

Research on the optimal design of cutting and excavation control for a loess landslide based on numerical simulation

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Abstract. Based on the numerical simulation method, a research on the optimal design of cutting and excavation control was conducted for Zhonglou Mountain Landslide in North Shaanxi, China. Three excavation slope angles, namely, 53° , 54° and 55° , were chosen for numerical simulation calculation and comparative analysis under the condition of long-period rainstorm. The results of analysis show that the excavation slope angle of 55° is relatively dangerous under the condition of long-period rainstorm; the excavation slope angle of 54° can save an excavation volume of 41.19m^3 per meter of width compared with the angle of 53° , and it is also safer and more stable. Therefore, it is concluded that the angle of 54° is the safest and most economical excavation slope angle for cutting and excavation control. The above method provides technical reference for control of similar landslides and also has certain scientific value and practical significance in engineering.

Introduction

Landslides, as part of the natural environment, are recognized as the third type of natural disaster in terms of calamities and world importance, following earthquake and flood (Zillman, 1999). Therefore, the research on landslide hazard control engineering has become a hot topic in engineering research (Stead D, 2006; Fleurisson, 2012; Khanh, 2013; Jiang, 2016; Luo, 2016). Key techniques in landslide prevention and control can be summarized to two points: one is correct understanding of the nature of landslide; the other is effective and reasonable prevention and control of landslide (Wang, 2005). Warren Hare (2015) used a mixed-integer linear programming model to optimize the construction design of roadside slope; Yang (2015) conducted a research on the optimal design for a slope reinforced with anchor group based on stress and displacement fields; Shamsoddin (2016) considered damage factors to optimize the final excavation slope angle of a mine.

In this paper, geological models were established according to the characteristics of Zhonglou Mountain Landslide in North Shaanxi, China, to conduct a research on the optimal design of cutting and excavation control based on numerical simulation and calculate the slope stability at different excavation slope angles; the safest and most economical excavation slope angle was obtained, providing technical reference for control of similar landslides.

Engineering geology

Zhonglou Mountain Landslide is located in the loess gully region in North Shaanxi, China. The landslide mass is about 80m wide, 65m high and 5~35m thick, with a volume of about $5.5 \times 10^4\text{m}^3$. The upper part of the entire landslide soil mass is Upper Pleistocene eolian loess with vertical joints development and containing numerous loess holes and sinkholes. The deformation behavior of Zhonglou Mountain Landslide is well correlated with the changes in rainfall. The slope exhibits no deformation when there is little or light rain, but shows certain deformation and forms tension cracks and shear deformation zone in local areas after heavy or long rain (see Fig. 1). These signs indicate this

landslide mass is at the stage of creep deformation. The above conditions suggest that the landslide is lack of stability and has great potential safety hazards; therefore, control measures are urgently needed.



Fig. 1 Shear deformation zone at the front edge of the landslide (A shear deformation zone at the front edge of the landslide, which is about 1m wide, can be clearly seen at the exposure strata on the right side of the landslide)

Establishment of numerical model

A two-dimensional finite element model was established according to the landslide section along the main sliding direction, as shown in Fig. 2.

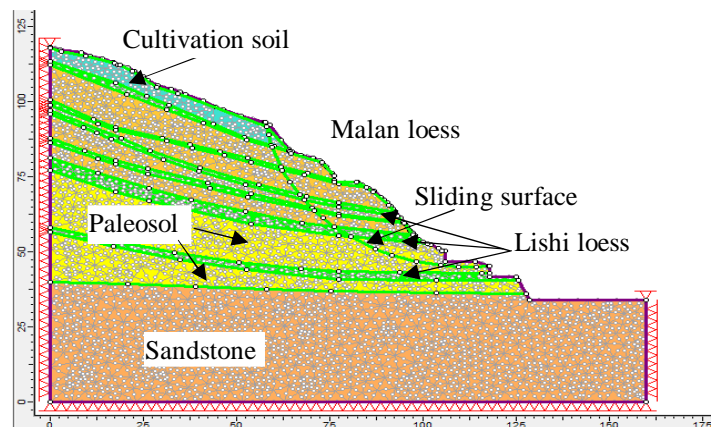


Fig. 2 Zhonglou Mountain Landslide computation model (This model is 160m long and 120m wide. The upper part of the model has no constraint conditions; the left and right boundaries constrain horizontal displacement; the bottom boundary is fixed)

The landslide stability is mainly affected by rainfall. For the condition of long-period rainstorm, the parameter values for numerical simulation calculation of the landslide rock-soil mass are determined under saturated condition. Table 1 shows the values of physical and mechanical parameters for numerical simulation calculation of Zhonglou Mountain Landslide soil mass under the condition of long-period rainstorm.

Table 1 Physical and mechanical parameters under the condition of long-period rainstorm

| Name of stratum | Saturated density (kN/m ³) | Saturated cohesion (kpa) | Saturated internal frictional angle (°) | Saturated modulus of elasticity (Mpa) |
|------------------|--|--------------------------|---|---------------------------------------|
| Cultivation soil | 18.5 | 6.5 | 10 | 5 |
| Malan loess | 18.9 | 8.5 | 11.4 | 6 |
| Lishi loess | 20.8 | 11.7 | 15.2 | 9 |
| Paleosol | 21.3 | 26.8 | 21.7 | 10 |
| Sandstone | 22.5 | 25200 | 28.2 | 54000 |

Fig. 3 shows the calculated result of total displacement of the landslide along the main sliding direction under the condition of long-period rainstorm. As can be seen from Fig. 3, the total displacement of the landslide is relatively big under the condition of long-period rainstorm, and the soil mass displacement above the sliding surface is obviously bigger, with a trend of downward sliding.

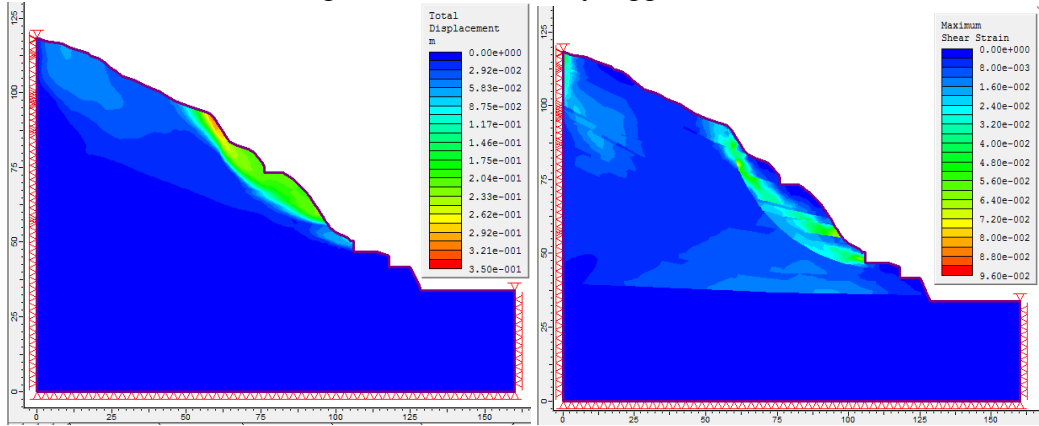


Fig. 3 Distribution of total displacement under the condition of long-period rainstorm

Fig. 4 Distribution of maximum shear strain under the condition of long-period rainstorm

Fig. 4 shows the distribution of maximum shear strain of the landslide. As can be seen, a shear strain increase zone appears at the soil mass above the sliding surface under the condition of long-period rainstorm; at this point, the landslide is liable to failure, so prevention and control measures should be taken to avoid disasters and losses arising therefrom.

Research on the optimal design of cutting and excavation control based on numerical simulation

Establishment of models with different excavation slope angles

Cutting and excavation is a relatively economical control measure for landslides in the loess region. Therefore, cutting and excavation was applied for controlling Zhonglou Mountain Landslide. Numerical models with different excavation slope angles were established, and a research on optimal design was conducted based on numerical simulation calculation to find out the optimal excavation slope angle at which the landslide was in a stable state under the condition of long-period rainstorm. Based on actual calculation, the excavation slope angles of 53° , 54° and 55° were chosen for comparative analysis.

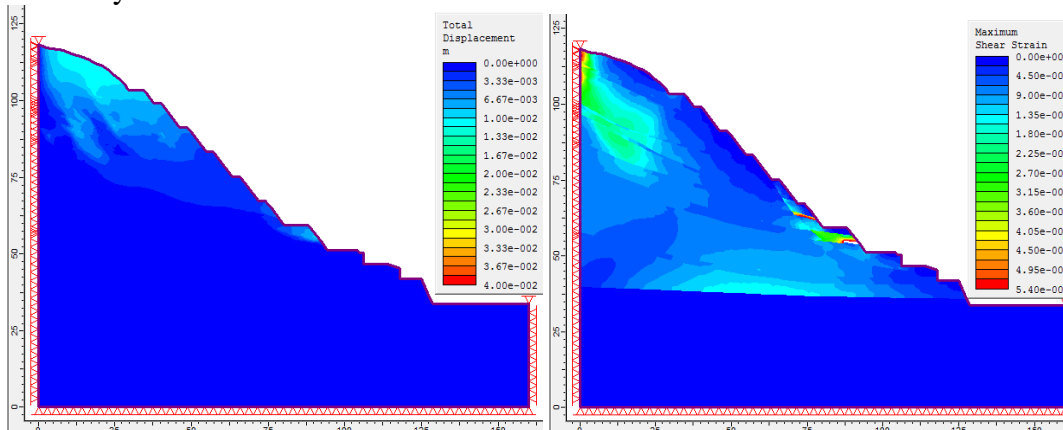


Fig. 5.a Total displacement

Fig. 5.b Maximum shear strain

Fig. 5 Numerical simulation results when the excavation slope angle is 53°

Comparative analysis of numerical simulation results

Fig. 5, 6 and 7 show the calculated results of the numerical models using three different excavation slope angles under the condition of long-period rainstorm. As can be seen, the cutting slope &

unloading measure is effective for Zhonglou Mountain Landslide. After cutting at the angle of 53° , the landslide is in a quite stable state; when the excavation slope angle is 54° , the landslide is in a basically stable state; when the angle increases to 55° , the horizontal displacement and the total displacement increase significantly, and the maximum shear strain zone appears, suggesting that the landslide is in a dangerous state when the excavation slope angle is 55° .

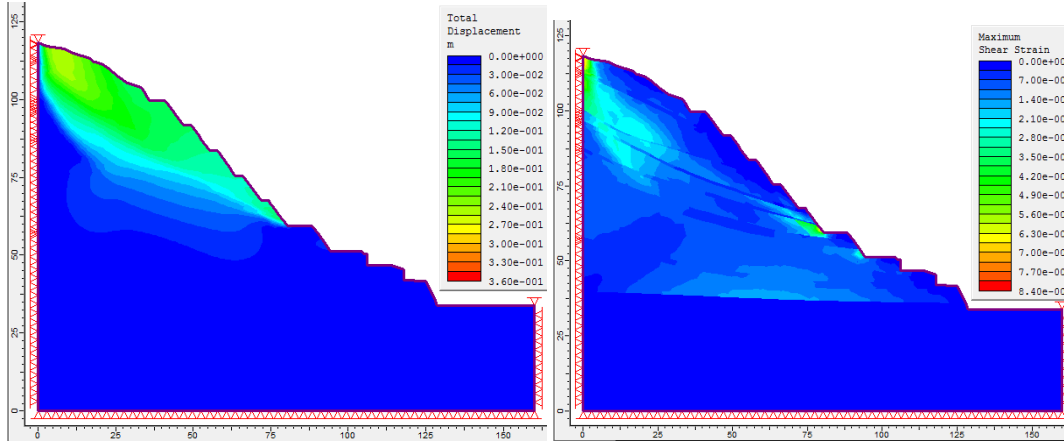


Fig. 6.a Total displacement

Fig. 6.b Maximum shear strain

Fig. 6 Numerical simulation results when the excavation slope angle is 54°

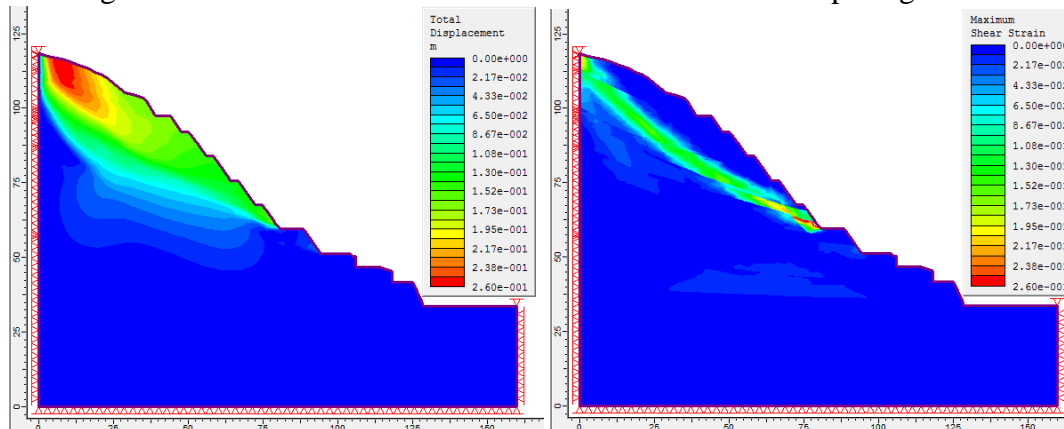


Fig. 7.a Total displacement

Fig. 7.b Maximum shear strain

Fig. 7 Numerical simulation results when the excavation slope angle is 55°

Analysis on economic benefits of optimal design

The main control measure for this landslide is hierarchical slope cutting. The cutting volume is in inverse proportion to the excavation slope angle, i.e., the bigger the designed slope angle is, the smaller the cutting volume will be. According to the analysis on the economic benefits of the optimal design for the 1m-wide section of the main sliding surface, the excavation volume is 529.64m^3 when the excavation slope angle is 54° , and 570.83m^3 when the angle is 53° . There is a difference of 41.19m^3 between the excavation volumes at these two different excavation slope angles. Therefore, cutting slope & unloading at the excavation slope angle of 54° can ensure safety and stability, which is also more economical.

Conclusions

(1) Under the condition of long-period rainstorm, the total displacement of soil mass above the sliding surface of Zhonglou Mountain Landslide is obviously bigger, with a trend of downward sliding; a shear strain increase zone appears at the soil mass above the sliding surface; at this point, the landslide

is liable to failure, so prevention and control measures should be taken to avoid disasters and losses arising therefrom.

(2) Numerical models with different excavation slope angles were established for Zhonglou Mountain Landslide, and a research on optimal design was conducted based on numerical simulation calculation. As can be seen, the excavation slope angle of 54° can save an excavation volume of 41.19m^3 per meter of width compared with the angle of 53° . Therefore, the optimal excavation slope angle for landslide control is 54° at which the landslide is in a stable state under the condition of long-period rainstorm. This excavation slope angle can ensure safety and stability, which is also more economical.

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