In-situ stress measurement at deep position and optimization of roadway support structure parameters in underground mines

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Abstract. In view of the fact that the mining depth is increasing year by year and the ground pressure disaster is becoming more and more serious in a coal mine, the in-situ stress in deep areas was measured by using the stress relief by overcoring method. The confining pressure rate test and the temperature compensation test were carried out in the laboratory. In-situ stress states and its distribution law ware obtained. Appropriate mechanical parameters and support parameters were selected through research on roadway support theory. By adopting numerical simulation software, the primary support and the secondary support of roadway ware numerically simulated and compared, which can offer a scientific, reasonable and economic plan for the secondary support of roadway. After field application, the roadway support effect had been significantly improved.

1. Introduction
With the deepening of mining depth in coal mines, it is more difficult to support the roadways, which lead to the collapse and destruction of the roadways in serious cases. In order to ensure safe and efficient mining, mining and support design must be optimized. In-situ stress is a natural stress that exists in stratum and is not disturbed by engineering. It is also called initial stress, absolute stress or in-situ stress of rock mass. It can be considered that in-situ stress is the fundamental force causing deformation and destruction of roadways. Only by grasping the characteristics of in-situ stress in the specific engineering area, can appropriate mining methods be selected, and the optimum section shape, section size, support form and support structure parameters of roadways and stopes be determined through numerical simulation calculation and analysis, so as to maximize the output and improve the economic benefits of mines under the premise of ensuring the stability of surrounding rock[1].

2. In-situ stress measurement at deep position

2.1 Measurement method
The improved hollow inclusion strain gauge was used to measure in-situ stress by using the stress relief by overcoring method. The strain gauge adopts full temperature compensation technology and uses thermistor to compensate the temperature of the test[1-3], which can effectively reduce the influence of temperature change on the accuracy of in-situ stress measurement. DDS-163 data...
collector was used to automatically collect the strain value caused by stress relief of strain gauge in the process of relief.

2.2 Measuring point arrangement

In order to ensure that the measured stress can accurately reflect the distribution law of in-situ stress of the entire mining area from space, it is necessary to correctly determine the number of measuring points and reasonably arrange the location of measuring points. The selection of measuring points generally follows the following principles: (1) representative areas of strata; (2) generally far away from faults, avoiding rock fracture zones and fault development zones; (3) as far as possible away from larger excavation bodies, such as large goafs and large chambers; (4) avoiding stress concentration areas such as bends and forks of roadways and stopes; (5) try to measure in three or more segments or levels[4]. In this survey, 11 measuring points were selected from 6 levels of the mine for in-situ stress measurement. The buried depth, location, drilling parameters and RQD values of drilling core are shown in Table 1.

Table 1. Location of each measuring point and borehole characteristic parameters.

| Measuring point | Buried depth(m) | Location                          | Strike(°) | Dip(°) | Bore depth(m) | RQD values(%) |
|-----------------|-----------------|-----------------------------------|-----------|--------|---------------|----------------|
| 1ª              | 1123            | F4-3th level track                | 305       | 7      | 9.75          | 49.67          |
| 2ª              | 1061            | Outside the F15-24100 yard        | 229       | 6      | 9.84          | 77.33          |
| 3ª              | 1061            | Outside the F15-24100 yard        | 239       | 4      | 9.81          | 59.33          |
| 4ª              | 785             | Inside the F15-24080 high-level roadway | 12      | 10    | 8.68          | 44.00          |
| 5ª              | 793             | Inside the F15-24080 high-level roadway | 95      | 6     | 9.04          | 36.07          |
| 6ª              | 869             | Track downhill of E group in east district | 125     | 4     | 9.70          | 10.45          |
| 7ª              | 869             | Track downhill of E group in east district | 106     | 4     | 9.22          | 49.62          |
| 8ª              | 514             | -320 pedestrian cross-cut         | 230       | 4     | 11.28         | 92.92          |
| 9ª              | 514             | -320 pedestrian cross-cut         | 269       | 3     | 10.65         | 95.83          |
| 10ª             | 914             | Outside E8-30010 in central district | 178     | 10    | 9.29          | 32.37          |
| 11ª             | 914             | Outside E8-30010 in central district | 195     | 7     | 9.35          | 32.82          |

2.3 Field strain measurement

The data collected in this field test is relatively good. As can be seen from Figure 1, the working state of most strain gauges is normal, and the curves change regularly. That is, in the initial stage of relief, the strain values measured by each strain gauge are very small and change very slowly. When the depth of relief reaches the bonding position of the strain gauge, the strain values of each strain gauge tend to be stable. The stable strain value is the basic data to be used when calculating in-situ stress.

2.4 Temperature compensation and confining pressure calibration test

After the field stress relief test is completed, the core with strain gauge taken out from the field is used for temperature compensation test in a thermostat, and then confining pressure calibration test is carried out in the laboratory[5]. Temperature compensation test is to use full temperature compensation technology to collect strain data and temperature values of strain gauges when the temperature rises in the laboratory through the acquisition instrument, so as to obtain temperature strain rate, which can be used to calculate the additional strain values caused by temperature change[6],
and then to correct the stable strain values measured in the process of in-situ stress measurement. The final strain values due to stress relief are obtained. The Poisson's ratio and modulus of elasticity of the rock at the location of the measuring point are obtained by confining pressure calibration test with the core containing strain gauge.

![Stress relief curve of measuring point 1](image)

**Figure 1. Stress relief curve of measuring point 1**

2.5 *Calculation results of in-situ stress*

Based on the data obtained from field and indoor tests, the magnitude and direction of principal stress of each measuring point are calculated by using three-dimensional in-situ stress calculation software, as shown in table 2. Because the upper coal seams of 6#, 7#, 10# and 11# have been mined out, the vertical principal stress value is relatively small.

**Table 2. Calculation results of principal stress of each measuring point.**

| Measuring point | Buried depth(m) | Maximum principal stress | Intermediate principal stress | Minimum principal stress |
|-----------------|-----------------|--------------------------|-------------------------------|-------------------------|
|                 |                 | Numerical value (MPa)    | Direction (°) | Dip (°) | Numerical value (MPa) | Direction (°) | Dip (°) | Numerical value (MPa) | Direction (°) | Dip (°) |
| 1#              | 1123            | 65                        | 60                  | -1      | 38                  | -151          | -76      | 31                  | 149           | 15     |
| 2#              | 1061            | 43                        | -132               | 13      | 26                  | 60            | 76       | 22                  | 137           | -3     |
| 3#              | 1061            | 44                        | 60                  | -2      | 28                  | 155           | -72      | 24                  | 149           | 17     |
| 4#              | 785             | 34                        | -158               | -17     | 22                  | -141          | 71       | 18                  | -67           | -5     |
| 5#              | 793             | 36                        | 60                  | 15      | 25                  | 49            | -74      | 19                  | -30           | 3      |
| 6#              | 869             | 44                        | 56                  | -14     | 25                  | -27           | -12      | 17                  | 21            | 70     |
| 7#              | 869             | 44                        | 61                  | -6      | 26                  | -30           | -9       | 18                  | 6             | 79     |
| 8#              | 514             | 31                        | 53                  | 6       | 17                  | 131           | -73      | 15                  | 146           | 16     |
| 9#              | 514             | 29                        | -131                | -7      | 18                  | 137           | -17      | 17                  | 160           | 72     |
| 10#             | 914             | 40                        | 43                  | -8      | 28                  | 132           | 2        | 14                  | 27            | 81     |
| 11#             | 914             | 43                        | -131                | 9       | 23                  | 133           | -5       | 16                  | 42            | 79     |

2.6 *Distribution law of in-situ stress field*

According to the calculation results of principal stress of each measuring point in Table 2, the distribution characteristics of in-situ stress field in mining area are drawn as follows:

(1) There are two principal stresses near the horizontal direction at each measuring point. The average angle between the two principal stresses and the horizontal plane is 10.2 degrees, and the maximum angle is 17 degrees. Another principal stress is close to the vertical direction. The average angle between it and the vertical direction is 13.1 degrees, and the maximum is 20 degrees.
(2) The maximum horizontal principal stress of each measuring point is close to the horizontal direction. Compared with the gravity stress, the maximum horizontal principal stress is 1.62-2.45 times of the gravity stress, which indicates that the in-situ stress field of the mining area is dominated by horizontal tectonic stress. The direction of maximum horizontal principal stress is nearly NE, which is consistent with the direction of maximum horizontal principal stress of regional tectonic stress field.

(3) The minimum principal stresses of six measuring points (excluding 6#, 7#, 10# and 11#) are also close to the horizontal direction. The difference between the two principal stresses in the horizontal direction is very large. The ratio of the maximum horizontal principal stress to the minimum horizontal principal stress is 1.98 on average. According to Mohr-Coulomb strength theory, the difference between the two principal stresses is shear stress. The failure of rock mass is usually caused by shear failure. There are large shear stresses in the horizontal plane, which are the main causes of deformation and failure of underground roadways and stopes. They must be paid enough attention[7].

(4) The value of vertical principal stress is basically equal to or slightly larger than the gravity stress, and its ratio to the gravity stress is 0.95-1.25.

(5) The maximum horizontal principal stress, the minimum horizontal principal stress and the vertical principal stress all increase approximately linearly with depth. The linear relationship between maximum horizontal principal stress and vertical depth is as follows:

$$\sigma_{max} = 4225.00472.0H + 0.85$$

The linear relationship between minimum horizontal principal stress and vertical depth is as follows:

$$\sigma_{min} = 4157.00256.0H + 0.75$$

The linear relationship between vertical principal stress and vertical depth is as follows:

$$\sigma_v = 3003.00289.0H + 0.86$$

The results are shown that the gradient of the maximum horizontal principal stress varying with depth is larger than that of other principal stresses, and the principal stress field in the mining area becomes more dominant with the depth increase.

3. Optimization of deep roadway support structure parameters

3.1 Problems in Deep Roadways

The main problems of roadways in deep mining are drawn as follows: there are roof caving, roof slip and roof separation subsidence. The roof caving height is between 3 and 4 M. There are many roof slip, roof separation subsidence, failure of bolt support and support plate falling off and in roadway. There is a serious "rotten root" phenomenon at the root of the straight wall of the roadway. The reinforcement net is squeezed into a "big belly" phenomenon by the broken rock of the surrounding rock behind, and the roadway floor appears a "bulging belly" phenomenon.

These problems mean that pressures of roadways are relatively large on the top and side, and the support parameters of original designs cannot meet the requirement. Therefore, the support design of roadways should be optimized.

3.2 Optimum support scheme for deep roadways

Through theoretical analysis, in order to increase stiffness and reduce deformation, a satisfactory roadway optimization scheme is as follows:

1. The thickness of shotcrete is increased from 150 mm to 200 mm.
2. Add pre-stressed anchor cables (strands) to the top of relatively dangerous roadways. The diameter of anchor cable (strand) is 15.24 mm, the length is 8.3 m, the length of the hole is 8.0 m, and the exposure is 0.3m. The length and width of the anchor plate are about 150 mm and the thickness is 10 mm. Design Initial Stress of anchor cable is 18-20MPa.
3. Optimize the cross-section shapes of the roadways. The cross-section shapes of the roadways is optimized from the original straight wall semi-circular arch to the straight wall semi-circular arch plus inverted arch. The height of the wall and the diameter of the semi-circle are unchanged, and the bottom of the roadway is designed as an arch with a height of 0.75m.
4. Add resin bolts which is 3 m long and 20 mm in diameter along the direction of 30 degrees downward inclination on the two sides of roadway floor.
4. Numerical simulation analysis of deep roadway support

4.1 Selection of numerical simulation methods
FLAC is a computer software highly respected by the international geotechnical engineering community at present [8], and has been widely used in engineering geology, rock mechanics and structural geology. The optimization of the parameters of the roadway support structure was carried out by FLAC for numerical simulation analysis.

4.2 Build a calculation model and determination of boundary conditions
According to the experience of rock mechanics, the influence range of roadway stress is 3-5 times of roadway radius. The roadway simulated by this calculation model is horseshoe shape, and the size of the roadway is 3.8m wide, 1.45m high wall height and 1.9m high arch height. The overall calculation size of the model is 39.9m × 41.35m. The elastic-plastic constitutive relation is adopted in this model, and Mohr-Coulomb criterion is used in yield criterion.

Boundary conditions of the model: under the burial depth of 710m, the overlying soil on the upper boundary of the model acts as a load, and the force is $\gamma h$. The left and right boundaries are fixed in the X-direction displacement, and the bottom is fixed in the X-direction and Y-direction.

4.3 Numerical simulation results

4.3.1 Analysis of stress field
From the Figure 2-5, it can be concluded that before optimization, the compressive stress in X-direction of the top of the roadways is 30-32.5MPa, the compressive stress in Y direction is 27.5-30MPa, the stress in X-direction of the bottom of the roadways is 22.5MPa and the stress in Y-direction is 22.5MPa, and there is a phenomenon of stress concentration in some areas around the surrounding rock of the roadways, so that the deformation of the roadways will continue...
until it weakens. The stress environment of the roadways is relatively poor. After optimization, the compressive stress in X-direction of the top of the roadways is 22.5-25MPa, the compressive stress in Y-direction is 25MPa, the compressive stress in X-direction of the bottom of the roadways is 27.5MPa, and compressive stress in Y-direction 22.5MPa. The stress concentration in X-direction of the bottom is not as strong as before and there is no stress concentration region in Y-direction. The stress environment of the surrounding rock of the roadways is well improved.

4.3.2 Calculation and analysis of displacement vector field. From the Figure6-9, it can be seen that before optimization, the settlement of the top of the roadways is 250-300 mm, the arching height of the bottom of the roadways is about 600-700 mm, and the approaching amount of the two sides of the roadways is 500 mm. In contrast, by adding the support of pre-stressed anchor cable in time, maintaining and strengthening the strength of wall protection, and optimizing the stress release of roadway floor effectively, the settlement of the top of the roadways is reduced to 35 mm, the arching height of the bottom of the roadways is 50 mm, and the approaching amount of the two sides of the roadways is 40 mm. The requirements for the roadways during continued service are well maintained.

4.3.3 Calculation and analysis of plastic zone. From the Figure10-11, before the optimization, the plastic zone has a large range, and the bottom has a trend of tensile stress failure, and most of the surrounding rock at the top has entered the plastic yielding stage. However, the plastic zone of the surrounding rock is much smaller after optimization. Especially, the plastic zone above the roof is obviously reduced, which is shown that the stability of the roadways is obviously improved after optimization. The purpose of the roadway support system optimization is achieved, which meets the requirements of roadway ventilation, transportation and safe production.
5. Conclusions
The in-situ stress at deep position of the coal mine was measured by using hollow inclusion strain gauge with complete temperature compensation. The magnitude and direction of in-situ stress of measuring points was obtained by calculating. The distribution law of in-situ stress in mine area and the change law of in-situ stress with depth are mastered. Through the simulation analysis, the stress environment is improved significantly by optimizing the support system of deep roadways. The effect of roadway support has been obviously improved after the optimization scheme was adopted in the mine, which ensures the safe and efficient production of the mine.

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