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ScienceDirect
Tectonophysics 466 (2009) 438–457
TECTONOPHYSICS
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Effects of seismic anisotropy and geological characteristics on the kinematics of the neighboring Jiufengershan and Hungtsaiping landslides during Chi-Chi earthquake

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Abstract

The Chi-Chi earthquake (Mw = 7.6) of September 21, 1999 triggered many landslides in central Taiwan. Two of these landslides, Hungtsaiping (HTP) and Jiufengershan (JFES) were situated as close as 2 km from each other but had significant differences in their kinematics. JFES landslide was a catastrophic rockslide-avalanche and the HTP landslide was relatively slow-moving. The authors conducted a study to explore the reasons for such differences. Factors such as the characteristics of strong ground motion, sliding direction of landslide, and friction angle of the sliding surface were considered in the study. An analysis of 12 strong-motion records collected in the study area showed that the distribution of horizontal pseudostatic coefficients, earthquake energy ratio and permanent sliding-block displacements (Newmark displacement) were anisotropic with their predominant direction mostly in the E/W–ESE/WNW trending. This direction is perpendicular to the axis of the main geological structures of the studied area. The computed Newmark displacement in the sliding direction of the JFES landslide is larger (44%) than that of the HTP landslide with sliding surface inclination of 21° and friction angle of 28° We can conclude that the seismic anisotropy and the corresponding sliding direction are important contributing factors to the kinematics of studied landslides. The back-calculated friction angle of the sliding surface that corresponds to a critical Newmark displacement for the JFES landslide is about 3.5° higher than that of HTP landslide. The material (colluvium) on the sliding surface in HTP should be less velocity-dependent than that of the JFES landslide (rock) according to the back calculations. The importance of seismic anisotropy, sliding direction, and mechanical properties of sliding surface on the kinematics of deep-seated landslides is demonstrated.

Keywords: Earthquake; Seismic anisotropy; Landslide; Colluvium; Newmark method; Velocity-dependent friction law

1. Introduction

Because of the nature of tectonic movements that created the island of Taiwan, most of the geological structures in this region are aligned in the NS to NE–SW directions. The main ridges of the mountain ranges created by tectonic movements are roughly parallel to these NS to NE–SW trending geological structures. The Chi-Chi earthquake (Mw = 7.6) of September 21, 1999 triggered many landslides in central Taiwan (Hung, 2000; Liao, 2000; Huang et al., 2001; Khazai and Sitar, 2003; Lin and Tung, 2003; Lin et al., 2003; Wang et al., 2003a,b). For Chi-Chi earthquake, the EW components of the horizontal peak ground accelerations (PGA) are stronger than those in the NS direction according to most of the strong-motion records (Shin, 2000). The major principal direction of PGA is almost perpendicular to the NS trending Chelungpu fault (Loh et al., 2000). Lin and Tung (2003) suggested that the thrusting process of the Chelungpu fault may have played an important role in the orientation of the Chi-Chi earthquake-induced landslides. It is generally believed that the intensity of ground motion,

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0040-1951/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.tecto.2007.11.008

geological and morphological factors, as well as material properties, determine the occurrence and kinematics of seismically triggered landslides (Keefer, 1984; Keefer, 2000; Parise and Jibson, 2000; Helmstetter et al., 2004). In addition to its wealth of strong-motion records, the Chi-Chi earthquake triggered a number of large landslides. These well documented events offered a unique opportunity to evaluate the above described factors and their relationships to the characteristics of landslides.

Jiufengershan (JFES) and Hungtsaiping (HTP) are two of the most noticeable large and deep-seated landslides induced by Chi-Chi earthquake (Wang et al., 2003a; Lee et al., 2004; Wei and Lee, 2006). The closest distance between these two landslides is 2 km. Fig. 1 is an aerial photo of the JFES and HTP landslides after Chi-Chi earthquake. The distance and velocity of the sliding block were large enough to characterize the JFES landslide as a catastrophic rockslide-avalanche. On the other hand, most of the displaced areas in the HTP landslide were only slightly disturbed with relatively modest displacement. The material within the failure zone at HTP is mostly colluvium. The differences in kinematics observed in these two landslides triggered by the same earthquake motivated the research.

The seismic record of the Chi-Chi earthquake (Lee et al., 1999, 2001a) and earlier studies associated with this earthquake

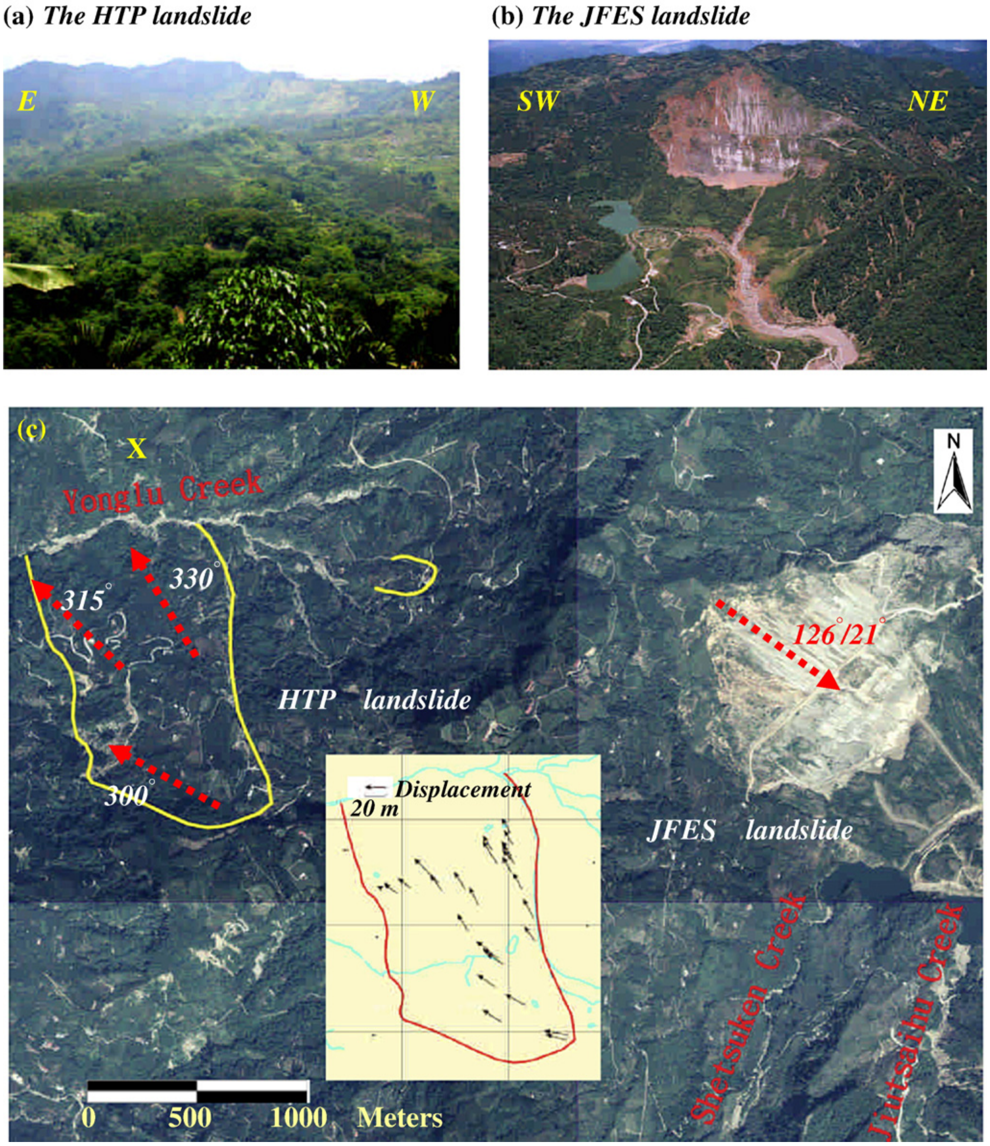

Fig. 1. (a) Photo of the HTP landslide after the Chi-Chi earthquake. View southward from point X (upper left corner of (c)) at north side of Yonglu Creek. (b) Photo of the JFES landslide. (c) The aerial photo of the JFES landslide (east slope; right side) and HTP landslide (west slope; left side). Displaced materials of the JFES catastrophic rockslide-avalanche followed the dip direction and ran out more than 1000 m southeastward and dammed two creeks (shown in (b)). The HTP landslide was less violent and the sliding direction was northwest. Most of the displaced areas of HTP landslide were only slightly disturbed (shown in (a)). The horizontal surface displacement vectors and the boundary of the HTP landslide (as shown in (c)) were identified by digital aerial photogrammetry based on the aerial photos taken before and after the Chi-Chi earthquake (Lee et al., 2004). The displacement vectors can be further divided into three groups, trend 330°, 315°, and 300°.