Three-dimensional classification and zoning method of surrounding rock and its application based on big data geomechanical information

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Abstract. The study aims to address some prominent problems of the existing classification methods of roadway surrounding rock, such as poor adaptability and applicability. For this purpose, using geomechanical information coupling with the three-dimensional (3D) geological modeling technology, a 3D classification and zoning method of surrounding rock is proposed on the basis of the big data geomechanical information database. This method can realize advanced prediction and evaluation analysis of rock mass quality in unexposed areas. The method first establishes an acquisition workflow of the big data geomechanical information based on the rock mass rating (RMR) and then forms a statistics technology of the big data geomechanical information and database sample based on borehole core data. Finally, it realizes the assignment of RMR for the unexposed areas by combining the 3D evaluation technology of 3DMine software and the supplemented information obtained from onsite geological survey. The 3D classification and zoning method is applied to the Jiama mine and compared with quality statistics obtained from an onsite survey. The results from the proposed model based on the borehole core database statistics are consistent with the onsite survey results. This indicates that the proposed method has excellent feasibility and applicability to solve some of the problems with the existing methods. In addition, the 3D classification and zoning method realizes extra mechanical application for borehole cores except for geological exploration and improves the application extent of borehole cores from multiple angles.

1. Introduction

Ground support has always been a challenging and important problem for the management of mines. The challenge lies in the fact that the geological conditions are complex and changeable and the technicians cannot accurately identify the structural characteristics of the rock mass and its quality, resulting in excessive support of surrounding rock or untimely support. Importantly, the cost due to the excessive support of the roadway and the casualties and property losses caused by the untimely support considerably hinder the business operation of an enterprise. The former is the key and core of surrounding rock control. Research worldwide has resulted in various methods such as rock mass rating (RMR), basic quality (BQ), quality (Q), mining RMR (MRMR), and geological strength index (GSI) for the comprehensive evaluation of rock mass quality (RMQ) [1-8]. These methods describe the various characteristics of the rock mass structure, rock strength, and groundwater. On the basis of such descriptions, the established failure criterion [9] is used to quantitatively determine the mechanical parameters of different RMQ using calculation software [10]. Finally, the expert system of
surrounding rock support, support system formulation, and numerical simulation are adopted to determine the rock mass support scheme [11-14]. The abovementioned processes constitute the current complete idea and technical method for classification control of surrounding rock, which have been generally accepted by a majority of technicians. However, many mine technicians believe that this set of technical method is not suitable for onsite application and cannot identify differences of RMQ for large mining areas under complex conditions. Therefore, the guiding role for production is still extremely limited. Therefore, it is imperative to explore a classification and zoning method of surrounding rock that is universal, replicable, extendable, and can cover a large area.

In view of the outstanding problems of the existing classification methods of roadway surrounding rock in the large-scale mining, such as the poor adaptability and applicability, a three-dimensional (3D) classification and zoning method of surrounding rock is proposed based on the big data geomechanics information database. This method is applied in the second phase of underground mining at the Jiama mine in Tibet. The results confirm that this method is feasible and applicable to solve some of the prominent problems generally faced by existing methods, such as poor applicability and non-promotion.

2. Database construction of big data geomechanical information

2.1. Evaluation method selection of RMQ
The evaluation method of RMQ suitable for big data statistics of geomechanical information should have two characteristics—1) the mechanical information should be quantified, and 2) large-scale mechanical information should be obtained quickly using a single main method. The RMR, Q, and MRMR are the main methods for evaluating RMQ; because they can be mutually converted using the GSI value, any of the above methods can be selected. This study adopts the RMR as an example for analysis.

2.2. Big data acquisition of geomechanical information
Geological drilling to seek orebody is a necessary process for any mine in the early stage. The geological core obtained through strict specification and operation contains massive data of geomechanical information, which can capture the rock strength (uniaxial compressive strength or point load strength), RQD, discontinuity spacing, roughness, weathering, and part of the fault information near the mining area when using the RMR method. In addition, a rapid survey tool for engineering geology is applied to some areas in the early stage of development and mining [15,16] to achieve accurate acquisition of discontinuous separation, occurrence, infilling, and groundwater. It is possible to realize the spatial acquisition of a large amount of geomechanical information near the mining area in the early stage of mining through the workflow shown in Figure 1; this lays the foundation for the database construction of the big data geomechanical information. Owing to the insufficient acquisition of geomechanical information caused by the large spacing between drill holes or other reasons, it is necessary to further increase data as the mining engineering continues.
2.3. Big data statistics of geomechanical information and database construction

After obtaining the big data geomechanical information using the above acquisition means, to realize the 3D classification and zoning method, the information must be calculated and the corresponding database needs to be constructed according to the method requirements and the applicable rules of the calculation software. As an example, 3DMine software is employed to build the database [17], and the constructed statistical samples are shown in Table 1.

Table 1. Sample statistics of database for the big data geomechanical information

| Drill hole number | Roundtrips | Beginning depth | End depth | Lithology | Strength of intact rock | RQD | Discontinuity spacing | Discontinuity condition | Groundwater | Correction of discontinuities direction |
|-------------------|------------|-----------------|----------|-----------|-------------------------|-----|-----------------------|------------------------|-------------|---------------------------------------|
| **                 | ...        | ...             | ...      | ...       | ...                     |     | ...                   | ...                    | ...         | ...                                  |

3. 3D classification and zoning method of surrounding rock and its realization

According to the characteristics of 3DMine software, the 3D classification and zoning of surrounding rock based on the big data geomechanical information of drill holes obtained through software is realized by combining the RMR method and the probability statistical method. The 3D classification and zoning method of surrounding rock and its realization process are shown in Figure 2. Based on the characteristics of big data analysis method, this method is closely related to the number of drill holes and the amount of geomechanical information obtained. The more the drill holes and geomechanical information obtained, the higher the accuracy of the surrounding rock classification evaluated by the method. Therefore, it is necessary to gradually enrich geomechanical information at different stages of geological exploration to improve the accuracy of rock mass classification.
Figure 2. Realization process of the 3D classification and zoning method of surrounding rock

This method can establish a basic correlation for the geomechanical information between adjacent drill holes and simultaneously consider the effect of typical structures, such as faults. Therefore, some limits such as planarization, localization, and “one hole view” for rock classification are overcome, and the advanced prediction and evaluation analysis of the RMQ in the unexposed areas are realized.

4. Engineering application

Considering the scope of the second phase of underground mining in the Jiama mine in Tibet as an example, the application of the 3D classification and zoning method based on the big data of geomechanics is described in detail in the study area. Further, to verify the feasibility and applicability of this method, a statistical review of RMQ focusing on 105 roadways is performed using GSI.

4.1. Engineering background

The designed production capacity of the underground mining in the Jiama mine is six million tonnes each year, and the mining method is the delayed filling open stoping method. The integrity and strength of rock mass change greatly due to the fissures, faults, skarnized marble orebody, and diageneis condition, which results in large differences of RMQ in the different areas. These conditions considerably hinder the selection of support classification, setting of stope structure parameters, and control of the stability of the roadway in a large area. Moreover, particularly in case of the Jiama mine, which is located in a high-altitude area in Tibet, the huge manpower is required for conducting onsite engineering geology surveys of the large-scale and multi-level area. RMQ must be determined accurately for the safe, efficient, and economical mining of the second-phase mining area.

In response to these difficulties, based on the large number of prospecting cores in the second-phase mining area and the partially exposed roadways, a big data geomechanical information database was constructed at the early stage of preparation for mining. On the basis of this database, 3D classification and zoning were realized. This work aims to solve the technical problems of classification support to the greatest extent in the early stage of large-scale mining.

4.2. Big data geomechanical information database
The borehole core library in the Jiama mine is a large-scale library with high standard, large storage, and complete information, built under the guidance of the Chinese academician Duoji. All cores used in the statistics of the big data geomechanical information are from this core library. Table 2 lists the specific statistical data.

**Table 2. Big data sample statistics of borehole core database**

| Item                          | Value          |
|-------------------------------|---------------|
| Number of effective boreholes | 67            |
| Statistics length             | 6202.94 m     |
| Elevation range               | 4400–4490 m   |
| Total round trip              | 4110          |
| Sample statistics with 0.5 m  | 6230          |

Based on the basic geomechanical information of the cores, the RMR statistics of the single borehole is realized and the sample statistics with a length of 0.5 m is combined, according to the workflow shown in Figure 3.

**Figure 3. Acquisition and management process of big data geomechanical information**

Figure 4 indicates that the distribution of the RMR values is relatively discrete, with an average value of 61.65, but the regional distribution between 55 and 85 is relatively concentrated, thereby showing a good characteristic of normal distribution. The RMQ in the second-phase of underground mining is relatively good. According to the RMR index, the RMQ is mainly II and III, while V is distributed in some areas. This indicates that there are faults and fracture zones with poor quality, which is verified by subsequent geological prediction of typical faults.
Figure 4. Basic statistical distribution of the big data of RMR

4.3. Three-dimensional classification of surrounding rock

To realize the 3D classification and zoning for the second phase of underground mining, based on the existing borehole RMR, it is necessary to use the block valuation method to realize the spatial assignment of the rock mass in the study area. Existing widely used 3D space valuation methods mainly include Kriging interpolation and the distance power inverse ratio method [18,19]. Owing to the obvious occurrence of faults and fracture zones in this study area, the occurrence mainly near parallel and steep dip (Figure 5). Further, the metallogenic complexity of skarnized marble, the main part of this 3D classification uses the distance power inverse ratio method, and the faults and fracture zones use a single assignment method. Table 3 lists the related basic parameters of the distance power inverse ratio method.

Table 3. Basic parameters for 3D classification.

| Basic parameters                          | Value      |
|------------------------------------------|------------|
| Powers of distance                       | 2          |
| Spindle search radius                    | 173.5 m    |
| Sub-block valuation in all directions    | 3          |
| Minimum number of selected samples       | 11         |
| Maximum number of selected samples       | 30         |

Figure 5. Distribution of faults and fracture zones
Figure 6 shows the resulting 3D evaluation model of RMQ obtained using the above parameters, based on the RMR classification standard of I–V. Clearly, the generated 3D model has different classifications in different zones and can realize the division of RMQ in a large range. The classification statistics is calculated for the model as shown in Figure 7. The proportion of RMR in the range of 40–80 is the highest, followed by the distribution of V in the form of faults and fracture zones. The statistical distribution shows good consistency with Figure 4.

Figure 7. RMR distribution statistics of rock mass in the second phase of underground mining

According to the four mining levels (4420, 4440, 4465, and 4490 m), the 3D classification and zoning model of Figure 6 is drawn and cut separately, as shown in Figure 8. In addition, four mining-level roadway layouts are drawn to present the different classifications at different locations of each roadway. Thus, a more reliable basis for the selection of roadway control countermeasure and the decision of support investment is provided. Note that based on Figure 8 and combined with the correction of continuity orientation adjustment for the roadway model, a more accurate evaluation of RMR is achieved.

Figure 8. 3D classification and zoning for the rock mass in the second phase of underground mining (Section 2nd)
4.4. Statistics and comparison of onsite surrounding rock classification

To further verify the reliability of the 3D classification and zoning model, based on the convenient and fast advantages of using GSI for onsite evaluation, the onsite surrounding rock survey and classification statistics for 105 roadways were achieved using the GSI method in the second phase of underground mining [20]. Figure 9 shows the specific results. For comparison with the research method proposed above, the conversion of RMR and GSI is carried out according to the following equation:

\[ \text{RMR}_{99} = \text{GSI} + 5 \]  

where RMR classification revised by Bieniawski in 1989 is considered, with RMR_{99} > 23, and the index of the groundwater parameters is set to 15, without considering the revised score of the discontinuity orientation adjustment.

From Figure 9, the classification results of the onsite survey are highly consistent with the results derived from the 3D classification and zoning method based on the big data geomechanical information. The scaled RMR is also concentrated between 50 and 80 and the probability density distribution is similar to those shown in Figures 4 and 7.

![Figure 9. Investigation statistics of onsite surrounding rock classification](image)

Figure 9. Investigation statistics of onsite surrounding rock classification

To further demonstrate the reliability of the 3D classification and zoning method based on the big data geomechanical information, the results of the borehole core database, the 3D classification and zoning model, and the RMQ of the onsite survey were compared. Because of the different statistical units and values, the distribution of RMQ in each interval is unified into a percentage form to unify the comparison scale; Figure 10 shows the statistical results. The distribution intervals of different classifications indicate that the results obtained from the borehole core database statistics and the 3D classification and zoning model are basically the same as the quality statistics obtained from the onsite survey. Therefore, the 3D classification and zoning method based on the big data geomechanical information is confirmed to be highly feasible. It can realize the advanced prediction and evaluation analysis of RMQ in the unexposed area, and it is important in guiding engineering practice.

The 3D classification and zoning method of surrounding rock and its application based on the big data geomechanical information combines the advantages of big data statistics of a large amount of geomechanical information of cores and the limited data supplement of some onsite engineering geology surveys. Therefore, this method has excellent adaptability for the advanced prediction and evaluation of the RMQ in the unexposed areas in the early stage of mining.
Figure 10. Comparison of RMQ results obtained by the 3D classification and zoning model and the onsite survey

5. Conclusion
The acquisition workflow for the big data geomechanical information is proposed, and the statistics of the big data geomechanical information and database sample is developed on the basis of borehole data.

The 3DMine software is closely combined with the RMR method and the big data statistical probability method to realize the 3D classification and zoning method. The implementation of this process realizes the advanced prediction and evaluation of the RMQ in the unexposed areas.

The application results of the 3D classification and zoning method in the Jiama mine confirm that the method is feasible and applicable. Thus, the method is important in guiding engineering practice and can solve some prominent problems generally faced with traditional methods, such as poor applicability and non-promotion.

The 3D classification and zoning method realizes the multi-purpose of geological prospecting boreholes and increases additional mechanical information collection and large-scale rock quality classification other than prospecting and exploration.

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