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Experimental Study on the Formation of Debris Flow from Landslide Clastic Deposition

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Abstract: The Debris Flow from Landslide Clastic Deposition is a special type of debris flow originated from landslide collapse following earthquakes or strong rainfalls. The consequential accumulation of debris in the channels will become the source for debris flows later when there is sufficient rainfall. Due to massive loose materials produced by landslide, the amount of rainfall required for debris flow happening is significantly less than before the occurrence of landslide. The analysis of start mechanisms of debris flow is of great significance for disaster prevention and control. This research explores the characteristic parameters affecting the initiation of debris flow from clastic accumulation, including surface slope of clastic accumulation, soil clay content, median grain size and non-uniformity coefficient. The experimental results suggest that neither the surface slope nor the clay content but the median grain diameter and non-uniformity coefficient in clastic deposition have significant influence on required discharge per unit width. Moreover, the initiation and erosion unit width flow increases when median grain diameter and non-uniformity coefficient increase. Based on experimental data, formulas calculating unit width discharge are developed. Furthermore, compared with the hydrologic calculation value, these formulas are validated with the influences of median particle size and non-uniformity coefficient in debris-flows in Niujuan and Wenjia gully.

Keywords: clastic deposition, debris-flow, grading, initiation flow, discharge formula

1 Introduction

The Wenchuan earthquake (Ms = 8.0) occurred on May 12, 2008, in Sichuan, China, has not only caused severe casualties and property loss, but also triggered tens of thousands of landslides over a broad area (Dai 2010), which further leaded to approximately 5-15 km^3 loose materials (Robert and Alexander 2011) and numerous secondary geological disasters (Huang and Xu 2008, Yin 2009, Xu et al 2009). In the next few years, those loose materials accumulated in gullies or on slopes, resulted in massive debris flows after received heavy rains (Tang et al 2012). This type of debris flows resulted from landslide collision is called Debris Flow from Landslide Clastic Deposition. The initiation of this type of debris flows is not due to the geographical features of gullies but downward erosion in the loose accumulation body that activates the original non-debris flows or low frequent debris flows, and later on induced by rainfalls (Tang et al 2009).

Examples of such debris flows happened in Wenjia gully in Wenchuan earthquake region. Before the Earthquake, Wenjia gully was a non-debris flow gully (Bin et al 2013). The catchment is in an area of 7.81 km^2, with main channel of 3.25 km; gully mouth lays at 883 m asl and the highest peak 2,402 m asl, forming an average longitudinal gradient of 467.4‰. During Wenchuan Earthquake a large landslide was triggered in Wenjia Gully. Limestone rocks estimated at 27.5×10^6 m^3 dropped from the altitude between 1,780 and 2,340 m and slid downward at a high speed (Xu et al 2009). After multiple collisions during the sliding process, limestone rocks were disintegrated into clastics. Some of those crushed materials, estimated at 20×10^6 m^3, remain on a relatively flat place called Hanjiadaping with a gradient <10° and are free from debris flow; other rocks avalanched further downward, and entered into a Platform at 1,300 m. Still some others stopped between 985 m and 1,400 m, forming a deposition area in a volume of 30×10^6 m^3 (Xu et al 2009).

These deposits, with maximum thickness of 150 m (Figure 1), are mainly consisted of broken angular-shaped gray lime stones and brown soil, combining in a loose structure with surface slope averagely 13° (Xu et al 2009), which was the main source to produce debris flows.

In the next three years, five debris flows at large- or ultra-large scale (Table 1), mainly formed from deposition on Platform 1,300 m, have burst in Wenjia gully. Their total amount was about 420×10^4 m^3, accounting to 14% of the entire deposition. Yet the deposition area was incised a channel in a depth up to 70 m by multiple debris flow flushes (Xu et al 2009). The remaining deposition materials and the highly incised channel pose high potential of debris flow risks in Wenjia gully.

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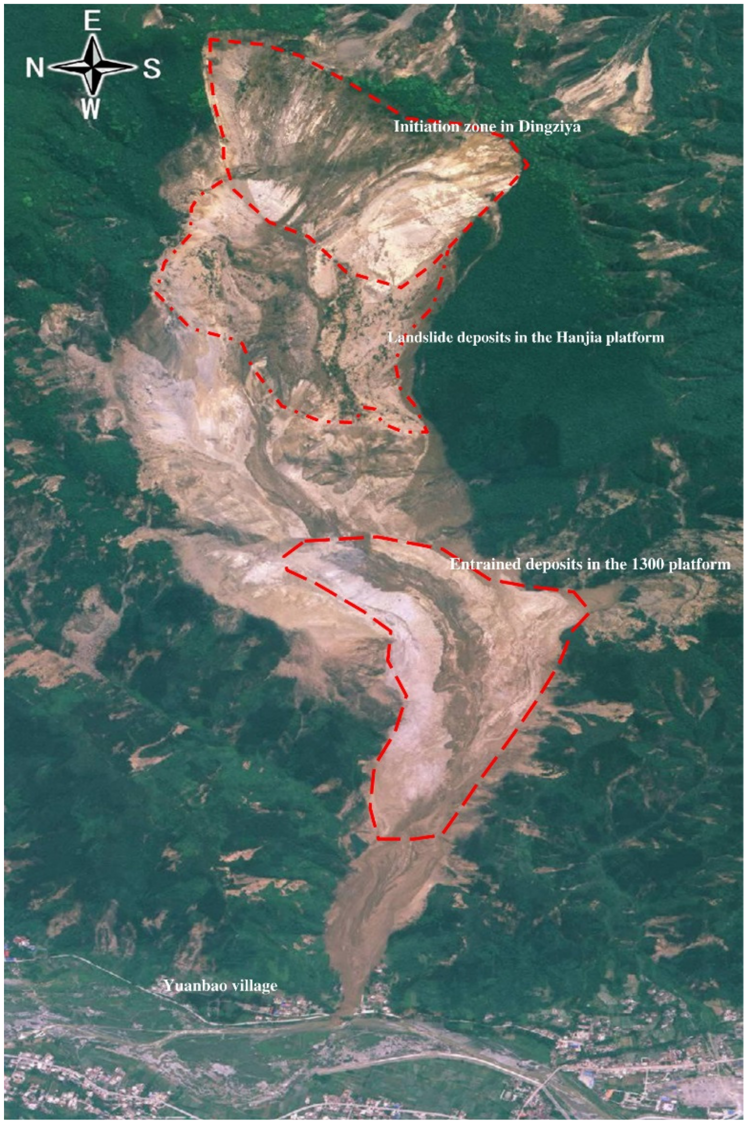


Figure 1. Wenjia Gully (Tang et al 2012)

Table 1. Debris flows triggered after rainfalls in Wenjia Gully (Xu 2010)

Date	Total Rainfall (mm)	Maximum Rainfall (mm/1 hour)	Debris Flow Scale (10^6 m^3)
2008-9-24	88.0	30.5	0.5
2010-7-31	60.2	51.7	0.2
2010-8-13	185.9	70.6	3.1
2010-8-19	72.6	31.9	0.3
2010-9-18	52	29.0	0.17

Figure 2. Debris in Niujuan Gully

Figure 3. Debris in Dazhai Gully (Liu 2010)

Debris deposition similar to that in Wenjia gully are widely distributed in Wenchuan earthquake region. Take Niujuan gully as an example (Figure 2), landslide disintegration in this tributary gully after earthquake led to a clastic accumulation (1×10^6 m^3) of 300 m long and 100 to 150 m wide. Later in rainy seasons, a large number of debris flows occurred, among of which, the two largest were on Sept 26, 2008, and Aug 14, 2010, where 0.17×10^6 m^3 and 0.15×10^6 m^3 materials rushed out, respectively.

Earthquake is not the only force that causes landslide clastic deposition, other factors including rainfalls and coal mining also produce loose materials to contribute to debris flows. For instance, rainfalls have induced massive clastic deposition in Dazhai gully in Guizhou Province (Liu 2010, Kong et al 2010) (Figures 3 & 4). Clastic deposition generated after coal mining exists in a Madaling gully in Guizhou province (Wang et al 2013, Qi et al 2013).

Figure 4. Debris in Madaling Gully

In recent years, many researches on debris flow process and landslide characterization have been conducted in field (Li 1998, Feng et al 2005, Chen et al 2006, Zhang et al 2010), yet it is less understood the influence of the characteristics of landslide clastic deposition on debris flow initiation. This study investigates the initiation process and associated influence factors of this type of debris flows. The results are insightful for early warning and control of debris flows.

2 Test Methods

2.1 Experimental parameters

There are many factors affecting the initiation of debris flow. As debris accumulation is generally generated during the colliding and disintegrating of large landslides, the final clastic deposition is characterized by loose structure. Fluid erosion in those areas normally occurred on the surface of the deposition. For example, in Wenjia gully in an incision of up to 70 m, this depth has not reached the gully bed (Xu 2010). In this case, the slop bottom is not likely to contribute to the debris deposition. In general, the angles of a slope to initiate a debris flow is 8 ~ 25° (Zhuang 2010). Different degrees of surface slopes could either slow down or speed up the erosion on the deposition. To analyze the influence of slope angle on debris flow initiation, this experiment was designed with three surface slope angles, 5°, 10° and 18°, which covers the major range of assumed initiation slope.

In term of two kinds of debris flows of same volume concentration, the type of clay it contained would directly influence the magnitude of yield stress in debris flows (Ma 2011, Qian and Fei 1990). When volume concentration and clay content remain the same, sticky clay component would create greater debris flow yield stress and correspondingly stronger stickiness in the debris flow (Yu 2010). In this experiment, pure montmorillonite clay was used to mimic the clay contents in Niujuan gully and Wenjia gully depositions. Six group materials with various less clay contents of 0%, 0.77%, 1.5%, 3%, 5% and 8%, respectively, were used in this experiment to study the influence of clay on debris flow formation and erosion discharge per unit width.

The distribution of deposition particle sizes, which is represented by the median diameter (d_{50}) of all particles and the non-uniformity coefficient (*Cu*) of the cumulative curve, greatly influences the formation of debris flows. Previous study has indicated that there is a direct relationship between the diameter and the initiation of debris flow (Han et al 2011); the non-uniformity coefficient also imposes a great influence on the flow initiation (Zhang 2011b). Our experiment is intended to further explore the effects of deposition characteristics on the flow initiation. The deposition characteristics are described with four parameters: surface slope of clastic deposition, clay content, median diameter and non-uniformity coefficient (Iverson and Lahuse 1989, Cui 1992). Their relationships with debris flow initiation and discharge per unit width, respectively, are investigated through experimental tests.

2.2 Experimental device

As shown in Figure 5, the experimental device mainly contains two water supply pools and a trench. The water was pumped into the #1 tank from the #2 to keep the water depth consistent in the #1 tank, to further ensure the stability of water flow through the valve and flowmeter, which is key to regulate and stop water flow. The length and width of the device are 5 m and 1 m, respectively, and bottom slope angle is 10°. During the process of the experiment, the average surface length and the thickness of the accumulation body in the trench reached to 2 m and 0.25 m, respectively. Erosion on the top and back of the accumulation body was recorded by a video camera. The density of debris flow in downstream also was measured. The discharge per unit width of the initiation of debris flow corresponds to the beginning of erosion. Following down-cutting erosion, a gully was gradually formed on the accumulation body. With careful observation on the erosion process, the corresponding erosion unit width flow of the accumulation body was recorded.

2.3 Experimental materials

To simulate the clastic deposition, a mixture of clay, gravel particles, coarse sands and fine sands was used to build accumulation bodies. The maximum particle size was controlled less than 50 mm to ensure that the large gravel size would not deviate the experimental results from the influence of the median diameter (d_{50}). The diameter distribution curve is given in Figure 6.

2.3.1 The Particle Gradation in Accumulation Body

The particle gradation diagram in accumulation bodies in Wenjia and Niujuan gullies were obtained through field sampling (Figure 7). Taking into account the size limit of the device, and the change of median diameters and non-uniformity coefficients, the design of 14 groups with different gradations (Figure 8) and 6 groups of accumulation body models with different clay contents was based on the variation of field gradation clay contents, median diameters and non-uniformity coefficients. In addition, 24 experiments were conducted to study the corresponding relationships

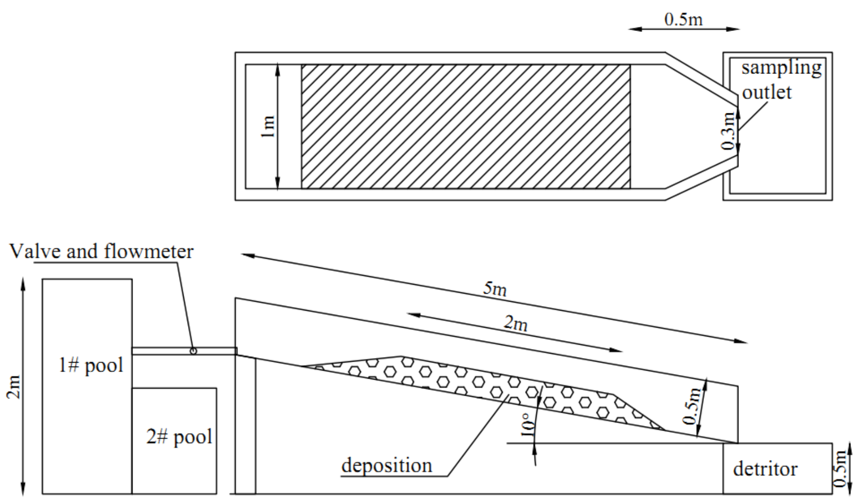


Figure 5. Experimental Device

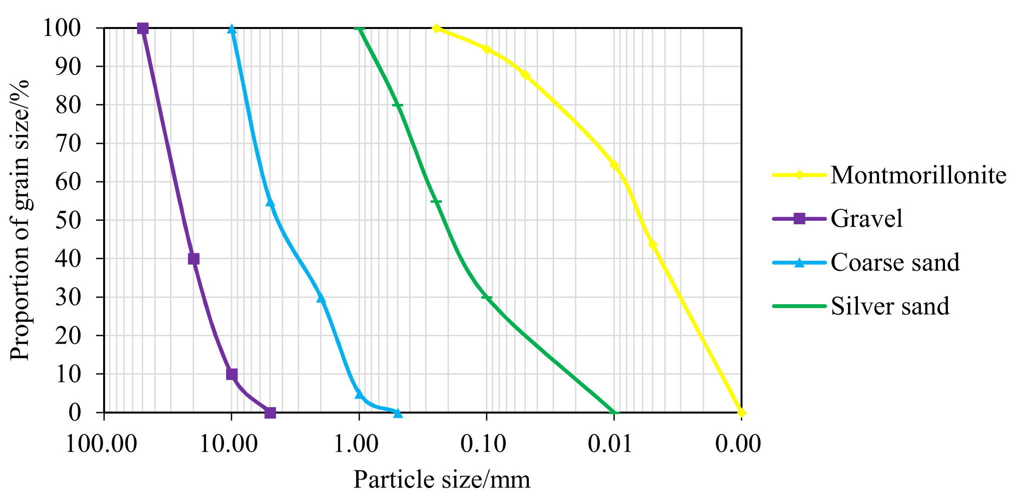


Figure 6. Gradation curve of experimental particles

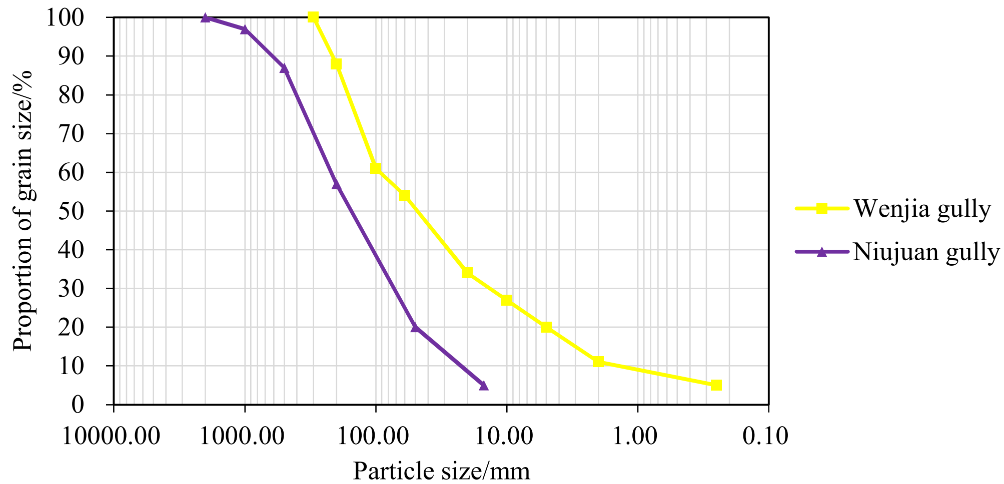


Figure 7. Clastic deposition gradation in Wenjia and Niujuan gullies

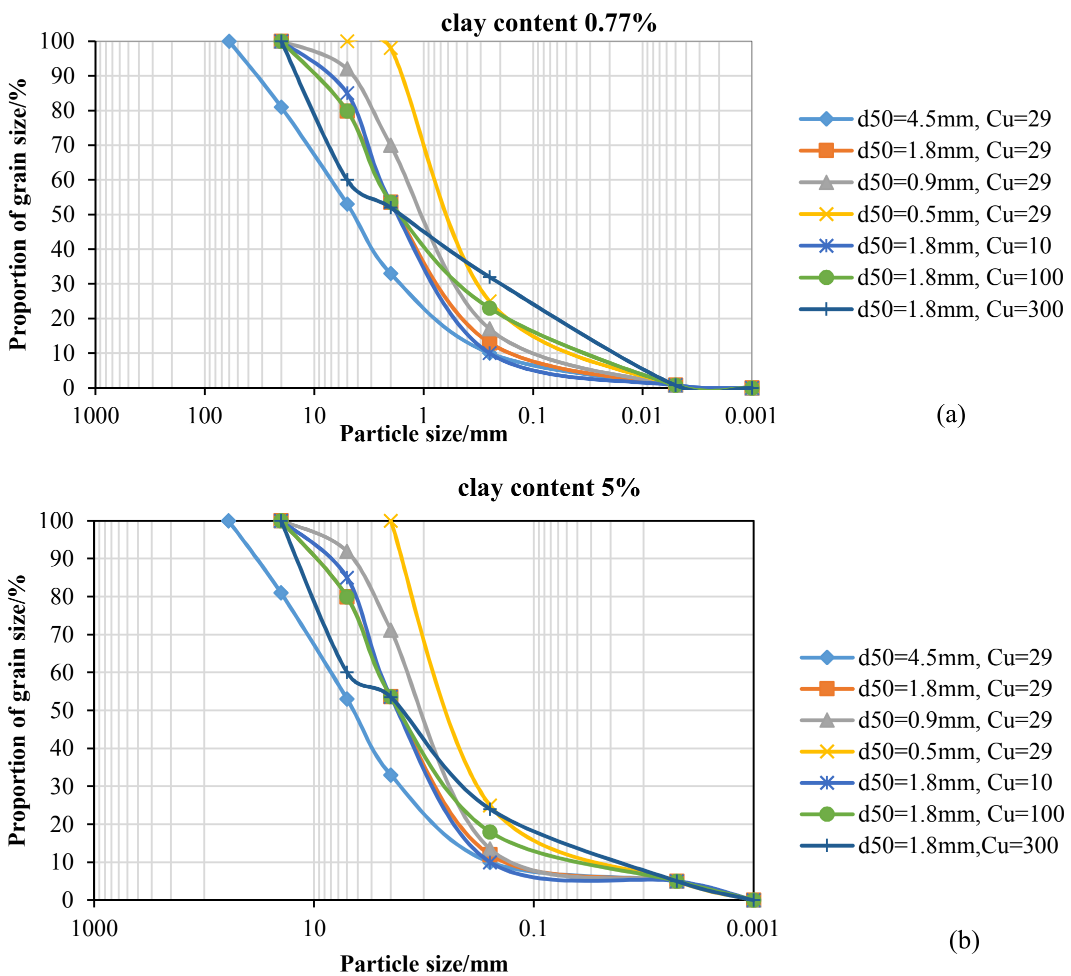


Figure 8. Experiment particle distribution

between the variation of each factor to the debris flow initiation and the unit width flow required for erosion (Table1).

2.3.2 Accumulation body

In the experiment, the accumulation body was designed to keep a loose state naturally inside the trench. The surface lengths of accumulation body were set as 2 m for all three slop angles. Taking account that in the field when landslide collapses and deposits, the movement gradually slows down and then a repose naturally forms in the front end of the deposits, so that in this experiment, this repose is set at an angle of 30° for back water slope and 5° for reverse slope.

3 Results

The debris flows developed on the accumulation bodies showed a repeating pattern of "water confluence upstream – down-cutting the accumulation body – blocking and breaking – accumulation body collapsing – further down cutting". The erosion gradually formed a large channel on the accumulation body. The gullies, in which incision depth continually increased after the flow took away solid particles, was created by downstream slope erosion (Figure 9). Additionally, the corresponding water flow was regarded as the starting flow of per unit width for the debris flow. Erosion on deposit finally created channels with increased widths as water flow continued. The results generated in this test are very close to that in Wenjia gully (Figure 10).

Relationships between debris flow initiation and erosion with different surface slopes, clay contents, median diameters, and non-uniform coefficients are obtained from this experiment.

Figure 9. Debris deposit at downstream of back slope

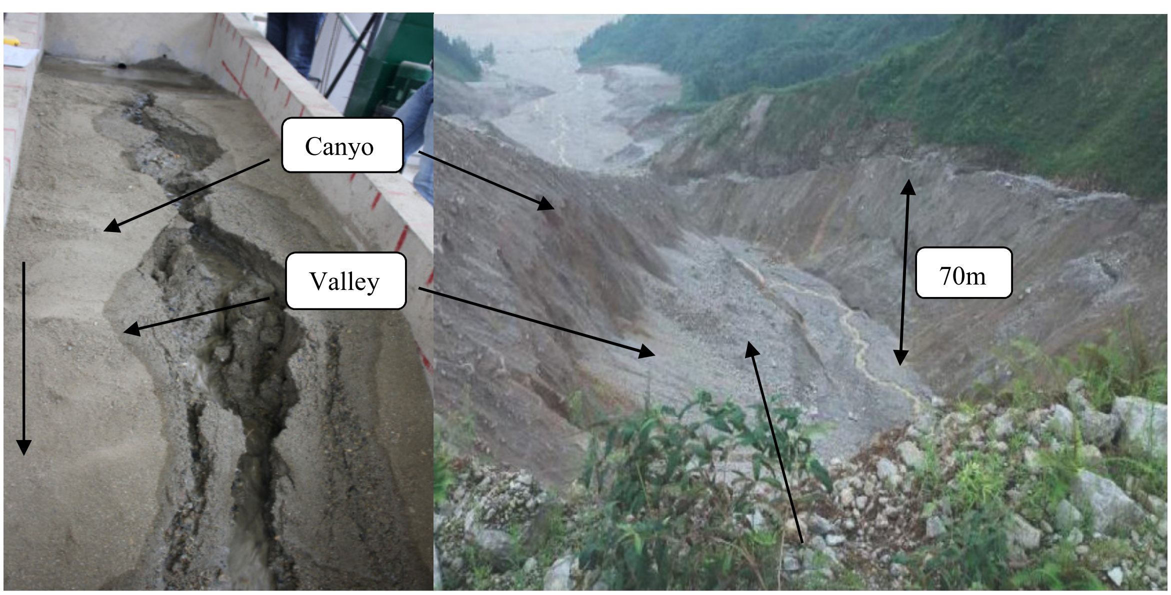


Figure 10. Comparison of the encroaches in the experiment and in Wenjia gully

3.1 Relationships between unit width flow and surface slopes

In the experiment, the effective surface length of the accumulation body was only 2 m, meanwhile the back water slope had a relatively large length up to 1 m with an angle of repose. Thus, the debris flow was mainly produced from erosion on the inward flow radial turbine slopes in the experiment, whereas in field erosion normally starts on the surface. The change of surface slope did not have obvious influence on the initiation unit width flow (Figure 11), but the increasing surface slope accompanied with the accelerating erosion speed of unit width flow was the reason to form the narrow channel. Figure 12 shows change of channel width under different surface slopes.

3.2 Correlation between unit width flow and clay content

The influence of clay content on unit width flow is tested using materials contained different proportions of clay but with same median diameter and non-uniformity coefficient (Figure 13). It indicates that when clay content is less than 5%, it has little influence on unit width flow either or erosion. When clay content is greater than 5%, the bonding effect of clay will restrain the erosion to extend to both sides of the accumulation body. Therefore, increasing clay content results in a narrower erosion channel in the accumulation body (Figure 14).

The increase trend of unit width flow is due to the increase of clay content (>5%) with increased stickiness. Although previous studies confirm clay have influence of debris flow (Ma 2011), however, in the field when clastic deposition possesses weak stickiness, it is normal that the clay content has nothing to do with the unit width flow of initiation and erosion.

3.3 Relationship between unit width flow and median diameter

Figure 15 shows the correlations between initiation or erosion unit width flow and median diameter, respectively. The results suggest a strong linear correlation between median diameter d_{50} and unit width flows.

According to Figure 15, the correlations between initiation or erosion unit width flow and median diameter under the condition of low clay content (≤5%) is expressed in Eqs. 1 and 2,

$$Q_1 = A_1(d + 1.262) \quad (1)$$

$$Q_2 = A_2(d + 0.987) \quad (2)$$

where Q_1 is the unit width flow of initiation (10^{-4} m^3/s·m), Q_2 is the unit width flow of erosion (10^{-4} m^3/s·m), d is a corresponding median diameter, dimensionless, $d = d_{50}/d_0$, d_{50} is the median diameter (mm), d_0 is the unit median diameter, d_0 = 1 mm; $A_1 = 0.298\times10^{-4}$ m^3/s·m, $A_2 = 0.684\times 10^{-4}$ m^3/s·m.

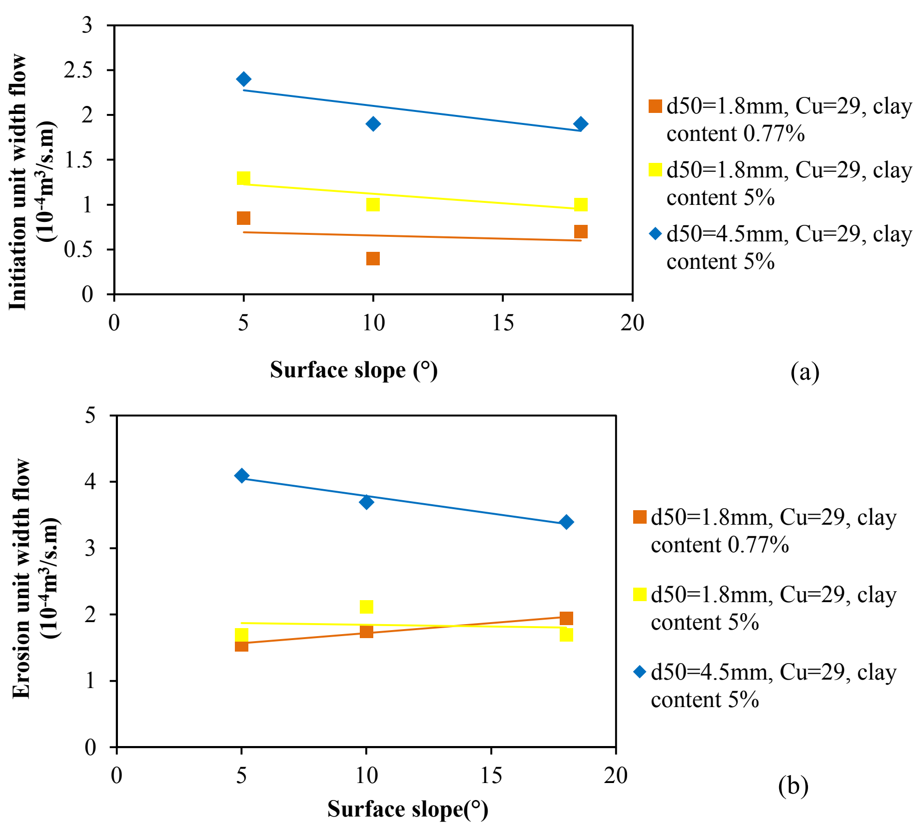


Figure 11. Relationship between surface slope and unit width flow. (a) Initiation unit width flow; (b) Erosion unit width flow

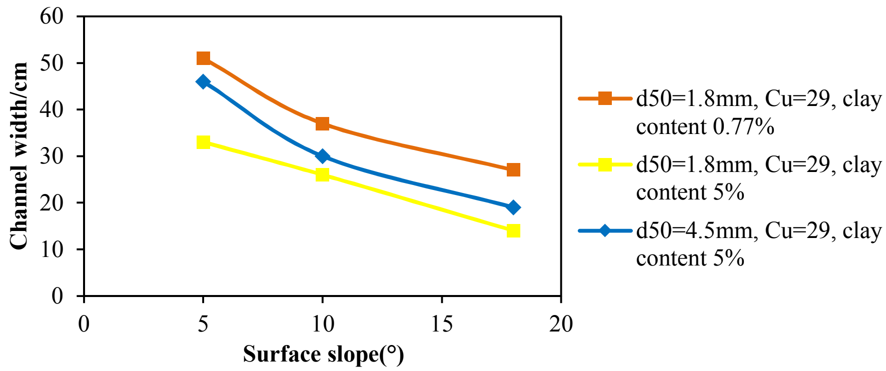


Figure 12. The relationship between width of surface slope and top back slope

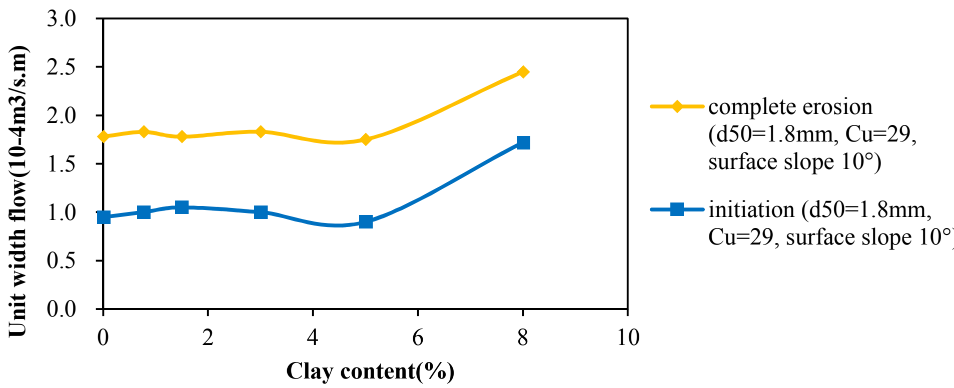


Figure 13. Relationships between clay content and unit width flow

Figure 14. The effect of clay content on erosion, higher clay contents result in narrower channels. The measurement position is located in the middle of the deposition, d_{50} = 1.8 mm, Cu = 29, surface slope 10°

3.4 Relationship between unit width flow and non-uniform coefficient

The correlations between initiation and erosion unit width flow and non-uniformity coefficient is given in Figure 16, respectively. The result shows a positive exponential correlation between the unit width flows.

The correlations between initiation and erosion unit width flow with non-uniformity coefficient are expressed as Eqs. 3 and 4,

$$Q_3 = B_1 Cu^{0.211} \quad (3)$$

$$Q_4 = B_2 Cu^{0.237} \quad (4)$$

where Q_3 is the unit width flow of initiation (10^{-4} m^3/s·m), Q_4 is the unit width flow of erosion (10^{-4} m^3/s·m), and Cu is non-uniformity coefficient, B_1 = 0.433×10^{-4} m^3/s·m; B_2 = 0.735×10^{-4} m^3/s·m.

3.5 Experimental model and field application

This experiment shows that the median diameter and non-uniformity coefficient are the key factors influencing debris flow initiation and digging up. According to the experimental results, two comprehensive empirical formulas describing the unit width flows for initiation or erosion are developed (Eqs. 5 and 6) (Figure 17).

$$Q_5 = C_1(Cu^{0.2}d + 1) \quad (5)$$

$$Q_6 = C_2(Cu^{0.2}d + 1) \quad (6)$$

where Q_5 is the unit width flow of initiation (10^{-4} m^3/s·m), Q_6 is the unit width flow of erosion (10^{-4} m^3/s·m), the coefficient C_1 = 0.2×10^{-4} m^3/s·m, the coefficient C_2 = 0.4×10^{-4} m^3/s·m, Cu is non-uniformity coefficient, and d is corresponding median diameter, dimensionless.

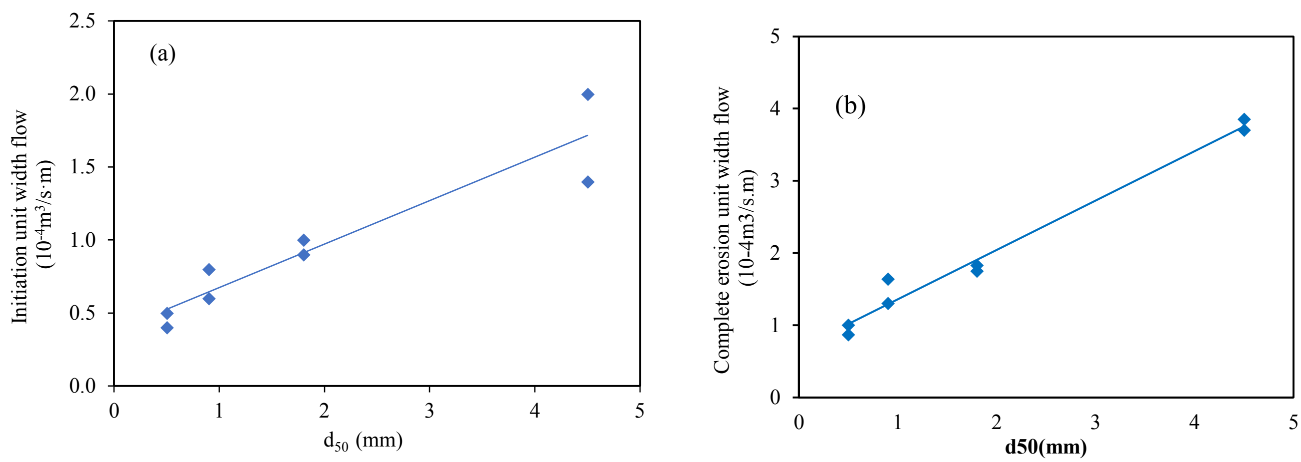


Figure 15. Relationship between median diameter of debris and the unit width flows (Cu =29, surface slope 10°)
(a) Initiation unit width flow; (b) Erosion unit width flow

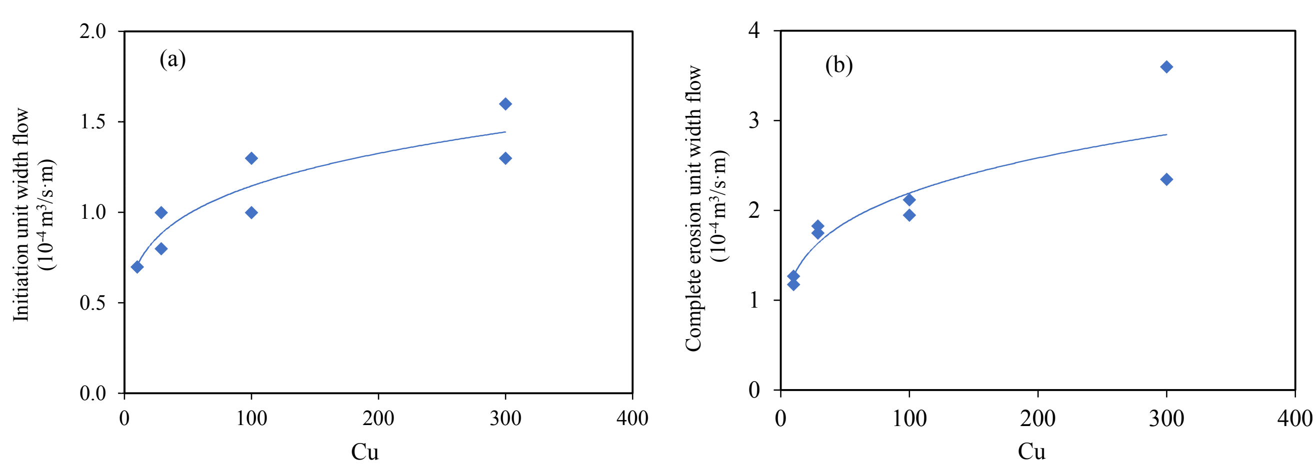
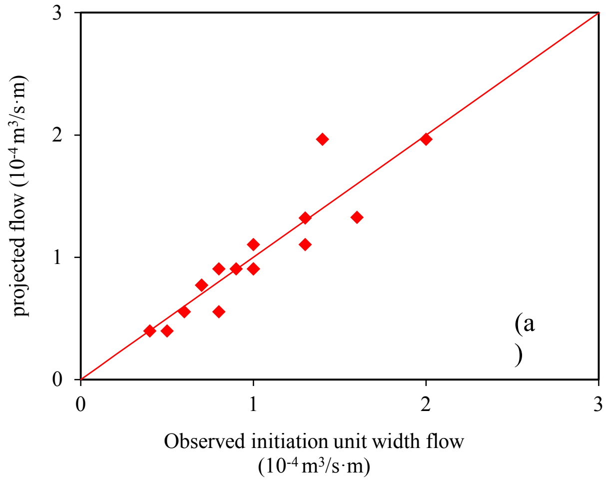


Figure 16. Relationships between non-uniformity coefficient and unit width flows (d_{50} = 1.8 mm, surface slope 10°)
(a) Initiation unit width flow; (b) Erosion unit width flow



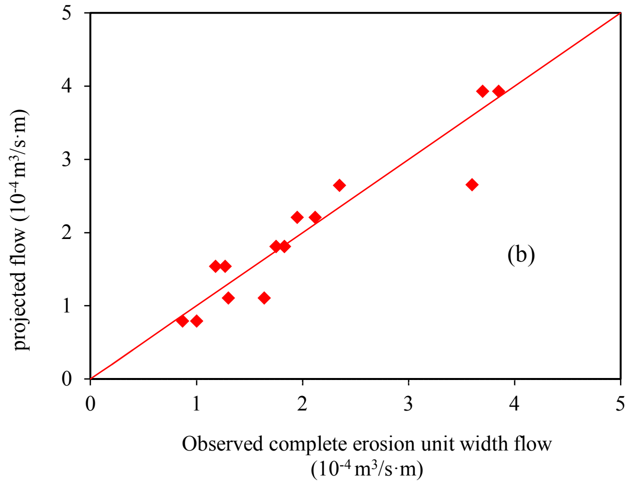


Figure 17. Model verification or comparison of model-projected flow value and the observed experimental flow values. (a) Initiation unit width flow; (b) Erosion unit width flow

In this study, the analysis on main factors affecting debris flow formation are based on theoretical assumption because that experimental method is unable to completely simulate all physical conditions in the field (Paola et al 2009). Limited by the experimental device size, key factors considered in this experiment are deposit particle size, slope and clay content, which are set with values in a range close to that in the field. Therefore, it is necessary to verify the experimental results based on field studies.

Using the clastic deposition's d_{50} and Cu in Wenjia gully and Niuquan gully, Eqs. 5 and 6 are used to calculate unit width flows in the field.

The peak water flow of rainstorm could be calculated by hydrologic manual on the basis of corresponding data as p = 99% in hydrologic calculation to verify the unit width flow of initiation in Eq. 5 (Table 2). The hydrological calculation is based on the local basic data to get the different frequency of water flow in gully. Because the frequency of debris flow is more than once a year, we choose p = 99% as the corresponding calculating frequency. The outbreak of debris flow in Wenjia gully on August 13, 2010, formed a large deep trench. The erosion phenomenon in this experiment reflected the erosion in Wenjia gully, which was the reason that the rainfall peak on the same day in Wenjia gully was chosen to compare with the unit width flow of erosion in Eq. 6. The hydrologic calculation values and the formula values are given in Table 3.

3.6 Deviation analysis and prediction in other gullies

After the comparison between the unit width flow in Wenjia gully and in Niujuan gully, it is obvious that the experimental formula of initiation and erosion values is smaller than hydrological calculation in the field test. The differences were mainly caused by experiment device limitation.

In field, since the length of clastic deposition reached to several hundred meters, the debris flow started from the erosion of the deposition surface. Because of device length limitation in the experiment, the inward flow radial turbine slope length of accumulation body is excessively long. The surface slope had significant influence on the unit width

Table 2 Comparison of the different frequencies of rainfalls and water flows

	P (%)	10 min rainfall (mm)	Maximum 1-hour rainfall (mm)	Water flow (m^3/s)
Wenjia gully	99	5.9	25	11
Niujuan gully	99	5.63	10.75	6.42

Table 3 Comparison of results according to hydrologic and formula calculations

	d_{50}/m (m)	Cu	Surface slope (°)	Average width of deposition (m)	Unit width flow of initiation (10^{-2} m^3/s·m)	Initiation hydrologic calculation (10^{-2} m^3/s·m)	Unit width flow of erosion (10^{-2} m^3/s·m)	Erosion hydrologic calculation (10^{-2} m^3/s·m)
Wenjia gully	158	115	13	300	0.81	3.7	1.64	6.8
Niujuan gully	180	19	16	60	0.65	1.07	1.3	-

Table 4 The characteristics of Wenjia gully and Niujuan gully

	Length of clatic deposition (m)	Back slope length (m)	Average surface slope (°)
Wenjia gully	800	110	13
Niujuan gully	1800	60	16

Table 5 Calculation chart of unit width discharge of debris flow initiation

	Average surface slope (°)	Median diameter (mm)	Non-uniformity coefficient	Formula 5 (10^{-2} m^3/s·m)
Madaling gully	10	80	333	0.51
Dazhai gully	15	70	100	0.35

flow of debris flow. Therefore, debris flow was formed by erosion upward from the back water slope. Actually, changing the accumulation body surface slope showed less influence on the unit width flow. Thus, the obtained formulas reflect the correlation between unit width flow and formation of accumulation body debris flow but exclude the factor the length of surface slope.

Through investigation in the field, characteristics of Wenjia gully and Niujuan gully (Table 4) was obtained. The length ratio of the inward flow radial turbine slope to the deposition was less than 1:7.3. The same situation appeared in the Niujuan gully where the length ratio of the inward flow radial turbine slope to the deposition was 1:30. The surface slope still played an important role in forming debris flow, which is proven from the comparison between the experimental fitting formula value with hydrologic calculation, a larger unit width flow of initiation was required when the surface slope decreased, vise versa.

In spite of the deviations of experimental formula calculations from actual field situations, the correlations between debris flow initiation or erosion with median diameter and non-uniformity coefficient were properly captured in the experiment. Based on the deviation analysis, prediction on other debris gullies including Madaling gully and Dazhai gully in Guizhou province caused by clastic deposition was given. The unit width flow required to form the debris are shown in Table 5.

With an average surface slope of 10° in Madaling gully clastic deposition, the actual unit width flow of initiation could be 6-8 times to the calculated value because of the relatively flat surface slope. With an average surface slope of 15° in Dazhai gully clastic deposition, the actual unit width flow of initiation could be 2-4 times to calculated values when taking into account the possible influence of slope.

4 Discussion

Many flume experiments were carried out to simulate the initiation of debris flow (Zhang 2011a, Zhuang et al 2010).

Because of the influence of the loose degree of accumulation body, the water flow for occurrence of debris flow formed by accumulation body is relatively small.

In this paper, the author fails to consider the differences between experimental accumulation body and field accumulation body in consolidation, particle shape and smoothness etc.

As time goes by, landslide clastic deposition is gradually consolidated. Meanwhile, the initiation flow has changed over time. The erosion depth of accumulation body in the test is only 0.25 meter. Limited experimental conditions cannot simulate the conditions for field accumulation body. The upper reaches of the catchment conditions are simplified into water in order to replace rainfall conditions.

This work also failed to reveal the relationship between initiation and unit width flow of erosion on accumulation surface slope due to the limitation of experimental device. Thus, exploration of other factors influencing clastic deposition in initiating debris flow needs to be considered in future studies.

5 Conclusions

The experimental study was conducted using a debris flow experimental device, and Wenjia gully and Niujuan gully were used as the field studies to verify the developed empirical formula. Observations on debris flow initiation and accumulation erosion process reach conclusions as follows:

(1) The landslide clastic deposition is quite easy to form debris flow in situation of rainfall conditions. This kind of debris flow is characterized by high frequency, large scale and serious harm. The formation of debris flow is affected by many factors including the accumulation characteristic which is an important factor in affecting the initiation of debris flow.

(2) The key factors influencing debris flow form landslide clastic deposition are median diameter d_{50} and non-uniformity coefficient Cu. According to data obtained from the experiment, we developed two comprehensive empirical formulas to describe the correlations among unit width flow, initiation and excavation. The median diameter d_{50} and non-uniformity coefficient Cu played an important role in the process of debris flow. Based on the two factors, through field test, the unit width flow of debris flow can be roughly estimated to the critical rainfall intensity.

(3) Verification of formula was done by analyzing data collected in the field, which gives the result that the formula calculated values are relatively smaller than those of hydrologic calculations but they are consistent in an overall trend and are useful to predict alike situations in other gullies.

Acknowledgements

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References

Bin, Y., Y. Ma and Y.F. Wu, 2013. Case study of a giant debris flow in the Wenjia Gully, Sichuan Province, China. Nat Hazards, **65**(1): 835 - 849.

Chen, X.Q., C. Peng, Z.L. Feng, J. Chen and Y. Li, 2006. Artificial rainfall experimental study on landslide translation to debris flow, China. Chinese Journal of Rock Mechanics and Engineering, **25**(1): 106 - 116.

Cui, P., 1992. Studies on condition and mechanism of debris flow initiation by means of experiment. Chinese Science Bulletin, **37**(9): 759 - 763.

Dai, F.C., 2010. Spatial distribution of landslides triggered by the 2008 Ms8.0 Wenchuan earthquake, China. J Asian Earth Sci, **40**(4): 883 - 895.

Feng, Z.L., P. Cui and S. He, 2005. Mechanism of conversion of landslide to debris flows, China. Journal of Natural Disasters, **14**(3): 8 - 14.

Han, L., B. Yu and K. Lu, 2011. Relationship of frequency of debris flows and the particle size in the channel. Resources & Environment in the Yangtze Basin. **20**(9): 1149 - 1156.

Huang, R.Q. and Q. Xu, 2008. Catastrophic Landslides in China. Science Press, Beijing, 1 - 5. (in Chinese).

Iverson, R.M and R.G. Lahuse, 1989. Dynamic pore-pressure fluctuations in rapidly shearing granular materials. Science, **246**(4931): 796 - 799.

Kong, J., S. Tian, A. Fayou, Y. Cui and Z. Ni, 2010. Guizhou Guanling landslide formation mechanism and its characteristics, China. Journal of Mountain Science, **6**(11): 725 - 731.

Li, S., 1998. Formation mechanism of the landslide-type debris flow, China. Acta Scientiarum Naturalium Universitatis Pekinensis, **34**(4): 519 - 522.

Liu, C.Z., 2010. Preliminary findings on Dazhai landslide-debris flow disaster in Guizhou province of June 28, 2010, China. Journal of Engineering Geology, **18**(5): 623 - 630.

Ma, Y., 2011. Research on Clay Minerals and Yield Stress of Debris Flow by Experiments, China. Chengdu University of Technology.

Paola, C., K. Straub, D. Mohrig and L. Reinhardt, 2009. The "unreasonable effectiveness" of stratigraphic and geomorphic experiments. Earth-Science Reviews, **97**(1-4): 1 - 43.

Qi, X., B. Yu, Y. Zhu, T. Wang and Y.J. Chen, 2013. Characteristics of Madaling landslide forming debris flow in Duyun, Guizhou, China. The Chinese Journal of Geological Hazard and Control, **24**(1): 1 - 6.

Qian, N. and X.J. Fei, 1990. High Sediment Flow, China. Beijing, 51 - 65.

Robert, N.P. and L. Alexander, 2011. Mass wasting triggered by the 2008 Wenchuan earthquake is greater than orogenic growth. Nature Geoscience, **4**(7): 449 - 452.

Tang, C., J. Zhu and J. Ding, 2012. An empirical statistical model for predict ting debris-flow runout zones in the Wenchuan earthquake area. Quaternary International, **250**(2): 63 - 73.

Tang, C., J. Zhu, W. Li and J.T. Liang, 2009. Rainfall-triggered debris flows following the Wenchuan earthquake. Bull Eng Geol Environ, **68**(2): 187 - 194.

Wang, Y.C., N.P. Ju, J.J. Zhao and X.Q. Xiang, 2013. Formation mechanism of landslide above the mined out area in gently inclied coal beds, China. Journal of Engineering Geology, **21**(1): 61 - 68.

Xu, Q., 2010. The 13 August 2010 catastrophic debris flows in Sichuan province: characteristics, genetic mechanism and suggestions. China. Journal of Engineering Geology, **18**(5): 596 - 608.

Xu, Q., X.J. Pei and R.Q. Huang, 2009. Large-scale landslides induced by the Wenchuan Earthquake. Science Press, Beijing, 381 - 406. (in Chinese).

Yin, Y.P., 2009. Great Wenchuan Earthquake: Seismogeology and Landslide Hazards. Geological Publishing House, Beijing, 1 - 15. (in Chinese).

Yu, B., 2010. Study on the method for deposition depth calculation of debris flow with different densities, China. Journal of Disaster Prevention and Mitigation Engineering, **30**(2): 207 - 211.

Zhang, M., R.L. Hu, Y.P Yin and F.P. Cui, 2010. Study of transform mechanism of landslide-debris flow with ring shear test, China. Chinese Journal of Rock Mechanics and Engineering, **29**(4): 822 - 832.

Zhang, J.N., 2011a. The character and mechanism study on the debris flow cause by dam-break in gully, China. Chengdu University of Technology.

Zhang, H.H., 2011b. A Study on Debris Flow Disaster Caused by Flood-Triggering Channel Accumulation in Post-earthquake Meizoseismal Areas, China. Chengdu University of Technology.

Zhuang, J.Q., P. Cui, K.H. Hu, X.Q. Chen and Y.G. Ge, 2010. Research on debris flow initiation due to bed failure after Wenchuan Earthquake. Chinese Journal of Sichuan University (Engineering Science Edition), **42**(5): 230 - 236.