IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Analysis of Deep Ground Stress in -830m~-1030m Northwest Jiaodong of a Mine

To cite this article: Guilin Li *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **237** 032127

IOP Conf. Series: Earth and Environmental Science **237** (2019) 032127 doi:10.1088/1755-1315/237/3/032127

Analysis of Deep Ground Stress in -830m~-1030m Northwest Jiaodong of a Mine

Li Guilin[1*], Wang Jianbo[1], Zhao jie[1], Cheng Li[1], Wang Xi[1]

[1]Deep Well Mining Lab Branch of Shandong Gold Mining Technology Co.,Ltd., Yantai 264000,China

[*]Corresponding author's e-mail: liguilinstd@126.com

Abstract. At present, Northwest Jiaodong of a mine has entered the operating environment of -1030m, which is one of the few gold mines in China that have entered the kilo meter operation. The preliminary exploration shows that the mine reserves are abundant and the grade is ideal at about - 1500m. However, with the continuous deepening of the ore-body to the deep, the underground pressure is increasing, and the mining difficulty is also increasing, which brings a lot of difficulties to the deep mining. Many problems need to be studied urgently, and the measurement and calculation of ground stress becomes one of the urgent problems in deep mining. Through accurate measurement of in-situ stress, the design and exploitation of deep wells can be carried out scientifically, so as to avoid the harm caused by pressure enhancement.

1. Introduction

Northwest Jiaodong of a Mine is one of the largest underground gold mines in China, and its output once ranked first in China. Located in the northwest Jiaodong of Shandong province, this mine is a typical altered rock type deposit with complex occurrence conditions.The mine body extends 360 meters, controls the slope depth to exceed 1200 meters, and the average dip Angle reaches 29 degrees. There are a series of shortcomings, such as great difficulty in mining and difficulty in expanding the mining scale[1,2,3].

After more than 40 years of continuous mining, the middle section of its production has reached the level of -830m, and the stage of -930m and -1030m have started the construction of transport roadway and the work of exploring and penetrating the vein. It is one of the few underground mines with a mining depth of more than 1000 meters in China [4,5]. With the continuous extension of ore body to the depth, engineering geology and ore body occurrence conditions become more and more complex, and surrounding rock pressure significantly increases, and the probability of natural environmental disasters such as surrounding rock collapse, roof overhanging, slabs and rock burst also increases significantly, which brings serious harm to the safety production of the mining area.

With the development of mining industry, the scientific research of underground stress field measurement equipment and calculation theory has been developed rapidly, and the application technology is becoming more and more mature. At present, more than 30 countries have carried out geostress survey in the world. Some famous research institutes in the world now has scientific theory [6] detection equipment and technology, such as the Swedish rock stress measurement laboratory (RSM), the United States Carnegie institution, scientific and industrial research council (CSIR) in South Africa, the former Soviet union mine geological mechanics and mine surveying science research institute, institute of civil engineering (LNEC), Portugal, etc., and the applications in the aspects of technology research in China is relatively lag. However, with the demand of deep mining, especially in recent years, the research and development of underground deep mining technology and theory, the detection and application theory of deep mining stress field will also get rapid development.

The main task of underground stress field detection in deep mines is to measure the magnitude, direction and variation law of underground stress.We should find out the activity intensity and mode of the ground stress and find out the direction of the main stress and the basic law of its change with depth.These tasks will solve a series of rock mechanics problems faced by deep mine construction. It will avoid various disasters and achieve scientific and reasonable support and construction[7,8].

2. Selection of Ground Stress Measurement Points

In this paper, the geological mining environmental conditions of -830m ~ -1030m in Northwest Jiaodong of a Mine were studied. According to different construction conditions and environments of -830m, -930m and -1030m respectively, the ground stress measurement points of the original underground rock were explored, and the measurement points with construction requirements and representative lithology under mining conditions were selected.

2.1. The principle of point selection

The basic principles of geostress measurement of the original rock are as follows.

- Typicality: The selection of measurement points should be based on the structure of underground rock, and the site with construction requirements and lithological characteristics should be selected, and the nearby tunnel project under construction should be avoided. The stress field, unstable area and interference source should be avoided to ensure the authenticity of the protolithic stress.
- Integrity: Escape fault area; Avoid data impact caused by fault.
- Lithological requirements: The rock mass around the measuring point should be homogeneous and complete, and the borehole should be located in this kind of rock , and the integrity of coring and the reliability of ground stress measurement results are verified.
- Construction requirements: The measuring points should be arranged in the ore body or the surrounding area; The measuring point should be as close as possible to the designed roadway; Construction should meet the future lithological requirements; The ground stress field where the roadway is designed should be representative.

2.2 Determination of ground stress measurement points

The purpose of the measurement of the Protolith stress is to obtain the magnitude and direction of the stress field of the Protolith stress around the mining area, so as to further provide decision-making for the production of the mining area, such as mining design, ground pressure management and lane support.

In the process of the selection of measuring points, according to the basic principle of the selection of measuring points, the location of six representative geostress measuring points were determined. The stress concentration areas should be avoided, such as the bend, fork and bend of roadway and stope, fault, rock fracture zone and fault development zone, and the selected measuring points should be far away from large goaf and adit. The table 1 shows the real data.

Table 1. Measuring point arrangement and drilling parameters.

Boring number	burial depth(m)	measuring point position	dip angle of hole	azimuthal angle of hole
-830m-1#	860	165 lanes in the middle section of -830m	-1.8°	182°
-830m -2#	860	165 lines in the middle section of -830m	-2.5°	166°
-895m -3#	925	-895m slope road sandstone adit	-3.6°	245°
-940m -4#	970	-940m ramp transfer tunnel	-5.6°	246°

-1030m -5#	1060	-1030m north end of the middle drift	5.7°	94°
-1030m -6#	1060	179 lanes in the middle section of -1030m	1.6°	269°

This paper stipulates that the dip Angle of drilling is "+" and the elevation Angle is "-".

3. Testing of Ground Stress

According to the geological structural characteristics and lithological conditions of -830m, -930m and -1030m underground in gold mine, the Swedish LUT stress tester was used to measure the stress of rock mass.

Therefore, according to the stress-strain relationship and the measured rock elastic constant, if the elastic strain of the hole wall is measured, the rock mass stress can be solved.

According to elastic recovery strain and elastic constant of rock, rock mass stress is calculated. Firstly, the elastic recovery strain of 12 strain gauges pasted on the pore wall of rock mass was measured to calculate the six original rock stress components at this point, and the main stress was calculated from these six stress components in the original rock.

Since the stress component $\sigma_r, \sigma_\theta, \sigma_z, \tau_{r\theta}, \tau_{\theta z}, \tau_{zr0}$ in the cylindrical coordinate system has the following relationship with the stress component in the cartesian coordinate system:

$$
\begin{aligned}
\sigma_\theta &= \frac{\sigma_x+\sigma_y}{2}\left[1+\left(\frac{a}{r}\right)^2\right]+\frac{\sigma_x-\sigma_y}{2}\left[1+3\left(\frac{a}{r}\right)^4\right]\cos 2\theta-\tau_{xy}\left[1+3\left(\frac{a}{r}\right)^4\right]\sin 2\theta \\
\tau_{r\theta} &= \frac{\sigma_x-\sigma_y}{2}\left[1+2\left(\frac{a}{r}\right)^2-3\left(\frac{a}{r}\right)^4\right]\sin 2\theta+\tau_{xy}\left[1+2\left(\frac{a}{r}\right)^2-3\left(\frac{a}{r}\right)^4\right]\sin 2\theta \\
\tau_{z'} &= -\mu\left[2\left(\sigma_x-\sigma_y\right)\left(\frac{a}{r}\right)^2\cos 2\theta+4\tau_{xy}\left(\frac{a}{r}\right)^2\sin 2\theta\right]+\sigma_z \\
\tau_{\theta z'} &= \left(-\tau_{zx}\sin\theta+\tau_{yz}\cos\theta\right)\left[1+\left(\frac{a}{r}\right)^2\right] \\
\tau_{rz'} &= \left(\tau_{zx}\cos\theta+\tau_{yz}\sin\theta\right)\left[1-\left(\frac{a}{r}\right)^2\right]
\end{aligned} \tag{1}
$$

Where, r, θ, z' and x, y, z are cylindrical coordinates and cartesian coordinates respectively; a is radius, r is the distance from the calculate point to the center of the borehole, θ is pitch angle of the calculate point, μ is Poisson's ratio.

When $r=a$ at the hole wall, the above formula becomes equation (2).

$$
\begin{aligned}
&\sigma_r = \tau_{r\theta} = \tau_{rz'} = 0 \\
&\sigma_\theta = \left(\sigma_x+\sigma_y\right)-2\left(\sigma_x-\sigma_y\right)\cos 2\theta-\tau_{xy}\sin 2\theta \\
&\sigma_{z'} = -\mu\left[2\left(\sigma_x-\sigma_y\right)\cos 2\theta+4\tau_{xy}\sin 2\theta\right]+\sigma_z \\
&\sigma_{\theta z'} = 2\tau_{yz}\cos\theta-2\tau_{zx}\sin\theta
\end{aligned} \tag{2}
$$

The right-hand side of the equation (2) contains six unknown stress components in rectangular coordinates.The left-hand side of the equation can be measured by strain relief method.But six unknown stresses cannot be determined by three equations.Therefore, when measuring strain, each point should measure enough strain (greater than or equal to 6) to determine the six stress components in rectangular coordinates.

The probe of LUT rock triaxial strain geostress measuring instrument is equipped with 3 strain gauge pistons in luluol Sweden university. Each piston surface is pasted with 4 strain gauges, forming a strain flower, so 12 strain values can be measured at a time.

The three strain flowers are distributed 270, 30 and 150 degrees along the Z axis (α), and the angle between the four strain flowers on each piston and the Z axis (β) is 90, 45, 0, 135 degrees, respectively.

In this arrangement, eight constants $a_1, a_2, a_3 \cdots a_8$ are obtained by changing the relationship between pore wall strain and rock mass stress.

$$\begin{aligned}
a_1 &= \left(3-2\mu^2\right)/E \\
a_2 &= -\mu/E \\
a_3 &= \left(1-2\mu^2\right)/E \\
a_4 &= 1/E \\
a_5 &= (1-\mu)\left(3+2\mu\right)/2E \\
a_6 &= (1-\mu)/2E \\
a_7 &= (1-\mu)\left(1+2\mu\right)/2E \\
a_8 &= (1+\mu)/2E
\end{aligned} \tag{3}$$

Where the elastic modulus E and poisson's ratio μ values can be measured on-site by a biaxial test device in the formula. Unloading curve was selected in the elastic range, and the elastic modulus and poisson of each measuring point were obtained from the experimental results of confining pressure ratio determination, as shown in table 2.

Table 2. Elastic modulus (E) and Poisson's ratio (υ) values of each measuring point.

Boring number	Elastic modulus E/MPa	Poisson's ratio(υ)
-830m-1#	59781	0.17
-830m-2#	58712	0.19
-895m-3#	56232	0.25
-940m-4#	60340	0.18
-1030m-5#	57191	0.16
-1030m-6#	60955	0.20

4. Calculation of Ground Stress

Through calculation, the geostress components, the magnitude and direction of three-dimensional principal stress, the maximum horizontal principal stress, the minimum horizontal principal stress and the vertical principal stress of six geostress measurement points in the deep position are listed in tables 3,4,5 respectively.

Table 3. Calculation results of ground stress components at each measuring point.

Boring number	σ_x (MPa)	σ_y (MPa)	σ_z (MPa)	τ_{xy} (MPa)	τ_{yz} (MPa)	τ_{zx} (MPa)
-830m-1#	15.248	32.33	21.345	-3.732	-0.571	1.826
-830m -2#	14.529	32.373	21.688	-0.127	-1.692	1.494
-895m -3#	20.246	34.990	25.079	2.133	-2.778	-2.021
-940m -4#	22.367	36.770	26.919	-0.504	-2.169	-3.010
-1030m -5#	17.048	41.920	28.234	-2.195	-2.658	6.559
-1030m -6#	25.430	40.684	29.128	-4.281	-3.017	0.687

Table 4. Three-dimensional principal stress calculation results of each measuring point.

Boring number	burial depth (m)	maximum principal stress σ1			intermediate principal stress σ2			minimum principal stress σ3		
		Size (MPa)	orientation (°)	dip angle (°)	Size (MPa)	orienta-tion (°)	dip angle (°)	size (MPa)	orientation (°)	dip angle (°)
-830m-1#	860	33.18	282.21	4.56	21.66	31.11	76.16	14.08	191.15	13.03
-830m-2#	860	32.64	271.15	8.93	21.72	38.22	75.39	14.23	179.32	11.47
-895m-3#	925	36.14	260.34	15.55	24.75	131.31	66.15	19.43	355.41	17.61
-940m-4#	970	37.23	269.47	12.03	28.09	158.20	59.57	20.74	5.84	27.49
-1030m-5#	1060	42.90	278.40	13.75	30.31	35.22	61.54	13.99	182.03	24.40
-1030m-6#	1060	42.52	284.58	13.01	28.42	110.56	76.93	24.31	14.89	1.32

Table 5. Maximum and minimum horizontal principal stress and vertical principal stress calculation results of each measuring point.

Boring number	burial depth(m)	$\sigma_{h\max}$ (MPa)	σ_{hmix} (MPa)	σ_z (MPa)
-830m-1#	860	33.110	14.468	21.345
-830m-2#	860	32.374	14.528	21.688
-895m-3#	925	35.292	19.944	25.079
-940m-4#	970	36.788	22.349	26.919
-1030m-5#	1060	42.112	16.856	28.234
-1030m-6#	1060	41.803	24.311	29.128

Based on the linear regression calculation of the data in table 3, 4, 5, the distribution law of the geostress field is obtained as follows in the deep mining area.

$$\sigma_{h.\max} = -7.11 + 0.0461H \tag{4}$$

$$\sigma_{h.\min} = -9.34 + 0.0294H \tag{5}$$

$$\sigma_v = 0.0266H \tag{6}$$

5. Conclusions

In view of the underground geological structure characteristics of -830m, -930m and -1030m in Northwest Jiaodong of a Certain, six ground stress test points were selected, and the regression curves of the maximum horizontal main stress, the minimum horizontal main stress and the vertical main stress changing with depth were obtained through accurate measurement and calculation. As can be seen from figure 1, the deep geostress field of this mine is mainly composed of horizontal tectonic stress, and the maximum principal stress is roughly in the east-west direction, so it is summarized as follows.

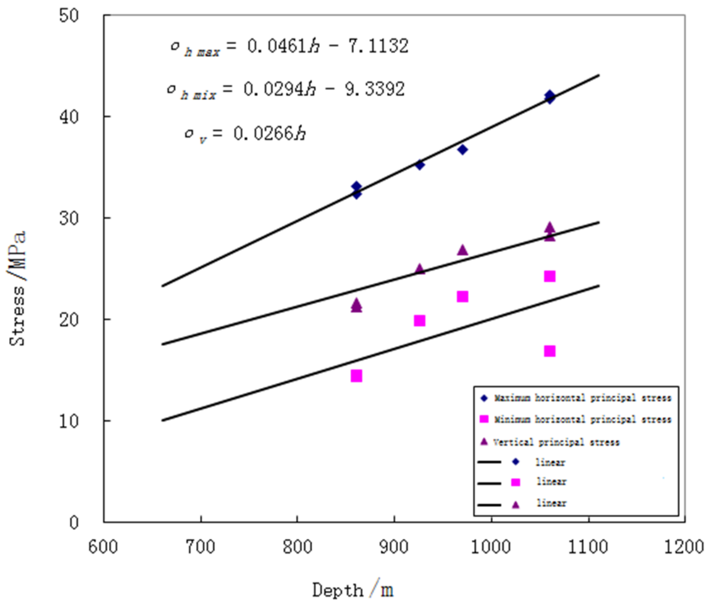

Figure 1. Regression curve of maximum horizontal principal stress, minimum horizontal principal stress and vertical principal stress with depth.

- In the process of deep mining, when building the Chambers, tunnels and other underground structures near the measuring points, the roadway strike and the axial direction of the Chambers should be consistent with the direction of the maximum principal stress as far as possible, or as close as possible to the direction of the maximum principal stress, so as to reduce the cost of roadway support in the production process and ensure the safety of production.

- The deep mining area is dominated by horizontal tectonic stress, so it is easy to cause floor heave, slab and caving of roadway. Reasonable support should be provided in time when the roadway excavation direction is perpendicular to the maximum principal stress. At the same time, due to the disturbance of environmental dynamics on stress and the release of energy, rock burst disaster is easily induced under the action of high ground stress.

References

[1] Li Changhong, Cai Meifeng, Qiao Lan, et al. (1999) Analysis of causes of cave-in of a mainore-pass and its prevention measures. China Mining, 8(6): 37-39.
[2] Cai Meifeng, Qiao Lan, Li Changhong. (2000) Measuring Results And Regularity of in situ stress in Xincheng Gold Mine. Nonferrous Metals, 52(3): 1-6.
[3] CAI M F,QIAO L,LI C, et al. (1995) Application of an improved hollow inclusion technique for in situ stress measurement in Xincheng goldmine, China, International Journal of Rock Mechanics and Mining Science, 32(4): 435-739.
[4] CAI Meifeng, LIU Weidong ,LI Yuan. (2010) In-situ stress measurement at deep position of Linglong gold mine and distribution law of in-situ stress field in mine area. Chinese Journal of Rock Mechanics and Engineer-ing, 29(2): 227-233.
[5] Liu huanxin, Wang jianbo, Zhao jie, et al. (2018) Practice on ground pressure control in deep mining of large-scale gold mines in Jiaodong. Gold, 9(39): 39-44.
[6] CAI Meifeng. (2000) Principle and techniques of in situ stress measurement. Beijing: Science Press.
[7] CAI Meifeng, HE Manchao, LIU Dongyan.Rock (2013) mechanics and engineering. Beijing: Science Press.
[8] WANG Lianjie, PAN Lizhou, LIAO Chunting,et al. (1991) In situ stress measurement and its application. Bei-jing: Geological Publishing House.