

# **Cement Stabilization of Organic Subgrades for Pavement Preservation**

**Khaled Sobhan**

Florida Atlantic University, FL, USA, ksobhan@fau.edu

**Dronnadula V. Reddy**

Florida Atlantic University, FL, USA, dreddy@fau.edu

**Juan Carlos Ramirez, M.S., E.I.**

Dunkelberger Engr. & Testing, Inc., FL, USA, juanr@detinc.net

## **ABSTRACT**

Many flexible pavements in Florida are underlain by thick deposits of organic soils and peats at shallow depths. These soils undergo long term secondary compression due to sustained overburden pressure of the pavement, causing excessive premature structural distress in the form of cracking, rutting and differential settlement. The main motivation of this research was to investigate the effects of cement stabilization on the compressibility behavior of organic-rich soils having organic content in the range of 67% to 90%. The undisturbed soil samples were collected from the subsurface of SR 15/ US 98 roadway which experienced severe distress due to the presence of organic layers. It was found that cement stabilization at dosages between 35% and 55% (by dry weight) drastically reduced the  $C_a / C_c$  ratio (ratio of secondary compression index to primary compression index) of the organic soils to values resembling a nearly granular soil with desirable compressibility characteristics. This optimized mix design may provide appropriate guidelines for Deep Mixing Methods in subsurface organic layers for long-term preservation of the roadways built over problematic soils.

**Keywords:** Organic Soil, Cement Stabilization, Secondary Compression, Pavement

## **1. INTRODUCTION**

Northwestern Palm Beach County in Florida is characterized by its soils rich in organic matter found at relatively shallow depths. Organic soils and peats in this area are known to have high void ratios, low specific gravity, high moisture contents, and large secondary compression due to sustained overburden stress from the pavement structure. Frequent and costly rehabilitation is necessary to maintain the functionality of these roadways which often experience premature distress in the form of cracking, rutting, and differential settlement. In an effort to develop effective rehabilitation strategies, 24 experimental pavement sections were constructed in 2008 along the alignment of SR15/US98 with various geosynthetic reinforcing products embedded in the asphalt overlay, and a comprehensive field testing and monitoring program involving FWD, rut and ride quality measurements was undertaken. The results of these investigations have been previously reported by Sobhan et al. (2010). One of the alternatives which was considered but not implemented was Deep Mixing Method with cementitious materials. The current study, therefore, focuses on cement stabilization of organic soils and peat obtained from the SR 15 / US 98 test sections to evaluate if the compressibility characteristics of these problematic soils can be fundamentally altered for long term preservation of the roadway structure. It is expected that the optimized mix-design developed in this study could provide some criteria for the design of Deep Mixing Methods in Florida organic soils.

During May of 2009, a series of Shelby tube samples were retrieved from SR 15/US 98 test sections for use in the current study. These were extracted with the help of a truck-mounted drill rig provided by the Florida Department

of Transportation (FDOT) State Materials Office in Gainesville. Samples were taken from depths ranging from 7.5 to 14 feet measured from the roadway surface. The site characteristics are given below.

## 2. SITE GEOTECHNICAL CHARACTERISTICS

The existing roadway consists of a thick AC layer averaging almost 330mm (13 in.), a lime rock base layer averaging 305mm (12in), and a sand fill subgrade averaging almost 0.9 m (36 in.), overlying organic soils (silty muck and peat) ranging from 3 to 5m (9 to 16ft) in thickness. Previous geotechnical characterization including 92 test borings, field piezocone penetration tests, and laboratory consolidation and shear strength tests on undisturbed specimens revealed that the organic soils had the following properties (Sobhan et al. 2007): the organic contents range from 25% – 92%, moisture content ranges from 160% - 650%, void ratio ranges from 3.2 – 13.9, undrained shear strength ranges between 17 – 40 KPa (2 – 6 psi), and the  $C_\alpha/C_c$  ratio ranges between 0.028 and 0.052. Typical pictures of these problematic soils and their approximate depths are given in Figure 1. From a mechanistic standpoint, the primary consolidation process in organic layers is quite rapid, followed by significant secondary compression stages under sustained overburden pressure due to the dead weight of the pavement structure and granular fill. Results of the primary and secondary compression tests are summarized in Figure 2.



Figure 1: (a) Silty organic layer from 1.5m to 3.0m; (b) Fibrous peat layer from 3.0m to 6.0m.

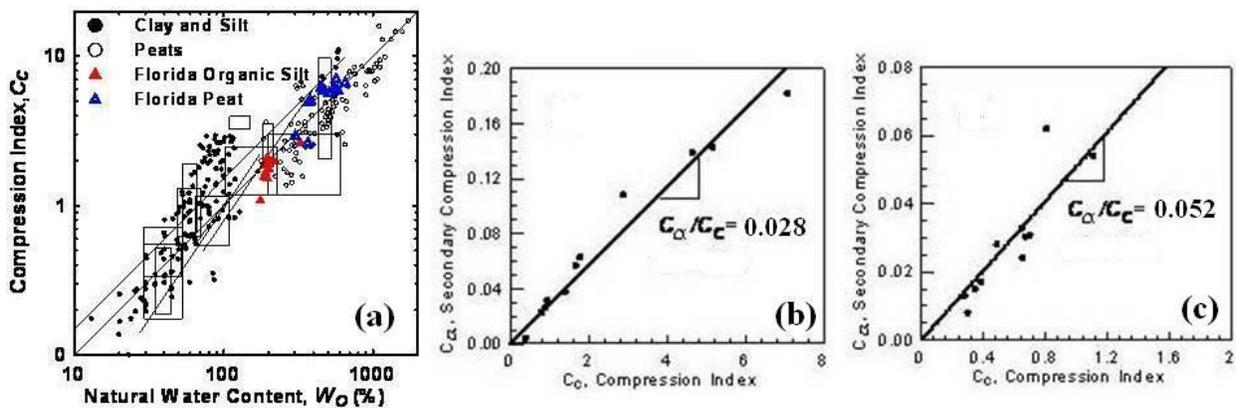


Figure 2: (a) Variation of compression index with water content; (b) and (c)  $C_\alpha/C_c$  ratio for Florida peats (b) and organic silts (c)

A significant body of literature exists on the laboratory compression behavior of organic soils and peat (Mesri et al. 1997; McVay and Nguyen, 2004). Laboratory time-stress-compressibility relationship was developed for

Florida organic soils following the procedures outlined in the literature (Mesri and Godlewski, 1977). In addition, the strength, modulus and deformation characteristics were also interpreted directly from the cone tip resistance data, which are described elsewhere (Sobhan et al. 2007). These geotechnical investigations were used as a basis to determine the ideal locations for the construction of test sections. As mentioned previously, the Shelby tube samples for this study were retrieved from the subsurface at ten different spots underneath the test sections.

### 3. OBJECTIVES

The objectives of this study were as follows:

1. To determine if the highly compressible nature of Florida organic soils and peats can be effectively controlled by conventional cement stabilization;
2. To quantify the effectiveness of cement stabilization by evaluating the time-stress-compressibility ( $t$ -log  $\sigma'_v$  -  $e$ ) relationship for treated soils undergoing primary and secondary compression tests; and
3. To develop the criteria for optimum cement dosage in order to attain the desired control of the secondary compression behavior

### 4. EXPERIMENTAL PROGRAM

#### 4.1 SPECIMEN PREPARATION

The sample preparation consisted of four main tasks including: mixing, compacting, curing, and the control of any swelling pressure during the curing period. The mixing process was carried out at the soil's natural moisture content and the stabilizing agent was introduced in a dry state in an effort to simulate field conditions (Dry Soil Mixing technique) practiced in Deep Mixing Method (DMM). The Dry Soil Mixing method recommends the introduction of the stabilizing agent in a powder form for soils with moisture content higher than 75 percent; for soils with lower moisture contents, added water is recommended. For the laboratory mixing task, the cement was added by small increments followed by a mixing period of 2 minutes. General purpose type I Portland cement was utilized as the stabilization agent. The main goal during the compaction effort was to reach a representative density close to the in-situ conditions (about 70 pcf for the muck and 65 pcf for the peat). During the compaction, the soil was placed in three equal layers into the container designated for curing and the same compaction energy was applied to each layer. The energy of compaction was determined by a trial and error procedure until the desired compaction level was achieved. Once the samples were mixed and compacted, they were inundated with water and the treated soil was allowed to cure for a period of 7 days. During the curing time, no overburden pressure was applied, but any swelling effects exerted by the percolation of water were controlled.

#### 4.2 METHODOLOGY

The testing program was composed of two series of tests, namely Test Series I and Test Series II, each series consisting of six simultaneous consolidation tests. The two series were composed of a conventional incremental loading (primary consolidation) and a creep stage (secondary compression). For the primary consolidation phase, the Increment Load Ratio (ILR) utilized was unity, which was held constant for a loading period of 24 hours. The specimens were incrementally loaded up to a desired stress level and then secondary compression (under constant load) was allowed for a period of 14 days. The mix design for the two test series are described in Table 1. The soil utilized for Test Series I consisted of organic silts (sometimes referred to as "muck") with an organic content of 67.0% and a preconsolidation pressure of 0.60 tons per square foot (tsf). It was incrementally loaded up to a load of 2 tsf and then allowed to undergo secondary compression for 14 days under the last applied load. The soil utilized for series II was a peat with an organic content of 89% and a preconsolidation pressure of 0.12 tsf. It was incrementally loaded up to a load of 1/2 tsf and then allowed to undergo secondary compression for 14 days under the last applied load. The loading protocol for Test Series I and II are shown in Table 2, where the stress level is defined as the ratio of vertical applied pressure to the preconsolidation pressure ( $\sigma'_v/\sigma'_p$ ).

**Table 1: Mix design for Test Series I and II**

<b>Test Series I</b>	<b>Specimen #</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>
	Cement % (by dry weight)	0.00	11.29	25.18	37.46	50.27	56.48
	Cement (kg/m <sup>3</sup> )	0.00	29.22	65.68	99.56	131.12	160.59
<b>Test Series II</b>	<b>Specimen #</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>
	Cement % (by dry weight)	0.00	16.90	39.05	59.37	77.91	89.68
	Cement (kg/m <sup>3</sup> )	0.00	24.44	55.26	84.23	111.51	137.26

**Table 2: Loading schemes**

<b>Pressure (tsf)</b>	<b>Stress level (<math>\sigma'_v/\sigma'_p</math>)</b>	
	<b>Test Series I (<math>\sigma'_p = 0.60</math> tsf)</b>	<b>Test Series II (<math>\sigma'_p = 0.12</math> tsf)</b>
1/16	0.10	0.52
1/8	0.21	1.04
1/4	0.42	2.08
1/2	0.83	4.17
1	1.67	NA
2	3.33	NA

## 5. EXPERIMENTAL RESULTS

### 5.1 PRIMARY CONSOLIDATION

The objective of this phase of the experimental program was to understand how the different stresses and cement stabilization levels altered the engineering characteristics of the subject soil compared to untreated control specimens. Specifically, the impact on the void ratio and the compression index was measured and analyzed.

#### 5.1.1 EFFECT ON VOID RATIO ( $e$ )

For both test Series I and II, it was noted that even with constant unit weights, the initial void ratio decreases with increasing cement content in a rather consistent manner. This was attributed to the addition of fine cement particles that filled the void spaces between soil grains. This behavior is depicted in Figures 3 and 4. Figure 3 clearly shows that with *increasing cement content*, (i) the void ratio decreased at the same stress level; and (ii) the total change in void ratio from zero to final stress level was drastically reduced, or in other words the volume change tendency was effectively stabilized. Figure 4 shows the total change in void ratio between the zero to final stress levels at each cement content. For the case of Test Series I, the change in void ratio between the stress levels of 0.00 and 3.33 is significantly higher at 0.00% cement content ( $\approx 4.0$ ) than it is at 56.48% cement (nearly zero). For the case of Test Series II, the change in void ratio between the stress levels of 0.00 and 4.167 is appreciably higher at 0.00% cement content ( $\approx 3.0$ ) than it is at 89.68% cement (nearly zero). The success of the stabilization process was clearly evident; the modified soil became stronger in resisting void ratio alterations due to applied loads and it was particularly pronounced with cement contents in excess of 35% for Test Series I, and 50% for Test Series II.

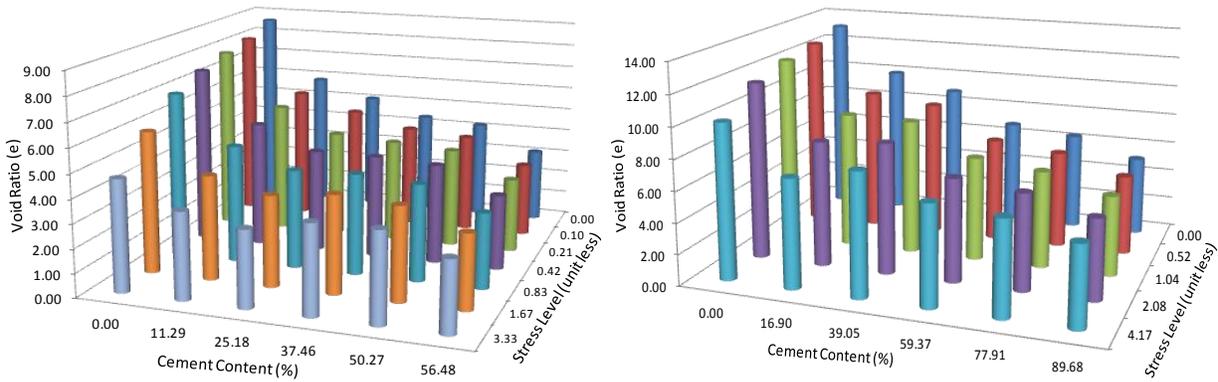


Figure 3: Void ratio with varying cement content for Test Series I (left) and II (right)

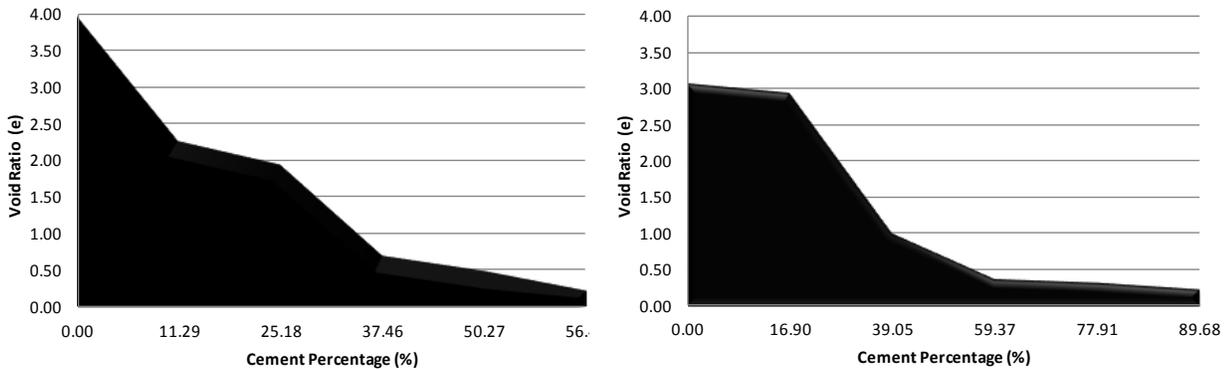


Figure 4: Decrease in void ratio ( $\Delta e$ ) with cement content for Test Series I (left) and II (right)

### 5.1.1 EFFECT ON COMPRESSION INDEX ( $C_c$ )

This data was obtained from typical void ratio versus log of pressure (in tsf) plots. By definition,  $C_c$  is the slope of the  $e$  versus  $\log(\sigma'_v)$  curve [ $C_c = \Delta e / \Delta \log(\sigma'_v)$ ] and is typically computed at the virgin zone of compression. Because the  $C_e/C_c$  concept applies both to the compression and recompression zones (Mesri et al, 1987),  $C_c$  was acquired from the entire range of the curve and subsequently used in the compressibility analysis.

Figure 5 shows the variations of  $C_c$  with different cement percentages at each stress level. Figure 6 presents the total decrease in compression index ( $\Delta C_c$ ) between the initial to maximum stress levels at each cement dosage. It was found that in most cases, with *increasing cement content*, (i) the compression index decreased at the same stress level; and (ii) the total change in compression index from initial to final stress level drastically reduced, or in other words, the potential for large primary consolidation settlement was effectively stabilized. Based on the observed behavior, the stabilization effects were again found to be maximized with cement contents exceeding the 35% and 50% thresholds for Test Series I and II, respectively (similar to the effects on void ratio).

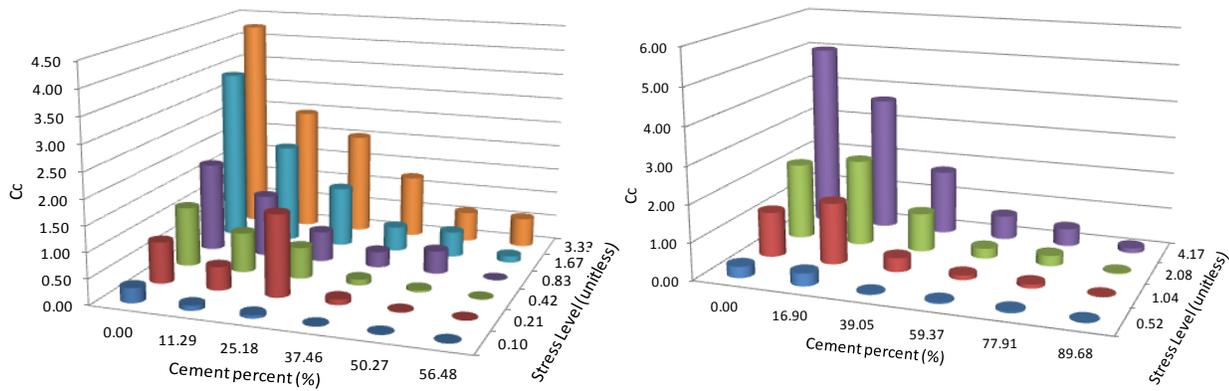


Figure 5:  $C_c$  with different cement dosages for Test Series I (left) and II (right)

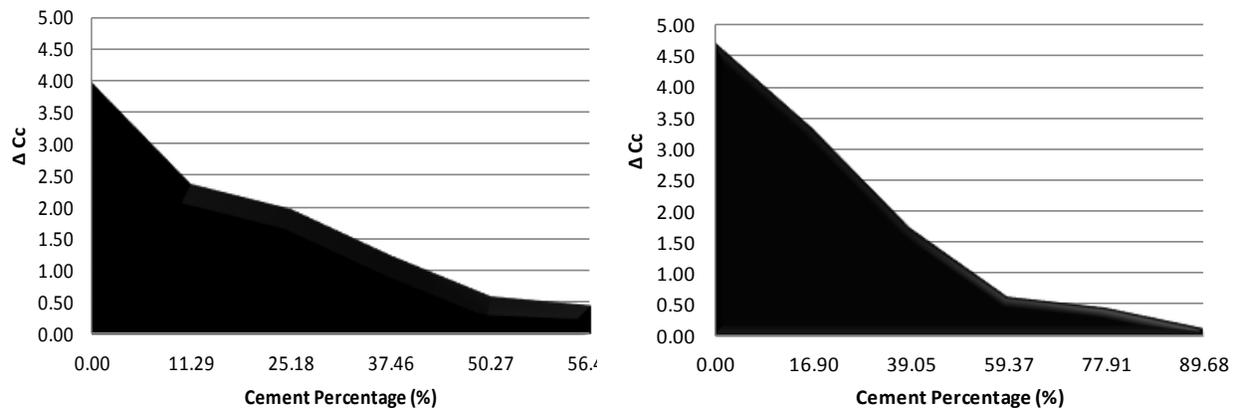


Figure 6:  $\Delta C_c$  with different cement dosages for Test Series I (left) and II (right)

## 6. SECONDARY COMPRESSION

### 6.1 EFFECT ON SECONDARY COMPRESSION INDEX ( $C_\alpha$ )

$C_\alpha$  is defined as the change of void ratio with respect to the log of time [ $\Delta e / \Delta \log(t)$ ], and was obtained from the void ratio versus time (in minutes) semi-log plots at a constant stress level. Variations in  $C_\alpha$  with cement content and different stress levels are shown in Figure 7. Figure 8 shows the total decrease in the secondary compression index,  $\Delta C_\alpha$  (between the initial and final stress levels) at each cement dosage. Trends were found to be similar as found in the case of void ratio and compression index, reported previously. This is significant because it implies that the long-term and continuing settlement of organic soils due to sustained load from the infrastructure elements in the field may be effectively stabilized with cement treatment at appropriate dosages.

### 6.2 EVALUATION OF THE $C_\alpha / C_c$ RATIO

Mesri and Godlewski (1977) postulated that for any given soil, there is a unique relationship between ( $C_\alpha = \Delta e / \Delta \log t$ ) and ( $C_c = \Delta e / \Delta \log \sigma'$ ), that holds true at all combinations of time (t), effective stress ( $\sigma'$ ), and void ratio (e). At any given effective stress, the value of  $C_\alpha$  from the first log cycle of secondary compression and the corresponding  $C_c$  value computed from the  $e$ -log  $\sigma'$  curve (at the end of primary consolidation) are used to define the relationship between  $C_\alpha$  and  $C_c$ . These values are plotted in Figures 9 and 10 to develop the unique  $C_\alpha / C_c$  relationship for cement-treated Florida organic soils.

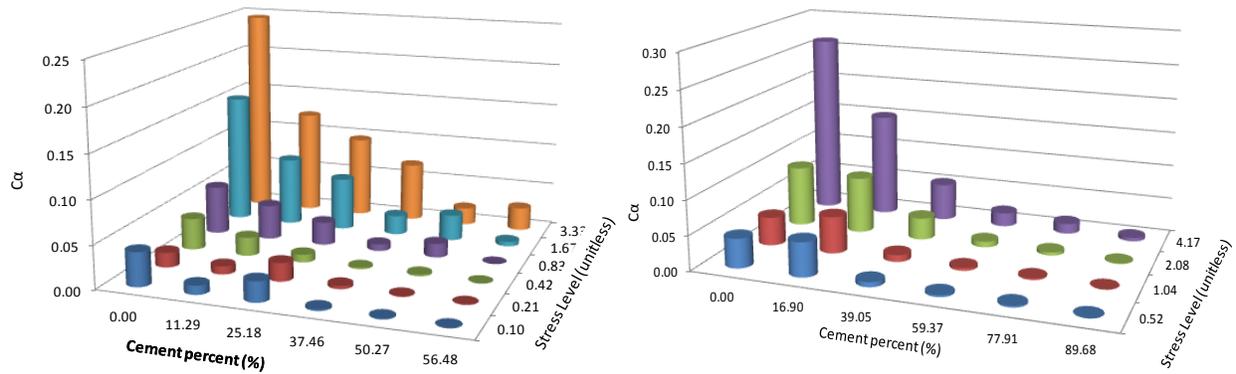


Figure 7:  $C_a$  with different cement dosages for Test Series I (left) and II (right)

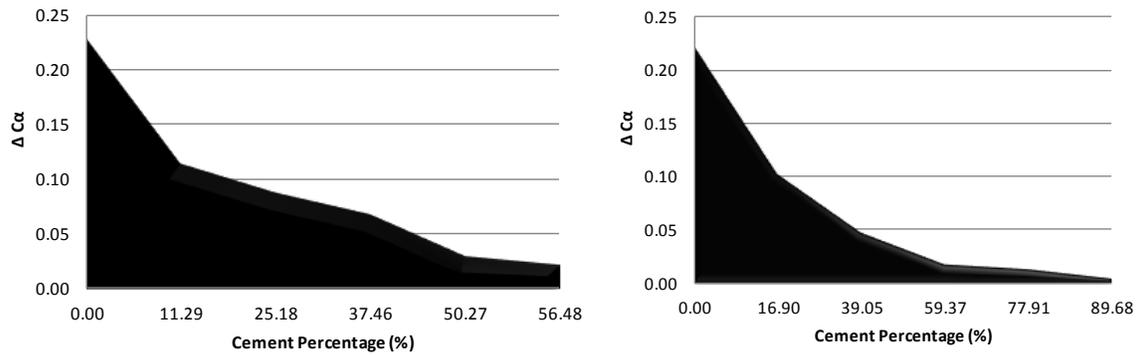


Figure 8:  $\Delta C_a$  with different cement dosages for Test Series I (left) and II (right)

The  $C_d/C_c$  ratios were plotted against cement content in Figure 11 to investigate any possible correlations. It is found that the  $C_d/C_c$  ratio decreases with increasing cement. As the  $C_d/C_c$  ratio decreases, the soil engineering behavior is known to shift from that of peaty soils, to organic clays and silts, to inorganic clays and silts, to shale and mudstone and finally to a granular material (7). Following these guidelines available in the literature, the possible fundamental transformation of specimens belonging to Test Series I and II are shown in Figure 11.

It is found that the  $C_d/C_c$  ratios reached a desirable level (close to granular soils) at a cement content of about 35% and 60% for Test Series I and II, respectively. With cement additions in excess of these dosages, no noticeable improvement were observed. Unlike Test Series I, the peat (Test Series II) did not enter the granular range, and was rather stabilized in the shale and mudstone range. For comparison purposes, the transformation of another soil (organic content between 50 – 60% and moisture content between 240 – 289%) due to cement addition is also shown here from the literature (Hwang et al. 2005). These results are encouraging, since the compression behavior of organic soils appears to be fundamentally changed (by cement stabilization) to that of an approximate granular soil, which is considered to be an excellent foundation material by the geotechnical and pavement engineers.

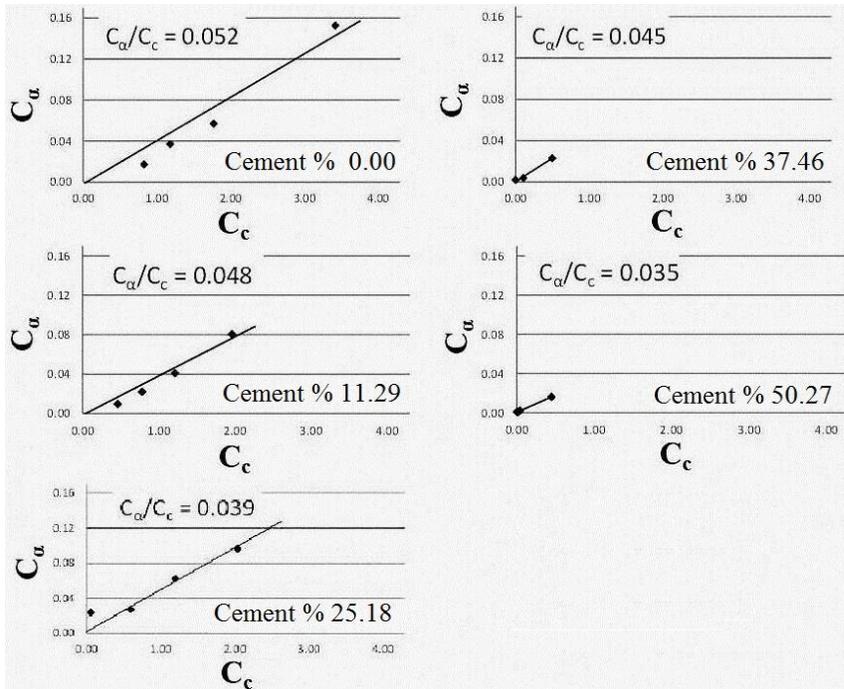


Figure 9:  $C_a$  vs.  $C_c$  for all cement contents for Test Series I

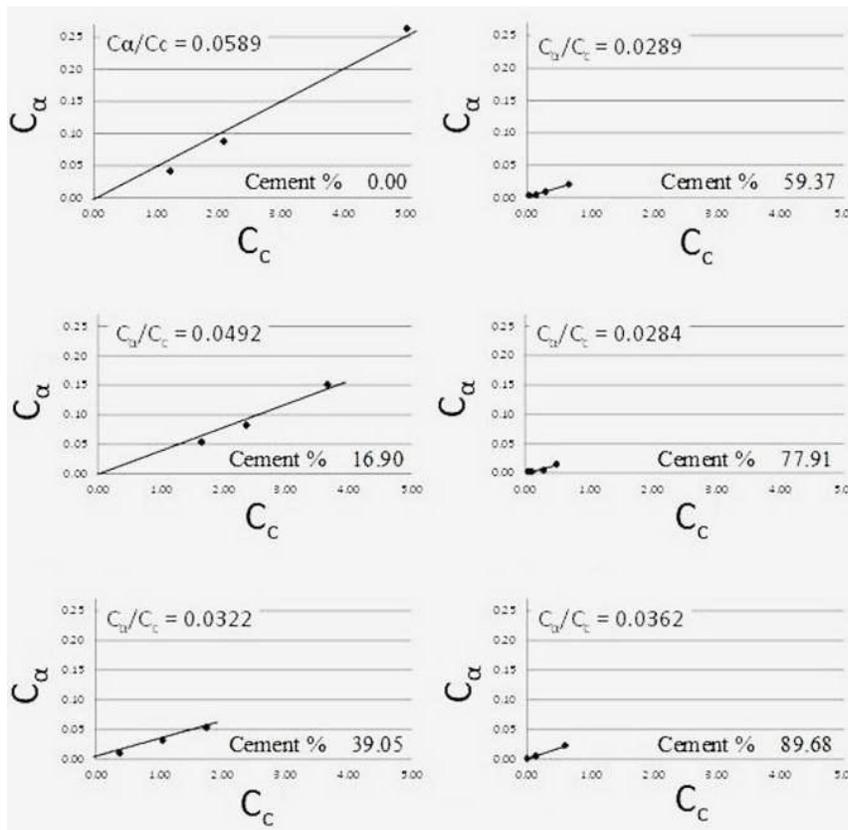


Figure 10:  $C_a$  vs.  $C_c$  for all cement contents for Test Series II

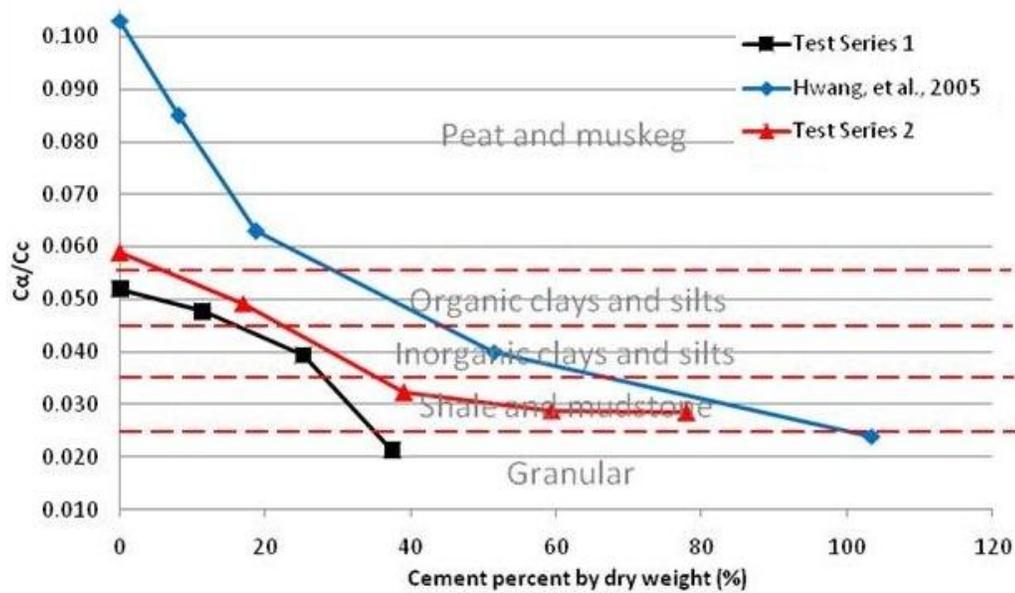


Figure 11: Variation of  $C_a/C_c$  with cement content

## 7. SUMMARY AND CONCLUSIONS

Flexible pavements built over soft compressible soils pose a serious challenge to engineers involved with pavement maintenance and rehabilitation. Often the traditional solutions such as milling and resurfacing are ineffective and costly due to frequent repairs or reconstructions. When organic soils and peats are encountered, a deep mixing solution with cementitious materials may be a better alternative to a near surface strategy, such as milling and resurfacing. The current study was undertaken to evaluate the effectiveness of cement stabilization in controlling the secondary compression behavior of organic subgrade soils underlying SR 15 / US 98 in southeastern Florida. Following specific conclusions can be drawn from the study:

- Both the compression index,  $C_c$ , and the secondary compression index,  $C_a$ , can be significantly reduced by cement stabilization.
- Cement stabilization can alter the engineering behavior (analyzed by the  $C_a/C_c$  ratio concept) of highly organic soils to a more desirable performance close to that of a granular material.
- For the silty organic layer underneath SR 15 / US 98 (with organic content of 67.0%, water content of 408%, and unit weight of 101 pcf), the optimum cement dosage was around 35% by dry weight.
- For the peat layer at the same site (with organic content of 89%, water content of 512%, and unit weight of 90 pcf), the optimum cement dosage was around 55% by dry weight.

## 8. REFERENCES

- Hwang, J., Humphrey, A., Bobet, A. and Santagata, M. (2005), "Stabilization and Improvement of Organic Soils." Final report, FHWA/IN/JTRP-2004/38, Purdue University.
- McVay, M. C. and Nguyen, D., (2004), "Evaluation of Embankment Distresses at Sander's Creek – SR-20," Final report, BC-354, RPWO # 17, Florida Department of Transportation.

- Mesri, G., Stark, T. D., Ajlouni, M. A., and Chen, C. S. (1997). "Secondary Compression of Peat With or Without Surcharging," *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 123, No. 5, pp. 411-421.
- Mesri, G., and Godlewski, P. M., (1977), "Time-Stress-Compressibility Interrelationship," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 103, No. GT5, pp 417-430.
- Mesri, G., Castro, A., and Godlewski, P. M., (1987), " $C_u/C_c$  Concept and  $K_o$  During Secondary Compression," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 113, No. 3, pp 230-247.
- Sobhan, K., George, K. P., Pohly, D. and Ali, H. (2010). "Stiffness Characterization of Reinforced Asphalt Pavement Structures Built Over Soft Organic Soils," *Transportation Research Record: Journal of The Transportation Research Board*, Volume 2186, pp. 67-77.
- Sobhan, K., Ali, H., Riedy, K. and Huynh, H. (2007). "Evaluating the Compressibility Behavior of Organic Soils using Laboratory Characterization and Rapid On-Site Piezocone Penetration Testing," *International Journal of Geotechnical Engineering*, Volume 1, Issue 1, pp. 9-18.
- Terzaghi, K., Peck, R.B. and Mesri, G. (1996). "Soil Mechanics in Engineering Practice", 3rd edition, John Wiley & Sons, Inc

### ***Authorization and Disclaimer***

*Authors authorize LACCEI to publish the paper in the conference proceedings. Neither LACCEI nor the editors are responsible either for the content or for the implications of what is expressed in the paper.*