Freezing–Thawing Behavior of Lime Treated Fine–grained Soil

Abdulrahman Aldaood[1], Amina Khalil[2], Marwen Bouasker[3], Muzahim Al-Mukhtar[4]
[1,2]Civil Department, College of Engineering, Mosul University, Mosul, Iraq
[3,4]Centre de Recherche sur la Matière Divisée, CRMD, France

ABSTRACT

This research study was carried out to investigate the impact of freeze-thaw cycles on the mechanical and the mineralogical properties of lime treated fine-grained soil. The unconfined compressive strength, wave velocity, volume change, water content, pH and electrical conductivity values were determined during freeze-thaw cycles. Furthermore, Mercury porosimetry and X-ray diffraction tests were carry out to determine changes at microscopic level. The soil used in this study was taken at a site near Jossigny region in eastern part of Paris–France. The soil samples were treated with optimum lime percent 3% depending on the pH method, then cured for 28 days at 20 °C. The soil samples were subjected to 12 cycles of freeze-thaw following ASTM procedure. The result referred that, natural soil exhibit no strength resistance against freeze-thaw cycles and failed during the first hours of freeze-thaw cycles. Analyses indicated that freeze-thaw cycles reduce the unconfined compressive strength of all the tested samples. Moreover, water content during the applied cycles increases and induces significant volume changes. During freeze-thaw cycles, the cracks propagation which caused by the formation of ice lenses in the pores of lime treated soil samples were consider to have significant. The changes in the micro-structural and mineralogical properties reduce the durability of the lime treated soil samples when subjected to freeze-thaw cycles.

KEYWORDS : freeze-thaw, lime treatment, mechanical properties, microscopic properties.

1. INTRODUCTION

Cyclic freeze–thaw is considered to be one of the most destructive actions, which can induce significant damage in pavement structures. Damage due to freeze–thaw cycling can take various forms, the most common ones being cracking and spalling on different scales (Yarbasi et al., 2007). Mechanical and physical properties of the soil, such as porosity, moisture content, and type of soil, play an important role in the degree of damage from freeze–thaw cycles (Kamei et al., 2012). The strength and durability of soils are also reduced by freeze–thaw cycles (Wang et al., 2007; Bin-Shafique et al., 2011; Jafari and Esna-ashari, 2012). Al-Kiki et al. (2011) showed that natural clayey soil did not sustain the effects of environmental conditions, but that after stabilization with lime, the mechanical characteristics improved. Similar observations were documented by Aldaood et al. (2016). The stabilization of fine–grained soils with hydrated lime, quicklime, cement or other binders leads to a material with improved mechanical and physical properties under environmental conditions. Quick lime, which is non-hydrated calcium oxide, absorbs water from the moist soil, thereby changing into calcium hydroxide that hardens the links between soil particles and improves the soil strength. The immediate reaction that takes place between lime and clay is cationic exchange between the ions associated with the surfaces of the particles and the calcium ions in the lime, leading to flocculation (Bell, 1996). This reaction is succeeded by a long-term one which can take months or years to complete, depending on the rate of chemical breakdown and the hydration of the silicates and aluminates in the clay. This reaction is known as the pozzolanic reaction and results in the formation of a cementitious material. A number of studies have been performed in order to analyze the behavior of lime–treated clays, but few have been carried out on the durability of the material, in particular the effect of

Academic Journal of Nawroz University
(AJNU) Volume 7, No 4 (2018).
Regular research paper : Published 21 December 2018
Corresponding author's e-mail : alzubydi.1979@gmail.com

doi : 10.25007/ajnu.v7n4a273

freeze–thaw cycles (Ingles and Metcalf, 1973; Al-Kiki et al., 2011; Al-Mukhtar et al., 2012). The durability and strength properties of natural and stabilized soils under freeze–thaw cycles have been investigated by many researchers. Dempsey and Thompson (1968) studied the durability of lime stabilized soil samples, and reported that the unconfined compressive strength of soil samples could be used as indicator of the freeze–thaw durability of the lime–soil mixtures. The same conclusion was drawn by Shihata and Baghdadi (2001) during their work on the durability of cement–soil mixtures. Wang et al. (2007) pointed out that the physical and mechanical properties of compacted clay drastically changed with freeze–thaw cycles. The strength of the soil samples reached minimum values after 3 to 7 cycles of freeze–thaw. Therefore they suggested that the designed strength of soils in cold regions must be taken into account after 7 freeze–thaw cycles. Research work presented in this paper is an attempt to analyse the mechanical and mineralogical properties of lime treated soil under freeze–thaw cycles. A series of unconfined compression and wave velocity tests were carried out. Water content and volume change variations were calculated after each freeze–thaw cycle. pH and electrical conductivity tests were also performed with respect to these cycles. Mineralogical properties of lime treated soil were also investigated using x-ray diffraction and mercury intrusion porosimetry tests.

2. MATERIALS AND TESTING METHODS

2.1 Materials

Fine-grained soil from an area near Jossigny region in eastern part of Paris (France) was selected for this study. The soil samples were obtained at a depth varied between (1.5 – 2.0 m) below the ground level. The natural water content in situ was determined and being about 18.5%. About 91% of the particles were smaller than 0.08 mm and 19% were lower than 0.002 mm. The grain size distribution analysis referred to soil composition of 17% sand, 64% silt and 19% clay. Based on the Atterberg limits values and according to the Unified Soil Classification System (USCS), the soil was classifies as low plasticity clay (CL).

The quicklime added is supplied by the French company LHOIST, is a very fine lime and passes through an 80 µm sieve opening. The activity of the lime used was 94%.

2.2 Samples Preparation

An experimental program was performed in order to conduct a precise parametric study. The natural soil samples were stabilized by 3% lime; representing the optimum lime percent; based on the Eades and Grim method (1966). Firstly, the soil was oven dried for 2 days at 60°C, then pulverized and sieved through sieve (4 mm). After that, the soil is mixed with the predetermined amount of lime and then thoroughly mixed in dry state until the mixture had a homogeneous and uniform appearance. A required amount of water was added to the mixture and remixed thoroughly. The mixing continued until the final mixture gets a uniform moisture distribution. The wet mixture is then kept in plastic bags and left for 24 hours for untreated soil and 1 hour for lime treated soil. Finally, the soil samples were compacted according to an (ASTM D-698) procedure, at a rate of 1 mm/min. The soil samples were compacted at the optimum moisture content (11%) and maximum dry unit weight (17,7 kN/m^3) of the standard compaction curve of natural soil. All prepared samples with lime, were immediately wrapped with cling film and coated with paraffin. In order to study the effect of freeze-thaw cycles on the mechanical properties of soil the compacted soil samples were cured at room temperature (20°C) for 28 days.

2.3 METHOD OF TESTING

2.3.1 Freeze-Thaw test

At the end of the curing time of 28 days (which represent the initial state), the treated soil samples were subjected to 12 freeze – thaw cycles following the procedure reported by ASTM (D-560), and using the rapid freeze-thaw cabinet as shown in figure (1). The soil samples were supported on 6 mm water saturated felt pad and the assembly was placed in the rapid freeze-thaw cabinet having a constant temperature of -23° C for 24 hours, then the soil samples subjected to the thawing at 21° C for 23 hours. The rise and decrease in temperature takes place in 30 minutes. During the thawing cycles, free water was made in order to keep the felt pad saturated, and the sample was permitted to draw up water by capillary action. After that, the weights and water content of the soil samples were recorded at the end of each cycle. Moreover, volume change variations were considered by measuring the height and diameter of soil samples (nearest to 0.1 mm) to evaluate the durability. Each volume change and weight values reported in this study were the average of four samples.

Fig (1) : Soil samples subjected to freeze–thaw cycles using a freeze-thaw cabinet

doi : 10.25007/ajnu.v7n4a273

2.3.2 Unconfined Compression and Wave Velocity Tests

The compressive strength of the lime treated soil samples were determined at the end of (1st, 3rd, 5th, 7th and 11th) of thawing cycles, and at the end of (2nd, 4th, 6th, 8th and 12th) of freezing cycles respectively. The unconfined compressive strength was determined according to the ASTM procedure (D-5102). The load was applied to the soil samples with a strain rate of 0.1 mm/min, using a hydraulic press (INSTRON 4485), and the loading process continued until the failure of samples occurred. The wave velocity (type Vp) of soil samples were measured before performing the unconfined compression test. The PUNDIT instrument and two transducers (a transmitter and a receiver) having a frequency of 50 kHz were used.

2.3.3 PH and Electrical Conductivity Tests

At the end of the unconfined compression test, a portion of failed samples was used to determine the pH and electrical conductivity. For pH test, the Eades and Grim (1966) pH test method was used. In this test, 20 gm of oven-dried soil passing sieve # 40, poured into 100 ml distilled water, then the slurry regularly shaken for 30 seconds every 10 minutes. After 1 hour the pH and electrical conductivity values of the slurry were measured.

2.3.4 Mineralogical and Micro-structural Tests

Pore size distribution assessment was carried out using a Pore Seizer Porosimeter (9320). The mercury pressure is raised continuously to reach more than 210 MPa. For each failed sample in compression, samples were carefully trimmed into approximately cubes having 1 cm3 and then subjected to vacuum-dried to remove the pore water. MIP tests were conducted on the soil samples after the end of 28 days of curing and at the end of 12th cycle of freeze-thaw.

For the X-Ray diffraction test (XRD), fractured samples produced after the unconfined compression test were powdered and sieved through a 400 µm sieve to serve as samples for XRD tests. Before testing, the soil sample was dried for 24 hours at 40°C. A Philips PW3020 diffractometer was used for XRD analysis. This test was conducted on natural (raw) soil samples, and the samples were subjected to 12 freeze – thaw cycles.

3. RESULTS AND DISCUSSION

3.1 pH and Electrical Conductivity

The variation in pH and electrical conductivity (EC) values of the soil samples under freeze-thaw cycles is given in figure 2. The pH and EC values generally decreased with an increasing number of freeze-thaw cycles. The reduction in pH and electrical conductivity (EC) values can be explained by lime consumption from the additional pozzolanic reaction that occurred during the period of thawing and by lime leaching due to water adsorption from capillary rise, which lead to the decrease in calcium(Ca^{+2}) and hydroxyl (OH^{-}) ions.

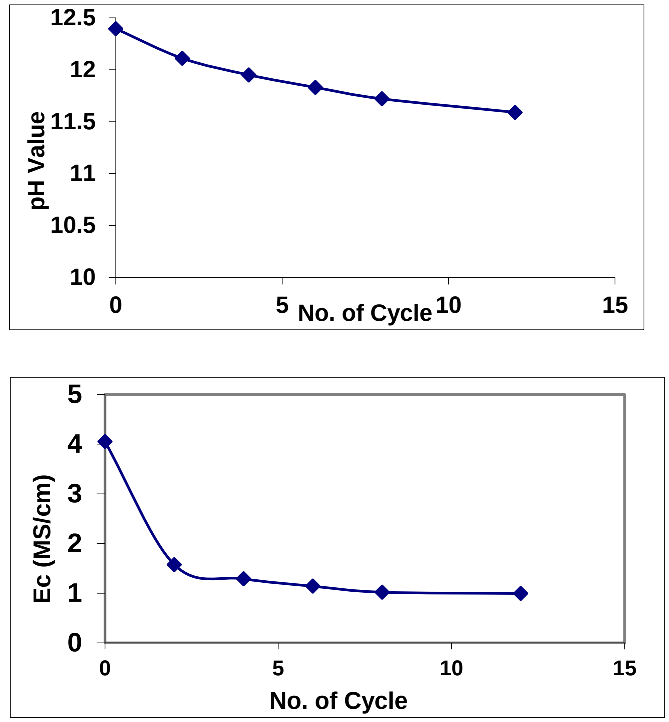

Fig (2) : pH and Ec variation with cycles No.

3.2 Unconfined compressive strength (UCS)

Figure 3 shows the variation in the UCS value of the soil samples with freeze – thaw cycles. It is observed that there is a continuous reduction in the unconfined compressive strength with increasing freeze–thaw cycles. A comparison of the unconfined compressive strength of the soil samples tested in a thawing state versus the soil samples tested in a freezing state shows a lower unconfined compressive strength for the soil samples that undergoing thawing, as shown in figure 3.

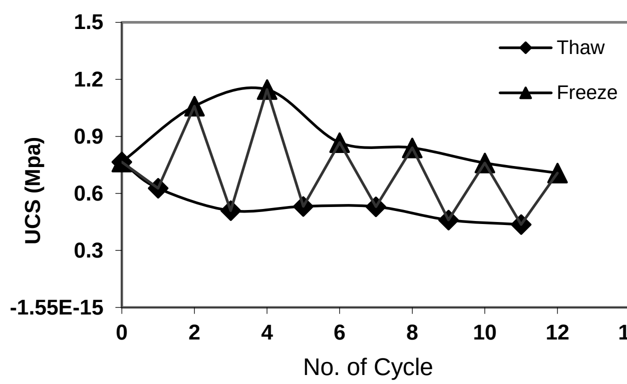

Fig (3) UCS of soil samples with freeze – thaw cycles

The difference between these states is attributed to the presence of water, which increased the distance between the soil particles and led to a decrease in both cohesion and the angle of internal friction of the soil sample. In the freezing case, the presence of ice lenses among soil particles acted as a cementing material and gave additional strength to the soil samples. Another significant result is that during the freeze–thaw cycles the unconfined compressive strength of the soil samples increased until the 4th (freezing state) cycle and then decreased. This is attributed to more strength gain occurring during the thawing period when the temperature was 21 °C, and after this stage the detrimental effect of the freeze–thaw cycles became stronger than the positive effect of pozzolanic reactions, which then caused a reduction in the unconfined compressive strength. The effect of the freeze–thaw cycles on the unconfined compressive strength of the treated soil samples is attributed to several reasons:

1. Presence of water available within the void space. In this study the amount of water available in the soil samples was measured during the freeze – thaw cycles, as shown in figure 4. The water content increased during freeze – thaw cycles due to the water absorption during thawing. As a result of the water content increasing, the volume of the soil samples also increased with an increasing number of freeze–thaw cycles, as shown in figure 5. However, this figure shows that, after the 10th cycle the volume of soil samples decreased.

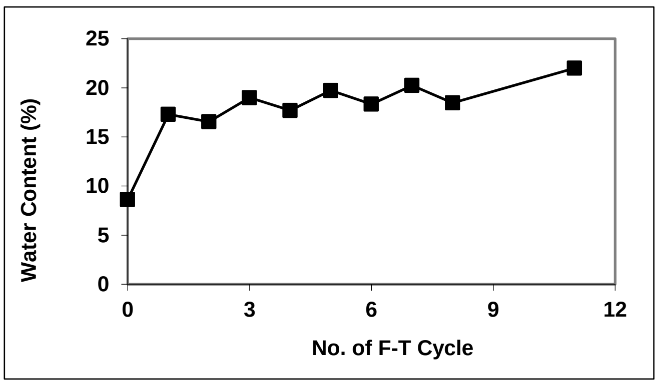

Fig (4) : water content of soil measured during the freeze – thaw cycles

This behavior due to the damage of soil samples which cause fall down of small portions; especially from the bases; of the samples. The volume of the frozen samples was more than the volume of the thawed samples due to the presence of ice lenses. Ice lenses cause crack propagation which leads to a loss of strength and decrease in the volume of soil samples by the crumbling of some portions of cracked samples, thereafter accelerated degradation of the samples occurred.

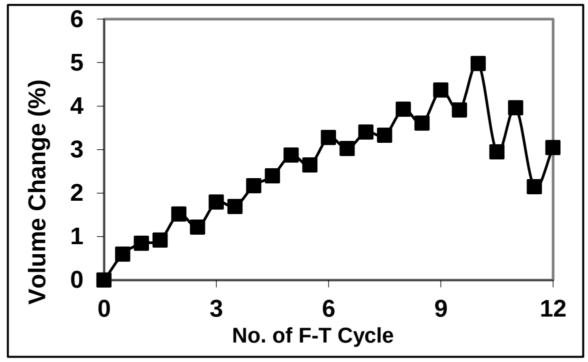

Fig (5) : Volume change of soil samples with number of freeze–thaw cycles

2. Detrimental effect of freeze–thaw cycles on pozzolanic reactions, it is well known that the strength gain of treated soil samples usually depends on the curing temperature, thus the freezing temperature (−23 °C) was more significant than the thawing temperature (21 °C) on the deceleration of the pozzolanic reactions.

3.3 Wave velocity

Wave velocity variations in the soil samples under the effect of freeze – thaw are presented in figure 6.

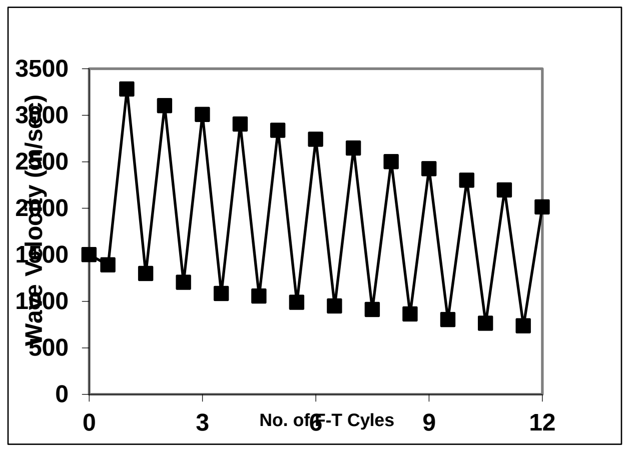

Fig (6) : Wave velocity variations in soil samples under freeze – thaw cycles

It is seen that the reduction in wave velocities increases with an increase in freeze – thaw cycles, this is because more cracks propagated on the sample surfaces, as shown in figure 7 . The freeze – thaw cycles decreased the wave velocity values of all soil samples, in both thawing and freezing states.

Fig (7) : Cracks propagation at the end of freeze-thaw cycles

The wave velocity values of soil samples tested in thawing state decreased from (1480 m/s), for soil samples that were not subjected to freeze–thaw cycles, to (740 m/s) at the end of 12th cycle. This reduction is attributed to the presence of the water available (soil samples will be saturated) thus reducing the wave velocity values, because in general the velocities in solids are higher than velocities in liquids, which in turn are higher than velocities in gases (McIntire, 1991). Therefore it is expected that high velocities occur at high solid and low water and air contents. The changes in soil structures due to freeze–thaw cycles applied, which are represented by increased cracks, will cause a reduction in the treated sample capability to transfer waves.

3.4 X-ray diffraction analysis

XRD patterns of the natural soil samples and the freeze – thaw cycled samples are presented in figure 8. The XRD pattern of the natural (raw) soil samples indicated that the soil was composed mainly of kaolinite and illite as clay minerals, and contained quartz, calcite, and feldspars as non-clay minerals. Identification revealed that the natural soil initially contained no cementing materials. After the treatment with lime and 12 freeze – thaw cycles, the compounds formed were products of the reactions between soil and lime, namely calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH), this is attributed to the effect of the initial curing time which caused the pozzolanic reaction. After the freeze – thaw cycles there was a remarkable decrease in pozzolanic compounds (CSH and CAH) in soil samples. This may be attributed to the presence of a higher water content in the soil samples, which delayed the pozzolanic reaction compounds during thawing.

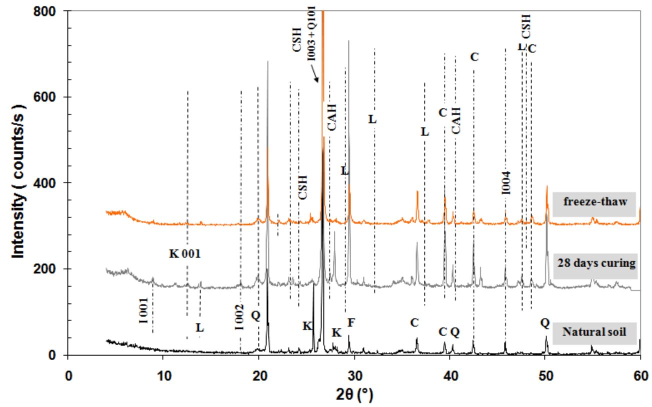

Fig (8) : XRD patterns of the natural soil samples and the freeze – thaw cycled

3.5 Pore size distribution analysis

Figure 9 presents the effect of initial curing and freeze – thaw cycles on the pore size distribution of soil samples. It can be seen that the cured soil samples exhibit a bi-modal pore size distribution, with less pronounced peak of pores centered on 1 µm. Freeze – thaw cycles resulted in the distribution of soil samples from bi-modal to tri-modal. A decrease in the amount of macro-pores centered on 3 µm and an increase in the amount of pores centered on 6 µm can be noted after the freeze – thaw cycles. This means that the effect of freeze – thaw cycles was concentrated in pores of more than 1 µm for all the soil samples. While the micropores of less than 0.1 µm did not change significantly, and the amount of these pores did not seem to be affected by freeze–thaw cycles. Thus, freeze – thaw cycles changed the soil structure to a coarser one.

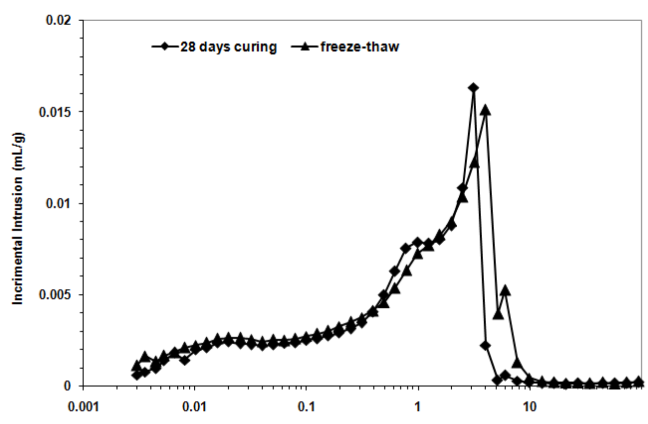

Fig (9) : pore size distribution of soil samples

4. CONCLUSIONS

Based on the test results, the following conclusions can be drawn:

1. The unconfined compressive strength of the lime treated soil samples, increased before applying freeze – thaw cycles. Lime treated samples reveal better durability to freeze – thaw cycles.

2. The electrical conductivity and pH values of all the

soil samples decreased with freeze–thaw cycles and reveals the changes in the mineralogy due to lime–soil reaction.

3. Water content increased greatly in the first cycle and then slightly during the following cycles in all the soil samples. The tested samples rapidly reached saturation after a small number of cycles. However, volume changes increased continuously with the number of cycles.

4. Visual observations show that the presence of cracks and fissures developed with freeze–thaw cycles, resulting the changes in the pore size distribution (coarser structure) of the soil samples. All these phenomena result in reducing the unconfined compressive strength during freeze–thaw cycles.

REFERENCES

1.Yarbasi,N., Kalkan, E., Akbulut, S., 2007. Modification of the geotechnical properties, as influenced by freeze–thaw, of granular soil with waste additives. Cold Reg. Sci. Technol. 48 (1), 44–54.

2.Kamei, T., Ahmed, A., Shibi, T., 2012. Effect of freeze–thaw cycles on durability and

3.strength of very soft clay soil stabilized with recycled bassanite. Cold Reg. Sci. Technol. 82, 124–129.

4.Bell, F.G., 1996. Lime stabilization of clay minerals and soils. Eng. Geol. 42, 223–237.

5.Bin-Shafique, S., Rahman, K., Azfar, I., 2011. The Effect of Freezing–Thawing Cycles on Performance of Fly Ash Stabilized Expansive Soil Subbases. Geo-Frontiers (ASCE). pp. 697–706.

6.Jafari, M., Esna-ashari, M., 2012. Effect of waste tire cord reinforcement on unconfined compressive strength of lime stabilized clayey soil under freeze–thaw condition. Cold Reg. Sci. Technol. 82, 21–29.

7.Wang, D.Y., Ma, W., Niu, Y.H., Chang, X.X., Wen, Z., 2007. Effects of cyclic freezing and thawing on mechanical properties of Qinghai–Tibet clay. Cold Reg. Sci. Technol. 48 (1), 34–43.

8.Aldaood, A., Bouasker, M., Al-Mukhtar, M., 2016. Effect of water during freeze–thaw cycles on the performance and durability of lime-treated gypseous soil. Cold Reg. Sci. Technol. 123, 155–163.

9.Al-Kiki, I., Al-Attalla, M., Al-Zubaydi, A., 2011. Long term strength and durability of clayey soil stabilized with lime. Eng. Technol. J. 29 (4).

10. Ingles, O.G., Metcalf, J.B., 1973. Soil Stabilization Principles and Practice. John Wiley & Sons, New York.

11. Al-Mukhtar,M., Khattab, S., Alcover, J.F., 2012. Microstructure and geotechnical properties of lime-treated expansive clayey soil. Eng. Geol. 139–140, 17–27.

12. Dempsey, B.J., Thompson, M.R., 1972. Vacuum saturation method for predicting freeze– thaw durability of stabilized materials. Highway Research Record 442. Highway Research Board, Washington, D.C., pp. 44–57.

13. Shihata, S.A., Baghdadi, Z.A., 2001. Simplified method to assess freeze–thaw durability of soil cement. J. Mater. Civ. Eng. 13 (4), 243–247.

14. Eades, J., Grim, R., 1966. A quick test to determine lime requirements for lime stabilization. Transp. Res. Board 139, 61–72.

15. McIntire, P., 1991. Nondestructive testing handbook, Vol. 7: Ultrasonic testing American Society for Nondestructive Testing, Columbus.

doi : 10.25007/ajnu.v7n4a273