The formation mechanism of river erosion-induced loess landslide

X Q Yuan¹, Z Duan¹² and F S Zhao¹
¹School of Geological Engineering and Geomatics, Chang’an University, Xi’an, Shaanxi, China
²Xi’an University of Science and Technology, Xi’an, Shaanxi, China
Corresponding author’s e-mail address: 253136313@qq.com

Abstract. The Jingyang South Plateau is located near the right bank of Jinghe river, belonging to Weibei Loess Plateau. Since the large-scale irrigation from 1976s, many river erosion-induced loess landslides have occurred in the Jingyang South Plateau. Landslide disasters has seriously affected local economic development and the safety of people’s live and property. To better understand the formation mechanism of landslides in this area, this paper uses field investigation, reduced triaxial compression shear test on saturated Q2 loess and numerical simulation to understand the formation mechanism of erosion-induced loess landslides. It is concluded that (1) Under the reduced confining pressure stress path, the yield strength of saturated Q2 loess is related to the initial confining pressure and shear rate. (2) The formation mechanism of river erosion-induced landslide of loess has been proposed: river erosion is the fundamental cause of river erosion-induced landslide of loess, and some blocks of soil laying at the foot of the slope plays a key character for the stability of the slope. This research could be helpful in preventing landslide disasters.

1. Introduction
The landslide had occurred more than 40 times in the south tableland of Jingyang in Shaanxi province since the large-scale irrigation in 1976s. The landslide disaster had destroyed the 113.33ha of farmland, caused 29 people deaths. The landslide disaster has seriously affected the local economic development and the safety of people’s live and property [1-2].

In view of the seriousness and harmfulness of the loess landslide in south tableland of Jingyang, many scholars had conducted in depth research on the types, development characteristics, distribution rules and formation of loess landslides [3-5]. It was generally accepted that large areas of agricultural irrigation was the major cause of loess landslide. However, it was also found that there was the other kind of loess landslide, called river erosion-induced loess landslide, which was different from the irrigation-induced loess landslide. The river erosion-induced loess landslide developed at the intersection of the south tableland of Jingyang and Jinghe river. The continuous erosion of the Jinghe river was the main triggering factor of river erosion-induced loess landslide. So this paper divides the loess landslide into irrigation-induced loess landslide and river erosion-induced loess landslide from the perspective of the triggering factor. Several large-scale landslide disasters were belonged to irrigation-induced loess landslide in history, such as Dongfeng landslide and Jiangliu landslide. Therefore, many scholars had conducted an in-depth study on the formation mechanism of irrigation-induced loess landslide and there were few researches on the formation mechanism of river erosion-induced loess landslide [5-6]. However, through the field investigation, the river erosion-induced loess
landslide was wide distribution and could make great harm to the local, so it was very meaningful to study the mechanism of river erosion-induced landslide. To understand the mechanism of river erosion-induced landslide, this paper used field investigation, reduced triaxial compression shear test and numerical simulation analysis. Finally, based on the present results, the prevention of loess landslide has also been put forward.

2. The river erosion-induced loess landslide

The Jingyang South Plateau is located on the right bank of Jinghe river, south of Jingyang county in Shaanxi province. It is a component of Loess Plateau in Weibei. Its plateau is broad and its climate belongs to a warm temperate continental monsoon climate. Affected by the new tectonic movement and the Jinghe concealed fault, the northern mountainous region in the area showed a slow upward trend over many years, forming the Loess Plateau on the south bank of Jinghe river. Due to the fast uplift of the northern mountainous region and the Jinghe river continually eroded the south bank, the steep slope was formed along the south tableland of Jingyang where collapse and landslide was very developed (figure 1).

Trough the field investigation along the south tableland of Jingyang with a length of 27.1km and the interpretation of the landslide using the Google Earth Plus historical remote sensing image function, there were 50 river erosion-induced landslides, all occurred in the intersection of the south landslide tableland of Jingyang and Jinghe river (figure 1). The number of the river erosion-induced loess landslide would show an increasing trend with the continuous effect of the erosion of Jinghe river rotating sliding. After landslide occurred, the geomorphic feature was obvious, the back wall was steep and smooth, the perimeter of the landslide deposit body was clear and easy to identify, the body of landslide would extend into the Jinghe river (figure 2). If the body of landslide is enough large, it will form a dammed lake in the Jinghe river. That is a very dangerous thing to the inhabitants of the downstream. So, in view of the seriousness and harmfulness of river erosion-induced landslide, it is very meaningful to study the formation mechanism of river erosion-induced loess landslide.

3. Reduced triaxial compression shear test

It is considered that the continuous erosion of the Jinghe river is the main triggering factor of the river erosion-induced loess landslide. The internal stress in the slope body is continuously changed and adjusted when the slope is eclipsed by the river [7-10]. It is very important to recognize the stress-strain behaviour of saturated \( Q_2 \) loess in this condition for studying the formation mechanism of river erosion-induced loess landslide. Therefore, this paper chooses the reduced triaxial compression shear test to study the deformation and failure characteristics of the saturated \( Q_2 \) loess.

The experiment was carried out with initial confining pressure of 100kpa, 200kpa, 300kpa, 400kpa, 500kpa and the shear rate was \( \Delta q = 0.04kPa/min \), \( \Delta \sigma_3 = -0.04kPa/min \). Considering the Jinghe river’s water level and its flow rate changed with the seasons, this experiment compared the shear rate \( \Delta q = \)
0.06kPa/min with Δq=0.12kPa/min under initial confining pressure 300kpa in order to study the impact by the erosion rate.

The stress-strain curve under different initial confining pressure conditions was showed in figure 3. As showing in figure 3, the saturated Q2 loess exhibited strain softening characteristics under the decompression stress path. The higher the initial confining pressure was, the more obvious the strain softening characteristics exhibited. The yield strength was a positive correlation with the confining pressure.

The stress-strain curve under different shear rate was showed in figure 4. As showing in figure 4, the yield strength increased with the increase of the shear rate. The curve of elastic deformation stage was steeper under a faster shear rate. The faster the shear rate, the smaller the deformation.

4. Numerical simulation research

4.1. Simulation program

In order to study the gestation and development process of river erosion-induced loess landslide and reveal the formation mechanism of river erosion-induced loess landslide from the perspective of stress-intensity relationship of soils, this paper used FLAC3D numerical simulation software to simulate the change process of stress and strain before landslide occurred. The figure 5 showed the numerical calculation model. The table 1 showed the numerical simulation materials and parameters. This paper set two different side eclipse rate simulation program as the table 2 showed.
### Table 2. Numerical simulation program.

| M-C model | stable water level |
|-----------|--------------------|
| simulation of lateral erosion | erosion rate | 1/3 block | 1/5 block | 9m |
| M-C model | M-C mode |

#### 4.2. The result of the simulation

The figure 6 showed the plastic development of 1/3 lateral model and the figure 8 showed the plastic development of 1/5 lateral erosion model. As showing in figure 6 and figure 8, the soil was subjected to tensile stress at the top of the slope and the shear plastic was mainly distributed on the foot of the slope when the slope was not eroded by the river. The shear plastic zone was small at the initial stage. The extent of the plastic zone would continue to expand from the foot of the slope to the interior and the top of the slope when eroded by the river. Finally, a shear fracture surface was formed and the slope slid along the fracture surface. Comparison of plastic zone development at two shear rates, the plastic zone of 1/5 lateral erosion developed faster than plastic zone of 1/3 lateral erosion.

The figure 7 showed the shear strain development of 1/3 lateral erosion model and the figure 9 showed the shear strain development of 1/5 lateral erosion model. As showing in figure 7 and figure 9, the shear strain in the slope was in the shape of an arc. The peak strain increment was always concentrated on the foot. As the degree of lateral erosion increased, the shear strain increment zone gradually widened, the range of the peak strain increment and the peak value increased. Finally, the shear strain value and the range reached maximum when landslide occurred. Comparison of the shear strain development at two shear rates, the width and size of the shear strain of 1/3 erosion developed greater than the shear strain of 1/5 lateral.

![Figure 6. The plastic zone development of 1/3 lateral erosion model.](image)

![Figure 7. The shear strain development of 1/3 lateral erosion model.](image)
5. Discussion on the formation mechanism of river erosion-induced loess landslide

The formation mechanism of river erosion-induced landslide of loess had been studied through field investigation, reduction-pressure triaxial shear test and numerical simulation analysis. River erosion is the main triggering factor and the formation of river erosion-induced loess landslide is a complicated process. The stress and strain of slope gradually changed with the river erosion and is also affected by the rate of the river erosion. From the result of the triaxial shear test and the numerical simulation, it is considered that there is some block of the soil at the foot of the slope, which plays a key role for the stability of the whole slope. If that part of the soil is destroyed by river erosion, the landslide will occur. It is also considered that river erosion rate has a great impact on the formation of the river erosion-induced loess landslide. The landslide more easily occurs when the river erosion rate is higher.

6. Conclusion

1. Under the reduced confining pressure stress path, the yield strength of the saturated Q2 loess is related to the initial confining pressure and the shear rate. The greater the initial confining pressure and the higher the shear rate, the higher the yield strength.

2. River erosion is the fundamental cause and the formation of river erosion-induced loess landslide is a complicated process. It is considered that there is some block of the soil laying at the foot of the slope, which plays a key role for the stability of the whole slope. If that part of the soil is destroyed by river erosion, the landslide occurs.

Acknowledgments

The authors would like to thank Dr. Zhao and Dr. Duan for supporting this work and acknowledge the great help and support from all who participated in the works carried out for this study.

References

[1] L. M. Fan, “Development pattern of slumping bank type landslides at the south bank of Jinghe, Shaanxi province”, COAL GEOLOGY OF CHINA, V16, n5, pp.33-35, 2004.

[2] D. Y. Wang, “Geological Hazard of Cliff Collapse, Landslide and Their Occurrence in Southern Jingyang County of Shaanxi Province”, Bulletin of Soil and Water Conservation, V24, n4, pp.34-38, 2004.
[3] X. Y. Lei, “The Hazards of Loess Landslide in the southern Tableland of Jingyang County, Shaanxi And Their Relationship With the Channel Water Into Fields”, Journal of Engineering Geology, V3, n1, pp.56-64, 1994.

[4] Y. L. Jin, “The mechanism of irrigation-induced landslides of loess”, Chinese Journal of Geotechnical Engineering, V29, n10, pp.1493-1500, 2007.

[5] L. Xu, “Dicussion on infiltration of surface water and their significance to terrace loess landslides”, The Chinese Journal of Geological Hazard and Control, V19, n2, pp.32-36, 2008.

[6] L. Xu, “Loess Landslide Types and Topographic Features at South Jingyang Plateau, China”, Earth Science-Journal of China University of Geosciences, V35, n1, pp.155-161, 2010.

[7] L. Liang, “Influence of stress path on consolidated undrained shear strength of loess”, Rock and Soil Mechanics, V28, n2, pp.364-366, 2007.

[8] B. C. Zhou, “Study on numerical modeling of constitutive relations for remolded under reduced triaxial compression path”, Chinese Journal of Rock Mechanics and Engineering, V26, supp1, pp.3190-3195, 2007.

[9] C. L. Chen, “Influence of stress path on deformation and strength characteristics of saturated intact loess under drainage condition”, Shuili Xuebao, V39, n6, pp.703-708, 2008.

[10] S. X. He, “Experimental researches on unloading deformation of clay in excavation of foundation pit”, Rock and Soil Mechanics, V24, n1, pp.0017-0021, 2003.