Characteristics and Risk Assessment of Fluid Properties in Daqing Debris Flow

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Abstract. In the history of the Daqing debris flow development zone on the right bank of Dadan River in Lijiang, the debris flow disaster occurred many times, resulting in the destruction of the farmlands near the valley and the destruction of the road and bridge, which seriously threatened the safety of the lives and property of the nearby villagers. On the basis of the field investigation and sampling laboratory test of the Daqing debris flow basin and the analysis of the local hydrological and topographic features, the source and fluid characteristics of the Daqing debris flow are studied. On this basis, the risk of debris flow is evaluated; the development trend is predicted and the related protective measures are put forward. The research shows that the main source of the Daqing debris flow development zone is the loose solid particles; the reserves are 260 thousand cubic meters and the dynamic characteristics are obvious; the debris flow is in the strong period of the eruption of debris flow. Under extreme rainstorm conditions, the risk of debris flow is 0.59, which is moderately dangerous. So scientific and effective precautions should be taken to reduce the damage to the villagers and roads in the basin caused by debris flow.

Introduction

The Daqing debris flow development zone, located at the Hengduan Mountains, has active crust movement. It is one of the regions with the highest frequency of geological disasters in the northwest of Yunnan Province. Daqing gully, a major geological disaster site in Lijiang, has existed for many years and has experienced numerous large-scale geological disasters such as landslides, collapses and mudslides, which have had a tremendous impact on the livelihood of residents along the route. In particular, the effect of scouring and silting on the provincial highway S220 across the gully bridge is even more pronounced. Since both sides of the Daqing gully inhabited by a large number of villagers, the contradiction between man and land is tense. Excessive grazing and reclamation of wasteland lead to serious destruction of vegetation on the slope , then ecological imbalances are further aggravated. According to the field geological survey and related data, the Daqing gully is located on the right bank of the Cheng Hai fault zone. The surface bedrock is broken and the mountain high slope is steep. And the rock mass is easy to slide along the slope. Under the trigger of extremely heavy rainfall, the recurrence of mudslides is more likely. Therefore, it is necessary to analyze the physical and dynamic characteristics of Daqing debris flows to determine the danger of outbursts of Daqing mudslides and take effective protective measures to ensure the safety of life and property of local villagers and the provincial S220 bridge.

As a natural phenomenon widely distributed in mountainous regions, debris flow disaster is difficult to study systematically due to the late start of research, the cause of formation, and the complexity of movement laws[1]. However, the majority of experts and scholars are still exploring on the dynamic characteristics of debris flow, fluid structure and related risk assessments. Through field investigations, Yao Lanfei[2] combined with the background of debris flow disasters, built a risk assessment index system for debris flow based on previous research results, and established a risk assessment model based on the theory of grey clustering assessment and the theory of the connection and membership degree. Huang Xun[3] took the debris flow depth as the joint point, starting from the three perspectives of stress increase, strength attenuation and material basis, comprehensively considering the effects of debris flow shear stress, deadweight static force, pore water pressure change, and substrate volume reduction on the impact on the ditch material, as well as the mechanism of the instability of gully materials and their participation in debris flow activities. Cao Hongli[4] combined the watershed and dynamic characteristics of debris flow to simulate the movement process of Jinggou debris flow, reproducing the movement state, contact force, velocity and displacement of Jinggou debris flow.

Analysis of Physical Characteristics of Daqing Debris Flow

The physical characteristics of debris flow are generally described by the particle size distribution of the gully substance, which can better describe the source composition of the debris flow and the rules of erosion and deposition during the movement. It is an important means to study the debris flow handling, deposition and handling mechanisms. At the same time, it is also the basis for studying the characteristics of debris flow.

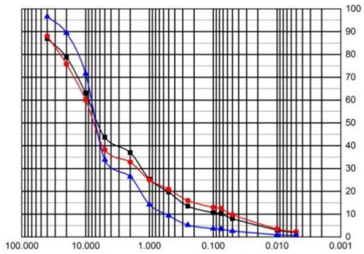
Site Survey Analysis. The main trench of the Daqing debris flow development zone has a total length of 750m with a relative height difference of 270m, the average gradient of the gully bed is 350‰. The three-axis measurements of the pebbles with a particle size greater than 60 mm are performed randomly every 2.5m along the axis of the main ditch. The mean value is taken as the average particle size, and the lithology of the particles is recorded. The statistical results show that basalt accounts for 41%, sandstone 31%, and shale, limestone, clastic rock, and a few other rocks account for 28% of the surface sediments in Daqing debris flow zone. The smaller particle size and better roundness are generally shale and sandstone. The particles with large particle size are generally basalt and limestone, but their roundness is poor, and the surface has different degrees of abrasion. It is shown that the collision and friction between the coarse particles in the process of fluid movement in the process of debris flow eruption is obvious, and it also reflects the strong impact force of the debris flow. The statistical gravel group was divided according to the scope of the "Standard for Soil Test Method" (GB/T 50123-1999)[5], and the percentage of different gravel groups was given, as shown in Table 1.

Table 1 The conglomerate division of Daqing debris flow gully

group name	boulder B	pebble CB	gravel soil(G, S, M, C)
size range(mm)	>200	60~200	<60
granularity percentage(%)	12.5	43	44.5

From the results of the gravel group, it can be seen that the Daqing debris flow fluvial sediments are dominated by Quaternary scouring and loose material; the particle size range is relatively wide; the number of gravel groups is also relatively large, and the ratio of large solids is 55.5%. This shows that the rich material in this area also verify the wide gradation characteristics of loose crushing debris in the gullies and the complexity of the fluid components during the outburst of debris flow.

Indoor Gravel Soil Grading Test. Partition sampling was performed on the Daqing debris flow development zone and brought back to the laboratory for air drying for screening tests to remove pebble granules with a particle size greater than 60 mm. Finally, gradation was finished based on the "Geotechnical Engineering Survey Specification" (GB50021-2009)[6]. Analysis of the test can obtain the particle size distribution curves of the partitioned deposits in the Daqing debris flow development zone, as shown in Figure 1.



Blue-forming area; Black-circulation area; Red-accumulation area

Fig.1 Grain gradation curve of the material source of the Daqing debris flow

It can be seen from the particle size distribution curve plot of Daqing debris stream source that the gradation curves of different regions are relatively steep, and there is little difference in the particle gradation curve between the accumulation region and the circulation region, and the formation gradation curve is lower. Among them, the content of clay less than 0.005mm is about 0.65% to 2.31%, the content of fine particles less than 0.05mm is about 2.72% to 9.55%, and the content of particles larger than 2mm is about 62.09% to 73.21%, according to the non-uniform coefficient and the curvature coefficient reflected the discontinuous solid particle gradation, and the fine-grained mass is less than 30%. It belongs to the typical loose gravel soil with large rocks. These loose gravel soils have large porosity and reserves of up to 260,000m^3. It is easily weathered and provides abundant source conditions for the outburst of mudslides.

According to the relevant literature, the maximum amount of rainfall on a single day in 10 years of Daqing debris flow development zone is 76mm, and the maximum amount of rainfall on a single day in 20 years is 88mm, and the maximum rainfall on a single day in 50 years is 103mm. In extreme weather conditions, it is fully capable of providing sufficient precipitation conditions for the outburst of mudslides. This basin has a relative elevation difference of 270m, a slope of 33° or more, a steeper slope, and a lower valley cut, most of which is a "V" gully. Gully development, and the catchment area is 2.68km^2. It can collect enough water in a short time and have the terrain conditions of debris flow outbreak. In summary, according to the wide source gradation of the Daqing debris flow development zone, the abundant accumulation of surface sediments, the deep valleys, steep slopes, and as well as the water supply provided by the maximum rainfall intensity, it can be judged that the Daqing debris flow is currently in its prime period, and there is a high possibility of another outbreak.

Debris Flow Bulk Density. The bulk density of debris flow is one of the basic parameters for studying the dynamic characteristics of debris flow. This study uses the empirical formula method and uses Eq.1 to calculate:

$$\gamma_H = (\gamma_s f + 1)/(f + 1) . \tag{1}$$

In the formula:γ_H - debris flow bulk density, t/m^3; γ_s - solid matter specific gravity, t/m^3, take 2.7 t/m^3; f - volume ratio of solid to liquid.

Calculate the bulk density of Daqing debris flow at different frequencies according to Eq.1, as shown in Table 2.

Table 2 Bulk density at different frequencies of Daqing debris flow

frequency	10%	5%	2%
γ_H (t/m^3)	1.45	1.60	1.77

According to the field investigation of Daqing debris flow development zone and the results of particle grading test, the author chooses the calculation to determine the debris flow density of 1.65 t/m^3, which belongs to a dilute debris flow. When it is actually applied, it will increase appropriately according to the increase of rainfall intensity.

Debris Flow Velocity. The determination of the debris flow velocity helps to calculate the impact of debris flow in the later period and design protective measures scientifically and reasonably. At present, the calculation of the velocity of debris flow at home and abroad is not yet mature, and the calculation methods emerge in an endless stream, with large geographical distinctions. Considering that Daqing debris flow development zone is located in the southwest region, for the sake of similar reference in the region, the Southwest China formula is used for calculation[7].

$$V_c = \frac{1}{\sqrt{\gamma_H \varphi + 1}} \frac{1}{n} R^{\frac{2}{3}} I^{\frac{1}{2}} \quad (2)$$

In the formula: V_c - debris flow section average velocity, m/s; γ_H - debris flow bulk density, t/m^3; *1/n* - debris flow bed roughness coefficient; R - hydraulic radius, take the average mud depth, m; I- hydraulic slope, ditch slope, ‰; φ - sediment correction factor, $\varphi=(\gamma_c-\gamma_w)/(\gamma_H-\gamma_c)$.

According to the actual investigation, the above parameters can be determined, and the average velocity of the debris flow can be calculated as 5.17m/s.

Flow Calculation. Currently there is no continuous flow monitoring data in Daqing debris flow development zone. According to the local rainstorm data provided in the "Hydrology Manual of Yunnan Province", it is assumed that debris flow and rainstorm occur at the same frequency and in synchronization, and the relevant characteristics of debris flow are calculated.

$$Q_m = q \cdot F^{2/3} \cdot n \quad (3)$$

In the formula: Q_m - average annual peak discharge, m^3/s; q - Annual average flood peak modulus, value 2.0; F - watershed catchment area, km^2; n - overflow flood ratio factor, 10% take 1.78, 5% take 2.31, 2% take 3.08, results are shown in Table 3.

Table 3 Result table of flow calculation for Daqing debris flow

section position	watershed catchment area(km^2)	Q_m/(m^3/s)		
		P=10%	P=5%	P=2%
Daqing gully	2.68	7.22	9.31	11.95

Total Amount of Single Debris Flow. Accurate calculation of total amount of debris flow related to the rationality of debris flow interception facility design, including the total amount of single debris flow and the total amount of solid particles washed out by a single debris flow. Specific reference is made to the Eq.4 and Eq.5 listed in the "Specification for Engineering Exploration of Debris Flow Disaster Prevention and Control" (DZ/T 0220-2006)[7].

$$Q = KTQ_{\mathrm{m}} \quad (4)$$

$$Q_H = Q_{\mathrm{m}}(\gamma_H - \gamma_w)/(\gamma_C - \gamma_w) \quad (5)$$

In the formula: Q - the total amount of single debris flow, m^3; Q_H - the total amount of solid particles washed out by a single debris flow, m^3; T - the time of debris flow eruption, s; γ_H - the bulk density of debris flow, t/m^3; γ_C - the solid bulk density, t/m^3; γ_W - The clean water bulk density, t/m^3.

By checking the history of the debris flow outbreak time in this basin and visiting nearby villagers, since the record, the duration of the longest debris flow has been about 50 minutes. Because the basin area is 2.68km^2; the K value is 0.202, and the calculation results are shown in Table 4.

Table 4 The single total amount of Daqing debris flow

section position	Q（m^3）			Q_H（m^3）		
	P=10%	*P*=5%	*P*=2%	*P*=10%	*P*=5%	*P*=2%
Daqing gully	10762.56	11892.13	13101.22	5955.12	6457.53	7136.77

From the above calculation results, it can be seen that the dynamics parameters such as bulk density, flow velocity, flow rate, and single total amount of the Daqing debris flow are large. In the case of relatively large slope gradient, the dynamic parameters will have a significant amplification effect during the movement of debris flow to the downstream. This will also directly lead to huge impact when the debris flow moves. Combined with the analysis of the physical characteristics, topographical conditions, and precipitation conditions of the Daqing debris flow development zone in the early stage, it can be inferred that the Daqing debris flow is currently in its prime period. Once it encounters extreme rainfall conditions and triggers mudslides, it will bring great harm to the villagers and transportation lines along the route.

Daqing Debris Flow Risk Assessment

The risk assessment of Daqing debris flow needs to be combined with multiple influencing factors to make a comprehensive judgment and express it in degrees of danger. Referring to numerous documents, Liu Xilin's calculation method for the risk degree of single gully debris flow has a high reference value[8]. His evaluation formula is as follows.

$$Hs = 0.286m + 0.286f + 0.143s_1 + 0.086s_2 + 0.057s_3 + 0.114s_6 + 0.029s_9 . \quad (6)$$

In the formula: H_s - the risk degree of single gully debris flow, the value range is 0~1; m, f, s_1, s_2, s_3, s_6 and s_9 are respectively selected seven influence factors, and the conversion values and their corresponding conversion functions are shown in Table 5. Through actual survey, comparison and analysis, the required parameters for risk assessment of Daqing debris flow can be obtained, and the risk degree of Daqing debris flow can be obtained by the Eq.6.

Table 5 Evaluation results of the risk degree of Daqing debris flow

evaluation factor	conversion factor	conversion function	conversion value
debris flow scale $m(\times 10^3 m^3)$	M	$m \le 1, M=0$; $1<m\le 1\,000, M=\log m/3$; $m>1\,000, M=1$	0.72
debris flow frequency f(%)	F	$f\le 1, F=0$; $1<f\le 100, F=\log f/2$; $f>100, F=1$	0.26
gully basin area $s_1(km^2)$	S_1	$0<s_1\le 50, S_1=0.245\,8\times s_1^{0.349\,5}$; $s_1>50$, $S_1=1$	0.32
main gully length s_2(km)	S_2	$0\le s_2\le 10, S_2=0.290\,3s_2^{0.537\,2}$; $s_2>10$, $S_2=1$	0.58
watershed relative elevation s_3(km)	S_3	$0\le s_3\le 1.5, S_3=2s_3/3$; $s_3>1.5, S_3=1$	0.51
watershed cutting density $s_6(km/km^2)$	S_6	$0\le s_6\le 20, S_6=0.05s_6$; $s_6>20, S_6=1$	0.016
instable gully ratio s_9(%)	S_9	$0\le s_9\le 60, S_9=s_9/60$; $s_9>60, S_9=1$	0.52

Table 6 Risk degree division table

risk degree	very low danger	low danger	moderate danger	highly danger	extremely danger
criteria	0~0.2	0.2~0.4	0.4~0.6	0.6~0.8	0.8~1

From the above analysis, it can be seen that the risk degree of Daqing debris flow is 0.59, and the risk degree classification of table 6 indicates that the risk of Daqing debris flow belongs to moderate danger. According to the site investigation of Daqing debris flow development zone, Daqing debris flow formerly belonged to low-frequency debris flow. However, with the destruction of mountains in recent years, the exit position of the gully ditch has receded; the bedrock on the surface has been exposed and broken, and small-scale landslides have occurred locally. The solid deposits in the gullies have increased more than before; plus in recent years, the climate has become warmer and local extreme heavy rainfall has caused frequent outbreaks of the Daqing debris flow. This is also the reason why the calculated value of the Daqing debris flow risk degree approached the high-risk range.

Therefore, it is necessary to take scientific and effective preventive measures in a timely manner to prevent it, and to avoid irreparable damage caused by the sudden outburst of the debris flow.

Preventive Measures

(1) Strengthen publicity and education; popularize debris flow disaster prevention and reduction knowledge and improve the escape evacuation skills of the local people in the outbreak of the debris flow.

(2) Slope protection projects and trench slag blocking projects are set up to intercept solids before the debris flow potential energy is converted into kinetic energy, and to increase the safety factor of existing projects, restore hillside vegetation, prohibit mountain deforestation, and reduce the debris flow material conditions.

(3) Set up slag blocking dams and anti-collision piers at the inflow surface of bridge piers to ensure the safety and smoothness of provincial highway S220 when the debris flow erupt.

(4) Strengthen the monitoring of rainfall and slope stability; establish a forecast and early warning mechanism, and immediately notify villagers to withdraw once there are signs of an outbreak of Daqing debris flow.

Conclusion

Through the analysis of the physical characteristics and the risk assessment of the Daqing debris flow, the following conclusions are drawn:

(1) The Daqing debris flow development zone has abundant reserves of solid deposits, which is as high as 260,000m^3. The terrain is steep and steep, with a maximum rainfall limit of 76mm, adequate rainfall, and basic conditions for the outburst of the debris flow.

(2) Through the analysis of physical characteristics of Daqing debris flow, it is found that the parameters of its dynamic characteristics are large, and the dynamic parameters in the process of debris flow movement have a significant amplification effect along the path. It can be inferred that the Daqing debris flow is currently in the prime of life, once it breaks out, it still has strong impact and destructive power.

(3) The risk degree of the Daqing debris flow development zone is 0.59, which is moderately dangerous but approaching highly dangerous. The possibility of an outbreak triggered by extreme rainfall is very high.

(4) In response to the risk of outbreak of Daqing debris flow, corresponding preventive measures were put forward to reduce the damage to local people's production and life and provincial highway S220 caused by the outbreak of Daqing debris flow.

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References

[1] Zhang Nan, Fang Zhiwei, Han Xiao et al. The spatial and temporal distribution law and cause analysis of debris flow disasters in China in recent years [J]. Frontiers of geology, 2018, 25 (02): 299-308.

[2] Yao Lanfei. Hazard assessment and prediction of debris flow in the Aobu section of G314 line [D]. HeFei University of Technology, 2017.

[3] Huang Xun. Large scale debris flow dynamic characteristics and risk quantification in strong earthquake area [D]. Chengdu University of Technology, 2015.

[4] Cao Hongli. Basic characteristics and dynamics numerical simulation of debris flow in well ditch in Wubao [D]. Xi'an University of Science And Technology, 2017.

[5] GB/T 50123-1999, Standard for Soil Test Method [S].

[6] GB50021-2009, Code for Investigation of Geotechnical Engineering [S].

[7] DZ/T 0220-2006, Specification for Engineering Exploration of Debris Flow Disaster Prevention and Control [S].

[8] Liu Xilin. The origin of the calculation formula for the risk of gully debris flow and its application examples [J]. Journal of disaster prevention and mitigation engineering, 2010, 30 (03): 241-245+26.