Survey and analysis the "8.13" debris flows fan in Longchi Area of Dujiangyan City, Sicuan Province

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Abstract

The disasters of debris flows occurred more frequently in the earthquake zone after the 2008 Wenchuan tectonic earthquake. And the growth of perniciousness of debris flow as a geometric progression, the accumulation characteristics of debris flow directly responded to the damage degree. On August 13, 2010, debris flow disasters were broke out of more than 50 gullies in the study area, which initiated by strong rainfall, and destroyed the buildings and roads in earthquake reconstruction area. According to the field observation of 36 debris flow gullies and statistical analysis between deposits features and drainage basin characteristics, establish functional equation as deposits thickness, deposits width, run out distance, deposits gradient. On this basis, a geometric statistical model of debris flow fan was established by the characteristics of fan accumulated characteristics as Engineering Grade-increase Debris Flow. The validation showed that the established model was suitable for the prediction of the debris-flow accumulation characteristics in the Wenchuan earthquake area. The results of the study will help authorities select safe sites for rehabilitation and relocation in the future and can also be used as an important basis for debris-flow risk management.

Keywords: Debris flow fan, Deposits features, Statistical model, Dujiangyan city

1. Introduction

Since the "5.12" Wenchuan Earthquake, numerous debris flows were triggered in the central quake-affected area, particular in the rainy season. Because of the strong earthquake, the geological environment more vulnerable to landslides (Tolga et al, 2011), and triggered more than 56 000 landslides in the central part of the area of Wenchuan earthquakes (Dai et al, 2011), the substantial volumes of landslides for debris flow can be generated (Alexander, 1989). The hazard scope of debris flow fans is directly determined by its accumulated characteristics (Liu et al, 1995). The formed of the deposits fan link between landscapes and channel basin, because large volumes of sediment can be transported from hill-slopes to valleys (Webb et al, 1988; Benda, 1990; Eaton et al, 2003). There is many ways to study the sedimentary characteristics of debris flows, such as the statistical analysis (Tang et al, 2012, 2014), numerical simulation (Tang et al, 2011) and test model (Liu et al, 1995).

The study area is located in the “5.12” Wenchuan Earthquake region. On August 13, 2010, a total of 52 debris flows was triggered by continuous heavy rainfall. To above research, deposits zones of earthquake-caused debris flow not only controlled by the drainage area, watershed elevation, source reserves, but also controlled by the most fundamental factor as the topographic features of alluvial fans and the physical properties of debris flow. In this paper, 36 debris flows were investigated as shown in Fig.**2**, and their fans relative complete, found that the posterior border longitudinal slope was greater than anterior border longitudinal slope in the accumulated area of the debris flows, and statistical model was established by the data of 36 debris flows, to provide references for risk assessment and management for debris flow in quake affected area.

2. Study area

The study area, located at upstream of Minjiang River, which belonged to Dujiangyan City of Sichuan Province, and the landforms belonged to the highland and ravine. The tributary distributed along both sides of the Longxi River like as the dendritic. The exposed lithology included granite, limestone and dolerite (Fig.**1**). Accompanying intensive structure activities, especially the causative fault of "5.12" Earthquake as Yingxiu-Wenchuan fault passed through the Bayi gully, lead to the bedrock exposed, rocks crushed, and formed a lot of unconsolidated deposits of Quaternary and widely distributed as in Fig.**2**, which providing a lot of sources for "8.13" debris flow.

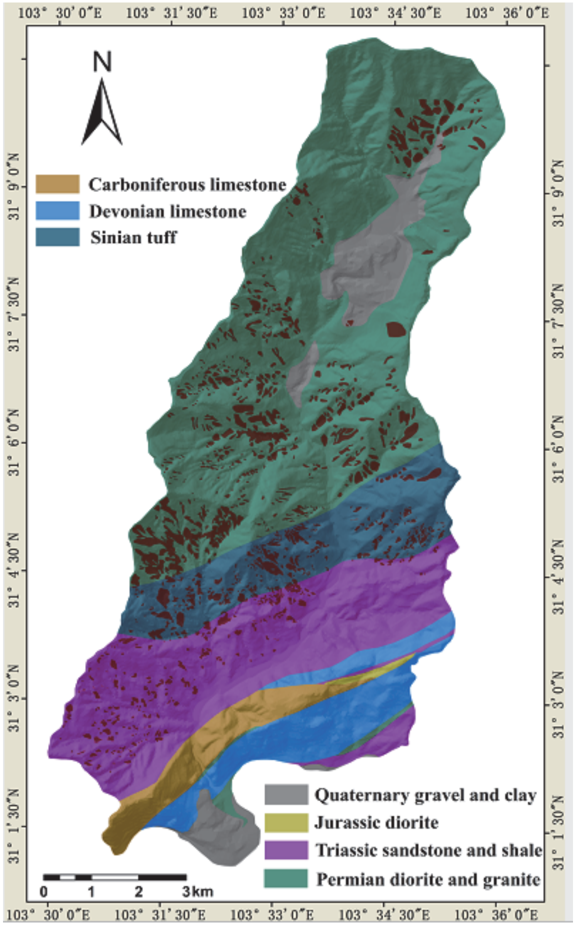

Fig.1 Lithology figure of study area.

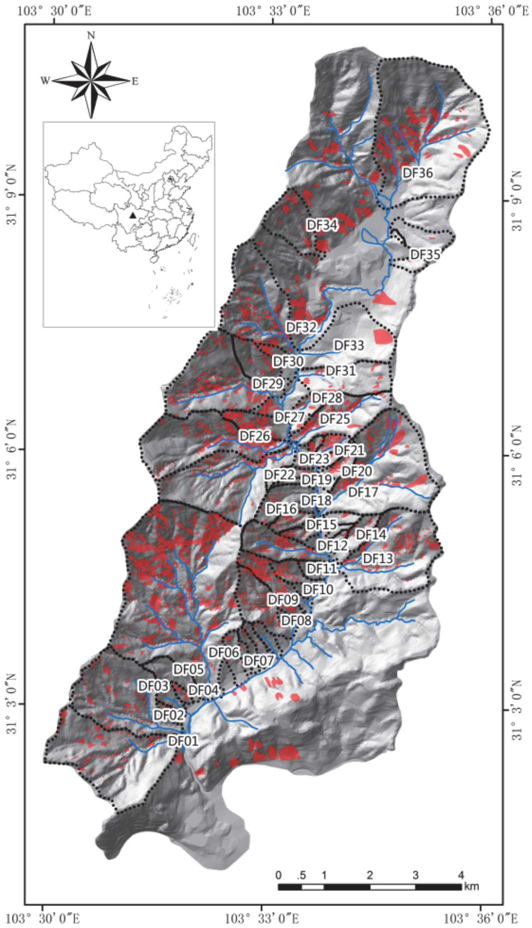

Fig.2 Distribution and provenances in study area

The study area belongs to the humid monsoon region, and located in the subtropical seasons area. Seen from the Fig.**3**, and found that the rainfall mostly concentrated from June to September, and about 83% of the annual precipitation falls.

Rainfall characteristic is one of the most important triggering factors for debris flows (Shieh et al, 2009; Chang et al, 2009), and heavy rainstorms occurred On 13 August 2010, initiating debris flows in Longchi of earthquake affected area (Q et al, 2012). According to data from recording Dujiangyan station, on August 4, 2010, the thundershowers began, and rainfall intensity suddenly increased at 14:00 of August 13, 2010, then freshet induced the debris flows at 16:00. The rainfall intensity of *24*mm/h recorded when debris flow occurred, and peak intensity of *75*mm/h recorded during that time period. The pre total rainfall precipitation is about *30*mm before debris flow occurring, cumulative rainfall for debris flow of *150* mm in 3h was recorded from 14:00 until 17:50 (Fig.**4**).

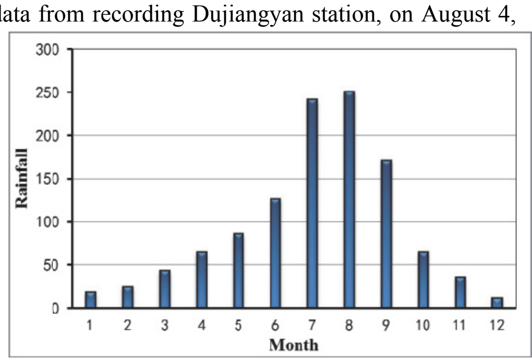

Fig.3 Average precipitation in the Longchi area

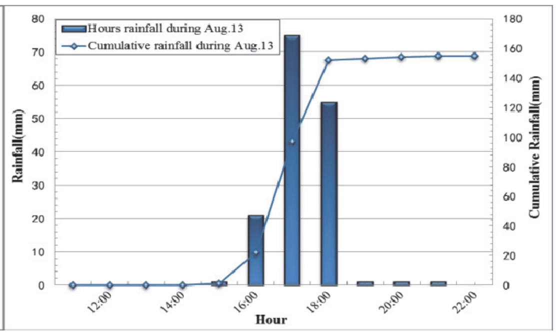

Fig.4 Hourly and cumulative rainfall for the 13 August, 2010

3. Data analysis

The most important characteristics for debris flow run-out zones on alluvial fans is the maximum run-out distance, the maximum cumulate width, the profile thickness. And the influenced parameters for accumulated characteristics of debris flow, such as the debris-flow volume, the flow velocity, the cumulated slope, the solid material properties, and the landslide deposit volumes to be studied (Chuan et al, 2012). According 22 typical debris flow gullies in studied area by previous researched (Ding, 2011), and through field measurement of the deposit slope and profile thickness of the fans, to get the data of accumulated characteristics.

Field investigations of 36 debris flow fans in studied area, found that the run-out volume of debris flow positively related to maximum run-out distance, maximum run-out width and the maximum profile thickness. Due to the similar topography, lithological and geological structure, which lead the material composition and particle size, and the geometric characteristics of deposit fans to similar (Fig.**5**).

（*a*）Debris fans of Changheba gully. （*b*）Debris fans of Zhichang gully. （*c*）Debris fans of Shuida gully.

Fig. 5 Typical debris flow fans in the study area

3.1 Landslide deposit volumes

The occurred possibility and broken-out frequency of debris flow directly affected by the conditions of landslide deposits and precipitation, and watershed features, et al. Through *Spss* software to statistical analyses 22 debris flow gullies, found that the empirical relationship between landslide deposit volumes and debris flow run-out volumes was positive correlation, according to the relative coefficient of R^2 and significant coefficient of P, the relationship between landslide deposit volumes and run-out volumes shown as below (Fig.**6**):

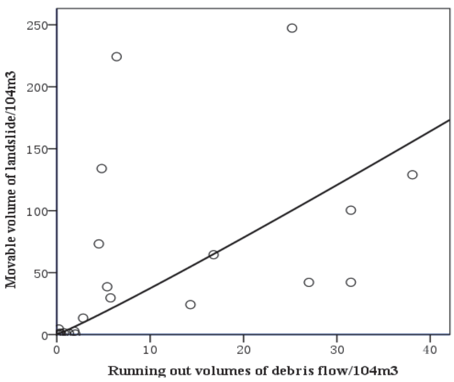

Fig.6 Empirical relationship between the landslide volumes and run-out volumes

$$V=3.916W^{1.068}, R^2=0.72 \& P=7.41\times10^{-7} \quad (1)$$

Where V is debris flow run-out volumes (m^3); W is landslide deposit volumes (m^3); R is the correlation coefficient; P is the significant coefficient.

According to the field data statistical analyzed, the relationship between the landslide deposit volumes and run-out volumes of debris flow was positive correlation, and the average value of the landslide deposit volumes transformed into debris flow run-out volumes was 0.57, and the fluctuation amplitude of conversion rate of landslide deposit volumes to run-out volumes was 0.29~1.

3.2 Elevation different

The elevation different of catchments provided the potential energy for landslide starting. According to the regression analyzed of correlation and significance, the regression equation between the elevation difference of catchment and the debris flow run-out volumes established as exponential distribution (Fig.**7**):

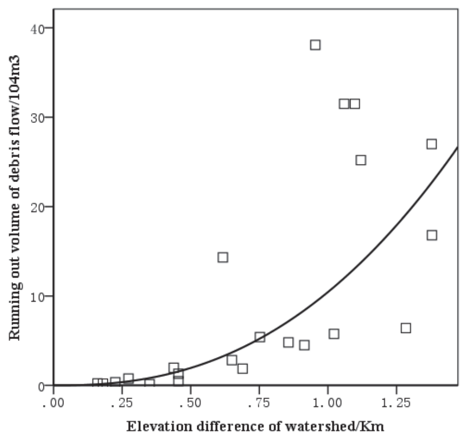

Fig.7 Empirical relationship between the landslide volumes and elevation difference

$$V=H^{2.408}+0.001, R^2=0.8 \& P=4.55\times10^{-8} \quad (2)$$

Where H is elevation difference of catchments (m).

3.3 Channel longitudinal slope

According to the field investigation and statistical analysis, found that the relationship between channel average longitudinal gradient and accumulation characteristics on run-out zone was positive correlation. And the average of specific value for channel average longitudinal gradient to elevation different is 3.637, the fluctuation amplitude of ratio about 0.791~9.583. The average of specific value for channel longitudinal slope to maximum lateral width was 3.997, the fluctuation amplitude was about 1.522 ~11.153.

All the above analysis as known, run-out volumes of debris flow related to the landslide deposit volumes, elevation different and channel longitudinal slope. Moreover, the result shows that the run-out volumes determined run-out distance, lateral width and profile thickness of debris flow on the alluvial fans. Through a great deal of statistical analysis, the regression equation as follows:

$$V=0.014W+7.074H+2218.94J-3658.95,\quad R^2=0.92\&P=0.009 \tag{3}$$

Where W is landslide deposit volumes for debris flow (m^3); V is run-out volumes of debris flow (m^3); H is elevation different of catchments (m); J is channel average longitudinal gradient.

4. Run-out zones characteristics

In the process of depositing of debris flow on the alluvial fans, the run-out distance, lateral width and profile thickness controlled by watershed of gullies characteristics and fluid properties characteristics. In order to analyze the geometry features of the debris flow fans, by statistics deposited parameters of 36 debris flow ditches, such as outlet width, max lateral width, length of fans, fans slope.

4.1 Debris flow fan slope

Up to now, the shape of debris flow fans of the 3*D* model universal unified, the fan slope of posterior border slightly steeper than anterior border, generally speaking the anterior border slope of the deposit fans only a few degrees (Liu et al, 1992). In the conditions of lowly fan slope, the sine value approximately equaled to tangent value, namely $\sin\alpha \approx \tan\alpha$, α_1 is posterior border slope, α_2 is anterior border slope, α_3 is alluvial fan slope.

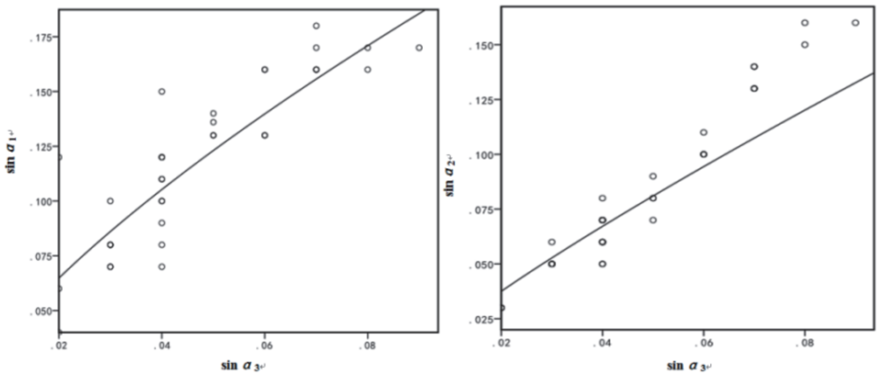

Fig.8 Empirical relationship of deposit slope

By the regression analysis(Fig.**8**), the posterior border slope, anterior border slope and alluvial fan slope met the conditions as following:

$$\left.\begin{aligned}\sin\alpha_1 &= \sin\alpha_3^{0.699}, R^2 = 0.98\&P = 0.0001\\ \sin\alpha_2 &= \sin\alpha_3^{0.839}, R^2 = 0.99\&P = 0.0001\end{aligned}\right\} \tag{4}$$

Where symbols mean is as the same as above.

From 36 debris flows fans data, known that the slope of fans satisfied relation as $\alpha_1 > \alpha_2$, $\alpha_1 > \alpha_3$, and $\alpha_2 > \alpha_3$. Further, the average specific value for $\sin\alpha_2$ to $\sin\alpha_3$ was about 1.54, and the fluctuation amplitude of ratio about 1.07~2.67; The average specific value for $\sin\alpha_1$ to α_2 was about 2.55, and the fluctuation amplitude of ratio ranged 2.08~3.70; The average specific value for $\sin\alpha_2$ to $\sin\alpha_3$ was about 1.69, and the fluctuation amplitude of ratio ranged 1.39 ~1.93.

4.2Run-out characteristics

The run-out zones mainly consists of run out distance, lateral width and thickness. When the debris flow stopping and silting on the alluvial fan area, the accumulation characteristics mainly due to the original slope reduced along gullies in accumulation area, and unconstrained conditions of the lateral on alluvial fan, leading to the kinetic energy of debris flow dissipated quickly along the flow direction, and the potential energy of fluid along vertical flow direction dissipated quicker than the flow direction. By the analysis of regression, discovered that the relationship between run-out characteristics and landslide deposit volumes was nonlinear as follows (Fig.**9**):

$$\left.\begin{aligned}L_{max} &= 113.86V^3 - 21.665V^2 + 2.689V, R^2 = 0.94\&P = 0.0001\\ D_{max} &= 239.334V^3 - 82.022V^2 + 7.964W, R^2 = 0.89\&P = 0.0001\\ h &= 8.459V^3 - 2.605V^2 + 0.222V, R^2 = 0.96\&P = 0.0001\end{aligned}\right\} \tag{5}$$

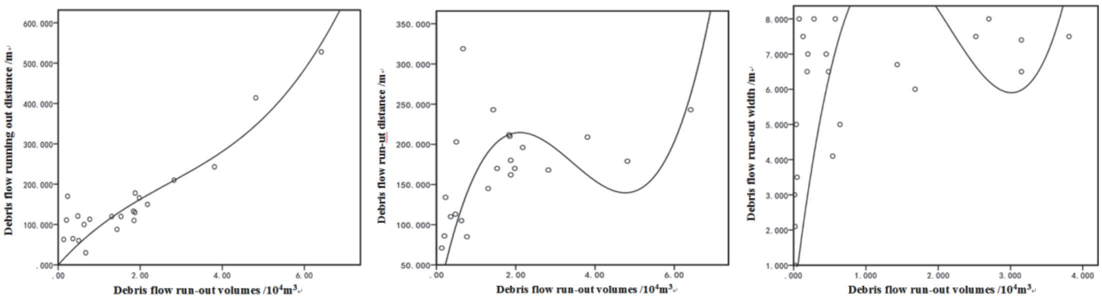

Fig.9 Empirical relationship of deposit features.

Seen the Fig.**10**, according to the correlation and significance, shown that the relationship between run-out characteristics and landslide deposit volumes as follows:

$$\left.\begin{aligned} L_{max} &= 1.038W^3 + 0.024W^2 - 9.538\times10^{-5}W, R^2 = 0.7\&P = 0.00015 \\ D_{max} &= 7.661W^3 - 0.07W^2 + 1.71\times10^{-4}W, R^2 = 0.76\&P = 0.0002 \\ h &= 0.267W^3 - 0.03W^2 + 6.305\times10^{-4}W, R^2 = 0.7\&P = 0.00011 \end{aligned}\right\} \quad (6)$$

Where W is landslide deposit volumes (m^3), L_{max} is max run out distance (m); h is profile thickness (m);

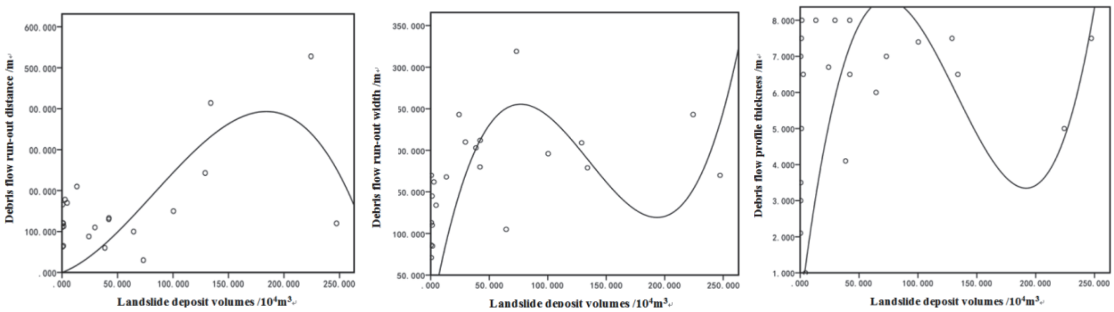

Fig.10 Empirical relationship between deposit features and landslide deposit volumes

According to the statistical of field survey data (Fig.**11**), found that the length of debris flow fan satisfied the relation as $L_3 \approx L_1 + L_2$, and $L_2 > L_1$. Further, the average value of L_2/L_1 was 1.46, and the fluctuation amplitude of the ratio about 1.07~1.98. The average value of L_2/L_3 was 0.59, and the fluctuation amplitude of 0.52~0.7. The relationship between the run out distance and the max profile thickness was positive correlation, the ratio of the max run-out distance and the max profile thickness was 22.53, and the fluctuation amplitude of 12.56 ~40.33.

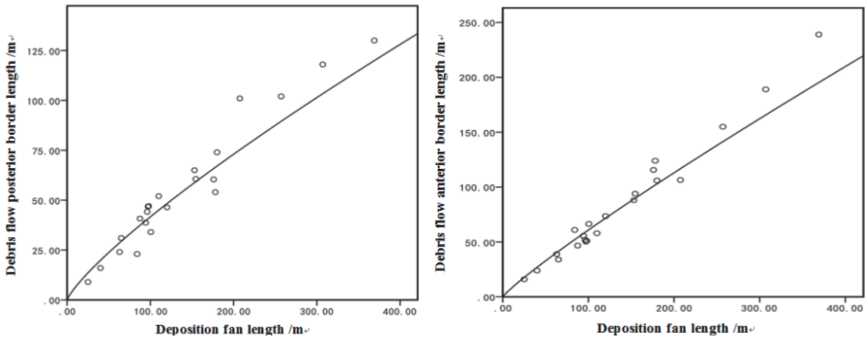

Fig.11 Empirical relationship of deposit length

The relationship between run out distance and length of debris flow fan analyzed, namely contained the length of posterior border to max lateral width, and the length of anterior border to max lateral width, satisfying the following conditions:

$$\left.\begin{aligned} L_3 &= L_{max}^{0.99}, R^2 = 0.98\&P = 0.0001 \\ L_1 &= L_3^{0.81}, R^2 = 0.99\&P = 0.0001 \\ L_2 &= L_3^{0.892}, R^2 = 0.99\&P = 0.0001 \end{aligned}\right\} \quad (7)$$

Moreover, through the regression analysis of profile thickness and landslide deposit volumes in the study area, found that relationship as follows:

$$V=352.28h^3-85.03h^2+6.1h-359.94,$$
$$R^2=0.88\&P=0.0017 \quad (8)$$

4.3 Debris flow deposit fan model

Through the field survey of debris flow deposition on the alluvial fan, found that the shape of fan was similar. On the basis of previous research shown that the deposition of debris flow occurred below 10° (TANG et al, 2011). On the other hand, the accumulation characteristics obviously affected by the terrain feature of accumulation area of debris flow gullies, for one classification: non man-made condition that the terrain feature of accumulation area has non effects of human engineering, leading to outlet slope of gullies steeper than alluvial fan slope, and the speed of alluvial fan decaying more than outlet (Fig.**12**-(***a***)); For the other classification: man-made condition that the gullies outlet or alluvial fan influenced by artificial factors, such as engineering construction (highway, embankment), making the slope of terrain suddenly increased (Fig. **12**- (***b***)). Based on the field observation and statistics, the debris flow model in the study area as Fig.**12**- (***b***)

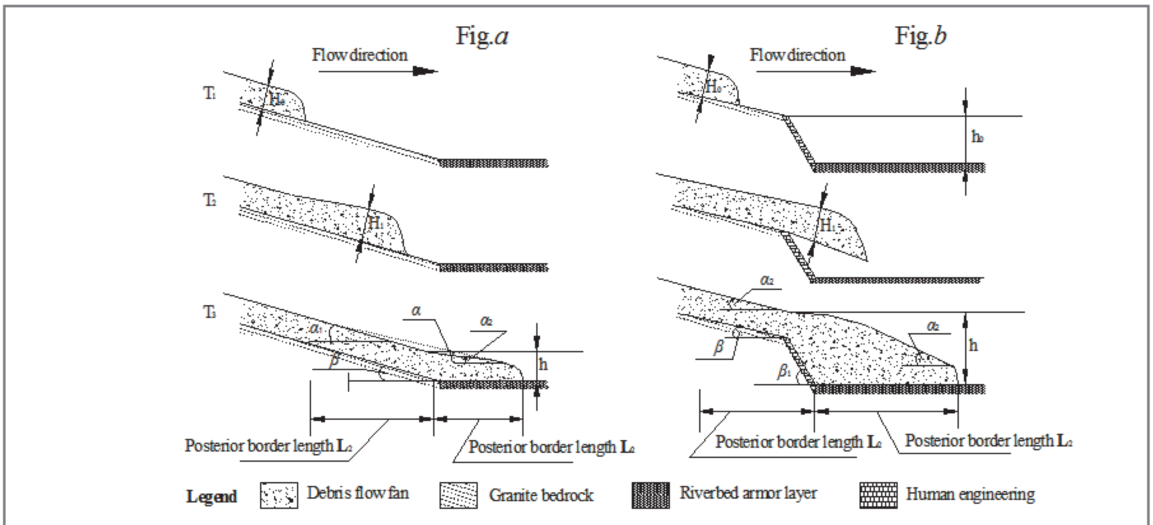

Fig.12 Two classifications of deposit fans model

By statistic, the deposit fan model of 36 debris flow gullies in the study area alike the Fig.**12**- (***a***), and the lateral width of any position along the flow direction related to the length of posterior border L_1, length of anterior border L_2, outlet width a, and the relationship as follows:

$$D_{1x}=a+0.28L_{1x}, D_{2x}=a+0.28L_1+0.08L_{2x} \quad (9)$$

Where L_{1x} is posterior border length of arbitrary point distance (m); L_{2x} is anterior border length of arbitrary point distance (m).

By the above study shown, the geometric shape of debris flow fan mainly due to the accumulation area feature, fluid properties, and the debris flow run out model obtained in the study area in the following Tab.**1**:

Tab.1 Prediction model of the study area

Function equation	R^2	Parameter ratio	Ratio range
$V=0.014W^3+0.0004W^2-1.3\times10^{-6}W$	0.73	W/V	2-3.5
$L_{max}=113.86V^3-21.665V^2+2.689V$	0.94	V/L_{max}	74.9-210
$V=H^{2.408}+0.001$	0.8	V/H	1.12-9.77
$\sin\alpha_1=\sin\alpha_3^{0.699}$	099	$\sin\alpha_1/\sin\alpha_3$	2.08-3.70
$\sin\alpha_2=\sin\alpha_3^{0.839}$	0.99	$\sin\alpha_2/\sin\alpha_3$	1.39-1.93
$L_1=L_3^{0.81}$	1	L_3/L_1	2.05-3.6
$L_2=L_3^{0.892}$	1	L_3/L_2	0.52-0.7
$h=8.459V^3-2.605V^2+0.222V$	0.96	V/h	70794.65-329765.
$V=0.014W+7.074H+2218.94J-3658.95$	0.92		

5. Validation of prediction model

In order to verify the practicability of deposit model, this paper took the debris flow gullies in Wenchuan earthquake area for example, owing to in the central part of the area of Wenchuan "5.12" earthquake zone, which leading to the lithology is similar, geographical position closed, structure alike, namely the occurring background and moving mechanism of debris flow is closely. According to the prediction model of Longchi area, contrast to run out characteristic of Shaofang gully, Modao gully, Sanshengong gully, Chamagudao gully, Maliu gully, Hongchun gully, Xioajia gully, the evaluation result as following (Tab.**2**):

Tab.2 Validation result of prediction model in the earthquake zone

Gully Name	Actual run out distance /m	Predict run out distance /m	Amplitude range /m	Error range	Actual lateral width /m	Predict lateral width /m	Amplitude range /m	Error range
Shaofang	70	113.57	113.58-182.37	0-1.6	250	247.31	132.37-247.31	0.01-0.47
Modao	357	305.13	176.07-604.32	0.51-0.69	193	238.12	176.07-604.32	0.08-2.58
Sanshengong	47	22.02	12.59-43.21	0-0.73	39	18.79	12.59-43.21	0-3.06
Chamagudao	72	144.01	83.27-258.80	0-2.96	80	112.20	83.27-112.20	0-3.11
Maliu	271	294.32	169.42-581.48	0-1.15	264	230.57	169.42-581.48	0-3.33
Hongchun	390	393．75	226.69-777.78	0-0.99	350	300	226.62-777.78	0-1.22
Xioajia	170	334.37	192.24-660.49	0.13-2.88	260	254.76	192.45-660.49	0-1.54

According to the results of prediction and verified in the table, contrast predicted results of run-out distance and width to field measured data, found that the error of predicted results to field results was not great, the error range of debris flow run-out distance was 0~2.96, the error range of run out width was 0~3.33.

6. Conclusion and Discussion

According to the study of group debris flows in the study area of Longchi area, field investigation and statistical analysis the characteristic of debris flow, found that the accumulation characteristics and particle properties is similar. Based on the statistics, prediction model for run-out characteristic on the alluvial fan created.

(1). The field investigation found that the deposits fan slopes of 36 debris flows in study the area is similar, and the slope mainly concentrated in 5°~9°, the average value of slope about 7°. The longitudinal slope of posterior border of debris flow fan concentrated in 0.05~0.16, and the average was about 0.119; The longitudinal slope of anterior border of debris flow fans ranged from 0.05 to 0.15, and the slope of average was 0.083; The longitudinal slope of debris flow fan was about 0.033~0.07, and the average value was 0.047.

(2). In the study area, the debris flow run-out volumes, run-out distances and width, profile thickness related to the landslide deposit volumes, elevation difference of catchments and the channel longitudinal slope. According to the geometry and materials of debris flow, the statistic model of debris-flow fans established, the lateral width, the section thickness and profile width diffusion rate and the accumulation volumes of debris flow fans, water shed elevation positively associated with the channel average longitudinal gradient was inverse correlation. Contrast to the fan data as known in Wenchuan area, the error of prediction model for debris flow run-out zone was in the range, and otherness of individual debris flows owing to the strongly effected of moving environment and spatial relations of tributary outlet and the main stream, so that the research about the characteristics of blocking river is particularly important in the future.

References

Alexander D (1989), Urban landslides. Progress in Physical Geography 13: 157-191

Benda L (1990), The influence of debris flows on channel sand valley floors in the Oregon Coast Range, U.S.A. Earth Surf Proc Land 15:457–466

Chuan Tang, Jing Zhu, Ming Chang, et al (2012), An empiricalestatistical model for predicting debris-flow runout zones in the Wenchuan earthquake area. Quaternary International 250:63-73.

CHANG Ming, TANG Chuan, ZHANG Dandan (2014), Debris Flow Susceptibility Assessment Using a Probabilistic Approach: A Case Study in the Longchi Area, Sichuan Province, China. J. Mt. Sci. 11(4): 1001-1014

Chuan Tang, Jing Zhu, Ming Chang, et al (2012), An empirical-statistical model for predicting debris-flow runout zones in the Wenchuan earthquake area. Quaternary International 250:63-73.

Chang FJ, Chiang YM, Lee WS (2009), Investigating the impact of the Chi–Chi earthquake on the occurrence of debris flows using artificial neural networks. Hydrol Process 23:

2728-2736.

Ding Jun (2011), Research on Magnitude and Run-out Distance of Debris-flows in Strong Earthquake Area. Chengdu University of Technology. (in chinese)

Dai FC, Xu C, Yao X, et al. (2011), Spatial distribution of landslides triggered by the 2008 Ms 8.0 Wenchuan earthquakes, China. Journal of Asian Earth Sciences 40 (4): 883-895.

Eaton SL, Morgan MA, Kochel RC, Howard AD (2003), Role of debris flows in long-term landscape denudation in the central Appalachians of Virginia. Geology 31:339-342

Liu Xilin, Tang Chuan (1995), Debris flow hazard analysis .Science Press. (in chinese)

Liu xilin, Tang Chuan,Zhang Songlin et al (1992), Geological Hazards to Agriculture in Jiangxi Province and Their Control. The Chinese Journal of Geological Hazard and Control（4）: 32-40 (in chinese)

Shieh CL, Chen YS, Tsai YJ, Wu JH (2009), Variability in rainfall threshold for debris flow after the Chi–Chi Earthquake in central Taiwan, China. International Journal of Sediment Research 24(2): 177-188.

Q. Xu, S. Zhang, W. L. Li, et al(2012), The 13 August 2010 catastrophic debris flows after the 2008 Wenchuan earthquake, China. Nat. Hazards Earth Syst. Sci 12:201-216.

TANG Chuan, Li Weile, Ding Jun et al (2011), Field Investigztion and Research on Giant Debris Flow on August 14, 2010 in Yingxiu Town,Epicenter of Wenchuan Earthquake.Earth Science-Journal of China University of Geoscience 36(1)：172-180.(in chinese)

Tolga Gorum, Xuanmei Fan, Cees J. van Westen, et al (2011), Distribution pattern of earthquake-induced landslides triggered by the 12 May 2008 Wenchuan earthquake. Geomorphology 133:152-167.

Webb RH, Pringle PT, Reneau SL, Rink GR (1988), Monument Creek debris flow, 1984: implications for formation of rapids on the Colorado River in Grand Canyon National Park. Geology 16:50-54.