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PRELIMINARY STUDIES ON DEFORMATION CHARACTERISTICS AND PREDICTION OF SURFACE MOVEMENT IN LOESS GULLY REGION****

1. Introduction

Loess gully region are mainly distributed in the middle reaches of Yellow River and the loess plateau region (including Shanxi, Shaanxi and Gansu provinces). The special mechanical properties of loess and fragmented terrain make surface deformation and movement caused by mining damage unusual features of the law [1, 2, 3]. Based on the surface movement observational data on the Huangling mine, as well as the geological conditions on Weibei mine, this paper analysis on surface movement and deformation characteristics as well as mining damage in the loess hilly areas.

2. Geological conditions of observation area

Huangling coal mine is located in the southern loess plateau of northern Shaanxi, which is a medium cut loess plateau area. A lot of vertical and horizontal valley are its main features, plateau surface fragmented, cutting depth is 100–200 m, ditch elevation is 920–1000 m, plateau surface elevation is about 1200 m, the highest point is up to 1463.8 m. Overlying loess layer thickness is 80–130 m above the bedrock thickness, which is about 150m; coal seam thickness is 2.5–3 m, inclination is 3–5° and the seam beds regularly. The length of mining face is 200 m, face advance is 10–16 m every day. In order to obtain detailed information

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on surface movement, the four layout of survey lines were establish above No 302 and 303 working areas, two survey lines Z and D; two along strike survey lines A and C along dip. Observing lines layout is shown in figure 1.

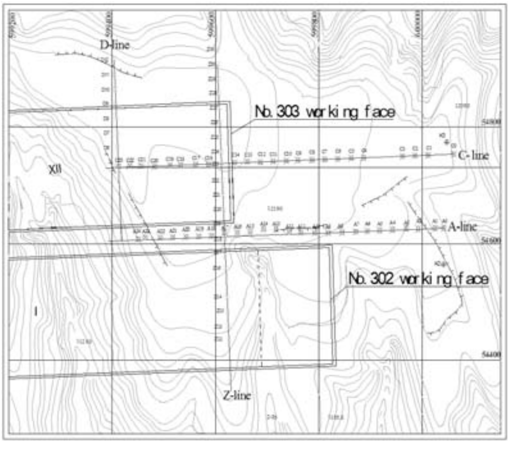

Fig. 1. Layout of survey lines in No 302 and 303 working faces

3. Analysis on surface displacement and deformation characteristics

3.1. The characteristics of displacement angle

Mountain partial loads expand the scope of surface movement, and mainly occurred in the soil. The results decrease of the angle of draw so measured strike is 56°, upward angle of the draw is 53.5. Loess with development vertical cracks made discontinuous surface movement and the basin of subsidence becomes narrow, angle of critical deformation increases in this case, the measured angle of critical deformation is 70° [4]. When the longwall face rate is high, a bedrock movement and deformation are transmitted to the soil layer within a short time, so the angle of advance influence is up to 85°. Obviously loess and trench terrains on the surface of loess gully region have a greater impact on the rockmass movement and deformation angle values.

TABLE 1
Displacement Angle of Strata in 302 and 303 face

Name of angle	strike	downward	upward
Angle of draw	56°	53.5°	53.5°
Angle of critical deformation	70°	70°	67.5°
Angle of break	82.8°	82.0°	82.0°
Angle of full subsidence	74.5°	—	—
The angle of advance influence	85°	—	—

3.2. The prediction of movement and deformation

According to observations maximum subsidence is 2294 mm, maximum horizontal movement is up to 917 mm, maximum horizontal deformation is 30.1 mm/m. Surface deformations come violently and there is a quite big difference between strike and dip of the face. The value of surface movement and deformation made a sudden increase or decrease on some place of surface for the special gully terrain. Development vertical fracture in the loss of surface is the important reasons for partial variation of surface movement and deformation [5]. The Z-line subsidence profile is shown in figure 2, the curves of subsidence vary in upwards and downwards parts consecutively. The value of horizontal deformation affected by the hill and it's slide increases apparently on downhill direction. In figure 3 Z16 and Z17 points' horizontal deformation are greater than 20 mm/m. In the process of observing cracks in the river trough and the front face were found which is about 100–200 mm width and the height of stage cracks is 150–600 mm; about 3–4 cracks spacing 8–10 m were found in boundary of mined-out area. These cracks continued to expand over time, maximum width is up to 600 mm. The distance of cracks in front of the face is up to 45–72 m, when mining is away from the crack of 3–5 days, the crack reached the maximum separation, then gradually have been closed.

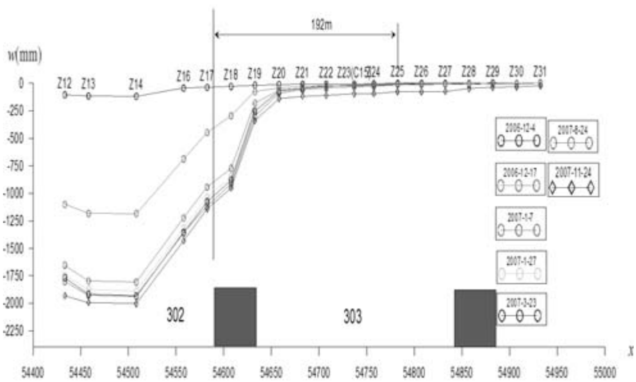

Fig. 2. Curves of surface subsidence of Z survey line

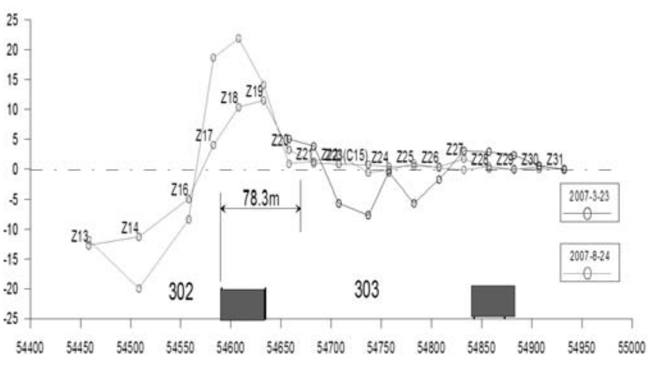

Fig. 3. Curves of surface horizontal movement of Z survey line

TABLE 2
The maximum surface subsidence and deformation in 302 and 303 face

Movement and deformation	Z-line (strike)	A-line (dip)	C-line (dip)
Subsidence [mm]	2294	1174	2094
Slop [mm/m]	24.4	21	13.9
Displacement [mm]	893	917	802
Curvature [10^{-6}/m]	0.65	1.27	0.19
Horizontal strain [mm/m]	25.1	30.1	8.3

3.3. The prediction of surface movement parameters

The parameters of probability surface deformation were integral obtained from observations results. Subsidence factor is 0.854; horizontal movement factor is 0.38; propagation angle of extraction is 67º. The thickness of collapsible loess is more than 100 m, loess weight produced by the compression deformation and collapsible sink result subsidence factor increases. Gully leads to the surface displacement changes suddenly and to ditch slope of the trend, meanwhile, horizontal movement factor become larger. Overburden thickness is small and lithology built soft rocks, so a smaller turning point offset is only 0.08*H* (*H* is the mining depth). Other parameters are shown in table 3.

TABLE 3
The maximum surface subsidence and deformation in 302 and 303 face

name of observation line	subsidence factor η	horizontal movement factor b	tangent of main effect angle $\tan\beta$	the displacement distance of inflection point d	propagation angle of extraction θ_0
Z-line	0.882	0.39	2.98	—	—
C-line	0.825	0.383	1.87	19.78	67º
Average	0.854	0.387	2.425	19.78	67º

3.4. Analysis of surface dynamic movement and deformation

As the stability of overlying strata is poor, particularly nature of bedrock and soil are quite different, the surface dynamic movement and deformation after mining is dramatic high. From figure 4 we can see initial period is 18–20 days, active period is 107–112 days and weakening period is 198–202 days. Surface point subsidence mainly happend in the active period, when occurs 97% total subsidence. The surface largest subsidence speed is up to 82 mm/d.

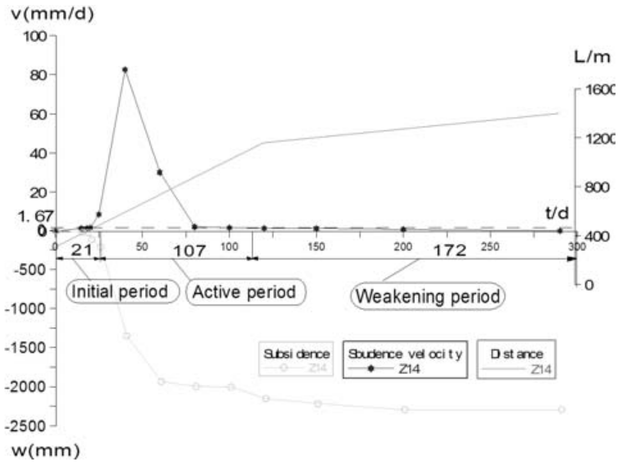

Fig. 4. Shape of the surface subsidence and subsidence velocity curve

4. Mechanism analysis of overlying strata movement and deformation

From the character of surface deformation, collapsible loess and mountain gully terrain are the main reason of surface unconventional movement and deformation. Additionally the thickness of bedrock in the area is small and the main strata is soft rock. When the movement and deformation of overlying strata passed to the contact of bedrock and the loose less layer, the transmission of ground pressure is in forms of non-uniform because the mechanical properties of bedrock and loose layer are quite different. The surface soil layer divides into the blocks, blocks move and the horizontal movements are the highest. The horizontal movement along sliding slopes leads to the cracks releasing concentrated deformation and continue to form a temporary balance [6]. Strata movement and deformation encountered in the natural structure of loess with development original vertical fracture, discontinuous movement and deformation occur in loess. The total subsidence depends on horizontal movement and horizontal deformation. The mountain rocks unit weight make the surface points sliding along a slip surface rather than to the mined-out area. It can further intensified the damage of surface cracks as well as its non-continuity. According to statistics observed due to the role of the mountain, after stability the surface points still moved by 18.2 mm every month, the horizontal deformation increased by 2.5 mm/m monthly. So for loess gully region most important is not only the expected of conventional movement and deformation but also the emergence location of the step cracks and its degree of damage.

Analysis results in the loess gully of Weibei mine shows that the ratio of soil layer thickness and mining depth are the most critical factors for the surface movement and deformation. With the increasing of h/H proportion the maximum level of movement and deformation will increase. The fitting formulas are follows:

$$\varepsilon_{\max} = 1.33MKe^{2.3673\left(\frac{h}{H}\right)} \quad (1)$$

$$U_{\max} = 195.2\ln\left(\frac{h}{H}\right) + 254K \quad (2)$$

where:

M — the mining height,
K — the influence coefficient for gully (generally the value is 3–4),
h — the soil layer thickness,
H — the mining depth.

The two estimating formulas take full account of the factors of soil layer thickness and mining height, which can be more accurate to estimate movement and deformation of loess gully. Formula (2) is applicate for mining height less than 3 m. When mining height is higher, the maximum subsidence will extremely increase. Although the scope of application of estimating formulas has it's limits, we can study the mechanics of surface strata to judge the location and extent of surface cracks. More important is to give us a guide to expect movements and deformations as well as practical significance in prevention of surface cracks.

5. Conclusions

In this paper, base on the measured data, the characteristics of surface movement were summarized in loess gully region. The main features include larger angle of critical deformation and small angle of the draw, therefore range of movement boundaries become smaller; subsidence factor is greater; the curves of horizontal movement and deformation show discontinuous and mutagenicity. Dynamic surface subsidence in the active period reached 97% of the total subsidence with very intense surface movements. After the detailed analysis we can know the loess and surface topography of trench slope, which have a great impact on surface movement and deformation. Specifically the mountain body unit weight bring slippage along the structural surface of strata, which influence the width of surface cracks further increase, leading to surface fluctuations in the distribution of the abnormal movement and deformation. Finally from analysis of a large number of measured data two expected formulas about maximum of horizontal strain and displacement are obtained which take into account the mining depth and thickness of coal seams. It is helpful to expected movement and deformation in loess gully region and it is certainly significant to mining damage research.

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