A Method For Predicting Frost Heave Using Porosity Rate Function

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다공성 함수를 이용한 Frost Heave 예측 방법

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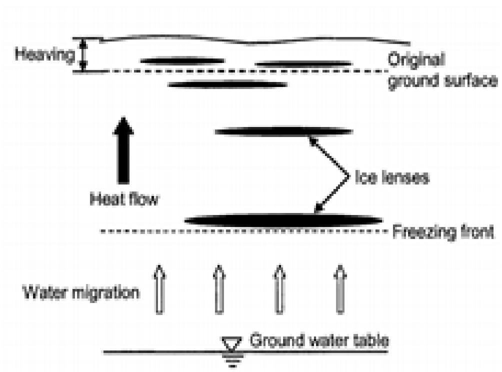
Abstract

The porosity model is a phenomenological model used to describe the frost heave process without resorting to the micro-mechanical processes that lead to ice growth. This model is a thermal-fluid-mechanical (THM) multi-physics model and it is relatively accurate in describing the frost heave process, but in long-term simulations, the porosity growth is difficult to converge and eventually causes model failure. So we reproduce the model on COMSOL and try to introduce new variables to solve the convergence problem of the model.

1. Introduction

Frost heave is a phenomenon occurred frequently in the cold regions when the ice lens continuously grows within the soil body as a result of the freezing of pore water in voids, which is continuously supplied due to capillary action inside the surface. eventually causes ground surface expansion(Taber,1930). It has a great effect on the engineering structure and would course significant damage and it's forming is as shown in Fig[1] therefore, Understanding frost heaving mechanisms is the crucial part of cryogenic geology.

How to describe and predict the frost heave has been researched for decades. Michalowski[2] proposed a constitutive model for a frost-susceptible soil and the porosity rate function was introduced to describe the ability of soil in increasing volume change. And that function had been modified to describe the porosity development coupling with thermal physics and solid mechanics by Michalowski and Zhu[3]. On this basis, we remodeled the model in COMSOL and compared the experimental data results.

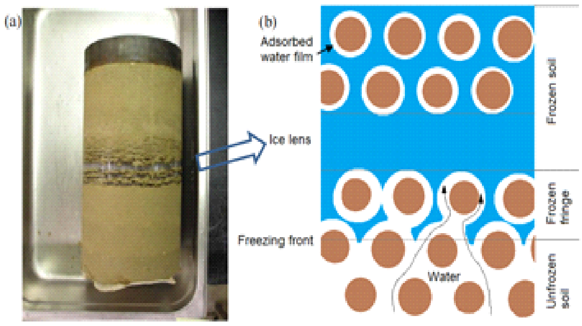


[Fig. 1] A schematic of frost heave

2. Porosity Rate Function

2.1 Frost Heave

Ice lensing is the process of forming and growing of ice lenses. When the temperature of the soil drops below the freezing point of water, ice is produced in the soil pores. Ice lenses nucleate immediately behind the freezing front (referred to as frozen fringe) and the free water from surrounding voids and the unfrozen region of the soil is drawn and contributes to the growth of ice lenses as show in Fig[2].

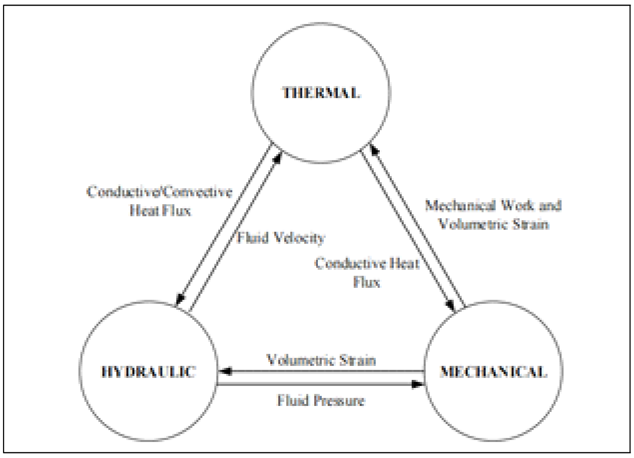


[Fig. 2] Illustration of freezing soil and ice lens (a) Frost heave specimen (Lay, 2005),
(b) Illustration of freezing soil

2.2 Numerical Modeling

2.2.1 Thermal-hydro-mechanical (THM) modeling

To simulate this phenomenon, we performed multi-physics modeling of frost heave using COMSOL. There are three basic algorithms for multi-physical modeling: one-way coupling, loose coupling, and full coupling (Minkoff et al., 2003[5]). We used thermal-fluid-mechanical (THM) multi-physics modeling. Thermal-hydro-mechanical (THM) modeling deals with multi-physical processes where temperature, hydraulic pressure, and mechanical deformation are simultaneously considered. The mechanisms in a coupled THM system are shown in Fig[3].



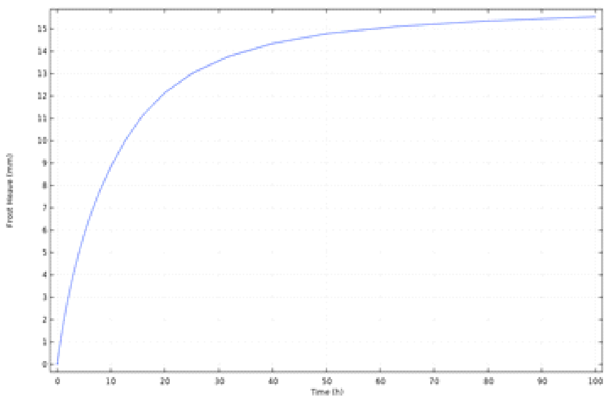
[Fig. 3] The interaction mechanisms in a coupled T-H-M flow system(Neaupane et al.1999)

Among modeling, the porosity rate function which coupled THM model is used as the control equation to describe the change of soil porosity so as to achieve the purpose of predicting the amount of frost heave. The form of porosity rate function as shown below:

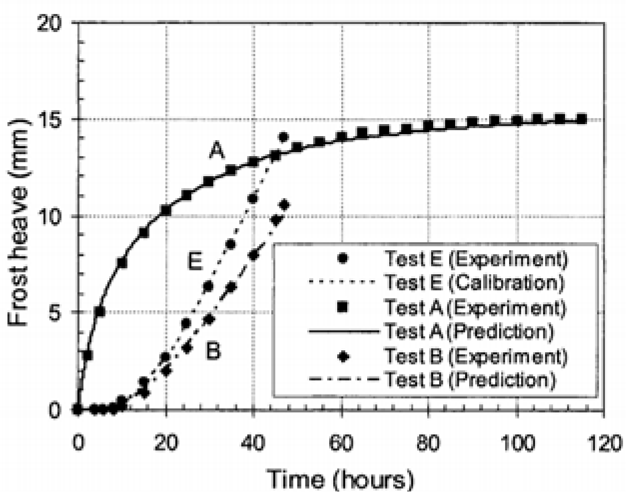
$$\dot{n} = \dot{n}_m \left(\frac{T-T_0}{T_m}\right)^2 \cdot e^{1-\left[\frac{T-T_0}{T_m}\right]^2} \cdot \frac{\left|\frac{\partial T}{\partial l}\right|}{g^T} \cdot e^{-\left(\frac{|\bar{\sigma}_{kk}|}{\zeta}\right)} \cdot e^{-\frac{\theta_i}{\theta_w}}$$

Where, T T_0, T_m represent the current temperature, freezing temperature and the temperature when porosity rate reach the maximum value,respectively. g^T stands for the temperature gradient at the point where $T = T_m$. The term $\frac{\left|\frac{\partial T}{\partial l}\right|}{g^T}$ represents the relationship between the rate of change of the gap ratio according to the temperature gradient in the direction of heat flow. In addition, The term $e^{-\left(\frac{|\bar{\sigma}_{kk}|}{\zeta}\right)}$ indicates the relationship of decreasing pore rate change rate according to the stress state of the soil. the last term in the expression $e^{-\frac{\theta_i}{\theta_w}}$ is a term that sets the void ratio from increasing to infinity. The comparison of frost heave amount prediction provided by Michalowski and Zhu with the result given by COMSOL are shown in Fig[4]:

(a)



(b)

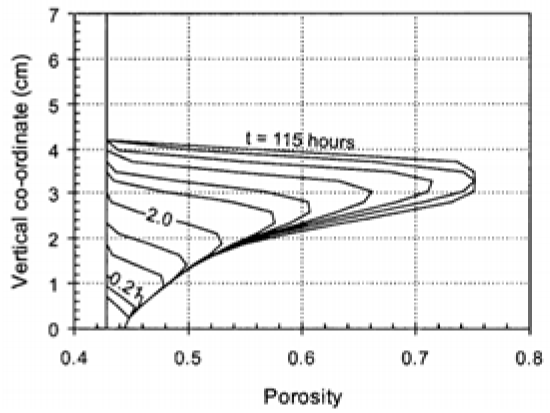


[Fig.4] (a) COMSOL simulation result (b)frost heave amount matching with experimental data Test A (Michalowski and Zhu, 2006)

3. Result

The model gives a good frost-heave growth curve on COMSOL, whereas, a porosity threshold of 0.75 was introduced, at which heave ceases. This was to indicate that frost heave stops or reduces to an insignificant rate after an intense growth at the stabilized freezing front (Fukuda et al., 1997).

The porosity rate function also reproduced the process successfully(Fig.5). but, theoretically, as long as the supply of unfrozen water is maintained in the saturated soil, the growth of the ice lens will continue until the porosity n = 1. The unfrozen water content affects the porosity convergence at the same time, thus, our next research focuses on trying to cancel the porosity threshold and try to introduce a new variable to solve this problem.



[Fig.5] Porosity at time=0,0.21,0.52,1,2,115 hours

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