ESTIMATING WATER OUTFLOW RATE OF THE BEDROCK SECTION IN MINE SHAFTS USING HYDROGEOLOGICAL ANALYSIS METHOD

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1. ABSTRACT

This article presents a method to estimate the water outflow rate of the bedrock section of mine shafts on the basis of carefully analyzing the informations gathered from more than 70 pitshafts of about a dozen coalfields in China. This paper details: 1. The characteristics of water outflow rate of the bedrock section of mine shafts under different hydrogeological conditions; 2. Weak points of the existing method of predicting water outflow rate of the bedrock section of mine shafts and the reasons for the suggested method; 3. The suggested hydrogeological analysis method for estimating the water outflow rate of the bedrock section of the mine shafts.

2. Introduction

In recent years, improper working methods were chosen from time to time prior to shaft sinking due to comparatively bigger errors in estimating the water outflow rate of the bedrock section of the shafts (hereinafter called expected water outflow rate), and, the actual water outflow rate turns out to be very much larger than originally expected when the shaft is sunk causing great difficulty in slowing down the sinking speed and increasing the cost of construction. For this reason, it is now in China one of the urgent research programs waiting for early solution to estimate more accurately the water outflow rate during shaft sinking.

Since 1979, many water controlling and combatting activities have been practised in South, East, North and Northeast China, investigation and research have been carried out in the meantime on this subject. This article presents a method of estimating the expected water outflow rate on the basis of summarizing and analysing the actual data from a variety of shafts and applying hydrogeological theories.

3. The Characteristics of Water Outflow Rate from Bedrock Section of Mine Shaft under Different Hydrogeological Conditions

The common hydrogeological feature in the coal fields which is rich in coal measures of Carboniferous and Permian Periods in North, East and Northeast China is: the Quaternary strata is quite thick, normally 100 - 200 metres, with the max. over 400 metres, it contains abundant amount of water; within the bedrock, the water-bearing fissures spread widely in median-grained sandstone and conglomerate with faults well developed, resulting in a complicated hyurogeological situation of the bedrock, which brings forward serious difficulties for the sinking of mining shafts.

At present the average depth of coal mines in China is about 500 metres, the deepest being over 1100 metres. In the process of shaft sinking, normally it will go through two kinds of aquifers:

1. Porous water-bearing layer of Quaternary deposition for which freezing method or other special sinking methods are normally adopted with less water problems.
2. Fissured water-bearing layers in bedrock, among them, the main one is fissured sandstone in coal measures, the few others are crevice water in igneous rock layers and crevice-water and karst water in thin limestone and thick conglomerate.

Three particular types of water outflow events

Type 1: The water outflow rate and the depth of pouring-in point in the shaft below the Quaternary strata are related to the position of each aquifer on the walls of the shaft. When the shaft is sunk through the frozen Quaternary strata and the deeply-weathered band of bedrock, and comes upon the shallowly buried single aquifer, comparatively larger water outflow will usually occur. However, the water outflow rate from each aquifer of sandstone is normally less than 150 tonnes/hour, and the rate from each aquifer of conglomerate is normally less than 250 t/h. The water outflow rate will decrease rapidly with increase of shaft depth, the water outflow rate might drop down to less than 20 t/h when it is of about 150 metres deep in the bedrock zone. This type of water outflow events normally occurs in the shafts which do not pass through faults, and where no faults with throw larger than 30 metres are presented within about 500 metres to the shaft. Such water outflow normally comes from the sandstone and conglomerate with mainly weathered fissures.

Type 2: The water outflow rate and the depth of pouring-in point in the shaft below the Quaternary strata are not in close relation with the position of each aquifer on the shaft wall, but mainly controlled by the faults. When the shaft is sunk through each aquifer whereby a fault is exposed, the water outflow rate will be normally larger than 150 t/h; if the fault lies in the range of 500 metres from the shaft but does not cut through the shaft, the water outflow rate will normally be less than 150 t/h.

Type 3: The water outflow rate and the depth of pouring-in point in the shaft below the Quaternary strata are only related to the lithological characters of rocks of each aquifer, they are not directly related to the faults or the position of aquifer on the shaft wall. The water mainly comes from the lithification fissures of igneous rock and the distribution of fissures is in conformity with the shape of the igneous rock. The water outflow rate is more than 100 t/h.

4. The Weak Points of the Existing Method for Predicting the Water Outflow Rate and the Reasons for the Suggested Method

1. The weak points of existing prevailing method for predicting water outflow rate.

At present, except for certain cases where the analogue method or empirical formula is used, the following formulas are widely used in the calculation of the expected water outflow rate:

$$Q = 1.366\,K\,\frac{(2H - S)\,S}{\lg R_o - \lg r_o} \quad \text{(pressure free water)}$$

$$Q = 2.73\,K\,\frac{MS}{\lg R_o - \lg r_o} \quad \text{(pressure water)}$$

$$Q = 1.366\,K\,\frac{2HM - M^2 - h^2}{\lg R_o - \lg r_o} \quad \text{(pressure water transfers to pressure free water)}$$

where:

Q - expected water outflow rate	(tonnes/hour)
K - permeability coeficient	(metres/day)
r_o - radius of the shaft	(metres)
R - radius of effected zone	(metres)
$R_o = R + r_o$	(metres)
M - thickness of water-bearing layer	(metres)
S - Drop of water level	(metres)
H - Water head [original water head (level)]	(metres)
h = H - S	

The above formulas are valid for calculation of water outflow rate when the flow of water is an even, laminated and steady flow. But in actual shaft sinking, it is very rare to find such ideal conditions especially in the process of shaft sinking, the underground water normally appears in a form of unsteady flow. It is obvious that the natural conditions are different from the prerequisites for above formulas, so that they fail to interpret the reality. Hence the comparatively big deviation appears between the calculated result and actual water outflow rate. (see table 1)

Table 1. The Comparison between the Calculated Water Out flow Rate and the Actual Rate from the Bedrock Section of the Shaft

Name of Shaft	Calculated water outflow rate using the formulas			Actual water outflow rate measured from grouting boreholes or shafts (tonnes/hour)
	lithological characters of aquifer	thickness (m)	water outflow rate(t/h)	
Main shaft Huang-huai colliery Guang-dong province	Sandstone of Dalong group and Andesite	30	21	Max. water outflow rate from one borehole on face is 262
Ventilation shaft Beiyuan colliery Jiangxi province	Conglomerate	230	small	Actual water outflow rate measured in the shaft is more than 600
Main shaft Datun colliery Jiangsu province	Conglomerate	100	small	More than 200
Main shaft Zhangshuanglou Jiangsu province	Five layers of sandstone	50 in total	25	More than 200
Main shaft Linhuan colliery Anhui province	Sandstone layers K_2, K_3	50 in total	small	More than 300
Main shaft Jiangzhuang mine Shandong province	Three layers of sandstone and one layer limestone	30 in total	small	More than 150
Main shaft Jiulongkou mine Hebei province	Sandstone		small	More than 150
Main shaft, 4th Hongyang colliery, Liaoning province	Diabase	63	17	More than 200

2. The reasons for the suggested method

2.1 Water content variation and uneven permeability of the fissured strata.

Field observation of many mine shafts has proved that there are a lot of differences in size, quantity and location of rock fissures for each shaft, so that the water contents and the permeability of rock vary greatly. For instance, the Zhangshuanglou main shaft was sunk in a water bearing sandstone of 6 metres thick at the depth of 500 metres from the surface, the total water outflow rate was 75 tones/hour, but the water outflow rate from one fissure of 50 mm wide, 6 metres long, in east side of the shaft, was 50 tonnes/hour. The investigation of measurements from many on-face grouting boreholes, clearly shows that the water outflow rate from boreholes differs greatly from one to the other. Among the 11 grouting boreholes on the prime working face in Huanghuai main shaft, the max. water outflow rate from one borehole was 262 tonnes/hour while the min. rate was 35 tonnes/hour. In Jiangzhuang auxiliary shaft, the water outflow rate from No. 6 grouting borehole was 26 tonnes/hour, after grouting in 80 tonnes of cement, the water outflow rate from nearby No. 7 borehole, which was drilled into the same water-bearing layer about 1 metre apart, was 27 tonnes/hour. The above 3 cases prove not only that even within the narrow space of the sinking shaft the water content in the same aquifer is quite different and the interconnection between water outflow rates from different boreholes of small distance apart is not clear, but also prove that the water outflow rate depends mainly upon the size of fissures instead of their quantity which is normally in hydrogeology a basic and most important parameter. At the same time they disclose a fact that the intention to use the above formulas with the data collected from just one inspection borehole and take the result of calculation to guide the shaft sinking operation is obviously not reliable.

2.2 The environmental conditions of water flow in the shaft.

In addition to the fissure gap space, the occurrence and the rate of water outflow into the shaft depend also upon the water entry channels and water source surrounding the shaft.

There are three basic relations existing between the occurrence as well as the rate of water outflow in the shaft and the environmental conditions of the shaft:

a. In case where no faults with throw bigger than 30 metres exist at or in the region of 500 metres reach from the shaft and the water content is poor in the Quaternary strata in the top section of the shaft and a clay layer in contact with the bedrock is widely spread over at the bottom of that Quaternary strata, the water outflow rate is quite small even when the shaft passes through hundreds of metres of sandstone with developed fissures.

b. When faults with a throw of more than 30 metres exist in the vicinity of the shaft, there are possibilities of shaft flooding even when thick layer of clay exists at the bottom of the Quaternary strata above the bedrock, or no water bodies exist in the Quaternary strata or on the surface.

c. If faults with a throw of more than 30 metres and aquifers of Quaternary strata or surface water bodies exist at the same time in or near the shaft, there is certainly water outflow dangerous to the life of the shaft. (since mine shafts are normally some distance away from limestone water of Ordovician Period, it is not refered to in this article).

From the discussion above it is clear that the occurrence and the rate of water outflow into the shaft are the result of the combined action of factors such as lithological characters of rocks, rock fractures and water bodies above or under the ground, etc. That is to say, they are dependent upon the local hydrogeological conditions of the shaft. All these factors are neglected when the formulas are used for calculation.

2.3 The changes of hydrodynamic conditions after the shaft being sunk.

Apart from the above-mentioned factors affecting the rate of water outflow into the shaft, there is another very important factor, i.e. the significant changes of patterns of both the original underground waterflow field and fissures within the surrounding strata. When the shaft is sunk, a comparatively large column of rock is removed, (this is different from a small diameter borehole), causing the loss of balance of inherent stress within the rocks. The walls of the shaft and also the rock behind the walls are damaged, resulting in new deformation of rocks and forming new tension fissures, encouraging the inrush of underground water. With the increase of the pressure difference inside and outside the shaft wall, the underground water flow speed increases accordingly. After the inrush of water into the shaft, it becomes the lowest draining point of the whole field, the affected zone expands continuously along with the pumping out of large quantity of water, and new sources of water might be drawn in. All these factors are important causes for large outflow of water after a shaft being sunk and the occurrence of later-arrived water.

Furthermore, it is impossible to draw conclusions from all these complicated conditions naturally existed and altered by human activities by the use of a few formulas which are applicable only under certain prerequisites. Only through on-site investigation and studying of detailed hydrogeological conditions of different types in and around the shaft and their changes after the shaft being sunk, can we predict more accurately the expected water outflow rate closer to the reality.

5. The Hydrogeological Analysis Method for Estimating Water Outflow Rate.

Summing up all kinds of hydrogeological conditions so far experienced and the actual water outflow rate from each aquifer respectively, the differnet hydrogeological conditions of mine shafts may be classified into six types of four classes (simple, medium, complicated and extremely complicated), in accordance with the regulations in China for water outflow rate during shaft sinking. This classification is used as a guideline for estimating water outflow rate and for combatting shaft flooding. Due to limited space available, the above classification can be summarized in the following list:

Hydrogeological conditions of mine shafts	Expected water outflow rate from each aquifer	Hydro-geolo-gicalclass	water combatting measures in shaft sinking
1. Sandstone layers exist in the shaft. Water content in Quaternary strata on top of bedrock is poor. Clay layer in contact with bedrock spreads widely at the bottom of Q.S. No faults with throw larger than 30 m exist in the region of 500 m from shaft.	less than 20 tonnes/hour	simple	Normal sinking method
2. Sandstone and Conglomerate layers exist in the shaft. There is a high water content layer of Q.S., with no clay layer at the bottom of it, on top of bedrock, or, there are surface water bodies, No faults with throw larger than 30 m in the region of 500 m from shaft.			
(1) More than 150 m below top of bedrock.	less than 20 tonnes/hour	simple	Normal sinking method
(2) Less than 150 m below top of bedrock	more than 40 tonnes/hour	compli-cated	Water combatting measures necessary
3. Sandstone layers exist in the shaft. There is no layer of high water content Q.S. or surface water bodies on top of bedrock, or, there is a thick layer of clay at the bottom of Q.S.			
(1) Faults with throw of more than 30 m exist more than 100 m away from shaft.	less than 40 tonnes/hour	medium	Use of water com-batting measures to be decided upon local conditions
(2) Faults with throw of more than 30 m exist within 100 m from shaft.	more than 40 tonnes/hour	compli-cated	Water combatting measures necessary
4. Sandstone layers exist in shaft. There is a high water content layer of Q.S., with no clay layer at the bottom of it, on top of bedrock, or, there are surface water bodies. Faults with throw of more than 30 m exist in range of 500 m from shaft, but no faults pass directly through shaft.	more than 40 tonnes/hour	compli-cated	Water combatting measures necessary

continued

5. Sandstone layers exist in the shaft. There is a high water content layer of Q.S., with no clay layer at the bottom of it, on top of bedrock, or, there are surface water bodies. Faults exist both at and near shaft.	more than 100 tonnes/hour	very complicated	Water combatting measures necessary
6. Conglomerate or thick layer of igneous rock bodies exist in shaft. There is a high water content layer of Q.S., with no clay layer at the bottom of it, on top of bedrock, or, there are surface water bodies.	more than 100 tonnes/hour	very complicated	Water combatting measures necessary

For the last few years the classification method described above has been used to estimate the water outflow rate of about 10 shafts and fairly good results have been achieved. These results cannot be enumerated here in detail due to the limited space available, only two examples however are picked out for demonstration.

In Datun main shaft, the expected water outflow rate calculated on the base of test pumping from inspection borehole was very small, and the normal sinking method was adopted. When the shaft was sunk to 167 - 185 metres, water outflow was encountered 4 times, with 3 of them flooded the shaft. The max. water outflow rate was 212 tonnes/hour. From the comprehensive analyses of data from both the shaft and the coalfield, the hydrogeological condition of this shaft in the top section of 220 metres was type 6, class 4, and the condition below 220 metres from the top of the shaft was type 2, class 1. So the depth of 220 metres was chosen as the dividing line of water combatting efforts. The actual work of shaft sinking proved that at depth between 185 - 220 metres, the water outflow rate was still more than 40 tonnes/hour, but below 220 metres it was only 4 tonnes/hour. Jiangzhuang auxiliary shaft passes through 4 layers of water bearing sandstone and one layer of water bearing limestone, the calculated total expected water outflow rate was quite small, but there are faults with throw bigger than 30 metres within the range of 500 metres from the shaft, and a layer of high water content Quaternary strata, with no clay layer at the bottom of it, exists on the top of the bedrock, the hydrogeological condition was type 4, class 3. The grouting borehole meassurement on the shaft working face proved that the water outflow rate into the shaft was more than 100 tonnes/hour, and the max. water outflow rate from one borehole of each aquifer was more than 40 tonnes/hour.

6. Conclusion

From years of water combatting activities, we realized that due to the lack of a comprehensive approaches to disclose the underground hydrogeological state and the comparatively bigger errors in the result of forecasting the water outflow rate by applying the formulas, it is very important to enhance the investigation and studying of hydrogeological conditions of mine shafts and to estimating the water outflow rate on this basis. Experiences have told us that in order to fulfil this task, we must handle the following nine relations carefully:

1. In studying the hydrogeological conditions of both the mining district and the coalfield, more attention must be paid to the particularity of the coalfield;

2. In studying the hydrogeological conditions of both the coalfield and the shaft, the stress on the coalfield must be put, while examining the shaft on the background of the general regularity, then to check whether there is any particularity for the shaft;

3. Both the original and the artificially altered hydrogeological conditions should be studied;

4. Do not study separately those factors dominating the underground waterflow, but study the combined action of all the factors;

5. It is more important to estimate the water outflow rate from each aquifer than that of the whole shaft;

6. Attention should be paid to the harmfulness of underground water, since the water standard is different from project to project;

7. When studying the lithological characters of rocks, the main point is to find out the thickness of each single layer and the softness and hardness of rocks in the strata;

8. The key factor in studying rock fissure is its width and size, and especially its relationship with the faults;

9. Be careful in collecting data about leak ratio and rock core recovery ratio, etc. which are simple hydrogeological parameters of great importance.