Research on dynamic inverse method of surrounding rock mechanical parameters of large underground caverns in excavation

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Abstract: Rock mechanical parameters are important factors to affect the stability of surrounding rock in underground engineering. With the development of underground cavern excavation progress, the mechanical parameters of rock mass will change significantly. In order to reflect the change of parameters during excavation in real time based on uniform design and optimization algorithm technology, dynamic inverse method of surrounding rock parameters during excavation of underground caverns is carried out. Considering the location, elevation and period of excavation, the parameters inversion are divided into excavation sections and staged. Verified by actual engineering, the calculated displacement values of the inversion agree well with the measured.

1. Introduction
The determination of rock mechanics parameters is the precondition for geotechnical engineering calculation. Due to the complexity of engineering topography, geology and measurement, rock mechanical parameters are difficult to measure accurately. In order to overcome the inaccuracy of the parameters, the dynamic surrounding rock mechanics parameters inversion was taken up. A large number of studies [1-7] have shown that it is a good way to invert the mechanical parameters by using on-site monitoring displacement data. The monitoring data of the underground cavern is used to invert the parameters, and the stability of the surrounding rock is analyzed and evaluated accordingly. It plays an important role in ensuring the safety of construction and avoiding the risk of major accidents in underground engineering.

Based on the research of the underground powerhouse engineering of a hydropower station, this paper come up with the method to inverse the rock parameters. The uniform design and artificial neural network technology was used to inverse the parameters in the excavation of the underground powerhouse, and the inversion parameters are used to calculate and analyze of the current excavation layer. The dynamic inversion method may optimize the design and construction of underground engineering effectively.

2. Rock mechanical parameters inversion method
As the surrounding rock parameters are the control factors for analyzing rock stability and supporting design. Dynamic surrounding rock parameter inversion of large-scale underground cavern group
excavation process plays an important role to get accurate parameters. The calculation flowchart of displacement inversion analysis is shown in Fig. 1.

The key technologies to be considered in inversion method are as follows:

1. According to the measured value of the multi-point displacement meter and the geological investigation data of the cavern group, the factors which affecting the deformation are analyzed. The sensitivity analysis is used to select the strong sensitivity parameters to inverse. In addition, based on the test results and the monitoring data, the range of the parameters are determined.

2. The uniform design theory is used to carry out multiple sets of feature analysis samples, then the genetic algorithm is used to establish the initial weight of neural network, then substitute the sample for neural network training, jointly obtain the approximation parametric solution of the error function minimum by genetic and gradient descent algorithm.

3. Constructing a closed-loop inversion system for the simulation of the construction process of underground caverns, the optimal parameters are obtained. Combined with positive analysis to obtain
a new set of samples closer to the measured values, which will be put into the original sample group and substituted into the system. The cyclic method can automatically increase the effective samples gradually when the training samples are insufficient, continuously improve the simulation precision, reduce the error, and ensure the high-efficiency and high precision output the optimal parameters.

4. The obtained optimal mechanical parameters are used for the forward analysis, and predict the response of the displacement for the next excavation.

3. Analytical procedure for engineering application

Calculation and analysis model. Taking the large underground power station caverns engineering as an example, its three-dimensional finite element numerical model is shown in Fig. 2. The underground powerhouse cavern includes the terrain, faults, strata and underground plant excavation of the hydropower station right bank. And the model consists of six strata, from left to right are (10) P2a-Ss+Sb, (9) P2a-Sb, (8) P2a-Ss, (7) P2a-Sb+Ss, (6) P2a-Ss, (5) P2a-Sb+Ss separately, the stratified excavation and computing mesh of FEM model are shown in and Fig. 3.

![Figure 2. Three-dimensional numerical mesh model](image)

![Figure 3. Cavern group numerical mesh model](image)

Parameters range of dynamic inversion. The 11 parameters with high sensitivity have been identified, based on the sensitivity analysis of lithologic parameters various types, actual test data and numerical analysis results of previous scientific research, which are (1) the young's modulus $E_1$, cohesion $c_1$ and friction angle $\varphi_1$ of sand and slate interbedded; (5) P2a-Sb+Ss, (7) P2a-Sb+Ss and (10) P2a-Ss+Sb; (2) the young's modulus $E_2$, cohesion $c_2$ and friction angle $\varphi_2$ of sandstone: (6) P2a-Ss and (8) P2a-Ss; (3) the young's modulus $E_3$, cohesion $c_3$ and friction angle $\varphi_3$ of slate: (9) P2a-Sb; (4) the equivalent modulus $E_f$ and equivalent cohesion $c_f$ of fault. The inversion parameters data range are shown as in Table 1.

| Inversion parameters | $E_1$ / GPa | $E_2$ / GPa | $E_3$ / GPa | $E_f$ / GPa | $c_1$ / MPa | $c_2$ / MPa | $c_3$ / MPa | $\varphi_1$ / $^\circ$ | $\varphi_2$ / $^\circ$ | $\varphi_3$ / $^\circ$ |
|----------------------|------------|------------|------------|------------|-------------|-------------|-------------|----------------|----------------|----------------|
| Lower limit          | 8.00       | 10.00      | 7.00       | 0.50       | 0.40        | 0.60        | 0.20        | 0.05           | 35.00          | 40.00          | 30.00          |
| Upper limit          | 20.00      | 25.00      | 18.00      | 2.00       | 1.50        | 1.80        | 1.20        | 0.30           | 50.00          | 55.00          | 45.00          |

Considering the unloading relaxation and mechanical properties of surrounding rock caused by excavation blasting, according to the depth of surrounding rock loose circle obtained by geophysical testing, the surrounding rock is divided into strongly disturbed zone, weakly disturbed zone and undisturbed zone, which is shown in Fig. 4. Based on the results of parameter sensitivity analysis, the mechanical parameters of the surrounding rock in the unloading zone are divided.
Inversion process and results. The training sample and the corresponding incremental displacement are combined into a sample pair, and the rock mass mechanical parameter inversion analysis system is introduced for training, and the nonlinear mapping relationship between the parameters and the corresponding incremental displacement is obtained. Then the actual corresponding incremental displacement is input to the trained neural network to obtain the rock mechanics parameter value. The parameter value obtained by the inversion is taken as a new sample, and the rock mass mechanical parameter inversion analysis system is retrained. Loop like this, artificial neural network error gradually decreases, until the error does not change, the calculation ends. The inversion results are shown in Table 2.

Table 2. The inversion results of parameter

| Young’s modulus of strongly disturbed zone / GPa | Young’s modulus of weakly disturbed zone / GPa |
|-----------------------------------------------|-----------------------------------------------|
| $E_{1,1}$ | $E_{1,2}$ | $E_{2,1}$ | $E_{2,2}$ | $E_{3,1}$ | $E_{3,2}$ |
| 7.27 | 8.13 | 6.89 | 7.44 | 8.51 | 7.16 |

The $E_{1,1}$, $E_{1,2}$, $E_{2,1}$ and $E_{2,2}$, $E_{3,1}$, $E_{3,2}$ are the young’s modulus of different lithology in strongly and weakly disturbed zone respectively. The inversion parameters are input into the positive analysis model for calculation, and the obtained calculated displacement values are compared with the actual monitored values. Taking construction stage VI to VII as an example, the comparison results are shown in Table 3. The results show that the calculated displacement values are not much different from the actual monitoring, indicating that the parameters of the group are reasonable and can be used as the input values of the surrounding rock mechanical parameters of the next excavation layer.

Table 3. Calculated displacement and measured comparison of excavation stage VI to stage VII

| Typical monitoring point | Surveying Depth / m | Calculated values / mm | Measured values / mm | Difference value / mm |
|--------------------------|---------------------|------------------------|----------------------|-----------------------|
|                          | VI      | VII     | VI-VII | VI      | VII     | VI-VII | VI-VII | |
| 1                        | 0       | 15.51   | 16.32  | 0.82    | 14.57   | 15.33  | 0.76   | -0.06   |
| 2                        | 2       | 12.56   | 13.25  | 0.69    | 13.13   | 13.70  | 0.57   | -0.12   |
| 3                        | 7       | 11.24   | 12.24  | 1.01    | 3.44    | 4.87   | 1.43   | 0.42    |
| 4                        | 15      | 6.64    | 7.43   | 0.79    | 0.79    | 1.32   | 0.53   | -0.26   |
| 5                        | 7       | 11.25   | 13.16  | 1.92    | 8.37    | 9.95   | 1.57   | -0.34   |
| 6                        | 15      | 6.06    | 9.60   | 3.55    | 5.48    | 8.78   | 3.30   | -0.25   |
| 7                        | 0       | 19.74   | 23.01  | 3.27    | 11.76   | 14.42  | 2.65   | -0.62   |
4. Conclusions

1. An algorithm based on inheritance, gradient descent and neural network is proposed, which can improve and supply the effective sample automatically, and solves the problem of inaccurate value of rock mechanics parameters;

2. According to displacement monitoring and geophysical prospecting results, inversion dynamic method achieve the purpose of surrounding rock parameters divided by sections and staged, which reflect the dynamic changes and develop process of surrounding rock mechanical behaviour.

3. The engineering application example shows that the mechanical parameters obtained by the inversion are acceptable, which verified the rationality and operability of this method.

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