The stability of a large slope after impoundment by using 3D numerical modeling at the reservoir

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Abstract: For the stability of large reservoir slopes after impoundment it is very important to correlate all factors which affect the dam's safety and its usage. If destabilization occurs, it will do harm to the thousands of people who live up the slope. The results from using 3D numerical modeling indicate that there are three failure planes in the slope, that is, there is a major failure plane and two secondary ones. The connectivity of the major one is low and for the others it is high, so the slope as a whole is stable but it may partially fail when the impounded water level reaches 1880m. The results also indicate that its deformation is small and it is wholly stable in the initial stage. As the impounded water level rises, so deformation increases. There is large scale local deformation or damage when the impounded water level reaches 1850m. The deformation and damage become greater and wider possibly leading to partial failure when the impounded water level reaches 1880m. However, on the whole, it is still stable, and it is a middle-superficial layer slope.

Résumé: La stabilité du réservoir qui se trouve à la région de glissement de terrain, d'une centrale hydraulique après la retenue d'eau. Et qui concerne la séciurité du fonctionnement du réservoir. Sur la base géologique, on a fait l'étude de la simulation numérique de sa stabilité d'un grand glissement de terrain après la retenue d'eau utilisant l'élément limitée tridimensionnel. Le résultst montre que la déformation du glissement de terrain est pétite au début de la retenue d'eau. La stabilité est meilleure. Au fur et à mesure, l'élevation de la retenue d'eau, il y a une tendance d'augmentation de la déformation. Lorsque le niveau d'eau atteint à la hauteur de 1850m. Il surgit la déformation et le sabotage partiel. Lorsque le niveau d'eau atteint à la hauteur de 1880m. La déformation et le sabotage s'accroissent. En généralement, la stabilité du glissement de terrain est stable. La retenue d'eau influence seulement l'instabilité partielle du front.

Keywords: 3D models, landslides, dams, failures, engineering geology, water table, stability

INTRODUCTION

The development of the west of China will involve the construction of many large scale hydraulic engineering works, especially in the southwest of China. The geological structure is complex and neotectonic movements are strong. Earthquake movements are also frequent. Geohazards frequently occur in these areas (Huang Run-qiu, Wang Shi-tian, Xu Qiang et al., 1994, Huang Run-qiu, Wang Shi-tian, Zhang Zhuoyuan, et al.,2001, Huang Run-qiu, Zhang Zhuoyuan, Wang Shi-tian, 1991, Huang Run-qiu, Xu Qiang, Tao Lian-jin et al., 2002)

The proposed hydrologic station in the upper reaches of the Yalong River will be the largest capacity reservoir in the catchment. The designed height of the dam is 305m. A large slope lies at the left bank of the dam site, a distance of about 300m from it (Wang Shi-tian, Huang Run-qiu,Li Yu-sheng et al.1998). If large scale deformation or damage occurs, it may not only induce a surge and the collapse or failure of the dam, because it is so near to the dam site, but it will do harm to the thousands of people who live up the slope. Therefore, its stability is viewed seriously by all departments.

Following on from earlier workers (Zhuoyuan Zhang, Shi-tian Wang, Lan-sheng Wang, 1994, Lu Shi-zong,Li Cheng-cun, Xia Ji-xiang et al. 1983), the stability after impoundment was studied by using 3D numerical simulation.

THE SLOPE AREA

General valley morphology

The Yalong River is "V" shape, the bank slopes are steep that the angle of gradient is 35°~40°on the left bank, and 40°~50°on the right bank.

Configuration of the slope

The slope is dustpan shaped in plan, with a cirque landform. Its toe elevation is 1660 m at high water and 6 m lower at low water, the crest is about 2020 m. The difference of elevation between the toe and crest is 460 m. Its length is about 1000 m, its width is about 570 m, and its area is about 0.57 km^2. The thickness is about 64~120 m; its average thickness is 80 m. Its remnant volume is $15\times10^6 m^3$ or so, and it lies in the left bank.

There are three flatter breaks in the slope. The first one is dumbbell shaped in plan following erosion by a gully, it lies between 1775 m and 1880 m and slopes 18°. The elevations of the others lie between 1875 m and 1925 m, and between 2040 and 2125 m; their angles are 18~26° and 23°.

STABILITY AFTER IMPOUNDMENT BY USING 3D NUMERICAL MODELLING

The site reconnaissance data show its stability under natural conditions. If there is large scale deformation or damage, it may not only induce a surge and the collapse or failure of the dam, because it is so near to the dam site, but it will do harm to the thousands of people who live up the slope. So it is necessary to study its stability.

Calculating Model and Selecting the Parameters

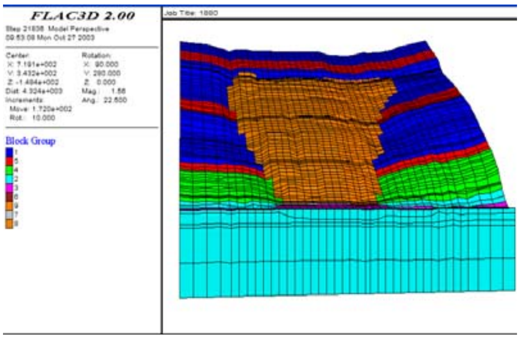

Figure 1. 3D numerical model

It mainly consisted of main slide, secondary slide, slope body and alleviation (Figure 1). The slope body consisted of two parts, the upstream one and the downstream one. The parameter data of the upstream one are higher than the downstream one.

The bedrock consists of nodular limestone, sandstone and slate.

The slope body is modelled as elastic-plastic and the bedrock as elastic in the model. The calculation only considered the affect of gravity, and mainly considered its stability under the condition of the normal impounded level, whose elevation is 1880m.

In order to monitor the development of deformation, I set a series of points that kept trace of the displacements in the slope body.

The calculation was done by using 3D-Flac (*ICG. 1997*), the mechanical parameter data of the rock and soil are as follows (Table 1):

Table 1. Mechanical parameter data of the rock and soil

	Bulk Modulus (MPa)	**Shear Modulus (MPa)**	**Density (MN/m^3)**	**Cohesion (MPa)**	**Internal Friction Angle (º)**	**Tensile Strength (MPa)**
group-3	750	346	0.023	0.04	36	0.0025
group-8	1053	458	0.025	0.06	34	0.003
group-9	926	379	0.024	0.06	32	0.002
group-7	556	227	0.0163	0.003	26	0.0015
group-6	521	187	0.016	0.003	22	0.001
group-5	10000	6000	0.0275	1.2	45	1.8
group-4	8696	4724	0.0275	1	40	1.5
group-2	7246	3937	0.027	0.05	38	1

Analysis of calculated results

Several phases in the development of the impounded level, 1770 m, 1750 m, 1800 m, 1850 m and 1880 m, were simulated in turn using 3D-Flac.

Displacement magnitude of the slope

The displacement magnitude moved downward along the dip direction of the slope after the normal impounded level (Figure 2). The part above 1920 m elevation mainly moved downward, the other mainly moved in a horizontal direction, especially the superficial part.

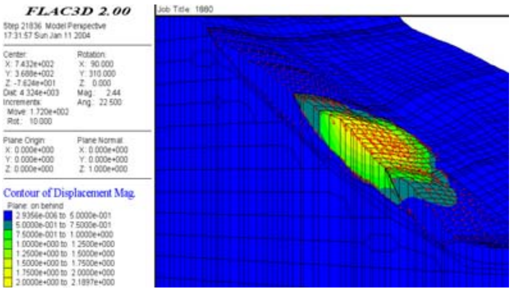

Figure 2. Contour map of U-Displacement

The displacement magnitude is larger in the middle part than in the upper and lower parts; and it is larger in the superficial part than in the interior part, so large displacements local to the middle and superficial part may indicate failure. The displacement magnitude is more than 0.5 m between 1850 and 1900 m; 0.5 to 0.7 m between 1720 and 1780 m and between 1920 and 1960 m. It is 0.7 to 1.75 m between 1780 and 1850 m and between 1900 and 1920 m. It is 1.75 to 2.17 m between 1850 and 1900 m. Elsewhere, it is less than 0.5 m, and there are no displacement in some parts. In the vertical direction, the dispersion of displacement is 0.25 m every 10 to 15 m in depth; the displacement is 1.75 to 2.17 m within 10 m depth in the superficial part; it is less than the others in the slope. Its displacement is 0.75 to 1.00 m close to the slope bottom.

Horizontal displacement (X-displacement)

Figure 3 shows that the slope has two areas: the upper one is sliding-gently and sinking and the middle and lower one is sliding.

Sliding-sinking areas: sliding area lies in the upper part between 2080 and 2120 m; its length is about 50 m from 2080 to 2120 m in the direction and its sinking displacement is about 1.2 m in the vertical direction. When the part slides to the lower part, there were a series of cracks in the back during its deformation so that the rock and soil sink along them. The depth is 1.2m.

Sliding areas: this is the part from 2080 m to the front part of the area. Its sliding direction is mainly toward the front part; its displacement is from 0 to 1.9 m. Its displacement is more than 0.40 m from 1960 m to the front part. The highest displacement is more than 1.00 m between 1920 and 1800 m.

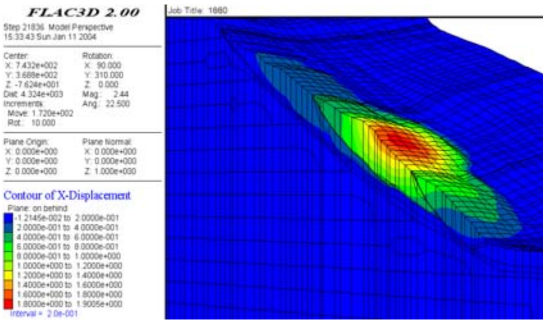

Figure 3. Contour map of horizontal displacement

Vertical displacement (Y-displacement)

Figure 4 shows that the slope is wholly sinking, that is, its displacement direction is downward. The settlement value is direct proportional to the thickness of the slope body; further, the settlement of superficial part is larger than the settlement of the middle and deep parts. The settlement is largest between the secondary sliding surface and the tertiary sliding surface, in particular, it is more than 1 m within the 40~50 m depth between 1920 and 1800 m.

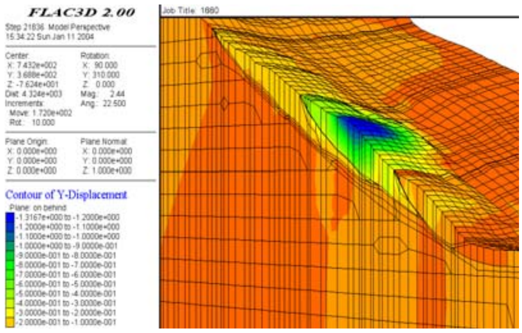

Figure 4. Contour map of vertical displacement

Displacement of Some Tracking Points

Some monitoring points were placed on the upper part, middle part and lower part of the slope. The points kept trace of the horizontal and vertical displacements, as shown on Figure 5. Horizontal displacement will gradually increase with the rising level of impoundment. When the impounded level is 1850 m, the horizontal displacement will be more than 1.2 m and the slope will partially fail. The deformation and damage are predicted to become greater and wider, possibly leading to partial failure, when the impounded water level reaches 1880 m. Furthermore, Figure 5 also shows that the displacement is larger in the middle part (18419 point and 19676 point) than in the upper (18260 point) and lower (18753 point) parts.

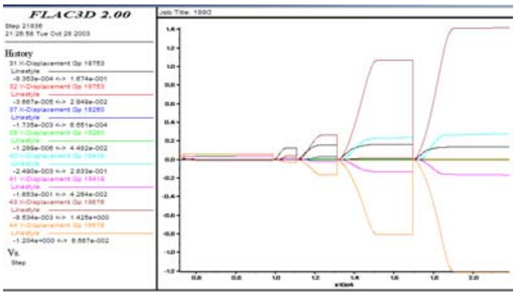

Figure 5. Displacement Histories at Some Points in the Slope

Y-displacement is predicted to move upward during the initial stages, but will move downward after the initial stages. The settlement will gradually increase with the rising level of impoundment. When the impounded level reaches 1850 m, the Y-displacement is predicted to be more than 0.8 m and the model shows the slope partially to fail. The deformation and damage are predicted to become greater and wider, possibly leading to partial failure, when the impounded water level reaches 1880m. The Y-displacement is more than 1.2 m when the impounded water level reaches 1880m. Furthermore, the figure also shows that the displacement is larger in the middle than in the upper and lower parts.

CONCLUSIONS

The 3D numerical modelling shows as follows:

- Displacement is predicted to be very small during the initial stages, its magnitude ranging from several centimetres to a few centimetres. The displacement will gradually increase with the rising impounded level. When the impounded level is 1850 m, the displacement is largest between the secondary sliding surface and the tertiary sliding surface and the slope will partially fail. The deformation and damage become greater and wider possibly leading to partial failure when the impounded water level reaches 1880 m.
  Deformation of the main sliding surface is small after reaching 1880 m impound water level, so, on the whole, it is still stable, and it is the middle-superficial layers of the slope that are most affected.

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