An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds)
©2014 China University of Mining and Technology Press, Xuzhou, ISBN 978-7-5646-2437-8

Shaft-lining Non-mining Fracture Multi-factor Forecasting Evaluation System Research

Yanchun Xu, Jianghua Li, Wenzhe Gu, Shiqi Liu
School of Resource and Safety Engineering, China University of Mining and Technology(Beijing),Beijing,China, jianghua_lee@163.com

Abstract The shaft-lining which has an important effect on underground mining, which is the throat of coal mine, but it is easy to rupture when going through the thick alluvium in the area of Huang He and Huai He. This article puts forward eight key influence factors of the fracture shaft-lining by analyzing the relevant mechanism of shaft-lining non-mining fracture and engineering geological and hydrogeological of the area where occurred shaft-lining non-mining fracture in Yanzhou Mining Group, and then collects detail datum of shaft-lining which have fractured, studies the effects of each influence factor on the fracture degree, using multivariate statistical minimum distance discriminant analysis method to establish the forecast evaluation system of thick alluvium shaft-lining fracture, and forecasts the fracture condition of each shaft-lining of Xinglongzhuang coal mine in 9/2014. The results show that the system has high reliability and is easy to operate. It provides a new method and approach for the accurate forecast of shaft-lining non-mining fracture and has a high use value. The system predicts the main shaft and west air shaft will rupture and need prevention of governance in Xinglongzhuang coal mine.
Keywords shaft-lining, non-mining fracture, influence factor, discriminant analysis, forecast evaluation system

Introduction

The shaft-lining is one of the most important passage for hoisting or transporting coal, ventilating the mine and carrying people up or down. So the shaft-lining plays an important role in mining, which is compared to the key of mine production. However, since 1980s, non-mining fracture of shaft-lining becomes a common form of mine geological disasters at many mines. Yuan and Wang (2011) reported that there have been hundreds of fractured shaft-linings which passes through cenozoic loose water contained alluvium up to now, the direct and indirect economic loss attaining millions of dollars. Ni (2005) found that many shaft-lining fractures again after fixing, which has a serious impact on mine safety production and makes a lot of loss to mines. So accurately forecasting and evaluating the condition of vertical shaft is of great significance for both coal mine safety production and economic returns improvement.

At present there are two principal methods to forecast the condition of shaft-lining: one is monitoring deformation of shaft in field, and then forecasting the condition of shaft-lining through analyzing the datum; the second is forecasting by system science or intelligence technology such as neural network, fuzzy neural network, etc. A great many of experts and scholars did a lot of studies in these respects, and some achievements have been made. For example, Gong and Li (2007) used Mahalanobis distance discrimination method, Shao and Zhang (2009) used Improved KNN algorithm, Liu and Wang (2005) used Multi-layered nonlinear neural network and fuzzy control approach to forecast the condition of vertical shaft. This paper analyzes the geological and hydrogeological condition of the area where the shaft-lining fractured in Yanzhou Mining Group, and puts forward 8 key influence factors of the shaft-lining non-mining fracture. Then using multivariate statistical minimum distance discriminant analysis method to establish the forecast evaluation system of thick alluvium shaft-lining fracture, and forecasts the fracture condition of each shaft-lining of Xinglongzhuang coal mine in 9/2014.

Failure mechanism analysis of shaft-lining

The research (Xu and Yang 2006) on engineering geology and hydrogeology of non-mining fracture shaft-lining shows that the thick loose layer area is the major rupture zone. As the fall of the loose bed bottom aquifer water levels (including the coal mining and the earth's surface water using), which lead to the increasing of effective stress in aquifer and consolidation sinking of the surrounding strata, the strata and the outer borehole wall generate relative motion, the final result is that the downward tensile stress named negative friction occurred on the side of borehole wall, and the negative friction which was not considered during the design of shaft-lining is the main factor that cause the shaft-lining fracture (Liang et al. 2010).

Liu and Chen (2007) found that the fracture of shaft-lining including not only the interaction between water and soil but also the country rock (soil) and borehole wall. Firstly, during the coal mining, the pore water pressure decrease with the confined water of aquifer which lies under the loose layer outflowing, which lead to the aquifer constantly being compressed, then the overlying strata will sink, and the size of its subsidence is directly decided on the compression amount of the bottom aquifer (Zhang et al. 2009; Jing 2001). Secondly, the coupling effect of borehole wall and country rock (soil) is the direct reason that cause the shaft-lining fracture (Meng and Ji 2013), when the aquifer compressed as well as the overlying strata sinking, the pressure at surface soil side changes. The stress, strain and lateral displacement of borehole wall generate extremum at the interface of surface soil and bedrock, and the extremum is larger than the ultimate strength of borehole wall, so that the shaft-lining fractured (Xu et al. 2003) .

The factors of the shaft-lining fracture

The key factors of the shaft-lining fracture include geological factors and wellbore design factors (including well construction and maintenance). Geological factors mainly consist of the alluvium thickness, water level and the alluvium compression rate (Zhou and Cheng 1995). Wellbore design factors mainly include wellbore diameter, pressure relief groove compression rate, service lives rate and governance methods(Cheng and Cai 2013). Taking comprehensive consideration of the engineering geological and hydrogeological conditions and wellbore rupture mechanism of non-mining fracture shaft-lining mining area, combined with the awareness of failure mechanism of shaft-lining, put up 8 key factors as the prediction index (Liu et al. 2005) :

1. The outside diameter of the wellbore(X_1): According to the theory of elastic mechanics, the external surface area of shaft-lining is proportional to the size of the additional force of shaft lining, the larger outer diameter is, the larger the borehole wall additional force is.
2. The alluvium thickness(X_2): According to the theory of soil mechanics, the greater the thickness of the alluvium is, the greater the additional force is.
3. The water level(X_3): The water level dropping is the driving force of loose formation compression and wellbore rupture, the lower the water level is, the more the loose formation compressed.
4. Pressure relief groove compression rate(X_4): In the case that pressure relief groove is effective, with the pressure relief groove compression rate drop, the pressure relief effect reduced.
5. Multiple fracture(X_5): Whether the borehole wall has many fracture areas is a key factor. And according to the degree of borehole wall fracture, four grades 0-3 were divided (degree 0,1,2,3).
6. Service lives rate(X_6): The rate of useful lives and design service lives, the longer the wellbore put into use or the longer the treatment time is, the possibility of wall rupture is higher.

7. Governance methods(X_7): The difference of formation and pressure relief groove treatment methods, the treatment effects are also different, it will influence the wall repeatedly rupture to some degree. Grouting method is regarded as 1 and pressure relief groove method as 0.
8 The alluvium compression rate(X_8): The high the alluvium compression rate is, the greater the borehole wall force is, the possibility of wall rupture is higher.

Sample collection

Taking overall consideration of the eight influence factors of the shaft-lining fracture, we totally collect 16 groups of different periods parameters of thick alluvium shaft-lining in Yanzhou Mining Group (table 1). The former 12 groups of the parameters are used to establish the forecasting evaluation system, among which the sample 1 to 4 are the parameters after the second management. The rest 4 groups of parameters from different shafts of Xinglongzhuang coal mine in 12/2012 are used to identify the reliability of the forecasting evaluation system.

Table 1 *The relevant parameters of the shaft-linings in Yanzhou Mining Group*

Coal mine	Sample	X_1 (m)	X_2 (m)	X_3 (m)	X_4 (%)	X_5 (/)	X_6 (%)	X_7 (/)	X_8 (%)	$W(X)$	Actual situation	Predict results
Yangcun	North air shaft	5.4	173.4	20	17	1	100	1	50	19.02	Fracture	Fracture
	Auxiliary shaft	6	184.45	20	18	2	80	0	50	14.63	Fracture	Fracture
	South air shaft	5	157.92	15	25	0	100	0	20	24.19	Fracture	Fracture
	Main shaft	5	185.42	14.3	30	2	80	0	50	25.88	Fracture	Fracture
Baodian	Main shaft	6.5	148.6	13.45	25	0	100	1	50	19.91	Fracture	Fracture
Xing long zhuang	Main shaft(2007)	6.5	189.31	14.49	28.5	0	100	0	50	13.06	Fracture	Fracture
	Auxiliary shaft (2009)	7.5	190.41	16.6	23.3	0	100	0	50	13.05	Fracture	Fracture
	East air shaft (2010)	5	176.45	7.79	15.2	3	100	0	20	16.82	Fracture	Fracture
	Main shaft (2011)	6.5	189.31	9.317	10.92	1	89.9	0	41.64	-15.29	No fracture	No fracture
	Auxiliary shaft (2011)	7.5	190.41	3.679	1.5	0	3.9	0	41.64	-13.69	No fracture	No fracture
	East air shaft (2011)	5	176.45	2.906	1.3	0	13.3	0	31.32	-29.57	No fracture	No fracture
	West air shaft (2011)	5.5	189.5	19.25	16.8	0	100	0	49.92	-14.54	No fracture	No fracture
	Main shaft(2012)	6.5	189.31	11.759	13.78	1	100	0	41.64	-8.08	No fracture	No fracture
	Auxiliary shaft(2012)	7.5	190.41	16.157	2.60	0	41	0	41.64	-21.03	No fracture	No fracture
	East air shaft(2012)	5	176.45	5.105	1.54	0	57	0	31.32	-42.04	No fracture	No fracture
	West air shaft(2012)	5.5	189 .5	21.380	19.21	0	100	0	49.92	-5.05	No fracture	No fracture

The establishment of mathematical model

Take the former 12 groups of data in table 1 as known samples, using multivariate statistical minimum distance discriminant analysis method to establish the linear discriminant function and criterion of the shaft-lining fracture and forecast the fracture condition of each shaft-lining in the samples. And by comparing with the actual situation, we analyze the accuracy and reliability of the discriminant function, thus the shaft-lining fracture forecasting evaluation system is established.

The discriminant of minimum distance discriminant analysis method is:

$$W(X)=\frac{1}{2}[D^2(X,G_2)-D^2(X,G_1)] \tag{1}$$

Where $D^2(X,G_1)$ and $D^2(X,G_2)$ are respectively the distance between pending identifying samples and their same kind of population G_1 and G_2.

The corresponding criterion is; when $W(X)>0$, the sample is close to population G_1, and we can judge it belongs to G_1; When $W(X)<0$, the sample is close to population G_2, and we can judge it belongs to G_2; When $W(X)=0$, it needs estimate further.

Shaft-lining fracture forecasting evaluation system

According to the parameters of the two population(overall) sample—fracture and none-fracture in table 1, and the analysis of the corresponding test statistics, when the significance level is 0.05, we can judge that the covariance matrix of the two totalities has the follow relation: $\sum^{(1)}=\sum^{(2)}=\sum$, which indicates that there is no significant difference and the samples are reasonable. When the significance level is 0.1, the mean vector of the two totalities#has the follow relation: $\mu^{(1)}\neq\mu^{(2)}$ which shows significant difference and indicates that the two totalities have different characters.

By calculating we can get the Shaft-lining fracture forecasting evaluation system.

$$\begin{aligned}W(X)=&7.9636X_1+0.3289X_2+1.7374X_3+2.3995X_4+7.5259X_5\\&-0.386X_6+30.4477X_7-1.3637X_8-87.7425\end{aligned}$$

When $W(X)>0$, it deems the Shaft-lining belongs to G_1, that is fracture;and when $W(X)<0$, it deems the Shaft-lining belongs to G_1, that is none-fracture. The shaft-lining fracture forecasting evaluation function and criterion compose the shaft-lining fracture forecasting evaluation system.

“Forecasting” the fracture condition of each shaft-lining of the samples by the new system, the results are shown in table 1. From table 1 we can find that the forecasting results of the 16 groups of samples are consistent with the actual situation, which shows that the shaft-lining fracture forecasting evaluation system is accurate and reliable, at the same time it verifies that the system is simple, convenient, and strong operability.

The parameters

Among the eight key influence factors of the shaft-lining fracture, we can get the shaft-lining external diameter, the thickness of alluvial layer, multi-fracture situation and repair pattern by referring relative datum directly, and the service rate can be obtained by analyzing statistical datum, only the drop of water level and the compression rate of pressure releasing slots needs to be calculated. Through the hydrological observation hole and the pressure releasing slots compressed quantity automatic viewer, we can observe the dynamic change of water level of loose bed bottom aquifer and compression quantity of pressure releasing slots respectively. Using statistical regression method to deal with observation datum, and estimate the relative parameters of a certain period of time in the future, thus we can use the shaft-lining fracture forecasting evaluation system to forecast the shaft-lining fracture condition in a certain period of time in the future.

Taking the forecasting evaluation of the main shaft of Xinglongzhuang coal mine in September 2014 as an example, we make a detailed introduction of the acquisition of the drop of water level and The compression rate of pressure releasing slots of the key influence factors of the shaft-lining fracture.

The drop of water level **（X_3）**

The aquifer water level of mine shaft of Xinglongzhuang coal mine is measured by the drilling Q $_{under-11}$, by collecting the water level of the main shaft from June 2007 to July 2013, we get the bottom aquifer water level dynamic variation graph.

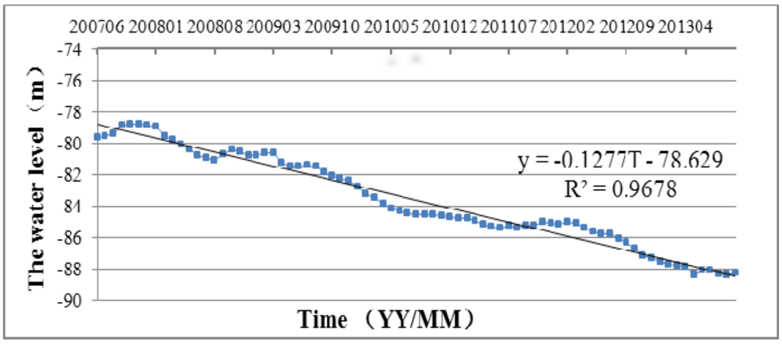

Fig. 1 *The bottom aquifer water level dynamic variation graph*

Analyzing the bottom aquifer water level dynamic variation of the drilling Q$_{under-11}$ by statistical regression method, we get a linear calculation formula of the bottom aquifer water level change over time, and forecast the aquifer water level of the bottom aquifer in September 2014:

$$
\begin{aligned}
y &= -0.1227\mathrm{T} - 78.629 \\
R^2 &= 0.9678
\end{aligned}
\tag{2}
$$

Where y is the bottom aquifer water level, T is time and R is correlation index.

Due to the degree of fitting of the regression equation – R^2 is 0.9678, which shows that the regression straight line has high degree of fitting to the datum. By calculating we can obtain the water level of Q $_{under-11}$ is -89.3 m in September 2014, and we can get the drop of water level is 10.7 m.

The compression rate of pressure releasing slots **（X_4）**

The pressure releasing slots compressed condition of the mine shaft of Xinglongzhuang coal mine is measured by the pressure releasing slots compressed quantity automatic viewer, by collecting the compression quantity of pressure releasing slots from June 2007 to August 2011, we get the compression quantity of pressure releasing slots dynamic variation graph of the main shaft.

According to the observations results of the Fig.2, we can get the linear regression equation the compression quantity of pressure releasing slots of the main shaft, and predict the compression quantity of pressure releasing slots of the main shaft in September 2014.

$$
\begin{aligned}
y &= 1.0977\mathrm{T}+7.6968 \\
R^2 &= 0.9209
\end{aligned}
\tag{3}
$$

Where y is the compression quantity of pressure releasing slots, T is time and R is correlation index.

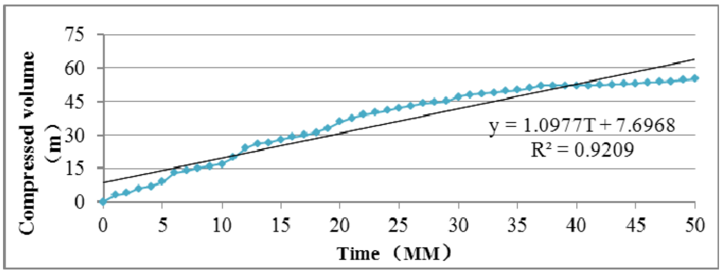

***Fig. 2** The dynamic change graph of compression quantity of pressure releasing slots of the main shaft*

Due to the degree of fitting of the regression equation – R^2 is 0.9209, which shows that the regression straight line has high degree of fitting to the datum. By calculating we can obtain the compression quantity of pressure releasing slots is 103.19 mm in September 2014, which engages 20.64% of the height of pressure-relief groove.

The fracture forecasting of shaft-lining in Xinglongzhuang coal mine

By collecting and analyzing the various parameters of each shaft-lining of Xinglongzhuang coal mine, we forecast the fracture condition of each shaft-lining in September 2014 with the forecasting evaluation system, and the results is shown in table 2.

***Table 2** The evaluation index and forecasting results of each shaft-lining of Xinglongzhuang coal mine in September 2014*

Shaft	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	$W(X)$	Predictions
Main shaft	6.5	189.31	16.132	18.78	1	100	0	41.64	11.5167	Fracture
Auxiliary shaft	7.5	190.41	10.494	4.52	0	100	0	41.64	-31.6961	No Fracture
East wind shaft	5	176.45	8.954	1.96	0	42.8	0	31.32	-28.8623	No Fracture
West wind shaft	5.5	189 .5	25.128	23.43	0	100	0	49.92	11.5856	Fracture

From the table 2 we can get that main shaft and west wind shaft of Xinglongzhuang coal mine will be fractured in September 2014, prevention management should be carried out in advance, while the east wind shaft and auxiliary shaft will not occur.

Conclusions

(1) Establishing the forecast evaluation system of thick alluvium shaft-lining fracture by analyzing the main influence factors of the frature of shaft-lining, that is

$$W(X) = 7.9636X_1 + 0.3289X_2 + 1.7374X_3 + 2.3995$$

$$X_4 + 7.5259X_5 - 0.386X_6 + 30.4477X_7 - 1.3637X_8 - 87.7425$$

X_1-X_8 show the different influence factor.

When $W(X) > 0$, the shaft-lining fractures, and when $W(X) < 0$, the shaft-lining doesn't fracture. The forecast evaluation system is simple, convenient and reliable.

(2) Forecasting the main shaft and west air shaft will rupture and need take steps to prevent and govern in Xinglongzhuang coal mine in 9/2014.

Acknowledgements

Based on the support of Yanzhou Mining Group, we write this paper. The authors are grateful to Yanzhou Mining Group for their funding to do experiments and provide field-testing sites and related data access, and thank IMWA conference for providing a stage for us.

References

Cheng H, Cai HB (2013) Safety situation and thinking about deep shaft construction with freezing method in China. Journal of Anhui University of Science and Technology 33(2): 1-6

Gong FQ, Li XB (2007) A distance discriminant analysis method of forecast for shaft-lining non-mining fracture of mine. Journal of China Coal Society 32(7): 700-704

Jing LS (2001) Research on the effect of surface soil subsidence on shaft-lining fracture and prevention measures. Journal of China Coal Society 26(1): 49-53

Liu HY, Li X, Zeng QB (2005) The nonlinear methods of forecast and judgement for shaft-lining non-mining fracture of Yanzhou mine. Journal of Engineering Geology 13(2): 231-235

Liu HY, Wang SJ, Zeng QB (2005)Judgement for nonmining fracture of shaft-lining in Yanzhou mine based on fuzzy neural network. Chinese Journal of Geotechnical Engineering 27(10): 1237-1240

Liu HY, Chen WZ, Wang ZM (2007) Theoretical analysis of shaft lining damage mechanism of Yanzhou Mine. Chinese Journal of Rock Mechanics Engineering (7): 2620-2626

Liang HC, Zhou GQ, Zhao GS (2010) Strain characters of shaft lining crack. Journal of China Coal Society 35(2): 393-397

Meng ZQ, Ji HG, Peng F (2013) Additional stress of shaft linings in thick alluvium constructed by freezing process. Journal of China Coal Society 38(2): 204-208

Ni XH, Sui WH, Wang DL et al. (2005) Research on prevention and control technology of coal mine shaft wall fracture. China University of Mining and Technology Press, Xuzhou

Qu P, Shen RC, Fu L (2011) Time delay effect on wellbore stability in coal seam. Journal of China Coal Society 36(2): 255-260

Shao LS, Zhang Y (2009) Forecast for non-mining fracture of shaft-lining of mine. Journal of China Coal Society 34(2): 184-186

Xu YC, Xu FK, Gong YZ (2003) Research on the horizontal movement characteristics of the deep loose bed within the coal industry. Journal of China Coal Society 28(4): 353-356

Xu HD, Jing LW, Yang RS (2006) Analysis of shear force between surface soil and vertical shaft inn mine. Chinese Journal of Rock Mechanics Engineering 25(2): 385-391

Yuan ZG, Wang HT, Hu GZ (2011) Forecast model of GA-SVM for shaft-lining non-mining fracture. Journal of China Coal Society 36(3): 393-397

Zhou GQ, Cheng XL (1995) Study on the stress calculation of shaft lining surrounded by special strata. Journal of China University of Mining & Technology 24(4): 24-30

Zhou GQ, Cui GX (1998) Numerical analysis on interaction between shaft wall and surrounding strata after aquifer grouting. Journal of China University of Mining & Technology 27(2) : 135-139

Zhang LM, Wang ZQ, Lu ZY (2009) Back analysis of vertical additional force on shaft lining based on monitoring information and its failure analysis. Journal of China Coal Society 34(5): 619-623.

Zhou XM, Hu QS, Ma CX (2012) Comparing research on effect of enclosure rock to enhance bearing capacity of shaft lining. Journal of China Coal Society 37(1): 26-32