Characteristics and Genesis of Loess High Slope on the West Side of Shuiliandong Colliery in Binxian County

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Abstract. The loess high-slope on the west side of water curtain cave colliery is an old landslide debris back-wall. There is an old landslide debris deposit at bottom of the slope. Surface water can infiltrate into the slope through loess uprightness joints and cranny. The groundwater flow gradually causes the formation of water cavities in the upper slope region. The slope further has loess stratification, obliquity (from 5° to 10°) and paleosols place. Surface water infiltrates into paleosols and induce water cavity exit with the top water cavity transfixion. The paleosols ideally prevents water. The loess stratification leans to ravine. The slope is unstable and will fail under the action of precipitations.

1. Introduction

Water curtain cave coal mine is located 5km from Binxian County, Shaanxi Province and it belongs to the jurisdiction of Bin County Chengguan, which is next to Xiagou coal mine on the east, and next to Dafosi coal mine on the west. Industrial site is located in Bin County Chengguan town water Curtain Village Shizì ditch, from 312 national highway about 2km. Industrial site used semi-filling and semi-excavating construction mode, the ranges of ground elevation after digging were between 950.00 to 956.00 meters , and the industrial sites north and south long about 350.00m, east and west width of about 150.00m finally.

According to survey, there are many Loess sinkholes at the top of the slope, and some of them formed Innateness bridge (Figure 1). From the collapse in the loess sinkholes and the surrounding vegetation growth state, we can draw a conclusion that the formation time of the Loess sinkholes is different from each other. The outlet of the loess sinkholes can be seen on the hillside of the posterior edge slope, which indicates that the loess sinkholes on the top of the slope and the cavern on the hillside of the posterior margin slope have been connected, and the land subsidence of the surface between the cavern of the slope top is also found. The upper strata tend to gully for the effect of catchment, where will form a penetrating beaded loess sinkholes if the hole at the top of the slope and local subsidence further develop, and cause local instability of the slope finally [1,2]. On the other hand, the bottom of the gully is impacted by the water flow erosion, continuous cutting and loose matter is taken away by the water flow, which makes the foot of the slope is easy to form an empty and the slope become steeper constantly [3]. With the affection of long-term precipitation and short-term heavy precipitation, the slope is prone to have large-scale destruction. Mine wellhead and
public facilities, living and welfare facilities, auxiliary production facilities of proposed water curtain cave coal mine are threatened by slope instability.

![Innateness Bridge water cavity](image1.jpg)

**Figure 1 Innateness Bridge water cavity**

2. Geological conditions of slope
The original slope is about 300.0m long, about 180.0m high, the slope overall tendency is about 86°, the slope of lower part is 25°–35°, the slope of upper part is 55°. For the whole slope, it is broken relatively, we can see that multilayer ancient soils are exposed to air, and residues piled up at the lower part of the slope where have suffered a landslide (Figure 2). The slope is about 140.0m high after flating field, and it becomes steeper than before as a whole [4,5].

![Landslide soil Debris of Slope](image2.jpg)

**Figure 2 Landslide soil Debris of Slope**

2.1 Topography and Geomorphology
The geomorphology unit of the area is the Loess Gully, which displays "V" type, and it’s width is about 20.0–50.0m and the maximum relative height difference is about 40.0m, the top of this slope is the Loess plateau which has the 3–5 level platform, and each stage platform is about 2.0m. The north side of the slope is a gully with a loess sinkholes in it, and the vertical joints of the loess and the developed fissures can be seen on the inner walls of the gully.
2.2 Stratigraphic Lithology

The lithology of the stratum is mainly: Slope of the Quaternary Holocene, alluvial loess-like silty clay (Q_{4}^{al+pl}), Holocene aeolian loess (Q_{eol}^{4}), Holocene residual black square soil (Q_{el}^{4}), Upper Pleistocene aeolian loess (Q_{eol}^{3}), Upper Pleistocene residual paleosol (Q_{el}^{3}), Middle Pleistocene aeolian loess (Q_{eol}^{2}), Middle Pleistocene residual paleosol (Q_{el}^{2}), Lower Pleistocene, alluvial silty clay and round gravel (Q_{al+pl}^{1}) (Figure 3).

(1) Loess, the upper part is plastic-hard plastic, slightly dense, slightly wet, the soil is relatively uniform, a small number of wormholes, pinhole is developing, containing a small amount of calcareous tuberculosis, with collapsibility; the lower part is hard plastic, medium dense, wet, uniform soil, a small amount pinholes, large holes, containing a small amount of calcium tuberculosis.

(2) Ancient soil, 5~6 layers of paleosols included in the loess layer, hard plastic, medium density, slightly wet-wet, lump structure, partially visible small pores, contain calcareous tuberculosis, particle size 30~40mm, containing a lot of white calcium stripes, 0.20m thick calcareous tuberculosis layer is commonly seen at the bottom of the layer.

(3) Silty clay, plastic-hard plastic, dense, uniform soil, visible iron-manganese, mica, calcium nucleus and shells, snail shell fragments, partially visible brown stripes, layers of 0.20~0.50m thick calcareous tuberculosis amid.

2.3 Structural Plane

The loess high slope is located in the Miao bin depression area of the north of the Wei bei fold belt in the south of Ordos Basin. The depression consists of Triassic, Jurassic and Cretaceous, and has a simple structure, which is mainly characterized by a wide fold of N50° ~70°, and a formation dip angle of 5° ~17°.

Drilling revealed that the Quaternary Lower Pleistocene of the site is an alluvial layer with level occurrence and visible horizontal bedding [6,7]. The Quaternary Holocene, the Middle Pleistocene and the Upper Pleistocene are both inclined to the ravine and the ravine down-stream, with an inclination of 8° ~10°, which tends to NE (Figure 3).

2.4 Surface Water and Ground Water

There is normally a current in the ravine where the site is located, but the flow is not large, and the flow is only large during the rainy season.

The groundwater depth in the site valley is 0.90~2.00m. On the west of the site, spring flows out, which is distributed in a line, on the contact surface of the Quaternary and the underlying bedrock. The
spring is replenished by the upstream underground water, and is discharged in the form of spring water along the ravine. It is a descending spring. Although the flow is not large, it flows constantly.

3. **Deformation Failure Characteristics of Slopes and Analysis of Their Causes**

3.1 *Topography and Geomorphology*

![Figure 4 Sketch for Slope Failure Mode](image)

3.2 *Causes Analysis Topography and Geomorphology*

It can be seen from the characteristics of deformation failure above that the slope failure is mainly controlled by three factors, namely vertical joint of loess, tendency of loess layer, paleosol layer, and water accumulation in the slope.

1. Due to the vertical joint development of the Quaternary Holocene and upper Pleistocene loess in the upper part of the loess slope, in the rainy season, especially in the rain-storm and continuous rainy season, the rainwater infiltrates along the vertical fissure, so that the fissure expands under the action of hydrodynamic erosion and transportation. Under the long-term continuous hydrodynamic action, the water cavities develops and expands along the slope aggravating the damage.

2. The upper loess and paleosol layer slightly lean to the side of the valley, and the center of the slope also leans to the valley. Under the action of long-term tensile stress, a tensile stress concentration zone is generated within a certain range of the slope top soil and the slope body [8]. Cracks are generated in the direction that is parallel with ravine, and gradually penetrate, and the subsidence concave land and the reverse slope step are generated at the trailing edge of the slope body. At the same time, a shear-compressive stress concentration zone is generated at the bottom of the water cavities (crack). Over time, the upper part of the stress concentration zone is first destroyed, causing the stress concentration zone to move downward which finally leads to the instability and damage of the slope.

3. The paleosols layer is a good aquifuge. While rainwater seeps into the top of the paleosols layer leading to a large amount of water accumulation, the soil layer is saturated with water, resulting in a rapid increase in the water content and unit weight of the soil (increased slope weight). Under the action of hydrodynamic pressure and hydrostatic pressure, the strength of loess decreases sharply, and the shear stress in the shear stress concentration zone of the soil exceeds the peak shear strength. Meanwhile, the progressive destruction develops over time. On the one hand, the crack in the top of the slope develops downward to reach the failure surface. On the other hand, the central failure zone
extends upwards and downwards, and when it is penetrated into the compressive-shear failure zone at the foot of the slope, there is large-scale instability of the slope.

4. Conclusions
The main factor that causes the slope to be unstable:
(1) Vertical joints and fissures of loess are developed, and finally a penetrating water cavity is formed;
(2) The upper loess layer tends to the ravine with a dip angle of 5°~10°, and the center of gravity of the slope body tends to either.
(3) The paleosols layer is a good aquifuge.
(4) In the case of heavy rainfall or long-term rainfall, a large amount of surface water infiltrate along the loess joints and fissures to the paleosols layer, resulting in the saturation and softening of the soil layer at the top of the paleosols. Under the effect of hydrodynamic pressure and hydrostatic pressure, a water cavity is initially formed, then, the horizontal and vertical penetrating water cavities or slopes are partially collapsed. Finally, the slopes are affected by heavy rainfall or long-term rainfall, and its weight increases sharply, resulting in large-scale destruction of the slope.

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