Forecasting the potential unstable zone of a high slope after landsliding, Yunnan, China

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Abstract: The Xiaowan Hydropower Project lies on Lancang River of Yunnan province in China. The dam is 292 m high, 13 m wide at the top, about 69 m wide at the base and has a maximum capacity of electrical generation of 4200MW. A 6-degree slope occurs to the dam, downriver and on the left bank. When digging a road, part of the 6-degree slope began to slide. For security of the project, countermeasures had to be taken. So it was necessary to find the potentially unstable zone. The potentially unstable zone of the dug slope was of most concern. Through investigation, it is known that landsliding happens along original joints and faults, and it was speculated that the next landslide will continue to happen along them. By analyzing the location of joints and faults and the deformation failure mechanism of landsliding, the possibly unstable zone was deduced. Based on plentiful investigation data and the test results, a numerical model of the 6-degree slope was built in ANSYS, replacing joints and faults with low strength material in the model and simulating fore and aft the partial landsliding. Results show that the stress and strain of the slope change after landsliding. By comparing the tracks and curves of the stress and strain fore and aft slides, the zone of potential instability of the slope was identified. The stability factor was about 1.13. Finally, a 30 m potentially unstable zone was identified and countermeasures designed. The study shows that identification of the zone by both methods is consistent and this approach is practicable and the result is believable.

Résumé: Les travaux de la centrale hydraulique Xiewan se trouve au fleuve Lancant de la Province Yunnan. La hauteur du barrage est de 292m. La largeur du front du barrage est de 13m. La largeur du fond du barrage est de 69m. La capacité installée est de 4 200MW. Au cours de l'exécution des travaux, à cause de l'excavation sur la route haute, qui a fait en sorte que l'instabilité de la roche en haut de la pente de la montagne numéro 6. Il y avait l'effondrement de rocher. Pour la sécurité des travaux, il faut faire la mesure de soutènement. Car il faut conjecturer l'instabilité potentielle de la pente. Après la plusieurs investigation géologique, on a analysé et a fait le bilan que l'effondrement de rocher est au long de joint original de la pente abrupte et légère du failleux. La lithoclase se montre une variation du pérron. L'effondrement potentiel de l'avenir sera comme cette forme. Selon la localisation du joint, le failleux et le mécanisme de sabotage de la déformation de l'effondrement, on affirme presquement la zone de l'instabilité potentielle. Sur cette base, on a utilisé l'ANSYS pour analyser la pente du glissement de terrain avant et après l'effondrement avec l'élément fini de l'élasto-plasticité bidimensionnelle. Au cours de l'analyse, on a utilisé l'unité de la base résistance ramplaçant la diaclase de la pente et la matière du failleux. On poursuit aussi la contrainte, la déformation et le niveau de la contrainte calculée de la pente. D'après la comparaison du résultat de l'analyse avant et après l'effondrement, on a décidé que le domaine de l'instabilité potentielle était de 30m. Au cours de l'analyse, on a utilisé suffisamment la caractère de l'ANSYS pour l'effet de la simulation réelle de la contrainte. Il a été éviter le processus de la réduction du paramètre de la contrainte de la pente. On a uni l'analyse de mécanisme et la simulation numérique qui a donné la zone de soutènement efficatif de la pente. La conclusion est raisonable. La méthode est passable.

Keywords: excavations, landslides, joints, models, stain, stress, slope stability

INTRODUCTION

When we build hydropower project, transportation project or large foundation ditches, we need to excavate and cut the slope. After excavation or cutting, we should forecast the unstable zone and the behaviour of slope, and then we can take effective countermeasures. In recent years, much relevant research has been taken. As this paper describes, there are several main means of forecasting the unstable zone of cut slopes.

The first one is analogism. This is to say, we can investigate the behaviour, the characteristic and the deformation failure mechanism and location of joints and faults of the excavated slope, and then speculate the behaviour and the unstable zone of excavating slope. This is an experiential means.

The second is FEM. After taking finite element analysis and ordinarily begin to analyze the stress, strain and deformation. We know if only analyze these, the unstable zone of cutting slope can't be educed. So there is a kind of means (Griffiths & Lane 1999) or (Yinren Zheng, Shangyi Zhao & Luyu Zhang 2002) that slope stability analysis by strength (c and) reduction FEM and get safety factor -the reduce factor.

The third (Hong Zheng, Defu Liu & Xianqi Luo 2004) is determination of potential slide line of slopes based on the computational results from elastic-plasticity finite element analysis. An initial value problem related to a system of ordinary differential equations (ODEs) is formulated to define the potential slide lines (PSL) for two-dimensional cases. A prediction-correction algorithm for the ODEs and a necessary and sufficient condition that assures the convergence of the algorithm are presented. The skills for searching PSL with the presented method are discussed, and the procedures of this method have been validated against traditional limit analysis methods and limit equilibrium method. In this paper it is used for a homogeneous soil slope.

The fourth (Xingsong Cao & Depei Zhou 2004) is the analysis means based the wedge theory of elastic mechanics.

And the fifth (Xiaoyan Zhao, Houtian Hu & Liexin Pang 2005) is that the characteristics of unloading fractures and the influencing factors of their displacements are summarized through centrifugal tests in test chamber about the excavation in silt, clay, and completely weathered mudstone. From the tests, it is concluded that deformations of the existing fractures will increase with the accretion of its obliquity, depth and proximity to the unloaded surface. The relationships of stretch and obliquity of fractures, deformation modulus and angle to unloading direction of fracture are put forward The method of determining the width of unloading zones is presented for practical engineering projects, and feasibility of the method is proved through an application in the bank of Yangtze River in Chongqing City, China.

The upwards five means did not satisfy the requirement of our research situation – a 6-degree slope of Xiaowan hydropower. We were required to make further research that demonstrated that combining ground investigation with FEM analysis is feasible and reliable.

THE GEOLOGICAL BACKGROUND AND CONDITIONS

The Xiaowan Hydropower Project lies on Lancang River of Yunnan province in China. The dam is 292 m high, 13 m wide at the top, about 69 m wide at the base and has a maximum capacity of electrical generation of 4200MW. A 6-degree slope occurs near the dam, downriver and on the left bank. This is to say, the 6-degree slope is located in the downriver of left shoulder of dam. There are three roads, high routine road (altitude 1380m), up routine road (altitude 1245m) and down routine road (altitude 1000m) in the 6-degree slope. From upriver to downriver, there is a water cushion pond, a second dam, and, downriver cofferdam and guide cave.

When excavating the high routine road (altitude 1380m) in 2001, the part of the 6-degree slope began to slide. The landslide (elevation 1425m~1515m) is about 100000 m^3. Later, the high routine road was changed to be the tunnel of road. For security of the project, countermeasures to landslides had to be taken. In order to anchor the slope, it was necessary to find the potentially unstable zone of 6-degree slope. We carried out a geological anf engineering geological investigation (Figure 1 and Figure 2).

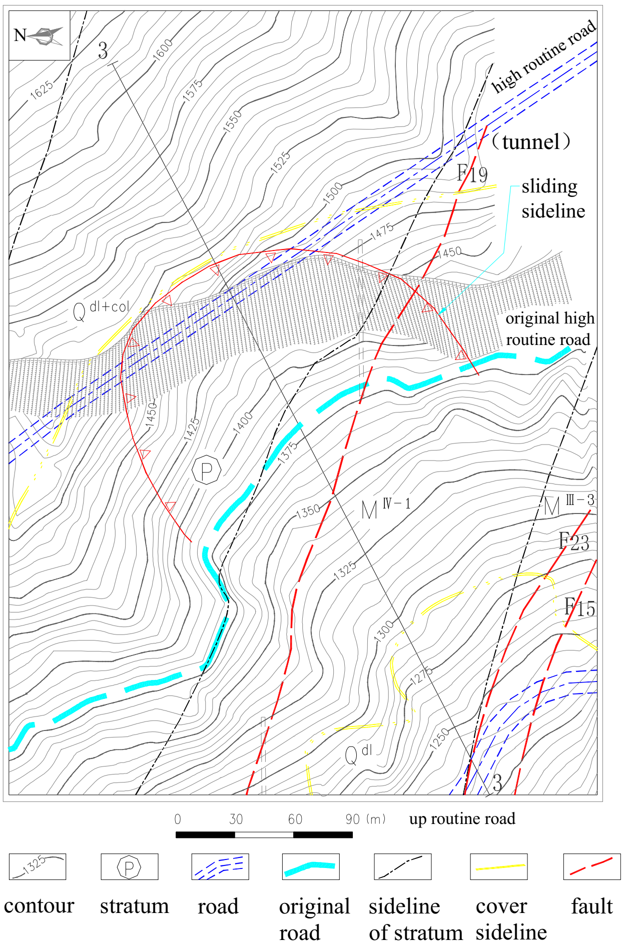

Figure 1. The engineering geology plane of slope

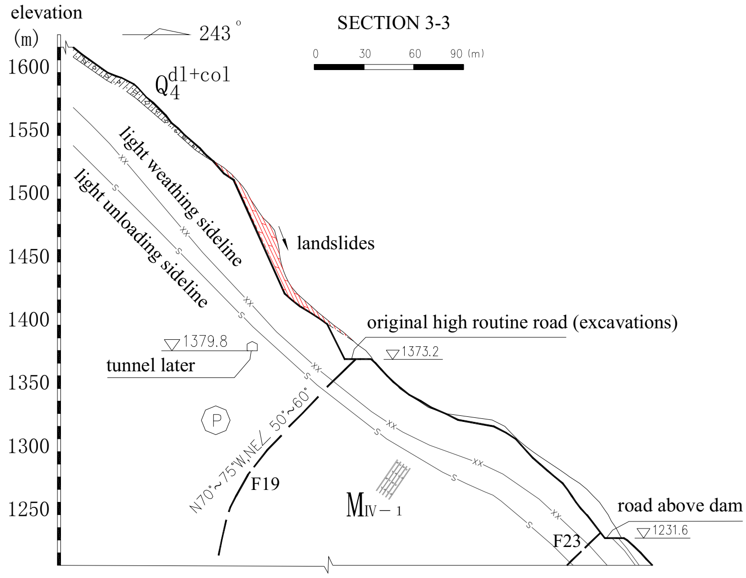

Figure 2. The engineering geology section of slope

The investigation found:

The 6-degree slope is high and steep; with a kind of "cavity of collapse and slide"topography. There are two types of rock in the slide area. One is hornblende and plagioclase gneissic rock (interlayer in M_{IV-1}) above elevation 1380m, the other is biotitic and granite gneissic rock (M_{IV-1}) below elevation 1380m. The line of strike of rock stratum is NWW and the strike of slope surface is SN in the near ridge. In the area of landslide, the strike of surface slope is NW, attitude of bed is N64~85ºW/NE56~75º. The strike of rock stratum is steep and oblique to slope. In cross section, the slope below elevation 1425m is 35º~44º, between elevations 1425m~1515m it becomes a cliff with average angle of slope is 62º, and above elevation 1515m it's a low slope. There is a small fault called F19 and several smaller faults. There are three groups of main joints: NWW orientation steep joint (bedding surface), NNW-NW orientation medium angle of slope joint, and about SN orientation steep joint. Totally this slope belongs to blocky structure rock mass. There is no groundwater in the slide area because good drainage and the part of slide are dry. The earthquake intensity is eight degree in this area.

FORECASTING THE UNSTABLE ZONE BASED ON INVESTIGATION AND DEFORMATION FAILURE MECHANISM ANALYSIS

According to the spot investigation, we found that the rock deforms to failure like a step (Figure 3). Evidence for this was: A series of step-type landslides visible at surface in the area of 6-degree slope, occurring along SN orientation steep and low joint; A lot of step like cracks and rifts, crack width is 9.5 ~ 20cm and the previous partial slide is step like, occurring along NWW orientation steep and slow joint. So we can identify the unstable zone by recognising the failure features, like steps, and the attitude elements of joints.

Figure4 shows the analysis of the unstable zone after a slide. The analysis followed several steps. The landslide (elevation 1425~1515 m) of volume about 100000 m^3 in 2001 was caused by the excavating road at the foot. It was deduced that the sliding was also a kind of foot cutting to the upward part of slope (above elevation 1515~1530 m). The slope angle between elevations 1425~1515 m is 66º after sliding last time, and it is unstable.

The investigation show the last time sliding mode is like open wide "L", and the average slope angle of low joint is 35º and steep joint is 62º. So we can forecast that the sliding happens as open wide "L" with slow angle 35º and steep angle 62º. It is well known that the zone of future sliding is decided by the slow joint's size, and the steep joint will become a break boundary. And the investigation date show that the average length of slow joint is 40 m.

From this we can identify potential unstable zones of a high slope after landslide. One is only considering the steep joint's impact; draw the line as angle 62º from the foot; the longest straight length is 10 m (K1-E1); and this steep zone is unstable. The other unstable zone arises from steep and low joint's impact; identified by drawing the line as angle 35º and length 40 m from the foot, then draw the line as angle 62º; the longest straight length here is 28 m (K1-K2-E2).

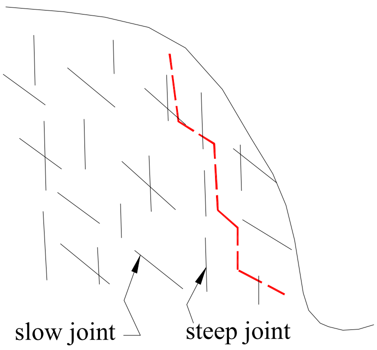

Figure 3. The sketch map of step landslide

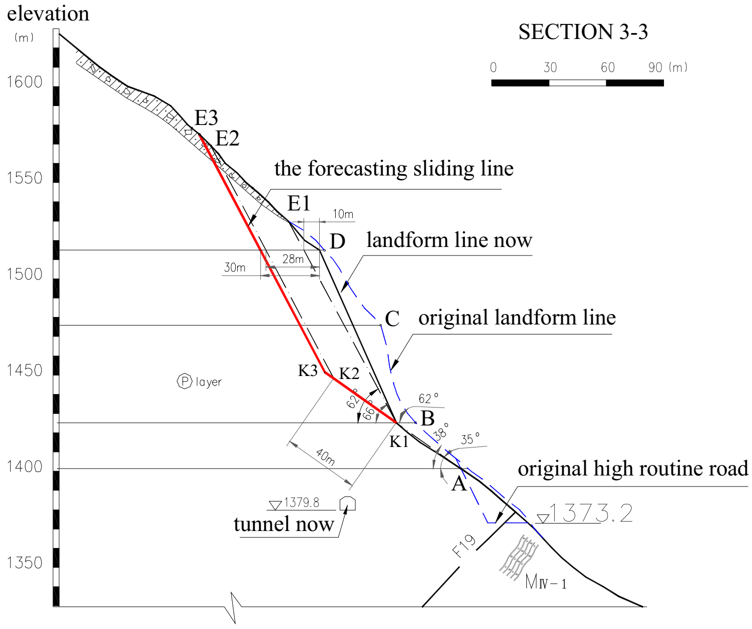

Figure 4. An analysis diagrammatize of unstable zone after landslide

FORECASTING THE UNSTABLE ZONE BASED ON ANSYS

It is well known that the stress and strain of slope will change when a slope is excavated or slides. Research (Jiazheng Pan 1980) or (Jiahuan Qian & Zongge Yin 1996) shows that if the slope can slide along many sliding surface, then it will happen to slope along the smallest resistance sliding surface. And commonly the rockmass will deform and fail along the section of highest stress intensity (Zhouyuan Zhang, Shitian Wang & Lansheng Wang 1994). We can simulate the stress, strain and intensity of stress of slope before and after the partial landsliding. We can then compare them and deduce the potential unstable zone of a high slope after landsliding.

With FEM technology progress, the stress and strain's simulation can be well realized. We know that ANSYS can realize the simulation of original ground stress, and have a real simulation of the redistribution of stress after excavation (Zhixiong Lan, Guobin Wang & Yushan Liu 2004). In order to carry out the analysis, we chose ANSYS.

After considerable geological investigation and testing, a numerical model of the 6-degree slope was built in ANSYS, replacing joints and faults with low strength material in the model and simulating before and after the partial landslide. Results show that the stress and strain of the slope do change after landslide. By comparing the tracks and curves of the stress and strain before and after landslides, the zone of potential instability of the slope was identified.

Building model

The numerical model of the 6-degree slope and mesh of model are shown in Figure 5. The model elevation scope is 1260m~1620m, and the number of mesh is 2207. In order to weaken the structure, the boundary parting is widened. We replace joints and faults with low strength material in the model. Simulating weathering disintegration and stress relief, the mechanical parameter of material is gradually raised from surface to inner. Rock parameters have been derived from rock mechanics tests (Table 1).

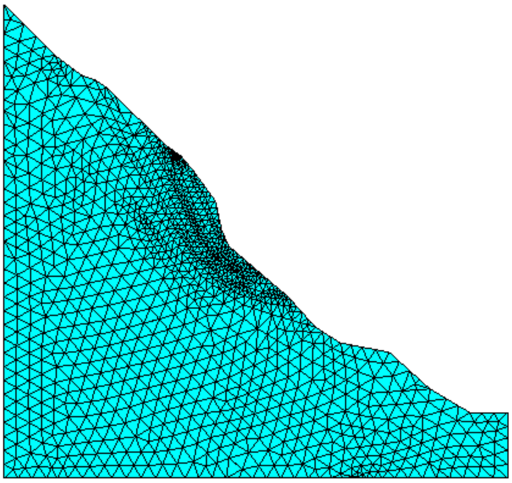

Figure 5. Mesh of model before landslide

Table1. Mechanics parameters of rock mass in slope

materials	(kg/m^3)	(kpa)		C (kpa)
rock	2750	2.2e7	0.22	2000
joints and faults	2700	1e7	0.28	800

The result of simulation before sliding

In order to get the stress, strain, deformation and the calculation stress convergence factor, we locate the track line in the slope. The calculation stress convergence factor N is the calculation stress σ_e divide the yield stress of material σ_y.

$$N = \sigma_e / \sigma_y$$

The result of simulation before sliding show that the mass subject to sliding is a pre-existing deformation, and is subject to plastic deformation through it, and has a high calculated stress convergence factor N. The iterative calculation is un-convergence. Figure 6 through to Figure 8 show the pattern of convergence through to final convergence. As the model progresses, we can track the stress, strain and the stress convergence factor and obtain the relationship curve of deformation, the stress convergence factor and the distance to slope surface (Figure 9 and 10).

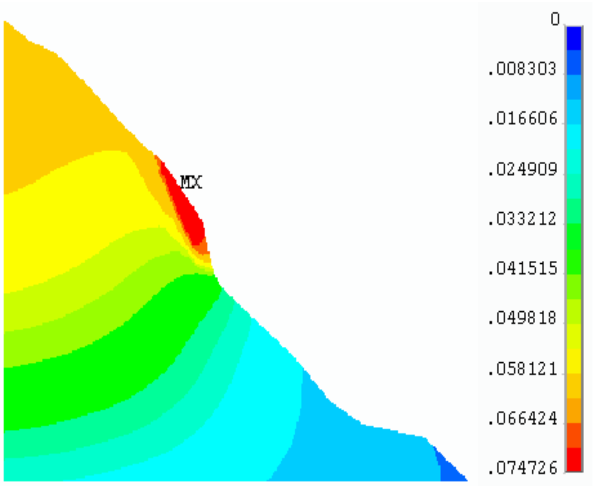

Figure 6. The nephogram of total displacement before landslide (unit: m)

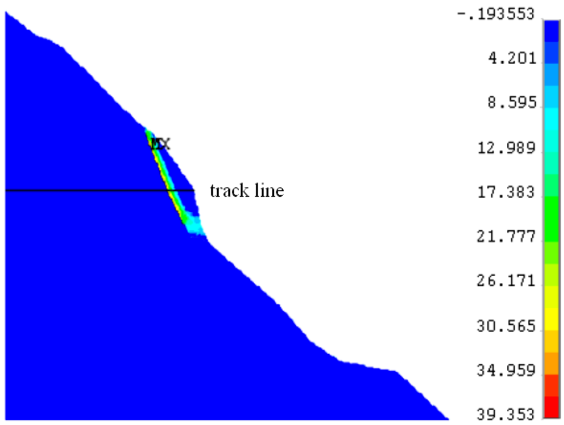

Figure 7. The track line and plastic strain before landslide

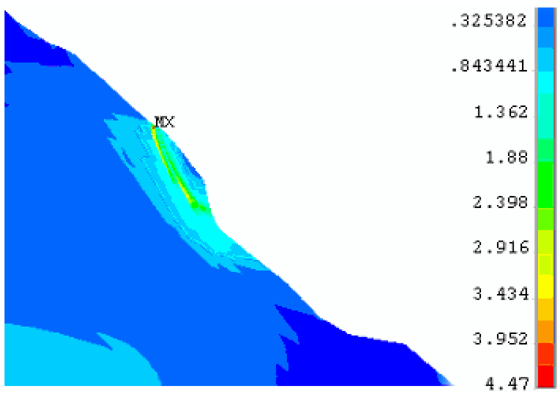

Figure 8. The stress convergence before landslide

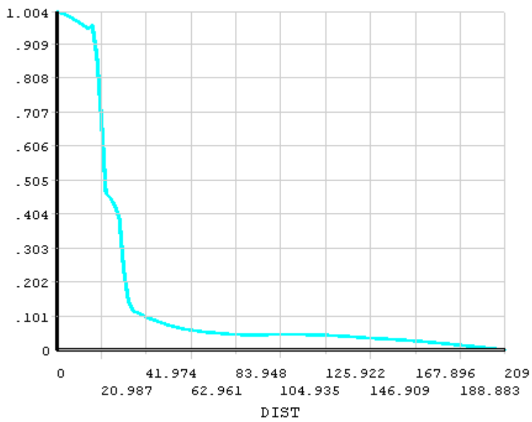

Figure 9. The relationship curve of level displaces and distance (unit: m)

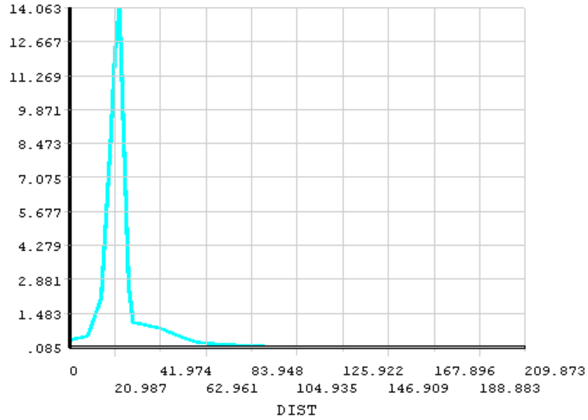

Figure 10. The relationship curve of stress convergence factor and distance

Analyzing from figure 9 and figure 10, the largest depth of the deformation and the stress convergence zone is about 18m. And actually the depth of sliding is 16m~20m. As the two depths are nearly equal we can draw a conclusion that our building model is valid.

The result of simulation after sliding

We broke the landslide and surrounding rock mass into elements for FEM analysis (Figure 11). Considering the original gravity stress, under the same boundary conditions, we then simulated sliding. Results are shown in Figure 12 through to Figure 15. The tracking curves show that the distance from the present slope surface to the stress convergence and plastic strain zone is about 30m (Figures 15, 16 and 17). The zone is in figure 4 (K1-K3-E3). This forecasting zone is nearly same as the zone (K1-K2-E2) based on the investigation and deformation failure mechanism analysis. The stability factor is 1.13 after calculation. It does not reach the slope stability factor required by standard (1.25), so the 30m zone need to be supported. After countermeasures design, we suggest the anchor wire of 35m.

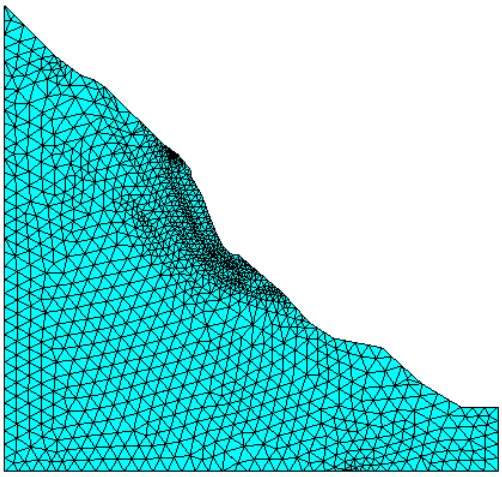

Figure 11. Mesh of model after landslide

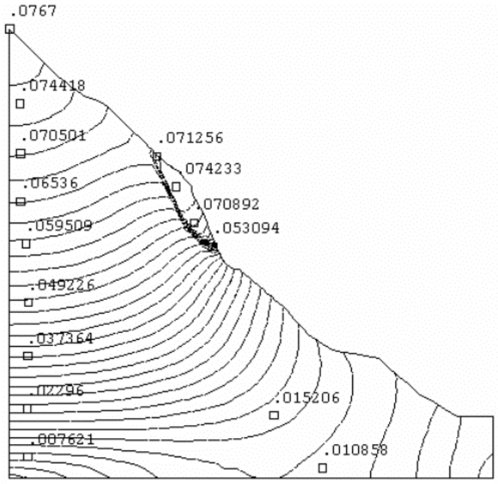

Figure 12. The displace isolines after landslide (unit: m)

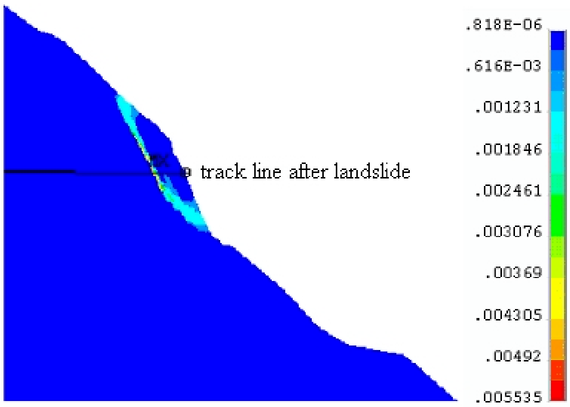

Figure 13. The track and strain after landslide

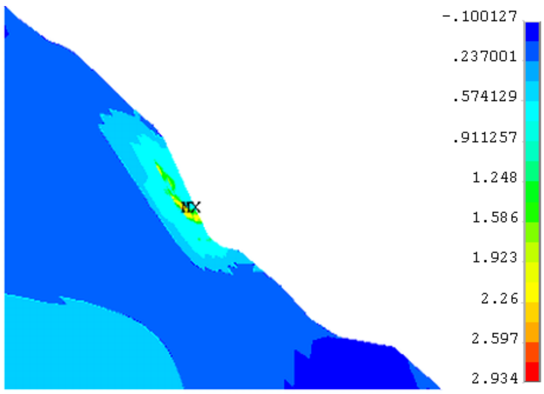

Figure 14. The stress convergence after landslide

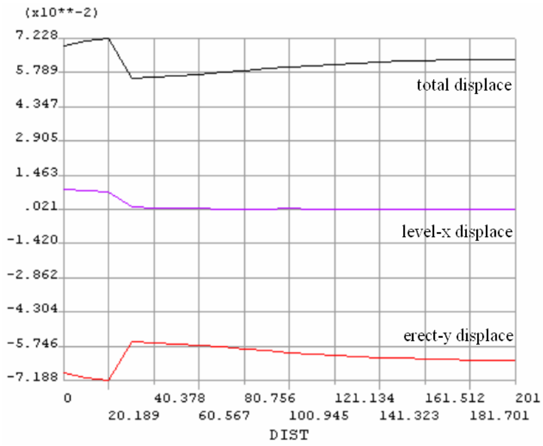

Figure 15. The relationship curve of displaces and distance (unit: m)

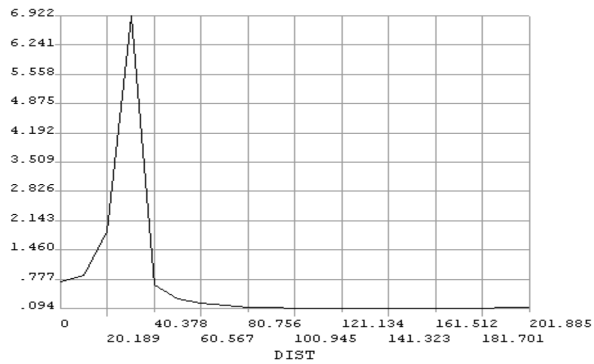

Figure 16. The relationship curve of stress convergence factor and distance

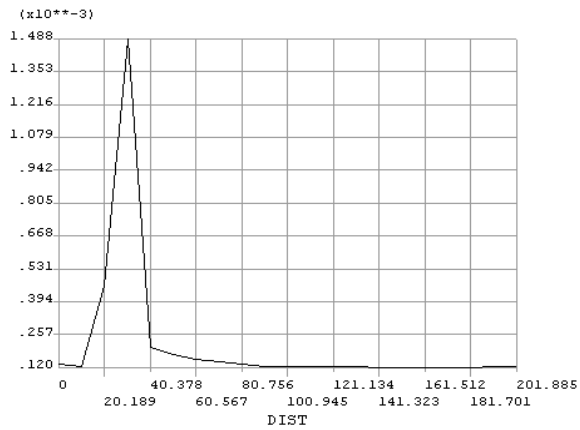

Figure 17. The relationship curve of strain and distance

CONCLUSIONS

The part of the 6-degree slope began to slide for excavating a road at the foot of slope. After investigation, it is known that the landslide happens along original joints and faults, and it is speculated that the next landslide will continue to happen along them. By analyzing the location of joints and faults and the deformation failure mechanism of sliding, the possibly unstable zone of 28~33 m depth was deduced.

Based on plentiful investigation data and the test results, a numerical model of the 6-degree slope was built in ANSYS. We replaced joints and faults with low strength material in the model and simulate before and after the partial landslide. By comparing the tracks and curves of the stress and strain before and after landslides, we find that the stress and strain of the slope change after sliding, and a 30 m potentially unstable zone was identified.The stability factor after calculation was 1.13. For security of the project, countermeasures had to be taken. We suggest the anchor wire of 35m after designing.

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