Safety evaluation of blasting fly-rock based on unascertained measurement model

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ABSTRACT. *The blasting fly-rock poses a potential risk to workers at the blasting site. Considering the uncertainty of various influencing factors of the risk, this paper introduces the uncertainty measurement theory to build a pre-evaluation model of blasting safety for fly-rock, in which the weight and identification criterion of each evaluation index are determined by information entropy and confidence, respectively. Then, the model was adopted to pre-evaluate the harms of blasting fly-rock in an earthwork excavating project. The case analysis shows that the model can quantify the uncertainty of each influencing factor, and realize objective evaluation of the risk of blasting fly-rock. The research findings lay a solid basis for reasonable and effective control of the harms caused by blasting fly-rock.*

RÉSUMÉ. *Les éclats de pierre pendant les explosions pose un risque potentiel pour les travailleurs sur le chantier. Étant donné l'incertitude de diverses facteurs influençants du risque, cet article introduit la théorie de la mesure de l'incertitude afin de mettre en place un mécanisme de pré-évaluation sur la sécurité de l'explosion envers les éclats de pierre, dans lequel le poids et le critère d'identification de chaque indice d'évaluation sont respectivement déterminés par l'entropie et la confiance. Ensuite, le modèle a été adopté pour pré-évaluer les dommages des éclats de pierre pendant les explosions dans un projet de terrassement. Cette analyse montre que le modèle peut quantifier l'incertitude de chaque facteur influent et réaliser une évaluation objective du risque des éclats de pierre. Les résultats de la recherche jettent une base solide pour un contrôle raisonnable et efficace des dommages causés par des éclats de pierre.*

KEYWORDS: *blasting fly-rock, safety pre-evaluation, unascertained measurement, index weight.*

MOTS-CLÉS: *éclats de pierre pendant les explosions, pré-évaluation de la sécurité, mesure de l'incertitude, poids d'indice.*

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1. Introduction

Blasting, as a basic construction means in mining, railway construction, highway excavation site formation, hydropower dam construction, demolition and other fields, has an irreplaceable advantage because of its high efficiency and low cost. With realizing the expected purposes of engineering, blasting also produces a series of negative effects, especially the risk of blasting fly-rock, including casualties, as well as buildings and equipment damage. It is important to control the blasting stones and prevent accidents caused by blasting fly-rock. Therefore, a majority of scholars have carried out extensive and in-depth researches on the harmful effects of blasting fly-rock. Wang *et al.* (2012) used a fault tree analysis method to find out the causes of the blasting fly-rock, which provide the scientific basis for the design, construction and safety management of blasting operation based on the field investigation. Jiao *et al*. (2009) systematically analyzed the types and causes of fly-rock in urban demolition blasting, and put forward effective measures to prevent the harms of fly-rock. A BP neural network model was introduced to research the blasting fly-rock distance by Liu *et al.* (2013). The BP neural network model was established with a minimum resistance line, unit explosive consumption and the maximum dose of a single hole to predict the blasting fly-rock. Pan *et al*. (2014) established a safety assessment model of blasting fly-rock by introducing an unascertained measure method due to the characteristics of blasting fly-rock harmful effects are numerous and difficult to measure accurately. Among the above studies on the harmful effects of blasting vibration, most of them are mainly focused on the study of the safety evaluation and control measures of blasting fly-rock, while the research on the damage effects of blasting vibration is less. At present, a majority of scholars for the fly-rock disaster prediction of the blasting are still based on the empirical formula (Wu *et al*., 2012; Xiong *et al.*, 2009). However, the forecast results from the empirical formula and the actual monitoring data have a greater deviation. In the actual production process, accidents sometimes are occurred even the forecast results are safety. The reason is that there are some factors and uncertainties influencing the safety of blasting fly-rock. Therefore, it is necessary to improve and innovate the safety and evaluation methods of blasting fly-rock harmful effects to meet the actual production needs.

Aim to solve the problem of uncertainty factors in the pre-evaluation of blasting fly-rock harmful effects, an unascertained measure model is introduced to establish a safety pre- evaluation model of blasting fly-rock disasters, to improve the blasting scheme and provide a decision-making basis for reasonable and effective control of the blasting fly-rock (Morin and Ficarazzo, 2006).

2. Pre-evalution model of unascentained measurment

2.1. Establishment of the pre-evaluation index system

There are many factors that cause fly-rock accidents of project blasting, which can be divided into three aspects: blasting parameters, construction technology and safety protection (Zhang *et al*., 2010). In the model of blasting fly-rock disaster pre-evaluation based on unascertained measurement, we should take full account of the actual situation of project blasting and all aspects of harmful effects, as well as use the theory and method of system engineering to establish a comprehensive structure. A decision-making basis is provided by convenient blasting fly-rock disaster safety pre-evaluation index system for the blasting fly-rock harmful effects prevention (Monjezi and Dehghani, 2008; Monjezi *et al*., 2011). Regarded this goal as a starting point, a secondary safety pre-evaluation index system for engineering blasting fly-rock disasters is established in this paper, as shown in Figure 1.

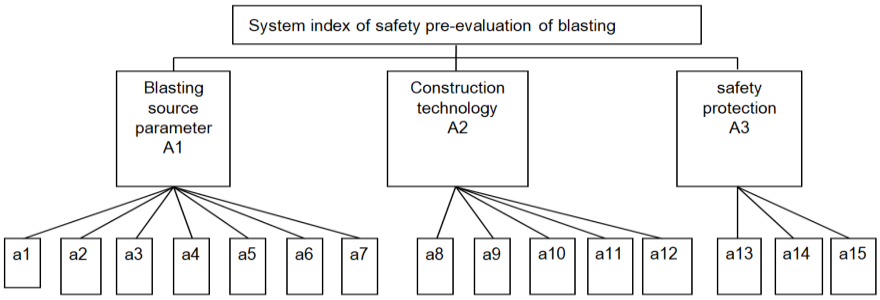

Figure 1. System index of safety pre-evaluation of blasting fly-rock

2.2. Uncertainty calculation of pre-evaluation system

2.2.1. Unascertained measurement of a single index

Given a_1, a_2, …, a_i indicates n factors to be evaluated concerning the object, it is noted as A={a_1, a_2, …, a_i} called 'domain'. Each single-factor pre-evaluation index ai has j evaluation grades as b_1, b_2, …, b_j, then a_{ij} is used to indicate the observed value of single-factor ai as an object to be pre-evaluated on the jth evaluation grade b_j.

The single-factor pre-evaluation index ai, when it is in the jth evaluation grade, is marked as a_{ij}. This paper adopts an expert grading method, providing that the sum of the value of points on the grade of all the evaluation about each pre-evaluation factor is 100 points, the related experts will give 0~100 respectively to each grade bj of the evaluation on each pre-evaluation factor ai, marking $\sum_{j=1}^{j} a_{ij} = 10C$. $u_{ij}=a_{ij}/100$ indicates that the observed value a_{ij} makes ai stay at the unascertained measurement angle of the grade bj of the evaluation. u_{ij}, as the result of 'degree' measurement, is a possibility measure. As a result of measurement, this possibility measure must satisfy three measurement criteria: non-boundedness, additivity and normalization. On this basis, we can obtain the measurement matrix of a single pre-evaluation index as the evaluated object (Chakraborty *et al*., 2004; Dehghani and Ataee-Pour, 2011; Iphar *et al.*, 2008; Kecojevic and Radomsky, 2005).

$$u_{ij} = \begin{bmatrix} u_{11}, u_{12}, \cdots, u_{1j} \\ u_{21}, u_{22}, \cdots, u_{2j} \\ \vdots \quad \vdots \quad \cdots \quad \vdots \\ u_{i1}, u_{i2}, , \cdots, u_{ij} \end{bmatrix} (i = 1,2,\cdots,n) \tag{1}$$

2.2.2. Determination of the index weight

The description of the uncertainty of observed values should be the quantitative measurement of uncertainty and the distribution function of observed values, which is called entropy (Qiu, 2012). Entropy is the basic concept of simple giant system (Tao *et al*., 2011; Tu *et al*., 2010). Entropy was first brought forward in thermo-dynamics by Clautheus and used to describe the state of a system, and in later years it was introduced to many other domains. For a discrete random variable, its information entropy $S = -k\sum_{i=1}^{k} p_i \ln p_i$, where $P_i \geq 0$, and $\sum_{i=1}^{n} p_i = 1$. Entropy has such characteristics as symmetric, non-negative, additive and extreme values. The space of natural state $X=(x_1, x_2, \ldots, x_n)$ is an uncontrollable factor. In the formula, xi is the state that has been occurred. The prior probability distribution of each state that occurred in X is $P(X)=\{P(x_1), P(x_2), \ldots, P(x_n)\}$. The uncertain extent of this state is defined as an entropy function:

$$H(x) = -\sum_{i=1}^{n} p(x_i) \ln p(x_i) \text{ , } 0 \leq p(x_i) \leq 1, \sum_{i=1}^{n} p(x_i) = 1 \tag{2}$$

The u_{ij} in the formula (1) is the unmeasured measure of the evaluation factor a_i of the object to be evaluated at the jth evaluation grade b_j. If the uncertain measure u_{ij} is regarded as $P(x_i)$ in (2), then we have:

$$H(u) = -\sum_{j=1}^{j} u_{ij} \ln u_{ij} \tag{3}$$

$$v_i = 1 - \frac{1}{\ln j} H(u) = 1 + \frac{1}{\ln j} \sum_{j=1}^{j} u_{ij} \bullet \ln u_{ij} \text{ , } w_i = \frac{v_i}{\sum_{i=1}^{i} v_i} \tag{4}$$

Where w_i ($0 \leq w_i \leq 1$, and $\sum_{i=1}^{i} w_i = 1$) is the weight of the pre-evaluation index and a_i. $W=(w_1, w_2, \ldots, w_i)$ is the weight vector of blasting fly-rock safety pre-evaluation factor index.

2.2.3. Comprehensive evaluation system

U is the pre-evaluation of the object blasting, and the safety of the results comprehensive evaluation in the jth evaluation grade unascertained degree is shown as follows:

$$u_j = W \bullet u_{ij} = (w_1, w_2, ..., w_i) \bullet \begin{bmatrix} u_{11} & u_{12} & ... & u_{1j} \\ u_{21} & u_{22} & ... & u_{2j} \\ ... & ... & ... & ... \\ u_{i1} & u_{i2} & ... & u_{ij} \end{bmatrix} \tag{5}$$

Then $u=\{u_1, u_2, ..., u_j\}$ is a pre-evaluation vector of the blasting as an evaluated object, describing the uncertainty degree in the evaluation of the object at the jth evaluation grade. In order to obtain the degree of certainty, the difference in confidence needs to be marked. Because the grade division of evaluation is in order and the grade u_j of the jth evaluation is 'better' than the grade u_{j+1} of the j+1, the discrimination criteria of the maximum measure are not suitable to this case. We have to turn to use the discrimination criteria of confidence. Given the confidence is λ, (λ>0.5) and 0.6 or 0.7 is usually adopted, the confidence model is:

$$j_0 = \min_j \left\{ j : \sum_{j=1}^{j} u_{ij} \geq \lambda, j = 1, 2, ..., j \right\} \tag{6}$$

After taking the value of j into the formula (6), it's judged that the evaluated object of blasting effects belongs to the j_0 th evaluation grade u_j.

3. Case test

According to the above unascertained measurement pre-evaluation model, the safety pre-evaluation of blasting fly-rock disaster is carried out in an earthwork excavation project in Zunyi city. The single factor evaluation grade of each blasting fly-rock safety pre-evaluation is divided into: safe, safer, general, less safe, unsafe, by the expert group as shown in Table 1. According to Table 1, the matrix of single-index uncertain measure is obtained from the formula (6):

$$u_{ij} = \begin{bmatrix} 0.02 & 0.12 & 0.40 & 0.33 & 0.13 \\ 0.03 & 0.15 & 0.42 & 0.23 & 0.17 \\ 0.07 & 0.21 & 0.23 & 0.36 & 0.13 \\ 0.10 & 0.20 & 0.21 & 0.43 & 0.05 \\ 0.01 & 0.18 & 0.26 & 0.41 & 0.14 \\ 0.03 & 0.04 & 0.39 & 0.30 & 0.24 \\ 0.07 & 0.12 & 0.20 & 0.49 & 0.12 \\ 0.04 & 0.21 & 0.27 & 0.33 & 0.15 \\ 0.02 & 0.14 & 0.29 & 0.40 & 0.15 \\ 0.03 & 0.21 & 0.29 & 0.30 & 0.17 \\ 0.02 & 0.08 & 0.25 & 0.41 & 0.24 \\ 0.06 & 0.14 & 0.18 & 0.47 & 0.15 \\ 0.02 & 0.09 & 0.36 & 0.30 & 0.23 \\ 0.08 & 0.20 & 0.32 & 0.18 & 0.22 \\ 0.05 & 0.21 & 0.41 & 0.17 & 0.16 \end{bmatrix} \tag{7}$$

By the formula (3) to calculate the index weight of the pre-evaluated factors, we can have: W=(0.0879, 0.0678, 0.0393, 0.0681, 0.0826, 0.0954, 0.0763, 0.0469, 0.0773, 0.0485, 0.0860, 0.0682, 0.0773, 0.0247, 0.0538)

By the formula (5), we determine the final results of evaluation: u=(0.0393, 0.1409, 0.3016, 0.3529, 0.1646)

Assuming the confidence λ=0.7, both the discrimination criteria of confidence and the formula (7) are applied to judge that the grade of pre-evaluation of the blasting effects in this earthwork blasting is "safer". The uncertain measure takes notice of the orderliness of the evaluation space and gives a relatively rational criterion for the discrimination of confidence and the code of points for order, as it is just what the fuzzy comprehensive evaluation method does not have at all.

Table 1. Score results from the expert group

Evaluation factors	Evaluation grade				
	unsafe	less secure	general	safer	safe
Detonation dose a1	2	12	40	33	13
Explosive properties a2	3	15	42	23	17
Resistance line direction a3	7	21	23	36	13
Resistance line size a4	10	20	21	43	5
Detonation method a5	1	18	26	41	14
Delay time a6	3	4	39	30	24
holes and rows spacing a7	7	12	20	49	12
Charge structure a8	4	21	27	33	15
Charge quality a9	2	14	29	40	15
Packing length a10	3	21	29	30	17
Packing quality a11	2	8	25	41	24
Networking quality a12	6	14	18	47	15
Security check a13	2	9	36	30	23
Protective measures a14	8	20	32	18	22
Security alert a15	5	21	41	17	16

4. Conclusions

(1) Based on the entropy of the unascertained measurement model, the unascertained measurement theory of fly-rock disaster safety pre- evaluation models

of blasting is applied and established, as well as the application example is discussed. The safety pre-evaluation of the blasting fly-rock disaster is realized, which provides a decision-making basis for the reasonable and effective control and reduction of the blasting fly-rock accidents and the safe production of the project blasting.

(2) By the theory and method of system engineering, the safety pre-evaluation index system of earthwork blasting is constructed from three main aspects: blasting parameters, construction technology and safety protection.

(3) About the determination of the weight and recognition criteria of each evaluation index, the information entropy and confidence criterion are used respectively, and the unascertained degree of each factor influencing the safety of blasting fly-rock is quantified, so that the evaluation results are more objective.

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