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# Finite-Element Numerical Analysis and Developmental Characteristics of the Yushu Xihang Hydropower Station Landslide

Hou Xiaoqiang[1] and Zhang Shimin[2]

[1] Gansu Construction Vocational Technical College, Lanzhou, Gansu, China
[2] School of Civil Engineering, Lanzhou University of Technology, Lanzhou, Gansu, China

**Abstract.** The Yushu Xihang Hydropower Station landslide, has serious potential geological hazard and endanger the municipal engineering and public property, which are estimated nearly 1.2 billion yuan, at the slope toe on both sides of the Xihang west road and ShengLi road. Within the scope of the landslide, there are about 500 households and 1600 people in danger. According to the size, developmental characteristics and influence factors of the landslide after the field investigation, the finite-element numerical simulation method was taken to do the stability analysis under the earthquake and rainfall conditions. Also, referring to the plastic penetration zone of the simulation, the shear outlet was judged. These work will provide reliable basis for further retaining engineering measures to treat the landslide.

**Keywords:** Yushu Xihang Hydropower Station, Landslide, Stability Analysis, Plastic Penetration Zone, Shear Outlet.

## 1. Introduction

Seismic geological disasters have the great potential of damage, so the indirect damage of its induced landslide, collapse and debris flow is much larger than the direct earthquake damage[1,2]. The Yushu earthquake occurred on April 14, 2010 in Qinghai Province. According to the China earthquake networks center (CENC) measured data, the earthquake epicenter location is 33.1 N °, 96.7 E °, the focal depth 33 km and magnitude Ms7.1 (to be exact, its epicenter location 33.2 N °, 96.6 E °, its focal depth 4 km after correction)[3]. This earthquake has induced serious geological disasters, such as landslide. And, Xu et al scholars investigated the Yushu earthquake landslide characteristics and types, and analyzed its generating mechanism[4]. The Yushu Xihang Hydropower Station landslide (YXHSL), as one of the landslides induced by the Yushu earthquake, has many arc tensile fractures on the landside mass and has great possibility of crack and collapse on the side rock. Once the whole instability of the YXHSL occurs, it will jeopardize the front commercial or residential building blocks. Combined with Yushu seismic landslide characteristics[5], the deformation characteristics of the landslide plastic penetration area and cut export position were analyzed through the finite element numerical simulation.

## 2. The Engineering Geologic Condition

The landform types of the YXHSL slope belongs to tectonic erosion mid-high mountain, being composed of the Trias limestone and slate, with elevation decreased south-north topography extended with highest elevation 4150m. The landform type of the east side of the YXHSL is mainly constituted of the flat and open river terraces with banded south-north strike, which is long of 100m and wide of 180m, and belongs to tectonic erosion mid-low mountain with southwest high and northeast low topography and elevation 3691-3695 m.

## 3. The Developmental Characteristics of the YXHSL

## 3.1. The space form and scale of the YXHSL

The rear edge of the YXHSL shows as round chair shape, forming a finger shape terrain,and the front resembles a tongue. The profile of the YXHSL presents as a steep folding lines shape slope and has a steep in top and gentle in lower morphology with whole grade 40°-55°. The elevation of the YXHSL is range of 3719.7-3910.2 m, the south-north directional length of the YXHSL toe is about 170m and the length between the front to the rear edge about 245-363m. The attitude difference between the front to the rear edge is 123-176m. The landslide body thickness is 7.2-33.0m with average thickness 18m. The front width is 175m, and central and rear width 80-140m. The area covers 3.89 x 104 m2, and the volume 70.07 x 104 m3, so this is a medium-sized landslide. The sliding direction is nearly 79°. The front presents as irregular arc, and the rear edge presents as steep round chair shape with height 39.7m.

## 3.2. The characteristics of the YXHSL body

The exploration engineering confirmed that a continuous slide surface has formed under the YXHSL body. The slide surface shows as a dustpan concave with dip direction 79° and dip angle 20-30°. The thickness of the sliding body changes greatly, so the rear and side burial depth is 0-7.2m, and the central and front burial depth is 12.8-33.0m. The overall slide body characteristics is that the central and top is thick and the south-north side thin, and the front is thick and the rear thin.

The ground investigation and drilling reveals that the landslide body is composed of loess and gravel soil, and the loess mainly presents as brown yellow, slightly wet and dense, low dry strength, poor toughness and medium vibration response, and the gravel soil presents as brown yellow and pewter, slightly wet and dense or medium dense, with maximum gravel size 180mm and general size 20-40mm, greater than 20mm size accounted for 55-65% , 2-20mm size accounted for about 35% and others being soil and bits of sand, and gravel soil has poor grinding roundness and mainly is composed of limestone with edge or hypo-edge angle. The slide bed consists mainly of, the Batang Formation of the upper Triassic(T3), and fully or strongly weathered pewter limestone which is easy weathering and has low intensity with the attitude 23°∠42°.

The surface water and spring are not found in the landslide, but the loosing-rock pore water is found on the rear edge of Grade I terrace of Batang river which is out of range of the YXHSL toe. The field drilling investigation of groundwater reveals that the buried depth of the underground water is 7.5-10.2m, and the aquifer thickness more than 8 m in the toe front(namely outside of the landslide range and no effect on the landslide ). After the earthquake the YXHSL sliding deformation are mainly embodied as shear outlet and heave in the front edge.

## 3.3. The seismic fortification characteristics of the yushu region

According to the Code for Seismic Design of Building (GB50011-2010), the seismic fortification intensity of Yushu is 7 degrees. The basic earthquake acceleration value is 0.15 g, and the characteristic period of the seismic response spectrum is 0.45 s [6].

## 3.4. The parameters of YXHSL rock masses

The indoor test on the rock mass sampling of YXHSL mainly carries on the physical and mechanical properties and grain composition analysis. To reduce the influence of the heterogeneity and discreteness of the rock soil on the statistical indicators, the weighted average statistics method is adopted to deal with the physical and mechanical data. The Indoor shear strength test results show that the natural peak C for the gravel soil is 29-33kPa, with the mean 36kPa and the standard value 33kPa , and the natural peak φ is 24.0-31.5°, with the mean 30.4°and the standard value 29.7°. The single axis compressive strength of the bedrock ( T3 Trias limestone) in the natural state is 23.8-72.3MPa, with the mean 46.5MPa and the standard value 28.9MPa, and in the saturated state is 11.2 ~ 48.0MPa, with the mean 29.5MPa and the standard value 22.6MPa. The natural peak C of the shear strength for the bedrock is 3.9 ~ 20.6KPa, with the mean 11.7KPa and the standard value 6.5KPa, and the natural peak φ is 30.7 ~ 34.8 ° with the mean 32.7 ° and the standard value is 30.9 °. Considering the influence of the large particles dropped to do the indoor sampling and test on the physical and mechanical properties parameters, so the parameters for the numerical application should be corrected combined with the engineering experience (see Table 1).

Table 1: The physical and mechanical parameters

| stratum | Cohesive force C/KPA | | Friction angle φ/ ° | | Elastic modulus E(MPA) | Poisson ratio μ | Unit weight /KN/m³ | |
|---|---|---|---|---|---|---|---|---|
| | N | S | N | S | | | N | S |
| Loess | 24 | 16 | 26 | 18.2 | 40 | 0.36 | 18.0 | 18.5 |
| Gravel soil | 31 | 18 | 30 | 28 | 65 | 0.30 | 20.6 | 21.7 |
| Bedrock | 60 | | 32 | | 120 | 0.2 | 22.5 | |

Note: N and S represents the natural and saturated state.

# 4. The Finite Element Analysis of Landslide

## 4.1. The finite element theory

Fast Lagrangian method is one kind of numerical analysis method based on the explicit finite difference which can simulate rock or other material mechanics behavior. The calculation area is divided into several units, and each unit follows the linear or nonlinear constitutive relation under given boundary conditions. If unit stress makes the material yield or produce plastic flow, the unit grid can deform along with the material deformation. So this algorithm is very suitable for simulation of deformation problem [7].

Strength reduction algorithm usually being used for slope analysis, it is the ideal elastic finite element calculation that gradually reducing the geotechnical shear strength parameters until the slope reach damage state, and automatically stopped according to the elastic-plastic calculation results and the failure sliding surface formation(namely the plastic strain and displacement break belt formation), meanwhile, the strength reserve safety factor of the slope was get[8].

$$c' = c / f \tag{1}$$

$$\tan\varphi' = \tan\varphi / f \tag{2}$$

The shear strength reduction method completely integrates the strength reduction technology and numerical simulation methods. Under given evaluation indicators, it obtains the minimum safety factor of slope stability by adjusting the reduction factor to analyze the slope stability. Its advantages as follow: 1. The safety factor can be obtained directly, without the need to assume the slippage form and position, still can consider slope progressive failure process. 2. Because the finite element method meeting the overall static permission, strain compatibility and the stress-strain constitutive relation, don't introduce assumed conditions, and can maintain the close theory system. 3. Not restricted by the geometry of the slope or the material inhomogeneity for the numerical analysis method. So it is an ideal way to analyze the slope stress, deformation and stability[8].

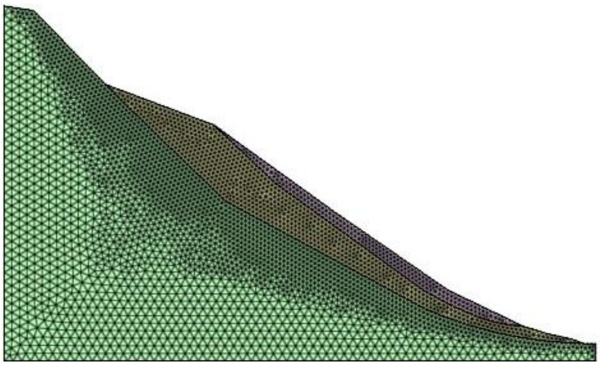

Fig. 1: Two-dimensional finite element model of the YXHSL

## 4.2. The finite element model of the YXHSL

Midas/GTS is one finite element software developed for geotechnical engineering, which has concise interface, before and after processing functions and powerful geotechnical material model library. Using the strong geometric modeling and the grid division technology, complex grid model can quickly and easily be created in the Midas/GTS interface. Also, it can meet most of the rock mass failure mode. So using this software to develop a numerical model of landslide is close to the truth condition, and the calculation results are relative safety[9]. According to the engineering geological conditions and the YXHSL slope body structure characteristics, representative geological section selected to establish two-dimensional finite element model(see Fig.1), computing based on the mohr-coulomb yield criterion and dividing by the triangle unit, is divided into 6637 nodes, 3454 units.

## 4.3. The finite element simulation of the YXHSL

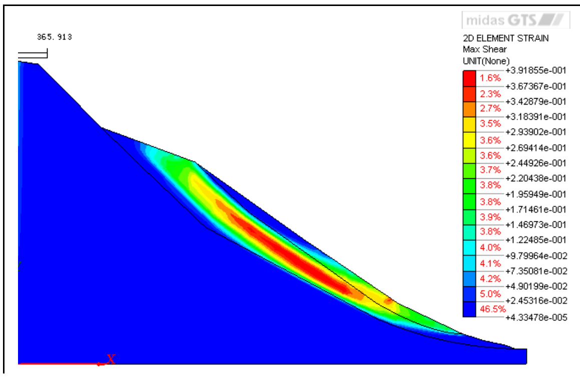


Fig .2: The natural condition safety factor 1.1375

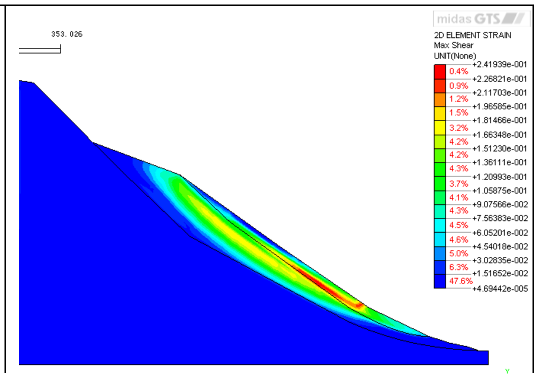


Fig. 3: The rainfall condition safety factor 0.9875

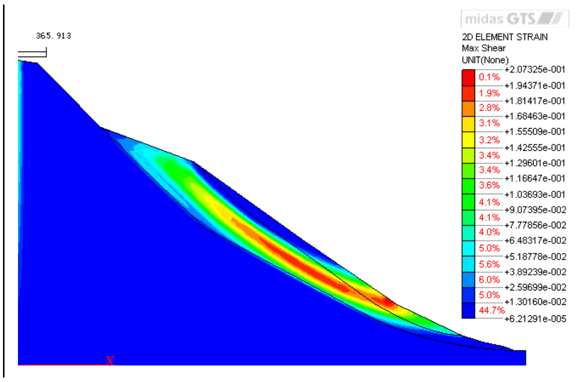


Fig. 4: The earthquake condition safety factor 0.9825

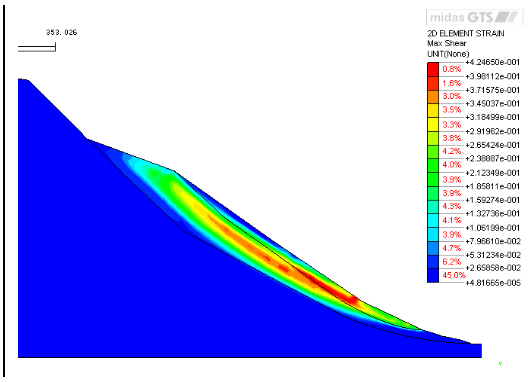


Fig. 5: The earthquake + rainfall condition safety factor 0.9375

Plastic penetration phenomenon, only happens in the soil element under plastic state. The displacement mutation phenomenon certifies that the soil cannot afford existing load in slip direction, so resulting displacement liquidity. Using finite element to do landslide stability analysis and sliding surface ascertainment mainly are base on the plastic strain contour map, plastic zone nephogram and numerical convergence of the minimum safety factor to judge the landslide stability and whether the plastic penetration zone exist. Meanwhile it also can accurately captured from the toe to the top of landslide that the plastic zone development process, plastic extended range, plastic location, plastic strain change, and the specific failure state.

The YXHSL is respectively analyzed under the natural, rainfall, earthquake, earthquake+rainfall condition. And, the landslide failure state is judged through the plastic shear nephogram, plastic contour map and minimum safety factor variation. Under the natural condition (Fig.2), the plastic penetration zone is not completely formed at the bottom of the toe, which in the gravel soil, the shear strain is larger and in range of 0.367-0.391. Still part of bottom gravel soil and loess toe zone is not fully formed plastic zone with decreasing shear strain in range of 0.264-0.318. The whole landslide with safety factor 1.1375 is in a stable state. In rainfall condition(Fig.3), the plastic penetration zone is fully formed at the bottom of the toe, which in the loess layer, the shear strain is larger and in range of 0.211-0.241. In the gravel soil zone, the shear strain is sharply decreased and in range of 0.166-0.196. So the shallow loess formed plastic penetration zone, with the whole safety factor 0.9875, is in unstable state. In the earthquake condition (Fig.4), the plastic penetration zone is completely formed in deep layers, which in the loess layer and gravel soil layer, the shear strain is in ranges of 0.181-0.207. The deep layers with the whole safety factor 0.9825 is in the unstable state. In the earthquake + rainfall condition (Fig.5), the plastic penetration zone is completely formed in deep layers, which in the loess layer, the shear strain is larger and in range of 0.371-0.424, and in the gravel soil layer, the the shear strain is larger and in range of 0.345-0.371. The deep layers, with the whole safety factor 0.9375, is in the unstable state.

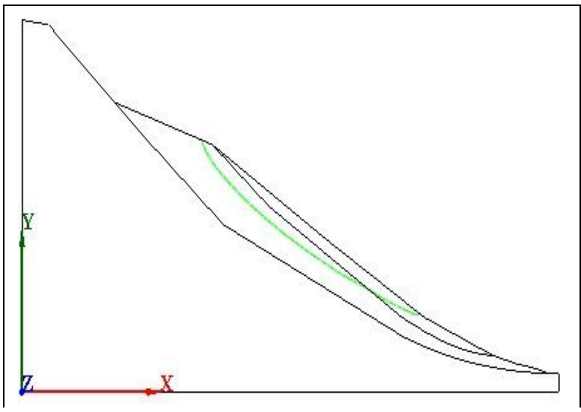


Fig. 6:The rainfall condition safety factor 0.9875

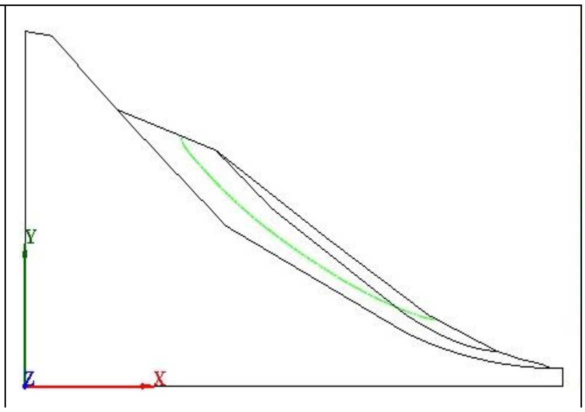


Fig. 7: The earthquake condition safety factor 0.9825

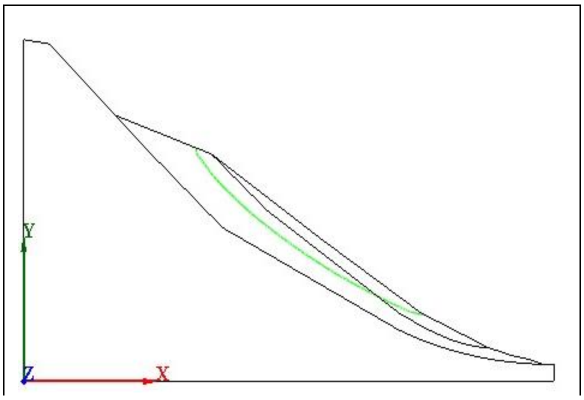


Fig. 8: The earthquake + rainfall condition safety factor 0.9375

From Fig.6 to Fig.8, it can be found that the sliding surface is nearly the same pattern and all cut through the loess layer and gravel soil layer with a smooth curve in three given conditions, namely not sliding on any interface of layers, also the landslide shear outlet position is almost the same and consistent with the ground shear outlet and heave position. For three condition, the thickness of the landslide are different, and the thickness in the earthquake condition is biggest, due to the applied 0.15 g horizontal seismic force and the reduced rock mass stability. In the rainfall and rainfall + earthquake conditions, the shallow landslide happens, owing to the increased soil bulk density, the significantly reduced C, φ value and the significantly reduced sliding stability of loess layer and gravel soil layer in the saturated state. So under different conditions, the sliding surface and pattern and the thickness of the landslide is different and not linear with the safety factor or the condition complexity, but the change of the geotechnical physical must be take into consideration and needs further researched.

## 5. Conclusions

Based on the harm degree, the development characteristics and the finite element simulation of stability analysis of the YXHSL, conclusions are getting as follow:

1. The shear outlet position of the finite element simulation is nicely consistent with the shear outlet and heave position investigated in the YXHSL site. So it is further suggested that the finite element simulation is reliable and can be used to providing basis for the landslide control measures.

2. By the results of the finite element simulation, the landslide all cut through the stratum in three conditions, not sliding on any interface of the stratum.

3. Through observing the plastic zone extension, the plastic zone development process, plastic extended range, plastic location and plastic strain change can be accurately captured from the toe to the top of YXHSL. Also it is useful to judge the specific failure state.

4. Under different conditions, the sliding surface and pattern and the thickness of the landslide is different and not linear with the safety factor or the condition complexity, but the change of the geotechnical physical must be take into consideration.

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