Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (24): 5739-5743, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.5739.5743

Study on the Law of Fault Open Affected by Water Pressure

[1]Huang Cun-Han and [2]Feng Tao
[1]Institute of Resources and Environment, Henan Polytechnic University,
Jiaozuo, 454000, Henan, People's Republic of China
[2]School of Energy and Safety Engineering, Hunan University of Science and Technology,
Xiangtan, 411201, Hunan, People's Republic of China

Abstract: Fault water inrush is a geological disaster occurring in underground coal mines, which can bring serious threat to mining produce. High water pressure in aquifers is an important factor causing fault water inrush. According to the clamped beam theory of material mechanics, the open displacement formula of fault is deduced to study the fault opening law under water pressure and its criterion is proposed. Based on the deduced formula, the effect laws caused by the aquifer water pressure and the rock's modulus are analyzed. The main results are as follows, the larger the water pressure is, the bigger the fault's open displacement will be and the greater the probability of water inrush will also be. It is negative correlation between the fault's open displacement and the rock's elastic modulus, where the weaker the stiffness of the rock is, the fault will open easier. The example's calculation shows that the faults will all open and it has been proven with the engineering practice.

Key words: Water pressure, fault open displacement, water inrush, rock beam

INTRODUCTION

The present studies show that about eighty percents of floor water inrush accidents relate to the faults directly or indirectly. Therefore fault water inrush is becoming one of the hot issues in mine water inrush research. Scholars discuss the fault water inrush's laws with the methods of the theoretical mechanics (Huang *et al*., 2010), numerical simulation (Li *et al*., 2009; Bu and Mao, 2009; Li *et al*., 2011; Guo *et al*., 2012), experimental study (Huang *et al*., 2009) and others (Liu and Wang, 2012; Shi and Li, 2012; Zhang and Dong, 2011; Zhang and Deng, 2012), which obtain large useful results. Such as, the failure mechanism of water-resisting floor affected by fault is studied with rock shear failure theory and the water inrush criterion is proposed according to the deduced formula of critical water pressure (Huang *et al*., 2010). Based on the model of hydromechanical coupling, the fault water inrush process is simulated with RFPA^{2D}-FLOW or other numerical simulation software (Li *et al*., 2009; Bu and Mao, 2009; Li *et al*., 2011). The effect laws of faults on the height of water flowing fractured zone in floor is obtained by similar simulation tests (Huang *et al*., 2009). Also the fault water inrush is forecasted with microseismic monitoring technique (Zhang and Dong, 2011; Zhang and Deng, 2012). In one word, these researches focus on the effect or process of the fault water inrush mostly, but the inner mechanics of water inrush is not revealed, especially the research on fault open displacement affected by water pressure is few in present.

In fact, combined with the water pressure and the ground pressure, just the opening fault is the water conductive fault, which will lead to the happening of water inrush. And it will provide certain theory basis and practical foundation to the water inrush quantity prediction of fault or the floor water inrush that study the law of the fault's open displacement affected by water pressure. Based on the clamped beam theory of material mechanics, the law of the fault's open displacement affected by water pressure discussed in the study.

CALCULATION PRINCIPLE

Force analysis of fault: Under the influence of ground pressure, the fault will active in mining stope and the fault can be named as the actived fault. Its producing process can be divided into two parts, one is the compression shear process along the initial fault plane and the other is tension process along the top of fault. The mechanical character of the fault plane is compressive, generally the normal positive stress of the fault plane is (Shi and Han, 2004):

Corresponding Author: Huang Cun-Han, Institute of Resources and Environment, Henan Polytechnic University, Jiaozuo, 454000, Henan, People's Republic of China

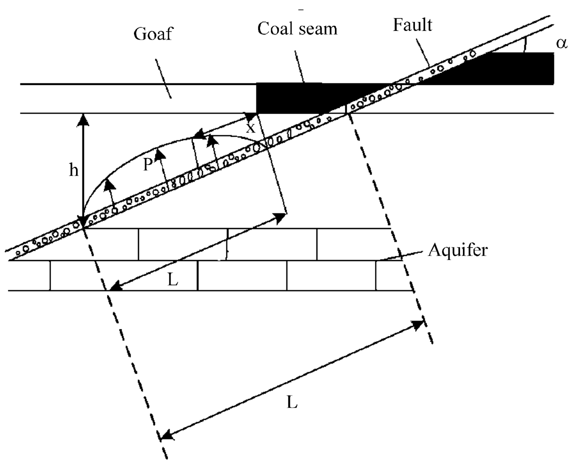

Fig. 1: Schematic diagram of fault opening under water pressure

$$\sigma_n = \gamma H\cos\alpha \quad (1)$$

where, σ_n is the normal positive stress of the fault plane and its unit is MPa. γ is the bulk density of the overlying strata and its unit is $kN{\cdot}m^{-3}$. H is the mining depth and its unit is meter. α is the dip angle of the fault and its unit is degree.

Under the condition of mining, the stress of the coal seam floor will release gradually, which leads to the uncoordinated deformation of the fault's two walls. On the other hand, the fault plane will be expanded by the water pressure from the aquifer. Thus, the wall of the fault near the goaf will move towards the goaf and the actived fault will open. Then, the fault becomes the water conductive fault. If the water flowing fractured zone of the coal seam floor connects with the water conductive fault, the fault water inrush will happen. The schematic diagram of fault opening under water pressure is shown in Fig. 1. Where, P is the water pressure of aquifer, h is the vertical distance from the coal seam floor to the aquifer.

Calculating model of fault open displacement: Based on the clamped beam theory of material mechanics, the fault open displacement affected by water pressure can be calculated. Of course, some mechanical hypotheses are necessary in order to calculate the problem easily. The water pressure in the fault is assumed as an invariable value. The rock strata between the floor and the aquifer is considered and the overlying one on the coal seam is ignored when calculates the normal positive stress of the fault plane. And the rock strata is a single one, its bulk density can be used as the average one of the practical rock stratum. Then, the normal positive stress of the fault plane is:

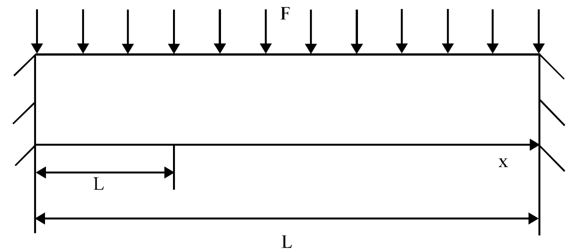

Fig. 2: Calculating model

$$\sigma_n = \gamma h\cos\alpha \quad (2)$$

According to the clamped beam theory of material mechanics, the span-depth ratio of the clamped beam is over eight times. Obviously, the fault meets this condition. Therefore, the calculation of the fault open displacement affected by water pressure can be considered to the rock beam bending problem with both ends fixed and uniform load. The calculating model is shown in Fig. 2.

Where, $F = P - \gamma\, h\cos\alpha$. L is the length of the fault between the coal seam and the aquifer. L' is the length of the fault between the aquifer and the mining face promoting point which is shown in Fig. 1.

Then, the moment equation of rock beam is (Liu, 2004):

$$M(x) = \frac{FL'x}{6}\left(1 - \frac{x^2}{L'^2}\right) \quad (3)$$

When $L' \approx L$, then:

$$M(x) = \frac{FLx}{6}\left(1 - \frac{x^2}{L^2}\right) \quad (4)$$

Thus, the flexing equation of the rock beam is:

$$\frac{d^2v}{dx^2} = \frac{M(x)}{EI} \quad (5)$$

where, v is the displacement corresponding to the point x, that is the open displacement of the fault at point x. E is the elastic modulus of the rock beam. I is the moment inertia of the rock beam. When $x \in (0, L)$, the equation can be integrated and simplified as:

$$v = \frac{7(P - \gamma\, h\cos\alpha)L^4}{60EI} \quad (6)$$

And:

$$I = \frac{bh'^3}{12}$$

where, b is the width of the rock beam and h' is the height of the rock beam respectively. By institution of them, the equation becomes as:

$$v = \frac{7(P - \gamma\ h\cos\alpha)L^4}{5Ebh'^3} \quad (7)$$

Here, v is the maximum open displacement of the fault. The equation is the expression of the fault's maximum open displacement affected by water pressure, which can be used to distinguish the fault opening or not under the water pressure. If P_c is the critical water pressure and v = 0 when the fault opens:

$$P_c = \gamma h\cos\alpha \quad (8)$$

Thus, if $P \le P_c$, the fault closes. Inversely, if $P > P_c$, the fault opens. And the fault becomes the water conductive fault, which can lead to the happening of water inrush easily under high water pressure. In fact, h can be considered as the thickness of the impermeable layer in Eq. 8. Obviously, the bigger h is, the larger P_c will be. Therefore, the water inrush will not happen easily if the thickness is big, which is consistent with the engineering practice. And it proves that the discriminant method of the critical water pressure is correct.

EFFECT FACTOR'S ANALYSIS OF FAULT OPEN DISPLACEMENT

Effect of water pressure: If the value of water pressure P changes from 1.0 to 5.0 MPa, the values of other parameters are shown in Table 1. Because the range of the joint area near the fault is about 20 m generally (Kang, 1996), the value of h' is chosen as 20 m. By institution of them into Eq. 7, the results of the calculation are shown in Fig. 3. It shows that the fault's open displacement increases with the increasing of the water pressure. The closing fault is opening gradually affected by the water pressure. Then, the fault changes into the water conductive fault. When the coal face is driven near to the fault, the water inrush will happen easily. The effect law of the water pressure is coefficient with the practice water inrush. Such as the hydrogeology condition is complex in Jiaozuo mining area (Liu, 2007). And the water pressure value of the Ordovician limestone aquifer is over 6 MPa in several mining area. So, the coal production is on the risk of the high water pressure of the aquifer seriously. For example, the water inrush accident of Zhongmacun mine in Jiaozuo mining area caused by the fault in 1958. The value of the water pressure is 2.5 MPa and the water inrush quantity reached over 6060 cubic h^{-1}, which led to flooded wells. And the accident is one of the typical water inrush accidents in China.

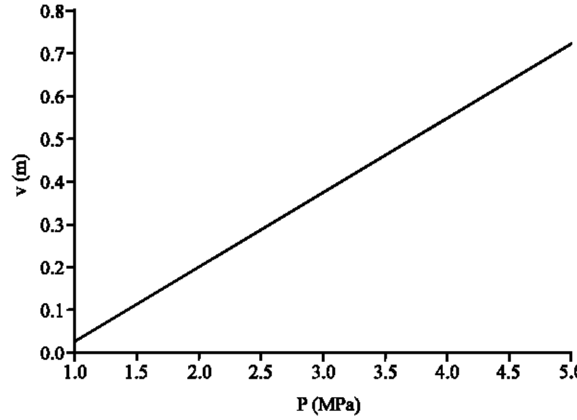

Fig. 3: Relationship between the fault's open displacement and water pressure

Table 1: Calculation parameters of water pressure

γ (kN•m^{-3})	L (m)	α (°)	E (GPa)	b (m)	h' (m)
20	200	30	10	10	20

Effect of rock's elastic modulus: According to the rock mechanics, the elastic modulus of rock or rock mass expresses the difficult degree of the rock or rock mass deformation. The bigger the value of the elastic modulus is, the larger the stress will need when the rock or rock mass produces certain elastic deformation. It shows that its stiffness is bigger than others. Conversely, the smaller the elastic modulus is, the smaller the stiffness of the rock or rock mass will be. Generally, the lithology of the rock or rock mass near the fault is weaker than that of other rock and its elastic modulus is also smaller than others. So it is assumed that the elastic modulus value of the rock beam varying from 1.0 to 10 GPa and the value of water pressure is 2.0 MPa. The values of other parameters are shown in Table 1. By institution of these values into Eq. 7, the results of the calculation are shown in Fig. 4. It shows that the value of the fault open displacement increasing with the decreasing of the rock's elastic modulus affected by the water pressure. It expresses that the weaker the lithology of the rock is, the easier the opening of the fault is. Now, the compression fault evolves into the open fault and the water-inconductive fault changes into the water conductive fault. Therefore, the weak lithology of the rock

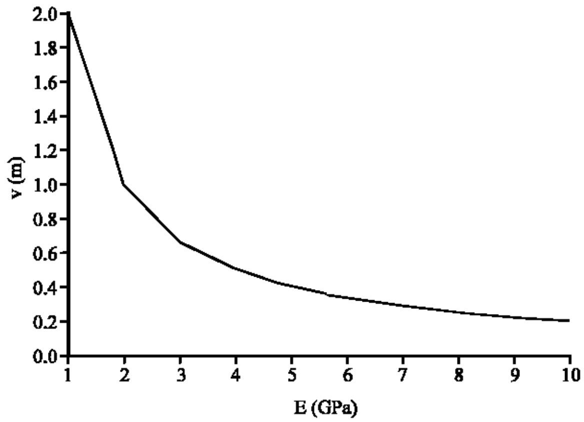

Fig. 4: Relationship between the fault's open displacement and rock modulus

will cause the fault water inrush easily because of the effect of high water pressure. It is consistent with the study result of Huang *et al.* (2010).

EXAMPLE AND RESULTS

Discriminant of fault water inrush: Zhangcun mine lies in the central part of Chaochuan mining area in Ruzhou City Henan Province. In present, the main mining coal seam is the □$_1$ coal seam. The geological structure condition is medium to complexity. The direct water filling aquifer is Taiyuan group limestone aquifer and the indirect one is the Cambrian limestone aquifer. And the distance between the two aquifers is about 20 m. The most effect faults on the mining of □$_1$ coal seam include F_{47}, F_{59} and F_{60}. The three faults all cut the stratum from □$_1$ coal seam to the Cambrian limestone aquifer. The Cambrian limestone aquifer will provide sufficient water source for the faults because it can supply the upper aquifer such as the Taiyuan group limestone aquifer directly. Therefore, the effect of the Cambrian limestone aquifer on the faults is considered.

In order to distinguish the faults open or not, the method proposed above is used. All related parameters are shown in Table 2, where P is the practice water pressure of the Cambrian limestone aquifer and γ is the average bulk density of rock stratum in coal seam floor. All parameters are instituted in Eq. 8 and the calculating results are shown in the last column of Table 2. It is found that $P>P_c$. According to the discriminant method, the faults are all open affected by high water pressure, which will lead to the happening of water inrush. Also it has been proven with the engineering practice.

Table 2: Calculation results of critical water pressure

Fault	α (°)	γ (kN•m^{-3})	h (m)	P (MPa)	P_c (MPa)
F_{47}	65	25.58	38.44	2.59	0.42
F_{59}	70	25.88	38.44	2.59	0.34
F_{60}	20	25.88	38.44	2.59	0.93

Table 3: Calculation results of critical water pressure

Fault	E (GPa)	b (m)	h' (m)	v (m)
F_{47}	21.1	10	10	0.053
F_{59}	21.1	10	10	0.079
F_{60}	21.1	10	10	0.077

Table 4: Calculation results of critical water pressure

Fault	L (m)	b_0 (m)	n	Q_0 (m^3•h^{-1})
F_{47}	43.80	1.293	0.05	571.3
F_{59}	48.24	1.229	0.05	638.2
F_{60}	48.00	1.777	0.05	1375.7

Prediction of fault water inrush's quantity: With the deduced equation of fault open displacement under water pressure, the open displacements of faults in Zhangcun mine can be calculated. The values of parameters are shown in Table 2 and 3, respectively. The calculating results lie in the last column of Table 3. Though every value of fault open displacement is small, its effection is great on the quantity of fault water inrush.

According to the mechanism of seepage conversion, the initial quantity of fault water inrush can be predicted under water pressure. The calculating equation is as follows (Wu *et al.*, 2009):

$$Q = \frac{L^2 b_0^2 \gamma_0 n^2 P}{8\pi\mu h} \quad (9)$$

where, Q is the initial quantity of fault water inrush, its unit is m^3 h^{-1}. b_0 is width of fault water inrush tunnel, which can be instituted with the width of fault zone. And γ_0 is the bulk density of water. μ is the dynamic viscosity of water, which is a constant. n expresses the porosity of rock in fault zone. Other parameters are introduced in Eq. 8.

In order to consider the effect of fault open displacement on the quantity of fault water inrush, b_0 is chosen as the sum of the fault open displacement and the width of fault zone. The values of parameters and calculating results are shown in Table 4. It can be found that the values of Q are all more than 500 m^3•h^{-1} from the table. In fact, the mix mum quantity of fault water inrush happening in Zhangcun mine before is 400 m^3•h^{-1} and the maximum one is 943 m^3•h^{-1}. Therefore, the calculating results are reasonable. And the effect of fault open displacement on Q is obvious from Eq. 9. It shows that the application of fault open displacement is important to predict the quantity of fault water inrush.

CONCLUSION

Based on the clamped beam theory of material mechanics, the maximum open displacement equation of mining fault affected by the water pressure is deduced as:

$$\nu = \frac{7(P-\gamma\ h\cos\alpha)L^4}{5Ebh'^3}$$

and the discriminant method to distinguish the fault open or not caused by the effect of water pressure is proposed.

The effect laws of the water pressure and the elastic modulus of rock beam on the fault open displacement are analyzed. The results show that the fault's open displacement increases with the increasing of the water pressure. And the weak lithology of the rock will cause the fault water inrush easily because of the effect of high water pressure.

The example analysis shows that affected by water pressure all faults in Zhangcun mine will open distinguished by the proposed method, which is proven with the engineering practice. And the application of fault open displacement is important to predict the quantity of fault water inrush.

ACKNOWLEDGMENTS

This study is funded by the National Natural Science Foundations of China (No. 51274095, 51104058 and 41204035), the Doctoral Fund of Henan Polytechnic University under Grant B2011-019 and the Young Key Teacher Foundation of Henan Polytechnic University.

REFERENCES

Bu, W. and X. Mao, 2009. Research on effect of fault dip on fault activation and water inrush of coal floor. J. Rock Mechanics Eng., 28: 386-394.

Guo, X.Z., C.A. Tang, Q.B. Feng and J.X. Zhang, 2012. Numerical simulation of water inrush in thick quaternary slope. Disaster Adv., 5: 838-842.

Huang, B.X., C.Y. Liu and J.L. Xu, 2009. Effect of little fault in working face on water conducted fissure height. J. China Coal Soc., 34: 1316-1321.

Huang, C.H., T. Feng and W.J. Wang, 2010. Research on the failure mechanism of water-resisting floor affected by fault. J. Mining Safety Eng., 2: 219-222.

Kang, Y.H., 1996. The Relationship Between Water Inrush of Ground Working Face and the Temperature Field of the Surrounding Rock. Coal Industry Press, Beijing, China, Pages: 114.

Li, L.C., C.A. Tang and Z.Z. Liang, 2009. Numerical analysis of pathway formation of groundwater inrush from faults in coal seam floor. J. Rock Mech. Eng., 28: 290-297.

Li, K., X.B. Mao and L. Chen, 2011. Research on fault activation and risk analysis of water inrush in mining floor above confined aquifer. Chin. Quarterly Mechanics, 32: 261-268.

Liu, B.Z., 2007. Countermeasure against preventing accidents of water inrush in Jiaozuo coal mining area. Coalgeol. Exploration, 35: 49-51.

Liu, H.W., 2004. Material Mechanics. Higher Education Press, Beijing, China, pp: 176-197.

Liu, X.L. and S.Y. Wang, 2012. Mine water inrush forecasting during the mining under waters. Disaster Adv., 5: 877-881.

Shi, L.Q. and J. Han, 2004. Floor Water Inrush Mechanism and Forecasting. China University of Mining and Technology Press, Xuzhou, China, pp: 35-70.

Shi, X. and L. Li, 2012. A study on prevention measures against water and sand inrush and their application in shendong mining area. Disaster Adv., 5: 1129-1135.

Wu, Y.H., W.Q. Zhang and K.Q. Zhao, 2009. Comprehensive Prevention Technology Research of Mine Water Disaster. China University of Mining and Technology Press, Xuzhou, China, pp: 200-202.

Zhang, H.M. and S. Dong, 2011. Deep rock-burst warning and fault water-gushing monitoring based on seismic monitoring technology. Metal Mine, 6: 16-19.

Zhang, B.H. and J.H. Deng, 2012. Microseismic monitoring analysis methods for disaster prevention in underground engineering. Disaster Adv., 5: 1420-1424.