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ESTIMATING SHRINKAGE OF COASTAL SOIL

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Introduction

Geotechnical design in coastal Louisiana is relatively challenging for many reasons including, but not limited to, soft soil behavior, estimating spatial variation of soil, making assumptions for weather and water conditions, estimating varying loading conditions, construction means and methods, etc. Earthen structures constructed in coastal Louisiana marshes typically undergo consolidation settlement and shrinkage. While there are a considerable number of studies in the literature discussing consolidation settlement, there are relatively few that delve into shrinkage of soil associated with coastal conditions, especially when there is water recharge. A typical coastal Louisiana marsh creation/restoration project may include construction of earthen terraces, earthen dikes and placement of hydraulic fill to a pre-determined target elevation. This involves understanding the behavior of foundation soils and fill over the desired project life. Typically, as water in soil pores is expelled due to self-weight consolidation of the earthen feature, the height and volume of the earthen feature change. At the same time, sun, heat, wind and vegetation evaporate water from the surface of the earthen feature. Thus, consolidation settlement and shrinkage are occurring simultaneously and are difficult to differentiate. Both processes may have considerable effect on the height and volume of the earthen feature. For this reason, consolidation settlement and shrinkage should both be considered by designers and contractors especially for Louisiana coastal projects using native clay and organic soil with high moisture content.

Figure 1: Soil Shrinkage

Soil shrinkage often starts when a saturated or wet soil is exposed to air, and water begins to evaporate. Shrinkage may occur when a submerged area is de-watered for an extended time, or when submerged soil is excavated and placed above the water level. ASTM D4943 provides a method to determine the shrinkage limit of a soil; however, this method does not consider a condition where soil may be exposed to air drying at the air-soil interface, but also can replenish water through capillary rise. The scenario of a soil being exposed to air drying, while also being in contact with a water source is more common for earth related projects in Louisiana's coast.

This article presents results from a simplified experiment to evaluate shrinkage of soil samples. Thirteen soil samples were allowed to air dry while a portion of the sample was submerged in a tray of water, over a time varying from 133 to 210 days. The test environment was inside and air conditioned with a temperature between 70° and 75° Fahrenheit. It was observed that a balance was achieved by soil samples between water loss from evaporation and recharge of water from capillary action in a controlled environment.

Laboratory Experiment

Thirteen soil samples from 3 different sites located in coastal Louisiana were used for this experiment. The map insert shows the location of the 3 different sites. Of the 13 soil samples, 11 were undisturbed samples obtained using a 3-inch outside diameter (OD) thin wall tube sampler two samples were remolded samples.

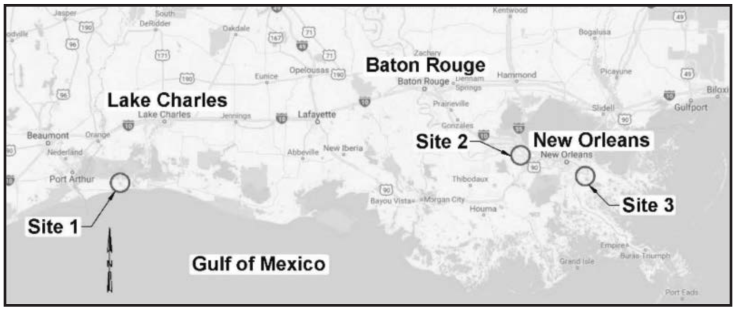


Figure 2: Site Locations

There was no standard procedure known to the authors to complete this observational experiment. The procedure used was as follows. Each sample was placed on a porous stone in a tray filled with tap water and measured to acquire a base reading (time zero). A filter paper was placed between the soil sample and the porous stone and a 3-inch outer diameter (OD) by 2-inch high ring was placed around each soil sample above the porous stone to provide sample containment below the water level. Water was replenished as needed to maintain a level above the porous stones, but not more than 2 inches in the tray (in contact with the sample but not over the support ring). Thereafter, soil sample measurements were taken weekly for the first month, then as required based on soil behavior. The measurements included height at four locations around the sample circumference and a diameter measurement at the top of the sample.

After a sample observation period varying from 133 to 210 days, moisture content, organic content, and Atterberg limit tests were performed on samples as summarized in Table 1. Soil samples were tested following applicable ASTM standards. Moisture content tests at the end of the experiment were taken at three locations:

- Top of sample (identified as sample #A in Table 1),
- 4-inches from top of porous stone (identified as sample #B in Table 1),
- and 2-inches from top of porous stone (identified as sample #C in Table 1).

Table 1: Summary of Laboratory Results

Soil Description	Site	Sample Number	Final Moisture	Organic Content	Liquid Limit	Plasticity Index
Black Peat (PT)	3	1A	691	54.2	613	332
		1B	955			
		1C	1020			
Dark Clay with organics (CH)	3	2A	7	6.5	86	57
		2B	37			
		2C	80			
Gray Clay trace organics (CH)	1	3A	8	2.2	61	39
		3B	28			
		3C	109			
Gray Clay with silt and sand (CL)	1	4A	6	4.9	47	21
		4B	24			
		4C	53			
Black Organic Clay (OH)	3	5A	42	16.0	117	86
		5B	83			
		5C	143			
Black Peat (PT)	3	6A	304	30.1	467	315
		6B	400			
		6C	446			
Brown Peat (PT)	2	7A	580	49.7	778	390
		7B	1103			
		7C	1073			
Black Peat (PT)-remolded	3	8A	513	48.4	587	341
		8B	704			
		8C	748			
Black Peat (PT)-remolded	3	9A	409	41.1	502	274
		9B	665			
		9C	634			
Gray Clay with organics (CH)	2	10A	13	9.8	66	37
		10B	70			
		10C	115			
Gray Clay with organics (CH)	2	11A	15	5.2	73	44
		11B	48			
		11C	88			
Gray Clay with organics (CH)	2	12A	26	5.7	58	35
		12B	52			
		12C	88			
Gray Organic Clay (OH)	2	13A	16	15.4	63	28
		13B	66			
		13C	147			

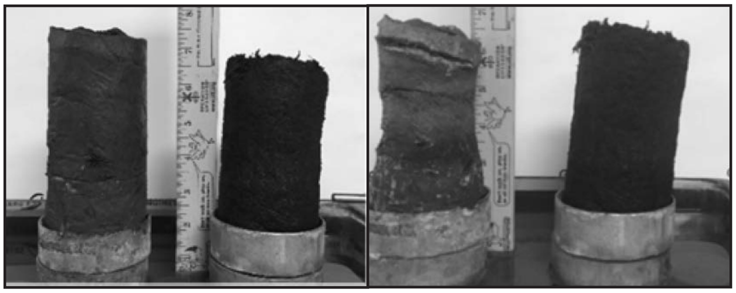
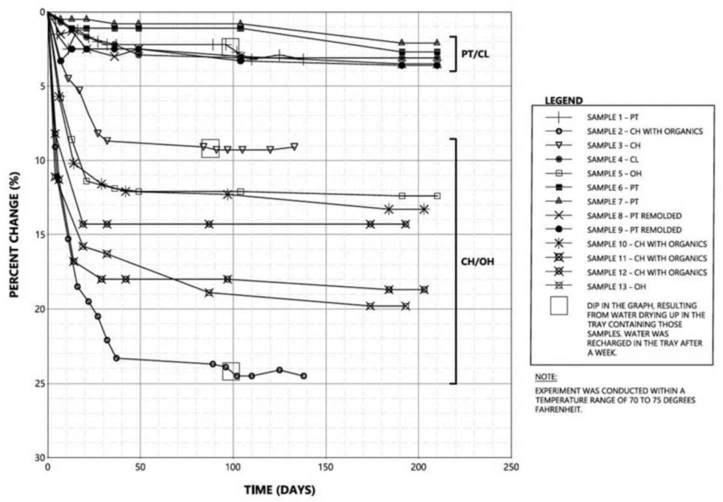


Figure 3: Typical samples at start (left photo) and end (right photo) of observation period. Sample 2 (CH) on left and Sample 1 (PT) on right.

Experiment Results

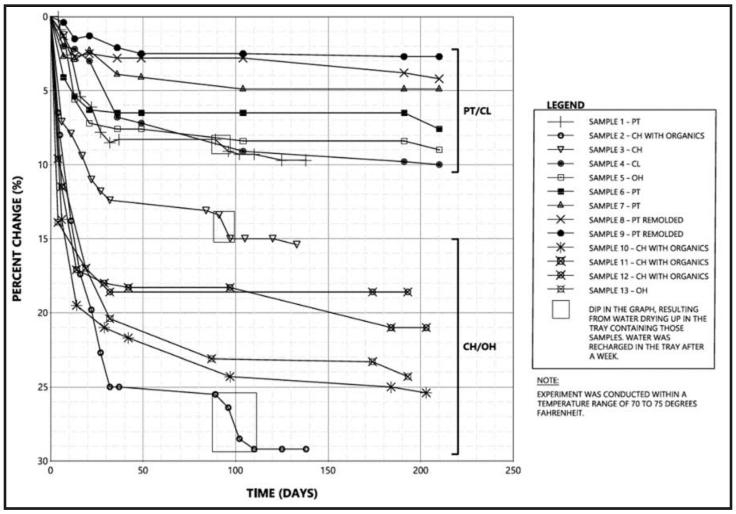
Graphs in Figures 4 and 5 below show the percent change in average height and diameter, with respect to time. As visible in Figure 4, height shrinkage of peat and low plasticity clay ranges from approximately 2 to 4 percent and height shrinkage of organic clay and high plasticity clay ranges from approximately 8 to 25 percent. As visible in Figure 5, diameter shrinkage of peat and low plasticity clay ranges from approximately 2 to 10 percent and diameter shrinkage of organic clay and high plasticity clay ranges from approximately 8 to 29 percent.

Figure 4: Sample Height vs. Time



A relatively sudden change in shrinkage was observed in Samples 1, 2 and 3 when water was not replenished in the tray. This can be seen in the both Figures 4 and 5 as a sudden dip in the data plots. The majority of the shrinkage appears to occur within the first 50 days of starting the test in a controlled environment. Beyond 50 days most samples appeared to reach equilibrium and there was less shrinkage or swelling, except when water recharge was not maintained.

Figure 5 - Sample Diameter at Top of Sample vs. Time



NOTE:
EXPERIMENT WAS CONDUCTED WITHIN A TEMPERATURE RANGE OF 70 TO 75 DEGREES FAHRENHEIT.

Discussion

We expected soils with higher moisture content (peat) to shrink more; however, this was not the case. Typically, when samples are air dried without moisture recharge, more shrinkage occurs in higher moisture content soil. However, when water recharge is available, shrinkage appears to be a function of the rate at which water is drawn into the soil structure through capillary action, versus the rate at which water evaporates. In the soil samples evaluated for this study, peat (PT) appears to be best able to maintain moisture through capillary rise, while high plasticity (CH) and organic clay (OH) were most susceptible to shrinkage. Height and diameter change in low plasticity clay (CL) was similar to that of PT; however, we believe this is a result of CL being less susceptible to shrink and swell instead of capillary action. Table 2 summarizes the ratio of moisture content at the top of the sample (the #A sample in Table 1) to the moisture content at the bottom of the sample (#C sample in Table 1) at the end of the test. The PT samples maintained a greater percentage of the moisture than CH or OH samples, while the CL sample was similar to the CH samples. This supports our belief that the CL sample was less susceptible to shrink and swell.

Table 2: Moisture Loss Comparison by Sample Type

Type of Sample	# of Samples	Sample A Moisture/ Sample C Moisture	
		Average	Range
PT	5	64.6%	54.1% - 68.6%
OH	2	20.1%	10.9% - 29.4%
CH	5	14.8%	7.3% - 29.5%
CL	1	11.3%	11.3%

Soil with smaller pore spaces is expected to have a greater capillarity than soil with larger pore spaces. For example, clay is expected to have a greater capillary rise than sand. Capillary action draws water into the soil from a water source (base of the sample in our experiment). However, while clay has a greater capillary rise than sand, the same small pore spaces that increase capillary rise, also reduce the space available for water to pass through the sample and reduce the soil permeability. Capillarity, initial water content, plasticity and permeability were likely the controlling factors in our experiment. While CH and OH have high capillarity, the rate at which water evaporated exceeded the sample's ability to replenish water through capillary rise due to its low permeability. CH and OH samples also had relatively high initial water contents and high plasticity. Although PT samples had higher initial water content than CH and OH, it appears that PT was able to replenish water nearly as fast as it evaporated through capillary rise. Organic fibers within peat likely had a significant effect on capillary rise. For the CL sample, post-test moisture content comparisons suggest capillary rise did not keep up with evaporation, and the smaller shrinkage was likely due to lower plasticity. The geometry of exposed surface area for evaporation versus the distance required for capillary rise and soil classification will contribute to shrinkage potential in the field. Our samples had a lot of surface area for evaporation when compared to an earth dike that proportionally may have much less surface area for evaporation compared to recharge area and capillary rise distance.

This information may be useful for estimating shrinkage potential for coastal construction projects; particularly for earthen containment dikes and earthen terraces used in coastal projects. For example, a containment dike built above the average water level might be estimated to shrink more if CH or OH soil is used to build the dike than if PT or CL soil is used. A culvert structure with above-water fill components might be expected to require additional fill to make up for shrinkage if high moisture native CH or OH materials are excavated from a submerged condition and used for fill.

The measurements shown in Figures 4 and 5 could be used to estimate shrinkage magnitude keeping in mind these tests were performed in an air-conditioned lab environment (no sun, no vegetation, low humidity and controlled temperature) versus field conditions. Shrinkage is in addition to other potential fill losses for containment dikes such as consolidation settlement of subsurface soil and fill.

Future Study Recommendations

It isn't clear how this information may translate to field observations in less controlled environments. It would be interesting to make several mounds of soil in a low emergent marsh area with some of the soil mounds in direct contact with the underlying saturated marsh soil, and some isolated by means of an impermeable barrier, or some other means, and monitor shrinkage over time against soil type, weather and other variables that may potentially affect shrinkage. Monitoring at regular intervals including visual observations and soil testing may help to better define expected field behavior for differing soils.

Acknowledgements

We thank Jason Kroll with National Oceanic and Atmospheric Administration for providing feedback on shrinkage of containment dikes constructed for a marsh creation project in coastal Louisiana and how the estimated shrinkage values based on air dried samples with no water recharge varied from that observed during construction. This prompted the authors to develop and perform this experiment. We also thank GeoEngineers laboratory personnel for monitoring the soil samples.

Bios

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