Study of the formation mechanism for the Dongxi slope in the three gorges reservoir area of China

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Abstract: The Three Gorges Reservoir project on the Yangtze River is one of the biggest hydropower projects in the world. Chongqing province is the main reservoir area. Dongxi slope lies at Dongxi town in Chaotian County, Chongqing. The slope consists of bedded soils. It is steep sloped in the lower and upper parts and gentle in the middle. An important road and the Lanchengyu petroleum pipeline cross the slope. If the slope fails, it will do harm to the road and the pipeline and it will lead to the loss of the property, and possibly loss of life of the people who live in the town. The stability data for the slide show that it is stable under the natural conditions but it will suffer either creep deformation or mass instability under storm or storm and earthquake conditions.

Résumé: Les travaux des trois gorges sont les plus grands travaux du monde. La ville Chongqing est la région principale du réservoir. Le glissement de terrain Dongxi localise à la commune Chongqing du quartier Chaotian. Le glissement de terrain se compose par le sol stratifié. Il y a la rampe abrupte au bord derrière et devant. Le centre est à faible plongement. Une route principale et un pipe-line Chengyulan traverssent le corps du glissement de terrain. S'il y aura l'instabilité. La route et le pipe-line seront détruits. Il y aura le perte des biens et des blessés. Les résultats stables montrent qu'il est stable à la période normale. Mais, à la période de l'orage ou l'orage plus la sismique, il est possible de perdre sa stabilité.

Keywords: reservoirs, failures, engineering geology, deformation, slope stability, landslides

INTRODUCTION

The Three Gorges Reservoir project on the Yangtze River is one of the biggest hydropower projects in the world. Chongqing province is the main reservoir area. Dongxi slope lies at Dongxi town in Chaotian County, Chongqing. An important road and the Lanchengyu petroleum pipeline cross the slope's front part.

In recent years, Dongxi slope has suffered deformation at different scales, each rainy season partial slumping leads to the road blocking which crosses the slope middle-front part. At present, it is temporarily stable, but in the rainy season, especially during heavy rainfall and storms, it will trigger a large scale sliding. If it fails, it will do harm to the road bend to Shaanxi province and the pipeline and it will lead to the loss of the property, and possibly loss of life of the people who live in the town.

SLOPE AREA SURVEY

The area is subject to a subtropical regions monsoon climate, with ample seasonal rainfall.. The main rainy season is May to September. It lies in a middle-low mountainous area in North Sichuan basin. Dongxi River which is one of branches of Jialing River is a incised river, and it is 'U' shape. It belongs to a tectonic denudation valley geomorphology. Its relief is high in the east and low in the west. The highest elevation point is 700 m, the lowest one which is Dongxi river valley is 565m. The front part one is close to the river, landform is steep, the degree of slope is 32° to 52°; the other is gentleness whose degree of slope is 15° to 30°. The dip direction of the slope is in concordance with the one of the rock stratum.

Geologically, the area mainly consists of Palaeozoic lower Ordovician system rocks and Quaternary (system) Holocene series deposits. The upper of slope debris is grey-yellow, and deep grey rock fragment and soil, slightly wet to wet, loose-slightly compact, hard plasticity, which consist of phyllite and quartzitic sandstone. The lower slope is grey-yellow crushed stone and soil which is structurally weak structure level, and it is distributed on the whole slope.

Loose rock pore water and rock bed crevice water are found in the ground water at the slope area. The former is mainly distributed in the debris, eluvium and slope wash of the slope. Its main recharge is from rainfall, its main discharge is infiltration from the phreatic water table and recharge rock bed crevice water. Other seeps are from the middle part of the slope and inflows of the Dongxi river. The latter is mainly distributed in the stronger weathering rock bed which several sets of joints are developing. Its main recharge is from the phreatic water of the soil layer. Its main discharge seeps from the base of slope or directly inflows Dongxi River.

The analysis of samples of groundwater and surface water shows that it is without colour and its PH is 7.5~7.6, which belongs to the HCO2-, SO42--Ca2+ type; it has no corrodibility to concrete.

The neotectonic movement mainly occurred during the later folding period – Yanshan period. Strongly ascending motion made the crust rise and so rivers eroded, mountains are steep, terraces are not developed during the Yanshan cycle, which involved landslides and slope debris etc. Unfavorable engineering geological phenomena are developing along the Jialing River and its branches. Most of the slopes were formed in this period and so will trigger a lot of large-scale slopes movements.

According to the results of monitoring, there is no large-scale seismicity in the area, and according to the national map of seismic intensity zoning (1:3,000,000) and the Chinese map of seismic intensity zoning (1990), the basic seismic intensity is VII.

CHARACTERS OF THE SLOPE

Characteristics of the slope's boundaries, scales and configurations

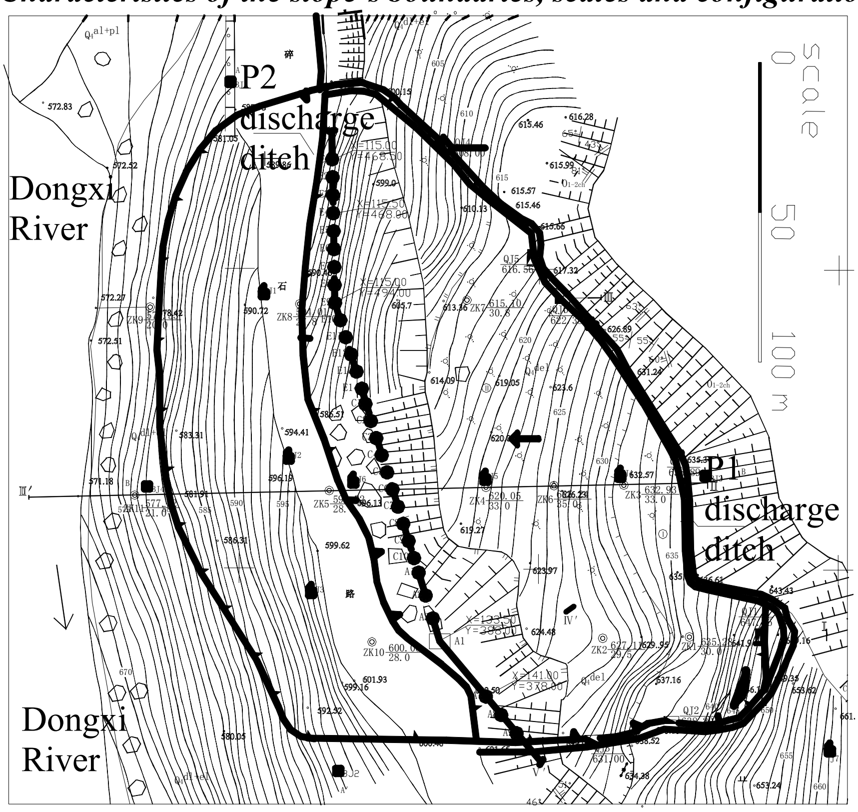

Figure 1. Map of Dongxi Slope

Dongxi slope has been reinvestigated in the recent years. It has a bowl-like shape, that is, its boundary is defined. The elevations of the upper parts is 635~650 m. Its northern upper parts are close to the ridge of the mountains and the south part has a curved tensile crack. The lower parts lie on the sloping ground between the Dongxi river and the road with elevations of 580~586 m. The difference of elevation is 44~60m between the upper parts and the lower parts.

The length of the slope is about 85 m. Its width is about 100 m and its area is about $8.5\times10^3 m^2$. The average thickness of the slope is 8.8~14.2 m, so its volume is $94\times10^3 m^3$.

- The macroscopic characteristics are as follows:
- The enclose bowl shape is well developed, and there is evidence of two-stages of sliding.
- Below the northern rock cliff is evidence, and there are titlted trees which grow during the slope development , that is, the tree trunks are curved and there are slide debris on the middle-upper parts too.
- The attitudes of bed in the slope are disordered.

According to the investigation data, the shape of the sliding surface is arcuate and at an angle of 5°~ 26° in the middle to upper parts.

Characteristics of the slope deformation

In recent years, Dongxi slope has suffered deformation at different scales. During each rainy season the slope suffers different types of sliding deformation in the different parts, especially the front part. In September, 2001, after cutting the road to serve the petroleum pipeline, a series of tensile cracks occurred and parts in the back of the road slid outwards several centimetres. For the moment, deformation characteristics of each part is as follows:

Deformation characters of the upper section

Because of the amount of movement, the displacement can be clearly seen. The vertical displacement of the tensile crack is 2 m near to the mountain ridge in the north, and the horizontal width is 0.4 m. There were a series of tensile cracks whose widths are from 2 mm to 50 mm. Depth is 100 mm and they extended about 10 m. The first-level sliding terrace is at an elevation of 632~633 m.

Deformation characters of the middle section

There are tilted trees and landslide debris on the middle parts. The second-level sliding terrace is in this part at an elevation from 614 to 619 m in the front part.

Deformation characters of the lower section

The deformation characters as a whole are not seen. There are no tensile and shearing cracks but there is some evidence of uplifts.

Deformation characters of the boundary parts

The north boundary is the cliff; there was evidence of slipping here. There were a series of shearing cracks whose widths are from 2 mm to 20 mm. Depth is 30 mm in the southern part. The lower shear plane is also evident, and the landslide slides along the bedrock. At present, it is temporarily stable as a whole; the deformations are stronger in the upper and middle sections of the slope and its boundaries and there are uplifts in the lower section of the slope.

INFLUENCING FACTORS OF THE SLOPE

The survey showed that the deformation of the slope is increasing. By analyzing the deformation characteristics, we know its causation and formation mechanism. It is important to evaluate its stability and establish the geological model and consider preventative measures. It is obvious that different triggering methods will cause different types of slope reactivation. So, it is necessary to study the slope development and scale of the slope reactivation under different influencing factors and find out the main ones and common ones.

Topographical conditions

The landslide area is steep sloped in the lower and upper parts and gentle in the middle. Its angle of slope is from 32° to 52° in the lower and upper parts and from 15° to 30° in the middle. Its enclosed bowl shape is very evident, that is, the north (upper) part is a cliff, the right boundary is the mountain ridge, the lower part is close to Dongxi river. In other words, the lower part has a favourable deformation space that is unfavourable for stability. The topographical condition is one of important influencing factors.

Lithological condition

The slope debris consists mainly of loose rock fragments and clay and its higher hydraulic permeability makes it susceptible to groundwater seepage. The slope debris is thick. The lower slope debris consists of phyllite which is a relatively water-resisting layer, but joints are developed which are affected by groundwater leading to their strength decreasing. So, the lithological conditions are also one of important influencing factors.

Water influencing the slope stability

The groundwater is recharged mainly from rainfall, which infiltrates into the loose rock fragments and clay of the middle and upper sections of the slope leading to increased the moisture content. This leads to reduction of strength of the loose rock fragments and clay that is disadvantageous for stability. So, the water is also one of important influencing factors.

Human engineering activities

Human engineering activities trigger deformation of the slope and failure. The main influencing factors are as follows:

- The base of slope was excavated because of extension of the road that leads to the formation of favourable deformation space that is unfavourable to the stability of its upper parts;
- The farmers irrigate their farmlands and this leads to the water infiltrating into the loose rock and soil; it is unfavourable to the stability of the slope.

Earthquake activity

Because of earthquake activity, the propulsive force and pore water pressure that leads to slope failure will increase. Furthermore, it will decrease the strength of the rock and soil that is unfavourable to the stability of the slope.

ANALYSIS OF FORMATION MECHANISM OF THE SLOPE

According to the analysis of the deformation influencing factors of the slope and the investigation data, the slope is a bedded soil one consisting of loose rock fragments and soil. The weak interbed was formed by the erosion and softening of water between the soil and bedrock. The weak interbed little by little became the sliding plane by the lasting effect of water. The loose material will easily slide along the sliding surface because its upper part is steep because of gravity action, especially in the saturated condition. The lower part has a deformation space available that is necessary to the failure of the slope. Furthermore, the deformation is accelerated by the human engineering activities. Under all the above conditions, the reactivation of the slope has been triggered.

STABILITY ANALYSIS

A representative section was selected (Figure 2) and stability coefficients of the ABC section and ABD section were calculated one by one under different engineering conditions. The parameters for the calculation and the stability coefficients are as follows:

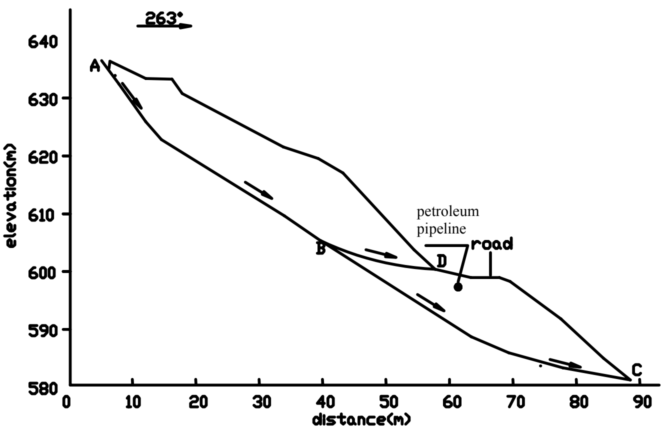

Figure 2. Cross Section of Dongxi slope

Table 1. The parameters for the calculation

Parameter	Natural condition			saturated condition		
Sliding plane	ρ (kN/m^3)	C (Kpa)	φ(°)	ρ (kN/m^3)	C (Kpa)	φ(°)
ABD Sliding plane	**21**	**25**	**28**	**22**	**19**	25
ABC Sliding plane	21	25	28	22	19~23	25~27

The calculated factors of safety show that the ABC part and ABD parts of the slope are stable or relatively stable under natural or earthquake conditions. Its factor of safety will quickly decrease and the slope will suffer either creep deformation or mass instability under storm or storm and earthquake conditions. The calculated factor of safety of the ABD section is less than the one of ABC section, so the ABD section is more likely to fail under the same condition. The calculated result is in accordance with observations.

CONCLUSIONS

According to the factors given above, the conclusions are as follows:

the reactivation of the slope is the result of the particular geological environment and human engineering activities in the area.

The presence of loose rock material is the intrinsic factor that contributes to the slope's reactivation, and human engineering activities and rain trigger this reactivation.

There is more deformation in the upper parts and the boundary parts but deformation of the lower parts are not evident.

The stability data for the slide show that it is stable under the natural conditions but it will suffer either creep deformation or mass instability under storm or storm and earthquake conditions.

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