京都大学防災研究所年報 第40号 B-1 平成9年4月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 40 B-1, 1997

Topographic Change in the Stream Channel by Viscous Debris Flow

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Synopsis

Among the various types of debris flow in China, viscous debris flow distributes vastly, and the hazards caused by it is a big problem. According to the data of debris-flow hazard, the hazards caused by viscous debris-flow amounts to 65 % of whole debris-flow hazards in recent 100 years. It mainly distributed in Yunnan, Sichuan and Tibet. The change in the elevation of the stream channel due to scouring and deposition is significant, the speed of the change is very fast. Any hyperconcentrated stream flow does not induce such a large change. The change in viscous debris-flow channel is mainly controlled by erosion and deposition by debris flows, which are affected by the conditions of gully topography, longitudinal slope gradient, geologic property, drainage scale and the dynamic action of debris flow. This article emphasizes the change in ravines of viscous debris-flow over several years, as well as in one year and by one event of debris flow.

Keywords: debris flow, stream channel, topographic change, Guxiang Gully, Jiangjia Gully

1. Significance of Studies on Viscous Debris Flow

In mountainous areas in China, under the various conditions of precipitation and snow-and-ice melting, there are different types of debris flow due to the different lithology. For instance, mud-flows occur in the loess areas. There are water-and-rock flows in the limestone, granite and volcanic-rock areas. And in the complex lithological mountainous areas, both the frequencies of the dilute viscous debris flow and the viscous debris flows are high.

Comparing various types of debris flow, the viscous debris flow has high density, consists of materials including clay to boulder, and has special motion, dynamics, and erosive and depositive effects. It often results in a disaster and an environmental change.

The viscous debris flow mainly distributes in the southwest of China, such as Xiaojiang River Basin , Dayingjiang River Basin in Yunnan Province, Anning River Basin in Sichuan Province, and Bomi District in Tibet. According to the preliminary statistics, in recent 100 years, there were 125 heavy debris-flow hazard spots which distributed over 46 districts in China. The 82 spots of them are the ravines of viscous debris flows, amounting to 65 percent of the total. The debris flow hazards in these area are caused mainly by the viscous type of debris flow. They distribute in 17 districts and cities in

Table 1. The change in Guxiang Ravine during 29 years

	width of bottom (m)	width of top (m)	depth (m)	length (m)	annual erosion depth (m)	erosion length upward to the source (m/year)
1965	50	475	225	2.1	13.6	73
1973	90	550	275	2.7	6.25	75
1994	110	600	300	2.9	1.25	9.5

Yunnan, Sichuan and Tibet.

2. Change in Viscous Debris-Flow Channel

The debris flow channel is heavily eroded and deposited by viscous debris flows. The rate of the processes is very fast. The rate of erosion and deposition by hyperconcentrated stream flow is not so fast as that by viscous debris flow. The magnitude and the rate of erosion and deposition are controlled by the topography, the property, the scale and the dynamic action of debris flows. Because the process of channel change is complicated, we should deduce a basic conclusion of the process being based on the data from the observation over long years. This section reports the results of survey at ravines of viscous debris flow.

2.1 Change in the channel for several years

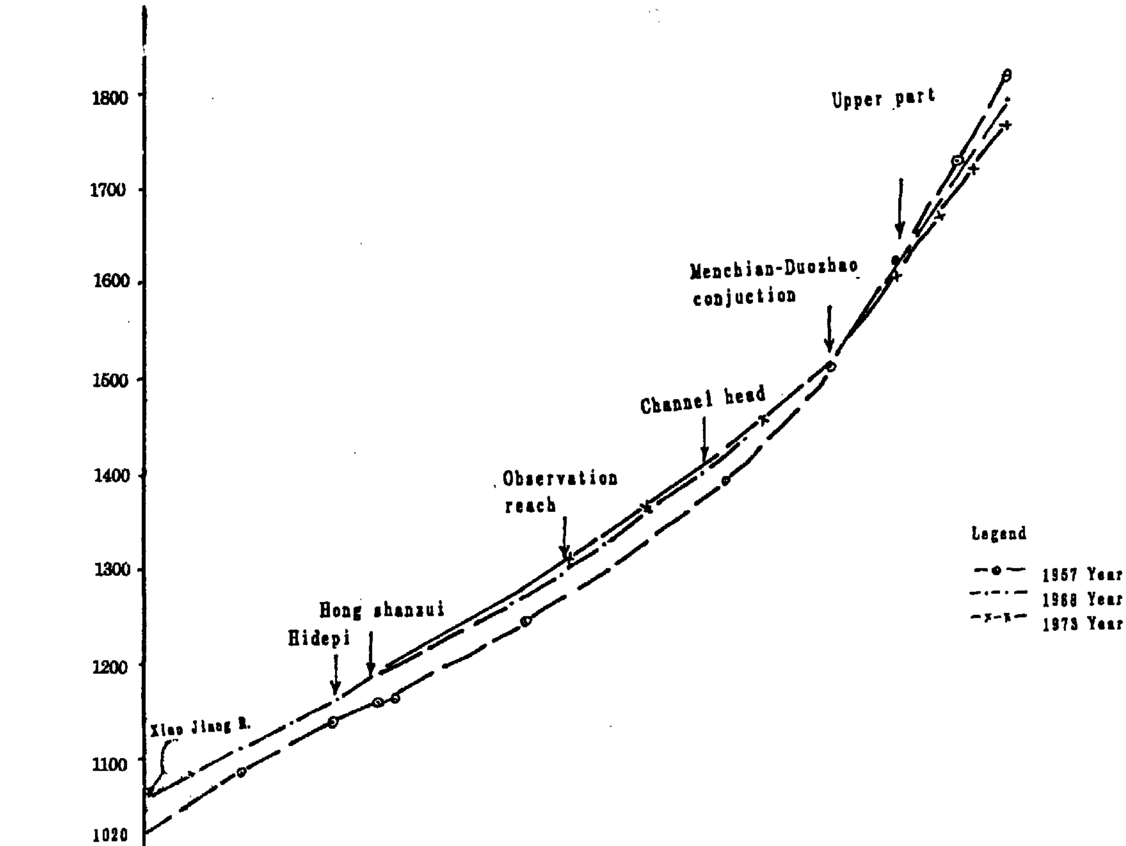
The effective factors of change in the channel over several years are multiple. If the observation data were not enough in quantity and time, we cannot obtain the correct concepts of the relationship among multiple factors. The followings are the analysis at two ravines where the observational studies on debris flow which were executed at the earliest period in China. One of them is at Guxiang Ravine in Tibet and another is at Jiangjia Ravine in Yunnan Province.

There are 6 tributaries in Guxiang Ravine which lies from east to west. Most of the slopes where erosion is on going are the moraine terraces. The main stream length is 2.5 km and others are about 1 km. These are young debris flow channels. Based on the survey data, the main stream channel change, for example, can be analyzed as follows: before 1950, it was less than 1 km long, several meters wide and less than 20 m deep. Hunters could stride over it. In 1954, it became 12.5 m wide at the bottom and 50 m wide at the top, and 1.7km long. The total volume of sediment discharge from this gully amounted to 8,669,000 m^3 between 1950 and 1954. Table 1 shows the observation data of the change in Guxiang Ravine during 29 years. The total volume of erosion amounted to 40,120,000 m^3 between 1954 and 1965, 7,070,000 m^3 between 1965 and 1973, and 2,900,000 m^3 between 1973 and 1994. From these data, we find that in the early period of 1950-1973, the rate of erosion was very high, and in the recent period of 1973-1994, the rate of erosion is low. The bedrock now appears at the bottom of the channel. The erosive process is relatively inactive today.

Jiangjia Ravine is a typical viscous debris-flow basin. Because the channel passes different altitude and geomorphological reaches, it consists of a distinct reach of erosion, a transitional reach and a depositional reach. Local processes of erosion and deposition extend to the whole channel reach. The observation of the channel reach for a long period clarified that the effective erosion occurs in the erosion reach and the level of the bottom has been decreasing. The effect of erosion and deposition in the transitional reach has been low. An uplift of the channel bottom has been remarkable in the depositional reach. From Fig. 1, we learn that the average annual scouring depth in the erosion zone at the upper reach is 2-3m, and the average annual depth of deposition at the lower reach is 2-2.5 m.

2.2 Change in the channel in one year

The change in the channel in one year refers to the cumulative effect of each debris flow to the channel. Mean of the annual frequency of debris flow is about 15 at Jiangjia Ravine, which is used to measure this annual change. According to the observation over several years, one debris flow can scour the channel bed 2-3 m deep, sometimes more than 5m. The magnitude of erosion and deposition by debris flow is controlled by many factors. It is difficult to quantify the effects of these factors. We intend to understand the influence of erosion and deposition at the channel in 1984. Figure 2 shows that the scouring and deposition range of one debris flow is very wide and it appears random.



Distance (m)	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000

Erotion-sedimentation(m)	1966-1973			+11	+12	+5	0	-8	-21
	1957-1966	+19	+24	+27	+21.6	+21	+13	+10	-23
Gradient (%)			5.6		6.4	6.7		9.6	>15.0
Average value of E-S.(m)			+2.3		÷2.1	+1.6		0.1-0	-2.7

Fig. 1 Change in the longitudinal cross section of Jiangjia Gully, Dongchuan, Yunnan

2.3 Changes in the channel by one event of debris flow

The change in the channel by one debris flow is measured by ultrasonic water level gauge. In the course of one debris flow, the previous flood and dilute viscous debris flow and the post-event of the dilute viscous debris flow and flood scour the bed, the intermittent surges of viscous debris flow deposits debris on the channel, while the continuous viscous debris flow scours the bed.

(1) **Deposition by the intermittent surges of viscous debris flow**

According to the observation data of 9 intermittent viscous debris flows in 1985-1986, we find almost all the viscous debris flows brings about deposition. We call the temporal layer made by deposition "adhesive layer" (Table 2).

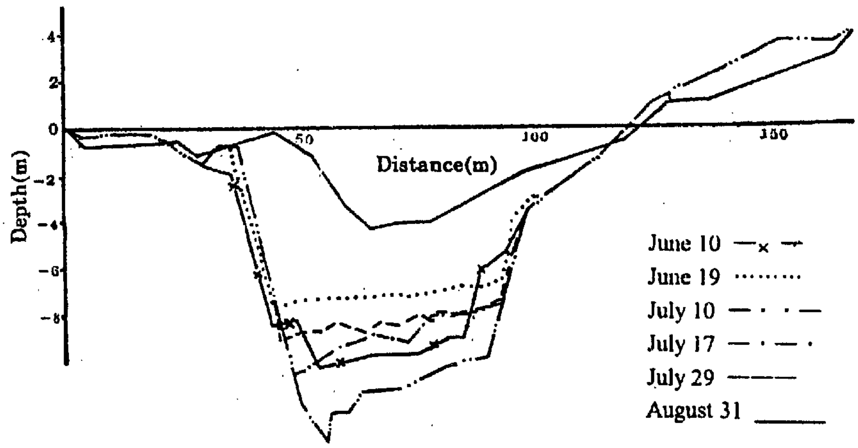


Fig. 2 Change in the cross section of the middle reach of the Jiangjia Gully in 1984

Table 2 Adhesive layer made by the intermittent debris flow

NO.	1	2	3	4	5	6	7	8	9
Date of Occurrence (MDY)	07 26, 1985	07 26, 1985	08 02, 1985	07 22, 1986	07 23, 1986	07 24, 1986	07 25, 1986	07 28, 1986	07 31, 1986
Depth of adhesive layer (m)	0.62	0.91	0.52	0.94	1.6	0.19	1.05	0.97	0.1

The depth of adhesive layer ranges from 0.1 to 1.6 m. According to the observation on July 25,1985 and July 22,1986, the thickness of adhesive layer increased with time due to the cumulative effect of debris-flow surges (Fig. 3). The thickness increases rapidly in the beginning stage, followed with a gradual increase stage. The depth of adhesive layer reaches its maximum at the relative time of 40-50 %, and keeps it to the end of the flow. One hundred percent of the relative time in this table associates the whole duration of a debris-flow event.

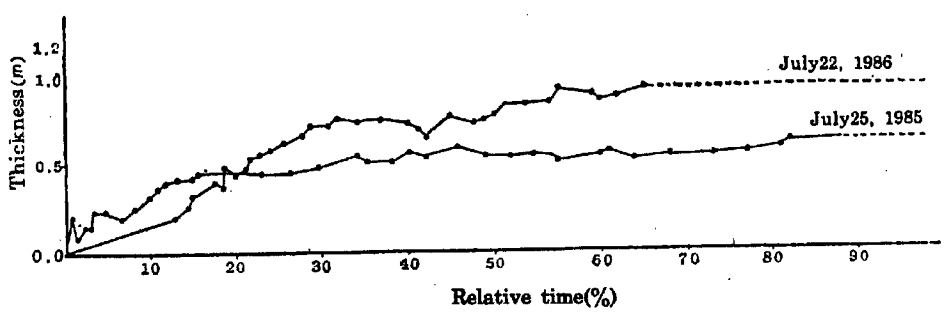


Fig. 3 Change in the depth of the adhesive layer on the channel bottom caused by the intermittent viscous debris flow

According to preliminary analysis, during the depth of adhesive layer increases, the thickness of each surge is affected by the property of debris flow body and longitudinal gradient of the channel bottom. For example, the adhesive thickness of each surge is between 3 and 11 cm for debris flows occurred on July 22,1986. The thickness is calculated by following formula:

$$h=\frac{\tau_B}{\gamma_C J}$$

where, h is thickness of adhesive layer, τ_B is yield stress, γ_C is density of debris flow, J is longitudinal gradient. Substitution with the observed data, γ_C=2.1g/cm^3, J=0.056, τ_B=0.361-1.324 gf/cm^2, makes h 3.07-11.26 cm. The calculated value by this formula conforms to the actual data from the observation.

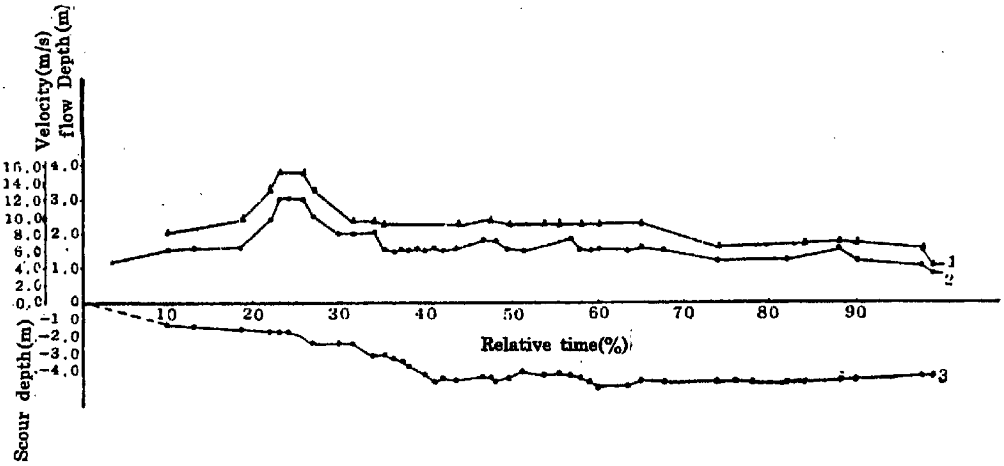


Fig. 4 The curves of velocity (1), flow depth (2) and dynamic scour depth (3) of continuous viscous debris flow

(2) Strong effect of erosion by a continuous viscous debris flow

The strong effect of erosion by a continuous viscous debris flow is proved by one debris flow which occurred on July 25,1986 (Fig. 4). The debris flow lasted for 3 hours and 12 minutes, and the maximum depth of the bed scoured was 4m. The erosion process almost finished at the former half of the period of debris flows. The maximum erosion rate was 3.6 m/hour, and average erosion rate was 1.42 m/hour. Continuous viscous debris flow and intermittent viscous debris flow have similar density(2.1-2.25 ton/m^3) . Why are there these two different effects? The main reason is that the latter has lower velocity than the former. Generally, the velocity of the former is more than 8m/s, and that of the latter is 6-8m/s. High velocity can result in strong scouring effect against loose bed. The frontal part of intermittent debris flow have high velocity, so that they erode the bed strongly, but the lower velocity of the middle and the tail of debris flow results in deposition. The intermittent viscous debris flow keeps a process of scouring at the surge front and deposition at the tail. The debris flow of the continuous type keeps high velocity all through the time, and keeps erosion until the scoring front reaches hard bed materials.

3. Conclusions

In summary, ① Viscous debris flow distributes widely in China, and the hazard caused by it is serious. The study on it becomes a project held by researchers in China and all over the world. ② The magnitude of erosion and deposition on the stream channel by viscous debris-flow is very large and the rate of the process is very fast, compared with that of any hyperconcentrated stream flow. ③ There are different change in longitudinal cross section of viscous debris-flow channel in different reaches. According to the observation over many years, erosion is dominant at the up-stream, at the down-stream deposition and in middle stream, erosion and deposition keeps a balance. ④ The topographic change in the channel cross section by viscous debris flow is remarkable. Sometimes, the change by erosion or deposition tends to 5m. This change is affected by the scale, the property, the density of debris flow and the location of cross section in the channel. ⑤ The change in the channel by one debris flow is controlled by the quantities, the flow type and the dynamic condition of the debris flow. The intermittent viscous debris flow usually deposits debris on the channel bottom, while the continuous viscous debris flow scours the bed.

Acknowledgment

The author thanks Dr. Hiroshi Suwa of Disaster Prevention Research Institute, Kyoto University for his support of revising and editing this manuscript.

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要　旨

粘性土石流が頻繁に発生する渓流で，土石流の観測と地形変動の調査行って，次の成果を得た。チベットの古郷溝では，1950年代に活発な土砂生産のため谷の開析が急激に進行したが，最近では，侵食速度が当時の 1/10 以下に低下している。雲南省の蒋家溝では粘性土石流が頻発して，つぎのような河床変動が進行している。侵食域における一年あたりの侵食深と，堆積域における堆積深はともに最大２～３ｍに達するほど河床変動が活発である。土石流通過域における堆積は，主として間欠流の繰り返しの過程で進行するのに対し，侵食は，間欠流に後続する連続流の出現中に進行するという特徴がある。

キーワード：土石流，侵食速度，河床変動，間欠流，古郷溝，蒋家溝