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Characteristics of Deformation and Destruction to the Mining Roadway Floor of "Three-soft" Thick Coal Seam by Field Measurement

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Abstract Characteristics of deformation and destruction is one of the key factors to water inrush from coal seam floor. In order to research the deformation and destruction of the "three-soft" coal seam mining floor, field measurement at 21021 working face was measured in Gaocheng Coal Mine in Zhengzhou Mining Area western by strain method. The depth and stratum of deformation and destruction and the extension of variation and width of strain peak in the front of mining working face are gained on mining effect of the "three-soft" coal seam roadway floor by analyzing the data of sensors in borehole at the haulage roadway and ventilation roadway. The variable degree of axial strain is much greater than the radial strain, and the width of strain peak and influence scope at haulage roadway are much greater than the ventilation roadway because of the influence of stress concentration. Thick soft coal seam and soft floor have a buffer action for stress and deformation under the normal condition, and the limestone groups ($L_{7\text{-}8}$) of middle section have an important controlling function to the stress distribution and deformation and destruction.

Keywords "three-soft"coal seam, mining floor, deformation and destruction, field measurement, buffer action

Introduction

The possibility of water inrush from mining coal seam floor depends on the actual filling water aquifer properties and resistance ability of floor, the relationship between two factors is reflected in the water inrush coefficient at home, and the water inrush coefficient is used to evaluate the danger of water inrush from coal seam floor under the goaf (Wang and Liu 1993; Zhang et al.1997). So, the deformation and destruction of mining coal seam floor and resistance ability of floor must be found out during the mining above the confined aquifer (Qian and Shi 2003; Zhang et al.2009), the relationship is simply showed in fig. 1. According to the water inrush coefficient： $T_S = \frac{P}{M}$, where $_{\text{s}}$ is of actual water pressure the main aquifer, it generally can be obtained through the analysis of hydrological long-time observation hole data; M is distance between the top of the water filling aquifer and the mining of coal seam floor, there are three zones distribution characteristics of goaf floor under normal conditions, namely destruction zone h_1, effective water resistant zone h_2 and initial fracture zone h_3. As the fig.1 shown that $M= h_1+ h_2+ h_3$， where, h_1 is generally obtained by field measurement and laboratory test or analytical method, h_3 is generally obtained by field measurement，the value can be zero, $h_2= M -h_1- h_3$.

From above analysis, we can see that the effective water resistant zone is the key value to accurately evaluate the mining water inrush dangerous problem, and it basically depends on the size of the value of the h_1 , because the value of h_3 is usually small in normal coal seam floor, and it can be zero. So the depth of deformation and destruction of mining coal seam floor is the key factor of safety evaluation aquifer above aquifer.

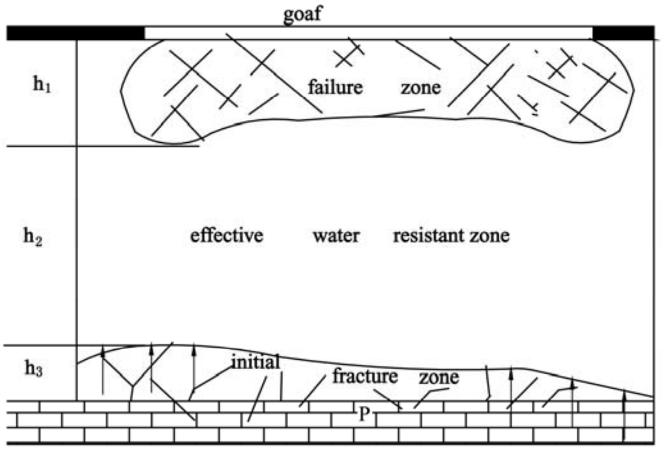


Fig.1 *The sketch of three zones of goaf floor*

Measurement method and experimental devices

Measurement method

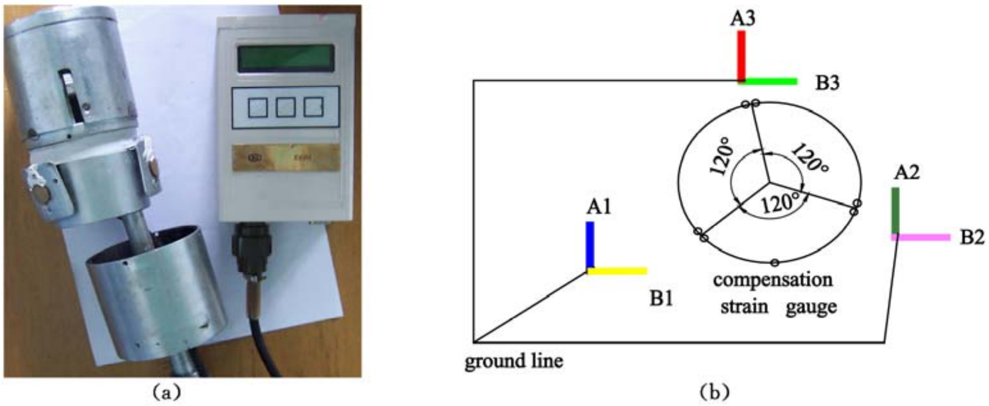
The research on depth of mining floor deformation and destruction can be mainly divided into three methods at home and abroad, namely field measurement (Wei 2005, Shi et al.2004, Liu et al. 2003, Zhang et al.2006, Guan et al. 2003, Xu 2010, Zhu et al. 2014), laboratory simulation test (physical simulation test (Wang et al. 2006; Gong et al. 2005) and numerical simulation (JAISWAL and SHRIVASTVA 2009, ISLAM et al. 2009)) and analytic calculation (empirical formula (Song et al. 2003) and theoretic calculation (Cai et al. 2005)). Because the deformation characteristics and the extent of destruction are related to many factors, such as mining depth, working face size, mining method,coal seam dip, mining height , coal seam formation and lithologic structure , et al. Therefore, compared with other methods, field measurement is the most reliable and effective method to reveal the characteristics of deformation and destruction to mining coal seam floor. Currently there are many field measurement methods to used in mining depth of coal seam floor, mainly, borehole water injection method (Wei 2005), borehole acoustic method (Liu et al. 2003), radio perspective method (Zhang et al. 2006), stress inverse analysis method (Guan et al. 2003) and borehole strain method (Xu 2010, Zhu et al. 2009, Zhu et al. 2014).

Compared with other field measurement test methods, Strain can effectively compensate for the borehole water injection method and the acoustic method. On the one hand, continuous strain data can be obtained by setting the strain sensors at different floor depth of the borehole to monitor the changes of the deformation and destruction, According to test data, advance distance and coal wall in front of the scope of influence of stress concentration can not only be determined by underground pressure, and the difference of vertical deformation and destruction of mining floor can also be reflected at different depth strain sensor data, and thus the depth of the deformation and destruction of mining coal seam floor is determined; On the other hand, the data of floor deformation are obtained after the working face advancing a certain distance of measuring points due to extended strain sensors wire by strain method, which can assure the sufficient deformation degree of the testing floor. So we select the strain method to measuring the deformation and destruction of mining coal seam floor.

Experimental devices

The strain sensor which is used to measure the deformation and destruction is developed in cooperation with the Institute of Engineering Geomechanics, Chinese Academy of Geological

Sciences, its outer diameter is about 91 mm (fig. 2(a)), receiver for testing is made of the Chinese academy of geological sciences institute of engineering geological mechanics ,its type is KBJ - 12 borehole strain recorder, measuring accuracy is ±0.1%, its minimum resolution 1με, and the measuring range between -19,999 με and +19,999 με. The internal structure of sensor is shown in fig. 2(b), the testing clips marked with A1, A2, and A3 are used for probing the axial strains to which they are subject, while the clips marked with B1, B2, and B3 for probing the radial strains from which they suffer. Each of the strain clips, after combination, is placed on the cylinder surface with a difference of 120°, and then the sensor is fabricated. There are 7 channels in each sensor, 4 working channels, 2 compensating channels, and 1 ground line channel.



(a) Photos of sensor and strain recorder *(b) Schematic of sensor's internal structure*

Fig. 2 *The sketch of borehole measuring device*

Previous relevant research has been shown that the sensor has more sensitive detector response to the surrounding rock deformation, and surrounding rock deformation degree can be revealed (Zhu et al. 2009). The measuring data is relatively stable when the working face is far from sensor position, and mining underground pressure has not spread to the measuring point; When mining pressure spread to the point of the sensor, the test data will change with synchronously. The data of sensor is sharply increase when the working face is closer to the measuring point, even the data value is beyond the receiver range of strain sensor, then the data is becoming to stable after the working face advance to face in a certain distance of measuring points, which reflects the influence of mining stress concentration range.

In addition, the outer wall of strain sensor is made in high elastic plastic materials, there is large measuring range when the sensor is at uniform stress before the floor is not destroyed, and it is better inductance to deformation and destruction. The three sets of test data is at a similar law before floor rock without damage, the sensor of the lateral stress is relatively uniform, and reflects the size of the data with the surrounding rock deformation and synchronous fluctuation change. If surrounding rock of measuring points is destroyed, it is bound to result in borehole deformation, plastic cladding is distorted and damaged, the three sets of test data is highly discrete, and even without reading. Therefore, mining-induced damage scope and depth of mining floor are obtained according to different depth of the strain sensor test data.

Face basic overview and borehole design parameters

The No.21021 working face of Gaocheng Coal Mine is located at the depth of -100 m level in No.21 Mining Area, its ground elevation ranges from +286.5 m to +307.3 m, and the elevation of working face ranges from -152.0 m to -84.0 m. The north of working face is -

110m level transport tunnel, its south is three central dip downhill tunnels, the east and west are the NO.21011working face and the NO.21031working face, respectively, they are the virgin area of the mine (fig. 3). The incline width of the working face ranges from 153.0 m to 155.0 m, the strike length ranges from 845.0 m to 936.0 m, the mining area is about 137137.0 m^2, the thickness of No.C2-1 mineable coal seam ranged from 1.6 m to 9.3 m, and average about 4.2 m, its dip angle is 8°-12°.

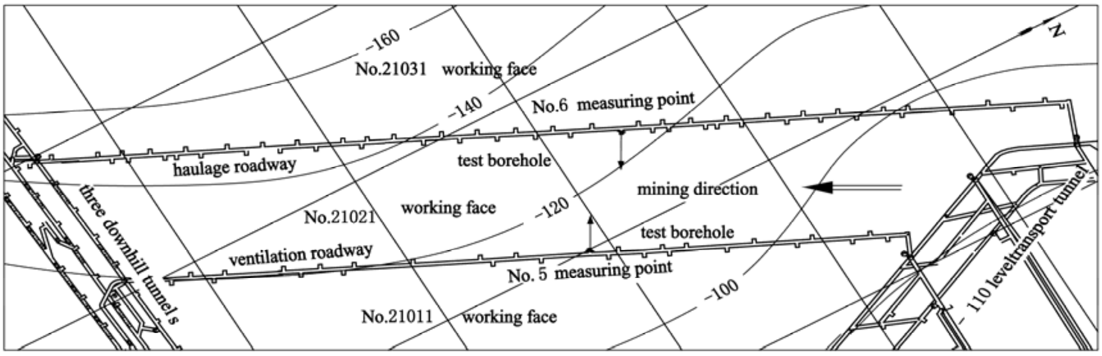


Fig. 3 *Schematic plane diagram of measurement borehole in roadway on 21021working face*

The main roof of the face coal seam is Dazhan sandstone, its thickness about 6.6 m, and its Protodrakonov scale of hardness 8.7, a higher strength. The immediate roof is sandy mudstone, its thickness from 5.6 m to 19.3 m, and its Protodrakonov scale of hardness 4.3, a lower strength. The immediate floor of the face coal seam is mudstone and sandy mudstone, its average thickness 11.0 m. The main floor of 10.5 m thickness is Taiyuan formation No.7-8 limestone, its strength is higher.

Thus, the design parameters of the borehole are shown in table 1according to the No.21021 working face geology and mining conditions.

Table 1 Designing *parameters of borehole in working face 21021*

Technical parameters	Haulage roadway	Ventilation roadway
Borehole opening diameter (mm) /depth (m)	146/5.0	146/5.0
Borehole orifice pipe diameter (mm) /length (m)	127/5.0	127/5.0
Borehole terminal diameter (mm)	108	108
Borehole depth l (m)	25.0	30.0
Borehole orientation (°)	116	295°
Angle between borehole direction and horizontal direction δ (°)	-50	-50°
Angle between borehole direction and roadway direction (°)	90	90°
Max thickness to seam floor h (m)	17.0	16.0

Sensors layout and measuring result

Sensors layout

The plane schematic of the boreholes positions are shown in fig.3, according to Zhu et al. (2009) and Zhu et al. (2014), the borehole in the ventilation roadway is drilled at No.5 measuring point, and two strain sensors are inset at its two different depths (fig.4). One sensor is located at 20.0 m away from the borehole opening and at 12.9 m to No.C2-1 floor, it is placed at the middle of the No.8 limestone stratum, the sensor is no reading due to improper installation. The other is located at 30.0 m from the borehole opening and at about 19.3 m to No.C2-1 floor, it is placed in the mudstone stratum between the No.8 and No.7

limestone strata. The another borehole in the haulage roadway is drilled at the No.6 measuring point (fig.3), and two strain sensors are also inset at its two different depths (fig.4). One sensor is located at the top of the No.8 limestone stratum, it is 12.2 m from the borehole opening and at about 10.6 m to No.C2-1 floor. The other is located at the top of No.7 limestone stratum, it is 19.6 m from the borehole and about 16.3 m to No.C2-1 floor, the sensor is no reading due to improper installation.

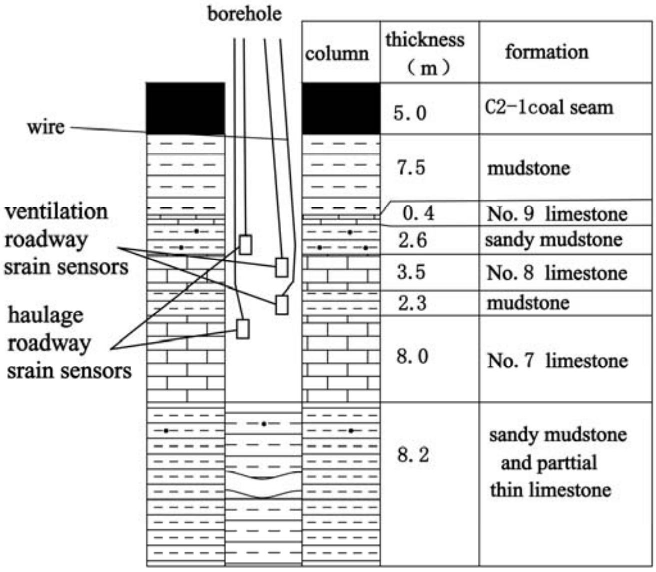


Fig. 4 *Schematic diagram of the sensor laying strata in the borehole*

Because of testing the blasting face, the data is measured every three days when the working face is about 60 m away from the measuring point, the borehole is basically unaffected by mining. Then the data are measured every two days while the face advanced from 60.0 m to 20.0 m. At last, the data is measured every day when the face advanced from 20.0 m until the data couldn't be acquired.

Measurement results and analysis

The strain curves measured are shown in fig.5 by the sensor used in the ventilation roadway when the working face is in advance. The sensor is inset at 30.0 m along the borehole, three channels of the sensor is damaged during installation and the other three operated normally until the working face advanced close to them. The curves show that variations in axial and radial strains are basically synchronic at the beginning, but then obvious difference appears at 24.0 m from the face to the borehole, the maximum difference occurs at 7.5 m; for the axial strain increment, the axial strain signals get from Channels A1 and A3 are basically synchronic, but the radial strain gets from Channel B1 shows obvious difference compared with the axial strain. According to underground theory (Qian and Shi 2003), it is possible to infer that the distance from the maximum stress peak to the working face in ventilation roadway and haulage roadway is about 7.5 m and 8.0 m respectively, mining scope of influence is about 24.0 m and 36.0 m respectively.

The strain curves measured by the sensor in the haulage roadway are shown in fig.6. The sensor is buried at 12.2 m along the borehole, the four channels in the borehole work very well until the face advances close to them. The curves show that variations in axial and radial strains are basically synchronic each other at the beginning; but then obvious difference occurs at 36.0 m from the face to the borehole, the maximum difference occurred at 8.0 m; for the axial strain increment, the strain signals obtain from A1 and A2 are basically synchronic, just like the radial strain signal from Channels B1 and B2, but the radial strain increment is obviously different from the axial one. The maximum depth of failure is up to 10.6 m from mining floor, and it ends to the middle of mudstone on the top of the No.8 limestone of Taiyuan Formation.

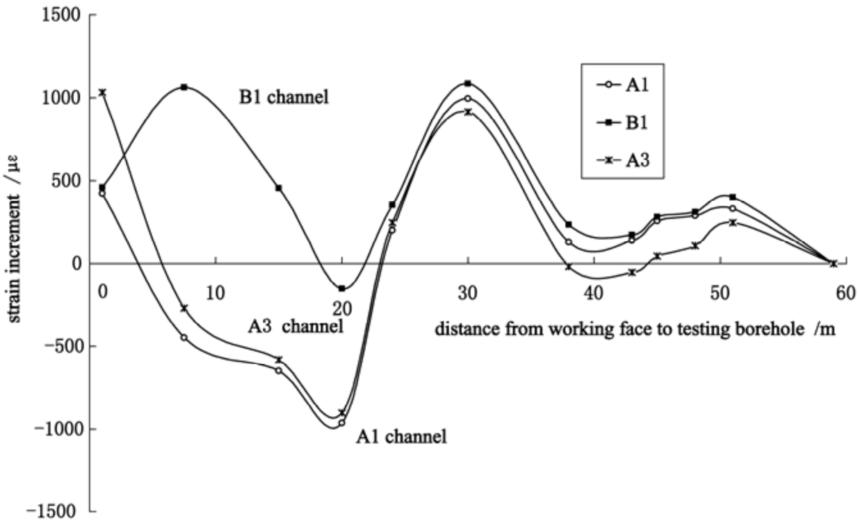


Fig.5 *The strain curves of field measurement in borehole of ventilation roadway*

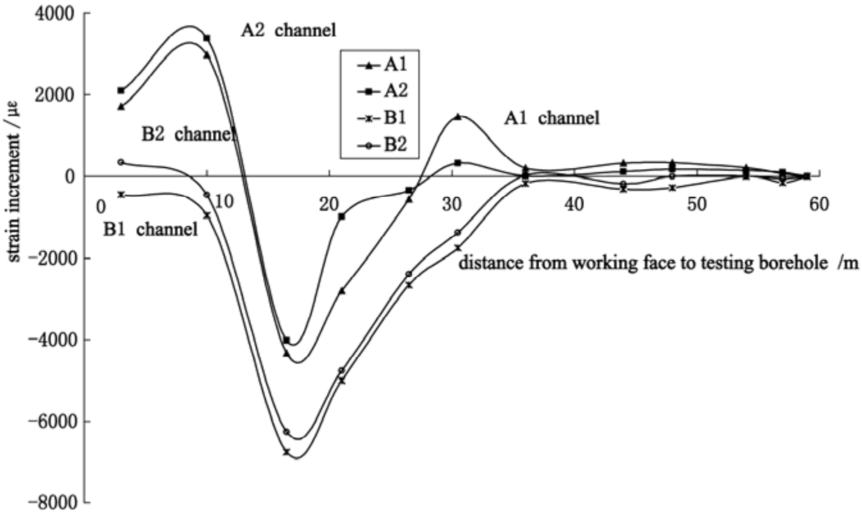


Fig.6 *The strain curves of field measurement in borehole of haulage roadway*

Through the comparison and analysis of curves of the Fig.5 and Fig.6, we can find strain increment is larger in haulage roadway than ventilation roadway. The main reason for the differences is that underground pressure influences is even stronger for haulage roadway than ventilation roadway, and perhaps is about depth of sensors.

Compared with the theoretical calculation of analysis

Combining the theory of limit plastic damage, the maximum depth of destruction and the crack length can be obtained under the condition of underground pressure, the formula is as follows (Zhang et al.1997):

$$h=\frac{x_a\cos\varphi_0}{2\cos(\frac{\pi}{4}+\frac{\varphi_0}{2})}\mathrm{e}^{(\frac{\pi}{4}+\frac{\varphi_0}{2})\tan\varphi_0} \tag{1}$$

Where, h is the plastic solution for the largest destruction depth of coal floor; x_a is the crack length of coal seam, and the value is estimated by following formula:

$$x_a=\frac{m}{F}\ln(10\gamma H) \tag{2}$$

Where, H is the average depth of mining coal seam; m is the average thickness of mining coal seam; $F=\frac{K_1-1}{\sqrt{K_1}}+(\frac{K_1-1}{\sqrt{K_1}})^2\arctan\sqrt{K_1}$; $K_1=\frac{1+\sin\varphi}{1-\sin\varphi}$; γ is the average unit weight of floor rock mass; φ is the internal friction angle of mining coal seam; φ_0 is the average internal friction angle of floor rock mass.

According to the No.21021 working face geological and mining conditions, physical and mechanical parameters of mining coal seam roof and floor rock are obtained:

m=4.2 m, φ=30°, γ=0.026 3 MN/m^3, H=403 m, φ_0=40°.

Put these data into formula 2 and formula 1, we can obtain the values of the crack length of coal seam and the largest destruction depth as follows:

$$x_a=7.7\,\mathrm{m},\ h=18.0\,\mathrm{m}$$

Comprehensive analysis combined with the measured data, we find that the crack length of coal seam is little difference between the formula (2) and field measurement, but the largest destruction depth values have obviously difference, soft roof and thick soft coal seam and soft floor have a buffer action for stress and deformation under the normal condition, and the limestone groups ($L_{7\text{-}8}$) of middle section have an important controlling function to the stress distribution.

Conclusions

(1)The maximum destruction depth of floor is up to 10.6 m to the mining “three-soft” coal seam by field measurement, occurring in the middle of mudstone stratum at the top of No.8 limestone stratum of Taiyuan Formation, its value is smaller than the theoretical calculation.

(2)The degree of stress concentration is even stronger for haulage roadway than ventilation roadway by underground pressure influence, influence scope and the maximum strain increment peak are greater in haulage roadway.

(3)The “three-soft” coal seam has an important buffer action for stress and deformation to floor under the normal condition, it is good for prevention and control of water disasters to mining above aquifer.

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