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# Application of black box model for height prediction of the fractured zone in coal mining

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**Abstract.** The black box model is a relatively new option for nonlinear dynamic system identification. It can be used for prediction problems just based on analyzing the input and output data without considering the changes of the internal structure. In this paper, a black box model was presented to solve unconstrained overlying strata movement problems in coal mine production. Based on the black box theory, the overlying strata regional system was viewed as a "black box", and the black box model on overburden strata movement was established. Then, the rock mechanical properties and the mining thickness and mined-out section area were selected as the subject and object respectively, and the influences of coal mining on the overburden regional system were discussed. Finally, a corrected method for height prediction of the fractured zone was obtained. According to actual mine geological conditions, the measured geological data were introduced into the black box model of overlying strata movement for height calculation, and the fractured zone height was determined as 40.36 m, which was comparable to the actual height value (43.91 m) of the fractured zone detected by Double-block Leak Hunting in Drill. By comparing the calculation result and actual surface subsidence value, it can be concluded that the proposed model is adaptable for height prediction of the fractured zone.

**Keywords:** black box; overlying strata movement; fractured zone; regional system

## 1. Introduction

Coal resources are the largest energy resources in China, and account for more than 70% of the national energy production and consumption, or about 50% of the world's energy production and consumption. Coal resources reserves are rich in China and account for 13.3% of the world's total proved reserves. As the basic energy, coal is positioned at a dominated role in China all the time, and its share will still account for 50% in the energy proportion of China by 2050 (BP 2017, Sun 2014). In recent years, resources exhaustion has been aggravated with the acceleration of mining exploitation; meanwhile, the width of protected coal pillar continuously increases with the increasing exploitation depth, which wastes massive coal resources. Notably, the majority of coal

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resources in China are underwater; only Jiangsu Province, Shandong Province, Henan Province and Anhui Province have anti-water loose layer, but remain coal rock pillars up to 5 billion tons (Xu 2009). Therefore, it is very necessary to adopt proper measures in order to avoid disastrous incidents such as water inrush and sand bursting in the exploitation process. Reasonable shrinkage of anti-water coal rock pillar can relieve massive backlog of coal and improve recovery ratio of resources, which has significant meaning to coal production.

Height prediction of water flowing fractured zone is the basis and premise of shrinking anti-water coal rock pillar. At present, the most universal method of height prediction in water flowing fractured zone is Specification for Contraction, Water Body, Railway, and Main Coal Pillar and Coal Mining, which proposed the statistical empirical formula. The massive empirical formula for calculating water flowing fractured zone was based on massive actual measurement. However, empirical formula just has the coal seam thickness parameter, which can lead to large height differences between the estimated covered-rock water flowing fractured zone and the actual one. In this paper, a new method of estimating the height of water flowing fractured zone was proposed. This estimation model explicitly considered the layer thickness, the coal seam thickness and the exploitation technology conditions above vacant exploitation zone, which had good scientific value and high innovation. This model focused on the rock parameters and could deduce the elastic modulus and strength of the strata above the mined area. However, the strata movement and destruction caused by coal mining is a complex process that belongs to the nonlinear system (Zhang *et al.* 2002, Liu *et al.* 2009). Although there are numerous methods for the identification of nonlinear systems, it still requires more sophisticated approaches to achieve an accurate prediction. The most common choices include artificial neural networks (ANN) (Bahrami *et al.* 2016), local model network (LMN) (Johansen *et al.* 2000) and Gaussian process (GP) (Murray-Smith R *et al.* 1999) models. However, these models have their own disadvantages. To be specific, ANN needs a lot of data for a system description, while LMN has problems for describing the off-equilibrium regions of dynamic systems. Our work focuses on the identification of the black box nonlinear, recursive input–output models (e.g., Farina and Piroddi, 2009, 2010a, 2010b).

In the computing and engineering science, the black box (Storch 2016, Nax *et al.* 2013) is a device, system or object whose inputs and outputs (or transfer characteristics) are concerned but internal workings are ignored. Its implementation is an “opaque” (black) process. As an open system, in order to analyze some incidents by a typical “black box approach”, only the response behaviors of the system are required to infer the (unknown) box. The usual representation of this black box system is a data flow diagram centered in the box, and almost everything, e.g., a transistor, an algorithm, or the human brain, can be referred to as a black box. The black box model has been widely applied and developed in many fields, such as biosystems, accident analysis, data processing (e.g., Ažman 2007, Chung 2015, Rogstad 2013, Sun 2008, Zhang 1999 and Xia 2003). However, the black box model has not been applied to the field of coal mining, especially the height prediction of water flowing fractured zone.

The overburden movement can be seen as a “black box” system. The internal structure and the mechanism of this region are unknown, but its internal laws can be deduced through the observation of the black box “input” and “output” variables. Thus, the overburden movement can be studied using black box method. Our work focuses on stepwise regression methods for model structure selection. In these methods, the input-output model structure is generally selected first; then, some factors such as coal seam thickness, overburden rock properties and distribution are selected as the black box “input”, and surface subsidence state is characterized as “output” variable; finally, the height of water flowing fractured zone is predicted, and the method is applied in actual mining.

In the present work, we made efforts to predict the height of water flowing fractured zone using an overlying rock black box model that incorporates both continuous and discontinuous profiles, and detailed analysis was carried out to predict the height considering the actual conditions of underground coal mining. The model was validated by taking parameters and observed values from Shandong coal mines in China to predict the height profiles, and Double-block Leak Hunting in Drill (DLHD) experiments were performed on 1101 working face in Shandong coal. It was found that the experimental data agreed well with the predicted results, indicating the good flexibility and application effects of the proposed model.

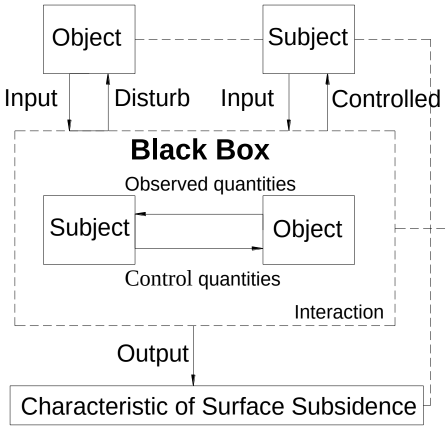


Fig. 1 Schematic of the overlying rock black box model

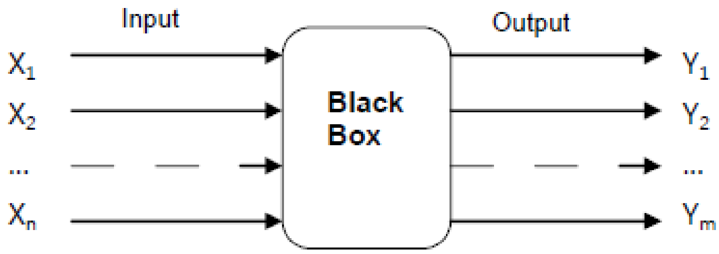


Fig. 2 Black box behaviors

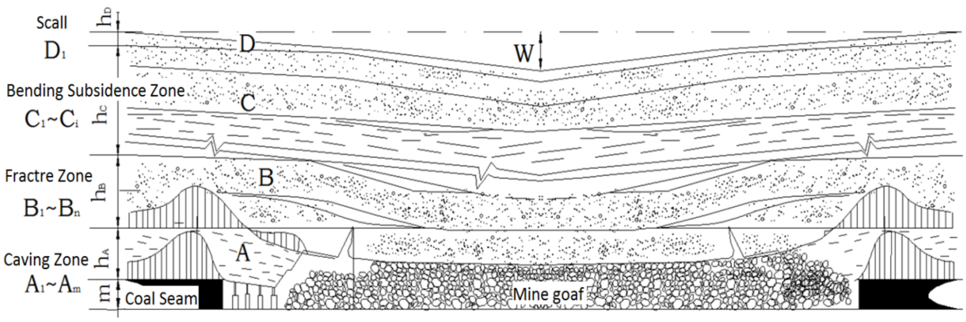


Fig. 3 Four kinds of composite structures

## 2. Model establishment and its applications

### *2.1 Overlying rock black box model*

For the black box, only input and output data can be obtained, whereas the internal structure of the system is unknown. The aim of the black box method is to avoid the complex internal structure but focus on the external characteristics to further invert the possible internal structure. Different systems can induce the same behavior output. Among these systems, if a system has the same input and output values, and can produce the same response to an external stimulus, it is called as the homogeneous system. In a large number of homogeneous systems, there are some similarities between the black box model and prototype, so that we can use these similarities to complete the height prediction of water flowing fractured zone.

In the overlying rock black box model, the mechanical properties of overlying strata, the horizon and the rock mass structure are selected as the Subject, and the thickness of artificial excavating coal seam and the area of mined-out section are used as the Object. The relationship between the subject and object can be summed up in two aspects. Firstly, the function of the object to the subject can be expressed by the observed quantities; secondly, the control function of the subject to the object can be expressed by the control quantities. The overlying rock black box model is the feedback coupling between the subject and the object, as shown in Fig. 1.

Study on the black box behaviors is to bypass the complex and unknown internal structure and study the external characteristics of the system. The behaviors of the system are determined by the input values ($X_1$, $X_2$,...$X_n$), and external output values ($Y_1$,$Y_2$,...$Y_n$), as shown in Fig. 2. By understanding the known variations of input and output data, the behavior changes are observed in a long enough time, and thus similar internal structure of the system can be deduced.

### *2.2 Model suitable conditions*

Theoretical analysis and field measurement indicate that the development process of the overlying strata is not a single movement from the bottom to upper layers, but a combined structure with regular movement (Gu 2001). There are many factors that control the movement of strata above the coal mining face, such as the mechanical properties and formation of overlying strata, the rock mass structure, the loose layer of impact, the influence of formation dip and structure, the mining thickness and depth, the mining ways, the re-mining effect, the mining time and so on (Liu 1983). In this paper, the overlying strata from top to bottom can be divided into four kinds of composite structures, including scall zone, bending subsidence zone, fractured zone, caving zone, as shown in Fig. 3. In order to establish the mathematical model of “input” and “output”, the overlying rock black box model is applicable to the following conditions:

(1) In terms of failure mechanism, the overburden rock mass is mainly damaged by tensile failure and shear failure. What’s more, the fault moves along the structural plane, and the rolling and sliding of rock structure body does basically not happen. Bending, fracture, caving and bed separation are the main damage forms of mining rock mass, whereas rock burst, interlayer fault and block rolling do not occur.

(2) By virtue of the longwall caving method (Fiscor 2016, Ghabraie 2015), the area of mined out section can make the overlying strata reach full movement and the overlying rock movement thus tends to be stable.

(3) The influence of geological structure on the movement of overlying strata is slight, and only

a small amount of or no-fault zone distributes in the mining area.

(4) Coal measure strata belong to the horizontal layered rock mass.

(5) Underground water bodies do not affect the mining process or the overlying strata movement.

(6) The thickness of the loose layer should be a fixed value, and the surface subsidence and horizontal displacement will not be affected.

### *2.3 Basic formula of overlying rock black box model*

According to the damage and movement of overlying strata, the overlying strata are divided into four representative parts: caving zone A, fractured zone B, bending subsidence zone C, and scall zone D. The effect of scall zone on the surface movement is different from that of other three kinds of structures. With the decrease of the thickness of scall zone, the range and the subsidence displacement of the subsidence basin decrease at the same and larger mining depth. Hence, the effect of scall zone with a certain thickness inside the black box can be ignored.

The mechanical properties of overlying rock have significant influences on the damage and deformation caused by mining process. The vertical deformation of rock is mainly related to compressive strength $\sigma$, elastic modulus $E$, cohesion $c$ and internal friction angle $\varphi$. The relationship between the four indexes and the output quantity $\Delta h$ can be transformed into complex function and objective function. By the multivariate Taylor theorem, it can be known that the complex function can be expressed by the two-term approximation.

$$f(x) = \Delta h = a_0 + \sum_{i=1}^{m} a_i x_i + \sum_{j=1}^{m} a_{ij} x_i x_j + \sum_{j=1}^{m} a_{jj} x_j^2 \tag{1}$$

where $\Delta h$ or $f(x)$ is the rock thickness variation; $\alpha_0$, $\alpha_i$, $\alpha_{ij}$, $\alpha_{jj}$ are constants; m=4; $x=(\sigma, E, c, \varphi)^t$ and $x_i$ is one factor.

Here,

$$\begin{cases} \Delta H_A = \sum_{i=1}^{I} \Delta h_{Ai} \\ \Delta H_B = \sum_{i=1}^{J} \Delta h_{Bi} \\ \Delta H_C = \sum_{i=1}^{M-1} \Delta h_{Ci} \\ \Delta H_A + \Delta H_B + \Delta H_C = m - W \end{cases} \tag{2}$$

where $\Delta H_A$, $\Delta H_B$ and $\Delta H_C$ are the thickness variations of caving structure, fracture structure and bending subsidence structure respectively; $\Delta h_{Ai}$, $\Delta h_{Bi}$ and $\Delta h_{Ci}$ are the thickness variations of a certain stratum in caving structure, fracture structure and bending subsidence structure respectively; I, J and M-1 are the numbers of strata in the caving structure, fracture structure and bending subsidence structure respectively; $m$ is the thickness of mining coal seam; and $W$ is the maximum value for mining subsidence.

Minimum norm type of Eq. (1) is as follows

$$f(x) = \Delta h = a_0 + \sum_{i=1}^{4} b_i X_i \tag{3}$$

Data matrix of the upper strata is

$$A = \begin{pmatrix} \sigma^2 & \sigma E & \sigma c & \sigma\varphi \\ E\sigma & E^2 & Ec & E\varphi \\ c\sigma & cE & c^2 & c\varphi \\ \varphi\sigma & \varphi E & \varphi c & \varphi^2 \end{pmatrix} \tag{4}$$

Its coefficient vector is $\hat{a} = (b_1, b_2, b_3, b_4, a_0)^t$, and the vector data is $Y = [y_1, y_2, y_3, y_4]^t$.

For caving structure, Y is determined by the expansion coefficient of the rock stratum, which is damaged by a certain rock stratum in the caving zone. Namely, $Y_A = (K_p - 1)m_r$, where $K_p$ is expansion coefficient of rock and $m_r$ is the thickness of rock strata.

The maximum deflection of Y in the structure of the curved sinking belt is generally calculated from the compression of the bending subsidence structure.

$$Y_C = \frac{400}{m_r \pi^2} \sqrt{\frac{3(1-u^2)q}{E}} \tag{5}$$

where $q$ is the self-weight stress of rock stratum and $u$ is the Poisson's ratio.

The thickness of the fracture structure varies between those of the caving structure and the bending subsidence structure. Therefore, $Y_B$=0.5($Y_A$+$Y_C$).

The solution of the data matrix equation can be obtained by the Moore-Penrose generalized inverse theorem; namely, $\hat{a} = A^+Y$. Here, $A^+$ is the data matrix pseudoinverse, and it is existent and unique for any matrix A. Because the matrix A is a full rank matrix, the minimum norm is $\hat{a} = A^t(A^tA)^{-1}A^tY$. Then, the multivariate Taylor expression of $\Delta h$ can be determined by compressive strength, elastic modulus, cohesion and internal friction angle.

Then, Eq. (2) can be rewritten as

$$\begin{cases} \Delta H_A = \sum_{i=1}^{I}(a_{A0} + \sum_{i=1}^{4} b_{Ai}X_{Ai}) \\ \Delta H_B = \sum_{i=1}^{J}(a_{B0} + \sum_{i=1}^{4} b_{Bi}X_{Bi}) \\ \Delta H_C = \sum_{i=1}^{M-1}(a_{C0} + \sum_{i=1}^{4} b_{Ci}X_{Ci}) \\ \Delta H_A + \Delta H_B + \Delta H_C = m - W \end{cases} \tag{6}$$

Through numerical prediction of $I$ and $J$, whether $\Delta H_A$, $\Delta H_B$ and $\Delta H_C$ meet the changing conditions can be tested based on their stratum type, and then the height of watering fissures can be calculated.

$$\begin{cases} H_f = h_A + h_B \\ h_A = \sum_{i}^{I} m_{Ai} \\ h_B = \sum_{i}^{I} m_{Bi} \end{cases} \tag{7}$$

where $h_A$ and $h_B$ are the heights of caving structure and fracture structure respectively; and $m_{Ai}$ and $m_{Bi}$ are the thickness of each layer.

### *2.4 Application of black box model and error analysis*

The model is applied to a coal mine located at the 1101 mining face at Shandong Coal based on the actual geological conditions. The coal mining depth is 205 m (below the surface), the coal

Table 1 Physical and mechanical parameters of rock strata

| No. | Stratum | Thickness /m | Elastic modulus /GPa | Compressive strength /MPa | Shear strength | |
|---|---|---|---|---|---|---|
| | | | | | $\tan\psi$ | C（MPa） |
| 1 | Loess | 75.62 | 50.000 | 0.10 | 0.310 | 0.01 |
| 2 | Mudstone | 10.41 | 10.691 | 21.13 | 0.625 | 1.75 |
| 3 | Fine sandstone | 20.91 | 6.804 | 37.09 | 0.518 | 5.23 |
| 4 | Mudstone | 15.36 | 4.153 | 17.07 | 0.554 | 1.37 |
| 5 | Fine sandstone | 4.55 | 13.807 | 66.89 | 0.510 | 7.96 |
| 6 | Mudstone | 13.45 | 4.810 | 57.51 | 0.910 | 4.51 |
| 7 | Fine sandstone | 1.40 | 7.668 | 48.52 | 0.557 | 7.48 |
| 8 | Mudstone | 7.11 | 4.809 | 35.76 | 0.570 | 3.22 |
| 9 | Fine sandstone | 4.55 | 12.128 | 50.03 | 0.623 | 3.32 |
| 10 | Mudstone | 7.21 | 3.908 | 17.84 | 0.607 | 1.25 |
| 11 | Fine sandstone | 1.43 | 5.473 | 47.69 | 0.568 | 6.81 |
| 12 | Mudstone | 4.15 | 4.166 | 41.03 | 0.574 | 3.91 |
| 13 | Sandy mudstone | 3.90 | 4.774 | 34.88 | 0.863 | 2.09 |
| 14 | Mudstone | 19.01 | 8.014 | 34.92 | 0.781 | 2.72 |
| 15 | Medium-fine sandstone | 10.03 | 8.407 | 75.83 | 0.619 | 13.42 |
| 16 | Mudstone | 2.08 | 6.305 | 29.21 | 0.708 | 3.27 |
| 17 | Coal | 3.59 | 0.605 | 9.60 | 0.563 | 1.81 |

Table 2 Black box model calculation results

| (i, j) | Measurement W/mm | Forecast W` /mm | Caving zone height/m | Fractured zone height/m |
|---|---|---|---|---|
| (1,3) | 2537 | 2132 | 2.13 | 29.21 |
| (1,4) | 2537 | 2457 | 2.37 | 37.97 |
| (1,5) | 2537 | 2749 | 3.07 | 40.23 |
| (2,3) | 2537 | 2511 | 10.27 | 40.36 |
| (2,4) | 2537 | 2733 | 11.34 | 42.75 |
| (2,5) | 2537 | 2945 | 12.17 | 49.89 |
| (3,3) | 2537 | 2601 | 27.45 | 39.47 |
| (3,4) | 2537 | 2847 | 31.34 | 47.58 |
| (3,5) | 2537 | 2935 | 32.75 | 51.34 |

seam thickness is 3.6 m, and the average dip angle of coal seam is 2°. The thickness of overlying strata in coal mine is 201.3 m, the layer number is 15, and the mining thickness is 3.6 m. Rock properties and thickness of Shandong coal mine layers are shown in Table 1.

The monitoring data of surface movement show that the maximum surface subsidence W is 2537 mm. Then, the output value of overlying rock black box model is W, and the input data include compressive strength $\sigma$, elastic modulus $E$, cohesion $c$, internal friction angle $\varphi$, layer number, overburden thickness and mining height. According to the actual experience of coal mining, $i$=1, 2 or 3, and $j$=3, 4 or 5. Then, there are nine groups of combination scheme. Substitute the values into the formula, and the black box model calculation results can be obtained using SPSS software, as shown in Table 2.

It can be seen that the minimum difference between the model prediction value and the actual surface subsidence value can be achieved when i=2 and j=3. Under this condition, the caving zone height is 10.27 m, the fractured zone height 40.36 m, and the maximum surface subsidence is 2537 mm. The field testing results show that the caving zone height is 11.32 m, and the fractured zone height is 43.91 m. These deviations are originated from two aspects: one is the deviation of applied mine exploitation conditions from actual geological conditions, and the other is the deviation of coal seam thickness parameters. It can be known from Section 2.2 that the mine exploitation depth is deep, and that the intensive motion of covered coal leads to the diastrophism of rock layer as wel as block rolling, thus producing the deviation of mining exploitation conditions. As for the rock mechanics parameters for model calculation, such as elastic modulus and internal friction angle, they can be achieved through the borehole histogram of the mining area. However, the coal seam histogram has the characteristics of locality and regionality, so that it cannot represent the whole overburden rock; meanwhile there are big differences between the rock mechanics parameters of the standard rock sample obtained from testing petrophysical parameters and those of actual rock mass.

## 3. Field monitoring results and model accuracy verification

### *3.1 On site observation method of water flowing fractured zone*

At present, the commonly used methods of water flowing fractured zone include the surface flushing fluid method, the physical exploration method and the television imaging detection method.

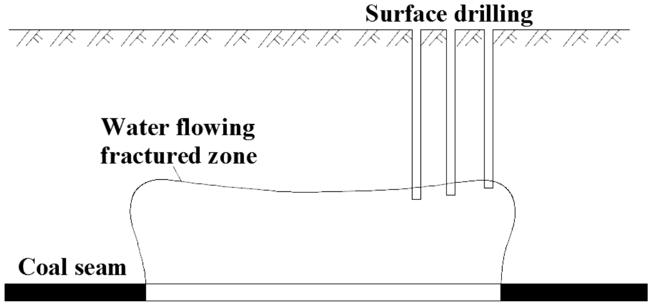


Fig. 4 Surface flushing fluid

### *3.1.1 Surface flushing fluid*

The method refers to drilling from the surface to the mined out area, and obtaining the height and distribution of mining induced fractured zone through observing the changes of drilling fluid consumption during drilling. However, the cost of drilling fluid consumption is large, and it is difficult to control the observation accuracy. Hence, this method can just determine the general position, but it is difficult to achieve accurate position, as shown in Fig. 4.

### *3.1.2 Physical exploration method*

The physical exploitation method includes ultrasonic imaging method and indirect radio frequency measurement. This method can acquire continuous cylindrical images of borehole wall, and structure morphology. According to the fractured zone morphology, the width, inclination and dip angle of the fractured zone can be determined. Based on the brightness of the images, the hardness of borehole wall can be reflected and the rock lithology can be distinguished. However, this method cannot observe some slight fractures.

### *3.1.3 Television imaging detection method*

Television imaging detection is a relatively intuitionistic imaging detection technology. It mainly gains the imaging information according to the position of the probe in the borehole, and then transmits the information to the computer, thus realizing direct observation on the development situation and damage depth of the fractures in borehole. It can achieve rough positioning of the two-belt observation, but the imaging is so opaque that it is difficult to obtain clear images.

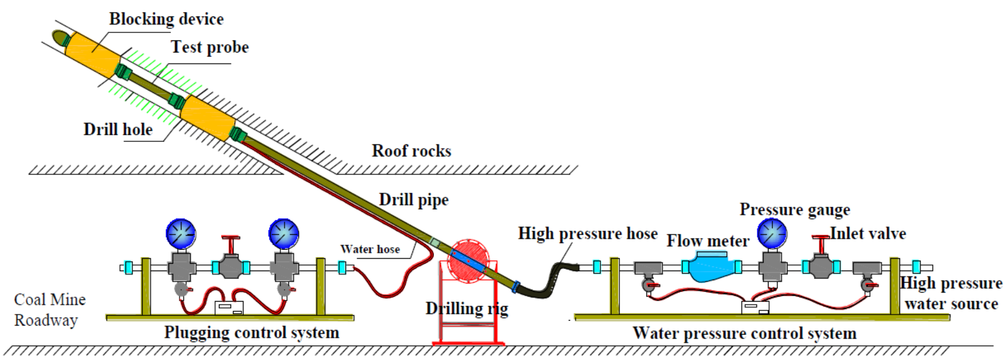


Fig. 5 Structure schematic diagram of Double-block leak hunting in drill

Fig. 6 Physical diagram of testing devices

### *3.2 Selection of monitoring tools*

In this section, the feasibility and accuracy of the height calculation formula for water flowing fractured zone are verified according to the characteristics of strata distribution and surface subsidence in Shandong coal mine. Firstly, we detected the height of fractured zone by Double-block Leak Hunting in Drill (DLHD) as shown in Fig. 5. Fig. 6 presents the physical diagram of testing devices. The technology of DLHD can detect the height of fractured zone of coalface overburden. Its principle is to estimate the results in advance by detecting the variation of leakage loss before and after rock mass destruction around the drill.

The technology is working at the coal mine roadway with the drilling towards the strata above the mined-out area. According to the measurement results of drilling hole, the data can be tested in the hole. DLHD consists of three steps: plugging control system, water pressure control system, and blocking test device. When the blocking device is filled with water from water hose, its volume increases a lot very rapidly. Thus, both ends of the blocking device are blocked and a confined space is formed by plugging control system. Then, water is injected into the confined space through high pressure hose controlled by water pressure control system. If there is a fracture in the roof rock, the injected water will be partially lost at the confined space. Through the flow meter, the leakage loss per meter hole per unit of time can be measured. The leakage loss reflects the development degree of the fractures. For each measurement, the drill keeps drilling for one meter, and then moves to the next location for another measurement. The leakage loss is monitored until the entire drill hole is measured. According to the variation of leakage loss per meter, the height of water flowing fractured zone can be determined.

### *3.3 Detecting the height of fractured zone*

#### *3.3.1 Design of the testing schemes*

According to the actual mining conditions and the roadway position of the 1101 working face (Table 1), we set up two testing holes (2# and 3#) and one control hole (1#), which are located at the intersection of track transportation tunnel and connecting tunnel. The track transportation tunnel passes through the goaf, while the connecting tunnel is completely in the rock. By comparing the variation of leakage loss, the water flowing fractured zone can be determined. The drilling construction site is shown in Fig. 7 and the drilling parameters are provided in Table 3. Fig. 8 shows the field operations in roadway.

Table 3 Drilling parameters

| No. | Name | Diameter /mm | Azimuth | Length/m |
|---|---|---|---|---|
| 1# | Control hole | Φ93 | N47° | 60 |
| 2# | Testing hole | | N317° | 160 |
| 3# | | | N335° | 133 |

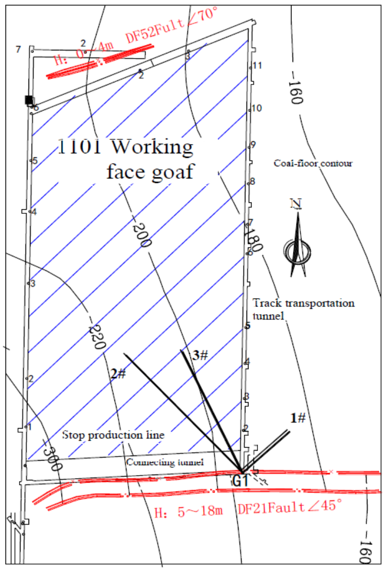


Fig. 7 Borehole arrangements

Fig. 8 Field operations in roadway

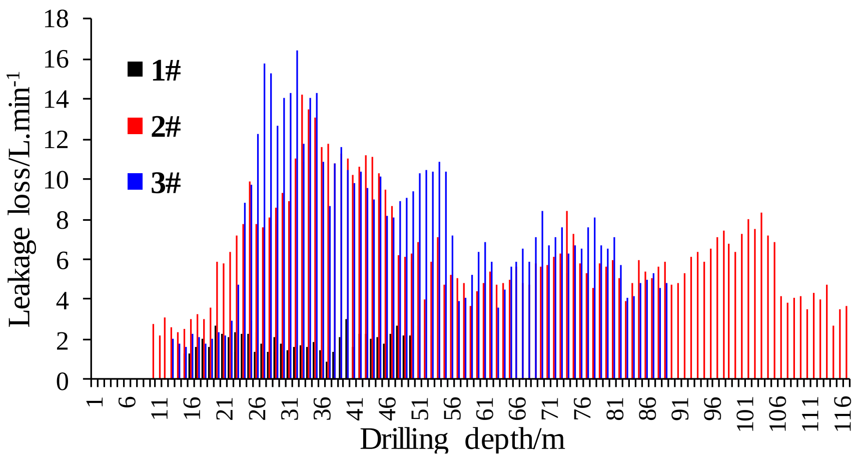


Fig. 9 Leakage loss per meter

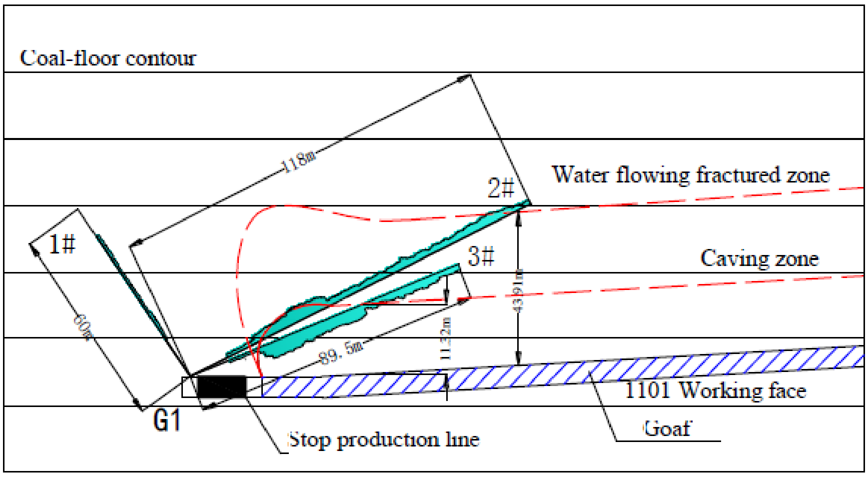


Fig. 10 Schematic diagram of height monitoring on the crack zone

### *3.3.2 Testing results analysis*

The test began on October 15th, 2014 and ended on October 20th, 2014. The test position of 1# started at 15 m, that of 2# at 10 m and that of 3# at 13 m. Fig. 9 shows the leakage loss per meter.

(1) Control hole (1#)

Because the hole was far away from the goaf, the roof strata are not destroyed, so that the leakage loss is small. The maximum leakage, 2.4 L/min, occurred at the position of 23 m.

(2) Testing hole (2#)

From 10 m to 22 m, the leakage loss was relatively stable at about 2.5 L/min. From 23 m to 34 m, the leakage loss gradually increased and varied in the range of 7-15 L/min. From 54 m to 106 m, the leakage loss values varied dramatically. Through data analysis, it can be known that the range from 22 m to 106 m is in the water flowing fractured zone.

(3) Testing hole (3#)

The leakage loss was relatively stable until 25 m, and then increased to a high level from 26 m to 57 m. At the position of 58 m, there was a sudden decrease of the leakage loss. Through data analysis, the height of caving zone is 21.3 m.

Fig. 10 shows the schematic diagram of height monitoring on the crack zone. As can be seen, the overlying rock is medium-hard rock and the mining thickness is 3.5 m. The testing results show that the height of caving zone is 11.32 m, and that the fractured zone height is 43.91 m.

### *3.4 Model accuracy verification*

According to the monitoring results of 1101 working face, the height of caving zone is 11.32 m, and the fractured zone height is 43.91 m. The calculation results by the black box model (see Table 2) show that the height of caving zone is 10.27 m, and that the fractured zone height is 40.36 m. It can be seen that the actual monitoring value is about 2 m larger than that obtained from the model. This may be caused by the error of the estimated method. On the whole, the results obtained from the two methods are basically consistent within the error range. Hence, it can be concluded that the proposed black box model has a desirable accuracy.

## 4. Conclusions

• The strata movement and destruction caused by coal mining is a complex process, and the overburden movement is influenced by many factors. The black box model of overlying rock can avoid the complexity of overburden movement, and realize the prediction of the height of water flowing fractured zone in coal mine by simple ideas and methods.

• By introducing actual geological conditions of coal mine into the black box model, the feasible values of the assumed stratum number can be determined by the maximum subsidence value of the ground surface. The actual height of fractured zone can be detected by use of DLHD. The testing results show that the proposed black box model is adaptable for height prediction of the fractured zone.

• The black box method provides a new method for the study of coal mining, but it requires a large number of experimental data and field observation data. Continuous efforts should be made to improve this method in the future.

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