Research on the Harnessing of Ordovician Limestone Confined-Water in Northern China Coalfields

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ABSTRACT

In this paper, it is briefly introduced that China's Ordovician limestone confined-water menaces coal mining and Ordovician water is prevented and cured to secure the safety of coal mining. The theory of "Down-Three-Zones" is presented on the basis of research and practice in recent ten years. The concept of "Down-Three-Zones" of floor water-eruption is described clearly. Finally, the principle and method of applying the theory of "Down-Three-Zones" are discussed.

1. An Introduction of Damage: China is rich in coal resources. The conditions of coal field geology are quite complicated. There is an area of two million square kilometre of Karst limestone in nine million six thousand square kilometres of territory. The resources of underground water are rather plentiful, but this menaces coal exploration. Sixty percent of coal mines in China are damaged by limestone confined-water in different scales, particularly coal mines located the Carboniferous-Permian coal fields of the Ordovician limestone distribution area of Northern China. Because there is the 500-800 metre thickness of Ordovocian limestone and the well developed Karst contains plentiful water, Karst water can have more than 100 Kg/cm^2 pressure. Limestone aquifers have only distances of several metres or several decade metres to coal seam, Karst water can enter the aquifuge and even the coal seam, large eruptions often occur. For example, a mine of 3 million ton production capacity had an eruption of 2053 cubic metres per minute. This is the largest confined-water eruption which has brought enormous economic damage and threatened the safe production of coal mining. Therefore, the prevention and cure of Ordovician water has immense advantage to the development of the coal industry.

2. There are several decades experience in the prevention of Ordovician water-eruption in China. The prevention of Ordovician water-eruption has two kinds of plans. 1) dewatering and depression: it refers to dewatering of aquifers as roofs of seam and depression of aquifers as floors of seam in mining areas. 2) comprehensive prevention under the condition of having water pressure in aquifers. Due to enormous water, electricity, equipment and lots of other factors, the former isn't used extensively, the latter fits to China's actual conditions and is used widely. So-called comprehensive prevention under the condition of

having water pressure in aquifers refers to mining under coal seam, understanding definite water pressure in order to prevent floor water-eruption, adopting suitable dewatering and depression, blocking up water-flowing, increasing discharge capacity of mines, exploring water-bearing structures, leaving coal pillars to prevent water-eruption, building sluice gates, reforming mining methods to decrease damaged depth of mining etc. Many mines containing large amounts of water have adopted the comprehensive prevention of Ordovician confined-water and have made considerable headway for more than ten years.

3. Forecast of Water-Eruption: Main key techniques of mining under the condition of having water pressure in aquifers are to forecast water-eruption possibility and mining safety. The forecast methods of water-eruption include:

1) Experimental Statistics Method: It mainly refers to applying experimental formulae to forecast water-eruption.

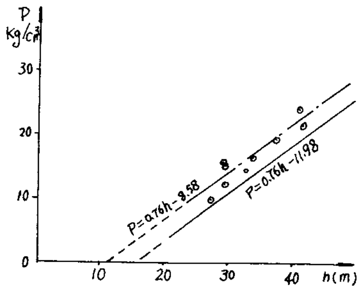
2) Theoretical Analysis Method: It mainly refers to building ideal mechanic equilibrium relations.

3) Comprehensive Exploration Analysis Method: It mainly refers to comprehensive analysis of observation datum obtained by many field and laboratory methods and building the theory fitting to actual conditions to forecast water-eruption.

1) Experimental Statistics Method: The mathematic statistics of many water-eruption materials leads to experimental methods suitable for some mine regions to forecast water-eruption. For example, there are 56 face water-eruptions in 110 total face and driving roadway water-eruption. The experimental relations of face floor water-eruption are deduced from these materials to use curve fitting method, their formulae are:

$$p = 0.76-11.9 \quad (a)$$
$$p = 1.1h-15.2 \quad (b)$$

where p - water pressure, MPa
h - aquiclude thickness, M



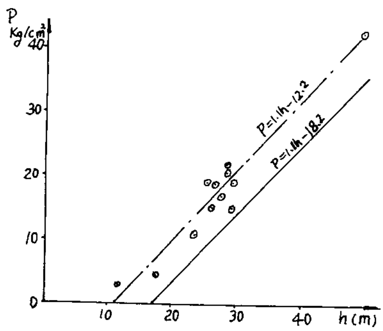


FIGURE 1 FOR a) RELATION

FIGURE 2 FOR b) RELATION

a) relation is suitable for floors having less solid sandstone. b) relation is suitable for floors having more solid sandstone.

a),b) experimental relations approximately reflect comprehensive effects which water pressure, aquiclude, geological structure and mining pressure have on floor water-eruption (see Figure 1, Figure 2).

2) Water-Eruption Coefficient Method: Water-eruption coefficient relations are shown in Table 1.

TABLE 1 - WATER ERUPTION COEFFICIENT RELATION

Time	**Before 1960**	**In the Late 1970s**	**In the 1980s**
Relation	$Ts = \frac{P}{M}$	$Ts = \frac{P}{M-Cp}$	$Ts = \frac{P}{MO-Cp}$
Symbol meaning	Ts-water-eruption coefficient P-water pressure Kg/cm^2 M-aquiclude thickness, M	Cp-floor damaged depth of mining pressure Kg/cm^2	MO-equivalent aquiclude thickness M

The water-eruption coefficient represents water pressure per unit thickness aquiclude, and the critical water-eruption coefficient is meant by the maximum water pressure per unit thickness aquiclude, which is obtained by actual water-eruption datum statistics. Though every water-erution cause and specific condition is different, actual materials show that more than 80 percent water-eruptions are related with faults. Therefore, critical water-eruption coefficient mainly reflects water-eruption conditions of faults and weak zones. It has definite grounds to use critical water-eruption coefficient to forecast water-eruption of faults and weak zones. It fits actual situations. However, its value is less to forecast general floor water-eruption. The critical water-eruption coefficient range of North China's mines is from 0.5 to 1.0, generally 0.7, that is, the water-eruption coefficient 0.7 of planned zones is safe. If more than 0.7, water erupts possibly. But this only fits to forecasting water-eruption of faults and planning of shallow safe mining.

3) Mechanic Equilibrium Relations: The mechanic equilibrium relations of forecasting floor water-eruption are based on structure mechanics and material mechanics. Aquiclude floors are regarded as beams and plates. When beams and plates are destroyed, water-eruption occurs. Beams and plates are forced from up and down directions (as side forces are transformed up and down). Forces considered mainly have water pressure, weight of aquiclude floor, and impulsive force of roof fall. Thus, many formulae are obtained. These

formulae are actually a kind of half experiment and half theory approximate formulae. The above mentioned research methods generally belong to the experimental statistics method, are to build relations among water pressure, aquiclude thickness, etc., by using actual water-eruption datum and experimental datum or are to build computation formulae under given conditions simplified, to apply some mechanics principles, and to lead into experimental datum. Physics and mathematics models of these methods mostly lack field observation experimental bases, can only reflect some causes and conditions similarly and summarily. They have definite reference values. But they have not general meanings actually, lack reliability and accuracy, can not master overall laws of floor water-eruption correctly.

In recent years, the comprehensive observation method has been applied to master the causes and conditions of floor water-eruption and to reveal the laws of floor water-eruption. This method is proved to be effective by recent year experiments.

4) Comprehensive Observation Research Method: In substance, this method is to select different kinds of representative geological and mining conditions, to move into floor aquiclude inside, to see floor aquiclude as research aim, to apply many kinds of methods to study control actions formed by geological structures on water-eruption, to study distribution characteristics of mining pressure and water pressure, to research forcing process, movement and deformation of floor aquiclude, to make simulation experiment in fields, and to master occurrence and development laws of floor water-eruption. General methods applied by comprehensive observation have:

a) Pressure Observation: Pressure equipments are set in stage tunnels of faces and observation tunnels to observe the show of support pressure and periodic pressure.

b) Rock Movement Observation in Bores: It is mainly used to measure displacement and deformation of floor rock along bores under actions of mining pressure. The number and distance of observation points in bores are determined on the basis of actual need.

c) Ultrasonic Observation in Bores: It is determined how the wave speed (Vp) changes with rock transverse tissure development degree with Ultrasonic Rock Parameter Determining Equipment. Finally, floor fissure development laws are analysed by Vp change.

d) Compressed Water Experiment: The principle of compressed water experiment is to use predetermined water pressure, to flood water into different distances of bores of floor rock. The aim is to determine compressed water variations under different mining pressure, to judge damaged depth and strength of floor aquiclude.

Several faces in a few mines are observed by using the above mentioned methods. On the basis of the analysis of enormous field observation datum, the floor water-eruption laws are understood further. To prevent floor water-eruption, the theory of "Down-Three-Zones" is suggested. The theory has good effects in applying process.

4. The Theory of "Down-Three-Zones": In recent years, with the increase of mining level, there was an increase of floor water-eruption, which brought about a great deal of losses in these mines. Therefore, it is very imperative to advance a new kind of theory preventing water-eruption to ensure safe production. The following is the description of the theory of "Down-Three-Zones". Based on results of field datum achieved by comprehensive observations over seven years, results of similar materials simulation and finite-element analysis, we find that three zones exist in the mine floors. They are: 1) damaged zone, 2) normal strata and 3) water-conducting zones.

1) Zone I: Damaged Zone (thickness h1): Damaged zone is located directly beneath the seam, which is not continuous medium because of the effect of mine pressure and could conduct confined-water. It is equal to the 'floor damaged - depth', and it is also divided into zones: lateral and vertical fissure zones, with no boundary between them. The lateral fissure zone is produced under the action of mine pressure or the movement of floor 'compression - expansion - compression'. Many lateral fissures are found at the shallow part. Confined-water below may come into this zone and function on the floor as a homogeneous load, which could bring about the 'floor bulge' and even water-eruption at certain positions. Vertical fissure zone is produced under the action of shear and lateral tensile stress. These fissures may then link up with the confined-water below. The floor damaged-depth depends on theoretically the following factors at the mining face, the mining method, (ie face and advance geometry), the thickness and dip angle of the seam, mining depth, and the floor structures.

a) Mining Method: It affects very much the damaged-depth according to collected data. It usually refers to the strike length of the face (the strike length has few relationships with the damaged-depth) with the advance of the face, it appears again at the same time of periodical pressure, eg, long wall face with roof caving, within 60-100 m strike length. Mining pressure appears clearly with maximum damaged-depth at 10 m before and after the wall. Dip length affects the controlled area distance of roof-caving, which is a main factor affecting the mining pressure. By field datum, when the dip length is less than 70 m, the damaged-depth is less 8-9 m; when 100-130 m, it equals to 13-17 m, when 180 m, it equals to 13-17 m, when 180 m, it might increase to 20 m. It is clear that when the dip length is too great, roof would cave in at several points with no regularities, which results in no increase of floor damaged-depth.

b) Mining Method: It refers to roof control (filling or not), coal pillars, coal cutting manner, the layer number in thick seam, long walls or short walls (on strike or dip direction), props and area of roof control. All in all, it affects appearance of mine pressure, ie the floor damaged-depth.

c) Thickness of Coal Seam: Affects the roof caving. The greater the thickness, the greater the floor damaged-depth generally. In mining thick seams, the influence of first layer is greater and by field datum, the damaged-depth does not increase with the number of layers, generally the damaged-depth would increase 2-4 m when the second layer is mined and little increase when other layers are mined.

d) Dip Angle of Coal Seam: Theoretically, the damaged-depth would decrease with the increase dip angle of the seam, for the decrease of vertical stress. It will be confirmed by field observation results as we are doing research at two faces (76 degrees and 25 degrees coal seam).

e) Mining Depth: Theoretically, the damaged-depth will increase with increase of mining depth, because of the increase of ground stress. This has not been proved up till now for lack of field datum, but we are doing reseach at faces with more than 1000 m mining depth (the maximum in this country).

f) Roof and Floor Structures: The roof structure affects the change of roof caving. The floor structure affects the floor damage.

Though so many factors, the below seams of Carboniferous and Permian period in North China have nearly the same geological and mining conditions. So we consider that the damaged-depth is closely related to the dimension of the coal face. According to field datum at 10 faces, we summed up the following statistical formula:

$$h1 = 1.86 + 0.11L$$

here h1 - Floor damaged-depth (metre)
L - Dip length of face (metre).

The relative coefficient R = 0.97 (see Figure 3), so it expresses the relationship between damaged depth and face dimension. It is very valuable to forecast water-eruption and design the face accordingly but it also should be improved by other data.

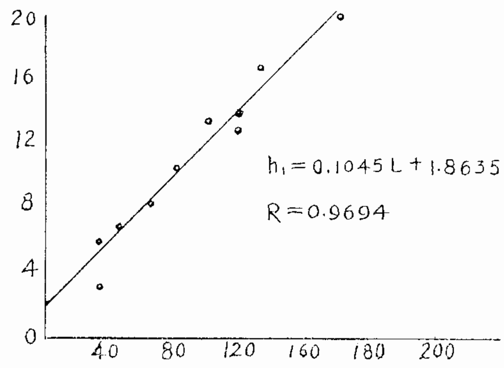


FIGURE 3
RELATIONSHIP OF FLOOR-DAMAGED DEPTH AND DIP LENGTH OF FACE

2) Zone II: Normal Strata (Protective Zone) (thickness h2): It is located beneath the Zone I, and is not affected by mine pressure, remaining in its original state. It has the ability to resist confined-water. It contains the effect zone of "Floor Damaged and Affected Zone" so called before plastic and elastic deformation zones and under formed zones. It is also called protective zone, for it can resist water, which changes from face to face, sometimes very little. It is equal to the difference of all floor thickness h and Zone I and III:

$$h2 = h-(h1+h2)$$

Here h, h1, h2, and h3 are floor thickness, Zone I, II and III respectively. When h>h1+h3, there exists protective zone; when h<h1+h3, there exists no protective zone.

3) Zone III: Original Conducting Zone: It refers to the height of confined-water in the floor. Sometimes it increases with the effect of mine pressure. Since the development of fissures is different from face to face, the height of water in fissure is different. In few cases, water might get at seam or cross out, which is special and might be treated in special method.

This theory is used mainly in forecast of water-eruption and mining design (selection of mining method, determination of face length, division of working section, etc.). By the theory, Zones I and III are water-considered, so they could not be considered as water-resisting layer, though they have still little water-resisting, depending on its thickness, property of strata and its combination.

5. Study of Mining Technology to Prevent Floor Water-Eruption: Two key problems in preventing water-eruptions are exploring and mining technology. How to mine out the seams menaced by confined-water under known geological conditions by changing mining effect in recent years? The authors suggested:

1) Short Wall Mining: Under the condition of thin floor aquiclude, short wall mining may be applied to decrease the damaged-depth. This method has been proven practical. We suggest that the face length be less than 70 m.

2) Strip Mining: If short wall is not still required, strip mining may be applied, considering the roof and their combination to decrease the mining effect. The mining factors should be selected by test data. According to field data, we suggest that the mining width be less than 30 m.

3) Bord and Pillar Mining: If strip mining is not still required, bord and pillar mining may be applied, which could reduce the mining effect on the floor.

4) Filling Gob: If the practical condition is suitable enough, filling gob may be an effective method to reduce mining effect.

5) Advance Direction of Faces: When laying out the faces, their boundary should not be parallel to the faults of 50-70 degrees to prevent the fault fracture coincided with shear zone.

6) Roof Control: When roof is too hard to cave in by itself, artificial caving should be applied to control initial pressure distance less than 10-15 m, not larger than 20 m.

7) Leave Coal Pillars: Faults coal pillars may be left according to the theory of "Down-Three-Zones".

8) Solidating Weak Parts by Grouting: For weak parts in the floor, grouting may be applied to solidate them at the proper time.

9) Dip Long (or Short) Wall Mining: When strike long wall is not suitable, dip long wall mining may be applied.

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