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A Case Study of a Cut Slope Failure Influenced by Snowmelt and Rainfall

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Abstract

In cold regions, frequent incidents of soil slope failures occur due to snowmelt and rainfall. These failures are triggered by an increase in the degree of saturation of soil due to infiltration of water derived from rainfall and snowmelt. This study investigates a soil slope failure occurred on November 27, 2015 at a cut slope of an expressway in Hokkaido, Japan. The soil slope failure is investigated using a recommended stability assessment approach considering non-isothermal coupled seepage flow simulation followed by a limit equilibrium slope stability analysis. It is concluded that at the thawing period, the slope stability is affected by rainfall and snowmelt water infiltration and later in November the failure happened due to overflow of water from a drainage ditch.

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Keywords: slope failure; snowmelt water; rainfall infiltration; drainage ditch breakage; numerical modelling

1. Introduction

Frequent incidents of soil slope failures occur due to snowmelt and rainfall in Hokkaido, Japan. Increase in the degree of saturation of soil due to infiltration of water derived from rainfall and snowmelt trigger these type of failures under the influence of continuous weather changes throughout the year. Many studies on the effect of rain infiltration

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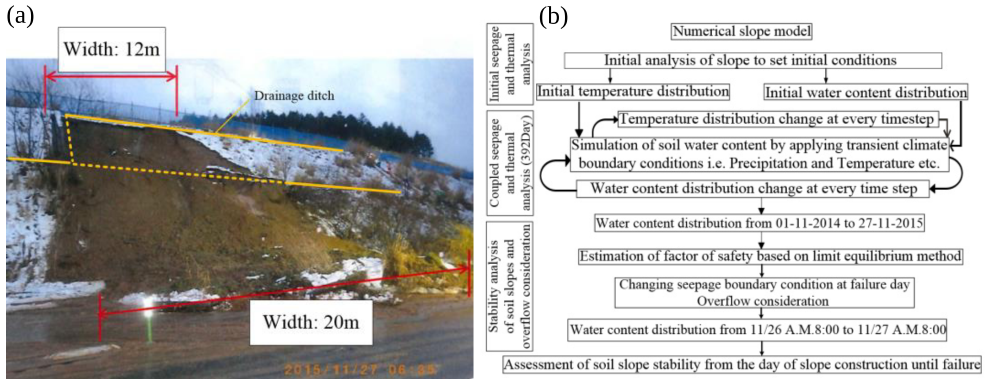

Fig. 1. (a) Slope failure on 27-11-2015. (Lat. 42°38'27.1"N, Lon. 140°26'25.0"E) and (b) Analytical procedure adopted in this study.

on slope instability have been carried out by numerous researchers [1, 2]. Almost all of these studies have not considered the influence of snowmelt water. However, in Hokkaido, failure at cut slopes or landslides at natural slopes often occurred due to snowmelt. For example, a large scale landslide occurred on April, 2015 caused by snowmelt water infiltration [3]. Frequent small to large scale slope failures are reported along a national highway near Sapporo, Hokkaido, Japan [3]. Therefore, the prediction of slope failure at the thawing period is indispensable for the disaster prevention measures in cold regions. This study investigates a soil slope failure occurred at a cut slope of the expressway in Hokkaido, Japan. The studied cut slope is located in Kuromatsunai Town. The failure occurred on November 27, 2015 and the slope surface was covered with snow on this day. The slope is comprised of two benches as shown in Figure 1(a) and the failure occurred on the upper side of the bench. A considerable amount of rainfall and snowmelt were also occurred as observed from the data recorded from a nearby meteorological telemetry. Furthermore, initial disaster investigation revealed that the failure was induced by overflow of water from a drainage ditch. It is considered that a considerable amount of rainfall and snowmelt flowed and overflowed at the intersection point of the drainage ditch. The objective of this study is to investigate the cause of the slope failure and to suggest some preventative measures for the mitigation of soil slope failures in cold regions. For this purpose, back analysis of the soil slope failure is performed using a recommended stability assessment approach considering non-isothermal coupled seepage and thermal analysis (coupled analysis) followed by a limit equilibrium slope stability analysis.

2. Numerical modelling methodology, analytical conditions and simulations

A numerical modelling approach to simulate the slope failure has been adopted and followed as given in Figure 1(b) [4]. In order to simulate the slope failure process, at first, numerical slope stability analysis was performed without the consideration of water that overflowed from the drainage ditch. To estimate the initial water content distribution and initial thermal condition for coupled analysis, initial seepage and thermal analysis were performed separately. A climate boundary condition at the slope surface with a specified time length of five years is applied and performed (01-11-2009 to 31-10-2014). Climate boundary condition will be clearly explained later. The computed hydraulic state and thermal state reached inter-year equilibrium with the input climate conditions as on 01-11-2014, the initial day [5]. After setting up the initial conditions, melting snow and rainfall infiltration analysis has been performed by keying in a climate boundary condition at the slope surface with a specified time length of 392 days (01-11-2014 to 27-11-2015). Using the derived moisture content distribution from coupled analysis, long term slope stability analysis (392 days) has been performed using limit equilibrium technique based on the method given by Morgenstern and Price (1965) [6]. Finally, the overflow from the drainage ditch is considered during the failure day and the slope stability is analysed using Factor of Safety (FOS) calculations. The proposed simulations are performed using a commercial code SVOffice 5GE (SoilVison Systems Ltd [7]). In this study, SVFlux and SVHeat modules of SVOffice 5GE are used to perform non-isothermal coupled seepage flow and SVSlope module is used to perform the slope stability analyses.

The slope geometry for the numerical simulation is prepared in consideration to the actual cut slope as shown in Figure 2(a). The model slope is 20 m high and the slope angle is 35 degrees. SVFlux and SVHeat make use of an automatic adaptive mesh technique [8]. Hence, four history points (2 m from the shoulder of the drainge ditch and 1(0.3 m), 2 (0.8m) 3 (2.0 m) and 4 (4.0 m) from the surface) were made to observe the fluctuation of volumetric water