Analysis of sand-sliding slope stability under different excavation extents

Yu Zhang, Jinhai Yu, Shibo Huang, Jiang Wang*
College of Engineering, Tibet University, Lasha 850000, China

Abstract: To study the stability of sand-sliding slopes under different excavation extents, this paper selects a specific sand-sliding slope along the G318 highway from Yupu to Ranwu as the research object. Through field surveys, literature review, and numerical simulation, the stability of the sand-sliding slope is analyzed. The study shows that: (1) After the slope excavation, the overall maximum shear strain increment increases with the gradual increase of the excavation footage, the stress at the slope foot gradually increases, and the stress contour at the excavation site gradually concentrates towards the slope foot.

Keywords: Sand-sliding slope; Excavation; Numerical simulation; Stability analysis

Introduction: The section of National Highway G318 from Yupu to Ranwu is characterized by complex topography, diverse stratum lithology, frequent seismic activity, and developed geological structures, making it highly susceptible to adverse geological phenomena. This leads to frequent occurrences of sand-sliding slope disasters along this highway segment. As a common natural disaster in mountainous areas, sand-sliding slope disasters pose significant threats to passing vehicles, pedestrians, and human engineering activities. Although not as sudden as collapses or landslides, the long-term and severe nature of these disasters is comparable to those geological hazards. The stability of slopes is influenced by many factors during excavation, and this paper focuses primarily on the impact of excavation extent on slope stability. The excavation extent refers to the horizontal distance from the slope foot at the front edge of the slope to the excavation site, measured vertically along the slope body.

Currently, numerous scholars have conducted extensive research on the stability of sand-sliding slopes. Internationally, Sharpe was the first to introduce the concept of debris flow in 1938. Jun Zhang utilized PFC2D to conduct foot-of-slope excavation on sand-sliding slopes, analyzing the movement patterns through particle displacement and speed . Na He measured the foot of the excavated sand-sliding slopes, analyzing the movement of slope particles, the morphology of slope accumulation, and the scale of collapses. Ke Xia and others employed GeoStudio numerical simulation software to analyze the impact of rainfall infiltration on the stability of sand-sliding slopes. Tangjin Ye and colleagues summarized the instability modes of sand-sliding slopes: particle rolling, local sliding, and the flow of sand and water, and used PFC, FLAC, and GeoStudio for numerical simulation of sand-sliding slope stability.

In summary, while a great deal of research has been done on the stability of sand-sliding slopes, in-depth studies on the stability of sand-sliding slopes under different extents of excavation have yet to be conducted. Sand-sliding slopes undergo sliding destruction at higher moisture contents and sliding failure at lower moisture contents, with PFC software providing better simulation results for sliding destruction, and FLAC software for sliding failure. Based on this, this paper will use FLAC 3D numerical simulation software to analyze the stability of sand-sliding slopes under different excavation methods.

1 Overview of the study area

The study area is located in the southeastern part of the Tibetan Plateau, stretching along the Parlung Zangbo River. The region is characterized by high elevations, with geographical coordinates ranging from 95°46' to 96°46' E longitude and 29°30' to 29°52' N latitude. The route covers approximately 128 km, starting from Bomi and ending at Ranwu, traversing mainly through high mountain gorges and low mountain valleys. The area is surrounded by high mountains, with the Nyainqentanglha Mountains to the north, exhibiting an EW orientation, and the Gangdise Mountains to the south, showing a NW-SE orientation. The geological strata within the study area are complex, encompassing a range from the Cenozoic to the Proterozoic era, providing a rich material basis for the formation of sand-sliding slopes. Through investigations, several typical sand-sliding slopes were selected, and their slope lengths, heights, and foot angles were averaged to serve as the external parameters for the numerical simulation models, which were 55m in length, 30m in height, and had a slope angle of 34°.

2 Stability analysis under diff erent excavation extents

2.1 FLAC 3D Numerical simulation calculation

FLAC3D incorporates various geotechnical constitutive models, among which the Mohr-Coulomb model was chosen for this study. The model mesh was created in AutoCAD, outlining the slope profile and saved in DXF format, then imported into ANSYS for extrusion and mesh division. Physical and mechanical properties were selected based on field measurements and laboratory tests, as shown in Table 1:

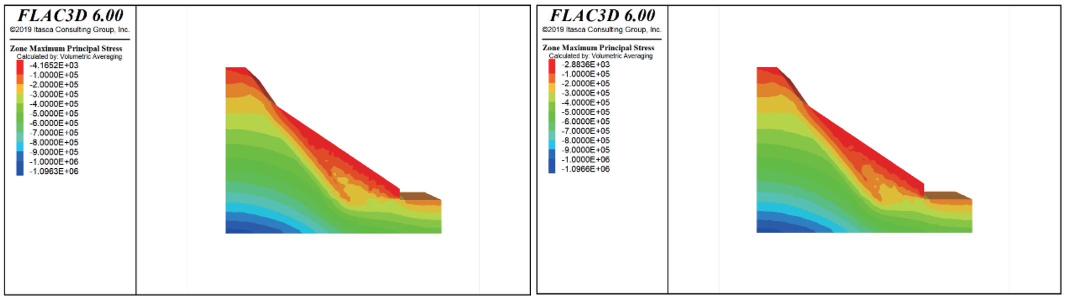
Table 1 Basic model parameters

Type	Cohesion (MPa)	Internal Friction Angle (°)	Elastic Modulus (GPa)	Poisson's Ratio	Density (g/cm³)	Tensile Strength (MPa)	Compressive Strength (MPa)
Bedrock	55.1	51.0	61.0	0.22	2.65	3.4	122.0

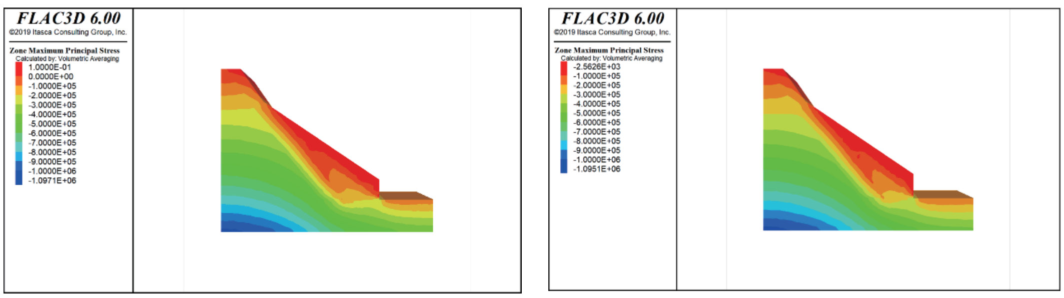
Loose Sand Soil	5	34	0.015	0.4	1.41	0	0.8

Considering the highway grade and actual excavation extents, the moisture content of the loose sand slope was controlled at 11%, with numerical simulations conducted for excavation extents of 5m, 7m, 9m, and 11m for comparative analysis.

The numerical simulations of the excavation extents on the loose sand slope yielded maximum principal stress distribution maps, as illustrated in Figure 1.



(a)5m excavation depth **(b)7m excavation depth**

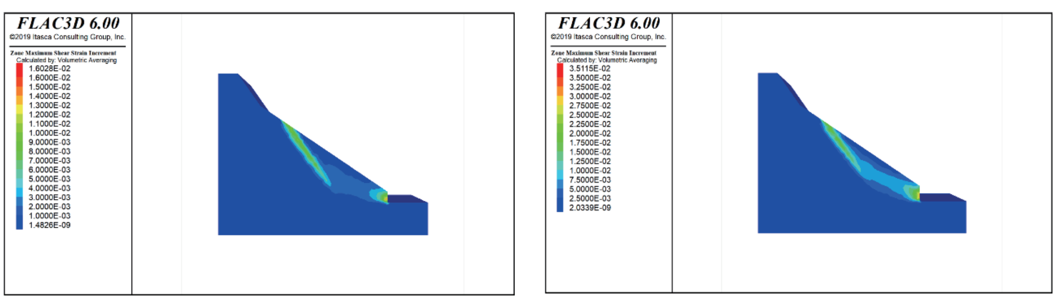


(a)9m excavation depth **(b)11m excavation depth**

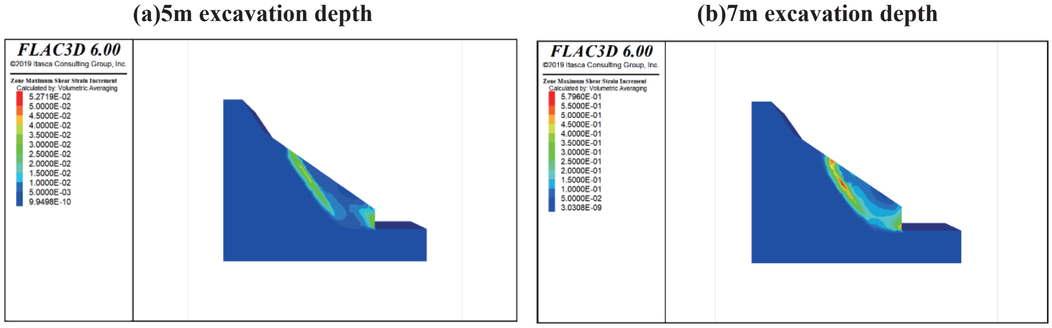
Figure 1 Maximum principal stress distribution maps for different excavation extents

The figures show that as the excavation extent increases, the maximum principal stress in the deeper parts of the slope is minimally affected, remaining stable around 1.09MPa. The most significant adjustments in maximum principal stress occur near the excavation site and in the shallow parts of the slope. The concentration of stress towards the slope foot with increasing excavation extents can lead to easier failure at this location.

The simulations also produced shear strain increment maps, illustrating the changes in shear strain across different excavation extents (Figure 2).



(a)5m excavation depth **(b)7m excavation depth**



(a)9m excavation depth **(b)11m excavation depth**

Figure 2 Maximum shear strain increment maps for different excavation extents

These figures indicate that post-excavation, the overall maximum shear strain increment increases with the excavation extent. At excavation extents of 5m, 7m, and 11m, shear deformation zones primarily develop at the slope angles and expand towards the interior of the slope, without connecting to the slope surface. The connection between the shear zone and slopesurface occurs at an excavation extent of 11m, making the slope foot more prone to failure.

According to the "Technical Code for Building Slope Engineering", slopes are considered unstable when the stability safety factor is below 1.0. The simulated safety factors for different excavation extents were 1.39, 1.24, 0.93, and 0.82, indicating stable conditions for excavations of 5m and 7m depths, and unstable conditions for 9m and 11m depths. The safety factor decreases with increasing excavation extent, primarily because the slope becomes steeper and more pronounced at the foot, causing severe stress concentration at this location during stress redistribution, leading to initial failures at the slope foot, which can propagate upwards, further reducing slope stability. The significant drop in safety factor when increasing excavation extent from 7m to 9m suggests that an excavation extent of 9m is a critical point for the stability of the slope.

3 Conclusion

This paper, through field surveys and the use of FLAC 3D numerical simulation software, analyzes the stability of sand-sliding slopes under different excavation extents and arrives at the following conclusions.

(1) Using FLAC 3D, the safety factors under different excavation extents were obtained as 1.39, 1.24, 0.93, and 0.82, respectively. The significant reduction in safety factor when increasing the excavation extent from 7m to 9m indicates that an excavation depth of 9m is a turning point for the slope's stability.

References:

[1]Song Z, Zhang G Z, Jiang L W, etal. Analysis of the main geological hazards and geological route selection of Sichuan-Tibet Railway[J]. Railway Standard Design, 2016, 60(1): 14-19.

[2]Yao J, Li X Z, Xu R C. Dynamic identification of three-dimensional stability of potential landslides in typical section of Sichuan-Tibet Railway under rainfall[J]. Journal of Disaster Prevention and Mitigation Engineering, 2021,41(03): 422-431

[3]Sharpe C F S. Landslides and related phenomena[M]. New York: Columbia University Press, 1938: 125.

[4]Zhang J. Study on instability model and prevention measures of progressive recharge failure of sand slide slope[D]. Chengdu University of Technology, 2012.

[5]He N. Experimental study on slope deformation and failure mechanism of dispersing granular mass [D]. Chengdu University of Technology, 2013.

[6]Xia K, Tian R Y, Lv J B, et al. Analysis and study on stability of sand sliding slope under rainfall conditions[J]. Highway, 2019, 64(06): 20-26.

[7]Ye T J, Li H, Lu H T, et al. Study on numerical simulation method for stability of sand sliding slope[J]. Plateau Scientific Research, 2020, 4(03): 96-104.

[8]Wu X F, Wang Y, Ye T J, et al. Seismic Dynamic Response and Instability Mechanism of Slopes in Nyingchi-Bome Section of G318 Highway, Tibet[J]. Journal of Southwest Jiaotong University, 2017, 52(3): 571-577.

[9]Chen Y M. FLAC/FLAC3D Foundation and Engineering example [M]. Background: China Water Resources and Hydropower Press. 2013

Foundation: “High-level Talent Training Program” for Graduate students of Tibet University(2021-GSP-S146).