Cold Regions Science and Technology 148 (2018) 148–158

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Experimental and numerical investigation of the effect of soil type and fineness on soil frost heave behavior

Wei She[a,*], Xiaoyu Cao[a], Guotang Zhao[b], Degou Cai[b], Jinyang Jiang[a], Xiangyu Hu[a]

[a] *Jiangsu Key laboratory for Construction Materials, Southeast University, Nanjing 211189, PR China*
[b] *China Railway Corporation, Beijing 100844, PR China*

ARTICLE INFO

Keywords:
Soil type
Soil fineness
Frost heave
Finite volume method
Modeling

ABSTRACT

The type and fineness of soil are commonly recognized as the two major factors affecting the frost heave behavior of foundation. This paper aims to study the effect of soil type and fineness on frost heave behavior by experimental and numerical methods. Optical and scanning electron microscopes were employed to study the microstructure of kaolin and montmorillonite soils. A finite volume method, considering the changes of thermal and water fields simultaneously, was used to model the frost heave behavior of finely grained soil. By coupling the rigid ice model with the modified Kozeny–Carman equation and estimating the hydraulic conductivity, the relationship between the frost heave ratio and specific surface area of fines was established. Based on the modeling results, a region of proportion range of three typical soil (silty, clay and sandy soil) was proposed based on the ternary plot of frost heave values. Microscopic test results show that the multilayer microstructure of kaolin results in high content of bonded water compared with that of montmorillonite, leading to higher frost heave value. This model is proved to be reliable by a good agreement between the predicted and measured frost heave values.

1. Introduction

The high-speed railway in China is currently undergoing rapid development and has become the preferred mode of public transportation owing to its high operating speed, low energy consumption and low environmental pollution. After 10 years of rapid development, China is gradually forming the world's largest high-speed railway network, covering most parts of China, including northeast, northwest, and north China, where frozen soil areas are widely distributed. The frozen soil region in China is approximately 7.2 million km^2, 55% of which includes seasonal frost areas. The total area of frozen soil region accounts for 75% of China's land area, ranking third after Russia and Canada (Cai et al., 2015). The Chinese high-speed railway inevitably faces frost heave, which has a significant impact on track regularity. The frost heave of soil is a complicated physical phenomenon, mainly due to the discontinuity of ice lenses. Understanding water migration, heat transfer and mechanical action in freezing soil can be beneficial to railway construction in cold regions.

This phenomenon was noticed in the early 17th century; however, it was erroneously assumed that frost heave resulted from the bending deformation of soil. A consensus of water migration being the key factor of frost heave was not reached until the 20th century. In 1961, Everett (1961) proposed the capillary theory based on the second law of thermodynamics, which was later named the first frost heave theory. This was the first attempt to obtain a thermodynamic description; this updated our knowledge on frost heave being closely related to the expansion and migration of water during freezing. Capillary theory can fundamentally explain for the drying or freezing phenomenon attributed to surface tension effect (Liu et al., 2017; Liu et al., 2016; Li and Li, 2014). However, this theory could not give a complete and precise explanation of all observed phenomena, such as the formation of a discontinuous ice lens(Rempel, 2010; Liu et al., 2014a; Liu et al., 2014b). Additionally, it underestimated the frost-heave pressure in fine-grained soil. In 1972, Miller (1972) found that the newly formed ice lens was not always located in the place where the frozen fringe was, and thereby proposed the second frost heave theory which divided frozen area into three types (the frozen region at the top, the frozen fringe in the middle, and the unfrozen region at the bottom). The frozen fringe is the area where the ice lens forms, and it has an important effect on freezing process, which attracted the attention of specialists all over the world (Zhou and Li, 2012; Lai et al., 2014). In addition, other numerical simulation methods, such as back propagation neural networks (Zhang et al., 2010) and the lattice Boltzmann method'(Song et al., 2016) were also applied to predict the frost heave amount in the frozen

---

[*] Corresponding author.
E-mail address: weishe@seu.edu.cn (W. She).

https://doi.org/10.1016/j.coldregions.2018.01.015
Received 15 June 2017; Received in revised form 18 December 2017; Accepted 23 January 2018
0165-232X/ © 2018 Elsevier B.V. All rights reserved.

region. After hundreds of years of exploration and development, our understanding of the mechanism of frost heave has deepened; however, it is still limited in terms of test equipment and methodologies, and there are still some factors requiring intensive research.

Konrad and Lemieux (2005) found that segregation potential increases linearly on increasing the kaolinite fraction, which is consistent with the fact that the specific surface area increases with an increasing kaolinite fraction for a given fine soil content in experiments. According to Anderson and Tice (1972) the specific surface area determines the amount of water, which remains unfrozen at 0 °C in non-saline materials. Sheng et al. (2015) obtained an empirical formula to predict the frost heave of fine soil regarding the specific surface area of the soil and pore geometry, based on laboratory measurements of samples covering both coarse- and fine- grained soils. However, only the link with the specific surface area, and not the fundamental explanation, was given.

In this paper, the effect of soil type and fineness on frost heave behavior are studied experimentally and numerically, respectively. Frost heave tests of four different types of finely grained soil samples, with different fineness, were carried out. Microscopic methods, such as optical microscopy (OM) and scanning electron microscopy (SEM), were employed in the study of the microstructural morphology. In addition, the finite volume method, considering the thermal and water content fields, was developed to analyze the frost heave behavior of finely grained soil. A new approach coupled the rigid ice model with the modified Kozeny–Carman equation by estimating the hydraulic conductivity k, was utilized to study the relationship between the frost heave ratio and specific surface area. The differences in soil compositions were considered to better study the effect and predict the frost heave in different soil types.

2. Materials and tests

2.1. Materials

To study the effect of the type and fineness of finely grained soil on frost heave behavior, 12 samples were grouped under four different conditions. The type and fineness of the four conditions are given in Table 1. It can be seen that there are two kaolin samples with mesh fineness of 4000 and 1250, and two montmorillonite samples with different mesh fineness of 1250 and 200 used in this experiment. The optimum water content represents the water content of the soil, with maximum dry density, to ensure that all samples were under the maximum compaction degree(TB 10621 (2014) The optimum water content needed to be determined by test as 3.1.1, before preparing the samples for the frost heave test. The particle size distribution of the four samples is shown in Fig. 1.

2.2. Experimental setup

The frost heave test setup developed in our lab consisted of a sample cell, expanded polystyrene (EPS) insulation materials, dial indicator, and a temperature and humidity environment box (ESPEC SETH-Z), as shown in Fig. 2. The sample cell was a Φ 10 cm × h 10 cm cylinder made of a Perspex with a thickness of 8 mm. There were 2-mm-thick round organic glass pads placed on the top surface of the soil sample, for convenience of measurement (Run et al., 2013) The dial indicators, whose range was 30 mm, with an accuracy of 0.01 mm, were installed at the top of the sample cells and fixed on the iron stand to ensure accuracy of measurement. The insulation material was wrapped around the sample cell, except the top of the sample cell, with a thickness over 10 cm. This was done to minimize the heat exchange between the samples and external environment for approximating the unidirectional freezing conditions. The temperature of the environment box could be controlled by a computer within a 0.1 °C deviation.

Table 1
Type and fineness of different soil samples.

Soil type	Grain size/mesh	Optimum water content by mass/%
Kaolin 1	1250	35
Kaolin 2	4000	60
Montmorillonite1	1250	42
Montmorillonite 2	200	38

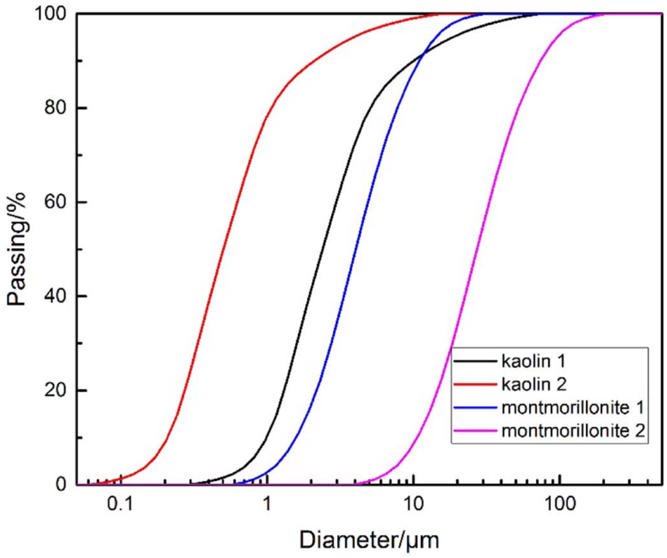

Fig. 1. Particle size distribution curve of soil samples.

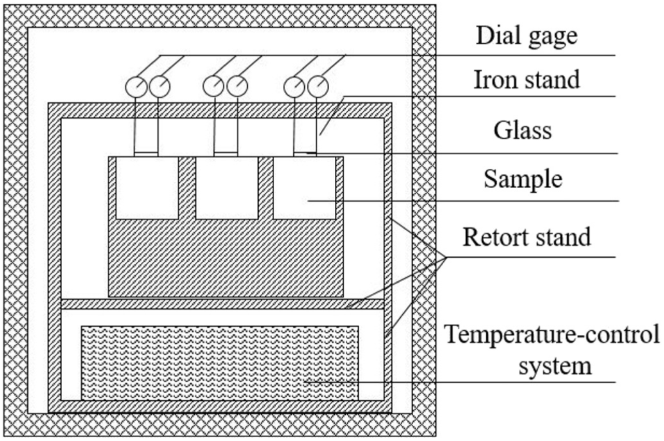

Fig. 2. The frost heave experiment apparatus.

2.3. Testing program

The testing program was designed to investigate the effects of soil type and fineness on frost heave behavior. All soil samples were required to be compacted equally in five layers and prepared with the optimum water content, listed in Table 1. After compaction, these samples were sealed using a plastic film to prevent water loss. Finally, before moving the samples into the environment box, all samples were kept for 24 h so that water could evenly be distributed throughout the sample.

The frost heave test consists of two steps: the constant temperature process and freezing process. During the constant temperature process, the temperature of the ESPEC SETH-Z was adjusted to 10 °C for 12 h to ensure that the internal temperature of the samples could reach 10 °C. Then, the freeing process started, during which the temperature of the ESPEC SETH-Z was set to −10 °C with a cooling rate of 1 °C/h. After the

Download English Version:

https://daneshyari.com/en/article/8906551

Download Persian Version:

https://daneshyari.com/article/8906551

Daneshyari.com