EFFECT OF FREEZE-THAW CYCLES ON VOLUME CHANGE AND MICROSTRUCTURE FEATURES OF BARCELONA SOIL

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A variety of factors such as stress acting, thermal cycle, moisture change histories, influence the amount and distribution of ice in frozen ground. The aim of the paper is to study the behavior of the Barcelona soil subject to freezing and thawing cycle at constant vertical stress under oedometric condition. In this work the behavior of Barcelona soil has been investigated using oedometers apparatuses working under temperature and suction controlled modified for temperature below zero degrees. The stress path followed by samples reproduce the in situ vertical stress interested by freezing and thawing.

Key Word *: freeze-thaw cycle, mercury intrusion porosimetry, pore size distribution*

1. INTRODUCTION

Frost action in soils involves the weathering processes caused by cycles of freezing and thawing. Frost heaving and thaw settlement are commonly seen in seasonally frozen soils, which could damage infrastructures. Furthermore, the global warming would change the active layer of permafrost (the upper crust layer where active freezing-thawing cycles occur), which leads to extensive settlement of the ground surface. Therefore, it is very important to understand soil behaviors during the freezing and thawing cycles. In this paper, the total volume change behaviors of Barcelona soil were firstly investigated through temperature-controlled oedometer tests. The applied vertical stress steps are 50, 70, 100 and 140 kPa. The thermal variance is from room temperature (20 ◦C) to -20 ◦C by certain target steps and then returns to room temperature again. Furthermore, to explore the microstructure features of Barcelona soil, the samples after oedometer tests are freeze-dried and used to conduct MIP tests. MIP results can provide valid estimates of pore size distribution of soils after different stress and thermal paths.

2. METHOD AND MATERIAL

(1) Temperature-controlled oedometer test

The experimental setup is composed by a thermal bath in which the refrigerating fluid circulates at controlled temperatures ranging between +30ºC and -30ºC. The refrigerating medium is a mixed fluid composed by 50/50 proportions of water and ethylene glycol. The water drainage is allowed through the bottom and connected to the reservoir. The vertical stress is applied through compressed air at the top of the sample regulated by steps. The air used to apply vertical stress on the top of sample has been desiccated through a salt mixture located in a chamber. A data acquisition system was used to record signals in millivolts from thermocouples and LVDTs onto the oedometer cells. Then a data processing system converted those signals to temperatures (ºC) and displacements (mm). The thermal bath has been isolated during the laboratory environment through a cap to avoid temperature fluctuations. The top cap of the oedometer has been replaced by a proper hard plastic cap because during the freezing process the metallic connection would be frozen. Such kind of frozen brine around the connection to the LVDT point measurement affects the measurement of the vertical displacement. To avoid this phenomena, the top cap was changed to plastic ones. Two thermocouples have been inserted in the apparatus just in contact with samples to check the temperature on the soil.

a) Material

Undisturbed core samples have been used at UPC Geotechnical Laboratory. The basic properties of Barcelona soil have been obtained and summarized in **Table 1.** The particle size distributions of Barcelona soil by sieve analysis (ASTM D22-63) is shown in **Figure 1**. The percentage of soil particles with d> 0.45mm is 50% for the material.

Table 1. Initial (natural) conditions of material

Properties	
Solid density, (Mg/m^3)	2.65
Dry density, (Mg/m^3)	1.36
Bulk density, (Mg/m^3)	1.50
Void ratio	0.96
Porosity	0.49
Water content, (%)	10.19
Degree of saturation, (%)	27.70

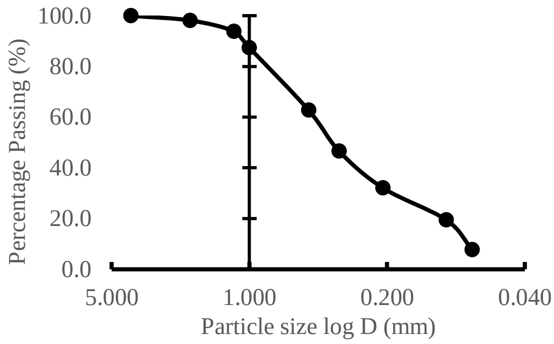

Figure 1. Particle size distribution

b) Test program

The sample has been trimmed and placed into the cell ring (50 mm in diameter and 20 mm high). It is loaded in four steps defined as follows:

1) Saturation stage with a back pressure p_w=10 kPa at the bottom of the sample. This phase lasted mostly 6 hours.
2) Compression phase up to the target vertical stress by steps. Each step lasted 24 hours. The maximum total vertical stress was140 kPa.
3) Temperature cycle: freezing and thawing. The temperature cycle from +20ºC to -20ºC has been applied by step at constant vertical stress. Each step lasted 6 hours. The samples have been maintained at the minimum temperature of -20ºC for 24 hours. The displacement has been monitored during this period to check the creep behavior of the frozen samples.

4) Unloading phase at temperature of 20ºC by step to zero vertical stress, sample dismantling.

(2) Mercury Intrusion Porosimetry (MIP) test

Mercury intrusion porosimetry (MIP) in the geotechnical field allows for a good estimate of the size distribution of the pores that are interconnected within a material. This is done by applying an absolute pressure while a sample is immersed in mercury. The applied absolute pressure causes the mercury to fill the pores, the larger ones first and then the smaller ones. The basic principle of the MIP technique is based on the Washburn equation (Equation 1) in which an absolute pressure p_{Hg} is applied to a non-wetting liquid (mercury) to force it to enter the empty pores. The equation, which applies to pores of cylindrical shape and parallel infinite plates (Webb, 2001), is where σ_{Hg} is the surface tension of mercury (σ_{Hg} = 0.484 N/m at 25 ◦C), θ_{Hg} is the contact angle between the mercury and the pore wall and x is either the entrance or throat pore diameter (n = 4) or the entrance width between parallel plates (n = 2). The value n = 4 is often used in MIP. The contact angle, which is very sensitive to surface roughness, is usually between 139◦ and 147◦ for clay minerals.

$$p_{Hg} = -\frac{n\sigma Hg\ cos\theta Hg}{x} \quad (1)$$

3. EXPERIMENTAL RESULTS

(1) Temperature controlled oedometer test

The experimental results of the oedometer test are presented in this section: oedometer test for Barcelona soil with σ_v= 50, 70, 100 and 140 kPa.

The experimental results for Barcelona soil are illustrated in **Figure 2 (a)-(d)**. The freezing-thawing cycle shows an accumulated plastic deformation

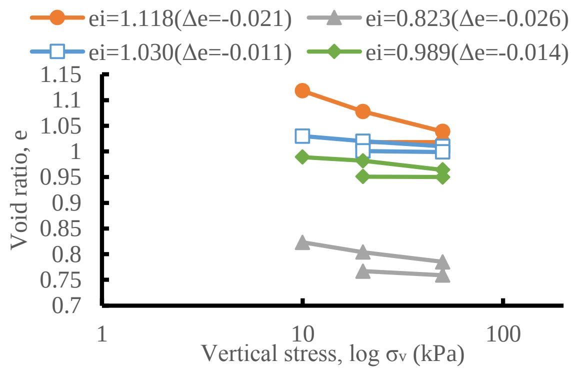

Figure 2(a). Oedometer tests in the logσv-e plane: σvmax=50 kPa

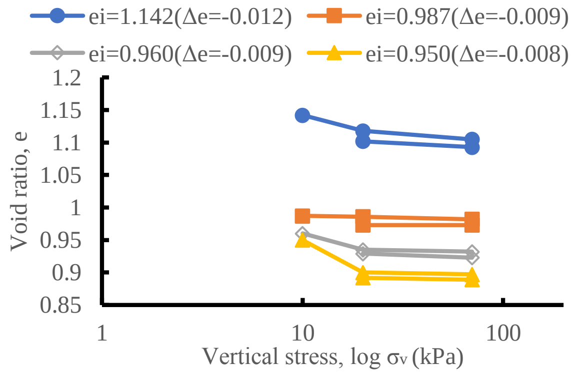

Figure 2(b). Oedometer tests in the logσv-e plane: σvmax=70 kPa

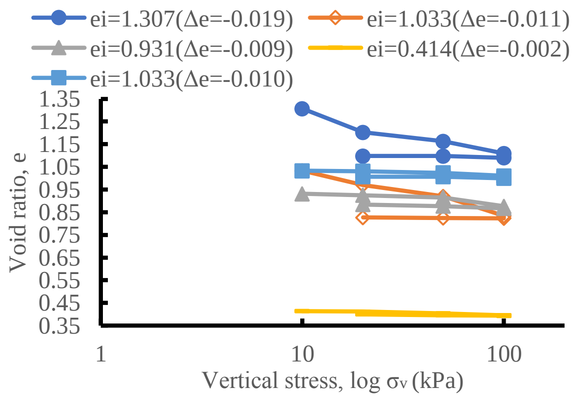

Figure 2(c). Oedometer tests in the logσv-e plane: σvmax=100 kPa

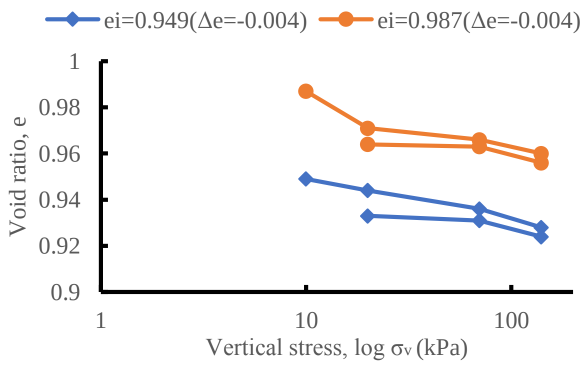

Figure 2(d). Oedometer tests in the logσv-e plane: σvmax=140 kPa

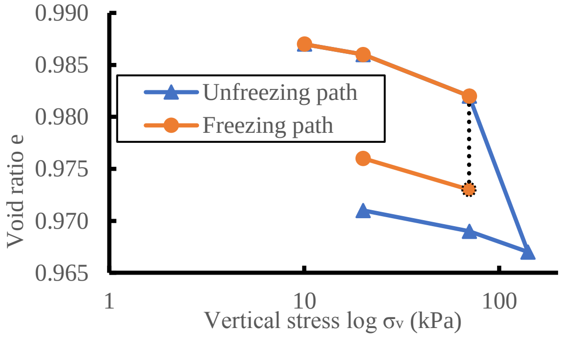

Figure 3.Comparision of two tests on Barcelona soil samples with a different temperature cycle

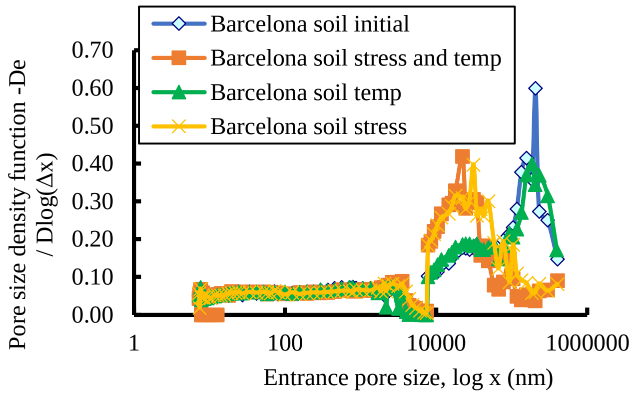

Figure 4, Pore size distribution curves from MIP

Δe (T)=~-0.026 for the sample with $\sigma_v$max=50 kPa, Δe (T)=~-0.012 for the sample with $\sigma_v$max=70 kPa, Δe (T)=~-0.019 for the sample with $\sigma_v$max=100 kPa and Δe (T)=~-0.004 for the sample with $\sigma_v$max=140 kPa.

In the unloading step, the point follows a line in the e-logsv plane with an inclination Cs=0.001~0.005 for $\sigma_v$max= 50 kPa, Cs=0.001~0.005 for $\sigma_v$max= 70 kPa, Cs = 0.002~0.004 for $\sigma_v$max= 100 kPa and Cs= 0.003~0.004 for $\sigma_v$max= 50 kPa. Cs is approximately zero and elastic deformation disappear after freezing and thawing process.

Figure 3 describes the comparision of two tests on Barcelona soil samples with a different temperature cycle. During the vertical stress loading stage, similar behavior can be observed for all samples in the stress range from 0 to 140 kPa. The small deviation of two curves is probably due to the initial inhomogeneity of prepared specimens.

(2) Mercury Intrusion Porosimetry (MIP) test

Figure 4 describes the pore size distribution functions for four samples regarding the intruded volume of mercury referred to the volume of solids for different entrance pore sizes x. The peak density of pore sizes for Initial condition is at around 250000 nm, Temperature condition is at around 200000 nm, Stress condition is at around 32000 nm and Stress and Temperature is at around 20000 nm. The reason why the freezing and thawing process enlarges the soil pore sizes is due to the density difference between water and ice, which the volume of ice is 1.09 times of that of water. Freezing usually occurs under water undrained conditions. Meanwhile, it is very interesting to find that the micropores less than 3000 nm are not affected by the stress and temperature paths.

4. DISCUSSION

When comparing the oedometer test results of Barcelona soil at different initial conditions, different loading stresses, it is interesting to find the initial void ratios of prepared samples do not affect the final freezing-thawing settlement. It is important to say that the stress load and unload and temperature freeze and thaw path could decrease the average area and perimeter of pores that means the soil would be compressed.

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