Stability analysis and treatment scheme of unstable slope in Tianshui Maijishan International Center

Wenwen Li[1], *Yan Liu*[1*], *Genzhu Guo*[2]
1.Gansu Forestry Vocational and Technical College, Gansu Tianshui 741020
2.The First Geological and Mineral Exploration Institute of Gansu Bureau of Geology and Mineral Resources, Gansu Tianshui 741020,

Abstract: through the field investigation of the slope of Maijishan international camping center in Tianshui, the deformation and failure characteristics of the slope are analyzed; Combined with geotechnical engineering exploration technology, the deformation and failure mechanism of the landslide in the international center is discussed; The stability of landslide is analyzed by transfer coefficient method. The results show that the landslide of Maijishan International Center in Tianshui is induced by earthquake and belongs to earthquake rainfall coupling landslide. The landslide mass is relatively stable in natural state. Under rainfall and earthquake + rainfall conditions, the unstable slope is in an unstable unstable state. The landslide is treated by "anchor cable frame + slope toe retaining wall + peripheral drainage channel". The research results can provide practical basis for the deformation mechanism and disaster prevention and mitigation of earthquake induced landslides in Maiji District, Tianshui.

Key words: earthquake landslide; Stability analysis; Governance measures

Introduction

Tianshui is a typical mountain valley basin city. The Loess in the area is widely distributed, thick, vertical joints and fissures are developed, and rainfall is concentrated, resulting in vertical and horizontal gullies, fragmented landforms, and fragile geological environment. Under the influence of natural factors and human engineering activities, landslides, debris flows, collapses, unstable slopes and other geological disasters occur frequently. It has been found that there are 1578 potential geological hazard points in Tianshui City, including 1168 landslides, 212 debris flows and 198 collapses. With the further development of urbanization and Rural Revitalization Strategy, the geological environmental problems in the region will become more prominent. It is of great practical significance to carry out in-depth research and prevention of local landslide and debris flow disasters.

Maijishan international campsite complex project is a tourism complex integrating leisure vacation, outdoor sports, camping experience, children's entertainment, research and education, which is located on the north bank terrace of Yingchuan river. During the construction of the project, a 6-14m high engineering slope will be formed, which will seriously affect the normal construction and operation of the project. This paper will analyze the geological environment background of the unstable slope based on field survey, on-site mapping and engineering survey, focusing on the study of the formation mechanism and stability of the slope, in order to provide technical support for disaster prevention and mitigation in the region.

1. Overview of geological environment background

The project is located in the first terrace of Yingchuan River, with the terrain generally inclined to the valley, high in the northeast and low in the southwest. The geomorphic unit belongs to Yingchuan River Valley accumulation area and loess hilly area. The exposed strata at the site are mainly silt, gravel sand and silty clay accumulated by Quaternary sliding, round gravel, gravel sand and Neogene mudstone accumulated by Quaternary alluvial proluvial deposits. The region is located in the Yinchuan Tianshui Wudu belt in the middle of the North-South seismic belt of Liupanshan, and the intersection of the East-West seismic belt in the northern margin of Qinling Mountains and the Tianshui Lanzhou belt in the middle, which makes the structure of the region very complex, and the faults and folds are very developed, showing a certain correlation with the distribution of geological disasters. According to historical records, since 186 B.C., the seismic zone has recorded 24 earthquakes with $m \geq 5$, including 20 earthquakes with $m \geq 6.0$-6.9, 7 earthquakes with $m \geq 7.0$-7.9, and 11 earthquakes with $m \geq 8$. The intensity and frequency of seismicity are high, with obvious characteristics of cluster distribution, and the activity trend of active quiet alternating.

The neotectonic movement is dominated by uneven intermittent ascending and descending movement, which is manifested by the deep cutting of river valleys and the formation of Yingchuan river terraces. The annual average precipitation in Tianshui area is 491.6mm, the maximum continuous precipitation in the area is 286.6mm, the daily precipitation is 113mm, and the maximum hourly precipitation is 57.3mm. Precipitation is unevenly distributed throughout the year. The precipitation from June to September accounts for 70% of the annual precipitation, and most of them occur in the form of heavy rain and rainstorm.

2. Disaster mechanism of disaster body

According to the field survey, there is an old landslide H1 in the loess hilly slope in the southeast of the proposed site. The landslide is irregular "dustpan shaped", with obvious high-level pull marks on the rear wall of the landslide, and the slope body is in the East— in the west direction, the slope aspect is 250 ° - 255 °, the overall slope is 10-30 °, the slope surface is stepped, the width of the steps is 5.0 ~ 15.0m, the longitudinal length of the landslide is about 280 ~ 320m, the average width is about 145m, the average thickness of the landslide is about 15m, and the landslide volume is about 65.3m×104m3, belonging to medium-sized landslide.

Figure 2-1 overall basic characteristics of H1 landslide

The field survey results show that the H1 landslide accumulation body is mainly composed of loess, mudstone and gravel. The loess is light yellow and yellow silty clay and silt, and the brownish red mudstone is mainly in lumps, mixed with calcareous and argillaceous nodules, which are unevenly distributed, with a layer thickness of 1.2-5.5m. The Neogene mudstone has low diagenesis and poor water permeability, which is easy to collect water and soften with water, reducing its strength. It is comprehensively determined that H1 landslide is an earthquake landslide, which is mainly reflected in: 1) the rear wall of landslide slope is high. The high tension surface is located at the top of the slope, which is formed by the overall downward displacement of the soil at the top of the Loess beam; 2) The stratigraphic sequence is disordered. The seismic landslide has large kinetic energy and long sliding distance, which makes the gravel layer and maroon mudstone appear intermittently in clusters, and the mudstone occurrence angle is 4-10 ° greater than the regional contact angle; 3) The slope platform is stepped. The non-uniform propagation of seismic wave causes the shear failure of some soil near the slope. Under the action of seismic wave vibration, the slope soil is loose and piled up, and the cracks are developed. Under the later weathering, frost heaving and hydraulic erosion, the slope is fragmented, forming numerous rills and tributaries. Under the action of short-term concentrated rainfall, it is easy to destabilize and damage again, such as the formation of secondary landslide. According to previous studies of domestic scholars, the damage of loess slope induced by rainfall is mainly manifested in:1) the surface water infiltrates into the interior of loess body, increasing its weight, increasing its sliding force, softening the soil body, and reducing its shear strength; 2) Water infiltrates along the joints and fissures of soil mass, and the intervention of water reduces the effective stress and forms a weak channel; 4) The groundwater is recharged by the infiltration of surface water, resulting in the buoyancy effect on the rock and soil mass.

3. Overview of unstable slope

According to the site visit, the sliding time of H1 landslide is unknown, and no casualties have been caused in history. At this stage, the H1 old landslide mass has no obvious signs of overall deformation. Due to the excavation of the front edge of the slope toe of H1 landslide mass by engineering construction, bw1 and BW2 unstable slopes are formed:

3.1 basic overview of bw1 unstable slope

Bw1 unstable slope is developed at the foot of the Yingchuan river terrace slope on the north side of the commercial street, and is distributed in an “armchair” shape as a whole. According to the planning, it needs to occupy the site at the foot of the slope, with a longitudinal length of about 27m and a width of 143m, resulting in a 4-9m high slope. The total plane area of the slope is about 4438m2, and the slope aspect is 236-266 °. At the top of the slope is a landscape Avenue with a planned width of 6m, and at the foot of the slope is a campsite business street, mainly with 2F pavement.

The material composition of bw1 unstable slope is mainly composed of landslide accumulation layer containing sandy gravel silty clay, and the soil structure is loose. Two obvious deformation tension cracks can be seen at the slope village road. After the slope toe is artificially cut and reconstructed, the slope body is gentle up and steep down in a broken line shape, the front edge of the slope body is steep, the relative height difference of the slope body is large, and the free space conditions are superior. According to the engineering survey data, there is lenticular sand gravel layer in the middle and upper part of the slope toe, with a thickness of about 3.5m, an extension length of 47m and an inclination of 23 °, which is a channel for groundwater enrichment and transfer.

3.2 basic overview of BW2 unstable slope

The BW2 unstable slope is developed at the foot of the Yingchuan river terrace slope on the north side of the dormitory building, and is generally distributed in a “strip” shape. According to the planning, it needs to occupy the site at the foot of the slope, with a longitudinal length of about 16m and a width of 94m, resulting in a 12-14m high slope, with a total plane area of about 1445m2 and a slope aspect of 265 °. The top of the slope is a landslide platform formed by the old landslide, with a width of about 55m. At the foot of the slope is 4f dormitory building in the campsite.

The material composition of BW2 unstable slope is mainly the silty clay of landslide accumulation layer, and the soil structure is loose. According to the field investigation, no obvious deformation characteristics are found at the front and rear edges. After the slope toe is transformed by artificial slope cutting, the slope body is gentle up and steep down in a broken line shape, the front edge of the slope body is steep, the relative height difference of the slope body is large, and the overhead conditions are superior. At the same time, according to the engineering survey data, there is lenticular sand gravel layer in the middle and upper part of the slope toe, with a thickness of about 2.0m, an extension length of 24m and an inclination of 18 °.

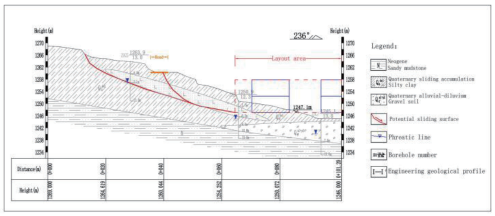

Figure 3-1 typical engineering geological map of BW1 slope

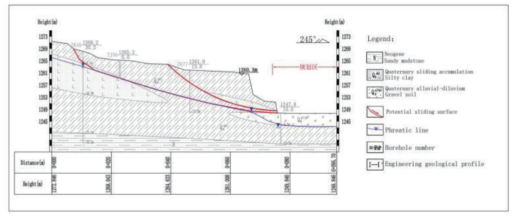

Figure 3-2 typical engineering geological map of BW2 slope

4. Stability calculation of unstable slope

Considering that the slope is an old landslide accumulation body with uneven soil and high water yield sandy gravel layer, and the groundwater level is located near this layer, combined with the field investigation and engineering survey report, it is comprehensively determined that the slope instability at the toe of the slope is a discounted sliding, and the instability of the homogeneous silty clay layer is a circular sliding. The calculation formula is as follows:

$$K_f = \frac{\sum_{i=1}^{n-1}(((W_i((1-r_u)\cos a_i - A\sin a_i) - R_{Di})\tan f_i + C_i L_i)\prod_{j=i}^{n-1} y_j) + R_n}{\sum_{i=1}^{n-1}((W_i(\sin a_i + A\cos a_i) + T_{Di})\prod_{j=i}^{n-1} y_j) + T_n}$$ Including:

R_n-$W_n((1-r_u)\cos a_n$-$A\sin a_n)$-$R_{Dn})\tan f_n$+$C_nL_n)T_n$-$W_n(\sin a_n$+$A\cos a_n)$+T_{Dn}

Where:y_j——Transfer coefficient;

WI - gravity of the i-th block (kn/m);

CI - cohesion of block soil in article I (kPa);

f_i——Article I internal friction angle of block soil (°);

Li - length of sliding surface of the i-th block (m);

a_i——Inclination angle of sliding surface of section I (°);

A - seismic acceleration;

r_n——Pore pressure ratio;

K_f——Stability coefficient;

4.1 selection of calculation section and determination of parameters

The section II - II ‘is selected to calculate and evaluate the stability of bw1 slope, and the section V - V’ is selected to evaluate the stability of BW2 slope. The potential sliding surfaces are broken line sliding of gravel layer and silty clay along the groundwater table and arc sliding in silty clay layer.

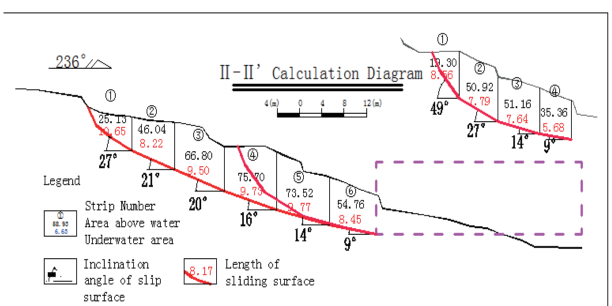

Figure 4-1 BW1 slope calculation model

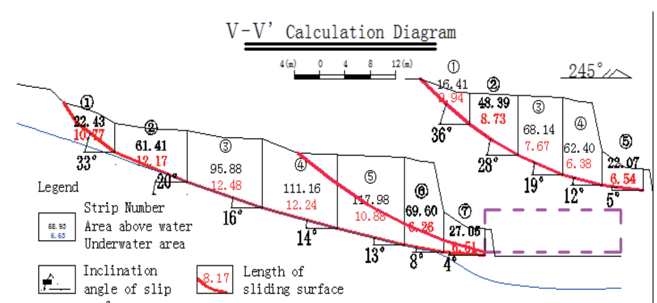

Figure 4-2 BW2 slope calculation model

4.2 Analysis and value selection of physical and mechanical parameters of rock and soil mass

A) . gravity of rock and soil mass

According to the indoor geotechnical test, the natural weight of silty clay in tj56 exploratory well (upper platform of BW2 slope) is 1.79~1.86g/cm3, and the saturated weight (saturation > 85%) is 1.89~1.94g/cm.

B) Shear strength parameters

The shear strength of sliding zone soil is determined according to the test results and back analysis.

Inversion value: according to the field investigation, the shallow layer (IV - IV ‘) of the current bw1 unstable slope has slipped. According to the exploration, the sliding surface is above the groundwater level. Therefore, the value of stability coefficient in the inversion process is as follows: restore the IV - IV' section of BW2 slope to the original ground, and the original slope shape is similar to the V - V 'section of BW2 slope, Under the condition of "self weight + rainstorm", the stability coefficient is taken as 0.98 to calculate its shear strength.

According to the laboratory test and inversion analysis, combined with the regional experience, the values of soil shear strength parameters are shown in table 4-1.

Table 4-1 values of rock and soil parameters for stability calculation

Rock and soil mass	Natural gravity (kn/m3)	Saturated gravity (kn/m3)	Shear strength				
			Value taking method	Natural state		Saturation state	
				Cohesion c (kPa)	Internal friction angle (°)	Cohesion c (kPa)	Internal friction angle (°)
gravel	/	21.8	Comprehensive value	/	/	10.0	27.8
Silty clay	18.5	19.2	Comprehensive value	18.5	21.5	17.8	20.3

4.3 Calculation condition

During the engineering survey, the water level of the exploration hole was measured. According to the investigation, the groundwater level can be seen in most of the boreholes, and the basic seismic intensity in the project area is VIII. According to the working condition requirements of the technical code for design and construction of landslide prevention and control engineering (dz/t0219-2006), the landslide stability is considered to be calculated under the following three working conditions:

② Working condition II: self weight + (groundwater), considering self weight and additional load, CφValue and natural bulk density, below the groundwater level, take the saturated shear strength and saturated bulk density.

③ Working condition III: self weight + rainstorm + (groundwater), water level rises by 1.6m, and above the water level, CφValue and natural unit weight of sliding mass, the following is CφValue, unit weight when saturated.

④ Working condition IV: self weight + earthquake + (groundwater), CφAccording to the technical code for building slope engineering gb50330-2013, the horizontal seismic influence coefficient is 0.025.

Table 4-2 stability calculation results

Disaster name	Section number	Calculation condition	Stability coefficient	stable state	safety factor
Bw1	IV - IV 'section	Working condition II	1.082	Basically stable	1.30
		Working condition III	1.045	Unstable	1.15
		Working condition IV	0.945	Unstable	1.15
BW2	V - V 'section	Working condition II	1.093	Basically stable	1.30
		Working condition III	1.053	Unstable	1.15
		Working condition IV	0.945	Unstable	1.15
	V - V 'section (shallow layer)	Working condition II	1.089	Basically stable	1.30
		Working condition III	0.097	Unstable	1.15
		Working condition IV	0.948	Unstable	1.15

4.5 Preventive engineering measures

According to the geological environment, slope structure, geotechnical engineering geological characteristics, causes and deformation factors of unstable slope, the comprehensive treatment measures of "anchor cable frame + slope toe retaining wall + peripheral drainage channel" are proposed.

Obvious tension cracks can be seen in the middle and upper part of bw1 unstable slope. Partial sliding has occurred in the shallow surface of the slope toe section, resulting in inconsistent slope types. Therefore, anchor cable frames are arranged within 1249 ~ 1258m of the surface elevation of the slope toe to anchor the slope. The slope is cleaned and straightened, and the slope is trimmed according to 1:2.3 near the service center (MS-1 anchor cable frame), The slope surface at the back of the commercial street shall be trimmed according to 1:1.5 (MS-2 anchor cable frame). One anchor cable frame shall be laid longitudinally and 18 anchor cable frames shall be laid horizontally. Each piece is 8.0m high and 9.0m wide. Each piece has three rows and three rows of anchor cables, with a vertical spacing of 2.5m and a horizontal spacing of 3.0m.

Table 5-1 calculation of allowable minimum cross-sectional area of anchor rod

slope	Standard value of Anchor Cable axial tension NAK (KN)	Tensile safety factor of anchor rod KB	Design value of tensile strength of reinforcement or prestressed steel strand FY or FPY (MPA)	Sectional area of reinforcement or prestressed anchor cable asmin (mm2)
Bw1	303.42	2.0	1320	460
BW2	457.11	2.0	1320	693

According to the calculation, MS-1 anchor cable and MS-2 anchor cable adopt 4φS1524 high strength low relaxation prestressed steel strand, MS-3 anchor cable adopts 5φS1524 high strength low relaxation prestressed steel strand.

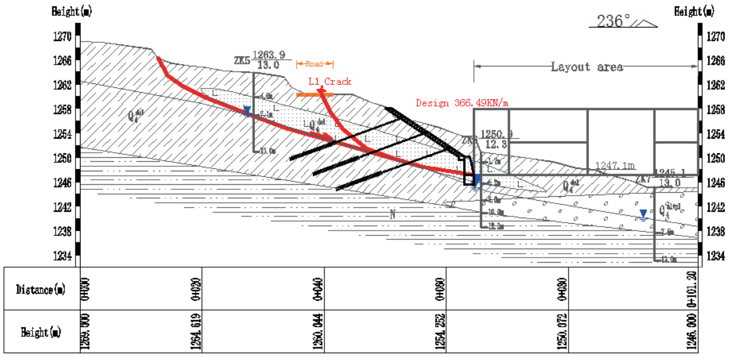

Figure 5-1 profile of typical treatment works

5. Conclusion

(1) The old landslide in Maijishan International Center was induced by earthquake and distributed in an armchair shape on the plane, with the distribution characteristics of long sliding distance, high and steep rear wall of the landslide and stepped sliding mass. The sliding mass is a mixture of Quaternary loess, gravel and Neogene mudstone, and the sliding bed is strongly weathered mudstone, belonging to loess mudstone landslide.

(2) The precipitation of Tianshui is unevenly distributed throughout the year. The precipitation from June to September accounts for 70% of the annual precipitation, and mostly occurs in the form of short-term heavy rainfall. As a result, rills and gullies on the slope of Maijishan International Center are developed, and the terrain is fragmented. Under the excitation of multiple rainfall, it is easy to cause the instability and failure of the high and steep free surface again.

(3) The unstable slopes bw1 and BW2 formed by engineering construction are analyzed by transfer coefficient method. The results show that the slope is basically stable in natural state; Under rainstorm conditions, it is in an unstable state; Under the condition of earthquake + rainstorm, the slope will lose stability and damage again, threatening the commercial street below. The slope is treated by “anchor cable frame + slope toe retaining wall + peripheral drainage channel”.

References:

[1] Guoqiang Yu etal Development characteristics and cause analysis of “7.25” mass flash flood geological disaster in Tianshui City [j]Northwest geology, 2014.3 (47): 185-191

[2] Sen Huang Research on early warning model of “7.25” mass rainfall landslide disaster in Tianshui City [d]Northwest University, 2021

[3] Xiao Tong,Jianbing Peng,Xinghua Zhu,Penghui Ma,Zhenjiang Meng Analysis and prevention of landslide and debris flow in honghuazui gully of Tianshui City [j]Soil and water conservation research, 2016,23 (03): 343-347+353

[4] Yanyu Shen etal Preliminary study on formation conditions of Tianshui mountain landslide [j]Resources, environment and engineering, 2013,27 (2): 193-195

[5] Yuxiang Cheng etal Correlation between fault activity and geological disasters in Tianshui area [j]Journal of engineering geology, 2007 (01): 33-37

[6] Chenghang Zhang,Maosheng Zhang,Guoqiang Yu Characteristics and mechanism of mass geological disasters in Tianshui City [j]Water and soil conservation bulletin, 2016,36 (04): 46-50+55

[7] Cunlin Xin etal Types and causes of geological disasters in Beishan Mountain, Tianshui City, Gansu Province [j]Chinese Journal of geological hazards and prevention, 2012, 23 (2): 89-95

[8] Shuxuan Zhang etal Cause and stability analysis of Hongqishan loess landslide group in Tianshui, Gansu [j]Geology of China, 2017,44 (05): 924-937

[9] Zhiliang Zhang The activity of the western end of the fault zone on the northern margin of the West Qinling Mountains and its impact on the Xining Chengdu Railway scheme [j]South China earthquake, 2020,40 (02): 85-91

[10] Yue Li,Yongjun Zhu,Qingyun Zhao, etal. Variation characteristics of maximum daily precipitation and estimation of possible maximum daily precipitation in Tianshui, Gansu □ J □. Drought meteorology, 2015, 33 (4): 581-586

[11] Qiang Feng,Chuan Tang,Ming Chen, Lingfeng Gong Investigation and analysis of “8.20” dengxi gully debris flow disaster in miankan Town, Wenchuan earthquake area [j]Journal of disaster prevention and mitigation engineering, 2022,42 (01): 51-59

[12] Peng Cui,Jianqi Zhuang,Xingchang Chen, etal. Characteristics of debris flow activities after Wenchuan earthquake and Countermeasures [J].Journal of Sichuan University: Engineering Science Edition, 2010, 42 (5):10-19

[13] Fanfa Huang,Jiawu chen,Xuanmei Fan,Jinsong Huang,Chuangbing Zhou Logistic regression fitting of rainfall induced landslide time probability and continuous probability landslide risk modeling [j/ol]Earth Science: 1-25 [January 11, 2023]

[14] Haizhi Liu,Hui Xu,Hongjun Bao,Wei Xu,Xufeng Yan,Chengpeng Xu Analysis of threshold characteristics of regional rainfall induced landslide [j]Journal of natural disasters, 2021,30 (04): 181-190

[15] Chenghang Zhang etal Characteristics and mechanism of mass geological disasters in Tianshui City [j]Water and soil conservation bulletin, 2016,36 (4): 46-50