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Heavy rainfall triggered loess–mudstone landslide and subsequent debris flow in Tianshui, China

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ABSTRACT

Continuous and heavy precipitation triggered a large loess landslide at the southern Dagou Village of Mapaoquan Town, Tianshui City, Gansu Province of China on July 21, 2013. The landslide debris rapidly turned into a debris flow that was deposited in the ravine mouth with the volume of 1.9×10^5 m^3. Detailed field mapping, three-dimensional laser scanning, aerial photograph interpretation, and laboratory tests were carried out to study the formation and moving characteristics of the landslide and subsequent debris flow. The results showed that: 1) The peak flow velocity and peak discharge of the debris flow were estimated to be approximately 7.2 m/s and 730 m^3/s, respectively. The velocity had a tendency to first increase and then decrease from the head to entrance in the Dagou gully. 2) The analysis of rainfall conditions showed that the effective antecedent rainfall within 7 days and hourly rainfall intensity which triggered the slide-debris flows was 239 mm and 20 mm/h, respectively. Compared with the critical rainfall in this area, the effective antecedent rainfall was found to be more significant in triggering this event. 3) The mean and effective particle sizes were approximately 0.73–1.3 mm and 0.036–0.087 mm, respectively, and had the same distribution along the gully as the velocity, which confirmed the process of the variation in the flow velocity. 4) The scale amplification was very obvious in the formation and moving process of the slide-debris flows.

1. Introduction

Debris flows occur when masses of poorly sorted sediment, agitated and saturated with water, surge down slopes in response to gravitational attraction (Iverson et al, 1997a). They differ from landslides because they are made up of loose particles that move independently within the flow, while landslides are coherent blocks of material that slide over a failure surface (Guthrie and Evans, 2007). However, under certain conditions, the landslide in the migration process of the short distance could overall or partly convert into a debris flow in the form of liquid, gradually stopping after a long distance migration, thus a slide-debris flow is formed (Iverson et al., 1997b), also known as flowslides (Dikau et al., 1996) or flow-like landslides (Hungr et al., 2001). Slide-debris flows usually show a high speed of moving, a large volume, and high flowability (Davies and Mcsaveney, 2009; Yoshida et al, 2012). Slide-debris flows have a tremendous destructive effect on villages, roads, bridges, and whatever other obstacles lie in its path of motion, and they can lead to a large number of casualties (Hungr et al, 2001; Chen et al, 2006).

Loess is widely distributed in the northwest area of China and is characterized by unique structural features and water sensitivity such as large pores and vertical joint development (Gao, 1988). Geohazards such as landslide and debris flow can occur easily under the condition of rainfall, and the northwest area is one of the most serious areas suffering from landslides and debris flows in China (Li, 2004). According to Gao (1988), for example, on March 7, 1983 a massive landslide occurred in Dongxiang, Gansu Province that had a volume of 4.1×10^7 m^3, destroyed more than 500 houses, and claimed 237 human lives. In 1984, the slide-debris flows in Liujiabao, Tianshui, Gansu Province buried hundreds of people with an accumulation volume of about 1.8×10^6 m^3 (Li and Zeng, 1988). On August 12, 1991, a massive slide-debris flows in Luoyugou, Tianshui, Gansu Province killed 200 people (Zhou, 2011). The probability of landslide occurrence is high and the volume is large in the loess area (Lei, 2011). The slide-debris flows often cause significant casualties and property losses, especially under the condition of heavy rainfall (Li et al., 2004).

Abundant studies have been conducted that investigate slide-debris flows, especially the mechanism of landslides converting into debris flows. Some of studies conducted soil tests, deriving evidence of the liquefaction under undrained shear condition (Anderson et al., 1995; Dai

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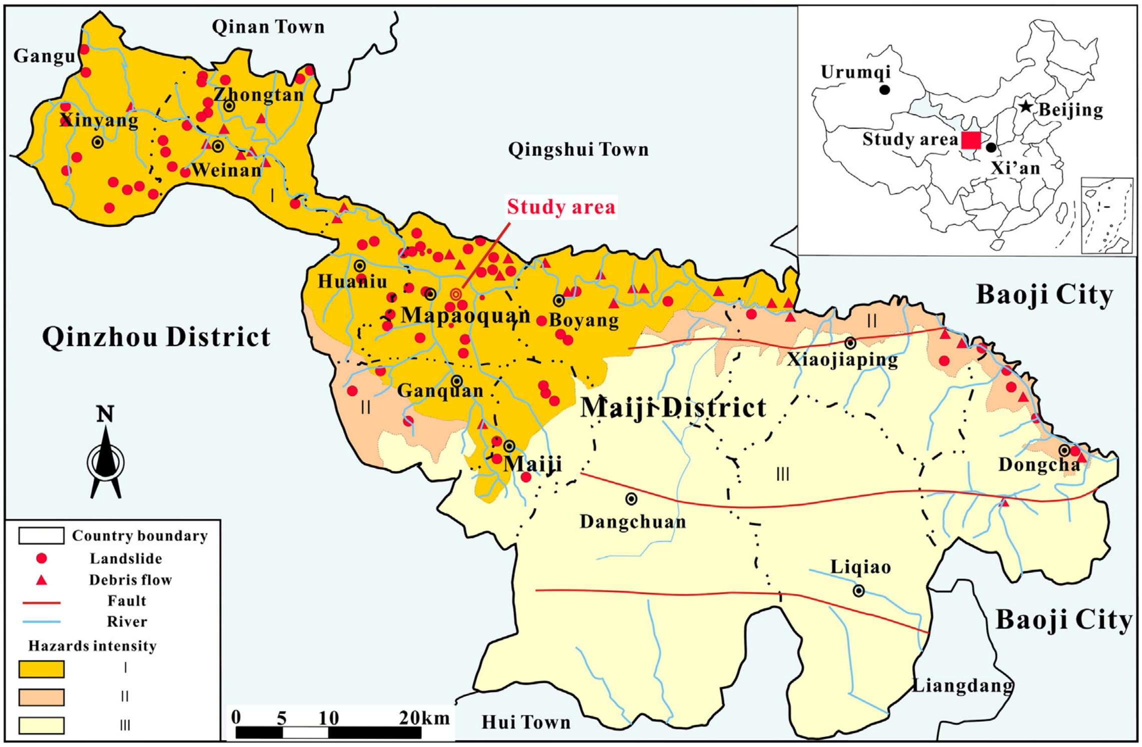

Fig. 1. Locations of the landslides and debris flows that occurred in Maiji District, Tianshui City (hazards intensity date from Tianshui Geological Engineering Investigation Institute).

et al, 1999; Emmanuel et al., 2006). Other studies have focused on flume experiments to analyze the converting mechanism, formation process, and trigger factors of slide-debris flows (Cui, 1991; Iverson et al, 1997b; Okura et al, 2002). Several significant conclusions have been proposed by these research efforts. However, due to the unique characteristics of loess, the mechanism behind slide-debris flows in loess plateaus has not been significantly studied, and because of this the formation processes of such landslides are still poorly understood. In order

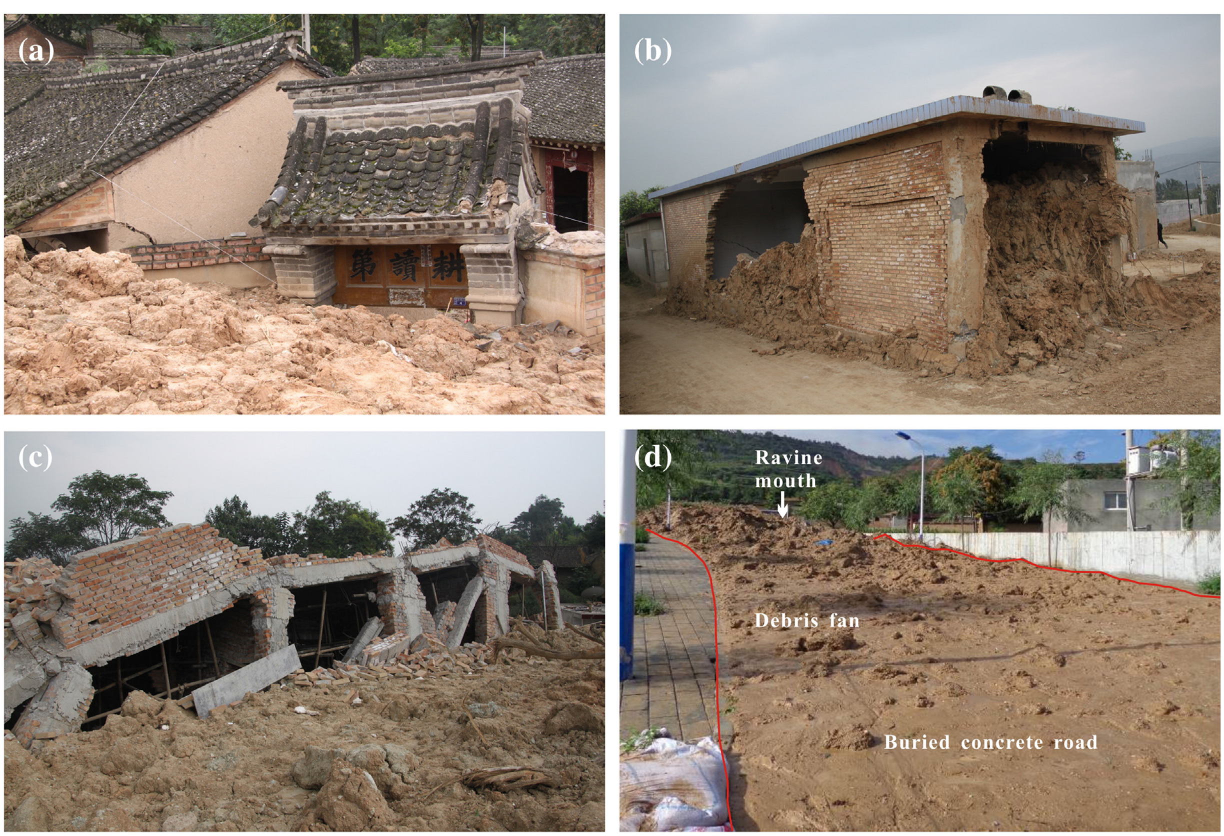

Fig. 2. The destroyed houses and buried concrete road in the debris flow fan.