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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称 博士（工学） 氏名 鄭 好

学 位 論 文 題 名

Study on a practical frost heave estimation with a combined thermal-hydraulic and mechanical simulation

(温度・流体および力学連成シミュレーションによる実用的な凍上評価法に関する研究)

For development of cold regions, frost heave related issues are critical challenges to engineers. The objective of this research is to build a numerical model of frost heave estimation in order to solve the engineering issues in cold areas. For those purposes, this model should achieve the following functions: thermal analysis, hydraulic analysis and mechanical analysis are supposed to be considered simultaneously in the model. Only with this comprehensive analysis, frost heave and its related issues could be discussed, evaluated and predicted properly, such as the frozen and thawing area estimation, the amount of frost heave and thermal erosion brought by water flow, frost heave stress, for example. Further, the author thought this model should be simple and practical enough. Parameters used in this model are easily available based on standard regulations in order to understand and apply the model conveniently and widely. Those ideas are the fundamental principles obeyed throughout this paper.

In the first chapter, the research background of frost heave is explained. As the population increases continually and the high energy consumption life style, the demand for energy would increase further. Under such situation, development of cold regions is an urgent task for more energy and space. Therefore, the frost heave related issues which are the most serious engineering obstacle in cold region development attract our attentions.

In the second chapter, the frost heave research history is reviewed and summarized. Various theories have been proposed in the research history in order to explain the mechanism of frost heave process. Those theories provides us a better understanding of frost heave, however there are still some obscure points that cannot be explained at the current stages. Several outstanding theories and famous large scale experiment are introduced in this chapter. Without a perfect theoretical method, we adopt a widely accepted and well-performed practical equation, Takashi's equation, to predict frost heave ratio.

In the third chapter, thermal analysis is explained in detail. The derivations of heat transfer equation with and without convection are provided. In this section, the latent heat caused by phase change, the freezing rate and direction are carefully discussed. Further the author also presents some basic skills of Finite Element Method and its related issues.

In the fourth chapter, the mechanical analysis is described from the governing equation. And also combine the frost heave ratio calculated by Takashi's equation into the mechanical evaluation. Further the popular method to deal with the nonlinear property of unfrozen soil is introduced and then we improve this idea. We adopt Duncan and Chang's equation to expresses the relationship between Young's modulus of unfrozen soil and differential stress. For frozen soil, the strength is dominated by temperature. However, for simplification, we assume a constant value for frozen soil.

In the fifth chapter, the hydraulic governing equation considering both saturated and unsaturated conditions is derived. Then empirical equations for specific capacity of soil and pressure dependent water content are introduced. Further we assume that the hydraulic conductivity for unfrozen soil is related to water pressure. In the case of frozen situation, we assume this value to be zero to represent the low hydraulic conductivity and we successfully evaluated the water flow due to thawing.

In the sixth chapter, first, simple one or two element examples are used to validate our numerical calculation results. The calculation results of heat transfer with latent heat, water flow and frost heave amount are confirmed. Based on this confirmed model, more complicated examples are discussed in order to discover influence of nonlinear property, the water flow influence to frost heave amount and temperature distribution. Finally, we examined those results according to our proposed model.

In the last two chapters (chapter 7 and 8), the preliminary study of a 3D frost heave experiment is introduced which is aiming to improve the existing Takashi's equation into 3D one. A temporary 3D frost heave equation is proposed. And in the concluding chapter, some useful findings are presented and this practical numerical model is demonstrated to be reliable and promising. At the same time, the author also points out the future research directions which can enrich and improve this practical frost heave estimation model.