Mechanisms on Mine Water Loss Based on a Theory of Mining-Fractures Development Pattern

Dongjing Xu[1,2], Suping Peng[1,2], Shiyao Xiang[2], Yunlan He[1,2], Le Xu[1,2]

[1] *State Key Laboratory of Coal Resource and Safe Mining, China University of Mining & Technology Beijing, 100083 Beijing, China*
[2] *College of Geoscience and Surveying Engineering, China University of Mining & Technology Beijing, 100083 Beijing, China*
email: xudongjinggg@126.com, psp@cumtb.edu.cn, xiangshiyao1989@163.com, yunlanhe@pku.edu.cn, xl199109@126.com

Abstract

Longwall mining could inevitably induce the generation of fractures in the overlying strata, the dynamic development of which is believed to be one of the most primary factors controlling groundwater leakage. A hypothesis, triangle fracture arch theory, was proposed for the evolution law of mining-induced fractures, considering two cases of ignoring compaction of gob with successive weightings or not. A connection between the evolution of mining-induced fractures, triangle fracture arch and groundwater leakage was developed. In conjunction with practical experience the first two double-stage arches happening in first weighting and periodic weighting for the first time would be seemed as the key parts of the whole fracture development by means of this theory, which led the widening of some fracture pathways for water to flow. Insight into the development of mining-induced fractures can help us know when, where, and how the mining-induced fractures develop and determine key fracture pathways controlling groundwater leakage paths during longwall mining, providing important theoretical basis for safe mining.

Key words: Water loss, mining fractures, triangle fracture arch

Introduction

An increase of energy needs was mainly driven by growing world population and industrialization. However, we must reconcile this with other demands such as environmental quality and the protection of water resources for a better life (Gordalla et al. 2013; Gregory et al. 2011; Osborn et al. 2011). Severe conflicts of interests are especially noteworthy in the protection of water resources and the exploitation of energy resources, even worse in some water-stressed countries. Originally, the water resources are under immense pressure due to the needs of agriculture, industries and drinking of the local inhabitant (Howladar 2012; Bayram and Önsoy 2015). The exploitation activities further aggravate this situation with the direct impacts on the water resources in the mining area such as exhausted springs, well-water level lowering, water flooding/inrushing, water contamination and so on (Zipper et al. 1996; Howladar 2012; Molson et al. 2012; Bayram and Önsoy 2015). China, one of energy giants, is based on coal as its main source of energy, with coal production and consumption accounting for approximately 77% and 65% of the national ones, respectively (Chang et al. 2003; Wu et al. 2009; Yu and Wei 2012; Zhang 2014; Xu et al. 2015). Water resources are extremely scarce and its protection is of vital importance in the mining areas of China.

Generally, the distribution of surface water mainly depends on the topography, vegetation, climate, the conversion between surface water and groundwater and so on (Kollet and Maxwell 2006), which could be isolated from major mining-induced impacts by a less permeable layer and is extremely localized relating to the mining front same as the shallower aquifers (Hill and Price, 1983; Liu et al. 1997). On the other hand, a complex succession of hydrogeological changes occur in hydraulic properties (e.g. hydraulic conductivity, heads, gradients and so on), groundwater chemistry, groundwater flow and groundwater sustainability among the deeper aquifers during and after mining (Booth et al. 1998; Sukhija et al. 2006).

Through the past studies, the dynamic development of mining-induced fractures in the overlying strata is believed to be one of the most primary factors that control the groundwater flow patterns and that lead to considerable water loss into mined panels from the deeper aquifers (Zhang et al. 2010; Islam et al. 2009; Zhang et al. 2014; Poulsen et al. 2014), which poses a great challenge to the hydrogeologists, geophysicists, geochemists as well as to environmentalists and engineers (Sukhija et al. 2006). Currently, a variety of methods, ranging from analytical methods and field experiments to numerical and physical simulation, have been used and mainly focus on the mining-induced effects on water environment (e.g. water level and parametric analysis of water), subsidence (e.g. land and strata subsidence) and the fractures evolution of the overburden strata (e.g. natural and induced fractures propagation, closure and connection) (Peksezer-Sayit et al. 2014; Zhang et al. 2014; Howladar 2012; Panthulu et al. 2001). But very few detailed studies of mining impact on groundwater leakage paths have been reported, more particularly, for the deeper aquifers.

Main objectives of this study are to (1) know when, where, and how the mining-induced fractures develop on the basis of water analysis (2) determine some dominant or key fracture pathways controlling the initiation of an water-conducting way and groundwater leakage paths during longwall mining and (3) spatially and temporally characterize preferential paths in groundwater leakage.

Methods

Under natural conditions, groundwater resources go into coal seams by infiltration and by vertical movement through the surrounding rocks. Nevertheless, overburden desaturation and drainage into the mine caused by numerous upward propagating fractures may occur during and after mining (Islam et al. 2009; Booth et al. 1998). As we all know, nature will eventually seek the most stable configuration when a void is created by external force, which may be enlargement, connection or closure of fractures. Accordingly, coal mining inevitably causes the fracturing of overburden strata, and groundwater flow is controlled by some dominant fractures along which groundwater can preferentially flow towards the mine workings (Howladar and Hasan 2014; Yang et al. 2007). Repetitive operation of mining activities and regular re-distribution of the stress field may lead the dominant fractures to develop directionally, creating a regular or potential fracture face, fracture passage to provide pathway for water movement or leakage.

In this paper a hypothesis approach on evolution law of mining-induced fractures would be proposed, which is triangular fracture arch evolution. Insight into this mechanisim can provide preference for some phenomena about groundwater losses into the mine workings and water disasters during mining process combined with the past results such as field observations, numerical modeling, and physical analogs (Zhang and Shen 2004; Wang and Park 2002; Wu et al. 2004).

Conceptual Models for evolution law of mining-induced fractures

It is assumed that mining-induced fractures evolve in the mode of triangle under complex and variable stress which may make it possible for interconnected system of fractures to form some regular potential face or pathway for water to flow. When mining excavations are made, mining process can be simplified as one that coal is mined with one mobile end at an increasing distance from the other fixed end along the direction of face advance. In addition, one end is constrained less, but the other is changeable and constrained more because of the increasing volume of the extraction and the enlargement in scope. It can be seen as simple repetition of this pattern in disregard of local geological and structural differences and disturbance to fracture evolution caused by previous mining, which would cause the overlying strata above the gob to plunge towards the panel setup entry coupled with effects from the deformation and movement of rock mass. Moreover, assuming that these evolution models are mainly controlled by fractures development in the cross-section of face advance with by that of face length less affected, we just consider the case of flat-lying coal seam for subsequent analyses.

Triangular fracture arch disregarding compaction process

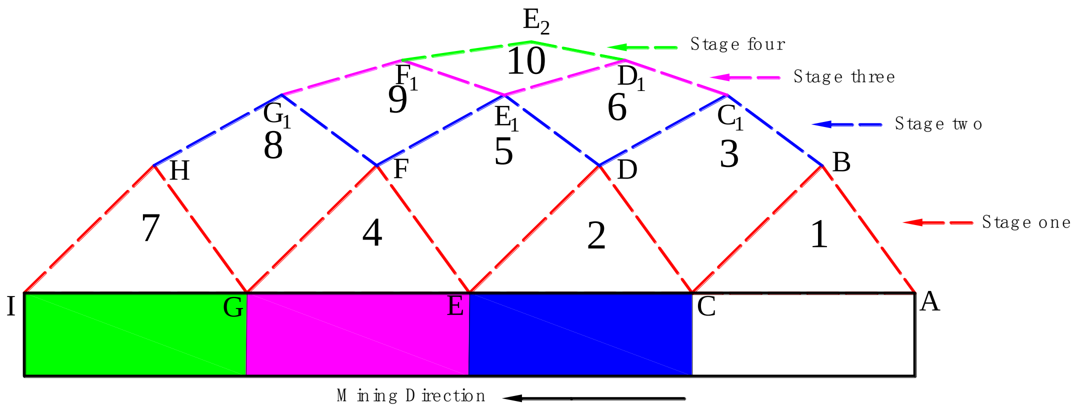

Figure 1 *The schematic diagram of triangular fracture arch illustrating evolution law of mining-induced fractures*

In this model we ignore closure phase of factures from compaction of gob with successive weightings for the moment. As we can see from Fig.1, along with the right-to-left advancing of face, there would eventually have a arch-like fracture arch created above the mined-out area. Moreover, its scope is also forward more than upward, and there is a tendency plunging towards the panel setup entry in overall shape of fractures. There exists criss-crossed potential fracture faces or pathways in its interior which conclude four or more stages of fracture development with nearly identical fracture porosity and permeability at the same stage, from the bottom up naming them as follows: stage one, stage two, stage three, stage four and so on. When coal face reaches a certain distance, the first triangular fracture arch at the first stage appears, namely, fracture ABC seen in Fig.1. And further advancing would cause the second fracture arch CDE.

We suppose that first weighting happens in location E after the formation of two triangular fracture arch at the first stage, fracture arches ABC and CDE, the effects of which can make these two adjacent fracture arches tend to close upward like arch and form the triangle fracture arch BC_1D of the second stage, and the fracture arch of double stage has gotten into shape. Meanwhile, it would widen the fracture pathways of AB and DE of at both sides of fracture arch AC_1E. On the other hand, locations G and I can be seemed as where periodic weighting occurs. Taking G for instance, when periodic weighting occurs the fracture arch EFG firstly emerges followed by DE_1F similar to BC_1D, then the tendency to close would cause it to evolve upward and form $C_1D_1E_1$ at the third stage. During this process, the fracture pathways of CD and GF of at both sides of fracture arch CE_1G would be widened likewise, and similar situations occur with further advancing. We can say that the effects on the evolution of fracture from weighting only cause the formation of triangle fracture arch of double stage, but the other stage evolution mainly depend on the tendency to merge between the neighboring arches. If the evolution of these triangle fracture arches can be classified in chronological order, we obtain a supposed collation in marked numerical order seen in Fig.1. In addition, it is under the influence of first weighting and periodic weighting for the first time where fracture arches develop well, that is, fracture arches AD_1G, AC_1E and CE_1G are the main parts of whole fracture development, because their distances to the panel setup entry are so close that initial deformation and movement of rock mass would give them enough chance to develop. And the fracture arches beyond these distances may be constrained by the interaction of surrounding rock and influence of initial mining. Among these important arches, fracture pathways AB, DE, CD and GF have been influenced and widened by first weighting and periodic weighting. This is the results in disregard of the compaction process after mining.

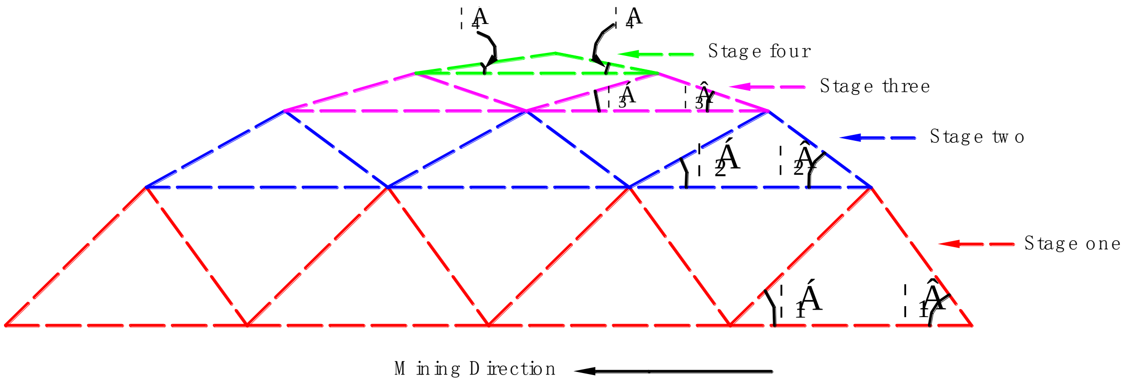

Figure 2 *The schematic diagram of triangular fracture arch illustrating fracture angles*

a) Lateral characteristics of triangle fracture arch

As mining advances, the highest point of every fracture arch moves forward and upward, and its front part grows in length and obviously longer than the rear one along the direction of face advance. These arches are getting so much more rounded with new triangle fracture arches constantly produced. As we can see from Fig.2, there has been an assumption that the fracture angles of every triangle fracture arch can be separated into two branches: front and rear crack angle, α and β, which are acute angles between the front part of every little triangle arch, the rear part and the horizontal line. In addition, some patterns can be concluded as follows: the front crack angle is smaller than the rear one among every little triangle fracture arch at every stage, which is caused by the tendency to the panel setup entry

b) Vertical characteristics of triangle fracture arch

From the vertical distribution of triangle fracture arch we can draw a conclusion that the nearer the triangle fracture arch get to goaf, the more the fracture develops and the larger the fracture angles are. That is, the front or rear crack angle at the first stage is respectively larger than that at the second stage, and so on. We can use triangle of tall and slim, triangle of short and stout to describe them more evocatively. Moreover, along with the upward development of fracture arches the spacing between fracture pathways above and below get smaller and smaller. When these fracture pathways of small spacing are connected, horizontal fractures would be created, then developing with an upward and forward trend.

Triangular fracture arch taking compaction process into consideration

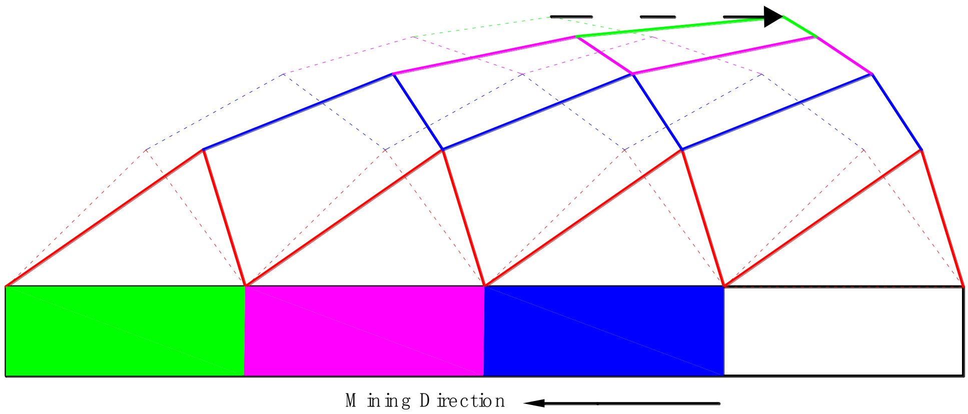

Figure 3 *The schematic diagram of triangular fracture arch considering compaction of of gob with successive weightings*

Based on triangle fracture arch, we can obtain another hypothesis of fracture arch evolution combined with the compaction of gob with successive weightings. It can be assumed that the rear compaction would constantly cause the established triangle fracture arches to incline towards the mined area as the distance of mining face from the panel setup entry increases, which can be seen in Fig.3. During this process, the fracture arches close to the panel setup entry (AD1G, AC1E and CE1G) have also been influenced, inducing fracture pathways C_1DE, D_1E_1FG and BC to widen, together with mining effects on the front strata of face advance. That is because the front part of these triangle fracture arches moving towards the mined space would be widened more than the rear one constrained by the adjacent strata. That fracture increases in the front of face advance and compacted in the back will make the probability of the front part of triangle fractures be extended more than the rear one.

All in all, we can know that whether in disregard of compaction or not would make the fracture pathways C_1DE, D_1E_1FG become the key parts of the whole fracture evolution.

Discussion and Conclusion

In this paper a hypothesis of triangular fracture arch about evolution law of mining-induced fractures has been proposed, which considered two cases: disregarding compaction process or not. This model put forward spatio-temporal evolution laws of mining-induced fractures charactering lateral and vertical development. According to the conceptual models for evolution law of mining-induced fractures, together with practical experience, we can obtain that as the mining advanced through the panel it would mainly create a series of triangle fracture arches in the cross-section of face advance, involving the fracture development of different stage vertically and the front part of every triangle fracture arch in length longer than the rear one with the rear crack angle more than the front one laterally. From Fig.2 we can get the results of fracture angles $\alpha_1<\beta_1$, $\alpha_2<\beta_2$, $\alpha_3<\beta_3$, $\alpha_4<\beta_4$, $\alpha_1>\alpha_2>\alpha_3>\alpha_4$, and $\beta_1>\beta_2>\beta_3>\beta_4$. During the process of first weighting and periodic weighting for the first time the first two double-stage arches would be seemed as the key parts of the whole fracture development, leading to the widening of fracture pathways AB, DE, CD and GF.

Moreover, if the compaction process of gob with successive weightings is taken into consideration, we can find that the established triangle fracture arches would incline towards the mined area, causing fracture pathways C_1DE, D_1E_1FG and BC to be widened seen in Fig.3. In accordance with the above both side, we can draw a conclusion that the fracture pathways C_1DE, D_1E_1FG would become the key fracture pathways of the whole fracture development under the role of two aspects.

On the other hand, during longwall mining groundwater could flow away through these key fracture pathways. It is assumed that the fracture arches possessing double stage, especially AC_1E and CE_1G, can exactly reach roof water-bearing zone. There is no doubt that water would move along the widened fracture pathways C_1DE and D_1E_1FG. That is why locations E and G where first weighting and periodic weighting for the first time happen would become the frequent site of water leakage, even water inrush.

Knowing when, where, and how the mining-induced fractures develop can give us a thorough understanding about key fracture pathways or groundwater leakage paths, providing theoretical basis and technical support for safe mining of coal seam.

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