CI is the consistency test index of the judgment matrix, and RI is the average random consistency index of the judgement matrix. The average random consistency index of the 1~9 order matrix is shown in table 7:

Table 7: The average random consistency index of the judgement matrix

Order number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

When the CR is smaller, the consistency of the judgment matrix is better. It is generally believed that when CR <0.1, it is considered that the judgment matrix is completely consistent with the conditions of consistency, which is acceptable.

As shown in Table 7, when n=4, RI =0.90

So it can be obtained by (2) formula: $CR = \frac{0.0033}{0.90} = 0.0037 < 0.1$

The same can be calculated:

B_1—C matrix : feature vector= $(0.098, 0.568, 0.334)^T$

λ_{max} =3.025 ; CI=0.012 ; CR=0.0.021<0.1

B_2—C matrix : feature vector=$(0.130, 0.342, 0.342, 0.130, 0.056)^T$

λ_{max} =5.055 ; CI=0.014 ; CR=0.012<0.1.

B_3—C matrix : feature vector=$(0.089, 0.587, 0.324)^T$

λ_{max} =3.010 ; CI=0.005 ; CR=0.009<0.1

B_4—C matrix : feature vector=$(0.159, 0.214, 0.382, 0.059, 0.159)^T$

λ_{max} =5.146 ; CI=0.037 ; CR=0.033<0.1

Therefore, all of the judgment matrices above are consistent with the consistency test condition and are acceptable.

2.7. Level Total Ordering and Consistency Test

On the basis of the results of single sorting at the same level, the last level can calculate the weight of the importance of the level of the importance of the factors affecting the coal spontaneous combustion in the fully mechanized mining face and the total ranking of the layers [2]. The general ranking is to calculate the importance weights of each element in the target layer (O) by using the results of single ranking in all levels at the same level, and then combine the weights under the single criterion from top to bottom. The total ranking

calculation results of the factors influencing the spontaneous combustion of coal in the goaf of fully mechanized mining face are shown in Table 8.

The consistency check of the level total sort:

$$CI_z = \sum_{i=1}^{n} w_i CI_i = \sum_{i=1}^{3} w_i CI_i = 0.006$$

$$RI_z = \sum_{i=1}^{n} w_i RI_i = \sum_{i=1}^{3} w_i RI_i = 0.6952$$

$$CR_z = \frac{CI_z}{RI_z} = \frac{0.043}{1.132} = 0.0086 < 0.1$$

The calculation results show that the overall ranking should conform to the consistency test condition, which shows that the calculation results meet the requirements.

Based on the analysis of the factors affecting the spontaneous combustion of coal in the combined mining of the close range coal seam, the consistency test condition of the matrix B is judged. Therefore, the eigenvectors of the judgement matrix obtained from the above analysis are consistent with the experimental conditions of B, and can be used as the weight factors of spontaneous combustion in fully mechanized mining face, and it can affect the risk degree of spontaneous combustion in goaf. The weight vector obtained by the total level of sort in descending order: promote the work speed, coal seam spacing, sulfur content of coal, the interlayer pressure difference, geological structure, coal quantity, pre grouting, goaf plugging seam mining method, coal metamorphism degree, the stability of ventilation system, the ventilation mode, the endothermic and exothermic coal.

Table 8: The hierarchy table of target layer C to target layer O

Layer B / Layer C	B_1	B_2	B_3	B_4	Combination weight	Total sorting
	0.063	0.131	0.279	0.527		
C_1	0.098	0.00	0.00	0.00	0.0062	14
C_2	0.568	0.130	0.00	0.00	0.0528	6
C_3	0.334	0	0.00	0.00	0.021	11
C_4	0.00	0.342	0.00	0.00	0.0448	7
C_5	0.00	0.342	0.00	0.00	0.0448	8
C_6	0.00	0.130	0.00	0.00	0.0170	12
C_7	0.00	0.056	0.00	0.00	0.0073	13
C_8	0.00	0.00	0.089	0.00	0.0248	10
C_9	0.00	0.00	0.587	0.159	0.2476	1
C_{10}	0.00	0.00	0.324	0.00	0.0904	4
C_{11}	0.00	0.00	0.00	0.241	0.1270	3
C_{12}	0.00	0.00	0.00	0.382	0.2013	2
C_{13}	0.00	0.00	0.00	0.059	0.0310	9
C_{14}	0.00	0.00	0.00	0.159	0.0837	5

3. Results and analysis

According to the analytic weights of each factor and total weight vector, the results show that the working speed of the maximum priority number is the highest, it indicates the influencing factors of coal spontaneous combustion danger degree of goaf, are the main factors that influence the spontaneous combustion of coal mined out area, the working face advancing speed fast or slow, affect. Coal in the oxidation zone of oxidation time. If the propulsion speed is fast, the coal in the oxidized zone will soon enter the asphyxiation zone, reduce the contact time between coal and oxygen, prolong the spontaneous combustion period of coal in goaf, and reduce the probability of spontaneous combustion of coal in essence. Next is the coal seam spacing. In the mining area, because the upper and lower coal seam is exploited at the same time, the spacing will inevitably lead to the interpenetration of the goaf area and the large air leakage between the layers, which is one of the main factors that lead to the spontaneous combustion of coal in the mining area.

Furthermore, the geological structure, because the mining face geology is more complex, coal mining face fault, seam seam and fissure development, coal soft. In the case of complex structure, coal is brittle, and when the surface of the working face is pushed through these places, a large number of floating coal is formed to oxidize and spontaneous combustion. At the same time, for the close joint mining of coal seam, the ventilation mode is also an important factor affecting the spontaneous combustion of coal. The correct selection of ventilation mode will not only help to reduce the leakage of the goaf, but also shorten the width of the oxidation zone.

Other factors also influence the close distance coal seam combined mining goaf coal spontaneous combustion, but these factors more weights, the starting point is the prevention and control of short distance coal seam combined mining goaf coal spontaneous combustion, for preventing the spontaneous combustion disaster has a guiding role, the main action to take preventive measures to provide a reasonable basis.

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