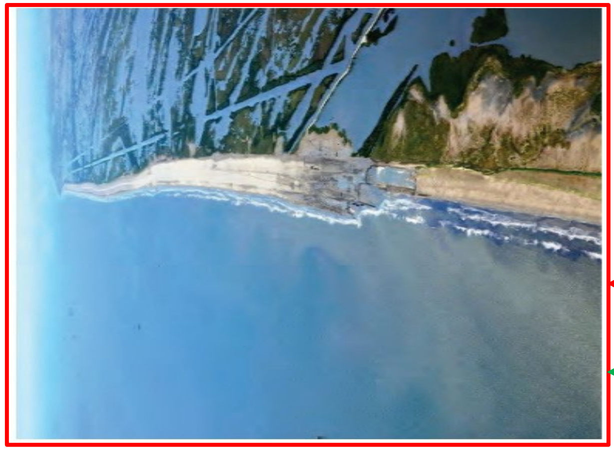
DEVELOPMENT OF A STANDARDIZED LOW-STRESS CONSOLIDATION TESTING PROCEDURE AND REGRESSION EQUATION FOR THE MARSH FILL

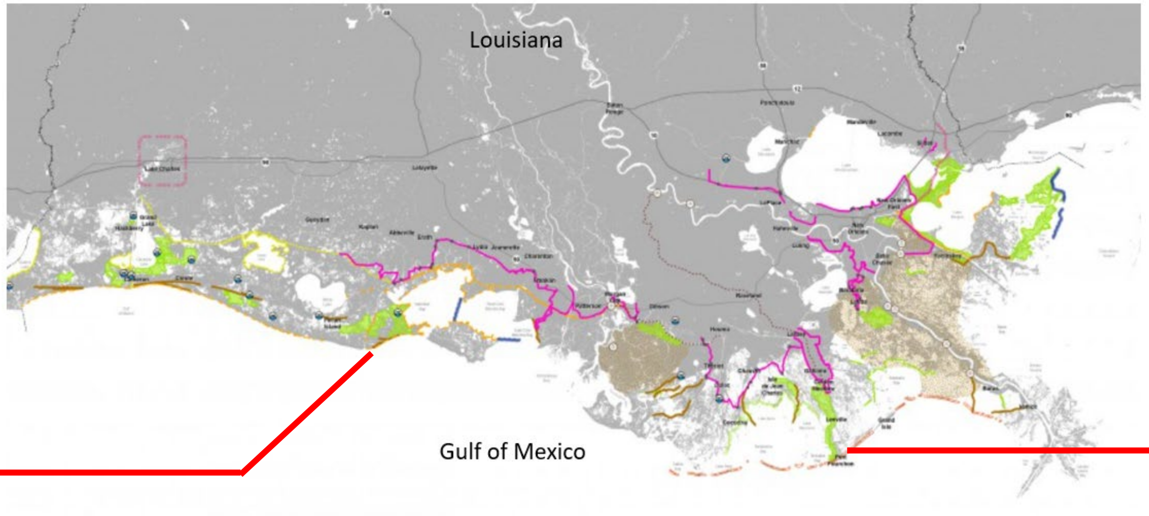
By

Omar Shahrear Apu, M.S.,

Ph.D. Candidate, Louisiana Tech University

Introduction





Created Marsh Island

Green color in the map indicating the marsh creation sites in the coastal Louisiana.

Monitor The Settlement of The Artificial Marsh Island is A Regular Geotechnical Work.

A Standard Test Method

Theoretical Modification for Louisiana Marsh/Dredged Soil

Research Objective

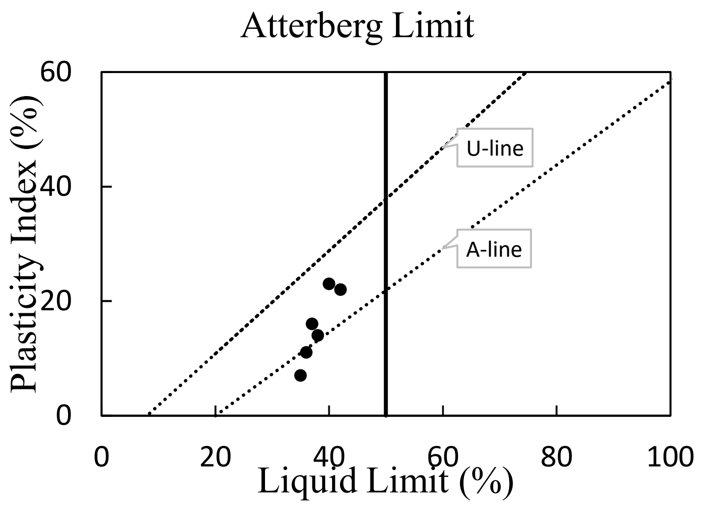
1. Collected and analyzed data and reports of low-pressure consolidation tests on dredged fill from CPRA offices and USACE websites.
2. Reviewed consolidation specifications EM 1110-2-1906, EM 1110-2-5027 Appendix D, ASTM D-2435 method B, CPRA Geotechnical Standards.
3. Developed a simplified version of the settling column for the self-weight consolidation test and modified the conventional oedometer implementing 3D printing technology.
4. Recommended procedures of consolidation tests specifically for dredged material and test data interpretation. Special attention was paid to the following:
   - Sample preparation
   - The seating load
   - Loading schedule to recommend
   - Void ratio/effective stress profile
   - Empirical equation

Slurry Sample Preparation

Soil samples are collected from the **No-Name Bayou** marsh creation site in Louisiana.

List of Geotechnical Test need to be done before slurry preparation:

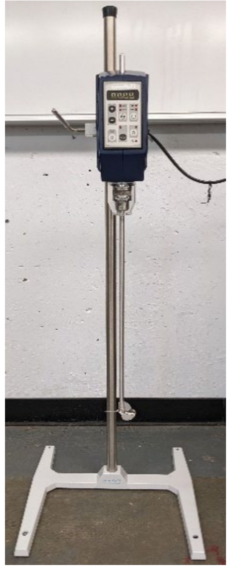
- Classify the soil based on the ASTM D2487.
- Specific Gravity according to ASTM D854.
- The Atterberg Limits according to the ASTM D4318.



Oven Dried Soil Sample

Measure Soil Mass

$$Water\ Content = {}^{Water\ mass}/_{Soil\ mass}$$



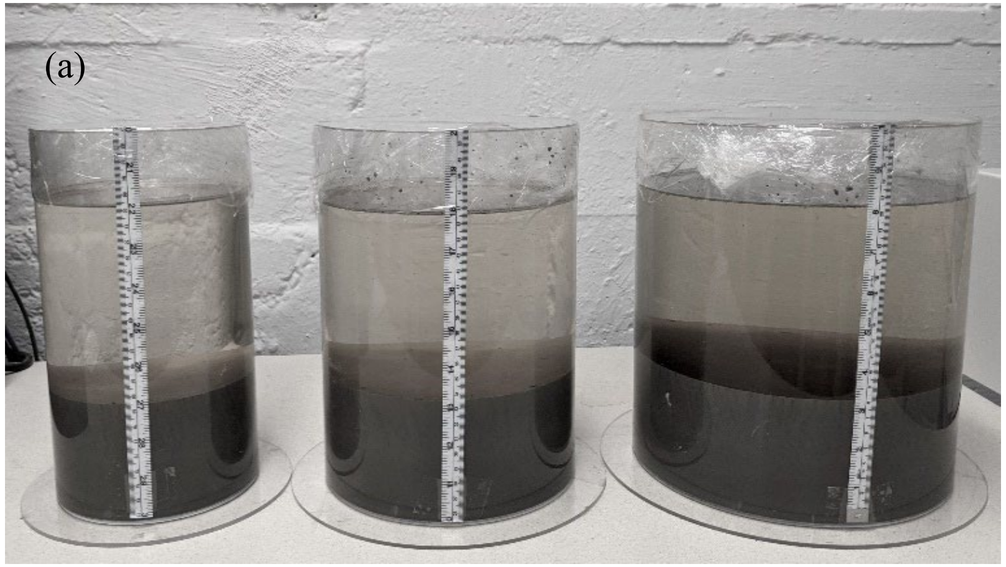
Mixing Grinder

Add Water for Expected Moisture Content

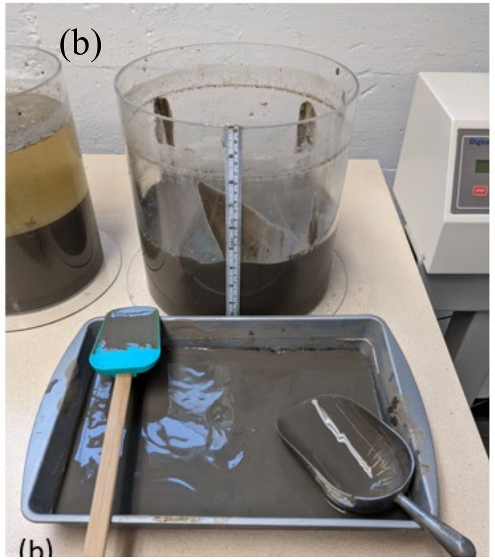
Mixed Until Become Homogeneous Slurry

Slurry Soil Sample

Simplified Settling Column Used in This Research



(a) The self-weight consolidation/settling column tests using acrylic plexiglass cylinders with diameters 10″, 8″, and 6″ (Right to left).



(b) Sample removal after completion of self-weight consolidation test.

Reasons Behind The Necessity of The Oedometer Test

- Minimize the settlement column dimension

  Average depth of the marshland are 3 to 6 meter

- Achieving the maximum stress in the laboratory

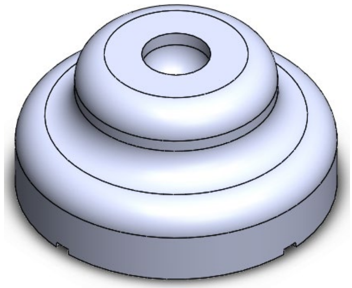
  Maximum Stress generate in the field is 107.25 kPa

- Illustrate void ratio vs effective stress profile that mimic the field/natural condition

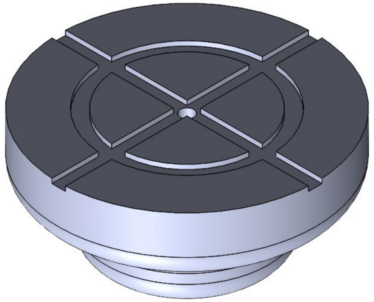
  Combined the settling column test and oedometer test result

Modify The Conventional Oedometer to Handle The Dredged/Marsh Soil.

Sketch of the part (dial cap) using SOLIDWORKS



Top view



Bottom view

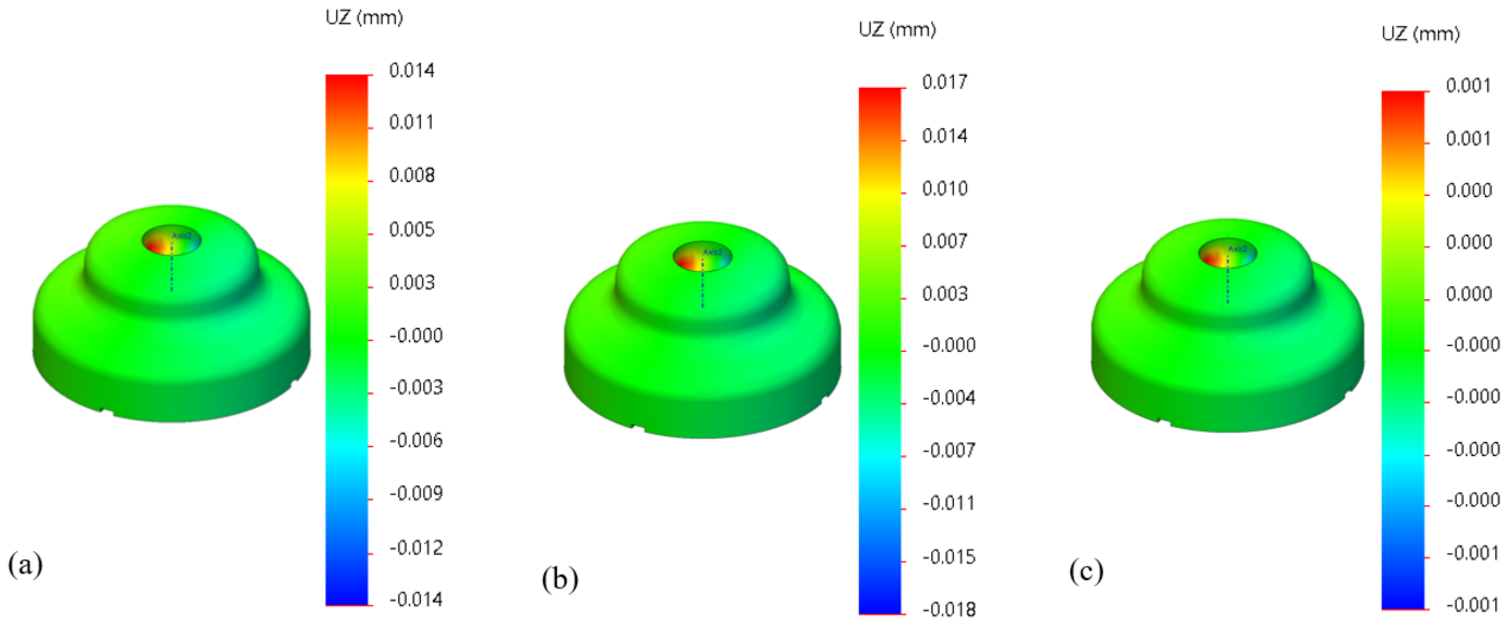
Original Stainless Steel dial cap

Top view

Bottom view

The Starting Load/Seating Load comes from the dial cap and the top porous stone

Deflection Analysis of 3D Printer Dial Cap Using SOLIDWORKS and Lab Experiment Data



(a) Polylactic acid (PLA)
(b) Acrylonitrile Butadiene Styrene (ABS)
(c) Stainless Steel

Comparison of Deflection of Dial Cap (Experimental vs Numerical Value)

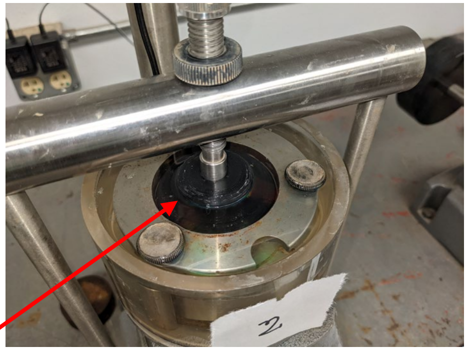
Stress (TSF)	Stress (kPa)	Deflection (mm)					
		Finite Element Analysis			Lab Experiment		
		ABS	PLA	Stainless Steel	ABS	PLA	Stainless Steel
1	107.25	0.0098	0.0060	0.0001	0.0218	0.0163	0.0016
2	214.5	0.0195	0.0140	0.0002	0.0310	0.0260	0.0024

Modified Oedometer Test

3D Printed Dial Cap

The seating pressure is 0.01 TSF

The seating pressure is 0.002 TSF



Could be possible up to run test of 70% moisture content soil sample

Stainless Steel dial cap

3D printed (PLA) dial cap

Could be possible up to run test of 100% moisture content soil sample

It lowers the seating pressure almost 5 times

Modified Oedometer Test

Seating Load:

The lightweight 3D printed material turned out that the newly achieved seating pressure was about 0.002 TSF, including the pressure that comes up from the weight of the porous stone, as opposed to the traditional 0.01 TSF

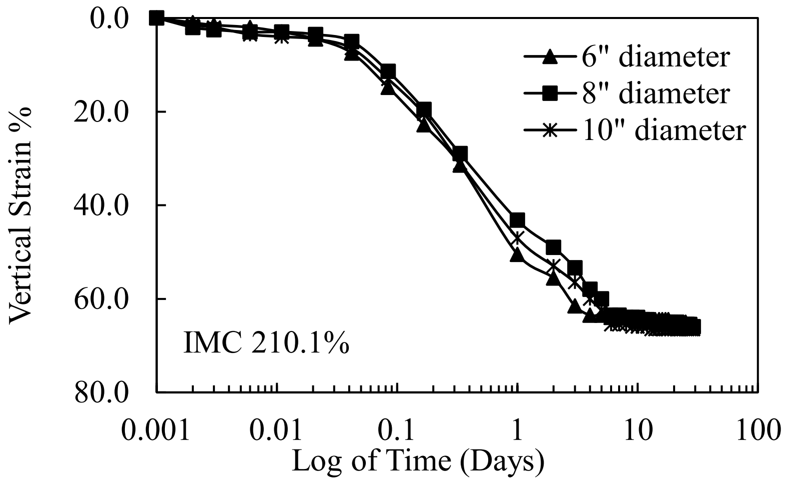
Loading Schedule:

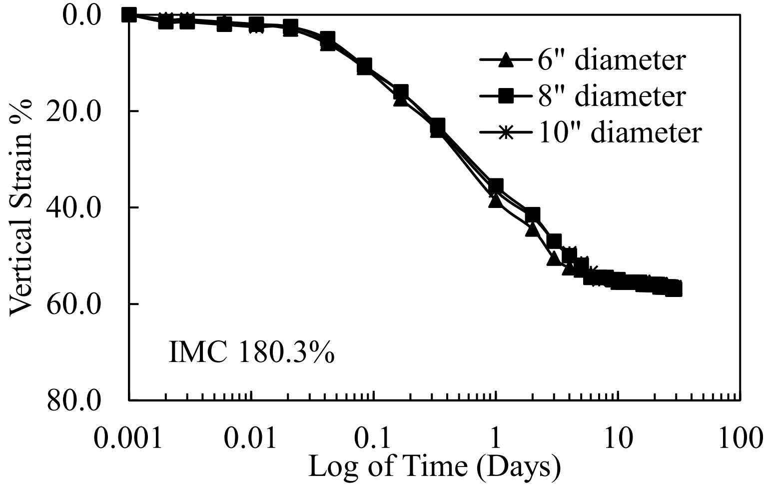
After applying 1 TSF load, the final settlement of the specimen was almost 50% of its initial height. For these reason, no further load was applied in this research. During the successful consolidation test, the following loading schedule was adopted: 0.002, 0.005, 0.01, 0.025, 0.05, 0.10, 0.25, 0.50, and 1.00 TSF.

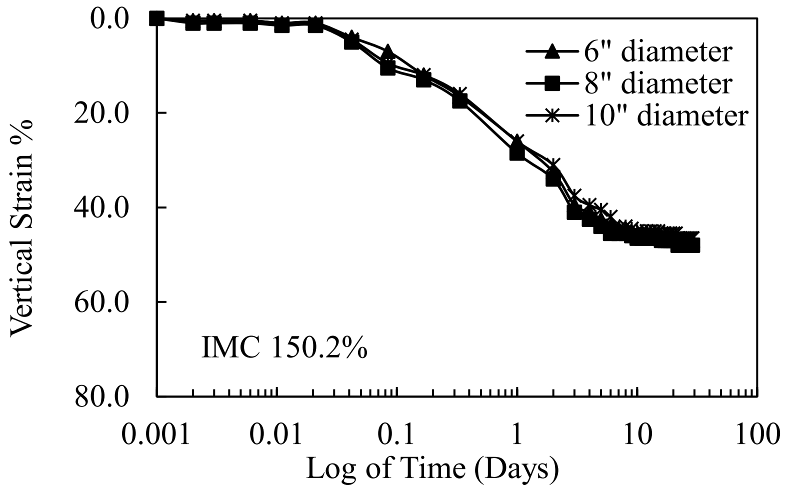
Settlement Reading Schedule:

The 1-D consolidation tests were completed following ASTM D-2435 standard and EM 1110-2-5027 Appendix D. Consolidation settlement readings were taken at the times 0.1, 0.2, 0.5, 1.0, 2.0, 4.0, 8.0, 15.0, and 30.0 minutes, 1, 2, 4, 8, and 24 hours. Reading should be taken until 100% of primary consolidation is completed.

Settlement Analysis of Self Weight/Settling Column Test







Settlement Reading Schedule:

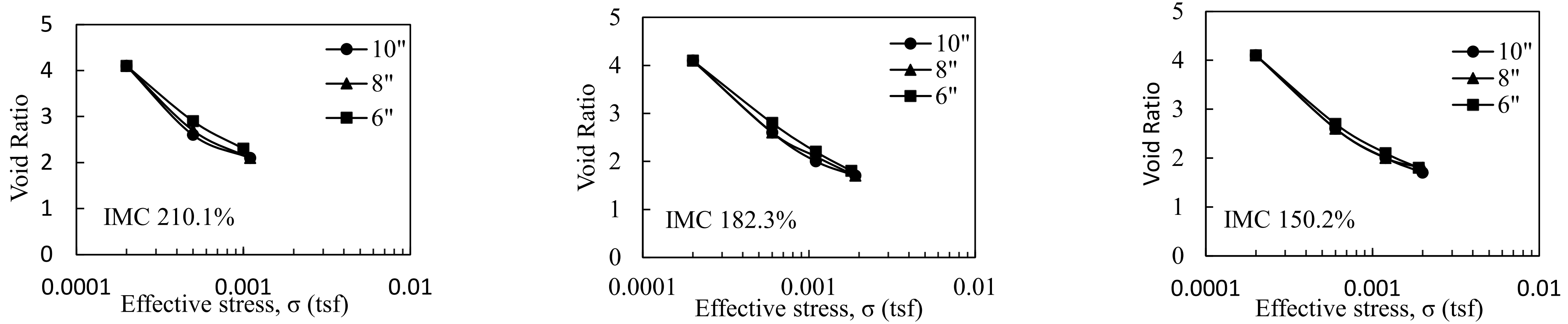
Readings were taken at 0, 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240 minutes, and then twice daily after that.

Findings:

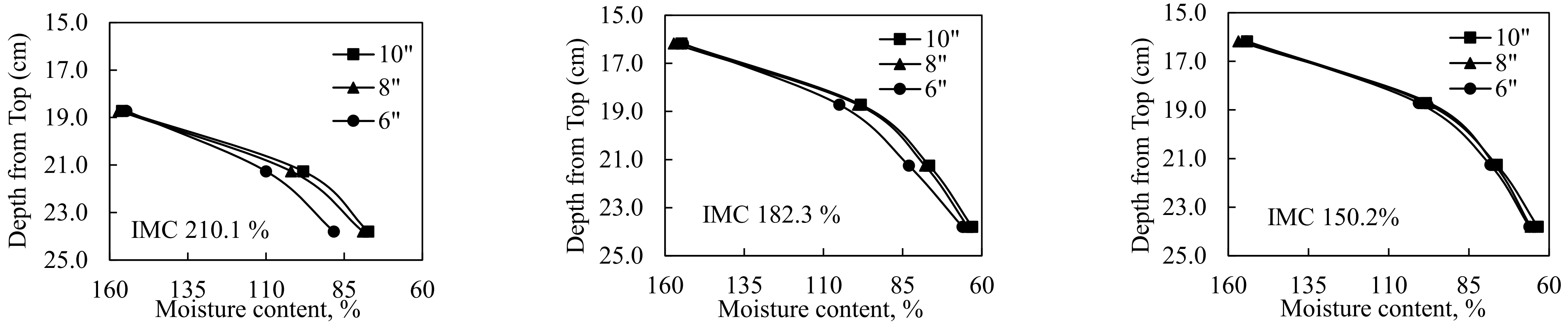
It could be concluded that any acrylic cylinders greater than the diameter of 6 inches would have negligible frictional effects on self-weight consolidation test results.

Analysis of Consolidation Properties

Effective stress vs. void ratio plots of the slurry soil samples of settling column Test

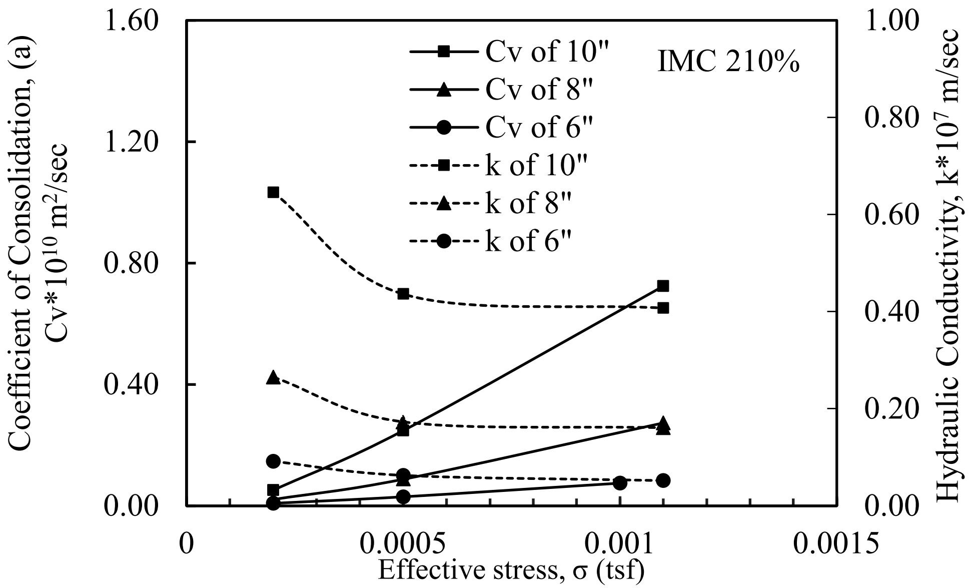


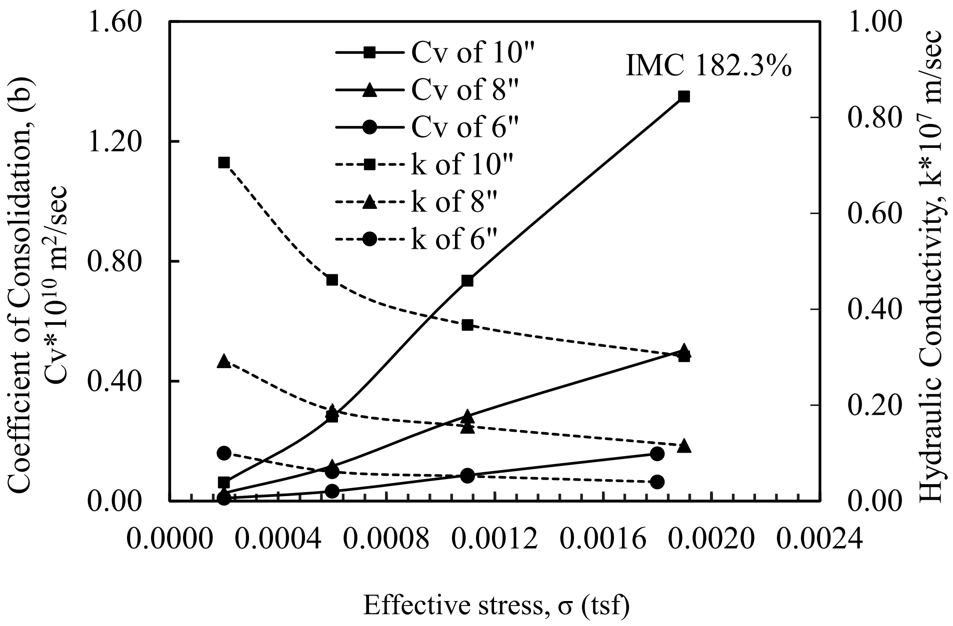
Moisture content vs depth of the slurry soil samples of settling column Test

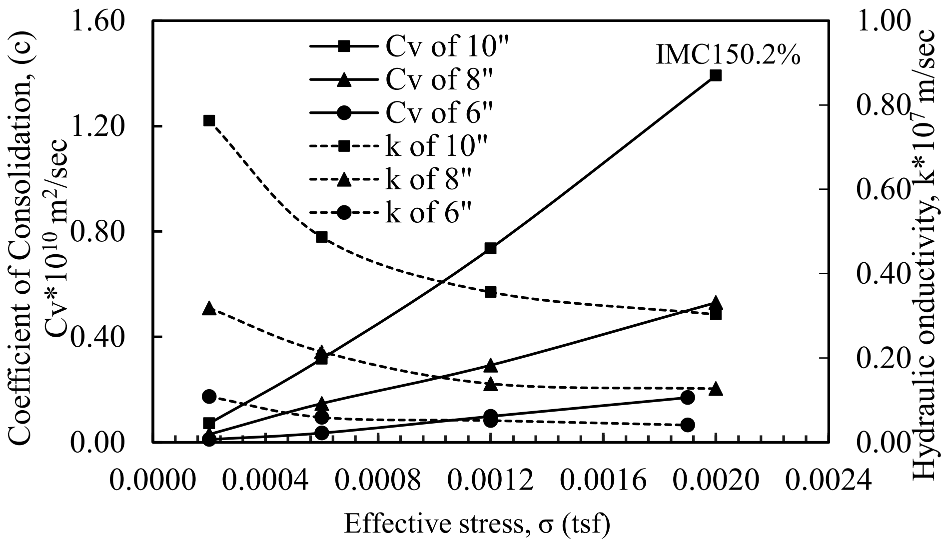


Analysis of Consolidation Properties

Effective stress vs. coefficient of consolidation C_V and hydraulic conductivity, K of the slurry sample of Settling Column Test





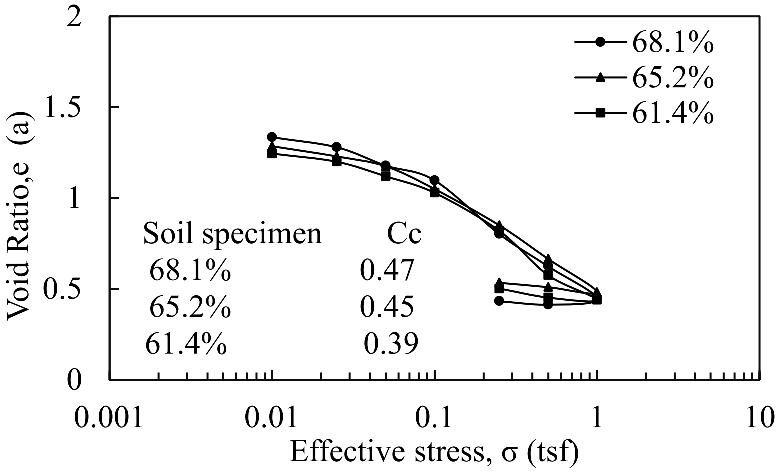


Findings:

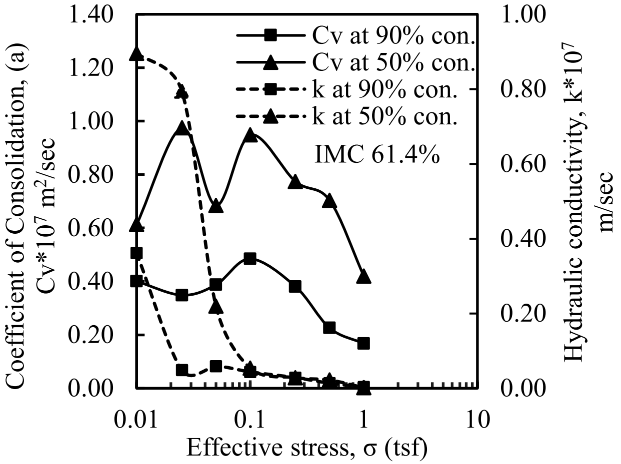
The higher the diameter of the cylinder, the less time is needed to consolidate the soil specimen.

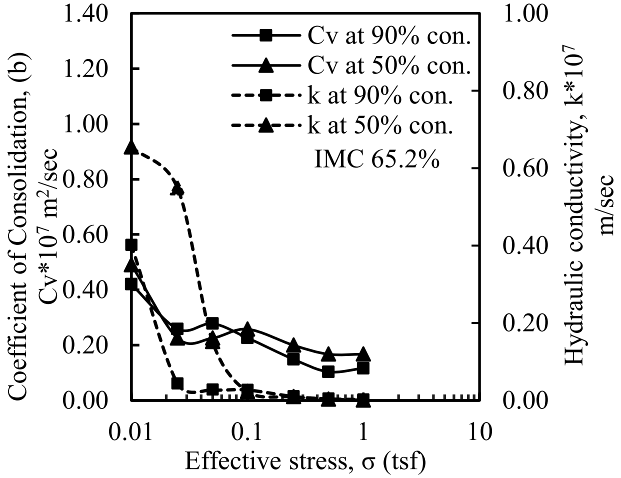
Analysis of Consolidation Properties

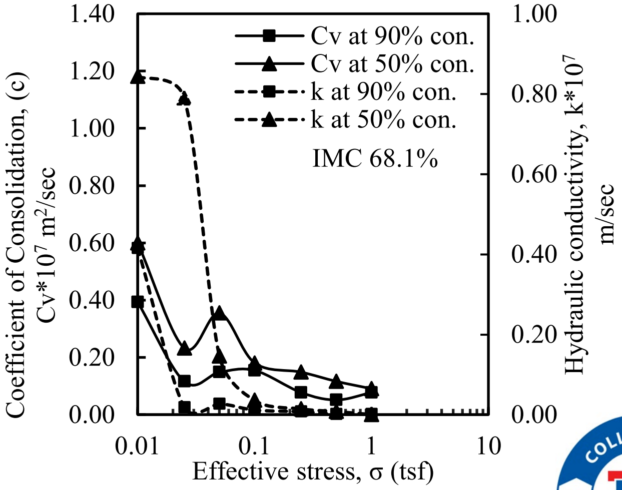
Effective stress vs. void ratio plots of the slurry soil samples of oedometer test using Stainless steel Dial cap



Effective stress vs. Coefficient of Consolidation and Hydraulic Conductivity plots of the slurry soil samples of oedometer test using Stainless steel Dial cap

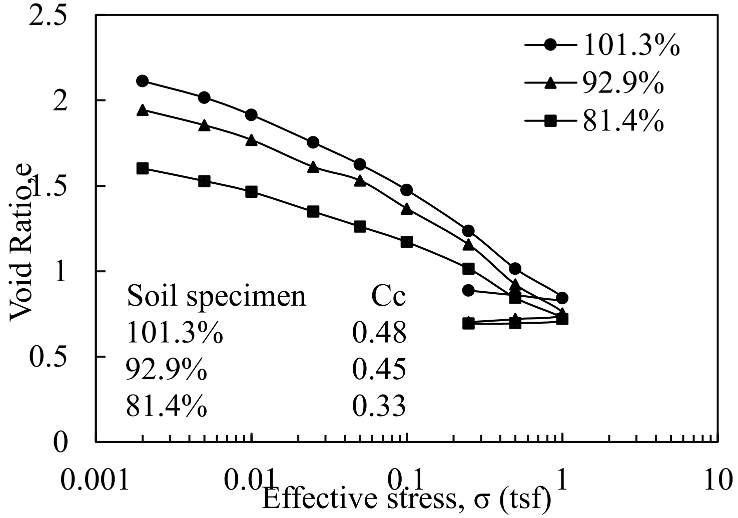




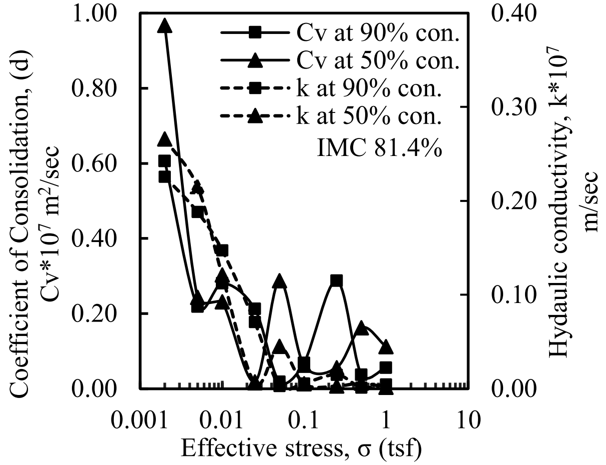


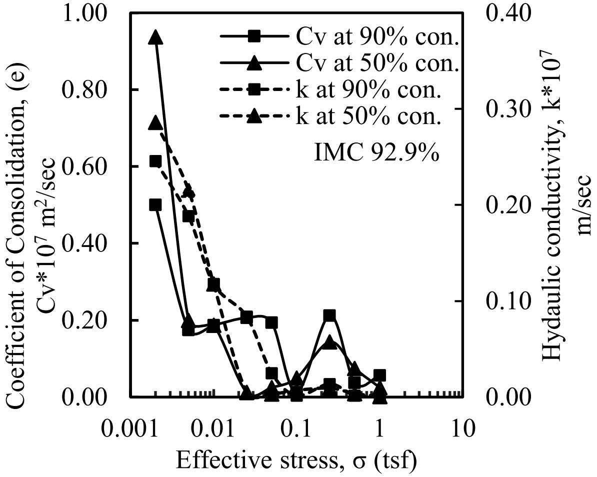
Analysis of Consolidation Properties

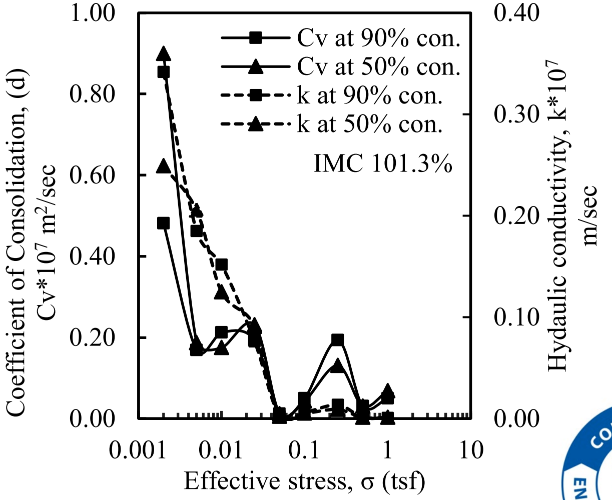
Effective stress vs. void ratio plots of the slurry soil samples of oedometer test using 3D printed Dial cap



Effective stress vs. Coefficient of Consolidation and Hydraulic Conductivity plots of the slurry soil samples of oedometer test using 3D printed Dial cap



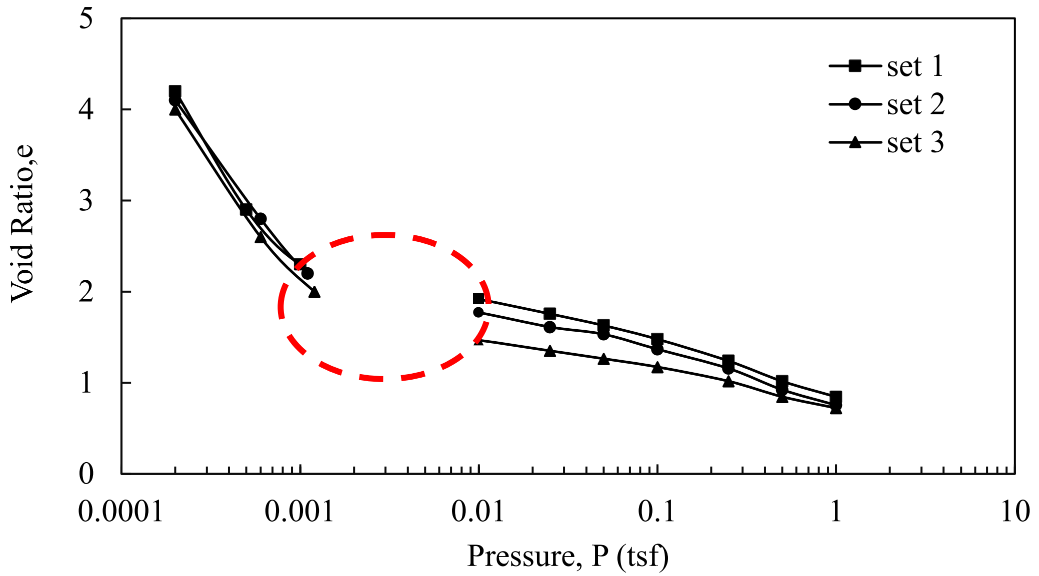




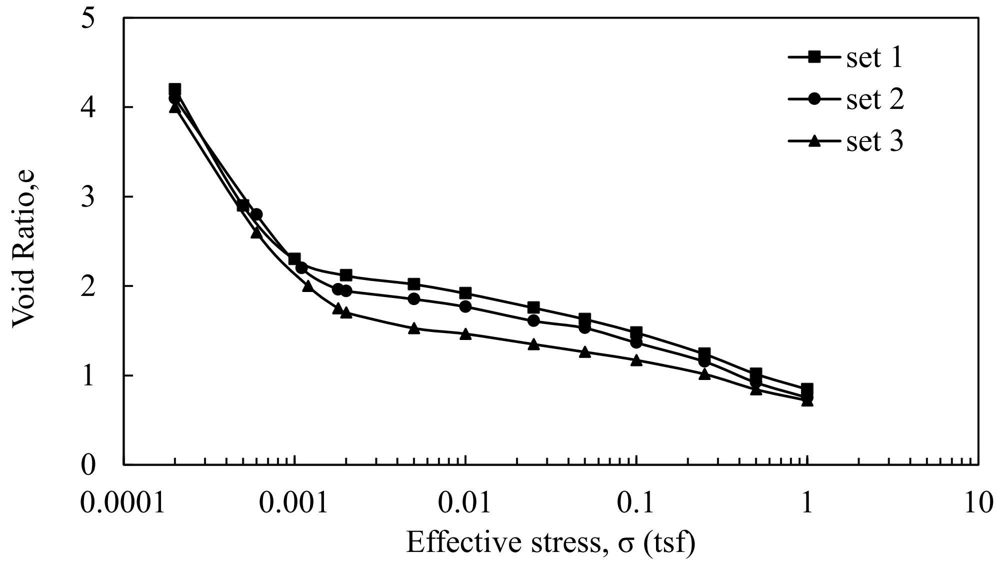
Analysis of Consolidation Properties

Combined Profile of void ratio verses effective stress of slurry sample

Using Conventional Oedometer



Using Modified Oedometer



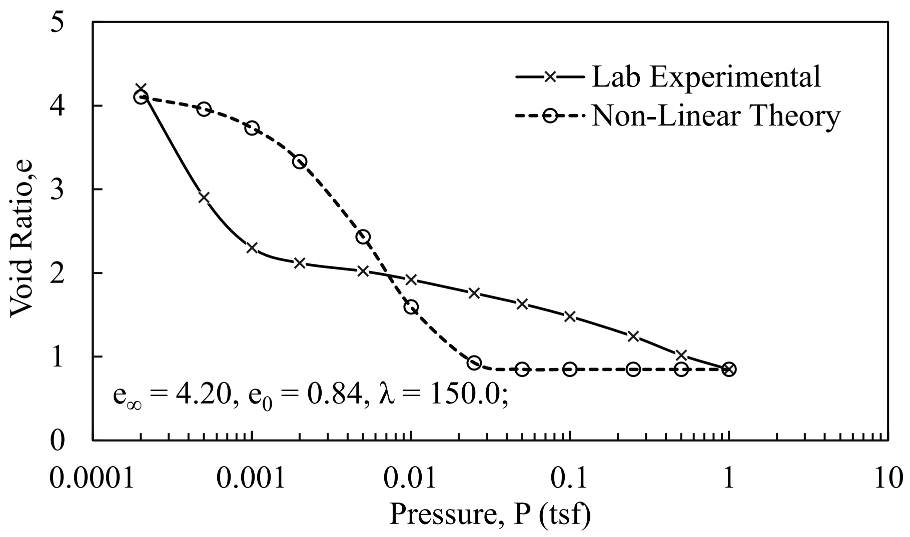
Validation Using the USACE Recommended Equation

USACE Recommended Equation

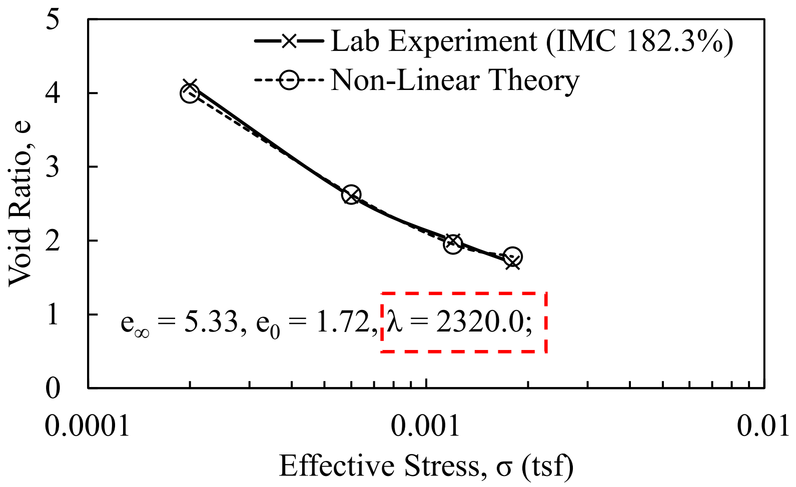
Non-Linear Theory: $e = (e_o - e_\infty)EXP(-\lambda\sigma') + e_\infty$ ……..Equation (1)

Linear Theory: $e = e_o - c_c log_{10}(\frac{\sigma'}{\sigma'_o})$ ……Equation (2)

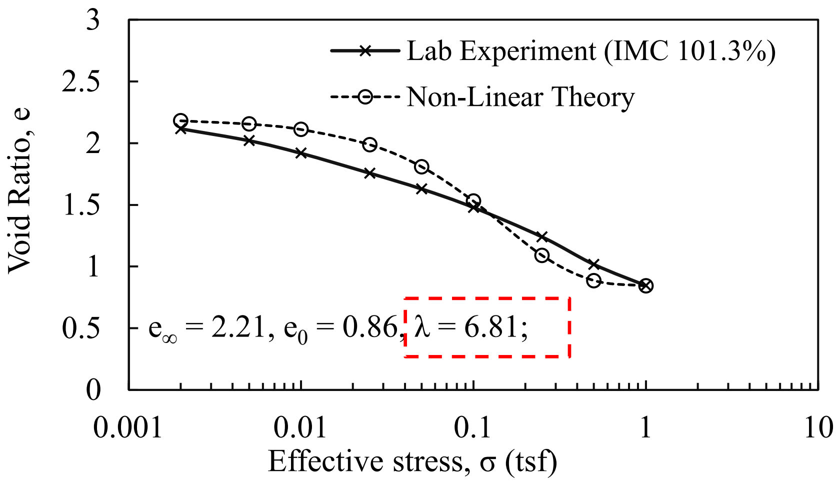
Combined Data Set



Settling Column Data Set

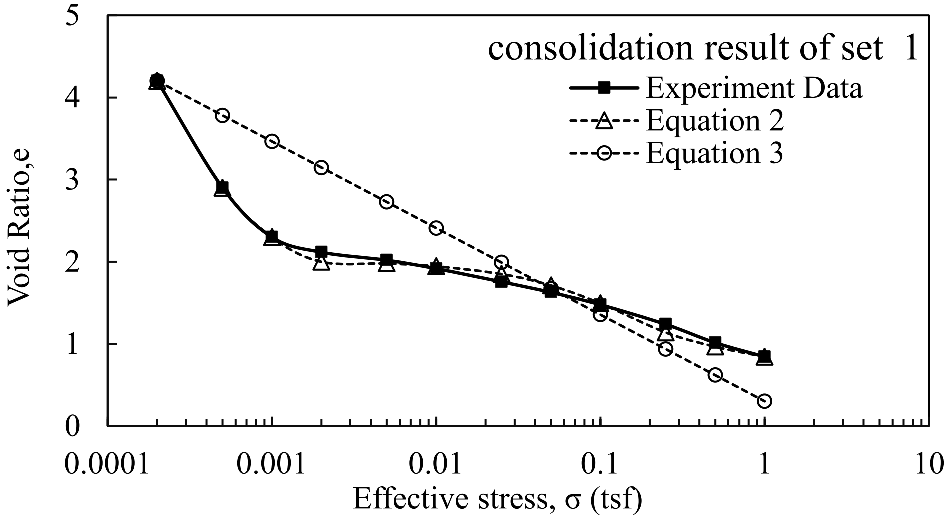


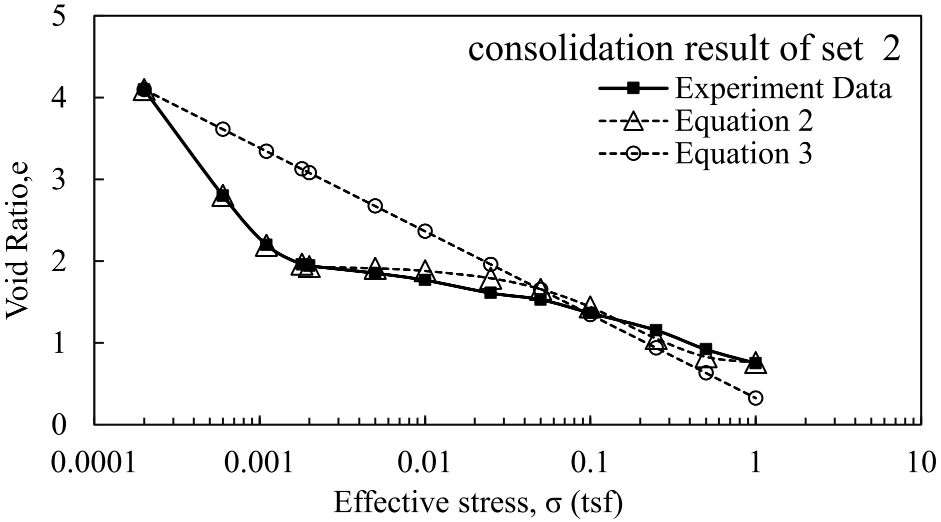
Modified Oedometer Data Set

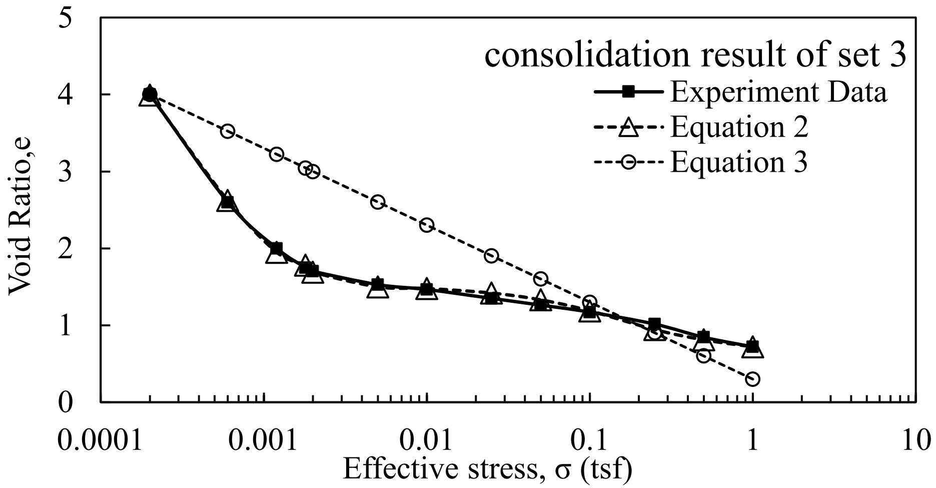


Consolidation Behaviors of the Slurry Samples

Laboratory Test (pressure vs void ratio) Curve with Best Apparent Fit Curve Fitted Using USACE Recommended Equation.







Parametric values of e_o, e_∞, λ and c_c for curve fitting

Profile	c_c	Effective stress (TSF)	e_o	e_∞	λ
1	1.05	< 0.002	7.01	2.06	4442.23
		> 0.002	1.52	0.72	4.81
2	1.02	< 0.002	5.33	1.73	2320.00
		> 0.002	1.84	0.82	5.53
3	1.00	< 0.002	5.52	1.69	2334.42
		> 0.002	1.52	0.77	5.87

Empirical Equations to Estimate Cc for Louisiana Marsh Soils

Properties of mash soils along coastal Louisiana line.

Statistical parameter	ω_n(%)	γ_d(Kg/m^3)	ω_l(%)	PI (%)	G_s	C_c	e_o
Range	24.4 - 418	296.37- 1602	37 - 394	17 - 268	2.35 - 2.72	0.16 - 2.86	0.669 - 12.74
Average	110.52	882.37	116.93	79.52	2.60	0.96	2.96
SD	83.86	371.35	105.37	73.98	0.11	0.73	2.48

Correlation coefficient, R matrix for various soil properties

	ω_n	γ_d	ω_l	PI	G_s	p_c	e_o	c_c
ω_n	1	- 0.632	0.450	0.450	0.124	- 0.421	0.972	0.796
γ_d	- 0.632	1	- 0.084	- 0.117	0.256	0.564	- 0.579	- 0.530
ω_l	0.450	- 0.084	1	0.995	- 0.173	- 0.221	0.386	0.645
PI	0.450	- 0.117	0.995	1	- 0.195	- 0.223	0.391	0.660
G_s	0.124	0.256	- 0.173	- 0.195	1	0.091	0.177	- 0.089
p_c	- 0.421	0.564	- 0.221	- 0.223	0.091	1	- 0.390	- 0.381
e_o	0.972	- 0.579	0.386	0.391	0.177	- 0.390	1	0.819
c_c	0.796	- 0.530	0.645	0.660	- 0.089	- 0.381	0.819	1

Note: c_c= compression index, e_o= initial void ratio, ω_l = liquid limit, ω_n= moisture content, γ_d = dry density, PI = plasticity index, G_s= Specific gravity, SD = Standard deviation

Assessment of Compression Index Considering the Sedimentation State

Sedimentation State

$$e/e_L = (A - B \log \sigma'_v)$$

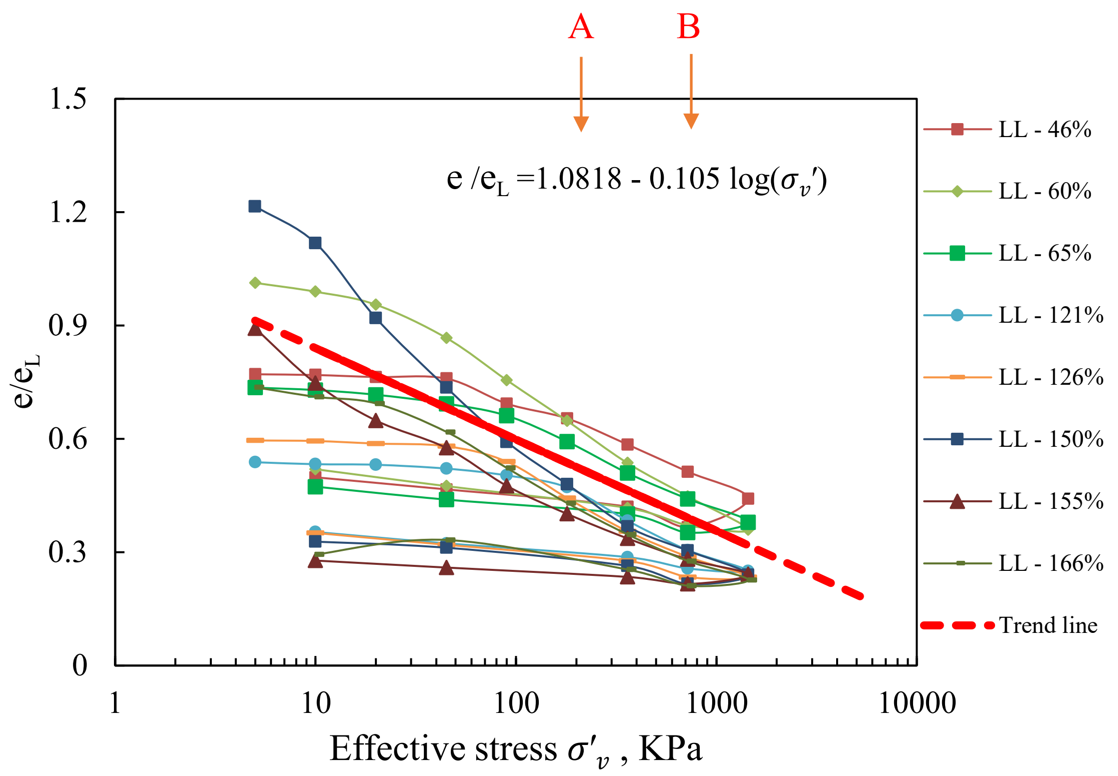
$$\Delta e_r = [e_0 - C_r \log(\sigma'_{vy}/\sigma'_v)] - e_L(A - B \log \sigma'_{vy})$$

$= e_0 - Ae_L + Be_L \log(\sigma'_{vy})$ [C_r, Recompression Index is very small]

σ'_{vy} = pre-consolidation pressure, e_L = Void ratio at Liquid Limit

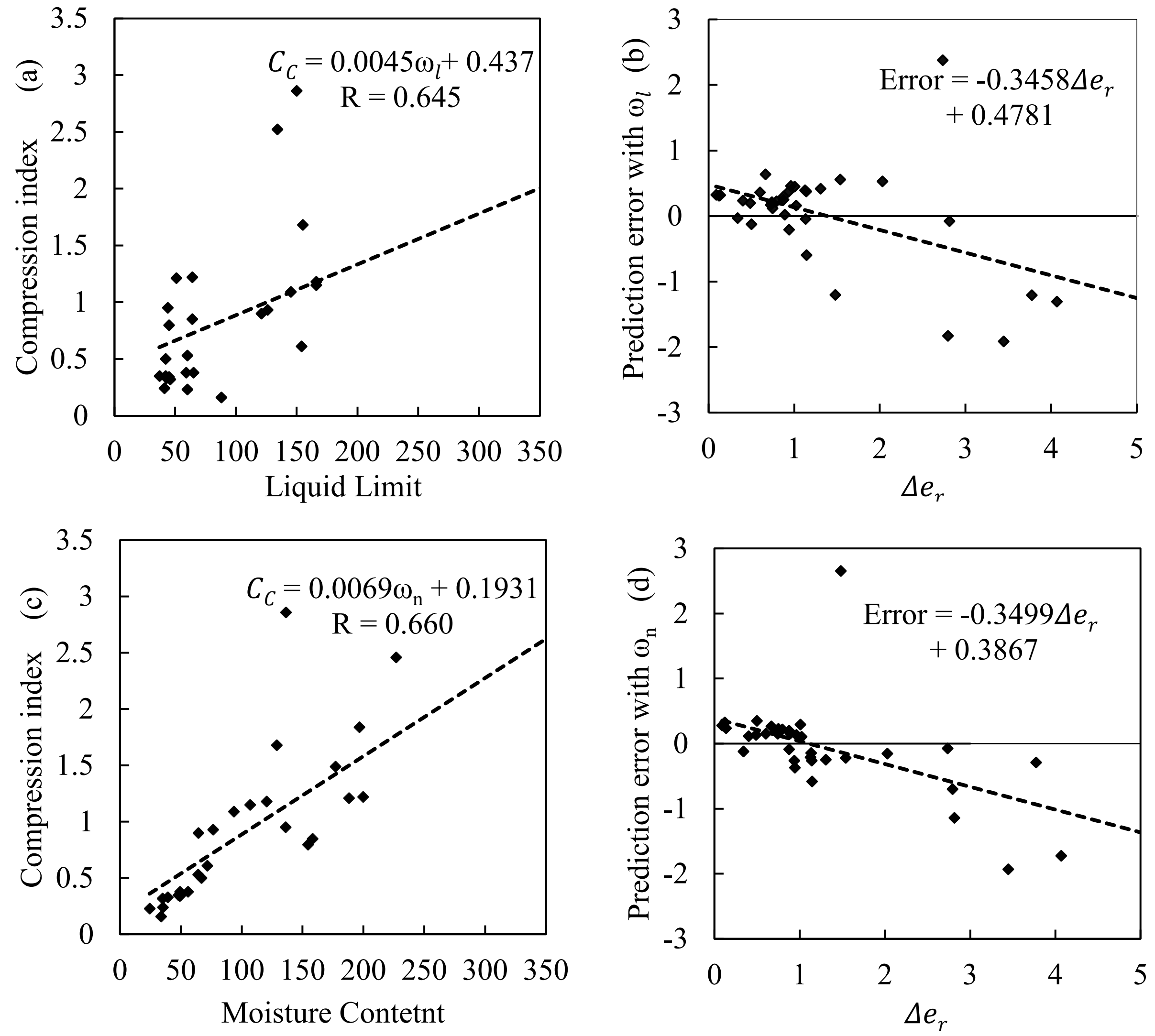
where A and B are the regression constants representing the compression characteristics of consolidated clay and effective stress (σ'_v) (KPa)

e/e_L-log σ'_v curves for specimens of Louisiana marsh soil



Empirical Equations to Estimate Cc for Louisiana Marsh

Empirical relationships for the compression index



(a) compression index with liquid limit; (b) error of prediction on liquid limit basis vs Δe_r ; (c) compression index with natural water content; (d) error of prediction on natural water content basis vs Δe_r.

Proposed empirical equation for predicting compression index

$$c_c = 0.0045\omega_l + 0.346e_0 - 0.374e_L + 0.0362e_L \log(\sigma'_{vy}) - 0.041$$

$$c_c = 0.0069\omega_n + 0.349e_0 - 0.372e_L + 0.0367e_L \log(\sigma'_{vy}) - 0.193$$

In saturated clay, e_L and e_0 can be converted into ω_l and ω_n,

$$c_c = 0.019\omega_n - 0.011\omega_l + 0.001\omega_l \log(\sigma'_v) - 0.112$$

$$c_c = 0.016\omega_n - 0.009\omega_l + 0.002\omega_l \log(\sigma'_v) - 0.135$$

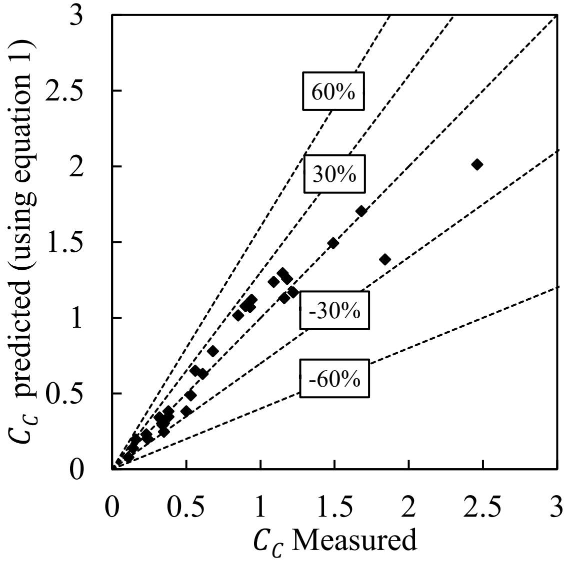
Empirical Equations to Estimate Cc for Louisiana Marsh Soils

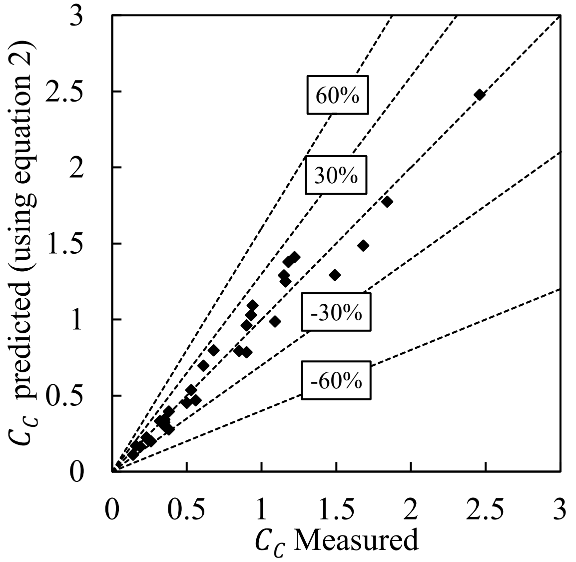
Prediction equations of the compression index for Louisiana marsh soils and their comparisons.

Predicting Equation Considering Sedimentation State

$c_c = 0.019\omega_n - 0.011\omega_l + 0.001\omega_l \log(\sigma_v') - 0.112$ ………. (1)

$c_c = 0.016\omega_n - 0.009\omega_l + 0.002\omega_l \log(\sigma_v') - 0.135$ ………..(2)





Comparisons between the measured and predicted compression index using Equations (1) and (2).

Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{f_t - a_t}{a_t}\right|$$

where, n is the number of data points, a_t is the value of a measured parameter, and f_t is the predicted one.

Empirical Equation	R	MAPE (%)
$c_c = 0.0045\omega_l + 0.437$	0.645	34.1
$c_c = 0.0065\mathrm{PI} + 0.4414$	0.796	21.3
$c_c = 0.0069\omega_n + 0.1931$	0.660	31.4
$c_c = 0.2413e_o + 0.2452$	0.819	18.1
$c_c = 1.3027 - 0.01512\gamma_d + 0.004196\omega_l$	0.803	17.9
$c_c = 1.2817 - 0.01449\gamma_d + 0.005995\mathrm{PI}$	0.803	17.4
$c_c = 0.403379 - 0.00486\gamma_d + 0.004166\mathrm{PI} + 0.166422e_o$	0.895	13.6
$c_c = 0.103612 - 0.00498\,\omega_n + 0.003031\,\omega_l + 0.355261\,e_o$	0.883	13.9
$*c_c = 0.019\omega_n - 0.011\omega_l + 0.001\omega_l \log(\sigma_v') - 0.112$	0.897	12.8
$*c_c = 0.016\omega_n - 0.009\omega_l + 0.002\omega_l \log(\sigma_v') - 0.135$	0.894	11.7

Conclusion

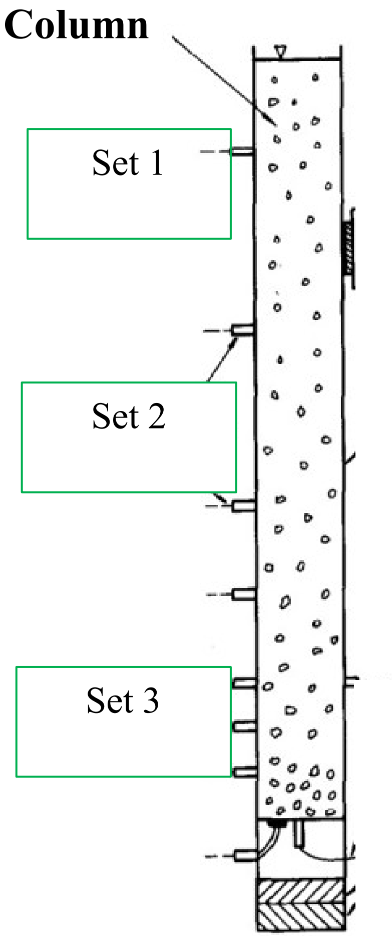
- This study is a proper guideline for a standard laboratory consolidation test procedure for dredged soils.
- Proper guideline for sample preparation is recommended, and special attention is paid to achieving a very low-stress seating load by using 3D printing technology.
- A loading schedule and a settlement reading schedule for modified oedometer tests are recommended in this thesis.
- A detailed calculation procedure for analyzing the consolidation properties from laboratory test data is illustrated in the thesis.
- This study proposed detailed methods for developing empirical equations and presented empirical equations for predicting the compression index of Louisiana marsh soil.

On Going Research Work

Settlement Column Test Setup Using Sensors and Numerical Modeling

Each Set Contains Three Types of Sensors in Different Depth

- Moisture Sensors
- Pore Pressure Sensors
- Total Pressure Sensors



Step 1 → **Conduct test using three types of sensors in different depth**
- Moisture Sensors
- Pore Pressure Sensors
- Total Pressure Sensors

Step 2 → **Parameters determined from the test**
- Void Ratio distribution
- Pore water Pressure distribution
- Effective stress distribution

Step 3 → **Finite consolidation parameter**
- Variable coefficient
- Finite Coefficient of consolidation

Step 4 → **Numerical modeling using Nonlinear Consolidation Theory and consolidation parameters**

Step 5 → **Validation/Comparison of test results**

Acknowledgement

Special thanks to my supervisor
Dr. Jay X. Wang, P.E., M. ASCE

The research presented in this study was sponsored by the
Coastal Protection and Restoration Authority (CPRA), Louisiana.

Thank you