Study On The Law Of Ground Strata Subsidence And Movement Induced By Caving Mining Of Slowly Inclined Large And Thick Ore Body

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Abstract. Taking the Western District of Chengchao Iron Mine as engineering background, based on the GPS monitoring data of nearly 8 years and the record of the ground surface movement, the law of ground strata subsidence and movement is studied. The studies have shown that the surface movement caused by underground mining has the characteristics of time delay and displacement angle development has the law of jumping. The strata movement caused by mining is divided into the stage of overlying strata collapse and the collapse stage of surrounding rock to goaf. In the first stage, the vertical stress plays a leading role and rock failure is shown as a regular barrel collapse. In the second stage, horizontal tectonic stress plays a leading role and the collapse mechanism of rock strata can be explained by the cantilever beam theory. According to the mechanism of strata movement analysis, strata movement of Chengchao Iron is divided into six regions, which respectively included vertical subsidence area, toppling sliding zone, dumping area, deformation zone, cumulative deformation area and undisturbed zone. The results of this paper can provide a theoretical basis for the surface movement prediction of caving mining in similar metal mine.

1 Introduction

The surface deformation caused by underground mining is a complicated process and related to various factors. No matter what kind of mining method is used, the key factors affecting the surface deformation are all the collapse and movement of the rock strata^[1-3]. Therefore, it is very important to master the collapse and movement of rock strata. At present, the research of surface movement in coal mining has achieved rich results^[4-6]. However, because of the irregularities of ore body shape, complexity of metallogenic regularity, the rock collapse and migration law of metal mine are very different from those of coal mine^[7].

Chengchao Iron Mine is one of the most famous metal mines of China. The sublevel caving method has been used since it was put into production in 1958. So far, there has been a serious surface subsidence which affected the normal production of mine.

In recent years, many scholars have carried out the research on the ground surface movement of metal mines and a lot of valuable research results were achieved. Huang Pinglu^[8] considered that the release of horizontal tectonic stress induced by mining have an important effect on surface deformation and rock movement of the east zone of Chengchao iron mine. The study of Zhu Jiaqiao^[9] showed that the east zone of Chengchao iron

mine was controlled by the geological structure in NWW direction, the damage type of ground surface is tensile failure and there were a series of parallel, high and steep dip tensile cracks. Based on the analysis of the deformation characteristics of deep rock mass, the deformation of deep rock mass is divided into the zone of fractured rock mass, the transition zone, the deformation zone and the undisturbed zone by Chen Congxin^[10-11]; Bai Weiwei^[12] divided the deformation and failure of rock into four stages: formation stage of underground gob, the collapse stage of rock at the top of gob, unloading deformation stage and movement of rock mass. Song Weidong^[13], Du Cuifeng^[14], Cao Shuai^[15] et al. took study in detail on the caving mechanism of overlying strata. Although the research on the deformation law of ground surface and deep rock mass of Chengchao iron mine has achieved many useful results, the correlation between underground mining and rock movement and the mechanism of surface movement are still not clear.

Because of the deformation of rock mass caused by underground mining is a time-dependent variation process. Therefore, the deformation of rock mass is not the same in different mining level. Therefore, on the basis of monitoring results of surface horizontal displacement and deep rock mass deformation and destructed form in recent 8 years, the strata collapse and moving regularity induced by caving mining is studied,

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then the mechanism of ground collapse and expansion is discussed. The results can provide a reference for the similar metal mines.

2 Engineering background

2.1 Engineering geology

Chengchao Iron Mine is divided into east and west two mining area by the No. 15 geological exploration line. The rock of footwall of mine is mainly granite, which is well. The rock of hanging wall far away from the orebody is hornstone and the rock near the orebody is mainly diorite. Metamorphic belt composed by the marble and hornstone is at the top of the ore body and exposed to the surface. There are 5 geological structures in the mine, whose directions are respectively NNW, NNE, NE, and NWW. Geo-stress measurement results show that the direction of the minimum principal stress is approximately perpendicular to the direction of the ore body. In the depth direction, the variation law of the intermediate principal stress is the same as that of the gravity. The maximum principal stress direction is N85° to 75° W, which is consistent with the trend of the ore body. The lithologic distribution is shown in Fig.1.

2.2 Present mining situation

The Western District of Chengchao Iron Mine has started to mine by sublevel caving method since 2002. The first mining level is -290m level, which was completed in July 2004. The orebody of -307.5m level started to mine in November 2002 and was completed in July 2004. The orebody of -342.5m level started to mine in July 2004 and was completed in Dec. 2006. The orebody of -358m level started to mine in Oct. 2005 and was completed in Sep. 2008. The orebody of -375.5m level started to mine in July 2007 and was completed in June 2012. The orebody of -395m level started to mine in May 2009 and the orebody of -410.5m level started to mine in March 2012. The mining boundary of different levels is shown in Fig. 2

Fig.1. lithologic distribution

Fig.2. Chart of Mining progress of above -375m level

3 Statistics and analysis of ground deformation monitoring data

3.1 Layout of monitoring points

The ground deformation was monitored by GPS technique and the vertical displacement of the important measuring point is measured by GPS technique combined with Leica DNA03 digital level. The number of GPS and digital level monitor points are separately 131 and 101. The part of GPS monitor points is shown in Fig. 3.

Fig.3. Layout diagram of a part of GPS

3.2 Monitoring data analysis

Based on the ground deformation monitoring data between Dec. 2007 and Sep. 2013, the ground surface moving line is drawn and as shown in Fig.4

Fig.4. Distribution of moving line from Dec. 2007 to Sep. 2013

It can be seen from that, after Sep. 2010, the ground surface moving line extended obviously to the direction of new auxiliary shaft. For a more detailed study, section

I through the new auxiliary shaft was selected to study which is shown in Fig.4. The section line is approximately perpendicular to the direction of the ore body which is used to study the impact of mining on the new auxiliary shaft.

Fig.5. Displacement angle of section I

The new auxiliary mining area located in the footwall of mine. The distribution of displacement angles on the section I are shown in Fig.5. It can be seen from Fig.5 that the horizontal distance from ground surface movement boundary to new auxiliary shaft is 17m in Sep. 2013. From Dec. 2007 to Sep. 2013, the horizontal expansion distance of ground surface movement range of footwall and hanging wall are separately 188m and 59m. The expansion rate of movement range of footwall is far greater than that of hanging wall.

The curves of displacement angles of footwall and their change rate on the section I are separately shown in Fig.6 and Fig.7.

Fig.6. Displacement angle curve of footwall

Fig.7. Change rate of displacement angle of footwall

It can be seen from Fig.6 and Fig.7 that the law of displacement angles change has the following characteristics.

① In Figure 5, when the bottom of gob is located at -360m, the displacement angle reduced by 6.29° during the period from Dec. 2008 to Dec. 2009 and reduced by 3.5° during the period from Dec. 2009 to Sep. 2013. It can be seen that when the bottom of gob is fixed, the displacement angles decrease with time, and change rate decreases with time within a short time and the reducing is most significant in the first half year.

② As shown in Figure 6, the change rate of the mobile angle in June 2009 was 4.9° per half year while reduced to 0.15° per half year in Dec. 2010. But the change rate increased to 0.75° per half year in the Dec. 2011. Then the change rate decreased with time and reduced to 0.10° per half year but increased rapidly to 0.81° per year during the next half year. It can be seen from the above analysis that the change rate of displacement angle showed the change of the wave shape, and the change period is about 1~1.5 years. The various cycle is about 1~1.5 years.

We can also get that the influence of underground mining on the ground surface movement is complex and time delay. After the completion of a certain level of mining, the movement range will not immediately expand which caused the displacement angles immediately increase. But the displacement angles decrease rapidly in the next half year.

As shown in Fig. 8, it is the distribution of the ratio of horizontal and vertical deformation of footwall on the section I. The list of data is shown in Table 1.

Fig.8. Ratios of horizontal displacement and vertical displacement of section

Table 1. List of horizontal displacement U and vertical displacement W

Monitor points	U/cm	W/cm	U/W	Monitor points	U/cm	W/cm	U/W
LG2	283.4	134.5	2.1	LC99	108.1	86.4	1.3
E02	12.2	3.3	3.7	SZ20	505.0	451.5	1.1

It can be seen from Fig.8 that the ratio of horizontal and vertical deformation reduces with the increase of the distance from the gob boundary before the monitor point E03. The ratio of the monitor point E03 is 2.48. Then the ratio increases grandly. It can be seen from Table 1 that the ratio of horizontal and vertical deformation near the gob boundary is greater than that of far away from the gob boundary which means that there is mainly horizontal deformation near the gob boundary.

As shown in Fig.9, it is the curve of cumulative horizontal deformation of monitor points LG2 and E04. Then point LG2 is located on the sloping land and the point E04 is located on the flat land.

It can be got from Fig.3 that the distance from the points LG2 and E04 to gob boundary are 142m and 134m respectively which means that the ground surface deformation of point E04 should be greater than that of point LG2. We can get from Fig.9 that the cumulative horizontal deformation of point LG2 is smaller than that of point E04 before the Oct. 2008. But after that, the cumulative horizontal deformation of point LG2 begin to be greater than that of point E04. In April 2012, the cumulative horizontal deformation of points LG2 and E04 are 293.1 cm and 192.8 cm. The cumulative horizontal deformation of point LG2 is greater than that of point E04 by 100.3 cm. The reason for this is that there are no cracks on the ground surface in the early stage of mining which result in the unbalanced displacement of the areas where the points LG2 and E04 are located is smaller. And then, with the expansion of the horizontal and vertical range of gob, the cracks begin to appear on the ground surface which caused the unbalance displacement become greater. At this time, the horizontal stress of downhill direction caused by the topography is released which coupled with the horizontal stress caused by the mining result in the increase of surface horizontal displacement and the increase is related to the slope shape, the relative position of gob and the structure face characteristics. When the rock mass in the downhill direction is bent and broken which caused the increase of the horizontal displacement, the displacement of point LG2 begins to be greater than that of point E04 in March 2011.

Fig.9. Cumulative horizontal displacement curves of monitoring points LG2 and E04

4 Analysis of strata collapse and expansion

Engineering geological of mining area and the characters of rock mass joint and cracks, the geological mechanics model of Chengchao iron mine is established and as shown in Fig.10.

Fig.10. The geological mechanics model of Chengchao Iron

According to the deformation monitoring data and macro damage survey data, the strata movement and deformation of west area of Cheng Chao iron mine can be divided into 2 stages. In the first stage, the overlying strata above the gob destroyed and extended to the surface, which caused the collapse of surface. Then the collapse pits will appear on the ground surface and expanded outward in the second stage.

4.1 The first stage

In the initial stage of underground mining, the gob gradually expanded along with the underground mining. Under the action of gravity, there was a small amount of falling of the overlying rock mass of the gob. Under the action of horizontal tectonic stress, the stress balance arch was formed in the overlying rock mass of gob which temporarily ensured the stability of the upper rock mass. The ground surface would not appear the obvious displacement. When the gob span increases to a certain degree, the stress balance arch cannot be formed which will cause the continuous fall of overlying rock mass, then the ground surface will collapse.

The collapse process of surrounding rock was monitored by the method of closed loop in drilling from 2004 to 2006. The curve of collapse of surrounding rock is shown in Fig.11.

It can be seen from Fig.10 that the failure and collapse of roof rock mass is intermittent and jumping. The collapse of the surrounding rock is not a continuous process but has the obvious characteristic of jumping. As shown in Fig.10, the curve has obvious platform stage. The collapse process can be divided into the following stages: ①slow collapse; ②collapse arrest; ③sudden collapse; ④collapse arrest; ⑤sudden collapse and ⑥ surface subsidence.

Fig.11. The curve of collapse of surrounding rock

In order to get the collapse process of overlying strata in the mining process, similar material model test was used to study. Based on the study results, the collapse range and cracking trace of overlying strata is shown in Fig.12.

Fig.12. Sketch map of rock caving process

The exposed area of roof is relatively small, and the collapse development of the surrounding rock is uniform, which is the initial stage. When the -342.5 m level is mined, due to the increase of exposed area of roof, a large area collapse of overlying strata will appear, then the surrounding rock begins to collapse quickly to the ground surface.

4.2 The second stage

After the appearance of collapse pit on the ground surface, the large-scale release of horizontal tectonic stress will cause the tensile deformation of surrounding rock and the fracture rock mass will dump to inside direction of collapse pit. Therefore, the movement law of rock mass is studied by using the theory of cantilever beam.

The rock mass of footwall is cut into cantilever beam model by the joints of NE and NWW direction. The force diagrams of cantilever beam are shown in Fig.12.

Before the appearance of collapse on the ground surface, the rock arm is in equilibrium of forces in the horizontal direction (As shown in Fig.13(a)). After the appearance of collapse, the horizontal stress at the inner side of the collapse pit reduced (As shown in Fig.13 (b)) which caused the unbalanced force of rock arm, then the rock arm began to inclined to collapse pit inside. After the toppling deformation of rock arm in the horizontal direction increased to critical value, the internal tensile stress will reach the allowable tensile strength or the horizontal stress will be greater than the shear strength, which caused the fracture failure of rock arm (As shown

in Fig.13 (c)).

In the first stage, the increase of the span and the height of the underground gob could cause the deformation and collapse of the ground surface. But the ground surface deformation was still in a certain range and did not transmitted to the area far from the gob. The underground mining is the main reason for the ground surface deformation in this stage and the gravity is the main driving force of collapse.

Fig.13. Schematic of failure process of cantilever beam

After entering the second stage, under the action of release and extrusion of the horizontal tectonic stress GX parallel to the strike of the ore bodies, the arch expansion deformation occurred in the surrounding rock mass of collapse pit. At the same time, the release of the horizontal tectonic stress GY which is perpendicular to the strike of the ore body caused the tension crack deformation of rock mass towards the collapse pit inside. The ground surface deformation was dominated by horizontal tectonic stress and the ground surface deformation is mainly horizontal movement, the vertical displacement is relatively small. But as time goes by, the ratio of vertical displacement and horizontal displacement increased.

4.3 Zoning of rock mass and its feature

According to the analysis of the strata movement mechanism, the rock strata can be divided into six areas based on the deformation state of rock mass, which is shown in Fig.14.

Fig.14. Zoning map of strata movement of Chengchao Iron Mine

(1)The vertical subsidence area is located above the mined area and mainly formed in the first stage of the

strata movement. The area size is expanded with the expansion of the gob.

(2)The second area is called topple over area which is the range of dumping and break after the formation of the vertical subsidence area. In this area, the rock pillar begins to slip to the gob and the dislocation tension cracks appears on the ground surface which is shown in Fig.15.

Fig.15. Ground fissure of mine road

(3)The third area is dumping area, in which the rock mass leaned because of the dumping and break of rock mass in the second area. However, there was no break in this area and open cracks appeared on the ground surface. The area was the main area of ground surface crack propagation. In this area, there were often larger transfixion cracks. The cracks in the transport tunnel are shown in Figure 16.

Fig.16. Crack of transport tunnel

(4)The fourth area is deformation area, in which the tilt deformation occurred in rock mass due to the release of the horizontal tectonic stress and micro-fractures appeared on the ground surface.

(5)The fifth and sixth areas are separately deformation accumulation area and unaffected area. The underground mining had less effect on these areas and there was no obvious deformation.

The six areas of rock movement and deformation will be extended downward and all around along with the mining.

5 Conclusions

Based on the GPS monitoring data of nearly 8 years and the record of the ground surface movement, the law of ground strata subsidence and movement is studied. The following conclusions are obtained.

(1)The surface movement caused by underground mining has the characteristics of time delay and displacement angle development has the law of jumping. When the bottom of gob is fixed, the displacement angles

decrease with time, and change rate decreases with time within a short time and the reducing is most significant in the first half year. The change rate of displacement angle showed the change of the wave shape, and the change period is about 1~1.5 years. The various cycle is about 1~1.5 years.

(2)According to the deformation monitoring data and macro damage survey data, the strata movement and deformation of west area of Cheng Chao iron mine can be divided into 2 stages. In the first stage, the vertical stress plays a leading role and the rock caving shows a regular barrel collapse. In the second stage, the horizontal tectonic stress plays a leading role and The movement and failure of rock strata can be described by the cantilever beam theory.

(3)According to the analysis of the strata movement mechanism, the rock strata can be divided into six areas which are separately vertical subsidence area, topple over area, dumping area, deformation area, deformation accumulation area and unaffected area.

(4)The results of this paper can provide a theoretical basis for the surface movement prediction of caving mining in similar metal mine.

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