



Analysis and Evaluation of Surrounding Rock Quality of Large Underground Factory Caverns Based on BIM Technology

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Abstract. The underground powerhouse cavern group of hydropower projects has the characteristics of large scale, complex geological structure conditions, and strong excavation disturbance. The analysis and evaluation of the surrounding rock quality are crucial for the stability, construction safety, and operation of the project. Therefore, this article takes a hydropower project as an example, based on geological modeling and attribute modeling BIM technology, establishes a comprehensive evaluation method for the surrounding rock quality of underground caverns that integrates geological, geophysical, and design multi professional and multi-source data, and uses three-dimensional geological modeling technology to establish the implementation methods of RMR, HC, and BQ three types of surrounding rock quality grading methods, realizing the visualization of surrounding rock quality grading and parameter values, quantitatively evaluating surrounding rock quality, significantly improving analysis efficiency, not only providing a new means for the classification of surrounding rock quality of large underground caverns, but also providing scientific basis for the design and construction of caverns, ensuring project safety, and having important project application value.

Keywords: Underground powerhouse cavern group; BIM technology; Attribute modeling; rock quality evaluation

1 Introduction

In the construction of hydropower projects, the surrounding rock quality of large underground powerhouse caverns [1,2], as the core hub, directly affects the stability, construction safety, and operational efficiency of the entire project. Underground factory caverns are usually located in complex geological environments, facing diverse geological and mechanical conditions such as lithological changes, structural development, and high ground stress. These factors interact with each other, resulting in complex and variable characteristics of the surrounding rock quality. However, the geological conditions of underground projects are complex and varied, and accurate analysis and evaluation of surrounding rock quality have always been difficult and key issues in the

project field. Therefore, a comprehensive and systematic analysis and evaluation of the surrounding rock quality of large underground powerhouse caverns in hydropower projects [3-8] is not only the foundation for ensuring the smooth progress of project construction, but also a key link in ensuring the long-term safe operation of the project.

Therefore, this article takes a hydropower project as an example, aiming to comprehensively analyze and evaluate the surrounding rock quality of a large underground powerhouse cavern group based on BIM technology, significantly improving the efficiency of analysis. By utilizing geological modeling, attribute modeling, and cubic mesh methods, the implementation of three rock mass quality grading methods, RMR, HC, and BQ, is established to carry out analysis and evaluation of the rock mass quality of large underground factory caverns, and to construct a BIM visualization system for rock mass quality evaluation. This not only helps to improve the design and construction level of underground powerhouse caverns, but also provides reference and inspiration for the construction of similar underground projects, which has important theoretical significance and practical application value.

2 Key BIM Technologies for Surrounding Rock Quality Evaluation

The classification of the surrounding rock quality of the large underground powerhouse cavern group was achieved through geological modeling and attribute modeling techniques. By using geological modeling techniques, adopting the geological 3D analysis and design system independently developed by Northwest Engineering Corporation Limited, Power China, the required indicators for evaluating the quality of surrounding rock are unified into a database, and three traditional grading methods, RMR, HC, and BQ, are created for implementation. By utilizing attribute modeling techniques and the cubic network function, the grading results are mapped onto the underground factory model, that is, quantitative data is expressed on the underground factory model.

2.1 Geological Modeling Technology

Geological modeling refers to the use of modern tools such as computers to achieve three-dimensional information visualization and data management of geological bodies. The core content of geological body modeling is to describe the geometric shape and project characteristics of existing geological objects, and the described objects already objectively exist. Due to the inherent characteristics of natural geological bodies and geological work, geological body modeling is based on discrete mathematical theory, using DSI as the underlying modeling technique, as shown in Figure 1.

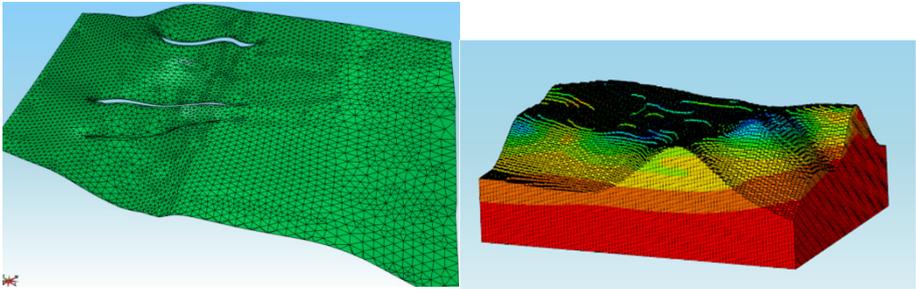
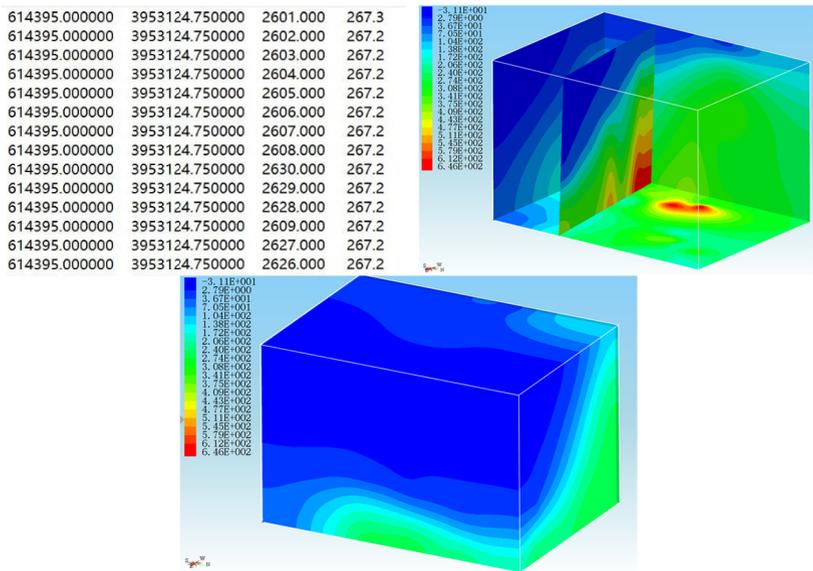


Fig. 1. DSI Interpolation Algorithm for Geological Modeling

2.2 Attribute Modeling Technology

Attribute modeling is used to describe the relationship between quantitative data and geological models or building shapes. For the attribute modeling of surrounding rock quality grading in this study, a rock quality grading based on a single indicator data and multiple methods was implemented in a 3D geological modeling software. Cube network is a medium for storing attribute data in attribute modeling, carrying a large amount of attribute data. Each unit can store information and perform data interpolation and operations. Based on this, a set of indicator data is assigned to the building shape. Figure 2 shows the process of assigning attribute data, Figure 3 shows RMR, HC, BQ projecting cube network data to the underground factory shape.



(a) Import data

(b) Assigning attribute data to 3D space (c) Arbitrary slicing of attribute model

Fig. 2. Attribute Parameter Assignment

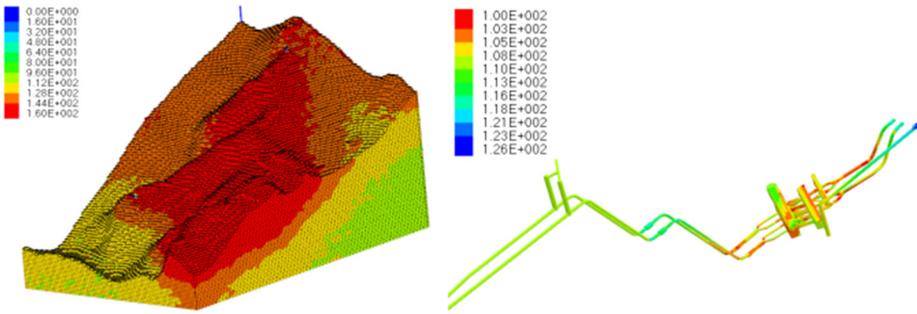


Fig. 3. Attribute Parameter Assignment

3 Analysis and Evaluation of Surrounding Rock Quality of Large Underground Factory Caverns

This study takes a hydropower project as an example, based on BIM technology, integrates multiple professional and multi-source data as grading indicators, and evaluates the surrounding rock quality of a large underground powerhouse cavern group using three grading methods: RMR, HC, and BQ.

Among them, the project area of a hydropower project is composed of thick sandstone and extremely thin shale and phyllite in the Upper Triassic Zagunao Formation. The surrounding rock of the underground powerhouse cavern group is generally intact, mainly weakly weathered to fresh rock, and the surrounding rock of the local fault fracture zone and its influence zone is weakly weathered. The bedding planes are developed, and the rock strata have an attitude of $NW320^{\circ} - 330^{\circ} SW55^{\circ} - 70^{\circ}$. The caverns are interspersed with each other, and the thickness of the surrounding rock between local caverns is relatively thin. There are steeply dipping faults represented by f31 and f33, interlayer compression zones represented by PH bands, and gently dipping structural planes represented by f20 in the factory area.

3.1 Surrounding Rock Quality Grading Database

The data to be collected for the evaluation of the surrounding rock quality of a large underground factory cavern group mainly includes geological, geophysical, and design data results, and the drilling, adit, geological surveying, and wave velocity are recorded in the geological database as the basic data for the classification of surrounding rock quality. The required data for grading is shown in Table 1. The exploration of the underground powerhouse cavern group of a hydropower project in this study includes 3 boreholes and 7 flat tunnels, as shown in Figure 4. The horizontal direction in the figure is the flat tunnel, and the vertical direction is the borehole. Figure 5 shows the exploration data, powerhouse and structural plane distribution model.

Table 1. Basic Data

Profession	data type	data
geology	drill	Weathering unloading, RQD, groundwater
	adit	Weathering unloading, Structural plane, groundwater
	Geological surveying and mapping	Stratigraphic lithology, geological structure
geophysical prospecting	velocity	V _p
design	design model	Cave design model

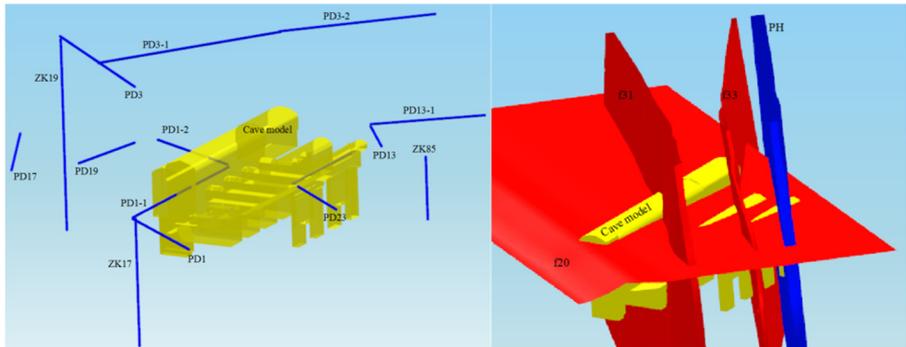


Fig. 4. Factory Model and Structural Surface Layout

3.2 Classification of Surrounding Rock Quality of Underground Factory Caverns

According to the requirements of the Geological Survey Code for Hydroelectric Power Projects (GB 50287-2016), the HC classification method, also known as the hydro-power classification method, is mainly used for the classification of surrounding rock quality in this project. At the same time, the BQ classification method and the internationally recognized rock classification method - RMR classification method are simultaneously used for the comprehensive evaluation and comparative analysis of the surrounding rock quality classification of underground powerhouses. The grading process is shown in Figure 4.

Considering the development of the bedding structure in the underground powerhouse of a certain hydropower project, the bedding plane is adjusted to NW320 ° NE (SW) \angle 75 °~90 °. Table 2 shows the rock types corresponding to the scores of different grading methods. Based on this, the PH band and main structural planes are assigned values to consider their impact on the deterioration of rock quality. The values are shown in Table 3.

Table 2. The rock mass categories corresponding to the scores obtained by different grading methods

Rock classification	I	II	III	IV	V
HC grading method score	>85	$85 \geq T > 65$	$65 \geq T > 45$	$45 \geq T > 25$	≤ 25
RMR grading method score	100~81	80~61	60~41	40~21	≤ 20
BQ grading method score	>550	451~550	351~450	251~350	≤ 250

Table 3. Score of structural plane parameters for different grading methods

classification method	PH strip scoring	f20, f33, f31 strip scoring
HC grading method	20-25	30-35
RMRgrading method	15-20	25-30
BQgrading method	200-250	275-300

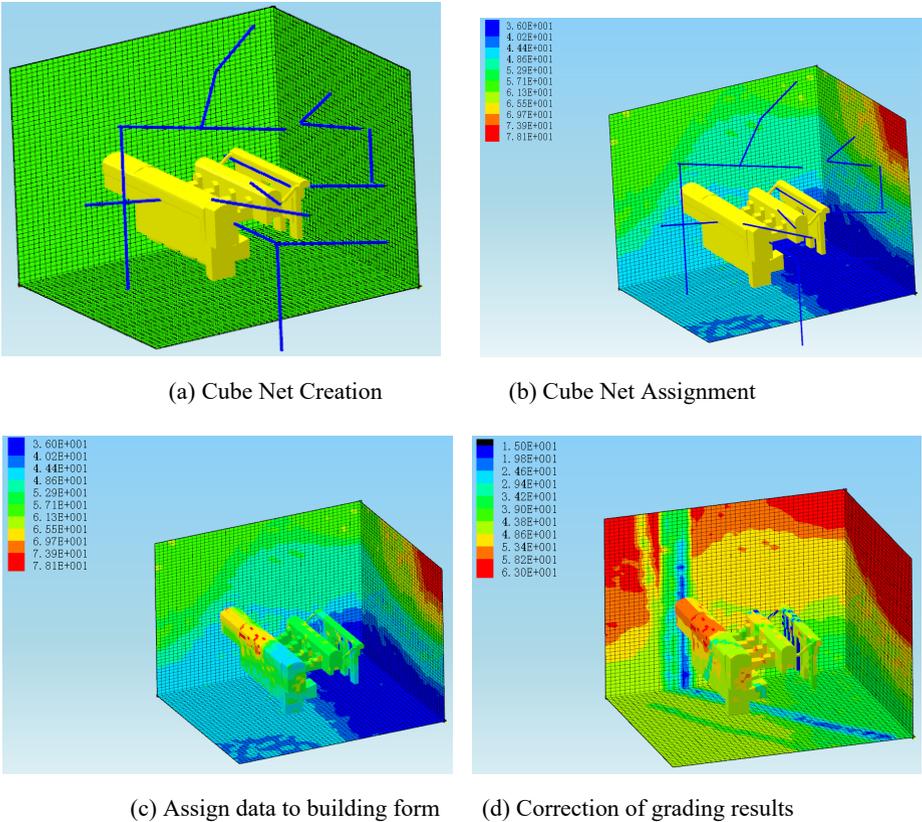


Fig. 5. Classification process of rock mass quality

3.3 Comparative Analysis of Grading Results

This study mainly uses the HC classification method for rock quality grading, and simultaneously verifies the BQ classification method and RMR classification method. According to the three-dimensional visualization of the rock quality grading workflow, the rock quality grading results of the above three methods can be obtained, as shown in Figure 6.

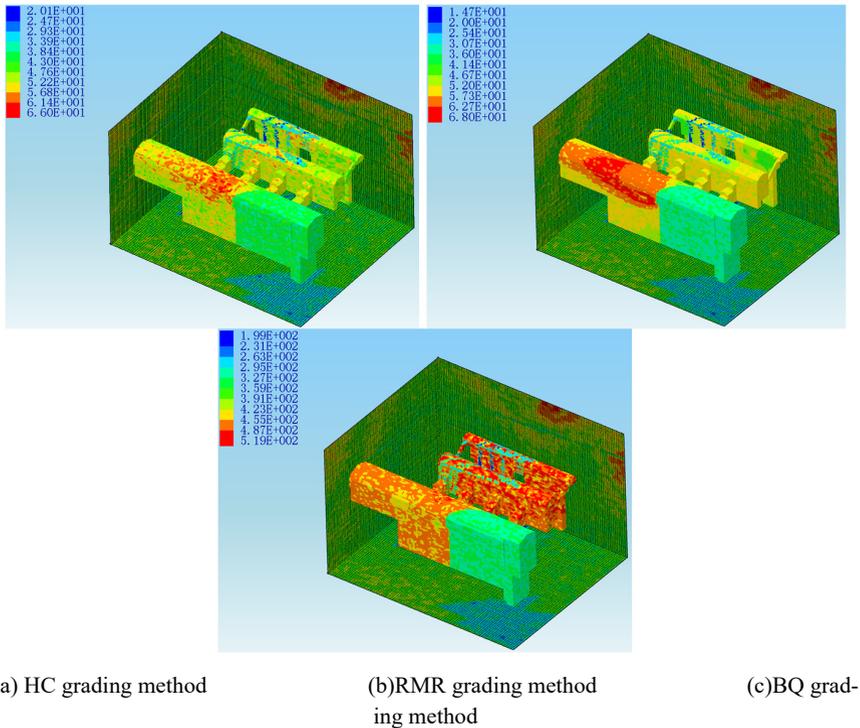
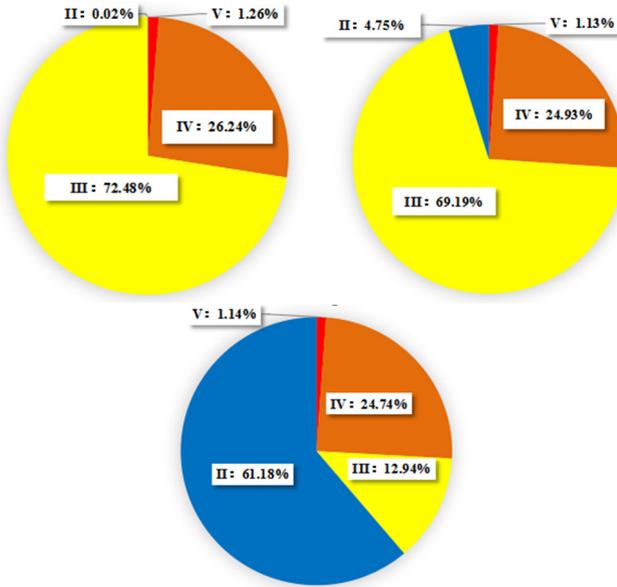


Fig. 6. Quality Grading Results of Surrounding Rock in Large Underground Powerhouse Cav-
erns

From Figure 5, it can be seen that the distribution trends of the rock mass grading cloud maps of the underground powerhouse under the three rock mass grading methods are similar. Among them, there are obvious boundaries in the main powerhouse, which are distributed in the bedding direction. This is consistent with the development of the bedding structural planes in the underground powerhouse obtained from previous surveys. The tail of the main transformer room and the tailgate room are affected by the PH strip, f33 fault, and f20 gentle dip structural plane, and the rock mass quality is poor.

Figure 7 shows the statistics of surrounding rock categories corresponding to different classifications in various classification methods. It can be seen that the proportion of IV and V surrounding rocks obtained by HC, RMR, and BQ classification methods

is similar. The difference between the three classification methods mainly lies in the proportion of Class II and Class III surrounding rocks. Among them, the proportion of Class II and III surrounding rocks obtained by HC and RMR classification methods is close, while the proportion of Class II surrounding rock obtained by BQ classification method is much higher than that of HC and RMR classification methods, reaching 61.18%. This result is significantly larger than the previous survey situation.



(a)HC grading method (b)RMR grading method (c)BQgrading method

Fig. 7. Pie chart of the proportion of surrounding rock using three grading methods

3.4 Analysis of Reasons for Differences in Results

Table 4 is a statistical table of factors considered in typical rock quality classification methods. It can be seen from the table that: ① All factors considered in each classification method are 6-8, of which 2-6 are basic factors and 1-3 are correction factors; ② Among the factors considered by various methods, geological factors are the most, followed by mechanical factors, and project factors are the least. Among them, the structural plane state refers to the relatively developed and weakest structural plane state within a certain section of the underground cavern, including: opening degree, filling material, undulating roughness, and extension length, etc; RQD is a rock quality index, which refers to the ratio of the cumulative length of columnar rock cores equal to or greater than 10cm in each drilling run to the footage of each drilling run, and the integrity of the surrounding rock; Integrity is measured by the rock integrity coefficient K_v , which is the square of the ratio of the longitudinal wave velocity of the rock mass to

the longitudinal wave velocity of the corresponding rock; Measurement of groundwater usage or pressure head; The rock strength is the saturated uniaxial compressive strength.

Table 4. List of Factors Considered in Typical Surrounding Rock Quality Grading Methods

Classification method	Structural				geologic factors				Mechanical factors				Project factors		
	Plane				Surrounding rock structure	Integrity	Weathering	Crustal stress	Geostress	Groundwater	Rock strength	Wave velocity	Structural plan	Orientation	Project method
	g	s	t	Q											
HC grading method	★				★			☆	☆		★	☆	☆	☆	
BQ grading method		☆			★			☆	☆		★	☆	☆	☆	
RMR grading method	★	★	★						★		★				☆

Note: ★ - Basic factors, ☆ - Correction factors.

The HC grading method takes rock strength, integrity of surrounding rock, and the state of structural planes as the basic factors, and corrects factors such as geostress, groundwater, and structural plane orientation. Based on years of project examples, it has been verified that the HC method has good applicability in rock classification in low to medium stress zones. A certain hydropower project belongs to the low stress zone, and this method is suitable.

The RMR grading method emphasizes block size, but does not consider the number of joint sets, geostress, etc., and does not provide clear recommendations for correcting the orientation of structural planes. In addition, the RMR classification method's discontinuous scoring criteria for rock strength, RQD, and joint spacing have a certain impact on the classification of rock quality.

The BQ classification method mainly uses the saturated uniaxial compressive strength of rocks and the integrity coefficient of surrounding rocks as the main factors to determine the quality of surrounding rocks, and uses groundwater, the orientation of major structural planes, and geostress as correction factors. Its classification results are too sensitive to the strength of surrounding rocks. In addition, the number, spacing, direction, and characteristics of structural planes have a significant impact on the quality of the surrounding rock of the cavern, and the BQ method has not given sufficient consideration to these factors.

Based on the above analysis, HC grading results are selected as the data basis to provide data support for subsequent design and construction.

4 Conclusion

This study is based on BIM technology that integrates multiple professional and multi-source data to achieve the classification of surrounding rock quality in large underground factory caverns, and carries out analysis and evaluation of different classification methods, ultimately establishing a complete process and chain of surrounding rock quality evaluation system. Based on the results and discussions presented above, the conclusions are obtained as below:

(1) Based on the established hierarchical index database, a method for constructing a three-dimensional geological attribute model of underground power plants using BIM technology is proposed, which enables rapid evaluation of large underground power plant cavern groups and significantly improves the efficiency of surrounding rock quality analysis and evaluation.

(2) Establishing a comprehensive 3D model that integrates geology and design not only intuitively and stereoscopically displays the spatial distribution characteristics, variation laws, and complex relationships between internal attribute parameters of geological bodies, but also achieves deep integration between the two professional fields of design and geology.

(3) Through the analysis of the grading results of a certain hydropower project, the HC grading method has the best effect. The proportion of Class II surrounding rock obtained from BQ grading results is much higher than that of HC grading method and RMR grading method, which is significantly higher.

The research results provide strong data support and decision-making basis for engineering design and construction, and can also provide reference and inspiration for the construction of similar underground projects, which has important theoretical significance and application value.

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