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THE CHARACTERISTICS OF GENESIS AND EVOLUTION OF DEBRIS FLOW FANS BASED ON FIXED POINT OBSERVATION

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ABSTRACT

The Liziao Gully and Huajiaopo Gully are 2 tributaries of Jiangjia Gully in its middle reaches, a well-known gully for its debris flows of high frequency. The two gullies are extremely similar in features of their drainage basins, including high frequency of debris flows and rapid formulation of debris flow fans. During field studies, process of movement and accumulation of debris flow fan are observed, and sampling and analysis of debris flows with different features are conducted. Terrain of debris flow fans and their longitudinal and transverse profiles are measured prior to and post rainy season each year. By analyzing evolution process, planar features, longitudinal and transverse section, accumulation rate and other parameters of debris fans in the 2 tributary gullies during 2006-2008, following conclusions are obtained: (1) Influenced by geological and lithological features in its drainage basin, Huajiaopo Gully is larger in unit weight and grain size of its debris flow, and its accumulation fan is formulated in Mound-shape. Whereas debris flow in Liziao Gully is smaller in unit weight and grain size, with debris flows moving on the fan and its accumulation is in a linguiform. Further evolution of debris flow fans is finished with Mound-shaped accumulation and channel shifting. (2) In case of accumulation in main channel, debris flow fans in tributary gullies are formed by aggradation and aggradation height is uniformly distributed at upper and lower parts of the fan. (3) Slopes of debris flow fans on both longitudinal and transverse sections are largely determined by fluidic properties of debris flows. The greater the unit weight is, the larger the slope of debris flows on both longitudinal and transverse sections is.

***Key words**: Jiangjia Gully, fixed point observation, debris flow fan, genesis and evolution*

INTRODUCTION

Debris flow fan is usually relatively flat in landform, hence an ideal place for human residence and human activities. For this reason it turns to be a major vulnerable place where debris flow-induced disasters are often observed. In order to make use of debris flow fans in a rational and effective way, it is significant to make an exploration of its initiation and evolution.

Up to now two approaches have been adopted to study accumulation of debris flows. For the first approach, static relations are usually established between its features and eigenvalues. Bull (1964) studied the exponential relationship between watershed area and area of debris flow fan, Tang (1990) reviewed longitudinal and transverse section features of debris flow fan, Liu (1995) argued that watershed area and gradient of main gully are two major morphological parameters for evolution of debris flow fan, Sorriso-Valvo *et alii* (1988) analyzed correlations between patterns and morphologies of debris fan and its physical conditions, Franzi & Bianco (2001) explored the relations between watershed area and accumulative volume. After an overall analysis of factors affecting the initiation of debris flow fan, CHEN *et alii* (2005) proposed that hinterland watershed area, channel gradient, width of main river valley and energy of main river and other factors might have substantial impact on evolution of debris flow fan, and pointed out that a positive exponential relationship could be set up between areas of debris flow fan and watershed, and there is a negative exponential relations between debris fan and channel gradient, as in the case of Xiaojiang watershed. All these studies based on relationships between debris flow accumulation and watershed features could be used for statistical forecast for judging characteristics of debris flow accumulation and determining accumulation morphology and evolution phases based on debris flow fan. However such approach based on geographical data could be only used to obtain static features of a debris flow fan, which could not reflect evolution process of debris flow fan.

For the second approach, an experimental or mathematical simulation of accumulation of debris flows is often applied. TIAN *et alii* (1993) presented a calculation formula for accumulation area of viscous and low-viscous debris flows; LIU (1990) discussed the relations between watershed area and debris flow discharge, between debris flow discharge and maximum length of debris flow fan, between areas of watershed and debris flow fan, and each relationship formula is established; WANG *et alii* (2000) set up a relationship formula between accumulation area and downstream flow slope and fluid intensity by doing small flume experiment. Numerical simulations of debris flow accumulation process have been extensively conducted. MIZUYAMA & YAZAWA (1987) discussed the debris flow depositional process and simulated a large scale debris flow event occurred in 1938; TANG (1994) established a mathematical model for predicting risk area of debris flow based on a flood numerical simulation model; WANG & FEI (1998) proposed a debris flow model based on two-facial fluid theory and established a corresponding equation and numerical solution. WEI *et alii* (2003) established a momentum model for debris flow risk zoning by using numerical simulation and GIS techniques and applied it in studies of debris flows in Chacaito Gully of Venezuela in 1999. These studies might be either conclusions of experimental results or a simulation of accumulation boundary of a debris flow. Due to constraint of data, they are only similar on qualitative terms.

By fixed point observation of real debris flows in its evolution of debris flow fan, time-series evolution characteristics of debris flow fan could be derived and served as a contrast with those obtained through spatial surveys. This approach could also be used for verification and modification of evolution model of debris flow fan based on simulative and mathematical models. Thus fixed point observation should not be ignored in studies of debris flow fan. Due to incidental nature of debris flows, observations and studies of evolution of real debris flow fan have been limited. A good example is studies done by CUI (1996), who made fixed point observations and samplings of debris flow fan of debris flows in Chaqing Gully, a tributary of Jiangjia Gully for three years from 1989-1991 and proposed to predict evolution of debris flow fan boundary by using GM (1, 1), an approach used in systems studies.

In Jiangjia Gully, about 10-20 debris flows are triggered each year although a maximum of 28 debris flows was recorded. As a gully of highly frequent debris flows, Jiangjia Gully has been an ideal place for observation and studies of debris flows. Liziao Gully and Huajiaopo Gully, two tributaries of Jiangjia Gully with similarly high frequency of debris flows, are selected as the study area. Constant observations and surveys of debris flow accumulation have been conducted and data for evolution of debris accumulation acquired in order to analyze evolution characteristics of debris flows such as planar morphology, longitudinal and transverse section and accumulation rate.

A SKETCH OF STUDY AREA

Huajiaopo Gully and Liziao Gully, two tributaries of Jiangjia Gully in the circulation area of the watershed, are located on the left and right side of the main gully with their debris flow fan being separated by the main channel at 103°09′12″E, 26°145′9″N (Fig. 1). With similar physical features (table 1), the two gullies, located at the same place of main gully, could be compared in evolution of their debris flow fans, which may be both quickly mobilized and readily observable.

TOPOGRAPHICAL FEATURES

Huajiaopo Gully and Liziao Gully could be divided into three sections: clear water convergence section, debris flow genesis and circulation section and accumulation section. The first section is relatively

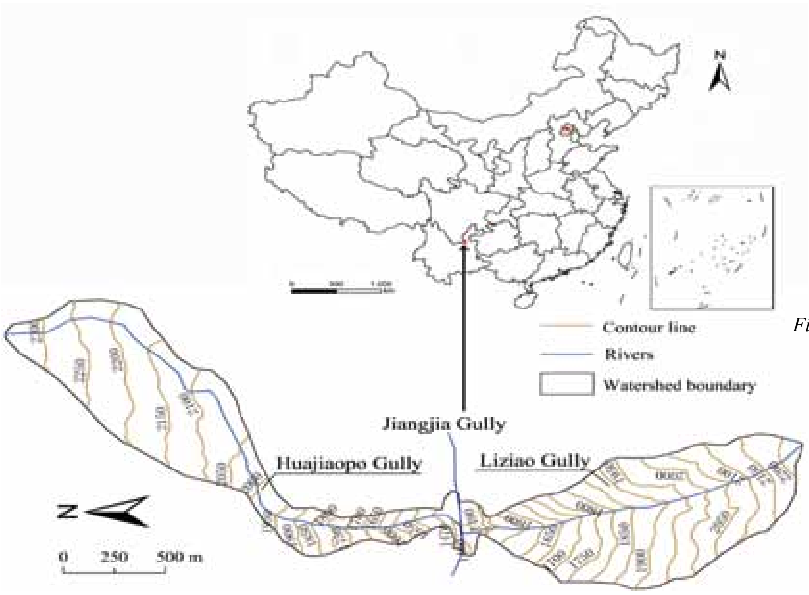

Fig. 1 - Location and map of Huajiaopo Gully and Liziao Gully

Parameters	Names of debris flow gullies	
	Huajiaopo	Liziao
Watershed area (km^2)	0.6540	0.6541
Circumference (km^2)	5.43	3.85
Length of main gully (km)	2.55	1.52
Channel gradient (‰)	340	507
Average slope(°)	21	31
Altitude of Gully Mouth (m)	1473	1471
Maximum altitude (m)	2340	2240
Relative height (m)	867	769
Percentage of basin area > 25° (%)	27	72

Tab. 1 - The basic parameters of Huajiaopo Gully and Liziao Gully

flat above an altitude of 2000 m with a slope of 15°. The second section is steep in relief with an altitude of 1400-2000 m and a slope of over 25° and some areas having a slope of 45°, where rock falls and landslides are frequently triggered and debris flows initiated and circulated. The third section, which is below altitude of 1400 m, has a flatter landform with a slope of 8° for most part, where debris flows are accumulated. A comparison of the two gullies indicates that Huajiaopo Gully is smaller in channel gradient and average slope than Liziao Gully since there is a larger proportion of clear water section in Huanjiaopo Gully (Tab. 1). It is however similar for both gullies in their middle sections where debris flows are mobilized.

GEOLOGICAL FEATURES

Being located in the Deep and Great Fault Belt of Xiaojiang River, the study area is characterized by tensely folded tectonics, extensively distributed joints and weathered rock with geological metamorphization. The dolomite of Dongying Group of Sinian system in Huajiaopo Gully, which is discordant with and above sandstone and slate of Kunyang Qunshang Group, is white-colored and presents a medium and thick-layered, hard and compact texture. Under impact from fracture, joints and later sliding, stratum has been split into boulders or gravels. Stratum in Liziao Gully is mainly composed of black sandstone and slate, which is soft in property and can be weathered into laminae or gravels. The middle and lower reaches of both gullies are well developed with landslides and rock falls on both bank slopes, which are sources for genesis of debris flows.

The deposits accumulated in both gullies are different in grain grading for their different stratum properties. Grains in Huajiaopo Gully are thoroughly coarser, which is indicated in grain grading curve of deposits as having a higher peak for coarse grains and a lower peak for fine grains. The median diameter of grains in deposits of Huajiaopo Gully is 10.3 mm, which is larger than that in Liziao Gully (6.4 mm) (Tab. 2).

Sample No.	Huajiaopo Gully					Liziao Gully			
	H1	H2	H3	H4	Average	L1	L2	L3	Average
Unit weight (kN/m^3)	20.58	19.89	20.48	20.97	20.48	18.42	17.93	17.74	18.03
>2mm gravel (%)	71.4	75.9	72.9	75.0	73.8	67.8	60.3	66.7	64.9
2−0.05 mm sand (%)	17.0	13.7	16.6	14.9	15.5	17.3	25.1	20.0	20.8
0.05−0.005 mm silt (%)	7.7	6.6	6.8	6.5	6.9	9.4	9.6	9.0	9.3
<0.005 mm mud (%)	3.9	3.8	3.7	3.6	3.8	5.6	5.0	4.3	4.9
D50 (mm)	8.9	10.4	9.1	12.7	10.3	7.9	4.6	6.8	6.4

Tab. 2 - Grain grading analysis of Huajiaopo Ditch and Liziao Ditch deposits

Fig. 2 - Multiple stacking of the Mound-shaped accumulation fan of debris flows in Huajiaopo Gully

Fig. 3 - Frequent avulsions of debris flows on accumulation fan in Huajiaopo Gully

PRECIPITATION

Huajiaopo Gully and Liziao Gully are both located in the circulation section of Jiangjia Gully where Dongchuan Debris Flow Observation Station of Chinese Academy of Sciences (Dongchuan Station) is based. Most part of the two gullies is situated at an altitude between 1300-2200 m, an area of subtropical to warm-temperate semi-humid climate with an annual rainfall of 700-850 mm (He, 2003). The rainfall collected at Dongchuan Station could be used as an indicator of characteristics of precipitation of Huajiaopo Gully and Liziao Gully. The precipitation data collected at Dongchuan Station from 2006-2008 show that annual average precipitation is about 500 mm, of which more than 80% is concentrated during rainy season (from May to September) and about 60% is distributed during three seasons from June to August. Under control of such precipitation pattern, most debris flow events in tributaries of Jiangjia Gully are observed during the rainy reason each year. During our observation period precipitation is lower than average annual precipitation for years.

ANALYSIS OF OBSERVATION DATA

Accumulation process of debris flow fans

Viscous debris flows with high unit weight have been observed in Huajiaopo Gully. When fluid mass arrives at the debris flow fan, surface roughness will become greater as slope turns to be flatter. Mound-shape accumulation will appear when flowing resistance has been met. Succeeding debris flow may continue to move and accumulate on the mounds, or goes other ways or directions with less resistance when it reaches where it is higher than its surrounding, and accumulates there. A debris flow fan will appear following numerous avulsion-accumulation processes. Such Mound-shape accumulations and avulsions on the debris flow fan of Huajiaopo Gully are clearly manifested.Compared with those in Huajiaopo Gully, the debris flows in Liziao Gully are smaller in unit weight and higher in fluidity with thinner stacks for each debris flows, hence presenting a lobate shape

(Fig. 4). Although stacking and avulsion is evident during such lobate-shape accumulation processes, the stacking is much thinner as compared with that in Huajiaopo Gully.

TOPOGRAPHICAL SURVEY

In order to study evolution characteristics of debris flow fan in Huajiaopo Gully, a large-scale topographical survey of the debris flow fan was done in 2006 and, for purpose of comparison a survey of debris flow fan in Liziao Gully was also conducted in 2007. For each gully, surveys were arranged in June and September, the starting and ending months of rainy seasons. When a significant change of accumulation fans was observed, there would be an additional survey. On dates 2006-08-15 and 2006-09-02 during observation period, a survey of accumulation fan in Huajiaopo Gully was done with each survey respectively marked No 0601 and No 0602. Since 2007 surveys were conducted for both gullies and there were altogether 5 surveys with dates being 2007-06-21, 2007-09-11, 2008-06-26, 2008-07-16 and 2008-08-25, each being marked No 0701, 0702, 0801, 0802 and 0803. Topographical surveying was done using total station, and a map at scale of 1:500 was produced. Since the average scoring and aggradation layer of deposit for each debris flow is less than 10 cm in thickness and the fan is in Mound-shape, the change may not be revealed on the map at this scale. In order to reflect the morphological characteristics of debris flow fan more accurately, fixed cross section surveys were added after topographical surveys were conducted (Fig. 5).

Fig. 4 - Lobate-shape accumulation of debris flow fan in Liziao Gully

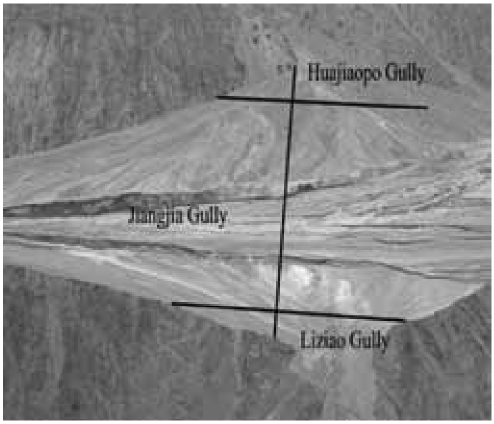

Fig. 5 - Locations for cross section surveys

SCOURING AND AGGRADATION FEATURES OF ACCUMULATION FANS

Previous observations of transverse section of main Gully indicate that there has been a constant aggradation since 2002 at the main gully where accumulation fans of both tributaries are joined (Cui *et alii,* 2004, 2006). During 2006-2008, main gully was still in aggradation process with the smallest height of aggradation being 2.15 m in 2006, the highest being 3.34 m in 2008 and the total height being 8 m (Fig. 6).

When the main gully is being constantly silted, there has been aggradation processes for debris flow accumulation fan in both tributary gullies (Fig. 7). Survey of aggradation has been conducted for 6 times in Huajiaopo Gully. Of all surveys for aggradation events, three surveys reveal obvious aggradation event, with aggradation height for each time respectively being 0.42 m, 0,56 m and 0.58 m. There are another three times of survey for aggradation, of which two times show aggradation events, with height of the higher aggradation being 0.09 m, one time shows scouring with its scouring height being 0.12 m. In considering accuracy of survey, it could be concluded that there has been no obvious aggradation for latter three times.

There has been 4 times of aggradation survey in Liziao Gully. Of all surveys for aggradation events, three surveys reveal obvious aggradation event, with each aggradation height respectively being 0.42 m, 0.32 m and 0.34 m. The fourth survey shows a scouring for 0.1 m, which could be regarded as having no aggradation for accumulation fan.

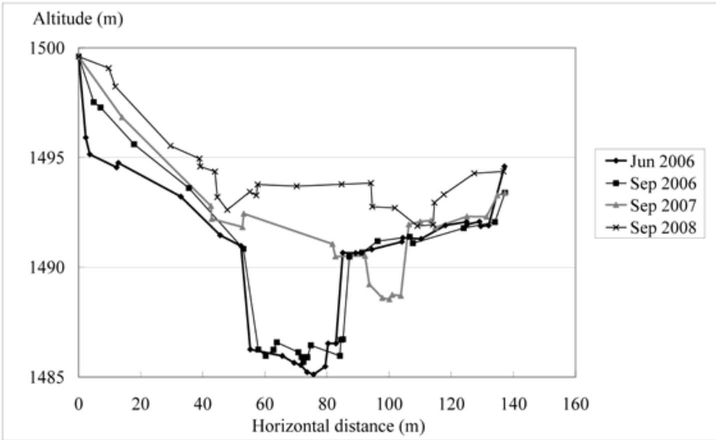

Fig .6 - Scouring and aggradation of the main channel in 2006-2008

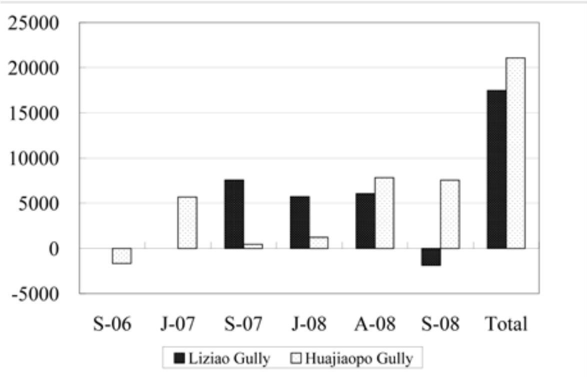

Fig. 7 - The average scouring magnitude of each survey

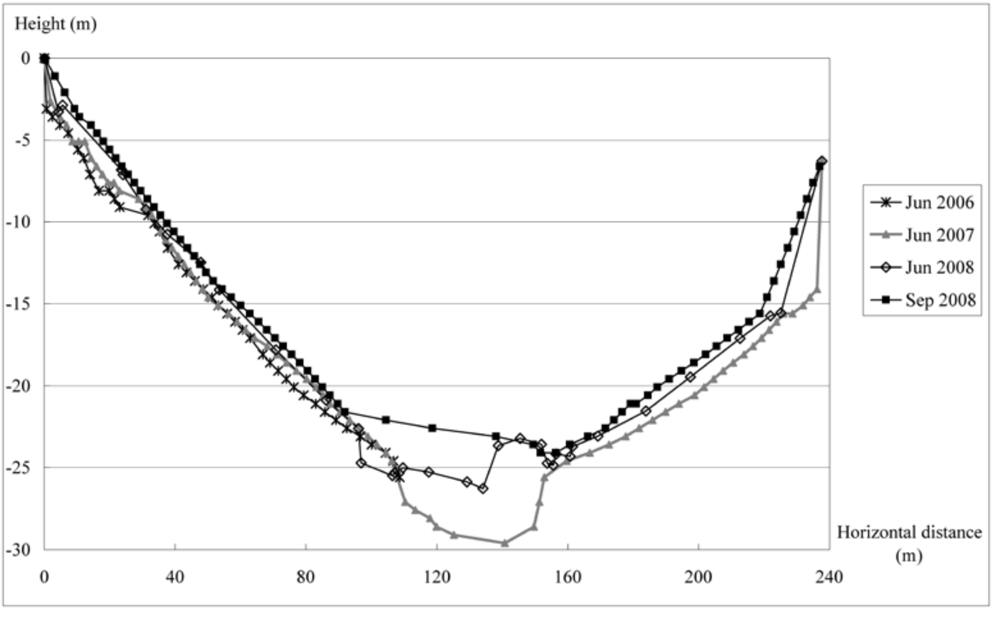

Fig. 8 - Longitudinal profile of debris flow fans in Huajiaopo Gully and Liziao Gully

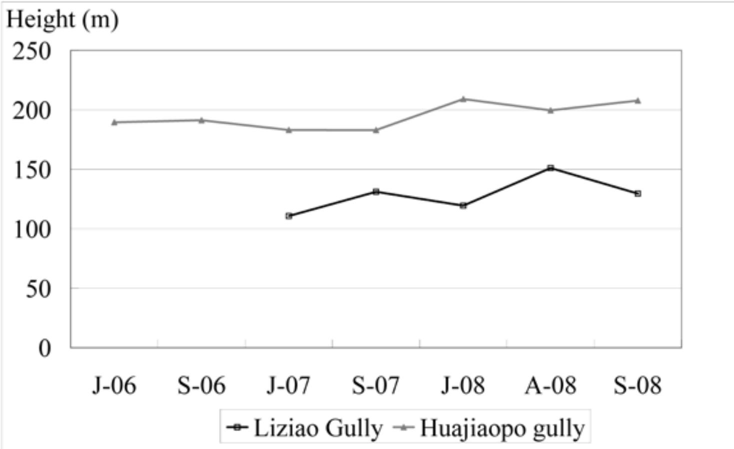

Fig. 9 - Longitudinal profile changes of debris fans in Huajiaopo Gully and Liziao Gully

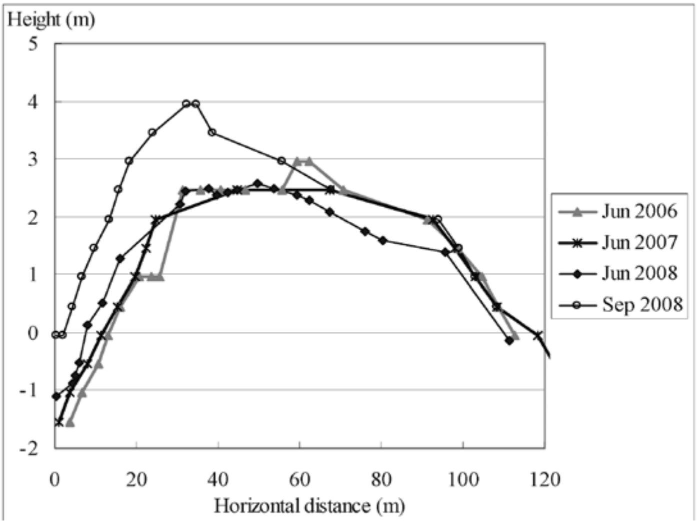

Fig. 10 - Transverse section of debris flow fan in Huajiaopo Gully

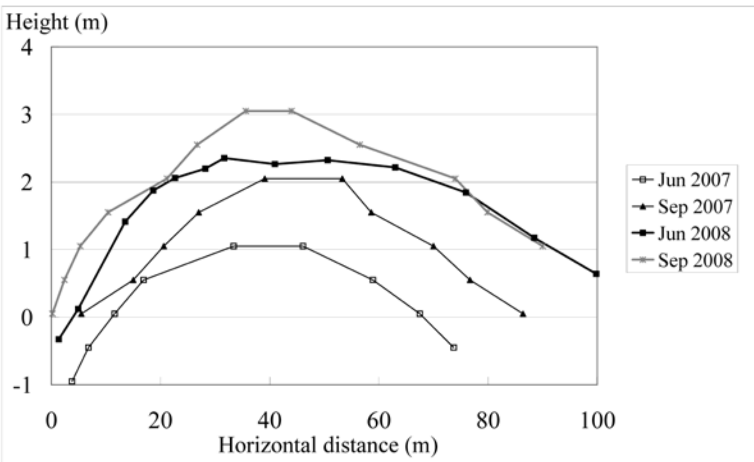

Fig. 11 - Transverse section of debris flow fan in Liziao Gully

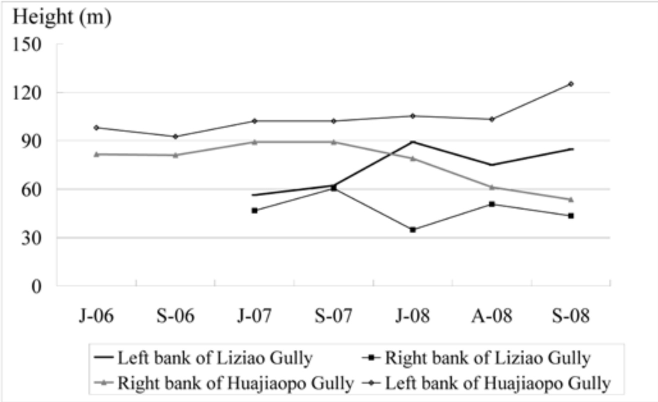

Fig. 12 - Change of transverse section gradient of debris flow fan in Huajiaopo Gully and Liziao Gully

CROSS SECTION FEATURES OF ACCUMULATION FANS

Longitudinal section

All cross section lines of accumulation fans surveyed at different time for both Huajiaopo Gully and Liziao Gully have generally been in parallel and there has no obvious change for longitudinal gradient, but a gradual rise in cross section lines has been observed (Fig 8), which indicates that there has been a sustained and balanced accumulation on the cross section, The longitudinal gradient of accumulation fan in Huajiaopo Gully is larger than that in Liziao Gully (Fig. 9).

Transverse section

The transverse section of accumulation fans of debris flows in Huajiaopo Gully and Liziao Gully takes the shape of convex which is similar to accumulation fans of other debris flows (Tang, 1990) (Figg. 10 and 11). Calculation of slopes at both sides of the two gullies shows that slopes in Huajiaopo Gully are larger than those in Liziao Gully. For both gullies the slope at the upstream side of main gully is larger than that at the downstream side of main gully. Put in other words the slope at right side of Huajiaopo Gully located at the right bank of main gully is larger while the slope at left side of Liziao Gully located at the left bank of main gully is smaller. Since 2007 both gullies have shown an increasingly larger slope for the side in the downstream direction of main gully and a smaller slope for the side in the upstream direction of main gully, which indicates an increasing variation for slopes of both sides for the two gullies (Fig. 12).

RESULTS AND CONCLUSIONS

Debris flow fan in Huajiaopo Gully is accumulated in a Mound-shape while that in Liziao Gully is accumulated in a lobate shape. Geolithological properties has determined that debris flows in Huajiaopo Gully are larger in unit weight and grain size, and debris flow fans are accumulated in a holistic and Mound-shape, whereas debris flows in Liziao Gully are smaller in unit weight and grain size and debris flow fan is formulated in a linguiform. Further evolution of debris flow fan is completed by Mound-shaped accumulation-channel avulsion. This result may be different from some studies done in the past. Experimental studies by Takahaski (1986) show that accumulation fan of debris flows is in circular or elliptical shape in its planar morphology when its unit weight is large and that the accumulation fan will be in strips when unit weight is small. Numerical simulation studies by Yang (2003) also show a similar result. The reasons for variation in morphology of debris flow fans may be that evolution of debris flow fans is initiated at different stages. The evolution of debris flow fans as revealed by observation data in this study may be initiated at a later stage when a debris flow fan has already taken its shape while past experiments and simulations were done at initial stage of evolution of debris flow fans.

When accumulation has already occurred in the main gully, debris flow fans in tributary gullies would be formulated by aggradation, where debris may be uniformly distributed at top and bottom of the fan. Observation data reveal that when the main channel was scoured deep, water flow in tributary gullies may incise debris flow fans and voluminous debris flow may move along deep ravines until it reached the main channel (Kang, 2004; Cui, 1999). The ravines on the debris flow fans may not be silted unless a big debris flow in tributary gullies is mobilized. In case that the main channel is silted, the front part of debris flow fan in tributary gully may be gradually covered by debris carried from main gully. As a result the debris flow fan may rise higher. With decline of gradient of debris flow fan, tributary gully may be soon filled with debris and succeeding debris flows may frequently change its channels. It is observed that there have been over ten avulsions for one debris flow event, which may result in an even aggradation pattern on debris flow fans. As is shown on longitudinal map, accumulation fan has a uniform aggradation pattern on its upper and lower part.

Slopes of debris flow fans on both longitudinal and transverse sections are largely determined by fluidic properties of debris flows. The greater the unit weight is, the larger the slope of debris flow fans. In Jiangjia Gully watershed, there has been a higher ratio of coarser grains for debris flows with a larger unit weight. Due to a larger resistance, such debris flows may stop at a place with a steeper slope and so a steeper accumulation fan may be formed.

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