

Research on the Surface Movement Law and The Inversion of Surface Subsidence Prediction Parameters of Repeated Mining in Shallow Buried Deep Coal Seams

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Abstract: In order to explore the surface deformation law of multi-coal seam mining under repeated mining conditions, and deepen the understanding of the estimated parameters of surface subsidence in the mining area, in order to provide a technical reference for the "Mining under three" pressed coal mining in the mining area. Based on the measured data of the 22208 working face of the live chicken and rabbit mine; Two methods, curve fitting method and surface fitting method, were used to obtain the estimated parameters of surface subsidence; The results show that under the condition of repeated mining, the protective coal pillars left after the excavation of the upper coal will hinder the surface settlement of the lower coal mining, and the surface subsidence curve will be lifted. During the mining process of the working face, it is affected by repeated mining, which leads to the breaking of the overlying rock layer and the activation and development of fractures, so that the maximum subsidence of the surface exceeds the actual mining thickness of the coal seam of 22208. Comparing the fitting results of curve fitting and surface fitting, it is found that the accuracy of the fitting parameters of the inclined sinking coefficient, the main influence tangent of the tendency, the offset distance of the trend inflection point and the offset distance of the inclined left inflection point obtained by the surface fitting method are improved by 3.9%, 5.6%, 4% and 3.1%, respectively, and the accuracy of the fitting parameters of the inclined horizontal movement coefficient is significantly improved to 13.2%, which is not affected by the layout of the observation line, which is more in line with the actual needs of the project. The research results can provide a technical reference for repeated mining in shallow buried deep multi-coal seam mining areas.

Keywords: Repetitive mining, Laws of surface movement, surface fitting.

1. Introduction

In China's coal-rich regions such as Shanxi, Inner Mongolia, Shaanxi, and Xinjiang, with the increasing depletion of near-surface recoverable coal resources, the future development trend of coal resources is gradually shifting to multi-coal seam mining, typical examples include the Shendong mining area and the Huainan mining area, where the geological characteristics of these areas are significant, and the coal seams are often distributed in multiple layers^[1]. According to the field monitoring data, compared with the mining of a single coal seam, the repeated mining activities of multiple coal seams significantly aggravate the degree of surface subsidence and deformation, resulting in a steeper subsidence basin morphology^[2], which causes more serious damage to the surface landscape and building structure. Compared with the initial mining, the surface movement characteristics under repeated mining conditions show significant differences^[3], which needs further research.

Many scholars have studied the law of repeated mining: Yubo Zhou^[4] systematically analyzed the law of surface subsidence of backfill mining through a combination of laboratory tests, mechanical analysis and numerical simulation. Based on the measured data of a mine, Pengjiang Deng^[5] used FLAC3D numerical software to simulate the horizontal displacement and the movement law of surface subsidence under different mining widths, retention widths, and other conditions, and finally used the orthogonal test method to determine the influence of different influencing factors on surface subsidence. Based on the measured rock strata of a mine, Yijia Zhu et al.^[6] used FLAC3D software to

simulate the mining process of multi-coal seam and multi-working face, and analyzed the movement law of rock formation and surface subsidence induced by multi-coal seam mining. The analysis results show that in the process of multi-coal seam mining, the mining of the new working face will have an impact on the stabilized goaf and increase the degree of surface subsidence. Xinhua Ren^[7] used numerical simulation method to explore the influence of mountain topography on surface movement and deformation according to the 1311 working face of a panel of a mine in Qinshui coalfield, and the analysis results showed that due to the change of the mining width and coal pillar size of the 1311 working face, the fracture area of the overlying rock layer continued to be compacted and closed, and finally reflected to the conclusion that the subsidence continued to increase to the surface. Yaguang Bai^[8] simulated the mining of 1# and 2# coal seams in a coal mine in Shaanxi by using the UDEC numerical simulation method, and finally obtained the overburden movement and fracture evolution law under the condition of repeated mining of shallow buried coal seams in this area. In order to study the influence of repeated mining on the upper goaf and rock strata of a working face, Bohui Xun et al.^[9] analyzed the deformation characteristics of the overlying rock under repeated mining by numerical calculation method, which provided theoretical support for the rational mining of the working face. Chuangye Wang et al.^[10] took a mine under Shendong Group as the engineering background, used the similarity theory to carry out similar simulation experiments, and analyzed the development of overburden fractures by comparing the changes of single-layer coal mining and repeated mining in terms of mine pressure appearance and mobile damage, and obtained the

characteristic effects of repeated mining, mine pressure and fracture evolution of coal seams in close proximity, which provided a certain theoretical basis for engineering practice. Chunyi Li et al. [11] proposed to use the surface fitting method to obtain the probability integral prediction parameters under the rectangular working face from a three-dimensional perspective, which is more in line with the actual needs of engineering. Hongzhong Xu et al. [12] used the logistic growth model to represent the time function of surface subsidence, and proposed the idea of using a nonlinear regression method to estimate the model parameters on the basis of the three-stage sum method, and verified the applicability of this parameter method by using the measured subsidence value of a certain point on a certain ore section.

Through the analysis of these literatures, it can be seen that in the past, the analysis of surface deformation characteristics mainly focused on the study of surface deformation characteristics under non-repetitive mining conditions, and compared with them, the surface deformation characteristics under repeated mining conditions may be more complex, but the research on surface deformation characteristics under repetitive mining conditions is relatively lacking and needs to be further strengthened. Based on this, the author first studied the surface deformation characteristics under repeated mining conditions based on the geological mining conditions of the 22208 working face of the live Jitu mine in Daliuta Coal Mine. Then, two methods, nonlinear curve fitting and surface fitting, were used to obtain and compare the prediction parameters of surface subsidence. Accordingly, the rock migration law under the condition of repeated mining of multiple coal seams is revealed.

2. Overview of the Study Area

Liuta Coal Mine (hereinafter referred to as "Liuta Coal Mine") belongs to Daliuta Coal Mine, which is one of the two super-large modern mines belonging to Daliuta Coal Mine of Shendong Coal Group, and is currently the backbone mine of Shendong Coal Group. The live chicken and rabbit mine is located on the Shaanxi side of the border between Shaanxi Province and Inner Mongolia Autonomous Region, and is under the jurisdiction of Daliuta Town, Shenmu City. The geographical coordinates of the well field are: east longitude 110°7'50"~110°16'28", north latitude 39°11'27"~39°16'49".

The mining area is rich in resources, stable coal seams, shallow burial depth, low gas content, simple hydrogeological conditions and superior natural conditions.

3. Analysis of Measured Data of Surface Movement and Deformation

In order to be able to analyze the movement of the land surface as accurately as possible, the H-line was selected to draw the movement curve of the land subsidence. According to the monitoring data of the H observation line above the 22208 working face, the dynamic subsidence curve of the 22208 working face was drawn. The dynamic sinking curve is shown in Figure 1.

It can be seen from Figure 1 that the upper coal seam is bifurcated into two parts at the H40 monitoring point, and with the continuous advancement of the 22208 working face, the subsidence curve appears wavy distribution, and the bottom of the surface subsidence curve is lifted near the remaining coal pillar, and the reason for this is that the 22208 working face belongs to repeated mining, and after the 22208 working face is mined below the protective coal pillar, the coal pillar is mined below the coal seam and the overall sinking and compacting is carried out. When the subsidence area is stabilized, this part of the coal pillar will hinder the subsidence of the surface above, resulting in the surface subsidence value above the coal pillar being less than the surface subsidence value of the non-coal pillar on both sides, so the subsidence curve will be lifted at the position of the coal pillar. In addition, it can be seen from Figure 1 that the first wave peak is at the monitoring point H20 and the second wave peak is at the monitoring point H45. According to the subsidence data of the monitoring point of the 22208 working face, the maximum subsidence value of H20 is 4460mm, and the maximum subsidence value of H45 is 4921mm. It can be seen from the geological mining conditions of the working face that the average mining thickness of the 22208 working face is 4.2m, but the maximum subsidence value in the measured area far exceeds the mining thickness, which is due to the fact that in the process of repeated mining in the study area, the interval rock layer is broken and the overlying rock layer fissures are activated and developed, so that the maximum surface subsidence exceeds the actual mining thickness of the 22208 coal seam.

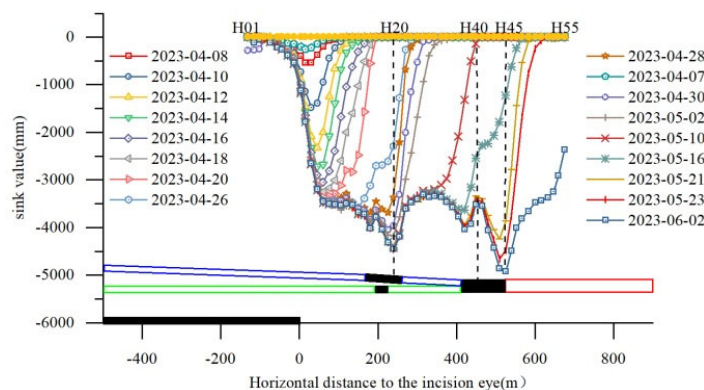


Figure 1. Dynamic sink curves

4. Determination of Prediction Parameters for Surface Subsidence

The probability integration method is one of the most

mature methods for calculating the estimated parameters of land surface subsidence. This method believes that in the process of surface subsidence, the continuity of rock layers is destroyed, the original relationship between rock masses

changes, and the rock masses are separated from each other and move relatively. The probability integration method integrates the probability density function in the entire mining area through the superposition principle to obtain the subsidence curve of the mining area. Based on the principle of small deformation and volume invariance, the horizontal movement function of the element is derived by using the element sinking function, and then the horizontal movement curve of the mining area is obtained by the integration method. According to the derivative relationship, the calculation formulas of horizontal deformation, surface subsidence and curvature can be obtained. In practical applications, the probabilistic integration method usually uses four calculation parameters by integrating parameters and clarifying their physical significance: sinking coefficient, horizontal movement coefficient, main influence tangent and inflection point offset.

4.1. Curve fitting method parameters are obtained

4.1.1. The estimated parameters of surface movement of the 22208 working face are obtained along strike with semi-infinite mining

As can be seen from the dynamic subsidence curve in Figure 1, the subsidence curve of the last observation (2023-06-02) has indicated that the 22208 working face has reached full mining. It can be seen from the geological mining conditions of the working face that the 22208 working face is still mining along the strike direction after the last observation, which makes it impossible to determine the actual mining width of the working face. Therefore, in order to facilitate the calculation of the estimated parameters of the surface movement of the working face, it is regarded as semi-infinite mining. Semi-infinite mining means that the coal seam on the right side of the mining boundary has been fully mined, and the coal seam on the left side of the mining boundary has been fully retained. The sinking and horizontal movement models

used are shown in Eq. (1) and Eq. (2).

$$W^0(x) = \frac{W_0}{2} \left[\operatorname{erf} \left(\frac{\sqrt{\pi}}{r} (x-s) \right) + 1 \right] \quad (1)$$

$$U^0(x) = bW_0 \exp \left(-\pi \frac{(x-s)^2}{r^2} \right) \quad (2)$$

where: x is the horizontal distance from the mining boundary on the left, W_0 is the maximum surface subsidence value, and the formula is $W_0 = mq \cos \alpha$: m is the thickness of the coal seam of the 22208 working face, q is the surface subsidence coefficient, and the inclination angle of the coal seam is α ; s is the inflection point offset distance, b is the horizontal movement coefficient, r is the main influence radius, and the formula is $r = H / \tan \beta$, where: H is the mining depth, and $\tan \beta$ is the main influence tangent. Bringing the coal seam thickness of 4.2 m and the average mining depth of 147 m into equation (1) can invert the expected parameters of strike surface subsidence in the study area. The fitting results are shown in Figure 2 and Table 1. As shown in Fig. 2, the fitting results of the strike subsidence in the area of H20~H45 are inconsistent with the measured data, and it can be seen from the surface subsidence curve of Fig. 1 that the subsidence curve is wave-shaped because this area is affected by the coal pillar of the upper working face, and the probability integral method is based on the random medium theory, which has limitations in dealing with the complex rock structure of "layer, block and scatter", and fails to fully consider the actual environment of coal mining, so there is a situation that some fitting results are inconsistent with the actual situation. In view of the influence of this part of the coal pillar on the surface movement and deformation, equation (2) is no longer used for the fitting of the strike horizontal movement curve.

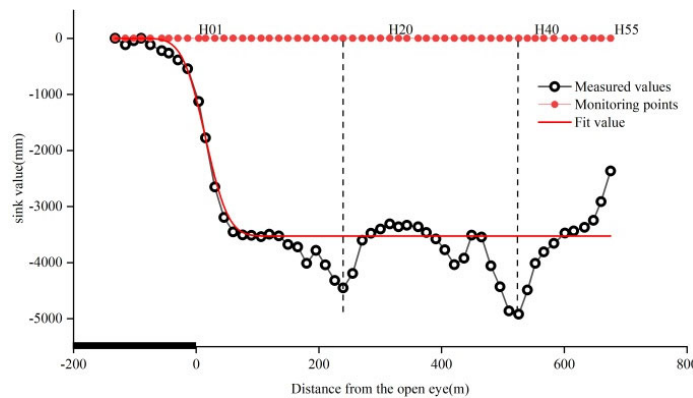


Figure 2. Trending subsidence fitting results

Table 1. 22208 working face trend fitting parameter table

parameter	q_1	$\tan \beta_1$	s/m
Fit value	0.855	2.1	14.4

4.1.2. The 22208 working face tends to be limited in mining, and the surface movement prediction parameters are calculated

According to the mining conditions of the working face, the inclination angle of the coal seam is 1° , which can be

regarded as a horizontal coal seam, so when the expected parameters of inclined surface movement are obtained, the cotangent value of the mining propagation influence angle is regarded as 0 and the direction of the upper and lower mountains is no longer distinguished. For finite mining, the subsidence and horizontal movement models used are shown in Equations (3) and (4).

$$W^0(y) = \frac{W_0}{2} \left[\operatorname{erf} \left(\frac{\sqrt{\pi}}{r} (y-s_1) \right) - \operatorname{erf} \left(\frac{\sqrt{\pi}}{r} (y-D+s_2) \right) \right] \quad (3)$$

$$U^0(y) = bW_0 \left[\exp\left(-\pi \frac{(y-s_1)^2}{r^2}\right) - \exp\left(-\pi \frac{(y-D+s_2)^2}{r^2}\right) \right] \quad (4)$$

where: D is the mining width of the inclined coal seam; S1 and S2 are inclined to the left and right, respectively. The rest

of the parameters are the same as above. The inclined mining width of 330 m, the coal seam thickness of 4.2 m and the average mining depth of 147 m are brought into equations (3) and (4) to invert the predicted parameters of inclined surface settlement in the study area, and the fitting results are shown in Fig. 3 , Fig. 4 and Table 2.

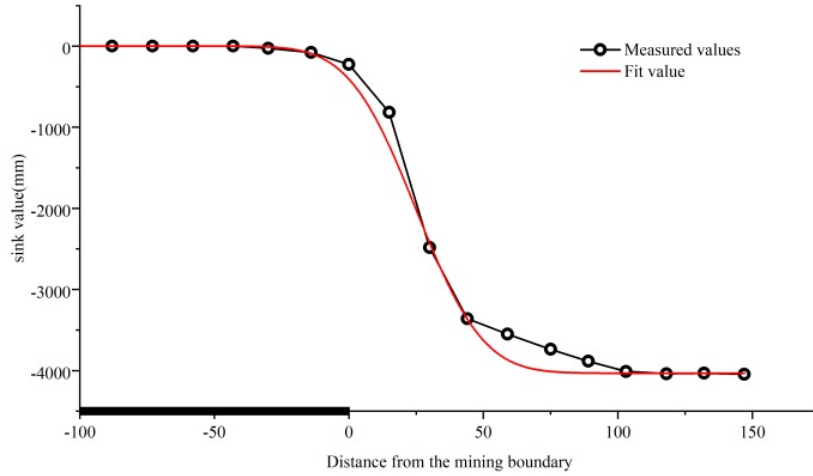


Figure 3. Inclined to sink curve fitting

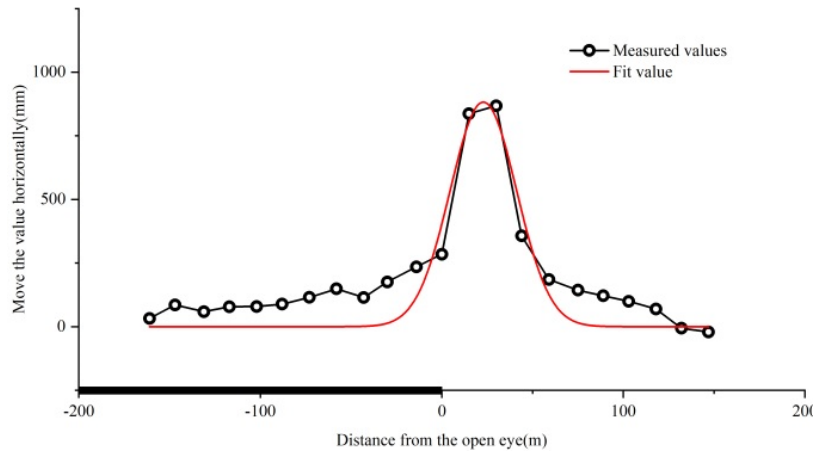


Figure 4. Tendency to move horizontally curve fitting

Table 2. 22208 working face tendency fitting parameter table

parameter	q_2	b	s_1/m	s_2/m	$\tan\beta_2$
Fit value	0.932	0.217	16.5	16	3.4

4.2. Surface fitting method parameters are obtained

(1) Sinking function model

$$W(x, y) = \frac{W^0(x)W^0(y)}{W_0} \quad (5)$$

Substituting Eq. (1) and Eq. (3) into Eq. (5) is a surface fitting sinking function model.

(2) Horizontal movement model

$$U(x, y, \theta) = \frac{1}{W_0} [U^0(x)W^0(y) \cos \theta + U^0(y)W^0(x) \sin \theta] \quad (6)$$

Because the magnitude of the horizontal movement value is direction-dependent, the fit direction needs to be included

in the horizontal movement model. Substituting equations (1), (2), (3), and (4) into equation (6), that is, the horizontal movement function model, if the observation station data is complete, through the models (5) and (6), the predicted parameters that can be obtained include: q_1 (trend sinking coefficient), q_2 (trend horizontal movement coefficient), b_1 (trend horizontal movement coefficient), b_2 (tendency horizontal movement coefficient), $\tan\beta_1$ (trend main influence angle tangent), s (trend inflection point offset distance), s_1 (inclination left inflection point offset distance), s_2 (inclination right inflection point offset distance).

According to the established models (5) and (6), the parameters of arbitrarily shaped observation stations (including mesh, line and scatter) can be optimized. In order to overcome the disadvantage that the initial value of a given parameter deviates too much from the true value and causes the iterative calculation to not converge, combined with the idea of Taylor's formula expansion method, the iterative mode is improved by using the Broyden algorithm, and the prediction parameters of surface movement are obtained, as shown in Fig. 5, Fig. 6 and Table

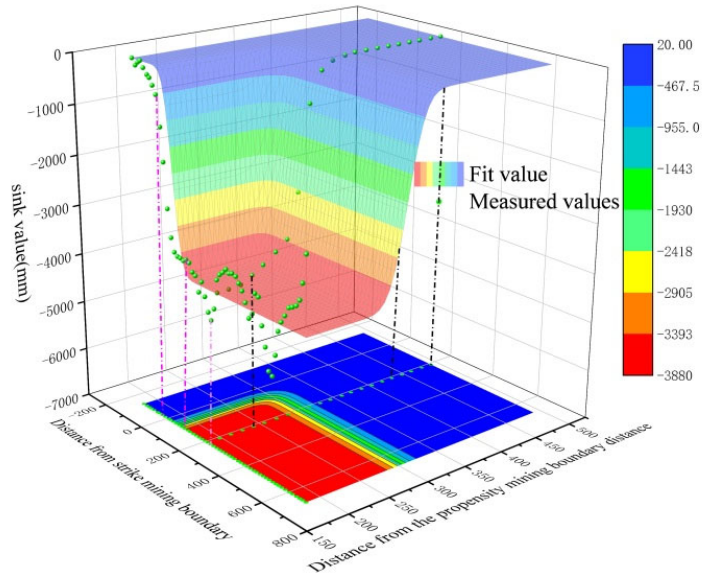


Figure 5. Measured subsidence surface fitting

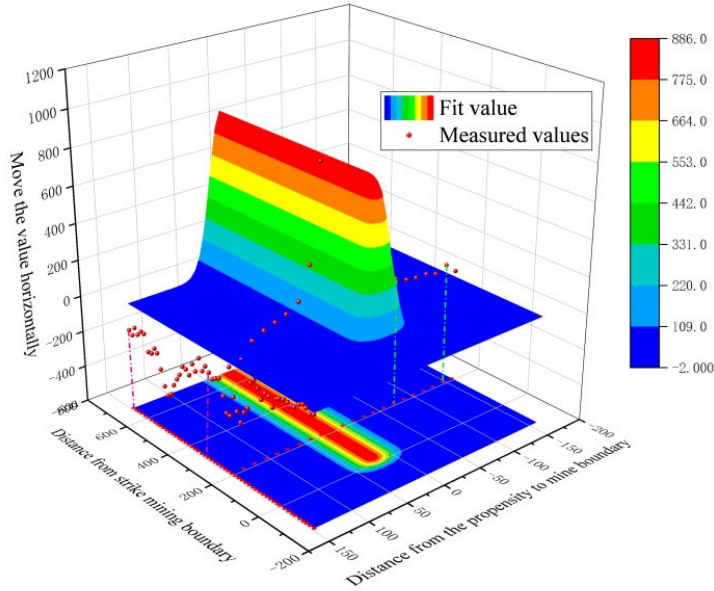


Figure 6. Measured horizontal moving surface fitting

Table 3. Fitting parameter table

	Surface fitting	curve fitting
q_1	0.842	0.855
q_2	0.97	0.932
b_1	0.37	—
b_2	0.25	0.217
$\tan\beta_1$	2.08	2.1
$\tan\beta_2$	3.6	3.4
s	15	14.4
s_1	16	16.5
s_2	16.1	16

Compared with the traditional nonlinear curve fitting method, it can be seen from Table 3 that the results obtained by the trend sinking coefficient, the main influence angle tangent of the trend and the offset distance of the right inflection point are almost the same, while the accuracy of the fitting parameters of the inclined sinking coefficient, the main

influencing tangent of the tendency, the offset distance of the trend inflection point and the offset distance of the inclined left inflection point are increased by 3.9%, 5.6%, 4% and 3.1%, respectively, and the accuracy of the fitting parameters of the inclined horizontal movement coefficient is significantly improved, reaching 13.2%. It should be pointed

out that because the inclination observation line is not laid along the inclination main section of the working face, the true predicted parameters of the inclination direction cannot be obtained only based on the observation data of the inclination observation line when the inclination nonlinear curve is fitted, and the surface fitting is not affected by the layout of the observation line.

5. Conclusion

(1) From the subsidence curve, it can be seen that the surface subsidence curve of the upper part of the coal pillar is lifted, so it is judged that the protective coal pillar left after the excavation of the upper coal will hinder the surface settlement of the lower coal mining under the condition of repeated mining. In addition, due to the influence of repeated mining, the mining of the 22208 working face leads to the breaking of the intervals of the overlying rock strata and the activation and development of fractures, so that the maximum subsidence of the surface exceeds the actual mining thickness of the 22208 coal seam.

(2) The nonlinear curve fitting method is used to obtain the predicted parameters, which only uses some of the measured values, and the error is large, and there are strict requirements for the layout of the observation line. In contrast, the nonlinear surface fitting method can not only make full use of all the measured data to obtain all the predicted parameters at one time, but also optimize the accuracy of the prediction parameters. In addition, the nonlinear surface fitting method gets rid of the limitation that the observation line is strictly arranged in accordance with the direction of the working face or tends to the main section, so that the measuring station does not affect the reference results regardless of whether it is arranged in a line, network or scattered shape, which is more in line with the actual needs of the project.

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