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THE EFFECT OF FREEZE-THAW CYCLES ON THE GEOTECHNICAL PROPERTIES OF CLAYEY SOIL TREATED WITH LIME

NIHAD BAHAALDEEN SALIH[1] and TAVGA ARAM ABDALLA
College of Engineering, University of Sulaimani, Kurdistan Region-Iraq

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ABSTRACT

Fine-grained soils (cohesive soils) exposed to freezing-thawing cycles exhibit to notable alterations on their physical and mechanical characteristics. The environmental conditions' influences on soil geotechnical properties are significant, especially when stabilized by hydrated lime. This study was carried out to explore the effect of freeze-thaw cycles on cohesive soil stabilized by various hydrated lime percentages (zero%, 5%, 10%, and 15%) by dry mass, which cured for 28 days at 30°C. One-dimensional consolidations, unconfined strength, and shear box tests were performed for untreated and treated soil samples subjected to 0, 1, 2, and 3 freeze-thaw cycles. Duplication of freeze-thaw cycles significantly impacts some geotechnical properties and decreases them such as LL, UCS, Cc, Cr, and C. The PL and ϕ values of the samples treated by hydrated lime and subjected to freeze-thaw cycles observed to be increased, which were due to the important role of hydrated lime addition. It is concluded that the hydrated lime can be effectively utilized to minimize the impacts of freeze-thaw periods on shear strength and compressibility of cohesive soil.

Keywords: Cohesive soils, Hydrated Lime, Freeze–Thaw cycles, Durability

1. INTRODUCTION

In cool districts, the frost motion and the associated frost heave is seriously impacting on fine-grain soils properties. This type of heave is due to the volume change of water, in the soil pores, during the freezing process. Generally, when the water is fully frozen its volume among the soil particles is increased by 9% and hence leads to heave and thus cracks occurrence (Xian et al., 2019). These changes impact many construction projects for instance highways, railways, pipeline, and structures construction. In addition, in cold regions also, soils mechanical characteristics significantly influenced due to frost lenses formed among soil grains throughout freeze in addition to water surplus through the melting period (Konrad, 1989). Freezing-thawing process affect soils strength, permeability and compressibility (Esna-Ashari and Jafari, 2012; Wang et. al., 2009; Li et al., 2012).

In some studies, soil consistency can be changed because of the freezing and thawing process (Yong et al., 1985; Viklander & Eigenbrod, 2000). While in other studies soil consistency was not changed significantly due to the freezing and thawing process (Yong et al., 1985; Eigenbrod, 1996). Hence, freeze-thaw cycles can alter some geotechnical properties (strength, permeability, and compressibility) severely (Hohmann-Porebska, 2002; Qi et al., 2006). Researchers were more emphasis on shear strength properties than soil modulus of elasticity. Soil modulus results were affected by freeze-thaw cycles, which showed firstly a decrease, then an increase with freeze-thaw cycles (Wang et al., 2007; Liu et al., 2016). Coefficient of consolidation (C_v) considered in few researches, C_v values reported in the literature of fine grained soils from permafrost regions were summarized in the study of Paudel and Wang (2009) and showed that the coefficient of consolidation was increased after freezing and thawing cycles.

Stabilized soils might behave in different ways during freeze-thaw cycles. The addition of lime to the clayey soil was improved its mechanical characteristics (Al-Kiki et al., 2011); however, the untreated soil was not capable to afford the effects of the environmental cases. In addition, comparable behaviors were reported in the study of Aldaood et al. (2014). The further stresses produced by seasonal temperature

nihad.salih@univsul.edu.iq; tavga.abdalla@univsul.edu.iq
[1] Corresponding author: College of Engineering, University of Sulaimani, Kurdistan Region, Iraq

changes also found to be resisted by the stabilized soil, especially during freeze-thaw cycles (Guney et al., 2006). Using of lime found to be useful, which discovered to be affecting on the engineering characteristics of soils. The role of lime in improving of the soil engineering characteristics such as strength and durability was mentioned in the studies of Bell (1993), Al-Rawas et al. (2005), and Guney et al. (2007). Moreover, limited studies have been conducted to study the durability of treated clay soil subjected to Freeze-Thaw cycles (Al-Mukhtar et al., 2012; Locat et al., 1996).

Other stabilization resources, fly ash, furthermore studied in the same regard. It was found that the F-Th cycles to be insignificant to improve plasticity property of treated soils by fly ash (Bin-Shafique et al., 2010). These impacts can substantially decrease the bearing capacity of foundation materials and their shearing resistance (Aldaood et al., 2014; Kamei et al., 2012; Wang et al., 2007). The main aim of current research is to examine the influence of hydrated lime content on the physical and mechanical behaviors of a cohesive soil exposed to three F–Th cycles.

2. MATERIAL AND MAETHODOLOGY

2.1 Materials

Barika soil selected in the current research, which is located in Sulaimani city, Kurdistan Region of Iraq has Latitude 35°33′40″ N and Longitude of 45°26′14″. The sample collected from 1.0 m to 2.0 m underneath the earth's surface. It is a light brown color, and it can be categorized as CL soil considering the Unified Soil Classification System (USCS) (Rashed et al., 2017; Salih, 2020). The grain size distribution curve of the soil sample and its engineering properties are shown in Fig. 1 and Table 1 respectively. For the purpose of soil treatment, locally-available manufactured hydrated lime was selected. Table 2 shows several physical properties and chemical composition of the used hydrated lime, which is a commercially available and typically use for construction purposes. The selected hydrated lime percentages for treating the cohesive soil of the current study are 0%, 5%, 10% and 15%. These percentages are taken with respect to the dry mass of the soil. Geotechnical laboratory experiments were conducted according to ASTM standards as follows: ASTM D4318 (2000) as utilized to obtain the soils Atterberg limits ASTM D4318 (2000), the soils specific gravity (G_s) was carried out according to ASTM D854 (2000).

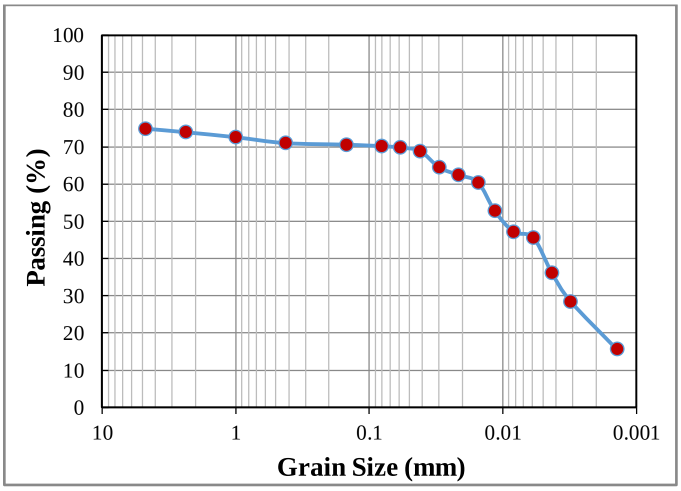

Fig. (1): Particle size chart for the investigated Barika Soil.

nihad.salih@univsul.edu.iq; tavga.abdalla@univsul.edu.iq
[1] Corresponding author: College of Engineering, University of Sulaimani, Kurdistan Region, Iraq

Table (1): Basic physical parameters for the tested soil (Barika soil).

Property	Value
Natural moisture content (%)	18.7
Color	Light Brown
LL (%)	44.6
LP (%)	19.5
PI (%)	25.2
Specify gravity	2.67
MDD (g/cm^3)	1.57
OMC (%)	27.25
Silt + Clay (%)	70
Uniaxial compressive strength (KPa)	174.2

Table (2): Physical and chemical compositions of used hydrated lime.

Chemical Name	Chemical Composition (%)
CaO	56.1
MgO	0.13
Fe2O3	0.12
Al2O3	0.72
SiO2	1.38
SO3	0.21
L.O.I	40.6
	Physical Properties
% passing sieve No.200 (0.075)	98
Surface Area (m^2/kg)	398
Specific gravity	2.78

2.2 The Study Methodology

In the current study, natural and treated cohesive soil specimens were tested to obtain some of the soil's geotechnical properties. Hydrated-lime was used to treat the natural soil specimens and cured for 28 days. At the end of 28 days curing, the treated specimens were exposed to three F-Th cycles, based on the procedures suggested by ASTM D560. For the freezing cycles, prepared soil specimens are subjected to -6 °C for 24 hours in a freezing apparatus. Then, the frozen specimens permitted to thaw at 30 °C, which lasted in a container with 100% relative humidity for 24 hours. In order to obtain a successful penetration for weakening frost and thaw, -6 °C and 30°C for F-T cycles were considered, which represent hydrated lime temperature. In the end of each of F-Th cycles, both of mass and water content for specimens were calculated.

Regarding the selected geotechnical properties to be checked, LL and PL tests were carried out for all specimens exposed to three F-Th cycles. The unconfined compressive strength (UCS) was determined for the specimens that exposed to F-Th cycles according to ASTM standard (D-2166). The cylinder mold and used equipment for preparation of the remolded sample are shown in Fig. 2. After the conduction of the required F-Th cycles (0, 1, 2, and 3 cycles), soil specimens are used to perform the unconfined compression test at 0.5 mm/min strain rate to gain the specimens' UCS.

Also, one dimensional consolidation experiments were performed for the stabilized samples with hydrated lime under 3 F-Th cycles according to ASTM D 2435- 11. Conventional one-dimensional consolidation test using oedometer device were used to measure soil specimens' compressibility, the used ring size is 50 mm in diameter and a thickness of 20 mm. The specimen-ring assembly was sealed in a nylon bag to minimize wetness wastage. After the specimen placed in the odometer cell, loading stage started with an applied pressure of 25 and end at an 800 kN/m^2, each stage was lasted for 24 hours. Then, the unloading stage was carried out; the load is decreased in stages of 800 kN/m^2-25 kN/m^2 in sequencing also applied within durations of 24 hours for each stage of unloading.

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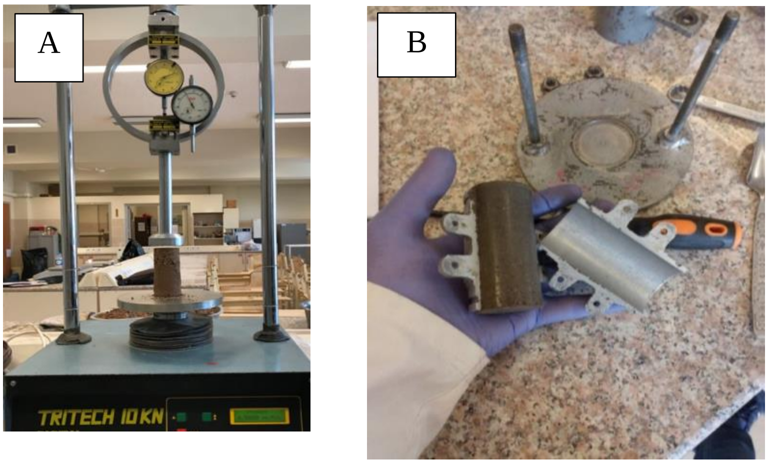

Fig. (2)**:**: A. Unconfined compressive strength device, B. Cylindrical mold for remolded soil specimens.

Moreover, direct shear experiment was performed for the soil specimens with the various percentages of hydrated lime under 3 F-Th cycles. Direct shear is a popular test for soils strength determination, which used for determination of the value of internal friction angle and the specimen cohesion (Head and Epps, 2011). Traditional shear box equipment was used, exposing the specimens to 27.78 kPa, 55.6 kPa and 83.33 kPa normal stresses by a sequence. The rate of displacement was selected to be 1.0 mm/min for each normal stress.

3. RESULTS AND DISCUSSION

All the obtained results of the tested soil specimens in the natural state or the treated state by hydrated lime are compared with other available similar studies in this section. The treated specimens were left for 28 days for curing purpose. This section includes the influences of F-Th periods on the obtained variations in consistency limits (LL, PL and PI), stress-strain behaviors (UCS), compressibility parameters (C_c, C_r and C_v), and shear components (C and ϕ).

3.1 Impact of F-Th cycles on the consistency limits of the soil

The effect of F-Th cycles on the variation of plastic limit, liquid limit and plasticity index for untreated and treated specimens with hydrated lime is presented in Fig.3a and 3c. The presented results in the figure show that with the hydrated lime percent increase for 0, 1, 2, and 3 F-Th cycles, LL & PI decreased by a small value, but with the 3rd F-Th cycle, there is a rapid increase in LL and PI values. For PL (Fig. 3b), a little change has been observed for the soil specimen subjected to all 3 F-Th cycles. While for the soil specimen stabilized by 10% hydrated lime, a rapid reduction in the value of PL for all 3 F-T cycles was noticed. The F-Th cycles impact on the consistency limits is noticed to be little. This result agrees with the results of some studies such as Yong et al. (1985), Eigenbrod (1996), and Zhang et al. (2019).

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[1] Corresponding author: College of Engineering, University of Sulaimani, Kurdistan Region, Iraq

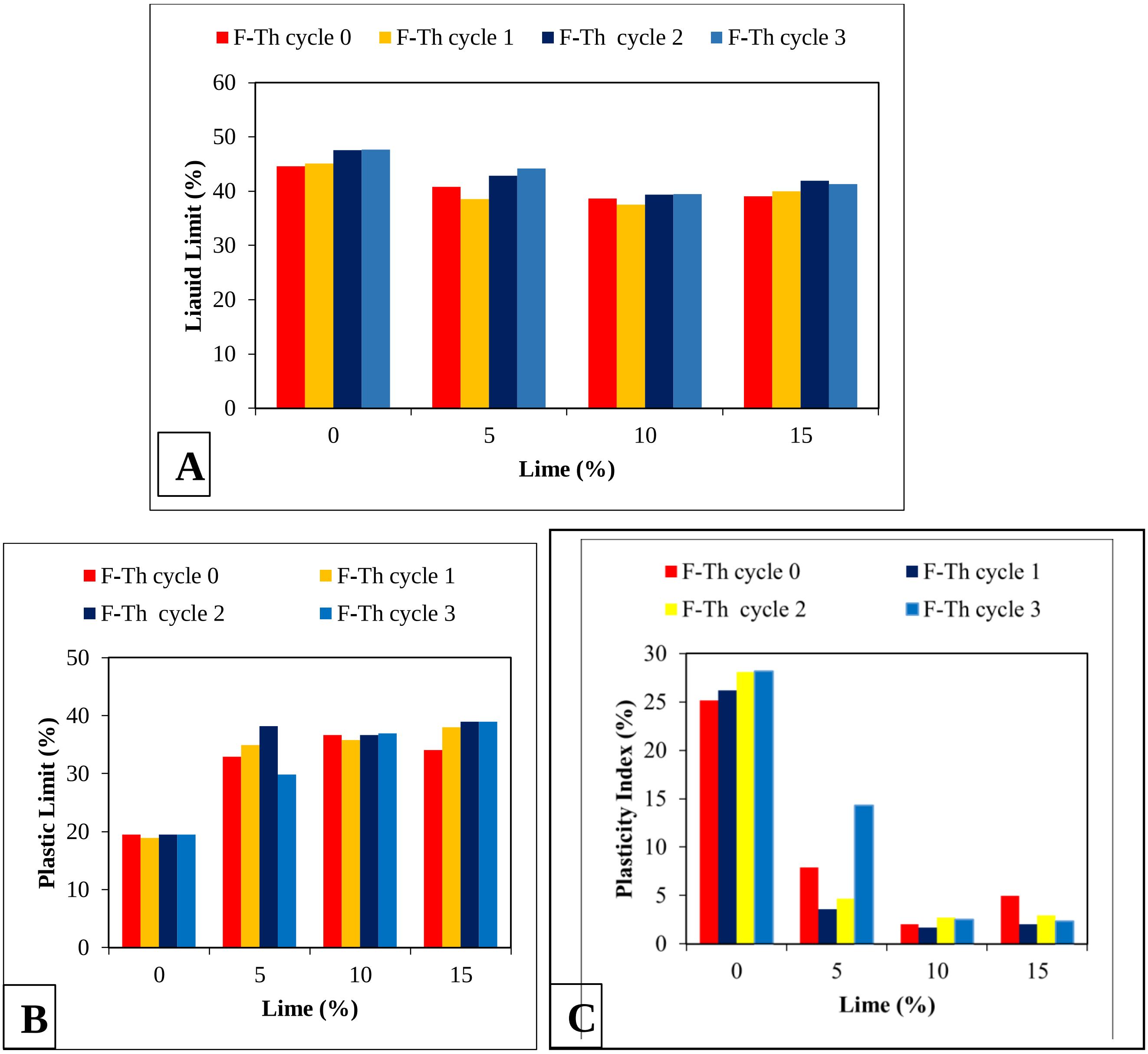

Fig. (3): Recorded changes in consistency limits of lime- stabilized soil samples with F-Th cycles: A. liquid limit; B. plastic limit, C. plasticity index.

3.2 Effects of F-Th cycles on unconfined compressive strength

The variation of UCS values for the treated and untreated specimens exposed to 3 F-Th cycles is presented in Fig.4. After saturation and exposing to the last cycle of F-Th process, unconfined strength tests were carried out in order to obtain the UCS. From the figure, hydrated lime noticed to has a major effect on the UCS values. The value of UCS for the untreated soil was increased due to F–Th cycles. Therefore, and hence, the natural soil specimen outcomes showed the weakening of its properties due to F-T cycles and it may require remediation, as it has been carried out in the current research. Also it is clear from the figure that the UCS values of the stabilized samples decreases with the F-Th cycles compared with the untreated natural soil specimen subjected to the same F–Th cycles (Konrad, 1989; Yildiz et al., 2004; Firoozi et al., 2015; Shareef, 2016). From the obtained results, the highest UCS value found to be for the 15% hydrated lime content for 0 F-Th cycles, which is 51.1%. While, for the other stabilized soil specimens after 1 to 3 F-Th cycles, the rapid decrease in the UCS values are 19.1 %, 26.88 % and 40.91 % respectively.

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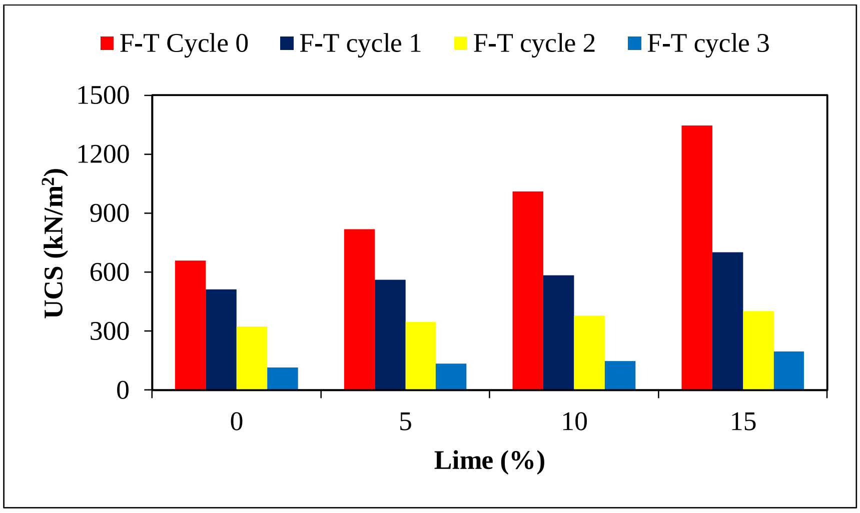

Fig. (4): Variation of UCS of lime-stabilized soil subjected to F-Th cycles.

3.3 Impact of F-Th cycles on the shear components (C & ϕ)

In this research, the tested soil specimens were exposed to 3 F-Th cycles. Rearrangement of soil particles and the curing time are two important factors to gain shear strength. The F-Th cycles directly affected the specimens shear strength components. In Fig. 5, with the increase in the hydrated lime percentage from 0% to 15%, the soil cohesion decreased that subjected to 0-3 F-Th cycles. Fig. 6 shows the obtained friction angle values increase that treated with hydrated lime and subjected to 3 F-Th cycles. However, a rapid decrease was noticed for the specimen that stabilized with 10% hydrated lime and exposed to 0 and 1 F-Th cycles. After that, the trend starts to increase up to 15% of hydrated lime content. Both of shear components (C and ϕ) showed several variations with F-Th cycles increase, ϕ increased slightly and C decreased, which agree with the findings of both of Hotineanu et al. (2015) and Yao et al. (2020) studies.

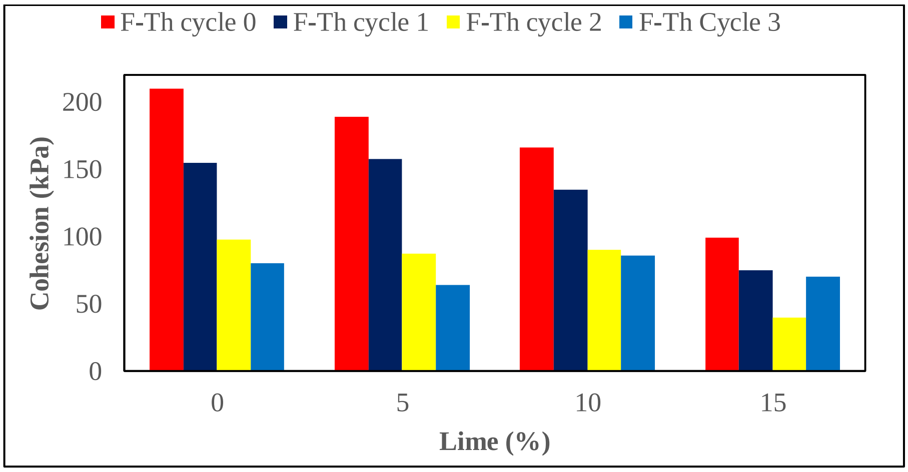

Fig. (5): Variation of cohesion of lime-stabilized soils subjected to F-Th cycles.

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[1] Corresponding author: College of Engineering, University of Sulaimani, Kurdistan Region, Iraq

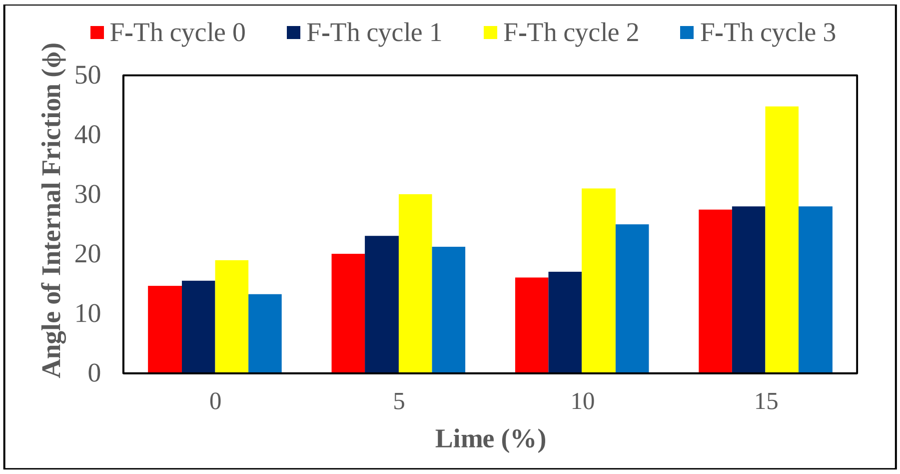

Fig. (6): Variation of angle of internal friction of lime-stabilized soil exposed to F-Th cycles.

3.4 Impact of F-The cycles on the compressibility parameters

One-dimensional consolidation tests were performed for both of the natural and lime-treated specimens with 0% to 15% lime exposed to 3 F-Th cycles applied after treated specimens were cured for 28 Days. After that, a relationship developed between compressibility parameters with 0% and 15% hydrated lime for all 3 F-Th cycles. As seen in Figs. 7 to 9, the compression index, expansion index, and coefficient of consolidation subjected to 0 F-T cycles with lime content of 0 % have the highest values. These values decrease with the increase of the hydrated lime content. However, the increase in the first two values can be noticed at 10% then after that they started to reduce by 15%. All of compressibility parameters (C_c, C_r, and C_v) continued to reduce with F-Th cycles increase. Nevertheless, both of the compression and expansion indices exposed to 2 F-Th cycles for all hydrated lime content lower than 3 F-Th cycles which presented in Figs. 7 and 8. Coefficient of consolidation starts to decrease by order of zero to 3 F-Th cycles for all untreated and treated specimens with hydrated lime as shown in Fig. 10; the decrease was at a much lower rate. The main reason for compressibility parameters decrease of stabilized soil by hydrated lime after exposed to 3 F-Th, cycles can enhance the formation of bonds among soil particles, which generated due to use hydrated lime (Paudel and Wang, 2009).

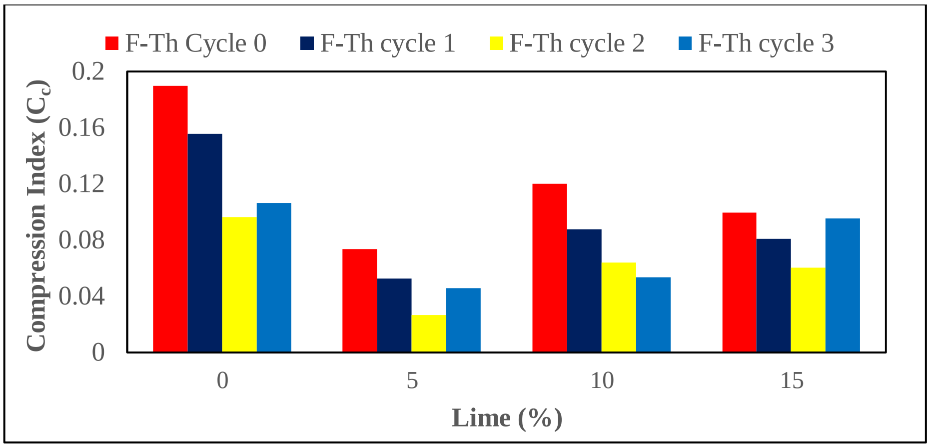

Fig. (7): Variation of compression index of lime-stabilized soil subjected to number of F-Th cycles.

nihad.salih@univsul.edu.iq; tavga.abdalla@univsul.edu.iq
[1] Corresponding author: College of Engineering, University of Sulaimani, Kurdistan Region, Iraq

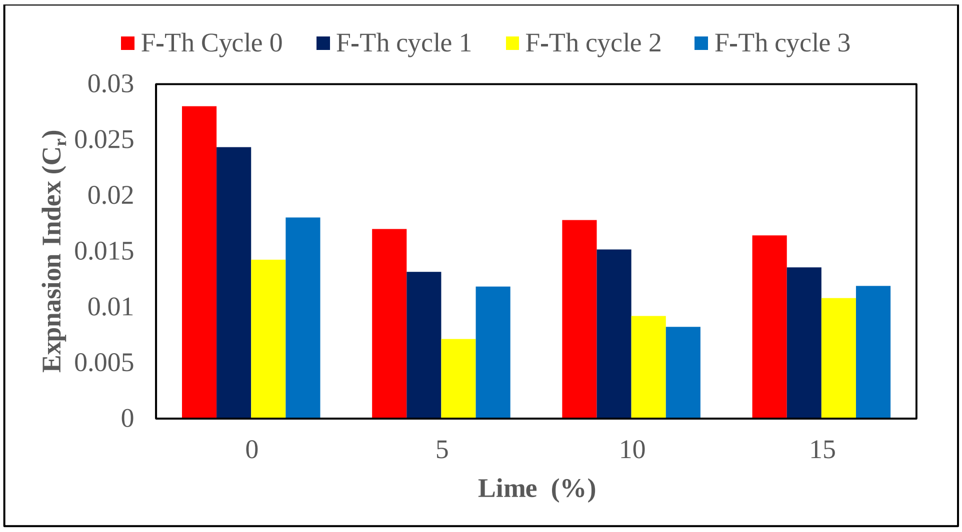

Fig. (8): Variation of expansion index of soil stabilized with lime exposed to F-Th cycles.

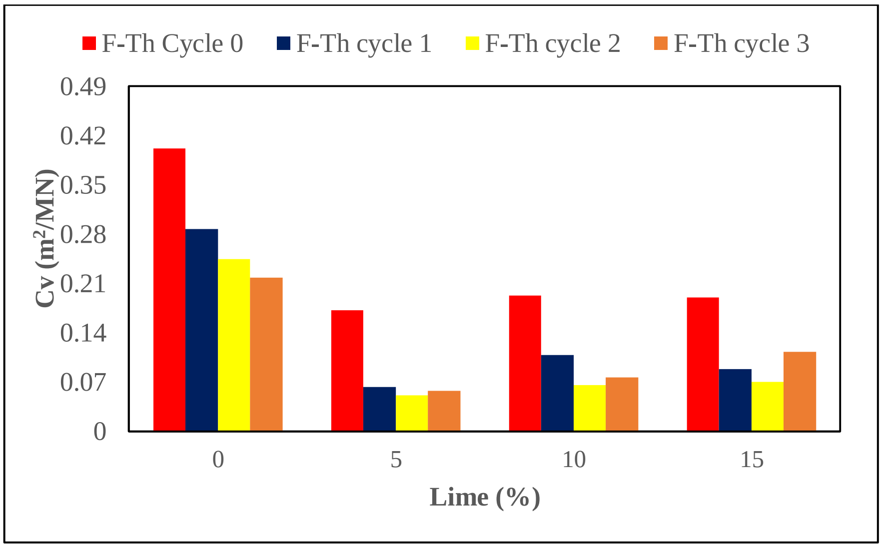

Fig. (9): Variation of coefficient of consolidation with hydrated lime percent for stabilized soil exposed to 4 cycles of F-Th.

4. CONCLUSION

The effect of hydrated lime on freeze-thaw cycles of fine-grained soils has been explored. Based on the obtained findings, the study yielded the following conclusions:

• Based on the F-Th cycles increase from 0 to 3, both of LL & PI were reduced. A remarkable increase is noticed in the values of both of LL and PI after 3 F-Th cycles.

• Based on the obtained outcomes, soil treatment by hydrated lime improved the freeze and thaw durability. The UCS of untreated and lime-treated specimens reduces with F-T cycles increase.

• The cohesion of the treated soil specimens by hydrated lime reduced after the application of all F-Th cycles. In contrast, the angle of internal friction value increased with the treatment by hydrated lime after subjecting to all F-Th cycles.

• The number of F-Th cycles increase effectively influenced the compressibility characteristics of the stabilized soil specimen by hydrated-lime. Lime stabilized soils showed high resistance to compressibility compare with the non-stabilized soils. The compressibility parameters (Cc, Cr, and C_v) decreased with F-Th cycles. However, both of compression index and expansion index values after subjecting to 2 F-Th cycles for all hydrated-lime contents lower than their values after subjecting to 3 F-Th cycles.

nihad.salih@univsul.edu.iq; tavga.abdalla@univsul.edu.iq
[1] Corresponding author: College of Engineering, University of Sulaimani, Kurdistan Region, Iraq

List of Symbols

Symbol	Description
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
C_c	Compression Index
C_r	Expansion Index
C_v	Coefficient of Consolidation
ϕ	Angle of Internal Friction
C	Cohesion
F-Th	Freeze-Thaw
UU	Unconsolidated Undrained Shear Test
MDD	Maximum Dry Density
OMC	Optimum Moisture Content

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nihad.salih@univsul.edu.iq; tavga.abdalla@univsul.edu.iq
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nihad.salih@univsul.edu.iq; tavga.abdalla@univsul.edu.iq
[1] Corresponding author: College of Engineering, University of Sulaimani, Kurdistan Region, Iraq