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Relationship Between Height of Water-conducting Crack and Its Influence Factors

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Abstract Once water-conducting cracks induced by coal mining contact an overlaying water body, water will flow and burst into mine, directly threating safe production in coal mine. The paper, on the basis of analysis and summing up of existing research methods of water-conducting, from theoretical derivation and in combination with production practices, analyzed the relationship between the height of water-conducting crack and the mining thickness and stratum properties, found the clear proportional relation between the height of water-conducting crack and the square root of mining thickness. It was pointed out that the relationship between limit coverture increment and stratum properties and mining thickness plays an important role in determination of the height of water-conducting crack when mining is conducted below bedrock with clay alluvial soil or similar rocks. The bedrock with clay alluvial is impossible to penetrate by descending crack when its thickness is more than double mining thickness. The paper provides a basis for future research on crack in specific coal mining conditions.
Keywords water-conducting crack, mining thickness, stratum properties, clay alluvial layer

Introduction

Coal mining destroyes the structure of aquifer, water leakage into the mining space through water-conducting cracks formated by mining activities. It's a threat to safety of mine production, and also a waste of water resources. Sometimes it will cause some social issues. Therefore, the research and analysis on height of water-conducting crack is necessary to combat water damage in coal mine, and same to mining in fragile ecological environment. This paper defines the influence factors on the height of water-conducting crack and their mutual influences through a series of analysis and derivation, combining with actual production.

Methods of research

Qualitative description about development of water-conducting crack appeared from 1960s. Subsequently field observations and analogy are used to preliminary forecast. It Launched many thematic studies on coal mining underwater since the 1980s in china. So far, empirical formula, simulation, numerical simulation, field-measurements and geophysical methods are widely used(Liu et al. 2010, Wang 2008).

Empirical formula

Empirical formula is widely used to calculate the height of water-conducting crack indoor, according to the coal seam inclination, covered lithology, stratified layers and other factors.

The formula comes from *Procedures on mining under Buildings, water, rail and coal pillar designing of main roadway* which draw up by Chinese Bureau of Coal Industry. The formula is showed in table 1.

Formulas in table 1 have certain application conditions. When thick coal seam layered gently inclined (0°~35°), middle inclined coal seam (36°~54°), thickness of single mining seams 1~3 m and accumulative thickness of mined seams less than 15m, it can be used. Formula 1 indicated that height of water-conducting crack is directly proportional to the thickness of coal mining; in formula 2, the height of water-conducting crack is directly proportional to the square root of thickness of coal mining. At present, empirical formula mainly used in the design of coal mining, calculation results have been used as basic design data and considered certain insurance factors.

Table 1 *Formulas for calculation of the height of water crack in coal mining under building, water and rail*[3]

Properties	Formula 1	Formula 2
Hard	$H_{li}=\frac{100\sum M}{1.2\sum M+2.0}\pm 8.9$	$H_{li}=30\sqrt{\sum M}+10$
Medium hard	$H_{li}=\frac{100\sum M}{1.6\sum M+3.6}\pm 5.6$	$H_{li}=20\sqrt{\sum M}+10$
Weak	$H_{li}=\frac{100\sum M}{3.1\sum M+5.0}\pm 4.0$	$H_{li}=10\sqrt{\sum M}+5$
Veryweak	$H_{li}=\frac{100\sum M}{5.0\sum M+8.0}\pm 3.0$	

Note:
ΣM —Cumulativemining thickness, m;
H_{li}—Height of water-conducting crack, m;
$\pm$ — deviation.

Simulation experiment

Simulation experiment is a model experiment technology based on similarity theory, which is a method of study the natural rules by using the similar features existed in different objects or phenomenon. Simulated the real physical process though the lab physical modal experiment, combined with the features of mine geological structure and the known physical and mechanical properties parameters of rock, modelled according to similarity theory, simulated the failure process of rock, analyzed the failure features and rules during the process of coal mining, mastering the height of water-conducting crack and it's calculation method. Because it is impossible to meet all the similar experiment conditions during the simulation process, so the key to realize the physical simulation experiment is to select appropriately similar parameters. Compared to the field test, physical simulation experiment is more easily controllable, repeatable, and cost saving in a certain way, which can carry out the regular experiment research comprehensively and repeatability(Gu 1995).

Numerical Simulation

Numerical simulation by means of professional calculation software and figure display technology and process analysis method to obtain the relevant overburden rock deformation information of coal mining, and then get more information about rock rotary fracture and height water-conducting crack after coal seam mining. At present, there are many kinds of software in the market which can realize the rock deformation simulation in coal seam mining. Most widely used softwares include FLAC, ANSYS and RFPA developed by doctor Chun-an Tang in domestic, etc. All the softwares mentioned above can carry out rock failure, height water-conducting crack and some relevant research work in coal mining under certain conditions. Relative speaking, numerical simulation research have the advantage of repeatability, intuitive, experiment data trackable record, etc. The key point of numerical simulation experiment depends on the experiment model built reasonability and correctness(An 2010).

Field measurement

Field measurement is one of the main way to ascertain the rules of water-conducting crack. In order to confirm the results of field measurement, the results of numerical simulation or physical simulation can compared to each other to reduce error. Filed measurement method mainly includes ground borehole flushing fluid method and underground upward hole injection experiment method, etc (Zhang 2011).

i) ground borehole flushing fluid method
In this method, the height of water-conducting crack was confirmed according to the consumption of borehole flushing fluid and the level change of the water in the hole. In the process of drilling down from goaf ground, when flushing fluid was obviously consumed and water level in the hole anomalous changed, but drilling process tended to be normal operation, it can be considered as local crack. When the consumption of flushing fluid was obviously increased, water level in the hole falling sharply and keep a increasingly tending until drill-hole finished. It can be considered as falling into water-conducting crack region. The point where consumption of flushing fluid obviously increased can be judged as the height point of water-conducting crack.

ii) underground upward hole injection experiment method
Which can detect the height of water-conducting crack by using the drilling double-end sealing measure leakage device. Mainly taking the method of drilling holes above the goaf in roadway or chamber near mining area. or probing from the droop hole which setted in special roadway. According to the sliding leakage situation of injection water to confirm the height of water-conducting crack.

Besides the research methods mentioned above, physical-prospecting, electrical method, etc have been used in practical production. It mainly include high density resistivity method, ultrasonic imaging method, acoustic CT tomography imaging method. But compared to the filed measurement, simulation experiment, numerical simulation, etc, the reliability of research results obtained by the methods mentioned above need to be improved.

Influence factors of height of water-conducting crack

Height of water-conducting crack depends on a serious mining factors, including thickness of coal mining, rock composition and its physical-mechanics properties. In the same conditions, coal mining method, roof management mode, repeated mining intensity play a important role for the height of water-conducting crack. The analysis of this paper is on the premise of fully mining conditions.

Relationship between height of water-conducting crack and thickness of coal mining

In original theory, when in the same condition, according to the maximum tensile deformation of ground after coal mining, height of water-conducting crack is directly proportional to the thickness of coal mining. This relationship obtained in calculation process of safety coal mining under water according to the maximum tensile values of ground or the bottom of river. According to the presently ground deformation calculate method, the formula 1 is used to calculate ε_0 ,which is the maximum tensile value of ground deformation.

$$\varepsilon_0 = d_1 \frac{m}{H} \quad (1)$$

In formula(1), d_1 is dimensionless coefficient, in specific horizontal coal seam it's a constant value; *m* is the thickness of coal mining, m; *H* is mining depth, m.
Instead ε0 with the maximum tensile deformation value ε_Γ, the relationship between height of water-conducting crack and thickness of coal minging can be obtained, shown in formula (2):

$$H_{\mathrm{T}} = \frac{d_1}{\varepsilon_{\Gamma}} m \tag{2}$$

$$\text{Make } \frac{d_1}{\varepsilon_{\Gamma}} = B_0 \text{, get } H_{\mathrm{T}} = B_0 m \tag{3}$$

In formula (3), B_0 is security coefficient, in specific coal area it's a constant value.

However, the calculate principal of H_T is not convincing enough. Combined with production date, the former Soviet Union mining experts have proven that, as the increased of m, H_T/m decreased, and it can be explained in this way: water-conducting crack size in the normal direction of bending rock strata depended on the curvature of each rock strata(Б,1980).

According to the calculate method above, the calculation of ground maximum curvature K_0 can expressed as formula (4):

$$K_0 = d_2 \frac{m}{H^2} \tag{4}$$

d_2 is dimensionless coefficient, in horizontal coal seam it's a constant value;
When mining depth equal to the height of water-conducting crack HT, if instead K_0 with the maximum calculation curvature K_{Γ}, can get formula (5):

$$H_{\mathrm{T}} = \sqrt{\frac{d_2}{K_{\Gamma}} m} \tag{5}$$

$$\text{make } C_0 = \sqrt{\frac{d_2}{K_{\Gamma}}} \text{, then: } H_{\mathrm{T}} = C_0 \sqrt{m} \tag{6}$$

In formula (6), it is proved that height of water-conducting crack is directly proportional to the square root of thickness of coal mining. a large number of production practice and theory research work have shown that this conclusion have application value.

Relationship between height of water-conducting crack and properties of covered rock

In formula (6), C_0 function depends on ultimate curvature K_{Γ}, and ultimate curvature is the maximum calculate curvature of height of water-conducting crack H_{T} 's rock layers. Ultimate curvature is the objective features of covered rock, and have relation with the property of covered rock.

On the premise of knowing ultimate curvature, height of water-conducting crack in each specific situation by deformation calculation method. When using all the coal top falls method in coal mining, thickness of coal mining equal to height of water-conducting crack, ultimate curvature have the formula(7) (Б, 1980) as follow:

$$K_{\Gamma} = \frac{7.25 q_0 m}{H_{\mathrm{T}}^2 (\mathrm{ctg}\delta_0 + \mathrm{ctg}\varphi_3)^2} \tag{7}$$

q_0 is the maximum subsidence, δ_0 is limiting angle, φ_3 is fully mining dynamic angle.
In formula(7), the amplitude change of δ_0 and $\mathrm{ctg}\delta_0 + \mathrm{ctg}\varphi_3$ is limited. According to the practical experiment generally the value usually taken 0.7 and 1.1. Inserted two value in formula(7), get rock calculate formula of height of water-conducting crack:

$$H_T = 2\sqrt{\frac{m}{K_{\Gamma}}} \tag{8}$$

Then C_0 in formula (6) can be obtained from formula(9) as followed:

$$C_0 = \frac{2}{\sqrt{K_\Gamma}} \tag{9}$$

K_Γ is a function related with the content of pelite, siltstone, clay shale in the rock. When based rock surface covered by clay alluvium, even H smaller than H_T get from formula (8), water-conducting crack can not reach clay alluvium surface. So, the relationship between the incremental of ultimate curvature ΔK and the thickness of clay alluvium play an important role in conforming height of water-conducting crack. According to the practical mining experiment conclusion of former Soviet Union, this relationship can be expressed by experience formula (10) (Б,1980):

$$\Delta K = 0.4 h_\Gamma \times 10^{-3} \tag{10}$$

h_Γ is the thickness of clay alluvium,m.

In order to get the mining depth that water-conduct crack not reach clay alluvium surface, Instead K_Γ in formula(8) with $K_\Gamma + \Delta K_\Gamma$ get formula(11):

$$H_\text{T} = 2\sqrt{\frac{m}{K_\Gamma + \Delta K}} \tag{11}$$

According to formula (11), height of water-conducting crack related with properties of covered rock. But whether the formula (11) is of practical significance to our coal mining in the similar condition need to be confirmed and deep research.

Relationship between height of water-conducting crack and the other features

Height of water-conducting crack depends on thickness of coal mining and properties of covered rock, etc. When the other conditions are the same, coal mining method, roof management mode, repeated mining intensity play a important role in the height of water-conducting crack. For example, height of water-conducting crack caused by fully mechanized caving mining usually more bigger than that caused by room and pillar mining method. If manages the roof with fully top falls method, height of water-conducting crack will get the biggest value. If manages the roof with solid fill method and other method not fully top falls methods, height of water-conducting crack will be very small. In certain conditions, deformation degree of covered rock on mined will be increased by repeated mining, and cause the increasing of height of water-conducting crack, but not all the cases will happen in this condition.

So, when predict height of water-conducting crack, especially minging in the coal area where needed prevention and control of mining damage, protect special aquifer, even ground surface water source, should make a comprehensive analysis of properties of rock stratum, thickness of coal mining, the roof managed way, repeated mining intensity and time interval,etc. Select the reasonable coal mining method, try to predict and control height of water-conducting crack precisely for purpose of mining safety and protecting water source.

Analysis of height of water-conducting crack caused by surface downlink

In coal mining process, it is frequently appeared cracks that across the thickness of coal mining from the surface to clay alluvium, if mining depth under water is smaller than height of water-conducing crack of covered rock, mine are probably to happen water flooding accident. Take northern shallow buried coalfield of Shan'xi, China for example, in coal mining process, diving isolation clay layer tensile damaged due to the bending-down reason, the crack occurred in the rock normal direction from the top surface of aquifuge, and form the down ward water-conducting crack. If water-conducting crack across the clay aquifuge, may lead leakage water into goaf, threaten the production safety, meanwhile, losing preciously water resource.

According to the practical of production and research, after coal mining, crack degree of surface is directly proportion to thickness of alluvial layer. Take Donbass coal mine of the former Soviet Union for example, when the other conditions were the same, on the one coal mining area, not found crack in the outcrop of surface rock, however ,on the other coal mining area where with thick deposit layer, found the maximum cracking 30 cm. Drilling a hole where thickness of alluvial layer is 2 m, and width of crack is 10 cm, the crack disappeared in the depth of 1.6 m. After a large number of field crack observation, it was found that as the increased of depth, crack would decreased slowly until disappeared (Б,1980).

According to a larger number of actual data and similarly material simulation experiment research, it is have been proved that cracks in alluvial layer would disappear in a certain depth. This phenomenon was caused by the special single bending features of alluvial layer. In general case, the depth of crack no more than two times the thickness of coal seam.

Conclusion

(1) Height of water-conducting crack is directly proportional to the square root of thickness of coal mining.

(2) Height of water-conducting crack is related with properties of covered rock in certain degree, especially when based rock covered with alluvial layer or other layers have the similar properties of rock layers. the relationship existed in the incremental of ultimate curvature, properties of covered rocks and the thickness of clay alluvium play an important role in conforming height of water-conducting crack.

(3) In the same conditions, coal mining method, roof management mode, repeated mining intensity play an important role in the height of water-conducting crack.

(4) If the thickness of alluvial layer not less than the two times thickness of coal seam, the downward water-conducting crack formed in alluvial layer from ground surface would not across the whole thickness of alluvial layer.

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