Application of FEM Intensity Double Reduction in a Highway Slope

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Abstract: Using the finite element strength double reduction method, a slope engineering at Bidu Expressway was taken as an example to establish a numerical analysis model. The displacement of the slope engineering and the extension of the plastic zone were calculated and analyzed. The calculation results showed that the original slope was The stability factor is 1.07. Based on this, two solutions for slope reduction and load reduction and anchor reinforcement are proposed. The calculation results show that the slope stability coefficients of the reinforcement schemes of the two schemes are 1.27 and 1.36, respectively. This scheme satisfies the project. Claim.

Keywords: Strength reduction method; finite element analysis; model; stability;

1. Introduction

The origin of the strength reduction method is based on the theory of numerical analysis, and has achieved good results since its development. Zienkiewicz（1975）first proposed the concept of strength reduction [1], and thought that this concept could be applied to the analysis and calculation of slope stability. Ugai (1989) [2] set the constitutive and properties of soil material as ideal elastic-plastic in the study, and combined the finite element numerical calculation method with the strength reduction theory to simulate and analyze various types of slopes. The results show that the finite element strength reduction method has good applicability for slope stability research. Ugai and Leshchinsky (1995) 3] applied the finite element strength reduction method to the study of the stability of the three-dimensional slope model, and compared the results obtained from the simulation calculation with the results obtained from using the limit equilibrium method. Through comparison and analysis, it is concluded that in the study of slope stability, the finite element strength reduction method and the limit equilibrium method have significant differences in theoretical basis and solving method. But the safety coefficient obtained is not very different, which proves the applicability of the finite element strength reduction theory to solve the slope problem. Wan Shaoshi, Nian Yankai et al. used numerical examples to study the effect of choosing different types of finite element units on the stability factor of the slope, and proposed the appropriate method of unit selection. Liu Hong-Shuai et al. (2010)[5] studied the stability of three-dimensional slopes under different constraints, and the results showed that different constraining methods have a significant impact on the results of slope stability.

The stability and protection technology of cutting slopes on expressways has always been an important topic in civil engineering and engineering geology. Based on the collapse of a slope on the Bi Du expressway, the author uses the FEM Intensity Double Reduction method for analysis. In addition, the author carried out numerical simulation analysis of the two schemes and conducted a comparison of plans. It provides some reference for similar project management.

2. An Overview of a Slope Project on the Bidu Expressway

2.1. Project overview

The construction area is located in the plateau mountainous area of Western Guizhou Province. Because of the effects of erosion and denudation, geological conditions are very complicated. The elevation of the road section is between 1763.0 and 1989m, and the maximum height difference is 226m. It belongs to medium-cutting erosion and denudation of low-mountain landscape.

The section passes through the lower part of a slope, and the left side is a high steep slope. The plane distance between the left side of the subgrade and the top of the slope is 222 meters, and the difference between the subgrade surface and the top of the slope is 127.4 meters. There are two telecommunication towers on the top of the slope, and the slope is dry land with some trees.

The construction area belongs to the Yangtze River basin and is located in the upper reaches of the Wujiang River. There is no surface water runoff in the site area. There is surface water development in the landslide area, and there are many water spills on the surface.

The construction area belongs to the north subtropical humid monsoon climate zone, with no severe winter and no summer heat. According to the meteorological data of the local weather station from 1961 to 1990, the average annual temperature is 13.7°C, the extreme maximum temperature is 34.1°C, and the extreme minimum temperature is -9.6°C. The average annual rainfall is 1100~1300mm, and the distribution is uneven during the year, mostly in April to September. And the maximum daily rainfall is 154.8 mm. The average annual wind speed is 1.6m/s, and the most wind direction is NE. The annual average relative humidity is about 81%.

2.2. Hydrogeological conditions

2.2.1 Stratigraphic lithology

The strata in the section area are overlying quaternary residual slope formation (Qel+dl), including gravel silty clay and gravel soil. The underlying bedrock is Permian Longtan Formation (P2l) sandstone, mudstone and intercalated coal, and the Permian Feixianguan Formation (T1f) consists of silty mudstone and interbedded with limestone.

2.2.2 Geological structure and earthquake

The joints and fractures of the rock mass in the field are very developed, the rock mass is fractured, and the joints occur. : L1=300° ∠54°、L2=30° -150°、L3=250° ∠60°、L4=0° ∠54°、L5=90° ∠70°。According to the “Seismic ground motion parameters zonation map of China” (GB 18306-2001) promulgated by the State Seismological Bureau, the characteristic period of the earthquake response spectrum in the field is 0.35s, the peak acceleration of the ground motion is 0.05g, and the intensity of the earthquake is sixth degree.

2.2.3 The composition of rock and soil

After exploration, the composition of rock and soil in the area is as follows:

Silty clay（Qel+dl）: Its content is generally 10% to 20%, the thickness is 0 to 13m, and most of them are distributed on the slope.

Gravels（Qel+dl） : Its color is yellow brown, brown purple. The composition is mudstone, sandstone and silty mudstone. The particle size is 20 ~ 60mm, the content is generally 50% ~ 70%, the thickness is 0 ~ 4m, and there are local distribution on the slope.

2.2.4 Strong weathered layer

Its color is gray black, black and gray yellow. The joints are extremely developed, the rock mass is extremely fragmented. And the closedness of each structural surface is extremely poor, it is open and fills with argillaceous matter. The integrity and entirety of the rock mass are poor. The rock mass is generally loose, and the rock is very soft. The cores are fragmented, granulated, and muddy, and the thickness is 10 ~ 15m.

2.2.5 Medium weathering layer

Its color is gray black, black. The joints are extremely developed, the rock mass is extremely fragmented. And the closedness of each structural surface is extremely poor, and the rock is very soft. In addition to the partial columnar cores in the siltstone layer, the cores of mudstone and carbonaceous mudstones are fragmented, granulated, and muddy.

2.2.6 Hydrogeology

The groundwater type of roadbed slope is bedrock fissure water. Groundwater is mainly supplied by atmospheric precipitation, and a small amount of precipitation penetrates downwards along the joints and crevices and accumulates in the bedrock fractures. Most of them are lost along the slope.

After rainfall, a small amount of precipitation penetrates downwards along the joints and crevices and accumulates in the bedrock fractures, and water flows along lower part. Because the slope height above the slope is limited, the catchment area is limited, and the bedrock fissure water on the slope is small. The bedrock fissure water flows out on the side slope or the roadbed side in the wet season, and the dry season is almost dry. Water seepage: Dry season Q=0～0.5L/s, rainy season Q=0.5～1L/s.

According to the experimental data of geological exploration, the geotechnical parameters of various layers are shown in Table 2.1 below.

Table 1.Table of geotechnical parameters

Rock and soil layer	weight (KN/m³)	Internal frictionangle (°)	Cohesive force(KPa)	Modulus of elasticity (MPa)	Poisson ratio
Slity clay layer	18.5	22.0	12.1	20	0.30
Medium weathered mudstone	25	25.6	40.0	40	0.34

3. Analysis of Slope Stability

The representative section is selected as the model to analyze the slope. The slope angle is 54° and the slope is 13.9 meters high. The soil structure is divided into two layers. The first layer is silty clay, and the second is the middle weathered mudstone layer. The slope angle of this slope is greater than 45°. And the reduction ratio of k=0.9 should be used to analyze the stability.

3.1 The establishment of a finite element model

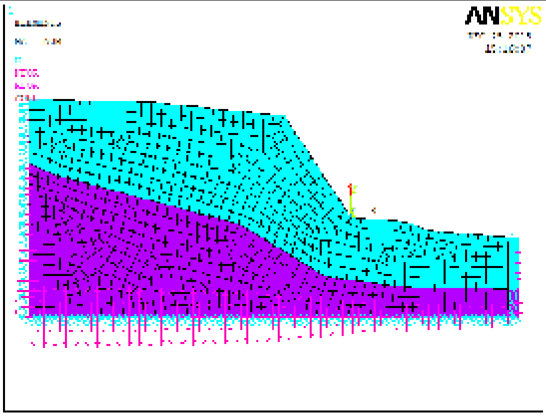

Figure 1. Slope unit division and load constraint

The finite element software ANSYS is used to model the slope of the area. We choose quadrilateral nodes, and free mesh generation. Horizontal displacement constraints are applied to the vertical boundaries on both sides of the slope, and the bottom edges imposes full constraints in the horizontal and vertical directions. After the model is completed, the slope structure is divided into 705 units, with 2244 nodes. The X direction of the model is 68 meters, the Y direction is 30 meters, and the gravity is 9.8N/Kg. The finite element model is shown in Figure1.

3.2 The result and analysis of the calculation

The parameters of the two layers of soil in the slope are shown in Table 2.1, taking k=0.9 as the reduction ratio. The calculation results show that when the reduction factor of [illegible]is 1.013, and the reduction factor of c is 1.126, the average reduction factor of the two, or the safety factor is 1.07, the slope reaches the limit equilibrium. From the definition of slope stability, the slope is in a stable state. But it can be seen from the plastic zone of the slope in Fig. 2, the plastic zone of the slope from the foot of the slope to the top of the slope has penetrated and the shape of the sliding surface has been formed. As can be seen from Figure3, a horizontal displacement with a maximum of 0.23m is generated at the foot of the slope. The slope displacement vector field shown in Fig. 4 shows that the inside of the slope has a very significant downward displacement trend. Through comprehensive analysis, the slope on the left side of ZK141+180 is not stable, and measures need to be taken to reinforce the slope to improve its stability and ensure the safety and quality of the project.

3.3 Reinforcement Measures for Slope

In view of the stability of the left side slope at ZK141+180, two tentative plans are preliminarily drawn up. The first is to reduce part of the slope soil, and excavate a secondary platform in the 1/2 place of the original slope. The slope of the platform is approached by 1:1 grading on the upward slope. It can reduce the slope rate and at the same time reduce the weight of part of the soil, so that the anti-sliding force of the slope can be increased to achieve the purpose of strengthening the slope. The second is to reinforce the slope by driving the anchor rod into the slope, and improve the stability of the slope. (The calculation still uses the reduction ratio of k=0.9, and the safety factor takes the two-parameter reduction average.)

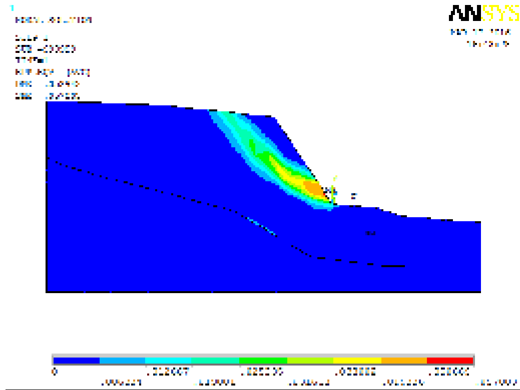

Figure 2. Cloud picture of the plastic zone distribution in the slope

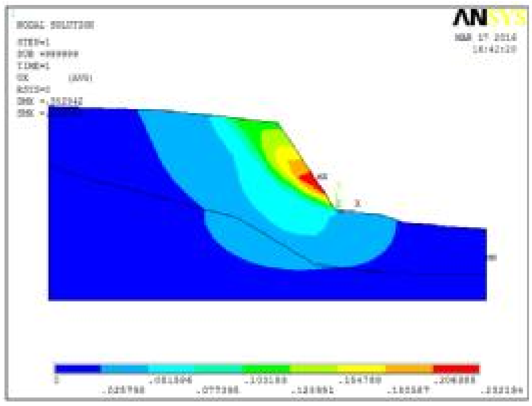

Figure3. Cloud picture of horizontal direction displacement of slope

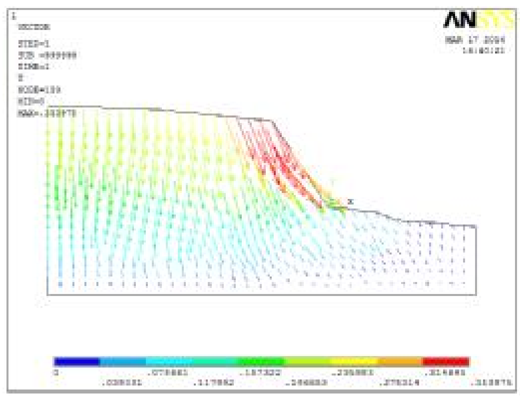

Figure 4. The picture of the displacement vector of the slope

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At the height of 1/2 of the original side slope, a secondary platform with a width of 2 meters was excavated. Above the platform, the finite element model of the slope soil after slope excavation according to slope ratio 1:1 is shown in Figure 5. The constraint condition of the calculation model is the horizontal direction constraint on both sides and the horizontal and vertical direction constraints on the bottom of the slope, and the rest boundary is set as the free boundary. Through analysis and calculation, the safety factor of slope is increased to 1.27 after slope reduction, and the analysis results are shown in Figure6 - 8.

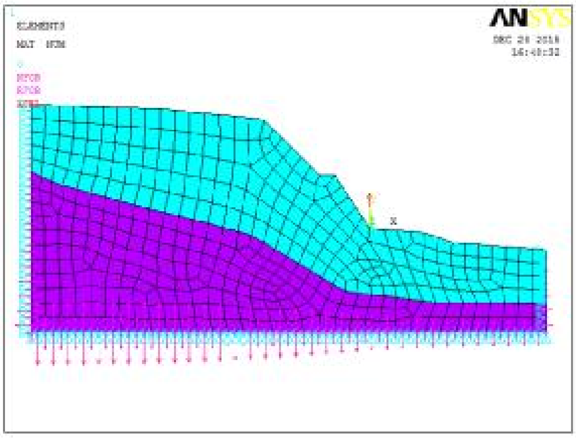

Figure 5. Finite element model of slope after grading

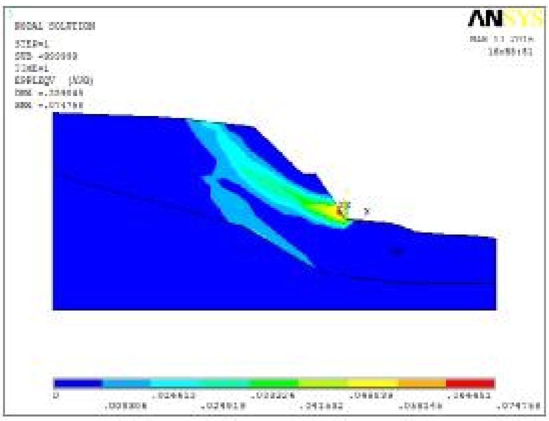

Figure 6. Cloud picture of the distribution of slope plastic zone

From figure 6 to figure8, the maximum displacement of the whole slope in the horizontal direction is 0.27m, which occurs in the range of the foot of the first grade slope. And it gradually decreases from the foot of the slope to the slope body, and the minimum horizontal displacement is only 0.03m. Two plastic zones are produced at the foot of the slope and in the contact surface of the two layers of soil. The plastic zone at the foot of the slope is round and wide, and its width is large, and it penetrates from the foot of the slope to the top of the slope. In the displacement vector picture, it is more intuitively found that the most dangerous slide area produced by the slope is the range contained in the plastic zone.

The above analysis results show that the stability of the slope can be improved by using t slope reduction method to reinforce the slope. However, from the perspective of workability, the excavation of the slope will produce a large number of discards, and requires large-scale construction machinery to enter the site. This requires a high degree of construction site conditions. This project needs to be combined with the construction site conditions, and it depends on the circumstances.

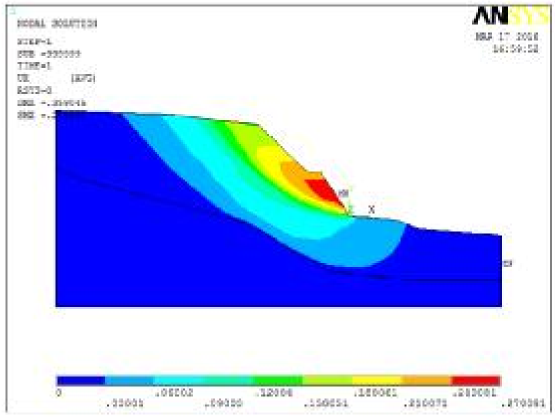

Figure 7. Cloud picture of horizontal direction displacement of slope

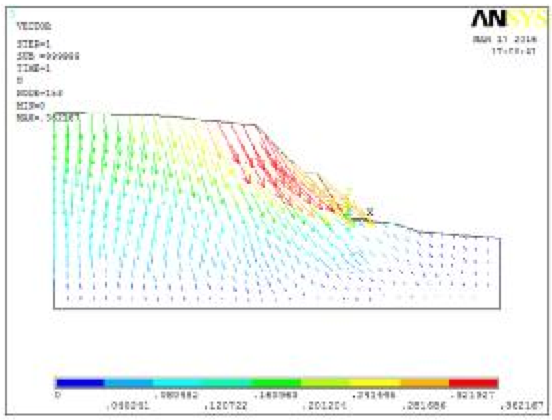

Figure 8. Picture of the displacement vector of the slope

Scheme two is bolting reinforcement

Based on the above calculation results for the stability of the left side slope at ZK141+180, the slope can also be reinforced with an anchor rod. The preliminarily planned reinforcement plan is to enter five rows of anchors at a distance of 3 meters on the slope, each anchor being 10 meters long, and the angle with the horizontal direction is 10 degrees downward. The concrete reinforcement arrangement of the anchor rod is shown in Figure 9.

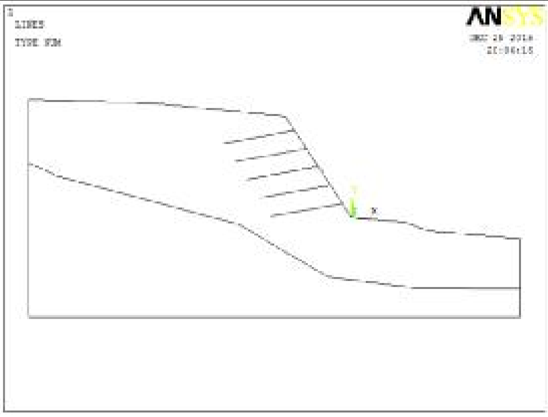

Figure 9. Layout of anchor bolt for slope reinforcement

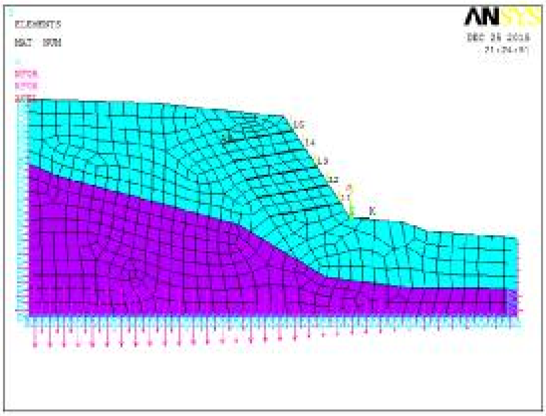

Figure 10. Finite element model of soil slope with anchor bolt

After adding the anchor, it is necessary to specify the element type of the anchor in ANSYS. It is more appropriate to select the LINK8 element to simulate the anchor bolt. The strength parameters selected in the reinforcement plan are 1, the elastic modulus is E=28GPa, and the Poisson's ratio is =0.26. In order to simulate the reinforcement effect of anchor rod in soil, it is necessary to couple anchor nodes with soil nodes in mesh generation of finite element models. The confinement of the soil model of the slope still adopts horizontal direction constraints on both sides, the horizontal and vertical double direction constraints on the bottom of the slope, and the rest of the boundary without constraints, and the gravity is 9.8N/Kg. The division of the finite element mesh after the coupling of soil and anchor rods and the model after constraint are shown in Figure10.

The analysis of the strength reduction of the slope after adding the anchor rod can obtain the stability coefficient of the slope is 1.36. The results of other analysis are shown in Figure 11-Figure14.

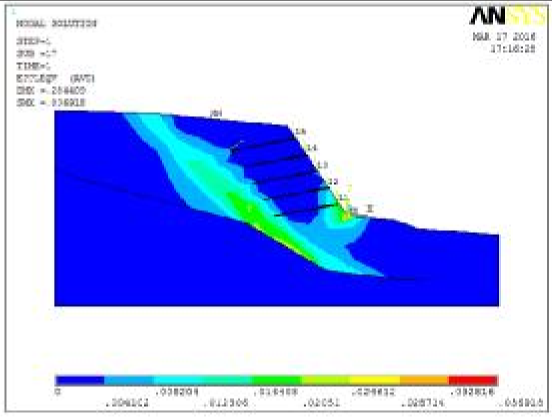

Figure 11. Cloud picture of the distribution of the plastic zone of the slope

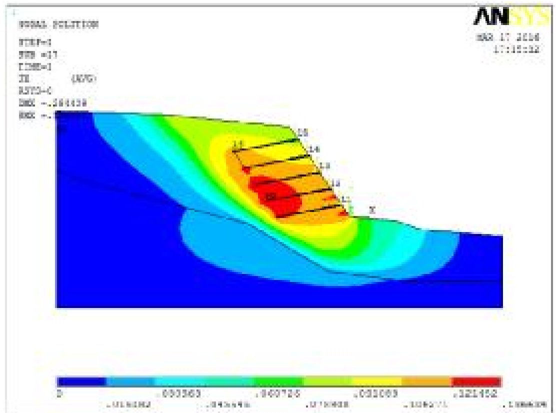

Figure 12. Cloud picture of horizontal direction displacement of slope

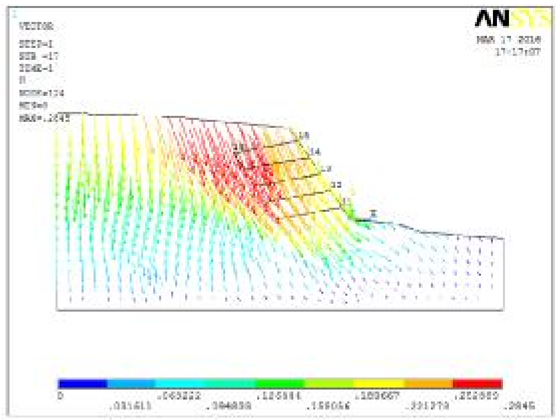

Figure13. Slope displacement vector graph

From Fig 11 to Fig 13, we can see that the shape of the slope changed significantly after 5 layers of anchor bolts were inserted into the slope. The position of the plastic perforation zone is obviously moved to the interior of the slope body, and its range is near the end of the bolt. This indicates that the slope damage has changed from shallow sliding to deep sliding.

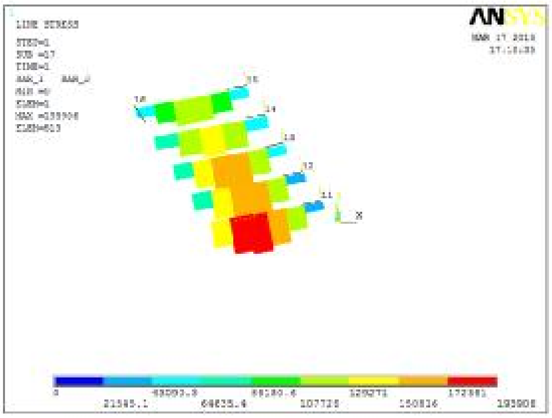

Figure14. Bolt shaft

The maximum area of the horizontal displacement is also moved from the slope to the interior of the slope, and the range is obviously larger than that of figure 3 and figure 7, but the numerical value is significantly reduced to only 0.136m. It indicates that the displacement of the post slope is effectively suppressed. From the displacement vector diagram of the slope, it can be seen that the most dangerous slip zone of the slope is the range of a few meters from the end of the anchor. Figure14 shows that the axial force distribution of the anchor rod is large in the middle and small at both ends. The lower the layer, the higher the maximum axial force, and the maximum axial force of the bottom rock bolt is 194KN.

From the above calculation results, it can be concluded that the stability of slope increases greatly after adding anchor bolts, and the safety coefficient meets the engineering requirements. Compared with the potential sliding surface generated by the slope in the original slope and slope reducing load reinforcement scheme, after reinforcement by bolts, the sliding surface of the slope moves to the deep soil far away from the slope, and the safety reserve of the whole slope is significantly improved. Therefore, compared with the slope reduction method of the first option, the second option is more suitable for the reinforcement of the left side slope at ZK141+180.

4. Conclusion

In the slope treatment project of ZK141+180 ~ ZK141+350 section of expressway, the dangerous slope is simulated and analyzed by using the conclusion. The conclusion of the analysis shows that the stability coefficient of the original slope is 1.07, and reinforcement measures need to be taken. This paper puts forward two schemes of slope reduction and anchor reinforcement. After comparison and analysis, the latter is recommended. There are many factors that affect the stability of slope, but this method has some reference significance for stability analysis and comparison

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