Principle and application of stratification transfer prediction method of mining subsidence in coal mining area

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Principle and application of stratification transfer prediction method of mining subsidence in coal mining area

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Abstract. According to the fact that surface subsidence is the result of the deformation through effect of transfer and superposition by each rock (soil) layer in the coal overburden, the paper proposed the basic principle and conditions of the stratification transfer prediction, and established a new prediction method based on transfer effects of the rocks (soil). The application result of this new method in 14021(3) workface of Panji coal mining area locates Anhui province show that not only does the stratification transfer prediction method of the mining subsidence have higher prediction accuracy in general than the probability integral method, but also improve significantly the prediction accuracy in the edge of the subsidence basin, the precision can be increased more than 80%. So, it could provide better technological support for prevention of mining subsidence in Panji coal mining area, Anhui province.

1. Introduction
A series of geological environment damage are caused by high-strength and large-scale underground mining activity in Chinese coal mining area and the mining subsidence is the most prominent. So far, mining subsidence area has run up to 8×10⁵hm² about in China and is increasing as fast as 200km²/a in the future. Not only does mining subsidence cause directly soil damage in coal mining area, but also indirectly induces geological disaster, aggravates soil erosion and damages ecological environment. Therefore, mining subsidence and its derivative geological environment damage have been the important restrictive factor for sustainable development in coal mining area. In result, prevention and control effectively of mining subsidence has become the important issue to be solved urgently.

Researching the basic law and impact factors of mining subsidence as well as scientific and accurate prediction method is the key to prevent and control mining subsidence. A lot of works have been done about the basic law and impact factors of mining subsidence by domestic and foreign scholars. Because underground mining activity is direct reason for mining subsidence occurrence and development, the influence law of mining factors on mining subsidence was attention. A lot of researches were taken on mining height, mining method, and geometric size of work face, etc. With the monitoring of mining subsidence and the deep analysis of rock mass movement observation data, it was found that the developing characteristics of mining subsidence were very different under different geological factors and same mining factors. So, studying the influence law of geological factors on mining subsidence is becoming research hotspots. Some typical research results focus on fold, fault, joint, tectonic stress, rock-soil ratio, unconsolidated layers, hardness of overburden, layered structure of overburden and so on.
Researching prediction method of mining subsidence has a development process from experience to theory \cite{4}. As the fastest growing method at theory stage, the theoretical model method has many branches \cite{5}. However, there are two shortcomings in the most of prediction method nowadays. First, lack of geological factors especially typical factors such as layered structure of overburden in the model; second, the difference in property between rock and soil layer is neglected. In result, most of prediction methods are neither accurate enough nor convenient enough to apply to practical prediction work. Focus on the problems above, the work established a new prediction method based on transfer effects of the rocks (soil) on the basis of revealing the basic law of layered structure impacting mining subsidence. The new method was test through the application in 14021(3) workface of Panji coal mining area, Anhui province. As well as, it could provide better technological support for prevention of mining subsidence in this coal mining area.

2. Stratification transfer prediction method of mining subsidence

2.1. basic principles

The layered structure of overburden in coal measures is a remarkable geological characteristic of coal occurrence. The rocks (soil) in the overburden are different in physical and mechanical properties with each other because of the difference in sedimentation, mineral composition, particle size and so on.

In result, the rocks (soil) in the overburden of coal measures could produce different shape and degree of deformation and movement caused by the same underground mining. And the different deformation and movement of the rocks (soil) construct the final shape of the surface subsidence. Therefore, the surface subsidence is the final result of transfer and superposition by the rocks (soil) in the overburden of coal measures with different deformation and movement.

According to the key strata theory of academician Qian Minggao, there are one or more hard rocks in the overburden usually, and one of them controls the deformation and movement of the whole overburden which called main key strata. So, the deformation shape of main key strata controls the effect of transfer and superposition by the rocks (soil) in the overburden.

The paper holds that, in theory, the quantity of the rock in the overburden determines the number of the transfer and superposition caused by mining disturbance. But, all kinds of key strata in overburden play a decisive role in the process of transfer and superposition actually. Therefore, the main key strata is the beginning both greatest contributor for the effect of transfer and superposition by the rocks (soil) in the overburden.

Based on the above analysis, the paper proposed the basic principle of the stratification transfer prediction method of the mining subsidence based on the layered structure of overburden, as follow:

(1) Constructing basic layering frame of overburden based on the different between rock and soil in the overburden. The soil is similar to the in-continuous medium; the rock is similar to the continuous medium. Therefore, the basic layering frame of overburden should be constructed according to this difference between soil and rock. And this work can provide help for subsequent subsidence calculation.

(2) Identifying the main key strata and calculating its subsidence displacement curve. The main key strata can be indentified using the method of academician Qian Minggao, and its subsidence displacement curve can be calculated by the displacement equation of voussoir beam \cite{6}.

(3) Correcting the subsidence coefficient. According to the effect of layered structure of overburden on the mining subsidence, the basic subsidence coefficient, which calculated using the method of Chinese standard named regulation for the construction of coal pillars and coal mining under buildings, water bodies, railways and main tunnels, can be corrected to the real subsidence coefficient.

(4) Calculating surface subsidence displacement curve. Taking the subsidence displacement curve of main key strata as boundary condition, the surface subsidence displacement curve can be calculated using probability integral method and corrected subsidence coefficient.
2.2. Assumed conditions
In order to clarify the scope of application of this new prediction method, the assumed conditions are given as follow: ① The main key strata are determined in the overburden; ② The dip angle of coal seam is generally less than 12°; ③ The properties of each rock layer are uniform; ④ Small structure, microstructure and groundwater in the overburden are not considered.

2.3. Prediction models
Taking the models of probability integral method and voussoir beam theory as the foundation, the paper constructed the stratification transfer prediction model of the mining subsidence in the trend main section of subsidence basin, the models are shown in formula (1)-(3).

\[ W(X) = q_m \cos \alpha \int_0^\infty \frac{\sigma(X)}{r} \exp\left(-\pi \frac{(\eta - X)^2}{r^2}\right) d\eta \]  
\[ \sigma(X) = 1 - \frac{1}{1 + e^{-\left(\frac{X}{A}\right)}} \]  
\[ q_n = \frac{1}{3} (q_1 + q_2 + q_0) \]  

Where \( X \) is coordinate projection to the surface subsidence curve (without considering the displacement distance of inflection point); \( q_1, q_2, q_0 \) and \( q_n \) are the final value, the basic value, the value corrected by sandstone layer coefficient and the value corrected by the average thickness of sand layers of subsidence coefficient, respectively; \( l \) is the length of fracture block in the voussoir beam; \( m \) is mining height; \( \alpha \) is dip angle of coal seam; \( L \) is length of workface; \( r \) is radius of influence.

3. Application of stratification transfer prediction method of mining subsidence in Panji coal mining area

3.1. Introduction of 14021(3) workface in Panji coal mining area
No.131 coal seam, whose average dip angle of the coal seam is 7°, with an average depth of 401m, is main coal seam in the 14021(3) workface that located western Panji coal mining area. The bedrock of No.131 coal seam is 66m thick and consists of mudstone, sandstone and sandy mudstone, covered by quaternary loose layer with 335m thick. The 14021(3) workface is 614m length and 130m width, with an average mining height of 1.918m. The mining subsidence in the trend main section of subsidence basin caused by 14021(3) workface had been observed 14 times from January 5, 1999 to May 8, 2000. The observed data are shown in Table 1.

| Coordinate | -100 | -50 | -30 | -20 | 0 | 10 | 20 | 30 |
|------------|------|-----|-----|-----|---|----|----|----|
| Value/mm   | 0    | 10  | 25  | 73  | 240 | 336 | 477 | 658 |

| Coordinate | 60 | 90 | 120 | 150 | 180 | 210 | 240 | -  |
| Value/mm   | 869 | 1141 | 1190 | 1314 | 1312 | 1324 | 1318 | -  |

3.2. Prediction parameters
The prediction parameters for probability integral method and stratification transfer method are shown in Table 2.

| Parameter name                               | Symbol | Units | Value |
|----------------------------------------------|--------|-------|-------|
| Length of fracture block in the voussoir beam | \( l \) | m     | 18    |
### 3.3. Prediction results

In order to reflect and differentiate the effect of the subsidence coefficient corrected and model refinement on prediction accuracy, the work firstly predicted the subsidence in the trend main section of subsidence basin caused by 14021(3) workface with “probability integral method$+ q_0$”, “probability integral method$+ q_s$” and “stratification transfer method$+ q_s$” respectively, and then analyzed the relationship of prediction results and measured value. The results are shown in Table 3 and Figure 1.

| Coordinate | Probability integral method$+ q_0$ | Probability integral method$+ q_s$ | Stratification transfer method$+ q_s$ |
|------------|-----------------------------------|-----------------------------------|-----------------------------------|
|            | Prediction value/mm | Absolute error/mm | Error rate/% | Prediction value/mm | Absolute error/mm | Error rate/% | Prediction value/mm | Absolute error/mm | Error rate/% |
| -100       | 11.9 | 11.9 | — | 12.8 | 12.8 | — | 0.1 | 0.1 | — |
| -50        | 60.9 | 50.9 | 509.0 | 65.6 | 55.6 | 556.0 | 5.4 | 4.6 | 46.00 |
| -30        | 104.3 | 79.3 | 317.2 | 112.3 | 87.3 | 349.2 | 28.3 | 3.3 | 13.20 |
| -20        | 133.2 | 60.2 | 82.47 | 143.5 | 70.5 | 96.58 | 61.5 | 11.5 | 15.75 |
| 0          | 207.5 | 32.5 | 13.54 | 223.4 | 16.6 | 6.92 | 232.5 | 7.5 | 3.13 |
| 10         | 253.0 | 83.0 | 24.70 | 272.5 | 63.5 | 18.90 | 382.9 | 46.9 | 13.96 |
| 20         | 304.1 | 172.9 | 36.25 | 327.6 | 149.4 | 31.32 | 553.7 | 76.7 | 16.08 |
| 30         | 360.2 | 297.8 | 45.26 | 388.0 | 270.0 | 41.03 | 714.5 | 56.5 | 8.59 |
| 60         | 551.5 | 317.5 | 36.54 | 594.0 | 275.0 | 31.65 | 1032.0 | 163.0 | 18.76 |
| 90         | 753.7 | 387.3 | 33.94 | 811.7 | 329.3 | 28.86 | 1186.0 | 45.0 | 3.94 |
| 120        | 934.5 | 255.5 | 21.47 | 1006.0 | 184.0 | 15.46 | 1268.0 | 78.0 | 6.55 |
| 150        | 1071.0 | 243.0 | 18.49 | 1154.0 | 160.0 | 12.18 | 1308.0 | 6.0 | 0.46 |
| 180        | 1158.0 | 154.0 | 11.74 | 1247.0 | 65.0 | 4.95 | 1325.0 | 13.0 | 0.99 |
| 210        | 1205.0 | 119.0 | 8.99 | 1298.0 | 26.0 | 1.96 | 1331.0 | 7.0 | 0.53 |
| 240        | 1227.0 | 91.0 | 6.90 | 1321.0 | 3.0 | 0.23 | 1333.0 | 15.0 | 1.14 |

Average error rate/% 83.32 85.37 10.65
3.4. Analysis

It is known from Table 3 and Figure.1 without observation point (-100):

(1) With probability integral method and basic value of subsidence coefficient, the maximum absolute error of measured value and prediction value is 387.3mm, minimum absolute error is 32.5mm, average absolute error is 157.05mm, and average error rate is 83.32%, respectively. With probability integral method and corrected value of subsidence coefficient, the maximum absolute error of measured value and prediction value is 329.3mm, minimum absolute error is 3.0mm, average absolute error is 117.87mm, and average error rate is 85.37%, respectively. Therefore, prediction error of the probability integral method is larger in general. The error rate of prediction value can reach 82.47-556% near the edge of goaf and rapidly decreased to less than 9% near the centre of subsidence basin. So, the prediction values become more accurate, the closer to the centre of subsidence basin. It shows that the probability integral method has high prediction accuracy near the centre of subsidence basin, but doesn’t work well near the edge.

(2) Using probability integral method and the corrected value of subsidence coefficient, the maximum and the minimum absolute error of prediction value decreased 58mm and 29.5mm respectively; the overall prediction accuracy and the average error rate increased 24.95% and 2.05% respectively, relative to the prediction value based on the basic value of subsidence coefficient. And the increase of the average error rate may be the result of the improvement of the corrected subsidence coefficient magnified the error rate near the edge of goaf. In the centre of subsidence basin nearby, the prediction accuracy of the probability integral method based on the corrected value of subsidence coefficient is obviously improved by 78.2-96.7%. Therefore, correcting subsidence coefficient can improve the prediction accuracy of the probability integral method near the centre of the subsidence basin, but the overall improvement effect is not obvious.

(3) With the stratification transfer method, the maximum absolute error of measured value and prediction value is 163.0mm, minimum absolute error is 3.3mm, average absolute error is 35.61mm, and average error rate is 10.65%, respectively. Its overall prediction accuracy is improved 77.33% and 69.79% comparing with base on the probability integral method with the basic or corrected value of subsidence coefficient respectively. Therefore, comparing with the probability integral method, the stratification transfer method has more overall prediction accuracy. Besides, the stratified transfer model not only inherits the predicted accuracy of the probability integral method near the centre of the subsidence basin and makes the error rate be about 1%, but also greatly reduces the prediction error near the edge of goaf, and the decrease is more than 80%. Accordingly, the prediction results of the stratification transfer method are closer to the measured values.
4. Conclusions
(1) According to the fact that surface subsidence is the result of the deformation through effect of transfer and superposition by each rock (soil) layer in the coal overburden, the paper proposed the basic principle and conditions of the stratification transfer prediction on the basis of revealing the basic law of layered structure impacting mining subsidence. A new prediction method based on transfer effects of the rocks (soil) was established based on the models of probability integral method and voussoir beam theory.

(2) The new method was tested through the application in 14021(3) workface of Panji coal mining area, Anhui province. The results show that, the stratified transfer model not only has the better predicted accuracy, but also greatly reduces the prediction error near the edge of goaf, and the decrease is more than 80%. Therefore, the prediction results of the stratification transfer method are closer to the measured values.

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References
[1] SONG Shijie. Study on the stratification transfer prediction method of the mining subsidence based on the key geological and mining factors, D. Xi’an: Xi’an University of Science and Technology, Xi’an, 2013.
[2] LIU Hui, DENG Kazhong, HE Chungui, et al. Surface subsidence law of filling with super-high-water material and skip mining, J. Journal of China Coal Society. 38(2013):272-276.
[3] SONG Shijie, ZHAO Xiaoguang, WANG Shuangming, et al. Influence analysis of overburden rock-soil ratio on mining subsidence in Yushen coal mining area, J. Safety in Coal Mines. 47(2016):200-204.
[4] SONG Shijie, ZHAO Xiaoguang, WANG Shuangming, et al. Analysis on influence of sandstone layer number in overburden strata upon mining subsidence and its numerical Simulation, J. Mining Safety & environmental protection. 41(2014):9-12.
[5] CUI X M, LI C Y, HU Q F, et al. Prediction of surface subsidence due to underground mining based on the zenith angle, J. International Journal of Rock Mechanics & Mining Sciences. 60(2013):246-252.
[6] XU Jialin, QIAN Minggao. Study on the influence of key strata movement on subsidence, J. Journal of China Coal Society. 25(2000):122-126.