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STUDY ON THE ANALYSIS METHOD OF SWELLING DEFORMATION OF PROTECTED SEAM DURING PROTECTIVE SEAM MINING

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Abstract: In view of the study on swelling deformation analysis method of protected seam during the mining process of protective seam, the analysis method of "four invariant points around area" is put forward for the first time. The method determines the swelling deformation of protected seam and analyzes it from the perspective of plane by analyzing the variability of "four invariant points around area" of protected seam before and after the mining of protective seam. Monitoring scheme and area analysis and calculation method are respectively designed applied in coal mine and laboratory; the monitor of "four invariant points around area" has been realized in the mining practice by arranging two measuring lines in the roof and floor of protected seam. The study scheme is designed to analyze the swelling deformation of the protected seam by the application of "four invariant points around area" in the engineering practice; the theoretical calculation method of irregular "four invariant points around area" after swelling deformation of the protected seam is put forward under laboratory conditions based on the Freeman boundary encode vector and measuring the length of quadrilateral side directly with the vernier caliper.; the reasonable scale of the "four invariant points around area" is discussed, it is suggested that different "four invariant points around area" should be established with different scale of 1 times, 1/2 times, 1/4 times and 1/8 times thickness of coal seam. The study shows that the method of "four invariant points around area" of swelling deformation is more accurate than the analysis method of "two fixed-point"; the more cells are divided at 1 times of the thickness of coal seam, the higher the accuracy of calculation is.

INTRODUCTION

With the increase of the depth of coal mining, ground stress, gas pressure and temperature rises, and this has seriously affected the safe and efficient production of coal mines. Mining the protective seam can reduce the original rock stress of the overlying protected seam, release elastic potential energy, make the protective seam and the surrounding rock produce swelling deformation, develop fractures, increase the permeability coefficient, release the adsorption gas from the protected seam and surrounding rock, provide fracture channels for the gas flow and provide the conditions for gas desorption-diffusion-seepage, that is, protective seam mining has the effects of pressure-relief, increasing permeability and fluidity (Ma *et al.,* 2012; Xu 2011; Tu *et al.,* 2006; Yuan Liang 2009; Xie *et al.,* 2014) and Yuan Liang, et al, 2013). Mining the protective seam is one of the important measures to solve the problem of coal and gas outburst.

The permeability of unloaded rock mass during the process of mining the protective seam mainly depends on the swelling deformation rate of the protected seam. Scholars at home and abroad have carried out a lot of researches on the swelling deformation characteristics of the protected seam, Tu Min *et al.,* (2006, 2007) has studied and divided the deformation with similar material simulation experiment and concludes the law that swelling deformation will increase the permeability. Zhang Shujin *et al.,* (2013) with asimilar material simulation experiment, has analyzed the swelling deformation law of the mining seam in dual protective seam of seam group and concludes that after mining dual protective

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seam the swelling deformation curve of protected seam is "M" type in the direction of trend. Ma Zhanguo *et al.,* (2008) has studied the motion rule of mining-induced overburden rock and the stress and deformation rule of the protected seam during the coal seam advancement process with physical simulation experiment. Shi Biming *et al.,* (2008), with a similar material simulation experiment, has analyzed the deformation characteristics in a vertical and horizontal direction and the influence of distance between the protective and overlying protected seam on the protective effect. Valliappan (1997) and Dziurzynski (2001) have studied and analyzed the overburden pressure relief deformation caused by the protective seam mining with numerical simulation.

The above research is mainly aimed at the characteristics of swelling deformation of protected seam and the important influence of swelling deformation on the protective effect during the process of protective seam mining, for the characteristic analysis of swelling deformation, the swelling deformation of the protected seam is represented by the two fixed distance changes in the normal direction of the protected seam. This method only considers the deformation characteristics of the protected seam in normal direction from the view of distance change between the "two fixed points", tensile creep, in fact, has occurred in tendency and normal direction of protected coal seam during the mining process of protective seam. Due to that the traditional coal seam swelling deformation analysis method reflects the swelling deformation of the protected seam by calculating the distance change between the two measuring points in the normal direction of the protected seam before and after the mining of the protective seam mining, the result can not reflect the lateral deformation of the protected seam and the swelling deformation characteristics of coal and rock body accurately. This paper puts forward the analysis method of "four fixed point area" and study on the swelling deformation characteristics of the protected seam from the two dimensional angle, In engineering practice and similar material simulation experiment, the area of the quadrangle is determined with the four constant measuring points in the protected seam, the swelling deformation rule is analyzed with analyzing the change amount of "four invariant points around area" before and after the mining of protective seam. Therefore, the analysis method of "four invariant points around area" uses the area deformation method of the protected seam instead of the traditional method of the distance change between the two points to analyze the swelling deformation; the result is more reasonable and practical than the traditional swelling deformation analysis method.

Now, the variation of the distance between "two fixed-points" is usually used to analyze the swelling deformation of the protected seam, the characteristics of swelling deformation of pressure relief coal is achieved by analyzing the distance change of the "two fixed-points" in the normal direction, before the protective seam mined and after.

In engineering practice, the measuring boreholes are arranged in the top and bottom of the protected seam through the panel crossheading or bed plate tunnel of the protective seam, and a displacement measuring point is arranged in the top and floor of the protected seam to measurement the swelling deformation of protected seam during the process of the protective seam mining, Dziurzynski and Krach (2011) and Du (2011), as shown in Figure 1. The displacement curves about the change of normal displacement with time and working face position in the roof and floor of the protected seam was obtained by the data of recording, and the swelling deformation characteristic is determined.

In the process of experiment simulation of similar materials, the equal distance measuring points are generally arranged on the roof of the protected seam. With the mining of the protection seam, the movement and deformation of measuring points on the roof and floor of protected seam are measured in the normal direction by using the displacement meter. The difference of displacement variation of the two points along the normal direction is expressed as the swelling deformation of the protected seam Ma *et al.,* (2008), as shown in Figure 2.

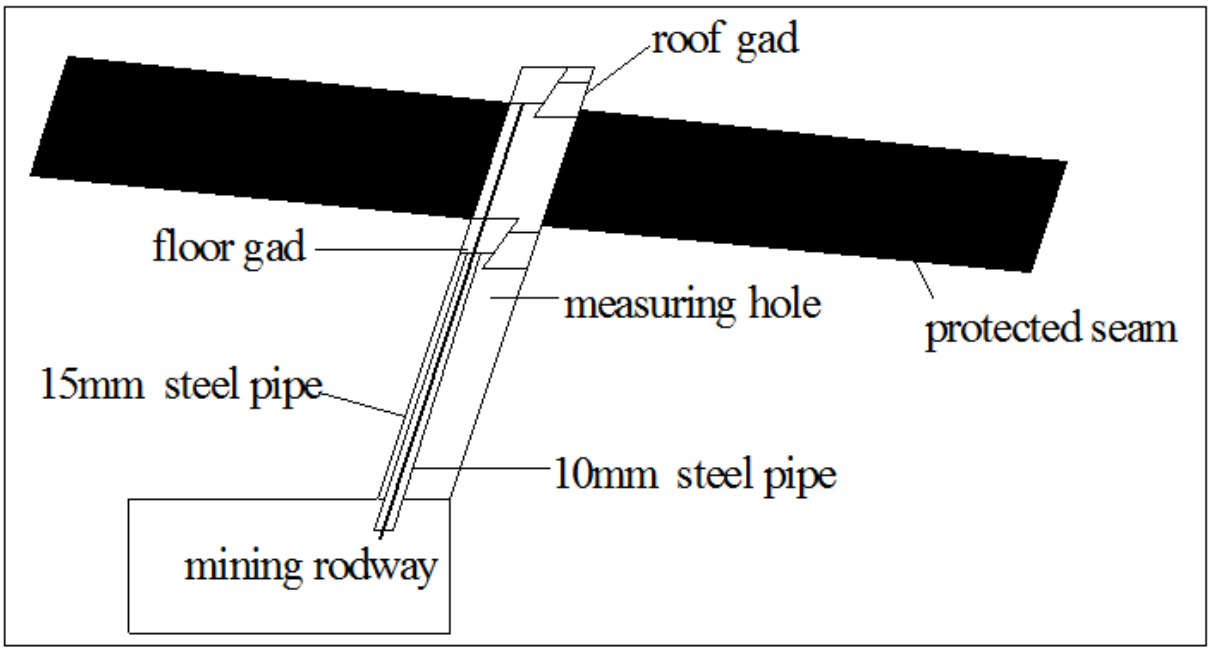

Figure 1: Analysis the swelling deformation of protected seam based on distance variation of two fixed point

ANALYSIS METHOD OF FOUR INVARIANT POINTS AROUND AREA OF SWELLING DEFORMATION

The scheme design of measurement and Calculation method of "four invariant points around area in the experiment of similar material simulation

The scheme design of measurement of "four invariant points around area" in engineering practice is that, two groups of survey lines of "two invariant point" are arranged in the top and bottom of the protected seam through the panel crossheading or bed plate tunnel of protective seam. Determine four invariant points in the protected seam, analyzing the change of "four invariant points around area", before and after the protection seam mining, and realize the measurement of "four invariant points around area" (Figure 3).

The measurement scheme and theoretical calculation of "four invariant points around area" of swelling deformation

The calculation method of "four invariant points around area" of swelling deformation in engineering practice is that the length of the sides 1l and12 along the dip and four fixed-point coordinates of "four invariant points around area" are gained by measuring the length of hole in the protected seam and the layout position of measuring borehole and then the "four invariant points around area " before swelling deformation in the protected seam can be calculated by the "irregular variability software V2.0.4" with the coordinate of each point as shown in Figure 4. Because of the low swelling deformation rate of protected seam, before the protective seam is mined and after, the approximate selection of the "four invariant points around area" is the rule. the down displacement amount (m1) at the top and the down displacement amount (m2) at the bottom of the left survey line of "two invariant points " are obtained according to measurement of the displacement amount of the roof and floor side deformation of the left hole 1#; Simultaneously, the displacement amount (m3) and (m4) of the two points on the 2# can be measured. Among them, the black area around the field is the area before the swelling deformation, the red is the area after the swelling deformation. With the low swelling deformation value of the protective seam in engineering practice, it can be approximately thought that the upper and lower boundary of the surrounding area after the swelling deformation of the pressure relief coal seam is the line between the upper two points and the down two points. The coordinates of the four fixed points after swelling

deformation can be obtained by calculation, taking the left lower corner of the enclosed area as the origin of coordinates. The area (s') of the enclosed area after the swelling deformation of the protected seam can be calculated by irregular variability software. According to the value of the change of the "four invariant points around area", the swelling deformation rate of the protected seam is:

$$n_1 = \frac{s' - s}{s} \times 100\% \quad (1)$$

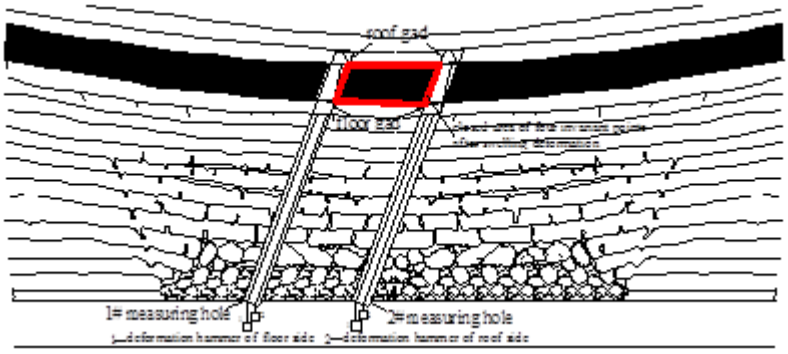

Figure: 3 Schematic diagram of measuring hole layout

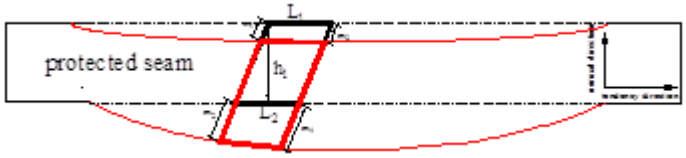

Figure: 4 diagram of four invariant points around the area of before swelling deformation and after

The scheme design of measurement and Calculation method of "four invariant points around area in the experiment of similar material simulation

Based on the visualizing characteristics of similar material simulation, in order to monitor the swelling deformation of the protected seam during the process of mining, the displacement monitoring points are selected on the protective seam. Choosing reasonable scale on the protected seam to arrange monitoring points and pasting the non-coding mark point on the monitoring points. Select four invariant points around area as the research object and make sure the area is quadrilateral, measure the displacement in the direction of dip and normal to the coal seam and the coordinate of four fixed points during the process of swelling deformation of the protected seam by using the XJTUDP software, as shown in Figure 5. Randomly selected four points on the protected seam are A_1 , A_2 , A_3 and A_4 respectively, before the swelling deformation of the protected seam. Assume the four points, after swelling deformation, are $A_1^{'}$, $A_2^{'}$, $A_3^{'}$ and $A_4^{'}$ (Figure 6).

For the experiment of similar material simulation, a steel nail can be used to arrange the four fixed points in different scale in the protected seam and the surrounding region, record the changes of "four fixed points around area" in the process of mining the protective seam and then analyze the swelling deformation rate. Because swelling deformation rate of the protected seam is small under protection seam mining, to simplify the calculation, the calculation model of the "four fixed-point area" is considered as a quadrilateral in the calculation and the length between each two measuring points in the quadrilateral can be fetched directly by using the vernier calipers, the swelling deformation ratio is gained by calculation of the "four invariant points around area" difference before and after the swelling deformation of the protected seam.

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Figure 5: Partial enlargement of mark points

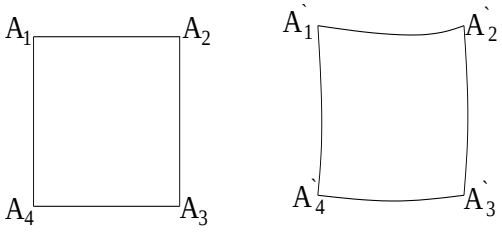

Figure: The diagram of analysis the four point surrounded area

Under the influence of disturbance stress, the four invariant points around area is a irregular quadrilateral after swelling deformation of the protected seam, With the mining of protective seam, using digital camera to take pictures for the area of the "four invariant points around area" obtained the boundary of image and coordinate values of each pixel points on the boundary pi $xl[i]\cdot x$ 、pi $xl[i]\cdot y$ through image segmentation, boundary extraction and tracking, (i means the i pixel point, i =0$\cdots N-1$). The starting point is set in the down-left side of target boundary based on the habit of tracking boundary algorithm, as shown in Figure 7. The vector relation of the adjacent points' position of the boundary target can be expressed by Freeman chain code, the possible eight colligated direction between two adjacent pixels on the boundary curve is defined as 0,1…7,denote respectively the eight directions of 0° ,45° ,90° ,135° ,180° ,225° ,270° ,315° .The position relationship between the previous pixel point and the position as well as the position relationship between the pixel and the next pixel are respectively defined based on the vector relation making principle of Freeman chain code. After the corresponding sum of the vector and the VC program calculation, we can get the quadrilateral $A_1^{'}A_2^{'}A_3^{'}A_4^{'}$ area:

$$S^{'}=\sum_{i=0}^{N-1} pixl[i]\cdot x\cdot B[i]+N_1 \qquad (2)$$

where N_1 is represented as the number of 1 in $B[i]$, $B[i]$ representation the vector relation making principle of Freeman chain code.

$$B[i]=\begin{cases}-1; & a_i=1,2,3\\ 0; & a_i=0,4\\ 1; & a_i=5,6,7\end{cases} \quad (3)$$

The swelling deformation rate of the protected seam is obtained by the area difference between the front and back of protective seam,

$$\mathrm{n}_2=\frac{S^{'}-S}{S}\times 100\% \quad (4)$$

where n_2 is the swelling deformation rate, S is the "four fixed points around area" of the protected seam before swelling deformation, $S^{'}$ is the "four fixed points around area" after swelling deformation.

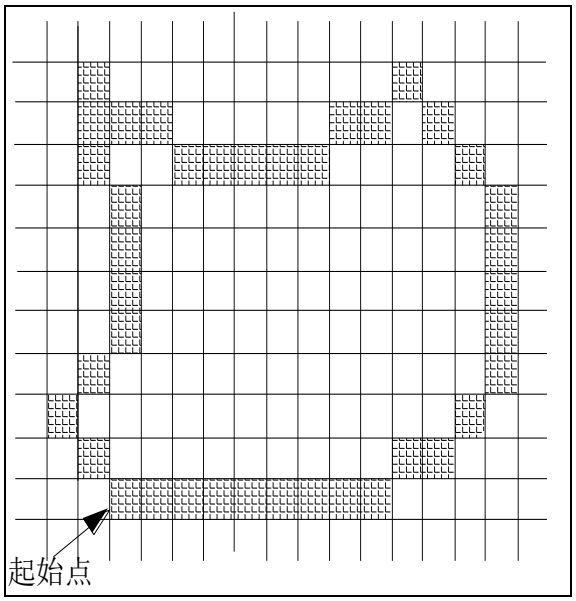

Figure 7: Object's figure of boundary

The reasonable scale analysis of the four invariant points around area

Because of the different thickness of the protective seam, The scale of "four invariant points around area in engineering applications and similar material simulation experiment should be chosen reasonably to calculate the swelling deformation of the protected seam accurately. Therefore, it is initially proposed to analyze the swelling deformation ratio of the protected seam by the basic unit of four invariant points around area" with 1 times, 1/2 times, 1/4 times, 1/8 times, and other different scales of the thickness of the protected seam, as shown in Figure 8.

In engineering practice, the seams, usually thick coal seam (thickness is 3.5~7.99m) or very thick coal (thickness ≥8m), need protective seam mining technology to prevent failure. To choose the "four invariant points around area" conveniently and increase the corresponding calculation accuracy, the thick coal seam is divided into units by the thickness of 1 times, 1/2 times or 1/4 times of the coal seam thickness; the extremely thick coal seam is divided into units by the thickness of 1/2 times, 1/4 times or 1/8 times of the coal seam thickness; Among them, the "four invariant points around area" in 1 times scale of coal seam thickness is divided into 4 units by the geometric scale of 1/2 times of the coal seam thickness; simultaneously, the "four invariant points around area" in 1 times scale of coal seam thickness is divided into 16 units by the geometric scale of 1/4 times of the coal seam thickness ;the "four invariant points around area" in 1 times scale of coal seam thickness is divided into 64 units by the geometric scale of 1/8 times of the coal seam thickness. The more the area units are in the 1 times scale of coal seam thickness, the higher is the accuracy of the calculation.

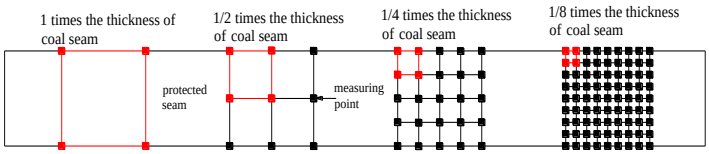

Figure 8: Cell division of different scale area

Consider 1.0 m of thickness of the protected seam as example, analysis of the swelling deformation, by using the analysis method of two invariant point distance variation and the analysis method of four invariant point area and undertake a comparative analyse the accuracy of two methods. The coal and rock swelling deformation ratio of analysis unit is 5%, calculated by the analysis method of two point distance variation, that is, coal and rock increases by 0.005m in the normal direction. Assuming the Poisson's ratio (ν) is 0.36, then the unit length of coal body increases by 0.0018m alone the dip direction of the protected seam by using the Poisson's ratio for estimation.

Since the coal and rock swelling deformation in the protected seam issmall, to simplify the calculation, the four points around domain area is assumed as regular quadrilateral. Then the four invariant points around area" is 1.006809 m2 after the swelling deformation. Because of the "four invariant points around area" is 1.006809 m2 in the original state, so swelling deformation ratio, calculated by the analysis method of "four invariant points around area will be

$$n = \frac{1.006809 - 1}{1} \times 100\% = 6.809‰ \quad (5)$$

Therefore, by using the analysis method of "the four points around domain area the swelling deformation value will be reasonably accurate and reflects compared with the swelling deformation characteristics of the protected seam than the traditional "two point" distance variation analysis method.

CONCLUSION

1. The characteristic of swelling deformation of the protected seam is one of the main indexes of protection effect investigation, this paper puts forward the "four invariant points around area" method for the swelling deformation analysis, analyzes the swelling deformation characteristics of the protected seam from two-dimensional view and considers the deformation effect of protected seam in the dip and the normal direction comprehensively, the result is more accurate and practical.

2. The study scheme and area calculation method are designed to analyze the swelling deformation characteristics of the protected seam by the application of "four invariant points around area" in the engineering practice; The theoretical calculation method of irregular "four invariant points around area" after swelling deformation of the protected seam is put forward based on the Freeman boundary encode vector under laboratory conditions and the area change calculation method by measuring the length of quadrilateral side directly with the vernier caliper.

3. The reasonable scale of the "four site area" is discussed and the "four fixed-pointed area" is established with the scale of 1 times, 1/2 times, 1/4 times, 1/8 times of the thickness of coal seam. The more the area units are in the 1 times scale of coal seam thickness, the higher the accuracy of the calculation is; it is initially proposed that the area unit division should be done by the 1 times, 1/2 times or 1/4 times scale of the seam thickness if the protected seam is thick coal seam and done by 1/2 times, 1/4 times or 1/8 times of the seam thickness if it is an extremely thick coal seam.

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