

Study on deformation of mining coal roadway affected by strip mining based on field measurement

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Abstract. To investigate the deformation characteristics of mining coal roadway affected by strip mining, through the field measurement of one mining coal roadway by strip mining of Xuzhou coal mine in China, based on the key stratum theory and strata movement theory, its deformation is analyzed and studied. From the field measurement, some special deformation characteristics of mining coal roadway affected by strip mining have been found. For the mining coal roadway by strip mining, there are two peaks of displacement, and their lag distance is long. Therefore, the support of the mining coal roadway by strip mining should be reinforced before the second pressure arrives. Those can provide valuable reference for the support of the mining coal roadways by strip mining under the similar conditions.

Keywords: deformation characteristics; field measurement; key stratum theory; mining coal roadway; strip mining

1. Introduction

In coal mine, the stability of mining coal roadway is very important for safety mining. Generally, the mining coal roadway will be affected by the dynamic pressure of coal mining very seriously. Moreover, the deformation of coal roadway is very large. Therefore, it is very important to study the deformation of coal roadway affected by the mining pressure. Nowadays, there have been some works on this problem, which can be divided into numerical studies, test investigation studies and theoretical studies.

For the numerical studies, by using the numerical simulation methods, the deformation of coal roadway affected by the mining pressure has been researched. For example, by using the finite-difference method for modelling the Rydułtowy coal mine in Poland, the stability of coal roadway has been researched (Rafał *et al.* 2021). Based on numerical model of coal measures strata of the Selby coalfield by FLAC3D software, the stability of coal mine roadway has been studied too (Coggan *et al.* 2012). Also using the FLAC3D numerical simulation, the asymmetric deformation mechanism of the reserved roadway in the Buertai Coal Mine of China under mining influences has been studied (Li *et al.* 2020). By using the FLAC2D software, the probability analysis for the stability of coal mine roadway has been conducted (Booth *et al.* 2016). Moreover, based on the three-dimensional numerical model by finite difference algorithm, the influence of disturbed coal seam on the stability of coal mine roadway has been studied (Essen *et al.* 2007).

Different from above studies, by using the numerical model of Universal Discrete Element Code (UDEC) software for a case study at the Dongtan coal mine in China, the failure mechanism of deep coal roadways under mining influences has been studied (Chen *et al.* 2016). Also using the numerical model of UDEC software for a case study of a longwall coal mine in the Western Coalfield of New South Wales, Australia, the failure mechanism of coal mine roadways has been studied (Mo *et al.* 2020). Based on the numerical model by boundary element method of Examine2D software, the stability of coal mine roadway has been studied (Seedsman 2013). Moreover, by using the discrete event simulation method, the deformation of coal mining roadway has been researched (Baafi *et al.* 2020). Finally, based on numerical model of longwall face, the stability of coal roadway has been analyzed (Seryakov *et al.* 2018).

In the test investigation studies, based on the laboratory test measurement or field measurement, the influence of mining pressure on the deformation of coal roadway has been researched. For example, based on the analysis of roadway deformation monitoring information from across the Selby coalfield in UK, the factors affecting the stability of coal mine roadways have been investigated (Kent *et al.* 1998). Based on the deformation monitoring information of Indian coal mine, the non-linear multivariate model was framed to analyze the influence of continuous miner on the stability of coal mine roadways (Mandal *et al.* 2018). Moreover, based on the field crossline-crossline (SH-SH) shear-wave data of coal roadway in eastern Ohio, the stability of coal roadway has been studied (Guy *et al.* 2003). Moreover, to characterize the behavior of coal mine road during retreating of longwall faces, based on the field measurement results of some roadways in Çayırhan coal mine in Turkey, a convergence model, represented by an exponential function, was developed based on statistical

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analyses (Unal *et al.* 2001). Apart from field measurement studies, some laboratory test measurement studies have been conducted too. For example, using the three-dimensional geomechanical model test of Ningtiaota coal mine in China, the convergence deformation of automatically formed roadway created by roof cutting and pressure releasing have been researched (Wang *et al.* 2020).

Finally, in the theoretical studies, based on the mechanical theory and some hypothesis, the influence of mining pressure on the coal roadway can be researched. Due to the extreme complexity of real engineering, it is very difficult to research the influence of mining pressure by theoretical method. Therefore, there are only a few theoretical studies. For example, based on an elastic foundation approach, the theoretical research on the stress distribution of dynamic pressure roadways has been conducted (Majumder and Chakrabarty 1991). Moreover, by means of theoretical analysis, the failure mechanism of roadway under the partial confining stress in deep coal mining has been analyzed (Guo *et al.* 2021).

From analysis of the above studies, it can be found that, the coal roadways for the longwall mining have been generally researched and the influence of multiple mining cannot be considered in most of the studies. Moreover, the numerical simulation and field test are the two main methods in this field. However, for the difficulty of determination the parameters and constitutive model of numerical model, the field measurement is the more suitable method to study the deformation of coal roadway affected by the mining pressure. Different from the longwall mining, as one kind of green mining technology, the strip mining is one suitable method to protect the environmental disaster caused by the underground coal mining. Moreover, it is often used to reduce operational losses (Skrzyrkowski 2021) and waste management (Skrzyrkowski 2020). Therefore, the strip mining technology has been developed very quickly. However, the stability of mining coal roadway is the key to ensure the safety of strip mining. Because the overlying strata movement of the strip mining is different from that of the long wall mining (Wu *et al.* 1997), the ground pressure behaviour of the strip mining is special. Therefore, the influence of the strip mining on the coal roadway has its particularity. Generally, the coal roadways of strip mining have been affected by the influence of multiple mining, and for the strip mining working face, the ground pressure behaviour is not very obvious. However, the stability of mining coal roadway affected by the strip mining has not been studied in previous studies.

Therefore, to reveal the special deformation characteristics of mining coal roadway affected by the strip mining, and propose the suitable suggestions on the support of this kind of coal roadways, it is a very important work to investigate the deformation characteristics of mining coal roadway of the strip mining and deeply analyze the mechanism causing it. To solve this problem, in this study, based on one typical strip mining area of Xuzhou coal mine in China, the field measurement has been conducted to investigate the deformation of mining coal roadway affected by the strip mining. Moreover, based on the key stratum theory (Kuang *et al.* 2019), the ground pressure behaviour of the strip mining working face has been

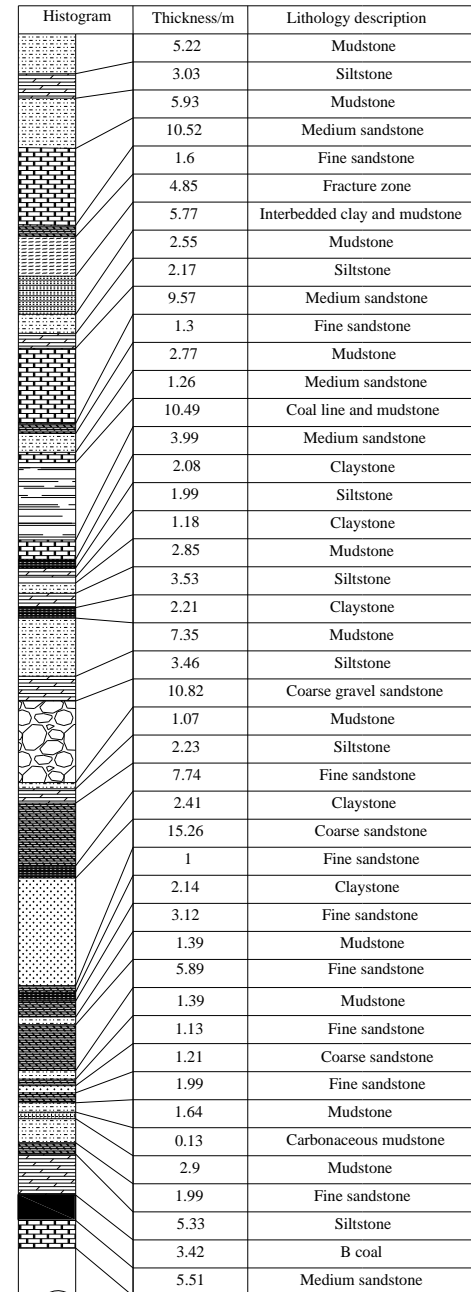


Fig. 1 Geological comprehensive column chart for strip mining area

analyzed to reveal the mechanism causing the special deformation characteristics of coal roadway affected by the strip mining.

2. Strip mining area and field measurement

There is an ancient county with dense buildings on the ground of a mining area in Xuzhou coal mine of China. To protect the ancient county from being damaged by mining, the green mining technology which is the strip mining is applied. The strip mining area is located between -392 and -600 m elevation. The mining depth is in the range of 426 to 636 m, with an average of 531 m. The strike and inclined

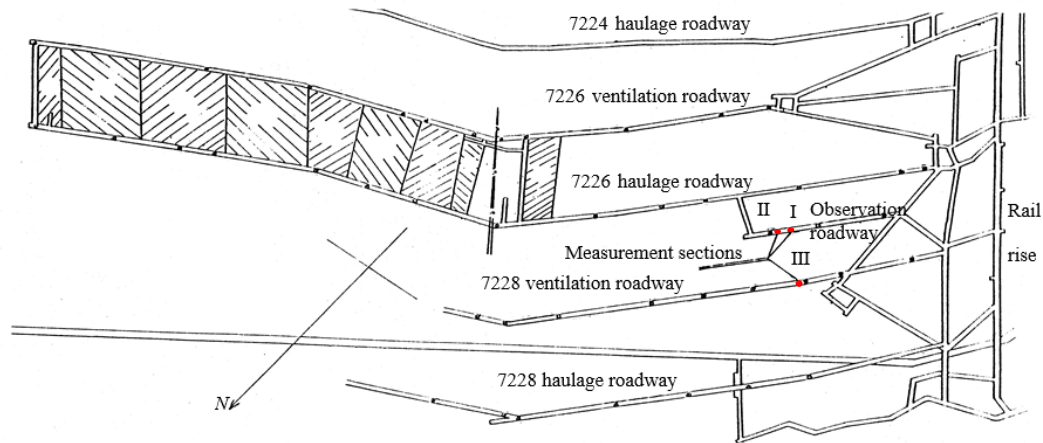


Fig. 2 Layout of strip mining area and field measurement sections

lengths of the mining area are about 350 m and 360 m respectively. And its area is about 7900 m². In this mining area, the coal seam *B* of Shanxi Formation of Permian is mined. The coal seam is a monoclinic structure, whose dip angle is between 28 and 35 degrees, with an average of 32 degrees. The thickness of the coal seam is between 3 and 4.2 m, with an average of 3.2 m. There is a carbonaceous mudstone interlayer in the mid-lower part of the coal seam, whose thickness is between 0.05 and 0.5 m. The geological comprehensive column chart of strata for the mining area is shown in Fig. 1. The hydrogeological condition of the mining area is simple and the water supply is insufficient. The ground elevation of the mining area is between +35.4 and +34 m, with dense ground buildings and flat terrain. The strike strip mining was used for this strip mining area, and the whole mining area is divided into four sections and four working faces, with a total of three strip coal pillars. The first working face is irregular, and the remaining three ones are strike strip mining faces with a length of about 50 m. The layout of the strip mining area is shown in Fig. 2.

In order to investigate the coal roadway affected by the multiple mining, the observation roadway is arranged in the middle of the second strip coal pillar, parallel to the coal pillar strike. For verification, two measurement sections (I and II) are arranged in the middle of the observation roadway, which are 10 m and 5 m away from the crosscut of the roadway. For comparison, there is a measurement section (III) in the ventilation roadway of 7228 face which is arranged at the same position of the measurement section (I). The locations of measurement sections are shown in Fig. 2. Moreover, in one measurement section, there are four monitoring points, which are respectively arranged in the roof, floor and two sides of the roadway, as shown in Fig. 3.

The observation roadway was excavated on January 26th. At that time, 7226 working face was being mined. At March of next year, the observation roadway was abandoned because of 7228 working face mining. Thus, it lasts for more than one year. The measurement sections were set up on January 31, and then measured. The last measurement was conducted on March 24 of next year, with a total of 38 times and a duration of more than 400 days.

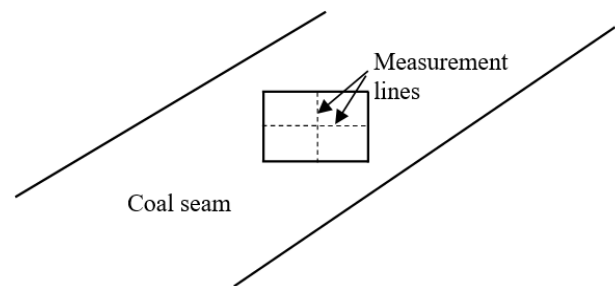


Fig. 3 Layout of measurement section

The deformation is measured by the tape extensometer. After the setting of the monitoring point, due to the instability of the monitoring point, the intensive measurement was carried out several times, with an average of once every seven days. After its stabilization, the measurement frequency decrease, which is once every ten days. In the process affected by strip mining, the measurement frequency increase again to once every seven days. Moreover, because the observation roadway is one full coal roadway, the roof delamination measurement was not conducted. In addition, the observation roadway is supported by the bolting with wire mesh. The spacing of bolts is 0.5 m, and the length of bolt is 2 m. It must be noted that, here, for focusing on the displacement, the load on the bolt has not been monitored.

3. Results and analysis

According to the measurement results, the convergence displacement and its velocity of the roadway with cumulative time and working face advance distance at three measurement sections can be obtained, as shown in Figs. 4 and 5.

It must be noted that, in Figs. 4 and 5, the first line of data on the horizontal coordinate axis is the cumulative measurement time, and the second and third lines are the distances between the measurement sections and the working face.

From Fig. 4, it can be found that, the convergence displacement of roof and floor is much larger than that of

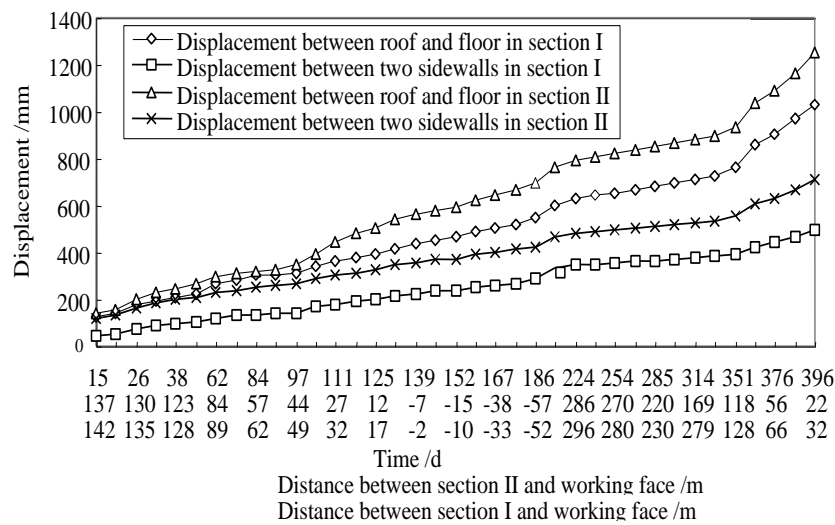


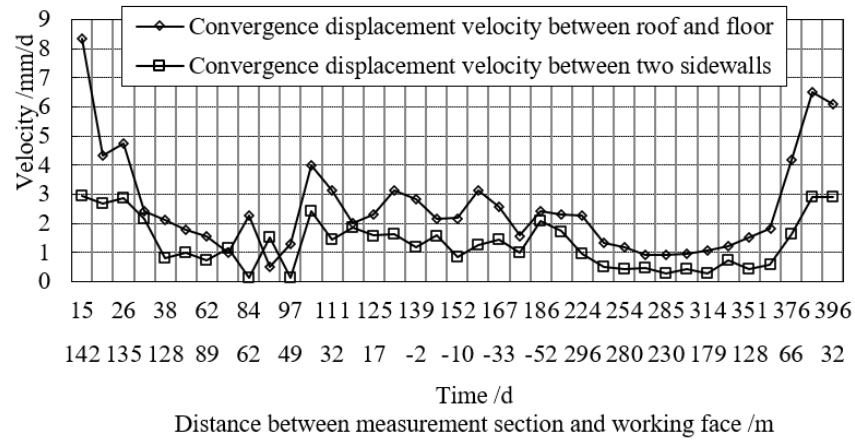
Fig. 4 Measurement results of convergence displacement for the roadway

the two sidewalls. And it is affected by the influence of mining seriously, while that of two sidewalls is almost not affected by mining. That is to say, the slope of the curve for the convergence displacement of roof and floor increases sharply with the mining, and that of the two sidewalls is almost always a gentle slope. The reason for this phenomenon is that, the sidewalls of this roadway is the integrated coal seam, thus, the deformation of integrated coal is not affected by the influence of mining seriously, and its value is not very large. However, the roof of the coal seam is the thin layers of siltstone, and thus, the separation layer will be occurred easily in this kind of roof which will cause large deformation between roof and floor. And the influence of mining on the separation layer of roof is obvious, thus, the influence of mining on the convergence displacement of roof and floor is serious. Moreover, from Fig. 4, for the first mining influence, the convergence displacement of sections I and II increase little, and while for the second mining influence, they increase sharply. The reason is that, as the first mining influence arrives, the coal pillar is still in the state for which one side is mined out and one side is the solid coal, and its stress is not too large. Moreover, at that time, the support conditions for the roadway are still good, so the mining influence on the convergence displacement of roadway is unobvious. While, as the second mining influence arrives, both sides of the coal pillar are mined out, which is in an island state, and the stress in the coal pillar is very large. At that time, the support condition of the roadway is poor. In addition, the roadway deformation has experienced a long time, and the loosening caused by coal rheology is also serious. Therefore, the effect of the second mining influence is obvious. For this influence, the support condition of the observation roadway deteriorates sharply, which makes the measurement work end.

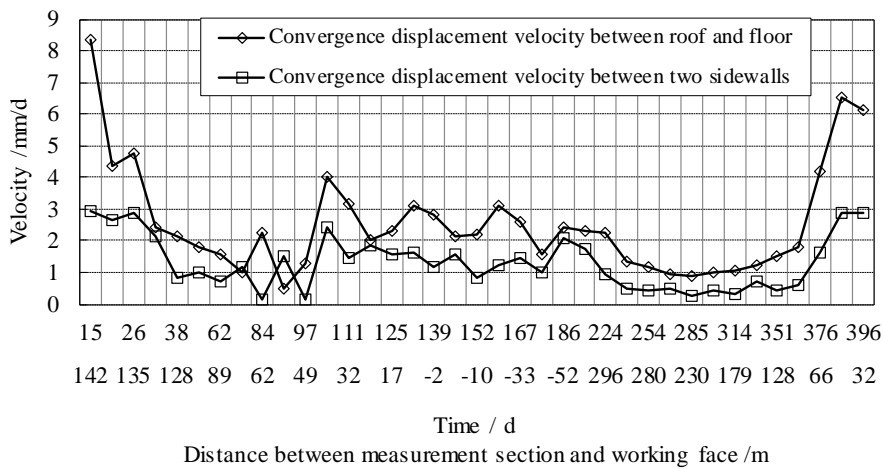
It can also be found that there is a big difference for the convergence of section I and section II, for which there is five meters space. The convergence of section II, which is five meters away from the crosscut, is much larger than that

of section I. The reason may be that section II is close to the crosscut, which is almost near the intersection, and the section area at the intersection is larger, which causes more obvious ground pressure behaviour.

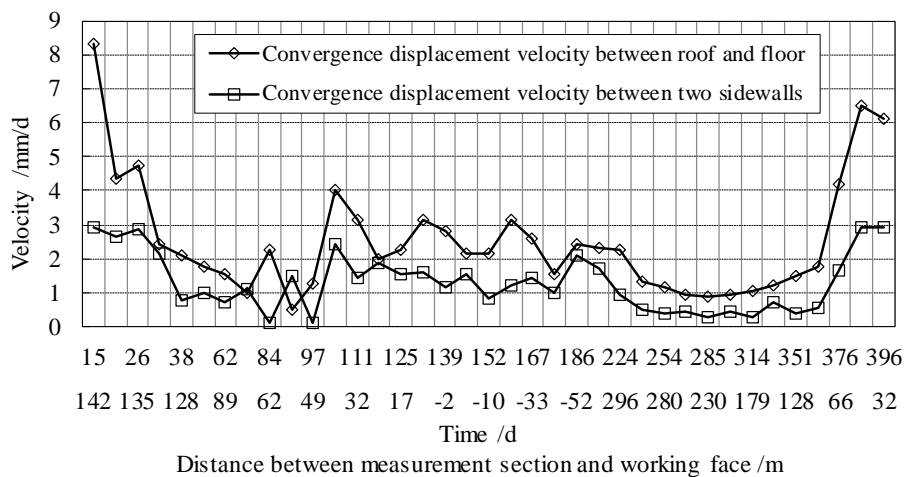
From Fig. 5, it can be found that in the first 50 or 60 days after the setting of the monitoring points, the convergence speed decreased sharply to stabilize at 1-2 mm/d. This is due to the unstable movement of the surrounding coal of the roadway caused by excavation of the roadway. When the working face is 20 or 30 m away from the measurement section, due to the influence of front abutment pressure, the convergence speed of the roadway increases sharply, and experiences the first peak. And then, it enters the severe mining influence period, and at that time, the convergence speed of the roadway is relatively large and very unstable. When the working face advances over the measurement section for about 30-40 m, due to the influence of lag abutment pressure, the convergence speed of roadway experiences the second peak, which is much less than the first one. After that, convergence speed of roadway enters a stable period until the influence of another mining face arrives. According to the previous studies (Qian *et al.* 2010), the universal laws of ground pressure behavior for the mining coal roadway are that, the mining influence appears from 10-20 m to 40-50 m in front of the working face, and lags behind 40-50 m. Those are almost as similar as the results of this field measurement. In this field measurement, the mining influence appears from 30-40 m in front of the working face, and lags behind 50-60 m, which is larger than the universal ones slightly. The previous study (Lu 1982) also shows that for the gob-side roadway of full mining working face, the peak value of convergence displacement velocity generally appears after the working face advances over about 5-20 m. This is different from the results of this field measurement, in which, the peak value appears 20-40 m in front of the working face. This difference can be explained by the difference of strata movement for the strip mining and full mining. The studies of ground pressure show that (Lu 1982,



(a) Section I



(b) Section II



(c) Section III

Fig. 5 Measurement results of convergence displacement velocity for the roadway

Qian *et al.* 2010), the lag pressure of mining working face is caused by the fall and rotation of its main roof hanging beam. And for the strip mining, after the working face advances over, generally there is no fall and rotation of its hard main roof. Therefore, it will not cause large lag

pressure, and there is no peak value of convergence displacement velocity for the coal roadway. Especially, in this field measurement, the measurement sections are arranged in the observation roadway which is in the middle of the coal pillar. For the observation roadway, that is

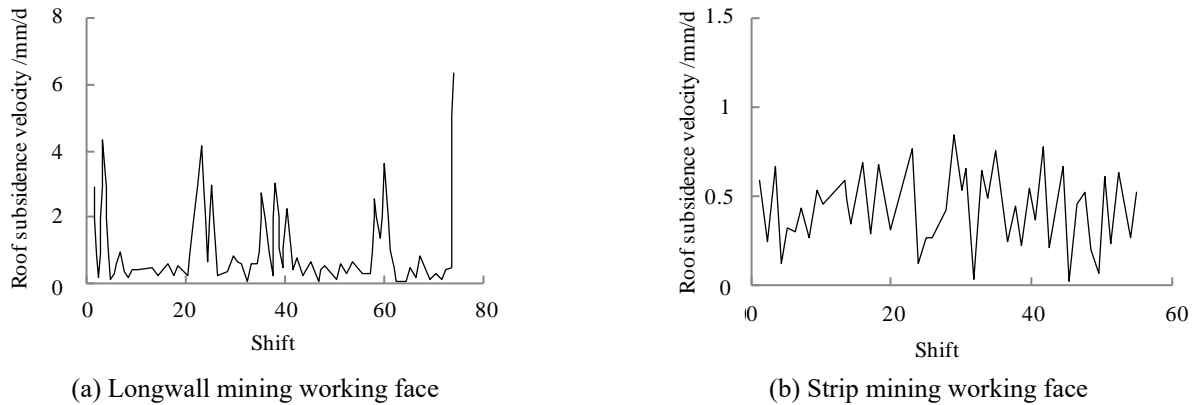


Fig. 6 Monitoring results of roof subsidence velocity for two mining working faces

equivalent to there is a coal pillar whose width is 25 m aside the roadway, and for such a wide coal pillar, the influence of lag pressure caused by the mining working face on the roadway will not be very large. The study shows (Kuang *et al.* 2019) that the front abutment pressure is caused by the integrity of overlying strata, which makes the disturbance of mining working face propagate forward and causes abutment pressure. This is also agreement with the results in this field measurement.

According to the basic information of overlying strata for this working face, based on the basic principle of the key stratum theory (Kuang *et al.* 2019), in the overlying strata, the coarse sandstone stratum which is 31 m above the coal seam and whose thickness is 15 m is the primary key stratum. Based on the key stratum theory (Kuang *et al.* 2019), the strata that control the movement of partial strata or all the strata up to the surface is called key strata. And there are one or more key strata in the overlying strata, among which the top key stratum controlling the movement of all strata up to the surface is called the primary key stratum. Accordingly, the other key strata are called sub-key strata. This control action implies that any deformation or fracture in the key stratum will lead to simultaneous deformation or fracture of the strata under its control. According to the key stratum theory (Kuang *et al.* 2019), for this strip mining area, the primary key stratum of the coarse sandstone stratum controls the movement of all overlying strata. Therefore, to ensure the success of strip mining, the primary key stratum should keep its integrity without breaking (Wu *et al.* 1997).

In order to analyze the integrity of the primary key stratum which is the coarse sandstone stratum in this mining area, the ground pressure measurement have been conducted in a typical longwall mining working face and a strip mining working face in the same coal seam.

The longwall mining working face is the working face 7152, whose length is 86 m and daily progress is 6 m. The ground pressure dynamic instrument is arranged at the middle of the working face to monitor the roof subsidence. The measurement frequency is once per shift. The monitored roof subsidence velocity curve is shown in Fig. 6(a). From the measurement, it can be found that, as the ground pressure behaviour appears at the working face for

the first time, the advances of working face are 31.5 m and 28.5 m for the ventilation roadway and haulage roadway, respectively. As the ground pressure behaviour appears for the second time, the advance spaces of working face are 51.5 m and 48.5 m for the ventilation roadway and haulage roadway, respectively. As the ground pressure behaviour appears for the third time, the advance spaces of working face are 59.5 m and 59 m respectively. As it appears for the fourth time, the advance spaces are 83.5 m and 78.5 m respectively. As it appears for the fifth time, the advance spaces are 94 m and 86.5 m respectively. As it appears for the sixth time, the advance spaces are 112.5 m and 104 m respectively. Obviously, for this longwall mining working face, the distribution of the average periodic weighting step distance shows a wave-shape, and the average periodic weighting step distances are 22 m, 9.25 m, 21.8 m, 9.25 m, and 19 m.

The strip mining working face is the working face 7226, whose length is 50 m and daily progress is 4 m. One ground pressure dynamic instrument is also arranged at the middle of the working face to monitor the roof subsidence. The measurement frequency is also once per shift. The monitored roof subsidence velocity curve is shown in Fig. 6(b). From the measurement, it can be found that, for this strip mining working face, there is no obvious ground pressure behaviour.

It must be noted that, because the advance distances of the working face for each shift are not exactly same, in Fig. 6, the shift is not fully correspondent to the advance distance.

According to the measurement of ground pressure behaviour for above two working faces, the movement of their overlying strata can be analyzed as follows.

The geological comprehensive column chart of overlying strata for working face 7152 is shown in Fig. 7. From Fig. 7, according to the key stratum theory, the key stratum of this working face is the siliceous sandstone layer which is 47.5 m above the coal seam and whose thickness is 15.25 m. This key stratum is similar as that of working face 7226. Moreover, there is a sandstone layer which is 16.9 m above the coal seam and whose thickness is about 9 m. For the longwall mining working face, there is collapse pit on the ground surface above this working face, thus the key

Histogram	Thickness/m	Lithology description
	168.5	
	4.53	Mudstone: variegation, argillaceous structure, brittle
	8.61	Siltstone: gray, argillaceous structure
	16.7	Sandstone: light gray, fine grain, locally mud
	1.08	Mudstone: variegation, massive, compact
	5.36	Siltstone: gray, argillaceous structure, locally fine sandstone
	5.7	Sandstone: light gray, siliceous cementation
	8.64	Mudstone: variegation, containing bauxitic, compact
	1.4	Sandstone: light gray, fine grain, siliceous cementation
	13.06	Siltstone: gray, containing uneven sandy
	6.57	Sandstone: light gray, fine grain, siliceous cementation
	4.44	Mudstone: dark gray, massive structure
	2.44	Sandstone: dark gray, medium and fine grain, siliceous structure
	14.6	Mudstone: dark gray, massive structure, locally sandstone
	2.4	Sandstone: gray, mainly quartz, siliceous cementation
	8.32	Mudstone: dark gray, compact, massive, brittle
	1.64	Sandstone: light gray, fine grain, mainly quartz
	2.41	Mudstone: dark gray, compact, locally containing sandy and plant fossil
	3.09	Sandstone: light gray, fine grain, mainly quartz
	11.41	Mudstone: dark gray, compact, locally containing sandy and plant fossil
	15.25	Sandstone: gray white, medium and fine grain, siliceous cementation
	10.43	Mudstone: variegation, massive, containing siliceous and bauxitic
	2.32	Siltstone: gray, argillaceous cementation
	3.09	Mudstone: dark gray, compact, locally containing sandy and plant fossil
	4.93	Siltstone: gray, argillaceous cementation
	9.76	Sandstone: light gray, fine grain, containing plant fossil
	6.95	Mudstone: dark gray, compact, containing bauxitic
	4.64	Medium fine sandstone: light gray, mainly quartz
	5.38	Mudstone: dark gray, containing plant fossil fragments
	3.25	Coal seam
	11.22	Sandstone: dark gray, locally fine sand
	17.11	Sandstone: gray white, medium and fine grain, siliceous cementation
	9.21	Mudstone: dark gray, containing plant fossil fragments

Fig. 7 Geological comprehensive column chart for longwall mining working face

stratum of this working face should have broken. The overlying strata movement for this working face can be described as in Fig. 8.

From Fig. 8, it can be found that, the long weighting step distance is caused by the fracture of sandstone layer whose thickness is about 9 m. At that time, the key stratum is still in the cantilever state for its high strength (Fig. 8(a)). When the sandstone layer is broken and the working face continues to advance forward about 9 m, the key stratum which is in the cantilever state is broken because it reaches

its limit span (about 30 m), and its breaking inevitably causes the sandstone layer in the lower part to break again (Fig. 8(b)). Therefore, the ground pressure behaviour will appear again in the working face, and obviously, the weighting step distance of this time is less than that of the last time. Since then, with the continuous advancement of the working face, this kind of weighting process will repeat, which causes the wave weighting phenomenon in the working face. This is also the typical weighting process for the longwall mining working face.

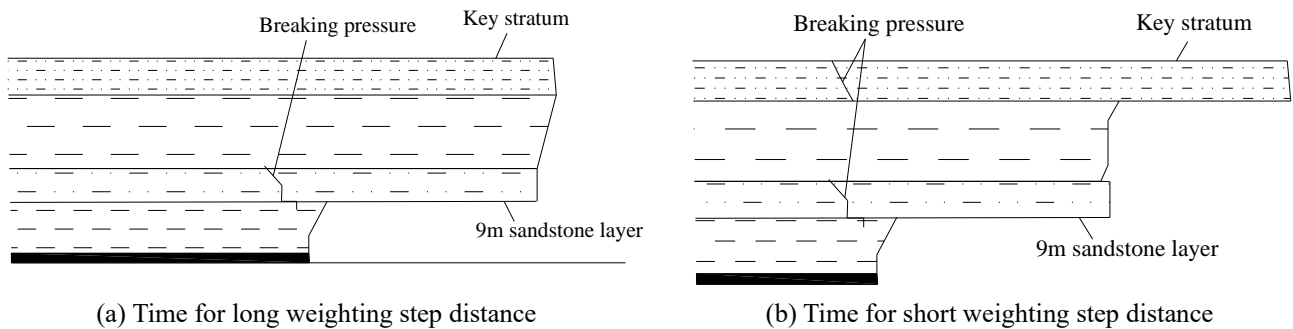


Fig. 8 Overlying strata movement for longwall mining working face

However, from Fig. 1, for the strip mining working face 7226, the interbedding strata between the coal seam and the key stratum are mostly sandstone and mudstone layers whose strength are low. Therefore, those rock strata will fall with the mining, and will not cause obvious ground pressure behaviour in the working face. Considering the ground pressure measurement results of the strip mining working face (Fig. 6 (b)), it can be concluded that the key stratum of working face 7226 does not break. Otherwise, the ground pressure behaviour caused by the key stratum breaking will appear in the working face. In order to accurately determine the integrity of the key stratum for the strip mining working face, we conducted similar ground pressure measurement in other strip mining working faces, and consulted the in-site technical person, which proved that there are no ground pressure behaviour for all strip mining faces. Therefore, we can conclude that the key stratum of the strip mining working face can maintain good integrity without breaking. This phenomenon also directly proves that the strip mining can maintain the stability of the overlying strata and ensure that the coal mining will not affect the ground surface.

Therefore, there is an integrated stratum (key stratum) in the overlying strata of the measurement stope. The key stratum will cause a large front abutment pressure, which is the reason for the measured front peak of roadway convergence displacement. Meanwhile, the existence of this integral stratum also makes the lag distance of mining influence increase, and makes the convergence displacement speed of roadway unstable in the whole mining influence process.

4. Conclusions

Different from the longwall mining, the mining coal roadway of strip mining will be affected by the mining influence many times. Moreover, the overlying strata movement of strip mining is much different from that of longwall mining. Therefore, the deformation of the mining coal roadway for strip mining has some special rules. To study the deformation of the coal roadway of strip mining, in this paper, in one mining area by strip mining of Xuzhou coal mine in China, the field deformation measurement has been conducted in one coal roadway and the ground pressure measurement have been conducted in the mining working face. Based on analysis of the roadway

convergence displacement and overlying strata movement, the special rules for the deformation of the mining coal roadway for strip mining have been revealed. From the field measurement studies, the main conclusions can be drawn as follows.

- The mining has great influence on the convergence deformation of roadway roof and floor, but that of the two sidewalls is almost unaffected.
- When the coal pillar is one-sided mined out, the mining influence on the convergence displacement of roadway is gentle. But when the coal pillar is in island state, the mining influence is serious.
- Due to the existence of the upper integrated key stratum which is hard and thick, there are two peak values for the convergence deformation of the coal roadway. And the peak value of the convergence deformation velocity appears 30-40 m in front of the working face, while the lag influence was 50-60 m behind the working face.
- In the whole mining process, for the transmission of mining disturbance by the key stratum, the convergence displacement velocity of the roadway is very unstable.
- Due to the particularity of roadway deformation by the influence of strip mining working face, special attention should be paid to the influence of peak pressure in front of the working face, and the support should be strengthened when the second mining influence arrives.
- Because the key stratum above the strip mining working face does not break, there is no obvious ground pressure behaviour in the strip mining working face.

It should be noted that, different from the general mining method, the strip mining is actually one special mining method, which can be used for some mining under special conditions, such as mining plants extracting hard coal in conditions of high convergence.

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