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Rock Blast-ability Classification Based on Unascertained Measurement Theory

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Abstract: In order to increase the accuracy of rock blast-ability classification, the comprehensive evaluation model of rock blast-ability classification was established based on uncertainty measurement theory by eight factors including rock density, tensile strength, impact strength, integrity coefficient, compressive strength, sturdiness coefficient, wave impedance and explosive specific charge. The uncertainty measurement function was obtained based on the in-situ data; entropy theory was used to calculate the index weight of all indexes, and the comprehensive evaluation results of rock blast-ability classification were obtained using the rules of credible recognition criteria. In order to optimize the blasting design, the evaluation model was used to evaluate the rock blast-ability in Guiyang Chaoyangdong road engineering and the evaluation results fit in anecdotally with actual situation. Therefore, the evaluation model was a significant basis for promoting the blast effect.

Keywords: *Rock blast-ability classification, Uncertainty measurement theory, Information entropy theory, believing degree criterion*

1. Introduction

The rock blast-ability classification is the index of rock damage degree of difficulty under the action of blasting, which is comprehensive embodiment for the rock mass physical and mechanical properties under dynamic load. In blasting engineering practice, The rock blast-ability classification can not only be used to estimate the explosive specific charge, but also provide important basis for selecting reasonable parameters of blasting design [1-3]. There are more and complex factors which can influence the rock blast-ability. And lots of scholars have carried out much research in the rock blast-ability classification both in China and abroad for years. However the evaluation of rock blast-ability classification has not yet reached a consensus [4].

One kind of methods is based on the evaluation indicators such as rock density, tensile strength, impact strength, integrity coefficient for rock blast-ability classification. Xue Jian-guang [5] and Li Rong [6] have objectively used Shannon entropy theory to determine rock blast-ability classification which was combined with the attribute recognition theory. Li Yong-qiang [7] established the model of rock blast-ability classification which employing the idea of weighted clustering analysis. Zhang De-ming [8] used the AHP analytic hierarchy process (AHP) to determine the weights of indicators and established a comprehensive evaluation model for rock blast-ability classification. Xing Zhan-li [9] used grey correlation analysis method to determine the weights of evaluation for rock blast-ability classification. Shang Jun-long [10] established the matter element evaluation model combined with game theory and predicted the rock blast-ability by using greatest relevance criterion. Pan Yong [11] used MATLAB to establish BP neural network model for which can be graded to forecast the rock blast-ability classification rock blast-ability classification which was based on the neural network technology.

Another kind of methods is based on the evaluation indicators such as Sturdiness coefficient, wave impedance and explosive specific charge for rock blast-ability classification. Jiang Cui-ping [12] and Li Shu-jian [13] had established the model of rock blast-ability classification based on weighted clustering analysis by using these evaluation indicators. Fang Chong [14-16] established the comprehensive evaluation model based on projection pursuit technology. In this model, the projection indexes were used for rock blast-ability classification and the projection direction was optimized by using ant colony algorithm, simulated annealing algorithm and artificial fish algorithm, respectively.

The scholars have used different methods to evaluate rock blast-ability classification, and the corresponding results have been obtained. Due to the fuzziness, complexity and uncertainty of the blasting progress, the methods of weighted clustering analysis, fuzzy evaluation, grey correlation analysis and neural network discrimination are all difficult to eliminate the influence of subjective factors so that the evaluation results are not objective enough. Because the difficulty of rock blast-ability classification lies in the uncertainty and concealment of affecting factors.

How to integrate the uncertain information and make a comprehensive analysis is the key to realization of rock blast-ability classification. This paper applies the uncertainty measure theory to comprehensive evaluation of rock blast-ability classification, and carries on the quantitative analysis.

2. Uncertainty Measurement Theory:

2.1. Uncertain measure of single index:

Given α_1, α_2, …, α_i to be evaluated concerning the object which indicates n units, noting A={α_1, α_2,…, α_i}; each single unit evaluation index α_i has j evaluation grades b_1, b_2,…, b_j, then α_{ij} is used to indicate observed value of single unit α_i as an object to be evaluated on the jth evaluation grade b_j. When it is in the jth grade of comment, is marked as α_{ij}.

If $\mu_{ijk} = \mu\ (\alpha_{ij} \in \gamma_k)$ indicates that the value of the α_{ij} belong to the kth evaluation rated. And let:

$$0 \le \mu(\alpha_{ij} \in \gamma_k) \le 1\ (i=1,, n; j=1,\dots, m; k=1,\dots, p) \quad (1)$$

$$\mu(\alpha_{ij} \in \mu)=1\ (i=1, 2,\dots, n; j=1, 2,\dots, m) \quad (2)$$

$$\mu\left|\alpha_{ij} \in \bigcup_{lij=1}^{k} \gamma_l\right| = \sum_{l=1}^{k} \mu\left(\alpha_{ij} \in \gamma_l\right) \quad (3)$$

The three equations is above, equation (1) is "none negative"; equation (2) is "integrity nature"; equation (3) is "additive" [17-18]. The μ satisfied all of these three equations represent the uncertain measurement. From this, we can obtain the measurement matrix of a single evaluation index as the evaluated object.

$$\left(\mu_{ijk}\right)_{m\times p} = \begin{bmatrix} \mu_{i11} & \mu_{i12} & \cdots & \mu_{i1p} \\ \mu_{i21} & \mu_{i22} & \cdots & \mu_{i2p} \\ \vdots & \vdots & & \vdots \\ \mu_{im1} & \mu_{im2} & \cdots & \mu_{imp} \end{bmatrix} \quad (4)$$

2.2. Determination of the index weight:

Let the value of ω_j indicate that α_{ij} is whether more important than other factors or not, let: $0\le \omega_j \le 1$, ω (ω_1, ω_2, …, ω_m). The uncertain extent of this state is defined as an entropy function:

$$v_j = 1 + \frac{1}{\lg p}\sum_{k=1}^{p} \mu_{jk} \lg \mu_{jk} \quad (5)$$

$$\omega_j = v_j \Big/ \sum_{i=1}^{m} v_j \quad (6)$$

2.3. Comprehensive evaluation system:

Because the measurement matrix of single evaluation index concerning the evaluated objects is known, then the classified weights of each index about the evaluated objects are obtained in Formula (5) and (6). Let:

$$\mu_{ik} = \sum_{j=1}^{m} \omega_j \mu_{ijk} \quad (7)$$

$$\left(\mu_{ik}\right)_{n\times p} = \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{1p} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ \mu_{n1} & \mu_{n2} & \cdots & \mu_{np} \end{bmatrix} \quad (8)$$

2.4. Believing degree criterion

Given the believing degree is λ, (λ>0.5), then 0.6 or 0.7 is usually adopted, let:

$$k_0 = \min\left| k : \sum_{i=1}^{k} \mu_i > \lambda, k = 1, 2, \dots, p \right| \quad (9)$$

Then it's judged that the evaluated object belongs with the j0th evaluation grade b_k.

3. Establishment of the index evaluation system:

The rock blast-ability classification is an extremely complex system, in order to realize reasonable evaluation criteria; we must establish a complete and scientific evaluation index system. Too much evaluation index, will increase the complexity of the evaluation process, too little evaluation index, cannot fully reflect the rock blasting grade comprehensive evaluation.

At the scene of the actual construction process, rock blast-ability classification includes many aspects, it is hard to take every factor into account. According to the related research[3, 8, 9, 12-13, 19] of comprehensive evaluation index system of rock blast-ability classification, choose eight factors as evaluation indexes, namely rock density, tensile strength, impact strength, integrity coefficient, compressive strength, sturdiness coefficient, wave impedance and explosive specific charge, respectively with a1, a2, a3, a4, a5, a6, a7, a8. By using the method of classification standard quantitative to indicate the classification and values which shown in table 1, each index can be divided into 5 levels, evaluation sets (A1, A2, A3, A4, A5), namely Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ, respectively easy, medium, hard, harder, the hardest.

***Table 1:** The classification standard quantitative of rock blast-ability*

Evaluation level	**Rock density a_1 (*t/m³*)**	**Tensile strength a_2 (*Mpa*)**	**Impact strength a_3 (*Mpa*)**	**Integrity coefficient a_4**	**Compressive strength a_5 (*Mpa*)**	**Sturdiness coefficient a_6**	**Wave impedance $a_7 \times 10^6$ ($Kg \cdot m^{-3}$) ($m \cdot s^{-1}$)**	**Specific charge a_8 (Kg/m^{-3})**
Ⅰ (A_1)	2.5~2.6	6.6~10	160~200	0.0494~0.2555	20~23	6~8	≤5	0.25~0.35
Ⅱ (A_2)	2.6~2.9	10~16	200~300	0.2555~0.4753	23~43	8~12	5~8	0.35~0.45
Ⅲ (A_3)	2.9~3.1	16~18	300~320	0.4753~0.5491	43~47	12~16	8~12	0.45~0.65
Ⅳ (A_4)	3.1~3.3	18~23	320~500	0.5491~0.7122	47~70	16~18	12~15	0.65~0.9
Ⅴ (A_5)	>3.3	>23	>500	>0.7122	>70	≥.18	≥15	>0.9

According to the definition of the relevant index to the single measure function and the assignment of each evaluation index standard which shown in table 1, the comprehensive evaluation of single parameter measurement function is built. The unascertained measurements of each single parameter values are calculated. The measurement function of each index, including rock density, tensile strength, impact strength, integrity coefficient, compressive strength, sturdiness coefficient, wave impedance and explosive specific charge, is shown in figure 1.

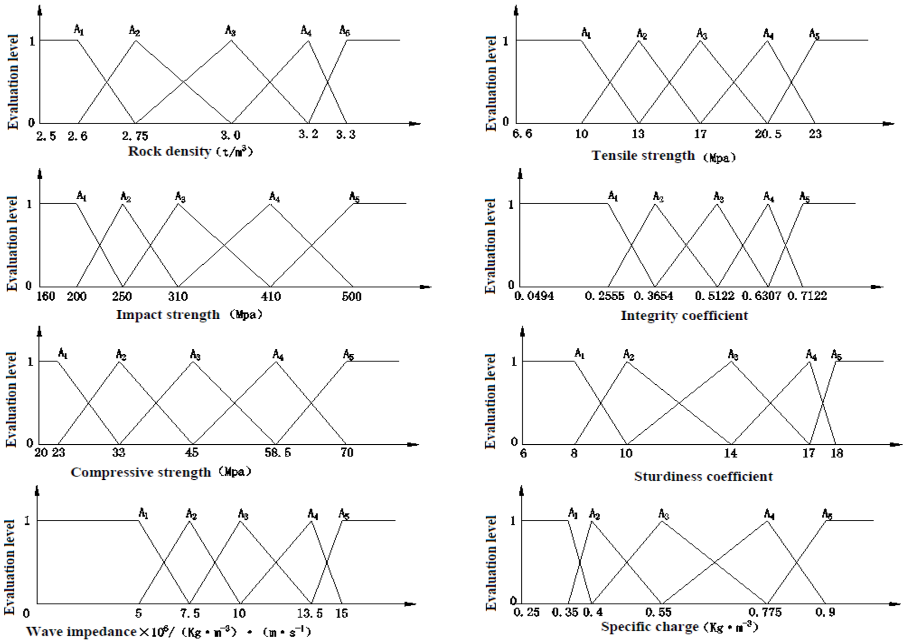

Figure 1. *The measurement function of each index*

4. Case test:

Due to Guiyang Chaoyangdong road project, its start-stop pile hole is from K3+000 to K4+200, total length is 1.2 km, mainly in the conditions of excavation is from K3+520 to K4+100 and the total length is 580m. The excavation of this blocks are divided into four sections: section one: K3+520 ~ K3+720, length of 200 m, excavated volume of 340800 m^3; Section two: K3+720 ~ K3+840, 120 m long, excavated volume of 89600m^3; Section three: K3+840 ~ K3+960(cape), 120m long, excavated volume of 118300 m^3; Section four: K3+960 ~ K4+100, 140 m long, excavated volume of 48500 m^3. From the geology survey, the lithology of grey thin to thick layer of granite and limestone, fine crystal structure, good integrity, joint fissure development, rock mass is given priority to with structural joints, structural plane is relatively flat, cementation, flooding softening is not obvious. Drilling is more difficult, the core is given priority to with columnar, short columnar, clip long columnar, belong to the solid rock. Its coefficient f was about 6 to 10. In order to get an efficient Blasting excavation, using the unascertained measure model on four sections in the excavation analysis of the comprehensive evaluation of the rock blast-ability classification, to provide a basis for optimization in the blasting construction.

The several representatives rock mass in four segments have been collected, all indexes of the rock blast-ability classification are shown in table 2.

Table 2: *Survey statistics of four regional rock blasting classifications in each index*

Number	Survey statistics of Four regional rock blast-ability classification in each index							
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
Section one	3.0700	17.38	440	0.7833	48	17	11	0.48
Section two	2.8126	13.32	240	0.7670	39	12	7	0.36
Section three	2.6038	11.12	210	0.7956	22	9	6	0.33
Section four	2.9622	15.21	330	0.7833	45	16	10	0.50

According to table 2, with the index data of rock blast-ability classification in four sections, combined with the unascertained measurement function with the corresponding single indexes in figure 1, the four section of the single index evaluation matrix had been obtained, respectively from (10) to (13).

$$\left(\mu_{1jk}\right)_{8\times5}=\begin{bmatrix}0&0&0.65&0.35&0\\0&0&0.89&0.11&0\\0&0&0&0.67&0.33\\0&0&0&0&1\\0&0&0.78&0.22&0\\0&0&0&1&0\\0&0&0.71&0.29&0\\0&0.47&0.53&0&0\end{bmatrix} \quad (10)$$

$$\left(\mu_{2jk}\right)_{8\times5}=\begin{bmatrix}0 & 0.75 & 0.25 & 0 & 0\\0 & 0.92 & 0.08 & 0 & 0\\0.2 & 0.8 & 0 & 0 & 0\\0 & 0 & 0 & 0 & 1\\0 & 0.5 & 0.5 & 0 & 0\\0 & 0.5 & 0.5 & 0 & 0\\0.2 & 0.8 & 0 & 0 & 0\\0.8 & 0.2 & 0 & 0 & 0\end{bmatrix} \quad (11)$$

$$\left(\mu_{3jk}\right)_{8\times5}=\begin{bmatrix}0.97 & 0.03 & 0 & 0 & 0\\0.63 & 0.37 & 0 & 0 & 0\\0.8 & 0.2 & 0 & 0 & 0\\0 & 0 & 0 & 0 & 1\\1 & 0 & 0 & 0 & 0\\0.5 & 0.5 & 0 & 0 & 0\\0.6 & 0.4 & 0 & 0 & 0\\1 & 0 & 0 & 0 & 0\end{bmatrix} \quad (12)$$

$$\left(\mu_{4jk}\right)_{8\times5}=\begin{bmatrix}0 & 0.15 & 0.85 & 0 & 0\\0 & 0.44 & 0.56 & 0 & 0\\0.4 & 0.6 & 0 & 0 & 0\\0 & 0 & 0 & 0 & 1\\0 & 0 & 1 & 0 & 0\\0 & 0 & 0.33 & 0.67 & 0\\0 & 0 & 1 & 0 & 0\\0 & 0.33 & 0.67 & 0 & 0\end{bmatrix} \quad (13)$$

The weight of each evaluation index to be determined by formula (5) and (6), the four sections of the evaluation index weights are:

ω_1 = (0.1020, 0.1342, 0.1034, 0.1706, 0.1147, 0.1706, 0.1072, 0.0973)

ω_2 = (0.1145, 0.1455, 0.1212, 0.1759, 0.1002, 0.1002, 0.1212, 0.1212)

ω_3 = (0.1415, 0.0912, 0.1064, 0.1544, 0.1544, 0.1079, 0.0898, 0.1544)

ω4 = (0.1208, 0.0940, 0.0953, 0.1638, 0.1638, 0.0993, 0.1638, 0.0993)

Given the believing degree λ was 0.6; the index measure evaluation vector formula (7) and the multi-index comprehensive measure evaluation vector of each section, combined with the believing degree evaluation formula (8) four section of rock blast-ability classification of unascertained measure evaluation results, as shown in table 3.

The results shown in table 3: the unascertained measurement evaluation of four sections, section one and section four level for Ⅲ difficult (blasting); Section two for Ⅱ level (medium); Section three for Ⅰ level (easy). Blasting parameters of the four sections in the early stage of the design and construction are the same, which results in the blasting construction section two, three rock too broken, which increased the material cost due to the high of the specific charge. The blasting in section one and four have made the large rock mass, more roots, which can increase the processing cost, influence the transport efficiency, increase the construction period. Through the unascertained measure analysis, the more clear the sample in each section of rock blast-ability we can see, to provide reliable basis for the selection of blasting parameters and optimized design.

Table 3: *The unascertained measurement evaluation results in four sections*

Number	**Comprehensive measure evaluation vector**					**Evaluation results**
	A_1	**A_2**	**A_3**	**A_4**	**A_5**	
Section one	0	0.0457	0.4035	0.3460	0.2047	Ⅲ (hard)
Section two	0.1454	0.5382	0.1404	0	0.1759	Ⅱ (medium)
Section three	0.6966	0.1491	0	0	0.1544	Ⅰ (easy)
Section four	0.0483	0.1494	0.5822	0.0665	0.1638	Ⅲ (hard)

5. Conclusion:

(a) The influence of factors on the rock blast-ability classification can be complex and fuzziness. In order to increase the accuracy of rock blast-ability classification, the comprehensive evaluation model of rock blast-ability classification was established by eight factors including rock density, tensile strength, impact strength, integrity coefficient, compressive strength, sturdiness coefficient, wave impedance and explosive specific charge. The evaluation model of rock blast-ability classification based on unascertained measurement theory was successfully established.

(b) The weight of each index was determined by using the information entropy theory, thus it could reduce the effect of subjective factors. The determination of rock blast-ability classification is based on the basis of believing degree criterion. The comparison analysis of evaluation results and blasting designs can provide a basis for optimization of blasting parameters.

(c) The evaluation model was used to evaluate the rock blast-ability in Guiyang Chaoyangdong road engineering and the evaluation results fit in anecdotally with actual situation. Therefore, this evaluation model can be a good method for rock blast-ability classification and offer significant basis for promoting the blast effect.

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