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Freezing-thawing resistance evaluation of sandy soil, improved by polyvinyl acetate and ethylene glycol monobutyl ether mixture

Ata Rezaei Fard*[1], Gholam Moradi[2a], Babak Karimi Ghalehjough[3b] and Alireza Abbasnejad[2c]

[1]Department of Civil Engineering, Islamic Azad University, Tabriz, Iran
[2]Department of Civil Engineering, University of Tabriz, Tabriz, Iran
[3]Department of Civil Engineering, Erzurum Technical University, Erzurum, Turkey

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Abstract. Freezing-thawing cycles have significant effect on soils engineering behavior in frozen areas. This effect is more considerable in fine-graded than coarse-grained soils. The objective of this study is improving soil durability and strength in continues freezing-thawing cycles. For getting this purpose mixture of Polyvinyl Acetate (PVAc) and Ethylene Glycol Monobutyl Ether (EGBE) has been added to fine-grained soil and final prepared samples were tested at different freezing-thawing cycles. PVAc was mixed with 1%, 2% and 3% of soil weight. Half of PVAc weight was used as weight of EGBE. Freezing-Thawing cycles were exposed to samples and they were tested at different cycles. Results showed that adding mixture of PVAc+EGBE improved strength and durability of samples up to 10 freezing-thawing cycles. Unconfined compress strength tests were applied to samples and stress and strain of samples were tested on failure time. Behavior of samples was different at different percentages of mixture. Results showed that increasing amount of PVAc from 1% to 2% had more considerable effect on final stress than 2% to 3%. Using higher percentages of PVAc + EGBE mixture leaded to that samples carried more strain before collapsing. Another result gained from tests was that, freezing-thawing effect was more considerable after fourth cycles. It means differences between first and fourth cycles were more considerable than differences between fourth and tenth.

Keywords: freezing-thawing; unconfined compress strength; polyvinyl acetate; ethylene glycol monobutyl ether

1. Introduction

In cold and frozen areas, soils are exposed to freezing-thawing cycles in winter season. These cycles have significant and considerable effect on soils properties and engineering behavior such as strength, compressibility and permeability at different engineering applications like pipelines, railroads, buildings constructions and roads. Resilient modulus that is one of important factor in designing pavements decrease significantly even with small numbers of freezing-thawing cycles (Simonsen and Isacsson, 2001). This effect is more important in fine-grained soils than coarse-grained soils (Zaimoglu, 2010). While a granular soil starts to freezing, ice causes segregation between particles of soil resulting changes in soil properties in both micro and macro scales (Hohmann-Porebska, 2002). These cycles cause reduction in ultimate strength of soils and undrained shear strength of soils (Graham and Au, 1985). By studying previous works, it found that stabilized materials should withstand additional stresses caused by temperature changes particularly at freezing-thawing cycles (Tsytovich 1973, Konrad 1989, Hohmann-Porebska 2002, Qi *et al.* 2006, 2008, Guney *et al.* 2006, 2008). So, increasing durability of soil in frozen areas is necessary. Lots of studies have been done and different methods with different materials have been tested to improve soil durability and strength while soil was exposed to freezing-thawing cycles.

Soil can be affected by freezing-thawing cycles and it can lead to more permeability. At study of Zhang and Shijie (2001) mechanism of freezing-thawing action has been studied on soil salinization. At this study that has been worked on northeast China, soil profile was divided into three layers of frozen, semi-frozen and unfrozen layers. It was evident that salinity in frozen layer was increased while salt mass and soil water were moving from the underlying beds towards the frozen layer during the process of soil freezing. Results showed that salinization of soil had no direct relation with groundwater table and it just affected by thawed perched groundwater above the frozen layer.

Yarbasi *et al.* (2007) were worked on waste materials as additives to granular soil in order to decrease negative effect of freezing-thawing cycles. They were used mixture of fly ash, silica fume and red mud for stabilizing the soil. Silica fume-lime, red mud-cement and fly ash-lime, additive mixtures were used at their study. Results showed that stabilized samples with above additive mixtures had high freezing-thawing durability as compared to un-stabilized samples. Particularly mixture of silica fume-lime

*Corresponding author, Ph.D. Student
E-mail: ata_rezaeifard@yahoo.com
[a]Ph.D.
E-mail: gmoradi@tabrizu.ac.ir
[b]Ph.D.
E-mail: karimi.babak@gmail.com
[c]Ph.D.
E-mail: abbasnejad_ar@yahoo.com

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can be used as an additive to enhance the freezing-thawing durability of materials used for earthwork applications such as road constructions. Additive mixtures had also improved the dynamic behaviors of the samples.

Arasan and Nasirpur (2015) have studied effect of polymers and fly ash on unconfined compressive strength of saturated sand. At their study different kinds of polymers such as styrene-acrylic-copolymer-SACP and fly ash were added to samples and unconfined compress strength tests were performed at different freezing-thawing cycles.

Uzer (2016) studied on effect of freezing-thawing cycles on soil stabilization of buildings foundation and infrastructures. Fiber portions of biomass as byproducts of the conversion process is generally used to produce bio-based products. Lignin-based biofuel co-products (BCPs) were used for stabilization of pavement subgrade soil. Results showed that BCPs were beneficial in the soil stabilization of low-quality materials for using in road construction.

On another study Yilmaz and Fidan (2018) investigated the effect of lime and perlite on improving clayey soil geotechnical characterization at different freezing-thawing cycles. Samples at this study were stabilized with 6% of lime content of dry soil weight and perlit was added in 0%, 5%, 10%, 20%, 25% and 30% proportions. Samples were compacted at laboratory and subjected up to 12 freezing-thawing cycles and were tested under unconfined compress strength. Results showed that perlite was improved the stability of samples in front of freezing-thawing cycles.

There are different methods (Using additives or reinforcing of soil by fibers) for improving resistance of soil against compression and tension. Shape and size of particles, relative density of soil are some of parameters that will have effect on void ratio, strength and soil behavior and therefore on its resistance at different conditions of loading (Ghalehjough *et al.* 2017, Ghalehjough *et al.* 2018, Tang *et al.* 2020). Different additive materials such as cement, lime and fly ash were used for improving soil engineering behavior (e.g., strength, swelling and permeability) in freezing-thawing cycles (Taspolat *et al.* 2006, Yilmaz and Fidan, 2018).

Güllü and Fedakar (2017) worked on improving resistance of sandy soil. They have stabilized marginal sand based on the compressive strength performances from UCS tests by use of sludge ash and polypropylene fiber (PF) as additives. They have used 0, 0.5 and 1% for polypropylene fiber and 10%, 15%, 20% and 30% for sludge ash by total dry weight of the sand+sludge ash mixture and freezing-thawing resistance of samples were tested.

Krainiukov *et al.* 2020 studied the effect of freezing-thawing resistance of silty sand reinforced by polyvinyl alcohol (PVA). A series of unconsolidated undrained triaxial compression tests were conducted to samples to determin geotechnical properties of samples. Different PVA concentration of 5%, 7.5% and 10% of water weight were added to silty sand and samples tested at 0, 5, 10, 15 and 20 freezing-thawing cycles. Results showed that adding PVA to soil had significant positive effect on resistance of samples at different freezing-thawing cycles.

At the study of Nguyen *et al.* (2019), mechanical strength of fine-grained soils treated with lime and effect of freeze thaw cycles on samples properties was studied. Samples were cured for 7, 28, 90 and 365 days. Damage at mechanical strength of samples after freezing-thawing cycles and lime treating mitigated freeze thaw damage.

Liu *et al.* (2020) studied on effect of freezing-thawing cycles on straw fiber-reinforced soil and tested the unconfined compressive. They have made research on interfacial strength behavior of reinforced samples and compared different reduction trends between fiber-soil and reinforced soil. At this study SEM was used for monitoring microstructure variations of reinforced soil.

Other studies used different methods for improving soil. In the literature, there are many numerical and experimental researches focused on the reinforcing the soil with different types of fibers and their effect at different geotechnical properties such as bearing capacity, settlement and freezing-thawing cycles (Roustaei *et al.* 2015, Tang *et al.* 2016, Gullu and Khudir 2014, Çelik *et al.* 2017). Ghazavi and Roustaie (2010) studied fiber reinforced clay at different freezing-thawing cycles. Hazirbaba (2017) stabilized sand in cold region by geofiber and synthetic fluid. On the other study by Orakoglua *et al.* (2017) dynamic behavior of fiber-reinforced soil under freeze-thaw cycles was studied. Wang *et al.* (2018) were worked on freezing point of saline soft clay after different freezing-thawing cycles.

The objective of this study is to explore stabilization and strengthen a sandy soil by adding Polyvinyl Acetate (PVAc) mixed with Ethylene Glycol Monobutyl Ether (EGBE) as additive. Unconfined compress strength tests have been done while different freezing-thawing cycles were objected to samples and effect of additives and behavior of samples were studied at different cycles.

2. Materials

2.1 Soil

Sandy soil was selected for preparing samples. It gained from city of Sofian in East Azerbaijan province of Iran. Soil was moved to laboratory, bigger particles were cleaned and then sieved. Grain size distribution of soil that was used for preparing the samples showed in Fig. 1. Due to ASTMD2487-17 (2017) soil is classified as poorly graded soil.

Some geotechnical properties of soil such as optimum moisture content and specific gravity were determined at laboratory condition for calculating volume of water and weigh of soil for preparing samples. Specific gravity of soil gained 2.65 due to ASTM D 854-14 (2014).

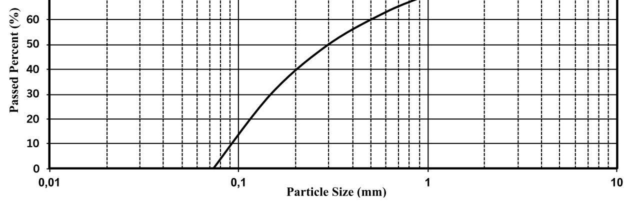

Fig. 1 Grain size distribution of samples

Table 1 Properties of PVAc

Shape	White and Wet
Density at 25°C	1.19 (gr/cm^3)
PH	4-6
Viscosity	Different at different Temperatures
Special volume at 28 C (L/Kg)	0.84 (mmHg)

Fig. 2 Picture of additives used for preparing samples (a) Ethylene Glycol Monobutyl Ether (EGBE) and (b) Polyvinyl Acetate (PVAc)

2.2 Polyvinyl acetate (PVAc)

Polyvinyl Acetate is a nontoxic thermoplastic and colorless resin prepared by the polymerization of vinyl acetate. It discovered in Germany by Dr. Fritz Klatte on 1912. It is widely used as one of the water-dispersed resins. Setting is accomplished by the removal of water due to evaporation or absorption into a substrate.

Polyvinyl Acetate resins produce clear, hard films that withstand oil, grease and water. It has good weather resistance too. Low cost, softening at 30-45°C, poor resistance to creep under load, high initial tack and good biodegradation resistance are some of other good properties of this material. Polyvinyl Acetate (PVAc) resins and other copolymers can also be used as sealants, hot-melt adhesives, plastic wood and fabric finishing. Properties of Polyvinyl Acetate (PVAc) were shown at Table 1.

2.3 Ethylene glycol monobutyl ether (EGBE)

Ethylene Glycol Monobutyl Ether (EGBE) with $C_6H_{14}O_2$ formula is an organic solvent that is used in food processing as sanitizer and processing aid. It is colorless liquid that can be used as solvent in surface coating, paints, links and cleaning products. Other products that contain Ethylene Glycol Monobutyl Ether (EGBE) can be

Table 2 Some properties of EGBE

Parameter	**Value**	**Unit**
Molecular Weight	118.2	(gr/mol)
Other Name	2-butoxyethanol	-
Physical State	Colorless Liquid	-
Melting Point	- 74.8	°C
Boiling Point	168.4	°C
Relative Density (Water=1)	0.9	(gr/cm^3)
Vapor Pressure (at 20° C)	<1	(mmHg)

firefighting foams, oil spill dispersants, leather protectors, asphalt release agents, photographic strip solutions and bowling pin and lane degreaser. Ethylene Glycol Monobutyl Ether (EGBE) is a primary component of liquid soaps, dry cleaning solutions, cosmetics, whiteboard cleaners, varnishes, latex paints and herbicides. Some properties of Ethylene Glycol Monobutyl Ether (EGBE) have been shown at Table 2.

The picture of Ethylene Glycol Monobutyl Ether (EGBE) and Polyvinyl Acetate (PVAc) was shown at Fig. 2.

3. Method

Soil was moved to laboratory, and sieved there. Specific gravity of soil was determined 2.65 due to ASTM D 854-14 (2014). Considering ASTM D891-09 (2009) the soil of samples was prepared due to selected grain size distribution graph.

For preparing samples, beside normal soil that was tested at different freezing-thawing cycles, different percentages of Polyvinyl Acetate (PVAc) and Ethylene Glycol Monobutyl Ether (EGBE) were added and mixed with soil to gain stabilized samples.

Series of experimental tests were done before preparing final stabilized samples. In these pre-tests, by considering information gotten from literature, behavior of prepared samples, price, feasibility and other executive factors, amount of additives were determined for preparing final soil-additive mixtures. Tests program and mix design of samples are shown at Table 3. Three percentages of 1%, 2% and 3% of dry soil weight of Polyvinyl Acetate (PVAc) were mixed with soil.

By considering the percentages of additive, freezing-thawing cycles and pre-tests for determining best percentages of additive, and minimum amount of 3 sample for each condition for ensuring the results, totally more than 120 samples were prepared and tested. The pre-tests number were about 30 and minimum 90 tests were done for the final tests.

For each percentages of Polyvinyl Acetate (PVAc), half of its weight of Ethylene Glycol Monobutyl Ether (EGBE) was used and added to the soil-additive mixture to get final sample. For example, for 1 kg of soil, 10 gr of Polyvinyl Acetate (PVAc) and 5 gr of Ethylene Glycol Monobutyl Ether (EGBE) was mixed together and added to soil to gain sample S1. Enough attention and time were paid for providing a homogeneous mixture of soil-additive samples.

Table 3 Program of tests

	Percentages of Materials Used in Samples		
Sample Name	**Weight of Normal Dry Soil**	**Weight of PVAc**	**Weight of EGBE**
S0	Definite Weight	0% of Dry Soil Weight	0.0 % of Dry Soil Weight
S1	Definite Weight	1% of Dry Soil Weight	0.5 % of Dry Soil Weight
S2	Definite Weight	2% of Dry Soil Weight	1.0 % of Dry Soil Weight
S3	Definite Weight	3% of Dry Soil Weight	1.5 % of Dry Soil Weight

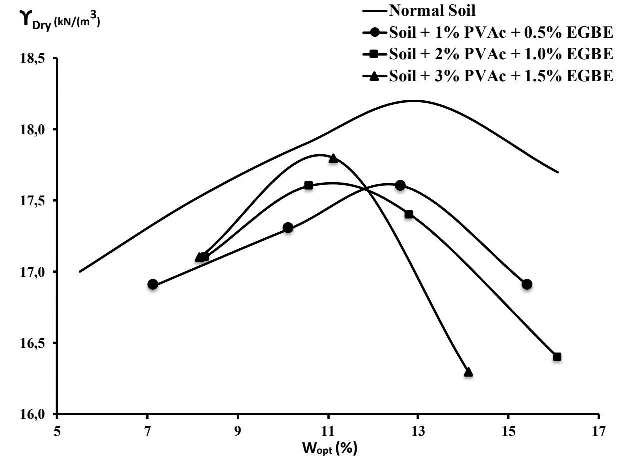

Fig. 3 Optimum moisture-maximum dry density graph of samples

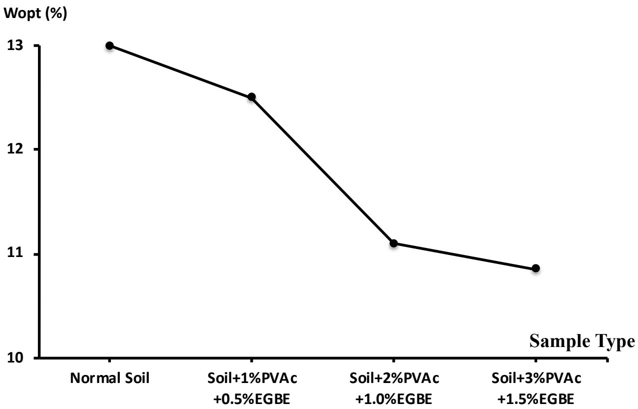

Fig. 4 Optimum moisture content of samples

Fig. 5 Moulds used for preparing samples

Fig. 6 Samples after gotten exited from moulds

Optimum moisture content of normal and stabilized samples was found due to Standard Proctor Test (ASTM D698 2012). Optimum Moisture-Maximum Dry Density graph and Wopt of each type of samples were shown at Figs. 3 and 4 respectively.

Tests results showed that by increasing the amount of PVAc+EGBE as additive, optimum moisture content of both normal soil and stabilized samples were decreased. This amount was 13% for normal soil and 12.5%, 11.11% and 10.85% for 1%, 2% and 3% of PVAc respectively.

Cylindrical PVC moulds with 5 cm diameter and 10 cm height were used for preparing samples. One side of moulds was cut to exit samples easily without destroying. Cut off side of moulds was fixed with banderol and plastic closure for preventing any deformation during compaction of soil in moulds. Fig. 5 shows some of moulds used for preparing samples.

Prepared soil-additive mixture (Mixture of Soil, PVAc and EGBE) was compacted in moulds at optimum moisture contents and left in laboratory temperature for 7 days for hardening to obtain stabilized samples.

Prepared samples were subjected to freezing-thawing tests according ASTM D 560-96 (1996) and previous scientific publication (Yarbasi *et al.* 2007, Ghazavi and Roustaie 2010). On Fig. 6 some exited samples were shown that were used at this study.

By considering previous researched and according to literature, normal and stabilized samples were placed in freezing-thawing apparatus at temperature of -20°C for 6 hours. At the next step samples were moved out of freezing-thawing apparatus to test room with temperature of 18°C for 6 hours (Yarbasi *et al.* 2007, Ghazavi and Roustaie 2010, Akbulut and Zaimoglu 2019).

Theses process were done up to 20 times and un-stabilized and stabilized samples were tested under compression machine. The compressive strength values of un-stabilized and stabilized soils are one the most important parameters of geotechnical properties of granular materials used in earthworks applications or road constructions. For determining the compressive strength of samples, cylindrical samples were broken in unconfined compress strength machine due to ASM D2166.

4. Results and discussion

The effect of additives used for stabilizing samples at freezing-thawing cycles was tested at laboratory. Additives were added to normal soil at different percentages and final samples were tested after different freezing-thawing cycles. For ensuring the results each type of samples was prepared and tested at least 3 times. Polyvinyl Acetate (PVAc) and Ethylene Glycol Monobutyl Ether (EGBE) mixture was used as additives and results showed that they could improve durability of soil at freezing-thawing cycles.

Samples were objected to different freezing-thawing cycles and unconfined compress strength tests were done to test their strength and durability. At the next step, by considering the results of tests, stress-strain graphs were drawn for normal and stabilized samples.

Fig. 7 shows stress-strain graphs of samples without any additives (Normal Soil) before and after freezing-thawing cycles. As seen at this figure, freezing-thawing cycles caused a decrease in soil stress capacity.

Because of soil structure and existence of some clay or silt in normal soil, it had some low strength under pressure loading. This maximum stress capacity for normal soil was about 3 Kg/cm^2 that was even decreased by applying freezing-thawing cycles.

After first cycle of freezing-thawing maximum stress with 33% decrease reached to 2 Kg/cm^2. This decrease continued to 1.91 Kg/cm^2 at fourth cycle. Amount of maximum stress were 1.5 Kg/cm^2 and 1.47 Kg/cm^2 at seventh and tenth cycles respectively. As there were not any additives at this type of sample, soil did not have any considerable durability and its structure changed after first freezing-thawing cycle and lost main part of its strength. Another point was that freezing-thawing cycles caused increase at the strain of samples at failure point. It was because of increasing water volume during freezing period that leads to increasing void ratio of soil. This increase in void ratio caused more deformation in sample under loading.

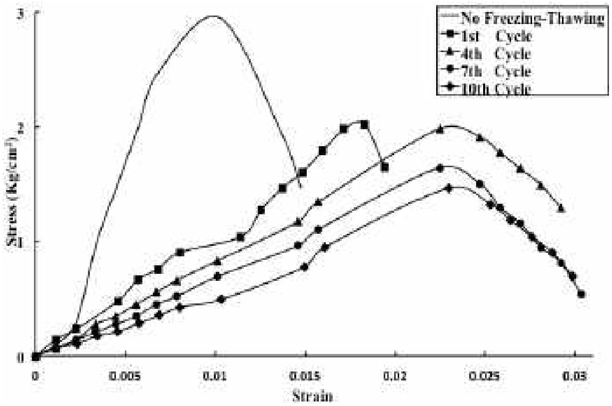

Fig. 7 Stress-strain graphs of samples without any additives

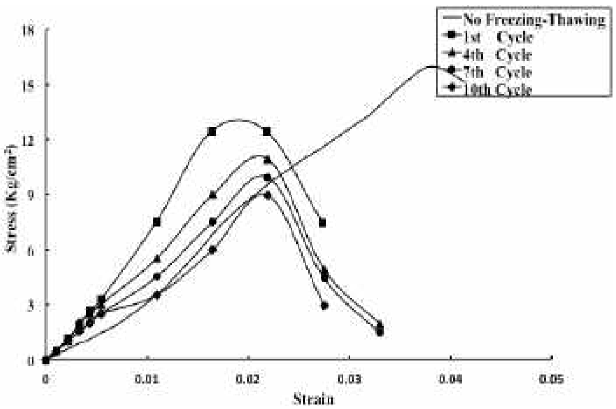

Fig. 8 Stress-strain graphs of samples with 1% PVAc and 0.5% EGBE

Fig. 8 shows stress-strain graphs of sample at different freezing-thawing cycles while 1% PVAc + 0.5% EGBE were added to soil. As seen at this figure adding this mixture to normal soil as additives, increased stress capacity of samples. Maximum stress of stabilized samples without applying any freezing-thawing cycle with more than 500% increase, reached to 15.85 Kg/cm^2 in comparison with normal soil. This increment at first cycle was from 2 Kg/cm^2 to 12.42 Kg/cm^2.

Maximum stresses at fourth, seventh and tenth cycles were 10.93 Kg/cm^2, 9.94 Kg/cm^2 and 8.94 Kg/cm^2 respectively. In summary maximum stress of samples decreased from 15.85 Kg/cm^2 before any freezing-thawing to 8.94 Kg/cm^2 after 10 cycles of freezing-thawing.

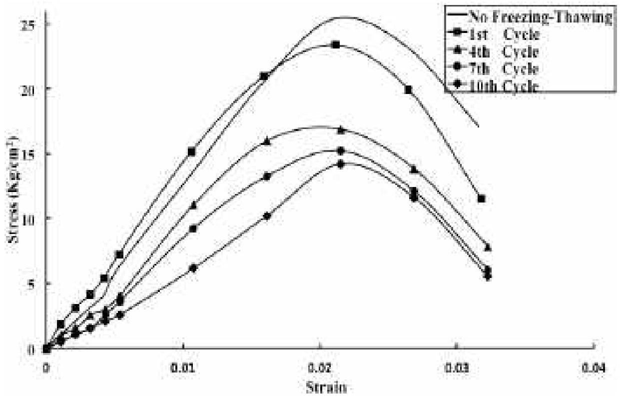

Fig. 9 Stress-strain graphs of samples with 2% PVAc and 1% EGBE

Fig. 9 shows stress-strain graphs of samples with 2% of PVAc plus 1% of EGBE added to soil for improving soil durability. As seen at this figure maximum stress of samples without any freezing-thawing cycles were about 25 Kg/cm^2 that in comparison with previous samples with 1% PVAc and 0.5% EGBE it showed near to 60% increment. By applying freezing-thawing cycles to samples the maximum stresses decreased to 23.38 Kg/cm^2, 16.91 Kg/cm^2, 15.24 Kg/cm^2 and 14.23 Kg/cm^2 at first, fourth, seventh and tenth cycles. One another result gotten from Fig. 9 is that against normal soil samples that first cycle of freezing-thawing had considerable effect on soil durability, differences of maximum stress on stabilized samples before applying freezing-thawing and after first cycle of freezing-thawing was not so much. The main negative effect on durability of samples appeared after fourth cycles of freezing-thawing.

Fig. 10 shows the results of stress of samples with 3% of PVAc plus 1.5% of EGBE as additives to samples with and without freezing-thawing cycles. As seen at this graph,

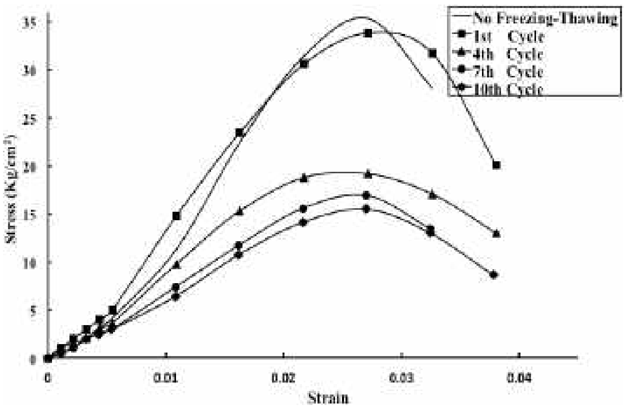

Fig. 10 Stress-strain graphs of samples with 3% PVAc and 1.5% EGBE

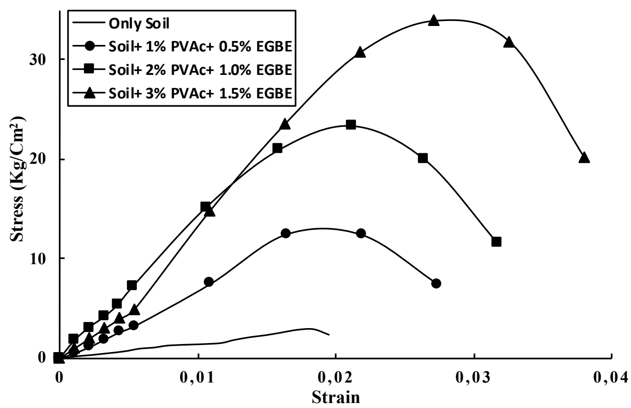

Fig. 13 Stress-strain graph of normal and stabilized samples with 1 freezing-thawing cycle

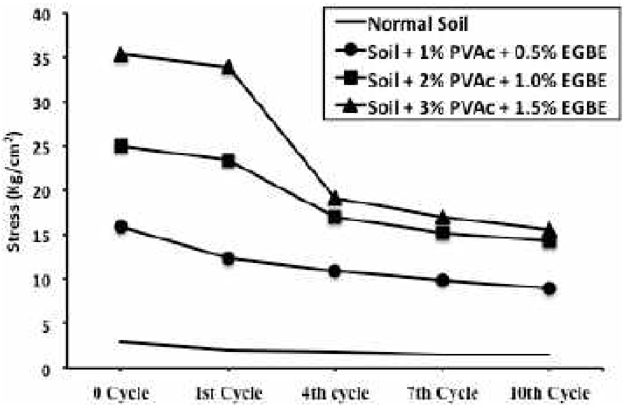

Fig. 11 Maximum stress of normal and stabilized samples at different freezing-thawing cycles

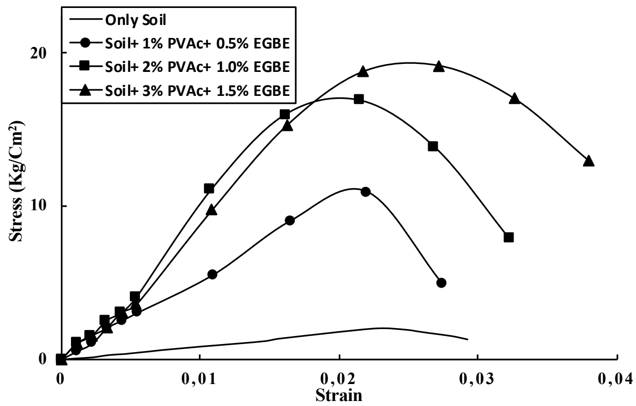

Fig. 14 Stress-strain graph of normal and stabilized samples with 4 freezing-thawing cycles

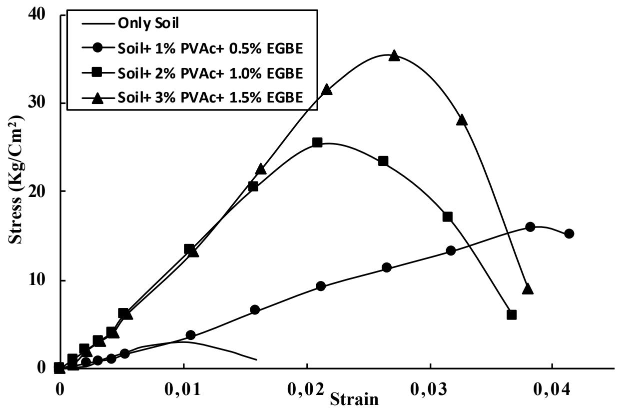

Fig. 12 Stress-strain graph of normal and stabilized samples without any freezing-thawing cycle

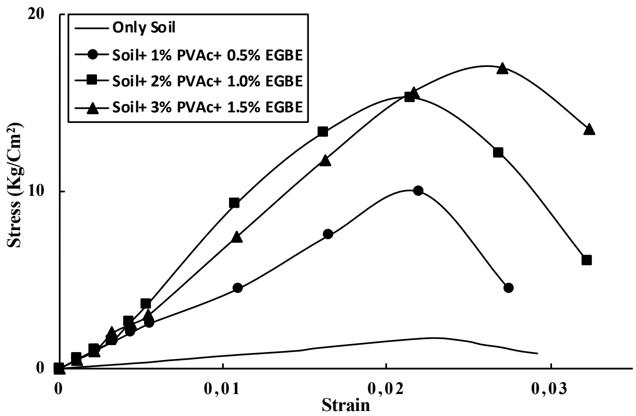

Fig. 15 Stress-strain graph of normal and stabilized samples with 7 freezing-thawing cycles

Table 4 E_{50} of different samples

E_{50} at Different Sample (Kg/cm^2)	
E_{50} = 312	Normal Soil
E_{50} = 436	Soil + 1% PVAc + 0.5% EGBE
E_{50} = 1200	Soil + 2% PVAc + 1.0% EGBE
E_{50} =1460	Soil + 3% PVAc + 1.5% EGBE

sample without any freezing-thawing effect could carry maximum stress of 35.37 Kg/cm^2 and it was 33.88 Kg/cm^2 after first cycle of freezing-thawing. Like previous stabilized samples there was not big differences before and after first cycle. But after fourth cycle of freezing-thawing, stress capacity of samples decreased to 19.20 Kg/cm^2, 16.94 Kg/cm^2 and 15.49 Kg/cm^2 at fourth, seventh and tenth cycles respectively. At the same time increasing percentages of additives caused an increase of stress in all samples at all freezing-thawing cycles.

By looking to all stress-strain graphs it found that exposing freezing-thawing to samples caused an increase on strain of samples. This increase is more considerable in samples with normal soil than stabilized samples. It has two reasons: 1. Because of bigger optimum moisture content of normal soil, freezing of more water caused bigger volume increase in normal samples and after melting the ice void ratio was increased so the samples showed more settlements. 2: adding PVAc+EGBE was caused increasing the strength of sample in front freezing effect.

Fig. 11 shows the maximum stress of normal and stabilized samples at different freezing-thawing cycles. As seen at this figure differences between first and fourth cycle of freezing-thawing is more considerable than other cycles. This difference increased by increasing the percentages of PVAc+EGBE. It means samples lost big amount of their strength at fourth cycles and after this cycle this loosing rate was small.

Rate of changes in maximum stress between zero and tenth cycle of freezing-thawing in samples with 3%PVAc+1.5% EGBE additive mixture was more than other types of samples. This rate was 228%, 175%, 177% and 204% for 3%PVAc, 2%PVAc, 1%PVAc and normal soil respectively.

Fig. 12 compare stress-strain graphs of normal and stabilized samples without any freezing-thawing effects. As seen at this graph by increasing amount of additives the maximum stress that samples could carry, were increased. It was increased from 3 Kg/cm^2 in normal soil to 35.37 Kg/cm^2 at samples with 3% of PVAc and 1.5% of EGBE. Amount of maximum stresses were 15.97 Kg/cm^2 and 25.42 Kg/cm^2 in samples with 1% and 2% PVAc respectively.

By looking to stress-strain graphs E_{50} (Secant modulus of soil) of samples can be calculated. As seen at Table 4, by increasing the amount of additive mixture, E_{50} of samples were increased too. E_{50} of normal soil was 312 Kg/cm^2 that with 40% increase, reached to 436 Kg/cm^2 in the samples with 1%PVAc + 0.5%EGBE.

The most effect was seen while percentages of PVAc increased from 1% to 2%. This increase was 275% that caused E_{50} reaches from 436 Kg/cm^2 to 1200 Kg/cm^2. At the next step by increasing percentages of PVAc from 2% to 3% amount of E_{50} with 21% increase reached to 1460 Kg/cm^2.

Stress-strain graphs of normal and stabilized samples were shown on Figs. 13, 14, 15 and 16 after one, four, seven and ten cycles of freezing-thawing respectively. As seen at all of these figures maximum stress of samples with 3% of PVAc + 1.5% EGBE were more than other types of samples.

At first cycle, the maximum stress of samples with 3% PVAc + 1.5% EGBE was 33.88 Kg/cm^2 that it was 23.38 Kg/cm^2 and 12.47 Kg/cm^2 for samples with 2% and 1% of PVAc respectively.

As seen at Fig. 14, after four cycle of freezing-thawing, maximum stress of samples with 3% PVAc + 1.5% EGBE with 43% decrease in comparison with first cycle of freezing-thawing reached to 19.20 Kg/cm^2. This amount of decrease was 28% and 13% for samples with 2%PVAc + 1% EGBE and 1% PVAc + 0.5% EGBE respectively after fourth cycle.

By looking to all graphs, it found that differences between maximum stress of samples with 3%PVAC + 1.5%EGBE and 2%PVAC + 1%EGBE were less that

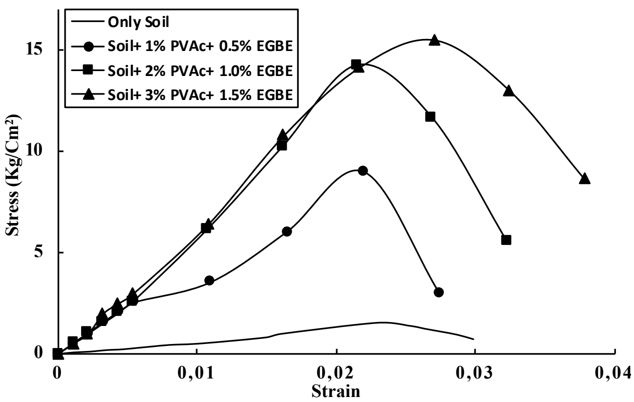

Fig. 16 Stress-strain graph of normal and stabilized samples with 10 freezing-thawing cycles

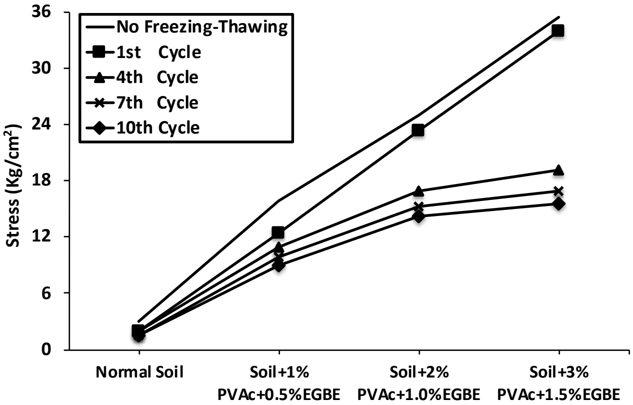

Fig. 17 Maximum stress of normal and stabilized samples at different freezing-thawing Cycles

differences of maximum stress of samples with 2%PVAC + 1%EGBE and 1%PVAC + 0.5%EGBE. On the other word effect of increasing of PVAc from 1% to 2% was more than while PVAc increased from 2% to 3%.

Another result gained from all tests was that, increasing percentages of PVAc + EGBE mixture were increased the strain of samples could carry at failure moment. Even at samples with 3% and 2% of PVAc that there were not big differences at maximum stress, the differences between strains of samples was considerable. It means by increasing amount of PVAc+EGBE as an additive the sample failed with bigger strain. Differences of strain between samples with 1% and 2% of PVAc were less than differences of samples with 2% and 3% of PVAc.

Fig. 17 shows maximum stress of normal and stabilized samples at different freezing-thawing cycles.

Behavior of stabilized samples before any freezing-thawing cycle and after first cycle of freezing-thawing was not so big. It means first cycle of freezing-thawing had not considerable effect on strength and durability of this types od samples and after first cycle of freezing-thawing, it shows its effect. Increasing percentages of PVAC+EGBE additives leaded to increasing differences between first and fourth cycle.

After fourth cycle of freezing-thawing, by increasing the numbers of cycles, rate of change in maximum stress of samples decreased. This was completely vivid at seventh and tenth freezing-thawing cycles. The positive effect of additives was considerable up to ten freezing-thawing cycles and this effect was not considerable after tenth cycles. So main tests and results continued up to ten cycles of freezing and thawing.

5. Conclusions

Adding Polyvinyl Acetate (PVAc) and Ethylene Glycol Monobutyl Ether (EGBE) as additives to sandy soil had positive effects on strength and durability of samples at different freezing-thawing cycles. Firstly, it decreased optimum moisture content of samples. This decrease in optimum moisture content causes samples reach to maximum density with less amount of water. Less water content of sample leads to less volume increase during freezing period and less increase in void ratio of frozen soil. So, it caused less damage on samples and had positive effect on soil behavior during freezing period. On the next step these additive mixtures improved durability and strength of samples up to ten freezing-thawing cycles too. After hardening the PVAc and EGBE the strength of samples was increased. Therefore, it will help improving aggregate behavior at the projects that both bearing capacity and durability of soil is important.

By considering the factors such as: test results, percentages and price of additives, this method can be applied for real projects such as stabilization of granular materials of pavements. By increasing amount of PVAc + EGBE percentage to soil, maximum bearing capacity of samples was increased.

The behavior of samples was different with different percentages of additives. Percentages of additives can be selected by final goal of soil improvement. By considering the result of tests it found that using 2% of PVAc will be better for increasing strength of samples at freezing-thawing cycles that if improving the settlement of soil was the purpose, using 3% of PVAc will get better results.

In other words, results showed that increasing amount of PVAc from 1% to 2% had more considerable effect on strength of sample in comparison that PVAc increased from 2% to 3%. If the main goal of a project is increasing maximum settlements and strains, then increasing percentages of PVAc + EGBE up to 3%+1.5% can be a better way.

After considering all graphs and results, PVAc + EGBE mixture improves strength and durability of samples up to ten cycles of freezing-thawing and percentages of this mixture depends on goal of a project.

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