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Research Article

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Research of the deterioration mechanism and the prevention techniques of the main structure of conveyor gallery in colliery industrial environment

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ABSTRACT

In the colliery industrial environment, the materials of reinforced structure suffer relatively serious aging. The cracking and deterioration of concrete and the corrosion of steel member lead to the degeneration of structural performance and the decline of structural reliability. In this paper, the experiment is combined with the test engineering instances of colliery industrial ground environment and the main reinforced structure of conveyor gallery at Jiahe Colliery, Chacheng Colliery, Woniushan Colliery and Zhangji Colliery attached to Xuzhou mining group co., Ltd in China. During the experiment, colliery industrial environment is analyzed qualitatively and quantitatively; and at the same time, damage degradation characteristics and security design check method of reinforced structure of conveyor gallery are studied. Then, deterioration mechanism of reinforced concrete conveyor gallery under the coupling action in the industrial environment is investigated from the aspects of material & components & structure. Finally the corresponding prevention and control technology are proposed, which provide sound proof for the reliability of reinforced concrete conveyor gallery.

Key words: colliery industrial environment; main structure of conveyor gallery; deterioration mechanism; prevention techniques

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INTRODUCTION

Exposed to the severe industrial environment [1~3] (natural environment, complex artisan and chemical environment), the conveyor gallery deteriorate quickly, which reduces the structural capacity [3~6]. Therefore, investigation of the deterioration mechanism of the conveyor gallery in colliery industrial environment and the prevention techniques are of great necessity. Meanwhile, it is of significant importance to the repair, reinforcement and maintenance of the conveyor gallery.

2. PROJECT OVERVIEW

The conveyor galleries in Jiahe, Chacheng, Woniushan and Zhangji colliery were built in the 1960s~1990s (Parts appearance were shown in Figure 1. General situation can be seen in table 1). They are reinforced concrete structures. Base, support frame and conveyor comprise the conveyor galleries. The conveyor itself is made up of precast reinforced concrete truss, precast reinforced concrete slab and retaining structure. The conveyor contains steel component. The unique usage and artisan of the conveyor make the environment even worse. The frequent alternation of dry and humid air, the continuously increasing concentration of poisonous gas and liquid ion, the accumulation of solid attachments on the component, and long-term vibration load all contribute to the severe deterioration of the structural component, such as cracking of surface concrete, reinforcement rust, which pose a great threat to normal production and safety.

Fig 1: The main structure of belt corridor of ChaCheng coal

Tab1: General situation of the colliery

Position	Building Time	Material		
		Concrete	Rebar	Steel Member
Jiahe colliery1	1980s	200#	HPB235	——
Jiahe colliery 2	1980s	200#	HPB235	——
Chacheng colliery	1970s	200#	HPB335	——
Woniushan colliery	1960s	200#	HPB235	——
Zhangji colliery	1990s	C20、C40	HPB235、HRB335	Q235

To ensure the normal operation of conveyor gallery, the author fully detected the surroundings, artisan and mechanical environment of the 4 collieries and examined the design methods. In the meantime, the author studied the deterioration mechanism of conveyor gallery, and then proposed a technique that can reinforce the conveyor gallery after deterioration.

3. INDUSTRIAL ENVIRONMENT OF COLLIERY

3.1 Natural Environment

The natural environment of conveyor gallery is quite severe. On the one hand, the temperature and the humidity change frequently, on the other hand, the concentration of corrosive gas, liquid and solid media is very high. Especially important, most of them are acid. Among the gas media, Cl_2, HCl are high corrosive, moreover, SO_2, NO_x, H_2S, CO_2 are intermediate corrosive or low corrosive. Liquid media, which mostly consist of chloride and sulfate of Sodium, calcium and magnesium, are low corrosive. Among the solid media, the chloride of calcium and magnesium are high corrosive. The concentration of the corrosive media in the gas and solid environment can be seen in Tab 2 and 3.

Tab2: Corrosive medium content in gaseous environment

Sampling Position	ρH_2S/ （mg • m^{-3}）	ρHCl/ （mg • m^{-3}）	ρCl_2/ （mg • m^{-3}）	ρCO_2 （ppm）
JiaHe colliery1	0.0110	1.4040	1.2450	444
JiaHe colliery2	0.0177	1.3440	1.6803	443
ChaCheng colliery	0.0107	1.5917	1.3887	453
WoNiushan colliery	0.0107	1.4035	1.2200	454
ZhangJi colliery	0.0084	1.1059	1.3628	450

Tab3: Corrosive medium content in solid environment (weight percentage, %)

Sampling Position	W_{Na2O}	W_{MgO}	W_{Al2O3}	W_{SiO2}	W_{CaO}	W_{Fe2O3}
JiaHe colliery1	2.7	1.7	8.5	47.3	28.7	3.5
JiaHe colliery2	2.4	1.6	8.4	49.4	28.2	3.4
ChaCheng colliery	2.5	1.4	8.8	52.2	26.1	3.5
WoNiushan colliery	2.6	1.5	8.0	46.2	24.1	3.5
ZhangJi colliery	2.7	1.8	7.8	40.6	34.1	3.8

3.2 Mechanical and Artisan Environment

After elevated from the derrick, coals are transported by conveyor gallery to coal preparation plant or coal bunker. The unique function of the conveyor gallery makes the unique layout of the structure. The body of the conveyor gallery forms an angle to the ground, and acts directly to the corbel section of the retaining frame. Therefore, stress concentration exists at the corbel section. Meanwhile, due to the movement of conveyor gallery, the strong effects of the dynamic load make the interior part of structural component fatigue, which poses a great threat to the structural safety. These all contribute to the unique artisan and mechanical environment.

4. DETERIORATION CHARACTERISTICS OF MAIN STRUCTURE

4.1 Foundation

The backfill soil and ground on the foundation is intact, at the same time, the environment of backfill soil around foundation relative to the upper structure corrosion environment is relatively mild,

4.2 Supporting Frame

The frequent alternation of dry and humid air, the gas, liquid and solid poisonous media, and the longtime vibration all contribute to the reinforcement rust, concrete cracking and surface concrete falling. Crack width is concentrated in 0.56 mm to 3.93 mm. The rust rate ranges from 6.00% to 16.00%. Moreover, the corbel is also influenced by the conveyor, and therefore suffers more deterioration. The deterioration is so severe that the concrete cannot meet the designed requirement. Some appearance can be seen in Figure 2 and 3.

Using crack viewer to test crack width, using ultrasonic-rebound synthesis method to test Strength of concrete, using weighing method to test steel corrosion rate. The test results can be seen in table 4.

Fig 2: Concrete crumbling and steel bar rusting

Fig 3: Concrete crumbling and steel bar rusting

Tab4: Corrosive medium content in gaseous environment

Position	Appearance	Carbonation Depth（mm）	Matertial Concrete Intensive Grade	Rebar Corrosion Rate（%）
Jiahe colliery1	Part of concrete damaged, rebar corrosion is serious，crack width is concentrated in 0.96mm~3.57mm	27.0~38.0	C15~C20	7.5~12.3
Jiahe colliery 2	Part of concrete damaged, rebar corrosion is serious，crack width is concentrated in 0.84mm~3.41mm	27.0~38.0	C15~C20	6.8~11.4
Chacheng colliery	Part of concrete damaged, rebar corrosion is serious，crack width is concentrated in 0.98mm~3.64mm	28.0~39.0	C15~C20	8.6~13.5
Woniushan colliery	Part of concrete damaged, rebar corrosion is serious，crack width is concentrated in 1.15mm~3.93mm	27.0~41.0	C15~C20	8.7~15.7
Zhangji colliery	Part of concrete damaged, rebar corrosion is serious，crack width is concentrated in 0.56mm~2.95mm	27.0~35.0	C15~C20	5.6~11.5

Fig 4: Truss component corrosion serious

Fig 5: Steel component corrosion serious

4.3 Conveyor

Concrete crumbling is of great significance and widespread in precise reinforced concrete truss bracing. Reinforced concrete beam, slab and opening show cracking and bar rusting on the top and at the bottom of some bracing. The concrete deteriorates so severely that it cannot meet the design requirement. Some of the steel component of conveyor gallery shows some extent of rust. Rust rate of C shape beam ranges from 5% to 15% and rust rate of angle bracing ranges from 5% to 10%. Part appearance of the truss component can be seen from Figure 4 and 5.
The test results of member and material can be seen in table 5.

Tab5: Corrosive medium content in gaseous environment

Position	Appearance	Carbonation Depth（mm）	Material		
			Concrete Intensive Grade	Rebar Corrosion Rate（%）	Steel Member Corrosion Rate（%）
Jiahe colliery1	Part of concrete of beam damaged, rebar corrosion is serious，crack width is concentrated in 0.88mm~3.23mm	16.0~34.0	C15~C20	5.4~10.2	——
Jiahe colliery 2	Part of concrete of beam damaged, rebar corrosion is serious，crack width is concentrated in 0.74mm~3.11mm	17.0~34.0	C15~C20	5.1~10.1	——
Chacheng colliery	Part of concrete of beam damaged, rebar corrosion is serious，crack width is concentrated in 0.94mm~3.46mm	18.0~36.0	C15~C20	7.6~12.5	——
Woniushan colliery	Part of concrete of beam damaged, rebar corrosion is serious，crack width is concentrated in 0.99mm~3.63mm	17.0~39.0	C15~C20	8.5~14.9	——
Zhangji colliery	Part of concrete of beam damaged, rebar corrosion is serious，crack width is concentrated in 0.66mm~2.76mm	17.0~22.0	C25~C30	5.4~10.5	5.0%~10.0%

5. CHECKING METHOD OF THE DESIGH OF STRUCTURE

5.1 Checking Method of the Design

Checking can be performed by using structural design software or hand calculation with the latest code.

5.2 Checking Parameters

Models were built according to the layout and dimension on the drawing or field measurement. Concrete strength was tested in the field. Machinery was considered as dead load and live load; in the meanwhile, wind and earthquake load were considered. According to the “Code of Seismic Design of Buildings” (GB50011-2010)[7], the following parameters are taken[8,9]: wind pressure 0.35kN/m^2, live load 4.0kN/m^2, 10.0kN/m^2 for those containing cycling equipment, Surface roughness category Class C, Seismic Prevention category Class C, Intensity 7, Acceleration: 0.10g, Team: 2nd team, Seismic Level: 2. Reduction factor was taken into account for the deteriorating concrete and capacity[5].

6. CAUSES AND MECHANISM OF THE DETERIORTATION OF THE MAIN STRUCTURE

6.1 Causes of the Deterioration

1) Most of the conveyors were built in 1980s and before. Due to the poor construction quality and the difficulty involved in the construction, concrete was not shaken completely, which resulted in the poor surface of the concrete and the bar exposure. Moreover, the design did not take durability design into consideration, the cover was too thin and the bar was not processed against rust. Therefore, corrosive media are more likely to enter and corrode the inner part of concrete.

2) Coupling effect of colliery natural environment, unique artisan and mechanical environment: Prelonged vibration of conveyor made the continuous deterioration of components. Moreover, no proper maintenance was carried out. There is no cover for the steel and concrete component. Frequent washes of the conveyor made the conveyor contact the acid environment directly, which accelerates the deterioration of mortar, concrete and steel and surrounding areas. This is external cause for the insufficient durability of conveyor.

6.2 Deterioration Mechanism

1) Intact concrete is of high alkalescency. The passivation film on the rebar surface is stable. Acid media such as CO_2，H_2S，HCl，Cl_2，SO_2 and water enter the inner part of concrete and act with the alkali material, which will lower the alkalescency of concrete. When the pH is lower to 11.5, the passivation film will no longer be stable. When the pH is lower to 9~10, the function of passivation film will disappear completely. Meanwhile, Cl- enters the inner part of concrete. When the concentration of Cl- in the solution on the concrete surface is high enough, the Cl- will dissolve the passivation film. Under the effects of water and oxygen, the de-passivated rebar begins to rust and concrete cracks will lower the binding action between rebar and concrete, force area, and structural durability.

Some of the reaction formulas are:

CO_2: $CO_2+H_2O\rightarrow H_2CO_3$ $Ca(OH)_2+2H_2CO_3\rightarrow Ca(HCO_3)_2+H_2O$

$Ca(OH)_2+H_2CO_3\rightarrow CaCO_3\downarrow+2H_2O$

HCl: $CaCO_3+2HCl\rightarrow CaCl_2+CO_2\uparrow$ $Ca(OH)_2+2HCl\rightarrow CaCl_2+H_2O$
$2Cl_2+2H_2O\rightarrow 4HCl+O_2\uparrow$ $Ca(OH)_2+2HCl\rightarrow CaCl_2+2H_2O$

SO_2: $SO_2+2Cl_2+3Ca(OH)_2+2H_2O\rightarrow CaSO_4\downarrow+2CaCl_2+6H_2O$ $H_2O+SO_2\rightarrow H_2SO_3$
$Ca(OH)_2+2H_2SO_3\rightarrow Ca(HSO_3)_2+H_2O$ $Ca(OH)_2+H_2SO_3\rightarrow CaSO_3\downarrow+2H_2O$

2) The poor quality of supporting frame and truss make the entrance of acid media into concrete easier. Under the effect of frequent alternation of dry and humid environment, cracks will appear on the interface of mortar and form into capillary, which will increase the penetrability of concrete. Meanwhile, the accumulation of fatigue due to dynamic load makes the concrete crack. Cracks enlarge as time goes by. Corrosive media (CO_2, H_2S, HCl, SO_4^{2-}, Cl- and Na_2SO_4) enter and corrode the concrete, which in turn makes it easier for the acid media to enter the concrete. Alternation of dry and humid environment, to some extent, accelerates the rate of spread and penetration.

Some of the reaction formulas are:

$Na_2SO_4+Ca(OH)_2+2H_2O\rightarrow 2NaOH+CaSO_4\cdot 2H_2O\downarrow$
$MgSO_4+Ca(OH)_2+2H_2O\rightarrow Mg(OH)_2+CaSO_4\cdot 2H_2O\downarrow$

3) Some of the steel components are exposed in the air and act with the surrounding media such as O_2, CO_2, SO_2, which results in loose oxide and chemical corrosion. The steel consists of different crystal and impurity, and these components have different Electric potential. When exposed to the water, primary battery will form on the steel surface. Moreover, the severe colliery environment accelerates the pace of electrochemical corrosion. The chemical and electrochemical actions, on one hand, corrode the surface of the structure and lower the capacity, on the other hand, corrosion on the surface of the component will cause stress concentration and the fragile rupture of steel. These all will lower the structural capacity and durability and severely influence the safety of main structure.

4) Under the vibration load of conveyor for a long time, damages of the components of conveyor accumulate and crack will first appear on the weakest section. As time goes on, crack will enlarge. Under the action of frequent alternation of dry and humid environment, cracks will appear on the interface of mortar and form capillary, which will increase the penetrability of concrete. These all increase the penetration factors, which will cause more acid media to enter the concrete and accelerate the deterioration rate. Meanwhile, the deterioration of material lowers the capacity of the component and structure, which gradually makes the displacement larger.

7. RESTORATION, REINFORCEMENT AND PROTECTION TECHNIQUES OF MAIN STRUCTURE

Considering the unique industrial environment and current situation, deterioration mechanism should be considered when we are designing to avoid further deterioration [10]. Restoration and reinforcement are necessary, so is durability maintenance. Different strategies should be taken according to the different deterioration rate. To fully display the structural potential, the reinforcement design should not only consider the current situation, which includes load capacity and continuous operation after earthquake, but also take economy and construction convenience into consideration.

For the supporting frame, the severely deteriorated concrete should be removed first. After anti-rust processes are carried out for the rebars, polymer or modified mortar or concrete is used to restore the concrete component. Then for those components which have insufficient capacity, enlarge their section area or attach carbon fiber. Last, put on 20mm-thick polymer mortar for protection.

For the conveyor, the severely deteriorated concrete should be removed first. After anti-rust process esare carried out for the rebars, polymer or modified mortar or concrete are used to restore the concrete component. Then for those components which have insufficient capacity, are attached to carbon fiber and put on 20mm-thick polymer mortar for protection. For C-shape steel beam, after the removal of rust, is attached to glass or carbon fiber and then put on 20mm-thick polymer mortar for protection. For steel components, after the removal of rust, smear anti-rust lacquer.

8. THE MAIN CONCLUSIONS AND SUGGESTIONS

1) Most of the current conveyor galleries have been built for a long time. The internal cause of deterioration includes poor design and construction techniques, poor quality of concrete. The coupling reaction of concrete with surrounding corrosive media and unique artisan, mechanical environment are the external cause of deterioration. Under the coupling action of internal and external causes, the durability of the main structure cannot meet the requirement of the later use.

2) The coupling action of natural deterioration of concrete itself and the fatigue caused by vibration accelerate the

deterioration rate of concrete components, lower the reliability of concrete structure, and cannot guarantee the designed life-span. Therefore, advice is proposed to restore the component first, enforce those that have insufficient capacity and carry out a long-term maintenance.

3) The structure of the conveyor is quite special: Precast reinforced concrete truss and reinforced concrete slab deteriorate similarly; Cracks appear along the rebars, concrete cracks, rebars rust severely; Under the chemical and electrochemical action, on one hand, the surface of the concrete is corroded and overall capacity decreases, on the other hand, some local component corroded, which causes stress concentration and brittle rupture. These all lower the capacity, durability, and pose a great threat to the safety of the main structure. Therefore, for the reinforced concrete, after restoration and reinforcement, a long-term maintenance should be carried out. For the steel component, removal of rust and smearing of anti-rust lacquer is needed as well as regular check.

4) Considering the unique industrial environment and current situation, deterioration mechanism should be considered when we are designing to avoid further deterioration. Restoration, reinforcement and long-term maintenance should all be considered and applied to improve the capacity according to the type of component and deterioration condition, durability of the component and structure as well as the life of the conveyor.

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