Evaluation of Deformation Pattern and Safety Stability of Road Embankment on Sloping Foundation

Can Wang [1], Dongxue Li [2]*,Xiaohong Lai[2]

[1]Chongqing Design Group CO.,LTD. Chongqing.401120,China
[2]Chongqing Jiaotong University. Chongqing.400074,China

*Corresponding author E-mail address:770185736@qq.com

Abstract. For the deformation and instability of highway embankment on sloping foundation, this paper adopts finite element software PLAXIS to numerically simulate the deformation pattern and safety stability of embankment on sloping foundation under the working conditions of construction period, operation period and rainfall period. The analysis results show that: during the construction period, the deformation sensitive points of the embankment are mainly distributed in the top of the outer slope of each layer of the embankment filling layer; during the operation period, the decay of the strength of the embankment soil body will trigger the arc sliding damage, and the deformation sensitive points are located in the top of the slope tensile cracking area and the foot of the slope at the sliding shear exit; during the rainfall period, the rainwater will infiltrate to a certain depth to produce local landslides, and the deformation sensitive points are located at the top of the embankment outer slope. Finally, the relationship curve between the displacement of deformation-sensitive points and the stability of the embankment is established by simulating the deformation damage process of the embankment, and then the safety and stability of the embankment is evaluated.

Keywords: Slope foundations; Embankment deformation; Numerical simulation; Safety and stability

1 INTRODUCTION

Different foundation conditions inevitably appear in the construction of highways in mountainous areas, and the safety and stability of slope foundations are particularly prominent compared with flat foundations[1]. In past studies, when the stability of slopes was calculated using the strength discounting method, the slopes usually failed and stopped at the irregularities of the local sections of the slopes[2]. However at present, scholars engaged in the direction of embankment stability are more and more focused on studying the relationship between embankment deformation and stability[3-4]. Jin Leilei et al[5] used strain gauges, displacement gauges and high-speed camera meters to monitor the deformation and damage process of model slopes, and look for the correlation between the two. Chen et al[6] used the centrifuge model test to simulate the deformation of slope at the foot of the slope with dry and wet cycles and the deformation

B. Yuan et al. (eds.), *Proceedings of the 2024 8th International Conference on Civil Architecture and Structural Engineering (ICCASE 2024)*, Atlantis Highlights in Engineering 33,
https://doi.org/10.2991/978-94-6463-449-5_60

of slopes on the slope of unsaturated expansive soils. conditions and slope stability. Li et al[7] conducted centrifuge model tests on steeply dipping stratified carbonate rock slopes to analyze the slope failure process and slope deformation data. The above studies show that the slope deformation and displacement as a criterion can truly reflect the stable state in which the slope is located, and it is most accurate to use the displacement mutation as a criterion for stability analysis[8-9].

In this paper, PLAXIS finite element software is used to simulate the deformation and damage process of embankment filling and strength reduction on slope foundation. The study takes a section of Chongqing Inner Ring Highway widening roadbed project on sloping foundation as a prototype, and obtains the relationship between slope deformation and displacement and safety stability through data analysis, and proposes the criterion of slope safety condition by deformation and displacement reaction to provide safety early warning basis for the solid engineering.

2 FINITE ELEMENT MODEL AND PARAMETERS

2.1 Project Overview

Taking a section of Chongqing Inner Ring Highway widening roadbed project on sloping foundation as a prototype, the embankment slope is divided into three levels, the original geomorphic cross-slope is 1:3, and filling is carried out in six layers. According to the current specification requirements, the original landform cross-slope is located in 1:5~1:2.5, the original ground should be dug steps, step width should not be less than 2m. Simulation analysis of embankment deformation and safety stability for three specific conditions: construction, operation and rainfall.

2.2 Finite Element Modeling and Methods

Combined with the roadbed widening prototype, the boundary range is considered to be a 60m long × 12m thick foundation, with a rock layer below the soil layer, and the top of the embankment has a width of 24.0m, a height of 20.0m, and slope ratios of 1:1.5, 1:1.75, and 1:2; the mesh division is performed using a 15-node triangular cell, with fixed constraints at the bottom and horizontal constraints on both sides, and the filling rate is simulated by 0.7m/d. The soil ontological relationship is simulated by Mohr-Coulomb model; the soil consolidation calculation process adopts Biot consolidation theory; the contact between soil and foundation is simulated by Goodman contact unit. The calculation parameters of embankment fill and foundation soil layers were determined according to the engineering ground investigation report.

3 CHARACTERIZATION OF EMBANKMENT DEFORMATION

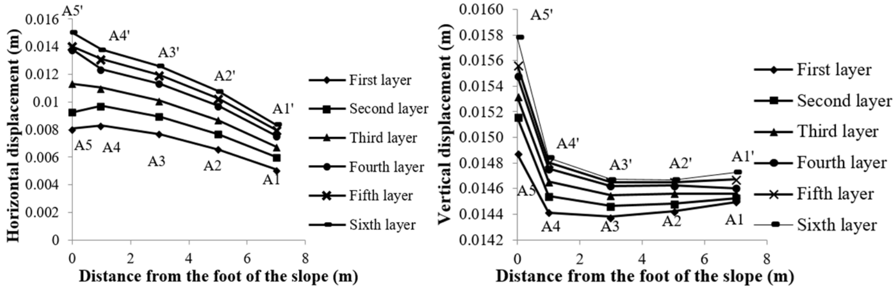
3.1 Fundamental Provisions

In order to fully characterize the deformation of the embankment and grasp the deformation of different points on the embankment surface, three groups of deformation monitoring points were set up and numbered as follows:(1) Group A: points on the foundation surface at the outside of the foot of the slope, from left to right are A1, A2, ..., A5; (2) Group B: points on the top surface of the top of the slope, from left to right are B1, B2, ..., B5; (3) Group C: the points at the top of the slope top surface of each layer of filling, from bottom to top, are C1, C2,..., C6, where C6 overlaps with B1;

3.2 Characterization of Deformation During Construction Period

The mechanical parameters of the embankment soil body did not deteriorate during the construction period, and the deformation was mainly caused by the filling loading process. Through the simulation and calculation of the embankment filling process by finite element software, the horizontal and vertical displacements of each point of embankment surface A, B and C groups were obtained, as shown in Fig. 1.

As can be seen from Fig.1, the points in group A move from A to A5 with the increase of the number of filling layers, and the horizontal and vertical deformation of point A5 is the most sensitive and A5 is the most representative of group A. The points in group B are the monitoring points at the top surface of the slope after the completion of filling, and point B1 is the edge of the top of the slope, which has the largest horizontal and vertical displacements, and the horizontal and vertical displacements of group C are the most sensitive to the increase of horizontal and vertical displacements of the slope after the completion of filling, and the amount of deformation and displacement of the points increases gradually with the increase of the filling soil. increase both horizontal and vertical displacements gradually increase, showing a certain linear relationship.



(a) (b)

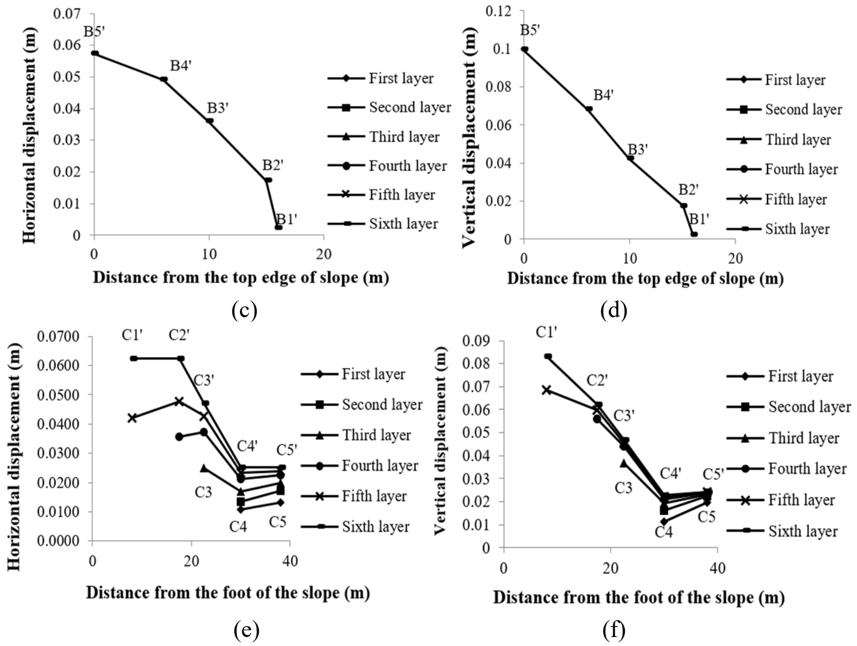


Fig. 1. Displacement of points on the surface during construction. (a) and (b) represent horizontal and vertical displacement of group A ,(c) and (d) represent horizontal and vertical displacement of group B, (e) and (f) represent horizontal and vertical displacement of group C

3.3 Analysis of Deformation Condition In Operation Period

According to the simulation principle of gradual reduction of soil strength during operation period, PLAXIS is used to simulate the process of continuous decay of mechanical parameters of the fill soil, calculate the slope stability coefficient discounted to damage and the displacement of each monitoring sensitive point, and derive the displacement-stability coefficient relationship curve, and the most likely sliding surface of the embankment. As can be seen from Fig. 2. The displacements and stability coefficients of each group of points have a good functional relationship. Among them, the horizontal displacement at point A5, the vertical displacements at points B1, B2, and B3, and the horizontal displacements at points C4 and C5 on the slope face are large, easy to measure, and can be used as displacement monitoring points. In the comprehensive analysis, it is more reasonable to use the horizontal displacement of point A5 at the foot of the slope and the vertical displacement of point B1 at the top of the slope as the monitoring sensitive points.

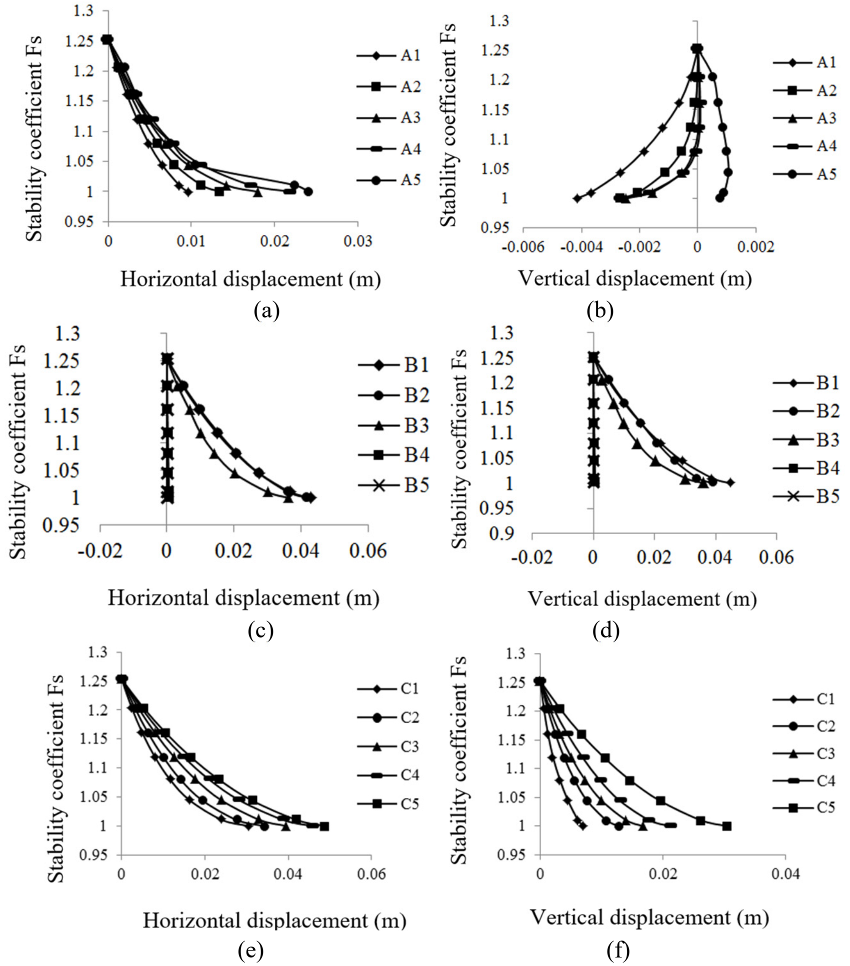


Fig. 2. Displacement-stability coefficient relationship curve. (a) and (b) represent horizontal and vertical displacement of group A ,(c) and (d) represent horizontal and vertical displacement of group B, (e) and (f) represent horizontal and vertical displacement of group C

3.4 Analysis of Deformation Condition During Rainfall

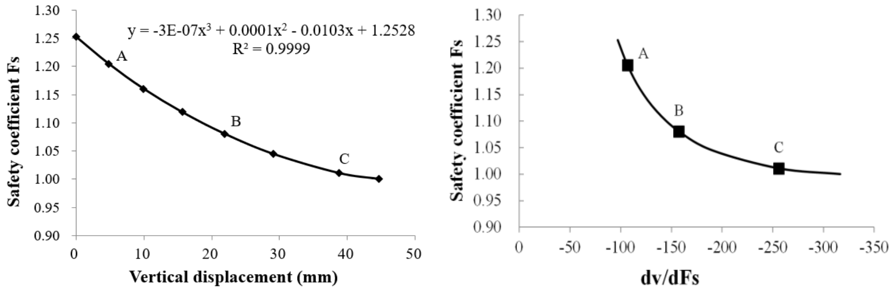
The effect of rainfall infiltration on the embankment slope is mainly to increase the embankment soil bulk weight and reduce the mechanical parameters of the soil in the infiltration range. In this paper, combined with the pavement structure and general rain-water infiltration, finite element simulation is used to calculate the deformation of the embankment in the three cases of rainfall infiltration depth of 0.5m, 1m and 2m. The results show that: when the rainfall depth is 0.5m and 1m, the damage form of the embankment is the overall arc sliding damage mode, and the rainfall has little influence on the safety and stability of the embankment, and the monitoring sensitive points are still A5 and C2; when the rainfall depth reaches 1.5m or even deeper, the embankment undergoes localized sliding damage within the range of rainfall infiltration, and rainfall has a large influence on the safety and stability of the embankment, and the sensitive points of deformation monitoring are set on the top of the slope. Point C1 and point B4 at the foot of the first level slope are more important.

4 EVALUATION OF EMBANKMENT DEFORMATION AND SAFETY STABILITY

Using the strength discount module of PLAXIS, a set of embankment stability coefficients is obtained after discounting the geotechnical parameters of the embankment, and the displacement and stability coefficient of the point at the top of the slope are recorded, and this displacement-stability coefficient curve relationship graph is established, as shown in Fig. 3.(a), at which time it is difficult to find the curve mutation characteristic point. After a variety of numerical function combinations, the final choice to establish the vertical displacement of the monitoring point at the top of the slope and the stability coefficient of the first-order derivative of the relationship, as shown in Fig. 3.(b), that is:

$$f(x)=dv/dFs\sim Fs$$

where: v is the vertical displacement and Fs is the stability coefficient. the curve of f(x) can better find the displacement eigenvalues A, B and C. According to the development of the vertical displacement at the top of the slope (B1), the judgment criterion of the embankment stability is developed. When the vertical displacement at point B1 is 0~4.8mm, the stability coefficient is 1.25~1.205, and the risk degree is primary; when the vertical displacement is 4.8~21.9mm, the stability coefficient is 1.205~1.08, and the risk degree is intermediate, which should be on-site investigation to eliminate the hidden dangers; when the settlement is 21.9~38.7mm, the stability coefficient is 1.08~1.011, the degree of risk is dangerous, and the site should be warned and the crowd should be evacuated; when the settlement is more than 38.7mm, the stability coefficient is less than 1.011, the degree of risk is damage, and the road should be closed for emergency repair.



(a) Displacement-stability coefficient relationship (b) First-order derivative curve

Fig. 3. Stability coefficient development law with displacement

5 CONCLUSION

Through the deformation-stability study of the roadbed slope after strength reduction, it is concluded that the vertical deformation at the top of the slope is a sensitive point for monitoring, and the functional relationship curves of vertical displacement at the top of the slope and the first-order derivative of the stability coefficient are established, so as to obtain the safety condition judgment standard of the roadbed slope. This study provides a safety warning basis and treatment suggestions for slope foundation widening in a section of Chongqing Inner Ring Highway. The numerical simulation is not equal to the actual project, and the various unfavorable factors of the whole life cycle of the roadbed slope should be fully considered in the future, so that the simulation data can be closer to the real situation.

FUNDING

This research was funded by (1)Humanities and Social Science Research Project of Chongqing Municipal Education Commission (Grant No.: 22SKGH171).(2)Natural Science Foundation of Chongqing Science and Technology Bureau (Grant No.: CSTB2022NSCQ-MSX1345).

REFERENCES

1. Yin P B , Yang K B , Zhao M H, et al. (2022) Determination Method for the Foundation Horizontal Resistance Ratio Coefficient Under Consideration of the Slope Effect. China Journal of Highway and Transport. 35 (11): 12-20. DOI:10.3969/j.issn.1001-7372.2022.11.002.
2. Tomáš Kadlíček , David Mašín. (2023) Surface layer method for analysis of slope stability using fine elements. Computers and Geosciences.164. 105799-105817. DOI:10.1016/j.compgeo.2023.105799.
3. Liu J N , Jiang X, Y J Qiu. (2015) Deformation Coupling Characteristics of Sloped Weak Ground under Embankment Load Journal of the China Railway Society. 4: 94-100. DOI: 10.3969/j.issn.1001-8360.2015.04.014.
4. Chen X B , Xu W G, Liu X P. (2011) Effect of rain infiltration on additional settlement and stability debasement of granular soil fillings embankments. Ournal of Central South University (Science and Technology). 42 (3): 765-771. DOI:10.1016/j.compgeo.2010.04.003.
5. Jin L L, Dong H K, Ye F, et al. (2024) Investigation of the block toppling evolution of a layered model slope by centralized test and discrete element modeling. Journal of Rock Mechanics and Geotechnical Engineering. 6 (1):112-122. DOI:10.1016/j.jrmge.2023.02.019.
6. Li B, Feng Z, G Z, Wang W P, et al. (2016) Processes and behaviors of block topple avalanches resulting from carbon slope failures due to underground mining. Environment Earth Sci.75 (8): 694.1-694.26. DOI: 10.1007/s12665-016-5529-1
7. Zhang H, Chen C, Zheng Y, et al. (2020) Centrifuge modeling of layered rock slopes sustainable to block flexible toppling failure. Bulletin of Engineering Geology and the Environment.79: 3815-3831.DOI:10.1007/s10064-020-01797-9

8. Zhao S Y, Zheng Y R, Zhang Y F. (2005) Lecture on Extreme Analysis Finite Element Method - II Exploration of the Criteria for Slope Instability in the Finite Element Strength Discounting Method. Geotechnical Mechanics. 26 (2): 332-336. DOI:10.16285/j.rsm.2005.02.035.
9. Rezaei, M., Seyed Mousavi, S.Z.(2024) Slope stability analysis of an open pit mine with considering the weathering agent: Field, laboratory and numerical studies. Engineering Geology, 333, 107503-107512. DOI:10.1016/j.enggeo.2024.107503.