

# Study on deformation regularity and stability analysis of bedding rock slope in secondary excavation

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**Abstract:** The study on the regularity and stability of rocky slope under secondary excavation can provide an optimization for the design parameters of slope support in highway reconstruction and expansion project. Based on the widening project of Laiwu--Linny section of Beijing-Shanghai expressway, in order to obtain the deformation law of the rock slope under the second excavation, finite element software was used to analyze the safety factor, displacement field and stress field. The result shows that (1) the vertical and horizontal displacement of both the existing slope surface and the new slope face had an increasing trend under the second-stage excavation, and the vertical displacement increment in the middle of slope is obvious; (2) The toe of slope is the area where shear stress is concentrated, Shear failure occurs and tensile stress exists on the slope roof; (3) Interface and exposed area of rock strata have strongly bedding sliding trend during the second excavation, which should be protected and monitored. The results can provide technical support for engineering construction and provide references for similar projects.

## 1. Introductions

Bedding rock slope is a side slope with the same direction [1-2], which the stability excavation has always been a concern question in highway reconstruction and expansion project. Scholars have done many research on the regularity of excavation deformation of bedding rock slope, such as model test, numerical simulation and field monitoring etc. Feng Jun [3-5] revealed the deformation law and stability influencing factors of the bedding rock slope excavation by the physical model test and FLAC3D software. Li Lianghui [6] analyzed the excavation stability of rock cutting slope with ANSYS based on the SRM (strength reduction method). Wang Weiming [7] simulated the excavation process of rock slope with block element method based on dynamic simulation. Lai Zhisheng [8] proposed granular structure parameters under the rock slope excavation, and use numerical simulation to study stress and displacement tendency under different step slope ratio, step width, height of the slope. Base on the project of baihetan hydropower station, Nu-Wen Xu [9-11] revealed the evolution mechanism and failure process of rock slope by using high precision micro-seismic monitoring system and RFPA finite element numerical simulation.



The present researches mainly focus on the stability of rock slope under the initial excavation. However, few studies on the regularity and stability of rock slope under secondary excavation. Scholars always combined with highway reconstruction project for slope secondary disturbance, and the slope safety factor in the construction process, after the excavation and reinforcement of slope stress and displacement field. Based on the Guangxi expressway reconstruction and expansion project, Luo Genchuan [12], Wang dawei [13], proposed reasonable support measures to stress and strain cloud map of slope through FLAC3D analysis contrast before and after excavation. Meanwhile, the present research results have limitations, such as strong regional characteristics and unsystematic change rules of disturbance process[14]. Based on the widening project Laiwu - Linyi section of Beijing-shanghai expressway, the paper used numerical simulation to analyze the deformation characteristics and stability of the slope under the secondary excavation.

## 2. Project Profile

Laiwu - Linyi section of Beijing-shanghai expressway projects, along the line which has low mountains, hills, piedmont alluvial plains, river terraces, alluvial flat etc. Geological conditions is complicated, upper layer overburden different thickness quaternary, underlying strata mainly limestone, marl and shale, mixed granite.

Along a typical K593 + 260 ~ K593 + 555 right slope, the slope inclines to  $239^\circ$ , the joint scenario is  $76^\circ \angle 10^\circ$  being a heeling plane. And the structural plane Angle is less than the slope angle, causing a poor slope stability. The high slope of 26 m, the slope form is irregular step shape. It is designed to expand the slope to form four steps, The slope rate of each grade is 1:1, the top three slopes are 10m high, the fourth grade side slope is 10.7m high, a wide 2m platform is set at the top of the first three slopes, As can be shown in figure 1.

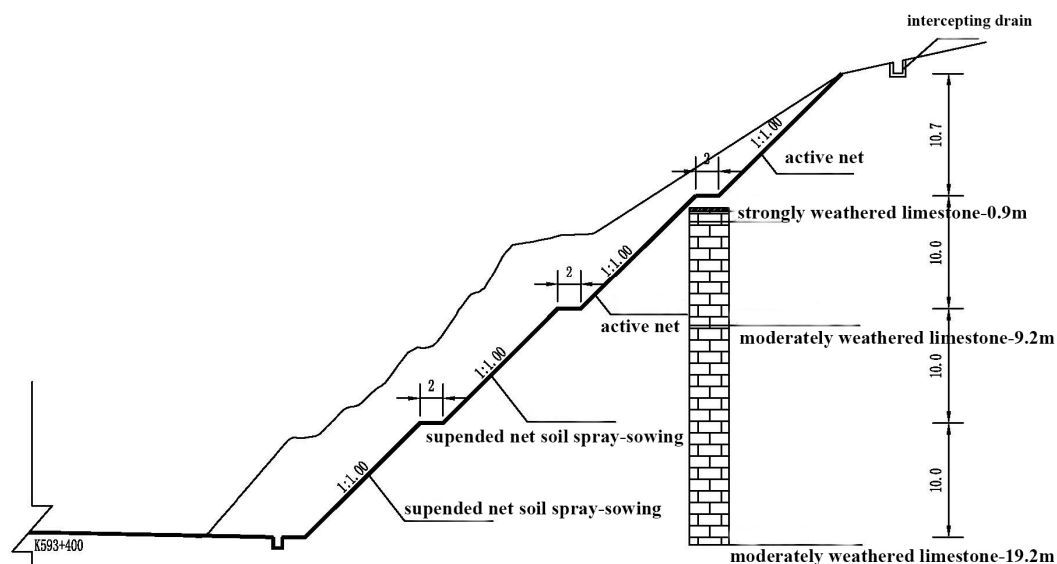


Fig1 K593+260~K593+555 main section

## 3. Finite Element Simulation

### 3.1. Model Establishment

The research choose the right slope of K593+260 —K593+555 and use finite element software Midas -GTS, the slope height is 40m. Geometric model size of the length, width, height are at least 2.5

times, 1.5 times, 2 times the height of slope, respectively[15]. Slope rock material choose elastic-plastic model and D-P convergence criterion. The model was evenly divided by 1m grid and filled with main four node unit and auxiliary triangle unit, A two-dimensional contact model selected Goodman unit to simulate the structural surface. The x-y bidirectional displacement constraint was applied to the bottom of the model, and the normal constraint was applied to the side boundary. Lastly, the model was applied gravity load.

### 3.2. Parameter Selection

The physical and mechanical parameters were selected according to the actual geological survey data, and the structural plane parameters were selected according to GB503300-2002 *Technical Code for Building Slope Engineering* , as shown in table 1.

Table1 Physical and mechanical parameters of rock mass

Material	Density (kN/m <sup>3</sup> )	C (kPa)	$\phi$ (°)	E (GPa)	Poisson Ratio
residual soil	20	20	24	0.06	0.3
strongly weathered limestone-1	23	20	29	5	0.25
strongly weathered limestone-2	23.3	21	33	10	0.25
moderately weathered limestone-1	23.6	24	51	20	0.2
moderately weathered limestone-2	24.2	26	45	25	0.2
structural plane	-	100	30	-	-
bolt	78.5	-	-	200	0.28

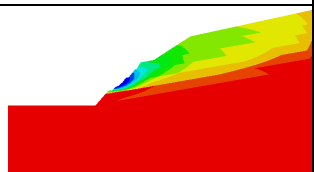
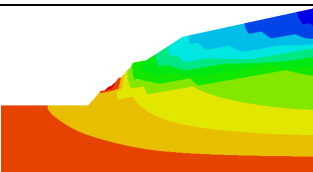
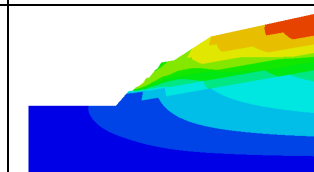
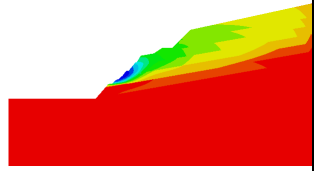
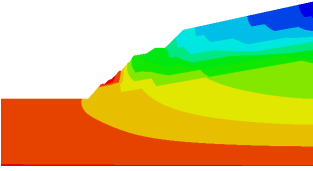
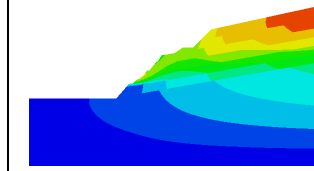
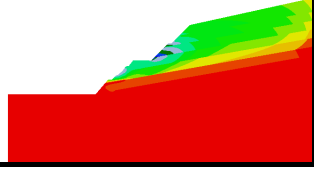
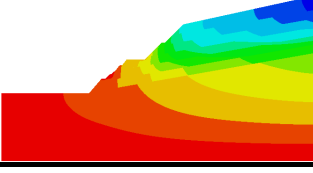
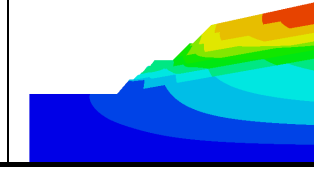
## 4. Result analyze

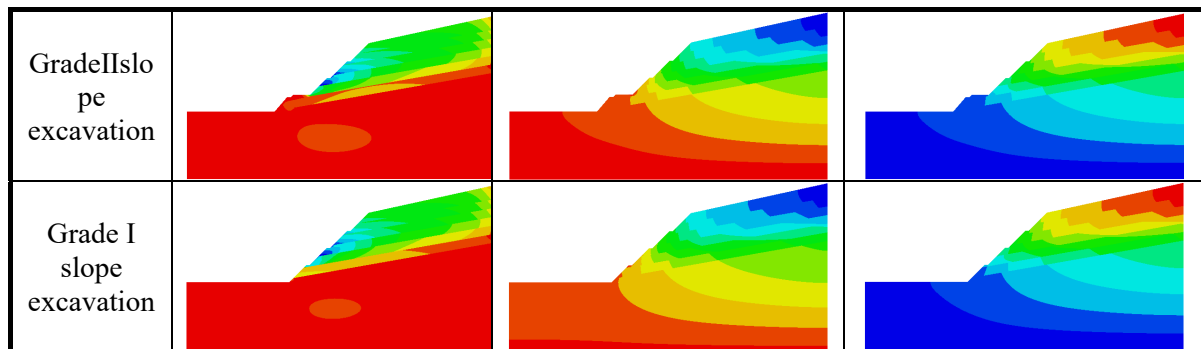
The research analyzes the variation of displacement field, stress field and safety factor before and after excavation, to study deformation law of rock slope under secondary excavation.

### 4.1. Displacement stress

Table 2 show that cloud maps of lateral displacement, vertical displacement and total displacement in the slope after excavation.

Table 2 Cloud map of displacement field during the second excavation

Constructi on phase	Lateral displcement	Vertical displacement	Total displacement
Existed slope			
Grade IV slope excavation			
Grade III slope excavation			



It can be seen from table 2, lateral displacement near slope vary obvious, However, the displacement of vertical and the total in slope vary slightly under the second excavation due to the vertical displacement is mainly influenced by gravity and structural plane. In addition, the horizontal displacement field of the middle part of the existing slope is in a circular arc, it may occur layer slippage. Both displacement field distribution and lateral displacement tends to increase by one-grade and two-grade slope excavation, In order to further quantitatively analyze the rule of displacement field under excavation, according to the measurement points of the existing slope surface and the secondary excavation face, the displacement value is extracted corresponding to figure 2, the results and more detail are shown in figure 3.

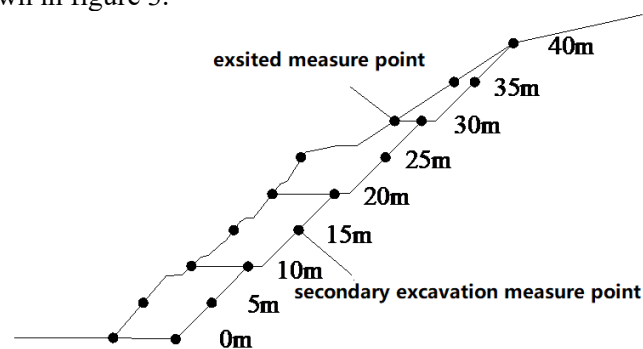
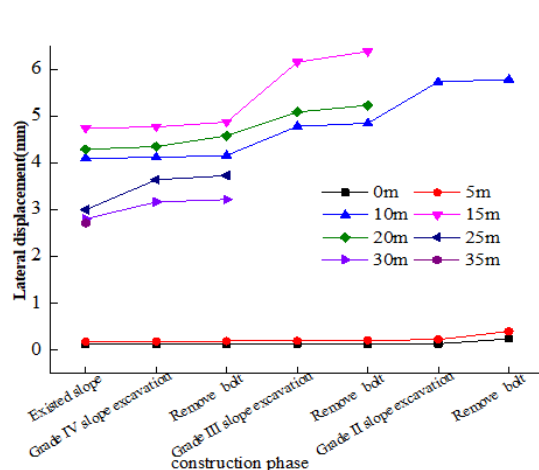
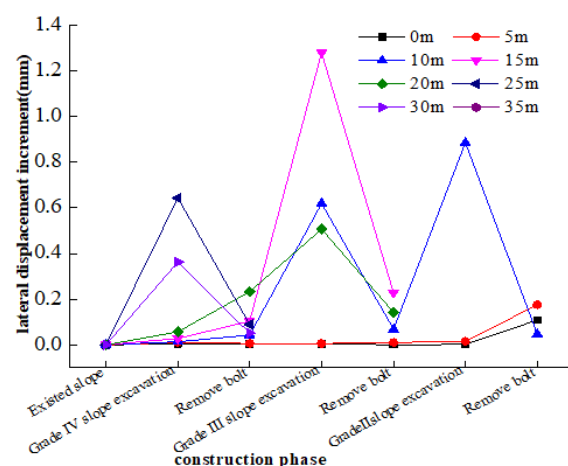


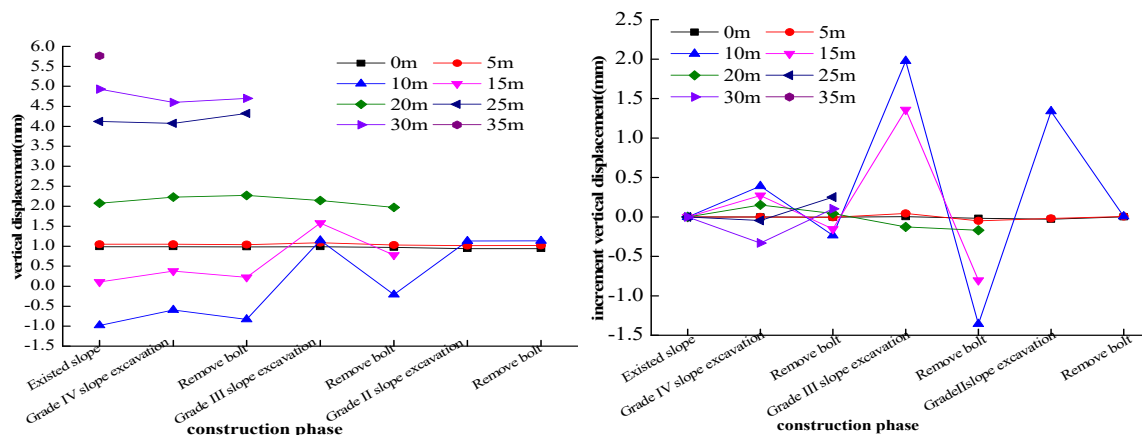
Fig2 Data extraction point of the model



(a) Accumulated horizontal displacement



(b) Horizontal displacement increment



(c) Accumulated vertical displacement

(d) Vertical displacement increment

Fig3. Displacement of existing slope measurement points in each construction stage

Figure 3 shows that the lateral displacement of measuring point increase under second excavation construction propulsion. However, the vertical displacement have no obvious changes, local area has a uplift trend. Before the excavation, the maximum lateral displacement happened in the range of 10m~20m in height of slope, and minimum displacement occurred in the slope toe. After four-grade slope excavation, the lateral displacement of 25m and 30m measurement points increased significantly and the vertical displacement increment at 30m is -0.33mm. It show that the place uplifts after excavation and unloading. The displacement of the 20m measuring point reached the maximum, After the removal of the three-grade slope support system. After three-grade slope excavation, the lateral displacement of slope from 10m to 20m increased obviously, the horizontal displacement increment at 15m reached 1.28mm, the vertical displacement at 10m and 15m increased significantly, it indicates that three-grade slope excavation increases the tendency of the back strata to slide downward and large deformation occurred in the range of 10m~20m on the existing slope. After the two-grade slope support system of the existing slope remove, the lateral displacement of slope from 10m to 20m increased slightly with a significant bulge. Meanwhile, the horizontal displacement increment at 10m reached 0.88mm and the vertical displacement increment reached 1.34mm, it indicate that the slope excavation of this grade has obvious disturbance to the rock mass, the stability of the excavation should be careful to protect. After the removal of grade I support system of the existing slope, horizontal displacement increased significantly at 5m and 10m, the displacement increment at 5m reaches 0.18mm, there was no significant change in vertical displacement. It indicates that bottom rock has been strongly disturbed under the excavation, the displacement trend of the rock increased under the third and second grade slope excavated, and the removal of the existing anchor system increases the deformation trend towards the free face of the slope.

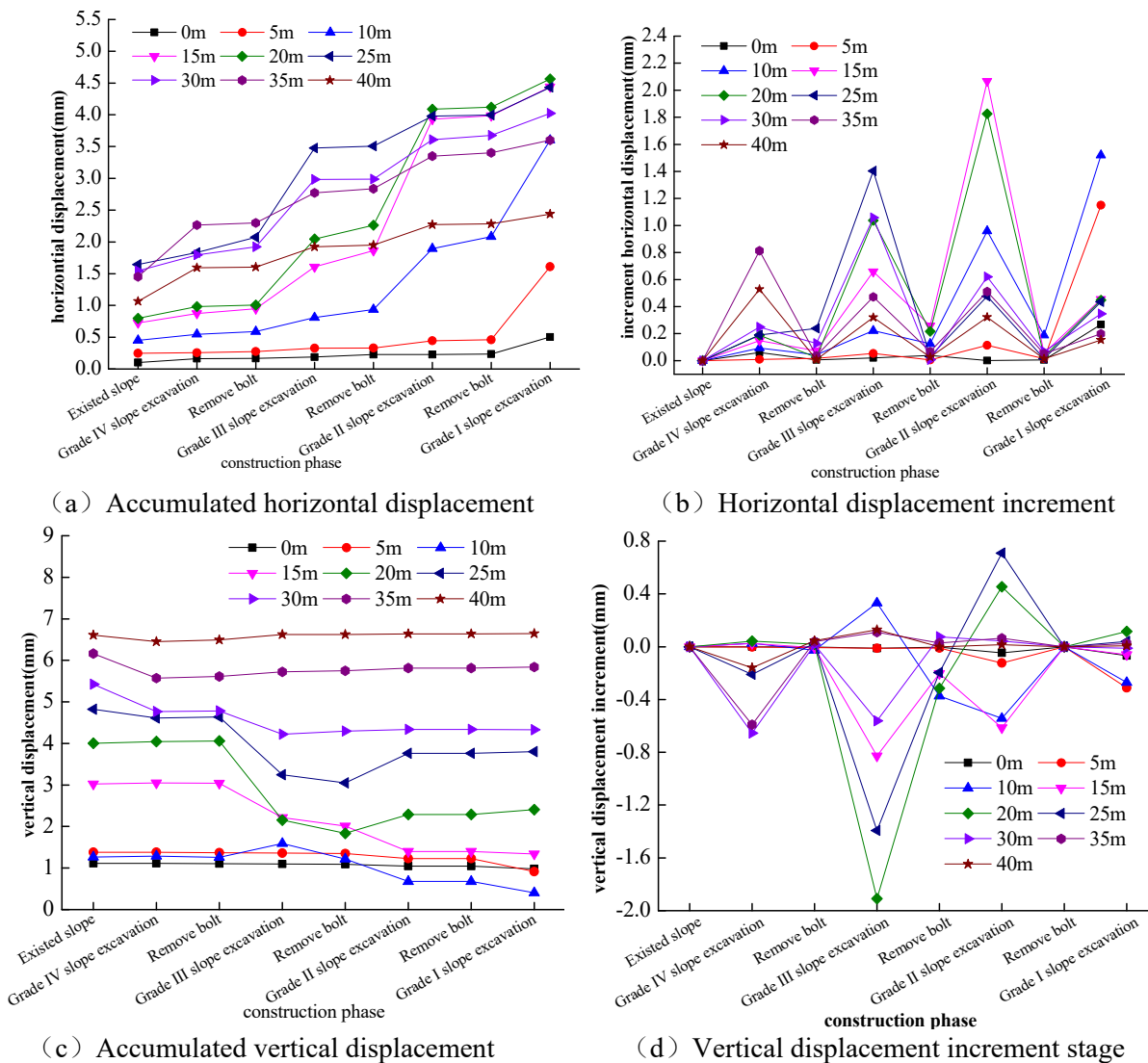


Fig 4. The displacement of the measured point on the slope surface under secondly excavation in each construction

Figure 4 that the lateral displacement of measuring point increases gradually with the excavation, and the vertical displacement change slightly along a uplift trend in the local area. Before excavation, the lateral displacement significant change in the range from 25m to 35m, Meanwhile, the displacement trend towards free face is obvious. After the excavation of the four-grade slope, the lateral displacement at 35m and 40m increased significantly, and slope surface relatively obvious uplift occurred at 30m and 35m. After removing the grade III support system of the existing slope, the lateral displacement increment is the largest at 25m. After the excavation of the grade III slope, the lateral displacement increase significantly with obvious uplift at 20m, 25m etc. After the removal of the secondary slope support system of the existing slope, the horizontal displacement at 15m and 20m is more obvious than that at other measuring points. After the grade II slope excavation, the horizontal displacement increment increased obviously at 15m and 20 m, which reached 2.06mm and 1.82mm respectively. The vertical displacement increased both 20m and 25m, Meanwhile, the uplift occurred at 10 m and 15 m because of excavation unloading. After the grade I slope excavation, the horizontal displacement increment is large with slight uplift at 5m and 10m. It can be seen that the corresponding excavation face of each slope is obviously deformed towards the free face of slope, which shows that the horizontal displacement increases and the vertical displacement uplift, and the removal of the

existing slope anchor system slightly increases the deformation trend of the slope towards the free face of slope.

#### 4.2. Stress filed

Stress datum are extracted from existing slope surfaces and measured points on secondary excavation surfaces corresponding to different heights in Fig. 2, the stress datum of existing slope test points are shown in Fig. 5, and stress data at the measured point of slope face in the second excavation is shown in FIG. 6.

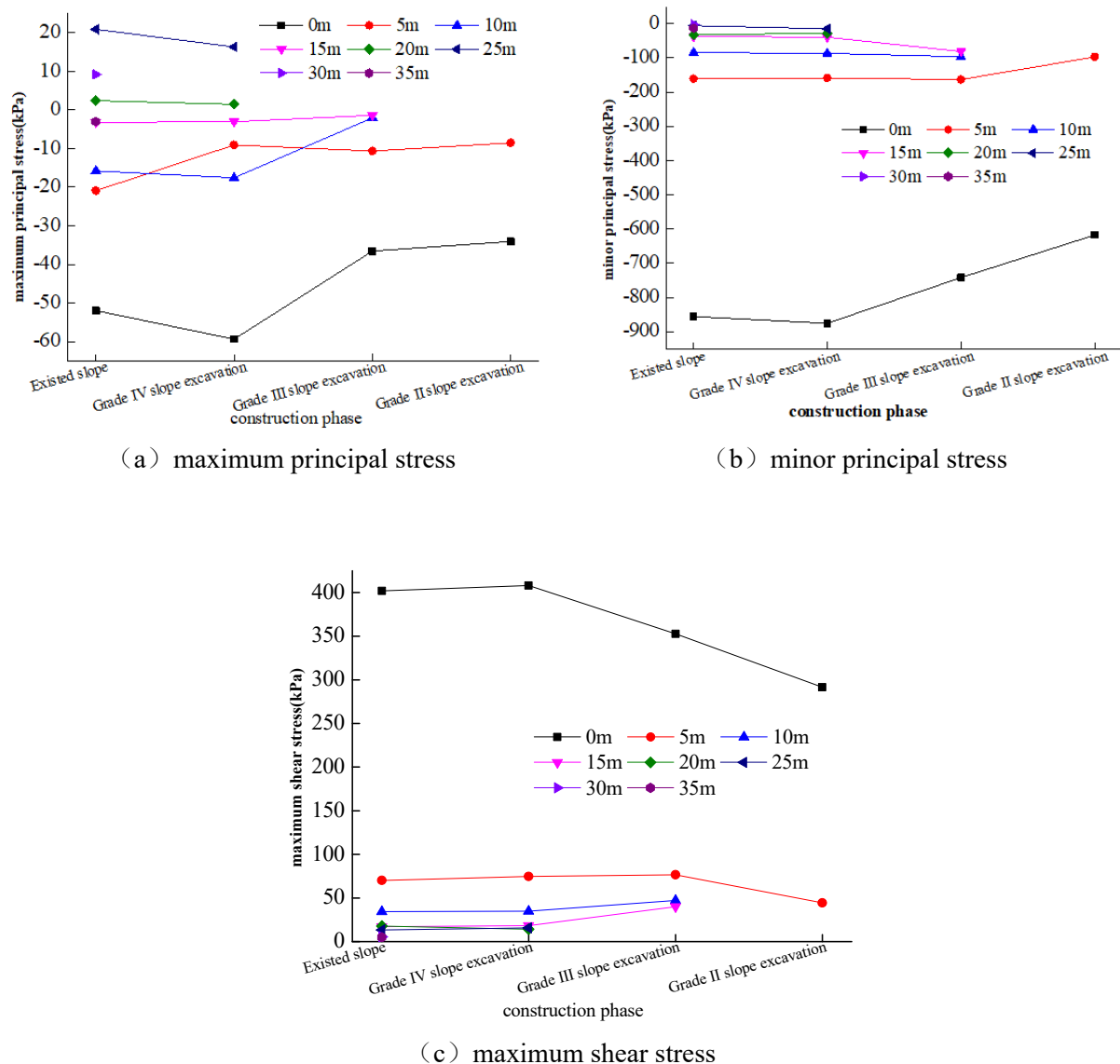


Fig5. Existed slope stress measurement

As can be seen from figure 5, the maximum principal stress increased from 52kPa to 59kPa, the minimum principal stress increased from 855kPa to 875kPa, the maximum shear stress increased from 401kPa to 407kPa, which indicate that the stress release process of the existing slope could cause by the second excavation. After grades IV slope excavated, the stress release at the foot of the existing slope is obvious and 0m stress concentration increases, so the stability of existing slope foot should be paid to attention. After the second excavation completed, the maximum principal stress down to



35.5%, the minimum principal stress decreased by 27.9%, and maximum shear stress decreased by 27.5%. The maximum principal stress at 10m and 15m of the existing slope was also slightly reduced, and the maximum principal stress turned into tensile stress in height 10m after the excavation of grade 3 slope. Both the minimum principal stress and the maximum shear stress also showed an increasing trend, It shows that the rock strata within excavation height are unstable with the process of slope excavation

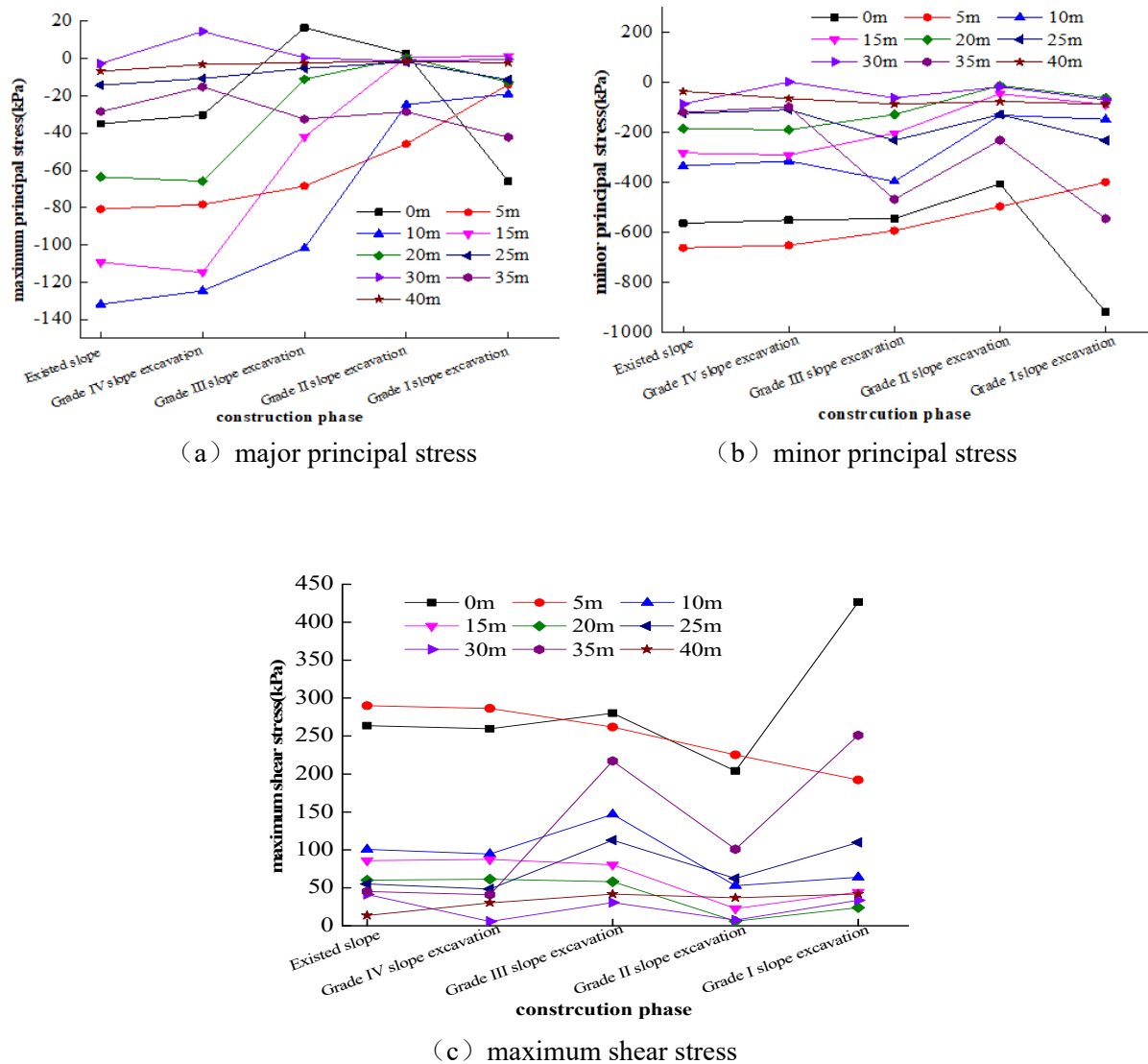


Fig 6 Stress at measuring point of slope surface in the second excavation

Figure 6 shows that has a stress release under the excavation of the new slope surface, However, the stress increases at the top and toe of the slope. The maximum principal stress (compressive stress) happened respectively at 30m, 35m and 40m measuring points under four-stage slope excavation. The maximum principal stress (compressive stress) was significantly reduced at ranging from 5m to 20m with grade III slope excavation, the maximum principal stress at slope foot (0m) overturn compressive stress to tensile stress, However, the maximum principal stress, minimum principal stress and maximum shear stress at 35m all increased remarkably, which can be seen that the stress redistribution on slope caused by the three-stage slope excavation is unfavorable to stability.

During the excavation of the second grade slope, the maximum principal stress in the range of 0m~15m was significantly reduced, Meanwhile, both the minimum principal stress and the maximum



shear stress obviously decreased from 0-35m, which indicate slope happen the stress release. With grade I slope excavation, the maximum principal stress is increased at the slope foot and 20m, 25m, 35m, the minimum principal stress and maximum shear stress of the slope foot and the measuring point in the range of 10m~40m were increased, the stress variation were most obvious at the slope foot and 35m. It can be inferred that the stress redistribution might cause by the first grade slope excavation, and the stress concentration happened at foot and top of slope, so the region should be protection and emphasized.

#### 4.3 Safety factor

Safety factor is the common method to evaluate slope stability recently, Zienkiewicz[16] proposed the concept of safety factor of slope and proved rationality. The study combines SRM method with finite element method to obtain safe coefficient. The safety factor at different construction stages during the second excavation of the slope, and safety coefficient of each construction stage relative to the previous construction stage is shown in table 3. The variation trend of slope safety coefficient in each construction phase is shown in figure 7.

Table3 Safety factor of slope in each stage in the second excavation

construction phase	Existing slope	Grade IV slope		Grade III slope		Grade II slope		Grade I slope	
		excavate	support	excavate	support	excavate	support	excavate	support
safety factor	1.53	1.55	1.58	1.11	1.59	1.20	1.30	1.10	1.19
range ability	-	1.2%	1.6%	-28.8%	43.7%	-22.6%	8.3%	-15.4%	8.0%

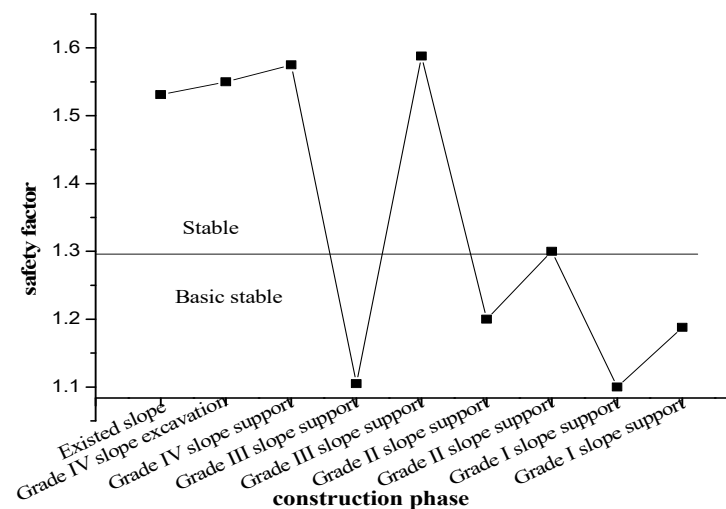


Fig 7 Safety factors of the slope in each stage during the second excavation

As can be seen from FIG. 7, the stability of slope under second-stage excavation is significantly different. After the excavation of the four-stage slope, safety factor increases from 1.53 to 1.55, which indicate that slope stability improves slightly, which might the excavation reduced the slope body self-weight. The safety factor of the slope rapidly reduced to 1.11, down by 28.4% after grade 3 slope excavation, the slope decline from stable state to basic stable state, almost down to unstable state. It can be seen that the existing three-stage slope is an key anti-sliding section, the geological data show that there is a boundary between the strongly weathered rock and the moderately weathered rock in the excavation area. The excavation of this grade slope increases the trend of slope sliding instability. After three-stage slope support, the slope safety factor rise to 1.59, slope stability improved significantly and reaches steady state. It indicates that there is a sliding surface at the Grade 3 slope,

the support measure of the slope have worked. The slope safety factor of the second grade slope after excavation was significantly reduced to 1.20, down by 22.6%. It can be seen that the slope excavation of this grade has obvious influence on slope stability. After secondary slope support, the slope safety factor increased to 1.30 by 8.3%. It indicates that support contribute significantly to slope stability, However, slope emerge basically stable. Before grade slope excavation, the removal of existing anchorage system has no influence on slope safety coefficient. It indicates that the anchoring system of the existing first step slope has lost its effect to slope stability, and the removal of the existing anchorage system less affect to the slope stability when the secondary excavation was carried out. The slope safety factor of the first grade slope was reduced to 1.10 by 15.4% almost in unstable state. It can be seen that the first grade slope excavation has obviously influence on slope stability. The safety factor of slope increased by 8% to 1.19 after grade 1 slope support, while the slope as a whole remains basically stable.

At last, Comprehensive analysis of the second excavation construction process, it can be found that the first, second and third grade slope excavation has the most obviously reduce slope stability. It can be seen that surface exposes the interface and structural surface of rock strata shows a strong trend of bedding sliding, therefore, grade IIIIII slope should be monitored and protected during the secondary excavation.

## 5. Conclusions

Based on the widening project of Laiwu--Linny section of Beijing-Shanghai expressway, the paper combine finite element method and SRM to analyze the safety factor, displacement field and stress field. At last, the following features can be summarized as follow

(1) After the second excavation, both vertical and horizontal displacements of existing and new slopes tend to increase, Meanwhile, the vertical displacement increment in the middle of slope increase obviously.

(2) The toe of slope is the area where shear stress is concentrated and happened shear failure, and tensile stress main occur at the top of the slope.

(3) During the second excavation, There is a strong trend of bedding sliding in the interface and exposed areas of the structure, so those regions should be emphasis protection and monitoring, bolt support system could been used in unstability slope construction

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