Laboratory investigation of geotextile position on CBR of clayey sand soil under freeze-thaw cycle

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Abstract

In cold regions, soil experiences repetitive freeze–thaw cycles that are considered as one of the most important phenomena in cold region engineering. Approximately 30 percent of soils around the world and a large portion of fertile lands are subjected to daily or seasonal freeze-thaw cycles. These cycles cause considerable changes in water content, solute movement, permeability, strength parameters, erosion rate, and other physical or chemical characteristics of the soil. Nowadays, one of the ways for improvement the physical and mechanical characteristics of the soil is to incorporate geosynthetic material as a layer between the embankment and the ground surface. This paper presents results of some California Bearing Ratio tests a clayey sandy soil. Moreover, effect of freeze–thaw cycles on the compressive strength of geotextile-reinforced soil is investigated. The geotextile layer was placed in five positions in different depths of 1.3, 2.6, 3.9, 5.85 and 7.8 cm beneath the surface of the mold and then the sample was exposed to freeze-thaw cycles. It was found that the optimum depth of the geotextile layer is 3.9 cm. In addition, it could be observed that reinforcing the soil can diminish the weakening effect of freeze-thaw cycles up to 41.7%.

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1. Introduction

Freeze-thaw cycles are a common phenomenon in cold climates, which can cause considerable changes in physical or chemical characteristics of soil such as water content, solute movement, permeability, strength parameters, and erosion rate. Approximately 30 percent of soils around the world and a large portion of fertile lands are subjected to daily or seasonal freeze-thaw cycles. These cycles usually happen in early spring or late autumn and are more frequent in the upper parts of the gerund due to more severe temperature changes. These cycles could be repeated more than 100 times in some cases. An embankment constructed in a cold region in Canada was damaged by freeze-thaw cycles over a year due to the resulting decrease in load bearing capacity [1]. Highways which were left without pavement may be damaged by freeze-thaw cycles in few years [2].

Lafleur et al. [3] have performed unconfined compression tests on a clayey soil in order to evaluate and compare the effect of woven and nonwoven geotextile layers. It has shown that the woven geotextile has less contact productivity than the non-woven geotextile [3]. Yarbesi et al. [4] examined the stabilization effects of silica fume–lime, fly ash–lime, and red mud–cement additive mixtures on two different types of granular soil. The results indicate that the samples stabilized with these additive mixtures exhibit higher levels of freezing–thawing durability in comparison to unstabilized samples. Moreover, these additive mixtures have been shown to improve the dynamic characteristics of the specimens.

Hazirbaba and Gullu [5] utilized California Bearing Ratio (CBR) tests in order to evaluate the improving effects of geofiber and synthetic fluid additives on the performance of fine-grained soils under freeze-thaw cycles in soaked samples as well as unsoaked ones. For soaked samples it could be observed that adding geofibers alone can improve the CBR performance, while synthetic fluid treatment results in poor CBR performance. On the other hand, for the unsoaked samples simultaneous application of synthetic fluid and geofibers generally increased the resistance to freeze–thaw cycles. Observations also indicated that addition of synthetic fluid alone could not be very effective against the detrimental impact of freeze–thaw cycles for unsoaked samples [5].

A kaolinite clay sample reinforced by polypropylene fibers and steel was exposed to 10 closed-system freeze–thaw cycles by Ghazavi and Roustaie [6]. It was observed that as the number of cycles increases the unconfined compressive strength of clay samples decrease by 20–25%. In addition, inclusion of fibers increases the unconfined compressive strength of clay soil samples while decreasing the frost heave. For instance addition of 3% polypropylene fiber could increase the unconfined compressive strength of the soil specimens by 60% to 160% before and after the cycles being applied, while the frost heave was decreased by 70%.

The effect of freeze–thaw cycles on strength characteristics of soil specimens reinforced with geotextile layer was studied by Ghazavi and Roustaie using UU Triaxial compressive tests [7]. A geotextile layer was used to reinforce clayey soil samples at their mid-height. Then the samples were exposed to up to 9 closed-system cycles. Images of the samples were also taken using Computerized Tomography (CT). It was observed that the undrained triaxial compressive strength of unreinforced specimens decreases as a result of increasing the number of cycles. Reinforced samples however exhibit higher strength values and it was observed that the amount of strength reduction could be reduced from 43% to 14% by reinforcing the soil specimens. Using CT images it was revealed that the free water gradually moved down to the lower parts of the specimens through the voids Moreover, sample reinforcement was shown to be effective on reducing the changes in the values of cohesion and resilient modulus of the soil affected by freeze–thaw cycles [7].

Utilization of geosynthetic layers reduces the outward horizontal stresses transmitted to the underlying foundation soil from the overlying soil layer on the top. This is known as shear stress reduction effect of geosynthetics. This effect causes an increase an increase in the load-bearing capacity of the foundation soil by inducing general shear, rather than a local-shear failure. ([8]; [9]; [10]; [11]).

Tom and et al. [12] overviewed the influence of geotextile reinforcement on enhancing the strength of pavements. The effects of reinforcement layer position and application of multilayer geotextiles were studied. Soils were collected from three different sites with CBR value of 7.6, 12, and 12.9. Then, CBR tests were performed on subgrade soils with geotextile layer placed above the surface and at a 4 cm depth from the top surface in single and multiple layers. The significant role of geosynthetics in the design and maintenance of modern pavements was emphasized by this study. Moreover, the experimental results indicated that the strength of the subgrade could be increased as a result of geotextile reinforcement, which was shown to be more effective on the soil with the least CBR value. The improvement of the subgrade strength was more significant when the geotextile layer was placed at the top of the subgrade soil, where the CBR value increased from 7.6 to 13.6 for the unreinforced and reinforced soil samples, respectively. The use of multilayer reinforcement was shown to be uneconomical since the increase in the CBR values was not considerable compared to single layer reinforcement.

Michael and Vinod [13] attempted to investigate the application of different types of coir geotextile materials on reinforcing the subgrade. Reinforced and unreinforced soil samples were subjected to Soaked California Bearing Ratio tests. Five different types of geotextiles were used in the study and the effects of placement position and stiffness of the material were examined. Geotextile layers were cut to the size of the mold and were placed in 0.2, 0.4, 0.6, and 0.8 ratios of the total depth of it (12 cm). The results indicated that inclusion of coir geotextiles could have an enhancing effect on the results of CBR tests. The CBR of value of the unreinforced saturated sample was 18.2%, which have increased by 18.6% to 36% for different placement depths. For different types of geotextile material the maximum CBR ratio improvement is observed to be in the range of 1.37 to 1.97, while the smallest values of CBR were obtained when the geotextile layer is placed at 0.2 ratio of the mold's total depth.

2. Materials

2.1. Soil

In this paper laboratory tests were performed on clayey sand soil classified as SC in Unified Soil classification System [14]. Clayey sand soil is an inseparable part of pavements and highly vulnerable to freeze-thaw cycles. Grain size distribution curves is shown in Fig.1. Standard Proctor Compaction tests were conducted on the soil and a maximum dry mass density and optimum moisture of approximately 20.11 kN/m^3 and 10% was obtained as shown in Fig. 2.

2.2. Geotextile material

HYTEX-62-nonweven geotextile material is used to reinforce the specimens for which physical and mechanical properties are summarized in Table 1.

3. Details of the experiments

The main goal of this research is to investigate the effect of geotextile reinforcement on the CBR values of highly compressible clayey soil exposed to freeze-thaw cycles. The soil is compacted at maximum dry density with the optimum water content based on Standard Test Method for CBR of laboratory compacted soil [15]. Two freeze-thaw cycles were applied to the specimens according to Standard Test Methods for Frost Heave and Thaw Weakening

Susceptibility of Soils [16]. The optimum placement depth of geotextile material is attempted to be determined.

3.1. Specimen preparation

The optimum moisture content, which was previously determined in the specimen preparation procedure (part 2.1) was added to the soil. Afterwards the combination is sealed in two-layer plastic bags for 24 hours in order to make the moisture content inside the soil specimen uniform. Water content was examined before and after preparation of the specimens [17]. One of the soil samples was compacted without any geotextile layer using the automatic compaction apparatus, while five other samples were prepared by placing one layer of geotextile layers at different depths of 1.3, 2.6, 3.9, 5.85 and 7.8 cm beneath the standard CBR mold which is schematically shown in fig 3. The abovementioned procedure was repeated for the freeze-thaw tests whereas the samples were completely sealed using paraffin and plastic layers. During the compaction, the soil container was immediately protected from extra moisture content using a plastic layer. The same action is taken to protect the soil samples after the compaction is completed.

3.2. CBR test

CBR is an easy and economical test for measuring the bearing capacity of sub-bases and subgrades of road pavements and airfields. The CBR of a soil is defined as the ratio of stress required to cause a standard piston to penetrate 2.54 mm and 5.08 mm into the soil with maximum dry density to a standard penetration stress at each depth of penetration [15].In this study the CBR tests were carried out according to ASTM D, 1883–2007, where the diameter and height of the utilized standard unsoaked molds are 15.2cm and 11.7cm, respectively and the diameter of the CBR apparatus piston is 5cm. Modified Proctor compaction energy was used for the CBR samples in accordance with ASTM D 1557–2007. CBR tests were performed in unsoaked conditions. The CBR values reported in this paper represent the average of two samples based on Yoder and Witczak research [18].

3.3. Freeze-thaw cycles

Freeze-thaw cycles are among the most effective phenomena, which can weaken the soil. The aim of this study is to present useful information about frost heave potential, thaw weakening, and the effect of freezing and thawing cycles on CBR performance. In this study it is assumed that no external source of water is available during the freezing process and therefore the change in in-situ water content during summer and winter is negligible. Since freezing of in-situ soils usually occurs from the top and lateral freezing can be neglected [19], one-directional freezing was simulated by applying insulation at the bottom and around the CBR mold. The details of the freeze–thaw setup are demonstrated schematically in Fig. 4. According to the existence of external water sources, the freeze thaw cycles can occur in two systems, closed and open. Since fine grained soils have low permeability and the traffic loading period is short, a closed system could be a proper choice for modelling freeze thaw cycles in these type of soils.

A wide variety of freezing temperatures and durations could be selected based on the type of soil and its location. According to Cook (1963), the majority of deteriorative effects on the strength of compacted soils occur within the first three cycles [20]. In order to investigate the changes in natural freezing conditions, Chamberlain [19] proposed to employ at least two freeze–thaw cycles. It was observed by Lee et al. [21] that for simulating of the soil effects of freeze–thaw on the resilient characteristics of cohesive soils one or two freeze–thaw cycles are sufficient. It should be noted that ASTM D 5918-06 also recommends two freeze-thaw cycles. As an initial cycle it is suggested that the sample is frozen by holding the temperature at -3°C for 8 h. Then the freezing procedure is applied through the top of the sample by lowering the temperature holding it at -12°C for 16 h. After raising the temperature and holding it at +12°C for 16 h, it is held at 3°C for another 8 h. The second cycle is the same as the first one. Hence, in this study two freeze-thaw cycles based on ASTM D 5918-06 were imposed on compacted soil samples. The soil sample was frozen and thawed by applying specified constant temperatures gradually to the sample, while a surcharge of 3.5 kPa was applied to the top. At the end of the second thawing cycle, the bearing ratio was determined. The entire testing procedure was completed within a five-day period. Table 2 demonstrates temperature setting and timing.

The water content should remain constant during the five-day period of freeze-thaw cycles since small changes in water content may introduce noticeable errors on CBR values. Therefore, the top and bottom parts of the samples were sealed by paraffin and plastic. The water content was examined before compaction and after the CBR tests and compared to the optimum moisture content that has been reported.

4. Results

4.1. Improving effects of geotextile

The CBR values are commonly reported for standard piston penetrations of 2.54 mm and 5.08 mm. Generally, soil samples reinforced by geotextile exhibit more strength compared to unreinforced ones regardless of the position of the reinforcing layer. Soil has a high compressive strength and a low *tensile strength, for which the geotextile layer compensates. In the failure area of the soil, the* geotextile starts to deform and absorb the tensile stresses. The effect of geotextile reduces as the distance between the failure area and the geotextile layer beneath it increases. The positions of five geotextile layers are at the depths of 1.3, 2.6, 3.9, 5.85 and 7.8 cm, beneath the standard CBR mold, respectively. Fig 5 demonstrates the pressure values versus penetration for the unreinforced and reinforced samples.

Table 3 presents the CBR values for standard penetration depths of 2.5 mm and 5 mm for different geotextile positions. The results indicate that the optimum position of the geotextile layer, for which the highest value of CBR is obtained, is 3.9 cm beneath the standard CBR mold. Moving away from the optimum layer (layer three), the impact of the geotextile layer becomes less significant. Putting one layer of reinforcement at 100% depth of CBR mold, performs as well as having no reinforcement in the sample [22]. So, for the geotextile layer placed at the depth of 7.8cm (layer 5), the CBR value is approximately equal to that of the unreinforced sample.

According to ASTM D 1883-07, when the value of CBR for 5 mm is higher than that of 2.5 mm, the criterion for measuring the strength of the soil is the CBR value for 5 mm penetration [15]. Improvement percentages of the strengths of reinforced soil samples compared to unreinforced sample are shown in Table 4.

Based on the data presented in table 3, placing the geotextile at the depth of 3.9 cm beneath the CBR mold can improve the strength of the sample by a considerable ratio of 42.2%. By comparing the result obtained for layer 5 with the other layers, it could be seen that placing the geotextile layer at the depth of 7.8 cm or more in the standard CBR mold, doesn’t result in noticeable improvements. The result for this case is almost the same as the unreinforced sample.

4.2. Freezing and thawing performance

Freeze-thaw cycles generally have negative effects on strength of the soils and deduct the CBR values. Geosynthetics have successfully been used in cold zones to improve the efficiency of roadways [23]. Utilizing geotextile layers can reduce the adverse effects of freeze-thaw cycles. To examine this, samples were subjected to two freeze-thaw cycles according to Standard Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils [16]. Fig 6 presents the pressure values versus penetration for the unreinforced and reinforced samples under freeze-thaw cycles. The CBR values for the standard penetrations of 2.5 mm and 5 mm under freeze-thaw cycles for different geotextile positions are summarized in Table 5. The results show that the optimum position of the geotextile layer, which corresponds to the highest value of CBR is 3.9 cm beneath the standard CBR mold.

Improvement percentages of the strengths of reinforced soil samples compared to unreinforced sample under the freeze-thaw cycles are shown in Table 6.

From Table 6 it can be seen that under the freeze- thaw cycles positioning the geotextile layer at the depth of 3.9 cm beneath the CBR mold can improve the strength of the sample by a significant ratio of 41.7% compared to the unreinforced sample.

For the reason that the CBR samples are large among the other soil samples, two temperature sensors were set inside of the soil samples in order to be sure about the temperature adaptation between the freezer and inside of the sample. Fig 7 shows the temperature of freezer and inside of the CBR sample during the first freeze-thaw cycle. Regarding to this figure, it can be said that although the temperature variation of the soil sample is less than the changes of freezer temperature change, but after about four hours from the beginning of the cycle, temperature of central part of the sample will reached a freezer temperature.

Fig 8 demonstrates the CBR values with and without freeze-thaw cycles. It can be seen that, in both conditions the use of geotextile layer has an improving effect on the CBR values of the soil samples. CBR value for the unreinforced sample was decreased by about 61.6% under the effect of freeze-thaw cycles and placing a geotextile layer at the optimum depth (layer 3) can reduce the effect of freeze-thaw up to 16%.For the non-optimal depths of geotextile layer, increasing the placement depth layer reduces the CBR values.

The alterations in mechanical characteristics of the specimens are resulted from the alterations in its physical conditions during the freeze-thaw cycles. As it can be seen in Table 1, since the geotextile layer is permeable, it allows water to pass through it freely. Ice crystals which are formed during the freezing phase start to melt during the thawing phase and therefore free water could be seen in the specimen. Gravity force makes this free water move down in the specimen and the process is facilitated by the permeability of the geotextile layer. By measuring water contents in different parts of the reinforced samples after exposure to freeze-thaw cycles the above phenomenon can be confirmed. As it is anticipated the lower parts of the specimen exhibit higher water content values than the upper parts. Nonetheless, the difference is more significant for reinforced samples since the geotextile layer drains water from the upper parts of the specimen. Therefore, as the number of cycles and the number of enlarged pores left after the thawing phase increases the strength of the soil sample is reduced. This can explain the improving effect of reinforcement on the strength decrease of the soil samples since lower water content results in the upper part of the soil sample being more resistant.

5. Conclusions

In this paper, an experimental study was carried out in order to investigate the improving effects of geotextile layers in different positions on the CBR strength and freeze–thaw performance of a clayey sand soil. The main conclusions of this study can be summarized as:

- Existence of a single layer of geotextile in the soil generally results in an increase in the load bearing capacity and CBR value of the soil.

- By increasing the penetration depth of the standard CBR piston in the soil, the CBR values increase due to more geotextile deformation and higher tensile stress absorption through the soil.

- For the clayey sand soil which is tested in this study, the optimum geotextile position is approximately at the depth of 3.9 cm beneath the standard CBR mold. By placing a single layer of geotextile at the depth of 3.9, the CBR value can be increased by up to 42.2% in comparison to the unreinforced specimen.
- By taking distance from the optimum placement depth of the geotextile layer, the improvement decrease. It can be observed that at the depth of 7.8 cm the CBR values for the reinforced and the unreinforced samples are practically the same. This can be result of low radius effect.
- Freeze-thaw cycles decrease the CBR values in both reinforced and unreinforced samples by about 61-66%. This phenomenon can be due to drainage function of the geotextile layer which drains water from the upper parts of the specimen. Therefore, as the number of cycles and the number of enlarged pores left after the thawing phase increases, the strength of the soil sample is reduced.
- Existence of a non-woven geotextile layer can reduce the effects of freeze-thaw cycles. The most significant improving effect of geotextile reinforcement is to decrease the reducing effect of freeze-thaw cycles form 61.6% to 45.6% by placing the geotextile layer at the optimum depth. Comparison

of the results for the unreinforced and reinforced samples indicate that placing the geotextile layer at the optimum depth can increase the CBR value by about 41.7%.

Based on the observations of this paper, utilization of geotextile layers in cold regions, where shallower soil layers can be subject to freeze-thaw cycles is generally recommended. Using geotextile layers increases the peak strength of the soil while decreasing the negative effects of freeze-thaw cycles. This can generally result in a significant reduction of maintenance costs of the buildings and pavements.

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Fig captions

Fig. 1 Grain size distribution of the clayey sand soil

Fig. 2 Dry density versus moisture content of clayey sand by modified Proctor compaction

Fig. 3 Placement of geotextile at different depth in CBR mold

Fig. 4 schematic of the CBR test setup

a) Plan view of insulated CBR sample

b) Close up cross section of an insulated CBR sample

Fig. 5 Pressure versus penetration for samples with different geotextile positions

Fig. 6 Pressure versus penetration for samples with different geotextile positions under two freeze-thaw cycles according to ASTM D 5918-06.

Fig. 7 Temperature of freezer and reinforced CBR samples in a cycle

Fig. 8 Comparison of the CBR values for the unreinforced and reinforced soil samples with and without freeze-thaw cycles

Table captions

Table 1 Physical and mechanical properties of the geotextile material (HYTEX-62-nonweven)

Table 2 boundary temperature conditions

Table 3 CBR values for standard penetrations of 2.5 mm and 5 mm

Table 4 Improvements of the soil strength

Table 5 CBR values for standard penetration of 2.5 mm and 5 mm under freeze-thaw cycles

Table 6 Improvements of the soil strength under the freeze-thaw cycles

Fig 1

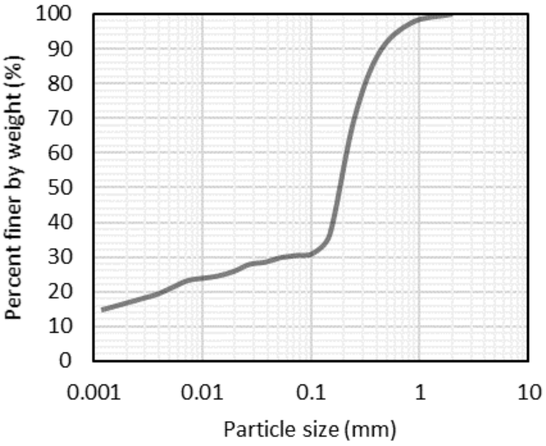

Percent finer by weight (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
Particle size (mm)

Fig 2

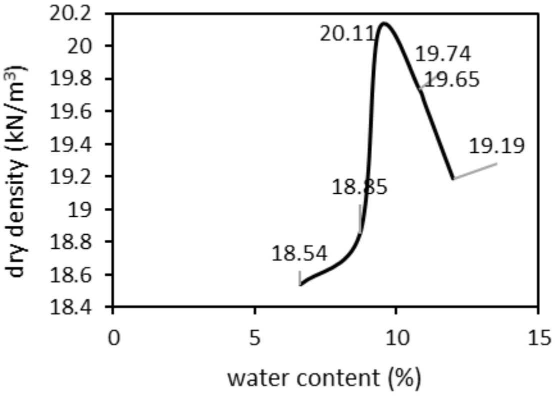

20.2
20
19.8
19.6
19.4
19.2
19
18.8
18.6
18.4
dry density (kN/m3)
0
5
10
15
water content (%)
20.11
19.74
19.65
19.19
18.85
18.54

Fig 3

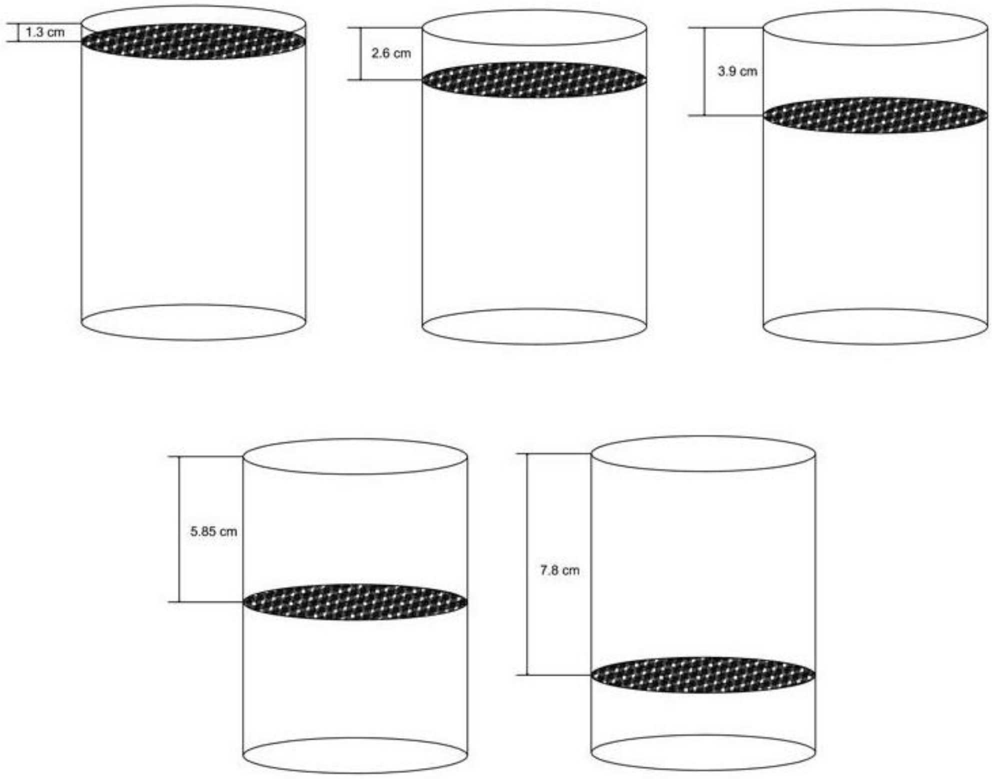


Fig 4 a

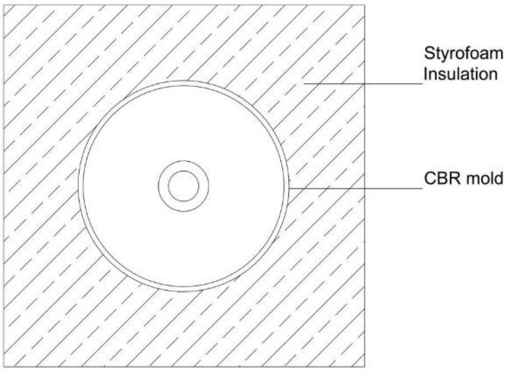

Styrofoam
Insulation
CBR mold

Fig 4 b

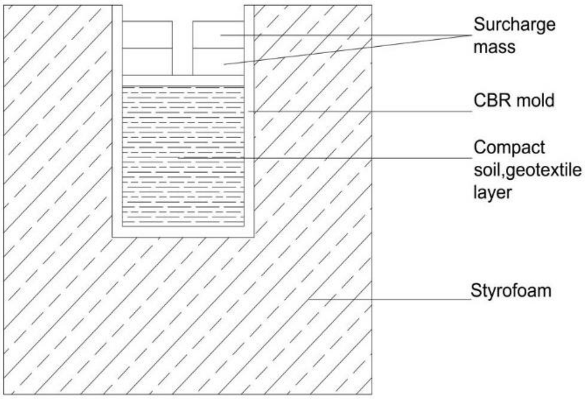

Surcharge
mass
CBR mold
Compact
soil,geotextile
layer
Styrofoam

Fig 5

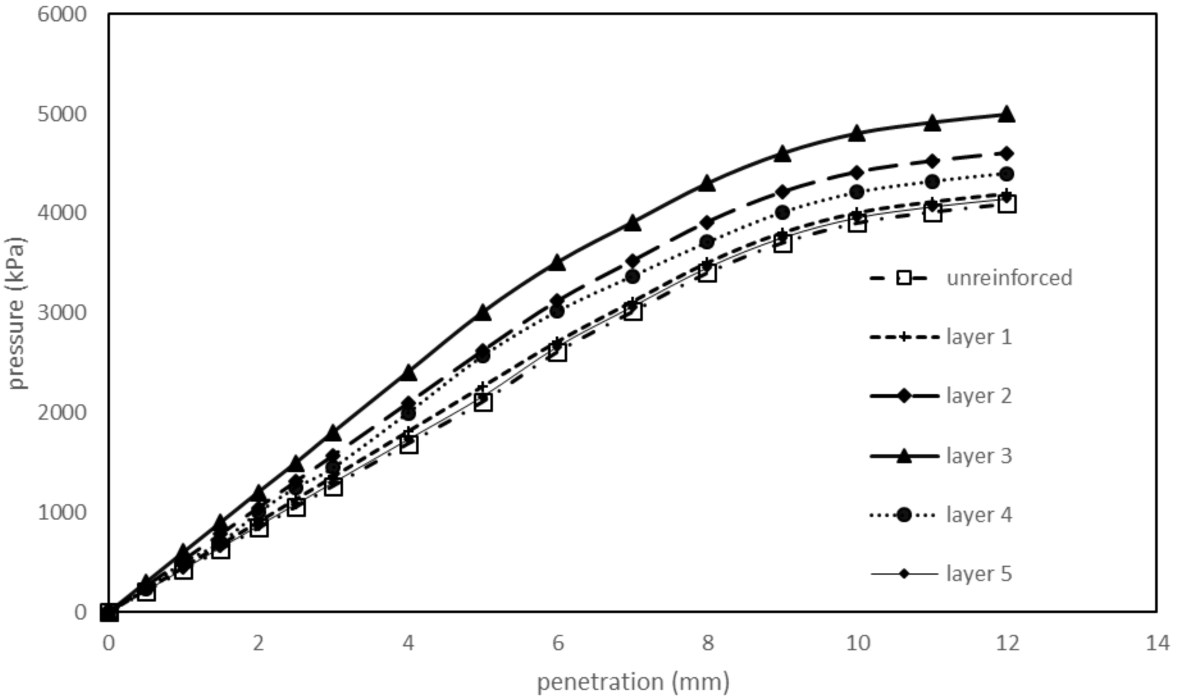

6000
5000
4000
3000
2000
1000
0
pressure (kPa)
0
2
4
6
8
10
12
14
penetration (mm)
unreinforced
layer 1
layer 2
layer 3
layer 4
layer 5

Fig 6

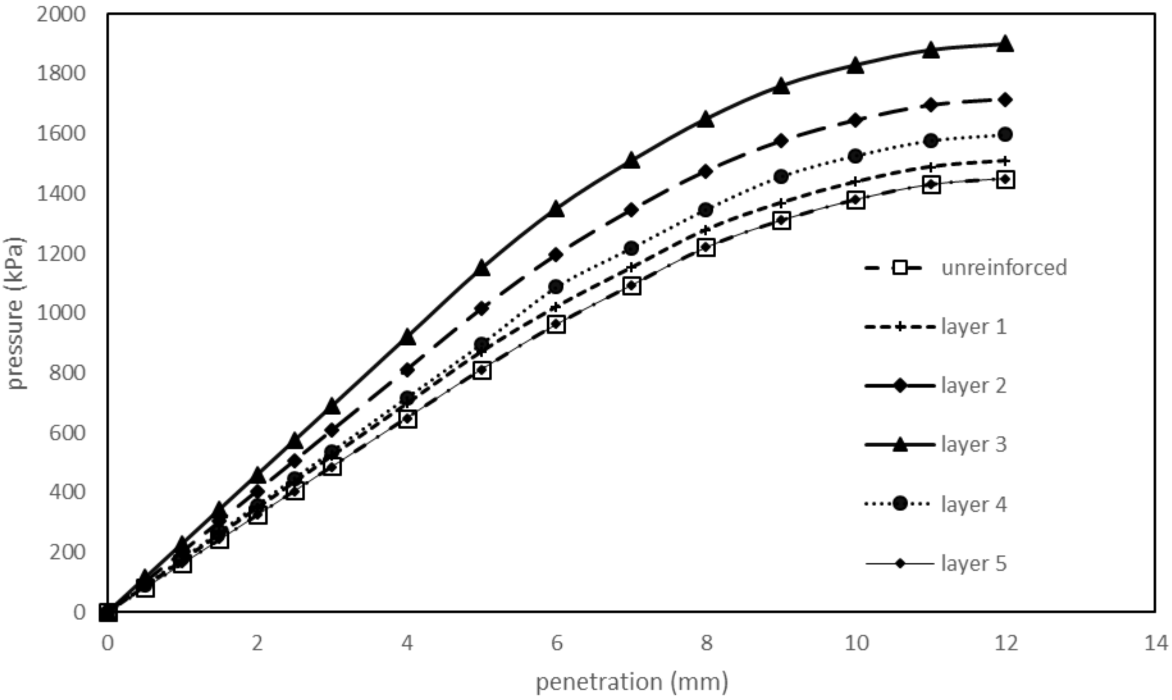
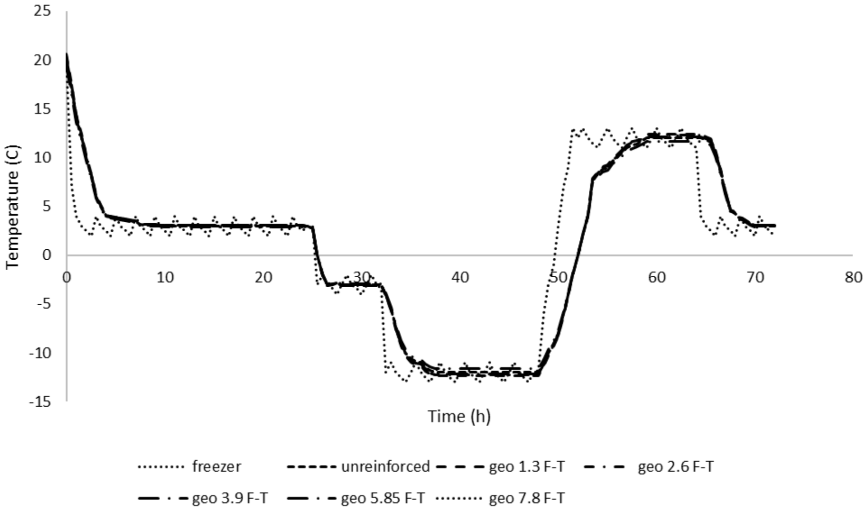

2000
1800
1600
1400
1200
1000
800
600
400
200
0
pressure (kPa)
0
2
4
6
8
10
12
14
penetration (mm)
unreinforced
layer 1
layer 2
layer 3
layer 4
layer 5

Fig 7



25
20
15
10
5
0
-5
-10
-15
Temperature (C)
0
10
20
30
40
50
60
70
80
Time (h)
freezer
unreinforced
geo 1.3 F-T
geo 2.6 F-T
geo 3.9 F-T
geo 5.85 F-T
geo 7.8 F-T

Fig 8

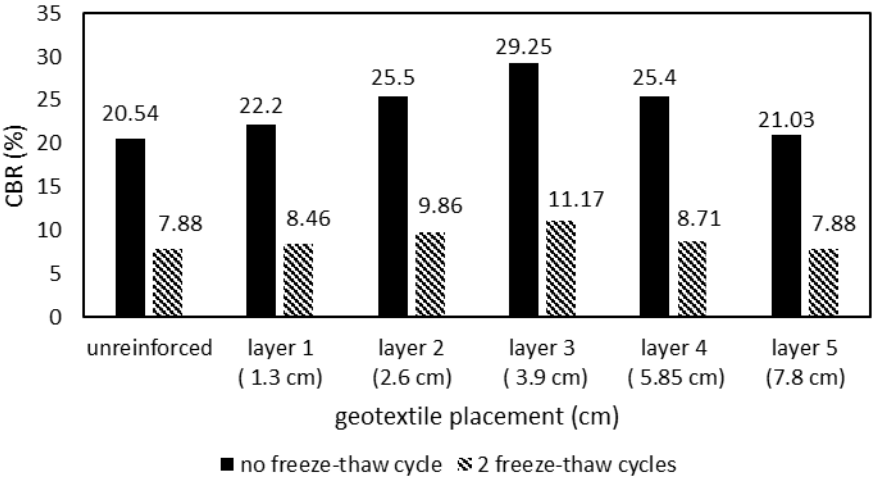

35
30
25
20
15
10
5
0
CBR (%)
20.54
7.88
22.2
8.46
25.5
9.86
29.25
11.17
25.4
8.71
21.03
7.88
unreinforced
layer 1 (1.3 cm)
layer 2 (2.6 cm)
layer 3 (3.9 cm)
layer 4 (5.85 cm)
layer 5 (7.8 cm)
geotextile placement (cm)
■ no freeze-thaw cycle
▨ 2 freeze-thaw cycles

Table 1

Geotextile properties	**Value (unit)**
thickness	3.3 (mm)
CBR puncture resistance	6200 (N)
Tensile strength	39 (kN/m)
Water permeability	55×10-3 (m/s)
Opening size	70 (μm)

Table 2

day	Elapsed time (h)	Top temperature (°C)	Comments
1	0	3	24 hour conditioning
2	24	-3	First 8 hours freeze
	32	-12	Freeze to bottom
3	48	12	First thaw
	64	3	
4	72	-3	Second 8 hours freeze
	80	-12	Freeze to bottom
5	96	12	Second thaw
	112 to 120	3	

Table 3

Sample condition	**Depth of geotextile layer(cm)**	**CBR value for 2.5 mm penetration**	**CBR value for 5 mm penetration**
unreinforced	-	10.54	20.54
reinforced	1.3 (layer 1)	12.02	22.2
	2.6 (layer 2)	14	25.5
	3.9 (layer 3)	15.7	29.25
	5.85 (layer 4)	13	25.4
	7.8 (layer 5)	11.3	21.03

Table 4

Sample condition	**Depth of geotextile layer(cm)**	**CBR value for 5 mm penetration**
unreinforced	-	-
reinforced	1.3 (layer 1)	8.08%
	2.6 (layer 2)	24.14%
	3.9 (layer 3)	42.4%
	5.85 (layer 4)	23.6%
	7.8 (layer 5)	2.3%

Table 5

Sample condition	**Depth of geotextile layer(cm)**	**CBR value for 2.5 mm penetration**	**CBR value for 5 mm penetration**
unreinforced	-	4.17	7.88
reinforced	1.3 (layer 1)	4.29	8.46
	2.6 (layer 2)	4.9	9.86
	3.9 (layer 3)	5.64	11.17
	5.85 (layer 4)	4.41	8.71
	7.8 (layer 5)	4.17	7.88

Table 6

Sample condition	**Depth of geotextile layer(cm)**	**CBR value for 5 mm penetration**
unreinforced	-	-
reinforced	1.3 (layer 1)	7.3%
	2.6 (layer 2)	25%
	3.9 (layer 3)	41.7%
	5.85 (layer 4)	10.5%
	7.8 (layer 5)	0%