Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 26 (2011) 1692 – 1697

Procedia Engineering

www.elsevier.com/locate/procedia

First International Symposium on Mine Safety Science and Engineering

Research on index system of rock slope safety evaluation for open pit mine

GAO Yu-kun, Bao Na, ZHANG Ying-hua, JIANG Li-ming, HUANG Zhi-an*

Key laboratory of Ministry of Education on Metal Mine Exploration and Safety, University of Science and Technology Beijing, Beijing, 100083, China

Abstract

At present, slope is one of the three major sources of geological disasters, and disasters caused by slope happened frequently. The index system of rock slope safety for open pit mine was comprehensively researched by the model of fuzzy evaluation and the analytic hierarchy process. The technical methods on the selection and resolution of the index system of rock slope safety evaluation for open pit mine, and the confirmation of weight of safety evaluation index system had been obtained. The comprehensive index system of rock slope safety evaluation for open pit mine can consist of 28 safety indexes which include 5 aspects (rock slope quality, slope morphology, human factors, slope safety management and other factors).

Selection and/or peer-review under responsibility of China Academy of Safety Science and Technology, China University of Mining and Technology(Beijing), McGill University and University of Wollongong.

Keywords: rock slope for open pit mine; safety evaluation; index system; model of fuzzy evaluation; analytic hierarchy process

At present, the slope (landslide and debris flow), earthquakes, volcanoes are called today's three major geological disaster sources [1]. The safety of the slope and its impact on surrounding environment has caused people's great attention. Frequent accidents make people gradually realize slope safety, especially open pit mine slope safety. At present the research of open pit mine slope mainly aims at the side slope stability and analyzing slope safety factors [2], but safety evaluation index system of open pit mine slope is less, and the only of slope safety of highway project risk factors, highway engineering slope and open pit mine slope have many similar safety factors. This article is of important significance for analysis on

* Corresponding author. Tel.: +86-13641010189 ; fax: +86-10-82385795.
E-mail address: huang_za@263.net.

doi:10.1016/j.proeng.2011.11.2355

constructing the open pit mine slope safety evaluation index system, and it provides guidance for open pit mine slope safety factors.

Through the methods of slope safety evaluation and weight determination, slope safety actions factors of the open pit mine rock slope was analyzed, and safety evaluation index system of open pit mine slope was constructed. According to the fuzzy membership functions, each index weight was determined, and open pit mine fuzzy comprehensive evaluation model of slope was constructed.

1. Analysis of open pit mine slope safety factors

1.1. Principle of weight determination

Each index is not equivalent in the evaluation index system, the influence is different, and dimensions of the evaluation indexes also vary. Therefore, we must have make reasonable judgment of each index position on respective system, that is, to identify each index weight in their system. Greater of the index impact on the system, the greater the weight when evaluating, on the contrary, the smaller it is.

1.2. Analysis of open pit mine slope s*afety factors*

Yu Tingan, Dai Xingguo [2], HouYu [3], Lv Guoqing [4] analyzed influence factors of open pit mine slope stability. With combination of literature, open pit mine slope safety factors is divided into factors of the rock slope's quality, factors of slope morphology, human factors, slope safety management and other factors.

slope rock's quality include: Stratum lithology, Geological structure, Attitude of rocks, Rock complete degree , Slope rock weathering degree, Slope rock structure, Interaction of slope weak structural plane.

Slope morphology: Height of slope, Degree of slope, Shape of slope, Protection of slope, Slope strengthening.

Human factors: blast, Slope cutting, Roof load-on, underground excavation, others.

Slope safety management: Safety education training, Safety awareness of employees, Leader attention degree, Management of facility, Slope displacement monitoring, Emergency plan and response.

Others: Underground water, precipitation, earthquake, Climate character, Plant cover.

2. Constructing safety evaluation index system of open pit mine

2.1. Index system of rock slope safety evaluation for open pit mine

According to scientific principle, systematic principle, unit division and synthesis principle, the principle of evaluation of index system settings, exclude those not easily obtained data for the index, only taking one from coefficient bigger indexes. Open pit mine slope safety evaluation index system is shown as Table 1.

Table 1. Index system of rock slope safety evaluation for open pit mine

Level first index	symbol	Level second index
slope rock's quality(A1)	A11	Stratum lithology
	A12	Geological structure

Level first index	symbol	Level second index
	A13	Attitude of rocks
	A14	Rock complete degree
	A15	Slope rock weathering degree
	A16	Slope rock structure
	A17	Interaction of slope weak structural plane
Slope morphology(A2)	A21	Height of slope
	A22	Degree of slope
	A23	Shape of slope
	A24	Protection of slope
	A25	Slope strengthening
Human factors(A3)	A31	blast
	A32	slope cutting
	A33	Roof load-on
	A34	underground excavation
	A35	others
Slope safety management(A4)	A41	Safety education training
	A42	Safety awareness of employees
	A43	Leader attention degree
	A44	Management of facility
	A45	Slope displacement monitoring
	A46	Emergency plan formulation and response
Others(A5)	A51	Underground water
	A52	precipitation
	A53	earthquake
	A54	Climate character
	A55	Plant cover

2.2. Index weight calculate

Determine the important degree between every index based on the grading evaluation of 15 geological experts and safety evaluation experts who are selected through investigation. Safety first level evaluation indexes of open-pit rock quality slope are calculated as follows:

$$A=\begin{bmatrix} 1 & 4 & 5 & 4 & 5 \\ 1/4 & 1 & 4 & 4 & 1 \\ 1/5 & 1/4 & 1 & 1/4 & 1/3 \\ 1/4 & 1/4 & 4 & 1 & 1 \\ 1/5 & 1 & 3 & 1 & 1 \end{bmatrix}$$

Use “sum and product method” to calculate weight vectors:

Get B after standardization by column:

$$B=\begin{bmatrix} 0.5263 & 0.6154 & 0.2941 & 0.3902 & 0.6000 \\ 0.1316 & 0.1538 & 0.2353 & 0.3902 & 0.1200 \\ 0.1053 & 0.0385 & 0.0588 & 0.0244 & 0.0400 \\ 0.1316 & 0.0385 & 0.2353 & 0.0976 & 0.1200 \\ 0.1053 & 0.1538 & 0.1765 & 0.0976 & 0.1200 \end{bmatrix}$$

Get weights after row sum standardization:

$$W=\begin{pmatrix} 0.4852 & 0.2062 & 0.0534 & 0.1246 & 0.1306 \end{pmatrix}^T$$

Calculate maximum characteristic root by

$$\lambda_{\max}=\sum_{i=1}^{n}\frac{\left[A\bar{W}_i\right]_i}{n\left(\bar{W}_i\right)_i}$$

$$AW=\begin{bmatrix} 1\times0.4852+4\times0.2062+5\times0.0534+4\times0.1246+5\times0.1306 \\ \frac{1}{4}\times0.4852+1\times0.2062+4\times0.0534+4\times0.1246+1\times0.1306 \\ \frac{1}{5}\times0.4852+\frac{1}{4}\times0.2062+1\times0.0534+\frac{1}{4}\times0.1246+\frac{1}{3}\times0.1306 \\ \frac{1}{4}\times0.4852+\frac{1}{4}\times0.2062+4\times0.0534+1\times0.1246+1\times0.1306 \\ \frac{1}{5}\times0.4852+1\times0.2062+3\times0.0534+1\times0.1246+1\times0.1306 \end{bmatrix}=\begin{bmatrix} 2.7284 \\ 1.1700 \\ 0.2767 \\ 0.6416 \\ 0.7186 \end{bmatrix}$$

$$\lambda_{\max}=\frac{1}{5}\left(\frac{2.7284}{0.4852}+\frac{1.1700}{0.2062}+\frac{0.2767}{0.0534}+\frac{0.6416}{0.1246}+\frac{0.7186}{0.1306}\right)=5.4262$$

Check the consistency: $CI=\frac{5.4262-5}{5-1}=0.1066$. Look-up the table, when n=5, RI=1.12, so

$$CR=\frac{CI}{RI}=\frac{0.1066}{1.12}=0.0951<0.1$$

So, judgment matrix meets consistency, and the results can be acceptable and the obtained weights can be used. The result is finished as shown in Table 3. The column map of various factor weights was shown as Fig. 6. From the column map, we can see that among the five first level indexes of slope rock mass quality(A1), side slope shape and structural(A2), man-made factors (A3), slope safety management(A4), other factors(A5), the weight of slope rock mass quality is biggest, the weight of side slope shape and structural which comes to second greatly decreases, the weights of slope safety management and other factors are close to each other, and the weight of man-made factors is lowest.

Similarly, calculate the weight of evaluation indexes of the slope rock quality, the biggest weight of geological-tectonic indexes is 0.2936. Calculate the weight of side slope shape and structural, slope reinforcement comes to the first, and calculate the weight of man-made factors, blasting index comes to the first. Calculate the weight of slope safety management, the index of leadership attention degree comes to the first, and calculate the weight of other factors, groundwater comes to the first. Fig. 2 is each level weight data of total sorting.

Table 2. Evaluation index weight value of first level

Degree of important	A1	A2	A3	A4	A5	ω	λ_{max}	CR
A1	1	4	5	4	5	0.4852	5.4262	0.0952

Degree of important	A1	A2	A3	A4	A5	ω	λ_{max}	CR
A2	1/4	1	4	4	1	0. 2062		
A3	1/5	1/4	1	1/4	1/3	0. 0534		
A4	1/4	1/4	4	1	1	0. 1246		
A5	1/5	1	3	1	1	0. 1306		

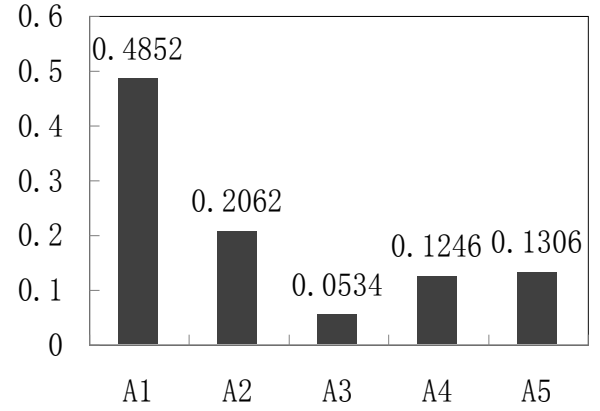

Fig. 1. The first level weight value

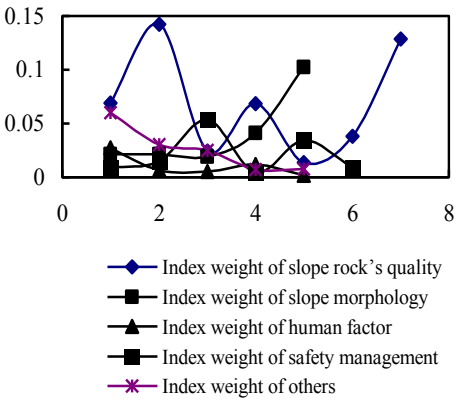

Fig. 2. Line chart of each level weight value of total sorting

3. Establishment of fuzzy comprehensive evaluation model for open pit mine slope safety evaluation index system

According to the fuzzy comprehensive evaluation model on rock slope safety evaluation index system for open pit mine, detailed evaluation procedures are as follows [5-7]:

3.1 Determine factors set.

For example U={A1， A2， A3， A4， A5}={Slope rock mass quality, Side slope shape and structural, Man-made factors, Slope safety management, Other factors}

3.2 Determine the comments set.

According to the rock slope safety evaluation index system for open pit mine of HuNing's Grading standards [1].

3.3 Make fuzzy matrix

Building the membership function of rock slope safety evaluation index system for open pit mine is a key work, which directly affects the quality of the evaluation results, determines the scientific and accuracy of the evaluation results. Fuzzy evaluation matrix for indexes is noted for (R1，R2，R3，R4，R5).

3.4 Single factor evaluation

Single factor evaluation is gained through fuzzy evaluation matrix of the main factors multiplied the weight of the main index relative to the factor.

3.5 Resulting from overall evaluation

- Evaluation results of indexes on index layer
- Assessment results of various factors on rule layer
- Overall evaluation results of target layers
- According to the principles of maximum membership degree, the security rating of B matrix corresponding to the maximum value is the safety grade of open-pit rock quality slope.

4. Conclusions

- The open-pit rock quality slope safety evaluation index system was established according to the present research on safety evaluation system of mine, which analyzed the stability and security comprehensively and in detail.
- The weight of every index was calculated by the analysis method of Analytic Hierarchy Process, which is the basis of the application of fuzzy comprehensive evaluation model.
- The fuzzy comprehensive evaluation model on the safety evaluation of open-pit rock quality slope was established based on qualitative analysis and quantitative analysis.

References

[1] Hu N. *Safety evaluation system establishment on Xiayukou Mine and Application Researching*. Taiyuan in Shaanxi Province: Xian University of Science and Technology, 2006. (in Chinese)

[2] Yu T A, Dai X G. Analysis on safety factors of open-pit slope stability. *Mining safety and environmental protection*, 2008, 35(1): 73-76. (in Chinese)

[3] Hou Y. Analysis of factors influencing on slope stability and measures for increasing it at jinduicheng open-pit mine. *China Mining Magazine*, 1999, 8(4):38-44.(in Chinese)

[4] Lv G Q. Factors analysis of side slope stability. *Science & Technology Information*, 2008, (3):108-112. (in Chinese)

[5] Lou F, Deng J. The application of AHP-Fuzzy in open mine slope stability analysis. *Mining Technology*, 2008, 18(2): 27~29. (in Chinese)

[6] Wang J F, Lv Z D. The determine method of membership function in fuzzy control. *Henan Science*, 2000, 18(4):348~351. (in Chinese)

[7] Zhang W H, Cheng Z B. Assessment System of Harmonious Mining Area Based on Analytic Hierarchy Process. *Journal of China University of Mining & Technology*, 2007, 36(6): 848-852. (in Chinese)