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Analysis of the seepage due to the thawing of permafrost, considering the gradient of the impermeable layer

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Abstract

Topographical deformation due to global warming has become a serious problem. However, scientific studies have not been sufficiently conducted to understand the mechanisms. Solifluction, a gradual mass movement related to freeze-thaw processes, is known as a typical topographical deformation. The purpose of this study is to simulate the solifluction process considering the seepage influence, and then establish a predictive numerical model. The authors adopted the Finite Volume Method (FVM) and Dupuit's assumption in order to precisely simulate the seepage flow. Consequently, according to this study, the authors suggested to adopt a non-linear assumption for appropriate estimation of seepage flow velocity.

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Keywords: FVM; solifluction; seepage; permafrost;thermal erosion.

1. Introduction

In recent years, it has been frequently reported that global warming causes various environmental issues, including topographical deformation such as solifluction and thermal erosion in permafrost regions. Permafrost is defined as a soil layer that remains frozen for a minimum of two consecutive years, and it is distributed over a wide area in the northern hemisphere of the earth. If permafrost starts to thaw, the soil layer is likely to deform and deteriorate in strength. When the thawing is accelerated, it allows water to flow underground. The water runs down along the

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gradient of the permafrost table, taking with it soil particles in the vicinity. These phenomena are known as solifluction and thermal erosion. Fig. 1 shows the deformation of and damage to structures due to thawing. The effects of this damage are not limited to topographical or geographical deformation, but also affect the decline in plant life and vegetation, as hydrological circulation through the surface is seriously affected. Finally, these mechanisms may limit ability of the earth to absorb carbon dioxide.

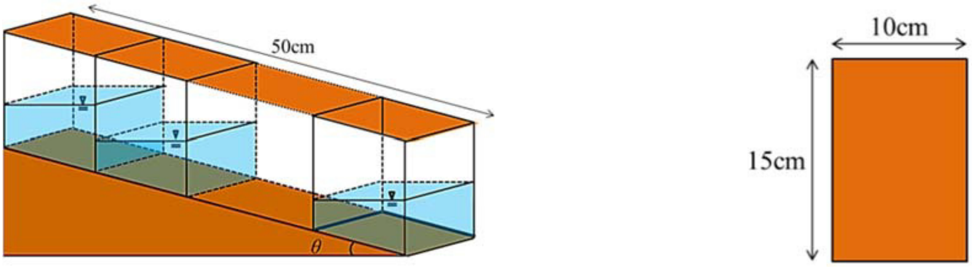
In this study, we aimed to elucidate the mechanism behind the land deformation caused by underground seepage through both experimental and numerical approaches. In order to simulate the phenomenon, many factors must be taken into account, such as thawing processes, water flow dynamics, the interaction between water and soil particles, etc. First, we focused on the underground seepage flow and attempted to confirm the applicability of the numerical method used, which includes the Finite Volume Method based on Dupuit's assumption.

(a) solifluction (b) thermal erosion (c) collapse of structure

Fig. 1. Damage caused by the thawing of permafrost

2. Analytical model and boundary conditions

Initially, we prepared an indoor experimental device in order to reproduce the underground water flow and corresponding soil deformation. The box-shaped device is 50 cm in the length, with a rectangular cross-section of 15× 10 cm. We then filled the device with fully saturated fine sand. By inclining the device, after removing the wall at the downstream end, water started to flow within the sand layer. We discretized into small elements along the stream-line and Fig. 2 shows the numerical model for the calculation.



(a) Complete view of the analytical model (b) Cross-section of the model

Fig. 2. Analytical model

3. Method and Equations

Underground water gradually flows according to the hydraulic pressure gradient within the foundation. Since the coefficient of permeability of sand is sufficiently small, at 0.025 cm/s, we assumed that the quasi-uniform flow proposed by Dupuit can be adopted. It says that the flow velocity along the stream-line can be assumed to be constant, regardless of the height from the bottom, and the velocity in the transverse direction to the stream-line is negligible. Fig. 3 illustrates a schematic diagram of the quasi-uniform flow and the distribution of hydrostatic pressure. Even though the water table, as a free surface, decreases continuously along the stream line, the difference in hydrostatic pressures between two points along the stream-line can be assumed to be approximately equal and constant, irrespective of the height [1].