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Research on the Influence of Interconnectivity Structure Parameters to Stability of Stratified Rock Slope

Gao Xue-chi[1], Feng Zhong-ju[2]*, Long Hou-sheng[1], Zuo Zhi-wu[1], WEN Jun-qiang[2], Feng Kai[2], Jiang Guan[2], Wang Fu-chun[2], Zhu Yan-ming[2], Yu Xiang[2], Wang Zheng-bing[2]

[1]Qilu Transportation Development Group, Jinan 250014, Shandong, China

[2] School of Highway, Chang'an University, Xi'an 710064，Shanxi，China

Email: qhnc@chnroad.com；ysf@gl.chd.edu.cn；longhousheng@163.com; zzw9000@163.com; 1329650697@qq.com; 1130347443@qq.com; 785175330@qq.com; 770747723@qq.com; 2317920917@qq.com; 474592150@qq.com; 272083649@qq.com;

Abstract: Based on the slope engineering of the expansion project from Laiwu to Linyi section of Beijing-Shanghai Expressway, this paper uses numerical simulation method and strength reduction theory to analyze the change law of stability and failure mode of rock slope under the change of structural plane inclination, cohesion and internal friction angle. The results show that: with the increase of structural plane inclination , the change law of the failure mode of the bedding layered slope is pull-bedding slip→shearing- slip→toppling failure; The change rule of the failure mode of the inverse-dip layered slope is from shearing- slip to toppling- slip; the stability of bedding layered slope and inverse-dip layered slope with steep structural plane inclination are increased with the growth of the structural plane cohesion, while the safety factors of the inverse-dip layered slope with a small structural plane inclination have no significant changes. The stability of bedding layered slope increases with the growth of the structural plane friction angle, while the inverse-dip layered slopes have obvious differences trend between steep and gentle structural plane inclination. The research can provide reference for similar projects.

1. Introductions

In the construction of highway and railway in steep slope area of mountainous area, the stability of slope has always been a key concern[1]. The stability of stratified rock slope is significantly affected by the structural plane, such as the high slope instability accident of Sun Jiaxiang-Liang Ping section in Wan Liang Highway[2], the landslide in the K15+455 ~ +645 section of Shi Zhong Highway caused by continuous rainfall[3], and the bedding landslide of Tie-xi in Cheng-Kun railway[4]. All of these disasters seriously affect project construction. Therefore, the research of failure types of stratified rock slope and its influencing factors is necessary.

The theoretical research on rock slope started relatively late in China, and the theoretical prototype was formed in the 1940s [5]. After that, number of scholars applied rigid limit equilibrium method and similarity experiment method to study the stability mechanism and failure types of rock slope[6-8], and achieved fruitful results. In recent years, with the continuous development of computer technology, it is a new trend to use numerical simulation method to analyze slope stability and failure modes. Lots of engineering practice experiences and researches showed that the failure modes of rock slope are as follows: creep-tensile rupture, toppling, sliding compression cracking, sliding-tension and sliding-bending etc.， which is closely related to formation lithology, geological structure, hydrogeology and engineering activities [9-13]. For engineering problems caused by slope instability, it is necessary to identify the reasons for slope instability before taking targeted measures. Therefore, it is particularly important to clarify the failure type of slope. With the deepening of relevant studies at home and abroad, scholars have found that structural plane strength parameters are important factors affecting slope stability and failure modes. Scholars like Lin Hang, Lu Dun-hua, Blesius and Mesut Cimen etc. have studied the effect of structural surface parameters on slope by using finite element simulation software. The results of existing studies show that the strength and inclination of structural plane can influence the safety factor of stratified rock slope and transform the failure mode [14-22].

However, most of the existing studies focus on the influence of individual parameters on the structural plane, or only on the failure mechanism and mode of slope rock mass under the condition of single structural plane inclination, the deficiencies still exists. Therefore, based on the reconstruction and expansion project of Laiwu to Linyi section of Beijing-Shanghai expressway, this paper uses the finite analysis method to study the influence of structural plane strength parameters on the stability and failure modes of the bedding rock slope and counter-tilt slope, improve the research in failure mechanism and provide a basis for scientific establishment of slope reinforcement measures.

2. Project Profile

The geological situation is complex. The landform undulates terribly along the reconstruction and expansion project line of Laiwu to Linyi section of Beijing-Shanghai expressway, quaternary overburden layer thickness is uneven, underlayer are mainly limestone, mudstone, shale, mixed granite, etc. Affected by topography, geology and road alignment, there are a large number of deep excavation of high road cut slope during the construction of reconstruction and expansion project. The cumulative total length is about 20km, the maximum excavation depth is 56 m, and the steep slope rate of road cutting is 1:0.75.

Among these highway slopes, the rock mass of the cutting slope in K551+714 ~ K552+115, K565+914 ~ K566+300, K593+260 ~ K593+555 segments show uneven weathering, obvious layered structure, partial failure of the original rock structure, and development of local joint fissures. Slope information is shown in table 1.

Table 1 Side information

The starting and ending stake number of designed road cutting	Relationship to the road	Slope height (m)	Grade height (m)	Slope ratio	Structural plane inclination
K551+714～K552+115	left side	39.7	10	1:0.75	anti-dip 53°
K565+914～K566+300	left side	45.2	10	1:0.75	anti-dip 16°
K593+260～K593+555	right side	40.7	10	1:1.00	dip 10°

Restricted by the requirement to keep the original road open to traffic, and exposed for a long time after the excavation of the slope construction, the layered structure of the slope will inevitably affect its stability.

3. Analysis on The Instability Mechanism of Stratified Structure Rock Slope

“Rock mass structure controlling theory” thinks that the structural plane and the rock mass structure formed by structural plane control the deformation, failure mechanism and mechanical rules of rock slope [23], and the stability and deformation of layered structural rock slope are also affected by the shear strength parameters of its structural plane. Under the influence of these factors, the bedding rock slope showed different instability modes like toppling-bench slip, bending-wreckage slip, bedding-slip and shearing-bedding slip etc., and the counter-tilt slope showed different characteristics of instability

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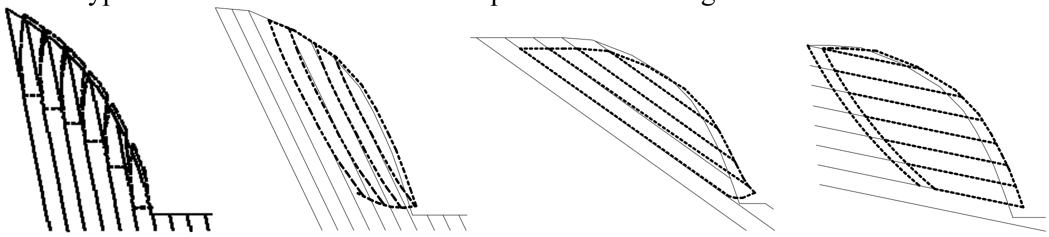
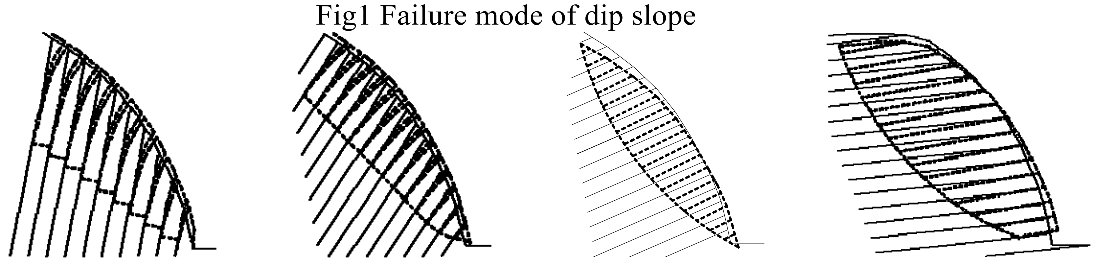
like toppling-bench slip, toppling- straight slip, shearing-slip and shearing-bedding slip etc. The failure modes of the typical stratified structural rock slope are shown in figures 1~2.



（a）toppling-bench slip （b）bending-wreckage slip （c）bedding-slip （d）shearing-bedding slip

Fig1 Failure mode of dip slope



（a）toppling-bench slip （b）toppling- straight slip （c）shearing-slip （d）shearing-bedding slip

Fig2 Failure mode of counter-tilt slope

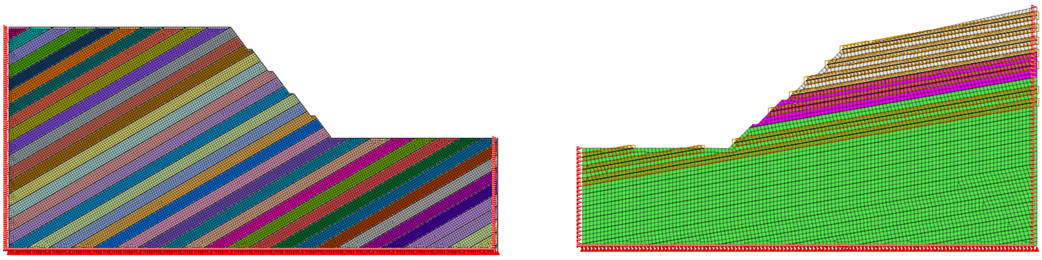
Due to the complexity of formation structure, the rock slope is more complex than the earth slope in the failure mechanism and stability analysis. The purpose of the division of the failure mode of rock slope is to provide a reasonable calculation model according to the failure form [24]. Slope failure occurs naturally in the shear strength of rock mass can't bear the area of the shear stress, so it is the structure plane parameters, the geometry position and inclination control the stability.

4. Finite Element Simulation

4.1. Finite Element Model Establishment And Parameter Selection

4.1.1. Finite Element Model

The side slope of model A (structural plane inclination analysis model) is 50 meters high, and the slope shape is the same as that of K551+714 ~ K552+115 (left side) slope. Model B (structural plane parameter analysis model) is established according to the slope form in table 1. The model is shown in figure 3. The finite element model was established by MIDAS/GTS software, and the Drucker-Prager yield criterion was adopted to avoid the difficulty of convergence caused by structural plane. Goodman element, a two-dimensional contact model, was used to simulate the discontinuity caused by the structural plane. The model size is 1.5 times of slope height from the toe of slope to one side of the boundary, 2.5 times of slope height from the top to the other side, and the total height of the upper and lower boundary of the model is 2 times of slope height [25].



（a）model A (structural plane inclination analysis model) （b）Model B (structural plane parameter analysis model)

Fig3 Slope finite element model

It should be noted that the stability coefficient of slope calculated by the D-P criterion matched with the compressive meridian of the M-C is relatively large compared with the M-C criterion. Aiming at this problem, the following conversion formula exists between the safety factors of the D-P criterion matched with the compressive meridian of the M-C and the M-C criterion:

$$f=\sqrt{\frac{(3\sqrt{\cos^2\varphi_0 f_1^2+\sin^2\varphi_0}-\sin\varphi_0)^2-12\sin^2\varphi_0}{12\cos^2\varphi_0}} \qquad (1)$$

In equation (1), f means the safety factors of the D-P criterion matched with the compressive meridian of the M-C; f1 means the safety factors of the M-C criterion; φ0 means internal friction angle.

In this way, the calculation error of slope safety factors in plane strain problem can be controlled within 3%, so the stability of rock slope can be analyzed by using D-P criterion matched with the compressive meridian of the M-C.

4.1.2. 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 2. The slope is regarded as homogeneous rock mass in model A, and the moderately weathered limestone 1 parameter is selected to calculate.

Table 2 Physical and mechanical parameters

material	bulk density (KN/m^3)	C (kPa)	φ (°)	E (GPa)	Poisson′s Ratio μ
strongly weathered limestone	23	20	29	5	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	-	-

4.2. Analysis Scheme

The analysis scheme of structural plane inclination change is shown in table 3, and the analysis scheme of structural plane parameter change is shown in table 4.

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Table 3 Rock mass parameters' analysis scheme

factors / working condition	properties of structural plane		
	inclination(°)	layer thickness（m）	dip
properties of structural plane change	0、10、20、30、40、50、60、70、80	5	anti-dip/dip

Table 4 Structural plane parameters' analysis scheme

working condition / parameters	1	2	3	4	5	6	7	8	9	10
cohesion *C*（MPa）	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2
internal friction angle φ（°）	15	20	25	30	35	40	45	50	55	60

5. Results Analysis

5.1. The Impact of Changing Dip and Inclination

5.1.1. Slope Stability Analysis

The calculated results of slope safety factors under the change of dip angle of structure plane are shown in figure 4. The dip angle of 10°, 30°, 50°and 80° plastic zone of slope and slope deformation graphic as been shown in table 5.

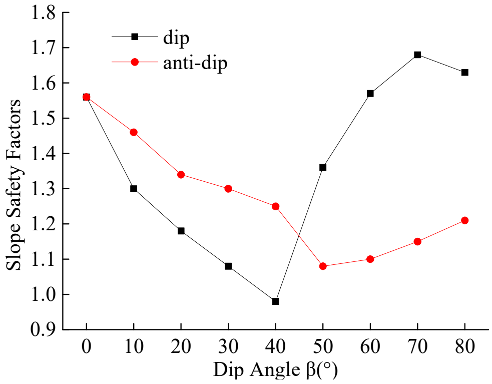
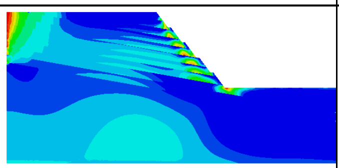
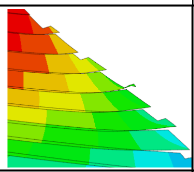
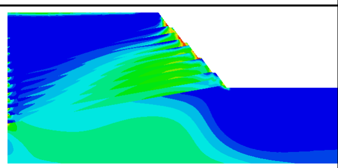
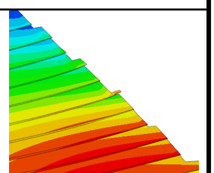
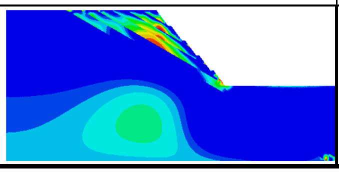
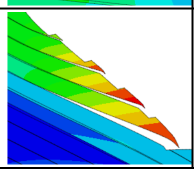
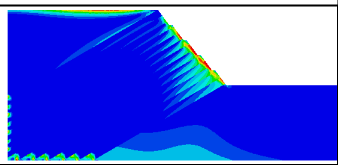
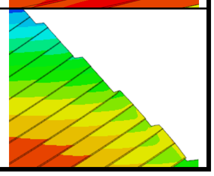
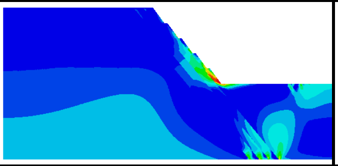
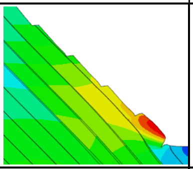
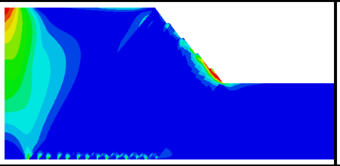
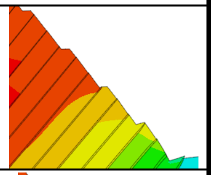
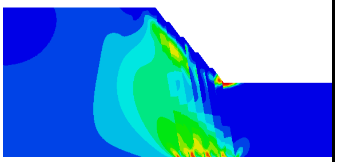
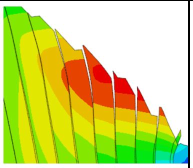
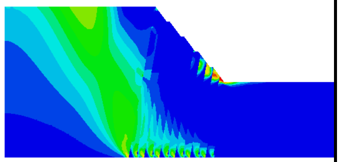
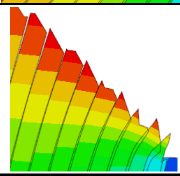


Fig4 Safety Factors Under influence of Structural Plane Inclination

Table 5 Cloud Graphic

dip angle	bedding layered slope		inverse-dip layered slope	
	Plastic Zone	deformation	Plastic Zone	deformation
10°				
30°				

dip angle	bedding layered slope		inverse-dip layered slope	
	Plastic Zone	deformation	Plastic Zone	deformation
50°				
80°				

It can be seen from figure 4 and table 5 that the structural plane inclination has a significant influence on the stability and deformation of the slope. The slope stability shows the rule of slow descent and sudden increase with the increase of structural plane dip angle. Failure modes of both dip and anti-dip slope were changed with the change of the relationship between structural plane inclination and slope surface inclination (about 53° in this working condition).

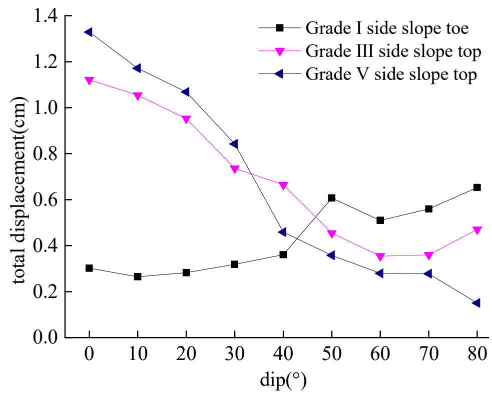
For bedding layered slope, with the increase of dip angle, the difference of dip angle between structure plane and slope surface decreases, then the failure mode evolved into the bending-wreckage slip near the slope toe area. There is no outcrop structural plane in the slope surface when the dip angle of the structure pane is greater than slope surface, then the possibility of the rock failure near the slope toe area decreases, and the slope stability improved with the increase of the dip angle of the structure plane. When the structural plane inclination is close to steep rise, the slope rock strata showed toppling-bench slip or toppling-bench collapse tendency in the direction of free face, and then the stability is slightly decreases.

For inverse-dip layered slope, the rock stratum is slightly bent into the slope, there is slight intercalated sliding, and there is no obvious rock deformation near the slope toe area when structure plane dip angle is less than 30°, then the failure mode of inverse-dip layered slope is shearing-slip of shallow layer. The tendency of slope strata toppling gradually increases, and slope stability decreases gradually with the increase of dip angle, then the failure mode will be toppling-slip. The main failure modes of slope change into toppling-bench slip or toppling-bench collapse, and slope stability improved slightly with the dip angle over 50°.

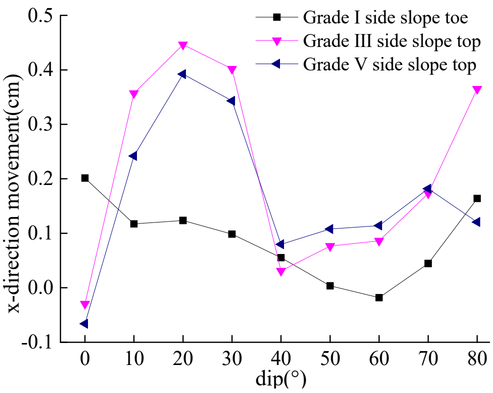
In summary, the stability trend of bedding layered slope is shown as first descending and then rising., and safety factors within the scope of 40° ~ 50° is lowest. The closer the structure plane angle 45° + φ/2, the unstable slope. In general, the stability of inverse-dip layered slope is better than bedding layered slope when the structural plane dip angle is small; the stability of inverse-dip layered slope is significantly lower than bedding layered slope with a steep the structural plane inclination.

5.1.2. Slope Surface Displacement

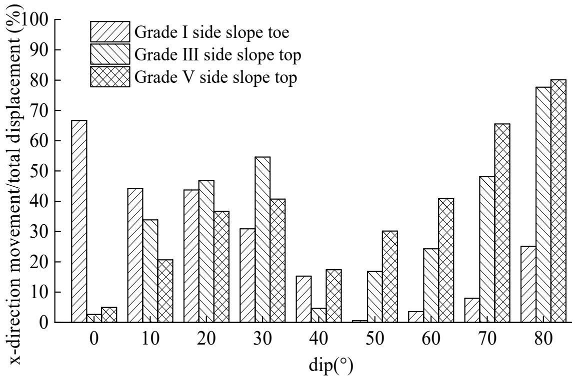
The bedding layered slope surface displacement with the change of structural plane dip angle is shown in figure 5.



a) total displacement



b) x-direction movement



c) Horizontal displacement ratio (x-direction movement/ total displacement)

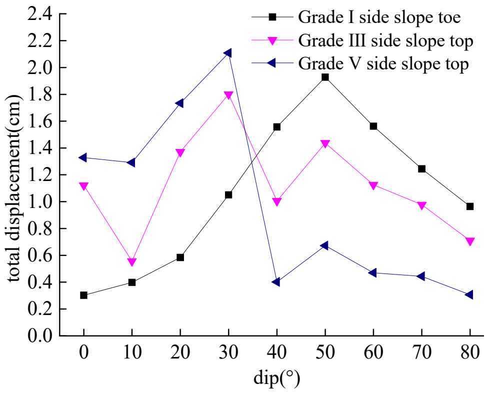
Fig5 Surface Displacement under Influence of Structural Plane Inclination

In Figure 5, the total displacement of Grade V and Grade III side slope top of bedding layered slope shows a trend of steep descent-stable with the increase of structural plane dip angle, and the x-direction movement shows a trend of steep increase-steep decrease -slow increase; Grade I side slope toe shows a trend of slow increase-mutations-slow increase, and the x-direction movement shows a trend of slow decrease -slow increase.

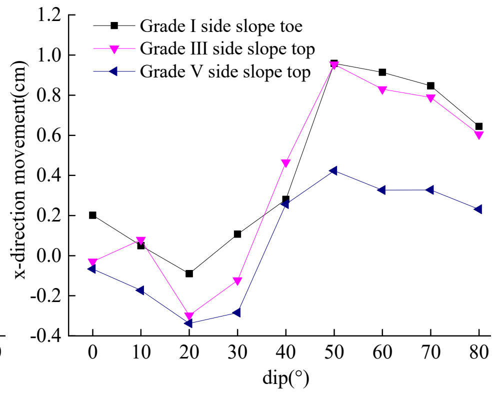
It can be seen from the Fig. 5 c) that the x-direction movement of Grade I side slope toe is most obvious when the structural plane is horizontal, then displacement trend decreases with the increase of structural plane dip angle, and increased again over 50°.The x-direction movement of Grade V and Grade III side slope top shows a trend of Increasing-decreasing- increasing with the increase of structural plane dip angle, the trend reaches the maximum at the structural plane dip angle of 30°, then decreased at 30°, and increased again over 50°.

In summary, the failure mode of bedding layered slope is changed by the dip angle of the structural plane. The slope may appear partial shearing-slip from slope toe area with near horizontal structural plane because Grade I side slope toe's x-direction movement trend is significantly obvious than Grade V and Grade III side slope. The slope may appear bedding sliding form slope toe area or pull-bedding slip when structural plane inclination is relatively small because of Grade V and Grade III side slope's x-direction movement trend is increasing. The slope may slip along outcropped structural plane near slope top area or shearing-slip when the structural plane inclination approaches the slope surface inclination because of the slope top's x-direction movement trend is most obvious, while the horizontal displacement trend near slope toe is minimized. The slope changes from slip failure to toppling failure when the structural plane inclination over the slope surface inclination because of Grade V and Grade III side slope's x-direction movement trend reaches strongest.

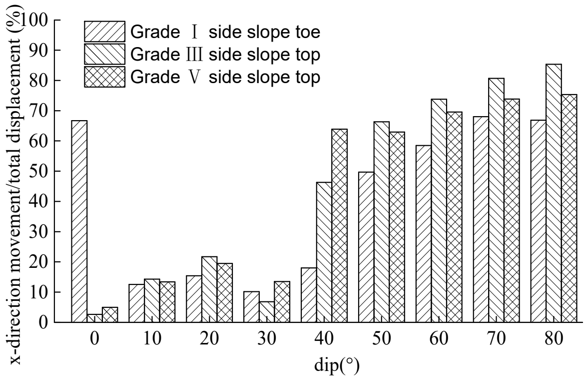
The inverse-dip layered slope surface displacement with the change of structural plane dip angle is shown in figure 6.



a）total displacement



b）x-direction movement



c）Horizontal displacement ratio (x-direction movement/ total displacement)

Fig6 Surface Displacement under Influence of Structural Plane Inclination

In Figure 6, the total displacement of Grade V side slope shows a trend of increase-mutations-stable with the increase of structural plane dip angle, and the x-direction movement shows a trend of negative increase- Mutation positive-slow decrease. Grade III side slope shows a trend of increase-mutations-decrease, and the x-direction movement shows same trend as Grade V side slope. Grade I side slope shows a trend of slow increase-mutations-slow increase, and the x-direction movement shows a trend of slow decrease- steep decrease- steep decrease.

It can be seen from the Fig. 6 c) that the x-direction movement of Grade I side slope toe is more obvious than Grade III and Grade V side slope when the structural plane is horizontal, then get unapparent within 30°, which indicates that the stability of inverse-dip layered slope with gently inclination. Both Grade III and Grade V side slope area's x-direction movement trend rapidly increasing with the structural plane dip angle over 40°, shows that the steep inverse-dip layered slope is prone to bending and toppling deformation.

In summary, the failure mode of inverse-dip layered slope is changed by the dip angle of the structural plane. The slope may appear partial shearing-slip from slope surface when structural plane inclination is relatively small because of Grade V and Grade I side slope's x-direction movement trend is weaker than Grade III side slope. The slope rock may appear toppling-bench slip or toppling-bench collapse with the structural plane inclination over scope 40°~50° due to strong x-direction movement trend of Grade V and Grade III side slope.

5.2. The Impact of structural plane cohesion

5.2.1. Slope Stability Analysis

K551+714~K552+115 section slope (anti-dip 53°), K565+914~K566+300 section slope (anti-dip 16°), K593+260~K593+555 section slope (dip 10°)'s safety factors under the change of structural plane's cohesion are shown in figure 7.

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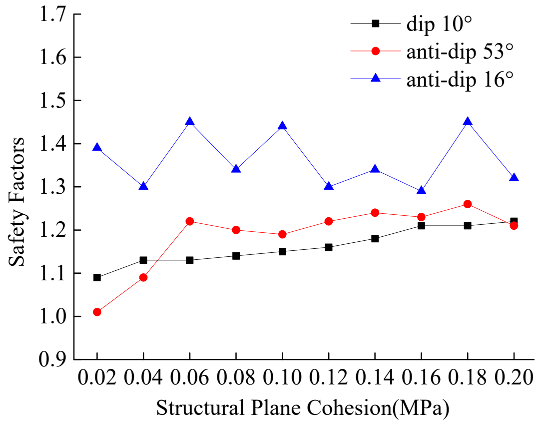


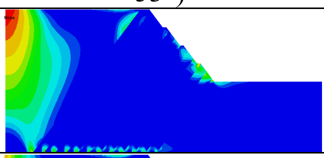
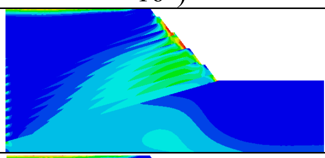
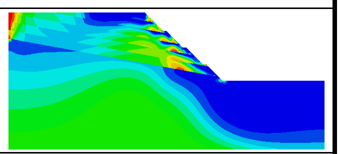
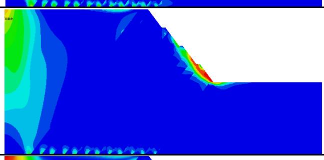
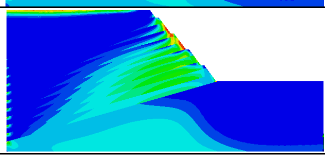
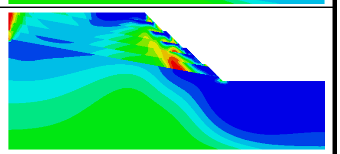
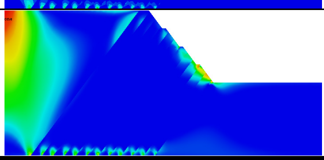
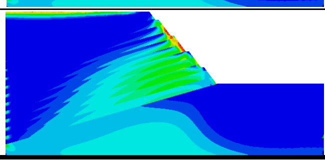
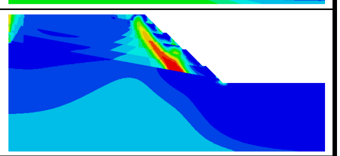
Fig7 Safety Factors Under influence of Structural Plane Cohesion

In Figure 7, for different types of slope, the influence of structural plane cohesion on slope stability is different. As a whole, the slope stability from high to low is K565+914~K566+300 section slope, K551+714~K552+115 section slope and K593+260~K593+555 section slope. The K551+714~K552+115 section slope and K593+260~K593+555 section slope's stability is slow increasing with the increase of the structural plane cohesion, and K565+914~K566+300 section slope's safety factors are fluctuating range 1.30~1.45. The influence of the change of structural plane cohesion on the stability is not obvious for inverse-dip layered slope, and the stability of slope can be small amplitude improved by increasing of the structural plane cohesion for bedding layered slope.

5.2.2. Plastic Zone Analysis

The cloud pictures of the plastic zone under the change of the structural plane cohesion are shown in table 6.

Table 6 Plastic Zone Distribution Affected by Structural Plane Cohesion

Cohesion (MPa)	K551+714～K552+115 section slope (anti-dip 53°)	K565+914～K566+300 section slope (anti-dip 16°)	K593+260~K593+555 section slope (dip 10°)
0.02			
0.12			
0.20			

As seen in table 6, the influence of the variation of structural plane cohesion on the bedding layered slope is obviously greater than inverse-dip layered slope.

For K593+260~K593+555 section slope which is bedding layered slope with an inclination of 10°, the plastic zone is triangular shape. The slope shows a strong trend of bedding slip and the plastic zone is distributed almost along the length of the rock when the cohesion of structural plane is small. Then the failure trend becomes the pull-bedding slip or shearing-bedding slip and the range of plastic zone starts to shrink when the shear strength of the structural plane gradually increases and approaches the shear strength of rock mass. The possible failure mode turns into the circle shearing-slip and the contours of the plastic zone become curved shape when the structural plane shear strength exceeds the shear strength of the rock layer.

For K551+714～K552+115 section slope which is inverse-dip layered slope with an inclination of 53°, the plastic zone mainly occurs in the middle and lower part of the slope surface and forms the circular arc area. There is no obvious change in the distribution of plastic zone between rock layers as the cohesion of structural plane increases. Therefore, the cohesive force of structural plane has no obvious influence on the failure mode of the slope. The failure trend of slope is the partial shearing-slip or toppling failure in the middle and lower area of slope.

For K565+914～K566+300 section slope which is inverse-dip layered slope with an inclination of 16°, the plastic zone is triangular in the upper and deep part of the rock. The distribution of the plastic zone did not change with the increase of the cohesion of the structural plane. Therefore, the cohesive force of structural plane has no obvious influence on the failure mode of the slope. The failure trend of slope is partial shearing-slip in the middle and upper part of slope.

5.3. The Impact of structural plane friction angle

5.3.1. Slope Stability Analysis

K551+714~K552+115 section slope (anti-dip 53°), K565+914~K566+300 section slope (anti-dip 16°), K593+260~K593+555 section slope (dip 10°)'s safety factors under the change of structural plane's friction angle are shown in figure 8.

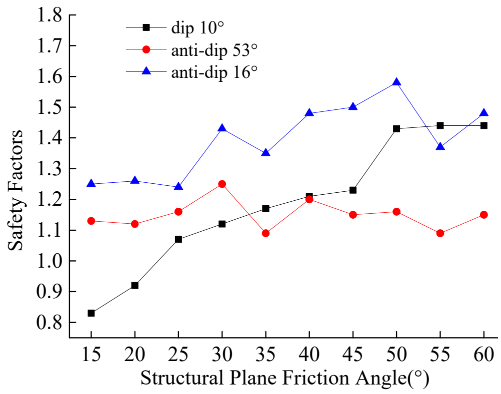


Fig8 Safety Factors Under influence of Structural Plane Friction Angle

In Figure 8, for different types of slope, the influence of structural plane friction angle on slope stability is different. As a whole, the slope stability from high to low is K565+914~K566+300 section slope, K551+714~K552+115 section slope and K593+260~K593+555 section slope when the friction angle is less than 30°, and the order is K565+914~K566+300 section slope, K551+714~K552+115 section slope, K593+260~K593+555 section slope when the friction angle over 30°.

For K593+260~K593+555 section slope, the stability showed a trend of "first increase and then stability". The shear strength and skip-resistance is enhanced with the increase of the structural plane friction angle, and then slope stability improved obviously. The failure mode of the slope is no longer controlled by the structural plane and changed from bedding sliding into shearing-bedding sliding failure when the strength of the structural plane exceeds a certain level.

For K551+714~K552+115 section slope, the stability showed a trend of "slow increase-fluctuation". The slip-resistance between rock formations increases and the slope safety factors showed a slow increasing trend when structural plane friction angle increases at a lower level. The slope failure mode changes into shearing-slip and the stability of slope has no obvious change when structural plane friction angle exceeds a certain level.

For K565+914~K566+300 section slope, the stability showed a trend of "stabilize-increase". The shear strength is relatively low when structural plane friction angle is in low level, and the slope

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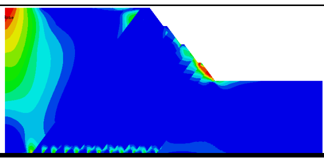
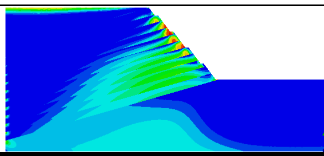
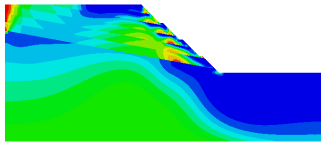
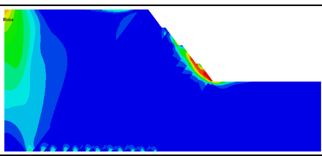
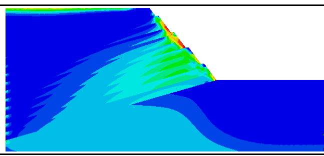
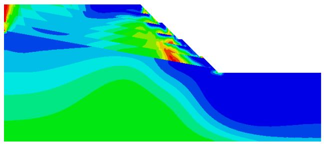
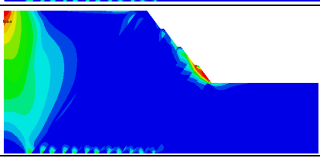
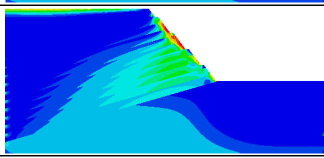
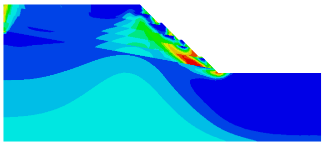
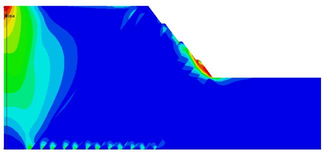
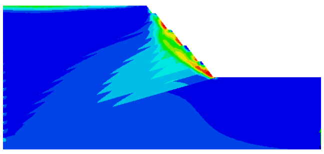
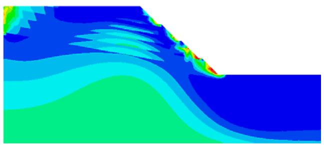
failure mode might be fracturing-slip. And then stability increases with the shear strength of the rock body is enhanced.

In summary, the slip-resistance between rock layers enhanced with the increase of structural plane friction angle, and improves the integrity of the slope directly. The stability of inverse-dip layered slope is less affected by slip-resistance between rock layers.

5.3.2.Plastic Zone Analysis

The cloud pictures of the plastic zone under the change of the structural plane friction angle are shown in table 7.

Table 7 Plastic Zone Distribution Affected by Structural Friction Angle

friction angle	K551+714～K552+115 section slope (anti-dip 53°)	K565+914～K566+300 section slope (anti-dip 16°)	K593+260~K593+555 section slope (dip 10°)
15°			
30°			
45°			
60°			

As can be seen from table 7, the influence of structural plane friction angle on the bedding layered slope is greater than inverse-dip layered slope obviously. As the structural plane friction angle increases, the plastic zone of K551+714~K552+115 section slope changed from serrated into circular arc; the plastic zone of K565+914～K566+300 section slope changed from triangular distribution into circular arc; and the plastic zone of K593+260~K593+555 section slope changes from a full-length distribution along the rock layers into a circular arc distribution on the slope surface.

6. Main Conclusions

This paper analyzes the influence of structural plane inclination and shear-strength parameters on slope stability and failure modes by finite element method, and obtains the following conclusions:

(1) For bedding layered slope, the change of structural plane inclination will affect the integrity of the combination of structural plane and rock mass. The worse the integrity, the lower the safety factor when structural plane inclination is close to the slope surface inclination. The integrity will transform the failure mode, the slope may occur the pull-bedding slip with a relatively small inclination, and the slope may occur the bedding slip along rock layers or shearing-slip with the increase of structural

plane inclination, and then the slope may occur the toppling-bench slip when the structural plane inclination over the slope surface inclination.

(2) For inverse-dip layered slope, the change of structural plane inclination has obvious influence on slope stability and failure mode. The slope stability is the worst when structural plane inclination range 50° ~ 70°, the failure mode may be shearing-slip with a structural plane inclination less than 50°, and may be toppling-bench slip or toppling-bench collapse with a structural plane inclination over 50°.

(3) The skid-resistance and slope stability can be enhanced with the increase of structural plane cohesion and friction angle of bedding layered slope, while the stability of inverse-dip layered slope change is not changed obviously. The relationship between shear strength of structural plane and rock mass determines the failure mode of slope.

References

[1] FENG Zhong-ju. Foundation Engineering in Opecial Areas. [M].,Chinese People's Publishing House, 2008. (in Chinese)
[2] SUN Shu-wei, ZHU Ben-zhen, MA Hui-min. Geomechanical model tests om slope hazards of typical high bedding rock slopes[J]. Chinese Journal of Geotechnical Engineering, 2008,30(9): 1349-1355.(in Chinese)
[3] LI Hong-wei. Deformation and failure mechanism of steeply dipping bedding high slopes[J]. Chinese Journal of Geotechnical Engineering, 2011, 33(1): 153-158. (in Chinese)
[4] HU Yu-dao. Vega landslide development rule and regulation in engineering practice[C]. China's typical landslide. Beijing: Geological publishing house, 1986. (in Chinese)
[5] Zhang Zhuo-yuan, Wang Shi-tian. Engineering Power Geology[M]. China Industry Press, 1964. (in Chinese)
[6] LIU Xiao-li, ZHOU Pei-de. Stability analysis of layered dip rocky slopes with elastic plane theory[J]. Rock and Soil Mechanics, 2002, 23(2):162-165. (in Chinese)
[7] ZHU Han-ya, MA Mei-ling, SHANG Yue-quan. Analysis of buckling failure of consequent rock slop[J]. Journal of Zhejiang University, 2004, 38(9):1144-1149. (in Chinese)
[8] CHEN Cong-xin, HUANG Ping-lu, LU Zeng-mu. Study on correlation between stability of consequent rock slope and obliquity of rock layer by simulation experiment[J]. Rock and Soil Mechanics, 2007,28(3): 476-481. (in Chinese)
[9] ZHANG Zhuo-yuan, WANG Shi-tian, WANG Lan-sheng. Engineering Geological Analysis Principle[M]. Beijing: Geological publishing house, 1994. (in Chinese)
[10] HUANG Run-qiu, ZHAO Jian-jun, JU-Neng-pan, DENG Hui，DUAN Hai-peng. Study on deformation mechanism control method of bedding rock slope along tangtun expressway[J]. Chinese Journal of Rock Mechanics and Engineering, 2007, 26(2):239-249. (in Chinese)
[11] GONG Wen-hui, WANG Ping, CHEN Feng. Analysis of sensitivity factors to stability of bedding rock cutting slope[J]. Rock and Soil Mechanics, 2007, 28(4): 812-816. (in Chinese)
[12] (FENG Jun, ZHOU Pei-de, Jiang Nan. A model for calculation of internal force of micropile system to reinforce bedding rock slope[J]. Chinese Journal of Rock Mechanics and Engineering, 2006, 25(2):284-288.(in Chinese)
[13] Liu Cai-hua, XU Jian, CAO Chuan-lin. Analysis of bedding-slipfailure mechanism of rock slope due to hydraulic drive[J]. Chinese Journal of Rock Mechanics and Engineering, 2005, 24(19):3529-3533.(in Chinese)
[14] SUN Yu-ke, MO Hui-chong, YAO Bao-kui. Slope stability analysis[M]. Beijing: Science Press, 1988. (in Chinese)
[15] LIN Hang, CAO Ping. Numeical analysis of failure modes and stability of stratified rock slopes[J]. Rock and Soil Mechanics, 2010,31(10):3300-3304. (in Chinese)
[16] WEI Jun-qi, WANG-Li-zhen, WANG Li. Study on stability analysis and stress monitoring of bedded rock slope[J]. Journal of Water Resources and Architectural Engineering, 2011, 9(6): 44-47. (in Chinese)
[17] FENG Jun, ZHOU DE-pei, LI An-hong. Test and numerical modeling of the stability of rock

bedding slope[J]. Journal of Engineering Geology, 2005, 13(3):294-299. (in Chinese)
[18] HUANG Shuai, WANG Rong, Wang Hong-xiang, Cai De-gou. Study on Influence laws of rock structural plane parameters on failure mode of bedding slope[J]. Metal Mine, 2015, 10: 140-145. (in Chinese)
[19] Blesius, L.J. A statellite based methodology for landslide susceptibility mapping incorporating geotechnical slope stability parameters[J]. ProQuest Dissertations and Theses Global, 2002:3050777.
[20] Mesut Cimen. Confined Aquifer Parameters Evaluation by Slope-Matching Method[J]. Journal of Hydrologic Engineering, ASCE, 2008, 13(3): 141-145.
[21] Lai, Zhi-Sheng; Wu, Jian-Ying; Ma, Jian-Xun. Study on excavation parameters for high rock slope of scattered structure[J]. Chinese Journal of Rock Mechanics and Engineering, v24, n12, p2183-2187, June15, 2005.
[22] A.N. Thanos Papanicolaou, Filippo Bressan, James Fox, Casey Kramer. Role of Structure Submergence on Scour Evolution in Gravel Bed Rivers: Application to Slope-Crested Structures[J]. Journal of Hydrologic Engineering, ASCE, 2018, 144(2): 03117008.
[23] Sun Guang-zhong. Rock structure mechanics[M]. Beijing: Science Press, 1998. (in Chinese)
[24] ZHENG Yi-ren, CHEN Zu-yu, WANG Gong-xian, LING Tian-qing. Engineering Treatment of slope or Landslide[M]. Beijing: ,Chinese People's Publishing House, 2010. (in Chinese)
[25] Zheng Yin-ren, ZHAO Shang-yi. Numerical simulazation on failure mechanism of rock slope by stregth reduction fem[J]. Chinese Journal of Rock Mechanics and Engineering, 2003, 22(12):1943-1952. (in Chinese)