Dynamic intelligent prediction and platform development of slope deformation and failure in high and steep open-pit mine

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Abstract. This study is devoted to the quantitative study of the influence of rock and soil factors such as the physical properties of rock mass, the mechanical strength of rock mass, the shape of slope and the structural plane of rock mass on the displacement of high and steep open pit slope, and the coupling of mining factors, environmental factors and rock and soil factors. Based on a large number of engineering example data, using the integration ability of big data to build a sample library as a slope displacement training sample, in order to quickly grasp the development law of slope displacement change. On the basis of this research, an accurate and standardized slope displacement prediction system is formed, so as to build a dynamic intelligent prediction platform for slope deformation and failure of high and steep open-pit mines, and apply it to engineering practice, in order to provide support for the dynamic evaluation of slope stability of high and steep open-pit mines and the safe and efficient development and utilization of mineral resources.

Keywords: High and steep open-pit mine, Displacement factor, Slope displacement prediction system, Big data, Intelligent prediction platform.

1. Introduction

As a resource-rich country, China is rich in mineral resources. Open-pit mining is a major mining method to develop and utilize mineral resources. Therefore, the stability of open-pit slope will directly affect the safe and efficient development and utilization of mineral resources. In recent years, open-pit slope failure accidents have occurred from time to time, which has a great impact on mine production safety and caused great economic losses(Figure 1).

Figure 1. Landslide accident and rescue site in mining area

Most of the mine accidents are caused by the long-term effects of gravity, karst and geological structure under unfavorable geological conditions, resulting in slope instability and slope landslide. Although the occurrence of slope instability is accidental, it is not unpredictable. The most obvious parameter to characterize the change of slope is slope displacement, which can best reflect the change status and future development trend of slope. Therefore, this project intends to reveal the displacement variation law and internal mechanism of high and steep open-pit slope, so as to achieve the purpose of predicting the deformation and failure of open-pit slope. Accurate monitoring of slope displacement and analysis of future evolution rules and trends are helpful to find abnormal signs in time and take disaster prevention and mitigation measures to minimize the losses caused by disasters. This can not only prevent and control slope landslide disasters, thus bringing huge economic and social benefits, but also provide important theoretical basis and technical support for enriching and developing disaster prediction theory and promoting the development of geology and geotechnical mechanics. It has very important theoretical and practical engineering application significance.

Due to the frequent accidents of slope instability in recent years, it has caused great damage to people 's lives and property safety and infrastructure facilities. Therefore, the prediction methods for slope stability have also received more and more attention. The stability of high and steep slopes has always been an important safety issue in the mining process of open-pit mines. High and steep slopes usually have a slow displacement process before collapse occurs. Therefore, slope displacement is one of the important indexes to evaluate the stability of high and steep slopes. Many scholars have achieved the purpose of analyzing slope stability by predicting the change of slope displacement.

2. Domestic and foreign research status and development trends

Throughout the development history of slope displacement prediction research at home and abroad [1], we can be roughly divided into three research stages. The first stage is to use the basic theoretical knowledge and formula methods of physics, rock mechanics [2-3] and other disciplines to study the change of slope displacement. Based on the creep theory and the experimental results, Japanese scholar Saito created a three-stage theory [4-5]. He divided creep into three stages : deceleration creep, stable creep and accelerated creep. He proposed an empirical formula for prediction and prediction with the strain rate of stable creep and accelerated creep as the basic parameters, and then established the differential equation of accelerated creep (Figure 2).

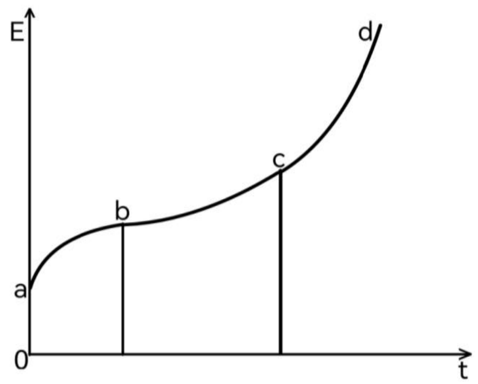

Figure 2. Saito Di 's three-stage theoretical model

With the development of mathematics and statistics, the study of slope displacement prediction has come to the second stage. This stage is mainly to establish a slope deformation model to predict future displacement changes. At this stage, a large number of scholars at home and abroad have established dozens of landslide prediction models and methods through unremitting efforts. It can be roughly divided into the following three categories: deterministic prediction model, statistical prediction model and nonlinear prediction model. The deterministic prediction model includes Su Aijun model [6], creep test prediction model and so on. This kind of model can generally reflect the physical essence of landslide and is mostly used for landslide or slope monomer prediction. The second type of statistical prediction model includes the well-known grey prediction model [7-9], time series analysis prediction model [10-12] and so on. This kind of model is mainly to analyze the existing slope displacement deformation observation value, find out the statistical law, and then predict the next displacement deformation. The third type of nonlinear prediction model [13-14] is a model formed by scholars combining nonlinear theories such as synergy theory, bifurcation theory and catastrophe theory, and has certain effect on the prediction of slope displacement. However, in general, these model methods at this stage can only be applied to the prediction of slope displacement under certain conditions, and cannot take into account the natural factors in the field. The universality is not strong. Because the situation of the slope is mostly complex and different, the accuracy of this kind of prediction model needs to be improved. Therefore, scholars at home and abroad have begun to integrate and apply advanced knowledge of other disciplines to predict (Figure.3).

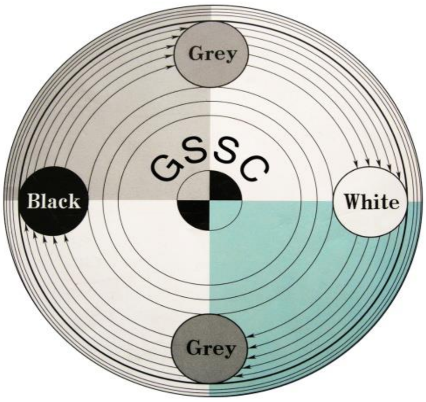

Figure 3. Grey prediction model

The third and current phase of the research is in progress. Machine learning [15-19] method is a non-linear computational tool, which uses different learning methods to learn and train the existing empirical data, get the training result model, and apply the model to the answer or prediction analysis of the problem under study. In recent years, with the strong development of artificial intelligence and machine learning, scholars at home and abroad have started to apply them to the geotechnical field, and slope prediction is one of the main focuses. This stage of research can be called the machine learning model stage. Such models will train and learn from existing data, build a model and apply the model to actual prediction, which can greatly improve the accuracy of prediction, and common machine learning models include artificial neural networks [20-22], deep neural networks, decision trees [23], long and short-term memory recurrent neural network models [24] and so on. These models can take into account a variety of factors, including the amount of displacement change of the slope itself and the influence of the surrounding environment, etc., and the accuracy of the prediction results is greatly improved, which is a common prediction method at present. To date, there is still no single model that can be applied to all types of slopes. As a promising direction in the field of artificial intelligence, deep learning is developed from the basis of artificial neural network, not only a machine learning method, but also a representation learning method, and its main model is various deep neural networks. The main principle is to build a multi-layer representation learning structure, using a series of non-linear transformation operations to combine simple initial features extracted from the original data to obtain a higher-level, more abstract representation. Deep learning will be a powerful solution for slope prediction problems with multiple impact factors, and this will be a major research direction for slope displacement prediction in the future (Figure 4).

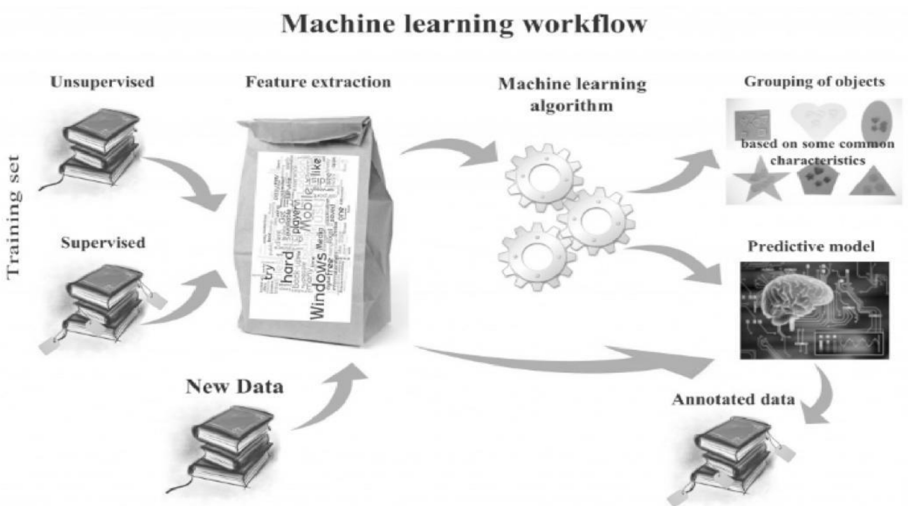

Figure 4. Typical machine learning process

3. Research content

This study intends to study the relevant examples and data of slope displacement, coupling mining factors, geotechnical factors and environmental factors, using the integration ability of big data and time series analysis method to build a slope displacement prediction system for high steep open pit mines, predicting the displacement evolution law of high steep open pit mines slopes by constructing an intelligent algorithm model, and on this basis, developing a high steep open pit mine displacement prediction platform integrating multi-source heterogeneous data and intelligent prediction model. On the basis of this, a platform for predicting slope displacement changes in high steep open pit mines is developed, integrating multi-source heterogeneous data and intelligent prediction models, with a view to providing reference for stability analysis of slopes in high steep open pit mines and exploitation of mineral resources. The specific technical route of this study is shown in Figure 5.

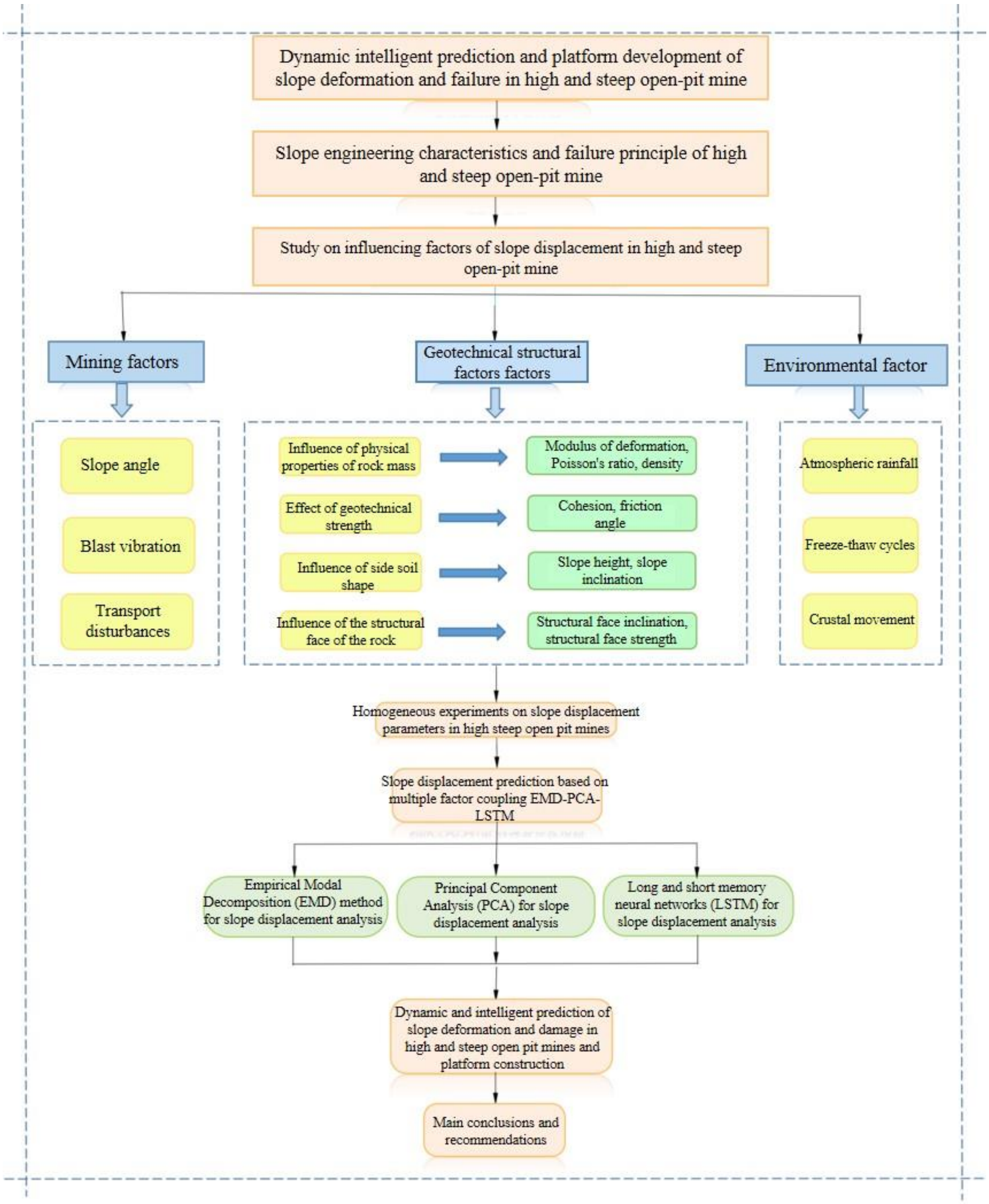

Figure 5. Technology roadmap

(1) Analysis of engineering characteristics and deformation and damage mechanisms of slopes in high steep open pit mines. The main factors affecting slope displacement include geotechnical factors, mining factors, environmental factors, etc. By identifying the key influencing factors and conducting quantitative research, the deformation and damage mechanism of slopes in high steep open pit mines can be revealed.

(2) Slope displacement prediction based on multi-factor coupled EMD-PCA-LSTM. Various algorithms such as empirical modal analysis {EMD}, principal component analysis {PCA} and long-short memory-neural network method {LSTM} are used to analyse the slope displacements of high steep open pit mines under the coupling of multiple factors.

(3) Dynamic intelligent prediction of slope deformation and damage in high steep open pit mines and platform construction. Through uniform experiments on the displacement parameters of high and steep slopes, relevant slope displacement change data are collected and formed into a sample library, and then the API functions of Matlab are combined with custom modules to form a general algorithm framework, and the simulation modules are integrated to form a complete simulation platform, so as to build a dynamic intelligent prediction platform for deformation damage of high and steep open pit mines.

3.1. Problems to be solved

(1) Quantitative identification of key factors influencing slope displacement. The project team proposes to adopt the method of numerical simulation to quantify the data from the research and analyse the geotechnical factors of the slope body of the high steep open pit mine, including the influence of the basic physical and mechanical properties, the geometric characteristics of the slope, the structural surface parameters of the bunker and other rocky slope displacement, while coupling these factors with the mining factors and environmental factors, so as to identify the main factors and key factors affecting the displacement of the demonstrated slope.

(2) Construction of sample database of slope displacement variation law. As it is often difficult to describe the characteristics of slope displacement under multiple factors, by referring to relevant literature, this project proposes to adopt the "uniform design method" to calculate and analyse the slope displacement, and conduct numerical simulation tests with the values of the calculation parameters (input variables) within the accepted range, and then carry out finite element simulation calculations for each scenario to obtain the corresponding The target values (slope displacements) are then calculated for each scenario by finite element simulation, so that a sample library can be constructed as a training sample for slope displacement analysis, in order to quickly grasp the law of slope displacement change.

(3) Short-term displacement of rock masses for evolutionary prediction. Through the integration capability of big data and time-series analysis, the coupled sample library of multiple factors is trained to build a slope displacement prediction and evaluation system for high steepness open pit mines. As a complex and uncertain chaotic body, it is unrealistic to pursue long-term prediction of the development and evolution of the slope of a high steep open pit mine, considering that its evolution is not predictable in the long term and it is deformable.

3.2. Analysis of the mechanism of deformation and instability damage of slopes in high steep open pit mines

Slope displacement is the most significant parameter characterising slope stability in high steep open pit slope projects. The main factors affecting slope displacement include mining factors, geotechnical factors and environmental factors. However, due to the influence of non-homogeneous, non-linear and discontinuous rock materials as well as environmental factors, little is known about the deformation and damage mechanism of rock masses under complex conditions, coupled with the large number of uncertainties in the process of rock mechanics analysis and simulation, it is very difficult to solve rock slope displacements or stresses by conventional analytical methods. This project makes use of the integration capability of big data and relevant mathematical models to couple multiple factors such as geology, engineering and environment to reveal the change pattern of slope displacement of high steep open pit mines and its intrinsic mechanism, and to provide support for the construction of subsequent evaluation index systems and prediction models.

3.3. Construction of an index system for evaluating slope deformation and damage in high steep open pit mines

The main factors affecting slope displacement in high steep open pit mines include geotechnical factors, mining factors and environmental factors. The geotechnical factors include the physical properties of the rock (deformation modulus E, Poisson's ratio v, density ρ), the mechanical strength of the rock (cohesion, friction angle), the shape of the slope (slope height, slope inclination), the structural surface of the rock (structural surface inclination, structural surface inclination), etc. The mining factors mainly include the slope angle, blasting vibration, transport disturbance, etc. The environmental factors mainly include atmospheric precipitation, freeze-thaw cycles, crustal movement, etc. The influence law of these factors is extremely complex, and the amount of contribution to the slope displacement also varies. In fact, slope displacement is the result of the combined effect of the above factors, which is a typical non-linear black box problem. By collecting a large amount of engineering example data, principal component analysis and correlation analysis are used to identify and determine the key influencing factors in each type of influencing factors, and then construct an evaluation index system to provide a basis for the establishment of an intelligent prediction model.

3.4. Construction of a slope displacement prediction model for high steep open pit mines based on multiple algorithms

Based on a large number of engineering examples, this project couples multiple factors such as mining factors, geotechnical factors and environmental factors, and fully considers the weight of each factor, and uses the integration ability of big data to build a sample bank as a training sample of slope displacement. Considering the uncertainty and the non-linear effect between the influencing factors, the time-series analysis method with strong generalization ability is adopted to establish the slope displacement prediction model in order to quickly grasp the slope displacement change pattern.

As an effective dynamic data processing method, time series analysis can be used to fit the observed mining, geotechnical and environmental factors to analyse the statistical regularity of these observed data. By analysing the statistical regularity of the time series, the best mathematical model is constructed to fit these laws, and the slope dynamics are tracked continuously, changing the prediction model in real time, thus enriching the subsequent information, removing the outdated early information, making the model more in line with the dynamic laws of the time, and predicting the possible future values of the time series, and finally giving an accuracy analysis of the prediction results.

3.5. Slope deformation instability prediction platform development and application

Using the established intelligent prediction model for slope displacement in high steep open pit mines, an intelligent prediction platform (applet) for slope displacement in high steep open pit mines will be developed. The project will use Matlab API functions and custom modules to form the overall algorithm framework, and integrate simulation modules to form a complete simulation platform. The problem of errors due to the numerical solution of the predictive control simulation by Matlab will be solved by using the recursive solution method of discrete objects. Matlab's GUI programming environment is also used to build a predictive control simulation platform that integrates object input, algorithm loading, simulation system, output analysis and data traversal.

Matlab, as a scientific software with high-speed performance numerical computing capability, has been widely used in predictive control research. It is particularly important for the current reduction of complex problems in predictive control to the standard form of LMI (Linear Matrix Inequality).

4. Conclusions

This study focuses on the deformation and damage of slopes in high and steep open pit mines, and is carried out through a multi-method technical coupling of theoretical analysis, model construction and platform development, with a view to revealing the intrinsic mechanism of deformation and damage of slopes in high and steep open pit mines, identifying and determining the key influencing factors affecting slope deformation and damage, and establishing an intelligent prediction model with strong generalisation capability. The research direction focuses on the frontier of the discipline and the major needs of the country. The research results are of great theoretical significance and practical application value, and can enrich and promote the development of the field of open pit slope stability research to a certain extent.

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