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Effects of near-fault seismic loadings on run-out of large-scale landslide: A case study

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ABSTRACT

This study presents the run-out analysis of the Daguangbao landslides subjected to near-fault multi-direction earthquake forces using discontinuous deformation analysis (DDA). The Daguangbao landslide is the largest landslide induced by the 2008 Wenchuan earthquake. In order to investigate the effects of near-fault seismic force on landslide run-out, kinematic behavior of sliding mass is simulated by a dynamic discrete numerical analysis method called DDA. In this simulation, based on the shape of failure surface and the feature of slope geology, the whole slope is divided into three parts: base block, upper sliding mass, and lower sliding mass. Then two sliding masses are divided into the smaller discrete deformable blocks based on pre-existing discontinuities. Size effect of the huge landslide is also considered. Baseline corrected real horizontal and vertical ground motions are taken as volume force acting to the base block. The results show that seismic force has a significant influence on the landslide progression, sliding distance, and shape of post-failure. Results of the horizontal-and-vertical situation are in good agreement with those obtained from post-earthquake field investigation, remote sensing image and description from the survivors.

1. Introduction

A strong earthquake can induce a large amount of landslides and cause very serious property damage and human casualties. This phenomenon was recorded at least as early as in ancient China dated back to 1789 BCE (3792 years ago), and in ancient Greece 2385 years ago (Keefer, 2002). There have been many reports about very serious damages caused by the earthquake induced landslides for the last few decades, especially after a series of disastrous earthquake events occurred in recent years. For example, 9272 landslides induced by the 1999 Chi-Chi earthquake ($Ms = 7.6$) caused 2400 deaths, more than 8000 casualties and over 10 billion US$ of economic loss in Taiwan (Chang et al., 2005). 30% of the total fatalities (officially 87,350) had been victims of co-seismic landslides due to the 2005 Kashimir earthquake ($Ms = 7.6$) (Havenith and Boureau, 2010). Less than three years later, the 2008 Wenchuan earthquake shocked the Sichuan province and induced as many as 60,104 landslides (Gorum et al., 2011), which directly caused more than 20,000 deaths (Yin et al., 2009), a quarter of the total deaths, and over one third of the total lost was caused by the earthquake induced landslides. In spite of their geomorphic and economic significance, earthquake induced landslides are not well understood. There are two important aspects for a problem of earthquake induced landslide. One is the slope fail or not under seismic loadings, say, stability analysis. The other is where and how far it will go once the fail occurs, say, run-out analysis. This paper focus on the run-out analysis of an earthquake induced landslide.

Many numerical methods now exist to investigate the dynamic process of landslide (Savage and Hutter, 1989; Chen and Lee, 2000; Denlinger and Iverson, 2001; Crosta et al., 2003a, 2003b; McDougall and Hungr, 2004; Crosta et al., 2005; Chen et al., 2006; Crosta et al., 2007). These methods are usually based on continuum mechanics and assume that the avalanche thickness is very much smaller than its extent parallel to the bed, i.e. thin layer depth-averaged models. These models can take account accurately of detailed topography effects, shown to be significant, with a reasonable computational time, making it possible to perform sensitivity studies of the parameter used in the model. They can provide effective properties that make it possible to roughly reproduce the deposit shape but also the dynamic as shown in Favreau et al. (2010) and Moretti et al. (2012) for examples. However, conventional continuum approaching model, which neglects the contact between rocks, makes it impossible to trace the position of individual rock during a landslide. In contrast, discontinuum numerical simulation methods are powerful tools in simulation of failure and run-out process of rock avalanche controlled by weakness surface. Discrete element method (DEM) (Cundall, 1971) and discontinuous deformation analysis (DDA) (Shi and Goodman, 1985, 1989) are two of the most commonly used methods. Both DEM and DDA employ the equations of dynamic motion which are solved at finite points in time, in a series of time steps, but there are some subtle but significant differences in their formulations of the solution schemes and contact mechanics. In the solution schemes, equations of motion in DDA are derived using the principle of minimization of the total potential energy of the system, while the equations of motion as implemented in DEM are derived directly from the force balance equations, which still resultant unbalanced force after a time step and damping is necessarily used to dissipate energy. In the contact mechanics, the DDA used a penalty

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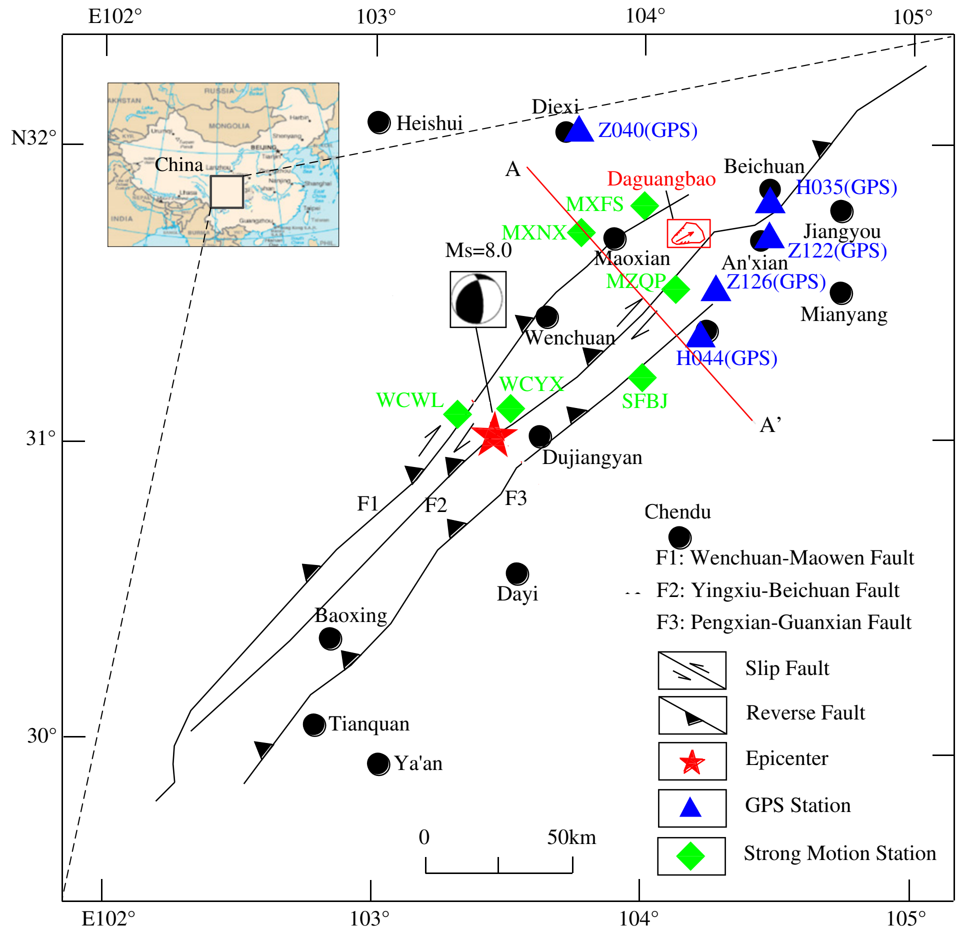

Fig. 1. Locations of the Daguangbao landslide, GPS stations and strong motion stations.

method in which the contact is assumed to be rigid. No overlapping or interpenetration of the blocks is allowed as same as real physical cases, whereas soft contact approach is used in DEM. The soft contact approach requires laboratory or field measured joint stiffness, which may be difficult to obtain in many cases. Many comparisons of basic models (sliding, colliding and rolling models) between the DEM and DDA were carried out and show that the results from DDA are more close to the analytical values than that from DEM (Zheng, 2010). Compared to DEM, DDA has a simpler and more straightforward physical meaning (Wu, 2003).

DDA is a dynamic numerical analysis method capable of evaluating the impact area of an earthquake induced landslide when seismic impacts are integrated into simulations. Hatzor and Feintuch (2001) is the first to validate the use of DDA in simulating dynamic landslides by studying the dynamic of block sliding on an inclined plane, in which they assume that the base block is fixed and earthquake accelerations are directly considered as body force and added to the sliding block in DDA. Based on the same inputs model of seismic loadings, Makris and Roussos (2000), Shi (2002), Kong and Liu (2002), Ishikawa et al. (2002), Hatzor et al. (2004), Tsesarsky et al. (2005), Yagoda and Hatzor (2010), and Bakun-Mazor et al. (2012) studied the dynamic response or/and stability analysis of tunnel, slope, dam, foundation or ancient masonry structure using DDA. Alternatively, Sasaki et al. (2004) developed an acceleration input method different from the original DDA algorithm to simulate the dynamic behavior of a slope with sliding block. In his method, the seismic accelerations were applied to the base block, which is different from the former seismic loadings input model. Sasaki et al. (2007) applied the same earthquake input model to analyze several cases of simple block structures under harmonic accelerations to acquire the relationships between natural frequencies of elastic block structures and applied accelerations. Later, Wu et al. (2009), Wu (2010), Wu and Chen (2011) and Wu and Tsai (2011) applied the DDA to simulate the kinematic behavior of sliding rock blocks in the Tsaoling landslide and the Chiu-fen-erh-shan landslide induced by the 1999 Chi-Chi earthquake. In this paper, we apply the latest DDA code, in which multi-direction seismic forces can be considered, to study the effects of seismic force on run-out of earthquake induced landslide.

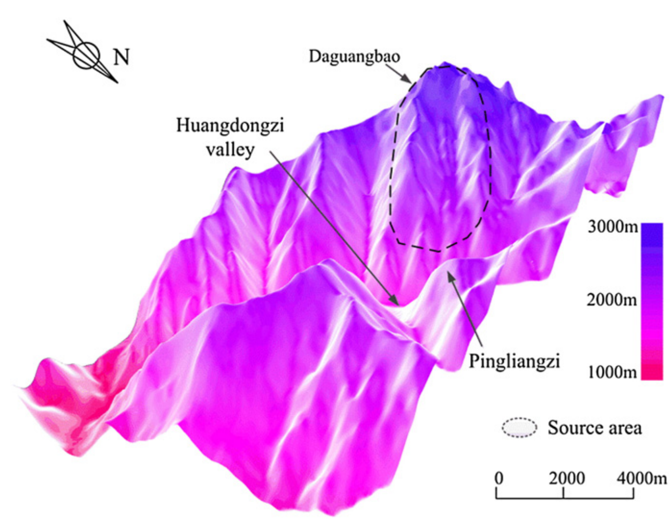

Fig. 2. Pre-earthquake 3D topography model of the Daguangbao area. (The data set is provided by the International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences).