Measurement of In-situ Stress in Ningdong Mine Area and In-situ Stress Distribution Law

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Abstract. In order to acquire the in-situ stress state and its distribution law in Ningdong mine area, in-situ stress measurement tests were conducted respectively in the coal mine of Zao Quan mine, Yang Changwan mine and Mei Hua mine. 3D in-situ stress states of five test points in three levels were obtained by using 3D stress relieving measurement technology and hollow inclusion strain gages combined with experiments of the rock core confining pressure test. The general distribution state and characteristics of in-situ stress field in Ning Dong mine area can be concluded as follow: Horizontal stress field acts as the main part, the direction of principal stress is horizontal basically the direction of the maximum principal stress N50.3 E in average. In-situ stress value in mine area increases linearly with the mining depth, and establish the model of in-situ stress of mine area.

1. Introduction
The significance of measurement of in-situ stress is to tell the state of stresses in a geological region. It is very important guide for underground excavations and mining activities. In-situ stress state in the mine area is of great significance in optimizing design, enhancing economical effect, predicting and controlling rock burst or gas explosion, deformation and instability of tunnel [1-4].

At present, there are many methods for measuring the in-situ stress, such as hydraulic fracture method, borehole caving method, Kaiser, stress recovery method, source mechanism analysis method, etc[5-9]. But there are various drawbacks during the process of measuring or the methods themselves. While, as a mature measure technology for in-situ stress, stress relieving method can accurately verify the 3D state of in-situ stress in the rock body. By using the method of cased drilling, in-situ stress is finished to relive [10, 11]. Because resistance strain gauge is pretty sensitive to the change of temperature, it is necessary to eliminate the influence of changing temperature through using complete temperature compensation technique method and improve the precision of measurements [12, 13].

2. Tests of In-situ Stress Measurement

2.1. Mine Background
Ningdong mine located in east of Yinchuan, capital city of Ning Xia province, showed in the Figure 1. Ningdong mine area includes Zaoquan mine, Yangchangwan mine and Meihua mine, which is located in the easy of Ningxia province. The mine area consists of a series of folds (NNW or nearly SN) and
faults and it extends eastward to the Erdos Syncline and stretches westward to tectonic zone in Liupan mount.

![Map of Ningdong mine area](image)

**Figure 1.** The location of Ningdong mine area on the map

2.2. **Measurement method of in-situ stress**

In order to increase the reliability of measurement, every strain flower in CSIRO hollow inclusion strain cells will change from three strain gauges to four strain gauges. There are twelve strain gauges in the hollow inclusion strain cell, which includes three in circumference (A90, B90, C90), three in axial direction (A0, B0, C0), three in direction of 45° intersection angle (A45, B45, C45), three in direction of 135° intersection angle (A135, B135, C135). The position of strain gauges in the hollow inclusion strain cells is presented in Figure 2 as follow.

![Sketch map of three dimensional strain measurement of hole wall](image)

**Figure 2.** Sketch map of three dimensional strain measurement of hole wall

The calculation formulas of 3D in-situ stress are listed as follow:

\[
\varepsilon_0 = \frac{1}{E} \left\{ (\sigma_x + \sigma_y) k_1 + 2 (1 - \nu^2) \left[ (\sigma_x - \sigma_y) \cos 2 \theta - 2 \tau_{xy} \sin 2 \theta \right] k_2 - \nu \sigma_z k_4 \right\} \tag{1}
\]

\[
\varepsilon_\theta = \frac{1}{E} \left[ \sigma_z - \nu (\sigma_x + \sigma_y) \right] \tag{2}
\]

\[
\gamma_{46} = \frac{4}{E} \left( 1 + \nu \right) \left( \tau_{yz} \cos \theta - \tau_{xz} \sin \theta \right) \tag{3}
\]
In the formulas, \( \sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{zx} \) respectively represent 6 components in 3D in-situ stress, which are used to calculate the values and directions of principal stress \( \sigma_1, \sigma_2, \sigma_3 \). \( E \) is the deformation modulus of rock in measuring point. \( \nu \) is the Poisson’s ratio of rock in measuring point. \( k_1, k_2, k_3, k_4 \) are all correction factors.

2.3. Test Points Layout
Five test points are conducted according to the reality of practice. The conditions of the testing points are listed in Table 1.

Table 1. Relevant conditions of five in-situ stress test points

| Test Point | Depth (m) | Test Position | Depth of Hole (m) | RQD (%) |
|------------|-----------|---------------|-------------------|---------|
| 1          | 288       | Zaoquan mine 1070m shaft station | 9.56           | 81.2    |
| 2          | 182       | Zaoquan mine 1174m shaft station | 8.68           | 77.8    |
| 3          | 344       | Yangchangwan mine 1058m sump     | 8.42           | 79.7    |
| 4          | 143       | Meihua mine crossheading 50m     | 8.23           | 80.6    |
| 5          | 122       | Meihua mine coal bunker 100m     | 8.36           | 79.4    |

3. Analysis
With the increase of reliving depth of the trepanning, the strain values are gradually stable as two sets of representative curves of in-situ stress are listed in Figure 3 below.

Figure 3. Representative curves of set of core hole confining pressure rate 2#(a), 3#(b)

3.1. Results of Stress Relieve
The stable values of five test points are obtained in the Table 2, every test point contains twelve strain gauges measuring strain values in twelve directions.
Table 2. Stable stress values of test points in final (Unit: με)

| Test Point | A₀ | A₄₅ | A₀₀ | A₁₃₅ | B₀ | B₄₅ | B₀₀ | B₁₃₅ | C₀ | C₄₅ | C₀₀ | C₁₃₅ |
|------------|----|-----|-----|------|----|-----|-----|------|----|-----|-----|------|
| 1¹         | 400| 163 | 585 | 671  | 670| 694 | 276 | 324  | 639| 530 | 584 | 152  |
| 2²         | 114| 241 | 318 | 237  | 125| 133 | 214 | 471  | 168| 149 | 325 | 478  |
| 3³         | 154| 264 | 1111| 491  | 183| 154 | 257 | 520  | 180| 267 | 387 | 634  |
| 4⁴         | 233| 528 | 1129| 541  | 173| 145 | 215 | 252  | 249| 192 | 520 | 428  |
| 5⁵         | 124| 338 | 636 | 346  | 76 | 342 | 508 | 457  | 93 | 120 | 586 | 545  |

3.2. Test Results of Temperature Calibration and Final Strain Value
Temperature of strain gauge is changing in the process of stress reliving. It is necessary to eliminate extra strain values caused by the temperature from the final values. In-situ stress of every strain gauge and its corresponding additional temperature strain ratio are displayed in Table 3 and Table 4.

Table 3. Additional temperature strain rate of strain gauge of test points in different directions

| Test point | Temperature strain ratio(μ/°C) |
|------------|--------------------------------|
| A₀ A₄₅ A₀₀ A₁₃₅ B₀ B₄₅ B₀₀ B₁₃₅ C₀ C₄₅ C₀₀ C₁₃₅ |
| 1¹ | 54 | 32 | 13 | 45 | 31 | 28 | 22 | 24 | 63 | 43 | 24 | 34 |
| 2² | 2 | 7 | 6 | 5 | 27 | 13 | 2 | 14 | 44 | 29 | 4 | 21 |
| 3³ | 54 | 30 | 11 | 34 | 52 | 31 | 12 | 33 | 59 | 35 | 35 | 10 |
| 4⁴ | 21 | 7 | 3 | 20 | 49 | 1 | 30 | 28 | 24 | 3 | 11 |
| 5⁵ | 51 | 31 | 11 | 31 | 51 | 32 | 13 | 33 | 51 | 29 | 13 | 35 |

Table 4. Final strain values of calculating in-situ stress of test points (Unit: με)

| Test Point | A₀ | A₄₅ | A₀₀ | A₁₃₅ | B₀ | B₄₅ | B₀₀ | B₁₃₅ | C₀ | C₄₅ | C₀₀ | C₁₃₅ |
|------------|----|-----|-----|------|----|-----|-----|------|----|-----|-----|------|
| 1¹         | 346| 131 | 572 | 626  | \ | 666 | 254 | 300  | 576| 560 | 118 |
| 2²         | 112| 234 | 312 | 232  | 98 | 120 | 212 | 457  | 124| 120 | 321 | 457  |
| 3³         | 100| 234 | 1100| 457  | 131| 123 | 245 | 487  | 121| 232 | 352 | 624  |
| 4⁴         | 212| 521 | 1126| 521  | 124| 124 | 214 | 222  | 221| 168 | 517 | 417  |
| 5⁵         | 73 | 307 | 625 | 315  | 25 | 310 | 495 | \    | 42 | 91  | 573 | 510  |

3.3. Results of Confining Pressure Tests
When calculating in-situ stress, the modulus of elasticity of rock (E) in test point and its poisson’s ratio (ν) values are need to be known. Confining pressure tests are conducted on the five rock cores to get the modulus of elasticity of rock (E) and the poisson’s ratio (ν), showed in Table 5.

Table 5. E, ν, k of different test points

| Test Point | E(GPa) | ν  | k₁  | k₂  | k₃  | k₄  |
|------------|--------|----|-----|-----|-----|-----|
| 1¹         | 30     | 0.25| 1.107| 1.113| 1.069| 0.948|
| 2²         | 32     | 0.24| 1.109| 1.117| 1.067| 0.941|
| 03³        | 42     | 0.20| 1.118| 1.130| 1.074| 0.898|
| 4⁴         | 28     | 0.25| 1.105| 1.109| 1.068| 0.949|
| 5⁵         | 25     | 0.20| 1.105| 1.1  | 1.066| 0.909|

3.4. Calculation Results of In-situ Stress
According to the results of confining pressure test, it is easy to calculate the primary stress of test point through putting E and ν into formulas (1) ~ (4).
Table 6. Calculation results of principal stress of test points

| Test Point | Depth (m) | Maximum Principal Stress $\sigma_1$ | Intermediate Principal Stress $\sigma_2$ | Minimum Principal Stress $\sigma_3$ |
|------------|-----------|---------------------------------|---------------------------------|---------------------------------|
|            | Value (MPa) | Direction (°) | Obliquity (°) | Value (MPa) | Direction (°) | Obliquity (°) | Value (MPa) | Direction (°) | Obliquity (°) |
| 1º         | 288        | 14.62           | 60.1          | 8.22         | 4.31          | 353.42       | 7.12         | 312.54       | 79.44          |
| 2º         | 182        | 7.52            | 308.27        | 8.67         | 37.03         | 351.95       | 4.89         | 84.79        | 78.12          |
| 3º         | 344        | 15.09           | 284.83        | 7.55         | 15.36         | 4.04         | 8.12         | 313.34       | 278.58         |
| 4º         | 178        | 11.63           | 288.74        | 5.78         | 19.52         | 7.59         | 4.93         | 341.83       | 279.56         |
| 5º         | 157        | 7.12            | 283.84        | 12.36        | 13.86         | 0.158        | 4.2          | 284.59       | 282.36         |

4. Results

4.1. Stress Field Distribution Law

Distribution laws of in-situ stress in Ningdong mine area are obtained as follow:

(1) The direction of maximum primary stress $\sigma_1$ is nearly horizontal. In the five test points, there are four points whose intersection angles between $\sigma_1$ and horizontal plane are less than 10°, which shows that it is very approximate to horizontal.

(2) The ratio of maximum horizontal principal stress value and geostatic stress value change from 2.09 to 1.82, the average is 1.95. The ratio of maximum horizontal principal stress value and vertical principal stress value change from 2.62 to 1.51, the average is 1.93. Horizontal tectonics stress is in the dominant position in Ningdong mine area.

(3) Vertical principal stress is nearly equal to or slightly bigger than geostatic stress. In the five test points, one indicates that vertical principal stress is appropriate to geostatic stress and the ratio of vertical principal stress and geostatic stress is 1.06. Other three points show that the vertical principal stress is bigger than geostatic stress, and the ratio of vertical principal stress and geostatic stress change from 1.12 to 1.21. The last point demonstrates that the vertical principal stress is smaller than geostatic stress, and the ratio of vertical principal stress and geostatic stress is 0.71.

(4) The trend of maximum horizontal principal stress are all NE-SW in the five points. The average trend degree is N50.3°E, which is coincided with the direction of maximum horizontal principal stress in horizontal tectonics stress field.

(5) In the five test points, there are three test points whose minimum principal stress trend is near to horizon level. It means that the difference values between the two principal stresses are big. In the five ratios of $\frac{\sigma_{h,\text{max}}}{\sigma_{h,\text{min}}}$, the maximum is 3.74, the minimum is 1.53. The relevant ratio values are displayed in Table 7.

Table 7. Ratio of relevant stress

| Test Point | $\sigma_{h,\text{max}}/\sigma_v$ | $\sigma_{h,\text{max}}/\gamma H$ | $\sigma_v/\gamma H$ | $\sigma_{h,\text{max}}/\sigma_{h,\text{min}}$ |
|------------|-------------------------------|-----------------------------|-----------------|-------------------------------|
| 1º         | 2.05                          | 1.81                        | 1.13            | 2.05                          |
| 2º         | 1.94                          | 1.76                        | 1.10            | 1.53                          |
| 3º         | 1.82                          | 1.51                        | 1.21            | 3.74                          |
| 4º         | 2.09                          | 1.97                        | 1.06            | 2.35                          |
| 5º         | 1.89                          | 2.62                        | 0.71            | 1.70                          |

4.2. Stress Field Model

Through the method of linear regression, regression curves and formulas of $\sigma_{h,\text{max}}$, $\sigma_{h,\text{min}}$ and $\sigma_v$ with depth are obtained as follow.

$\sigma_{h,\text{max}} = 0.0458 H + 0.5600$ MPa

$\sigma_{h,\text{min}} = 0.0267 H + 1.3111$ MPa

$\sigma_v = 0.0236 H + 0.3603$ MPa
In the formula, H is the depth of test point, unit is m.

Figure 4. Regression curves of $\sigma_{h, \text{max}}$, $\sigma_{h, \text{min}}$ and $\sigma_v$ changing with depth

5. Conclusion
(1) 3-D stress statements of five test points are measured in Ningdong mine area through using 3-D stress relieving technology, which basically reveal the distribution laws of in-situ stress in mine area.

(2) Horizontal tectonic stress is in the dominant positive in Ningdong mine area. Maximum principal stress trend is appropriate to horizontal level and the average trend is N50.3E.

(3) The difference value of two principal stress values of five test points in horizon is big, which indicates that strong shear stress exists in horizontal plane.

(4) The stress value in Ningdong mine area show linear increase with increase of the depth. Due to the beginning stage of coal mining in mine area, accurate in-situ stress measurement materials can not only provide reliable calculation foundation for mining design, tunnel support and stress control.

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