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Risk Identification of Lijiadagou Landslide and Debris Flow Hazards Chain in Yong'an Town, Fengjie County of Chongqing City

Q. H. Song[1,2*], S. C. Ren[2], X. L. Li[3], B. L. Chen[2], K. Li[2] and D. J. Tan[2]

[1]Army Logistics Academy, Chongqing Key Laboratory of Geomechanics & Geoenvironment Protection, 401331 Chongqing, China.
[2]Technology Innovation Center of Geohazards Automatic Monitoring, Ministry of Nature Resources (Chongqing Institute of Geology & Mineral Resources), 401120 Chongqing, China.
[3]College of Traffic & Transportation, Chongqing Jiaotong University, 400074 Chongqing, China.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Lijiadagou landslide and debris flow hazards chain in Yong'an Town of Fengjie county is one of the representative geohazards. By using satellite remote sensing technology, field investigation and observation, survey and analysis, mechanical analysis and other technical means, this paper makes qualitative or semi quantitative analysis on the hazard environment, instability probability, vulnerability analysis of elements at risk, risk loss, etc. The risk factors of Lijiadagou landslide and debris flow were identified. The conclusion shows that the unique landform and climate of Lijiadagou lay a foundation for the occurrence of multiple debris flows in the history. Under the alternate control of multiple factors such as the nature of the rock and soil mass, the stratum structure that controls the sliding, the complex geomorphic environment, continuous heavy rainfall and the rise and fall of the water level, there are high risks of landslides and debris flows, threatening about 6,000 residents in the middle and front range of Lijiadagou. The risk economic loss of hazards is about 80 million yuan, and will cause serious social impact. It is urgent to strengthen monitoring and

**Corresponding author: E-mail: songbook@163.com;*

early warning, and at the same time take targeted measures against the landslide source area to cut off the hazards chain from the source, so as to achieve a multiplier effect with half the effort.

Keywords: Landslide; debris flow; hazard chain; risk identification; uncertainty.

1. INTRODUCTION

Debris flow is a physical process between the movement of blocks such as collapse and landslide and the flow of mountain floods. It has both the structural properties of soil and the characteristics of water liquidity [1]. At the same time, analysis of a large number of typical engineering examples shows that debris flows often have the characteristics of disaster chains. Debris flow is mainly derived from landslide, collapse and broken surface. Therefore, the activity of material source is the key to early warning [2]. More and more researches are paying attention to this point [3-6]. For example, Xu et, al. provides a solution for landslide risk management by proposing an integrated “Air-Space-Ground” investigation system that allows for the early detection, real-time prediction, and warning of catastrophic geohazards [7].

Fengjie county, Chongqing City, is an important county town for the relocation of immigrants in the world-famous Three Gorges Project. Its relatively fragile geological environment and unique topography gave birth to more than 1,000 landslide-debris flow hazards, among which Lijiadagou landslide and debris flow is one of its typical representatives. Therefore, it has attracted the attention of many scholars. For example, as early as 15 years ago, Zheng et, al. [8] made a detailed and systematic study on the formation environment, basic characteristics and formation mechanism of debris flow in Lijiadagou as early as 15 years ago from the perspective of engineering geology, predicted and evaluated the harmness and development trend of debris flow, and put forward reasonable and scientific suggestions. Qian [4] [9] conducted field investigation and engineering geological survey to study the formation conditions and zoning characteristics of debris flow in Lijiadagou ditch. Based on the semi-quantitative comprehensive evaluation and susceptibility grade standard, the risk of debris flow has been systematically evaluated and studied, and it is judged as a mild susceptibility grade [9].

After five years of development, some new changes have taken place. In particular, the hazards of landslide and debris flow are intensified, and the range of risk area and the elements at risk are also changed correspondingly. Dynamic risk identification and assessment is urgently needed. Therefore, on the basis of previous works, this paper focuses on the identification and preliminary risk assessment of landslide and debris flow disaster in recent years [10].

2. GENERAL CHARACTERISTICS OF LIJIADAGOU LANDSLIDE AND DEBRIS FLOW HAZARDS

The Lijiagdaou landslide and debris flow are located in Yong'an Town, Fengjie county, on the north bank of the Yangtze River (Fig.1). The middle and lower reaches of the debris flow are located in the central urban area of Sanma Mountain, Fengjie county. The central geographical coordinates are 109°27'58" east longitude and 31°22'48" north latitude.

The mud-rock flow ditch is distributed in a north-south direction and merges into the Yangtze river. It is 4.2km long from north to south, 1040m wide from east to west, and 400m wide at the downstream. It is funnel-shaped with large upper part and small lower part, which is favorable for water collection and formation of debris flow. The watershed elevation is 455～979m. The gully mouth elevation is 145m, the maximum elevation difference is 834m, the average slope of gully bed is 304 ‰, the maximum slope is 545 ‰, and the gully zone is 2.5km^2. Lijiadagou is a deep-cut gutter, with a cutting depth of 15～45m, a width of 40～400m, a slope of 12°～55°, and an average annual flow of 12.50m^3/s. The upstream water system is dendritic. There are 6 first-level branch trenches and multiple second-level branch trenches on the upstream and west sides, all of which are seasonal gullies. The water volume during the flood season is 1.4～2.2m/s, and the branch trench slopes and sinks. The slope and catchment zone of the tributaries are large. The accumulation at the bottom of the tributaries is silty clay with gravel, and the deposit layer at the mouth of the furrows is thick (Fig.2).

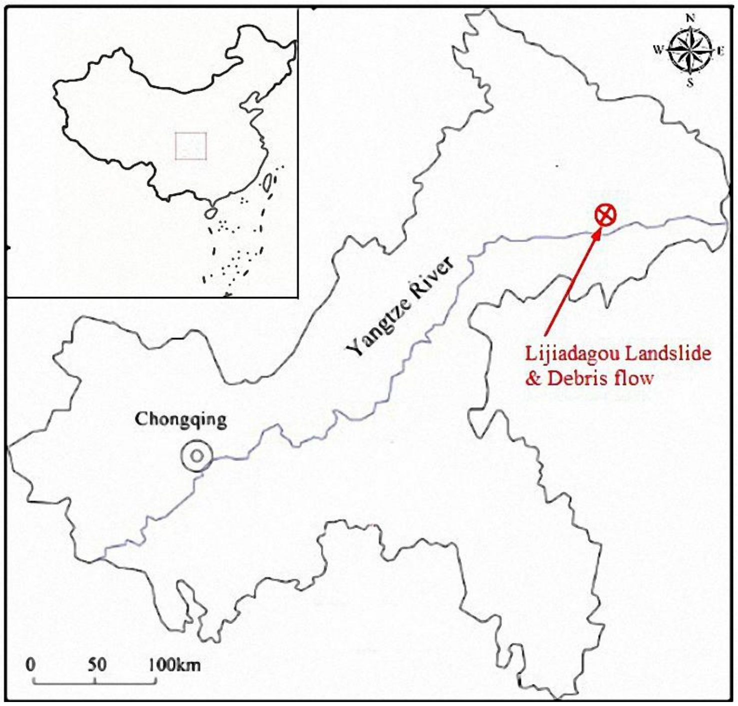

Fig.1. Location map of the study area

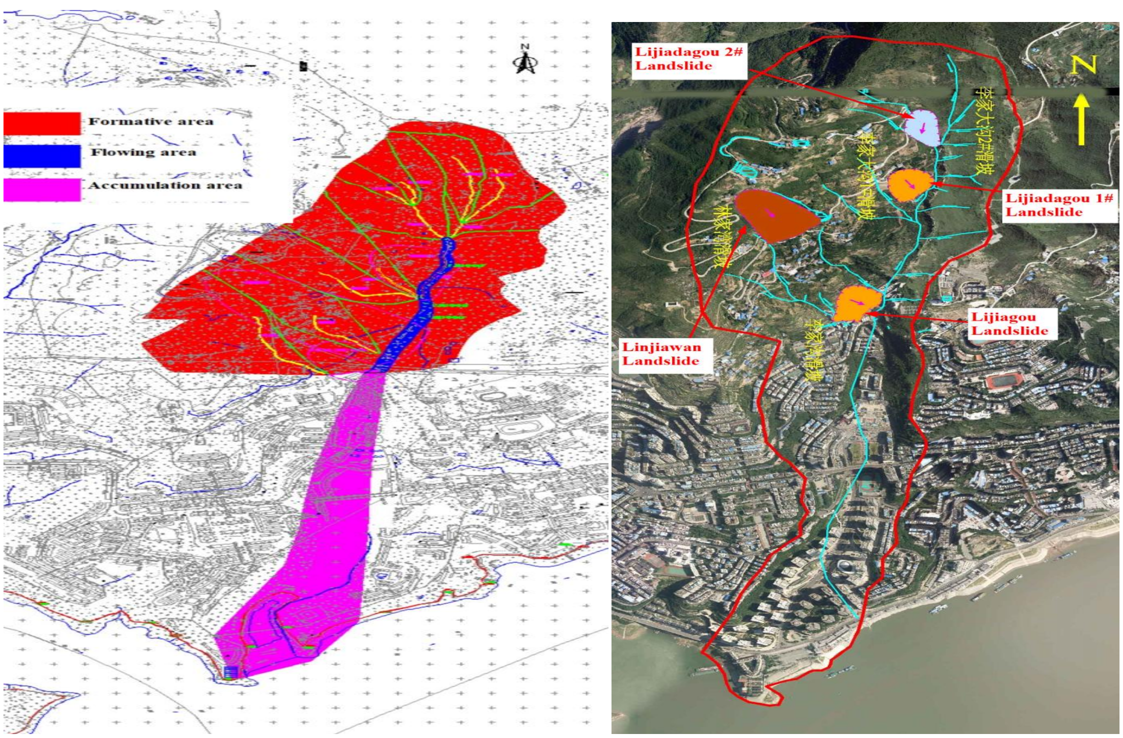

Fig. 2. Plane, remote sensing and water system characteristics map of Lijiadagou landslide and debris flow hazards

3. ANALYSIS ON FORMATION CONDITIONS OF LIJIADAGOU DEBRIS FLOW

3.1 Analysis of Topography and Geomorphology Conditions

3.1.1 The formation area

The topography and geomorphology conditions are mainly manifested as the slope topography with large height difference and steep terrain. The branch gully cut on the slope is relatively shallow, the material structure of the slope is loose, and the regional vegetation coverage is small, mainly by surface erosion and ditch erosion. The main effect of soil erosion is strong, and the slope is easy to slide to provide a large amount of source conditions for the formation of debris flow; at the same time, due to the steep terrain, the effect of stagnation on rainfall is small, and rainwater is easy to collect in the valley to produce strong hydrodynamic force. It provides favorable water source conditions for the occurrence of debris flow (Fig.3). This area mainly plays a role in gathering water and providing a source of loose solids during the formation of debris flow.

3.1.2 The circulation area

The topography and geomorphology conditions are mainly gullies and valleys, the valleys are deep and narrow, the terrain is steep, and the valleys are "V"-shaped. This kind of topography and geomorphology conditions is conducive to the collection of loose deposits and water flow, resulting in a rapid and direct flow of debris through the zone; In addition, the slope on both sides of the gully is steep, the gully water has a strong scouring effect on the Quaternary loose materials on the gully bank, and the ditch bank collapses and slides, which also provides a large amount of solid source for the formation of debris flow, which may cause the gully to be blocked and the outburst may cause the sudden outbreak of debris flow. as shown in Fig.4.

3.1.3 The accumulation area

The middle and front part of Lijiadagou is the original accumulation area of debris flow. Due to the current urban construction in this area, the original terrain and landform has been transformed (Fig.5).

3.2 Analysis of Solid Source Conditions

According to the field investigation, the solid material sources that may participate in debris flow activities can be divided into three parts: slope erosion type material source, landslide type material source and gully accumulation type material source, and the total amount of material sources is about 80.6× $10^4 m^3$.

3.2.1 Slope erosion types of source materials

The main geological causes of this kind of source materials are residual slope deposit, colluvial slope deposit, etc., which are mainly distributed in steep slope cultivation zone and barren zone. The soil erosion is relatively strong, and local sliding or slope debris flow generally occurs under the long-term scouring effect of surface water, which becomes the provenance of Lijiadagou debris flow. As shown in Fig.6, the total amount of slope erosion source is about 6.4× $10^4 m^3$.

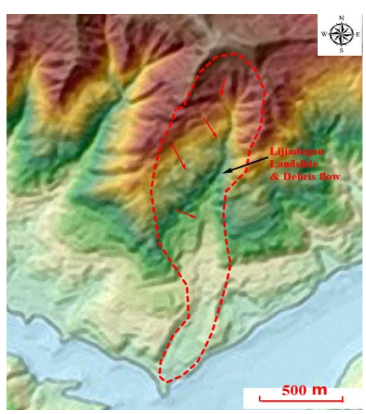

Fig. 3. The topography and geomorphology conditions of Lijiadagou landslide and debris flow hazards

(a) Topography and landform of the forming area

(b) Collapse and landslide of the gully bank in the circulation area

(c) Topography and landform of the circulation area

Fig. 4. Photograph of developmental features of Lijiadagou landslide and debris flow

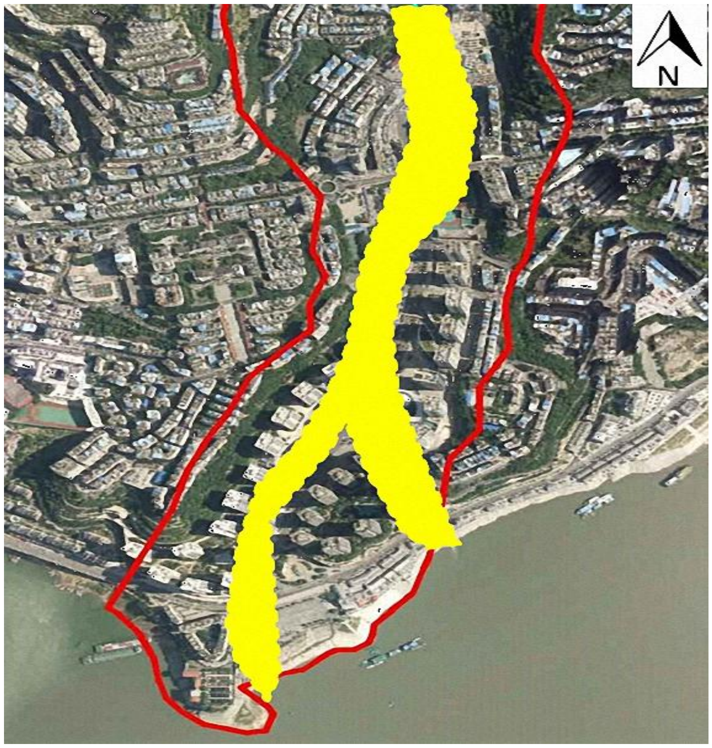

Fig. 5. The elements at risk in accumulation area

Fig. 6. Slope erosion and local slippery

3.2.2 Rockfall-Landslide type provenance

The main geological causes of this type of provenance include landslide deposits, artificial accumulations, residual landslide deposit and so on.

The artificial accumulation is mainly a quarry waste slag, located at the back edge of 3# branch ditch, the slope material is loose, the thickness is about 2 ~5m, and the total volume is about $1.8\times10^4m^3$. It is easy to produce partial slippage or overall slippage under the action of rainwater and become the source of debris flow, as shown in Fig.7.

Loose deposits in gullies and banks directly collapsed into debris flow gullies under the action of scouring and cutting by water flow. The areas with strong ditch bank landslides are mainly distributed in the ditch section with an elevation of 375.0~590.0m, and are distributed in the 20~30m on both sides of the ditch. In the area, the total amount of solid sources that can be provided is about $24.8\times10^4m^3$.

3.2.3 Gully accumulation type provenance

it is mainly distributed behind the Gufang dam and the gentle slope of the gully, and the total amount of loose solid provenance that may be added to the debris flow is about $4.1 \times 10^4m^3$ (Fig.5).

3.3 Water Source Conditions

The average annual rainfall of the area where the debris flow is located is 1107.3 mm, and the maximum monthly rainfall is 358.4mm. The rainfall is very rich, and most of them are concentrated in May to September, forming rainstorm and continuous heavy rainfall, which is extremely unfavorable to the stability of the slope and provides abundant water conditions.

The catchment area of Lijiadagou reaches $1.53km^2$, the flow rate is $8.60m^3/s$ during the wet season, and $0.70m^3/s$ during the dry season. It is mainly recharged by atmospheric precipitation, with high hydrodynamic force, strong ability to erode and carry solid materials, and easy to form a highly destructive dilute debris flow.

4. THE BASIC SITUATION OF THE LANDSLIDE IN THE SOURCE AREA OF LIJIADAGOU

There are four landslides in the provenance zone, including Lijiagou landslide, Linjiawan landslide, Lijiadagou (Gufang) 1# landslide, and Lijiadagou (Gufang) 2# landslide.

4.1 Lijiadagou (Gufang) 1# Landslide (No. HP57)

4.1.1 Basic overview

Lijiadagou (Gufang) 1# landslide is located in Mingyue Community, Yong'an Town, and the plane form is skip-shaped, with a length of about 250m, a width of about 241m, and a height difference of about 105m. The area is about $7.52\times10^4m^2$, the average thickness of the sliding body is about 7m, the volume is about $46.64\times10^4m^3$, and the main sliding direction is 139° (Fig.8). The landslide is mainly composed of silty clay, marl and sandstone blocks.

Fig. 7. Loose slag from the quarry

4.1.2 Deformation characteristics

The deformation of Lijiadagou (Gufang) 1# landslide began around 2012. After heavy rains during the flood season, the ground and residential buildings in the middle and rear parts of the landslide showed varying degrees of ground deformation and house cracks. The most recent deformation occurred after the heavy rain on August 31 in 2014, and the cracks on the ground at the middle and rear of the landslide increased (Fig.9).

4.1.3 Stability development trend and threat objects

According to the analysis of the deformation, the Lijiadagou (Gufang) 1# landslide is currently in the creeping deformation stage as a whole, but there is a local slumping phenomenon. After rainfall over the years, the local slumping phenomenon is obvious. It is qualitatively judged that the status quo is basically stable as a whole, and it may develop to an under-stable state under the conditions of heavy rain, continuous heavy rainfall, and continuous erosion and erosion at the foot of the slope, until it becomes unstable.

The landslide mainly threatened the safety of the lives and property of 46 people in 12 households at the rear of the landslide area, as well as 35 houses and 13 acres of arable land. The instability turned into mudslides and threatened the elements at risk of urban area. Based on the above analysis, it is recommended to carry out engineering treatment and effect monitoring on Lijiadagou (Gufang) 1# landslide.

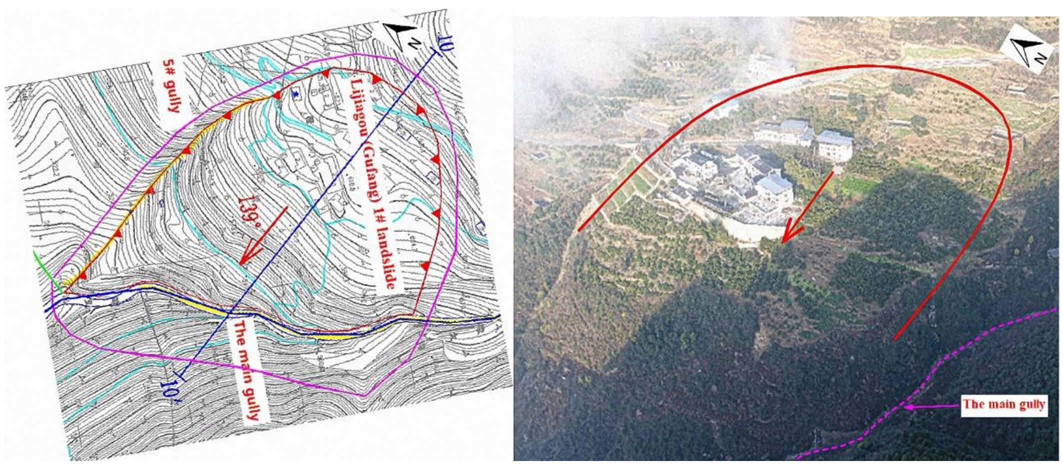

Fig. 8. The plan and overall view of Lijiadagou 1# landslide

Fig. 9. Photo of house wall cracking and falling front edge within the range of Lijiadagou 1# landslide

4.2 Linjiawan Landslide (No. HP56)

4.2.1 Basic overview

Linjiawan landslide is located in Mingyue Community, Yong'an Town, and its plan form is skip-shaped, with a length of about 420m, a width of 230m, a height difference of about 155m, and a plane zone of about $8.7\times10^4 m^2$. The average thickness of the body is about 9m, the volume is about $47.7\times10^4 m^3$, and the main sliding direction is 132°. The landslide is mainly composed of silty clay, marl and sandstone blocks (Fig.10).

4.2.2 Deformation characteristics

According to the investigation, the deformation of Linjiawan landslide began around 2010. After the rainstorm during the flood season, cracks appeared in the residential houses in the front of the landslide. Since then, during the rainstorm or continuous rain, the surface and residential houses in the landslide zone would be deformed to varying degrees. The most recent severe deformation occurred after a heavy rainstorm on August 31 in 2014, as shown in Fig.11.

4.2.3 Trend of stability development and threat objects

The deformation of the Linjiawan landslide is mainly manifested as cracks in the walls of houses and ground cracks. It can be judged qualitatively that the current situation is basically stable, and it may develop to an unstable state or even instability under the condition of rainstorm and continuous heavy rainfall. The landslide mainly threatened the safety of the lives and property of 308 people in 83 households in the front part of the landslide, as well as 265 houses and 60 acres of arable land. The instability turned into mudslides and threatened the urban area. Based on the above analysis, it is recommended to carry out engineering treatment and effect monitoring on Linjiawan landslide [10].

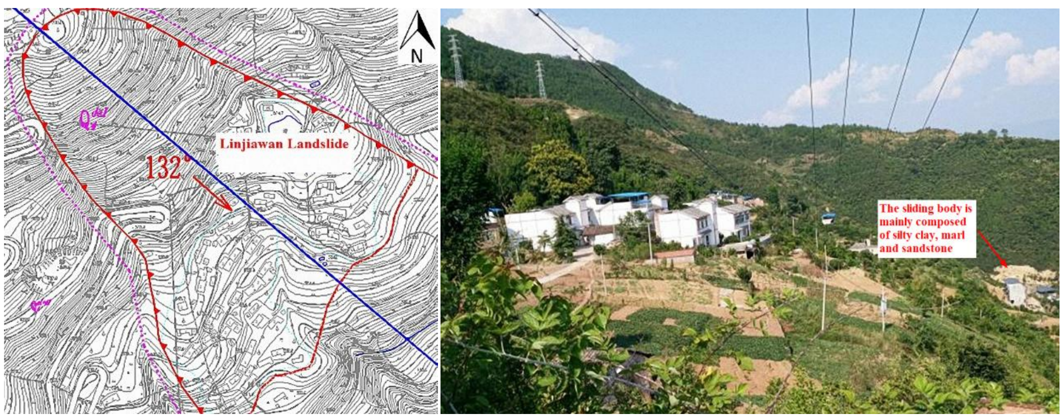

Fig. 10. The plan and overall view of Linjiawan landslide

Fig. 11. Deformation of houses and roads within the range of Linjiawan landslide

4.3 Lijiagou Landslide (No. HP55)

4.3.1 General situation

Lijiagou landslide is located in Mingyue Community, Yong'an Town, and its plane form is skip-shaped, with a length of about 200m, a width of about 185m, a height difference of about 85m, and a plane area of about $5.28\times10^4 m^2$. The average thickness of the sliding body is about 8m, the volume is about $42.24\times10^4 m^3$, and the main sliding direction is 135°. The landslide is mainly composed of silty clay, marl and sandstone blocks (Fig.12).

4.3.2 Deformation characteristics

The deformation of the landslide began around 2010. After the heavy rains during the flood season, the ground surface deformation and dislocation occurred in the middle of the landslide. The most recent deformation occurred after the heavy rain on August 31 in 2014, and the ground in the middle and rear part of the landslide showed a significant surface drop, as shown in Fig.13.

4.3.3 Trend of stability development and threat objects

The deformation of Lijiagou landslide is mainly manifested by the surface cracking and dislocation, and it is currently in the creeping deformation stage as a whole. It can be judged qualitatively that the current situation is basically stable, and it may develop to an unstable state or even instability under the condition of rainstorm and continuous heavy rainfall.

The landslide mainly threatened the life and property safety of about 200 households with 800 people in 4 residential buildings in Qianyuan residential area. Based on the above analysis, it is suggested to carry out engineering treatment and effect monitoring for Lijiagou landslide.

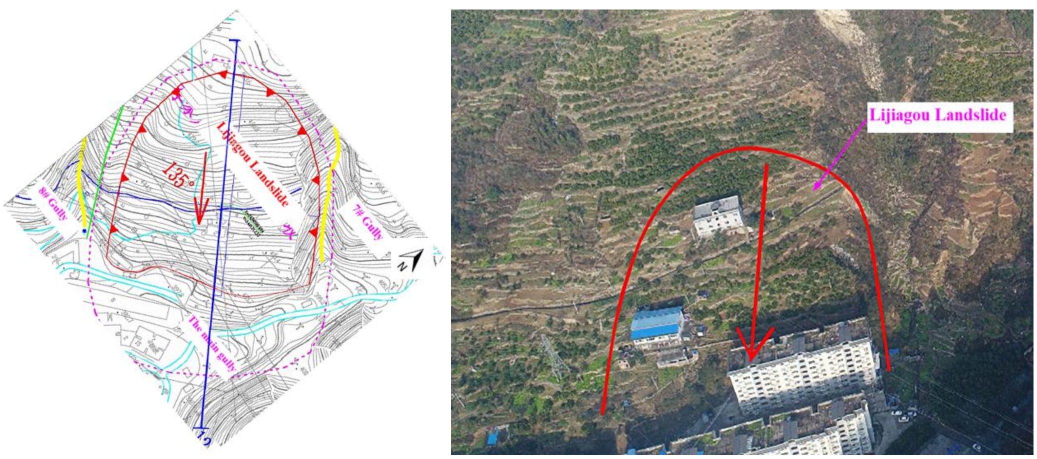

Fig. 12. The plan and overall view of Lijiagou landslide

Fig. 13. Photograph of ground fall in the middle of Lijiagou landslide

4.4 Lijiadagou (Gufang) 2# Landslide (No. HP58)

4.4.1 Basic overview

Lijiadagou (Gufang) 2# landslide is located in Mingyue Community, Yong'an Town, with length approximately 180m, width approximately 200m, elevation difference approximately 115m, and plane area approximately $3.6×10^4m^2$. The average thickness of the sliding body is about 6m, the volume is about $21.6×10^4m^3$, and the main sliding direction is 190° (Fig.2).

4.4.2 Deformation characteristics

The deformation of the landslide is mainly manifested as a local collapse of the front edge.

4.4.3 Trend of stability development and threat objects

It is qualitatively judged that the current situation of Lijiadagou (Gufang) 2 # landslide is in a stable state as a whole. In the case of heavy rain and continuous heavy rainfall, the front edge is prone to collapse, and the weakening of the sliding resistance of the front edge may cause the rear sliding body to deform until it loses stability. The threat of the landslide is mainly cultivated land. If the landslide slides into the main ditch as a whole, it may turn into a debris flow and threaten the urban area of Fengjie.

4.4.4 Suggestions for landslide prevention and control

It is suggested to continue to carry out mass monitoring and mass prevention for Lijiadagou (Gufang) landslide [10].

5. ACTIVITY CHARACTERISTICS AND DEVELOPMENT TREND OF LIJIADAGOU LANDSLIDE AND DEBRIS FLOW HAZARDS CHAIN

Based on the above analysis, it can be considered that there are topography and landform conditions, solid material source conditions and water source conditions for the formation of debris flow in Lijiadagou area. Its historical activity characteristics and development trends are as follows:

5.1 Characteristics of Historical Activities of Debris Flow

- When the rainfall reaches 50 mm in 12 hours, debris flow is easy to break out in the gully, and no debris flow occurs when the rainfall is less than 50 mm.
- In the case of long rainfall, when the total rainfall reaches 164.1mm, debris flow will occur at the mouth of the ditch.
- Continuous rainstorm for more than 6 hours, debris flow may break out in this gully.
- Debris flow is characterized by narrow valleys and many steep slopes. The slope material is mainly gravel and loose structure due to rainstorm erosion, so it is easy to produce highly destructive debris flow.
- The debris flow gully is prone to high-frequency small-scale debris flow with high activity and strong activity intensity.

5.2 Development Trend of Lijiadagou Landslide and Debris Flow Hazards Chain

The debris flow gully is narrow, and there are local unstable bodies on both sides of the gully. These unstable bodies have been deformed or are in a potential unstable state. Under the condition of heavy rain, the material source migrates into the gully, and the possibility of blocking the ditch is extremely high. Debris flow will occur on the basis of the debris flow that has occurred.

6. CONCLUSION

Based on the risk identification of Lijiadagou landslide and debris flow hazards chain, this paper determines the position, range, characteristics and activity characteristics of landslide and debris flow hazards chain. The natural properties, risk zone, spatial information, and relevant basic data of landslide and debris flow were obtained by comprehensive satellite remote sensing technology, field investigation and observation, survey and analysis, mechanical analysis and other technical means, which laid a good foundation for subsequent quantitative risk assessment for landslide and debris flow hazards.

Lijiadagou landslide & debris flow hazards chain threatens the life and property safety of about 6000 people in the middle and front of Lijiadagou, and the economic loss of the threatened object is about 80 million yuan, which will cause serious social impact. According to the potential risk of debris flow, the potential risk level of debris flow is large.

It is recommended to carry out a detailed survey of the Lijiadagou landslide and debris flow hazards chain to find out the source conditions, channel conditions, water source conditions, etc. of the debris flow, especially the scale and stability of the geological hazard body in the source area, which can be transformed into the loose solid material reserves of debris flow, and then the prevention and control of landslide and debris flow hazards should be carried out in different stages.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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