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Numerical Simulation of Coupled Water and Salt Transfer in Soil and a Case Study of the Expansion of Subgrade composed by Saline Soil

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Abstract

Salt expansion is one of the major problems of subgrade involving saline soils. Salt expansion is induced by the crystallization of salt when the soil water content or temperature decreases. A case of salt expansion in subgrade composed by saline soil is introduced. It is located in G314 Road, which is one of the national highways in China, from Urumqi to Khunjerab. There is 3.40 ~5.91% salt within 1.0 depth in the ground surface of the G314 (K587 + 035), which belongs to strong sulphate salty soil. The maximum salt expansion is up to 20 cm in G314 Road, which has a serious impact on the road. Salt expansion is majorly controlled by the salt crystallization and the transmission of water and salt. Based on the solute transport theory in porous media, the water flow theory and thermal conduction theory, the govern differential equations of coupled salt crystallization, salt transmission and water flow are established in this paper. The coupled water and salt transfer problem of saline soil is solved by a software named as COMSOL with the use of a secondary development module. To verify the method for simulating the coupled water and salt transmission process, the water and salt transfer process in a 1D soil column is simulated and the results are compared with the theoretical solution. The results show that coupled model of water and salt established in this paper can accurately predict salt migration and crystallization of saline soil.

Keywords: Saline soil, Coupled water and salt transfer, Unsaturated soil, Salt expansion, Crystallization, Subgrade

1 Introduction

Most of salt expansion problems are related to the transmission and crystallization of salt. Salt expansion is a complex problem coupled by the crystallization of salt, the migration and redistribution of water and salt and includes the following mechanisms: (1) Salt crystallization is introduced when salt

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concentration is greater than the solubility of saline soil; (2) The migration and crystallization of water and salt comply with the law of conservation of mass; (3) Salt expansion is majorly controlled by the transmission and crystallization of salt (Chen et al., 1989).

Some coupled models of water and salt transmission have been proposed by domestic and foreign scholars. B.A. Ковда systematically summarized the movement of water and salt in terms of former Soviet Union, and a mathematical model of salt transport was established (Zhang, 2012). Other studies have been designed to investigate the interaction between salt and water movement (Warrick et al., 1971). Bear and Gilman introduced a theory to describe simultaneous heat, water, and solute transfer in unsaturated soil (Bear et al., 1995). Solute transport processes, molecular diffusion, mechanical dispersion and chemical reactions are included in the process of salt migration and crystallization. Numerical simulation of coupled water and salt transfer in saline soil was early proposed, and carried out by the finite difference method (Huang et al., 1993). Seepage diffusion migration is the main form of salt transmission, the change of temperature is a major factor in the migration of salt, while the crystallization process was not considered in those models. The migration and crystallization between water and salt comply with the law of conservation of mass. Function relationship exists between solubility and temperature (Xu et al., 1991), and crystallization is produced when salt concentration is greater than the solubility in saline soil, the content of sodium sulfate crystals were strictly mathematical calculations with this relationship (Zhao, 2012). Salt redistribution and crystallization has important practical significance to solve practical engineering problems salt damage. Therefore, it was needed to explore the characteristics between salt, temperature and water in saline soil.

Based on the solute transport theory in porous media, the water flow theory and thermal conduction theory, the differential equations of coupled salt crystallization, salt transmission and water flow are established in this paper. In order to verify the validity of the numerical simulation of coupled water and salt transfer in saline soil, the water and salt transfer process in a 1D soil column is simulated and the results are compared with the theoretical solution.

2 A Case Study of the Salt Expansion in Subgrade

A case study is carried out in G314 Road where the characteristics of the water and salt coupling migration and salt expansion in saline subgrade are analyzed. G314 Road is one of the national highways in China, from Urumqi to Khunjerab. There is 3.40 ~5.91% salt within 1.0 depth in the earth's surface of the G314 (K587 + 035), which belongs to strong sulphate saline soil (Kang, 2008). Salt expansion is the result of accumulation of salt migration, crystallization of salt and soils swelling. The maximum salt expansion is up to 20 cm in G314 Road and has caused serious impact on the road, such as bulge, wave, cracking etc. Temperature is an important factor affecting the salt expanding that made the pavement of highway uplift and produced longitudinal cracks. The temperature decreased from 33℃ to 20-25℃ from late June to late September. Due to the decrease of temperature, the solubility of sulphate reduced and the salt in water was saturated or supersaturated so that the crystallization is formed in the subgrade. Meanwhile, the average salt expansion reaches 17mm in G314 Road. Therefore, the study of the migration and crystallization of salt is an important step for understanding the salt heaving mechanism, which in turn can serve service in the design and disease control of saline soil engineering.

3 Mathematical Model of the Coupled Water and Salt

3.1 Salt Crystallization

Sodium sulphate saline soil is easy to crystallize in the evaporation and cooling conditions, which will cause the salt expansion problem. Sulfate sodium in soil pore water gradually saturated, and the

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