The Prediction of Distribution Characteristics of the In-situ Stress for Liuhuanguogou Mine Field

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Abstract – he distribution characteristics of the in-situ stress for the mining area of Liuhuanguogou mine field was tested by using the stress relief method. The value of the in-situ stress of the non-exploited region was predicted by using the theoretic analysis method and the advice of roadway layout was put forward.

Keywords – Prediction ; In-situ stress; Roadway Layout

I. INTRODUCTION

Liuhuanguogou coal mine is situated at the foot of Tianshan Mountain in Xinjiang, China. The mine field is situated in South wing of the Akord syncline. The strata lean towards northwest which is a monoclonal structure, going from NE to SW. The angle of coal-bearing strata is about 17° ~ 19° . There are 18 coal-strata and the coal seams of No.4-5, 7 and 9-15 are the mining coal seam. And the aggregate thickness is 35.75-46.33m and the average is 41.66m. Geologic feature of the mining coal seam and the lithologies of roof and floor is shown in table 1. To make the roadway layout and support design more reasonable, the in-situ stress was measured in the mining area and the distribution rules of the in-situ stress of the non-exploited region was predicted.

II. IN-SITU STRESS MEASUREMENT

The task on the in-situ stress measurement started from 15 September, 2009 to 30 September, 2009. The number of in-situ stress spots which was finished was 2. In-situ stress was measured by drilling overcoring stress relief method. And the CSIRO HI sensor which was manufactured by the Australian SCT company was adopted. In addition, the data was tested and analyzed.

TABLE 1 :Geologic Histogram

NO.	Rock property	Rock thickness /m
1	sandstone	49.75
2	mudstone	10.50
3	4-5 coal seam	6.15
4	siltstone	2.16
5	7 coal seam	2.80
6	siltstone	16.63
7	9-15 coal seam	30.90
8	siltstone	6.10

The first spot was located in opening position of return air crossheading of W (4-5)101 rail crossheading. Stress sensor

was installed inside the sedimentary rocks. The holes of in-situ stress was constructed with an up-angle of 41° and an azimuth of 320° . The diameter of guide hole was 105 mm and the length was 10.20 m. The diameter of mounting hole of stress sensor was 38 mm and length was 0.47 m. The installation depth of the stress sensor was 10.55 m.

The second spot was located in Return Airflow Dip about 5 m at slope changing points with an elevation of 796 m. The holes of in-situ stress was constructed with an up-angle of 41° and an azimuth of 50° . The diameter of guide hole was 115 mm and the length was 10.15 m. The diameter of mounting hole of stress sensor was 38 mm and length was 0.47 m. The installation depth of the stress sensor was 10.55 m. The test results of the in-situ stress were shown as table 2.

III. THE PREDICTION OF IN-SITU STRESS

A) Estimation method of in-situ stress value near the point of measurement

1) Weight stress field

According to the principle of continuous medium mechanics, for the linear elastic and isotropic rock, the weight stress at h meters below surface without load can be calculated by the formula with considering

$$\sigma_z = \rho h \quad \sigma_x = \sigma_y = \frac{\mu}{1-\mu} \sigma_z \quad (1)$$

Where, σ_x and σ_y is the component of horizontal weight stress, σ_z is the component of vertical weight stress; μ is the Poisson's ratio of rock mass.

In the weight stress field, rock mass is in the elastic state and the stress is small in shallow rock mass. The value of stress in the rock mass goes up as the depth goes down. The rock mass changes the state from elastic to latent plasticity when the depth gets to a certain value. And this depth value is the critical depth H_{cr} .

The stress component can be calculated by the formula (1) at the critical depth;

$$\sigma_z = \gamma H_{cr} \quad \sigma_x = \sigma_y = \frac{\mu}{1-\mu} \gamma H_{cr} \quad (2)$$

TABLE 2: The Test Results Of The In-Situ Stress

<i>spot</i>		$\sigma_{\max}$	σ_{mid}	$\sigma_{\min}$	σ_v	$\sigma_{\max}/\sigma_{mid}$	$\sigma_{mid}/\sigma_{\min}$
The first spot	size/MPa	7.32	5.83	3.20	5.86	1.23	1.82
	dip/°	63.9	3.6	25.8			
	azimuth/°	336.4	238.9	147.1			
The second spot	size/MPa	7.44	4.72	3.50	6.74	1.58	1.35
	dip/°	62.9	17.7	19.8			
	azimuth/°	351.6	222.9	126.3			

At the critical depth, the status of stress should base on the yield criterion of rock mass - Hoek-Brown criterion. So

$$\sigma_1 = \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^2} \quad (3)$$

According to the formula $\sigma_z = \sigma_1$, $\sigma_x = \sigma_y = \sigma_3$, we can get a expression of H_{cr} when the formula (2) is used in the formula (3).

$$H_{cr} = \frac{\lambda m + \sqrt{(m\lambda)^2 + 4s(1-\lambda)^2}}{2\gamma(1-\lambda)^2} \cdot \sigma_c \quad (4)$$

Where, m and s are the constant of rock nature, relating to the rock mass structure and can be referred relevant literature ;

σ_c is the uniaxial compressive strength of rock block, MP_a ;

γ is the average weight density of soil for overlying strata, MN/m^3 , $\gamma=0.020$ soil on value overlying strata, $\gamma=0.027$ rock mass on Overlying Strata, $\gamma=0.025$ overlying strata.

λ is side pressure coefficient, $\lambda = \frac{\mu}{1-\mu}$

Assuming that the rock mass is an ideal elastic-plasticity body , so the stress in rock stratum can be calculated by the formula (4) when the critical depth is more than the depth of H_{cr} , and so :

$$\sigma_z = rh$$

$$\sigma_x = \sigma_y = \sigma_z + \frac{1}{2}m\sigma_c - \sqrt{m\sigma_c\sigma_z + \frac{1}{4}m^2\sigma_c^2 + s\sigma_c^2}$$

$$(h > H_{cr}) \quad (5)$$

2) Tectonic stress field

1) elastic state

When the tectonic stress is small, all strata are in normal elastic state. Because the rock is isotropic , the expression of the in-situ stress in the rock strata was simplified as

$$\sigma_v = rh$$

$$\sigma_H = \lambda\sigma_v + \sigma_T = \frac{\nu}{1-\nu}\sigma_v + \sigma_T \quad (6)$$

$$\sigma_h = \lambda\sigma_v + \lambda\sigma_T = \lambda(\sigma_v + \sigma_T)$$

σ_v is the horizontal direction stress ,it is approximately equal to rh in the tectonic stress field , showed according to the experiment results at home and abroad ;

σ_H is the horizontal maximum stresses, σ_h is the horizontal minimum stresses ;

λ is lateral pressure coefficient ;

σ_T is horizontal tectonic stress.

2) elastic-plastic state

In the construction of the stress field of mining area, when σ_T is large enough, soft rock maybe enter into the natural plastic state, but its deep part is still in elastic state. Therefore, the stress calculation method of the shallow stress(plastic) and the deep stress(elastic) should be different which will be calculated separately.

σ_1 and σ_2 is in the horizontal direction, σ_3 is in the vertical direction. so

$$\sigma_3 = rH_{cr}$$

$$\sigma_1 = r\sigma_3 + \sigma_T \quad (7)$$

Meanwhile, stress at this point should be calculated according to Hoek-Brown criterion which is the formula (3). When formula (7) is used in formula (3), the calculation formula of H_{cr} can be obtained.

$$H_{cr} = \frac{1}{\gamma} \frac{2\sigma_T(1-\lambda) + m\sigma_c - \sqrt{[2\sigma_T(1-\lambda) + m\sigma_c]^2 - 4(1-\lambda)^2(\sigma_T^2 - s\sigma_c^2)}}{2(1-\lambda)^2} \quad (8)$$

The condition of $H_{cr}=0$ can be obtained by formula (8);

$$2\sigma_T(1-\lambda) + m\sigma_c = \sqrt{[2\sigma_T(1-\lambda) + m\sigma_c]^2 - 4(1-\lambda)^2(\sigma_T^2 - s\sigma_c^2)}$$

So

$$4(1-\lambda)^2(\sigma_T^2 - s\sigma_c^2) = 0 \quad (9)$$

$$\sigma_T = \sqrt{s}\sigma_c$$

Rock mass is elastic when $\sigma_T < \sqrt{s}\sigma_c$, stress in rock strata can be calculated by the formula (6), when $\sigma_T = \sqrt{s}\sigma_c$, rock mass enter into critical state which is from elastic state into the plastic state, and the depth of plastic zone is zero (on the surface). When $\sigma_T > \sqrt{s}\sigma_c$, if the shallow rock mass entered into plastic yield, firstly, the depth of the plastic zone should be calculated by the formula (8). If the depth of the rock is more than the depth of H_{cr} , the rock stress should be calculated according to the formula (6). If the depth of the rock is less than the depth of H_{cr} , the rock stress should be calculated according to the following formula (assuming the rock mass as an ideal elastic-plastic material):

$$\sigma_1 = \lambda\sigma_3 + \sigma_T \quad \sigma_3 = rh$$

$$\sigma_1 = \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^2}$$

$$\sigma_2 = \lambda(\sigma_3 + \sigma_T) \quad (10)$$

When the formula of in-situ stress is deducted as above, the rock is considered as isotropic, and the formula is suitable for both the approximately level strata and nearly vertical layered strata, but r and λ should be changed and the particular way is same as the station of self-weight stress field type.

When estimating the value of the rock in-situ stress in type tectonic stress field, the key is to calculate the tectonic stress σ_T which can only be gotten by measuring the stress of a little bit hard strata. If the stress of the hard rock strata in the mining area has been measured, the stress of other stratas (to be estimated strata) can be obtained in a simple way as following and nearly horizontal layered elastic rocks and nearly vertical layered rocks which to be discussed are divided into two cases.

The elastic modulus of hard strata E_1 , Poisson ratio ν_1 and the measured stress σ_{H1} , σ_{h1} , σ_{v1} are known, and the rock elastic modulus E_2 and Poisson ratio ν_2 of rock in-situ stress are calculated. The strata is assumed as elastic rock strata.

For the approximately level strata, then:

$$\varepsilon_1 = \frac{1}{E_1} [\sigma_{H1} - \nu_1(\sigma_{h1} + \sigma_{v1})]$$

$$\varepsilon_2 = \frac{1}{E_2} [\sigma_{H2} - \nu_2(\sigma_{h2} + \sigma_{v2})] \quad (11)$$

The strata in a small plot of the same mine which can be approximately regarded that they have the same tectonic deformation, that is $\varepsilon_1 = \varepsilon_2$, then

$$\frac{E_1}{E_2} = \frac{\sigma_{H1} - \nu_1(\sigma_{h1} + \sigma_{v1})}{\sigma_{H2} - \nu_2(\sigma_{h2} + \sigma_{v2})} \quad (12)$$

At the same time we can get that

$$\sigma_{v2} = \gamma_2 h_2 \quad (13)$$

$$\sigma_{H2} = \sigma_{T2} + \frac{\nu_2}{1-\nu_2} \sigma_{v2} \quad (14)$$

$$\sigma_{h2} = \frac{\nu_2}{1-\nu_2} (\sigma_{v2} + \sigma_{T2}) \quad (15)$$

There are four unknown numbers σ_{v2} , σ_{H2} , σ_{h2} , σ_{T2} as well as four equations (12)-(15), thus they can be solved. In this way, the in-situ stress value of soft rock and other strata can be calculated according to the measured in-situ stress value of the hard rock strata.

B) Estimation method of in-situ stress value near the point of measurement

The in-situ stress at an elevation of 696 m (below the second spot about 100 m) can be estimated by the in-situ stress of 2 spots which has been measured.

At an elevation of 696 m, the elastic modulus and Poisson's ratio of the rock are estimated by the elastic modulus of rock mass at the measuring spots. $E = 12 \text{ GPa}$, $\nu = 0.31$.

According to the experimental results, $\sigma_1 > \sigma_v$ in both the two measured spots, therefore, it can be seen that the type of Liuhuanguo coal mine is the tectonic stress field. The in-situ stress at an elevation of 696 m of Liuhuanguo coal mine is estimated by the first spot and the second spot. The results are as follows:

The data is used in the formula (12)–(15) by the first spot, thus we can get:

$$\begin{cases} \frac{14}{12} = \frac{7.19 - 0.33(3.20 + 5.86)}{\sigma_{H2} - 0.28(\sigma_{h2} + \sigma_{v2})} \\ \sigma_{v2} = 0.025 \times (1160 - 696) \\ \sigma_{H2} = \sigma_{T2} + \frac{0.28}{1-0.28} \cdot \sigma_{v2} \\ \sigma_{h2} = \frac{0.28}{1-0.28} \cdot (\sigma_{v2} + \sigma_{T2}) \end{cases}$$

Solution of the above equations, $\sigma_{v2} = 11.6$, $\sigma_{T2} = 4$,

$\sigma_{H2} = 8.5$, $\sigma_{h2} = 6$.

Due to $\sigma_{T2} = 4$, $\sqrt{s}\sigma_c = 28 \times 0.3 = 8.4$, $\sigma_{T2} < \sqrt{s}\sigma_c$, the rock mass is elastic. The stress in the rock strata can be calculated by formula (6), thus the values of in-situ stress at an

elevation of 696 m are $\sigma_{v2}=11.6$, $\sigma_{T2}=4$, $\sigma_{H2}=8.5$, $\sigma_{h2}=6$.

Based on the same equations, the values of in-situ stress at the elevation 696 m are estimated by the second spot are: $\sigma_{v2}=11.6$, $\sigma_{T2}=4.356$, $\sigma_{H2}=8.856$, $\sigma_{h2}=6.199$.

Finally, the weighted mean of the two estimated values are regarded as the final estimated value of in-situ stress. The elevation of the second spot is closer to the point estimated (at an elevation of 696 m), so the weight of in-situ stress value is

6 and the weight coefficient is $\frac{3}{5}$. The weight of in-situ stress

value which is calculated by the first spot is 4 and the weight coefficient is $\frac{2}{5}$. $\sigma = \frac{2}{5}\sigma_1 + \frac{3}{5}\sigma_2$ (σ_1 is the value of in-situ

stress which is calculated by the first spot, σ_2 is the value of in-situ stress which is calculated by the second spot)

The final value of in-situ stress at the elevation of 696 m are: $\sigma_{v2}=11.6$, $\sigma_{T2}=4.2$, $\sigma_{H2}=8.7$, $\sigma_{h2}=6.1$.

IV. SUGGESTIONS ON THE ARRANGEMENT OF MINING AREA TUNNEL

The crossheading strike of the working face of W (9-15) 102 is 235° which consistent with the direction of the

maximum horizontal principal stress force, but the open-off cut is vertical with that. In practice, it is found that the bursts occurred frequently during tunneling the crosseheading and the open-off cut, especially during tunneling the open-off cut. Due to the roadway under high pressure, the roof broke easily and is difficult to be controlled.

Based on the test results of in-situ stress, it is suggested that when arranging the roadway, the azimuth angle of the roadway is controlled as far as possible between $220^\circ \sim 250^\circ$.

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