International Journal of Sediment Research ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

International Journal of Sediment Research

journal homepage: www.elsevier.com/locate/ijsrc

Original Research

Threshold criterion for debris flow initiation in seasonal gullies

Yang Wang [a,d,*], Peng Cui [a,c], Zhaoyin Wang [b], Shuangqing Liang [a,d]

[a] Key Laboratory of Mountain Hazards and Earth Surface Processes/Institute of Mountain Hazards and Environment, CAS, Chengdu 610041, China
[b] Department of Hydraulic Engineering, Tsinghua University, Beijing 100084, China
[c] CAS Center for Excellence in Tibetan Plateau Earth Sciences, Beijing 100101, China
[d] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 27 February 2016
Received in revised form
27 December 2016
Accepted 9 March 2017

Keywords:
Grain composition
Seasonal gully
Non-uniform sediment
Debris flow initiation
Critical gradient
Critical discharge

ABSTRACT

A series of flume experiments were done to investigate the effect of grain composition on the critical gradient and discharge of debris flows initiated in seasonal gullies. The results indicated that the critical gradient and discharge for debris flow initiation decrease initially, and then increase as the mass content of fine particles (< 2 mm) increases. As the mass content of fine particles increases, the angle of repose, permeability of widely graded gravel soils, and the incipient motion conditions of the coarse grains in non-uniform sediments decrease at first, and then increase. The mass content of fine particles of all inflection points is the same. The theoretical model based on the combination of hydrodynamic force and shear stress is more applicable to the prediction of the critical gradient for debris flow initiation. The critical discharge model considering the effect of non-homogeneity of the soil and the size of coarse and fine grains provides a more accurate prediction of debris flow initiation than other models based on the mean diameter.
© 2017 International Research and Training Centre on Erosion and Sedimentation/the World Association for Sedimentation and Erosion Research. Published by Elsevier B.V. All rights reserved.

1. Introduction

Debris flow constitutes a major hazard in mountainous areas, which results in considerable loss of life and damage to infrastructure including communication networks, settlements, agricultural lands, and water supply systems (Guo et al., 2016; Zhou et al., 2015). Debris flow is also a major factor in coastal hazards caused by either tsunami or hurricane-induced storm surges and extreme waves (Biria et al., 2015; Choowong et al., 2007; Morton & Sallenger, 2003). Debris flow is usually initiated either by the erosion of gully bed materials or by landslides. In comparison to debris flows initiated by landslides, those initiated by the erosion of gully bed materials have been far less analyzed and are poorly understood (Cannon et al., 2010). These debris flows are composed of lower contents of fine particles, and the gully beds have higher hydraulic conductivity (Hu et al., 2014). The drainage capacity of the gully beds is high, so the water content is always below the saturation level as the debris flows are initiated (Berti & Simoni, 2005). Extensive research has been done on the initiation of debris flow due to gully bed failure. Cui (1992) considered the water moisture in the initiation of a debris flow. Other scientists (Gregoretti, 2000; Gregoretti & Fontana, 2008; Iverson & Lahusen, 1989; Takahashi, 1978, 1991; Tognacca & Bezzola, 1997; Tognacca et al., 2000) considered that the gully beds usually were saturated before the initiation of a debris flow.

There are three major mechanisms of debris flows initiation due to gully bed failure: (1) One of the most important initiation mechanisms of debris flows is shallow slope instability due to surface flow (Iverson et al., 1997; Johnson & Rodine, 1984). Here, a debris flow occurs when the shear force is equal to the resisting force. (2) Another important mechanism is best described as the equilibrium of single particles based on hydrodynamic drag force. According to this mechanism, a debris flow initiates when a large amount of sediment is moved (Gregoretti, 2000). (3) The third important mechanism is that the debris flow is initiated by fluid impact and energy transfers in the liquid phase (Wang & Zhang, 1990).

For the Wenchuan Earthquake, a large number of landslides and rock falls were deposited in the gullies, which provide abundant loose solid materials that are usually recognized as the most important factor contributing to the occurrence of debris flow. Relative studies indicate that debris flows can occur frequently in the first 5–10 years (Cui et al., 2014). Field investigations indicate

* Corresponding author at: Key Laboratory of Mountain Hazards and Earth Surface Processes/Institute of Mountain Hazards and Environment, CAS, Chengdu 610041, China.
E-mail addresses: wangyangcas@163.com (Y. Wang), pengcui@imde.ac.cn (P. Cui), zywang@tsinghua.edu.cn (Z. Wang), liangshuqngqing812@126.com (S. Liang).

http://dx.doi.org/10.1016/j.ijsrc.2017.03.003
1001-6279/© 2017 International Research and Training Centre on Erosion and Sedimentation/the World Association for Sedimentation and Erosion Research. Published by Elsevier B.V. All rights reserved.

ARTICLE IN PRESS

Table 1
The grain compositions of typical gully bed materials in the Wenchuan Earthquake area (Fang, 2012).

Typical debris flow gully	Particle size (mm)										
	60	20	10	5	2	0.5	0.25	0.05	0.01	0.005	< 0.005
Shenxi Gully		50.1	19.2	12.4	9.0	4.7	2.3	1.1	0.7	0.2	0.3
Yinxingping Gully	3.0	35.1	14.9	9.0	9.4	12.3	7.3	3.7	3.0	1.1	1.1
Wenjia Gully		21.5	19.5	18.6	16.2	12.7	3.7	0.7	3.4	1.2	1.9
Huangyao Gully	18.4	32.0	11.1	12.3	10.3	6.1	3.5	5.4	0.2	0.4	0.1
Weijia Gully		24.5	14.9	17.2	19.2	12.7	3.7	2.7	3.4	0.2	1.1
Yinchang Gully	13.7	37.0	12.8	7.6	7.7	7.6	4.9	2.9	3.9	0.9	0.9
Niujuan Gully		21.2	16.9	14.5	18.0	12.3	10.8	2.2	2.6	0.6	0.8
Hongjia Gully	3.1	25.5	17.1	11.6	12.1	9.7	4.9	1.5	8.9	3.2	2.2

that seasonal gullies are common in small catchments of mountainous regions (Ding, 1989). Because the surface flow is weak in earlier stages, the gully bed materials following selective removal of fine particles have high hydraulic conductivity and loose structure compared to colluvium. Such coarser gully bed sediments facilitate high subsurface flow velocities. In the Wenchuan Earthquake areas, the gully bed materials are usually composed of widely graded gravel soils where the content of clay particles is less than 2% and the content of grains larger than 2 mm is over 60% (Fang, 2012). The grain compositions of typical gully bed materials in the Wenchuan Earthquake areas are listed in Table 1.

There is no common conclusion about how debris flows are initiated by either progressive erosion of the gully bed due to sudden surface water flow or instability of the sediment layer as the shear stress is not always adequate to maintain sediment stability in a seasonal gully. For the lowest clay content soil, the extra pore pressure is limited and it is difficult for the pore pressure to overcome the soil strength. Therefore, the seasonal gully bed failure is difficult to initiate without surface flow.

The key issue regarding the initiation of debris flows in a seasonal gully is to understand the changes in the mechanical behavior of the sediment material (Bovis & Jakob, 1999). The grain composition of the soil reflects the percentages of grains of various sizes in the loose material, which directly affects the permeability, shear stress, density, etc. The physical and mechanical properties of the gully bed materials are determined by the grain composition.

The Wenjia Gully is a typical post-earthquake debris flow gully and eight disaster events have occurred after May 12, 2008. The source materials on the 1300 m platform are non-cohesive and loose in structure, which indicates that the sediments remain unstable at present and in the future (Ni et al., 2012; Yu et al., 2013). Before the artificial step-pool system was built on the Wenjiagou Gully in 2009, debris flows in Wenjia Gully were two-phase debris flows. Two-phase debris flows consist of gravel and boulders, and exhibit clear relative movement between the solid phase and the liquid phase, a high resistance, and an abnormal size distribution (Wang et al., 2005). A small number of studies have been done on two phase debris flows, compared to viscous debris flows. Therefore, the Wenjia Gully is selected as the study area.

In the fields of debris flow research, 0.05, 1 and 2 mm are proposed as the demarcation particle sizes of fine particles and coarse particles (Wu et al., 1993). Two (2) mm is regarded as the demarcation particle size of fine grains which are part of the debris flow slurry and coarse grains which are transported by the debris flow (Fei & Shu, 2004). The seasonal gully bed sediments is lack of clay, and though the fine sand and silt existed certain cohesive force, the main role of fine particles is filling the pores among coarse particles. In seasonal gullies, the amount of particles smaller than 2 mm has a decisive influence on the initiation of debris flow. Therefore, the demarcation particle size is selected as 2 mm.

In engineering, extensive literature exists regarding permeability and strength of gravel soils, where 5 mm is regarded as the demarcation particle size of coarse and fine grains. Large-scale permeability tests and shear tests have indicated that permeability and shear stress increase initially and then decrease as the amount of fine particles (< 5 mm) of gravel soils increases (Guo, 1998; Li & Xing, 2006; Wei et al., 2008). Grain composition affects the actions of exposure and shelter, hence, the mean diameter cannot be used to reveal the difficulty of particle motion initiation (Chiew & Parker, 1994; Li et al., 2016). Earlier research indicated a positive correlation between the critical condition of debris flow initiation and the mean diameter of the sediment layer (Gregoretti, 2000; Takahashi, 1978; Tognacca et al., 2000). Most previous studies used homogeneous sand or narrowly graded sand or a single material without considering the effect of inhomogeneity of gully bed materials on debris flow initiation. Therefore, the threshold criteria from these studies has a narrow range of applications.

The main objective of this study is to obtain the threshold criteria with definite physical meaning for debris flow initiation in seasonal gullies. A series of flume tests were done to investigate the effect of grain composition and hydrodynamic conditions on debris flow initiation. Inhomogeneity and non-saturation of gravel soils were taken into account in the experiments. The impact of hydrodynamic and shear forces on debris flow initiation was considered comprehensively.

2. Experimental method

2.1. Experimental flume

The experimental flume consisted of an upstream reservoir (the water tank), two sluice gates, and a downstream channel (Fig. 1). The upstream reservoir was 1.1 m long, 1.0 m wide, and 1.4 m high. The downstream channel was 6.0 m long, 0.3 m wide, and 0.5 m high. The slope ranged from 0° to 30°. The sluice gates were located at the connection between the water tank and flume. One sluice gate inside the water tank was used to control the water volume and the other located outside the water tank was used to control the water flow by completely opening or closing the gate. The fixed bed located at the inlet side was 1.0 m high and 0.2 m above the bottom of the channel. Cuboids of 0.3 m long, 0.01 m wide, and 0.01 m high were fixed at the bottom of the flume every 0.1 m to increase the bed roughness. Each side of the flume was made of transparent tempered glass for observations during the experiments. The glass was 1.5 m long by 0.5 m wide.

Please cite this article as: Wang, Y., et al. Threshold criterion for debris flow initiation in seasonal gullies. *International Journal of Sediment Research* (2017), http://dx.doi.org/10.1016/j.ijsrc.2017.03.003

Download English Version:

https://daneshyari.com/en/article/8911179

Download Persian Version:

https://daneshyari.com/article/8911179

Daneshyari.com