Analysis and evaluation of development characteristics of debris flow in Longshougou

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Abstract. Long Shougou is located at the exit of Hei he River in Zhang ye City, which is directly facing the reservoir of Long Shougou Hydropower Station. Through site survey, UAV flight and indoor simulation calculation, the development characteristics and risk of Long Shougou debris flow were analyzed and evaluated. The results show that: Long Shougou debris flow is in the "development period", belonging to "small", "easy" and "high frequency" debris flow; The length of Long Shougou Channel is 1.70 km, the circumference is 3.76 km, the area is 0.72 km^2, the relative height difference is nearly 584 m, the longitudinal gradient is 342.27 ‰, and the overall bending coefficient is 1.14; Gully sediments are mainly gully bed deposits and slope collapse deposits, with total reserves of 20.94 ×104 m3 and dynamic reserves of 7.76 ×104 m^3; Calculated according to the designed rainstorm frequency of 1%, the flow velocity of debris flow at the gully mouth is 2.64m /s, the total amount of primary overflow is 17,296.41m^3, the primary outflow of solid matter is 7956.35m^3, and the overall impact pressure of debris flow is 16.32kPa. The maximum impact force of a single stone is 2.56kN according to 0.5m; It is suggested to consider the impact of the annual inflow of debris flow on the water quality of the Longshou hydropower station reservoir and the impact on the power station switching station near the Gulou port, and do a good job in the relevant sediment discharge measures.

Key words: LongShou Gully; Debris flow; Formation conditions; Development characteristics; Risk assessment

1. Introduction

Debris flow is one of the most common natural disasters in mountainous areas, it is a high concentration of solid and liquid mixed flow containing a lot of solid materials (mud, sand, stone), with explosive and sudden, fierce, destructive characteristics [1].Once the debris flow breaks out, the downstream towns, roads, cultivated land and existing buildings will be seriously damaged in an instant, and the safety of people's lives and property will also suffer huge losses. The formation condition analysis and risk assessment of debris flow are important components of debris flow prevention and control [2]、[3] 、[4].In recent years, many scholars and geologists have done a lot of research on the causes, processes and prevention measures of debris flow disasters from different angles. Yang Qiang et al. [5]analyzed the formation conditions of 241 debris flows in the middle and upper reaches of Bailong River Basin on the basis of analyzing the disaster modes, disaster causing modes and debris flow prevention and control, and determined the division of multiple sources and disaster modes of debris flows. Shang Yingqi et al. [6] analyzed the formation conditions, ditch characteristics and development trend of Tanguanguou debris flow, and identified the development characteristics and harm degree of Tanguanguou debris flow. Zheng Guoqiang [7]analyzed the formation conditions of debris flow from the three aspects of the channel topography, potential material source and water source of Wenma high-speed Pingqiao Ditch, calculated the potential outflow amount, and evaluated its risk. Ma Siqi et al. [8]studied the source characteristics and influencing factors of debris flow in Siergou and used FLO-2D software to simulate and analyze the risk of debris flow, providing geological basis for disaster prevention and reduction of debris flow in the area. Zheng Ruijie et al. [9]calculated the dynamic parameters of debris flow in Niupengzigou and analyzed the disaster characteristics of debris flow. CFX software based on finite volume method was used to simulate the movement and accumulation process of possible debris flow in Niupengzi ditch. Zhao Yupeng et al. [10]used Massflow software to simulate and reproduce the dynamic process of debris flow in gully and valley, and obtained the dynamic characteristics of debris flow under the combination of "wide and slow or narrow steep gully + wide and slow main gully". These studies provide reference for the evaluation and treatment of similar geological hazards.

The formation of debris flow is related to factors such as topography, geology and hydrological conditions[11]. The characteristics of debris flow distribution in China are regional. Debris flow is mainly distributed in the southeastern margin of the Qinghai-Tibet Plateau and surrounding areas of Sichuan Basin, etc. Due to the special climate, topographic and geological conditions in northwest China, debris flow is also relatively developed[11].

Based on previous studies and relying on the construction of a hydropower station in Zhangye City, Gansu Province, this paper analyzed the formation conditions, development characteristics and mechanical parameters of the Longshougou debris flow through field investigation, UAV flight and indoor simulation calculation, and carried out the risk assessment of debris flow, providing a theoretical basis for the subsequent prevention and control of debris flow.

2. Basin characteristics

2.1 Landform

Longshougou is located on the east side of Pandao Mountain in Zhangye City, and is connected with Longshou Hydropower Station reservoir (Heihe River Basin) in Upper gully area, with an overall direction of nearly southeast. According to the survey, the total length of Longshou Ditch is 1.70 km, the circumference is 3.76km and the area is 0.72 km2. The terrain in the basin is high in the north to the west and low in the south to the east. The highest elevation is 2330m, and the lowest is the Heihe elevation 1746m, with a relative elevation difference of nearly 584m. The section shape of the gully is asymmetrical "V" font (see Fig.1).

Fig.1 Overall terrain characteristics of LongShougou

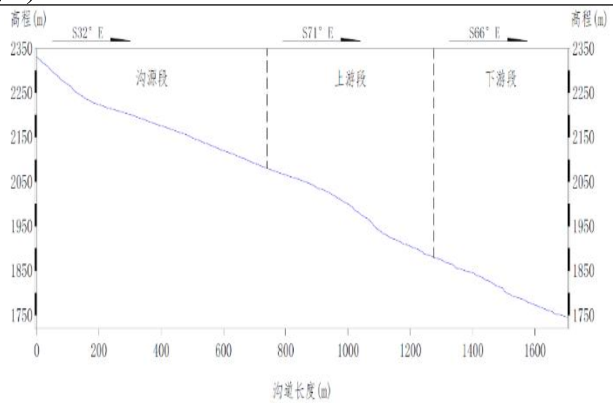

Fig.2 LongShougou longitudinal profile

2.2 Segmentation feature

According to the terrain characteristics of the gully and the longitudinal profile of the gully (see Fig.2), Longshou Gully is divided into three sections: the source section, the upper section and the lower section. Gully bed gradient is not only an important control factor for the initial runoff of debris flow, but also a decisive factor for the level of debris flow potential energy, which controls the formation and movement characteristics of debris flow[12]. River bed gradient of different sections is shown in Table.1.

The trench length is 0.74km, the elevation is 2080 ~ 2330m, the relative elevation difference is 40 m, and the width is 15 ~ 20m. The slope of this section is steep, about 30°~40°, and the gradient is large, which is 337.84‰. The channel is relatively straight, and the bending coefficient is 1.10, which is a U-shaped valley. There are more branch trenches and larger catchment area, which provides a larger catchment area for the formation of debris flow.

The upstream ditch is 0.53km long, the elevation is 1880 ~ 2080m, the relative elevation difference is 80m, and the width is 20 ~ 30 m. The slope of this section becomes steeper, about 40°~50°, and the gradient becomes larger, which is 377.36‰. The channel becomes straight, and the bending coefficient is 1.08, which is a V-shaped valley. The catchment area is relatively small, the vegetation of gully is sparse, and the erosion and weathering of rock mass are serious, which provide topographic conditions for the flow and migration of debris flow.

The downstream ditch is 0.43km long, with an elevation of 1746~1880m, a relative elevation difference of 20m, and a width of 10~15m. The slope of this section becomes slow, about 25°~35°, and the gradient becomes smaller, which is 311.63‰. The channel becomes curved, and the bending coefficient is 1.23, which is a V-shaped valley. The catchment area is relatively small, the vegetation in the channel is sparse, and the erosion and weathering of the surface rock mass are serious, which provides the topographic conditions for the accumulation of debris flow.

The overall slope of Longshou Ditch is steep, and the average longitudinal gradient is large (342.27 ‰). The overall channel is relatively straight, except for the local sharp bends in the downstream, and the overall bending coefficient of the channel is 1.14.

Table.1 Statistical results of bed gradient in different sections of LongShou Gully

section	Trench bed elevation range /m	Trench length/m	Channel bending coefficient	slope/‰
Gully source member	2080～2330	0.74	1.10	337.84
Upper section	1880～2080	0.53	1.08	377.36
Downstream section	1746～1880	0.43	1.23	311.63
average	/	/	1.14	342.27

3. Formation condition

3.1 Topographic condition

The study area belongs to the Zhangye Basin and the northern margin of Qilian Mountains in the south, and the study area belongs to the denudation and erosion alpine landform. Longshougou Gulou is located at the edge of the tertiary planation plane on the top of Pandao Mountain, with an elevation of 2286 ~ 2346 m. The mouth of the ditch is opposite and converges in the reservoir of Longshou Power Station, with an elevation of about 1746m and a relative elevation difference of 584m. The cutting depth is relatively deep, the slope is large, nearly 40°~60°, the gully and beam are interphase, the small gully is relatively developed, the bank slope on both sides is steep, the vegetation coverage is low, and the material source is sufficient, which provides better topographic and hydrodynamic conditions for the occurrence of debris flow.

3.2 Provenance condition

Provenance conditions, as sufficient conditions for the formation of debris flow[13], determine the scale and influence range of debris flow development[14] Through the field investigation and the laboratory classification test, according to the causes, they can be divided into gully bed alluvial sediments, landslide sediments and slope erosion sediments (Fig. 3~Fig. 5). Longshougou gully has large cutting depth, large bank slope on both sides of the basin, low vegetation coverage rate, and obvious development of alluvium deposits in gully beds, mostly SLATE fragments, accumulate from gully source to gully mouth, and participate in debris flow activities in the form of bottom erosion. The development degree of landslide deposits is moderate, and they are generally gradually eroded and transported by rain and deposited in gullies and slopes. Slope erosion source is one of the typical sources of debris flow gully, and the development degree is relatively small, mainly due to the water and soil loss of slope body and the formation of cover layer under the action of rain erosion, and the erosion of right bank slope is more serious than that of left bank slope.

Fig.3 Alluvial deposit source

Fig.4 Deposit source of landslide deposit

Fig.5 Characteristics of slope erosion sources

Fig.7.Characteristics of the upper section of debris flowaccumulation area

The statistical results of debris flow source in Longshougou are shown in Table.2. The total resource reserves in the basin are 20.94×104m3 and the dynamic reserves are 7.76×104m3. The total reserves of gully bed alluvial and diluvial sources are 8.18×104m3, accounting for 39.1% of the total, and the dynamic reserves are 4.09×104m3, accounting for 52.8% of the total dynamic reserves. The total reserves of landslide deposits are 7.94×104 m3, accounting for 37.9% of the total,and the dynamic reserves are 2.66×104m3, accounting for 34.1% of the total dynamic reserves. The total reserves of slope erosion sources are 4.82×104m3, accounting for 23.0% of the total, and the dynamic reserves are 1.01×104m3, accounting for 13.0% of the total dynamic reserves.

Gully bed alluvial sediments are the most important source of debris flow, followed by landslide sediments, and slope erosion sediments are the least. It shows that the source characteristics are closely related to channel morphology and material composition characteristics.

Table.2 Statistical table of debris flow sources in Longshougou Basin

Provenance category	alluvium Source of accumulation	Landslide deposit Source of accumulation	Slope erosion source	total
Total reserves /×$10^4\,m^3$	8.18	7.94	4.82	20.94
Dynamic reserves /×$10^4\,m^3$	4.09	2.66	1.01	7.76

3.3 Water source condition

Water source condition is the most common triggering and promoting effect in debris flow disaster. When the loose deposits on the surface of the channel are soaked by the water source, the original mechanical properties of the deposits are changed, and the force promoting sliding is generated.

Located in Zhangye City, Gansu Province, Longshougou Basin is a cold temperate continental arid climate with an average annual precipitation of 198mm, with the highest rainfall from July to September. It is mainly supplied by atmospheric precipitation and has an average annual temperature of 7℃. Strong solar radiation, sufficient sunshine, scarce precipitation, large evaporation; The temperature difference between day and night is large, the summer is short and hot, and the winter is long and cold. Longshou Gully is characterized by "steep, narrow and long", which provides strong hydrodynamic and erosion (pressure) force for debris flow migration. Therefore, debris flow disasters occur frequently in the rainy season, and the probability of debris flow formation is greater under the conditions of heavy rainfall.

4. Basic characteristics

4.1 Partition feature

According to the characteristics of Longshougou and source distribution, the distribution area of debris flow is divided into circulation area, circulation accumulation area and accumulation area, as shown in Fig.6.

The flow area is the gully source section (2080~ 2330m), which has steep slope, large gradient, more branch gullies, large catchment area and good hydrodynamic conditions. The flow is smooth, the slope erosion source is more concentrated, which is conducive to the accumulation of material source.

The flow accumulation area is the upstream section (1880~2080m), the channel becomes steeper, the gradient becomes larger, the channel width becomes narrower, and the catchment area becomes smaller, which is conducive to the flow of debris flow sources. The sources of sediments are concentrated, the debris flow is washed and silted, and the sediments appear simultaneously in the ditch.

The accumulation area is the downstream section (1746~1880m), the channel becomes slow, the ratio becomes smaller, near the mountain pass, the accumulation becomes thicker, the particle size near the channel mouth gradually decreases, and the material source finally flows into Longshou Reservoir.

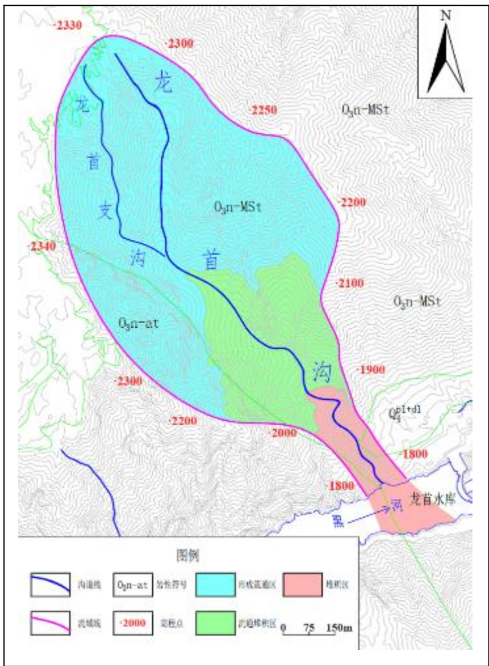

Fig.6 Plane distribution area of debris flow

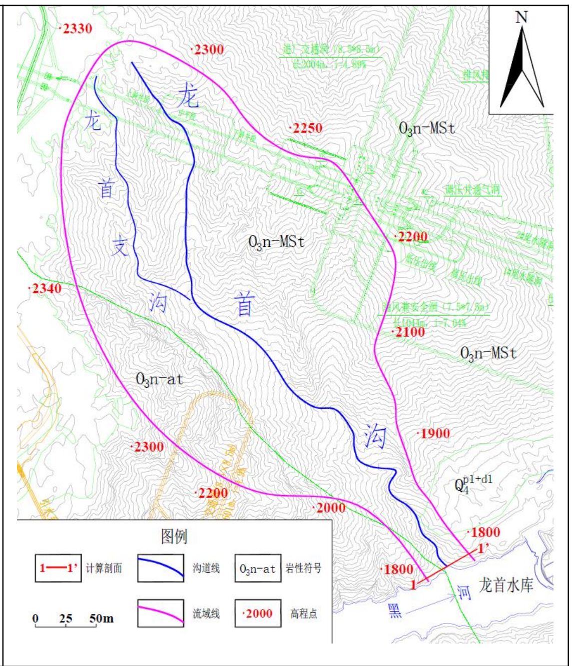

Fig.8 Calculation profile layout of LongShougou

4.2 Deposit characteristics

The characteristics of debris flow deposits are mainly manifested in particle size composition, gradation, uniformity and sorting, etc., which is the basic basis for determining fluid properties of debris flow and calculating subsequent characteristic values [15].

According to the field investigation in the study area, the physical characteristics of deposits developed in the upper and lower sections of Longshougou have obvious differences. The deposits in the upper section are mainly composed of lumps (Fig. 7), with particle size >20 cm accounting for 40%, 6 ~ 20cm for 30%, 2 ~ 6cm for 20%, and the rest <2cm. The deposits in the lower section are mainly composed of gravel (Fig. 3), with particle size >20cm accounting for 10%, 6 ~ 20cm for 20%, 2 ~ 6cm for 50%, and the rest <2cm. It shows that the particle size is smaller the closer to the lower section after the long-term erosion and accumulation of the channel, which is basically consistent with the characteristics of alluvial and diluvial sediments and slope and diluvial sediments.

4.3 Qualitative characteristics of debris flow

According to the 《Debris Flow Disaster Prevention Engineering Survey Code》[16] various factors or identification markers are evaluated and obtained:

(1) Among the 16 characteristic indicators of Longshougou debris flow, except for 3 items of "main river type, main river mainstream and loose matter storage", which are inconsistent with the characteristics of "development period (mature period)", the other 13 characteristic indicators are consistent with the characteristics of "development period (mature period)". It is concluded that the development stage of Longshougou debris flow is "development stage", which belongs to heavy rain, gully and mud-rock debris flow.

(2) According to the quantitative evaluation table of debris flow gully prone degree [16], the evaluation score of Longshougou debris flow is determined to be 110 points, which falls within the range of 87-115 prone interval values, and belongs to the "prone" type debris flow.

5. Dynamic characteristics

5.1 Calculated profile setting

The dynamic characteristic value of debris flow is mainly calculated by setting the typical section, which is generally set in the position with obvious characteristics, rather than in the place with large slope, complex deformation and engineering construction. The location of typical section of Longshougou debris flow is shown in the figure, taking section 1-1 'as an example.

5.2 Severe

The above analysis has determined that the quantitative evaluation score of the prone degree of debris flow in Longshougou is 110 points. According to Table G.2[16], the debris flow severity is 1.759t /m3 and the solid material severity is 2.65t /m3.

5.3 Flow rate

There is no fixed and unified method to calculate the source of debris flow at present [17] and the most commonly used method is storm flood. Since there is no clear manual for the calculation of debris flow in Gansu Province, the formulas listed in 《the Manual for Calculation of Rainstorm and Flood in Small and Medium-sized River Basins in Sichuan Province 》(which has been reviewed and used by experts for many years, and its applicability and accuracy have been verified) were combined to calculate the relevant parameters in Gansu Province to ensure the accuracy and credibility of the results.

The storm flood flow Qp is calculated as follows:

$$Q_p = 0.278\psi \frac{S}{\tau^n} F \tag{1}$$

Calculate the peak flood flow according to the following formula:

$$Q_c = (1+\phi) Q_p \cdot D_c \tag{2}$$

When the design rainstorm frequency P=0.5%、1%、2%、5%、10% , the storm flood flow Qp is 13.63 m3·s-1、11.46m3·s-1、9.55m3·s-1、7.08m3·s-1、5.30m3·s-1 ,respectively；The peak flow QCS were 50.93m3·s-1、42.81m3·s-1、35.67m3·s-1、26.45m3·s-1、19.82m3·s-1,respectively.

5.4 Velocity of flow

The velocity of debris flow is closely related to discharge, bulk density, material composition, gradation composition and other elements in the channel[18]. According to the field investigation results, the flow velocity of dilute debris flow is calculated according to the Tieryuan formula stipulated in the code:

$$V_C = \frac{1}{\sqrt{\gamma_H \cdot \varphi + 1}} \cdot \frac{1}{n} \cdot H_c^{\frac{2}{3}} I_c^{\frac{1}{2}} \quad (3)$$

When calculating the flow velocity of debris flow, the problem of mud depth under the overflow flow of debris flow with different frequency of rainstorm will be encountered. Generally, the mud depth of debris flow mud mark corresponding to a certain rainfall frequency is obtained by on-site mud mark investigation and visit. However, it is difficult to correctly identify the mud depth corresponding to the mudflow mud mark position corresponding to a certain rainfall frequency in practical work. The mud depth of debris flow under different frequency rainstorm can be obtained by calculating the width of cross section flow, the calculation formula of debris flow flow under different frequency rainstorm and the calculation formula of debris flow velocity.

$$V_C = \frac{Q_C}{A} \quad (4)$$

$$A = B \cdot H_C \quad (5)$$

In combination with (4) and (5) :

$$H_C = \left(\frac{Q_C n_c}{I_C^{1/2} B} \right)^{5/3} \quad (6)$$

When the design rainstorm frequency P=0.5%、1%、2%、5%、10% , the average velocity of the section is 3.20m·s-1、2.64m·s-1、2.16m·s-1、1.55m·s-1 and 1.12m·s-1 , respectively. The average mud depth is 0.64m、0.48m、0.36m、0.22m、0.13m , respectively.

5.5 Gross amount

（1）Total volume of one pass

The peak value calculated by the stormwater method of P=0.5%, P=1%, P=2%, P=5% and P=10% for each section is calculated according to the calculation formula provided in Appendix I of the specification [16] :

$$Q = 0.264TQ_c \quad (7)$$

（2）A solid flushes out the total amount of matter

The solid effluents of a debris flow are calculated according to the calculation formula provided in Appendix I of the Code [16] :

$$Q_H = Q(\gamma_c - \gamma_w)/(\gamma_H - \gamma_w) \quad (8)$$

When the design rainstorm frequency P=0.5%, 1%, 2%, 5% and 10%, the total amount of primary overflow is 20574m3、17296m3、14410m3、10686m3、8005m3 , respectively. The solids flushed out were 9464m3、7956m3、6628m3、4915m3、3682m3 respectively.

5.6 Impact force

（1）Overall thrust pressure of debris flow

The overall impact pressure of debris flow is calculated according to 《the formula stipulated in the Design Code for Debris Flow Disaster Control Engineering》 (DZ/T 0239-2004) :

$$P = \lambda \frac{\gamma_c}{g} V_c^2 \sin \alpha \quad (9)$$

The calculation process mainly selects the section of the engineering part to be laid for calculation. The building form factor is λ=1.33 for rectangular buildings.

（2）Maximum impact force of a single stone

The maximum impact force of a single block of stone is calculated according to the formula and combined with the characteristics of debris flow deposits investigated on site, the maximum impact force of a single block of stone with a particle size of 0.5 m is calculated:

$$F_s = \gamma \cdot V_C \cdot \sin\alpha \cdot \sqrt{\frac{W}{C_1 + C_2}} \quad (10)$$

When the design rainstorm frequency P=0.5%, 1%, 2%, 5% and 10%, the overall impact pressure is 24.0kPa、16.32kPa、10.88kPa、5.60kPa、2.95kPa , respectively. The maximum impact force of a single stone is 3.10kN、2.56kN、2.09kN、1.50kN、1.09kNrespectively.

5.7 Height of climb and maximum surge height

Calculation of debris flow climbing height and maximum thrust height according to Appendix I of code [16] :

$$\Delta H = \frac{V_c^{\ 2}}{2g} \quad (11)$$

$$\Delta H_c = \frac{bV_c^{\ 2}}{2g} \approx 0.8\frac{V_c^{\ 2}}{g} \quad (12)$$

When the design rainstorm frequency P=0.5%, 1%, 2%, 5%, 10%, the climbing height is 0.84m、0.57m、0.38m、0.20m、0.10m , respectively. The maximum lifting heights were 0.52m、0.36m、0.24m、0.12m、0.06m , respectively.

The total amount of debris flow depends on the frequency of heavy rain and the duration of debris flow induced by heavy rain. The duration of debris flow directly affects the estimation of debris flow and solid matter. Since there is no record of the duration of debris flow activity in this area, it is difficult to estimate the debris flow and the total amount of solid matter of a debris flow activity correctly. Based on the comprehensive consideration of factors such as trench area, trench length and slope, catchment area topography, vegetation and other conditions, combined with reports or literatures of similar projects, it is determined that the duration of debris flow activity is about 2000 s, and the total amount of debris flow once in 100 years under the design rainstorm frequency of flood in the accumulation area is: Q=17296.41 m3。

The flood control standard of the hydropower station is once in 100 years, and the frequency of P=1% is used in the design. The average mud depth of the mouth of the Longshougou debris flow is 0.48 m, and the flow velocity of the debris flow is 2.64 m/s.

6. Debris flow risk assessment

The scale of debris flow disaster can be divided into four levels: small, medium, large and super large according to the amount of solid material rushed out at one time [14].

The design standard of the hydropower station in Zhangye City is once every 100 years, and the design parameter is P=1% frequency. The calculation results of dynamic characteristic values show that the total amount of debris flow at one time is 7956.35m3, which is less than 1× 104m3 and is considered "small". The peak flow of debris flow is 11.46m3 /s, less than 50 m3/s, which is "small", so the outbreak scale is comprehensively divided into "small" (Note: when the "total amount of a deposit" and "peak volume" are not at the same level, the scale level is determined according to the high principle).

Dear friend: The total amount of debris flow at one time is 17,296.41m3, the amount of solid outflow at one time is 7956.35m3, the vegetation in the ditch is sparse, the mountain cut by the ditch is deep, the slopes on both sides are seriously eroded, and the accumulation fan has obvious new scour marks. Combined with the local rainfall conditions, the frequency of debris flow at

Longshougou is once a year to 5 years. It is concluded that the occurrence frequency of debris flow in Longshougou is "high frequency" debris flow.

7. Impact of debris flow on existing buildings

Longshougou gully and its bank slope are steep, gully cut degree is large, gully bed longitudinal gradient is large, bank slope vegetation coverage is low, and the sediment source in the basin is rich. Under the comprehensive action of terrain and sediment source conditions, the possibility of debris flow in Longshougou is high, and it belongs to easy type debris flow. The reservoir of Longshou Power Station is opposite to the mouth of Longshou Gully, and the debris flow flows directly into the reservoir after the mouth of the gully, and the range of debris flow is large. The calculation results of flow velocity and outflow at the mouth of Longshou Ditch are shown in Table.3.

Longshougou belongs to high-frequency debris flow, is in the development stage, and the eruption scale is small. When the design frequency is 1%, the flow rate of debris flow can reach 2.64m /s, which is a fast speed. The total amount of debris flow at one time is 17296.41 m3 and the amount of solid outflow at one time is 7956.35 m3. Based on the above research data, it is suggested to consider the impact of the annual inflow of debris flow on the water quality of the reservoir of Longshou Hydropower Station and the impact on the corresponding buildings such as the switch station near the Gulou port, and do a good job in the relevant sediment discharge measures.

8. Conclusion

Combined with field investigation and data analysis, the following conclusions are drawn:

(1) The channel length is 1.70km, the circumference is 3.76 km, the area is 0.72 km2, the height difference is nearly 584m, the average longitudinal gradient is about 342.27 ‰, and the overall bending coefficient of the channel is 1.14.

(2) The sediment sources in the basin are mainly gully bed sediments and landslide sediments. The total reserves are 20.94 ×104m3, and the dynamic reserves are about 7.76 ×104m3.

(3) Calculated according to the design rainstorm frequency of 1%, the flow velocity of debris flow is 2.64m/s, the total flow of a single overflow is 17,296.41m3, the total outflow of a solid material is 7956.35m3, the overall impact pressure is 16.32kPa, the design rainstorm frequency of a single stone is calculated at 0.5 m, and the maximum impact force is 2.56kN.

(4) The comprehensive score of the vulnerability of debris flow in Longshougou was 110 points, and the development stage was "development stage", belonging to "small", "easy" and "high frequency" debris flow.

(5) The mouth of the gully is directly adjacent to the reservoir of the Longshou Hydropower Station. It is suggested to consider the impact of the annual inflow of debris flow on the water quality of the Longshou Reservoir and the impact on the corresponding buildings such as the switch station at the gully port, and take relevant sediment discharge measures.

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