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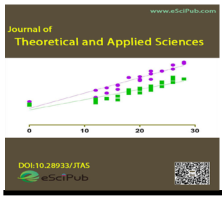

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Application of AHP-GRA in safety evaluation of blasting flying stones

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ABSTRACT

Blasting flying stone is one of the six hazards in rock and soil blasting construction. In order to determine the risk level of blasting flying stone, 3 first-grade indexes such as blasting design and construction are selected, and 11 second-grade indexes such as warning range are not set, so as to establish the blasting flying stone safety evaluation model of AHP-GRA. The analytic hierarchy process (AHP) was used to calculate the weight of the evaluation index. The grey correlation method was used to determine the correlation degree between the blasting flying stone and the safety level of an airport. The risk level of an airport was calculated based on the weight of the evaluation index, and the engineering verification was carried out. The results show that there is no warning signal, no notice before detonation and the warning range is too small, which are the main factors of the flying stone accident. The model presented in this paper is used to evaluate the blasting flying stones in an airport, and the evaluation results are basically consistent with the reality. It can be seen that the evaluation model can scientifically and reasonably evaluate the risk level of blasting flying stones, which has important practical significance.

Keywords: Blasting flying stone; Safety evaluation; Analytic hierarchy process; Grey relational degree

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Blasting flying stones is one of the six major hazards in rock and soil blasting construction, which will cause a series of serious problems such as equipment damage and casualties. According to incomplete statistics, 20% of blasting accidents are caused by personnel casualties and building damage caused by flying stones, and the wounding accidents caused by flying stones in China's open pit mines are as high as 27% [1]. From 1978 to 1998, there were a total of 412 blasting accidents in open-pit mines in the United States, among which the blasting flying stones caused casualties accounting for 28% [2]. In 1979, flying stone blasting accidents in Japan accounted for 61% of the total blasting accidents [3]. Therefore, it is of great practical significance to analyze the main causes of flying rock accidents, establish a complete evaluation system of flying rock accidents and determine the risk level of flying rock accidents. Wang Zhiwei et al. [4] established the analytic hierarchy model of flying stone injury accidents, and concluded that the main reasons for such accidents were too large charge amount and no clear warning range. Liu Qing [2] et al. used BP neural network model to predict the distance range of blasting flying stones, which proved to be in line with the actual engineering situation.Ren Yuhui [5] et al. used FTA-AHP to carry out risk analysis on blasting flying stone accidents, obtained the main risk factors and put forward measures. Pan Tao et al. [6] evaluated the safety of the hazard effect of flying stones through the unascertained measure theory. Tao Ming et al. [7] obtained the main influencing factors of flying rock accidents through FTA analysis, and put forward targeted measures. Jia Yujie et al. [8], based on FTA and AHP theories, conducted risk analysis and calculation on the cause of flying rocks, and put forward targeted measures. On the research achievements in the field of statistical analysis, the research Angle and evaluation system is not complete, the evaluation results objective problems in outstanding, it is difficult to effective evaluation on the extent of the harm of blasting slungshot and forecast, be badly in need of a scientific and reasonable evaluation model to determine the blasting slungshot risk level, in order to solve the above problems.In blasting slungshot risk level in the comprehensive evaluation model, using AHP to GRA the comprehensive statistical analysis on the cause slungshot, analyze relationship among various factors analytical hierarchy process (AHP), to set up the comparison matrix, and study the complex problem decomposition, determine reasonable evaluation index weights, the application of grey correlation method to determine the blasting slungshot risk level, has important research significance and practical significance.

1. Selection and classification of blasting flying stone risk evaluation indexes

1.1 Selection of risk assessment indexes for blasting flying stones

Blasting slungshot risk evaluation index selection accuracy directly affect the final evaluation results, adhering to the purpose of evaluation index selection, comprehensive, feasibility, objectivity and other principles, carried out A statistical analysis of A large number of blasting slungshot accidents, combined with an airfield outside A, B, C three mountain blasting excavation status [10], the largest proportion of 11 selected risk factors, according to its property is divided into three major categories, survey statistics and analysis results are shown in table 1, blasting slungshot evaluation system is shown in figure 1.

1.2 Classification of blasting flying stone evaluation indexes

The risk of blasting flying stone is very low,

low, ordinary, high and very high. The 11 indicators selected are all specific descriptions of the actual situation, and experts are invted to score them according to the actual situation. Through consulting a large number of literature and consulting field experts, the standard data of each grade is determined as follows: Ⅰ{96，96，……，96}；Ⅱ{86，86，……，86}；Ⅲ{76，76，……，76}；Ⅳ{66，66，……，66}；Ⅴ{56，56，……，56}.

Table 1 Percentage of influencing factors of blasting flying stones

The evaluation index	Operation error	The parameter design is not reasonable	The charge is too high	Weak Intercalation	Joint	Warning range is not set	The warning range is too small	No warning signal	No notice before initiation	Number of people not counted before detonation	Stray current interference
The percentage（%）	8.3	5.2	4.9	7.9	6.5	12.5	9.3	11.7	12.4	11.8	9.5

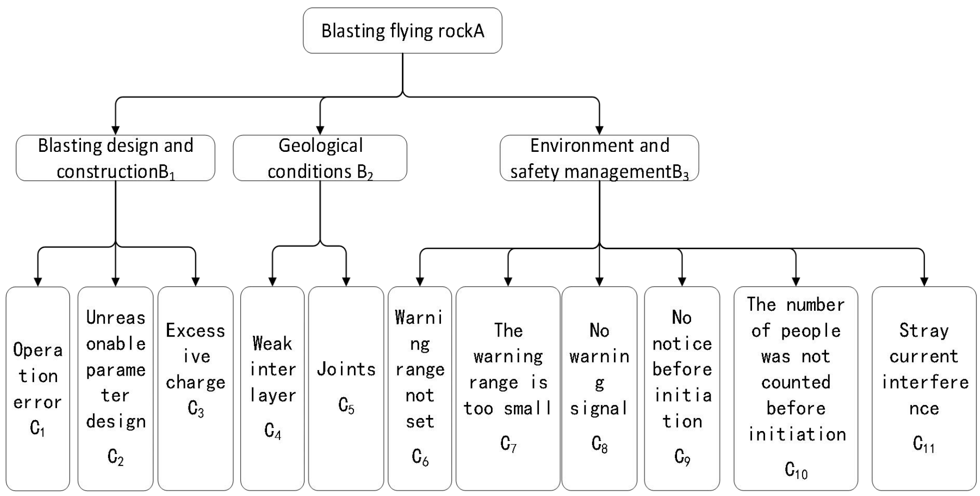

Figure 1 risk assessment index system of blasting flying rock

2. Mathematical model

2.1 Analytic Hierarchy Process

1. The analytic hierarchy model has been built, as shown in Figure 1.

2. Construct the judgment matrix

Let n elements associated with the upper layer be B1, B2..., Bn, AIJ is used to represent the importance of BI relative to Bj, and the value of AIJ is determined by using the judgment table of pairwise factors and "9 scale method", so as to obtain the judgment matrix A of the lower index relative to the upper index:

$$A=[a_{ij}]_{n\times n} \quad (1)$$

3. Evaluation index weight calculation and consistency test

① Calculate the NTH root of the product of elements in row A of matrix:

$$M_i=(\prod_{j=1}^{n}a_{ij})^{1/n} \quad (i=1,2,\ldots\ldots,n) \quad (2)$$

② Normalized treatment:

$$w_i = M_i / \sum_{j=1}^{n} M_j \quad (i=1, 2, \ldots\ldots, n) \tag{3}$$

Then W= (w1,w2...Wn) is the eigenvector.

③ Find the maximum characteristic root, and carry out consistency test:

First, find the maximum eigenroot:

$$\lambda_{\max} = \frac{1}{n}\sum_{1}^{n}\frac{(AW)_i}{w_i} \tag{4}$$

Secondly, the consistency index CI was calculated:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{5}$$

Then calculate the consistency ratio CR:

$$CR = \frac{CI}{RI} \tag{6}$$

In the formula, Ri is the average random consistency index, and the third-order matrix is 0.58; The fourth-order matrix is 0.90;The 5th order matrix is 1.12; The sixth order matrix is 1.24 and so on.Finally, the consistency judgment was made:

$$CR < 0.1 \tag{7}$$

When Formula 7 is satisfied, it is considered that the judgment matrix has passed the consistency test and its weight is accepted; otherwise, it is considered that the judgment matrix is wrong and needs to be corrected.

2.2 Grey correlation method

2.2.1 De termine the parent sequence and subsequence

Established subsequence (comparison sequence) X_0（i）, i = 1,2...N. As can be seen from the above, the risk of blasting flying stones is divided into five levels, and its data sequence is: Ⅰ{96，96，……，96}；Ⅱ{86，86，……，86}；Ⅲ{76，76，……，76}；Ⅳ{66，66，……，66}；Ⅴ{56，56，……，56}.

Suppose there are m parent sequences, and each parent sequence has n evaluation factors, then these parent sequences can be expressed as Xj (i), j= 1,2...m;i= 1,2..., n. In the master sequence of this paper, experts and front-line workers score N indicators of each evaluation object according to the weight of each factor calculated by AHP.

2.2.2 Mean processing of data

The mean processing of data is to divide all the data in a data column by the average value of the data column to get a new data column {Xi (k)} [9].

$$X_i^{(0)}(k) = \frac{X_i^{(0)}(k)}{\overline{x_i}} \tag{8}$$

2.2.3 Calculate the correlation coefficient

$$L_{0i}(k) = \frac{\min_i \min_k \left|x_0^{(1)}(k) - x_i^{(1)}(k)\right| + \delta \max_i \max_k \left|x_0^{(1)}(k) - x_i^{(1)}(k)\right|}{\left|x_0^{(1)}(k) - x_i^{(1)}(k)\right| + \max_i \max_k \left|x_0^{(1)}(k) - x_i^{(1)}(k)\right|} \ldots\ldots \tag{9}$$

Type:

$$\min_i \min_k \left|x_0^{(1)}(k) - x_i^{(1)}(k)\right|$$

Minimum difference of two stages

$$\max_i \max_k \left| x_0^{(1)}(k) - x_i^{(1)}(k) \right|$$

Maximum difference of two levels

δ is the resolution coefficient, which is generally 0.5.

2.2.4 Calculate the correlation degree

Due to the large number of correlation coefficients and scattered information, in order to make the obtained data more objective, this paper combines the weight obtained by the analytic hierarchy process with the correlation coefficient, and its calculation formula is as follows:

$$r_{oi} = \sum_{j=1}^{n} w_i l_{oi}(k) \tag{10}$$

3. Engineering Examples

The project is to carry out blasting excavation for three mountains outside an airport in Guizhou. According to the on-site geological survey, the landform of the construction area belongs to the dissolution basin, the site rock mass is relatively broken, the thickness of the upper overburden is uneven, the joints and fissures in the rock are relatively developed, mainly moderately weathered limestone, and the hardness coefficient of the rock mass is between 6-8. Some areas are in the weak interlayer zone. The construction difficulties of blasting excavation: to avoid the occurrence of blasting flying rock accidents, ensure the safety of personnel, and do not affect the airport navigation; at the same time, within the safe distance of the blasting area, there are a large number of construction machinery and construction personnel working in the site during the peak period, so certain preventive measures must be taken for blasting construction, and the blasting flying rock must be controlled within the safe range, without damaging the construction personnel and machinery Prepare.

3.1 Analytic Hierarchy Process to calculate the weight

Taking blasting excavation in an airport as the background, the safety evaluation index system of blasting flying stones is shown in Figure 1. The calculation method is introduced by taking the criterion layer as an example. The judgment matrix A is obtained from Formula 1, and the weight vector is obtained from Formula 2 and Formula 3. The results are shown in Table 2.

Table 2 Judgment matrix and weight of criterion layer

A-B	B_1	B_2	B_3	W
B_1	1	3	1/5	0.1884
B_2	1/3	1	1/7	0.0810
B_3	5	7	1	0.7306

Matlab is used to calculate the maximum characteristic root of the middle layer is 3.0459. Ci =0.02357 is calculated by formula 5, RI is 0.58 (A is A third-order matrix), and Cr =0.0404 < 0.1 is calculated by formula 6, so it meets the consistency test.Similarly, the maximum eigenvalue, consistency index and random consistency ratio of judgment matrices B1-c, B2-c and B3-c can be obtained. The calculation results are shown in Table 3.

Table 3 Maximum eigenvalue and consistency test results of the judgment matrix

Judgment matrix	λ_{max}	CR	Order number
B_1-C	3.0183	0.0176	3
B_2-C	2	0	2
B_3-C	6.5681	0.0902	6

The results obtained according to Equations 5 and 6 are consistent with the results of consistency test. In order to determine the degree of influence of the indicator layer on the target layer, the weight of each evaluation index needs to be calculated. The calculated results are as follows:W = (0.2364, 0.1664, 0.1160, 0.1150, 0.1036, 0.0675, 0.0594, 0.0453, 0.0395, 0.0374, 0.0135), It can be concluded that there is no warning signal > no notice before initiation > too small warning range > no warning range > operation error > joint > number of people not counted before initiation > unreasonable Parameter Design > too large charge > stray current interference > weak interlayer.According to the weight obtained by AHP, experts and front-line workers were asked to score, and the results are shown in Table 4.

3.2 Grey correlation method to calculate correlation degree

Taking "blasting construction design" in blasting flying rock safety evaluation system as an example, the grey correlation method is used for analysis and calculation. Table 5 shows the reference sequence and comparison sequence of blasting construction design.

(1) Determine the reference sequence and comparison sequence

Table 4 safety index weight and expert scoring of Feishi

Target layer	Criterion layer	Index layer	Expert scoring
Blasting slungshot	Blasting construction design（0.1884）	Operation error（0.1036）	80
		Unreasonable parameter design（0.0453）	86
		Excessive charge（0.0395）	86
	Geological conditions（0.0810）	Weak interlayer（0.0135）	83
		Joints（0.0675）	82
	Environment and safety management（0.7306）	Warning range not set（0.1150）	80
		The warning range is too small（0.1160）	79
		No warning signal（0.2364）	82
		No notice before initiation（0.1664）	75
		The number of people was not counted before initiation（0.0594）	85
		Stray current interference（0.0374）	85

Table 5 reference sequence and comparison sequence of blasting construction design

Middle layer	Index layer	Reference sequence	I	II	III	IV	V
Blasting construction design	Operation error	80	96	86	76	66	56
	Unreasonable parameter design	86	96	86	76	66	56
	Excessive charge	86	96	86	76	66	56

(2) The initial value of the data is processed by formula 8, and the matrix obtained is as follows:

$$A_1 = \begin{vmatrix} 1.00 & 1.00 & 1.00 \\ 1.20 & 1.12 & 1.12 \\ 1.08 & 1.00 & 1.00 \\ 0.95 & 0.88 & 0.88 \\ 0.83 & 0.77 & 0.77 \\ 0.70 & 0.65 & 0.65 \end{vmatrix}$$

(3) Calculation of correlation coefficient: the first step is to calculate the two-level minimum difference and two-level maximum difference, and the second step is to calculate the correlation coefficient according to formula 9.

$$\min_i \min_k \left| x_0^{(1)}(k) - x_i^{(1)}(k) \right| = 0.00$$

$$\max_i \max_k \left| x_0^{(1)}(k) - x_i^{(1)}(k) \right| = 0.35$$

The correlation coefficient calculated by equation 9 is shown in Table 6.

Table 6 correlation coefficients of reference series and comparison series

Grade index	1	2	3
I	0.47	0.59	0..59
II	0.69	1.00	1.00
III	0.97	0.59	0.59
IV	0.51	0.43	0.43
V	0.33	0.33	0.33

(4) Calculation of correlation degree

The correlation degree is calculated by equation 10 and MATLAB as follows: R_1 = (0.55, 0.91, 0.72, 0.47, 0.33), and the maximum correlation degree R1, max = 0.91, which indicates that the safety risk level of blasting design and construction is grade II, and the risk is low. Similarly, it can be calculated that:

1) R_2=(0.58,0.83,0.72,0.50,0.41), $R_{2,\ max}$=0.83, It shows that the risk level of geological conditions is grade II, and the risk is low.

2) R_3=(0.61,0.87,0.62,0.41,0.34), $R_{3,\ max}$=0.87, It shows that the risk condition of environment and safety management is grade II, and the risk is low.

3.3 Calculate the risk level of flying rock

blasting in an airport

To sum up, the grey correlation degree of the middle layer is shown in Table 7.

Table 7 weight and grey correlation degree of middle layer of blasting flying rock

Interface	Weight	I	II	III	IV	V
Blasting design and construction	0.1884	0.55	0.90	0.72	0.47	0.33
Geological conditions	0.0810	0.58	0.80	0.72	0.50	0.41
Environment and safety management	0.7306	0.61	0.83	0.62	0.41	0.34

According to formula 10, the grey comprehensive correlation degree of blasting flying rock can be obtained.

$$R=(0.1884,0.0810,0.7306)\times\begin{vmatrix}0.55 & 0.90 & 0.72 & 0.47 & 0.33\\0.58 & 0.80 & 0.72 & 0.50 & 0.41\\0.61 & 0.83 & 0.62 & 0.41 & 0.34\end{vmatrix}=(0.59,0.83,0.68,0.48,0.37)$$

The maximum correlation degree R2, max = 0.83, so the risk level of flying rock accident in the blasting excavation process of a, B and C airports is grade II, and the risk is low.

4. Conclusion

(1) Combined with a large number of literature and engineering examples, 11 evaluation indexes are selected to establish the safety evaluation system of blasting flying rock, and the risk classification of flying rock is carried out. The weight of each evaluation index is calculated by using the analytic hierarchy process. Combined with the grey correlation degree, the grey comprehensive correlation degree of reference sequence and comparison sequence is obtained. The safety evaluation of blasting flying rock in the airport is carried out, and the risk level is obtained, It is consistent with the actual situation of the project, which shows that the method is feasible to evaluate the safety of blasting flying rock in the process of blasting excavation.

(2) Blasting excavation is a complex system, which is restricted by many uncertain factors, such as blasting design and construction, rock geology, safety management level and so on. Based on previous scholars' research, this paper makes a preliminary exploration on the evaluation system of blasting flying rock, which has some limitations. It does not fully consider all the influencing factors, does not dig out quantitative indicators, and has to solve the problem These two problems can make it better serve the needs of blasting flying rock safety evaluation.

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