Preliminary study of the flooding characteristics on proluvial fan under different peak discharges

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Abstract: The changes of flooding area and surface morphology on a proluvial fan from typical middle-small scale gully in Southwest China were studied under different peak discharges based on large scale of field solid model experiments. The results showed that: in the model fan, 1) the changes of flooding area and surface morphology before and after floods increased with the increases of peak discharges. Most flooding occurred on the concave bank around top rush point, which also made the local surface morphology changed dramatically, i.e. the increases of width-depth ratio of river channel. 2) Buildings on the upper fan less than 20m away from the river bank could be affected seriously by the extreme floods, while the distance on the lower fan was 40m. On the middle part of model fan, buildings less than 10m away from the river bank would suffer disasters under small floods, and the distances were 30m and 80m under middle and extreme floods, respectively.

1. Introduction

Due to the characteristics of large amount, wide distribution and complex developed mechanism, the flash flood disasters had become the key point and difficulty on flooding disasters prevention and mitigation in China. Since the Chinese government approved the national plan for the prevention and control of flash flood disasters in 2006, the projects of national non-engineering measures and investigation & assessment on flash flood disasters have been or are being implemented \cite{1}. Accordingly, the National flash floods monitoring and early warning system had also been established initially, which means great progress has been made on the disaster prevention of flash floods in China.

However, for the related previous studies mainly focused on the cause analysis of flash floods\cite{2,3}, the mathematical description on flash floods & debris flows processes\cite{4,5} and the macroscale risk or hazard assessment\cite{6,7}, the systematic knowledge on flash flood disasters, especially the characteristics of disaster bearing body and the disaster mechanism at watershed scale, are still insufficient. Therefore, some deficiencies are still existed on the practice of flash flood prevention, such as the lack of knowledge on layout of water and rainfall monitoring stations and the hazard zoning on riverside villages. One important reason for these is that the flooding ranges under different scales of flash floods were still unclear.

With the increase of peak discharge, the flooding position, flooding range and the degree of landform changes are both the important basis for the local flash flood defence strategy making and residential distribution planning, and these problems can only be solved by practical case investigation and experimental study. By contrast, it is hard to acquire exact information on different peak discharge conditions within the same gully for the field investigation of disaster cases, while the experimental study can get more reliable first-hand data. Hence, this paper, taking the important habitats of...
mountainous residents in southwest China, i.e. the proluvial fan, as the study prototype, attempts to analyse the impacts of different peak discharges of flash floods on the changes of flooding area and surface morphology based on field conceptual solid model experiments, in order to provide references for local risk zoning and flash flood disasters prevention.

2. Method and Data Processing

2.1. Model scale and similarity criteria
The experiment was based on a conceptual solid model because the intent of this study was not to restore any specific disaster cases. In order to achieve better simulation of the actual disaster environment and improve the applicability of experimental results, the solid model experiments were performed on the proluvial fan of the Jiangjia gully in Yunnan Province, a typical mid-sized debris flow gully with hot & dry climate.

The geometric scale was set to 1:20. According to the Froude similarity criteria, the flow discharge scale was set to be equal to the geometric scale to the power of 1/2.5, and the time and flow velocity scales were set to be equal to the geometric scale to the power of 1/0.5, respectively. Accordingly, the prototype of this solid model was a small scale flash flood gully with a 40-meter-wide channel and a 160-meter-wide and 300-meter-long proluvial fan, and the scale was common in the mountain area of southwest China.

2.2. Model facilities
The experimental facilities consist of three parts, i.e. a flow control flume, a small pool, and a canal. The Parshall flume was chosen as the flow control flume because of its high precision and low head loss, and it was also the flow outlet of the entire system. The distance between the outlet and the lower flow merging point, i.e. the experimental observing channel length, was about 35m. The pool, about 15m³, was connected to the Parshall flume by a sluice gate and drew water from the higher ground through the cement canal. 8 cross-sections with an interval of 2m between each other were arranged along the channel of the artificial fan to record the landscape changes before and after each flood event.

The effect of building distribution on flooding was also considered in this work [8]. Considering the local typical pattern of villages on proluvial fans, the building models, mainly constructed by local bricks, were placed all over the fan except for within the river channel. During the experiment, if the building models were washed away or inundated seriously, they would be identified as suffering disasters; otherwise if the building models were just inundated slightly, they would only be identified as suffering hazards.

2.3. Experimental design
The peak discharges from the experimental outlet were controlled by different water levels settings on the pool. The default peak discharges were divided into three degrees, and each degree of flood would be repeated twice. The main indexes for measurement were the changes of the 8 cross-section areas and the flooding ranges before and after each scouring. Erosion pins and cross-section mark methods were used to measure the surface morphology changes and the flooding width of each cross-section, respectively. The concrete conditions design is shown as follow:

| Experimental No. | 1  | 2  | 3  | 4  | 5  | 6  |
|------------------|----|----|----|----|----|----|
| Water level inner pool (m) | 0.4 | 0.4 | 0.8 | 0.8 | 1.0 | 1.0 |
| Peak discharge (l/s) | 140.6 | 140.3 | 212.7 | 211.4 | 273.8 | 277.2 |
| Prototype discharge (m³/s) | 251.5 | 251.0 | 380.5 | 378.2 | 489.8 | 495.9 |
| Prototype flood scale | small | middle | extreme |
3. Results and Discussion

3.1. Changes of Flooding area under different peak discharges
The flooding width of each cross-section was used to reflect the general flooding range on proluvial fan. The experimental results show that the flooding area of model fan increased with the increase of peak discharge. As for the specific flooding positions of fan, the average flooding width of the three cross-sections nearest to the gully outlet were less than 20%, and the maximum value was only 32% (Figure 1), which means the upper fan was affected slightly by the changes of peak flows. On the contrary, the middle fan suffered the greatest impacts from the changes of flows. On this area, when the peak discharge maintained at a small scale, the flooding flow would only spread to the low-lying area because of the limited flow power. While the peak discharge became larger and larger, the flooding flow would not only spread to low-lying area but also partly return to the channel of downstream, and lead to larger flooding range at the same time. The returned flow inner channel downstream can hardly cause flooding, thus the flooding area on the bottom of fan were mainly caused by the upstream diffusive flow.

![Figure 1](image.jpg)

**Figure 1.** Flooding width of each cross-section on the model fan under different peak discharges

3.2. Changes of surface morphology under different peak discharges
The experimental results indicated that the absolute change of the cross-section area, i.e. the absolute change of surface morphology, increased with the increase of peak discharge. However, the changing degrees of the 8 cross-sections were different: the four cross-sections on the middle fan presented the largest increases during the whole experimental processes, while the two cross-sections near the outlet of gully changed little; the last two cross-sections on the bottom of fan presented a certain change when the experimental scale of flood reached extreme (figure 2).
Figure 2. Area changes of each cross-section on the model fan under different peak discharges

The channel near the outlet of gully was straight, and its morphology had become stable during the long-term of test scouring, thus the peak flow can go through it smoothly without any large morphological adjustment; when the flood flowed through the middle fan, the top rush and flooding occurred because of the river bend, then the local surface morphology adjusted dramatically to adapt to the new hydrological circumstance; when the rest of flow came to the lower fan, the channel had no need to changed intensely because of the sharp decrease of flow energy.

The slope of proluvial fan was far less than the channel inner gully, thus most sediment carried by flood deposited on the fan when they flowed out of gully. Generally, the channel on the fan turned to be wider and shallower after the experimental scouring. Some parts of the cross-sections, especially the cross-sections on the middle fan, might appear to be scouring, and the main reason for this was the serious lateral erosion made the channel became wider and wider.

3.3. Risk zoning

Based on the experimental results, it was believed that the horizontal distance between the buildings and river bank was more important than that of vertical distance on the proluvial fan. Accordingly, the risk zoning of proluvial fan from the middle-small scale gully in southwest China with the climatic characteristic of hot & dry was provided in this part, conceptually.

3.3.1. The upper fan. The upper fan referred to the area around the outlet of gully. Floodplain and channel with wide and shallow morphology developed in this section because of the long-term balance of scouring and silting, thus the high level bankfull discharge could be afforded in this area. Besides, no top rush occurred during the flooding for the local straight channel. For these two reasons, large amount of floods could flow though this section rapidly and smoothly in general. Only in the extreme flood scale of experiment, the buildings less than 20m away from the river bank could be affected seriously (Figure 3 left). Therefore, the security distance was 20m in this section. Actually, the upper fan can hardly suffer flash flood disasters according to the results of field investigation, because most buildings there were located on the terraces of hillsides.
3.3.2. The middle fan. The horizontal distance between buildings and the river bank was very sensitive on flash flood prevention in this section. The flash floods with small scale would impact the buildings seriously less than 10m away from the river bank, while the buildings less than 30m away from the river bank could only suffer limited flash flood hazard; when the flash flood scale changed to middle class, buildings less than 30m away from the river bank could be affected seriously, while the buildings less than 80m away from the river bank could suffer flood hazard; when the flood scale changed to extreme class, no buildings could survive in the floods (Figure 3 middle).

3.3.3. The lower fan. The flood flow in this section decreased significantly since the top rush and large area of flooding had been occurred upstream. Hence, the flood flow could go through this section with tiny bank collapses in the flash floods with middle and small scales. However, when the flood scale changed to extreme scale, the flooding flow upstream increased sharply, and part of it spread to the low-lying area rapidly, the rest flowed back to the channel and increased the flood pressure downstream. These resulted in large area of flooding on the bottom of fan. Nevertheless, the security distance in this section was only 40m, because most flooding caused by the diffusive flow with low power (Figure 3 right).

4. Conclusion
The changes of flooding range and surface morphology on a proluvial fan under flash floods were studied preliminarily based on a large scale of field conceptual solid model, and the risk zoning of the fan from a flash flood gully were also summarized, accordingly.

The results showed that the flooding area of fan increased with the increase of peak discharge, and the flooding mainly occurred on the concave bank around top rush point; the changes of surface morphology of fan also increased with the increase of peak flow, resulted in the enlarge of width-depth ratio of river channel. It was believed that the horizontal distance between the buildings and river bank was more important than that of vertical distance on the proluvial fan. For the proluvial fan from a middle-small scale flash flood gully in southwest China with hot & dry climate, the buildings on the upper fan, i.e. the outlet of gully, less than 20m away from the river bank could be affected seriously by the extreme floods, while the distance on the lower fan was 40m. On the middle fan, buildings less than 10m away from the river bank would suffer disasters under small floods, and the distances were 30m and 80m under middle and extreme floods, respectively.
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