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Slope management criteria for Alishan Highway based on database of heavy rainfall-induced slope failures

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ABSTRACT

In this paper, a study of slope failures along the Alishan Highway (locally, known as "Tai-18") is carried out. An innovative empirical model is developed based on 15-year records of typhoon rainfall-induced slope failures. This model is intended for assessing the likelihood of slope failure along Tai-18 in the future. The rainfall data considered in the proposed model include the maximum hourly rainfall and the effective cumulative rainfall. The effective cumulative rainfall is defined at the point when the curve of cumulative rainfall goes from steep to flat. Then, a simple criterion is established for assessing the potential of slope failure and issuing warning and/or closure for Tai-18 during a future extreme rainfall. Slope failures during Typhoon Saola in 2012 and those in Japan demonstrate that the new empirical model is effective and applicable to other regions with similar rainfall conditions.

1. Introduction

In Taiwan, two-thirds of the total land area is in the mountainous area and one-third in the plains. The majority of the population and economic activities concentrate in the narrow alluvial plains and basins of the western corridor, which results in over-dense population in the plains. Therefore, the mountainous areas have to be developed and utilized when the plains can no longer meet the demand of the population and the economic activities. Rapid development of the communities in the mountainous areas has increased the impact of slope failures and landslides, in terms of loss of properties and lives, in these areas.

The main geology of Taiwan was formed between Miocene and Quaternary. Taiwan is located at the collided subduction zone of the Philippine Sea Plate and the Eurasian plate, which results in many folds and faults in the formed mountains. In addition, Taiwan is also located in the western North Pacific typhoon belt. Due to a number of reasons such as typhoons, storms, rainy season, negligence of the ecological environmental protection and soil conservation among citizens, and improper hillside development and overexploitation of farm, the debris flows and landslides often occur, which cause the blockage of roadways, isolation of the mountain areas, injury to people, and loss of properties and lives.

The disaster prevention along roadways in the mountainous areas should first rely on warning and prevention. To enhance the accuracy and timeliness of the highway slope-failure warning system, a variety of factors should be considered and their impacts should be studied. Various rainfall parameters have been used for highway slope warning systems in different countries. Jamaludin and Ali (2011) suggested that the empirically based rainfall threshold is an economic approach for a slope warning system. In India and Iran, the rainfall threshold has also been used for such purpose (Sengupta et al., 2010; Nafarzadegan et al., 2012). In Australia, Italy, and Malaysia, the power law of hourly rainfall intensity and rainfall duration has been used for the slope warning systems (Aleotti, 2004; Flentje and Chowdhury, 2006; Jamaludin and Ali, 2011). In Japan, combined use of hourly rainfall intensity and cumulative rainfall to manage highway slopes has been reported (Kuramoto et al., 2002; Sato et al., 2002). Considering that rainfall is the direct cause of slope failure in the mountainous areas in Taiwan, the typhoon-induced rainfall is selected as the basis for the proposed slope management system in this paper.

Here, the slopes along the most important access roadway from the plains to the mountain of Chiayi area, namely, Tai-18 (the Alishan Highway), are examined. In the past, studies of the slope failures along the Alishan Highway were focused on the largest landslide in the area, which is located at Woo-wan-chai (Chang et al., 2005) and the integrity assessment of the rock mass behind the shotcreted slope (Wu et al., 2005). Although advanced methods such as Artificial Neural Network (Lin et al., 2009) and Artificial Evolution Neural Network (Chang et al., 2011) have been developed for assessing the failure potential of the slopes along the Alishan Highway, the developed models are often difficult to be updated based on ever-changing rainfall patterns and data.

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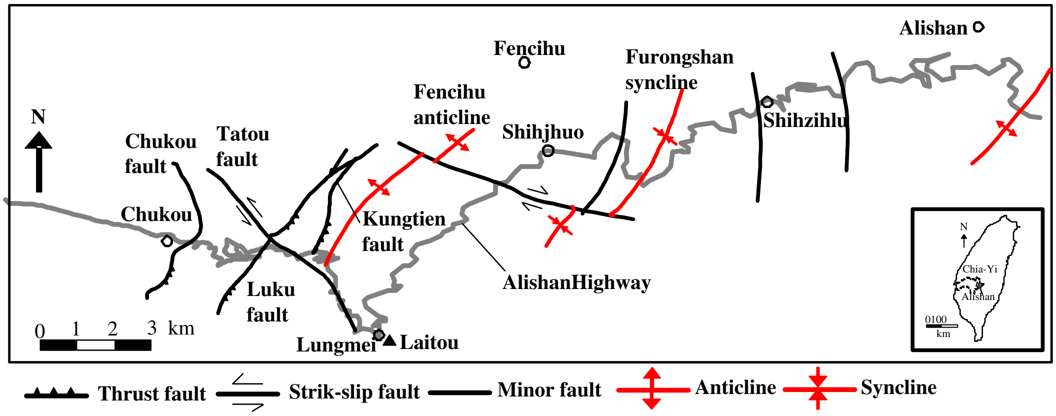

Fig. 1. Main geological structures along Alishan Highway.

The highway and county authority need an accurate and simple criterion to manage the Alishan Highway, especially during typhoon season in Taiwan. In this study, a set of criteria is established based on a database of slope failures along Tai-18 (the Alishan Highway), caused by typhoon rainfalls, over a period of 15 years. The results provide a basis for establishing an early warning system for managing Tai-18.

2. Location, geology and rainfall of the study area

2.1. Location and geology of the study area

The location of the study area is an important mountain sightseeing area in Taiwan-Alishan Highway. Alishan Highway is the main traffic artery from Chiayi to Alishan National Scenic Area and Yushan National Park, with a total length of 109.985 km. This study focuses on the mountainous sections of Tai-18, which covers Fanlu Township, Jhuci Township, and Alishan Township, all in Chiayi County. From west to east, these mountainous sections include Chukou in Fanlu Township (34 k, elevation 280 m), Lungmei (51 k, elevation 1050 m), Jhuci Township, Shihjhuo (64 k, elevation 1300 m), Shizihlu in Alishan Township (77 k, elevation 1,500 m), Alishan (89 k, elevation 2200 m) and Tzutzong (97 k, elevation 2280 m). The outcrop of the rock along these road sections mainly consists of the sedimentary rock layers from mid-Miocene to Pleistocene. These sedimentary rocks include the sandstone and interlayered sandstone and mudstone (known as Nanchuang Formation) from Miocene age, the Kuantaoshan and Tawo sandstone from the age of Miocene to Pliocene, and the Chinshui shale from the age of Pliocene to Pleistocene (Chen et al., 2003).

Fig. 1 shows the main geological structures along Alishan Highway, as reported by Liu et al. (1989). The study area is geologically classified as the inner foothill zone with the Chukou Fault located at the western boundary. Extensive thrust faults and asymmetric folds are common features along the Alishan Highway. The strikes of the fault and fold axis are NE and NW, respectively. From the west to the east, the Chukou Fault, Tatou Fault, Luku Fault, and Kungtien Fault govern the rock mass between the Chukou Fault and the Kungtien Fault. In addition, folds, such as Fencihu Anticline and Furongshan Syncline, are the main geological structures east of the Kungtien Fault.

2.2. Rainfall

Rainfall is an influential factor that contributes to the slope failures along the Alishan Highway (Lin et al., 2009). The study area is geographically located between the western foothill zone and the Alishan Mountain, and rainfall is mainly influenced by the topography and the monsoon. Rainfall pattern in the study area is the heavy rain brought by typhoons and during rainy season. The Alishan station in the high altitude (elevation 2413 m) is the first rainfall station established by the Central Weather Bureau of Taiwan, which has been in service since 1984. The Laitou rainfall station in the low altitude (elevation 1090 m) was established in 1989. The Fencihu rainfall station (elevation 1404 m) in the medium altitude was established in 1994. These rainfall stations are shown in Fig. 2. Different average annual rainfall data from the Alishan station (3915 mm, from the year of 1984 to 2010), Fencihu station (3866 mm, from the year of 1994 to 2010), and Laitou station (3153 mm, from the year of 1989 to 2010), as shown in Table 1,

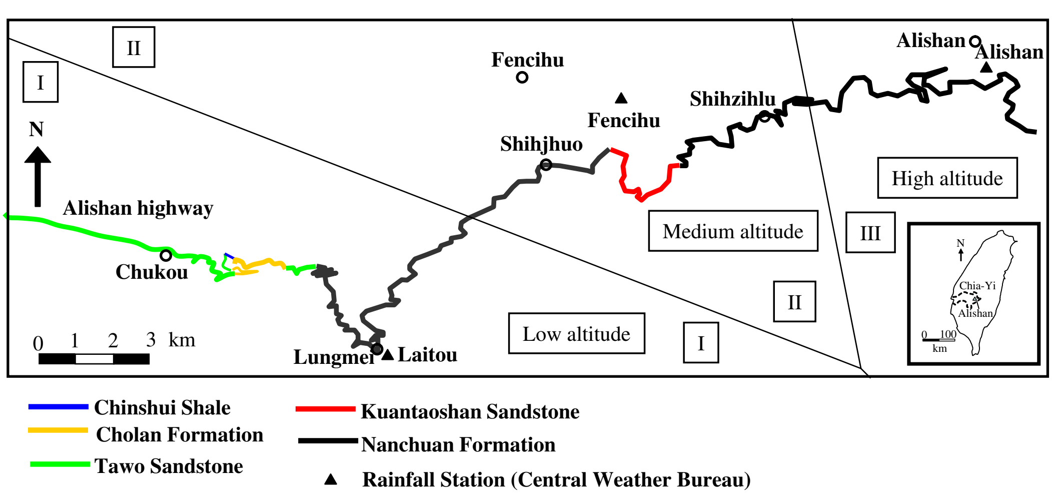

Fig. 2. Three investigated zones divided by the distances to rainfall stations.