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Failure characteristics of gently inclined shallow landslides in Nanjiang, southwest of China

Shuai Zhang [a,b], Qiang Xu [a,*], Qun Zhang [c]

[a] State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu 610059, China
[b] Faculty of Science and Technology, Technological and Higher Education Institute of Hong Kong, Tsing Yi, Hong Kong
[c] Geo-environmental Monitoring Station of Sichuan Province, Chengdu 610081, China

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ABSTRACT

Large number of rain-induced landslides occurred on 16 September 2011 in Nanjiang, southwest of China. The typical depth of failure surface was from 1 to 5 m at the gently inclined interface between the superficial red silty clay and bedrock. In order to explain the failure characteristics of these shallow landslides, we conducted a rainfall infiltration simulation test, calculated rainfall infiltration depth using modified Green-Ampt (G-A) infiltration model as well as considered the atmospheric effects on the slope failures. Results show that the permeability of red clay is extremely low and the rainfall infiltration depth is limited to around 0.5 m during a rainstorm. The rainfall infiltration capacity can be enhanced within the depth of atmospheric influence, which is determined as 5.4 m in the study area. With the increase of soil depth and the lower degree of weathering, the void ratio and permeability are gradually reduced; thus, the rainfall infiltration continues following a decreasing trend until the bedrock is reached. Within the shallow landslides in the study area, under the condition of rainfall, the slope can keep in a stable state when the depth of wetting front is less than the thickness of soil layer. When the wetting front proceeds to the interface between the silty clay and bedrock, the potential slip surface can develop on such soil-bedrock interface, in relation to the increased pore water pressure and ground water level. Consequently, shallow failures will occur along the soil-bedrock interface in a depth of 1–5 m.

1. Introduction

Extreme rainfall occurred on 16 September 2011 triggered numerous widely distributed shallow landslides with gentle inclination in Nanjiang County, Sichuan, China (Zhang et al., 2016). Typical depth of the failures was from 1 to 5 m with slope angles from 10 to 30°. Most failure surfaces were located along the interface between the red silty clay and bedrock. These shallow failures are unlikely to occur according to mechanical equilibrium theory. When the overlaying soil layer is thin and flat, the soil slopes are expected to be much more stable since the gravitational force along the inclination direction of the sliding surface is small. The failure mechanisms of these large-scale landslides are worthy to be investigated, because they occurred in the regions with high population density.

Numerous researches on the failure mechanisms of rainfall-induced landslides have been conducted (e.g., Rosenqvist, 1984; Skempton, 1985; Moore, 1991; Lee and Dai, 1999; Dewoolkar and Huzjak, 2005; Rahardjo et al., 2005; Spagnoli et al., 2010; Xu et al., 2011; Wen and He, 2012; Miao et al., 2014). During the rainy season, perched groundwater can develop due to rainwater infiltration and accumulation at a certain depth of soil. Montgomery (1997) investigated a soil landslide occurred in the United States caused by the local perched water. Lee and Dai (1999) studied the regional landslides occurred in Hong Kong. It is concluded that the existence of the perched water in residual soil layer and the increase of pore water pressure are the main cause of rain-induced landslides. Huang and Qi (2002, 2004) investigated the relationship between matrix suction of unsaturated soil and the slope stability. Shear strength of rock and soil mass will be influenced by the decreased matric suction which in turn contributed to the slope failures. Most soil materials at the sliding surfaces are hydrophilic clay or gunk, which is easy to be soften under the influence of rainwater infiltration (Wang et al., 2009), such phenomenon can explain the main failure mechanism of many rain-induced landslides. According to an investigation conducted by Hutchinson (1961) on a gently-inclined landslide that occurred in Norway, the sliding surface is a highly sensitive sandwich clay layer. Michael (2000) revealed a five-stage failure process of a landslide in horizontally layered sedimentary rock with horizontal shear surface, i.e., unloading rebound, creep deformation of the weak layer, progressive deformation, mudding expansion, and gravity-induced differential settlement. Zhang et al. (2015) investigated the mechanisms of rain-induced landslides occurred in the red bed area and quantified the variation of water pressure before and after the

* Corresponding author.
E-mail addresses: zhangs@ust.hk (S. Zhang), xuqiang_68@126.com (Q. Xu), 782961232@qq.com (Q. Zhang).

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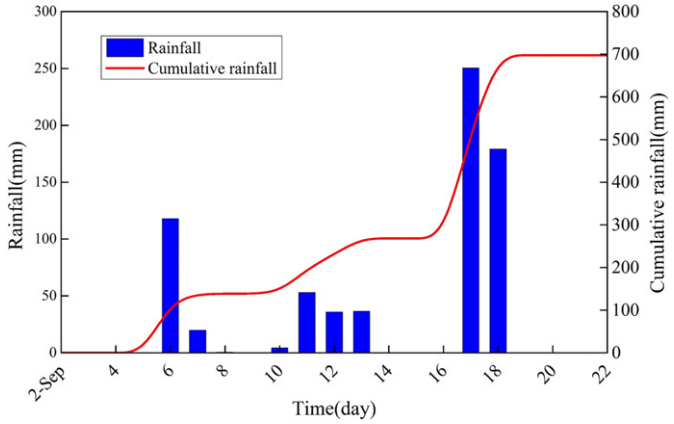

Fig. 1. Rainfall distribution from 05 September to 18 September 2011.

landslide using numerical simulation and ring shear test. The findings provide a theoretical basis for predicting the occurrence of gently-inclined landslide in the red bed area in the eastern Sichuan Basin.

Failure depth of shallow landslides is closely related to the depth of atmospheric influence, while current studies are mostly focusing on the landslides with homogeneous soil materials, which cannot explain the specific failure characteristics of shallow landslides occurred in Nanjiang County. A series of investigations on the triggering factors, geological conditions, and distribution patterns have been done on the red-layered landslides occurred in Nanjiang (Zhang et al., 2014, 2016; Li et al., 2014). However, the failure mechanisms of the gentle-inclined landslides with typical sliding thickness of 1–5 m still need to be explored.

The paper aims to investigate the failure mechanisms leading to shallow landslides in Nanjiang County, Sichuan, China using a case study of Gatuping landslide. The specific depth of failure surface under the influence of rainfall infiltration is investigated firstly based on physical simulation test and analyzed using modified Green-Ampt (G-A) infiltration model. Effects of atmosphere on the slope failures is then considered and verified by the field observation data. This research can provide theoretical basis and technical support for studying the failure mechanisms and disaster prevention of shallow soil landslides.

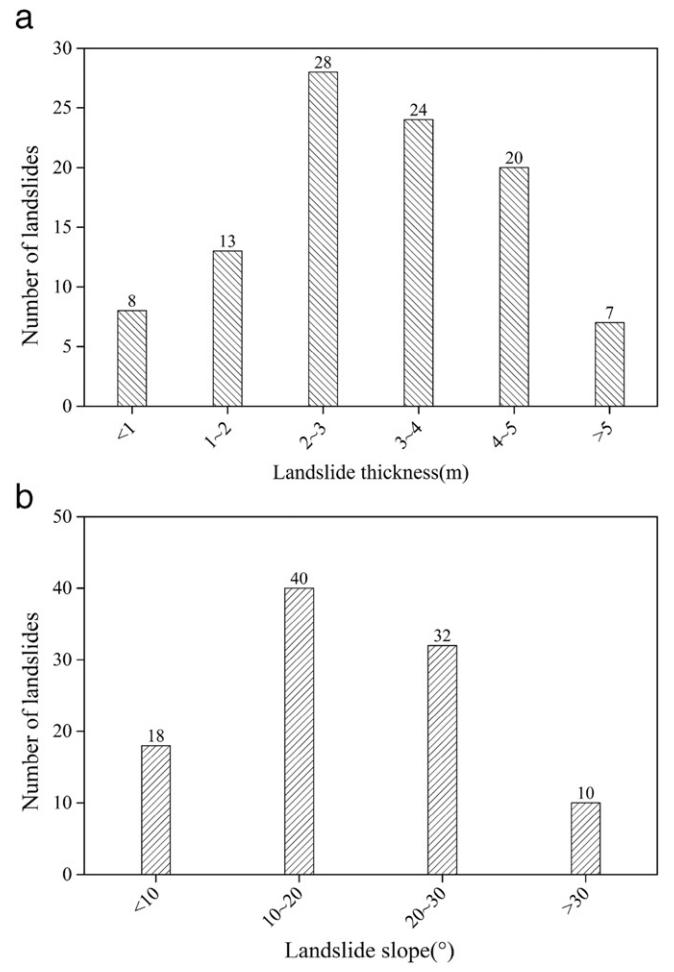

Fig. 2. Relationship between number of landslides with (a) landslide thickness; (b) slope angle of landslides.

Fig. 3. Typical soil-bedrock interface observed in the study area.

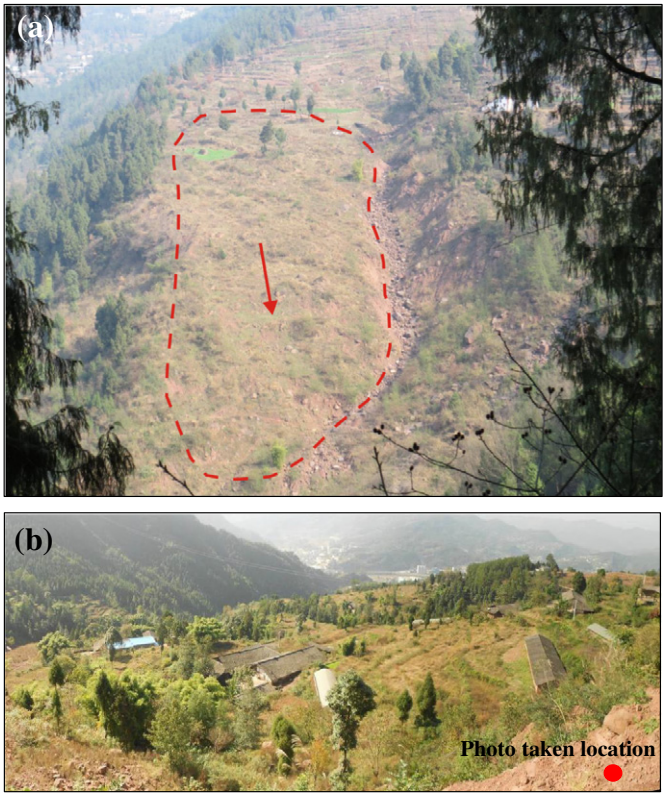

Fig. 4. Gaituping landslide. (a) An overview; (b) buildings at risk located at the right-front of the landslide; photo was taken above the landslide.