International Core Journal of Engineering Volume 8 Issue 7, 2022
ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0072

Analysis and Prevention of Rock Slope Instability Induced by Excavation

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Abstract

In order to avoid the frequent occurrence of slope failure, it is necessary to study the causes and prevention measures of slope failure. Taking the excavation instability of a highway rock slope in Guizhou province as an example, the instability of rock slope was analyzed, and 3DEC was used to analyze the supporting effects of two reinforcement schemes. The following conclusions are drawn :(1) excavation is the main factor inducing the instability of rock slope. (2) Based on the two reinforcement schemes of 3DEC, the supporting effect is analyzed from two aspects of rock mass displacement and maximum shear strain increment, and it is concluded that the slope is in a stable state, but the supporting effect of scheme 1 is better.

Keywords

Slope Excavation; 3DEC; Layout of Reinforcement.

1. Introduction

Along with our country highway network in southwest China Twenty five longitudinal and five horizontal side two ring united layout is put forward, in the southwest of the highway construction has entered a stage of rapid development, but due to the complexity of engineering geology in southwest, many sections needed by the excavation of high and steep slope, and the high and steep slope excavation deformation and supporting has a crucial effect on the stability of whole slope [1,2]. At present, in most cases, the design of high and steep slopes only calculates the stability of slopes through simple limit equilibrium method, and the construction is mostly based on experience, which often ignores the deformation and failure process of slopes during excavation [3-5], but this has great potential safety hazards Therefore, studying the deformation and failure mechanism of slope excavation and accurately evaluating slope stability are urgently needed technical problems in engineering [6-8]. In order to study the causes of slope instability and its prevention and control measures, this paper analyzes the causes of slope instability by taking a rocky slope excavation failure case of a highway in Guizhou Province, and uses 3DEC discrete element software to conduct simulation and comparative analysis of reinforcement schemes. It has certain reference value to the study of slope stability of similar engineering.

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2. Slope Engineering Overview

A highway section passes through the middle and lower part of the slope. The lateral slope of the upper left side of the slope is generally slow to gradually steep, and the valley bottom gully is located 60 m away from the right side. The slope elevation of the section is between 560 m and 664 m, and the slope overlay of 104 m relative elevation includes clay and gravel soil Pebble soil and slope bedrock include strongly weathered slate and moderately weathered slate, among which, the thickness of strongly weathered slate is 19~30 m, and the rock trend is consistent with the slope direction, which belongs to bedding rock slope. Relevant mechanical parameters obtained by combining geological mapping and drilling data are shown in Table 1.

Table 1. Mechanical parameters of SLATE rock mass

Terms		Strong weathered rock	Moderately weather
Density	ρ/Kg/m^3	2300	2350
Elasticity modulus	E/GPa	41.2	62.1
Poisson's ratio	μ	0.22	0.21
Bulk modulus	K/MPa	2.45e4	3.57e4
Shear modulus	G/MPa	1.69e4	2.57e4
Cohesion	c/MPa	0.95	2.4
Friction angle	φ/(°)	43.9	48
Tensile Strength	σ_t/MPa	5	12

3. Analysis of Slope Excavation Process and Instability

The slope is in a stable state in natural state. According to the design, the slope is excavated in four steps from top to bottom, and the total excavation height is 39 m. As shown in Fig.1, the first step is the excavation elevation of 642 m, the excavation slope ratio is 1:1, the excavation height is 11m, and the transverse and longitudinal excavation lengths are 50 m and 31m. The excavation broke the initial stress balance of the slope body, and the rock mass underwent unloading and springback deformation. However, the excavation scale was small, and the disturbance degree to the rock mass was low. The rock mass did not collapse and remained stable, so no reinforcement measures were taken.

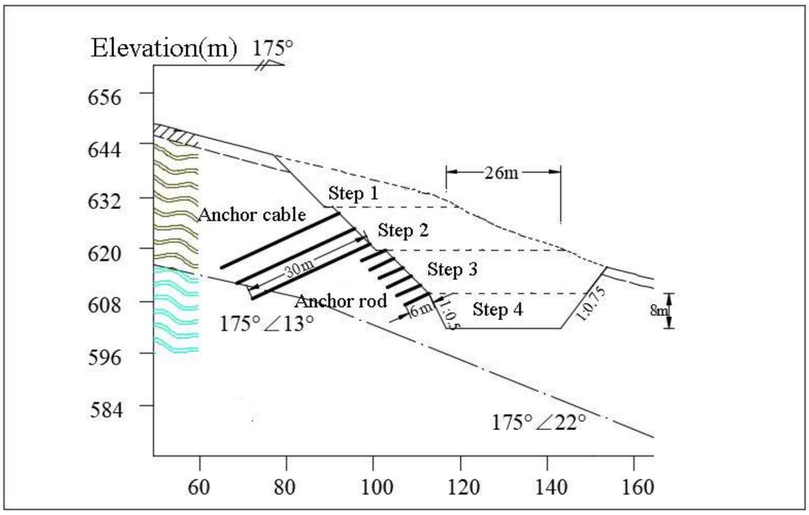

Fig. 1 Schematic diagram of excavation design

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In the second step, the slope rate is 1:1, the excavation height is 10 m, the transverse and longitudinal excavation lengths are 50M and 43m, and a 2 m wide platform is reserved at the foot of the slope in the first step. The excavation breaks the equilibrium state formed after the excavation of the first step, and the stress redistribution expands on the basis of the stress redistribution range of the first step, resulting in the increase of the unloading rebound deformation of the slope rock mass during the excavation of the first step. After excavation, anchor cable frame beam is used for reinforcement. Three rows of anchor cables are set on the excavation surface, one row is set at the top and foot of the slope 2 m away from the second excavation surface, and one row is set in the middle of the slope surface. The horizontal spacing of anchor cables is 3 m, the downdip angle is 25°, the length of anchor cables is 30 m, and 16 anchor cables are set in each row. Under the action of anchor cable anchoring, the slope rock mass did not collapse and remained stable.

In the third step, the excavation slope rate is 1:1, the excavation height is 10 m, the transverse and longitudinal excavation lengths are 50 m and 36m, and a 2 m wide platform is reserved at the foot of the second step. In the third step, due to the anchoring effect of anchor cable, the displacement of rock mass in slope and above area of the second step is small. After excavation, anchor frame beams are used for reinforcement. 6 rows of bolts are set at the average position of the excavation slope. The transverse spacing of bolts is 3m, the downdip angle is 25°, the length is 6 m, and 16 bolts are set in each row. After the excavation, the anchor reinforcement measures were taken in time, which greatly restricted the deformation of slope rock mass during the third step excavation. No shear failure of slope rock mass occurred, and the slope was in a stable state.

In the fourth step, the excavation slope rate is 1:0.5, the excavation height is 8 m, the transverse and longitudinal excavation lengths are 50m and 26m, and the reverse slope of 53° is formed. No platform is set for this excavation. The fourth step of slope excavation has a large angle (63°), and the excavation method is different from the previous three times. The excavation is carried out at the foot of slope in the third step. Although the excavation height and scale are small, the excavation leads to stress concentration at the foot of slope in the third step, resulting in greater disturbance to rock mass and shear failure of rock block. In the fourth step, the slope toe of the excavation face is close to the interface between strong and moderately weathered slate, and stress will be released along the interface, resulting in stress concentration at the slope toe of the excavation face in the fourth step, shear failure of rock mass occurs, and tensile stress at the top of the slope will increase, resulting in tensile failure. Specifically, cracks and deformation of anchor cable and anchor frame beam appear, as shown in Fig. 2. Partial collapse failure occurs on the excavated slope surface in the first and third steps, and tensile cracks appear on the back edge of the slope top, as shown in Fig. 3.

Fig.2 Cracking and deformation of anchor frame beam

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Fig. 3 Tensile crack deformation at the rear edge of the slope top

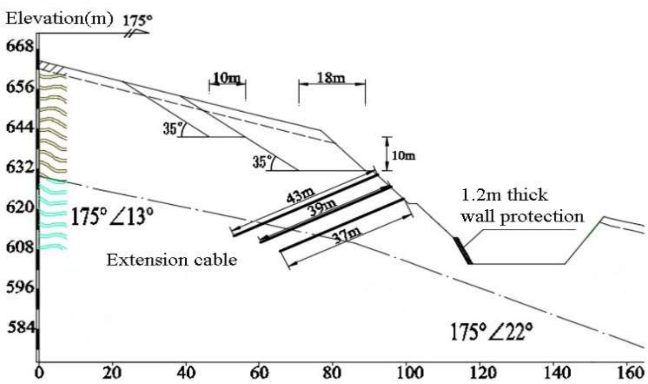
4. Study on Strengthening Mechanism of Unstable Slope

After the end of the slope excavation, the rock mass is in an unstable state, easy to occur overall instability failure, not only will prolong the construction period, but also will cause huge life safety threats and property losses to the site construction personnel. Therefore, it is necessary to take reinforcement measures to ensure the stability of the slope Based on 3DEC, the supporting effects of the two reinforcement schemes were compared and analyzed to determine the final reinforcement scheme.

4.1 Slope Reinforcement Scheme

Reinforcement scheme 1 is: lengthening anchor cable + wall protection + earthwork removal, as shown in Fig. 4(a). The specific plan is as follows: For the second step excavation slope anchor cable to strengthen supporting structure design, the original is in the original anchor position horizontal distance of 1 m set extension cable, a top-down set three rows, each row set 16 root, a total of 48 root, length of 43 m respectively, 39 m, 37 m, angle of 25 °, on the fourth step excavation slope reinforcement facing wall with 1.2 m thick. At the same time, from the first step excavation slope toe according to shun practice two earthwork excavation again, the first step in the excavation for the first time that is, from the original edge direction after excavation slope foot to the top level excavation 18 m, 35 ° excavation to the top again, again with the first excavation slope foot horizontal vertical height of 10 m for a second excavation, 10 m, excavation to 35 ° excavation to the top.

Reinforcement scheme 2 is: anchor cable + protective wall + earthwork removal, as shown in Fig. 4(b). The specific scheme is as follows: Three rows of anchor cables are set on the basis of the original anchor bolt support structure on the slope excavated in the third step. The positions are respectively at the top of the slope, the middle of the slope and the foot of the slope. The distance from the original anchor bolts is 1 m horizontally, and 16 anchor cables are set in each row, all 30 m in length and 25° in inclination Angle. The parameter values of wall setting and earthwork clearing and excavation as well as anchor cable and wall are the same as in Plan 1.



(a) Slope reinforcement scheme 1

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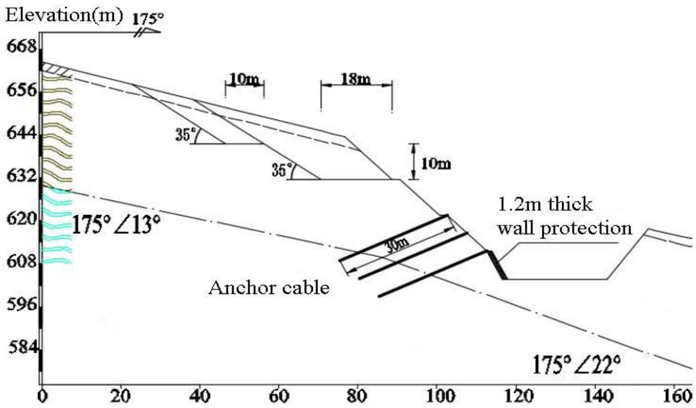

(b) Slope reinforcement scheme 2

Fig. 4 Design drawing of slope reinforcement scheme

4.2 Establish Slope Reinforcement Model

3DEC (3 Dimension Distinct Element Code) is suitable for simulating the mechanical behavior of discrete media under quasi-static or dynamic loads, and has good suitability for stability analysis of jointed rock slope excavation It is feasible to use discrete element method to study slope stability and failure mechanism [9-12]. According to the design of slope excavation, a model is established. The model size is 50 m in X direction, 170 m in Y direction, 90 m in maximum and 36 m in minimum in Z direction. The strongly weathered slate is soft and prone to elastoplastic failure, so its constitutive model is elastoplastic and molar-Coulomb failure. Coulomb slip failure is selected for joint constitutive model.

In 3DEC, anchor cable structural element and local strengthening element are adopted to simulate instead of anchor cable and bolt. Mechanical parameters of the two elements are shown in Table 2 and slope mechanical parameters are shown in Table 1.

Table 2. Mechanical parameters of anchor cable element and local strengthening element

Anchor cable unit	Cross sectional area	m^2	181e-6
	Elasticity modulus	MPa	98.6e3
	Tensile yield strength	MN	5.0
	Slip strength of grouting	MN/m	112
	Grouting bond strength	MN/m	0.175
Local strengthening element	Axial rigidity	MPa/m	100
	1/2 effective length	m	1.0
	Ultimate bearing capacity	MN	100

4.3 Analysis of Supporting Effect of Slope Reinforcement Scheme

(1) Deformation analysis

Three-dimensional cloud maps of rock mass displacement under the conditions of two reinforcement schemes are shown in Fig.5. Comparative analysis is made according to the changes of maximum displacement values in the displacement concentration area of excavation face. Under the conditions of reinforcement plan 1 and reinforcement plan 2, the maximum displacement of rock mass on the slope top of excavation face increases by 0.9 mm and 1.5 mm respectively in the second step, and the displacement of wedge block on excavation face decreases by 0.7 mm and 1.9 mm respectively in the fourth step. The maximum displacements of slope rock mass during the first earthwork removal increase by 2.2 mm and 2.6 mm, respectively. The maximum displacement of slope surface during

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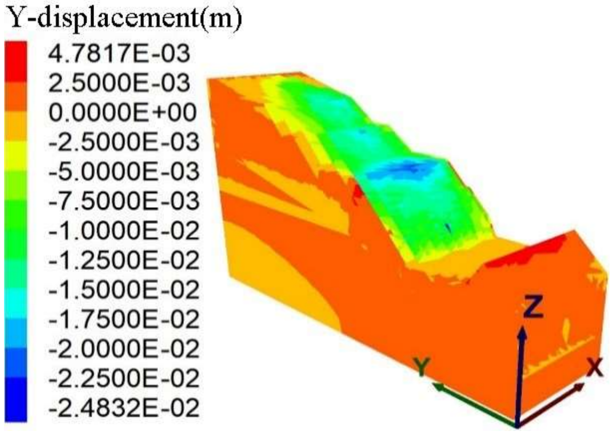
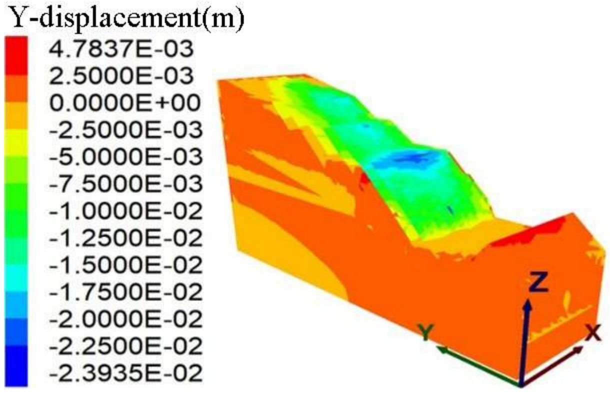
the second excavation increases by 5.1 mm and 5.4 mm respectively, indicating that the support effect of reinforcement scheme 1 is better.



(a) Reinforcement option 1

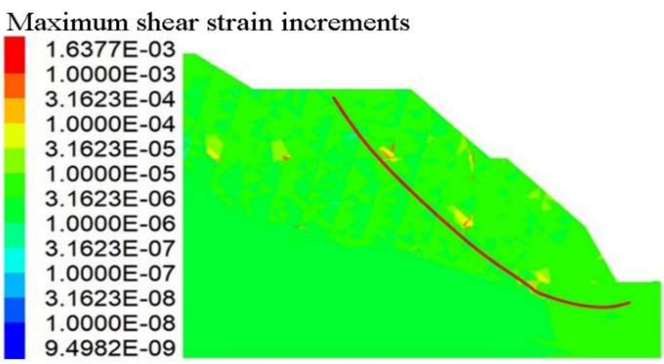


(b) Reinforcement option 2

Fig. 5 Three-dimensional cloud map of rock mass displacement

(2) Stress strain ratio analysis

Fig. 6 shows the cloud diagram of the maximum shear strain increment in the reinforcement area. Under the conditions of the two reinforcement schemes, the maximum shear strain increment of rock mass is approximately the same on the whole, but the maximum shear strain increment in the reinforcement area of the reinforcement scheme 1 is relatively small, so the support effect of scheme 1 is better.



(a) Reinforcement option 1

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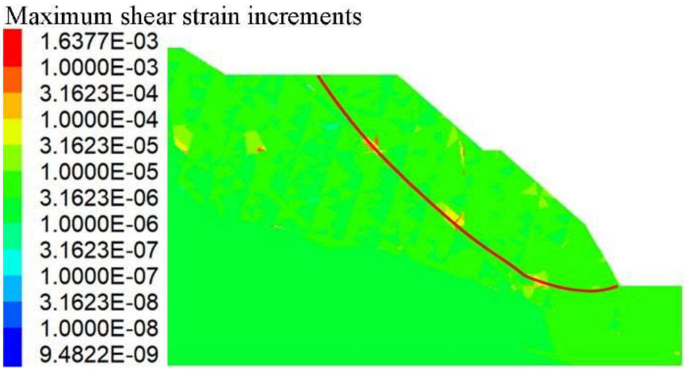

(b) Reinforcement option 2

Fig. 6 Cloud diagram of maximum shear strain increment in the strengthened area

The curve of maximum unbalance force of rock mass under reinforcement scheme 1 is shown in Fig. 7. According to the figure, when the maximum unbalance force is superposed to 91683 during calculation, the maximum unbalance force tends to 0, reaching the convergence condition, rock mass displacement does not increase any more, and the slope is in a stable state.

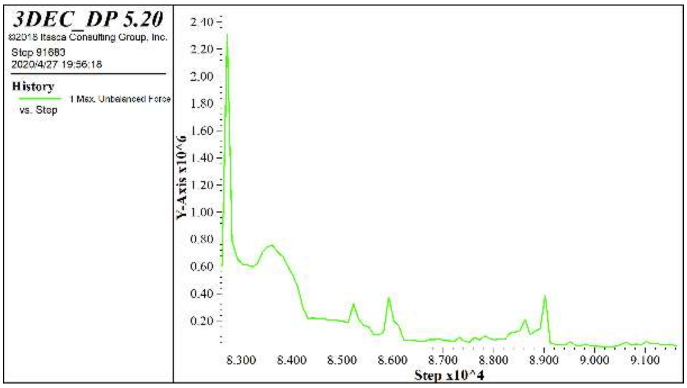

Fig. 7 Maximum unbalance force curve of scheme 1

The curve of maximum unbalance force of rock mass under reinforcement scheme 2 is shown in Fig. 8. According to the figure, when the maximum unbalance force is superimposed to 91801 during calculation, the maximum unbalance force tends to 0, reaching the convergence condition, rock mass displacement does not increase any more, and the slope is in a stable state.

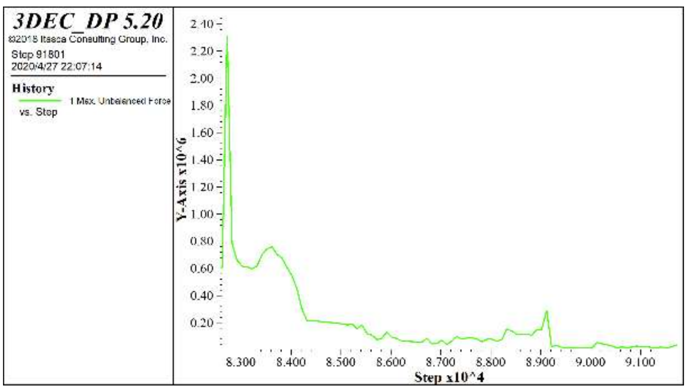

Fig. 8 Maximum unbalance force curve of scheme 2 rock mass

To sum up, under the two reinforcement schemes, the maximum unbalance force of rock mass has reached the convergence condition, and the slope remains stable. Considering the distribution of maximum shear strain increment of rock mass displacement, the support effect of reinforcement scheme 1 is better.

5. Conclusion

Through the study of the excavation process of the actual slope engineering and the numerical simulation study of the reinforcement scheme after the excavation, the following conclusions are drawn:

(1) In the natural state, the rock slope is stable, but the initial stress balance is broken due to the slope excavation disturbance, resulting in slope instability; Thus, excavation is the main factor inducing slope instability.

(2) Based on 3DEC, the supporting effects of the two reinforcement schemes are compared and analyzed. The results show that the maximum unbalance force of rock mass reaches convergence condition under the two reinforcement schemes, and the slope remains stable. Considering the distribution of maximum shear strain increment of rock mass displacement, the supporting effect of reinforcement scheme 1 is better.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (41302256), The Open Foundation of Key Laboratory of Geological Hazards in Three Gorges Reservoir Area of Ministry of Education (2020KDZ06).

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