Physics and Chemistry of the Earth 121 (2021) 102955

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: http://www.elsevier.com/locate/pce

# Effect of freeze-thaw cycles on shear strength of unsaturated bentonite modified clay

Xin Jing, Master [a], Zizhi Cui, Professor [a,*], ShuIng Doh, Doctor [b], Li Ma, Master [a], Lu Wei, Master [a], Dong Liu, Master [a]

[a] College of Civil and Hydraulic Engineering, Ningxia University, Yinchuan, 750021, China
[b] Faculty of Civil Engineering Technology, University Malaysia Pahang, LebuhrayaTun Razak, 26300, GambangKuantan, Pahang, Malaysia

ARTICLE INFO

*Keywords:*
Freeze–thaw cycles
Bentonite
Cohesion
Internal friction angle

ABSTRACT

Freeze–thaw cycles is a seasonal process which occurs in many north regions of soils. Understanding the effects of freeze–thaw cycle on the physico-mechanical behaviours of soils is critical for construction stabilisation and reduce the freeze-thaw damage of foundation engineering. Over the years, studies has been conducted to investigate the effect of freeze-thaw cycles to the periodic strength characteristics of clay. Additive reinforced materials are used to reduce the damages which caused by freeze-thaw cycles and has made series significant contribution to foundation engineering. In this study, bentonite would be added as an additive to investigate the strength characteristics of unsaturated bentonite modified clay after different freeze–thaw cycles. Specimens of natural clay were mixed with different saturation, dry density and bentonite content. The results indicated that dry density, saturation and bentonite content give significant effect on shear strength of bentonite modified clay after freeze–thaw cycles. Meanwhile, the cohesion and internal friction angle of soils gradually attenuated with the increase of dry density, freeze–thaw cycles and saturation. It is found that during the freeze–thaw cycles, the reduction of internal friction angle and cohesion is most obvious at the first freeze-thaw cycle, and gradually stabilized after 7th freeze-thaw cycle. Moreover, results shown that the content of bentonite can effectively improve the cohesion, and maintain positive effects to the internal friction angle. Therefore, appropriate content of bentonite can effectively improve the freeze-thaw resistance of clay.

## 1. Introduction

Ningxia Hui Autonomous Region is located in the northern of China's Loess Plateau, which is the arid-semi-arid region of the northwest China. It is dry with little rainfall and extreme winter. The average annual minimum temperature is −28.4 °C, and the sub-zero temperature can last for about 107d (Dong et al., 2018), and the maximum freezing depth is 1.3m or more (Zheng et al., 2006). In Ningxia, previous studies have shown that the rises height of capillary water in clay was more than 2.0m (Xue, 2012). This serious frost-heave and freezing damage after freeze–thaw cycles often cause deformation of the roadbed, slip of the slope, crack and uplift of the lining (Zhao et al., 2015). Therefore, the study of freeze–thaw cycle damage on clay in Ningxia should be taken seriously.

From the microscopic point of view, the migration of capillary water is the main source of water supplement during the freeze-thaw process (Lu et al., 2017; Xu et al., 2016; Ghanbarian and Hunt, 2017; Watanabe and Osada, 2017; Bing et al., 2015). In the area of capillary water migration, only the part of clay which near the groundwater is saturated ($S_r$>85%). The middle and upper zone of clay are in an unsaturated state which are unsaturated soils. Therefore, as shown in Fig. 1, soil freeze-thaw zone can be divided into three parts. Since there is little rain during winter in Ningxia, only groundwater is considered as the source of water supply. In zone-I, it is unsaturated clay, which is far from the groundwater level, and there is no groundwater recharge during the freeze-thaw cycles, so it is a non-water supplement freeze-thaw region. In zone-III, it is saturated clay that recharged by groundwater during freeze-thaw process, and which is a freeze-thaw problem of saturated soil. Unsaturated soil, especially in zone-II, which has a larger frost-heave property and a higher proportion in the freeze-thaw zone. The freeze-thaw deformation in zone-II is the main component of foundation freeze-thaw deformation, and it is the significant part to

* Corresponding author.
*E-mail addresses:* 11386312152@qq.com (X. Jing), czz2062428@qq.com (Z. Cui), dohsi@ump.edu.my (S. Doh), 1980232560@qq.com (L. Ma), 317997687@qq.com (L. Wei), 980532752@qq.com (D. Liu).

https://doi.org/10.1016/j.pce.2020.102955
Received 31 December 2019; Received in revised form 25 October 2020; Accepted 10 November 2020
Available online 17 November 2020