

# Rainfalls, Landslides and debris flows intergrowth relationship in Jiangjia Ravine

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## 1. Abstract

JiangJia Ravine is a world-famous debris flows valley in Dongchuan, YunNan, China. Every year a large number of landslides and collapses happened and caused enormous damages to people's properties and lives. With longtime observation and testing in JiangJia Ravine we have found out one kind of special landslides which both have the distribute of landslides and collapses. Both of the landslides and collapses give sufficient material to debris flows. When debris flows outbreak, there always exist some kind of intergrowth among rainfalls, landslides and debris flows. In order to learn this intergrowth and some key parameter we have carried out artificial rainfall landslide situ and model experiments, observed the phenomena such as collapse, surface slide and surface flows during artificial rainfall experiments. With moisture content testing and surface observation, the full course of turning landslides deposits into debris flows under rainfalls condition had been analyzed. Result shows the intergrowth relationship among rainfalls, landslides and debris flows in JiangJia Ravine. The moisture content dispersed in a certain range, critical state seemed to be exist in the process of turning landslides deposits into debris flows on rainfall conditions.

**Keywords:** Landslides and debris flows, Rainfall, Intergrowth, Moisture content.

## 2. Introduction

JiangJia Ravine lies in Dong chuan, Yun Nan, China. Every year 12-20 times debris flows and countless collapses and landslides outbreak during the rainy season (May-October) in JiangJia Ravine, this caused heavy calamity to local people. Therefore, it had been regarded as the word-famous unique landslides and debris flows research base. The special geology and geomorphy features of JiangJia Ravine provide the opportunity of ditch development, surface erosion, landslides and collapses deposits assemblment and transportation (WU Jishan, et al. 1990). Because of the unique environment of surface ditches densely spreading, landslides and collapse thickly growing, large scale debris-flow cleuches intensively distributing. So the special geology and geomorphy environment is one of the decisive factors that control the formation and development of the landslides and debris flows. It is the basic reason of the mud-rock flows frequently and

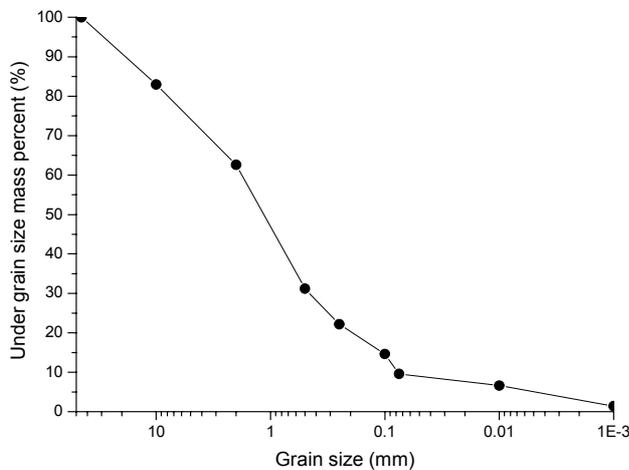
persistently form and develop. However, through longtime observation and investigation we have found out that not those large or middle scale of landslides which have the character of high position, enormous scale, distinctively sliding courses and sliding surfaces but those numerous steep slopes which have the character of relatively steep, low position, less scale and ambiguous slipping surface on the side of the ditches can frequently turn landslide deposits into debris flows. These unique landslides have both the collapse and landslide characters. On torrential rain eroding and surface runoff cutting these special slopes inclined to outbreak landslides, so this process both have the characters of gravitational corrosion, collapse and slide. The landslides deposits can easily be turned into debris flows on continuous storm and runoff scouring action in Jiangjia Ravine. Longtime observation and investigation on these special landslides shows that there exists a kind of intergrowth among rainfalls, landslides and debris

flows, this means that on condition of rainfall the deposits will easily be turned into landslides in Jiangjia Ravine special conditions. Big scale model experiment had been carried out to learn the effects of pore-fluid pressure and friction on the U.S. Geological Survey debris-flow flume (Iverson, R. M., et al. 1997,1990). Ring shear test apparatus had been used to learn the mechanism of debris flows(Sassa, K., 1984, 1985). Aimed at this special intergrowth relationship in JiangJia Ravine we had carried out artificial rainfall situ experiments, model experiments (HU Mingjian, et, al., 2001.) . During the experiment we observed the phenomena and surface flows, monitored the soil moisture content. Full process of rainfall induced landslides and their deposits turning into debris flows under rainfalls condition have been analyzed.

### 3. Deposits characteristics

**Table 1 Physical features of the JiangJia Ravine gravel soils accumulated randomly on both sides of the ditches**

category	Specific density	Saturated water content (%)	Void ratio (%)	Porosity (%)	Degree of saturation (%)	Unit weight (g/cm <sup>3</sup> )	Saturated unit weight (g/cm <sup>3</sup> )
value	2.77	18.9	0.51	33.9	31.3	1.79	2.13



**Figure 1 Grading curve of the JiangJia Ravine gravel**

### 3.2 Mechanical characteristic

In order to analysis mechanical characteristic of the gravel under rainfall condition, we carried out unconsolidated- undrained triaxial test(UU test) with the confining pressure of 100kPa, 200kPa, 300kPa. Before sampling we ejected the gravel that grain size greater than 5 mm. Test sample dry density was 1.79 g/cm<sup>3</sup>, the same as the natural dry density. Moisture content of test samples was 8%, 10%, 12%, 14%, 16% and 18%. Each moisture content had 3~4 samples with the diameter of

### 3.1 Physical characteristic

In JiangJia Ravine, there exists large quantity of gravel which had been produced by vast scale of landslides and collapses. The gravel soil accumulated randomly on both sides of the ditches with the characteristic of loosening, fragmenting. The gravel soil contains a lot of rock fragments, gravel and sand, small amount of silty sand or clay, so it has the attribute of looseness of structure, low cohesive strength and high internal friction angle. Through some gradation tests, the average control grain size  $d_{60}=5.53$  mm, average grain size  $d_{50}=3.71$  mm, effective grain size  $d_{10}=0.0045 \sim 0.0055$  mm, uniformity coefficient  $C_u=1005 \sim 1228$ , curvature coefficient  $C_c=33.5 \sim 41$ , so the gravel soil on both sides of the ditches is named of poorly-graded soil. Typical grading curve (Fig.1) and physical features (Tab.1)has been listed as follows.

61.8mm and height of 150mm. Testing results had been shown as Tab.2.

**Table 2 UU test result of the gravelly soil**

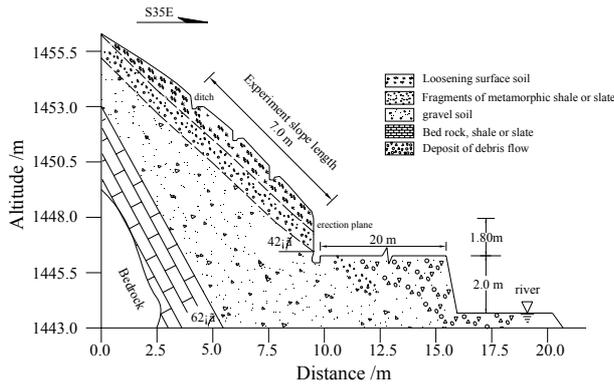
Moisture content /%	8.2	9.7	11.3	12.9	15	15.9
Cohesive strength /kPa	25.3	23.0	21.9	15.4	4.5	1.12
Frition angle /°	29.7	31.0	33.0	27.0	17.0	8.0

## 4. Artificial rainfall landslide situ experiment

### 4.1 Experiment setup

In order to study the intergrowth relationship between the rainfall, landslide and debris flow, we have carried out artificial rainfall induced landslide situ experiment. On consideration of some factors we choosed a little slope which had been piled by earlier landslides and collapses deposit accumulation. The little slope lies between the left of Jiangjia Gou's outlet, cross of the Chaqing Gou and Jiangjia Gou, gravel soil is the mail slope mass with the character of loosening and low cohesion. Natural drgree of the experiment slope is 42° , bedrock degree is 62° (Fig.2), from the bottom of the

slope to the middle of the Jiangjia Gou river is 30 m.



**Figure 2 Section map of the experiment slope**

Because of the deluvial slope washing and bilateral normal erosion, the experiment slope appears as a irregular cone in shape. Because the base of the slope embedded so deep in the deposit of the debris flow that the water is difficult to cut, so the experiment slope is very stable. The experiment slope had been divided into three blocks by some ditches to reduce the loss of the rainfall so the appearance like a trapezoidal with the dimension of upper bottom\* lower bottom\* height = 3.7\*7.4\*7.0m. We cut the base of the slope to a 1.8 m erection plane to simulate the water cutting (Fig.2).

On the experiment slope distribute 2 artificial rain fall sprayers on both sides, each can adjust the rainfall intensity. Use the fire engine as the artificial rainfall power, the fire engine can supply the Max. pressure of 740 kPa, Max. delivery lift of 17.5m, Max. horizontal transmission distance of 360 m. The diversion box connect the fire engine to 4 artificial rainfall sprayers (Fig.3) which can contribution the power to each sprayer. On the middle of the slope lay one self-recording hyetometer to record the quantity of rainfall. During the course of the experiment, sampled the gravel soil to test the moisture content, observed the displacement of the surface layer.



**Figure 3 Arrangement plan of the experiment**

## 4.2 Experiment course

This experiment course was divided into 6 sections, each section the rain fall time and rainfall quantity was listed as Tab.2. Because of the wind, the rainfall experiment was disturbed in some degree. Max., min and average rainfall intensity was 1.39 mm/min, 0.23 mm/min and 1.00 mm/min. The total rainfall quantity of the six sections was 94.87mm.

**Table 2 Rainfall time, intensity, quantity of each section**

section	time /min	intensity mm/min	Single quantity /mm	Total quantity /mm
1	25	0.97	24.25	24.25
2	13	1.39	18.07	42.32
3	10	0.23	2.30	44.62
4	15	1.07	16.05	60.67
5	14	1.05	14.70	75.37
6	15	1.30	19.50	94.87

After the rainfall experiment began for 4~5 min, surface layer of the slope began to slide and effusion, 3~4 min later small collapse appeared in one of the ditch back-wall with little runoff accompany. The runoff scoured the surface soil and carried out some fine-grained soil and clay and formed feculent sandiness stream. This course proceed about 5 min. After the fine-grained soil and clay fractional leaked, the coarse gravel gradually be compacted and the feculent sandiness stream begun to clarified. After this course continued for about 5 minutes, the slope maintained with a stabilization period.

After the stabilization period continued for about 6 minutes, as the second section increased rainfall intensity, the slide and effusion happened again. Runoff poured out from the backwall, scoured the slumping deposits and formed heavy feculent sandiness stream. The heavy feculent sandiness stream undercut the slumping deposits and formed many little rills. With the gravitation, surface conflux and sandiness stream scouring force, both sides of the rills deposits collapsed and came into being a high-ductility fluid. The high-ductility fluid flowed fast and formed into a minitype debris flow.

The loosen gravel slid and collapsed, the deposits collected downward, this made the front edge of the experiment slope small scale gibbosed and differentiated

from the original shape. The gibbosed gravel forcing and large quantity of water in the soil brought instability factors to the experiment slope.

Because of the wind, the rainfall intensity and single quantity of the following section was very low. Surface of the slope was compacted and the slope maintained with a stabilization period.

During the next 3 sections of the rainfall experiments, the loosening surface soil slid and collapsed with the erosion of rainfall and surface runoff, each section the slope would maintained stabilization for about 5~8 minutes. After the stabilization period different scale and shape collapses would happen. Until the 6<sup>th</sup> section rainfall, the loosening collapsed deposits piled on the front of the slope and caused the surface gibbosed. The sandiness runoff which provided great kinetic energy scouring the loosening deposits and cut a lot rills with different size, depth and length. The impact and scouring of the sandiness runoff caused both sides of the rills slid and collapsed, this again made the the runoff much more cloudiness and sandiness and the rills deeper and longer. Induced by the collapse of the rill sides, caused the gravel deposits landslide and conformed a landslide area of upper width\*lower width\*length=1.9m\*2.1m\*1.3m. The slip surface was irregular circle-arc in shape with some weak slip marks and the degree of 42°. The gliding mass made shear exit at the erection plane and slumped with the surface degree of 37°, this degree was correspondence with the natural angle of repose of the neighborhood loosening gravel. The landslide shape and scale was showed by Fig.4.

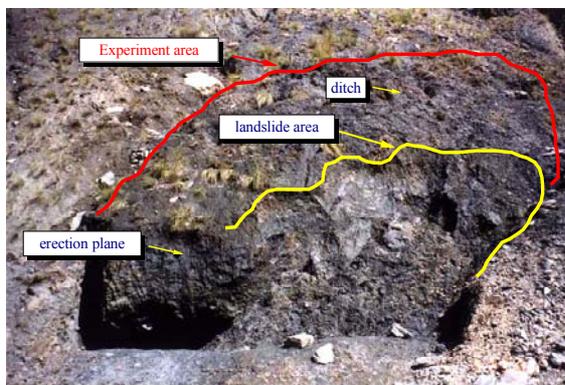


Figure 4 Photo of landslide area and shape

After the slope landslided, sandy stream poured out from the slip surface immediately and became clear and

small gradually. Along with the sandy stream little collapse happened and made the stream cloudy again. More little collapse happened more cloudy the stream be. The cloudy stream scoured the approximate saturated landslide deposits and formed some deep grooves. Along with the breakdown of the groove walls and supply of the deposits, the sandy stream turned into viscous mudflow and moved downward quickly, this course turned collapse, landslide into debris flow on condition of rainfall and maintained for about 2~3 minutes, from situ test the density of the debris flow had been tested out was 2.32 t/m<sup>3</sup>, serous fluid density was 1.80~1.95 t/m<sup>3</sup>, this was consonant with the outbreak of debris flows in Jiangjia ravine.

Moisture content testing showed that the original average moisture content was 7.8%, after 92 minutes rainfall with the average intensity 1.00 mm/min and total rainfall quantity 94.87 mm, moisture content of the surface layer (0.5 m) was 11.2%, average moisture content of landslide deposits and debris flow was 15.9% and 19.2% (Fig.5).

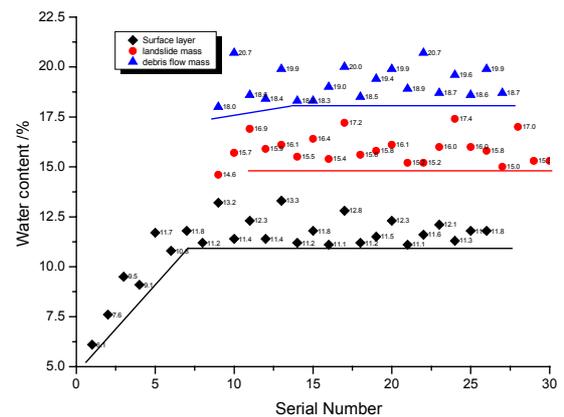


Figure 5 Statistical chart of moisture content

### 4.3 Experiment Acknowledgments

The artificial rainfall landslide situ experiment showed that intergrowth really exist between rainfalls, landslides and debris flows in the special geological and geomorphical condition of cliff slopes, ample rainfalls and undercutting of the slopes toe in Jiangjia Ravine. Loosening deposits of slope slide and collapse gradually saturated in the rainfall condition, the saturated deposits accumulated at the front edge of the slope. This accumulated deposits provide abundant soil to landslide, plentiful rainfall will turn the landslide deposits into debris flows. Rainfall, landslides and debris flows intergrowth each other is a unique natural phenomenon

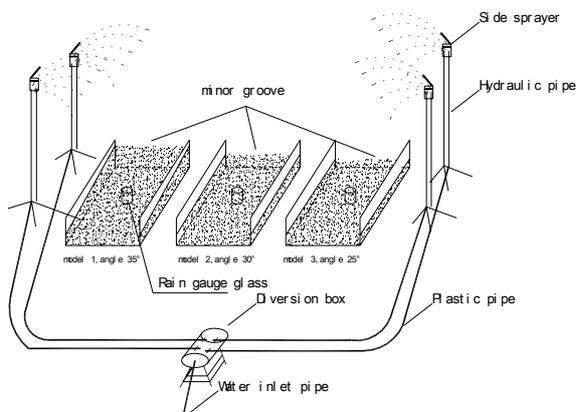
under the special geology and geomorphy condition in Jiangjia Ravine.

## 5. Artificial rainfall landslide model experiments

Based on the artificial rainfall landslide situ experiments and in order to disclose the moisture content and other parameters in the intergrowth between rainfall, landslides and debris flows, artificial rainfall landslide turned into debris flows model experiments have been carried out in Jiangjia Ravine.

### 5.1 Experiment Model and Correlative parameters

The model experiment test site located in a sloping field of Dongchuan Debris flows observation and Research Station. Three parallelly slope model had the same dimension of 2m \* 1m and different slope angle of 25°、30°、35°. Before the model experiment get rid of the weed and roots, on the upside of the model slope digged a minor groove with the depth of 10 cm. Each side has been blocked by galvanized sheet to avoid the rainfall overflow, as been shown in Fig.6.



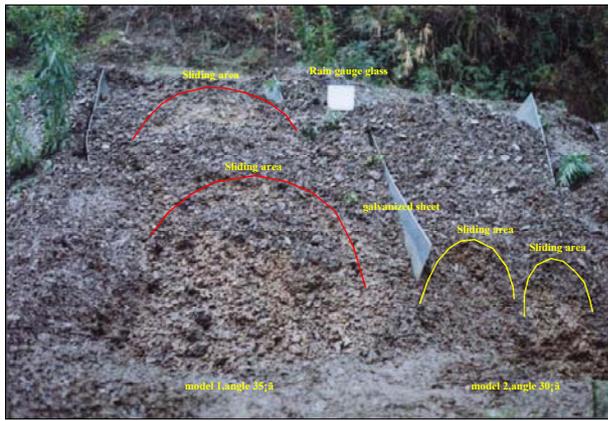
**Figure 6 Arrangement plan of the model experiments**

Before experiment moisture content of the gravel and gradation had been tested, three rain gauge glass had been laid on the experiment model in order to monitor the rain density. Artificial rain time based on the rain

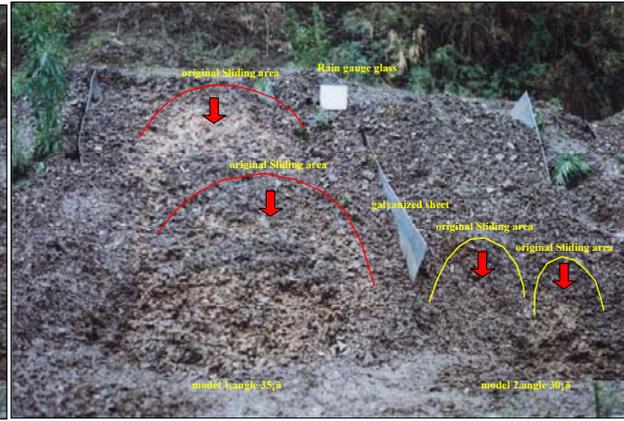
density, if the rain density was 0.7 mm/min, the rain time was about 70~100 min, the rain density was 0.8~0.9 mm/min, the rain time was about 60~70 min, the rain density was 1.1 mm/min, the rain time was about 50 min. During the experiments, observed the special phenomena such as collapse, landslide and debris flows and the transformation of the surface soil. Sampled in different layers to test the moisture content, recorded the time of the special phenomena happened and tested the moisture content of different time and different layers.

### 5.2 Phenomena of the experiments

Before the first experiment the moisture of the gravel had been tested out to be 5.4%~6.6%, natural density was 1.77~1.89/cm<sup>3</sup>. rainfall density was 0.9~1.1mm/min. After the experiment began for about 4~5min, the upper minor groove had some rain accumulated, the fine particle in the loose surface began to run off along with the muddy water, very minor slide had also happened. 15 min later, runoff formed on the surface of model 1. Another 15 min later, little collapse happened in the front of the model 1 and model 2. Because of the small natural moisture content of the soil and the high hydraulic permeability, again with the wind, 50 min rain time only had little slide and collapse happened, no landslide and debris not happened. So prolonged the rain time to achieve the aim. After continue artificial raining for another 40 min, base of slope in model 1 and 2 began to collapse, runoff all over the surface and affluxed stream at the front of the model slope, crisscross rills formed at this period. 6 min later, the front of model 1 slid, the deposit distegrated by the runoff washing. 16min later, the distegrated deposit moved down quickly and soon turned into minor mud flow with the mixture of rain and runoff as had been shown by fig.7.



**Photo 1 Sliding area had been formed**



**Photo 2 Model slope began to slide**



**Photo 3 Slide had been speeded up**



**Photo 4 Mud flow had been formed after sliding**

**Figure 7 Photos of slide turned into debris flow by model experiment**

## 5.2 Acknowledgments of model experiments

Some conclusions had been drawn from the model experiment was that rainfall, landslide and debris flows had been intergrown on condition of ample rainfall in the special geological, geomorphology and gravel character. The gravel moisture content test had shown that when the slope began to slide, the moisture content was about 15%~17%, the moisture content of slide deposits turned into mud flows was 18%~19%, this was content with the artificial rainfall situ experiment.

## 6. Elementary Conclusions

(1) Rainfall, landslide and debris flows had been intergrown on condition of ample rainfall in the special geological, geomorphology conditions and gravel character in Jiangjia Ravine. Ample rainfall, intense surface erosion and ditch development induced numerous landslides and collapses, deposits assemblage and transportation gave the debris flows erupt a well condition.

(2) Simple test shown that when the slope began to slide, the moisture content was about 15%~17%, the

moisture content of slide deposits turned into mud flows was 18%~19%. It seemed that there had some critical moisture content in the intergrowth of rainfall, landslides and debris flows, where or not? this would be validated in the latter experiments and research.

(3) This thesis was based on simple experiments and elementary analysis, enhance testing technology and monitor equipments to disclose the key factors in the latter experiments was a ultimate aim.

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