Mine Water Inrush Prediction Using the Probability Index Method

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ABSTRACT

In the past, many theoretical methods have been used to predict mine water inrush but their practical application is restricted probably due to lack of availability of sufficient field data and accepted design parameters. Based on the mine water inrush data, a new probabilistic method known as the probability index method is proposed to forecast mine water inrush from the floor strata. The paper presents the methodology of calculating the probability index of water inrush together with a case history from the Feicheng coalfield, China

*Key words***:** Mine water, inrush, prediction , Feicheng Coalfield, China.

1. INTRODUCTION

The research into prediction of mine water inrush has long been carried out in many parts of the world, especially in Hungary (Schmieder, 1978), Yugoslavia, Spain (Fernandez-Rubio, 1978), Poland, and China (Shi, 1999) where coalmines often suffer karst water hazards in a range of geological conditions. Between the 1940's and 1950's, the concept of relative thickness of water-resisting barrier was first suggested in Hungary. In the 1960's, this concept was finally absorbed in Mine Safety Regulations by the Hungarian Safety Authority and became a traditional Hungarian approach for designing protective barriers. According to this concept, the onset of an inrush was determined by 'the threshold hydraulic gradient of the protective barrier' (Kesseru, 1984), which was about 1.5m/atm. If the value of the relative thickness of a protective barrier was more than 1.5m/atm, there were very few water inrushes from the floor strata. In other words, about 85% of water

inrushes occurred in Hungary while the threshold value of the hydraulic gradient was less than 1.5m/atm.

In middle of the 1970's, China sent a delegation representing the Department of Science and Technology to Hungary to observe the method used, and the delegation brought back some data regarding water inrushes from the floor strata. After integrating the Hungarian research results with the Chinese practice, the researchers in China put forward the concept of the water-inrush ratio as a criterion for prediction of groundwater inrush from the floor. The water-inrush ratio is the inverse of the relative thickness of the protective barrier. Based on empirical data pertaining to hundreds of inrushes in China, 0.6atm/m was selected as the threshold value. If the water-inrush ratio was more than 0.6, water inrush would occur. Subsequent field experience indicated that the use of the water inrush ratio was not a precise indicator of the onset of mine water inrush. After the 1980's, the incidents of water inflow became the second largest cause of disasters after roof–fall accidents in coalmines in China (Song, 1989). Therefore, many attempts to study the water-inrush mechanism and to predict water inflow from the floor were tried in China, which included the Three-zone Theory (Jing, 1984, Li, 1988), the Tensile Fracture and Destruction Theory (Wang, 1992), the Plate Theory (Zhang, 1997), the Key Layer Theory (Li. 1996) and the Four-zone Floor Theory (Shi, 2000). However, these theoretical methods of forecasting water inrush were not successful because of the unavailability of sufficient field data and accepted design parameters.

As a consequence, many researchers pursued an alternative avenue of forecasting water inrush using obscure mathematics (Wang, 1989), rock mechanics (Xu, 1991), the application of GIS (Gao, 1996), neural network theory, among others. All these methods met with limited success. In this paper, the authors propose a new approach of predicting mine water inflow under karst conditions using probabilistic methods. This method is known as the probability index method for forecasting water inrush and is based on the back analysis of the case histories from the Feicheng coalfield. This new method of prediction of inflow is described in the subsequent sections.

2. BASIC CONCEPTS OF THE PROBABILITY INDEX METHOD

There are many factors influencing the occurrence of mine water inrush from the floor, but each factor makes a different contribution towards the occurrence of an inrush event. In order to quantify the contribution made by each individual factor to the occurrence of water inrush, main contributory factors are chosen from the database pertaining to the coalmine inundation case histories and a weight is assigned to each contributory factor. A mathematical relationship is used for combining these factors to obtain the probability index for a particular coalfield. Then the minimum probability index is taken as the threshold value to predict the incident of mine water inflow for a coalfield. A strict procedure is followed to calculate the probability index for inflow predictions for a particular coalfield.

2.1 Database of Mine Water Inflow

Feicheng coalfield with about 120 km^2 in area is situated in northern China. It is one of the leading producers of coal in the Shandong province and produces some 770 MT of coal annually. All coal seams are mined by the longwall method. It is rather serious that all the coalmines in the Feicheng coalfield have been threatened by sudden inrush of groundwater from the underlying karst aquifers. The coal bearing strata in the Feicheng coalfield pertains to the Permian-Carboniferous system. There are 9 coal seams mined in this coalfield, namely coal seam 3, coal seam 4, coal seam 5, coal seam 6, coal seam 7, coal seam 8, coal seam 9 and coal seam 10. There are 8 collieries in this coalfield, namely Yangzhuang Colliery, Chaozhuang Colliery, Daifeng Colliery, Taoyang Colliery, Baizhuang Colliery, Guozhuang Colliery, Gaoyu Colliery and Chazhuang Colliery, which are shown in Figure 1. During exploitation of the above-mentioned coal seams in the 8 collieries, some 180 cases of water inflow from the floor strata have been recorded, as shown in Table 1.

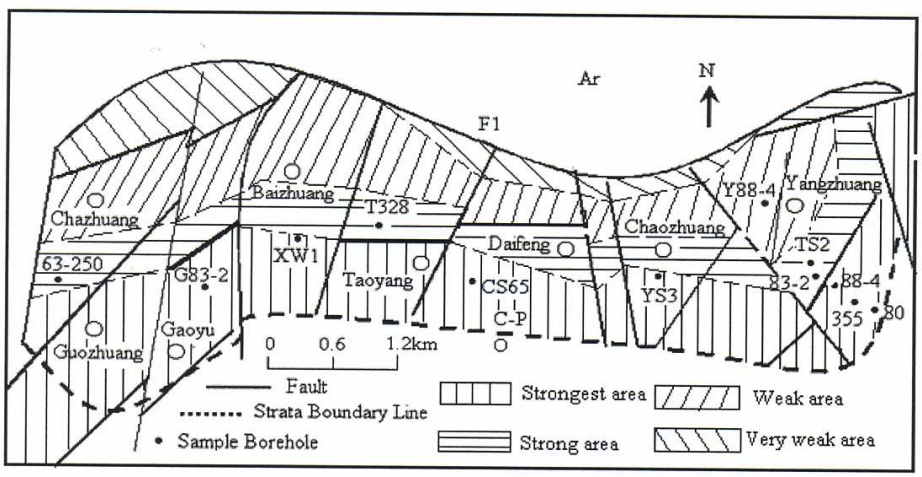

Fig. 1 - Outline map of the Feicheng coalfield

2.2 Factor Analysis

From studies of large numbers of water inrush incidents in the Feicheng coalfield, the major factors, which significantly affect the water inrush have been isolated. There are five primary factors controlling the incidents of water inflow, the main contributory factor being the type of aquifer; confined, unconfined or the karst aquifer. Based on hydrological data and the regional geological analysis, the source of water for mine water inundations in the Feicheng coalfield comes from the karst aquifers in the Ordovician limestone, which is about 800m in thickness. The coalfield can be divided into four areas: strongest water-bearing area, strong water-bearing area, weak water-bearing area and weakest water-bearing area (Figure 1). The case history analysis of water inrushes has indicated that most inflows are confined to the areas associated with the strong water-bearing formations.

Table 1 - Statistics of water-inrush in the Feicheng coalfield

Colliery	Coal seam 3	Coal seam 4	Coal seam 5	Coal seam 6	Coal seam 7	Coal seam 8	Coal seam 9	Coal seam 10	Total
Yangzhuang	0	0	0	0	0	0	10	2	12
Chaozguang	0	0	0	0	0	0	3	0	3
Daifeng	0	0	0	0	0	1	57	28	86
Taoyang	8	0	0	0	0	1	17	13	39
Beizhuang	4	0	0	0	2	1	0	0	7
Guozhuang	1	2	0	0	3	0	0	0	6
Gaoyu	0	0	2	1	11	0	0	0	14
Chazhuang	0	0	0	0	9	4	0	0	13
Total	13	2	2	1	25	7	87	43	180

The second important factor is the geological structure. The coalfield is mainly controlled by fault structures while the minor structures like small folds have their influence confined to the local area only. In general, the structural outline of this coalfield belongs to monoclinic structure type, the strata strikes in the direction NNE and dips 8° to 20° in the north direction. There are four sets of faults, with their strikes in NW, NE, NNE and ENE directions respectively in the inner region, intersecting the coalfield into the fault blocks of different sizes (Figure 1). The faults and the fractures make up the two main subsidiary factors of the structural features, which are strongly related to water inrush. The pathway of water inrush is either a fault or a fracture with the influence of the fold being negligible. The third factor is the nature and thickness of the strata between the mining horizon and the Ordovician limestone. The cases of water inflow studied show that the thicker the strata are between the mining horizon and the Ordovician aquifer, the greater is resistance to ground water outbursts from the floor strata.

The fourth contributory factor is groundwater pressure increasing the inflow potential while the fifth factor is rock pressure inhibiting the intergranular or pervious flow potential through the protective barrier layer. It may be noted that the strata pressure abutment zones inhibit the mine water inflow where as distressed zones promote the inflow incidences.

2.3 Weight Assigned to the Individual Factors and Calculation of the Probability Index

The mining practice shows that the five major factors have different degrees of influence on water inrush. Their degree of influence can be quantified by assigning weight to each factor. The more important the factor is, the heavier its weight is. There are two ways to decide the weighting. One is the use of probability theory and the other is the empirical evaluation. Based on the practical experience, the experts in the Feicheng coalfield have assigned the weights as P_A= 0.5, P_S= 0.3, P_T= 0.1, P_W= 0.05 and P_R= 0.05 to aquifer index (A), structure index (S), strata index (T) between mining horizons and the aquifer, groundwater pressure index (W) and rock pressure index (R), respectively. Figure 2 illustrates the relationship between the probability

index (E) of water inrush from the floor and the five factors. Equation (1) presents the mathematical relationship between various indices and the probability index (E).

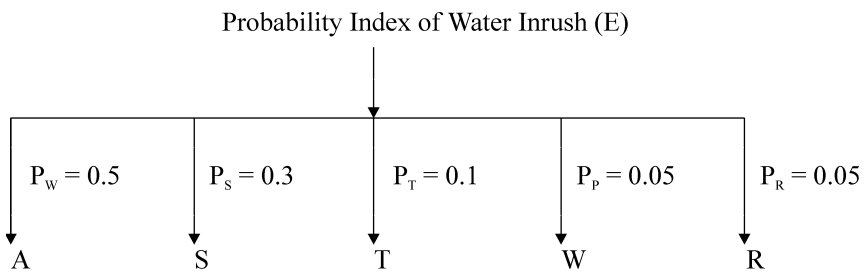

Fig. 2 - Relationship between the probability index of water inrush and the five factors

$$E = P_A A + P_S S + P_T T + P_W W + P_R R \quad (1)$$

or

$$E = 0.5A + 0.3S + 0.1T + 0.05W + 0.05R \quad (2)$$

Where, the value of individual indices is not more than 1. The aquifer index (A) depends on water-bearing capacity of the Ordovician limestone in different areas. The experts at the Feicheng coalfield are assigned 1.0 , 0.8, 0.6 and 0.4 weight indices to the strongest water-bearing area, strong water-bearing area, weak water-bearing area and the weakest water-bearing area, respectively. That is to say, if the mining area is in the strongest area, the aquifer index is equal to 1, namely, A=1.0; A=0.8 if the mining area is in strong area, and so on. The relationship between the aquifer index (A) and the water-bearing areas is shown in Figure 3.

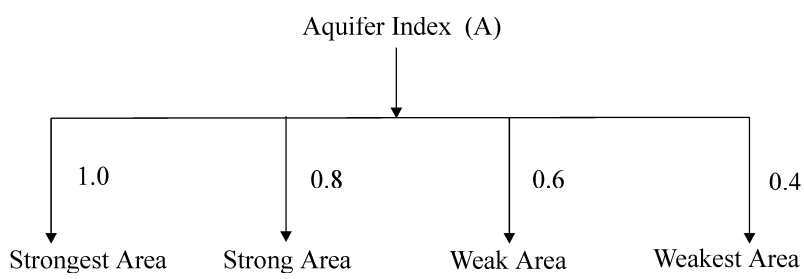

Fig. 3 - Relationship between the aquifer and the water-bearing areas

The structural index (S) consists of the two subsidiary factors, faults and fractures in the Feicheng coalfield. According to statistics, in 180 water inrush cases, 109 mine inundations were caused by faults, accounting for about 60%; 71, flooding were attributable to fractures, accounting for 40% cases approximately. Therefore, the weight of the fault factor (P_F) is 0.6; the weight of the fracture factor (P_J) is 0.4. The fault index (F) is controlled by the four subsidiary factors; fault throw, fault category (normal fault or reversed fault), fault combination (singular fault or multiple faults) and the angle of the fault. The weights of the four factors are P_h =0.5, P_n =0.3, P_c =0.15 and P_r =0.05. The fault throw index (h) is equal to 1 while the throw is more

than 20m, and h=0.8 while the throw is between 10m and 20m, and so on. If the fault is normal fault, the fault category index (n) is 1.0, n=0.4 if the fault is reversed fault. The fault combination index (c) is equal to 1.0 if two faults or more than two faults exist, or c=0.8. When the angle of the fault is more than 70°, the angle index (r) is equal to 1.0, otherwise, r=0.8. Two subsidiary factors, the fracture mechanics features and the fracture density influence the fracture factor. Their weights are P_o= 0.6 and Pg=0.4 respectively. The mechanical index (o) is equal to 1.0, 0.6 or 0.1 corresponding to tensile joints, shearing joints and compressive joints, and the fracture density index (g) is equal to 1.0 if there are more than 30 joints in $1m^2$, and so on (Figure 4. Formulae from (3) to (8) are used to calculate the indices.

$$S = P_F F + P_J J \tag{3}$$

or

$$S = 0.6F + 0.4J \tag{4}$$

$$F = P_h h + P_n n + P_c c + P_r r \tag{5}$$

or

$$F = 0.5h + 0.3n + 0.15c + 0.05r \tag{6}$$

$$J = P_o o + P_g g \tag{7}$$

or

$$J = 0.6o + 0.4g \tag{8}$$

The strata index (T) is composed of three subsidiary factors, namely, the rock thickness between mining horizons and the aquifer, rock combination and degree of rock damage. The weights of 0.5, 0.2 and 0.3 are respectively given to the rock thickness index (t), rock combination index (b) and rock damage index (d). If the rock thickness is more than 18m, t is equal to 1.0, or equal to 0.4. If there is sandstone in the strata between the mining horizon and the aquifer, the b is equal to 1.0, or 0.6. Similarly, d is equal to 1.0, 0.8, 0.5 or 0.2 corresponding to stronger damage, strong damage, weak damage and weakest damage.

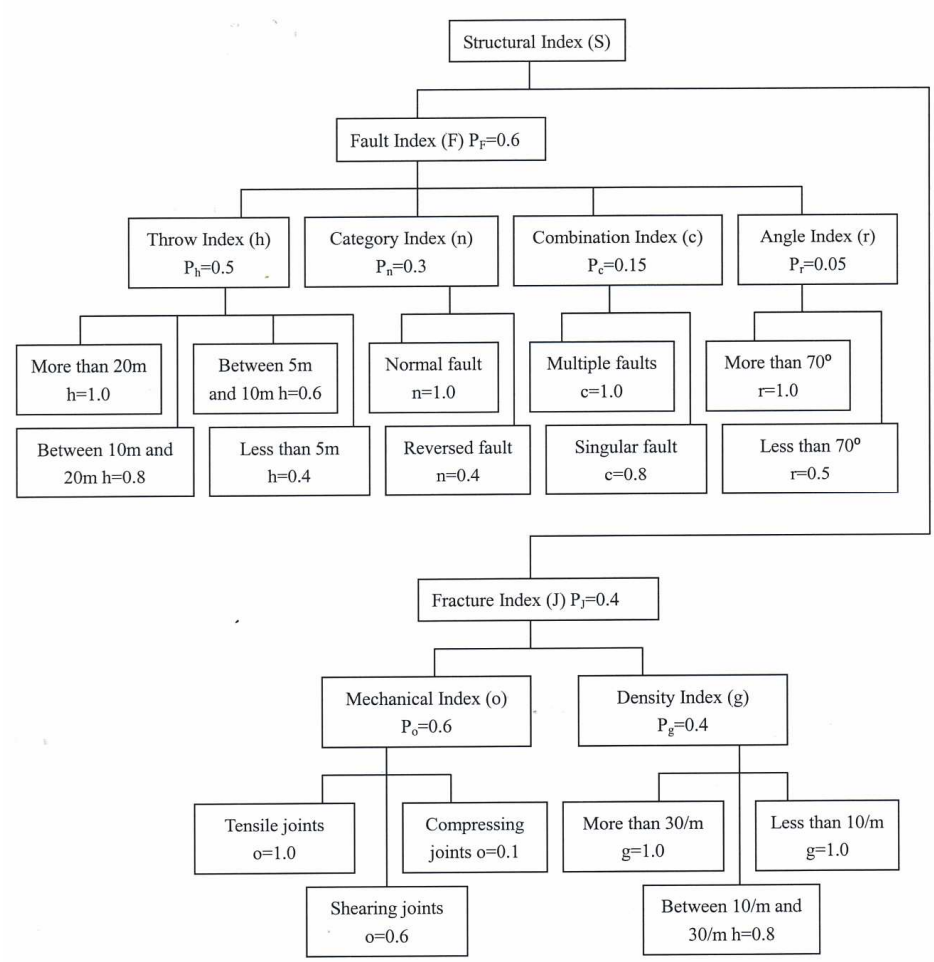

Fig. 4 - Relationship between structural index and the influencing factors

Equations 9 to 11 are used to calculate the probability indexes and Fig. 5 shows their relationship.

$$T = p_t t + p_b b + p_d d \tag{9}$$

or

$$T = 0.5t + 0.2b + 0.3d \tag{10}$$

$$t = \begin{cases} 1.0 \\ 0.4 \end{cases}, \; b = \begin{cases} 1.0 \\ 0.6 \end{cases}, \; d = \begin{cases} 1.0 \\ 0.8 \\ 0.5 \\ 0.2 \end{cases} \tag{11}$$

What weight should be given to the groundwater index (W) depends on the groundwater pressure. The groundwater pressure in the Feicheng coalfield is divided into four groups: more than 15Kg/cm^2, between 15Kg/cm^2 and

10Kg/cm^2, between 10Kg/cm^2 and 5Kg/cm^2 and less than 5Kg/cm^2. W is equal to 1.0, 0.8, 0.6 or 0.4 corresponding to different group (Figure 6).

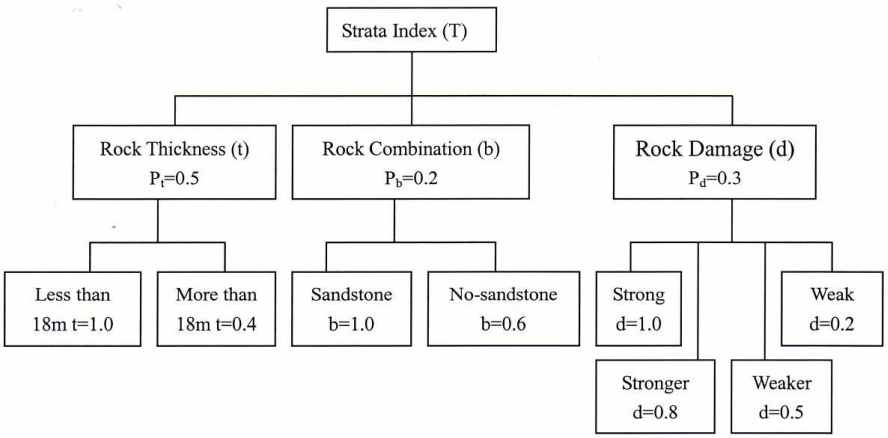

Fig. 5 - Relationship between the strata index and their influencing factors

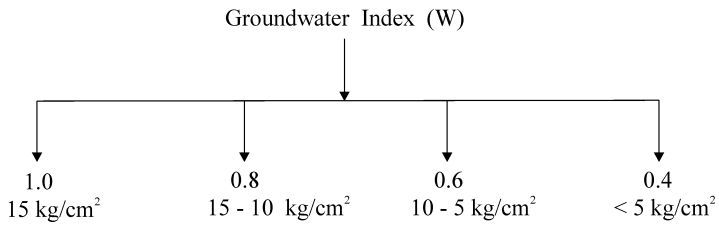

Fig. 6 - Relationship between the groundwater index and water pressure

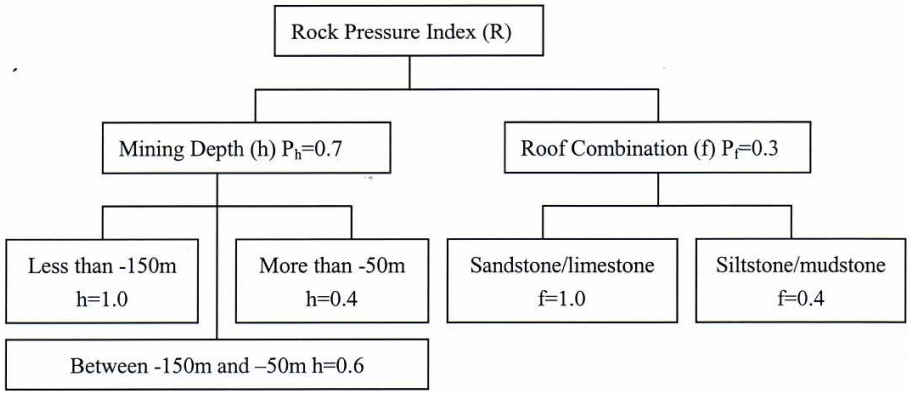

Fig. 7 - Relationship between the ground pressure index and the influencing factors

The rock pressure index (R) is influenced the mining depth and the roof rock combination indices. Figure 7 shows that different mining depth has a different mining depth index (h), and a different roof rock combination has different

rock combination index (f). Equations 12 to 14 are used to calculate the indices.

$$R = p_h h + p_f f \tag{12}$$

or

$$R=0.7\,h+0.3\,f \tag{13}$$

$$h = \begin{cases} 1.0 \\ 0.6 \\ 0.4 \end{cases}, \quad f = \begin{cases} 1.0 \\ 0.4 \end{cases} \tag{14}$$

2.4 Calculation of Results

All the indices described above, can be calculated by using a computer program. After examining all probability indices (E) of the cases of water inflow in the Feicheng coalfield, the minimum probability index of water inrush 0.72 was obtained. In other words E = 0.72 is the threshold value to decide whether water inrush will occur or not. In practice 91% cases of water inflow can be accurately forecasted by taking 0.72 as the threshold value.

3. CONCLUSIONS

There are two main factors which have an effect on the accuracy of forecasting water inrush from the floor using the probability index. One is how to decide on the factors influencing the water inrush; the other is how to build the mathematical model to calculate the probability index. The influential factors and the mathematical model are different in different coalfields and are even different in different areas in the same coalfield. Therefore, under general conditions, the threshold value obtained from one coalfield is not suitable for application to another coalfield. But as a method, forecasting the water inrush from the floor using the probability index has wider significance.

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