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Original Research

Laboratory evaluation of mechanical behavior of normal and Geotextile Reinforced Soils (GRS) under intermittent freeze-thaw conditions

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ABSTRACT:

The present paper investigated the effect of temperature reduction on shear strength parameters of soil using a tri axial test. This test consisted of a cylindrical soil sample exposed to a uniform mall-round confining pressure, and then an extra vertical load was exposed until its failure. In the first phase, five different tests were done at different temperatures; and the reduction of sample strength was studied due to the temperature reduction from 23°C to -32°C. Results of these test indicated that temperature variation had a significant negative effect on shear strength parameters of the soil. Reduction of soil cohesion was the greatest effect of temperature. An increase in the period of temperature variation led to soil failure in lower strain. Reduced percentage of angle of internal friction of soil during temperature variation was also less than soil cohesion. Finally, addition of geo textile to soil samples increased shear strength parameters of the soil.

Keywords:

Triaxial test, Temperature variation, Stress-strain diagram, Geotextile.

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INTRODUCTION

Most of the large cold zones, where a thick layer of soil is frozen seasonally or permanently, are located in active earthquake-prone areas. It seems that some of damages to structures during earthquakes are directly related to frozen ground and ice formation. For instance, a research, which was conducted in Alaska and Iowa states, clearly confirmed the importance of frozen ground effects on the stress of bridge bases against earthquakes (Ghazavi and Roustaei, 2013). It is significantly important to evaluate effect of frozen soil on the performance of upper buildings against earthquakes. Therefore, there is a need for a precise and reliable assessment of mechanical properties of the soil (Liu *et al*., 2010). In the present research, the effect of temperature reduction on shear strength parameters of soil using a triaxialtest has been performed which shows promising results.

In cold areas, soil infrastructures may be exposed to alternate freeze–thaw cycles throughout the cold seasons. Therefore, study on the effect of freeze–thaw cycles on mechanical properties of soil can be considered as a major issue in designing soil structures at in cold areas regions (Mirmoradi and Noorzad, 2010). An element with tensile strength is used to increase mechanical properties of the soil in traction and increase load bearing capacity and prevent loss of soil strength due to intermittent freeze – thaw. This method is associated with reinforcement by the help of geo-synthetics (Kalkan, 2009). Mechanism of action and behaviour of reinforced soil with geo-synthetics is based on the interactions between soil and reinforcing element; and friction phenomenon between soil and element plays a significant role in this field (Hazirbaba and Gullu, 2010). Application of reinforcing elements increases soil strength due to the provision of tensile force resulted from there in forcing elements and thus horizontal deformation decreases and overall stability of reinforced soil structure increases (Zaimoglu, 2010). In cold areas, sand-clay liners may be exposed to alternate freeze–thaw cycles during the cold seasons. It can significantly affect tensile strength and interaction between soil and geotextile, and reduce structure efficiency in long term. (Wang *et al*., 2007)

Since use of geotextile as are in forcing element is increasing in structures of earth dams, highways and retaining walls, it is necessary to study the mechanical properties of reinforced soil at different atmospheric conditions. Since use of geotextile as are in forcing element is increasing in structures of earth dams, highways and retaining walls, it is necessary to study the mechanical properties of reinforced soil in at different atmospheric conditions. geotextile as a reinforcing element is increasing in structures of earth dams, highways and

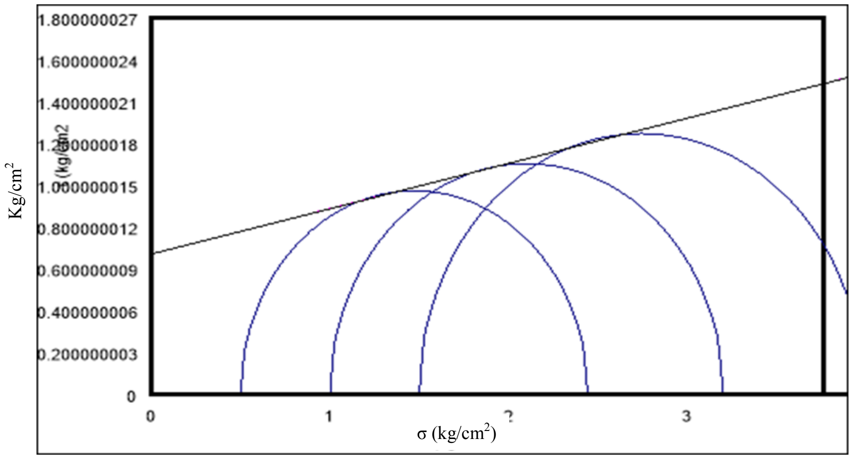

Figure 1. Mohr-Coulomb failure baseline at temperature of 23°C

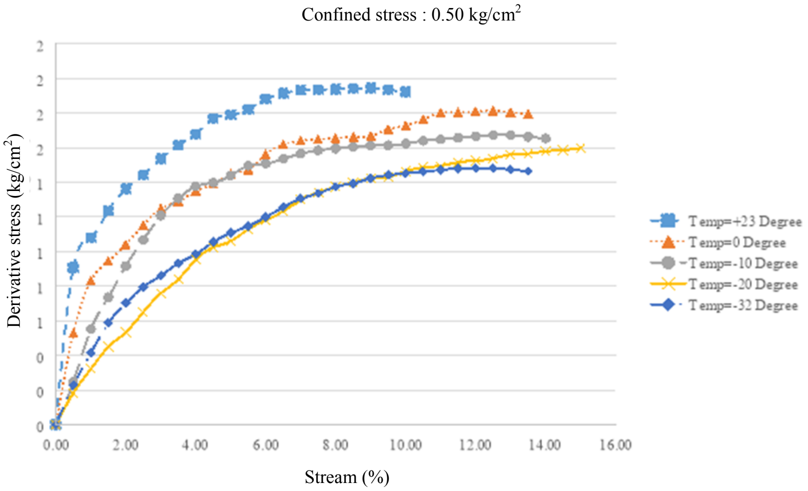

Figure 2. Stress-strain diagram at various temperatures and constant confining pressure of 0.5 kg/cm^2

retaining walls, it is necessary to study mechanical properties of reinforced soil different atmospheric conditions.

In cold weather areas, reinforced soils with geosynthetics in earth dams and gables may be exposed to intermittent freeze–thaw cycles throughout the cold seasons. Therefore, study on the effects of freeze–thaw cycles on mechanical properties of soil can be considered as a major issue in designing earth dams and gables in regions with cold climate. Freeze-thaw phenomenon affects the soil structure. When soil temperature is reduced to less than 0°C, water particles at soil pores are cold and ice formed. As a result of this phase change, the hexagonal crystalline structure of water expands to about 9%. These crystalline particles grow as long as other crystalline particles prevent or become close to solid particles of the soil (Andersland and Anderson, 1978).

When surface temperature of soil is less than 0° C, a frozen front is formed on the soil surface. Due to lower pore water pressure in frozen front, water flows from underlying layers to frozen boundaries and moves into the frozen soils. Even if soil has no access to external water, this water also freezes, and thus the frozen front moves from surface of the soil to internal layers. Due to the high and negative pore water pressure and water movement, contraction cracks in soil under front freeze were formed in the vertical direction.

Due to the progression of frozen front, these cracks will be filled ice, but some ice melts, and become

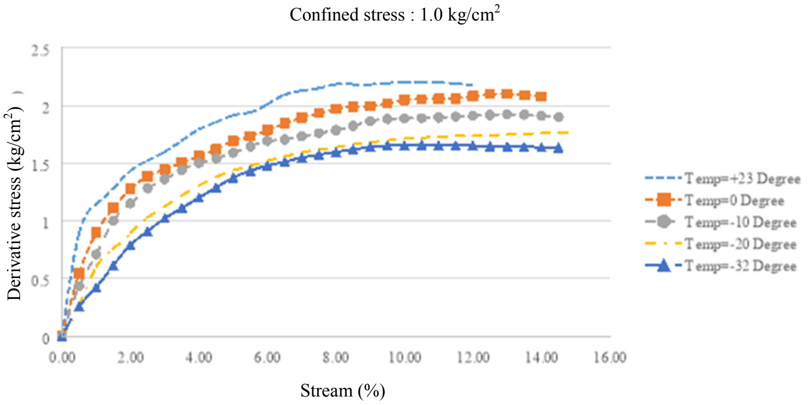

Figure 3. Stress-strain diagram at various temperatures and constant confining pressure of 0.1 kg/cm^2

Table 1. Triaxial test readings for a storage temperature of 23°C

	3		f'=	0.167	f'=	0.167	f'=	0.170
Δh	e	Ac	**σ3=**	0.50	**σ3=**	1.00	**σ3=**	1.50
0.001 "	Δh/ h*100	cm^2	a	F/A	a	F/A	a	F/A
0	0.00	11.4009	0	0	0	0	0	0
15	0.50	11.4582	36	0.529	37	0.54568	34	0.508
30	1.00	11.5161	57	0.831	62	0.89924	55	0.813
45	1.50	11.5745	66	0.945	77	1.11415	74	1.090
60	2.00	11.6336	73	1.041	89	1.27645	90	1.322
75	2.50	11.6932	81	1.153	97	1.3869	103	1.493
90	3.00	11.7535	88	1.247	102	1.44628	113	1.636
105	3.50	11.8144	91	1.290	106	1.50498	121	1.736
120	4.00	11.8760	96	1.349	111	1.56299	128	1.827
135	4.50	11.9381	99	1.391	116	1.62032	135	1.916
150	5.00	12.0010	104	1.449	122	1.69324	136	1.931
165	5.50	12.0645	106	1.474	125	1.73292	139	1.961
180	6.00	12.1286	113	1.563	130	1.78819	143	2.000
195	6.50	12.1935	118	1.618	135	1.84277	148	2.062
210	7.00	12.2591	121	1.642	139	1.89667	153	2.115
225	7.50	12.3253	122	1.649	143	1.93403	160	2.200
240	8.00	12.3923	123	1.656	146	1.97088	162	2.228
255	8.50	12.4600	124	1.662	149	1.99153	166	2.271
270	9.00	12.5285	125	1.669	150	1.99625	167	2.267
285	9.50	12.5977	129	1.706	152	2.0163	168	2.262
300	10.00	12.6677	131	1.728	156	2.05143	169	2.273
315	10.50	12.7385	135	1.764	157	2.05537	173	2.314

a critical cracks for water flow (Benson and Othman, 1993). Number and size of ice lenses depend on relative magnitude of freezing rate and availability of water. In a small temperature gradient, the progression of frozen front is slower, and thus water has more time to accumulate in a fixed location; hence, thicker ice lenses are formed. Due to the increase in freezing rate (by increasing temperature gradient), there is less time for growth of ice lenses, and frozen front progresses fast, so that more ice lenses with smaller thicknesses and distances and then more cracks are created. These soil cracks reduce interaction between soil and its reinforcing element and on the other hand, they reduce mechanical properties of the soil. According to Nerpin and Chudnovskii (1967), freeze–thaw phenomenon does not have any significant effect on the structures of Geo-synthetic Clay Liner (GCL). The present study investigated the effects of freeze–thaw cycles on the mechanical properties of cohesive Geo-textile Reinforced Soil (GRS) under tri axial test.

Table 2. Values of angle of internal friction and cohesion at different temperatures and normal state

S. No	Temperature (°C)	Angle of internal friction (degree)	Cohesion (kg/cm^2)
1	23	12	0.67
2	0	12	0.62
3	-10	11	0.59
4	-20	10	0.57
5	-32	9	0.54

Table 3. Tri axial test readings with one-layer geo textile for storage temperature at 0°C

Δh 0.001"	e Δh/h*100	Ac cm^2	σ3= a	0.50 F/A	σ3= a	1.00 F/A	σ3= a	1.50 F/A
0	0.00	11.4009	0	0	0	0	0	0
15	0.50	11.4582	36	0.529	37	0.5457	34	0.508
30	1.00	11.5161	57	0.831	62	0.8992	55	0.813
45	1.50	11.5745	66	0.945	77	1.1141	74	1.090
60	2.00	11.6336	73	1.041	89	1.2764	90	1.322
75	2.50	11.6932	81	1.153	97	1.3869	103	1.493
90	3.00	11.7535	88	1.247	102	1.4463	113	1.636
105	3.50	11.8144	91	1.290	106	1.505	121	1.736
120	4.00	11.8760	96	1.349	111	1.563	128	1.827
135	4.50	11.9381	99	1.391	116	1.6203	135	1.916
150	5.00	12.0010	104	1.449	122	1.6932	136	1.931
165	5.50	12.0645	106	1.474	125	1.7329	139	1.961
180	6.00	12.1286	113	1.563	130	1.7882	143	2.000
195	6.50	12.1935	118	1.618	135	1.8428	148	2.062
210	7.00	12.2591	121	1.642	139	1.8967	153	2.115
225	7.50	12.3253	122	1.649	143	1.934	160	2.200
240	8.00	12.3923	123	1.656	146	1.9709	162	2.228
255	8.50	12.4600	124	1.662	149	1.9915	166	2.271
270	9.00	12.5285	125	1.669	150	1.9962	167	2.267
285	9.50	12.5977	129	1.706	152	2.0163	168	2.262
300	10.00	12.6677	131	1.728	156	2.0514	169	2.273
315	10.50	12.7385	135	1.764	157	2.0554	173	2.314
330	11.00	12.8100	138	1.800	158	2.0591	176	2.332
345	11.50	12.8824	139	1.805	159	2.0627	177	2.342
360	12.00	12.9556	140	1.810	161	2.0813	178	2.336
375	12.50	13.0296	142	1.814	164	2.0994	179	2.331
390	13.00	13.1045	142	1.804	165	2.1023	180	2.332
405	13.50	13.1803	142	1.794	165	2.0902	180	2.327

MATERIALS AND METHODS

The present research used a tri axial pressure test to determine shear strength of the soil and determine stress-strain behavior of soil under different confining pressures. This test consisted of a cylindrical soil sample exposed to an uniform all-round confining pressure, and then an extra vertical load was exposed until the failure moment. In the first case, five different tests were done at different temperatures and reduction of sample strength was investigated after temperature education from 23°C to -32°C. In the second case, a geo textile layer was placed in the center of the sample under same conditions; and a two-layer geo textile was placed in a laboratory sample at different temperatures, and strain-strain graphs and plastic specifications were evaluated at the next stage (Zhu and Carbee, 1984).

Table 4. Values of angle of internal friction and cohesion at different temperatures with one-layer geo textile

S. No	Temperature (°C)	Angle of internal friction (degree)	Cohesion (kg/cm^2)
1	23	12	0.89
2	0	12	0.82
3	-10	11	0.80
4	-20	10	0.77
5	-32	10	0.75

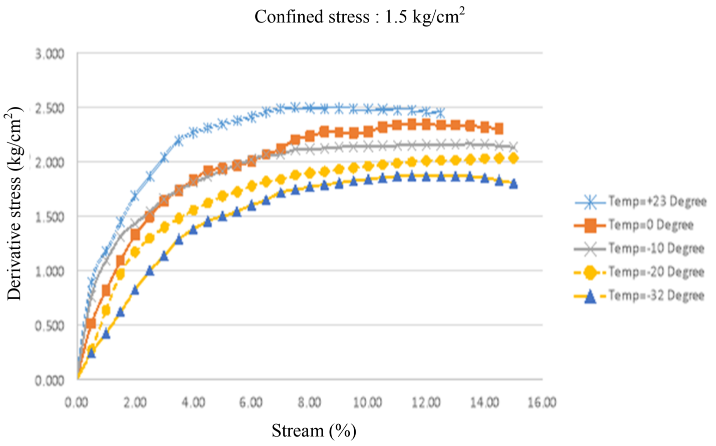

Figure 4. Stress-strain diagram at various temperatures and constant confining pressure of 1.5 kg/cm^2

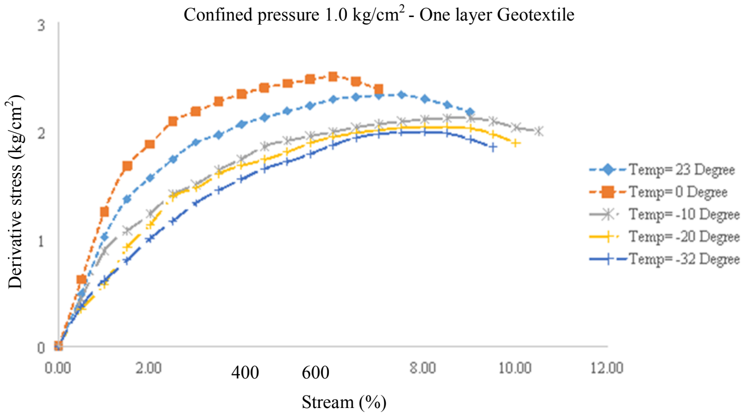

Figure 5. Stress-strain diagram at different temperatures and constant confining pressure of 0.5 kg/cm^2

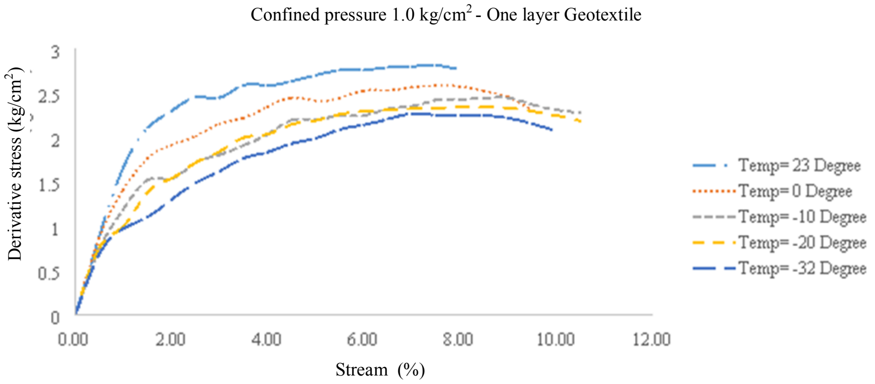

Figure 6. Stress-strain diagram at different temperatures and constant confining pressure of 1 kg/cm^2

RESULTS AND DISCUSSION

Test results without geo textile layers and different temperatures-storage temperature of 23°C

Tri axial pressure test was used to determine the shear strength of soil and determine stress-strain behaviour of soil under various confining pressures. The test consisted of a cylindrical soil sample exposed to an uniform all-round confining pressure, and then an extra vertical load was exposed until failure moment. In this research, these tests were used to study the behavior of soil under intermittent freeze–thaw.

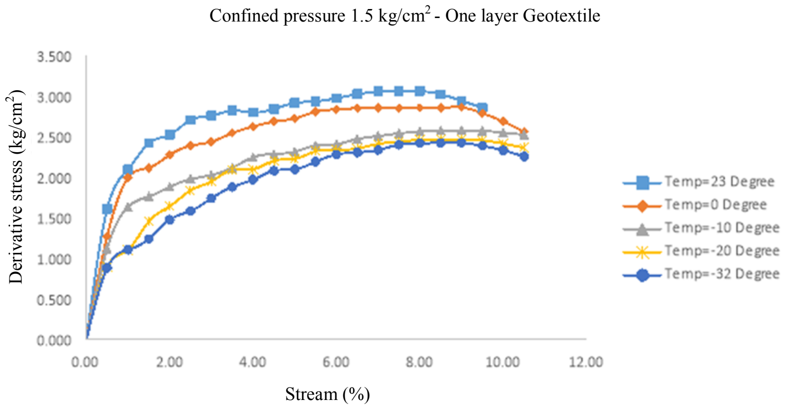

Figure 7. Stress-strain diagram at different temperatures and constant confining pressure of 1.5 kg/cm^2

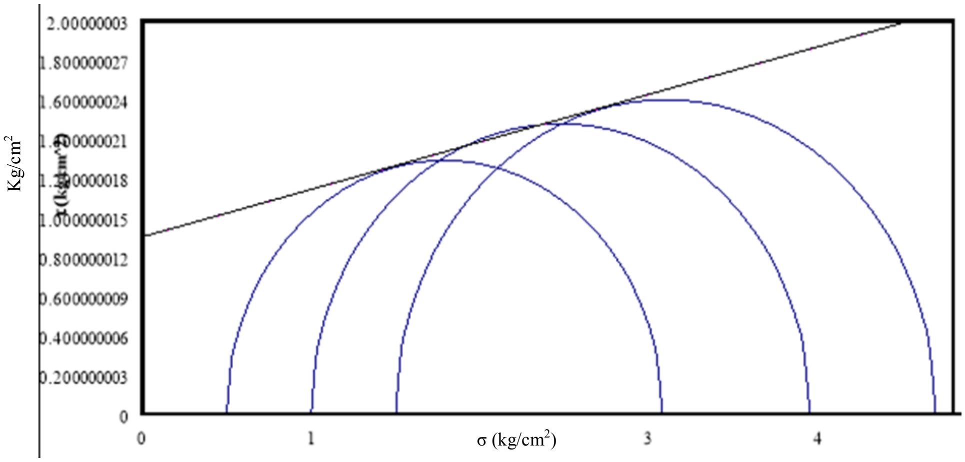

Figure 8. Mohr-Coulomb failure criterion for two-layer geo textile and temperature of -10°C

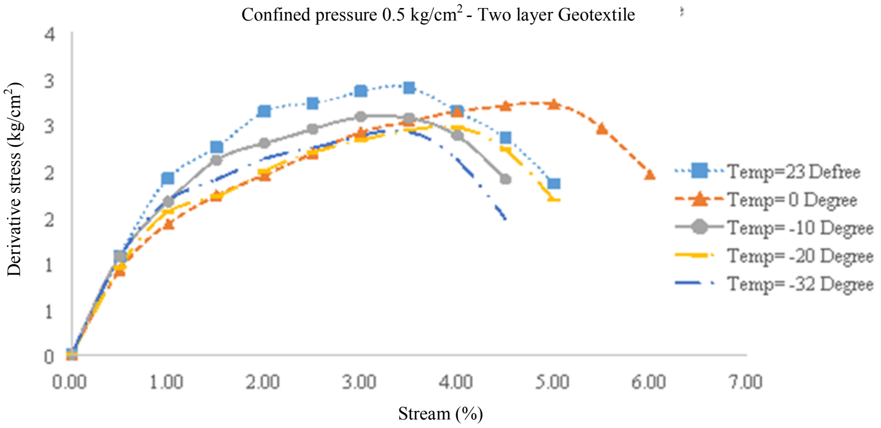

Figure 9. Stress-strain diagram at different temperatures and a constant confining pressure of 0.5 kg/cm^2 (two-layer geo textile)

Diameter of sample was 38.1 mm and its height was 76.2 mm for a temperature of +23. Loading speed of device was set to 0.76 mm/min. Sample was loaded under normal moisture and different confining pressure. Disturbed soil sample was tested with three different confining pressures including 0.5 kg/cm^2, 1 kg/cm^2 and 1.5 kg/cm^2. Density of samples in all different wet and dry states were equal to 1.9 kg/cm^2 and 1.66 kg/cm^2 respectively. It is also worth noting that sample was compressed up to 95% and was composed of 60% of

Table 5. Tri axial test readings with two-layer geo textile for storage temperature of -10°C

Δh	e	Ac	σ3=	0.50	σ3=	1.00	σ3=	1.50
0.001a"	Δh/h*100	cm^2	a	F/A	a	F/A	a	F/A
0	0.00	11.4009	0	0	0	0	0	0
15	0.50	11.4582	73	1.065	90	1.3178	119	1.758
30	1.00	11.5161	114	1.657	138	2.0003	166	2.450
45	1.50	11.5745	146	2.109	160	2.314	188	2.761
60	2.00	11.6336	160	2.291	174	2.5012	194	2.828
75	2.50	11.6932	171	2.447	189	2.6958	197	2.864
90	3.00	11.7535	181	2.578	197	2.7945	204	2.951
105	3.50	11.8144	181	2.565	202	2.8548	212	3.043
120	4.00	11.8760	169	2.374	210	2.9513	219	3.128
135	4.50	11.9381	136	1.904	208	2.9083	225	3.197
150	5.00	12.0010	0		192	2.6726	226	3.194
165	5.50	12.0645	0		174	2.4119	205	2.889
180	6.00	12.1286	0		0		176	2.460

sand and 40% of gravel. Table 1 shows readings for this tri axial test until strain of 10.5%. Results are presented in Mohr-Coulomb failure baseline and strain-stress diagrams are presented at different confining pressures. Figure 1 shows Mohr-Coulomb failure base line in general stress space and also failure line equation. Cohesion refers to the intercept. Figures 2, 3 and 4 shows strain-strain diagrams of this test under different confining pressures indicating comparison of strain-stress diagrams at constant limiting pressures and various temperatures. At lower temperature, deviatoric stress is reduced in all states indicating a decrease in strength characteristics of soil.

Soil plastic properties at different temperatures in unreinforced triaxial test

Angle of internal friction and cohesion are the most important soil plastic properties. These properties determine soil behaviour in plastic state. According to the previous sections, Table 2 compares temperature and value of cohesion and angle of internal friction for normal tri axial test and showed that the soil plastic properties are reduced by a decrease in the cohesion parameter.

Triaxial test with one-layer geo textile and storage at 0°C

All conditions and specifications of a sample the same as normal state for reinforcement with one-layer

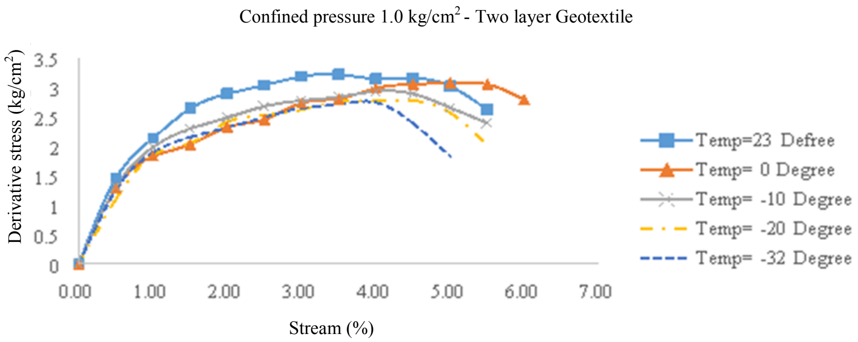

Figure 10. Stress-strain diagram at different temperatures and a constant confining pressure of 1 kg/cm^2 (two-layer geo textile)

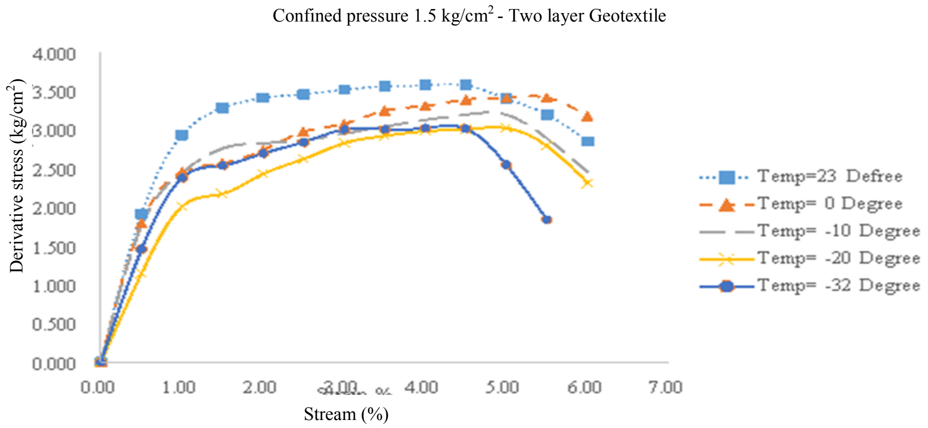

Figure 11. Stress-strain diagram at different temperatures and a constant confining pressure of 1.5 kg/cm^2 (two -layer geo textile)

geo textile. In this section, table of readings for laboratory soil data is like Table 3, only for temperature of zero. Laboratory data readings are shown up to strain rate of 13.5%. According to this table and readings, an increase is seen in the failure stress compared to the lack of geo textile indicating a positive effect of geo textile layer in laboratory soil sample.

Like the previous procedure, Mohr-Coulomb failure criterion and stress-strain diagrams are presented for different confinsing pressures. Mohr-Coulomb failure criterion for one-layer geo textile and a temperature of 0°C is shown in Figure 5. Tangent line equation on Mohr's circles are also shown for this test. According to these circles and tangent lines on them, the intercept of laboratory sample cohesion is equal to 0.82 kg/cm^2.

Stress-strain diagrams at constant confining pressure and different temperatures in the presence of one-layer geo textile

Figures 5 to 6 show a comparison of stress-strain diagrams in fixed limiting pressures in the presence of geo textile layers and different temperatures. In this case, decreased temperature reduces deviatoric stress indicating reduction of soil strength properties due to temperature variation.

Soil plastic properties at different temperatures with one-layer geo textile

Angle of internal friction and cohesion are the most important soil plastic properties. These properties determine the soil behaviour in plastic state and directly determine soil reaction at loads and specific environmental conditions. Table 4 compares temperatures and values of cohesion and angle of internal friction.

Results of tri axial test with two-layer geo textile and storage at -10°C

Laboratory samples are reinforced with a two-layer geo textile and put under loading. According to the procedure, we present are port of recorded data during test, a summary of final output of the test, Mohr-Coulomb failure envelope and finally a comparison of strain-stress graphs for tests. Other conditions are the same as previous ones. For the temperature of -10°C and also two-layer geo textile, readings of laboratory data are presented in Table 5 and 6.

According to Table 5, it is observed that less data is recorded than the previous state. This indicates sample declining due to loading and several temperature variations; however, differential stress is higher than the previous state. Figure 7 and 8 shows Mohr-Coulomb failure envelope for storage temperature of -10°C and two-layered geo textile indicating a cohesion of 0.9kg/cm^2 and angle of internal friction of 14° Figures 9, 10 and 11 shows a comparison of differential strain-stress diagrams for samples at constant confining pressure for different temperatures of experimental sample. After

Table 7. Angle of internal friction and cohesion values at different temperatures and comparison with temperature of 23°C

S. No	Temperature (°C)	Angle of internal friction (degree)	Cohesion (kg/cm^2)	Reduction of angle of internal friction (%)	Reduction of Cohesion (%)
1	23	12	0.37	-	-
2	0	12	0.62	0	7.4
3	-10	11	0.59	8.3	11.93
4	-20	10	0.57	16.67	14.92
5	-32	9	0.54	25	19.4

failure of sample, an increase in strain leads to decrease in the differential stress. This is due to the drop in soil sample strength because of temperature variation. Table 7 shows reduction of shear strength parameters of soil due to reduced temperature. This table shows reinforcement of a sample soil of tri axial testing. Temperature of 23 degrees was comparison basis. According to Table 7, 25% of angle of internal friction and about 20 % of cohesion will decrease in the case of reduced temperature from 23°C to -32°C.

Soil characteristics changed in the case of reinforcing samples with geo textile. In this study, we first put one-layer geo textile into the sample. Table 8 summarizes compared impact of app lie done-layer geo textile with absence of geo textile. According to this table, the soil cohesion received the greatest impact of geo textile and this indicated an increase in tensile strength of soil. In the third step of tri axial tests, laboratory sample was reinforced with two-layer geo textile. Table 9 presents results and comparison with a temperature of 23 °C.

Since 1977, numerous studies have been conducted on strain-stress behavior and strength parameters of reinforced sand using strain tri axial instrument of direct and flat strain. Seyghalaninejad and Matin (2014) performed experiments on geo textile reinforced soil (GRS) behavior under tri axial test. Results indicated that soil reinforcement by geo textile increases angle of internal friction and cohesion coefficient, and it eventually increases strength parameters of clayey soils. Furthermore, effects of reinforced plates on improving strength of clay under low all-round pressure are far greater and more perceptible than high all-round pressure (Seyghalaninejad and Matin, 2014).

Gray and Al Refeai (1986) compared strain-stress of geo textile reinforced dry sand to sand reinforced with separate fibers, which are randomly distributed, by tri axial tests. These tests were done using con-

Table 8. Comparison of angle of internal friction and cohesion values in reinforcement with two layer geo textile

S. No	Temperature (°C)	Angle of internal friction (degree)	Cohesion (kg/cm^2)	Comparison with temperature of 23 °C with two-layer geotextile		Comparison with lack of geotextile	
				Reduction of angle of internal friction (%)	Reduction of cohesion (%)	Increase in angle of internal friction (%)	Increase in cohesion (%)
1	23	15	0.98	-	-	20	31.63
2	0	15	0.91	0	7.14	20	31.86
3	-10	14	0.90	6.6	8.16	21.42	34.45
4	-20	13	0.87	13.2	9.18	23	34.48
5	-32	13	0.85	13.2	13.26	23.76	34.47

Table 9. Comparison of angle of internal friction and cohesion values in reinforcement with two layer geotextile

S. No	Temperature (°C)	Angle of internal friction (degree)	Cohesion (kg/cm^2)	Comparison with temperature of 23 °C with two-layer geotextile		Comparison with lack of geotextile	
				Reduction of angle of internal friction (%)	Reduction of cohesion (%)	Increase in angle of internal friction (%)	Increase in cohesion (%)
	23	15	0.98	-	-	20	31.63
	0	15	0.91	0	7.14	20	31.86
	-10	14	0.90	6.6	8.16	21.42	34.45
	-20	13	0.87	13.2	9.18	23	34.48
	-32	13	0.85	13.2	13.26	23.76	34.47

ventional tri axial devices on diameter of 36 mm and height of 80 mm. Gray and Al-Refeai (1986) reported the effect of freeze-thaw cycles on hydraulic conductivity of compacted clayey coil reinforced with Geosynthetic Clay Liner (GCL) (Gray and Al-Refeai, 1986). Khoshkhou *et al.* (2009) performed numerical simulation and laboratory study on the thermal diffusivity coefficient of frozen soil in different humidity conditions. This study investigated thermal diffusivity coefficient of clayey silt soil in weight moisture of 5, 10, 15, and 20% of soil freeze phenomenon. Results indicated that thermal diffusivity coefficient varies in two conditions: 1) occurrence of complete freezing in soil; and 2) Lack of complete freezing. Thermal diffusivity coefficient was desirable in the first condition, but there were additional errors which prevent easy calculation of this coefficient in the second condition and thus coefficient is unapplied when soil was not completely frozen and leads to irrational results.

Zhahony and Benjamin (2015) conducted research on mechanical properties of seasonally frozen and permafrost soils at high strain rate and concluded that basically maximum strength against pressure in perma frost samples with horizontal direction was higher than vertical direction. This anisotropy was probably due to triangular ice layout that is commonly found in permanent frozen low lands. Sayles (1973) early studies often focused on creeping performance of frozen soils (sand, silt, and clay).

Akili, (1971) studied the stress–strain behavior of frozen fine-grained soils (clayey soil and clayey silt) at different strain rates. Watson *et al*. (1976) conducted an in-depth study on ice melt and strength of permafrost using samples from central permafrost in a field. Baker *et al*. (1982) concluded that low compressive pressures (0 to 350 MPa) had little effect on compression or axial strain in failure.

Wilson *et al*. (1983) conducted an in- depth study on properties of dynamic properties of naturally frozen silt and samples with vertically direction and used central portion of samples. They concluded that there was a little difference between samples with horizontal or vertical direction in their kinetic properties; and compressive pressure (>500 MPa) had a little effect on Young's kinetic properties. Zhu and Carbee, (1984) conducted an experimental program consisting of applying uniaxial pressure on Fairbanks's deformed frozen clayey soils with varying strain rates and studies their mechanical properties such as uniaxial compressive strength. Using tri axial pressure tests,

Anderson *et al*. (1995) investigated the behavior of low stress of frozen sand. Shelman *et al*. (2014) examined and described frozen temperature on mechanical properties of seismic design of foundations using samples from five different modified soil samples. Radd and

Wolfe (1979) compared the shear strength of samples of a frozen ground and produced frozen samples in the laboratory and concluded that frozen ground samples were weaker than the laboratory samples at all test temperatures. They also recognized that the main variables which have potential to affect strength of frozen soil were as follows: freezing conditions, strain rate, sample direction, and sample size.

A few studies have been conducted on stress-strain behavior of soil using natural samples because there is little information about dependence of frozen soil stability properties on sample direction (Radd and Wolfe, 1979). The present research studied effect of temperature reduction on shear strength parameters of soil using a tri axial test.

CONCLUSION

1. Temperature variation has a negative effect on shear strength parameters of soil.
2. Reduction of soil cohesion is the major result of temperature effect.
3. Soil will lead to failure in lower strain due to an increase in period of temperature variation.
4. Reduction in percentage of angle of internal friction during temperature variation is lower than soil adhesion.
5. Addison of geotextile to sample soil increases shear strength parameters of soil.
6. Reinforced cohesion of soil is the major impact of geotextile.
7. An increase in number of geotextile layers leads to significant increase in amounts of shear strength parameters of soil.

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