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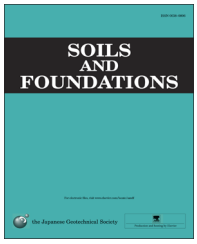

Individual landslide hazard assessment of natural valleys and slopes based on geotechnical investigation and analysis

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Abstract

Slope failures caused by rainfall on weathered granite are common occurrences in many parts of the world and it is more severe in Japan where there are a significant number of slopes susceptible to failure. At present, about 31,987 natural, and valley slopes are found to be susceptible to landslide disasters in Hiroshima Prefecture, the highest number of any prefecture in Japan. In Hiroshima Prefecture, the prefectural land is divided into 350 units of 5 km^2, and the hazard of each unit was assessed based on the rainfall data and past records of failures. However, the existing hazard assessment system was found not to be adequate of making better predictions of individual failures in the region, and moreover the system was developed without carrying out any reliable slope stability analyses. In this study, an attempt has been made to understand the mechanism of individual slope failure through seepage analyses and stability analyses. A series of laboratory model tests were conducted to develop the relationships among volumetric water content, degree of saturation, suction, and coefficient of hydraulic conductivity under unsaturated conditions. Field investigation and laboratory tests were conducted based on the four valleys which were identified as potentially hazardous zones in Higashi-Hiroshima city in Hiroshima Prefecture. Graphical relationships were developed among the volumetric water content, suction, rainfall intensity, coefficient of hydraulic conductivity, and degree of saturation for Masado soils. Based on the relationships developed, suction was calculated along the soil profile of natural valleys with the lapse of time. Thus, shear strength parameters were determined based on the degree of saturation calculated from the data of volumetric water contents. The stability analyses revealed that the factor of safety gradually decreases with the formation of High Moisture Content Belt (HMCB) and drastically reduces with the formation of the water table. The susceptibility of failure for each of the four valleys is given based on the hazard assessment system, and is compared and discussed.

Keywords: Hazard assessment; Landslide; Site investigation; Groundwater; Factor of safety

1. Introduction

Hiroshima Prefecture is located in the middle of western Japan and 2.85 million people are living in an area of 8477 km^2, about 75% of which is hilly and mountainous. Hiroshima Prefecture has 31,987 hazardous areas for landslide

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disasters, the largest number of such areas in any prefecture in Japan (Hiroshima Prefecture, 2014). Geologically, most part of Hiroshima is covered with heavily weathered granite, locally called "Masado". Masado profiles exhibit erratic weather front with varying material spatially due to the differential weathering patterns over the years (Nishida, 1981). From a geotechnical point of view, the failures of natural slopes are mainly caused due to the rise of groundwater level and the loss of inbound shear strength of soils due to the intensive seasonal rainfalls. The average annual precipitation in Hiroshima is 1538 mm, and the average monthly precipitation in the months of June and July are 247 mm and 259 mm, respectively (Aboshhi and Sokobiki, 1972; Murata and Yasufka, 1987). Japan has sustained many recurring disasters in granitic areas following heavy rains, resulting in a total of nearly 1500 casualties over the last 70 years, including 20 in Hiroshima in 1999 and 11 in Yamaguchi in 2009 (Chigira et al., 2011). There are records available of landslide disasters due to rainfall effects on Masado soils in some part of Malaysia, the United States of America, Thailand, China, South Korea, Hong Kong and India (Chigira et al., 2011; Philip, 1977; Phien-Wej et al., 1993; Zhang et al., 2000; Lin et al., 2011; Kim et al., 2011; Jiao and Malone, 2000; Muhammad and Mohd, 2012). Recently, the monitoring of natural slopes for the purpose of disaster prevention has been studied intensively (Jeng and Lin, 2011; Rahardjo et al., 2011; Huang et al., 2012). Over the years, considerable attempts have been made by researchers elsewhere in the world to examine the mechanism of failure in natural Masado slopes by examining its properties under different conditions. However, due to the complexity of its nature in analyzing slopes on Masado soils, one has yet to find a better methodology to analyze natural Masado slopes. Due to the risks these slopes present, the urgency of extensively examining the cause and remedial measure for these failures through proper hazard assessment system is very clear.

The presently available hazard assessment system, which was developed by prefectural government of Hiroshima, Japan, is shown in Fig. 1 (Hiroshima Prefecture, 2014). This regional hazard assessment system utilized by Hiroshima Prefecture government is entirely based on the measured rainfall and the rainfall–failure relationship in each 5 km × 5 km area obtained from the past records of landslide disasters (Kusano et al., 2007). In this system, the failure of slope/s and evacuation orders is given for an area of 5 km × 5 km, and the hazard of individual slope cannot be predicted. Accordingly, it can be said that the present hazard assessment is empirical, and is not adequate for more accurate assessment of slopes as it does not consider the geotechnical inputs in analyzing the slopes. Moreover, it is the shear strength parameters, cohesion, and internal angle of friction that must be considered under different conditions such as variation of degrees of saturation and suction under different rainfall intensities, unsaturated flow, development of water table, etc. which need to be taken into account. Therefore, the authors have taken initiatives to enhance the present hazard assessment for a better understanding of slope failures in the region by examining the individual slopes. The proposed enhancement is given in Fig. 1 with the presently available hazard assessment system.

One of the challenges in analyzing the slopes is to evaluate the in situ shear strength parameters spatially of the natural slopes with gradients of more than 25°. This has been successfully overcome by Tsuchida et al. (2011) who developed a methodology to evaluate the shear strength parameters by means of cone resistance data by recently developed

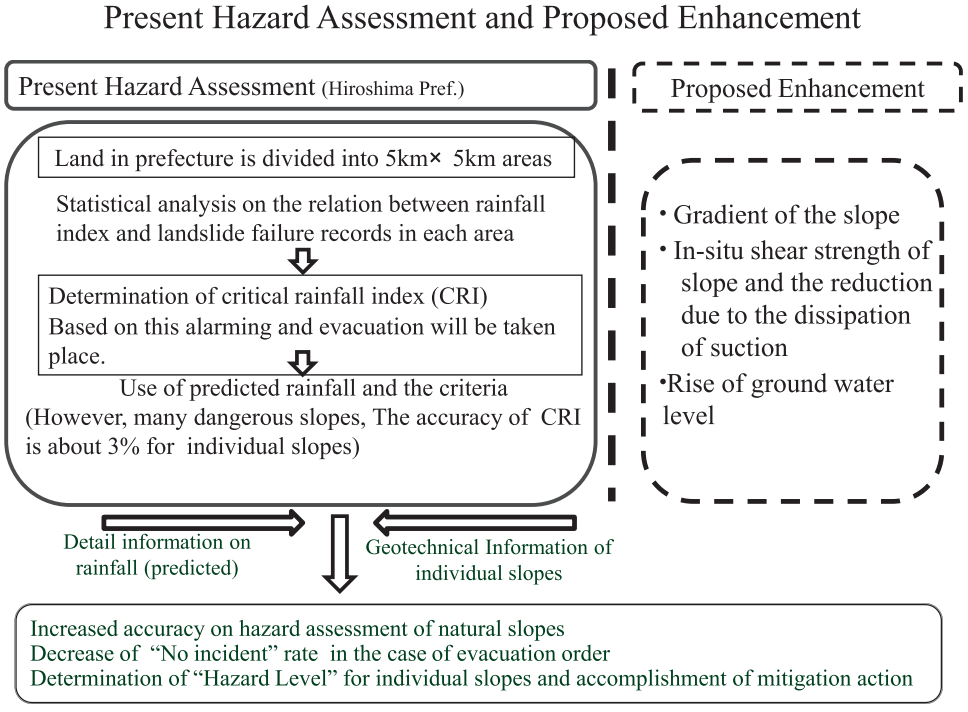

Fig. 1. Structure of the present risk assessment system and proposed enhancement.