A study on the Effect of the Impervious Curtain on the Slope of the Open Pit of Yuanbaoshan Coal Mine

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Abstract: Yuanbaoshan open pit is one of the biggest coal mines in china. The impervious curtain is designed to cut off Quaternary underground water supplying to the open pit. In this paper the engineering geological conditions are discussed. According to its engineering geological condition, several slope failure models of the slope are determined. The slope stability of the open pit is evaluated at this condition by using different evaluation methods. Finally the optimization position for building the impervious curtain is determined.

Key Words: slope stability, impervious curtain, failure model

Introduction

Yuanbaoshan coal open pit is located in Inner Mongolia on the plain of Jinyin river. It is designed to produce 5 million tons of coal every year and began stripping in 1990. Shenyang Coal Mine Design Institute evaluated the slope stability and designed the East, West and South slope that will be formed 30 years later according to the excavation planning. This design considers draining underground water around the open pit and makes the slope dry. To make the slope stable, 40 drainage wells are distributed around the open pit that make the underground water level of nearby region decrease seriously and greatly affect the agriculture and industry activity. The impervious curtain around the open pit is considered to solve these serious problems.

The designing of the impervious curtain wall which cut-off the total Quaternary system stratum and set on bedrock which is from 32 to 80 meters high (from south to north). It will change the boundary condition of the open pit forming high water pressures on the back of wall and greatly affect the stability of the open pit slope. 12 sections are choice at south, east and west wall to evaluate the stability of the slope at this condition, and to give the optimization position of the curtain. The position of the impervious curtain wall is determined by evaluation.

The engineering geological conditions of Yuanbaoshan open pit coal mine

This coal mine is divided into two parts, east-north part and west-south part, by Jinyin river. The impervious curtain wall is on the west-south part. The open pit is located on the left bank on the first terrace of Jinyin river flood land. The original topography is smooth. It will form an open pit where east-west length is 2.6 km, south-north width is 1.6 km after excavation. The open pit slope angle on Quaternary part is 21° and on bedrock it is 18°. The strata in the mine region include Jurassic, tertiary and Quaternary systems. The strata
from bottom to up are: (1) Jurassic system strata($I_3^+$), mudstone and gravestone, mainly distributed on east wall. (2) Jurassic system strata($I_3^-$), mainly sandstone and containing 12 layers of coal mine distributes in whole region. (3) Tertiary, Miocene epoch strata($N_2$), red sandstone and mudstone, unconformity on Jurassic system, distributed mainly in south wall. (4) Quaternary ($Q$), alluvium and flood material, the thickness at north east is 60m and about 10m at southwest.

Mine region is a syncline with axis of NE25°. It is cut by fault F1. The dip angle of bedrock is about 8°. The west wall strata dip direction is forwards the open pit. North wall dip direction is opposite to the wall, the dip angle is near 5°. The dip direction of east wall stratum is forwards the open pit. All of the fault dip angle is high and about 0.4 to 0.5 km long except F1 that is 5 km long.

The rock mass in Yuanbaoshan region is mainly sandstone, mudstone with loose structure and weak bonding, softening with water and low strength. The wide distribution of weakened structure surface and mud interface form potential slide surface in slope. According to statistics, there are 6 layers of weak strata in south wall and 9 layers in east and west wall.

The main aquifer in mine region is Quaternary deposit. The top part of Quaternary is gravel which has a permeability parameter of 255.4 ~636.9 m/d. The lower part is sand which has a permeability parameter of 122.6~146.6m/d. The permeability parameter is 14.7/d for tertiary strata and 0.08m/d for Jurassic strata. The underground water is supplied by Jinyin river and precipitation. After the impervious curtain building, the water level on the back of the curtain will return to original position.

![Diagram](image)

**Fig.1** The Engineering Geological Map of Yuanbaoshan Coal Open Pit

**The failure model of slope and stability analysis method**

The geological structure of each wall is different in Yanbaoshan coal open pit. Its failure model at deferent parts is very variable. According to its potential slide surface, the slope
failure model can be divided into four types. (1) Straight line slide failure model: When straight stratum bed dips to open pit and strata dip angle is smaller than slope surface angle, its failure model is a straight line type. The sections 6, 7, 8, 8B and the Quaternary material slide along bedrock are straight plane slides belonging to this failure model. (2) Circle slide failure model: At south and east wall, the rock mass is weak and soft. Its strength is lower, so the circle type of slide failure can take place there. (3) The slide surface is composed by mud interfaces and faults or joints. Its slide surface is represented by broken line model. When strata dip angle is changed from place to place in slope or cuts by fault, the broken line failure model will form, such as in west, east wall and the section 26 of south wall. (4) Combined slide failure model: When mud interface and structure discontinue or when the properties of rock mass are imhomogenous, the slide surface will be partly a curve and partly a straight line. This kind of failure surface model is mainly in the south and north wall.

Under the condition of slope failure model, when the angle of rock bed on slope foot is smaller than the upper part, the upper part of rocks and soil mass will be the origin of the slide body; especially when there are water pressures behind the impervious curtain. The slope forms a pushing model movement. That is, if the angle of rock bed is steep on slope foot and gentle on upper part, or cut by joints or fault, stability of upper slope is higher than the lower part. For this condition, the tensile slide is produced, then the upper rock mass will gradually slide. In a drag slide model, origin of force comes from the lower part. The possible drag sliding can occur along the soft interstrata under the action of impervious curtain. In Yuanbaoshan coal mine, this kind failure model can be formed at sections 3 and section 5 of east wall.

According to the failure models on the side slope, when dip angle is the same in slope rock mass, dipping to open pit, the straight plane analysis method is used. When slide-body is a circular sliding surface, Bishop method is adopted in stability analysis. When slide body is a broken line failure model, Sarma method is adopted in stability analysis. The Janbu method is mainly used to calculate the stability of composing slide failure model of the slope. Using above mentioned four methods, the stability of 12 sections (section 4, 7, 3, 5, 6, 7, 8, 8B, 24, 26, 28, 1) has been analyzed.

To keep the calculation parameters reliable, the statistical probability ellipse analysis method, t distribution method and standard deviation methods are used according to the sample numbers. The rock mass strength is determined by weakening parameter method. According to the density of joints, one can determine the value $\lambda$. The density of joints is determined by the parameter, R.Q.D. In east wall the density of joints is 6/m. In west and south wall it is 5/m. Hence the weakening parameter for east wall rock mass is 0.04 and for west and south wall rock mass is 0.05. The cohesion value used in calculation is the test value multiple this weakening parameter. The internal friction angle is using the laboratory testing value.

**Stability Analysis of the Slopes**

In the slope of Yuanbaoshan coal open pit, the most dangerous sliding planes are totally weak interface, or part of the sliding plane is along the weak interface. There is hardly any
difference between the shear strength of the interface and that of the structural plane. Because the soft rock easily produces deformation under tectonic action, the joints and cracks in the soft rock mass are not developed. The shear strength of the weak interface is lower. Besides taking the lower internal friction angle 9.7°, the mean 12° of internal friction angle is also used in the stability calculation. The residual water level in the slope bedrock is taken to be 10m above the sliding surface. At the same time, the safety factor is calculated when there is no bedrock groundwater in the impervious curtain. When the slope is able to slide along the interface between the Quaternary system and bedrock, considering the bedrock weathering and rolling, the dip angle of the sliding surface is taken 4°. The calculated results are discussed below.

When the impervious curtain is 200m from the edge of the open pit, the safety factors (FOS) of each possible sliding surface in the section 4 of west wall are more than 1.3. Hence the slope at this section is stable when the impervious curtain is 200m from the edge of the open pit. The stability analysis results of the section 7 of the west wall are illustrated in figure 2. As shows in this figure, the FOS of this section along the weak interface 25 is 1.216 which is not effect by the impervious curtain. When the impervious curtain is 200m from the open pit edge, the FOS of 1.216 is valid, if the sliding plane is along the weak coal seam 7 at up part and shears out at the bottom of the open pit. When the earthquake intensity is taken to be 6 degree, the FOS is only 1.156. This section is basically stable if the groundwater level of bedrock is not more than 10m high above the coal seam 7, and the strata below the coal seam 7 are not cut up in the excavation. In the north of the section 8 of the west wall, when the open pit deepens, especially the strata at the east of the fault 4 are throw down, hence the stability of this part of slope will be decreased. Therefore, the important conditions of ensuring the west wall stable are that the strata below the coal seam 7 are not cut up when the impervious curtain is 200m from the open pit edge.

![Fig. 2 Calculation Section of slope stability at line 7 of the west wall](image)

The safety factor of each section in the north of the section 6 in the east wall is more than 1.2 when the impervious curtain is 200m from the edge of the open pit. But the lower part of the slope at sections 6 and 7 are not stable when slide surface is along the bottom of the coal seam 7 or faults F₁ and F₂, but the stability is not affected by the impervious curtain. When these two parts of slope destabilize, the safety factor of the upper part of the slope is still more than 1.2, which is calculated according to the dragging land slide. We can conclude that the upper part of slope and imperious curtain are safe even when the lower part of the slope is unstable. The sections 3 and 5 in the south of the east wall are unstable.
when the sliding planes develop along the coal seam foot wall or fault F1. Only when the impervious curtain is 500m or 400m from the edge of the open pit, the safety factor is more than 1.2. It can be seen that the stability of the slope in the South of the line 6 in the east wall is largely decreased under the influence of the fault F1.

Fig. 3 Calculation section of slope stability at the line 6 of the east wall.

The calculated results for the sections 24 and 1 of the south wall show that all the safety factors of the potential sliding plane are more than or equal to 1.3 when the impervious curtain is 200m from the edge of the open pit, showing the slope is stable. When the impervious curtain is 200m from the edge of the open pit, taking the $\Phi=9.7^\circ$, the safety factor of sliding planes 2 and 5 at the section 28 of the south wall is only 1.171 and 1.187, showing that the safety factor of the slope is not adequate. Because there is no section controlling the geological conditions, the impervious curtain should be drawn back. If the impervious curtain is 200m from the edge of the open pit, the safety factor of the line 26 in the South wall is less than 1; when the impervious curtain is 400m from the edge of the open pit, the FOS is 1.134. When considering the earthquake intensity (6 degree) the safety factor will be 1.073. When the impervious curtain is 500m from the edge of the open pit, the safety factor will be 1.279, the south wall will be stable.

Fig. 4 The stability calculation Section 26 of the South wall.

Conclusions

(1) According to the stability analysis of each wall, rock mass structure, shear strength of the weak interface and the ground water level in front or back of the impervious curtain are three main factors that effect the slope stability of the Yuanbaoshan coal open pit. The strata of Tertiary system and fault F1 are the controlling factors in the rock mass structure. The strength of the weak interface $\Phi=12^\circ$ is suitable. To ensure slope stable, the groundwater level at the back of the impervious curtain should be no higher than 10m above sliding plane.
(2) The impervious curtain of west wall must have 200m distance at least to the border of the open pit. The curtain in north of 8B section should keep 300m distance to be suitable for future stripping in north of Jinyin river.

(3) 200m distance from open pit border to curtain can make the impervious curtain of east wall stable in north of section 6. From section 6 to section DC the distance must be over 400m and to section EF the distance must be over 500m to make the slope stable.

(4) The distance from curtain to the border of open pit must be more than 500m to the south wall. If the distance requirements can not be met due to other reason, reinforcement measures need to be considered.

(5) Stability calculations have not considered the seepage aspects of the curtain. Keeping the curtain wall quality and preventing seepage are important factors to keep this impervious curtain wall project successful.

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