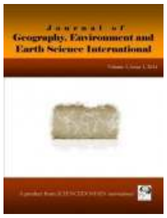


Journal of Geography, Environment and Earth Science International

10(2): 1-9, 2017; Article no.JGEESI.33092
ISSN: 2454-7352

A Case Study of Debris Flow Hazards in the Bayi Gully, Sichuan Province, China

Yu Ma[1*] and Cai-Xia Li[1]

[1]The Engineering and Technology of College, Chengdu University of Technology, Leshan, Sichuan, 614000, P.R. China.

Authors' contributions

This work was carried out in collaboration between both authors. The data for the work was sourced by author YM and analyzed by authors YM and CXL. The manuscript was done and edited by author CXL. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2017/33092
Editor(s):
(1) Wen-Cheng Liu, Department of Civil and Disaster Prevention Engineering, Taiwan Typhoon and Flood Research Institute, National United University, Taipei, Taiwan.
Reviewers:
(1) Yulong Chen, Tsinghua University, China.
(2) George Krhod, University of Nairobi, Kenya.
(3) Lalit Mohan Joshi, Kumaun University, Nainital, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/19073

Case Study

Received 30th March 2017
Accepted 11th May 2017
Published 15th May 2017

ABSTRACT

Many debris flow hazards were triggered in Earthquake area after the Wenchuan Earthquake. On 13 Aug.2010, a catastrophic debris flows were triggered by heavy rainfall in Bayi Gully, Dujiangyan county, southwestern china. This debris flows originating shortly after a rainstorm with an intensity of 75 mm/h transported a total volume of more than 116.5×10^4 m^3. Our primary objective for this study was to analyze the characteristics of the triggering rainfall and the debris supply conditions, and to estimate debris flow volume, mean velocity, and discharge. The debris flow destroyed the most downstream dam in the catchment during a heavy rain storm. The debris flow with a peak discharge of 1082 m^3/s, a total volume of 1.16 million cubic meter, a density of $1.88 g\cdot cm^{-3}$ and a yield stress of 6700 Pa caused 2 persons were missing, 1 persons were injured and 140 houses buried. After three rainy seasons, Only 30% sediment of debris deposition was taken away by 4 large-scale debris flow events. New debris flow will be triggered by rainfall in Bayi Gully in the future. It will be a long term work to prevent the debris flows in Bayi Gully.

**Corresponding author: E-mail: mayu526@qq.com, mayu.2008@hotmail.com;*

Keywords: Wenchuan earthquake; debris flow; formation; characteristics; prediction.

1. INTRODUCTION

Debris flows are ubiquitous hazards in mountain areas. Numerous debris flows were triggered in the earthquake-affected area. Before the Wenchuan Earthquake, the supply of loose solid material mainly by rock falls and regularly carried away by floods was not enough to store sufficient material for debris flow development in the Bayi gully catchment. Even there were twice small scale debris flows outbreaks in the historic records of the Bayi Gully [1]. However, During the period between the Wenchuan earthquake and September 2009, several debris flows occurred in Bayi gully on May 14 and May 19,2008 and July 17, 2009. total volume of debris flow is approximately 1.14×10^6 m^3 [2-3], caused 2 persons were missing,230 persons were injured and 40 houses buried. On August 13, 2010 heavy rainfall occurred in the Longxi River catchment, the maximum rainfall intensity in one hour was 75.0 mm, the cumulative rainfall was 229 mm and the duration of debris flow was 1 hour 40 min. [4]. The rainfall triggered 45 debris flows. The total volume of the debris flow deposits was $3.34\times10^6 m^3$. A lot of sediments were deposited in the downstream part of the Longxi River, and the average deposition height was 5 m. The debris flows damaged 4240 meters highway, 3130 meters levee, and 233 buildings. The economic loss was 550 million Yuan [5]. The largest and most harmful one is the Bayi gully. The large volume deposits silted in the watercourse, 1150m long, average 80m wide, average 12 m thick, the maximum thickness was more than 15 m, and of 116×10^4 m^3 total debris flow volume [5]. causing 2 people are lost, 1 people is wounded, 140 houses are seriously destroyed, DuWen road were silted and check dams, drainage engineering were destroyed (shown in Fig. 1) and 15 million direct economic lost.

Field investigation was conducted on this giant debris flow to analyze the movement and deposition of the material and to analyze the static and dynamic characteristics. The study attempts to find a partial answer to some questions regarding the activity, triggering thresholds and magnitude of debris flows in the earthquake-affected areas. It will help to get a better understanding of the generation of post-earthquake debris flows.

2. METHODOLOGY

Field investigation was carried out on the giant debris flow which occurred on August 13 from October 8–9, 2010. Also two debris flows were triggered on August 13 and 18, 2010. Fortunately the sizes of these two debris flows were not large compared to the size of the debris flow on August 13, 2010. Therefore, the topography of the fan of the Bayi Gully had not changed too much. Information was obtained by interviewing 2 local citizens.

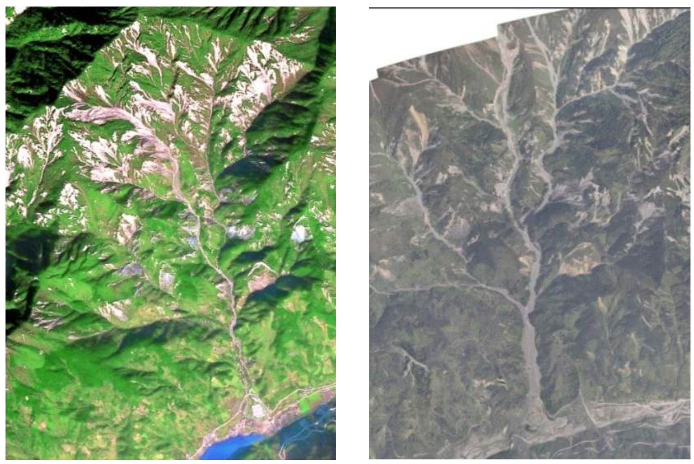
Rainfall amounts both hourly and cumulative were obtained from the two rainfall stations: the Dujiangyan station that 10.3 km away from the Bayi Gully and the Chaguan station that is 1 km away from the Bayi Gully. The course of rainfall from the morning to afternoon of August 13 could be described by 2 local citizens. The deposition area of the debris flow of August 13 was investigated with the help of these local citizens. They were able to indicate the range in depth of the deposits on the fan of the Bayi Gully.

a. Before 8.13 **b. After 8.13**

Fig. 1. The deposition fan of debris flow of Bayi Gully

3. BACKGROUND OF BAYI GULLY DEBRIS FLOW

Longchi Town of Dujiangyan City is located in the Sichuan basin characterized by a semi-tropical moist climatic region, with mild climate, plentiful precipitation and four distinguishable seasons. There exists a collection of hydrological data over a period of 50 years (1950s-now) in the Longchi Town area. In this area the average annual rainfall is 1134.8 mm, the maximum daily rainfall is 245.7 mm, the maximum 1 hour rainfall intensity is 83.9 mm, and the maximum cumulative rainfall is 289.9 mm. More than 80% of rainfall is concentrated between July and September. The rainfall characterized by large fluctuation, high intensity and high rainstorm frequency favors the development of disasters such as floods and debris flows etc.



a. Before 8.13 **b. After 8.13**

Fig. 2. Comparison of the Bayi gully before and after August 13th, 2010

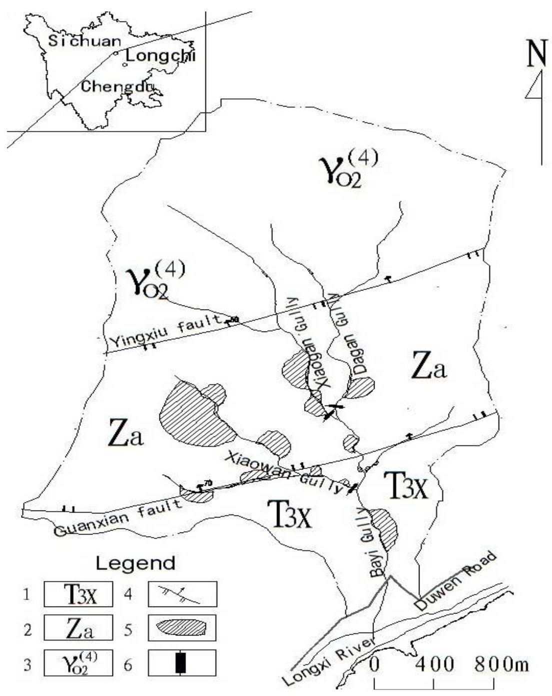


Fig. 3. Catchment of Bayi Gully

1. Triassic: Sand /Mud stone; 2. Sinian: Andesite; 3. Granitic rocks; 4. Fault; 5. Boundary of landslide source; 6. Dam

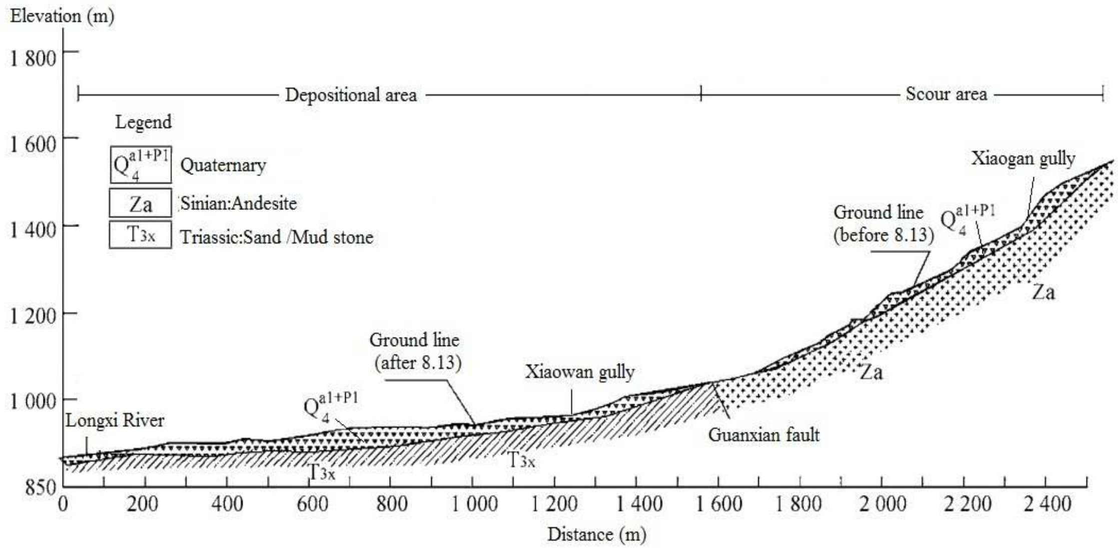


Fig. 4. Cross section of the debris flow in the Bayi Gully

Bayi Gully lies southwest of Longchi Town, with a catchment area of 8.63 km^2 and a 4.45 km long in the main channel. the gully mouth lies at an altitude of 850 m and the highest peak at an altitude 2456 m resulting in a difference in elevation of 1606 m. The average longitudinal gradient of the channel is 376.7‰. in the drainage area, The steep hillside slopes, deeply cutting-in canyons, short channels, and a v-shaped transect of channel of the Bayi Gully has steep side walls that provides suitable topographic conditions for debris flow outbreaks (shown in Figs. 2, 3, 4).

The Bayi Gully catchment consists of granites, sandstones, mudstones, shales, andesites, and limestones. The catchment is located in the Wenchuan Earthquake area, and it is crossed by the triggering Yingxiu-Beichuan Fault of this Earthquake. The northern part of the catchment covers the hanging wall of the Yingxiu-Beichuan Fault and the southern part covers the footwall. The hanging wall site of the fault shows more landslides, rock falls, and debris flows triggered by the Wenchuan Earthquake and subsequent rainfall than the footwall site. In the survey area, the new tectonic movement is mainly intermittent uplift and the terrain is strongly cut. Based on the modified ‘‘China Seismic Zoning Map’’ (GB18306-2001), the peak acceleration of ground motion was 0.20 g, the ground motion response spectrum characteristic period was 0.40 s, and the degree of seismic intensity was XI in this area.

4. THE CHARACTERISTICS OF BAYI GULLY DEBRIS FLOW

With the effect of heavy rainstorms at 16:00 on August 13th, a giant debris flow broke out in the Bayi Gully. Based on the investigation filed, we could determine that the giant flow was not triggered by the main channel but three branches of the channel (Dagan gully, Xiaogan gully and Xiaowan gully). The channel is narrow in the three branches, most parts of which are within 5 m, with the narrowest place of 2 m only in Xiaowan gully. The gradient of channel is big in the upstream of channel, about 25° and the minimum is about 6.4° in the downstream. Sediment on the surface of accumulative layer in the channel has comparatively small particle size, and above 50% of them has the particle size within 50 mm-70 mm (shown in Fig. 13). The slope of hillside in the channel is not in a steady state due to the steepness, with the slope gradient of 30°-60°. Moreover, as the deposit on the slope is quite loose, it is easy to collapse into the channel under the rainfall, and block the gully. Therefore, debris flow will be triggered again in Bayi Gully in the future if the heavy rain comes, and more severe or even giant debris flow will occur when the storm hits there.

The main channel is distributed from gully mouth of Bayi Gully to gully mouth of Xiaowan Gully. The debris flow, with the deposits in the course of the main channel, 900 m long, 80 m wide, 12 m thick, the maximum thickness was more than 15 m, the average longitudinal gradient of the channel was 112‰, and of 86.4×10^4 m^3 total debris flow volume. Some houses are seriously destroyed and silted in Jianjiansh, the minimum depth of deposit is estimated to be 7.5 m (shown in Fig. 5). The particle sizes of coarsen layer were decreasing from upper to lower (shown in Fig. 6).

The Xiaowan gully lies at an altitude between 930 and 1714 m, with the catchment area of 2.09 km^2. The channel is extremely narrow, most parts of which are within 3 m, with the narrowest place of 1.5m only. Fig. 7 shows that gully washing and erosion is serious, the sediment loading of watershed outlet is obviously added. Fig. 8 shows that many trees were destroyed. Therefore, it can be seen that this debris flows had great carrying capacity and destructive power. From our field observations, we suggest that the initiation of debris flows in the Xiaowan gully started with significant surface washed and ditch erosion.

The Xiaogan gully lies at an altitude between 1072 and 2079 m, with the catchment area of 2.96 km^2. During field investigation, the sizes of some big stones are surveyed and the largest one are up to 12 m in dimension with a weight about 320. Fig. 9 shows that highly weathered bedrock and colluviums derived from rock fall and landslides. Fig. 10 shows that new water dam derived from rock fall and other mass-wasting processes are located the source area. From the observations, we concluded the debris flows were initiated by water runoff from colluviums at the foot of a steep slope in the Xiaogan gully.

The Dagan gully lies at an altitude between 1072 and 2436 m, with the catchment area of 2.62 km^2. The main Characteristic is blockage. Fig. 11 shows that debris flow left the accumulation body along the sides of the channel after the blocking body was busted. Fig. 12 shows that new rockfill dam, from the observations, we concluded the debris flows were initiated by heavy rainfalls and floods broke these dams derived from landslides block channel, formed strong flows, eroded the bed of the channel in the Dagan gully.

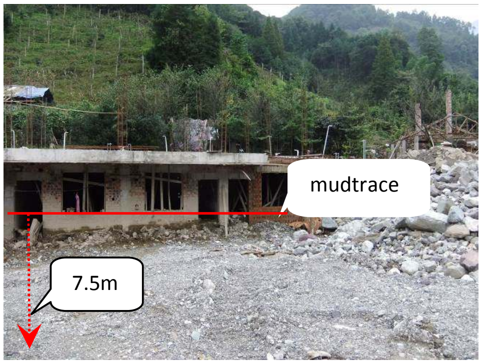


Fig. 5. Houses was destroyed and silted in Jianjianshu

Fig. 6. Change of particle of coarsen layer in deposition zone

Fig. 7. Washing and erosion in forming region of Xiaowan gully

Fig. 8. Trees were destroyed in pathway region of Xiaowan gully

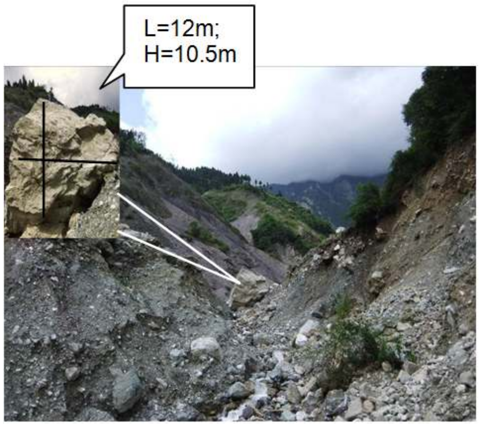


Fig. 9. blocks deposited in Xiaogan gully

Fig. 10. New water dam in Xiaogan gully

Fig. 11. Lateral dyke in Dagan gully

Fig. 12. New natural dam and silting behind the dam in Dagan gully

5. THE FORMATION OF BAYI GULLY DEBRIS FLOW

Generally speaking, the three prerequisites for debris flows are steep topography, an abundance of loose materials, and intense precipitation. From our intensive field observations, we concluded that the initiation of debris flows in the Bayi gully was the comprehensive effect of earthquake and rainfall. The former is a basic condition, which provided an abundance of loose solid materials for debris flows, while the latter was a trigger factor that carried these materials.

The formation condition of debris flow was changed by 39 landslides triggered by the Wenchuan Earthquake. The landslides formed deposited in the catchment of Bayi Gully with the volume of 757.61×10^4 m^3. The sediment, which is loose and its size is small, was easily erosion by flash flood and formed debris flow.

Rainfall is the factor of triggering debris flows in Bayi Gully. According to Longchi stations records, the cumulative rainfall in the Bayi gully was 229 mm, with a maximum rainfall in 1 hour of 75mm, and the duration of debris flow was 1hour40 min. The rainfall at 15:00 – 18:00 on 13th was respectively 22.7 mm，75.0 mm，53.3 mm per hour.

6. STATICS AND DYNAMICS CHARACTER OF DEBRIS FLOW

Statics character and dynamics character of debris flow are key parameters of debris flow features. The investigated deposits of the debris flow showed a mixed character of depositing, with obviously a reversed deposition of particle sizes, which shows sub-viscous debris flow. According to the sampling (small sample) in deposition area of debris flow on August 13, the density of debris flow can be calculated on the basis of the particle distribution (shown in Table 1, Fig. 13) of the debris flow deposit [6]:

$$\gamma_D = \gamma_0 + P_2 P_{05}^{\ 0.35} \gamma_V \tag{1}$$

In which: γ_D = density of viscous debris flow (g/cm^3); γ_V = minimum density of viscous debris flow (= 2.0 g/cm^3); γ_0 = minimum density of debris flow (= 1.5 g/cm^3); P_2 = the weight percentage of coarse particles > 2 mm；P_{05} = the weight percentage of fine particles < 0.05 mm. The calculation result shows that the density of the August 13 debris flow is 1.88 g/cm^3.

The flow velocity, discharge and the total volume of debris are three very important output parameters to evaluate the degree of risk and prevent debris flow hazards. The instantaneous outburst flood, which was formed by the broken dam, can be considered as the peak discharge of debris flow. Using some geometric characteristics of the broken dam, the peak discharge and the total volume of the debris flow and sediment can be computed according to Eq. 2–6 [7-8]:

$$V_C = \frac{1}{n} R^{2/3} \bullet I_c^{1/2} \tag{2}$$

$$V_C = K \bullet R^{2/3} \bullet I_c^{1/5} \tag{3}$$

$$V_C = 1.1 \bullet (g \bullet R)^{2/3} \bullet I_c^{1/3} (D_{50}/D_{10})^{1/4} \tag{4}$$

$$Q = A * V_C \tag{5}$$

$$W = 0.2 * QT \tag{6}$$

In where:

n--bed roughness;
Vc—the velocity of debris flow (m/s);
R-- the hydraulic radius (m), (shown in Table 2);
Ic--the slope gradient of channel bed (‰);
Kc—the factor that incorporates debris flow depth, obtained from Table 3.
D_{50}-- the medium particle diameter, which is the particle diameter at the middle of the grading curve (mm);(D_{50}=10.0 mm);
D_{10}-- the particle diameter whose accumulative content is 10%(mm); (D_{10}=0.2 mm);
Q-- flow discharge of debris flow (m^3/s);
W--total volume of debris blow (m^3);
T --duration of debris flow (s);

The calculation result can be seen in Table 4.

Table 1. Calculation of densities of debris flows

Positions	P_2/(%)	P_{05}/(%)	γ_D/（g·cm^{-3}）
The upper Reaches of the accumulative region	81.5	3.7	2.01
The lower Reaches of the accumulative region	85.7	0.9	1.88

Table 2. Parameters of the cross-section

The positions of cross-section	*B*(m)	*H*(m)	*A*(m^2)	*Ic*(‰)	*R*
Xiaogan G.	12.0	4.2	42.0	208	2.33
Dagan G.	11.5	3.1	31.5	139	2.03
Xiaowan G.	9.3	2.5	19.2	292	1.85

Table 3. Relationship between the velocity coefficient (K) and debris flow depth (H)

H	<2.5	2.75	3.0	3.5	4.0	4.5	5.0	>5.5
K	10.0	9.5	9.0	8.0	7.0	6.0	5.0	4.0

Table 4. The velocity and discharge calculation of debris flow

The positions of Cross-section	Vc(m/s)			*Q* (m^3/s)	*W*(m^3)
	Eq. (2)	(3)	(4)	(5)	(6)
Xiaogan G.	12.0	12.6	—	**504**	**62.9**
Dagan G.	10.2	10.3	—	**321**	**40.1**
Xiaowan G.	13.8	14.4	—	**277**	**34.6**
Bayi G.	—	—	15.3	**1082**	**135.1**

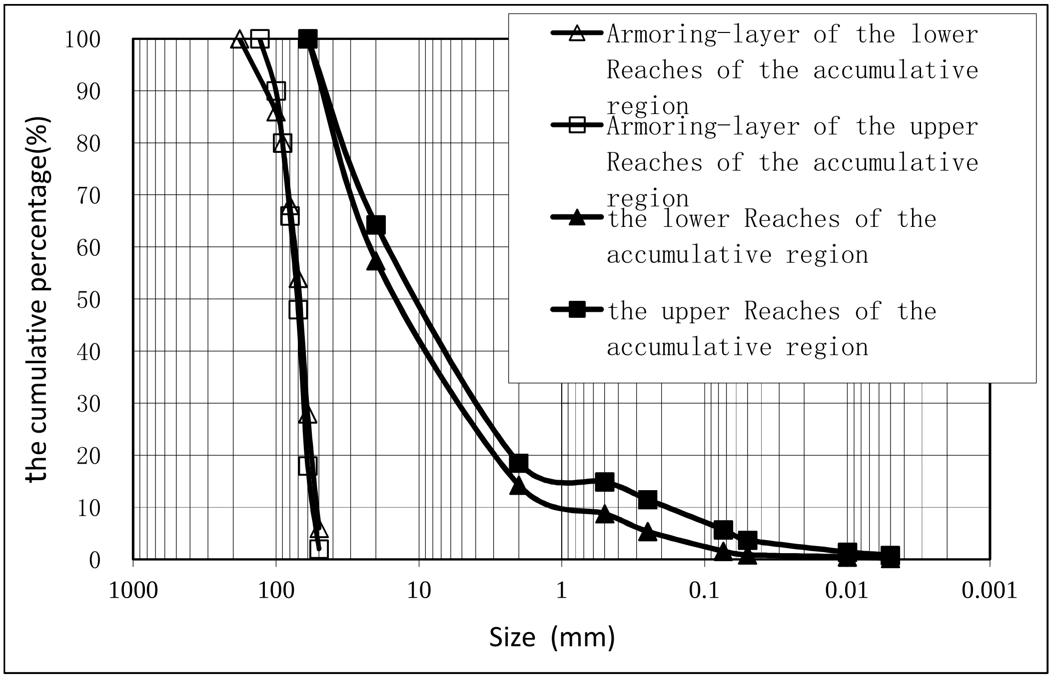


Fig. 13. Particle distributions of the sediment of the accumulative region

According to Eq. 6, the total volume of the debris flow on August 13 is 135.1×10^4 m^3. The amount is quite close to the outcome of the field investigation, which resulted in a total volume of 116.5×10^4 m^3. Since the volume calculated with Eq. 6 is relatively precise, the calculated peak discharge of 1082 m^3/s and velocity of 15.3 m/s calculated with Eq. 4 can be considered as a good estimate.

The yield stress of debris flow is a key parameter to controls the mobility character of debris flow, especially viscous debris flow. Yu [9] was able to determine in the field the yield stress of a debris flow deposit (deposited on August 13th, 2010) adjacent to the most downstream located broken dam according to Eq. (7):

$$\tau_B = \gamma' gh \sin\theta \tag{7}$$

In which: τ_B =the yield stress of debris flow (Pa);$\gamma'=(\gamma_C-\gamma_0)$,relative density of debris flow (kg/m^3);γ_C = density of debris flow (1880 kg/m^3),γ_0 = environment density, in the air $\gamma_0 \approx 0$, in the water γ_0 = 1000(kg/m^3); g = acceleration of gravity (= 9.81 m/s^2);θ =slope angle of the bottom of deposit (= 6.0°), h =maximum thickness of deposit of debris flow (= 3.5 m).

The yield stress of this deposit is τ_B = 6747 Pa. It is one of the reasons why the deposition of the debris flow on August 13th could be filed up in the channel of Bayi gully with the thickness exceeding 7.5 m.

7. CONCLUSIONS AND DISCUSSION

From our research, we can draw the following conclusions:

(1) Many landslide occurred in the BaYi Gully putting down757.61×10^4 m^3 of loose debris which are susceptible for erosion by floods and transformation into debris flows. Therefore, the Bayi Gully turned into a high-frequency debris flow gully.
(2) Continuous heavy rain on August 13, 2010 activated a huge debris flow with a total volume of 116.5×10^4 m^3. It lasted 1 hour and 40 min and destroyed the largest most downstream dam in the catchment, which amplified the impact of the outbreak. This disastrous debris flow killed 0 people, 2 were missing, and 1 people were injured. Together with the burial of 140 houses, the economic losses reached an amount of RMB 15 million Yuan.
(3) The debris flow in the Bayi Gully of August 13 had a viscous rheology, a density of 1.88 g/cm^3 and the yield stress estimated in the field was 6747 Pa and the peak discharge 1,082 m^3/s.

Source of solid materials in Bayi debris flow is formed by landslides from Wenchuan Earthquake, i.e. deposition of landslide-debris. A decrease 757.61×10^4 m^3 is found in the deposition in the Bayi gully after the Wenchuan Earthquake, debris flows were triggered four times on May 14 and May 19,2008 and July 17, 2009 and August 13, 2010 in the same gully, The total volume debris flows is approximately 114×10^4 m^3 before August 13, 2010 and 116×10^4 m^3 in August 13, 2010. By the comparison and survey on the deposition. There is only 30% of the total volume of deposition that took away by debris flows and floods. It is shown that there are still lots of loose deposition can form debris flows time after time.

The main reasons of formation the giant debris flow in the Bayi Gully on August 13th, 2010 are loose solid material and rain. Now there will still remain a great deal of solid material deposition and the extreme severe debris flow as that on August 13, 2010 may be triggered in the future rainy seasons. So the debris flow disaster should be prevented, and the prevention and control of debris flow of Bayi Gully is a long term task.

ACKNOWLEDGEMENTS

The paper was supported by Scientific Reserch Fund of SiChuan Provincial Education Department, (Grant No.16ZB0407) and The Engineering &Technology of College of Chengdu University of Technology Foundation (Grant No. C122016020).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Yu Bin, Ma Yu, Zhang Jiannan, et al. The group debris flow hazards after the Wenchuan earthquake in Longchi, Dujiangyan, Sichuan province. Journal of Maintain Science. 2011;29(6):738-746.
2. Shen Junhui, Zhu Rongchen, Liu Weiguo, et al. Possibility geological analysis of Gangou debris flow in Longchi Town in Dujiangyan induced by the earthquake of May 12 in Wenchuan. Journal of Mountain Science. 2008;26(5):513-517.
3. Zhang Ziguang, Zhang Zhiming, Zhang Shunbin. Formation conditions and dynamics features of the debris flow in Bayi Gully in Dujiangyan County. The Chinese Journal of Geological Hazard and Control. 2008;21(1):34-38.
4. Xu Qiang. The 13 August 2010 catastrophic debris flows in Sichuan Province: Characteristics, genetic mechanism and suggestions. Journal of Engineering Geology. 2010;18(5):596-608.
5. Ma Yu, Yu Bin, Wu Yufu, et al. Research on the disaster of debris flow of Bayi Gully, Longchi, Dujiangyan, Sichuan on August 13,2010. Journal of Sichuan University (Engineering science edition). 2011; 43(S1):92-98.
6. Yu Bin. Research on the calculating density by the deposit of debris flows. ACTA Sediment logical SINICA. 2008a; 26(5):789-796.
7. Yu Bin. Study on the mean velocity of viscous debris flows. Advances in Earth Science. (In Chinese). 2008b;23(5):524-532.
8. Zhang Jiannan, Ma Yu, Zhang Huihui. Study on earthquake debris flow in Dangan Gully, Hongkou, Dujiangyan, Sichuan Province. Journal of Maintain Science. 2010;28(5):624-627.
9. Yu Bin. Study on the method for deposition depth calculation of debris flow with different densities. Journal of Disaster Prevention and Mitigation Engineering. 2010;23(2):78-92.

Peer-review history:
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http://sciencedomain.org/review-history/19073