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INFLUENCE OF DEBRIS FLOW ON CHANNEL EVOLUTION

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ABSTRACT

Affected by the active plate motion, the upper Minjiang River develops more than 21 debris flow valleys. After the Wenchuan earthquake on May 12, 2008, the geohazards occur more frequently and seriously because of the increased debris source, and 9 debris flows blocked the mainstream. Based on the characteristics of debris-flow dams, model tests have been accomplished. Given the junction angle of 90°, influence of debris flow on channel evolution is discussed for different flow density, and discharge ratio and momentum ratio between debris flow and the mainstream water flow. The results show that there is a linear relationship between momentum ratio R_M (ratio between momentum for flow in tributary and mainstream) and shrink ratio S (index defined to describe the magnitude of channel shrink after inflow of debris) of mainstream, and also an exponential relationship between the ultimate average width B_m (index defined to describe the average width of river channel after dam failure) of mainstream and the coefficient of velocity variation F_v (ratio between velocity for flow in mainstream after dam failure and before its formation).

Key words: *debris flow, channel evolution, model test, earthquake*

INTRODUCTION

Channel evolution depends on interaction between water flow and river channel, including incision and deposition. Because of steep gradient, high discharge and low sediment concentration, incision plays a more important role in mountainous rivers, while it makes few changes for channel evolution in a short period. However, landslides, debris flows and collapses may produce significant impact on river channel. Channel segments in the dammed-lake reach will experience sediment deposition in the upper and erosion in the lower portion of the reach, and bed gradient is also undergoing continuous adjustment (Costa & Schuster, 1991; Schuster, 2000; Korup, 2002; 2005; Hsu & Hsu, 2009; Dang *et alii*, 2009).

Debris flows have great impact on channel change and always induce rapids and pools. The field investigation in Colorado Canyon by Dolan *et alii* (1978) points out that, steep tributaries flowing within the zones of bedrock weakness move large debris to the Colorado, forming the major rapids along the 450-kilometer river in the Grand Canyon, and accelerated flow through the rapids scours the deep pools that are located below them. According to Zhong (1999), there are more than 400 rapids along Jinsha River from Jinshajie to Xinshi town, of which 85 were formed by debris flows. Liang *et alii* (2001a; 2001b) conducted a lot of research on the impact of debris flow on river channel change. He (2003) combined the data of Xiaojiang River in Yunnan with model experiment results, concluding impact of debris flow on channel change from 4 aspects. Studies mentioned above have concluded what changes occur when the mainstream is injected by debris, but without explain of how the impacts work.

Fig. 1 - Debris flow dam in Mozigou(June 17th,2008)

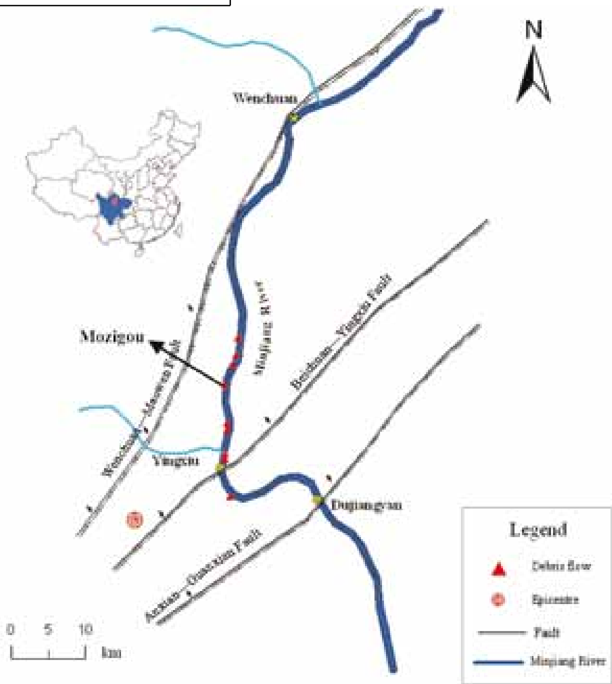

Fig. 2 - Distribution of debris flow dams in the upper Minjiang River

The upper Minjiang River lies in Longmenshan earthquake belt, where landslides and debris flows are common because of the influence of plate movement. At the same time, Wenchuan Earthquake produced significant influence for the initiation of geological hazards (Xu *et alii*, 2009; Cui *et alii*, 2009; Liu *et alii*, 2009). Before the earthquake, small debris flows were common and large debris flows used to break out in Baihua Gully, Fotang Gully and Luojuan Gully in Yingxiu town, but with low frequency. After the earthquake, both the magnitude and frequency of debris flow increased obviously. Nine debris flows blocked Minjiang River several times, of which a most serious one blocked mainstream every year after the earthquake in Mizigou (Fig.1). During Aug. 2010, several large debris flows occurred and the one in Yingxiu Town blocked Minjiang River, constraining the flow to rush into the newly built town.

There are plenty of debris flows in upper Minjiang River, making it an ideal area to study the effect of debris flow on channel evolution. According to our investigation, there were 9 debris-flow dams within 30km along the river after the earthquake, 20km away from the earthquake fault and 30km away from the epicentre (Fig.2). This paper tries to explain the influence of debris flow on channel evolution through a series of model tests based on our field survey in Mozigou.

MODELING EXPERIMENTS

Debris flow which blocked Minjiang River several times after Wenchuan earthquake in Mozigou is the prototype for this simple model (Fig.1, Table 1). Confined to the site condition, geometrical scale is defined as 1:250 in the experiment. According to the similarity criterion, scales for other parameters can be obtained as follows:

$\lambda_v = \lambda_L^{1/2}$, $\lambda_Q = \lambda_L^{5/2}$, $\lambda_{pi} = 1$

Where λ_L, λ_v, λ_Q and λ_{pi} are scales for length, velocity, discharge and grain size, respectively. According to the geometrical scale, λ_L=250.

Parameter	Mainstream	Tributary
Average width(m)	115	50
Velocity(m/s)	6~8	4.8
Discharge(m^3/s)	363	680

Tab. 1 - Parameters for debris flow dam in Mozigou

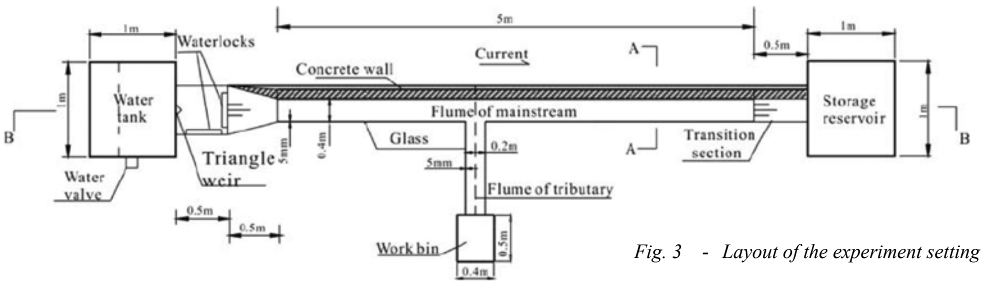

Fig. 3 - Layout of the experiment setting

No.	Density r_c(t·m^{-3})	Tributary discharge Q_b(L·s^{-1})	Tributary velocity v_b(m·s^{-1})	Mainstream discharge Q_m(L·s^{-1})	Mainstream velocity v_m(m·s^{-1})	Velocity ratio Rv*	Discharge ratio R_Q*	Momentum ratio R_M*	Block or not
1#	1.90	2.50	1.67	0.95	0.65	2.57	2.63	12.85	N
2#	2.07	3.27	0.46	0.71	0.61	0.75	4.60	7.19	N
3#	2.00	3.69	1.56	0.83	0.63	2.48	4.45	22.03	Y
4#	1.96	5.53	1.56	0.83	0.63	2.48	6.67	32.36	Y
5#	1.93	3.20	1.70	0.95	0.65	2.62	3.37	17.00	N
6#	2.16	7.16	0.71	0.95	0.65	1.10	7.53	17.88	N
7#	2.00	10.00	2.08	0.95	0.65	3.20	10.53	67.37	Y
8#	2.09	1.20	0.30	1.19	0.69	0.43	1.01	0.91	N
9#	2.05	5.09	1.72	1.19	0.69	2.49	4.28	21.88	Y
10#	1.96	8.78	2.00	0.95	0.65	3.08	9.24	55.75	Y
11#	2.10	1.05	0.03	1.19	0.69	0.05	0.88	0.09	Y
12#	2.00	8.34	1.79	0.95	0.65	2.75	8.78	48.38	Y
13#	1.95	9.32	2.08	0.95	0.65	3.20	9.81	61.23	Y

*$R_v=v_b/v_m$, $R_Q=Q_b/Q_m$, $R_M=Q_b v_b \gamma_c/Q_m v_m \gamma_w$, γ_w-*volume weight of water,* γ_c-*volume weight of debris flows*

Tab. 2 - Parameters for the experiment

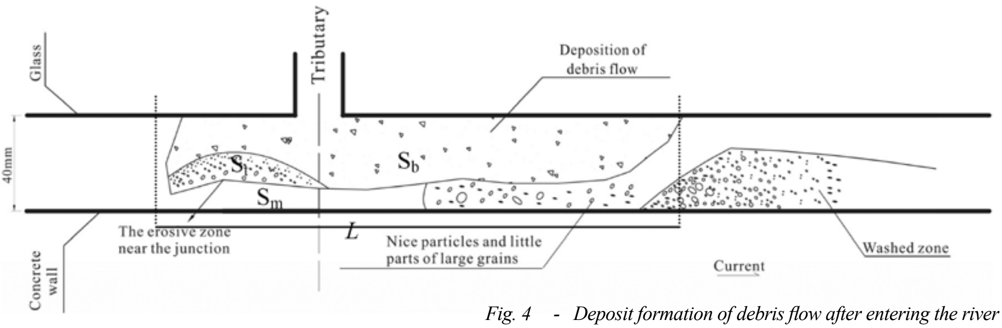

Fig. 4 - Deposit formation of debris flow after entering the river

The setting of the modelling experiment (Fig.3) consists of a concrete flume which is 0.4m wide and 5m long, with one-side toughened glass wall, a material box of 0.5m x 0.4m. x 0.75m, and a tributary flume orthogonal to the mainstream flume, which accords with characteristics of the debris dams in field. 13 sets of tests have been conducted, with parameters listed in Table 2.

DEPOSIT OF DEBRIS FLOW IN THE RIVER

After entering the river, debris flow deposits in three distinctive zones: the erosion zone near the junction, where the grain size increases from the edge to the centre; the deposition zone, where debris deposits en masse and keeps the original configuration; and the washed zone, where the grains washed from the dam are well sorted in size (Fig.4).

No.	S_{sum}/cm^2	S_b /cm^2	S_t /cm^2	S_m /cm^2	S	R_M
3#	9400.00	5675.48	824.52	2900.00	0.691	22.03
4#	8669.62	5235.87	600.91	2832.84	0.673	32.36
7#	12621.17	5959.11	3066.22	3500.00	0.723	67.37
9#	9209.94	5413.53	649.97	3164.44	0.656	21.88
10#	12403.51	8203.15	621.97	3578.39	0.712	55.75
11#	3867.98	3028.08	178.82	1300.00	0.664	0.09
12#	8851.89	6074.76	452.01	2325.12	0.737	48.38
13#	16871.48	8588.73	2977.33	4500.00	0.733	61.23

Tab. 3 - Shrink ratio of the river channel

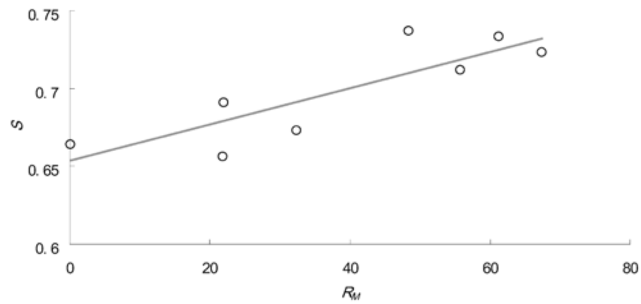

Fig. 5 - S-R_M relationship

The area of each zone changes with the density and discharge of debris flow. However, limited by conditions, a quantitative relationship between the ratios of these zones is beyond the experiments.

SHRINK OF THE RIVER

Even if there is no blockage, debris flow into the river may cause the shrink of channel. In order to explain the channel shrink easily, an index(S) is defined:

$S = 1 - S_m / S_{sum}$

where S_m is the channel area after dam failure, i.e. the area shrunk by the debris flow; and S_{sum} is the sum of the erosive area S_t, the deposition area S_b and the shrunk channel area S_m (Fig.4), following a equation as $S_{sum} = S_b + S_t + S_m$. Calculation for the experiments are listed in Table 3.

Furthermore, an empirical relationship between the shrink ratio S and the momentum ratio R_M is established as follows (Fig.5):

$S = 0.0012R_M + 0.6538 \quad (R^2 = 0.716)$

This relationship is proved in our field investigation. First, an increased density of debris flow raises the strength and height of the deposit (or the dam), and thus the channel shrinks further; second, if the debris flow has larger discharge or velocity, it will carry more sediment into the river and constrain the stream more strongly, which increases the shrink of mainstream eventually.

VARIATION OF MAINSTREAM VELOCITY

Deposition of debris flow into the mainstream shrinks the cross-section, and accelerated flow through the dam is formed. In order to explain the velocity variation, another index is defined:

$F_v = v_t / v_m$

where v_m is the velocity of water flow before the formation of debris dam and v_t is the velocity after the dam failure. In the experiment, F_v, the shrink ratio S and the average channel width B_m ($B_m = S_m/L$, where L is the length of confluence section), are recorded, while no remarkable relationship is established among them. These parameters are listed in Table 4, and the Pearson matrix of the correlation coefficients are listed in Table 5.

But there is roughly a power-law relationship between F_v and B_m (Fig. 6):

$B_m = 16.917 F_v^{-0.6876} \ (R^2 = 0.743)$

The outcomes above can be well exemplified in field investigations. When the average width of river channel gets bigger, velocity diversification for water flow overtopping the debris dam turns to be smaller, and vice versa. However, there is no obvious relationship between the shrink ratio S of mainstream and the

No.	S	S_m /cm^2	L/cm	B_m /cm	v_m/(m·s^{-1})	v_t/(m·s^{-1})	F_v
3#	0.691	2900.00	198.13	14.64	0.63	0.76	1.21
4#	0.673	2832.84	213.88	13.24	0.63	0.83	0.32
7#	0.723	3500.00	277.64	12.61	0.65	0.90	1.38
9#	0.656	3164.44	203.74	15.53	0.69	0.82	1.19
10#	0.712	3578.39	284.57	12.57	0.65	1.14	1.75
11#	0.664	1300.00	75.72	17.17	0.69	0.75	1.09
12#	0.737	2325.12	168.81	13.77	0.65	0.86	1.32
13#	0.733	4500.00	364.63	12.34	0.65	0.97	1.49

Table 4 Velocity variation index F_v

Table 5 Pearson matrix of the correlation coefficients

	S	F_v	B_m /cm
S	1	0.597	-0.735*
F_v	0.597	1	-0.810
B_m /cm	-0.735*	-0.810	1
Number of sample	8	8	8

* Correlation is significant at the 0.05 level (2-tailed).

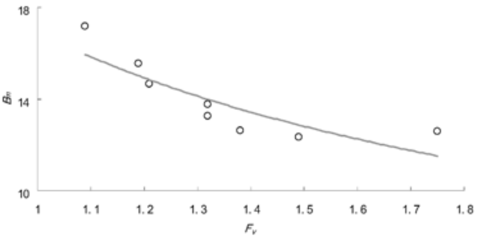

Fig. 6 B_m - F_v relationship

variation of mainstream velocity F_v, because some factors, referring to the size and configuration of dam breach, may play an indispensable function.

CONCLUSIONS

Influence of debris on channel evolution involves the following aspects:

- There is a linear relationship between momentum ratio RM and shrink ratio S of mainstream: S = 0.001 2RM + 0.6538, which shows that the magnitude of debris flow has great impact on channel evolution.
- An exponential relationship is established between the ultimate average width Bm of mainstream and the coefficient of velocity variation Fv: Bm=16.917Fv- 0.6876, which indicates that if the ultimate average width of mainstream gets smaller, rapids overtopping the debris dam will be formed more easily.

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