

Application Research Of 3D Digital Evaluation And Analysis Method In Geological Engineering

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Abstract

In order to adapt to the construction and development of informatization and digitization of engineering survey industry, a method of rock mass quality classification based on 3D geological modeling analysis is proposed. Based on a hydropower station as an example, this paper build a refinement 3D geological visualization model, simulate and analysis engineering geology of the hydropower station from the perspective of the three-dimensional digital. According to features of rock mass damage and elastic-plastic mechanics of dissipation energy principle, which gives the optimize evaluation index and method of rock mass quality classification in water resources and hydropower engineering, endowed with classification attribute values of each level and restructured model shows the spatial distribution characteristics of rock mass quality. In conclusion, this method improves the efficiency and intuitiveness of the engineering geology analysis and engineering rock mass quality classification. Furthermore, the 3D digital evaluation method was verified more rationality and intuitiveness in geological engineering comparing with traditional 2D geological analysis method.

Introduction

In recent years, with the rapid development of Internet, big data and cloud technology, the traditional two-dimensional static geological processing and analyzing mode has been difficult to meet the practical requirements of engineering geologist and design personnel(Laaziz Youness Ahmed et al,2020). Engineering survey industry also accelerated the pace of informatization and digitization construction. Among them with BIM technology represented by means of efficient engineering survey in water conservancy and architectural engineering industry plays a great value(Hassen Imen et al,2020). 3D geological modeling technology and software in Foreign have been very mature in the 1990s(Zhang Chunfeng et al,2015). In recent years the main technical architecture of 3D geological modeling technology and software in domestic come from universities and research institutes which good prototype system through continuous development, innovation, experiment and accumulation then moved into the company and got better application and popularization. Such as Lizheng 3D modeling system(Yu Zhuojing et al,2018), GeoView(Yabing Zhang et al,2020), Geo3d (ZhiYan)(Subash Bastola, Ming Cai, 2020), Creatar (super dimensional imagination)(Li Wanhong, 2020), 3DA (three-dimensional geological engineer assistant)(Zhang,X.et al, 2020) and so on. These software are mainly used for geotechnical survey, digital city, and mineral resources, etc. The other softwares are mostly used in petroleum and mine resource exploration, such as Deep Insight(Deep Exploration)(Gongwen Wang et al, 2015), Longruan GIS (Longsoft) (Hanhan He et al, 2020), Vrmine (Jiling)(Po-Tsun Yeh et al,2020), etc.

In this paper, GeoBIM, a geological 3D modeling platform developed by the latest ideas of 3D geological modeling, is taken as the object which combined with engineering examples and modeling ideas and on the basis of creating 3D geological model, the geological model analysis and application research are carried out(Shi Haoyu et al, 2020). GeoBIM 3D geological modeling software based on the classification thought of object-oriented. Based on the data structure to realize the geography, strata, fault, boundary 4 class fitting structure and geometric modeling of geological objects based on 3D unified model can be

carried out a series of engineering geological analysis application(Li Qing-yuan et al, 2013), including quality visualization classification of rock mass, 3D model of arbitrary cutting, dams and underground engineering geology analysis, etc. For the analysis under complex geological conditions of water resources and hydropower engineering survey, geological problems in design and construction to provide the theoretical basis and technical means(Su Xiaoning et al, 2020). In order to reflect accurate, fast and efficient advantage of engineering rock mass quality classification of the three-dimensional model, this paper based on the GeoBIM three-dimensional geological modeling to introduce the application in the rock mass quality analysis which can provide a richer and intuitive geological analysis data for the similar engineering information design and helpful for observing and analyzing the geological condition of project. Thereby assisting decision-makers to compare, select and optimize engineering schemes, so as to realize refined design and improve design level(Berliouxa 1994).

Case Study

2.1 Topography

The topography of the study area is characterized by alpine and canyon topography. The river is curved as a whole. After the upstream river turns sharply, it flows in the direction of NE10° and flows in the direction of NE41° at the axis of the dam and flows out in the direction of NE80°. The main flow is on the right bank of the dam site. The valley is "U"-shaped and the water level of the river is 3010m-3015m in normal water period. The water surface is 30m-35m wide. When the normal storage level is 3230m, the valley width is about 294.6m and the aspect ratio is 1.34. Large gullies are developed on both sides of the bank and the gullies on the right bank are all glacier debris flow gullies which develop glacial debris flow geological hazards. Most of the gullies on the left bank accumulate avalanche sloping gravel soil layer.

Create topographic surface: The data defining the topographic surface can use topographic point data, DEM data, elevation points and contour lines.

2.2 Stratum lithology

The stratigraphic lithology of the study area is dominated by Early Cretaceous granite ($K_V^{\delta a}$) and Quaternary (Q) strata.

The early Cretaceous granite ($K_V^{\delta a}$) is a Luoqingla compound rock mass of Mara intrusive body, mainly biotite monzonitic granite, which is produced in two rock formations in the dam site area, mainly manifested by different rock colors.

Quaternary (Q) strata mainly include collapse slope (Q^4_{col+dl}), proluvial (Q^4_{pl}), alluvial (Q^4_{al}), icy water accumulation (Q^4_{fgl}), (Q^3_{fgl}), etc which distributed at the foot of the slope on both sides of the dam site, Gullies and riverbeds.

Create the geological body: The geological 3D model is an underground 3D stratum space established based on the results of field surveys such as geological prospecting, geophysical prospecting, surveying and mapping, and testing. Determine the boundary of each layer through geological exploration, then create and define the grid surface of each layer and constrain the grid surface by the geological attribute points which formed from each survey result. Finally form a stratum entity with geological attributes. The accuracy of the stratum subject to the accuracy and density of the survey results.

Firstly, a research project database is established and all survey results are entered into the database. The database not only facilitates data storage and management, but also provides a basis for subsequent analysis and application models.

According to the single index spatial result data formed in the database (point cloud + attribute format, imported to the 3D visualization platform by importing point set commands) combined with the magnetotelluric method for detection, it can be concluded that the coverage depth range is 30m-75m and the elevation of the rock roof varies from 2950m to 3000m.

The boundary range and thickness of the overburden and the various bodies in the study area are determined, and on this basis, a 3D engineering geology model of the study area is created as shown in the following figure:

2.3 Geological structure

According to the geological surveying and mapping, 3D scanning interpretation, oblique photographic interpretation and flat cave exploration revealing structural surface statistics of the dam site, the fault structures in the dam site area are mainly small faults, and the overall faults are not developed. The main structural planes developed in the dam site area are NNW direction, dip SW/NE, high and steep dip angle groups. The structural planes of this group intersect the bank slope of the lower dam site obliquely, representing structural planes are F1, F13, etc. A total of 50 faults are developed on both banks of the dam site which 24 are on the left bank and 26 are on the right bank. They are mainly developed on the left and right bank abutments downstream. Gullies are formed along the fault belt and no obvious faults across the two banks are seen. The faults are mostly steep dips in the NNW trend which filled with extruded schistose or rock blocks. The width of the fault fracture zone is generally 10cm-50cm and it is weathered along the fault zone. Structural fissures are not developed and the development of fissures is rather chaotic. Through analysis there are mainly 6 groups of fractures developed.

2.4 Physical and mechanical properties of rock mass

According to the analysis of on-site exploration, geological surveying and other results, the riverbed cover in the study area is relatively thin and the composition of the material is slightly different. The exposed stratum is mainly Early Cretaceous granite ($K^1_{\eta Ya}$) with no obvious difference in physical and mechanical properties. Granite, the rock is relatively hard, have few cracks under weak weathering and the rock mass is relatively complete. In the study area, 23 sets of drill core samples and 28 sets of flat cave rock samples were taken, totaling 51 sets.

2.4.1 Rock wave velocity test

The study area completed a total of 16 flat cave walls elastic wave tests and the statistical results of the longitudinal wave velocity V_p distribution of each cave wall rock mass are shown in the figure below.

It can be seen from the figure that the rock masses with longitudinal wave velocities of $4450 < V_p \leq 5200$ m/s and $V_p > 5200$ m/s on both sides of the study area account for 43.0% and 29.1% of the measured rock masses. Relatively large proportion of relatively complete and complete rock masses. The proportion of rock masses with $V_p \leq 4450$ m/s is relatively small which is mainly rock masses with poor integrity and no broken rock masses are seen.

2.4.2 Rock mass integrity

The rock integrity index is determined by the square of the ratio of the longitudinal wave velocity of the rock mass to that of fresh rock. The integrity evaluation of the rock mass is to evaluate the integrity of the rock mass according to the geological survey specification of hydropower engineering (GB50287-2016). Combined with the seismic wave velocity test results of the flat cave rock mass in the study area, the longitudinal wave velocity of the fresh rock is selected as 6000m/s to evaluate the integrity of the flat cave rock mass in the dam site area.

It can be seen from the figure that the use of wave velocity to evaluate the integrity of the exploration flat cave rock mass in the study area shows that in some flat caves the integrity of the rock mass is relatively complete except for the entrance of the cave or where the fracture is developed. Completeness is the main priority, followed by poor integrity.

2.4.3 Rock RQD

The rock quality index RQD not only reflects the spacing of rock mass structural planes but also reflects the integrity of the rock mass. According to the internationally accepted rock mass quality classification standards, the RQD values corresponding to each level of rock mass quality are listed in Table 1.

Table 1
RQD limit value in rock mass quality classification

Basic quality classification of rock mass	RQD(100%) limit value
I	> 90
II	75–90
III ₁	62.5–75
III ₂	50-62.5
IV ₁	37.5–50
IV ₂	25-37.5
V	< 25

In view of the above classification standards of rock RQD, the three-dimensional model is combined with flat tunnel and borehole exploration data to extract the boundary value isosurfaces of the research area RQD (as shown in the figure). It can be seen from the figure that RQD varies with the deepening and increasing of the impact depth, the weathering and unloading degree of the rock mass gradually weakens, with RQD>80 the rock mass quality is better. However, the quality of the rock mass is poor in the sections near broken rock mass or unloading cracks and faults. On the same slope, the horizontal depth of the rock mass of poor quality in the flat tunnel gradually increases as the elevation increases and at the same time it is more broken.

Material And Methods

The rock mass quality classification implements the "single index scoring and summation" method, that is, the data of each single index is collected on site and then summed to obtain the rock mass quality. GeoBIM provides three types of rock mass quality classification functions: RMR, hydropower and BQ. These three classification methods are the sum of single index values. The single index required for the three methods includes the uniaxial compressive strength of rock UCS (RMR uses natural sample indicators, other saturation values), joint surface state, groundwater conditions, RQD and joint distance (RMR), rock wave velocity (hydropower and BQ). When the database collects and stores these single index values, it has the basic data on which rock mass quality classification depends.

The exploration points in this study are mainly arranged in the lower dam site area, so the rock mass quality in the lower dam site area is mainly analyzed. Use the cutting box command to assist in setting the spatial range of the rock mass quality classification to be carried out and create a cubic mesh based on this range. It is recommended that the size of the cubic mesh is close to the spatial interval of the index data. Zoning depended on the geological boundary surface (usually is the weathered and unloading surface, divisions of lithology or stratigraphic interface with distinct characteristics) which representing different geological units (after dividing the unit, you need to pay attention to whether each

unit contains complete original data). As shown in the Figure, since the lithology of the dam site area is granite of the Early Cretaceous, the impact of lithological differences on the classification is not considered.

After the interpolation calculation is completed, the rock mass grading starts and the program automatically adds up the grading single indicators in all cubic mesh grid cells within the grading range to complete the rock mass quality classification. According to the project type and the rock grade revision code, the revision work of rock mass quality classification can be further carried out. Finally, based on the parameter values of the rock mass quality classification, the parameter values based on the Hoek-Brown method and the hydropower method are completed.

The classification results and parameter values can be displayed on the building profile surface, and the relevant parameter values of the cubic net can be "assigned" to the building profile (surface object) through the surface command to obtain the rock mass quality classification distribution map, as shown in Fig. 13.

Results And Discussion

4.1 Results

After the grading is completed, you can view the rock mass quality classification results at any point by pushing the datum plane in the XYZ direction. The rock mass quality at a certain point can also be obtained quantitatively by extracting the isosurface map of the rock mass quality classification index RMR.

In order to verify the practicability of the quality classification method, taking the above-mentioned test area as an example. Five representative measurement points in the flat tunnel in the lower dam site area are selected to calculate the membership degree of each level, which is compared with the traditional comprehensive fuzzy judgment method to analysis. Comprehensive the rock quality index P1, RQD index P2, joint line density index P3, joint surface state index P4, groundwater condition P5 and other indexes, the rock mass quality is divided into 5 categories. Combined with on-site engineering geological survey and indoor test, the measured values of the quality indicators of each sample rock mass are shown in Table 2. The analysis results show that the method in this paper is the same as the result of the fuzzy comprehensive evaluation method ,has a high consistency with the site excavation and meets the needs of the project. The comparative analysis results are shown in Table 2.

Table 2
Comparative analysis of rock mass quality index classification results

Sample	Evaluation Index					3D Evaluation Method	Traditional 2D method	Actual excavation results
	P1	P2	P3	P4	P5			
1	47	30	0.18	0.49	15.5	III	III	III
2	51	46.7	0.44	0.48	10	III	II	III
3	30	38	0.33	0.33	16.3	IV	III	IV
4	54	87	0.28	0.45	19	III	III	III
5	52	71.6	0.51	0.36	0.05	II	II	II

4.2 Discussions

4.2.1 The role of 3D geological models

☒Improve design quality

Under the traditional CAD model, although the division of labor is very obvious, they are all independent of each other. Because of this, the deviations in the understanding of the project between the majors are basically based on the knowledge of the major and they cannot take care of each other, it is easy to cause conflicts(CauMon Getal ,2002). After using 3D digital evaluation method technology, the BIM models established by various disciplines can be unified and integrated under the same working platform. Each discipline can work together through a unified model and a common platform then comprehensively coordinate which can effectively control the professional factors in the design(Kamat V R; 2020). It can effectively control the occurrence of errors, omissions and deficiencies in the design due to poor information transmission and untimely communication which can improve design quality and reduce changes(Wu Qiang et al, 2020).

☒Effectively improve owner management methods

In the past, if the owners wanted to manage the quality, cost and schedule of the project, they had to pass professional knowledge or organization. This was because of the lack of professional knowledge(Zhang Yu et al 2002). And in 2D mode, communication is often flat, just a few drawings or a data report which is neither intuitive nor lack of timeliness. This will cause the owners and other parties in the project to have differences in their understanding of the project, resulting in more changes, lower quality and delays in the construction period(Pinto V et al 2002).After using BIM technology, the 3D visualization model established through BIM can incorporate the cost, quality, construction period and other related data information that the owner cares about into the model, such as material prices, equipment attributes, etc.which greatly improves the owner's project management efficiency(Jia Hongbiao et al 2002). It reduces cost and waste and eliminates the gray income of other project parties. It can be said that the owner is the biggest beneficiary of BIM(Cai Hejun et al 2001).

☒A weapon for project managers

The drawings formed by BIM technology are digitized and contain a wealth of data information, so that they can be integrated, analyzed and used through computers to provide reliable data support for project managers(Vistelius A B 1997). Project managers no longer need to search and recheck one by one with a dozen thick drawings in their hands as before(Hu Ruihua, Wang Qiuming 2002). Project managers only need to retrieve the information in the BIM model and database in front of the computer to accurately find the required component information, such as the layout of steel bars, the location of reserved holes, the size of components and unit prices, etc. which greatly improves work efficiency, issue instructions to the project in time and improve on-site management efficiency(De Kemp Eric A 1999). Moreover, project managers can also perform real simulation experiments on the BIM model, such as construction simulation, disaster escape demonstration, etc., so that not only can they understand the progress of the project at any time, make plans and adjust strategies at any time, but also improve the safety of the site(Mallet J L 1997). Greatly improve the quality of the project.

4.2.2 The advantages of 3D digital evaluation method

(1)The establishment of the model provides a new technical approach for the cognition and expression of engineering geological rock masses and provides comprehensive information for the analysis and judgment of the geologists(Kulatilake W 1990). The 3D model not only can enable geologists to escape the limitations of traditional 2D speculation but also make the geological speculation based on 3D models is more reasonable. It also makes the subsequent increase of exploration points more scientific(Zheng Wentang et al, 2020).

(2)Different from the traditional 2D engineering geological condition analysis, based on the 3D geological model, the values of related parameters on all exploration points can be imported through the database in the GeoBIM software and assigned to the 3D geological model of the dam site area(Zhang Chong et al 2006). The geological parameters of the rock mass around a point can be automatically obtained through interpolation. Through the 3D geological model, you can intuitively view the rock quality index RQD value, saturated uniaxial compressive strength value, water permeability Lu value and other geological parameters at any point(Jiao Yuyong et al 2000). GeoBIM software automatically generates the equivalent surface of a certain index, for example, the equivalent surface of the rock quality index RQD = 80% and the area of the rock quality index RQD > 80% in the rock formation is judged by the equivalent surface which is for the engineering geological classification of the dam foundation rock mass(Itasca Consulting Group Inc 2003). It is of great significance to judge the rock quality at the location of the dam foundation.

(3)The modeling results provide an accurate geological visualization model, paving the way for the application and promotion of 3D design in the future, providing model data for the design, construction, exploration layout and numerical simulation analysis of the project and providing visual reference for the analysis of designers and design(Liao Qiulin et al 2005). The 3D model serves the actual production

application, changes the traditional working mode and thinking and improves the production efficiency and accuracy(Wang Weihua; Li Xibing 2005).

(4)By exporting the modeling data, 3D collaborative design with hydraulic engineering, construction and other professions can be realized. In theory, it is possible to import finite difference, finite element and other numerical simulation software to analyze the stability of foundation pit excavation and realize the true value of modeling(Zhu Fusheng et al, 1997).

4.2.3 The disadvantages of 3D digital evaluation method

Through the cooperation and efforts of various professional and technical personnel, the application potential of 3D digital evaluation method in geological engineering has been initially explored which has laid a good foundation for further improvement of engineering construction and management(Zhong Denghua et al 2005). However, judging from the current development of BIM, there are still some shortcomings in the application technology of 3D geological analysis:

(1)BIM applications are all partial applications and the application points are relatively single. There is a lack of correlation between various applications, and there is no overall effect(Pan Wei et al 2004). The results are still "information islands", and they have not reached the full coverage of process and professionalism(Wang Chunxiang et al 2003). BIM has short information boards. It is difficult to play the overall role of BIM.

(2)The application lacks a master plan. From the experience of foreign BIM promotion and application, the driving force of BIM comes from the government and the owners, but the domestic engineering industry owners start BIM work late and the top-level design is not perfect, resulting in the lack of a unified action program when carrying out BIM work(Zeng Qianbang et al 2005), and the lack of a unified technical structure which resulting in poor scalability and promotion of research results, hindering the promotion of BIM applications(Yan Huiwu et al 2004).

(3)Lack of a unified engineering BIM standard, there are big differences between different links of different software, data interoperability is poor, data is difficult to integrate into effective information(Pu Hao et al 2005). It is difficult to achieve effective transmission and storage of data information. For example, in actual projects, the BIM model prepared by the design institute cannot be delivered to the construction company for construction, and the construction company re-models it according to its own standards, and the data fails to flow and waste is serious(Wu Jiangbin; Zhu Hehua 2005).

(4)The current benefits of BIM are not obvious and there are no relevant documents in the engineering industry that put forward rigid requirements for the use of BIM technology which has led to the lack of enthusiasm for some companies to promote BIM(Zeng Qianbang; He Xiaoping 2006).

Conclusion

(1) This paper uses the powerful surface creation and editing functions of geological 3D software to create a 3D geological model of a hydropower station's complex stratum based on measured and inferred point elevation data, and uses 3D digital evaluation methods to analyze its geological conditions.

(2) The three-dimensional geological solid model has strong visualization functions, simplifies the understanding and understanding of the stratum structure, can fully and accurately display the various geological attributes of the stratum, and can also produce three-dimensional flat and section maps. The output brings more convenience.

(3) The 3D geological model has strong practicability, and the efficiency and accuracy of creating maps are higher, which is better than traditional 2D design methods. The accuracy of models and drawings meet the design requirements of engineering buildings.

(4) 3D geological modeling is the trend and direction of the future development of geological work. With the help of three-dimensional geological models, the informatization, digitization and visualization of geological work can be greatly promoted, making the results of geological work more vivid, vivid and easy to understand.

Declarations

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Figures

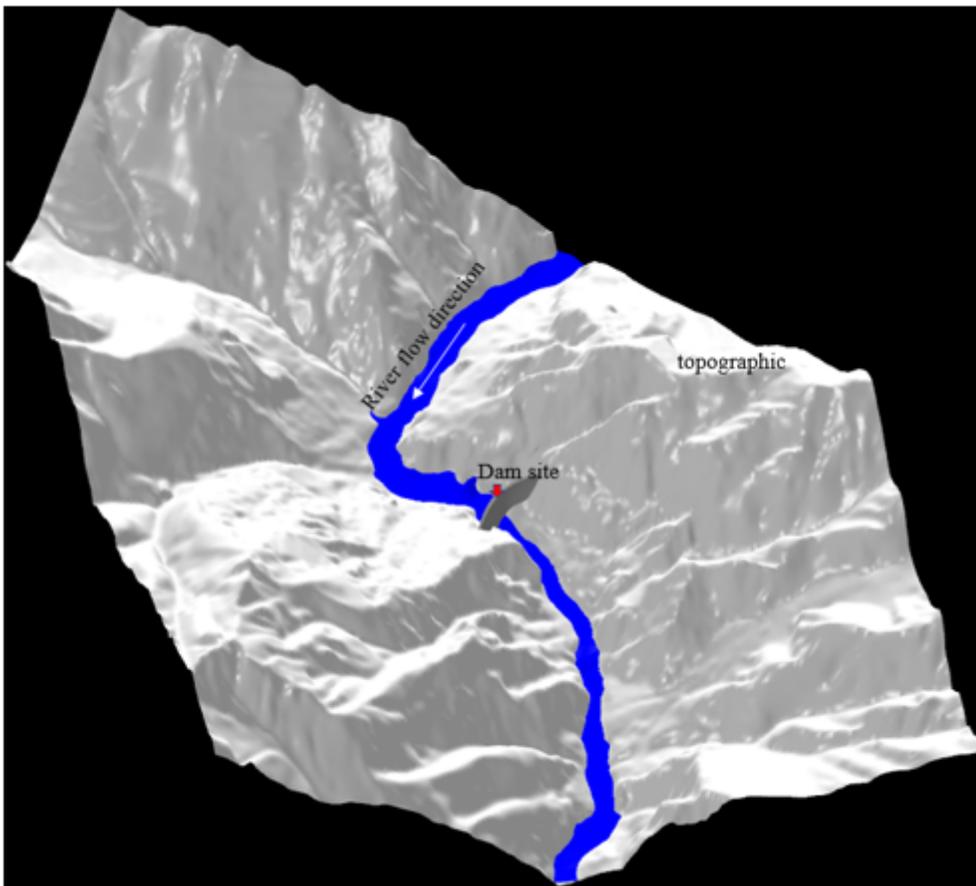


Figure 1

3D topographic map of study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square

concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

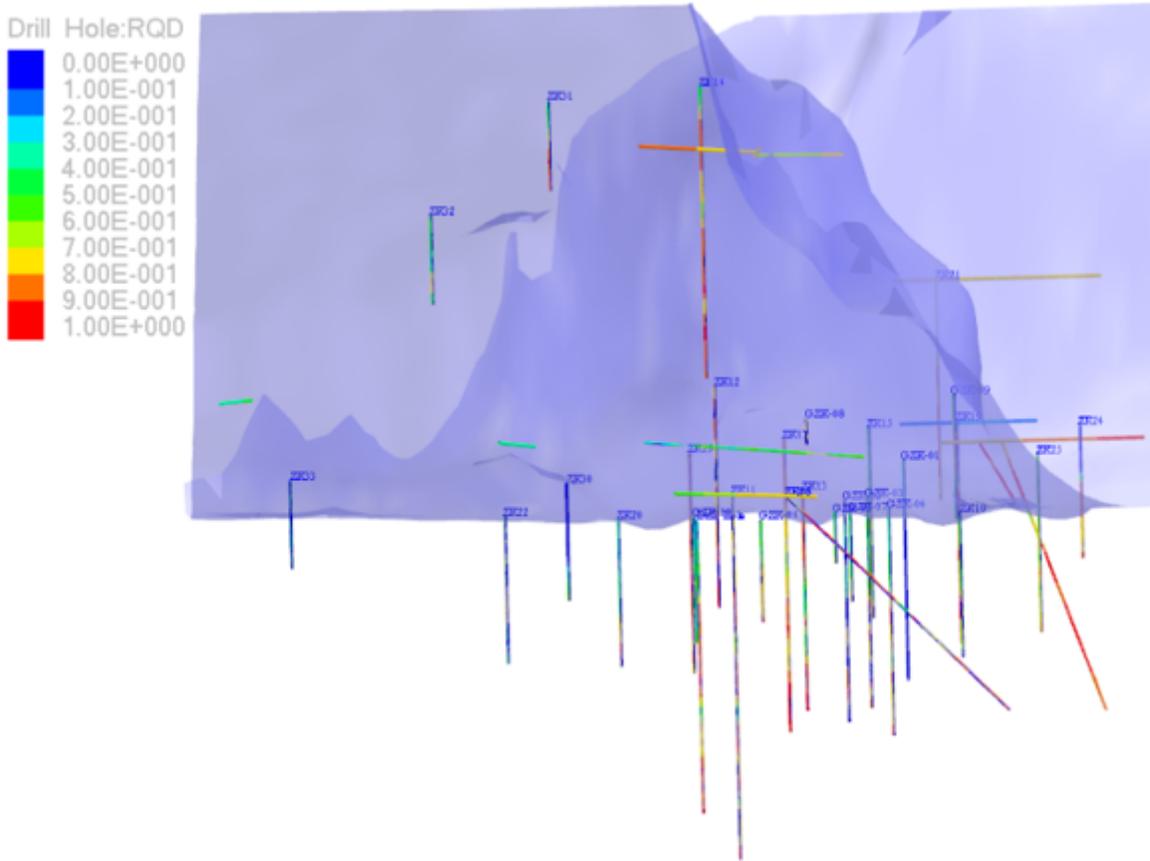


Figure 2

Project database storage management system and 3D visualization platform RQD display diagram

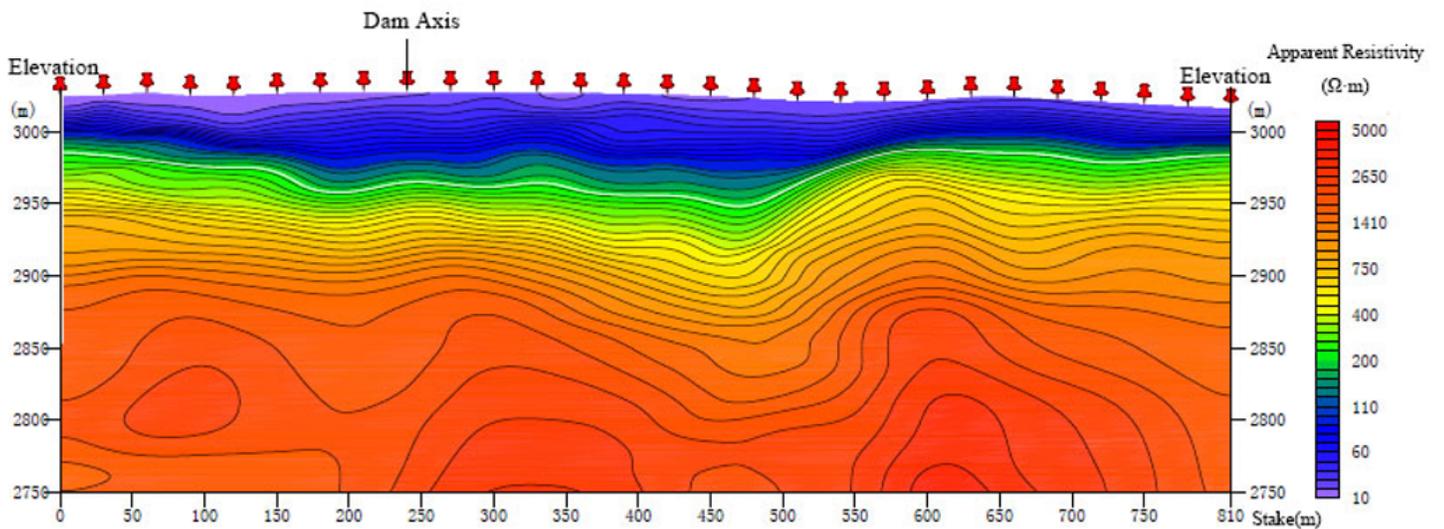


Figure 3

Cross-section of representative survey line geophysical prospecting results in study area

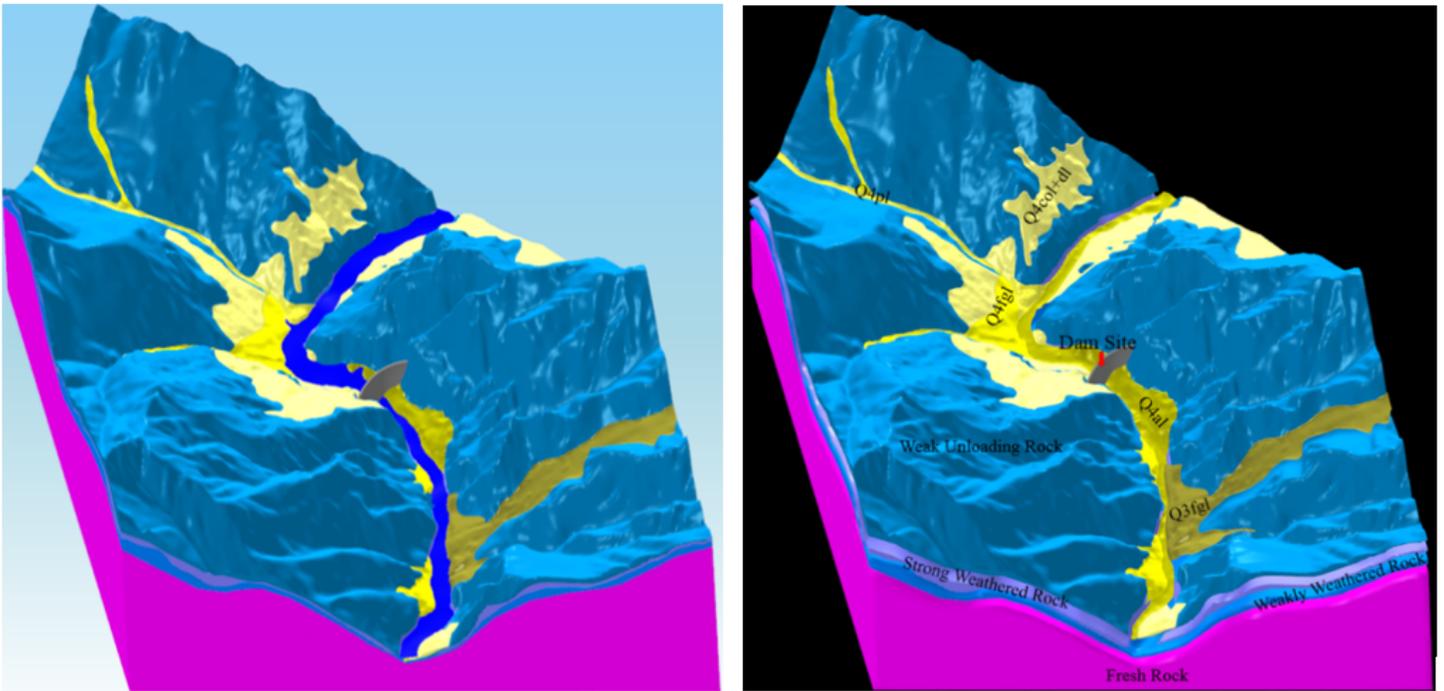


Figure 4

3D model of engineering geology in study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

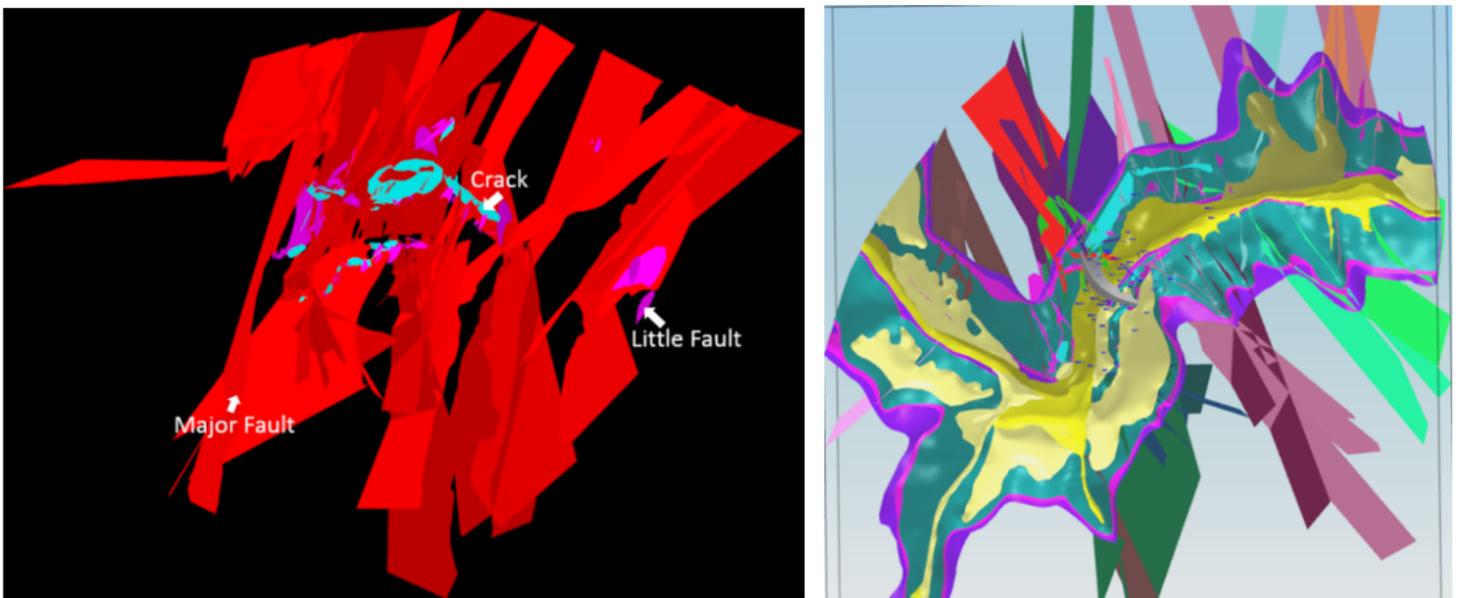


Figure 5

3D display diagram of structure distribution in project area

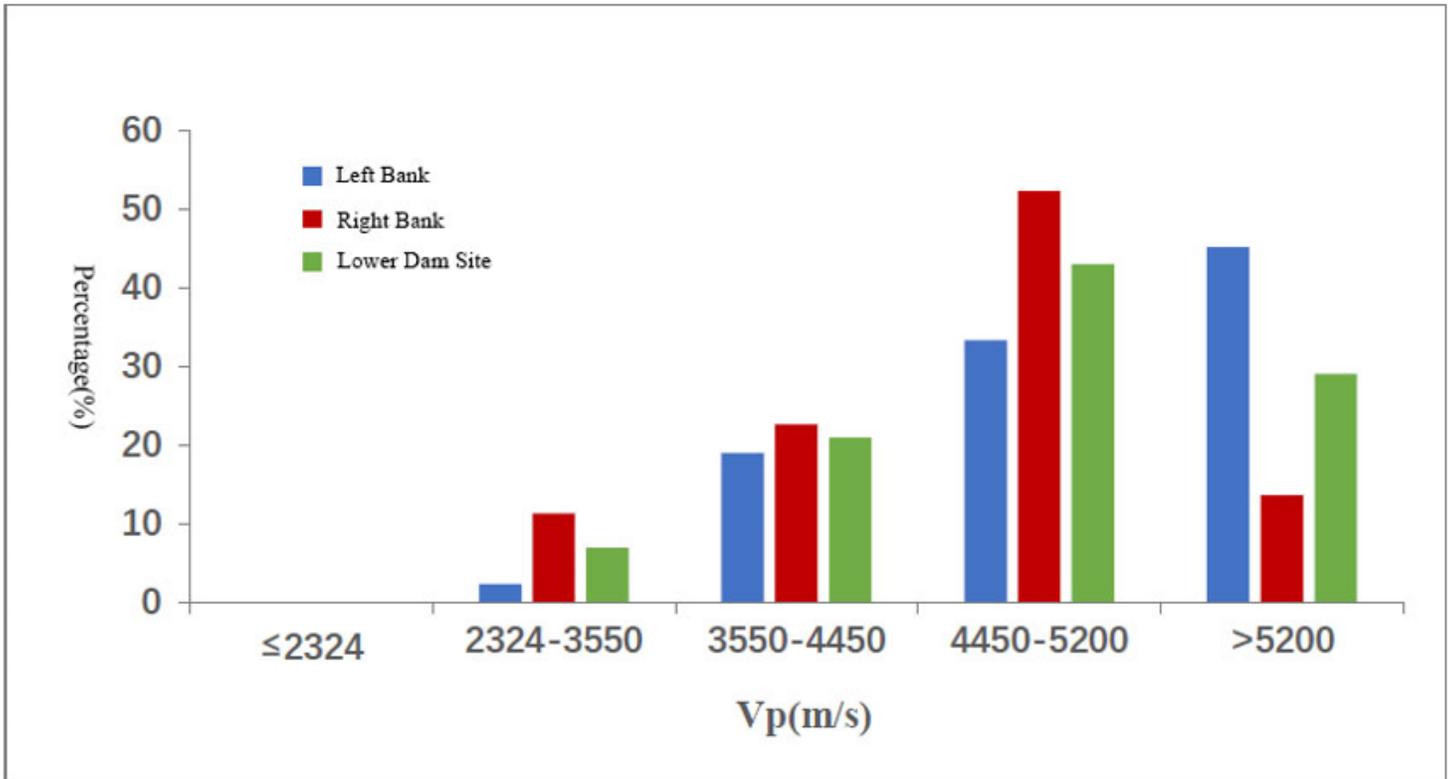


Figure 6

The statistical histogram of longitudinal wave velocity V_p distribution of cave wall in study area

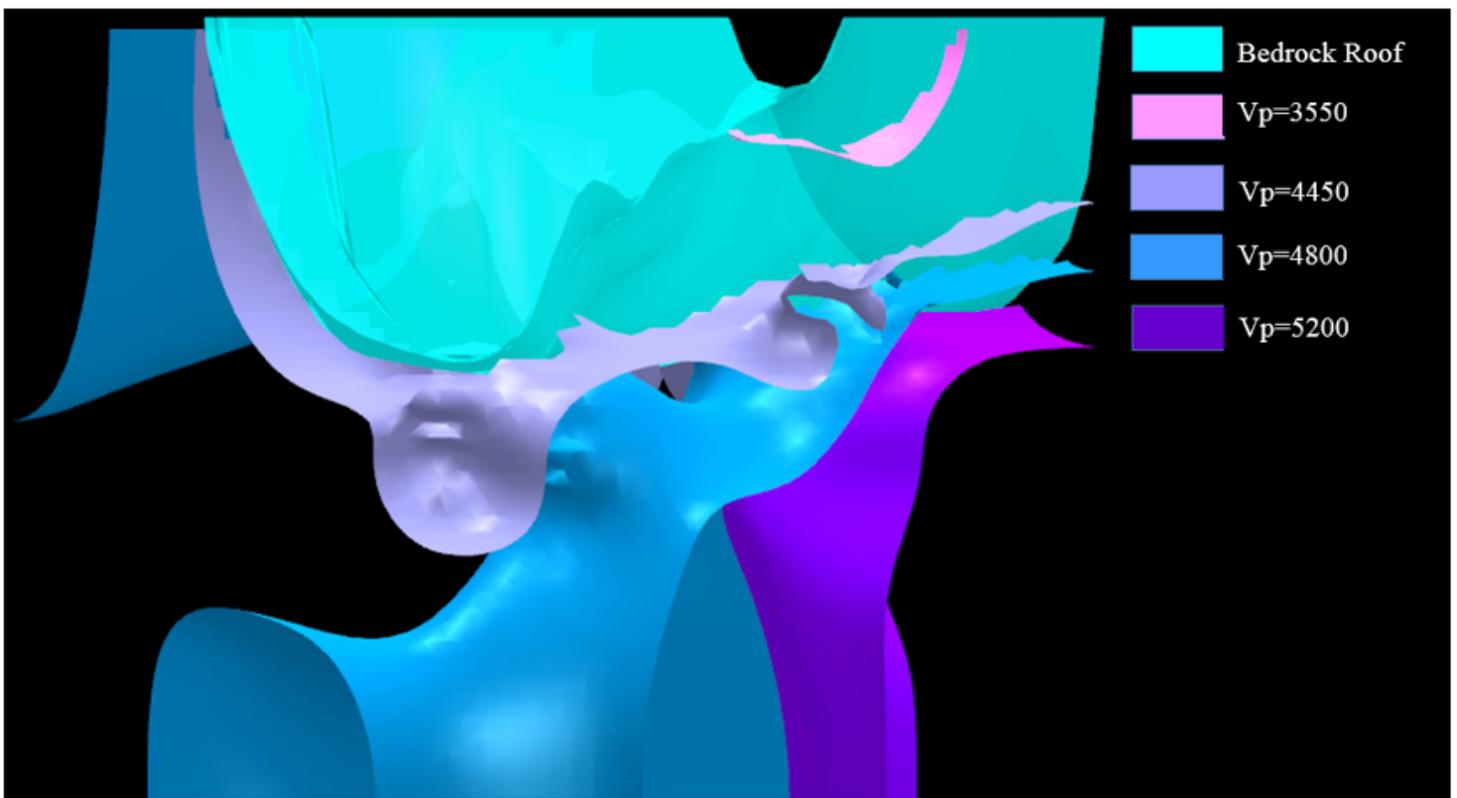


Figure 7

3D isosurface map of rock wave velocity



Figure 8

Integrity characteristics of each flat tunnel rock mass in study area

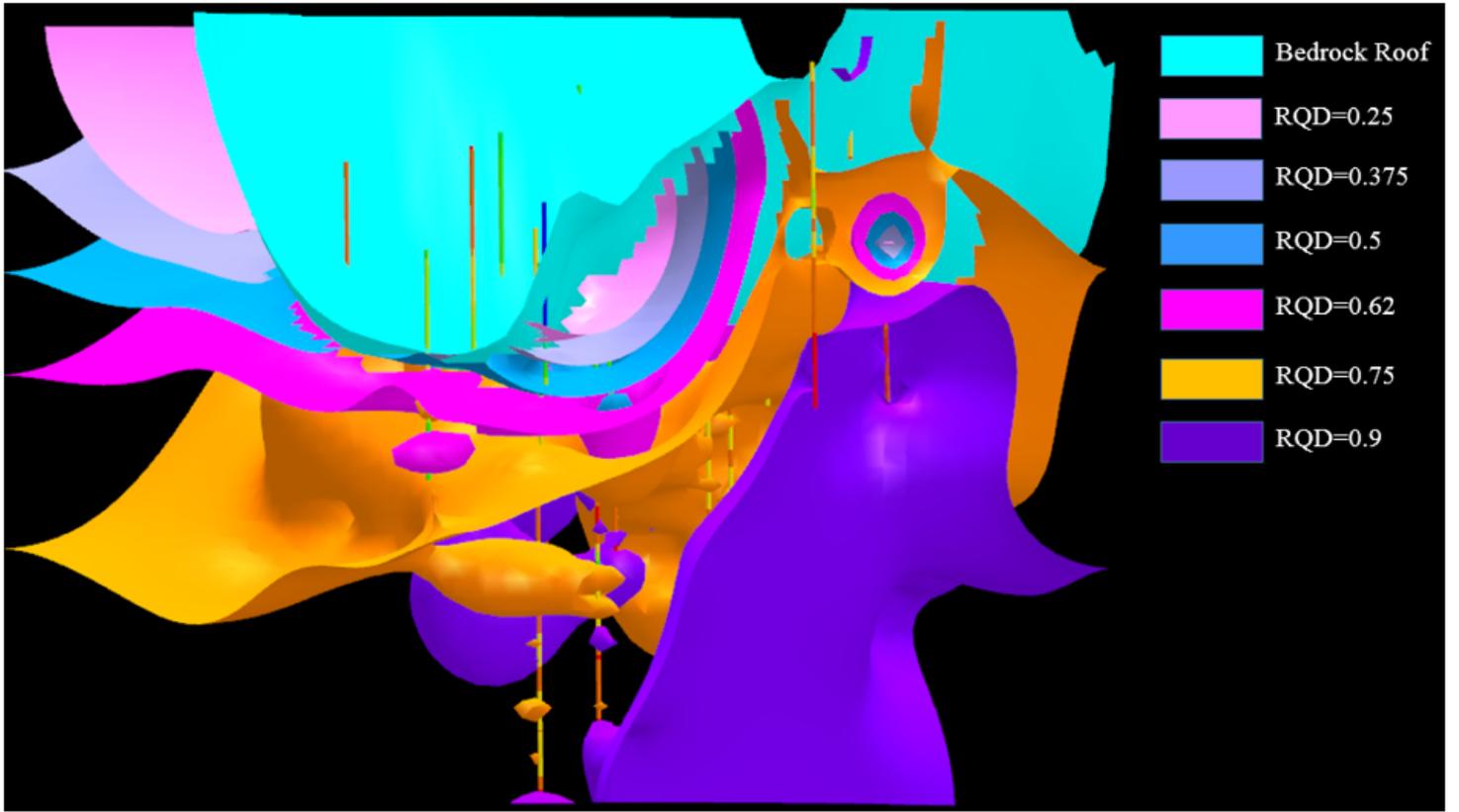


Figure 9

3D isosurface map of rock mass RQD

Classification Methods and Indicators



BQ:Rock saturation strength,
Rock integrity,Groundwater

RMR:Natural strength of rock,RQD,
Linear density, Joint state, Groundwater

HC:Rock saturation strength, Rock
integrity, Joint state, Groundwater

The screenshot shows the 'Project Explorer' window with a tree view of engineering parts. The tree is organized as follows:

- Engineering Part
 - Drilling → RQD, Linear density, Joint state, Groundwater
 - Flat Tunnel → Linear density, Joint state, Groundwater
 - Geological Point (The line density of the flat tunnel comes from the survey line method form)
 - Stratum Point
 - Breaking Point
 - Groundwater Point
 - Physical Geological Point
 - Karst Point
 - Sampling Point
 - Exploratory Well
 - Pothole
 - Geophysical Prospecting
 - Borehole Geophysical Prospecting → Rock wave velocity along the borehole
 - Point Geophysical Prospecting
 - Profile Geophysical Prospecting
 - Cavern Geophysical Prospecting → Wave velocity of rock mass along flat cave
 - Test
 - Indoor Test → Rock wave velocity divided by lithology, weathering, and unloading
 - Field Test
 - Construction Geology
 - Cavern Catalog
 - Slope Catalog
 - Grouting Record

Figure 10

Indexes required by each classification method and database entry method

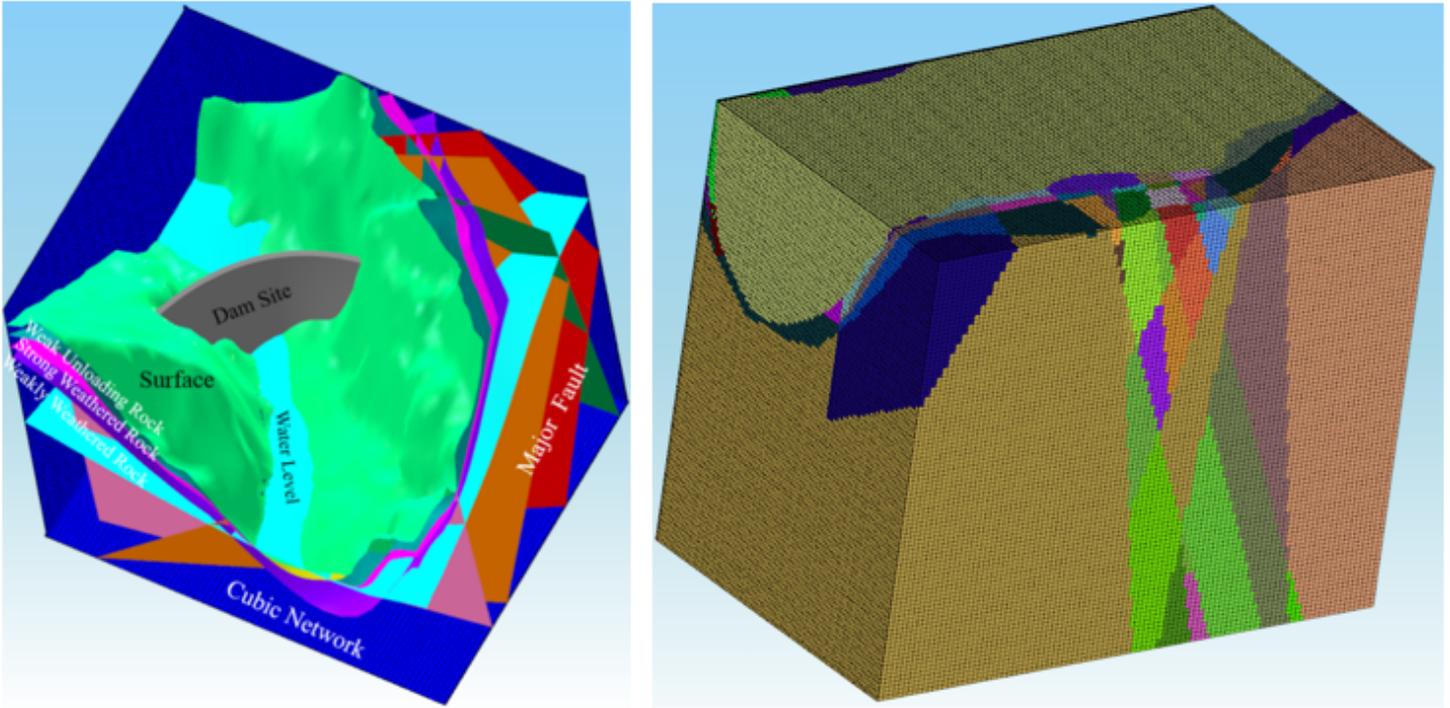


Figure 11

Rock mass quality classification attribute model and visualization results

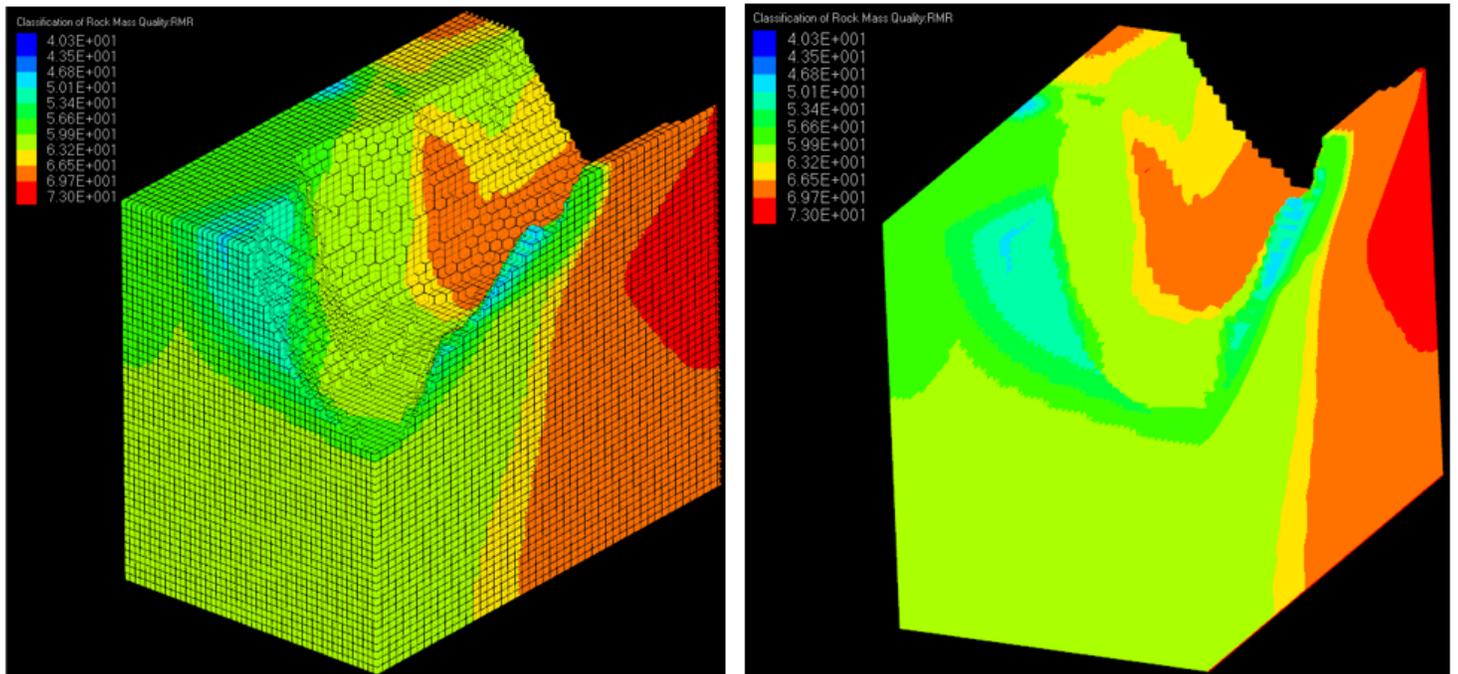


Figure 12

Results of rock mass quality classification

Underground Powerhouse:RMR

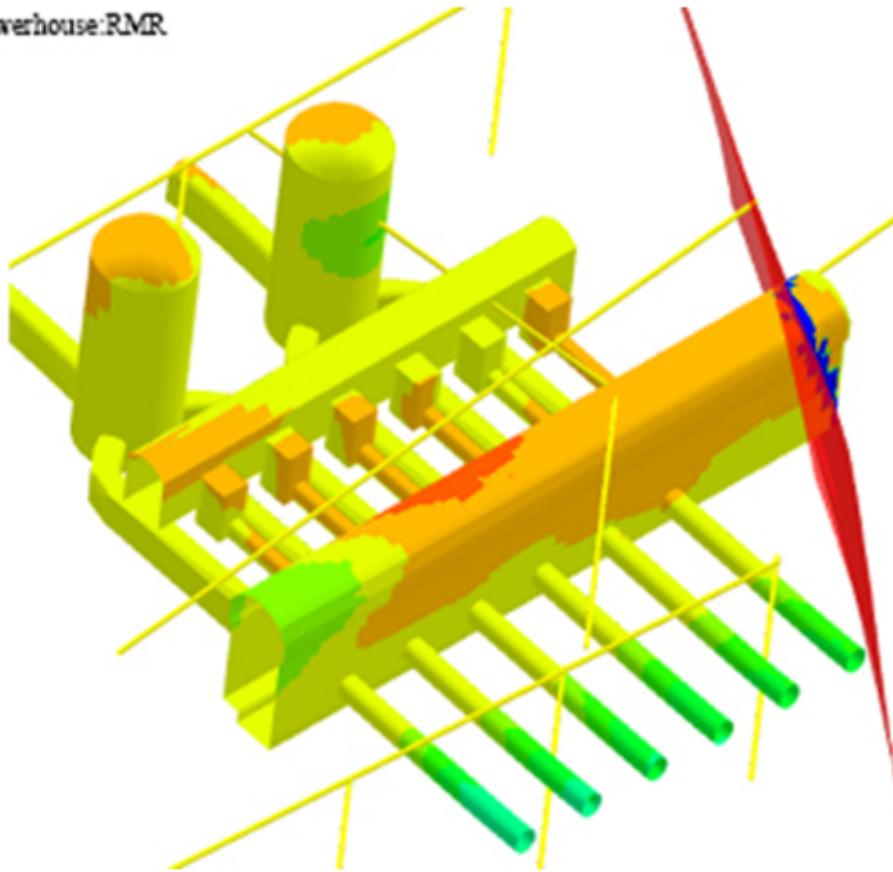
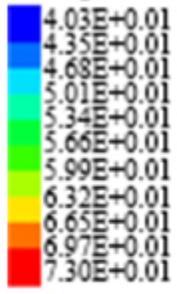


Figure 13

The rock mass quality classification results give building outline

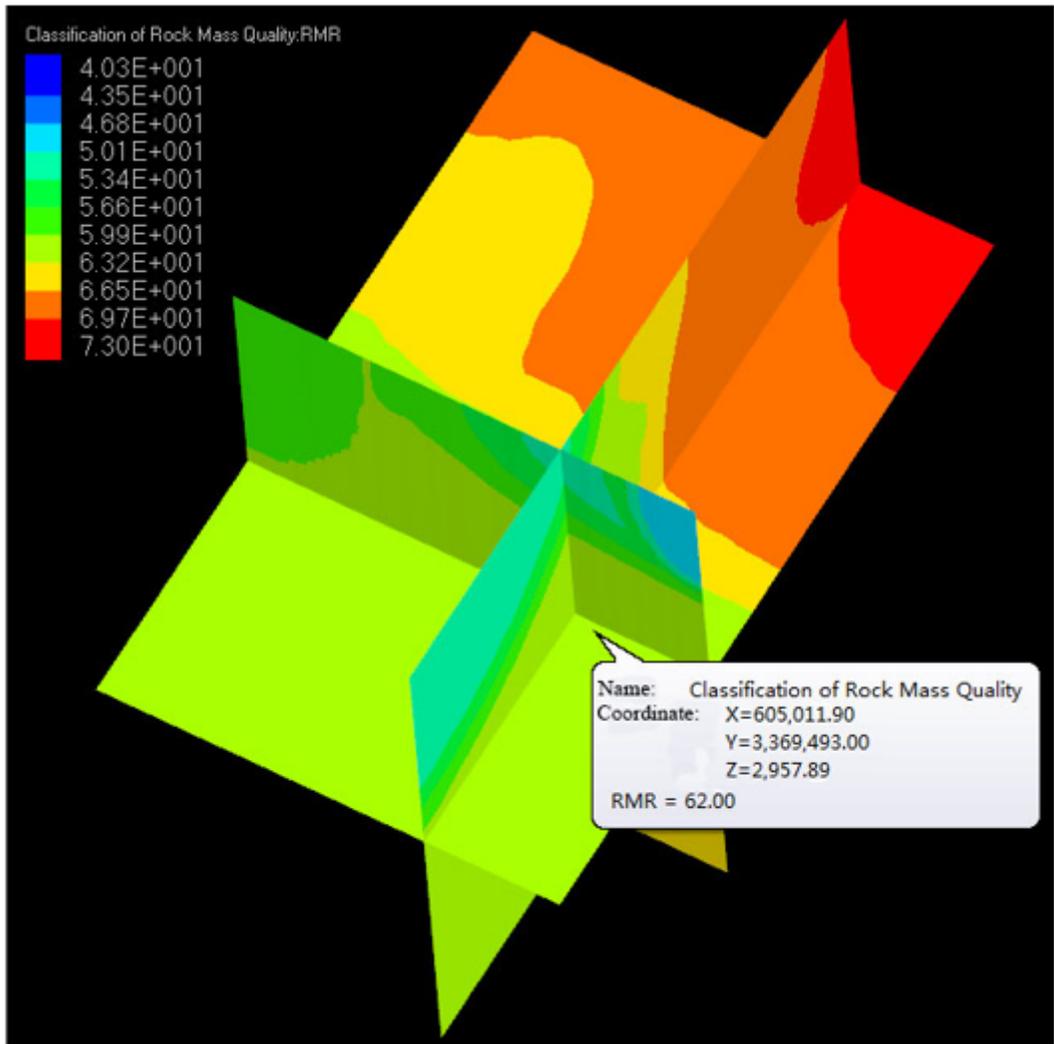


Figure 14

Query diagram of rock mass quality classification results at any part