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Research Article

Experimental Study on Damage and Fracture of Rock-like Mass Based on Intelligent Data Analysis

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Rock-like damage and fracture are a common geological phenomenon. It not only affects the construction quality and safety of the project but also affects the economic benefits. This study uses the finite element method to calculate the numerical simulation of rock. Therefore, we must study and explore it to improve the success rate and efficiency of drilling under such problems. This study conducts systematic analysis through experimental research on the theoretical knowledge of internal failure and stability of rock-like masses and other related finite element methods. On the basis of predecessors, combined with the professional knowledge I have learned, a set of relatively complete solutions is proposed. This study mainly uses the experimental analysis method and data collection method to study cloud computing related technology and finite element method, rock tensile fracture, and numerical model. According to the experiment, it can be concluded that the degree of rock crack development gradually increases with age. In the early and late stages of stretching, the rock mass will be significantly enhanced by the stress concentration.

1. Introduction

Cloud computing provides a new computing model by improving existing computer technology and hardware capabilities in a large-scale distributed resource environment. In the actual construction process of the project, due to the influence of various factors, there are countless phenomena of rock mass damage. It is very necessary and urgent to intelligently detect its damage. Intelligent detection is to analyze and process the collected information through various sensors and then draw conclusions and make corresponding decisions. Finite element analysis is to replace complex problems with simpler problems before solving. It regards the solution domain as composed of many small interconnected subdomains called finite elements, assumes an appropriate (simpler) approximate solution for each element, and then derives the solution to this domain to satisfy the conditions (such as structure of the equilibrium condition), so as to get the solution of the problem.

There are many theoretical results in the study of the numerical model of rock tensile fracture under thermal stress based on cloud computing. For example, Aliyu and Archer introduced a three-dimensional numerical model of a multifracture hot dry rock system using a coupled thermal-hydraulic-mechanical modeling process [1]. Shi et al. use a rock mechanics testing machine to perform uniaxial or triaxial compression tests on cylindrical rock samples, and the numerical simulation results verify the effectiveness of the plastic flow factor and engineering approximation methods [2]. Zhang believes that the initiation and formation of hydraulic fracturing is very important to prevent rock structure damage and increase oil production [3]. Although some scholars have studied water and heat on rock systems, not many people have analyzed them from the perspective of cloud computing. So, this is one of the innovations of this article.

Thermal stress will be generated by temperature change, which will further lead to thermal cracking of rock, which is a great threat to the safety of rock engineering. The study of thermal cracking has its purpose and significance.

This paper first studies cloud computing and related technologies, describes the cloud computing architecture, and analyzes its automated deployment, resource monitoring, and massive data distributed storage technologies. Then, research the finite element method of cloud computing environment. After that, the rock tensile fracture under the action of thermal stress is deeply understood and analyzed, and a numerical model of rock thermal fracture is proposed. Finally, a numerical simulation experiment is carried out to verify and draw conclusions.

2. Numerical Model of Rock Tensile Fracture under Thermal Stress Based on Intelligent Data Analysis

2.1. Intelligent Data Analysis. Cloud computing is a type of distributed computing. It refers to the use of a network "cloud" to break a huge data processing program into countless small programs. The results of these small programs are then processed and analyzed by a system of multiple servers and sent back to users. More accurate results can be obtained by simulating and analyzing rock tensile values through cloud computing.

Cloud computing is a service related to information technology, software, and the Internet. This computing resource sharing pool is called "cloud." Cloud computing gathers many computing resources and achieves automatic management through software so that resources can be provided quickly with the participation of few people. Cloud computing is not a kind of brand-new network technology, it is a new concept of network applications, the core of the cloud computing concept is centered on the Internet, the website provides a quick and secure cloud computing services and data storage, and each person can use the Internet on the network computing resources and huge data centres.

With the advancement of science and technology, Web technology has also entered the peak period of development. With the continuous expansion of business volume, some business systems or ordinary website processing capabilities have been fully tested [4, 5]. The core content of cloud computing is on-demand deployment. Therefore, cloud computing is fully deployed in accordance with the needs of customers. The reason why cloud computing can obtain such efficient support is mainly due to several extremely key features of the cloud computing system architecture. First, the cloud computing system is embedded with automation technology. The embedded technology of this technology makes the system self-governing. The characteristics of autonomy and autonomy make the task management and manual deployment of the cloud computing system very simple and convenient, making the system very intelligent in response to the needs of user applications [6, 7]. Second, the cloud computing system can quickly make correct responses according to user needs or changes in needs. The architecture of the cloud computing core platform is shown in Figure 1:

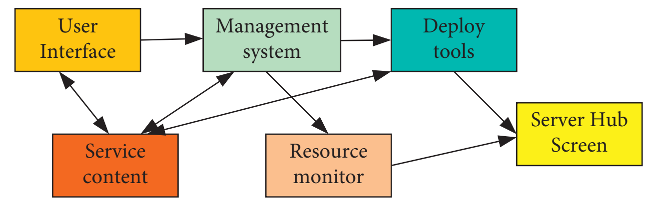

Figure 1: The architecture of the cloud computing core platform.

User interface refers to the information interaction interface, which is mainly used to realize the interaction when "cloud" users request services. The main function of the management system is to manage the available computing resources or services efficiently. Deployment tool refers to the autonomous function of embedded automation technology, which can automatically apply and deploy the requested resources according to the requests of "cloud" users and realize the dynamic configuration, deployment and recycling of resources [8, 9].

2.1.1. Automated Deployment. Automatic deployment is one of the core technologies of cloud computing, which can make the cloud computing system change the original state of the system into an available state without manual service operation. Automatic application deployment improves the overall quality of the software. Using good tools throughout the life cycle can minimize human intervention and save manpower time. Once human intervention is removed, the quality will be more predictable and better. [10, 11].

2.1.2. Resource Monitoring. The "cloud" system usually consists of many servers, and its resources have the characteristics of dynamic changes. However, the information resources required by the "cloud" users are accurate, timely, and dynamic. Therefore, a technology is needed. It is used to monitor these information resources in real time. Resource monitoring technology is a very important technical link for "cloud" to manage resources. It can not only monitor the useful resources of the system in real time but also provide information related to system performance for the rest of the subsystems, thereby making the system resource allocation is more reasonable and more efficient to use [8, 12].

2.1.3. Mass Data Distributed Storage Technology. The main component of the cloud computing system is composed of multiple computer servers, which can provide various information services for many users. The system uses distributed storage and redundant system storage [13, 14].

The value of cloud computing lies in its high flexibility, scalability, and high performance ratio. Compared with traditional network application modes, cloud computing has the following advantages and characteristics: virtualization technology, dynamically extensible, on-demand deployment, high flexibility, high reliability, high cost performance, and scalability.

2.2. Finite Element Method for Cloud Computing Environment. The most basic idea of finite element analysis is the element discretization, which decomposes the complex solution domain into several simple elements, converts the continuous medium into discrete structures through discretization, and then analyzes each discrete element separately. Finally, each element is integrated into a whole and the displacement is solved by the displacement method based on the principle of minimum potential energy. In order to disperse complex rock structures and structures quickly and effectively, solid elements, interlayer elements and infinite elements are often used to replace continuous zones, faults and structural planes of rock and concrete.

The finite element calculation involves the steps of model grid data reading, single-rigid calculation, total rigid assembly, equation solving, and result postprocessing.

2.2.1. Data Structure. The calculation model grid data are input in the form of a format file. The data file contains node coordinate data, element information, material information, constraints, and external force information [15]. According to the single-rigid calculation expression of the one-dimensional rod element, combined with the coordinate transformation rules, the single-rigid expression of the three-dimensional rod element can be directly derived as

$$s=\frac{\mathrm{WQ}}{K^{3}}\begin{bmatrix} K_m^2K_mK_nK_mK_p-K_m^2-K_mK_n-K_mK_p \\ K_n^2K_mK_n-K_mK_p-K_n^2-K_nK_p \\ K_p^2-K_pK_m-K_nK_p-K_p^2 \end{bmatrix}. \tag{1}$$

Among them, K represents the unit is single rigid:

$$\begin{aligned} K_m &= m_i-m_q, \\ K_n &= n_i-n_p, \\ K_p &= p_i-p_p, \\ K &= \sqrt{K_m^2+K_n^2+K_p^2}. \end{aligned} \tag{2}$$

There is no data correlation problem between the calculations of each unit. Traditional finite element parallel computing will encounter read-write conflicts during the assembly process, and atomic operations or unit grouping strategies are usually used to solve the problem. For the Map Reduce programming model, there is no need to explicitly save the total rigidity matrix. The single-rigidity matrix of multiple units is output to the reduce function through the map function. The position of the element in the total rigidity is located by the key in the key-value pair. The reduction and summation of the values of the key-value pairs with the same key can form the final total rigidity matrix result.

2.2.2. Algorithm Framework. The Map Reduce programming model process is as follows. After reading the model information from the calculation file, it is necessary to form a list of unit objects and group the units according to the number of maps to obtain the input key-value pairs of the Mapper. After the Mapper calculates the unit stiffness matrix, it outputs according to the global number of the node Reducer input key-value pairs, model constraints have been considered in the file read preprocessing process by setting the node degree of freedom number to 0. The Reducer will reduce and sum the values with the same key value to form a total rigidity matrix.

2.3. Rock Tensile Fracture under Thermal Stress. Rock burst is an underground project with serious soil pollution. During the mining process, the stress on the tunnel wall is redistributed by breaking the hard and brittle rock surrounding the tunnel. In the event of chipping, blasting, ejection, throwing, and other disasters, the elastic expansion energy is suddenly released to produce a nonlinear dynamic damage. Because rock burst is a worldwide geological disaster, it threatens the safety of deep-buried coal mines and underground engineering construction to a great extent. The research on the mechanism, prediction, and control status of rockburst is extremely important. The process of rockburst, to put it simply, is a process in which energy first gathers and then suddenly releases. The conditions of its generation are closely related to the lithological state, geological structure, and distribution of the in situ stress field of the stratum. From the perspective of rock lithology, rock bursts usually occur in hard and brittle rock formations. From the perspective of geological structure, the stress concentration area of underground caverns will increase the severity of rock bursts. The mechanism problem of cavern rockburst can generally be expressed as a hard and brittle rock mass that accumulates a large amount of elastic strain energy. After the cavern is excavated, the radial stress is eliminated, while the hoop stress increases sharply and the strain energy gradually concentrates. In the state of stress concentration, brittle fracture, tensile, or shear failure occurs, accompanied by sound and vibration to consume part of the elastic strain energy.

For the method of rockburst test monitoring, effective measurement and control methods are adopted for different projects to better observe the occurrence of rockburst and the severity of rockburst. As a nondestructive real-time passive monitoring method, microseismic monitoring is widely used in rockburst testing and has received sufficient attention from rock mechanics workers. The rock fracture principle it monitors can be used to study the mechanism of rock fracture. The sliding micrometer is a high-precision line measurement and monitoring instrument that can capture the entire distribution of displacement along the bore axis. The principle of measurement is to divide the test into several sections, put the metal measuring mark into the casing, and pour cement mortar to make the measured medium and the measuring mark stick together. When the medium is squeezed and deformed, the corresponding measurement mark can be observed. Compression means time-dependent deformation, which is caused by the concentration of shear stress around the excavation space. Both deviator strain and volumetric deformation may occur, and the latter is related to the expansion of geotechnical media. When the medium is extruded and deformed, corresponding measurement marks can be observed. It is assumed that the extrusion deformation is an elastic-plastic behavior of surrounding rock, and it is considered that the extrusion deformation will occur when the rock strain reaches its residual plastic state, so as to predict the change of rock burst. Acoustic emission (AE) monitoring method is a method of external stress that causes rock cracks to be accompanied by sound monitoring. Due to the different structure of the rock itself, the characteristic parameters of acoustic emission generated during the compression process are also different. At present, the acoustic emission monitoring method is widely used in the stability analysis of underground engineering caverns and the advanced forecasting of major mines.

2.3.1. Deformation and Fracture Characteristics of Hard and Brittle Rock. The hard and brittle characteristics of rock are mainly reflected in two aspects. "Hard" means that the rock has a higher compressive strength and a larger deformation modulus; "brittle" means that the rock has a small amount of deformation when it breaks. The characteristics of stress drop after the peak of the stress-strain curve are obvious. The characteristic of compression deformation is an intuitive manifestation of the "brittleness" of the rock. When the stress reaches the strength of the rock and breaks down, the rock does not show obvious permanent deformation, and then, it breaks under the ultimate strength and presents a sudden avalanche fracture. The temperature field mainly acts on the microstructure of the rock to induce thermal deformation of the internal particles, which is further reflected in the characteristics of the stress-strain curve of the rock. The increase in temperature increases the brittleness of the rock to a certain extent. When there is a seepage field in the rock (body), the seepage force will change the boundary conditions of the stress field of the rock mass, which is further reflected in the characteristics of the stress-strain curve of the rock. Because the rock pores (cracks) are extremely underdeveloped, the tension of the osmotic pressure on the rock is extremely weak, and the shape of the front peak is mainly controlled by the characteristics of the rock and the difference of the rock sample. The rock will have different macroscopic failure characteristics under different stress states, and the mechanics and deformation characteristics of the rock can be reflected from the macroscopic failure form.

The study of rock blasting process through the numerical simulation method is helpful for people to understand blasting knowledge deeply and improve the level of theoretical research; on the contrary, it can better guide engineering practice and blasting engineering design. LS-DYNA can not only deal with nonlinear dynamic impact and multirigid body dynamics problems but also deal with heat transfer, fluid, and fluid-solid coupling problems. The FLAC3D program can better simulate the mechanical behavior of failure or plastic flow of geological materials when they reach the strength limit or the yield limit. The fragmentation of blasting tests with different charge structures shows a good fractal structure. The functional relationship between the unit consumption chassis resistance line of explosive and the fractal dimension of blasting fragmentation in blasting test is regressed and analyzed. The fractal dimension of blasting fragmentation with different charge structures is compared. The relationship between the unit consumption difference of interval charge and continuous charge under the same conditions and the law of the influence of charge structure on the distribution of rock blasting fragmentation are obtained. The RFPA software can better simulate the process of rock fracture and instability.

2.3.2. Tension Failure Finite Element Method. Tensile failure refers to the phenomenon of rock failure that occurs when the material exceeds its own compressive strength. The basic assumption of finite element is that all nodes and element aggregates in the entire analyzed system are equally divided, and each grid is properly processed so that each segment is regarded as a new subfield. In the actual numerical calculation, the unknown quantity and boundary condition value can be determined according to the limit state equation.

2.4. Numerical Model of Rock Thermal Fracture. The phenomenon of rock thermal cracking is mainly caused by the characteristics of the rock itself. As a natural geological material, rock is often composed of many different mineral particles inside. When the rock is affected by external temperature changes, the various mineral particles inside will show different thermodynamics, which will cause various parts of the rock. There is a constraint between them, which prevents deformation in certain directions from occurring freely, which causes thermal stress inside the rock.

In geotechnical engineering, most of the engineering problems are more complicated, and the problem of multifield coupling is one of the main ones. Heat conduction is the heat transfer phenomenon when there is no macroscopic movement in the medium. When the rock and other contact objects have different temperatures or the temperature distribution of the rock itself is not uniform, the rock will transfer heat through the thermal movement of the tiny particles inside itself. This method is called rock heat conduction. The existence of temperature difference will cause two different molecules to be produced inside the rock. The temperature field of a rock is a collection that reflects the distribution of temperature values at various points inside the rock. It is a function of time and space, namely,

$$R = g(m, n, p, q), \tag{3}$$

where R is temperature, m, n, and p are space coordinates, and q is time.

Grad R is the temperature gradient, which represents the rate of temperature change that occurs on the isothermal surface at a certain point inside the object along the straight line direction, namely,

$$\text{grad}\, R = \frac{\lambda R}{\lambda m} a + \frac{\lambda R}{\lambda n} b + \frac{\lambda R}{\lambda p} c. \quad (4)$$

(1) Rock thermal stress: when the temperature of the rock changes due to external influences, the inside of the rock will generally expand or contract due to the increase or decrease in temperature. Depending on the heating conditions, the temperature field generated inside the rock will be different, so the thermal stress generated by the thermal expansion of the rock will also be different. Thermal shock is a typical thermal stress, which is formed due to rapid heating or rapid cooling. Rock thermal strain is caused by thermal stress. According to the assumption of elasticity, if the object is isotropic, the elastic constant of the object does not change with the direction, so the linear expansion coefficient of the rock will not change.

(2) Thermal-mechanical coupling problem: heat exchange is an important factor that determines the temperature field distribution of an object. The form of exchange is generally divided into the internal exchange of the object and the heat exchange between the object and the outside. These heat exchanges are usually considered to be time-based. The calculation of the temperature field distribution requires not only the heat conduction equation but also the setting of the preliminary conditions of the object. The boundary conditions are related to the heat exchange between the surface of the object and the environment. Regarding heat transfer, boundary conditions are generally divided into three categories. For the specific temperature value given at the limit of the object, we call it the first type of boundary condition. The entry and exit of heat at the boundary of a given object is called the second type of boundary condition. Considering the convective heat transfer conditions, it is called the third type of boundary conditions.

(3) The calculation of the thermal-mechanical coupling numerical model is mainly divided into a two-step process. First, the temperature field in the model is calculated from the temperature boundary conditions, and the calculated value of the temperature field is brought into the stress solving condition to calculate the stress field. The thermal-mechanical coupling tensile failure finite element program is based on the theory of rock tensile failure, using the finite element method to introduce the concept of tensile failure unit and analyze the process of rock tensile failure under thermal stress. The specific calculation process is shown in Figure 2.

In Figure 2, (1) calculate the temperature field according to the temperature boundary conditions, (2) calculate the displacement field, (3) calculate the stress field, and (4) judge whether there is unit cracking according to the stress field. If there is an element crack, split the element and modify the element grid. If there is no element crack, end the calculation.

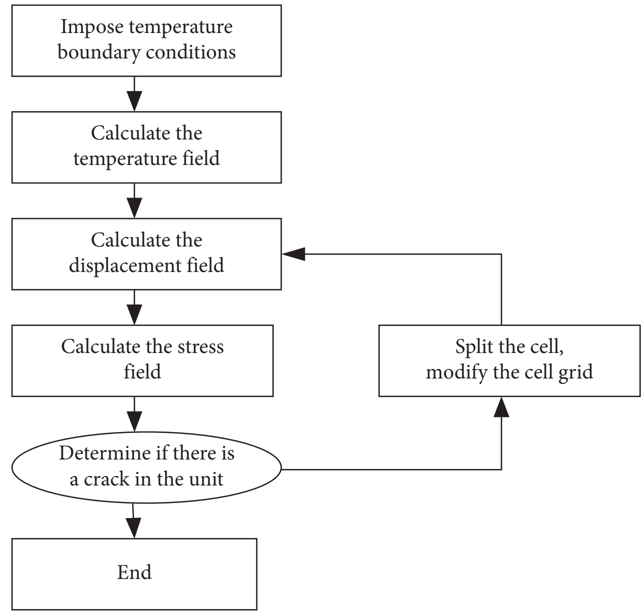

Figure 2: Thermal-mechanical coupling tensile failure finite element calculation process.

Table 1: Physical and mechanical properties of the cylinder.

Elastic modulus, E (GPa)	Poisson's ratio	Thermal expansion coefficient	Thermal conductivity
50	0.3	10×10^{-6}	1.5

Table 2: Set working conditions and their parameters.

Working condition	Interlayer buried depth	Interlayer inclination	Sandwich thickness	Slope angle
1	4	26	1.6	73
2	3	30	1.7	75
3	4	27	2	78
4	5	28	1.8	80

Table 3: Changes in temperature and first principal stress in the cylinder.

	Temperature	First principal stress
30	108	0
40	76	−6
50	63	1
60	48	7
70	30	11
80	25	15

3. Numerical Model Experiment

3.1. Model Verification. The verification model uses a thick-walled cylinder, the cylinder is a homogeneous rock material, the inner and outer radii are $x = 30\,\text{mm}$ and $y = 80\,\text{mm}$, and the inner and outer boundaries are applied with temperatures of 100°C and 20°C (to simulate what

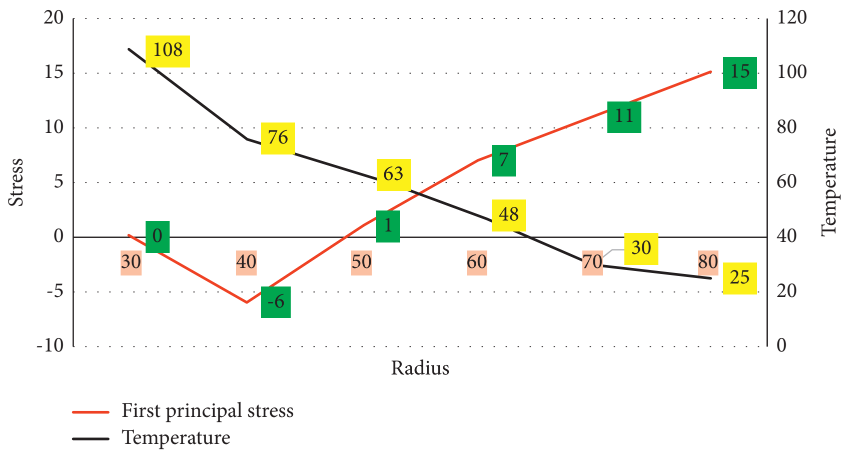

FIGURE 3: Changes in temperature and first principal stress in the cylinder.

TABLE 4: Change of the first principal stress monitoring point.

	First principal stress 1	First principal stress 2	First principal stress 3
Sandwich inclination	180	150	100
Sandwich thickness	80	100	120
Slope angle	100	120	140
Interlayer buried depth	90	110	130

happens when a thermal stress fracture occurs), respectively. The material parameters are shown in Table 1:

3.2. Thermal Stress Damage Caused by Temperature Gradient. The calculation example is a thick-walled cylindrical specimen. The cylinder adopts the numerical model and material parameters shown in Table 1, the tensile strength is 12 MPa, and two different temperature boundary conditions are applied. (1) The inner boundary temperature of the hole is 100. The temperature of the outer boundary of the hole is 20.(2) The temperature of the inner boundary of the hole is 20, and the temperature of the outer boundary of the hole is 100.

3.3. Selection of Calculation Conditions. According to the actual analysis of the embankment construction accident, comprehensively consider the influence of the buried depth, inclination angle, thickness, and inclination angle of the intermediate layer on the slope failure process, define four working conditions, and conduct digital simulation analysis on the slope failure process. The defined working conditions are shown in Table 2:

4. Experimental Results

4.1. Data Analysis of Thermal Stress Damage Caused by Temperature Gradient. According to the experimental design, the data collected in this study are the changes in temperature and first principal stress of the straight cylinder radius 30, 40, 50, 60, 70, and 80 mm. The specific situation is shown in Table 3:

As shown in Figure 3, we can see that the temperature decreases as the diameter of the cylinder increases, and the first principal stress first decreases and rises as the diameter of the cylinder increases. The numerical calculation results of temperature and first principal stress are consistent with their analytical solutions.

4.2. Analysis of Influencing Factors of Slope Failure Process. The greater the inclination angle of the interlayer, the thickness of the interlayer, and the inclination of the slope, the greater the first principal stress at the top of the slope. When the first principal stress is greater than the tensile strength of the rock mass, the crack extends from the top of the slope to the interlayer and penetrates the weak interlayer. The specific situation is shown in Table 4:

As shown in Figure 4, as the buried depth of the interlayer increases, the first principal stress concentration area on the top surface of the slope continues to decrease. The first principal stress of the top surface of the slope increases continuously with the increase of the thickness of the interlayer, the inclination angle of the interlayer, and the slope angle.

The results show that when the temperature outside the hole is higher than the temperature inside the hole, the maximum principal stress is concentrated at the outer boundary of the cylinder, and the cracks first occur at the outer boundary of the cylinder, extend radially to the inside of the hole, and finally break the disk through. When the temperature inside the hole is higher than the temperature outside the hole, the maximum principal stress is concentrated at the inner boundary of the cylinder, and the cracks first appear at the inner boundary of the cylinder and gradually form two main cracks in opposite directions around the round hole, and the two main cracks alternately expand outward until the failure of the cylinder.

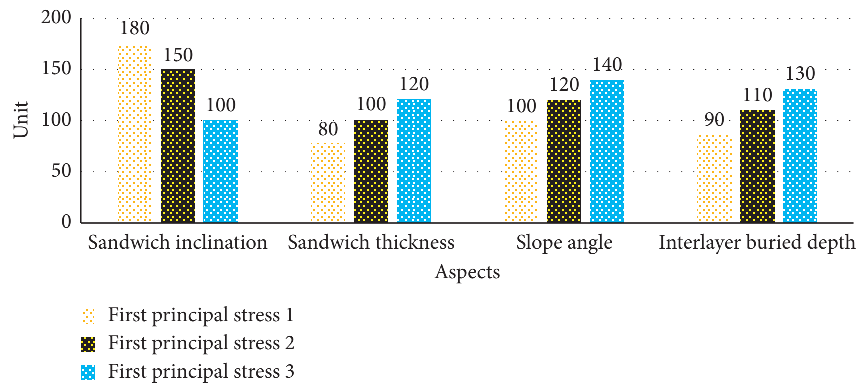

Figure 4: Change of the first principal stress monitoring point.

5. Conclusion

Thermal stress is the main factor leading to rock fracture. Based on the basic idea of cloud computing, this study uses the finite element method to simulate the plastic zone in the mountain by meshing the rock under a certain tension. When analyzing the rock deformation process, the material stress, displacement, and strain are mainly considered, and the calculated results are compared with theoretical values. Through the experimental research in this study, it is found that, for thick-walled cylindrical specimens, when the temperature outside the hole is higher than the temperature inside the hole, the maximum principal stress is concentrated at the last disc piercing the periphery of the cylinder expanding into the hole. Once the rock crack expands to a certain area, the thermal stress generated by the temperature no longer meets the crack condition. Aiming at brittle materials such as rock and using the principle of tensile failure, a digital model of thermal fracture with thermal-rigid coupling effect is established, and a new finite element method is proposed to analyze the thermal fracture process and mechanism of materials.

Data Availability

The data underlying the results presented in the study are available within the article.

Disclosure

The authors confirm that the content of the manuscript has not been published or submitted for publication elsewhere.

Conflicts of Interest

The authors declare that there are no potential conflicts of interest.

Authors' Contributions

All authors have seen the manuscript and approved to submit to the journal.

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