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To cite this article: Jian Zhao et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 113 012011

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Law of Strata Pressure Behavior in Shallow Coal Seam

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Abstract: The law of strata pressure behavior in shallow coal seam is analyzed, according to the load data of Jinjie Coal Mine 31109 working face hydraulic supports. The first weighting distance of main roof is 80 m, and the periodic weighting distance of main roof is about 20 m. And according to the load data in the middle and both ends of the working face, the working resistance of hydraulic supports and the setting load are a bit small, so they couldn’t meet the needs of supporting roof. Then, the front abutment pressure of working face is analyzed by numerical simulation. It does not only explain the reason that the load is too big, but also explains the reason that the strata pressure behavior in shallow coal seam is serious. The length of undamaged main roof rock beam verifies the correctness of the periodic weighting distance.

1. Introduction and background

A large number of shallow coal seams of Shendong coalfield are mined in China in recent years. The serious strata pressure behavior in shallow coal seam working face has become a technical problem to be solved urgently [1]-[4].

Yin XW[5] studied the pressure law of Pingshuo Coal Mine shallow coal seam fully mechanized caving face. Conclusion shows that the first weighting distance of main roof is 33.7 m, and the periodic weighting distance is 20.7 m. Ren YF[6] studied the breaking characteristics of overburden strata in the shallow buried depth work face by similar material experiment. Conclusion shows that before working face main roof caving, accelerating the mining speed is helpful to avoid the occurrence of hydraulic support crushing accident. Ju JF[7] studied the longwall chock sudden closure incident below coal pillar of adjacent upper mined coal seam under shallow cover in the Shendong coalfield. Conclusion shows that the deeper of the upper coal pillar and the thicker of the inter-burden, the safer it is to mine out of the upper coal pillar region.

However, the strata pressure behavior law of shallow coal seam of which thickness is 3 m is less studied. This paper takes Jinjie Coal Mine 31109 longwall fully mechanized working face as engineering background, studying law of strata pressure behavior in shallow coal seam by site monitoring and numerical simulation.

Jinjie Coal Mine is managed by China Shenhua Energy Company Shendong coal branch. There are 162 ZY12000/20/40D hydraulic supports in working face, and the maximum working resistance reaches up to 12 000 kN. The setting load of 31109 working face hydraulic supports is 25.2 MPa. But, when working face main roof caving, the load of some hydraulic supports are more than their maximum working resistance. The roof and equipment accidents occur frequently, such as roof collapse, hydraulic support failure and so on.

2. Law of strata pressure behavior

To study law of strata pressure behavior, the pressure gauges are arranged on the hydraulic props of hydraulic supports as monitoring points. 16 monitoring points are arranged on 16 of hydraulic
supports for monitoring the load as shown in figure 1. They are the tenth (10#) hydraulic support, the twentieth (20#) hydraulic support, the thirtieth (30#) hydraulic support and so on.

![Figure 1. Hydraulic support monitoring points arrange](image)

The maximum load at the end of each support cycle of hydraulic supports are monitored and recorded by the pressure gauges. Thus, the first weighting distance of main roof and the periodic weighting distance could be respectively analyzed by the load data of November 2013 and June 2014.

2.1. Weighting Distance of Main Roof
Influenced by the complex production site environment and the shearer operating efficiency, the daily mining distance is not a fixed value. So this paper only analyzes the relationship between hydraulic support load and mining distance, ignoring mining date. The hydraulic support load distribution after mining 100 m is as shown in figure 2.

![Figure 2. Load distribution when first weighting](image)

When mining distance is 80 m, the load of most hydraulic supports is more than 35 MPa, so the working face first time appears large area roof caving. And along the working face layout direction, the number of hydraulic supports with serious strata pressure behavior is more than half of the total number of hydraulic supports. Therefore, the first time caving distance of main roof is 80 m. So the first weighting distance of main roof is 80 m. When main roof caving, the hydraulic support average load is about 40 MPa, with a maximum of 51.6 MPa.

In addition, when mining distance is 63 m, there is also once small scale strata pressure behavior on hydraulic supports. But, according to the range and the intensity of roof caving, this is immediate roof large area caving. Therefore, the first weighting distance of main roof is bigger than the first time caving distance of immediate roof.

After first time caving, the main roof begins to periodic caving. When mining distance is 3 045~3 160 m in June 2014, the hydraulic support load distribution is as shown in figure 3.
Figure 3. Load distribution when periodic weighting

When mining distance is 3 065 m, 3 085 m, 3 106 m, 3 139 m, and 3 158 m, main roof caving. And the corresponding periodic weighting distance of main roof is 20 m, 21 m, 19 m, 14 m and 19 m respectively.

Ignoring the effects of immediate roof caving, geological structure and on-site mining process adjustment on strata pressure behavior, the periodic weighting distance of main roof is about 20 m. The hydraulic support load when periodic weighting is generally above 35 MPa, with a maximum of 53.7 MPa at 3 066 m.

2.2. Load Range Statistics

To evaluate the rationality of work resistance and setting load of hydraulic support, the number of load in different ranges is counted and analyzed. When mining distance is 3 045~3 215 m in June 2014, the statistics results of the fortieth (40 #), the eightieth (80 #) and the first hundred and twenty (120 #) hydraulic support are as shown in figure 4.

Figure 4. Hydraulic support load range statistics

Before main roof caving, the load on hydraulic support is mainly about 25~35 MPa, with an average of 29.7 MPa. But, the setting load of 31109 working face hydraulic supports is both 25.2 MPa, so it is unreasonable. Therefore, the setting load should increase to 30.0 MPa. The higher setting load is beneficial to balance the interaction force between hydraulic support and roof in a short time. And it is also helpful to reduce the sinking time of roof and the sinking amount. If the setting load is reasonable, the rock burst disaster would be avoided.

After caving, it forms main roof rock beam after working face. Before main roof caving again, main roof rock beam is stable movement. When main roof caving again, main roof rock beam is strenuous movement, the load on working face hydraulic supports increases sharply and strata pressure behavior is very serious.

When main roof caving, the hydraulic support load is 40.2 MPa on average. And the maximum load of the eightieth (80 #) hydraulic support which is in the middle of the working face exceeds 50.0 MPa, reaching 52.2 MPa. The area of each two hydraulic prop is 0.25 m², so the force on the eightieth (80 #) hydraulic support is 13 050 kN.

This value exceeds the maximum working resistance, so there is a security risk in 31109 working face. And according to load data of other time periods, when main roof caving, the problem that the hydraulic support load exceeds the maximum working resistance is very prominent.
Therefore, it needs to select a new model hydraulic support. The new hydraulic support needs higher work resistance, and the setting load shall be set at 30.0 MPa.

3. Numerical simulation and analysis
The buried depth of shallow coal seam is small, and the original rock stress near the working face also is small. But why the load is too big and the strata pressure behavior is very serious? It will further study the law of strata pressure behavior in shallow coal seam by numerical simulation.

The strata pressure around the longwall working face would be calculated by numerical simulation software FLAC~3D. The results would be helpful to grasp the abutment pressure distribution of working face and the damage status of surrounding rocks. Then, the comparative study would be made between the site monitoring results and the numerical simulation results.

3.1. Modeling and Solving
The average buried depth of the 31109 working face is 120 m, and the inclination angle of coal seam is less than 1°. The vertical stress near working face is 3.5 MPa, and the daily mining distance is 20 m. The numerical simulation model is as shown in figure 5. The main physical and mechanics parameters of coal seam, roof and floor are as shown in table 1\[8\]~[10].

| Position     | Thickness (m) | Density (kg·m⁻³) | Shear modulus (GPa) | Bulk modulus (GPa) | Cohesion (MPa) | Friction angle (°) |
|--------------|---------------|------------------|---------------------|--------------------|----------------|-------------------|
| Main roof    | 6.0           | 2 550            | 4.7                 | 6.0                | 1.2            | 30                |
|              | 3.0           | 2 700            | 1.6                 | 3.4                | 1.6            | 30                |
|              | 1.5           | 2 650            | 1.7                 | 3.5                | 1.7            | 32                |
| Immediate roof | 4.5          | 2 460            | 2.0                 | 3.2                | 1.1            | 18                |
| Coal seam    | 3.0           | 1 400            | 1.5                 | 2.8                | 0.6            | 20                |
| Floor        | 2.0           | 2 650            | 1.7                 | 3.5                | 1.7            | 32                |

The model is 300 m long, 350 m wide and 20 m high. Each block on the XY plane is 5 m×5 m. The length of working face is about 280 m, and the width of working face open-off cut is about 10 m. The constitutive model of all rock layers is Mohr-Coulomb model.

Firstly, original rock stress is be balanced by calculating. Secondly, tailgate, headgate and working face open-off cut are excavated. Finally, mining 20 m every time, until the working face is 80 m away from the model boundary, the total mining distance is 180 m.

3.2. Simulation Results Analysis
After excavating working face open-off cut, the maximum abutment pressure of open-off cut is 4.6 MPa as shown in figure 6, and stress concentration factor is 1.3.
Figure 6. Vertical stress after excavating open-off cut (unit: Pa)

With working face advancing, front abutment pressure is constantly increasing. When mining distance is 10 m, the peak of front abutment pressure is 6.1 MPa, and stress concentration factor is 1.7. When 80 m, the peak is 8.6 MPa, and stress concentration factor is 2.5.

When mining distance is 80 m, the vertical stress of rock layer around working face is as shown in figure 7. After that, the peak of front abutment pressure keeps at about 8.6 MPa, and stress concentration factor keeps at 2.5.

Figure 7. Vertical stress when 80 m (unit: Pa)

When mining distance is 90 m, the vertical stress of main roof in front of the working face coal wall is as shown in figure 8.

Figure 8. Vertical stress in front of the working face

The front abutment pressure is a curve distribution with peak of 8.6 MPa, and the peak of front abutment pressure is on the working face coal wall. Along the advancing direction, it gradually reduces to original rock stress level. In about 15 m away from coal wall, front abutment pressure reduces to 3.5 MPa.

Since that the peak of front abutment pressure is on the working face coal wall, one arch foot of the pressure arch is on the coal wall as shown in figure 9.
So hydraulic support and coal wall need to together support the peak of front abutment pressure. The load on hydraulic support not only include the weight of all cantilever immediate roof and part of main roof, but also the load to hydraulic support transferred from overburden strata through main roof rock beam. This is the reason that the load on hydraulic supports is too big. It further causes that the strata pressure behavior in shallow coal seam is serious.

3.3. Comparative Study
With working face advancing, the damage status of surrounding rocks of working face changes constantly. When mining distance is from 90 m to 170 m, the shear damage status of surrounding rocks is as shown in figure 10. In figure, none indicates elastic state, and shear-p indicates damaged roof caving, and shear-n shear-p indicates plastic state.

After main roof first time caving, the maximum length of undamaged main roof rock beam is always about 20–25 m. This conclusion is consistent with the periodic weighting distance of main roof.

4. Conclusions
(1) The first weighting distance of main roof of Jinjie Coal Mine 31109 working face is 80 m. And the
first time caving distance of immediate roof is less than the first weighting distance of main roof. The periodic weighting distance of main roof is about 20 m.

(2) The peak of front abutment pressure of shallow coal seam working face is on the coal wall. One arch foot of the pressure arch is also on the coal wall, causing that the strata pressure behavior is serious.

(3) The load on hydraulic support when 31109 working face roof caving is generally more than 35.0 MPa, with an average of 40.2 MPa. The load on some hydraulic supports can reach 53.7 MPa.

Acknowledgements
Financial supports from the Doctoral Program of Higher Education of China (20120023110023) and the Fundamental Research Funds for the Central Universities (2014QZ03) are highly appreciated.

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