A Model for the Formation of Ice Lenses in an Unconfined, Water-saturated, Porous Medium consisting of Spherical Particles

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ABSTRACT: A model for simulating the formation of ice lenses during freezing of unconfined uniform porous media is presented. The main notions of the model are that generation and jump are dependent on the freezing rate, and that growth is dependent on supercooling. The critical freezing rate is assumed to vary with changes in the number of particles near the ice lens due to the growth of the ice lens. The proposed model was computed for the unidirectional freezing of a porous medium consisting of 10 µm-diameter glass particles. The numerical results show that this model can represent the formation of intermittent layers of ice lenses in the porous medium. This model can be applied to ice formation in unconfined water-soaked porous media.

1 INTRODUCTION

When soil is frozen unidirectionally, the soil water sometimes forms regions of ice that are almost devoid of soil particles. These regions are called ice lenses, and repetition of the process results in the formation of intermittent layers of ice lenses (Figure 1a). The formation of ice lenses is recognized as a necessary condition for frost heave and is also reported to occur in other porous media (e.g. Dash et al., 1995; Mutou et al., 1998). This paper focuses on the process of ice formation in porous media consisting of fine particles.

Various models have been developed to describe frost heave (Kujala, 1997). Presently, the model most often used to describe the mechanism of frost heave is the secondary frost heave theory proposed by Miller (1972), since it can explain the formation of intermittent layers of ice lenses. The model emphasizes the importance of ice growing in the frozen fringe, which was assumed to consist of a network of pore ice extending from the base of the warmest ice lens to a position at or near the 0 °C isotherm. However, the configuration of ice in a porous medium depends greatly upon the conditions of freezing and the characteristics of the medium. Watanabe and Mizoguchi (2000) observed the formation of intermittent layers of ice lenses in an unconfined water-saturated uniform porous medium consisting of micro glass particles 9.7 µm in diameter. They found the ice in the medium does not penetrate the warmer pore than the growing ice lens.