Analysis of typical coal tunnel anchor network support accident cases in Huainan mine area and study of preventive measures

Xiaohu Liu*[1,2,3], Qun Zheng[1,2], Hua Cheng[3], Guofeng Yu[1,2], Yong Luo[1,2], Bo Ren[1,2], Diancai Xiao[1,2], Changrui Duan[1,2], Zheng Tong[1,3], Dechao Lu[1,2]

[1]Pingan Mining Engineering Technology Research Institute Co., Ltd., Huainan 232001, China
[2]Huainan Mining Industry (Group) Co., Ltd., Huainan 232001, China
[3]School of Civil Eng. and Architecture, Anhui Univ. of Sci. and Technol., Huainan 232001, China

Correspondence should be addressed to Xiaohu Liu; lxhhjjlty@163.com

Abstract. The frequent occurrence of accidents in deep shaft engineering seriously restricts the safe and efficient mining of coal mines. In this paper, 193 cases of coal mine anchor network support accidents have occurred in Huainan mine since 2000, and the accidents are classified into roofing injury, roofing blockage, anchor breakage injury, rescue personnel casualty, revealing the mechanism of accidents, finding personnel, technical and management defects through unsafe actions, roofing accidents, and hidden dangers of work at all levels and managers. The research results can be used as a basis for the prevention of similar accidents in the deep ground. The results of the research can provide technical reference for the design of coal tunnel support schemes in similar deep strata and for the safe and efficient mining of mines.

Keywords: Huainan mining area, China; Deep roadway; Coal roadway anchor network support; Accident case analysis; Preventive measures

1 Introduction

The Huainan mine is located in the central part of Anhui Province, China, which was opened in 1897 and has a long history. The mines are mainly located on both sides of the Huai River in northern Anhui Province, with 50 billion tonnes of coal resources identified above the -1500m level. With mining depths reaching -700m to -900m, the geological conditions of deep coal mining are complex and variable, and the prevention of casualties at the coalface is a difficult but necessary task in the field of coal mine safety in Huainan[1-4]. This paper presents a statistical classification of coal tunnel accidents in the Huainan mining area over the past two decades, revealing their intrinsic causes and proposing preventive measures[5-6].

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2 Statistical analysis of coal tunnel anchor support accidents

Since 2000, a total of 193 roofing accidents have occurred in the Huainan mine area, including 18 typical roofing accidents, as shown in Table 1.

Table 1. Statistics on roofing accidents in coal lanes

Mine Name	Time	Location of occurrence
Pang Yi Mine	2007.02.21	2652(1) Transportation channel excavation
Pang Er Mine	2011.07.03	1811 (1) Track Transportation roadway
Pang San Mine	2009.05.20	1251 (3) working face track air roadway
	2009.07.28	17171 (1) working face transportation channel connecting roadway
	2017.08.24	1632(3) Working surface
	2017.11.04	1612(3) Working surface
	2020.06.26	1652 (3) working face track gateway
Xie Yi Mine	2012.01.11	4271B6 working face cut
Xin Zhuangzi Mine	2003.03.29	560 working face transport trough
	2010.12.16	62110 Comprehensive Working Face
	2009.02.16	66108 working face transport trough
Ding Ji Mine	2013.12.02	1272 (3) working face
	2014.08.18	1222 (1) working face transport crossheading
Zhuji East Mine	2014.01.14	1122（1） working face transport crosshead-ing
Xie Qiao Mine	2004.11.16	12128 track crosshead joint roadway
	2006.10.10	13116 working face cut
	2014.09.14	11328 working face transport trough
	2018.05.11	13416 working face track trough

Table 1 shows that 18 typical accidents occurred in eight mines in the mining area. The accidents occurred in a wide distribution and involved a complex hierarchy of personnel. From the perspective of the types of accidents and the number of casualties, a total of 15 people were killed in the 18 accidents that occurred in the mines, including 10 incidents of roof fall injuries, accounting for 55.6% of the total number of accidents, with 9 deaths and 1 minor injury; 2 incidents of anchor rod (rope) breaking anchor, accounting for 11.11% of the total number of accidents, with 2 deaths; 4 incidents of roof rise blocking, accounting for 22.22% of the total number of accidents, with 58 people blocked. There were 4 incidents of roof blocking, with 58 people blocked and 4 fatalities; 1 incident of over-limiting gas caused by a roof rise; and 1 incident of buried equipment caused by a roof rise.

From the perspective of the site and depth of the accident, there were 7 accidents in the transport chute of the working face, accounting for 38.89% of the total number of accidents; 5 accidents in the track chute, accounting for 27.78% of the total number of accidents; 2 accidents in the cutting face of the working face and 3 accidents in the recovery face, and 1 accident in the track and return joint, accounting for 11.11%, 16.67% and 5.56% of the total number of accidents respectively. 1 accident occurred between -300 and -400m, 1 accident between -400 and -500m, 4 accidents between

-500 and -600m and five accidents between -600 and -700m. It can be seen that with the deepening of the mining depth and the harsh geological environment of coal mining, there is a rising trend in the number of accidents.

3 Classification of coal tunnel anchor network support accident cases

3.1 Type 1: Injury by roof slab - "2007. 2. 21" roof slab accident at Pang Yi Mine

This accident was caused by the failure to adopt reasonable safety blasting measures in the area of the excavation workings and the operation of the workings with an empty roof, which is typical of accidents caused by unsafe behaviour, and could have been avoided if the coal miners and the relevant management leaders had avoided unsafe operations and instructions (irregularities) during the operation. The unsafe acts in the following ccident case are analysed as shown in Table2.

Table 2. Results of unsafe action analysis of the "2007. 2. 21" roof accident at Pan Yi Mine

Action number	Action Name	Staff Level	Responsible persons in-volved	Action details Description	Violation of regula-tions or not
1	Adopting prohibited excavation techniques	1	Excavation workers	Li Jun arrived at the working face and did not blast as required and used a header to cut the lower coal body, resulting in an overhanging roof at the working face.	Yes
2	Failure to implement safety measures	1	Excavation workers	After the comprehensive excavation machine cuts the coal seam, it is then inverted to a distance of 8 meters from the excavation face to prepare explosives and blast the explosive device rock mass.	Yes
3	Illegal command	3	Management staff	The safety inspector Dai Dongjun came to the working face, Dai Dongjun looked at the site and asked "How much coal thickness?" Xu Weilin then took the initiative to measure the coal thickness with a ruler on the left side of the working face.	Yes
4	Poor manage-ment and supervi-sion	4	Management staff	The followers failed to catch the key aspects of safety hazards and the managers did not supervise the implementation of measures on site.	No
5	Individual access to empty roof operations	1	Excavation workers	After the comprehensive excavation machine cut the coal, it did not support the overhanging roof in time. Xu Weilin entered the empty roof area to measure the coal thickness against regulations and was killed by the falling gangue.	Yes

Note: The staff hierarchy classification in the above table is as follows: 1 - On-site mining operators; 2 - On-site lead shift squad and captain; 3 - On-site safety supervisors and section chiefs of this division following the shift; 4 - Technical vice president and section chiefs of the district team. In addition the classification of personnel hierarchy in Tables 3~5 is the same as that table.

3.2 Type 2: Roofing and blocking - Analysis of the "2011. 7. 3" roofing accident at Pan Er Mine

This accident was caused by the failure to use reasonable anchor support in some of the geological anomalies in the excavation workings, which led to severe deformation of the surrounding rock in the fault drenching zone and eventually caused a local roofing accident, a typical accident caused by unsafe behaviour. The accident could have been avoided if the coal miners and the technicians involved had avoided unsafe work and command practices (violations) during the operation. The unsafe acts in the following accident case are analysed as shown in Table 3.

Table 3. The analysis of unsafe actions in the "2011. 7. 3" roofing accident at Pan Er Mine

Action number	Action Name	Staff Level	Responsible persons involved	Action details Description	Violation of regulations or not
1	Delayed adjustment of support technology	3	technician	Under the influence of the FX10 fault, the lower chute is dug in the roof of the 11-2 coal, causing the distance between it and the 11-3 coal to be reduced.	No
2	Insufficient management of on-site surrounding rock deformation	2	On site technical management personnel	The steel strip supporting the surrounding rock of the tunnel is deformed, the roof of the tunnel sinks, and there is a small amount of water pouring on the roof, resulting in severe floor heave of the tunnel.	No
3	Insufficient stability of support technology	3	technician	The support shed legs did not wear iron shoes, causing severe drilling at the bottom, exacerbating the roof separation and poor stability.	No
4	Poor management and supervision	4	management personnel	The followers failed to grasp the key aspects of safety hazards, and the managers did not supervise the implementation of measures on site.	No

3.3 Type3: Broken anchor injury - Pan San Mine "2017.8.24" roof broken anchor injury accident

The accident was caused by a local stress concentration in the excavation face, resulting in a high stress load on part of the anchor cable, which eventually broke and injured someone, a typical accident caused by unsafe behaviour, which could have been prevented if the coal miners and related technical staff had avoided unsafe practices during the operation. The unsafe acts in the following accident case are analysed as shown in Table 4.

Table 4. The unsafe action analysis of the "2017. 8. 24" roof break anchor injury accident at Pan San Mine

Action number	Action Name	Staff Level	Responsible persons involved	Action details Description	Violation of regulations or not
1	Inadequate stress analysis	3	Technician	The transportation trough of the 1632 (3) fully mechanized mining face is affected by the superposition of adjacent goaf stress and the mining stress of this working face, resulting in stress concentration.	NO

2	Inadequate protection for on-site personnel	1	On site construction personnel	Cheng Shifu sat on the closed platform of the transfer machine below the accident anchor cable, wearing a helmet on his head near the accident anchor cable.	Yes
3	Insufficient stability of support technology	3	Technician	The anchor cable is broken 1.89m above the exposed end when the force exceeds its tensile strength, and there is a significant necking phenomenon at the fracture. The steel strand is in a refined and tensile shape.	NO
4	Inadequate management oversight	4	Administrative staff	The followers failed to grasp the key aspects of safety hazards, and the managers did not supervise the implementation of measures on site.	NO

3.4 Risk analysis based on accident tree

The analysis of the accident tree means that instead of considering the amount of probability of occurrence of the system, only two states of the system occurring or not occurring are considered. By qualitative analysis of the accident tree, it is also possible to know the magnitude of influence of the occurrence of each basic cause event on the occurrence of the topside accident event. Using Boolean algebra to simplify the accident tree, the "2007.2.21" roof accident at Panyi Mine is shown in Figure 1.

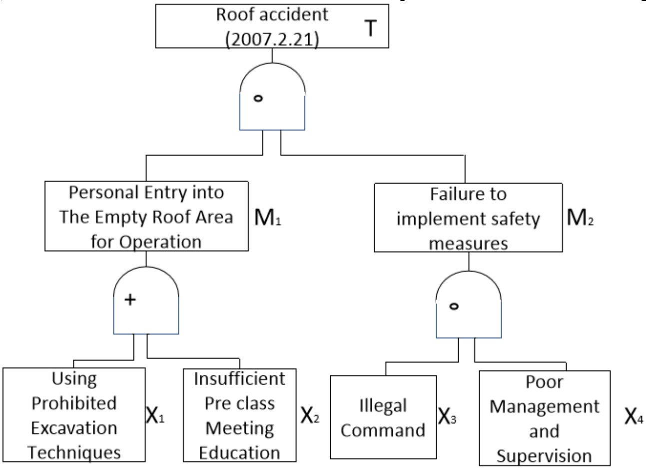

Fig. 1. Accident Tree Mind Map

$T=M_1 \cdot M_2=(X_1+X_2)(X_3*X_4)$, When the accident T is: $T = M_1 * M_2 = (X_1 + X_2)(X_3*X_4) = X_1X_3X_4 + X_2X_3X_4$

The minimum cut set of accident occurrence after simplification is $E_1=\{X_1, X_3, X_4\}$, $E_2=\{X_2, X_3, X_4\}$, from the analysis, it can be seen that there are two minimum cut sets for the occurrence of this roof accident. Calculate the importance of the basic event structure using formula (1):

$$I_j = \sum x_{j \in G_r} \frac{1}{2^{N_j - 1}} \tag{1}$$

I_j-Approximate Discriminant Values for the Importance Coefficients of the Basic Event X_j Structure; $X_j \in G_r$ -The basic event X_j belongs to the Minimum cut (path) set G_j; N_j -Basic events included in the Minimum cut (path) set to which the basic event X_j belongs.

$$= I_2 = 1*(1/4)=0.25;\ I_3 = I_4 = 2*(1/4)=0.5,\ I_3 = I_4 > I_1 = I_2$$

From the ranking of the importance coefficients of various basic events, it can be seen that the causes of this roof safety accident are in order ① Illegal Command, ② Poor Management and Supervision, ③ Using Prohibited Excavation Techniques, ④ Insufficient Preclass Meeting Education. It can be seen that accidents occur in the subjective consciousness of individuals and site safety management are closely related.

As can be seen from the above, coal mine anchorage support accidents in Huainan are still dominated by roof injury accidents, which are harmful to the personal safety of workers. In addition, there are more accidents in the coal tunnel with transport chute, which should be observed more often; and with the deepening of coal mining, the probability of accidents has a tendency to increase, so the research on the safety technology of deep coal mining should be strengthened to ensure the safe and efficient mining of coal in deep shafts.

4 Research on the "trinity" prevention and control measures for coal tunnel anchor network support accidents

For the prevention of accidents in the Huainan mine coal tunnel anchor network support, firstly, we should ensure the control of big risks, the elimination of big hidden dangers and the prevention of big accidents; secondly, we should lean the organization and management team, refine the process management and optimize the production and management mode for the coal tunnel production process, so as to achieve scientific, efficient and safe coal tunneling construction. From the technical security, geological survey technology, construction technology, technical security, refinement design security, weaving management security, organizational security, process management security, the establishment of training and education system, the overall realization of "technology - management - training" of the trinity of prevention and control measures[7-10].

5 Conclusions

By studying the depth of coal roadway floor accidents in Huainan mining area, they are divided into four types: roof injury, roof fall blocking, anchor breaking injury, and rescue personnel casualties. From multiple perspectives such as dangerous actions, personnel types, and whether violations occur, a "three in one" prevention and control strategy is established to provide technical reference for the prevention of similar deep strata coal roadway accidents.

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