Desiccation of Fiber-Reinforced Highly Plastic Clays

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ABSTRACT
The effects of fiber-reinforcement on the behavior of a highly plastic clay during desiccation and infiltration of water were investigated in this study. Soil specimens were prepared with and without fiber-reinforcement and subjected to identical infiltration and desiccation stages over a period of nine months. Surficial desiccation cracking, volumetric strains, matric suction and volumetric water content were measured throughout the duration of testing. The results of this study provide evidence that fiber-reinforcement reduces the size and depth of cracking on the soil surface, but increases the number of surficial cracks. The presence of the fibers was not, however, found to influence the total volumetric strains of the soil specimens during the desiccation stages. The desiccation of the clay also increased the maximum (saturated) hydraulic conductivity of the soil by approximately two orders of magnitude. While the presence of fiber-reinforcement did not significantly affect the hydraulic conductivity of the clay at high suctions, a reduction in the initial rates of evaporation and infiltration of water into the fiber-reinforced soil column was measured.

1. INTRODUCTION

The use of highly plastic clays in geotechnical structures becomes problematic in areas that experience severe daily and seasonal changes in environmental conditions (e.g. fluctuations in relative humidity, temperature and precipitation). In Texas, the daily ranges in relative humidity can causes suctions in surficial soils that range from 14,000 to 108,000 kPa (Kuhn 2005). These high values of surficial suction cause a high hydraulic gradient within the soil and flow of water out of the soil, causing volumetric strains which result in cracking (Tindall 1999). Surficial soils experience these daily changes in atmospheric conditions, while deeper soils may only experience seasonal changes or average changes, which cause non-uniform straining with depth into the soil (Aubeny and Lytton 2003).

Zhang et al. (2005) studied the effects of these daily and seasonal moisture fluctuations on slope stability and indicated that the failure of the slopes initiated with the wet and dry periods of the seasons. Atmospheric changes caused non-uniform shrink/swell strains along the soil depth, and the formation of desiccation cracks in the surficial soils (desiccated crust). As this process continued, the soil decreased in dry unit weight and strength due to an increase in the bulk soil volume caused by the shrink/swell cycles.

For roadway embankments, the Texas Department of Transportation's (TxDOT) current remedial measures for slope failures include re-compaction, lime stabilization, addition of drainage layers (such as a sand layer), reduction of the embankment slope, and the more recent alternative of adding fiber-reinforcement to the failed soil. The purpose of the fiber-reinforcement is to both increase the shearing strength of the soil and to reduce the cracking of surficial soils caused by cyclic wetting and drying.

Research conducted on the topic of fiber-reinforced soil has provided conflicting conclusions as to the effectiveness of the fibers in reducing cracking and volumetric strains (which plastic soils undergo during a series of wetting and drying cycles). For example, Al Wahab and El-Kedrah (1995) provided evidence that fiber-reinforcement reduced the cracking intensity (area of cracks divided by area of specimen) of a dark brown clay during several wetting/drying cycles. On the other hand, Zeigler et al. (1998) tested fiber-reinforced synthetic clays (mixtures of kaolinite and bentonite) and reported that the effectiveness of the fibers in suppressing cracking reduced significantly during multiple desiccation cycles after an initial wet/dry cycle. Accordingly, it is difficult to conclude the effects of fibers on the cracking of a clay soil from the current literature, especially for long term use in surficial soils.

The objective of this testing program was to evaluate the influence of fiber-reinforcement on the surficial cracking and hydraulic conductivity of clay exposed to cycles of desiccation and infiltration. For this study, a column test was designed and performed. These tests consisted of subjecting soil specimens of fiber-reinforced and unreinforced Eagle Ford clay to identical desiccation and infiltration cycles. Strains at the soil surface were quantified by measuring the radial deformations and surficial cracking. Instrumentation was used to monitor the volumetric water content and suction within the soil specimens, which allowed for the determination of the hydraulic conductivity function (K-function) of the soil.

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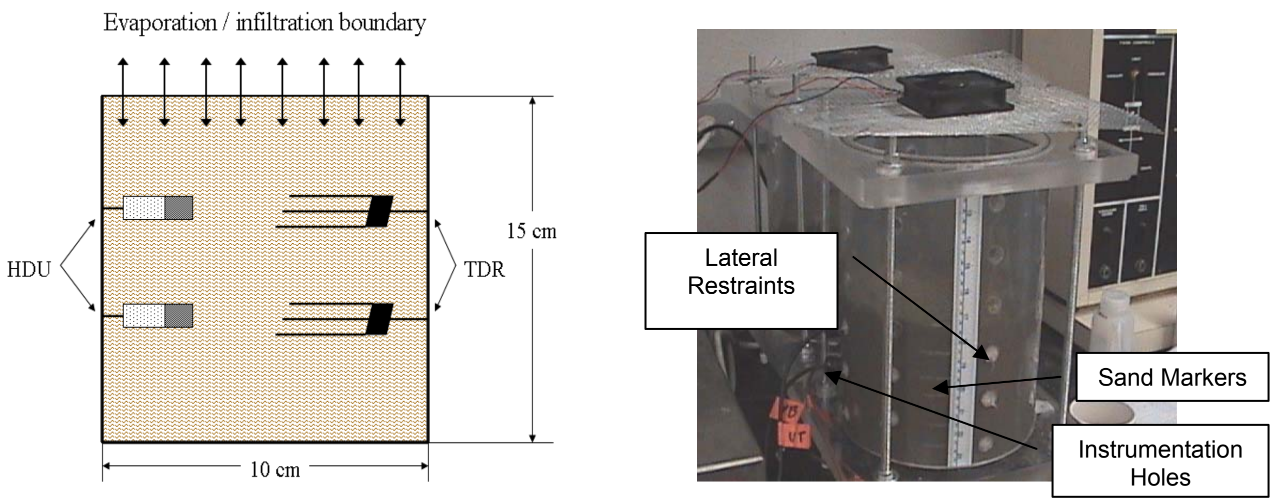
2. SOIL COLUMN DESIGN

Two identical columns were constructed for the testing program. The columns were constructed of a 300 mm high clear polyvinylchloride (PVC) tube with an inner diameter of approximately 200 mm. Acrylic plates were used as top and bottom plates, with groves cut into them for O–rings to seal of the top and bottom of the column. A 200 mm diameter hole was cut into the top plate to allow the top of the soil specimen to be subjected to different environmental conditions. A schematic of the soil column setup is shown in Figure 1a.



(a) Soil Column Setup Schematic (b) Soil Column Desiccation Testing Setup

Figure 1. Soil Column Testing Setup (a) Schematic and (b) Desiccation Testing Setup.

Initial column testing of soils indicated that the compacted highly plastic clays tended to pull away from the column walls during desiccation and resulted in minimal surficial cracking and surficial crack closure during the desiccation stage (Kuhn 2005). This was not considered representative of processes occurring in the field, and an alternate column design, in which lateral restraints were implemented, was used. For this alternate column design, holes were drilled into the side of the column so that lateral restraints could be placed into the soil specimen to prevent the soil from pulling away from the column during desiccation (Figure 1b). The lateral restraints used were plastic dry wall screws, model 25310 manufactured by ITW Buildex (Itasca, Illinois).

The soil specimens were compacted using six individual layers (25 mm per layer) to a final height of 150 mm. The soil was compacted at 2% wet of optimum to a target density matching 100% of standard proctor effort. At the top of each compaction layer, a small sand marker was placed in order to measure height changes. Time Domain Reflectometry probes (Soilmoisture Equipment Corporation, referred to as TDR's) and Heat Dissipation Units (Model 229-L Campbell Scientific, referred to as HDU's) were placed at elevations of 5 and 10 cm from the bottom of the column to measure volumetric water content and matric suction, respectively. A separate series of instrumentation holes (aside from the lateral restrain holes) were drilled into the side of the column at 60^{o} apart with diameters of approximately 3 cm. Wires extending from the instrumentation holes were secured into place with rubber stoppers and silicon rubber sealant. Calibration of the instrumentation probes is outlined in Kuhn (2005) and Freilich (2006).

After placement of the soil layers, the lateral restraints were carefully placed into the soil columns. The lateral restraint holes were then filled with silicon rubber sealant to prevent any flow into or out of the sides of the columns. The top of the column was sealed for 72 hours prior to testing in order to allow the instrumentation to come to equilibrium with the compacted soil.

3. MATERIAL PROPERTIES

3.1 Highly plastic clay properties

The highly plastic clay used for the testing program was processed Eagle Ford shale excavated from Round Rock, Texas, at the intersection of Hester's Crossing and Interstate 35. The excavated pieces of shale were dried in a temperature controlled room at 120ºF, broken down by hand, and then crushed into finer particles using a rock crusher.

The crushed particles were then passed through a series of sieves and only the particles passing the #10 sieve were used for the testing program. An outline of the soil data provided by Kuhn (2005) is presented in Table 1.

Table 1. Properties of the Processed Eagle Ford Clay (Kuhn 2005).

Test	Property	Value	ASTM Procedure
Specific Gravity	Specific Gravity, G_s	2.74	D 845 – 02
Atterberg Limits	Liquid Limit, LL	88	D 4318
	Plastic Limit, PL	39	
	Shrinkage Limit, SL	18	D4943
Particle Size Analysis	% Passing #200 Sieve	97	D 422 - 63
	% Finer than 0.002 mm	75	D 422 - 64
Standard Proctor Compaction	Optimum Water Content, w_{opt} (%)	24	D 1557
	Max Dry Unit Weight $\gamma_{d,max}$ (kN/m^3)	15.2	
Saturated Hydraulic Conductivity	Hydraulic Conductivity of Saturated Soil, K_{sat} (cm/s) (compacted at w = 24%, γ_d = 15 kN/m^3)	8.9x10^{-8}	D 5084

The Eagle Ford shale formation was chosen for this testing program due to the high shrink/swell potential of the processed clay. A common indicator of the swelling potential is the plasticity index and the liquid limit. The values of PI and LL from the Eagle Ford clay plot above the A-line in a Casagrande Chart, and therefore would be considered an expansive soil. Another indicator would be the presence of the smectite clay mineral in the soil, which is a highly expansive mineral. Hsu and Nelson (2002) reported that the Eagle Ford shale consisted of 38 – 88% clay minerals, with over 50% of these being smectites.

Kuhn (2005) conducted standard and modified proctor tests (ASTM D 1557 and D 698) and found optimum gravimetric water content values of approximately 24% and 14%, respectively. The maximum dry unit weight values obtained in accordance with the standard and modified Proctor compaction tests are 15.2 kN/m^3 and 17.8 kN/m^3, respectively.

3.2 Fiber-reinforcement properties

The fibers used for this study are commercially available fibrillated polypropylene fibers (GeoFibers, Synthetic Industries, Inc.). Properties and specifications, as listed by Li (2005), for the fibers are provided in Table 2. If mixed properly, the evenly distributed fibers should form an interconnected mesh that improves the mechanical properties of the soil (i.e. shearing strength and resistance to cracking). However, if an excessive amount of fibers is used the fibers may have an adverse effect on the soil mass, such as increasing in hydraulic conductivity and influencing compaction characteristics. Al Wahab and El-Kedrah (1995) and Miller and Rifai (2004) both studied the effects of polypropylene fibers in fine grained soils and reported that for fiber contents less then 0.5%, the fibers did not significantly effect the compaction or hydraulic conductivity of the soil.

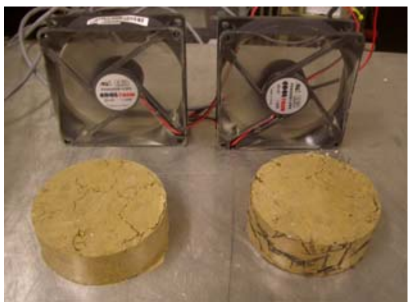
For the testing program, a fiber content of 0.3% (by dry weight of soil) was used. Fibers were mixed into the soil after the soil had been mixed to the proper water content. The moist soil was placed into a large mixing bowl and the fiber-reinforcement placed in a layer on top of the soil. The fibers were then mixed with the soil by hand until the fibers were evenly distributed into the soil mass. The fiber-soil mixture and unreinforced soil was then compacted into the respective soil columns using a drop weight. Based on the number of drops required to compact the soils to the desired density, it was determined that the compaction characteristics of the fiber-reinforced soil were approximately the same as the unreinforced soil.

Table 2. Properties of the Fiber-Reinforcement (Li 2005).

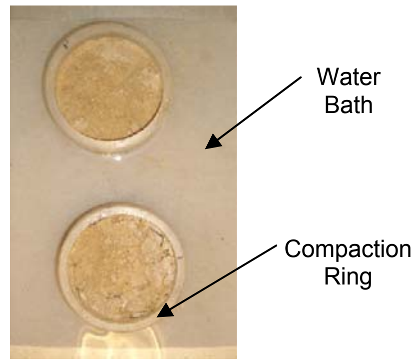
Property	Value	Units	ASTM Procedure
Length	5.04	cm	-
Diameter	~ 32	microns	-
Linear Density	2610	deniers (1/9000 g/m)	-
Specific Gravity	0.9	-	D 792
Average Tensile Strength	425,000	kPa	2256
Tensile Modulus	3.4 x 10^6	kPa	D 2101

4. SMALL SCALE TESTING OF EAGLE FORD CLAY SPECIMENS

An initial testing program was conducted on small disks of compacted soil (diameter = 7.6 cm and height = 2.5 cm) to compare with the results of previous testing programs, as well as with the results of the large scale column tests conducted in this study. The purpose of the testing of small disks of soil was to measure the effects of fiber-reinforcement on volumetric strains during wet/dry cycles. Two soil disks (one reinforced and one unreinforced) were subjected to a desiccation stage (immediately following the compaction of the disks), a subsequent infiltration stage, and a final desiccation stage. The desiccation stages involved placing the soil on a greased plastic plate and allowing the soil to come to equilibrium with the atmosphere (Figure 2a) for a duration of 48 hours. The soil disks were subjected to an average temperature of 72^{o}F and relative humidity of 52%. The infiltration phase consisted of placing the bottom of the soil disks in contact with water and allowing the soil to absorb water for 24 hours as shown in Figure 2b. For this testing procedure, no lateral restraints were used, and the soil was restrained from swelling by a greased acrylic ring (diameter = 7.6 cm and height = 5 cm). Changes in soil height and diameter were measured with a Vernier caliper during the desiccation phases of the testing. Cracking was also measured with a Vernier caliper, but was not taken into account in volumetric strain calculations as discussed in the following section.



(a) Desiccation Stage Setup



(b) Infiltration Stage Setup

Figure 2. Testing Setup for the (a) Desiccation and (b) Infiltration Stages.

During the desiccation of the soil disks, surficial cracking was observed within 30 minutes of air drying for both desiccation stages. The maximum measured crack dimensions were 1 mm in width and 1 mm in depth for the first stage and 2 mm in width and less than 3 mm in depth for the second stage. Accordingly, the degree of cracking increased from the first desiccation stage to the next. As radial shrinkage of the soil increased during desiccation, surficial cracks on the soil disks were observed to decrease in size with most cracks closing completely, which is in agreement with observations reported by Kuhn (2005).

The change in void ratio of the soil disks was calculated using the measured volumes and weight for the desiccation stages. Initial and final void ratio values were calculated for the infiltration stage. The change in void ratio versus the gravimetric water content (the S-curve) for the reinforced and unreinforced soil disks for the first and second desiccation stages are shown in Figure 3. During the first desiccation stage, both the reinforced and unreinforced soil disks show the same behavior (same change in void ratio with corresponding change in water content). This result is not in agreement with previous research (Al Wahab and El-Kedrah 1995 and Zeigler et al. 1998), in which the change in the void ratio for the fiber-reinforced soil was less then for the unreinforced soil. However, it is important to note that previous testing programs saturated the soil specimens by submerging them in water and allowing unlimited access to water, which was not the approach used in this program. Saturating the soil specimens prior to desiccation assumes that the soil in the field would be submerged in water for a period of time adequate to cause full swelling. A more realistic scenario is to perform partial saturation via capillary rise as in this study, which allows the soil specimen to come close to saturation without allowing unrestricted swelling and absorption of water.

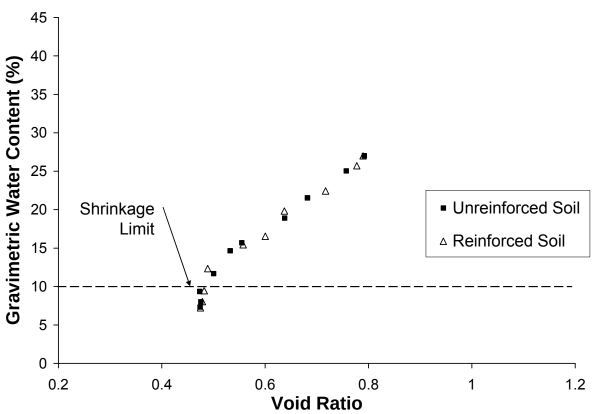
The water content of the reinforced specimen was observed to be greater than the water content of the unreinforced soil specimen after the infiltration stage. Accordingly, the initial point on the S-curve for the second drying stage (Figure 3b) is higher (greater void ratio and water content) for the reinforced that the unreinforced specimen. This is in agreement with data presented by Puppala and Musenda (1998), which hypothesized that the ability of reinforced soil to gain more water was caused by the fibers creating a flow network within the soil, providing for a more efficient distribution of water into the soil mass. This suggests that fibers increase swell potential of a soil under the conditions for small soil disk testing.

5. SOIL COLUMN TESTING OF COMPACTED EAGLE FORD CLAY

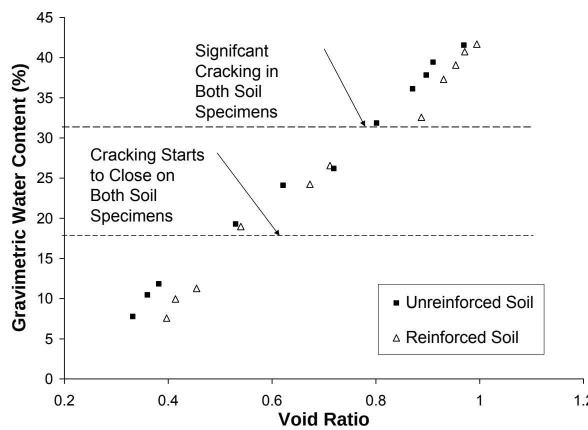
In the previous section, testing of small disks of soil was performed in order to measure the effects of fiber-reinforcement on volumetric strains during wet/dry cycles. The disadvantage of using such small soil specimens is that the fibers are much longer then the dimensions of the soil mass. This could potentially reduce the effectiveness of the fibers since they rely on interface strength mobilization (caused by displacements) along their entire length. Reducing this length of fiber in the soil specimen may even increase the severity of swelling during the infiltration cycles as indicated above. Large scale soil columns (200 mm in diameter and 150 mm in height) were constructed of fiber-reinforced soil and subjected to a series of desiccation/infiltration cycles in order to evaluate the effects of specimen size. The results from the testing program are presented in the following sections.

5.1 Surficial cracking on the soil columns

Surficial cracking of the fiber-reinforced and unreinforced Eagle Ford clay was measured with a Vernier caliper during each of the desiccation stages. Digital photographs of the soil surfaces were also taken throughout the desiccation process (Figure 5). It was evident from visual inspection that the presence of fibers reduced the size and depth of surficial cracking, but increased the total number of cracks on the soil surface.



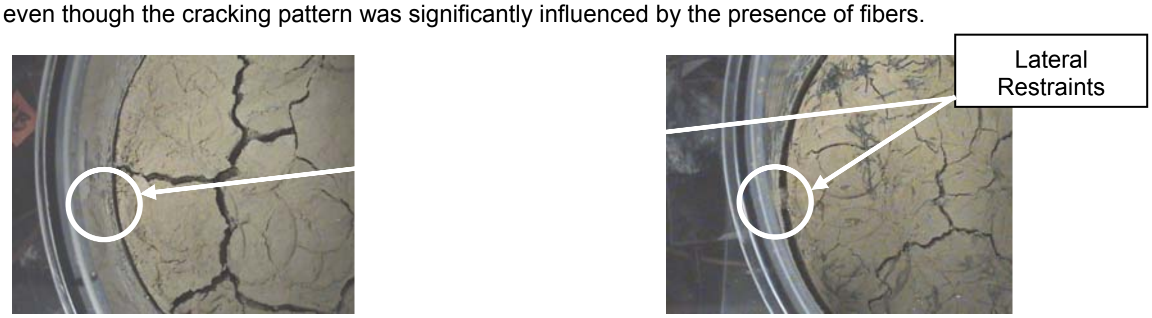
(a) First Desiccation



(b) Second Desiccation

Figure 3. S-Curves for the Fiber-Reinforced and Unreinforced Eagle Ford Clay Specimens during the (a) First and (b) Second Desiccation Stages.

In order to quantify the magnitude of cracking occurring during the desiccation stage, the crack intensity factor was used. The crack intensity factor (CIF) is defined as the area of surficial cracks divided by the total top surface area of the specimen (Miller et al. 1998). Cracking area was determined by measuring equivalent lengths and widths of each crack and assuming the cracks are approximately rectangular. A problem arose when determining the total top surficial area of the soil specimens. During the desiccation stages, the soil specimens shrank radially even with the lateral restraints present (Figure 4). The effect of including this radial separation in the CIF is shown in Figure 6. If the radial separation is not included, the fiber-reinforced soil exhibits a lower CIF (indicates less cracking/volumetric strains). However, when the sidewall separation is included in the CIF, both the reinforced and unreinforced soils exhibit approximately the same CIF. This indicates that both the reinforced and unreinforced soils experienced the same volumetric strains due to desiccation, even though the cracking pattern was significantly influenced by the presence of fibers.



Unreinforced Fiber-Reinforced

Figure 4. Radial Separation of the Soil Columns During the First Desiccation Stage.

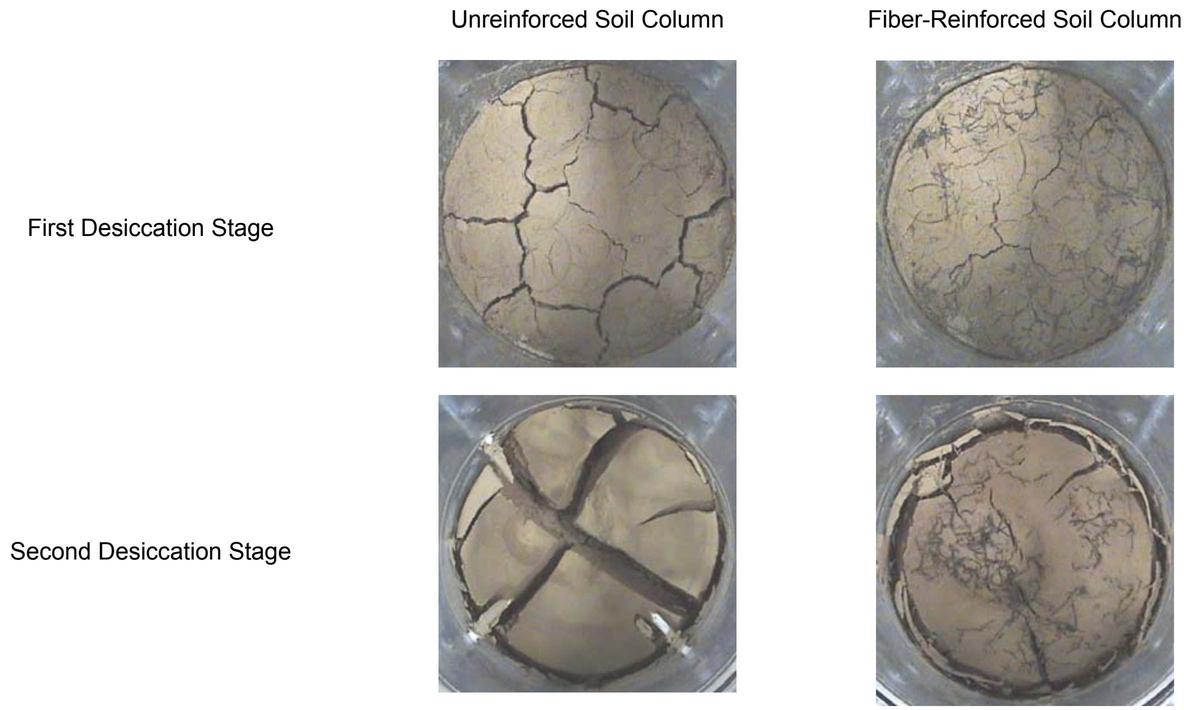


Figure 5. Examples of Soil Column Surface Pictures for the Soil Columns for Both Desiccation Stages (Photos Taken at 48 Hours).

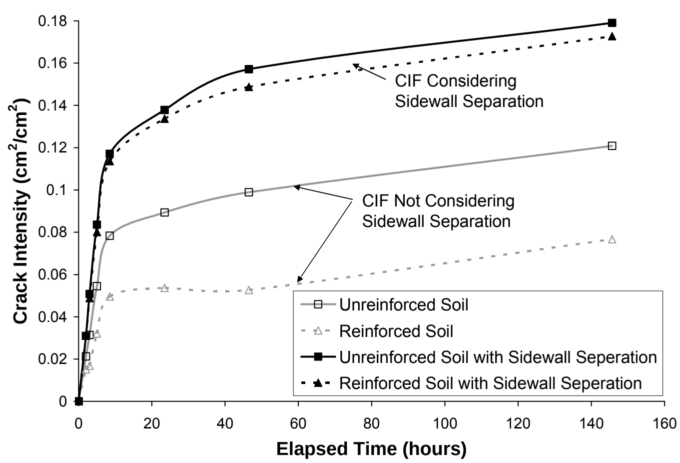


Figure 6. The Development of the Crack Intensity Factor With Time for the Soil Columns (First Desiccation Cycle).

The CIF values measured during the second desiccation stage (corrected for sidewall separation) are shown in Figure 7. Two important aspects are apparent from the CIF. First, the cracking during the second desiccation stage was more severe (almost 3 times greater) than during the initial desiccation stage. This increase can be attributed to the soil starting at higher initial water contents during the second desiccation stage due to the infiltration of water. The second important aspect is that the CIF values measured for the fiber-reinforced soil are lower then the unreinforced soil, unlike the first desiccation stage. Two possible explanations why fibers only affect the CIF in the second desiccation phase can be valid. The first explanation is that the reduction in crack size, caused by the presence of fibers, reduced the amount of water that was absorbed into the soil. The starting volumetric water content during the second desiccation phase was 46% for the unreinforced soil versus 42% for the fiber-reinforced soil. The second explanation is that during the first desiccation cycle, there was not enough displacement on the fiber-soil interface to mobilize the full interface strength. During the second desiccation stage, the volumetric strains were higher, and therefore higher interface strengths were mobilized, making the fibers more effective. However, it is also known that the fibers become less effective with increasing water content, as they may form a network of flow paths within the soil specimen (water present along the fiber-soil interface).

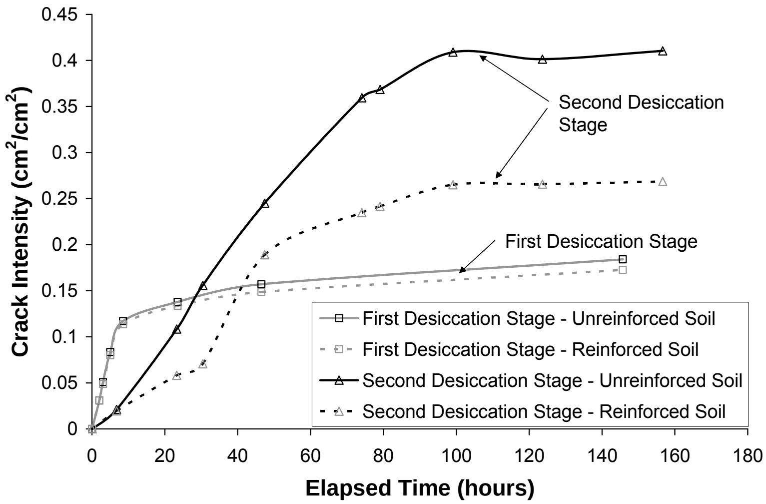


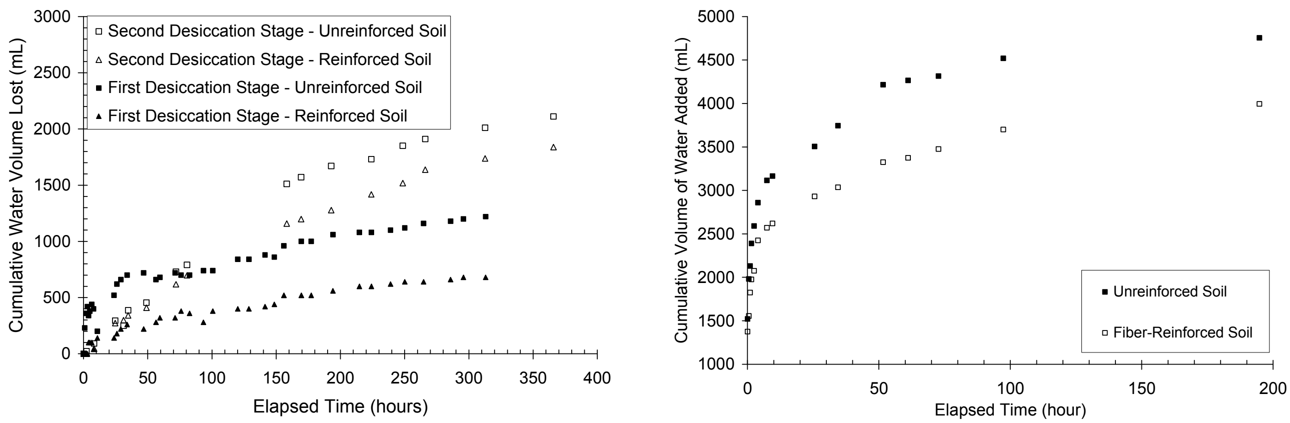
Figure 7. The Development of the Crack Intensity Factor (Including Sidewall Separation) With Time for the Second Desiccation Stage.

5.2 Rates of evaporation and infiltration from the soil columns

It is usually assumed that an increase in the severity of cracking of a soil specimen will significantly influence the rate at which water can enter or leave the soil. Over the duration of the desiccation and infiltration stages, the volume of water in the soil mass was calculated in order to quantify the rate at which water was entering or leaving the soil mass. The rates of evaporation and infiltration were defined as the flow rate of water per unit area of soil surface. The flow rate of water was defined using two different methods for the desiccation and infiltration stages. For the desiccation stages, the change in weight of the columns (with time) was measured and assumed to be equal to the change in the weight of water in the soil mass. The cumulative volume of water lost (converted from the change in weight of the soil column) for both desiccation stages is shown in Figure 8a. The loss of water from the unreinforced soil was higher then the reinforced soil throughout the second desiccation stage, and that the total loss of water for the unreinforced soil during the second desiccation stage is almost twice the amount lost during the first stage.

For the infiltration stage, the columns could not be easily weighed, so the amount of water added over time to keep a constant water level on the soil surface was measured (Figure 8b). The unreinforced soil column absorbed water at a faster rate than the reinforced soil, opposite of what occurred in the small scale testing. This increase in water absorption could be attributed to water filling the larger crack voids in the unreinforced soil, as well as the cracks providing more surface area for flow to occur. After all the cracks closed (within 2 hours), there is a significant reduction in the amount of water that was needed to maintain a constant head. Evaporation from the top of the water level into the atmosphere was also taken into account in the volume measurements by considering the mass of water that evaporated, under the same environmental conditions, from a metal dish during the testing time.

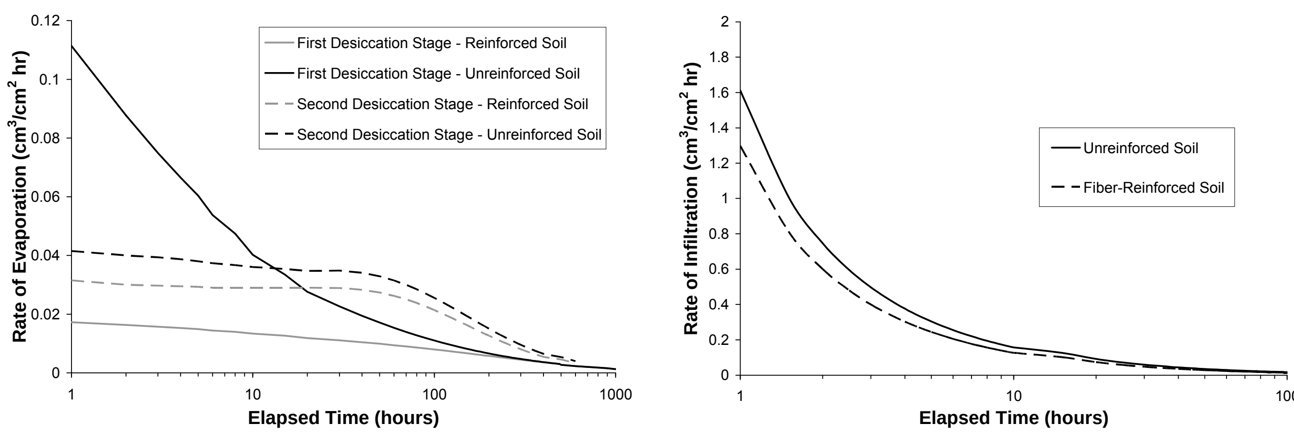
The rates of evaporation (for the first and second desiccation stages) and infiltration are shown in Figure 9. To reduce scatter in the calculated rates, power function curves were fit to the data points in Figure 8, and the derivatives taken in order to produce the rates of evaporation and infiltration. For both desiccation stages, there is a high initial rate of evaporation up to 100 hours, and then a reduction to a minimum value by 1000 hours. As expected, the rate of evaporation for the second desiccation stage is generally higher then for the first desiccation stage. This increase in the rate of evaporation is driven by the increased water content of the soil, and also in increase in the void ratio of the soil (caused by swelling in the infiltration stage) resulting in an increase in the hydraulic conductivity of the soil.



(a) Desiccation Stages (First and Second) (b) Infiltration Stage

Figure 8. Change in Volume of Water with Time for the (a) Desiccation Stages and (b) the Infiltration Stage

The rate of evaporation curves (Figure 9a) give insight into how the soil columns behaved during desiccation. The most noticeable trend in all four curves is a high rate of evaporation (for time less then 100 hours) that reduces to a constant minimum value (time greater then 1000 hours). This reduction can be attributed to the top soils forming a desiccated crust, which reduced the value of hydraulic conductivity of the top soil layers and restricted the flow of water from the lower soils. The top layers of soil control the flow of water out of the columns, so that as the desiccation of the surficial soils increase, the rate of evaporation out of the soil column decreases.



(a) Rate of Evaporation (Both Desiccation Stages) (b) Rate of Infiltration

Figure 9. Change in the Rate of Evaporation (a) and Infiltration (b) with Time.

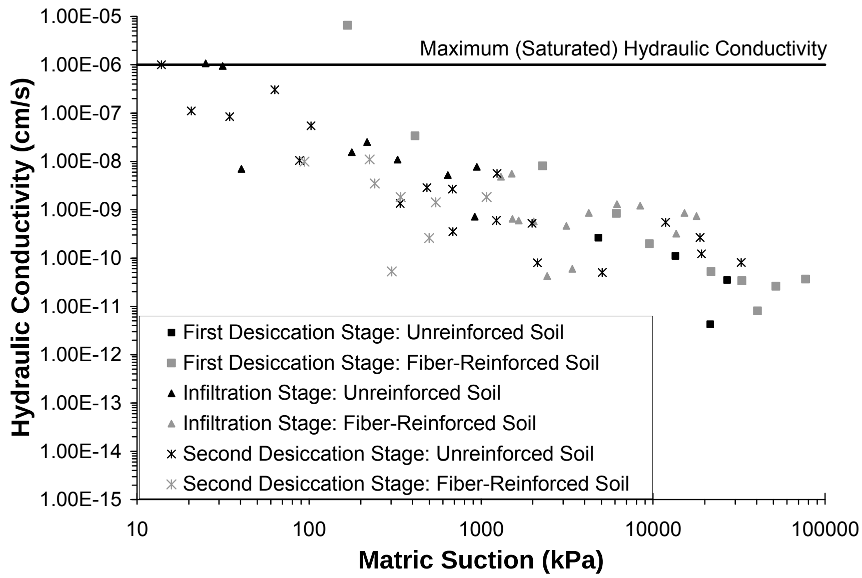
The rate of infiltration for the unreinforced soil is significantly higher then for the reinforced during the first 10 hours, but reduces to approximately the same value afterwards (Figure 9b). The lower infiltration rate into the fiber-reinforced soil is attributed to the soil mass having less cracking, and therefore smaller paths for water to flow into. After 10 hours, cracking on both soil surfaces had closed completely (sidewall separation closed after 24 hours) and the infiltration rates approach the same value. This lower initial infiltration rate for the fiber-reinforced soil was the cause of the fiber-reinforced soil absorbing less water then the unreinforced soil, as mentioned in the previous section. This significantly influenced the cracking intensity of the second desiccation stage. This also provides evidence that using small scale soil tests to determine the effectiveness of fibers (Section 4) may not accurately represent field conditions.

5.3 Calculation of hydraulic conductivity for the soil columns during desiccation

In the previous sections, the effects of fiber-reinforcement on the macrostructure of the soil (surficial cracking, volumetric strains, evaporation and infiltration) were explored. The hydraulic characteristics of highly desiccated soils (SWRC and K-function) are, however, most likely controlled by its microstructure of the soil (Meerdink et al. 1996). Using data obtained from the two layers of TDR probes (moisture content measurements) and HDU's (matric suction measurements), the hydraulic conductivity of the soil mass between the instrumentation can be calculated using the Instantaneous Profiling Method (IPM) (Watson 1966, Wendroth et al. 1993, Meerdink et al. 1996, Kuhn 2005, Freilich 2006). In order to use the method, Darcy's Law was considered valid and flow was considered one-dimensional. The calculated hydraulic conductivities of the reinforced and unreinforced soil masses can be used to determined the effect of fiber reinforcement on the hydraulic characteristics of the soil under highly desiccated conditions (high suctions).

The back calculated values of hydraulic conductivity for the soil columns (both reinforced and unreinforced) for all of the testing stages are shown in Figure 10. Although there are slight differences in the hydraulic conductivities for the reinforced and unreinforced soil, the change in the conductivity with desiccation appears to follow a single linear trend in terms of suction (in log-log space) no matter the desiccation/infiltration cycle. In terms of volumetric water content, the hydraulic conductivity of the soil for the infiltration stage plots on a different linear trend then for the desiccation stages. This may be due to water instantly saturating the area around the TDR probes (due to cracking around the upper probes) and increasing the volumetric moisture content readings. Water may have also surrounded parts of the HDU probes, but did not instantly saturate the probes as for the TDR's, therefore no significant changing in the matric suction values were measured.

(a)



(b)

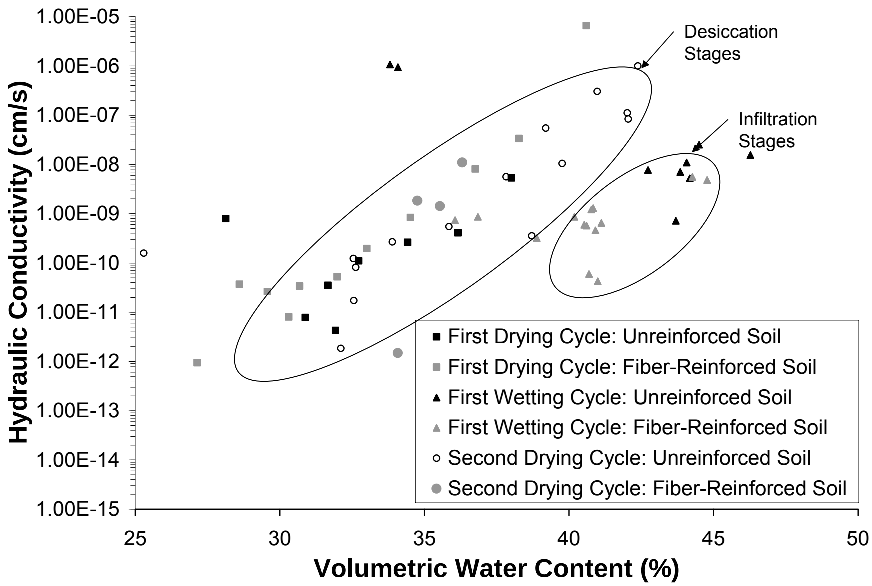


Figure 10. Change in Hydraulic Conductivity with Matric Suction (a) and Volumetric Water Content (b) for the First Desiccation Stage, Infiltration Stage, and Second Desiccation Stage.

At the lowest matric suctions measured (approximately 10 kPa), it can be assumed that the voids in the soil mass are becoming saturated. Therefore, the back calculated values of hydraulic conductivity at the lowest suctions should approach the maximum hydraulic conductivity of the soil, or the saturated hydraulic conductivity. Using the instantaneous profiling method, the maximum hydraulic conductivity of the desiccated soil columns was approximately $1x10^{-6}$ cm/s. This differs by more then four orders of magnitude from the saturated hydraulic conductivity value measured using a flexible wall permeameter and saturated Eagle Ford clay specimen, which gave a value of $8.9x10^{-9}$ cm/s. This difference in hydraulic conductivities indicates that the desiccation of the highly plastic soil can significantly increase the permeability of the soil during a single desiccation/infiltration cycle.

6. CONCLUSIONS

The testing program described in the following paper was conducted in order to evaluate the effectiveness of fiber-reinforcement in highly plastic clays during cyclic desiccation and infiltration. Based on the data obtained, it was evident that fibers did influence the behavior of the soil. Conclusions from the testing program are as follows:

- Specimen size influences the behavior of the reinforced soil during the infiltration of water. For small fiber-reinforced soil disks, the rate of infiltration into the soil was greater than into the unreinforced soil. For the larger soil columns, the opposite was true, which could be attributed to the fibers reducing the cracking intensity of the soil, which reduced the volume of water that could flow into the cracks and into the soil.
- The presence of fibers in the soil mass reduced the initial rates of evaporation and infiltration from the soil columns.
- Although fibers influenced the surficial cracking pattern and size, they did not decrease the volumetric strains of the soil during desiccation. This indicates that fiber-reinforced and unreinforced soils may experience the same volumetric strains if they start at the same initial conditions.
- The K-functions defined using the instantaneous profiling method indicate only minor effects of fibers and testing stage (desiccation or infiltration) on the variation in hydraulic conductivity with matric suction.
- The presence of surficial cracking and volumetric strains in both soil columns increased the saturated hydraulic conductivity of the clay by two orders of magnitude.

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