

Accumulation characteristics, mechanism, and identification of an ancient translational landslide in China

Abstract The fluctuation of the water level in a reservoir may induce various types of slope movements. Some of these movements are new, whereas others are old but reactivated. Many ancient landslide accumulations are distributed in the deep valleys of the eastern Qinghai–Tibet Plateau margin in China and will likely be reactivated after the completion of reservoirs and pose a risk to reservoirs, dams, facilities, and towns near mountainous areas. The Shuangjiaping ancient landslide, located in the Dadu River, Sichuan Province, China, is an example of this case. Since August 2010, the western part of the accumulation body has seen the gradual appearance of deformations. The Pubugou reservoir water level rises and inundates the front edge of the accumulation body, thus threatening the safety of the national highway G108 and 37 houses on it. This study is based on field work investigation, drilling work, aerial photography, and profile survey. The site-scale investigation shows that the deformation area is only a part of an ancient landslide accumulation, with an area of approximately $50.4 \times 10^4 \text{ m}^2$ and a volume of ca. $956 \times 10^4 \text{ m}^3$. Boundary and deposit characteristics of landslide accumulation are specified, which could be divided into four zones, namely, zones A and C, which are an avalanche accumulation area mainly composed of large blocks with diameter ranging from 1 to 3 m (some blocks have a diameter ranging from 5 to 10 m), zone B, a residual integrated rock mass accumulation area with “fake bedrock,” and zone D, a fine material accumulation area. A conceptual model is proposed to explain the mechanism and sliding process of this ancient landslide. The model includes translational sliding, stopping and hanging in air, avalanche accumulating, and transforming. The saltation of topography, material structure, and kinematic characteristics is the evidence used to identify the ancient landslide in deeply incised mountain areas. The current activity is found to be a surficial deposit displacement, and the whole landslide accumulation is stable or quasi-stable.

Keywords Reservoir · Qinghai–Tibet Plateau · Dadu River · Accumulation characteristics · Translational sliding · Mechanism · Identification

Introduction

Varnes’s system of landslide classification, which includes five types of movements, has been widely used in scientific literature (Varnes 1954, 1978; Cruden and Varnes 1996). A type of movement in this system, translational slide, is defined as the mass that is displaced along a roughly planar surface with insignificant rotation (Hungert et al. 2013). The word “translational slide” does not emphasize the material of mass or the dips of the sliding surface but the flatness of the rupture surface (i.e., this type may occur in rock, debris, and earth). However, a typical type of translational landslide mainly occurs in rock mass in China, which is composed of interbedding sandstone and mudstone with a gentle dip angle, that is, commonly 3° to 10° (Fan et al. 2009), which are closely related to the water

effect, particularly under heavy rainfall or rainstorm (Guzzetti et al. 2004; Mikoš et al. 2004; Pánek et al. 2011).

This type of landslide is widely distributed in the Sichuan basin and the Three Gorges area, where red bed, which is red-colored clastic sedimentary deposits in the Mesozoic and Cenozoic eras (Gornitz 2009), is commonly spread. Some classic cases of translational landslides have occurred in China, for example, the abundant landslides that occurred in the red bed area of eastern Sichuan basin after a rainstorm in 1981 (Wang et al. 1982), which comprise a number of landslides located in the Three Gorges area, such as Wanzhou landslide groups in Chongqing (Wu 2013) and Zigui landslide (Dai et al. 2004). The Tiantaixiang landslide, which occurred in Xuanhan County, Sichuan, on September 5, 2004, is a typical giant translational landslide with an extreme destructive effect (Fan et al. 2008, 2009).

Although the aforementioned cases occurred recently, numerous landslides that formed thousands of years ago and are distributed in deeply incised valley of mountain areas have yet to be identified. Owing to the engineering constructions conducted in mountainous areas, such as hydropower projects, town’s extension, human migration, and the construction of hydropower stations, many slope failures have occurred after the impoundment of reservoirs. Among these slope failures, some are new movement, whereas others are old and reactivated. The most famous case is the Vaiont landslide that occurred in 1963 (Müller-Salzburg 1964; Semenza and Ghirotti 2000; Genevois and Ghirotti 2005), after a dam was completed, which caused the death of almost 2000 people. Reservoir filling has induced hundreds of landslides since the early 1940s in Roosevelt Lake, USA (Schuster 1979). In China, the impoundment of the Three Gorges reservoir reactivated many ancient landslides, such as the Huangtupo landslide, which is the largest one in the reservoir (Deng et al. 2000; Cojean and Cai 2011; Hu et al. 2012; Tomás et al. 2014), Zhaoshuling landslide (Chai et al. 2013), Baishuihe landslide (Li and Yin 2010; Du et al. 2013), Shuping landslide (Wang et al. 2005, 2008), and Bazimen landslide (Du et al. 2013).

A large number of reservoirs are likewise distributed in deep incised river valleys in the eastern margin of Qinghai–Tibet Plateau in China. As previously mentioned, many new failures of slope have occurred, and ancient ones have been reactivated after either the filling or the drawdown of a reservoir, which may pose a threat to dams and other facilities (Cui et al. 2008). Therefore, identifying and evaluating stability of these landslide deposits are important. Such landslide deposits vary in size, type, formation mechanism, and age, some of which are large owing to ancient earthquakes (Wu 2013) and some transformed from translational landslides triggered by heavy rainfall in former times. However, these ancient landslides have been modified with the evolution of the river valley. Such landslides have hardly been recognized and identified owing to the dramatic change in the original features and topography of failure.

Shuangjiaping landslide, which is located 10 km downstream from the Shimian County on the left bank of the Pubugou reservoir, is a typical case of the aforementioned phenomenon. As the water level in the reservoir rose from August to October 2010 (i.e., reaching the normal retention water level of 850 m above sea level, some deformation appeared in the western part. Tension cracks existed on the national highway G108, and abundant cracks appeared on the dike dam of the reclamation project near the reservoir, where 37 houses were located. Thus, the reclamation project required careful field investigation and survey.

Thus, this study focuses on four problems. First, is the deforming slope composed of general residual deposits or an ancient landslide accumulation? Second, besides the deformation area, what are the scope and characteristic of the material structure of this landslide accumulation? Third, large blocks exist on the slope, with a volume ranging from 1 to 10 m³ and even larger. However, what are the mechanism and resource of these blocks in areas with gentle bedding? Fourth, how does a long, gentle stratum of a separate mound, situated on top of the landslide accumulation, form? In addition, what is the resource of such mounds?

Geological setting

Shuangjiaping landslide accumulation is located in Yingzheng Village on the left bank of the Dadu River which is 10 km downstream from the urban area of Shimian County (Fig. 1).

This landslide is in the transitional zone of western Sichuan plateau and basin, where middle-alpine gorge, steep slope on both banks, and bedrock are exposed. The strike of the mountains in the area is NE–SW. The northern part of the mountains is generally higher than the southern part. The highest point is the peak of the Liangtai Mountain, that is, 1,287 m a.s.l., whereas the lowest is the normal retention water level of the Pubugou reservoir, that is, 850 m a.s.l. (830 m a.s.l. before water filling).

The landslide area belongs to the upper Yangtze platform, which is located at the northern Sichuan–Yunnan meridional structural belt in the southeastern margin of the Tibetan Plateau. The Baiguowan

group of Triassic system (T₃bg) is widely exposed in the landslide area, which is primarily composed of gray sandstone and argillaceous siltstone, marlstone with shale, and gypsum bands. The strata are 3 to 5 m thick, with an altitude of N 70° E/SE \angle 5° to 10°, and two groups of vertical joints are widely distributed. The Quaternary system includes the residual colluvial deposit (Q^{col+dl}), landslide accumulation (Q^{del}), and alluvial deposit (Q^{al+pl}).

The Pubugou reservoir started water filling on November 1, 2009, and increased to 850 m a.s.l. on October 13, 2010 (Fig. 2a). When the water level increased to 840 m a.s.l. on August 15, 2010, deformation occurred in the western part of the accumulation; e.g., buildings were tilted and ground subsided. The climate in the landslide area is subtropical monsoon, with an annual average rainfall of 1,200.9 mm. Thus, rainfall is always concentrated in June to September every year, which accounts for approximately 82.6 % of the total annual rainfall in this period, as shown in Fig. 2b.

Methodology

This study involved three main types of fieldwork, namely, geomorphological mapping, detailed land surveying, and drilling exploration. Aerial photography, with a scale of 1:2,000, was used to map the location and geomorphology of the landslide area, as well as determine the area and boundary of the landslide accumulation. Twenty-eight drill holes, with depths ranging from 12.1 to 74.8 m, were performed to determine the structure of the landslide accumulation, including the material, component, and thickness of each deposit layer. However, the drill survey did not reveal the ground water table. The whole landslide deposit volumes were obtained by summing the volume of each subzone, which was obtained by multiplying the observed area of each subzone with an estimated mean depth. The precision of this approach heavily depends on the accuracy of site investigation and the depth of the deposit, as revealed by the boreholes. Despite its low precision, this method meets the demands of the present research.

Detailed ground survey and investigation were conducted using hand-held GPS and laser rangefinders. The boundary of each zone,

Fig. 1 Landslide location map

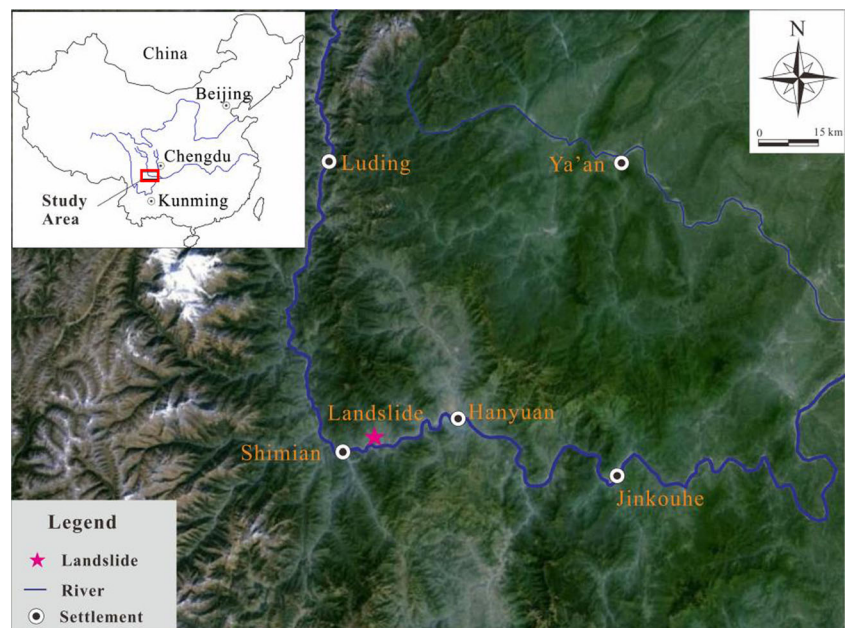
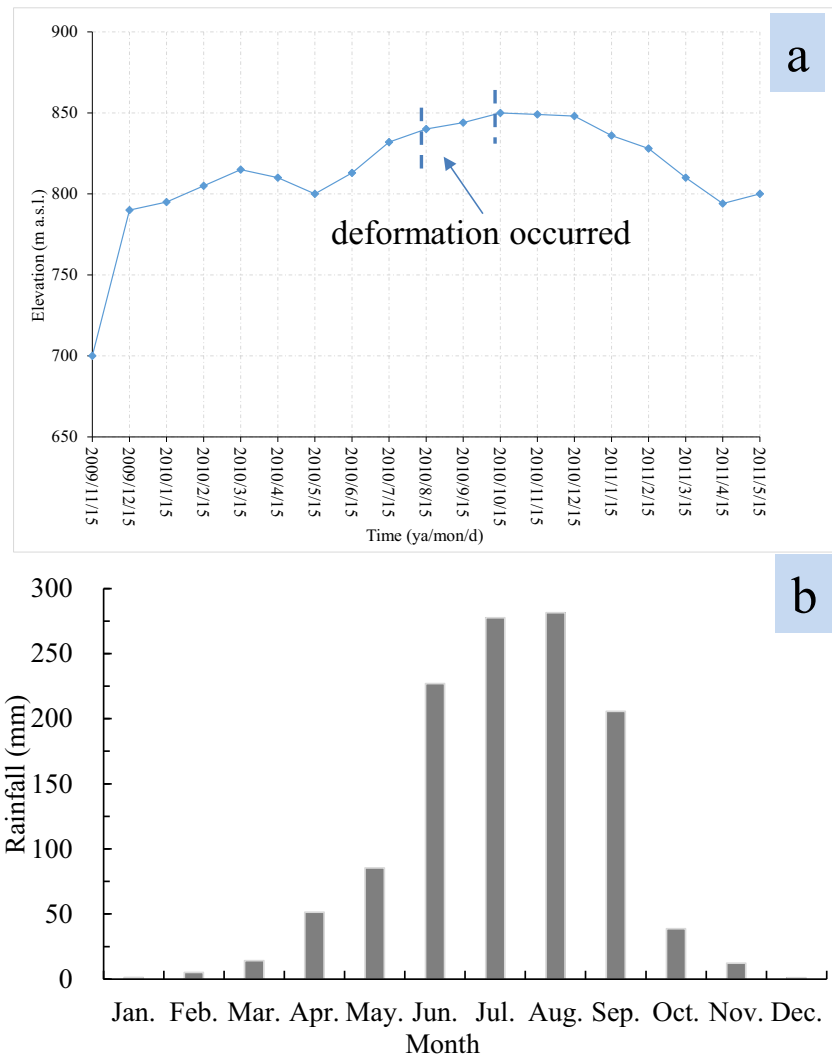


Fig. 2 a Variation of water level of reservoir in the first year. When the water level rose to 840 m a.s.l. at Aug 15, 2010, the deformation occurred in the west part of the accumulation, including tilted buildings and subsidence of ground. **b** Distribution of monthly average precipitation per year. Most of the precipitation concentrates in June to September, accounting for about 82.6 % of a year



the position, length, and width of cracks, and deformed constructions were determined and recorded. The scale and locations of the deformed phenomena, which are distributed on the landslide, were mapped on 1:2,000-scale aerial photograph. To better understand the slope structure, several 1:1,000-scale profiles were drawn to manifest the material and thickness of each layer and each zone according to the site-specific investigation and borehole work.

Results

Deformation

As shown in Fig. 3, the deformation on the slope primarily manifests as cracks and fissures, most of which are distributed in the western part of the landslide accumulation. In particular, the deformation can be observed next to the highway G108 and the dike dam, that is, at the front area near the water level.

These cracks, which are next to G108, mostly have an extending direction from NE 60° to 70°, lengths of 3 to 83 m and widths of 1 to 10 cm (Fig. 3(1 and 2)). The road subsided by approximately 10 to 20 cm. Moreover, the constructions have deformations as well, as shown in Fig. 3(1), such as cracks appearing on the ground and walls inclining to the free surface with an angle ranging from 2° to 5°.

Most of the cracks at the dike dam, which are small but numerous, are a few meters long and a few millimeters wide and most perpendicular to the river. Approximately 2 months were consumed to reach such a scale of deformation that appeared on the slope, which is considered a creep.

Boundary

The front edge is up to the water level of the Dadu River, which has been covered by filling water and cannot be measured. The brick platform to the large tension gully is the trailing edge, which is located on the northern boundary next to the vertical scarp, with a slope angle of 40° to 60°. The western boundary is up to the integrated bedrock, and the eastern is a little gully that is shallowly incised, as shown in Fig. 3(3). This landslide accumulation is irregular and has a length of approximately 1,050 m, a width of 750 m wide, an area of approximately $50.4 \times 10^4 \text{ m}^2$, and a volume of $956 \times 10^4 \text{ m}^3$. The elevation of the front edge is approximately 840 m a.s.l. and that of the trailing edge is 1,060 m a.s.l.

Topography

In the area of the landslide, the topography is gentler compared with the area outside, and many settlements are located on the slope. The topography from the vertical scarp to the water level

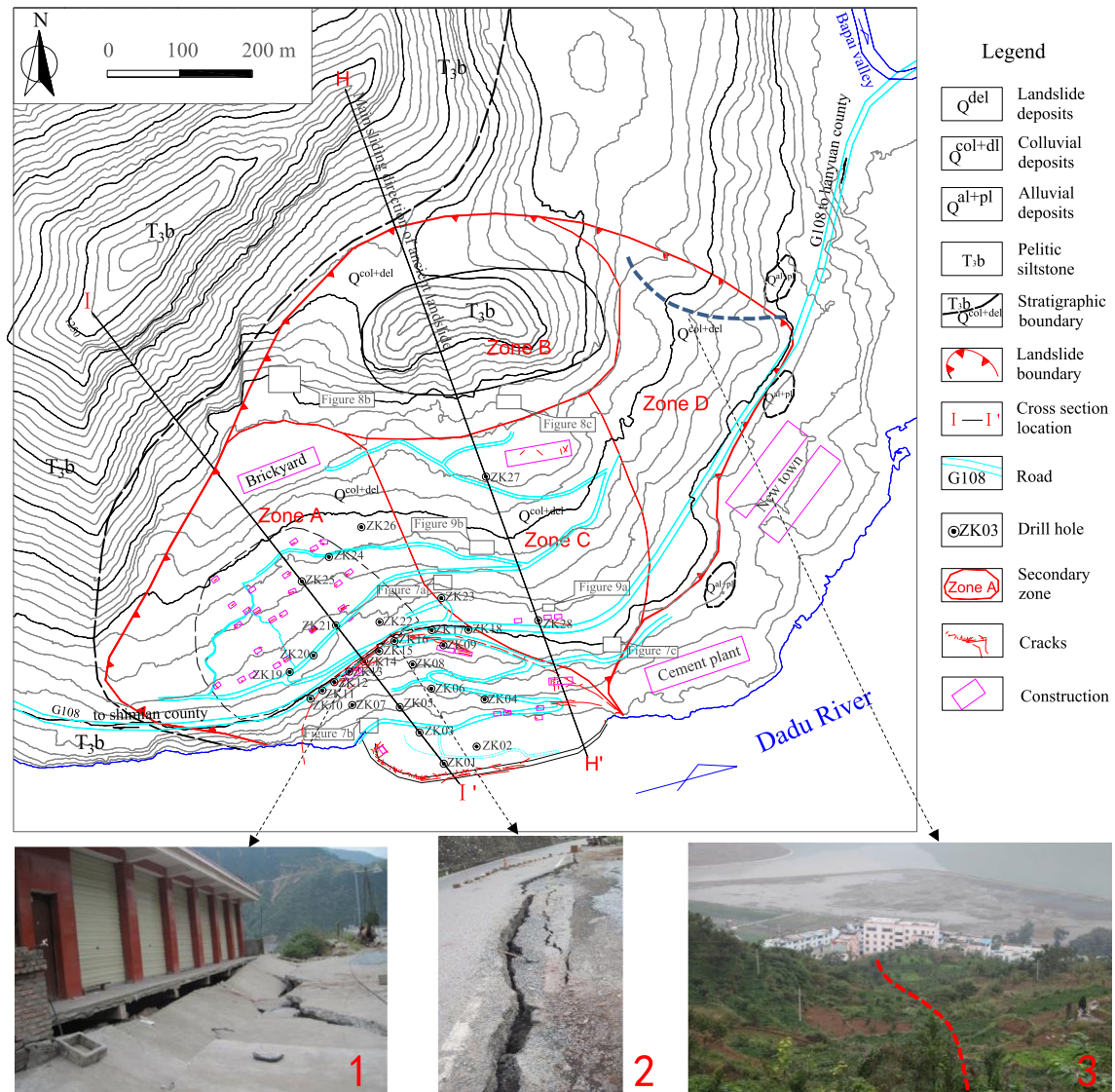


Fig. 3 The landform of Shuangjiaping landslide accumulation and observation locations in the text. 1 Tilted buildings outside the G108, 2 subsidence of ground surface of the G108, 3 little gully, eastern boundary of accumulation

can be divided into four sections: the cliff section, which is from the peak of the Liangtai Mountain to the brick factory flat ground, with a slope gradient of 40° to 60° and exposed bedrock, the gentle slope section, which comprises the area from the brick factory to the national highway G108, with a slope gradient of 7° to 15° , and covered by loose sediments, where settlements and cultivated land are widely distributed, the middle gradient slope section, which is from the national highway G108 to the flat ground and has a slope gradient of 22° to 36° , where deformations are most serious, and the flat ground section, which includes the lower and flat ground next to the river, that is, in front of the dike dam. The four sections could be clarified in the cross section I-I', as shown in Fig. 4. In addition, a bar-type rock mass is likewise located in the east of the brick factory flat ground. A long depression parallel to the vertical scarp can be found between this rock mass and the Liangtai Mountain. The topography is so special that this area is easily identified and observed in the field and aerial photography survey (Figs. 5 and 6).

Deposit material

With the evolution of the surface processes such as geological agent and human activity, the slope has significantly changed from its original features; thus, some slopes have been covered, whereas the others have been exposed. The site-specific investigation and borehole work show that the Quaternary deposit material of the landslide area primarily consists of four layers.

The first layer is the upper part, which is mainly composed of finer materials, such as 56 % breccia particles, 25 % gravels, 10 % sand, and 9 % silt (in some part, the sand and silt could reach 50 to 60 %), with a thickness of 1.5 to 5 m. The second layer, the landslide deposit, is composed of large stones, with a content of 50 to 70 %, a diameter of 1 to 3 m (some are 5 to 10 m), and a depth varying from 1.5 to 36.1 m. The space of these large rocks is filled by gravelly soil. Some of the large rocks even retain the initial stratum order, which is similar to bedrock. This layer is exposed by the excavation of human activity for building road and reclamation project for cultivated land, which could be observed in our

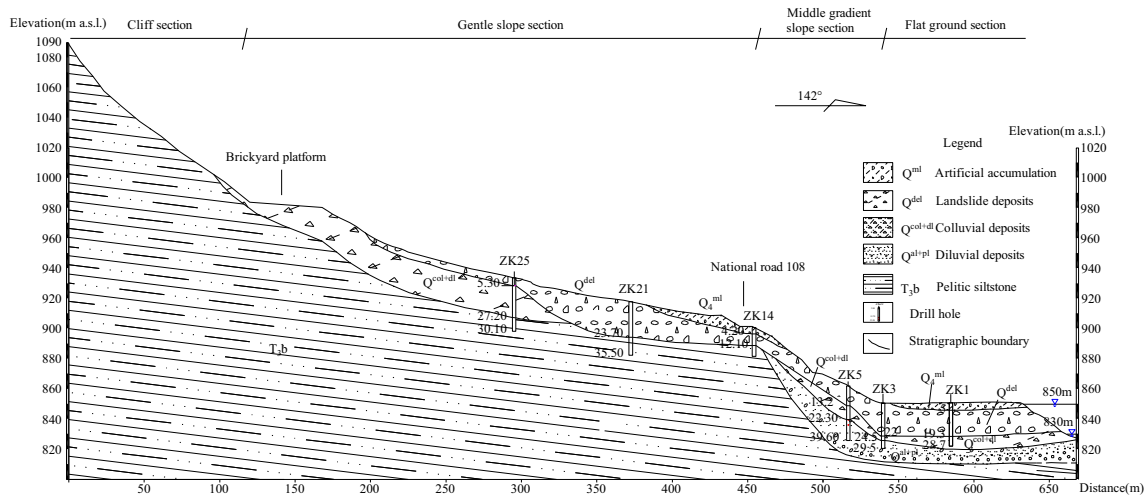


Fig. 4 Profile I-I'. A thin layer of particulate particles is on the top, and the medium is a layer containing abundant giant rock. Four sections of slope gradient are clearly seen

walkover survey, as shown in Fig. 7a, b. The third layer is residual colluvial deposit. The main contents of this layer are 50 % gravel, 25 % rock, 10 % breccia particle and sand, and 15 % silt and clay. The depth of this layer ranges from 2.5 to 14.3 m. This layer mainly distributes in the lower sector of the accumulation below G108 and is rarely observed in the upper. The lowest layer is alluvial deposits and consists of approximately 50 % pebble, 25 % boulder, 15 % gravel, and 10 % sand slit. This layer is not completely revealed

through drilling but is partially exposed on the surface behind the cement plant, as shown in Fig. 7c.

Accumulation features of subzones

In terms of geomorphology, deformation variation, and material structure, as shown in Fig. 3, the landslide accumulation area can be divided into four subzones, namely, zones A, B, C, and D.

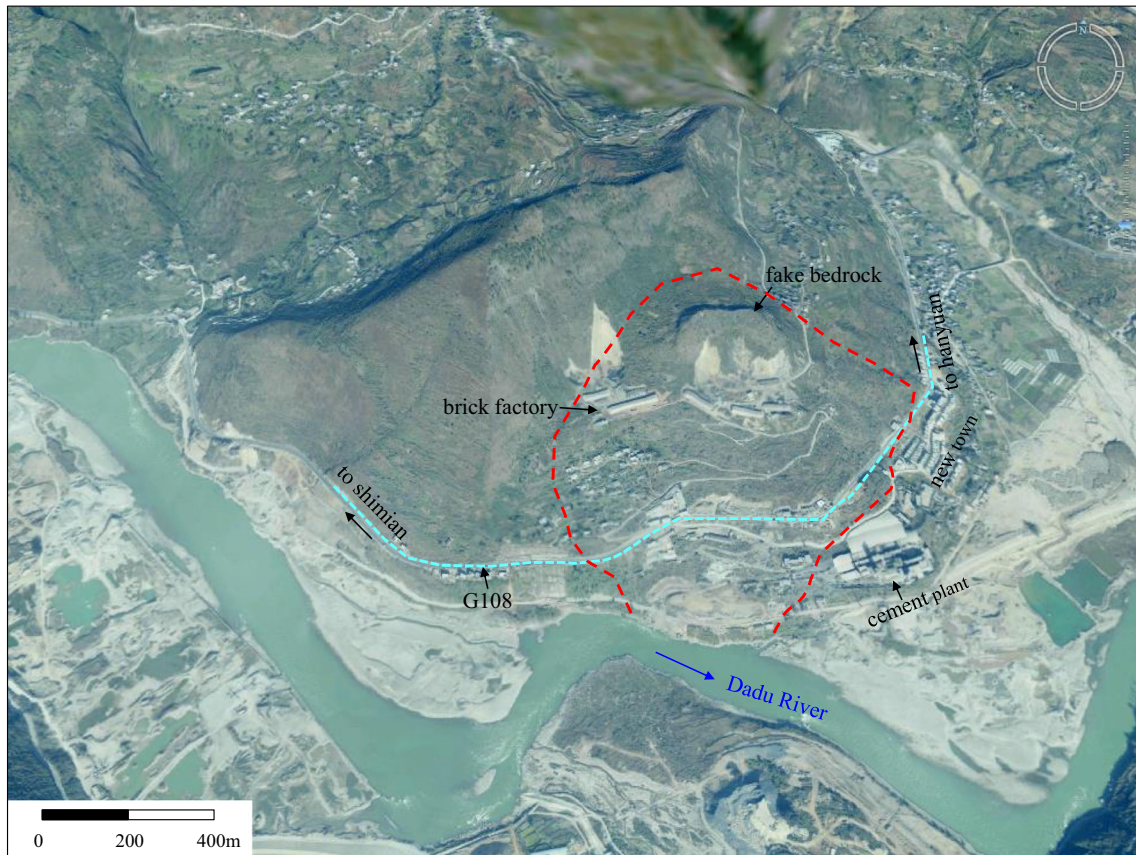
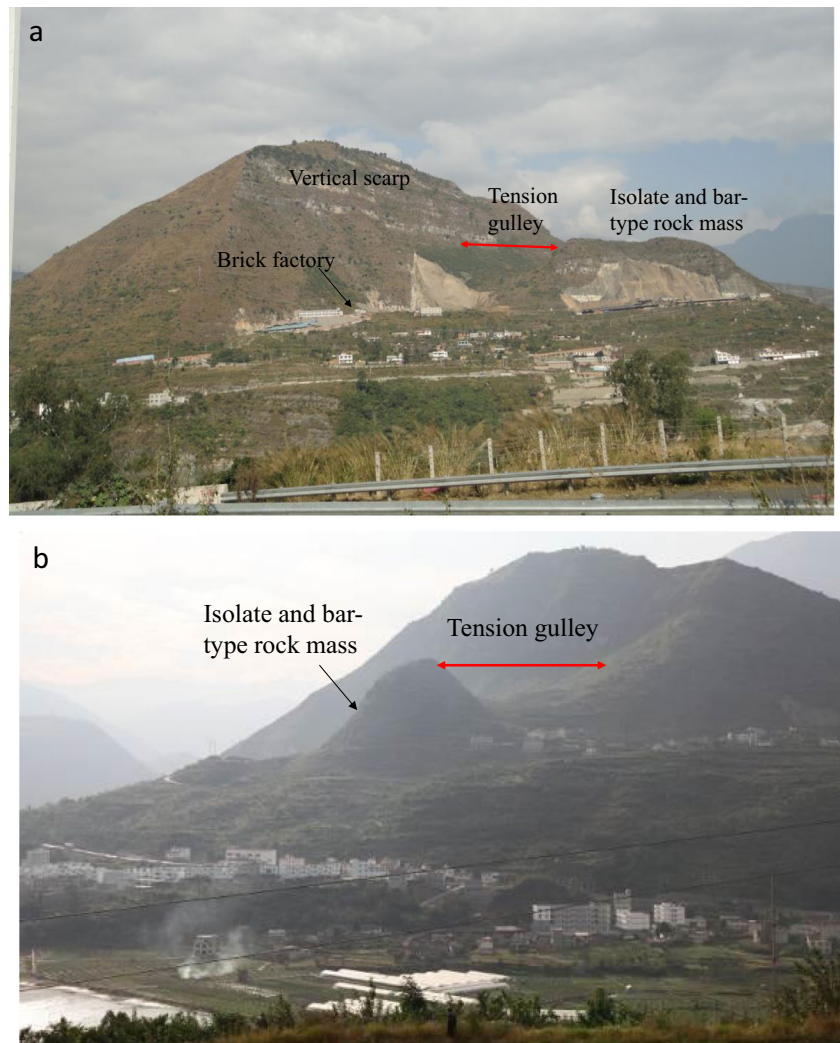


Fig. 5 Aerial image of landslide area, the gentle topography of landslide area, and isolate rock mass are both clearly observed

Fig. 6 The topography of the ancient landslide, the isolate and bar-type rock mass in zone B, the vertical scarp, and the big tension gully could be seen clearly. **a** Seen from the south, the right bankside of the Dadu River. **b** Seen from the east



Zone A

Located upstream of the landslide, zone A is a low-lying northward depression. The elevation of the front edge is approximately 840 m a.s.l. (covered in water), and that of the trailing edge is 990 m a.s.l. The height difference is 150 m. Zone A is approximately 550 m long and 350 m wide. This zone has an area of $20.3 \times 10^4 \text{ m}^2$, a volume of $324.8 \times 10^4 \text{ m}^3$, and an average thickness of 16 m. The western border of zone A coincides with the ancient landslide, and the eastern border is at the junction of Shuangjiaping village and the flat ground of brick factory. The northern boundary is the flat ground of brick factory, which coincides with the trailing edge of the entire landslide, and the front edge reaches the water level. The cross section of zone A is shown in Fig. 4, in which the material structure could be clarified.

In terms of structure, zone A is composed of loose sediments with an uneven thickness of 20 to 30 m. Owing to excavation, the thickness near G108 is 10 to 15 m (see Fig. 4). The site survey and drilling data reveal that the upper section is a thin layer of gravels, breccia particles, and sand. The landslide deposits in the middle are mainly composed of large stones that are 1 to 3-m diameter (Fig. 5) and gravelly soil. The lower section is composed of grayish yellow silt clay with 20 to 30 % gravels, which are commonly angular to sub-angular and have diameters of 2 to 7 cm. The

lithology of the deposit is yellow gray sandstone and argillaceous stone. No sliding surface was revealed by drilling.

The slope deformation caused by the water storage of the Pubugou reservoir is primarily concentrated in zone A, particularly below the national highway G108 and the neighboring houses. Subsidence and many long-large cracks appear on the road surface, and the buildings are tilted.

Zone B

Zone B is found at the northern part of the landslide body and mainly includes the displaced block, which is an isolate bar-type hill like a lying peanut with long axis EW. Zone B has a length of approximately 500 m, a width of 300 m, an area of approximately $12 \times 10^4 \text{ m}^2$, and a volume of $216 \times 10^4 \text{ m}^3$.

The block retains the original order of stratum as fake bedrock, with gentle angles and an altitude of $N 70^\circ E/SE \angle 5^\circ$ to 10° , which is the same as the parent rock mass. Two groups of weathering joints with altitudes of $N 83^\circ W/SW \angle 85^\circ$ to 90° and $N 3^\circ W/NE \angle 89^\circ$ occur in the fake bedrock, which are formed through the weathering effect on tectonic fissures.

A thick layer of residual deposit is observed around the fake bedrock. A U-shaped elongated depression occurs in the trailing edge, with approximately 70 to 90 m wide, in which the middle

Fig. 7 Giant rock exposed in the slope. **a** In the middle part, inside of the national road G108, most of the rocks with volume more than 1 m^3 . **b** At the front part next to a water channel, near the water level. **c** Alluvial deposits exposed behind the cement plant, with pebble and sand



part is higher than the both ends. Approximately 80 % of the depression, which is 60 to 70 m thick, is filled with residual deposit. The residual deposit is mainly composed of silt clay, breccia particles, and a few granule particles (see Fig. 8).

Zone C

Zone C is in the north of zone B and is the middle sector of the accumulation. This zone is a shield-shaped bulge ridge with a length of approximately 400 m, a width of 320 m, an area of $10 \times 10^4 \text{ m}^2$, and a volume of $300 \times 10^4 \text{ m}^3$.



Fig. 8 Characteristics of zone B. a Western edge of fake bedrock in zone B. b Residual deposit in the depression with gravel, sand, and silty clay. c Residual deposit at the southern part of fake bedrock



Fig. 9 Deposits of the zone C. a Large blocks at the inner side of national highway G108. b Giant block, retaining the original order of strata

The drilling survey shows that the thickness of accumulation in this zone is approximately 30 to 60 m. The material structure is similar to that of zone A, which is primarily composed of giant blocks that could reach several meters in diameter, and some larger blocks keep the original order (Fig. 9).

The exploration drilling and field investigation shows a thick layer of alluvial deposit underlain, which is likewise exposed at the front part of zone C (Fig. 10), including pebbles and sand (Fig. 7c). This layer of alluvial deposit is a terrace II (Xiong et al. 2009), which is approximately 50 m higher than the water level of 830 m a.s.l. before water filling of reservoir in the landslide area. Therefore, the landslide occurred as soon as the terrace formed. No deformations occurred in zone C after the impoundment of the Pubugou reservoir.

Zone D

Zone D is found in the eastern part of the accumulation and has an irregular shape, which is approximately 360 m long and 280 m wide. This zone has an area of approximately 8.2×10^4 m² and a volume of 115.2×10^4 m³.

In this zone, the deposits are thin and are mainly composed of shattered material, without large blocks. The eastern boundaries of zone D and the whole accumulation are insignificantly gully shallow incised.

Discussion

Mechanism and process

The lithology of the area is composed of gray sandstone with thin layers of gypsum underlying, gentle angle, and inclination to the south outside the slope. In general, the occurrence of landslides under its own gravity of the slope is difficult with such a rock mass structure. However, the situation may change immediately depending on the effect of water. Consequently, slope failure occurs.

According to the accumulation features described above and the existing pieces of evidence, a conceptual model for interpreting the formation mechanism and process of Shuangjiaping landslide is proposed and shown in Fig. 11. The model summarizes the following processes: translational sliding under a heavy rainfall, gravity bending failure, collapse, and accumulation. Detailed descriptions of these processes are included in the following paragraphs.

1. A weak intercalation occurs, such as shale and gypsum band, as well as numerous vertical tectonic and weathering fissures with the rock mass in the NE–SW strike. In the event of a heavy rainfall, the water seeps into the rock mass along the vertical fissures and converges to the weak intercalation (Fig. 11a).
2. The weak intercalation would be softened or undergo argillization and slip or squeeze out to the free surface (Zhao et al. 2012). Meanwhile, the vertical fissures above the weak intercalation would become a large crack as a long trough (Fig. 11b). The long-vertical scarp and the tension gully (Fig. 6a) next to the northern landslide boundary are the best evidence to justify the process of large crack formation.
3. Hydrostatic pressure is formed in the large vertical crack, and the water flow induces tremendous uplift pressure to the weak intercalation (Fig. 11c).

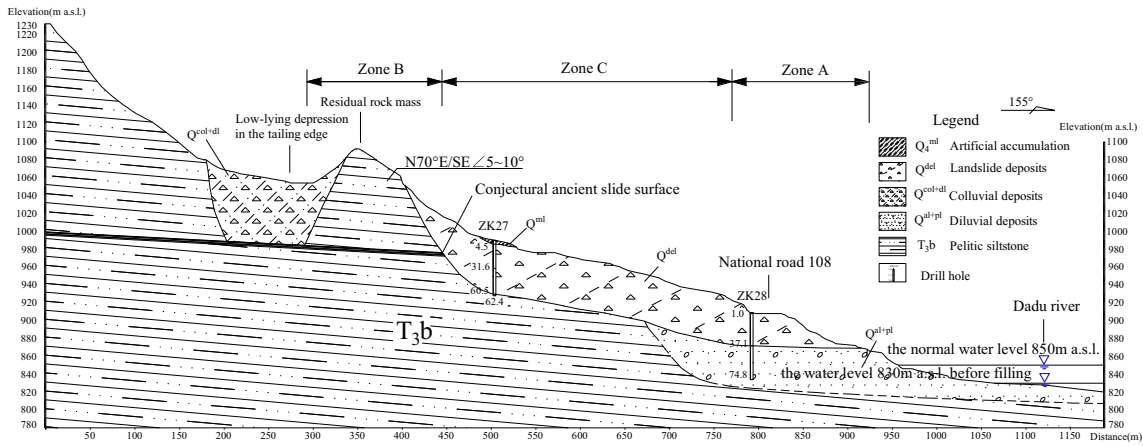


Fig. 10 Profile H-H' principal section of this accumulation. The direction is 156° that is estimated as the main sliding direction of ancient translational landslide. Additionally, zone A, zone B, and zone C are all could be observed

4. The combined force resulting from the tremendous uplift pressure and hydrostatic pressure induces the translational landslide (Fan et al. 2008, 2009). The overlying rock mass above the weak intercalation slides toward the free surface, and the water head decreases in the crack as the rock mass sliding.

When the water head in the crack becomes zero, the moving rock mass gradually stops under the effect of shear resistance. In this process, the front part of the moving rock mass is crushed, which accumulates along the slope below the sliding surface (the weak intercalation), whereas most parts of the rock mass remain on the slope and hang on air. On the trailing edge, a long-wide deep valley remains (Fig. 11d).

5. Given that the sliding surface is tens of meters higher than the river, the rock mass pushed out is hanged on air. Affected by the terrain, no support occurs under the bottom of the rock mass pushed out, and zone A is sunken in the bank slope. Owing to its own gravity, the bending failure of rock mass occurs and is divided by the ridge in zone C, which accumulates on the slope. Zone A is the main accumulation area (Fig. 11e).

With the evolution of the Dadu River, the long-term geologic force has evidently changed the features of the original slope. Hence, the Shuangjiaping landslide is an ancient and special accumulation body that has experienced the long process of sliding, accumulating, and remolding.

Identification evidence

The Shuangjiaping landslide has experienced long-term geological transformation. Consequently, many original landslide features have disappeared, and the original landform has significantly changed, with high vegetation coverage, which have caused difficulty in landslide identification. However, some evidence remains that can be used to identify such an ancient landslide.

1. Saltation of topography

The landslide is located on the left bank of the Dadu River, the upstream side of which is the steep slope and the majestic

mountain. By contrast, the topography immediately becomes gentle in the landslide area, with a slope angle of 10° to 20°, and is developed into a settlement of local resident, as shown in Fig. 5. Topography saltation occurs in alpine gorge region, is often caused by landslide, and will be the first important evidence of landslide identification in field investigation.

During field investigation, the isolate and bar-type rock mass in zone B has attracted the greatest attention. Its existence makes the landslide area sharply different from the mountains around and easily be recognized. The large tension gully, which is a negative relief, between the isolate rock mass and the parent rock mass is also an important evidence of landslide identification, as shown in Fig. 6.

2. Saltation of material structure

As previously mentioned, landslide accumulation generates abundant giant blocks, some of which maintain the original order of stratum. This unit is overlaid by a thin layer of crushed material, which is composed of rubbles, angular stones, and sand. On the contrary, only a thin layer of particulate matter described above (i.e., typical slope wash) lies on the outer surface area of the western part of the landslide. Integrated bedrock exposure also occurs next to the eastern part of this landslide, with a few slope wash. Thus, the characteristic of material significantly differs according to its surroundings, which is a strong and clear evidence for identifying the ancient landslide as well.

The exploration drilling and field investigation reveal a thick layer of alluvial deposit under the landslide accumulation with obvious dual structure. Therefore, the landslide overlaid on a terrace, and some failures of slope occurred previously.

3. Kinematic characteristic

According to the residential fake bedrock in zone B and the giant block that retains the original order of stratum in zone C, the ancient landslide accumulation is formed after a slide with short distance and low speed and accumulates in situ. The giant rocks that keep the original order of stratum

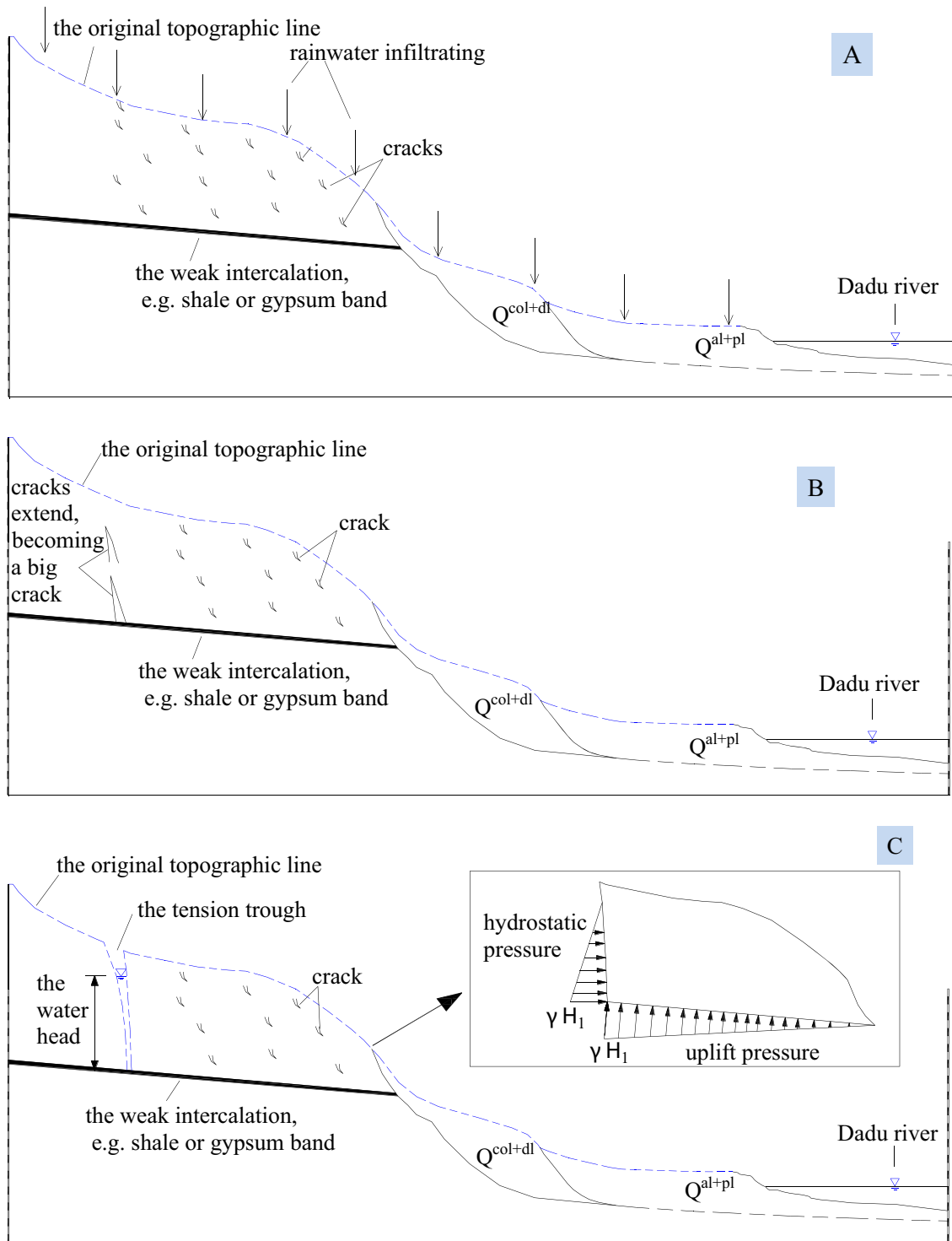


Fig. 11 Conceptual model of mechanism and forming process of this landslide accumulation. **a** Rainfall infiltration and converge. **b** Vertical fissures above the weak intercalation become into one big crack as a long trough. **c** Tremendous uplift pressure and hydrostatic pressure are formed. **d** Translational sliding occurs and the water head decreases, and most parts of the slide rock mass remain on the slope and hang on the air. **e** Long-term geologic force remolds the topography to present situation after the sliding occurred

in zone C demonstrate that after being pushed out, this landslide experienced gravity bending failure, collapse, and accumulation. This landslide did not move too far because of the gentle slope.

Stability

The major deformed area because of reservoir filling is zone A, and the continuous deformation has stopped. Before the present deformation event, no records were found on the superficial

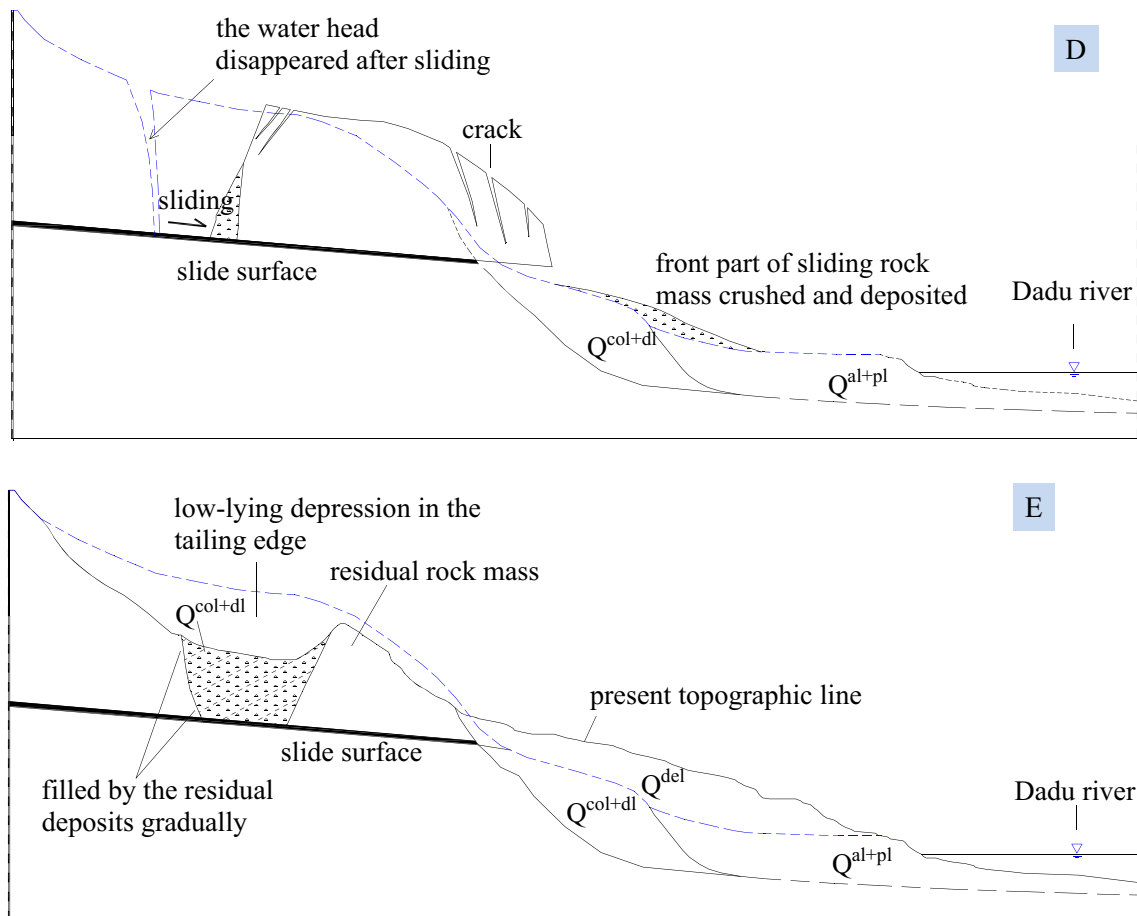


Fig. 11 (continued)

sliding or failure of this landslide accumulation. Thus, the current activity is partial reactivation only because of the superficial deposit displacements. The whole landslide accumulation is stable or quasi-stable.

Conclusion

The landslide described in this paper is a typical case that was reactivated by the impounding of a reservoir. The main accumulation characteristics, forming process, and identification evidence of this landslide are gained through a combined analysis of the detailed field works, borehole survey, and aerial photography data.

The primary conclusions are as follows:

1. The Shuangjiaping landslide could be divided into zones A, B, C, and D according to geomorphology and material structure. Zones A and C are the main accumulation area, which are mainly composed of giant rocks. Zone B is an area of residential rock mass, where the stratum retains the original order. Finally, zone D is an area of particulate matter. The characteristic of accumulation body is controlled by the original topography.
2. This landslide deposit has evolved from an ancient translational landslide, which has undergone the processes of translational sliding under a heavy rainfall, stopping and hanging in the air, gravity bending failure, collapse and avalanche accumulation, and transformation.

3. Topography saltation, material structure saltation, and kinematic characteristic could be important indicators in identifying ancient landslides during field investigation.
4. The current deformation event is only partial reactivation because of the superficial deposit displacements. The entire landslide accumulation is stable or quasi-stable.

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