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Study on the Stability of Tunnel Elevation Slope

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Abstract

In this paper, the stability of the elevation slope of a large section tunnel cavity under the influence of excavation disturbance is studied based on the fifth standard of National Highway 208 from Jinzhong to Changzhi section, Zihong No. 1 tunnel project. A sensitive analysis of tunnel elevation stability under single factor was carried out by FLAC-3D software to simulate the effect of different slope angles and different slope heights on the stability of tunnel elevation slopes. The results show that the slope stability decreases with the increase of slope angle when the slope angle varies from 15° to 45°. When the slope height varies from 20m to 40m, the stability of tunnel elevation slope decreases with the increase of slope height. In large section tunnel construction, the simulation is done by step-by-step excavation according to the construction sequence. The stability coefficient of tunnel opening slope gradually decreases under the influence of excavation disturbance, and the minimum value is 1.07. The stability coefficient of tunnel opening slope gradually increases to 1.13 with the completion of support.

Keywords

Stability; Tunnel Elevation Slope; Tunnel Excavation; FLAC-3D.

1. Introduction

Before the middle of the 20th century, with the development of productivity, people transitioned from the industrial era to the post-industrial era, and the development of productivity put forward higher requirements for transportation. In order to meet the process of industrialization, the old industrial countries such as Europe and the United States built a large number of public infrastructure during this period, including roads, railroads, tunnels and water conservancy projects. During the construction period, many slope instability problems occurred, which led to a large number of casualties and economic losses. Based on the circular sliding method, Fellenius [1] divided the slope into vertical soil strips to study the stability of slopes, which is called "Swedish strip distribution".

From the 1950s to the 1980s, a large number of methods for calculating slope stability emerged, focusing on the description of the relationship between engineering geology and slope stability, taking into account the analysis of the time effect of slope deformation, and based on the limit equilibrium theory combined with the Swedish arc-slide method. Morgenstren-Price method [4], Spencer method [5], Sarma method [6], etc. Among them, the Janbu method is the famous "Janbu bar separation method".

From the 1980s to the beginning of the 21st century, when computer technology was widely used in various fields, the study of slope stability also entered a new stage, and the calculation procedures of various methods emerged with the development of computer technology and developed into numerous numerical simulation methods, which made the calculation results more accurate and the use of methods more simple and neat. Yang He ping [7] studied the effect of retaining walls on slope stability using the limit equilibrium method utilized in the study of retaining walls, and added a design basis for the limit equilibrium method based on the results of the study. Wang Hong [8] utilized the limit equilibrium method in the study of open slopes in mining areas, compared and analyzed the advantages and disadvantages of different support methods based on the calculation results, and proposed a support method with better effect. In the study of high slope of loess medium, Yue Ying min [9] used the limit equilibrium method to analyze the stability of high slope of loess medium, evaluated its stability according to the results, discussed its support method according to the evaluation conclusion, and determined a more economical and safer support scheme. Liu Yihui [10] compared the finite element simulation results during the construction process and verified them according to the construction site conditions using the limit equilibrium method, and the verification results indicated that the finite element simulation analysis method could well simulate the stability of the excavation surface of the soft soil pipe curtain box culvert affected by seepage flow.

In the engineering construction, there are constantly new problems appearing, and some of them can no longer be explained by the previous theories. The research of slope stability combines the research methods of statistics, integrates the original geotechnical knowledge, and develops new research methods, such as: artificial neural network method, fuzzy mathematical method, nonlinear theory, gray system theory, etc. These theories have improved the accuracy of slope stability calculation and have a guiding role in slope stability analysis in actual engineering construction. Based on the metabolic GM(1,1) model, Jin bin Kang [11] studied the deformation of slopes. Combined with engineering examples, the time response equation and predicted values of slope deformation were obtained. Meanwhile, the deformation of the slope under the combined effect of one-year rainfall and self-weight is simulated by using finite element software, and the change trend of the obtained simulated value is basically consistent with that of the measured and predicted values, thus verifying the feasibility of the metabolic GM(1,1) model.

2. The Characteristics of Traditional Embroidery Art

The exit section of Zihong Tunnel No. 1 is also called the large mileage end cavern, and the slope of the large mileage end cavern slope is about 270° with a slope angle of 41°. The slope where the left and right line openings are located is in a basic stable state under natural conditions. According to the topographic conditions of the tunnel entrance, the elevation slope of the left and right line entrances is about 12~18m high, and the elevation slope, side slope and surrounding rocks of the entrance section are composed of sandstone and mudstone of the Lower Triassic Heshangou Group (T1h) and sandstone of the Middle Triassic Ermaying Group (T2e), which are strongly to moderately weathered, with the development of joints and fissures to be more developed, and the rock body is broken to be more broken, and is susceptible to adverse geological phenomena such as breakage and collapse. The elevation slope of the cave entrance at the large mileage end of the left and right lines is unstable. During construction, the support measures of slope release and slurry spraying are used for management.

3. Sensitive Study on the Stability of the Elevation Slope of the Tunnel Cavity under Single Factor

The large mileage end of Zihong No. 1 tunnel is also called the exit end. According to the survey data of the area where the tunnel is located, this paper will simulate and analyze the study of the slope stability of the elevation slope in two aspects: slope angle size and elevation slope height. In this paper, FLAC-3D is used to simulate the analysis. The surface of the slope is an undulating surface, which is simplified to a plane with the same slope for the convenience of calculation. For the convenience of the study, the following assumptions are used in the simulation:

The rock mass is assumed to be a uniform and continuous elastic-plastic medium, and the deformation of the rock mass is isotropic;

An elasto-plastic intrinsic model with mohr-coulomb yielding criterion is used;

Only the effect of self-weight stress is considered in the initial stress field, and the tectonic stress is neglected.

(1) Effect of different slope angles on the stability of elevation slopes

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1) Model establishment and parameter selection

According to the survey data, the slope angle of the elevation slope is changed under the condition that other factors remain unchanged. The slope angle is taken as 80m along the tunnel axis, 200m along the tunnel level, and 30m along the depth of entry. in the simulation, the front, back, left and right of the model are normal constraints, the bottom is fixed constraint, and the upper is free boundary. The initial stress field is considered as the self-weight stress field, and the elevation slope angle varies from 15° to 50°, with a gradient of 15°.

The slope angle of the tunnel elevation slope model is taken as 15°, 30° and 45°.

2) Simulation analysis of different slope angles

The sliding surface of the elevation slope mainly occurs at the part with the largest shear strain increment, and if the sliding instability damage of the elevation slope occurs, it will slide out along the part with the largest shear strain increment. The rock body in the part with smaller shear strain increment value and the part with no change is in a relatively stable state and will not be damaged by large deformation.

As shown in Figure 3-2, the displacement value of the rock body of the elevation slope increases while the angle of the slope gradually increases, and the location where the rock body slides is mainly at the upper edge of the elevation slope, because the right side of the elevation slope is a hollow surface without rock body support, and the rock body at the back edge of the elevation slope is continuously extruded outward under the action of the self-weight stress component. The rock body on the lower edge of the elevation slope is supported by the rock body of the slope angle, and the sliding displacement of the rock body is relatively small. The rock body of the elevation slope is influenced by the sliding surface, and the rock body displacement mainly occurs in the range between the sliding surface and the slope surface.

(2) Effect of different slope heights on the stability of elevation slopes

1) Model establishment and parameter selection

According to the survey data, the height of the elevation slope is changed while other factors remain unchanged. Take 200m along the horizontal direction of the tunnel, 30m along the depth direction, and the slope angle is 45°. The elevation slope model under natural working condition is established, and the model is normal constrained at the front, back, left and right, fixed constrained at the bottom and free boundary at the top during the simulation. The initial stress field is considered as the self-weight stress field. The elevation slope height varies from 20m to 40m, with a gradient of 10m.

The height h of the tunnel elevation slope model is taken as 20m, 30m, 40m.

2) Simulation of different slope heights

As shown in Figure with the increase of the slope height of the elevation of the cave entrance, the displacement of the rock body of the elevation slope is also increasing, and the location where the rock body slides is mainly at the upper edge of the elevation slope, because the right side of the elevation slope is a critical surface without rock body support, and the rock body at the back edge of the elevation slope is continuously extruded outward under the action of the self-weight stress component. The rock body on the lower edge of the elevation slope is supported by the rock body of the slope angle, and the sliding displacement of the rock body is relatively small.

4. Study of Finite Difference Method for Elevation Slope of Large Cross-section Tunnel Opening

(1) Effect of tunnel excavation on elevation slope stress at the cave entrance

In the tunnel excavation process, it will affect the stability of the cave slope, the tunnel excavation leads to the change of the original balance of the cave slope, the cave slope and the tunnel excavation affect each other, the stress of the cave slope is a dynamic development of the adjustment process, in

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this process its self-stabilization capacity is constantly decreasing, when the surrounding rock bearing capacity is less than its sliding force will occur when the landslide.

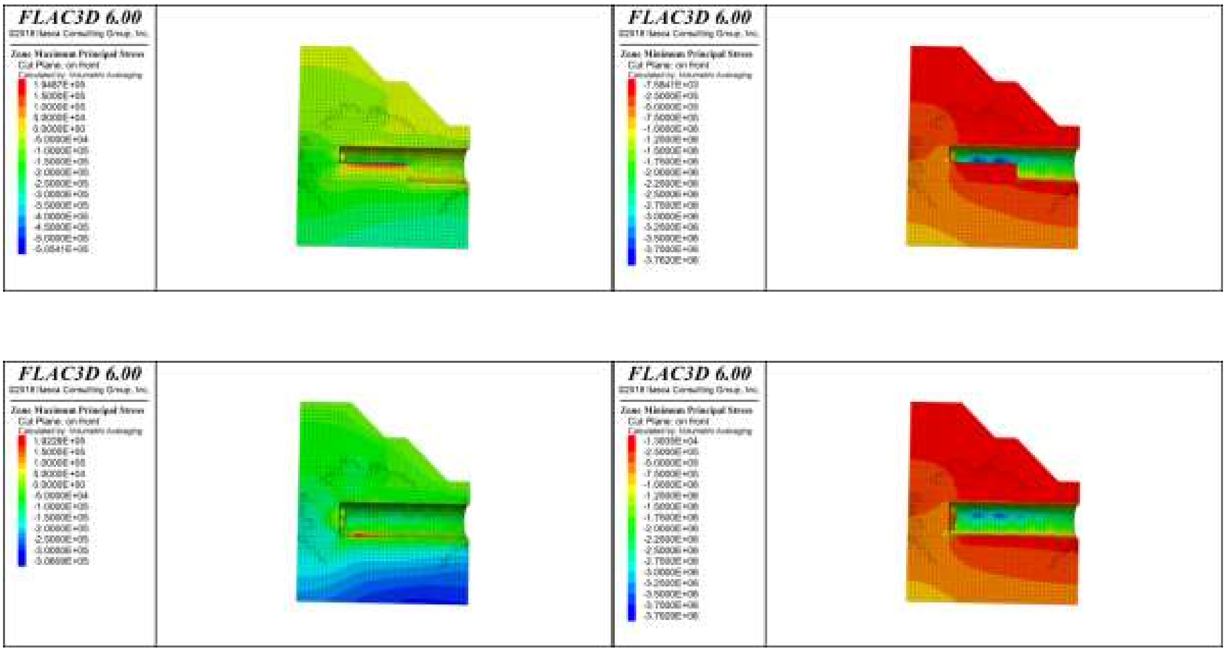

Figure 1. Stress of right tunnel excavation

As can be seen from Figure , the maximum principal stresses (a and c) and minimum principal stresses (b and d) in the elevation slope of the tunnel show a laminar distribution from top to bottom. The tension stress control area (positive values of tensile stress and negative values of compressive stress) in the cloud of maximum principal stresses (a) at the completion of the excavation of the upper slope is mainly distributed at the location of the tunnel floor and partly at the surface location of the elevation slope. The bottom slab position is caused by the rock at the bottom side of the tunnel losing the pressure of the surrounding rock above and arching upwards. The presence of tensile stresses on the surface of the elevation slope indicates that the rock on the surface of the elevation slope in this area is prone to sliding damage under the action of external forces. The main focus of the elevation slope of the tunnel is compressive stress, and as the rock burial depth of the elevation slope increases, the part of the elevation slope controlled by tensile stress also changes to compressive stress as the rock burial depth increases.

The comparison between the excavation completion maximum principal stress cloud (c) and the upper stage excavation completion maximum principal stress cloud (a) shows that the area controlled by tensile stress in the upper stage excavation completion maximum principal stress cloud (a) has become controlled by compressive stress in the excavation completion maximum principal stress cloud (c). It indicates that after the tunnel excavation is completed and the support measures are applied, the interface of the surface layer of the elevation slope which is prone to sliding damage disappears and the support plays a good controlling role.

(2) Effect of tunnel excavation on the stability coefficient of the elevation slope of the cavern

The effect of tunnel excavation on the elevation slope of the cave entrance cannot be observed visually through deformation and displacement. The specific changes of the stability of the elevation slope of the cave entrance section during the tunnel excavation are calculated by using FLAC-3D built-in side slope strength reduction method, and the stability coefficient of the elevation slope of the cave entrance section of the tunnel is evaluated by the stability coefficient of the elevation slope of the cave entrance section during each excavation step.

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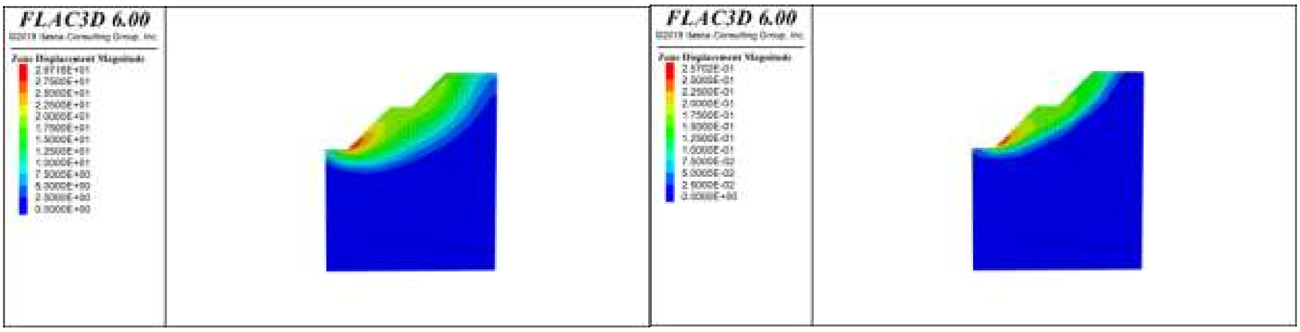

Figure 2. Strength reduction displacement of different sections

In this paper, the key sections are selected for analysis, as shown in Figure , after the excavation of the upper step of the right hole is completed Figure (a) the displacement range of the tunnel elevation slope is distributed throughout the elevation slope position, the same displacement occurs at the location above the tunnel entrance, when the right hole is completed excavation Figure 2 (b), the displacement of the tunnel elevation slope is reduced, the displacement above the hole entrance basically does not exist, and the value of the elevation slope displacement becomes smaller. The same pattern of change was observed in the left hole excavation, as the excavation was completed, the support formed a closed loop and then the sliding surface moved.

Calling the stability coefficients of each tunnel excavation step, the changes of the stability coefficients of the tunnel excavation and the elevation slope of the cave entrance are shown in Figure:

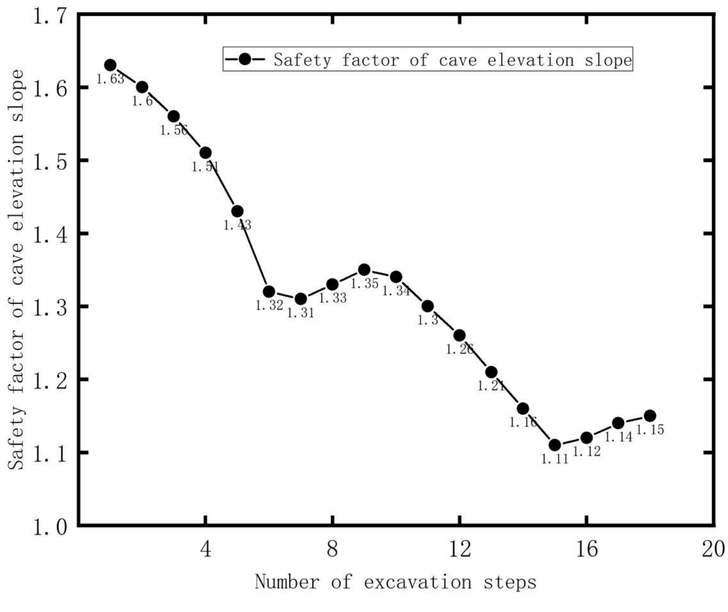

Figure 3. The variation curve of stably coefficient - excavation step number

As shown in Figure, the stability coefficient of the elevation slope of the tunnel opening under the initial conditions is 1.63. During the first 6 steps of excavation, the stability coefficient of the elevation slope of the opening has been decreasing, and the rate of change is getting faster and faster, in the 7th to 9th step, the excavation of the lower step is carried out, and after the lower step is supported, the stability coefficient of the slope of the opening rebounded slightly. According to the Technical Specification for Construction Slope Engineering (GB 50330-2013), the stability coefficient of the cave entrance slope at step 6 is 1.22, and the stability coefficient of the cave entrance slope is greater than the safety coefficient 1.10, which is in a safe and stable state, but with the construction of the lining, the stability coefficient of the cave entrance slope reaches 1.33, which is also greater than the safety coefficient 1.10, and the cave entrance slope is in a safe and stable state during the whole excavation The slope of the tunnel opening was in a safe and stable state throughout the excavation process. From step 10 to step 15, the upper step of the left tunnel is excavated, and the slope of the tunnel opening changes in the same way as the right tunnel, and the stability coefficient of the opening reaches a minimum of 1.07 in step 15.

5. Conclusion

(1) With the increase of the elevation slope height of the tunnel, the displacement of the elevation slope rock body is also increasing, the location where the rock body slides is mainly in the upper edge of the elevation slope, because the right side of the elevation slope is the critical surface without rock body support, and the rock body at the back edge of the elevation slope is continuously extruded outward under the action of the self-weight stress component. The rock body at the lower edge of the elevation slope is supported by the rock body of the slope angle, and the sliding displacement of the rock body is relatively small. As the slope height of the elevation slope increases, the stability coefficient of the elevation slope decreases.

(2) The change of slope stability coefficient of large section tunnel opening is: gradually decreasing in the process of excavation disturbance, especially in the upper step excavation stage, with the completion of the upper step excavation, the slope stability coefficient of the opening is 1.22. After the lower step excavation, the slope stability coefficient of large section tunnel opening gradually increases, and the slope stability coefficient of the opening is 1.33 at this time. In the 15th step, the slope stability coefficient reaches 1.07, and in the 16th to 18th step, the slope stability coefficient rises gradually and finally reaches 1.13, which is also in a safe and stable state.

References

[1] Fellenius W. Calculation of the stability of earth dams[C]. //Proce-edings of the Second Congress on Large Dams, 1936, 4: 445-463.

[2] Janbu N. Application of composite slip surface for stability analysis[C]. //Proceedings of the European Conference on Stability of EarthSlopes, Sweden, 1954, 3: 43-49.

[3] Bishop A W. The use of the slip circle in the stability of general slip surfaces[J], Geotechnique, 1955, 5(1): 7-17.

[4] Morgenstern N R, Price V E. The analysis of the stability of general slip surfaces[J], Geotechnique, 1965, 15(1): 79-93.

[5] Tamotsu FURUYA. A simple solution of the general limit equilibrium method of slices[J]. Landslides, 1984, 21(1).

[6] Sarma S K. Stability analysis of embankments and slopes[J]. Geotech-nique, 1979, 23(3): 423-433.

[7] Yang He ping. Stability analysis of a highway slope retaining wall by limit equilibrium method and finite element strength reduction method[J]. Highway Engineering, 2012, 37(03): 180-183.

[8] Wang H, Wu QH, et al. Stability analysis of open pit slopes based on limit equilibrium method[J]. Modern Mining, 2014, 30(09): 157-158.

[9] Yue Y. Min. Stability evaluation of loess high slope of a power plant project[J]. Science and Technology Information, 2012(07): 520-521+552.

[10] Liu Yi hui, Huang Mao song, et al. Stability analysis of excavation surface of soft soil pipe curtain box culvert considering the influence of seepage[J]. Journal of Geotechnical Engineering, 2021, 43(S2): 15-18.

[11] K Jin bin, GAO Gui yang. Prediction model for slope deformation of charcoal shale road graben based on gray theory[J]. Zhujiang Water Transport, 2022, 554(10): 36-38.