RESEARCH PAPER

FREEZE-THAW BEHAVIOR OF GYPSEOUS SOIL

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ABSTRACT:
This research work studied the influence of freeze-thaw (F-T) cycles and gypsum percent on the mechanical properties and durability of clayey soil. Different amount of gypsum percent (varied between 0-25%) was added to the clayey soil and subjected to 12 F-T cycles. The unconfined compressive strength UCS, P-wave velocity, gas permeability, pore size distribution and volume changes properties were measured for both un-cycled and F-T cycled samples. The tests results presented that the UCS, gas permeability and porosity values of samples influenced by F-T cycles. These values depend considerably on the amounts of gypsum percent and F-T cycles. Further, changes in soil porosity were observed during F-T cycles due to ice lenses formation and cracks propagation. Finally, the UCS, gas permeability and volume change values have been proposed to be used to evaluate extent of durability of soil samples.

KEYWORDS: Gypseous soil; freeze-thaw; UCS, mercury porosity; gas permeability.
DOI: http://dx.doi.org/10.21271/ZJPAS.31.s3.58
ZJPAS (2019) 31(s3):405-409

1. INTRODUCTION

In cold regions, F-T cycles influence the stability and performance of the engineering structures, especially infrastructures. F-T cycles are considered to be difficult challenges to the geotechnical engineers that causes damages to earthwork structures. In freezing state, the ice lenses form in the pores of soils and the water expands by about 9% causing cracking in the soils and reduce the shear strength (Formanek et al. 1984; Yarbasi et al. 2007).

Further, ice lenses strongly combined the soil particles together and keeping the soil well resistant to applied loads. Several investigators illustrated the destructive actions of F-T cycles on the geotechnical behavior of soils (Kamei et al. 2012; Aldaood et al. 2014 and 2016). Czurda and Ludwig (1991) reported that, the permeability of clay barriers increase with F-T cycles. Simonsen et al. (2002) presented that, the resilient modulus of five different types of soil (ranged between clay to sand) decreased after one of F-T cycles. Bing et al. (2007) studied the effect of the sodium sulfate salt on the deformation properties of red clay. They reported that, the deformation of the soil samples occur due two processes: (i) ice formation, (ii) salt crystallization. Wang et al. (2007) documented that, the geotechnical properties of clayey soil decreased with increasing
F-T cycles. Also, they suggested that, the designed soil strength should be taken after seven F-T cycles. Generally, gypseous soils are used as foundation layer along the many parts of the world (Al-Obaydi et al. 2010). Furthermore, the F-T durability of these soils is vital to assist their using in earthwork structures due to the varying their properties from site to the other depending on the gypsum percent and soil compounds (Aldaood et al. 2014). Therefore, this research program studied the effect of F-T cycles, on the UCS, P-wave velocity, gas permeability and porosity properties of clayey soil having different amount of gypsum.

2. METHODOLOGY

2.1 Materials

Clayey soil collected from the Jossigny region, Paris, France was used in this study. The Atterberg limits were (29% and 21%) for liquid and plastic limits respectively and the specific gravity was 2.66. The clay, silt and sand percentages were 19%, 64% and 17% respectively. Based on the Unified Soil Classification System (USCS), the soil was classified as sandy lean clay (CL). A very fine gypsum (finer 80 μm); supplied by the Merck KGaA company; Germany; was used in this study with 99% purity.

2.2 Methods of Testing

The same laboratory protocols of sample preparation and the all experimental tests used in the published paper (Aldaood et al. 2016) were used in this second paper. However, the natural and gypseous soil samples prepared for the experimental tests were exposed to both open and closed systems of F-T. In closed system the samples were covered by plastic bags to prevent water exchange with the freezer chamber.

3. RESULTS AND DISCUSSION

3.1 Evaluation of UCS and P-Wave Velocity

Data collected during F-T cycles represented the results of closed F-T system only. The results of soil samples that subjected to open F-T system were not measured, since these samples failed during the first hours of placing on the saturated felt pad, and before the commencement of the first F-T cycle, as presented in Fig.1. Water suction causes high collapsing levels at the bottom of the soil samples and the soil samples with 25% gypsum percent failed more quickly than others samples.

Fig.2 illustrates the variations in the UCS of soil samples with F-T cycles for various gypsum percents. It is observed that, the UCS of soil samples that tested in freezing state increased to a maximum value and then decreased for all gypsum percents. Further, increasing gypsum percent resulted in higher values for the UCS. This behavior related to the reduction in the void ratios of soil samples due to gypsum additions. Moreover, increasing the contact area between soil and/or soil-gypsum particles lead to higher UCS. The UCS of soil samples that tested in thawing state were decreased slightly with increasing freezing-thawing cycles. These values were lower than those values obtained in freezing state. The reason for the reduction in UCS is that, the soil samples before freezing possesses a dense and light packing. During freezing, ice lenses were produced causing a dispersion of soil packing and segregation of soil particle from each other. In thawing period, soil particles dispersion is retained leading to more void ratios. Moreover, ice formation inside the pores lead to micro cracks propagation in soil samples as presented in Fig.3, and causing volume expansion. Fig. 4 illustrates the changes in the volume of soil samples with F-T cycles. The volume increased with F-T cycles and more volume increasing were obtained for samples having 25% gypsum percent. This is due to that lower void ratios among soil particles associated with increasing gypsum percent, thus there was no available space accommodated to the ice lenses. The increasing in volume occurred due to that, water during freezing expands and causes 9% increasing in volume. Moreover, salt (i.e. gypsum) crystallization lead to the increasing of soil volume (Bing et al. 2007). Sequentially, the values of P-wave velocity followed the same trend of the UCS during F-T cycles, as presented in Fig.5. In thawing state, there was a slight reduction in P-wave velocity values with increasing the F-Tcycles. While, in freezing state the P-wave values increased to a maximum and then decreased for various gypsum percents. Note that gypsum percent showed insignificant effect on P-wave velocity values during F-T cycles.

3.2 Evaluation of Gas Permeability
The gas permeability of the soil samples decreased with gypsum percents. These values were \((2.2\times10^{-13}, 1.05\times10^{-13}, 3.05\times10^{-14}\text{ and } 1.1\times10^{-14}\text{ m}^2)\) for the samples having 0, 5, 15 and 25% gypsum percent, respectively. This behavior due to that, gypsum acts as filler materials among the coarser particles of the soil. Thus the voids ratio are reduced and the gas permeability decreases. The effects of F-T cycles on the gas permeability of soil samples have been illustrated in Fig.6. It is observed that, the gas permeability values of soil samples increased linearly with F-T cycles. The slopes of the lines are not similar for all the soil samples. The slopes of the lines were not very steep and become flatten with increasing gypsum percent. This indicated that, there was no significant damage in soil samples during F-T tests. However, the effects of F-T cycles on the gas permeability values vary and depending on the amount of gypsum in the soil samples. The gypsum percent reduces the effects of F-T cycles on the gas permeability values. This behaviour might be due to the role of gypsum addition in decreasing the soil voids, as mentioned above. The increasing in gas permeability values could be attributed to the changes in the soil structures and cracks propagation.

3.3 Evaluation of Pore Size Distribution (PSD)

Fig.7 present the variations in the PSD of soil samples with F-T cycles. Gypsum addition changed the PSD of natural soil samples form tri-modal to the bi-modal, and there was a decreasing in the amount of macropores with diameter more than 10 μm. While there is no significant changes in the micropores with a diameter less than 0.1μm. This means that, the PSD of natural soil changed from coarser structure to the finer one. This behavior related to the finer grain size of gypsum particles as compared to soil particles which act as filler materials as reported in section (3.1). The F-T cycles affected the PSD of soil samples and this effect was concentrated in macro pores \((\geq 1\mu m)\), while the micro pores \((< 0.1\mu m)\) did not change significantly, as illustrated in Fig.. Also, this figure consisted of bi-modal PSD curves with two classes of macro and micro pores. This type of modal is usually observed on compacted clayey soils. For higher gypsum percent, the PSD of soil samples practically changed from bimodal to uni-modal during F-T cycles and all the changes in pores diameter occurred for the macro pores with a diameter more than 10 μm. The variations of the PSD during F-T cycles are due to the growth ice lenses and cracks propagation which reflect the mechanical and gas permeability properties.

4. CONCLUSIONS

The following conclusions can be deduced:

1. Soil durability against F-T cycles depends on the gypsum percent, which was the main reason for the control the durability of gypseous soil.
2. The changes in soil structure after F-T cycles obtains, increased gas permeability and there is a dependence of gas permeability on the gypsum percent
3. Gas permeability values and volume changes were depend on gypsum addition and have been proposed to be used to evaluate the soil durability.
4. The measurements of variation of soil structure and mechanical properties can give an insight to the processes in action during F-T deterioration.

Figure 1. Soil samples failure in open freeze-thaw system
Figure 2. Unconfined compressive strength of soil samples with freeze-thaw cycles

Figure 3. Cracks propagation at the end of freeze-thaw cycles

Figure 4. Volume changes of soil samples with freeze-thaw cycles

Figure 5. P-wave velocity of soil samples with freeze-thaw cycles

Figure 6. Gas permeability of soil samples with freeze-thaw cycles
Figure 7. Pore size distribution of the soil samples

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