Effect of weathering cycles on strength and swell potential of fly ash stabilized expansive soil subbases

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ABSTRACT
An experimental study was conducted to investigate the effect of weathering cycles on the performance of fly ash stabilized expansive soil subbases. Specimens prepared from two high plasticity expansive clay soils were subjected to 36 wet-dry cycles (with tap water and saline water) and 36 freeze-thaw cycles (good drainage and poor drainage) in a laboratory controlled environment to simulate the weathering action. The detrimental effect of wet-dry cycles on stabilized soils is less significant compared to that of freeze-thaw cycles. The swell potential of stabilized expansive soils increased significantly with poor drainage condition due to freeze-thaw cycles. The vertical swell increases rapidly for first four to five cycles and then increases very slowly.

RÉSUMÉ
Une étude expérimentale a été menée pour étudier les effets des cycles météorologiques sur la performance des sols expansifs sous-bases stabilisés par des cendres volantes. Des spécimens préparés à partir de deux sols argileux à haute plasticité expansive ont été soumis à 36 cycles humides-secs (avec de l’eau du robinet et de l’eau salée) et 36 cycles gel-dégel (bon drainage et mauvais drainage) dans un environnement contrôlé de laboratoire pour simuler l’action météorologique. L’effet des cycles humides-secs sur les sols stabilisés est moins significatif comparé aux cycles gel-dégel. Le gonflement potentiel des sols expansifs stabilisés croît significativement avec les conditions de mauvais drainage causé par les cycles gel-dégel. Le gonflement vertical augmente rapidement lors des 4 à 5 premiers cycles puis ne s’accroît plus que très lentement.

1.0 INTRODUCTION

Expansive soil is one of the most prevalent natural hazards causing billions of dollars of damage annually to various civil infrastructures built over them (Puppala and Musenda 2000). Damages from expansive soils include structural damage, cracked driveways, sidewalks and basement floors, heaving of roads and highways, and disruption of pipelines and sewer lines. Several methods have been attempted to stabilize expansive soils using lime, cement, fly ash and other additives (Puppala and Musenda 2000; Buckley et al. 2005)

In recent years, beneficial reuse of fly ash in soil stabilization, especially for highway embankments, has increased significantly throughout the nation and the trend is expected to grow in future years (Buckley et al. 2005). In most subgrade applications, fly ash is used to stabilize the fine-grained soils so that a stable working platform can be provided for highway construction equipment (Ferguson 1993). A variety of laboratory and field studies have shown that cementitious fly ashes (Class C) are very effective in improving the geotechnical properties of expansive soils (Puppala and Musenda 2000; Cokca 2001; Edil et al. 2002; Buhler and Cerato 2007). The fly ash stabilized soils are typically strong and stiff, and provides necessary support as a subbase (Cokca 2001; Edil, et al. 2002; Bin-Shafique et al. 2004). Moreover, the stabilization of high plasticity expansive soil(s) with fly ash causes significant reduction of plasticity and shrink-swell potential (Abduljauwad 1995; Nalbantoglu 2004).

For fly ash stabilization, the selection of a mixture of soil, fly ash, and water usually depends on which one would provide the intended geotechnical properties on a short-term basis (Edil et al. 2002; Bin-Shafique et al. 2004). The long-term performance of fly ash stabilized soils in the context of field environment is often ignored (Bin-Shafique et al. 2010). The effect of the exposure to successive different weather cycles, such as wet-dry or freeze-thaw cycle is an important factor to understand the long-term performance of fly ash stabilized expansive soil. A very few studies have been conducted to evaluate the effect of weathering cycles on fly ash stabilized expansive soils so far. However, studies on the effect of weathering cycles on natural soils and soils stabilized with other cementitious materials, such as lime and/or cement, suggest that the weathering action might have a pronounced effect on the effect of weathering cycles on performance of fly ash stabilized soils (Zhang 2002; Toutanji et al. 2004; Bin-Shafique et al. 2010). In cold regions, freeze-thaw damage is one of the major problems in road construction and earthwork applications with any fine-grained soils (Cruzda and Hohmann 1997). Cracking and spalling are the most common results of freeze-thaw damage in stabilized subbases (Yarbaşı, 2007).

The effect of wet-dry cycles on cementitious materials is usually insignificant. In many cases, the strength of cementitious materials subjected to wet-dry cycles increases due to long-term hydration (Toutanji et al. 2004). However, the effect of wet-dry cycles with saline water, which simulates the groudwater in coastal area or the infiltration of deicing salts, is detrimental to the performance of cementitious materials (Toutanji et al. 2004). The salt attacks the bonding of the cementitious materials, thereby causing the mix to develop cracks and eventually fail. Thus, the effect of wet-dry cycles on fly ash stabilized expansive soils from saline water needs to be evaluated to understand the effect of weathering cycles on performance.

Despite all the advantages of using fly ash stabilized subbases, an unacceptable performance over long period due to weathering action would result in roadways of poor condition and a huge economic burden to a community. Thus, the evaluation of the effect of weathering cycles on performance of fly ash stabilized subbases is essential to assess the technical viability and economic sustainability of using them in highway construction.

This paper is focused on a systematic study of the effect of environmental exposures that are often encountered in field conditions on the performance of fly ash stabilized expansive soils. Specimens prepared from two high plasticity expansive soils stabilized with a Class C fly ash were subjected to different environmental exposures in a controlled laboratory environment and the change in geotechnical properties of the exposed fly ash stabilized expansive soils was evaluated to understand the effect of weathering cycles on performance.

2.0 MATERIALS

2.1 Expansive Soils

Two different types of expansive soils were stabilized with fly ash: 1) San Antonio Clay and 2) Helotes Clay. The San Antonio Clay was collected from a construction site (intersection of I-35 and SBC Center pkwy) at San Antonio, TX and the Helotes Clay was collected from Helotes, TX (the intersection of Loop 1604 and STH 16). The San Antonio Clay was collected at a depth of two feet and the Helotes Clay was collected at a depth of three feet. The soil samples were subjected to a series of tests, such as particle size analysis, specific gravity, Atterberg's limits, swell potential, and compaction tests to characterize the soils.

The properties of the soils are shown in Table 1. The plasticity index is 41% for the San Antonio Clay and 57% for the Helotes Clay. Both soils have similar specific gravity. According to USCS, both soils are classified as high plasticity clay (CH). Similarly, both the soils are classified as A-7-6 with a group index (GI) of 39 for the San Antonio clay and 57 for the Helotes clay according to AASHTO classification.

Table 1. Properties of expansive soils.

Sample ID	Soil Classification		Specific Gravity	P_{200} (%)	LL (%)	PI (%)	FVS (%)	w_N (%)	w_{opt} (%)	$(\gamma_d)_{max}$ (kN/m^3)
	USCS	AASHTO								
San Antonio Clay	CH	A-7-6 (39)	2.68	73	64	41	12.6	21	23	15.9
Helotes Clay	CH	A-7-6 (57)	2.71	89	81	57	14.4	22	26	15.1

Note: LL = liquid limit, PI = plasticity index, FVS = free vertical swell, w_N = natural water content, w_{opt} = optimum water content, $(\gamma_d)_{max}$ = maximum dry unit weight, N/A = not applicable

The particle size distribution curves and the compaction characteristics for both soils are shown in Figure 1. The grain size distribution is uniform for both soils. The percent fines (P_{200}) is 73% for the San Antonio Clay and 89% for the Helotes Clay. The maximum dry unit weight (standard Proctor compaction) and optimum moisture content of the San Antonio Clay is 15.9 kN/m^3 and 23%, respectively. Similarly, the Helotes Clay has a maximum dry unit weight of 15.1 kN/m^3 and an optimum moisture content of 26%. The sulphate content of the soils was also measured and was insignificant for both soils.

2.2 Fly Ash

Class C fly ash was collected from Boral Material Technologies in San Antonio, TX. Chemical and physical properties of Boral fly ash are shown in Table 2 along with the requirements of Class C fly ash (ASTM C 618). The total percentage of the three major metal oxides (SiO_2, Al_2O_3, and Fe_2O_3) is 61.7%, and the Sulphur Trioxide (SO_3) is 1.48%, which satisfies the requirements of both ASTM C 618 and AASHTO M 298. The lime (CaO) content, which is primarily responsible for cementitious property of fly ash, is 25.8% and has self-cementing capabilities. The specific gravity of the fly ash is 2.69. The moisture content is 0.02%, and the loss on ignition that represents unburned carbon is 0.14% for Boral fly ash.

3.0 METHODS

3.1 Specimen Preparation

For a meaningful comparison of the test results, all specimens were prepared at the maximum dry density (standard Proctor) and at the optimum moisture content of a specific soil. Specimens were prepared with the mixture of soil, fly ash, and water. Three fly ash contents of 5%, 10%, and 20% (by weight), were used along with the control (0% fly ash). To prepare the mixture of a specimen, the required amount of soil and fly ash was calculated from the target dry density and the volume of the specimen. All soil lumps were broken and sieved through a US # 40 sieve. The soil and fly ash was taken in a tray and was mixed in a dry state. After thoroughly mixing, the required amount of water based on optimum moisture content of the soil was added to the mixture. At the end of the mixing homogeneously, the tray was weighed, and if required, additional water was added to compensate for any loss of water due to evaporation. As soon as the mixture was ready, it was transferred to a mold and compacted statically in a Material Testing machine until it achieved the target volume.

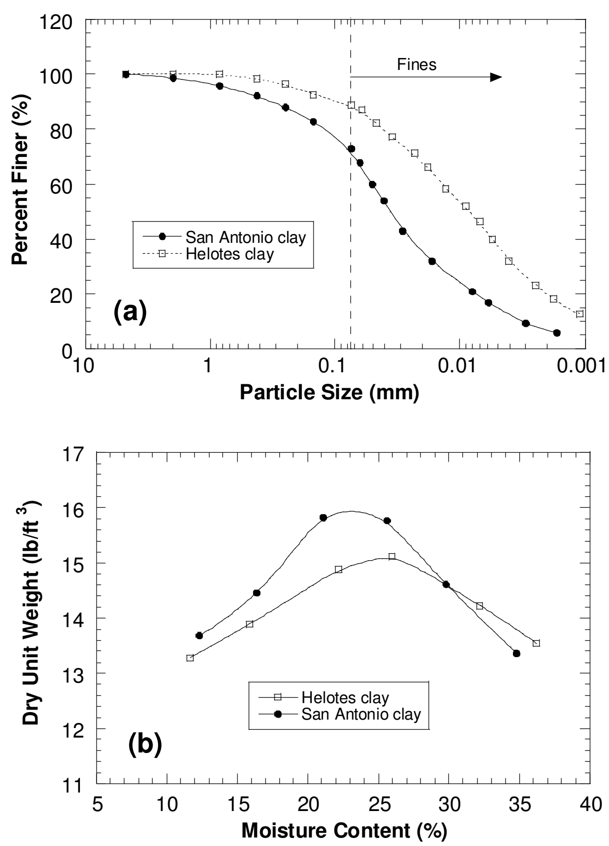

Figure 1. Particle size distribution and compaction curves of the soils

Thick-wall 50-mm diameter PVC pipes were cut into 375-mm long pieces for 250-mm long mold with an additional 125-mm extended collar as shown in Figure 2. The pieces of pipes were split and clamped together to use as molds to prepare the specimens for the unconfined compression tests. To compact all the specimens, a very thin layer of petroleum jelly was applied inside the molds to minimize skin frictions and boundary effects during vertical swell. The MTS machine was programmed in such a way so that it would compact the specimen exactly 125 mm. Ten replicates were prepared from each combination of soil and fly ash mixtures. After the compaction, the molds were wrapped with plastic wrap and allowed to cure for 7 days in a moist condition.

Table 2. Chemical and physical properties of fly ash.

Properties	Boral Fly Ash	ASTM C 618 Class C
Chemical Properties		
Sum of SiO_2, Al_2O_3, Fe_2O_3, %	61.70	50.0 min
Calcium Oxide (CaO), %	25.81	N/A
Sulphur Trioxide (SO_3), %	1.48	5.0 max
Physical Properties		
Moisture Content, %	0.02	3.0 max
Loss on Ignition, %	0.14	6.0 max
Specific Gravity	2.69	N/A

Note: N/A = Not applicable

After 7 days, two replicates from each combination of soil and fly ash mixtures were taken out of the mold and then one set was subjected to unconfined compression tests while the other set was subjected to swelling tests. From the remaining five replicates, four replicates were subjected to freeze-thaw cycles, and four replicates were subjected to wet-dry cycles.

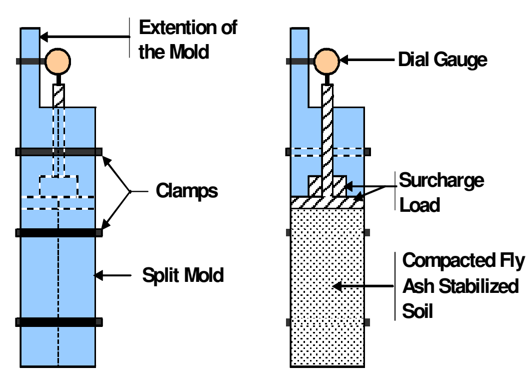

Figure 2. Experimental set-up for weathering cycles: (a) the split mold and (b) the vertical cross-section of the mold

3.2 Weathering Action

Specimens that were subjected to weathering action were kept inside the mold to simulate the confining pressure in the field. Non-woven geotextiles (adsorbent pad) were used to seal the bottom of the molds that were placed in plastic tanks. The split molds were secured tightly and kept in a vertical position using clamps. An additional surcharge of 7 kPa was added to all specimens to simulate the overburden pressure from the base and hot mixed asphalt layer using base plates (Figure 2). The extension rod of a base plate for the specimens prepared for swell testing was attached to a dial gauge.

For the dry-wet cycles, a tank was filled with tap water and the other one with saline water, and the specimens were placed in a submerged condition (ASTM D 560) at room temperature (approx. 25°C) for 24 hrs. Saline water comparable to groundwater in the coastal area (35 g/L NaCl) was used to create an aggravated situation. After 24 hrs, the water was drained out and the specimens were allowed to dry for 24 hrs to complete one wet-dry cycle. To enhance the drying process, an air circulating fan was used. The reading of the dial gauge was recorded after each wet cycle.

For the freeze-thaw cycles, two different situations are considered. The thaw water will drain out of the stabilized subbase layer very quickly for roadways with good drainage, whereas, the thaw water will remain inside the stabilized subbase layer for roadways with poor drainage or the roadway is constructed by stabilizing a portion of the total depth of the expansive soil subgade that has a very low hydraulic conductivity. For freezing, two tanks were placed in a freezer at -5°C for 24 hrs. Then the freezer was disconnected and the door was opened for 24 hrs to allow the temperature to rise to expedite thawing process. To simulate the subgrade in a roadway with poor drainage, the empty 125-mm of the mold on top of a specimen was filled and refilled with crushed ice during the thawing period and free potable water was made available to the absorbent pads under the specimens to permit absorbing water by capillary action during the thawing period (ASTM D 561). No ice was added to simulate the stabilized subgrade in a roadway with good drainage; however, a small amount of water was added at the beginning of the thawing period. The reading of the dial gauge was recorded after each thaw cycle for both draining conditions.

Following the similar procedure, the specimens were subjected to 36 cycles of weathering action. One set of replicates from all four weathering conditions were taken out from the mold and allowed to dry until they achieved their original weight. As soon as they achieved their original weight, the specimens were wrapped with plastic wrap so that the specimens cannot dry anymore and the water can be distributed evenly throughout the specimens. After 2-3 days, the specimens were subjected to unconfined compression testing. All specimens were trimmed to 100-mm long before testing to exclude any damage part at two ends of the specimens during weathering action. Another set of replicates were subjected to swelling tests that continued until the swelling stopped.

3.3 Test Procedures

Unconfined compression tests were conducted according to ASTM D 2166. A constant axial strain of 2%/min was applied. Loading was continued until the load decreased with increasing strain, or until 15% strain was reached. The unconfined compressive strengths were determined from the stress-strain curves. After finishing the unconfined compression tests, all specimens were subjected to Atterberg's limit tests to estimate the plasticity index.

4.0 RESULTS

4.1 Effect of Stabilization

The effect of stabilization and wet-dry cycles on plasticity, strength, and free vertical swelling are shown in Table 3.

Table 3. Properties of fly ash stabilized soils before and after wet-dry cycles.

Properties	Weathering Action	San Antonio Clay				Helotes Clay			
		0% Fly Ash	5% Fly Ash	10% Fly Ash	20% Fly Ash	0% Fly Ash	5% Fly Ash	10% Fly Ash	20% Fly Ash
Plasticity Index	Before weathering	41	24	18	14	57	32	27	26
	After wet-dry cycles	42	25	19	16	58	33	28	27
	After wet-dry cycles (SW)	34	22	16	12	51	30	25	23
UC Strength, kPa	Before weathering	179	382	533	640	191	364	456	567
	After wet-dry cycles	172	370	494	591	184	341	410	517
	After wet-dry cycles (SW)	182	364	482	578	196	329	406	508
Vertical Swell, (%)	Before weathering	12.6	7.2	4.1	3.2	14.4	8.3	4.2	3.6
	After wet-dry cycles	12.8	8.4	4.8	3.6	14.5	9.1	4.6	3.8
	After wet-dry cycles (SW)	12.7	8.3	5.6	3.5	13.2	8.7	4.4	3.7

Note: SW = Saline water, UC strength = Unconfined compressive strength

The plasticity of the stabilized soils decreased as the fly ash content increased; however, the rate of reduction decreased at higher fly ash contents (shown in later sections as “control”). The plasticity of stabilized San Antonio Clay soils decreased 17% (from 41% to 24%) due to adding 5% fly ash and then decreased only 10% (from 24% to 14%) after adding 20% fly ash. Similarly, the plasticity index of stabilized Helotes Clay soils decreased 25% (from 57% to 32%) due to adding 5% fly ash and then decreased only 6% (from 32% to 26%) after adding 20% fly ash. The presence of calcium in stabilized soils increases clay flocculation and reduces soil dispersion, and thus reduces the plasticity immediately (Lambe, and Whitman 1979).

A general trend of increasing unconfined compressive strength with increasing fly ash content was observed (shown in later sections as “control”). The addition of 20% fly ash increased the unconfined compressive strength from 179 kPa to 640 kPa for the San Antonio Clay and from 191 kPa to 567 kPa for the Helotes Clay. The pozzolanic reaction and the expulsion of water due to the collapse of the diffuse double layer around clay particles are responsible for improved compressive strength (Lambe, and Whitman 1979).

Fly ash stabilization also reduced the vertical swell potential of San Antonio Clay from 12.6% to 7.2% for a fly ash content of 5%, 4.1% for a fly ash content of 10%, and 3.2% for a fly ash content of 20%. Similarly, the vertical swell potential decreased from 14.4% to 8.3% for a fly ash content of 5%, 4.2% for a fly ash content of 10%, and 3.6% for a fly ash content of 20%.

4.2 Effect of Wet-Dry Cycles

The effect of wet-dry cycles on plasticity index of fly ash-stabilized soil is shown in Figure 3. The plasticity index increased slightly for all specimens due to wet-dry cycles using tap water. The leaching of calcium during wet-dry cycles might be the reason for slightly higher plasticity (Parsons and Milburn 2003). The plasticity index decreased significantly for all stabilized soils that were subjected to wet-dry cycles using saline water. The presence of cations in water might be the reason for reduced plasticity (Lambe, and Whitman 1979).

The effect of wet-dry cycles on unconfined compressive strength of fly ash stabilized soils is shown in Figure 4. A slight decrease of strength was noticed for

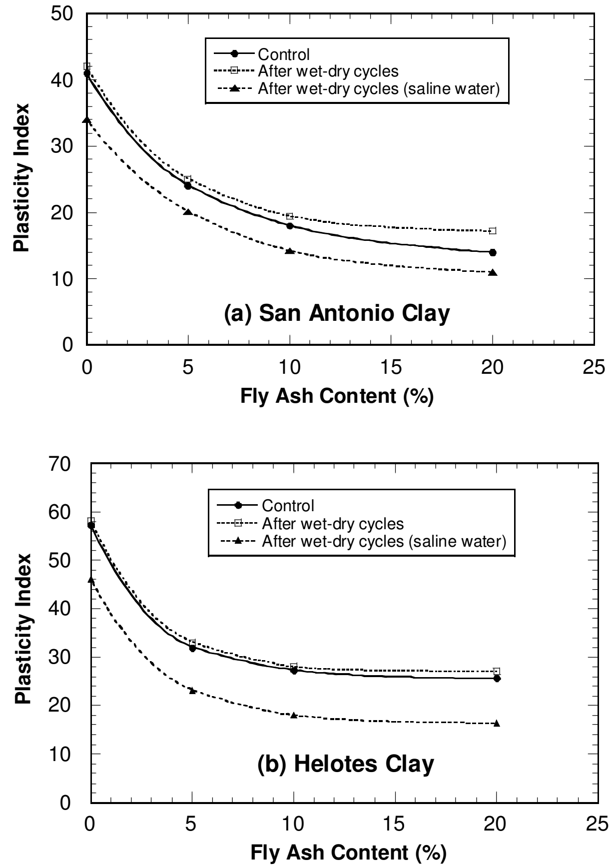

Figure 3. Effect of wet-dry cycles on plasticity index of fly ash stabilized (a) San Antonio clay and (b) Helotes clay

all specimens subjected to wet-dry cycles either with tap water or saline water. The wet-dry cycles decrease the strength, but at the same time the strength is expected to increase for extended curing. However, the overall impact shows a slight (approximately 10%-13%) decrease of strength. It must be noted here that all the unconfined compressive strengths shown in Figure 4 represent the strengths of stabilized soils at 4% wet of optimum moisture content of that particular soil, which is 27% for the San Antonio clay and 30% for the Helotes clay. Thus, the strengths of the weathered specimens are compared to those of the controls at a constant moisture content to determine the gain/loss of strength associated with weathering action. The strength of fly ash stabilized soils decreases with increasing moisture content similar to natural soil (Bin-Shafique et al. 2004). Thus, the comparison of strength of fly ash stabilized soils at different moisture contents might lead to serious inaccuracy.

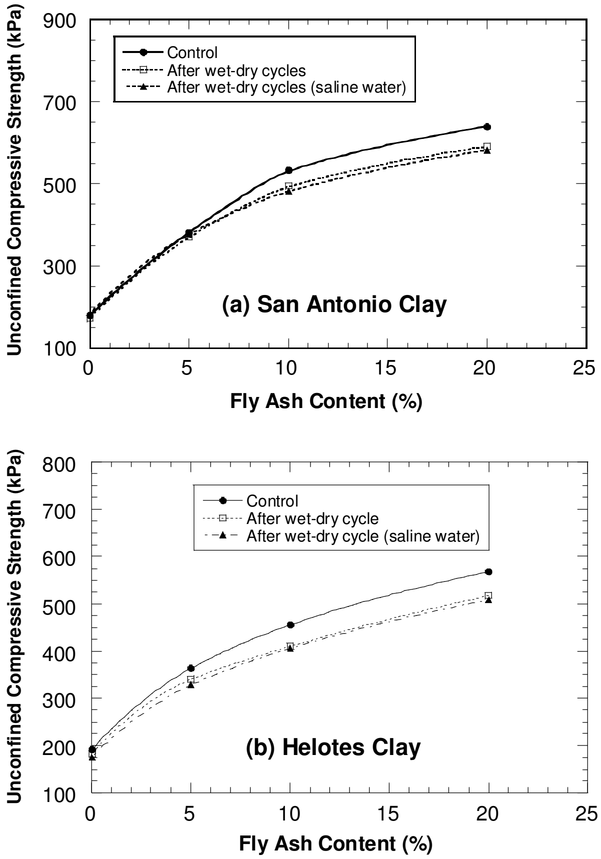

Figure 4. Effect of wet-dry cycles on unconfined compressive strength of the fly ash stabilized (a) San Antonio clay and (b) Helotes clay.

The vertical swelling of the fly ash stabilized both soils after 36 cycles of wet-dry cycle with both tap and saline water was slightly higher than that of controls. However, the vertical swelling after 36 wet-dry cycles was slightly less for both soils when saline water was used instead of tap water. The lower plasticity of stabilized soils after wet-dry cycles using saline water might be the reason of low vertical swell potentials.

4.3 Effect of Freeze-Thaw Cycles

The effect freeze-thaw cycles on plasticity, strength, and free vertical swelling are shown in Table 4 along with the controls. The effect of freeze-thaw cycles on the plasticity of both stabilized soils was insignificant. The plasticity increased slightly for both soils perhaps due to leaching of calcium.

The effect of freeze-thaw cycles on unconfined compressive strength of the stabilized soils is shown on Figure 5. In Figure 5, all the unconfined compressive of stabilized soils represent the strengths at 4% wet of optimum moisture content of the particular soil as in Figure 4. The unconfined compressive strength was about 13% lower for stabilized San Antonio Clay and about 18% lower for stabilized compared to those of the controls when no ice was added to simulate good drainage condition. In this condition, the loss of strength is little higher than that from the wet-dry cycles. However, the unconfined compressive strength was about 44% lower for stabilized San Antonio Clay and about 48% lower for stabilized Helotes clay compared to those of the controls when simulating poor drainage condition. Both the unstabilized soils also lost significant amount of the strengths. The rate of reduction was essentially similar to that of the stabilized soils.

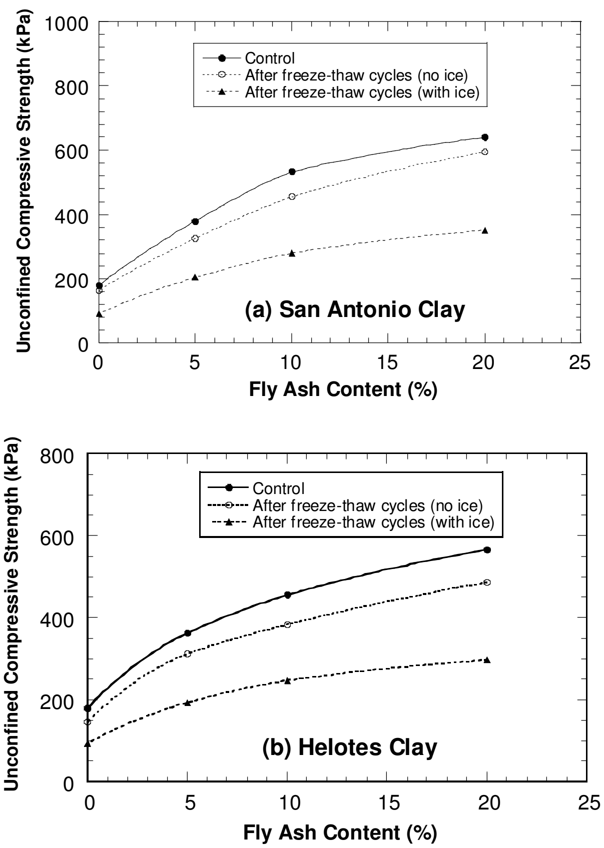

Figure 5. Effect of freeze-thaw cycles on unconfined compressive strength of the fly ash stabilized (a) San Antonio clay and (b) Helotes clay

The exact reason of this observation was not investigated. However, it might be caused from freezing of pore water, which exerts pressure to expand the volume of the stabilized soil (Hori and Morihiro 1998).

Table 4. Properties of fly ash stabilized soils before and after freeze-thaw cycles.

Properties	Weathering Action	San Antonio Clay				Helotes Clay			
		0% Fly Ash	5% Fly Ash	10% Fly Ash	20% Fly Ash	0% Fly Ash	5% Fly Ash	10% Fly Ash	20% Fly Ash
Plasticity Index	Before weathering	41	24	18	14	57	32	27	26
	After freeze-thaw cycles (GD)	41	26	20	16	58	33	29	28
	After freeze-thaw cycles (PD)	41	25	20	17	57	31	28	27
UC Strength, kPa	Before weathering	179	382	533	640	191	364	456	567
	After freeze-thaw cycles (GD)	164	326	455	594	146	313	384	487
	After freeze-thaw cycles (PD)	92	204	281	353	94	194	248	298
Vertical Swell, (%)	Before weathering	12.6	7.2	4.1	3.2	14.4	8.3	4.2	3.6
	After freeze-thaw cycles (GD)	13.1	7.8	4.4	3.4	14.8	8.6	4.3	3.8
	After freeze-thaw cycles (PD)	14.5	9.2	5.3	4.1	15.3	9.6	5.2	4.2

Note: GD = Good drainage, PD = Poor drainage, UC strength = Unconfined compressive strength

This pressure might loose the cementitious bonding of the stabilized soils and causes loss of strength. The loss of strength of the fly ash stabilized soils might be due to low permeability, higher degree of saturation, and the presence of freezable water, which are also often considered as the reasons for increased volume of fine-grained soil that are subjected to freeze-thaw cycles (Yarbaşı, 2007). The reduced unconfined compressive strength of fly ash stabilized soils due to freeze-thaw cycles was at least three times higher than that of the unstabilized soils.

The vertical swell after the freeze-thaw cycles is shown in Figure 6 along with the control and the vertical swelling from the wet-dry cycles using saline water. The vertical swell potential of fly ash stabilized soils after 36 freeze-thaw cycles increased approximately 6-9% for good drainage and increased approximately 12-15% for both soils for poor drainage. However, the vertical swelling of the stabilized soils was much lower than both unstabilized soils. The vertical swell potential increased perhaps due to expansion pressure of the pore water when becoming ice in addition to swelling pressure during freezing cycles.

The vertical swelling during the freeze-thaw cycles are shown in Figure 7. The vertical swelling of the stabilized soils increased rapidly up to four or five cycles and then reached stability, which is similar to the findings from other study (Hai-bin et al. 2007). The San Antonio Clay achieved the stability after 20 cycles, whereas, the Helotes Clay was swelling even after 36 cycles with a very small rate.

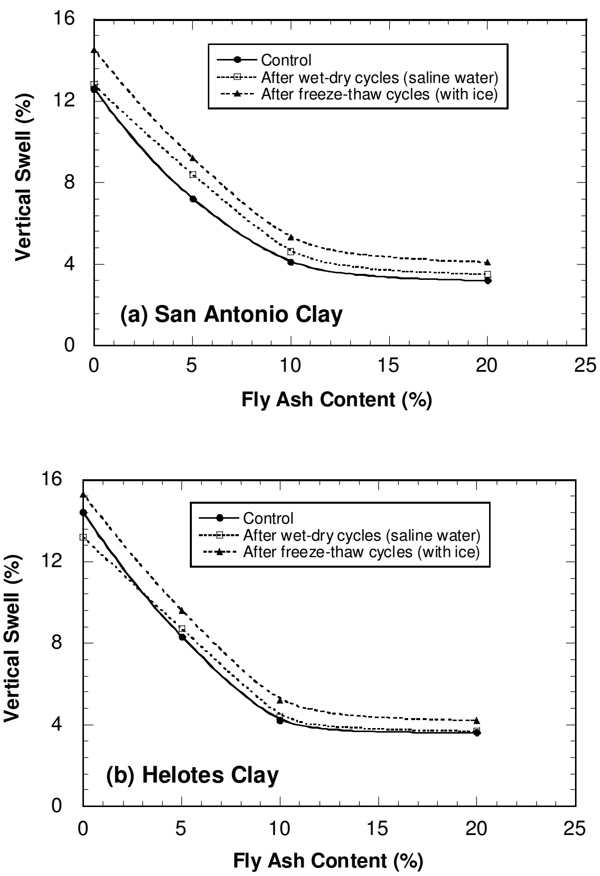

Figure 6. Effect of freeze-thaw cycles on swell potential of the fly ash stabilized (a) San Antonio clay and (b) Helotes clay

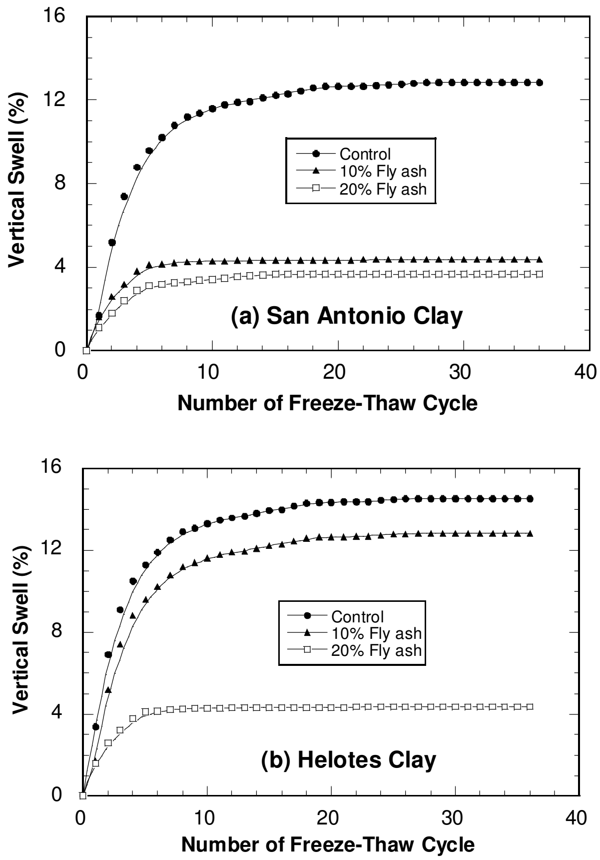

Figure 7. Vertical swell potential of the fly ash stabilized during freeze-thaw cycles (a) San Antonio clay and (b) Helotes clay

5.0 CONCLUSIONS AND RECOMMENDATIONS

This study to investigate the effect of weathering cycles on fly ash stabilized expansive soils suggests that the fly ash stabilization increases the unconfined compressive strength of expansive soils three to four times and decreases the plasticity and swell potential by approximately 50-66% and 75%, respectively. The wet-dry cycles with tap water decreased the unconfined compressive strength and increased the plasticity and vertical swell potential of the stabilized soils slightly. The effect of the wet-dry cycles with saline water was similar to tap water except the plasticity was reduced slightly. Reduction in strength due to salt attack was not observed (Toutanji et al. 2004).

The freeze-thaw cycles also increased the plasticity of the stabilized soils slightly. However, the unconfined compressive strength decreased about 10% for stabilized San Antonio Clay and about 20% for stabilized Helotes Clay when the freeze-thaw cycles were applied without adding ice to simulate roadway with good drainage. The loss of strength was more pronounced when the pore water was not allowed to drain before freezing. The unconfined compressive strength decreased about 44% for stabilized San Antonio Clay and about 48% for stabilized Helotes Clay when ice was added during the thawing period to simulate roadway with poor drainage. The loss of strength of stabilized soils is perhaps associated with the volume change of the pore water when it converted to ice during freezing because similar strength loss was also observed for unstabilized soil (Abduljauwad 1995; Bin-Shafique et al. 2010). Even after losing strength due to freeze-thaw cycles, the strength of stabilized soils was still at least three times higher than that of the unstabilized soils.

The wet-dry cycles and the freeze-thaw cycles with good drainage increased the vertical swelling slightly. However, the vertical swelling increased significantly for fly ash stabilized and unstabilized both soils due to freeze-thaw cycles when the pore water was not allowed to drain completely before freezing.

6.0 ACKNOWLEDGEMENTS

Financial support for the research was provided by the center for water research at the University of Texas at San Sntonio (UTSA) and by UTSA through a faculty research grant. The opinions and conclusions described in the paper are those solely of the authors and do not necessarily reflect the opinions or policies of the sponsors or others that assisted with the study.

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