Advances in Engineering Research : Possibilities and Challenges
ISSN Print: 3079-5192
ISSN Online: 3079-5206
https://doi.org/10.63313/AERpc.9064

Stability analysis of a landslide based on FLAC 3D

Xinglong Liang
School of Geosciences and Engineering, North China University of Water Resources and Electric Power, Zhengzhou 450046, China
Email: 2543890932@qq.com

How to cite this paper: Liang, X. L. (2025). Stability analysis of a landslide based on FLAC 3D. *Advances in Engineering Research: Possibilities and Challenges*, 3(1), 26-41. ISSN Print: 3079-5192; ISSN Online: 3079-5206.
https://doi.org/10.63313/AERpc.9064
Published: 2025-12-17

Abstract

This paper focuses on the problem of the 1# and 2# aqueducts in the sliding section of the Huaipai Yellow River water diversion project, which were damaged due to the reactivation of the ancient landslide body. A stability analysis of the initial state of the slope was conducted. The Midas GTS NX and FLAC3D joint modeling method was adopted: the geological CAD drawings were sorted out, the surface and solid models were established through Midas, and after cutting the sliding body, it was imported into FLAC3D. Based on the Mohr-Coulomb criterion, boundary constraints and gravity loads were applied for numerical simulation. The results showed that the maximum horizontal displacement was 3.9 cm (in the middle-upper part) and the maximum vertical displacement was 4.95 cm (in the middle-upper part of the sliding body); the surface was mainly under tensile stress, and the absolute value of the bottom compressive stress increased with depth; the maximum shear strain increment was small; the slope stability coefficient was 1.48. The conclusion indicates that the slope as a whole was in a stable state in the initial state.

Keywords

Landslide; stability analysis; three-dimensional model; finite element simulation

1. Introduction

Landslide is one of the main geological disasters in mountainous areas, referring to the process and phenomenon of the deformation and destruction of rock and soil on the slope under the influence of gravity and other external factors [1-3]. It has the characteristics of high occurrence frequency, wide distribution range, and fast movement speed. Due to the complex mechanism of landslide deformation and destruction, it often causes serious harm and poses a significant threat to people's lives and property safety [4-6]. A heavy rain can cause a landslide and bury a village and another village; a mountain collapse can also cause a mudslide, blocking rivers and destroying roads and railways. Therefore, studying landslides is an important part of geological disaster research [7]. The special geological environment conditions in China lead to frequent occurrence of geological disasters such as landslides, and the frequent occurrence of landslides induced by human engineering activities also leads to frequent occurrence of such geological disasters. Moreover, the landslide monitoring system is weak, making it difficult to achieve timely early warning, rapid response, and effective avoidance [8]. In conclusion, the prevention of geological disasters in China has a long way to go and many problems need to be solved.

The study of slope stability is crucial for preventing landslide disasters. This research is not only a current hot topic in the field of engineering geology but also an unsolved issue to this day [9-10]. Its scope is extensive, covering high-rise buildings, roads and bridges, tunnel construction, and waste disposal, etc. Ensuring the stability of the slope is the key to ensuring its safety and is related to the entire life cycle of the project [11]. If it cannot be effectively guaranteed, it will trigger geological disasters such as landslides, debris flows, and collapses. Therefore, conducting slope stability analysis and assessment is of great significance for future engineering governance and monitoring work [12]. Slope instability may lead to landslides, and in severe cases, it can damage the underlying structures, endangering people's lives and property, and causing incalculable losses [13]. In this context, conducting stability analysis of the slope and implementing effective prevention measures is a very meaningful task [14].

In traditional slope stability analysis, the use of a single software for modeling often encounters accuracy or efficiency bottlenecks under complex geological conditions: FLAC3D has significant advantages in numerical simulation and stability coefficient calculation, but the three-dimensional model construction and meshing in the pre-processing stage have limitations; while Midas GTS NX has diverse modeling capabilities, high-precision surface generation features, and flexible meshing functions, and the joint modeling of the two can achieve complementary advantages [15-18]. Based on this, this study takes the Huaipa landslide as the object, by organizing geological CAD drawings, using Midas GTS NX to construct a three-dimensional geological model and importing it into FLAC3D, applying the Mohr-Coulomb criterion to impose boundary constraints and gravitational loads, conducting displacement, stress, and maximum shear strain increment distribution analysis under the initial state, and calculating the stability coefficient, aiming to clarify the initial stable state of the slope, and providing a scientific basis for the reconstruction of the aqueduct and the landslide control.

2. The establishment of the three-dimensional model

2.1. General Project Overview

The Huaipai Yellow River Water Diversion Project is located in the areas of Mianchi County and Yima City in Sanmenxia City, Henan Province. It is an infrastructure project aimed at providing water for industrial and agricultural use as well as drinking water for people and livestock in this region. The total scale of the Huaipai Project is to draw water from the Yellow River at a rate of 7 cubic meters per second, and it is divided into four stages for water diversion. The headworks of the project is located at the Huaipai Fish Mouth on the right bank of the Yellow River in Chencun Township, Mianchi County. The first pumping station raises the water from the Yellow River to a 312-meter terrace, and after passing through the water distribution (distribution) pool and being treated in the sedimentation pool, it flows into the water conveyance channel. The channel line roughly extends along the contour lines and crosses the No. 1 inverted siphon, No. 1 and No. 2 aqueducts on the west slope, and is connected to the Huaizhong Tunnel through open channels. After exiting the tunnel, it crosses the No. 2 inverted siphon on the Jianhe Gou (2#), and immediately connects to the intake pool of the second pumping station. Then, two, three, and four pumping stations are set up along the slope.

Recently, due to mining activities and rainfall, the ancient landslide body has come back to life, causing severe damage to the No. 1 and No. 2 aqueducts. The main part of this landslide section project is to dismantle and rebuild the No. 1 and No. 2 aqueducts that were damaged by the landslide. The total area of the landslide is approximately 200,000 square meters, roughly distributed in a fan shape on the slope. The reconstruction project of the No. 1 and No. 2 aqueducts is located at the right front edge of the landslide. The landslide treatment area includes the No. 1 and No. 2 aqueducts and the nearby affected areas. Due to the influence of the landslide, the aqueducts have shifted northward by about 3 to 5 meters, and the aqueducts are severely damaged. The steel pipe sections are twisted and deformed, and some support frames have been pushed down by the landslide. The pipeline at this location is no longer usable (see Figure 1).

This water supply pipeline is the main water supply channel for industrial water and drinking water for urban residents in Yima City and Mianchi County. Due to the damage to this pipeline, currently, only the downstream reservoir, the Xizhan Village Reservoir, can provide temporary emergency water supply. According to the reservoir size and the current water demand, the reservoir water can only sustain for about 3 to 4 months. The municipal government requires that the pipeline water supply must be restored within 3 months. Therefore, as the basic data for this project, the stability analysis of the landslide is extremely urgent.

Figure 1. Damage to the aqueduct pipeline

2.2. Basic assumption

The geological structure of the landslide is extremely complex, including various types of joints and fractures. Due to the limited existing geological data, it is impossible to fully restore the original geological structure. Therefore, this study adopted a simplified and hypothetical approach to establish a model. While attempting to restore the actual situation as much as possible, the following assumptions were made：

(1) It is assumed that the rock mass is continuous, homogeneous, and isotropic. The rock mass is regarded as a continuous medium without obvious distribution characteristics, and its properties are uniform in all directions；

(2) The joint and fracture of the rock mass itself is not considered separately. In this study, the joints and fractures within the rock mass are not treated as individual objects for consideration, but the overall property of the rock mass is modeled and analyzed.

2.3. Establishment of three-dimensional computational model and meshing

Considering the complexity and unevenness of the Huaipai landslide, in order to accurately study the stability of the Huaipai landslide, a real three-dimensional model needs to be established. The FLAC3D software has many advantages in analysis, but it has some limitations in pre-processing such as model establishment and element meshing. Especially for complex slope models like real ones, during the model construction process, multiple data points of the elements need to be controlled, which makes programming with the FISH language difficult. Although FLAC3D 6.0 introduced the Building block 3D built-in module and Model Pane model editing section, there are still challenges in building a real three-dimensional model.

To address the modeling deficiencies of FLAC3D, this paper adopts the Midas GTS NX joint modeling method. By leveraging the diverse modeling methods of the midas software, it can automatically and quickly form a surface with high accuracy and strong operability, etc., and construct the landslide model. The three-dimensional geological model established by the Midas GTS NX software can be imported into FLAC3D for numerical simulation, and it has very good compatibility. The specific steps are as follows:

(1) Sort out the Huaipai landslide drawings. Sort out the Huaipai geological cross-section and plan CAD drawings, delete all layers and auxiliary data irrelevant to modeling, and retain the elevation data and stratum data of the Huaipai landslide required for modeling.

(2) Establish the initial surface model. Import the sorted current map into the Midas software, perform coordinate transformation according to the actual coordinates, and perform elevation assignment for lines and points. Use the terrain data generator TGM (its full English name is Terrain Geometry Maker) to generate the surface

GTS model. GTS is a way to represent the connection between coordinate points and continuous ground, which refers to the simulation representation of continuous ground using a large number of selected known x, y, z coordinates in any coordinate system. The landslide surface model is shown in Figure 2.

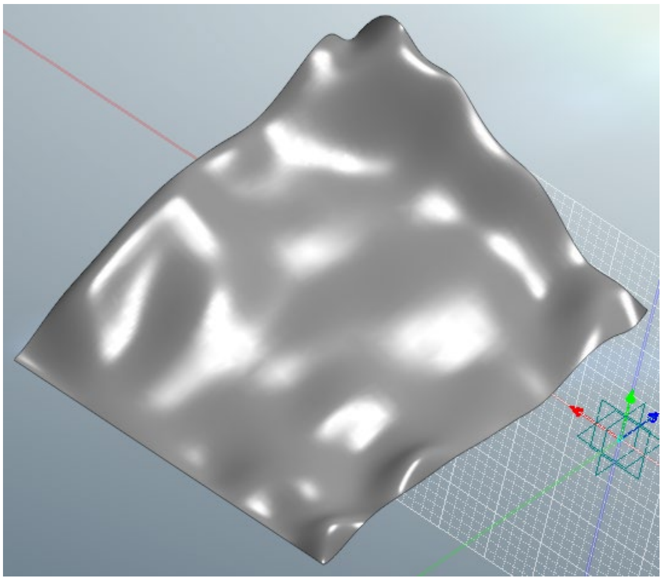


Figure 2. Landslide surface model

(3) Establish the physical model. Import the sorted out landslide surface map into the Midas GTS NX software and perform coordinate conversion based on the actual coordinates. According to the extension trend between adjacent exploration lines, connect them one by one, then expand and finally generate the GTS physical model.
(4) Generate the sliding body by segmenting the entities. Import the pre-processed contour lines of the landslide surface into the Midas GTS NX software. Perform coordinate transformation based on the actual coordinates and assign elevations to the lines. Generate a surface from the imported contour lines and cut it with the expanded entity of the landslide plane. Finally, generate the sliding body. The schematic diagram of model cutting is shown in Figure 3.

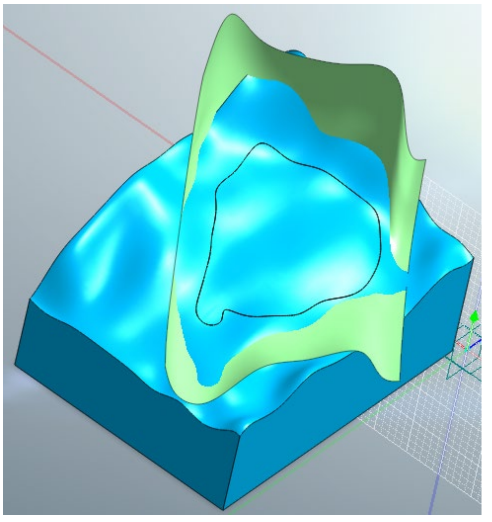


Figure 3. Schematic Diagram of Model Cutting

(5) Establish a three-dimensional model. Import the dwg files of the surface contour lines and the landslide planar diagram into the Midas GTS NX software. Use these point and line data to generate surfaces and divide them, thereby creating a realistic initial geological body. Utilizing the powerful Boolean operation tools of the Midas GTS NX software, various complex processing operations such as addition, subtraction, classification, connection, adhesion, and division can be carried out. These operations allow for precise modification and editing of the geological body to meet the requirements for establishing the three-dimensional model of the Huaipai a landslide, thus achieving the establishment of the three-dimensional model of the Huaipai landslide. The three-dimensional model of Midas GTS NX is shown in Figure 4.

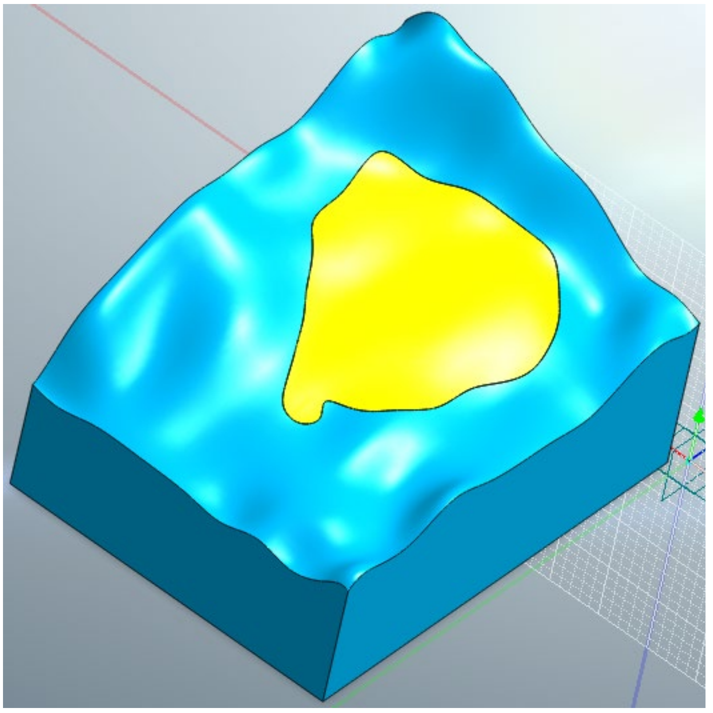


Figure 4. 3D model of Midas GTS NX

(6) Divide the grid and establish the FLAC3D model. Use the grid module in the Midas GTS NX software to divide the mixed grid, locally densify and optimize the number of grids, and export the FLAC3D model using the grid conversion tool. The FLAC3D model is shown in Figure 5. The base size of this model is 850m × 645m, and the maximum height is 532m. For the division of the model's unit grid, the maximum grid cell is 30m, which is designed in the bedrock part of the slope, and the minimum grid cell is 5m, which is designed in the sliding zone below the landslide body and gradually transitions. The model has a total of 71,006 grid cells and 12,005 nodes. Dividing the bedrock part of the model into a sparser grid can improve the calculation speed and reduce the calculation time. The rock layer parameters are selected based on the rock mechanical parameters determined by engineering geological investigation data.

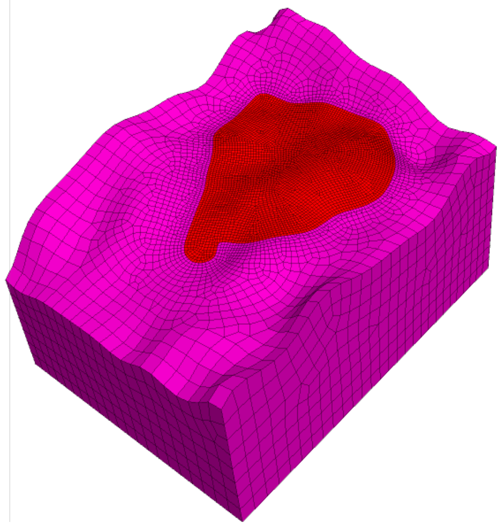


Figure 5. FLAC 3D Model

3. Analysis of the stability of the initial slope condition

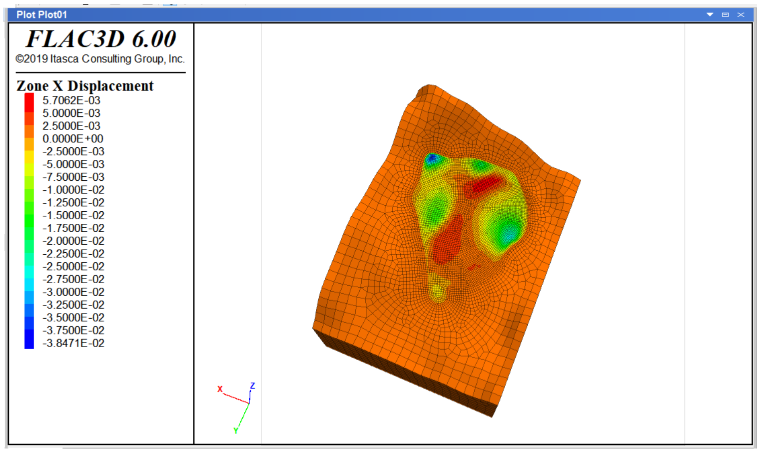
3.1. Boundary conditions and simulation schemes

Using the Mohr-Coulomb criterion, displacement constraints were applied around and at the bottom of the model, while the upper surface was set as a free boundary. Gravity acceleration was applied in the Z direction. The simulation analysis results not only displayed the cloud map of the overall outer surface, but also showed the cloud map of the middle section, with the section position being along the x-axis towards the center.

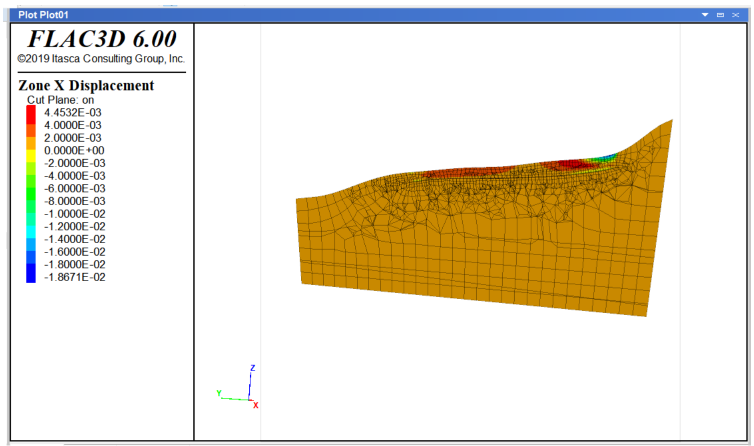
3.2. Displacement distribution

After the calculation is completed, the overall and sectional cloud maps are analyzed. A part of the steps has already formed in the initial state, and the steeper current slope is mainly located in the southwest. The sectional section is taken in the middle and southern part and passes through the current slope. The displacement is positive when it is in the same direction as the coordinate axis, and negative when it is opposite. The unit is meters.

The horizontal displacement cloud map and the vertical displacement cloud map in the initial state are shown in Figures 6 and 7 respectively.



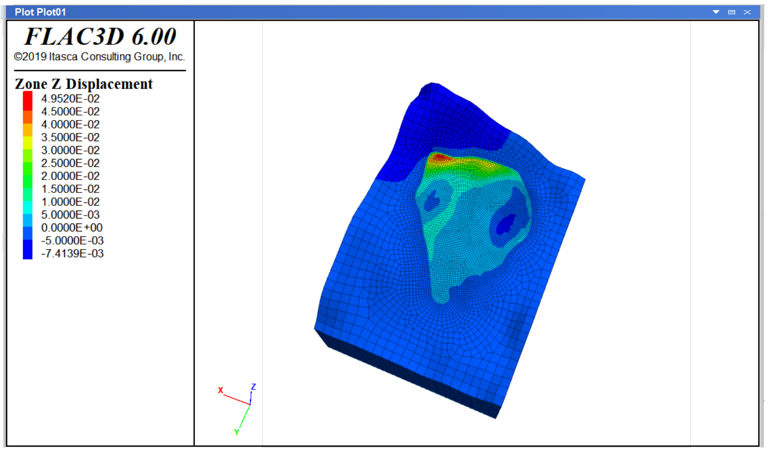
(a) Overall



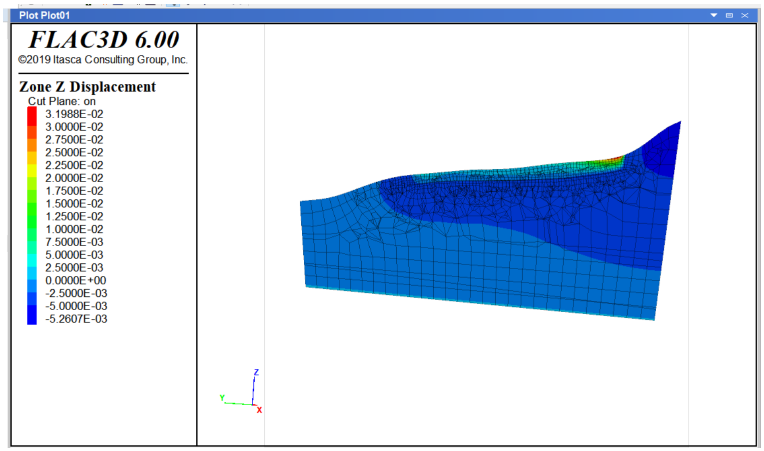
（b）Central section

Figure 6. Horizontal Displacement Cloud Map

Initially, only gravity was loaded. After equilibrium was reached, as shown in the above figure, the overall maximum horizontal displacement was 3.9 cm, in the negative direction, located in the upper part of the model; the maximum horizontal displacement in the middle section was 0.57 cm, in the positive direction, located in the middle of the sliding body.



（a） Overall



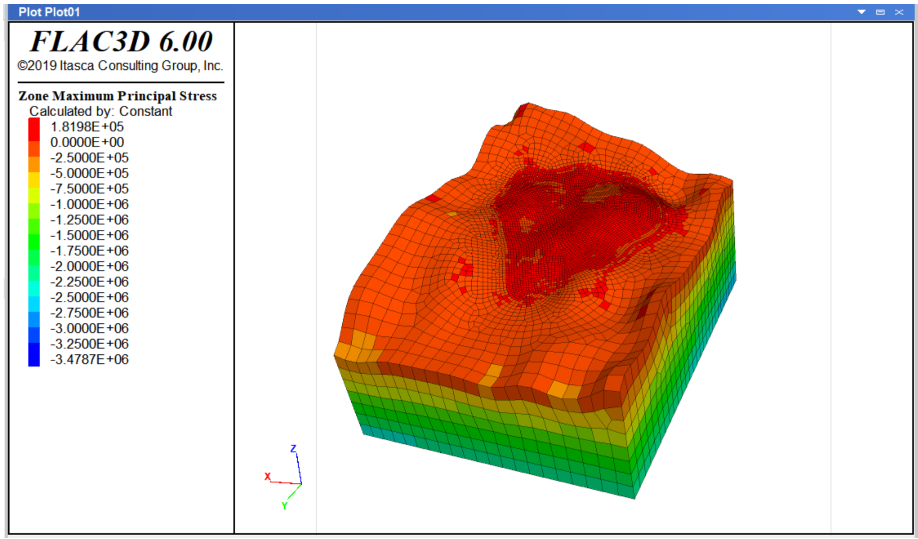
（b） Central section

Figure 7. Vertical Displacement Cloud Chart

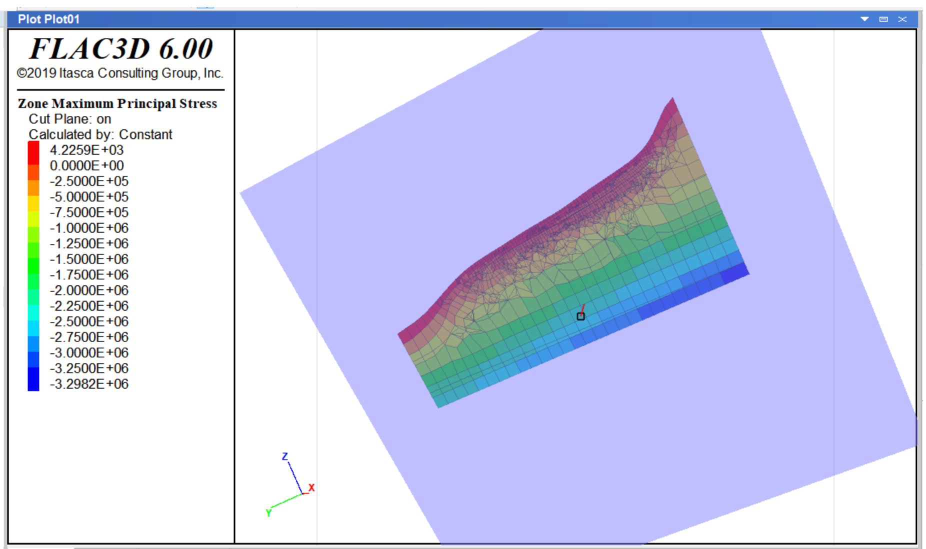
In the initial state, all the vertical displacements were downward under the influence of gravity. The maximum vertical displacement was 4.95 cm, located in the upper part of the model sliding body. The vertical displacement contour lines spread outward from this point and gradually decreased from the upper layer to the lower layer. The maximum surface displacement at the slope edge is approximately 4.95 cm. The maximum vertical displacement in the middle section is 3.19 cm, located in the upper-middle part. The vertical displacement gradually decreases from the upper layer to the lower layer. The displacement contour at the bottom is nearly horizontally distributed, and the contour at the slope edge is nearly perpendicular to the slope surface. The displacement fields of different sections are similar. As the terrain becomes gentler, the maximum displacement value decreases.

3.3. Stress distribution

In FLAC3D, it is stipulated that tensile stress is positive and compressive stress is negative, with the unit being Pa. The maximum principal stress contour map and the minimum principal stress contour map in the initial state are shown in Figures 8 and 9 respectively. The maximum principal stress mainly analyzes the tensile condition of the rock mass, while the minimum principal stress mainly analyzes the compressive condition of the rock mass.



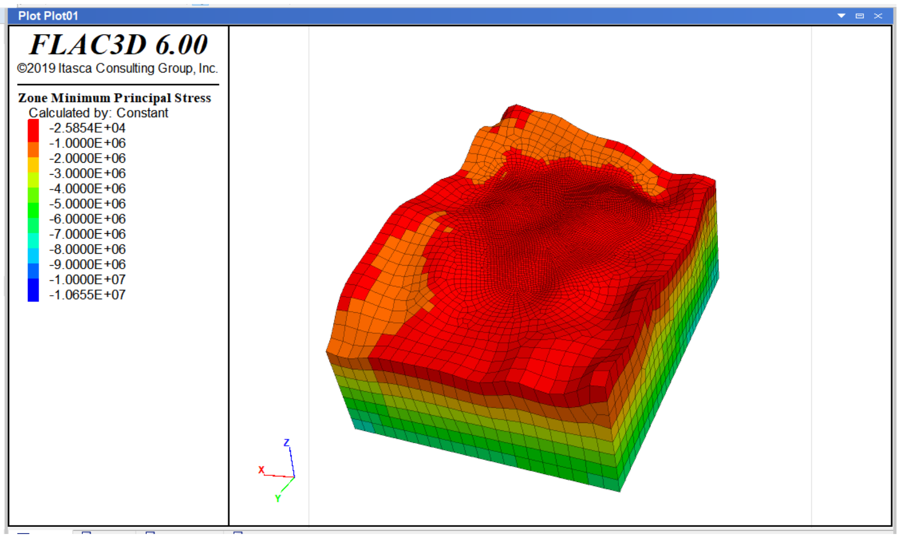
（a） Overall



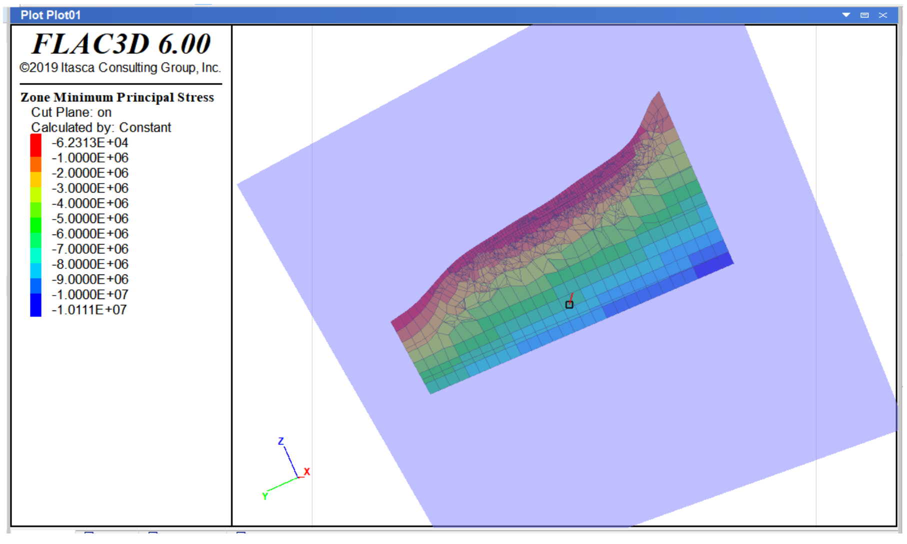
（b） Central section

Figure 8. Maximum Principal Stress Contour Map

As shown in the figure, the overall surface is mainly under tensile stress. The maximum tensile stress at the current slope is 0.18 MPa, located on the sliding surface. The maximum tensile stress contour line in the middle section is basically consistent with the surface direction, with a maximum tensile stress value of 0.0043 MPa, located on the slope surface. The stability of the current slope is good.



（a） Overall



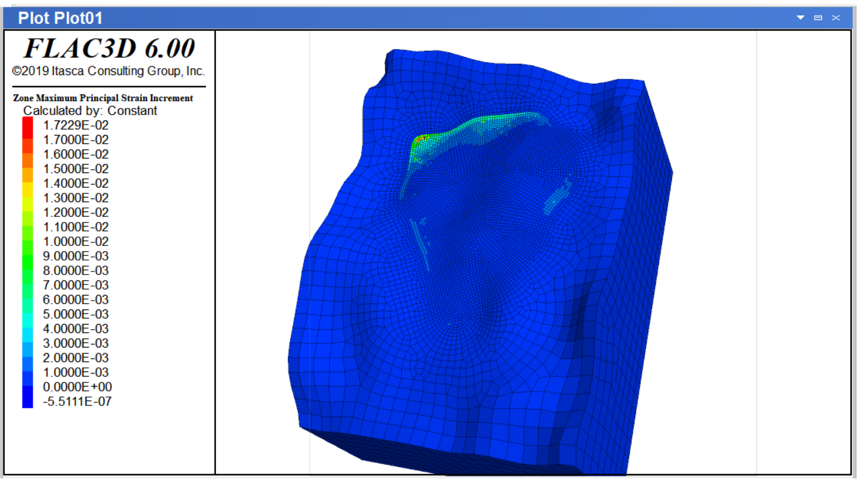
（b） Central section

Figure 9. Minimum Principal Stress Contour Map

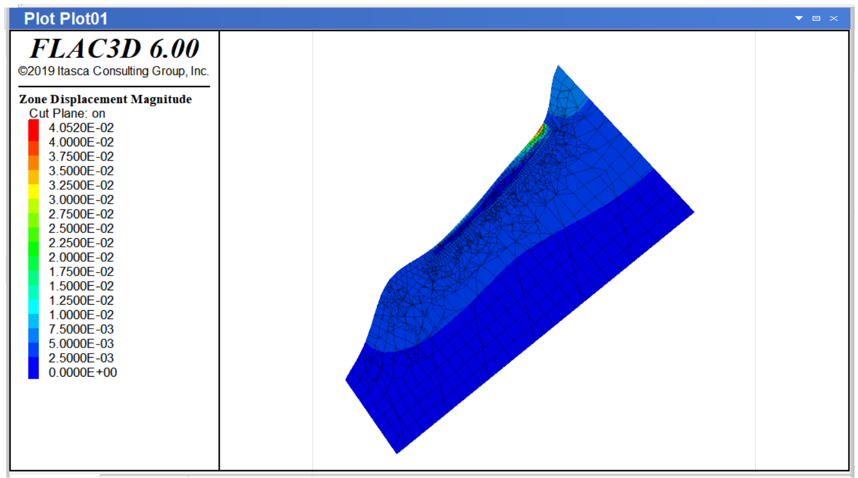
3.4. The distribution of the maximum strain increment

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your journal for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper.

The displacement stress contour map shows the initial state of slope displacement and stress distribution, but it is not easy to intuitively determine the stability of the slope. Therefore, it is also necessary to determine whether the local part of the slope is in a shear and tension state. When evaluating the stability of the slope, the increment of shear strain is an important reference indicator. By observing the absolute value of the increment of shear strain and its distribution, we can judge the stability of the slope. When the increment of shear strain is very small or close to zero, it usually means that the slope is in a relatively stable state, and there is no risk of a potential sliding surface causing large deformation or instability failure. However, in the area with a large increment of shear strain, there may be a case of shear failure. The size of the increment of shear strain reflects the stress changes within the rock and soil body and the deformation of the material. When the slope is subjected to external forces or the internal conditions change, the area with a large increment of shear strain often has a higher shear stress, which may lead to local shear failure. Therefore, when evaluating the stability of the slope, the analysis of the increment of shear strain is of great significance, which can help us understand the deformation behavior of the slope and the potential risk of failure, and thus take corresponding protective and reinforcement measures. The distribution cloud map of the maximum increment of shear strain is shown in Figure 10.



（a）Overall



（b） Central section

Figure 10. Cloud chart showing the distribution of the maximum shear strain increment

As can be seen from the above figure, the distribution of the maximum shear strain increment isaline along the horizontal direction and is basically consistent with the surface orientation. It gradually decreases from top to bottom, and the maximum shear strain increment at the center of the surface is relatively large, indicating that the initial state has good stability.

3.5. Stability coefficient analysis

The safety factor obtained through FLAC3D numerical simulation is 1.48, which is greater than 1.0. The stability of this slope is good, as shown in Figure 11.

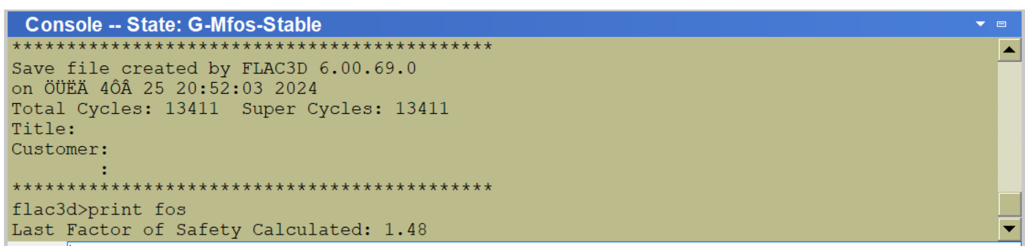


Figure 11. Slope Stability Coefficient

4. Conclusion

Based on the CAD drawings such as the geological profile and plan of Huaipa, using the Midas GTS NX joint modeling, a three-dimensional model of the Huaipa landslide was established. Through the FLAC3D software, numerical simulation analysis was conducted on the initial state of the slope.

The simulation results show that in the initial state, the horizontal displacement is mainly distributed in the upper part of the slope, and the displacement value increases with the increase of height. The vertical displacement is mainly distributed at the top of the slope, and the displacement value increases with the increase of height. The maximum principal stress is mainly distributed on the surface of the slope, and the absolute value of the minimum principal stress increases from top to bottom. The maximum value is located at the bottom of the model. The maximum incremental value of shear strain in the initial state is very small, and the maximum value is located in the upper part of the sliding body.

Finally, based on the displacement cloud map, stress cloud map, maximum incremental value of shear strain cloud map and slope stability coefficient, it can be determined that the slope is in a stable state in all three cases.

References

[1] Cao Aiwu, Chu Weijiang, Wang Rongfu, et al. Landslide Failure Process Simulation with Automatic Remeshing in FLAC3D[J].IOP Conference Series:Earth and Environmental Science, 2021, 861(3).

[2] Song Y S, Cho Y C, Hong S. Analyses on variations in the unsaturated characteristics of a mine waste-dump slope during rainfall[J]. Environmental Earth Sciences, 2016, 75(14): 1106.

[3] Zhan L, Zhang Z, Chen Y, et al. The 2015 Shenzhen catastrophic landslide in a construction waste dump:Reconstitution of dump structure and failure mechanisms via geotechnical investigations[J]. EngineeringGeology, 2018, (238): 15-26.

[4] Duffaut P, J Larouzée. Geology, Engineering & Humanities: 3 sciences behind the-Malpasset dam failure (France, Dec. 2, 1959) [J]. Quarterly Journal ofEngineering Geology and Hydrogeology, 2019, 52(4): 2018-186.

[5] Hany, El, Naggar, et al. Finite-element and limit equilibrium analyses of astabilised natural high slope[J]. Proceedings of the Institutuion Civil Engineers:Ground improvement, 2017, 170(GI2):89-101.

[6] Wang Li, Wang Shimei, Li Gao, et al. Construction of 3D Creep Model of Landslide Slip-Surface Soil and Secondary Development Based on FLAC3D[J]. Advaaces in civl engineering, 2019, (20): 30-40.

[7] Brace W F,Paulding BW,Scholz C.Dilatancy in the fracture of crystalline rocks[J].Journal of GeophysicalResearch,1966,71.

[8] Zhang ZL,Wang Tao. Stability and deformation of Xiaozhuang landslide: A large-scale creeping landslide in Gansu, China[J].Journal of Mountain Science,2022,19(3):756-770.

[9] Wang H, Chen Z X, Zhang D M. Rock Slope Stability Analysis Based on FLAC3D Numerical Simulation[J]. Applied Mechanics and Materials, 2012, 170-173: 375-379.

[10] B. Zhao, Y. S. Wang, Y. Wang, et al. Retaining mechanism and structural characteristics of htype anti-slide pile (hTP pile) and experience with its engineering application[J]. EngineeringGeology, 2017, 222: 29-37.

[11] S. Haldar, G. L. S. Babu. Effect of soil spatial variability on the response of laterally loaded pilein undrained clay[J]. Computers and Geotechnics, 2008, 35(4): 537-547.

[12] He Huachun, Zhou Liya, Lee Haiyu. Ground Displacement Variation Around Power LineCorridors on the Loess Plateau Estimated by Persistent Scatterer Interferometry[J]. IEEEACCESS,2021,9. DOI:10.1109/ACCESS.2021.3090201.

[13] He W S,Yuan L, Chang S M. Stability Numerical Simulation of Daping Landslide Group to Sunjiaya Tunnel[J]. Applied Mechanics and Materials, 2012, 170-173: 413-417.

[14] Zou Z, Chen H, Wang Z, et al. Improvement of the strength reduction method on the basis of FLAC3D in slope stability[J]. 2016.

[15] Majd A , Richard R .Modelling of the Torsional Simple Shear Test with Randomized Tresca Model Properties in Midas GTS NX[J].Geotechnical and Geological Engineering,

2023, 41(3):1937-1946.

[16] Szilvagyi Z , Ray R P .Verification of the Ramberg-Osgood Material Model in Midas GTS NX with the Modeling of Torsional Simple Shear Tests[J].Periodica Polytechnica Civil Engineering, 2018, 62(3).

[17] Mohsan M, Vossepoel F C, Vardon P J. On the use of different data assimilation schemes in a fully coupled hydro-mechanical slope stability analysis[J]. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 2024, 18(1): 121-137.

[18] Moon S W, Noh J, Kim H S, et al. Comparison of factors influencing landslide risk near a forest road in Chungju-si, South Korea[J]. Geoenvironmental Disasters, 2024, 11(1): 3.