Hazard degree identification of goafs based on scale effect of structure by RS-TOPSIS method

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Abstract: In order to precisely predict the hazard degree of goaf (HDG), the RS-TOPSIS model was built based on the results of expert investigation. To evaluate the HDG in the underground mine, five structure size factors, i.e. goaf span, exposed area, goaf height, goaf depth, and pillar width, were selected as the evaluation indexes. And based on rough dependability in rough set (RS) theory, the weights of evaluation indexes were identified by calculating rough dependability between evaluation indexes and evaluation results. Forty goafs in some mines of western China, whose indexes parameters were measured by cavity monitoring system (CMS), were taken as evaluation objects. In addition, the characteristic parameters of five grades’ typical goafs were built according to the interval limits value of single index evaluation. Then, using the technique for order preference by similarity to ideal solution (TOPSIS), five-category classification of HDG was realized based on closeness degree, and the HDG was also identified. Results show that the five-category identification of mine goafs could be realized by RS-TOPSIS method, based on the structure-scale-effect. The classification results are consistent with those of numerical simulation based on stress and displacement, while the coincidence rate is up to 92.5%. Furthermore, the results are more conservative to safety evaluation than numerical simulation, thus demonstrating that the proposed method is more easier, reasonable and more definite for HDG identification.

Key words: goaf; RS-TOPSIS method; hazard degree; scale effect

1 Introduction

In the mining process methods of open stope as room-and-pillar method, overall mining and shrinkage methods, usually lead to plenty of mined-out areas in the underground mine [1]. In China, with the strength of the mining resources increasing in recent decades, massive mined-out areas had been formed in the underground mining, and a lot of casualties had been caused by the collapse of mined-out area, with eventual great economic losses. The No.100 ore body of Guangxi Gaofeng Mine had brought out a number of mined-out areas because of long-term rot and private mining, which caused the large subsidence with a total volume of 848800 m³ on March 19, 1993 and formed reconstruction collapse crater in the ground space [2]. In a related development, the gypsum mining area of Shuangxi Gaofeng Mine had brought a number of mined-out areas because of long-term rot and private mining, which caused the large subsidence with a total volume of 848800 m³ on March 19, 1993 and formed reconstruction collapse crater in the ground space [2]. In a related development, the gypsum mining area of Shuangxi Gaofeng Mine had brought a number of mined-out areas because of long-term rot and private mining, which caused the large subsidence with a total volume of 848800 m³ on March 19, 1993 and formed reconstruction collapse crater in the ground space [2].

On November 6, 2005, it caused direct death of 33 people, missing of 4 people and direct economic losses of ¥7.74 million RMB. Underground mined-out area in Linan Gypsum Mine in Shimin County, Hunan Province China collapsed on August 19, 2006, killing 9 people, with subsequent collapsing area of about 18000 m² [3]. The long-term existing of underground goafs contributes to a heavy hidden danger of production safety and life and property security of mines. Therefore, it is imperative to assess the security status of underground goafs in advance and deal with them separately, with the aim of efficient elimination of safe hidden trouble. Hazard degree of goaf (HDG), is a measurement of loss damage possibility of goaf collapse to external objects when goaf collapses, which can be used to forecast the fatality of mined-out area.

Goafs belong to underground space, nonetheless, so the method of underground space stability analysis cannot be directly used to analyze goafs’ stability because of the different areas, shapes and complex environments of goafs. Thus, lots of researches about safety evaluation...
of goaf from different sides had been done by scholars in worldwide, mainly in the spheres of goaf precise survey and stability evaluation of mined-out area, etc. For example, FENNER [4] explored tunnels and abandoned goafs in mine using ground-penetrating radar (GPR) method. DAVID et al [5] successfully explored underground mined-out areas and geological anomalies adopting the earthquake imaging method. HUBER and VANDAPEL [6] explored the underground space in three-dimension (3D) based on 3D laser detection technology by installing laser detector on the car. On the hazard degree identification of mined-out areas sides, LI et al [7] studied the application of extension evaluation approach to the goaf hazard identification, and established an extension model for identifying the hazard degree of goafs. This was achieved by applying the correlated functions of matter elements, which achieved good results. DUAN [8] evaluated the mined-out area based on the fundamental theory and method of fuzzy comprehensive evaluation, and constituted a multifactor assessing model for goaf hazard degree. Thereby, quantitative analysis of underground goaf disaster hazard degree in Dabaoshan was realized.

In a related development, WANG et al [9] applied the grey relation analysis (GRA) to hazard degree evaluation of goafs, based on main factors influencing the safety of the mined-out stopes and their weight. Also, the feasibility and effectiveness of GRA were proved through practical examples. Meanwhile, GONG et al [10] constructed the Bayes discriminate model for forecasting the stability of underground goaf, and the re-substitution method was introduced to verify the stability of model. The engineering application indicated that the model had an excellent performance and high prediction accuracy. LIU et al [11] analyzed stability of cavity under open pit bench combing theory calculation and numerical analysis.

However, because of the environmental peculiarities of underground mined-out area, the HDG is affected by mining technological conditions, physicochemical properties of ore rock, specification size of goaf, stress fields of surrounding rock mass and other factors. Thus, hazard degree identification of goafs is a typical multiple attribute group decision-making problem, and it is much difficult to gain a considerable result. Additionally, several methods were applied to identifying the HDG, but the rock mass structure and properties, with various factors and some indexes such as geological structures are usually difficult to obtain rapidly on the spot, which contradict the convenient and quick identification of source of danger. At the same time, the coexistence of a large number of underground mined-out areas is common, which induces a heavy workload of previous evaluation methods like numerical analysis. Therefore, it is necessary to look for new methods mainly based on structural characteristics of goaf to identify the HDG [12].

Technique for order preference by similarity to ideal solution (TOPSIS), a well-known classical MADM method, was first developed by HWANG and YOON in 1981 [13]. In the past 30 years, TOPSIS had been widely applied. In the case of robot optimum seeking problem, PARKAN and WU [14] established selection model combined operational competitiveness rating with TOPSIS. The weights of evaluation indexes were determined using analytic hierarchy process (AHP), and the airline passenger service quality was evaluated using TOPSIS. GUAN et al [15] proposed a comprehensive multi-criterion decision method combining TOPSIS and AHP together. YANG et al [16] proposed a new approach about optimization of initial orbital elements based on the TOPSIS method. According to the feature of spacecraft initial orbit, a decision-making mathematical model on optimization of initial orbital was established successfully by assuming the normal orbit as ideal solution and the bias orbit as negative-ideal solution. CHENG [17] proposed a novel multi-objective robust optimization method on the basis of parameter design using inner-outer array, analysis of signal to noise ratio (SNR) and TOPSIS, and the most robust scheme was determined.

In this work, multi-index of scale effect of structure which was easy to be obtained was selected as the evaluation indicators because of the notably significant effect common in engineering geology, hydrogeology and the scale effect of structure on HDG. Classification criteria of HDG based on the scale effect of structure were established through expert questionnaire investigations. Then, the objective weightiness of evaluation indexes were obtained based on the application of rough set theory (RS) in data mining. On the basis of the above work, quantitative evaluation of the HDG was realized combining with the TOPSIS method, and finally the goal of identifying the HDG correctly and rapidly would be achieved by RS-TOPSIS method based on scale effect of structure.

2 Basic idea of RS-TOPSIS method

2.1 Rough set (RS) theory

The RS theory established by Pawlak is a mathematical tool to deal with fuzzy and uncertainty knowledge [18–19]. The main idea of the method is that it could induce decision of problem and classification rules by knowledge reduction under the premise of keeping the same ability for classification [20].

RS has been successfully applied to knowledge acquisition, target recognition, decision classification and