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Geotechnical and Geothermal Properties of Louisiana Coastal Sediments

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Geotechnical and Geothermal Properties of Louisiana Coastal Sediments

A Thesis

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Table of Contents

List of Figures

List of Tables

Abbreviations

CR: Compression Ratio

C_r: Recompression Index

C_c: Compression Index

C_v: Coefficient of Consolidation

Cs: Swelling Index

Cu: Strength in psf

e_0: Initial Void Ratio

RR: Recompression Ratio

mv: Coefficient of Compressibility

Kv: Coefficient of permeability

TV: Hand-operated torvane

LV: Laboratory miniature vane

qu: Undrained shear strength

σ'_v : Effective Overburden Pressure

σ'_p: Effective Preconsolidation Pressure

OCR: Overconsolidation Ratio

Γ: Moisture Unit Weight in pcf

Formulas

- γ=γd(1+ω%/100)

  Where γd = Dry Unit Weight

  ω= Moisture content

- Cc=Δe/Δlogσ'v (Creep Ratio)

  Where σ'v = effective vertical stress

- S= c+ σtanϕ

  Where s = Shear Strength
  c = cohesion
  ϕ = Friction Angle
  For Clay ϕ = 0
  s = c

- $k_t = (\frac{q}{4\pi(T_2-T_1)})\ln(\frac{t_2}{t_1})$

  Where $q = I^2 x \frac{R}{L}$

  I = applied current (amperes)

  R = total resistance of heater element inside probe (ohms)

  L = Length of probe (in)

  T = Temperature (F)

  t = Time (s)

- $k_c = \frac{(f_0 k_0 + k f_1 k_1)}{(f_0 - k f_1)}$

  Where f_0, f_1= Volume fraction of water and solids respectively

  k_0, k_1= Thermal conductivity of water and solids

  k_c = thermal conductivity of the composite medium

- $\lambda = \frac{2.30\ Q}{4\pi(T_2 - T_1)} \log_{10}(t_2/t_1) = \frac{Q}{4\pi(T_2 - T_1)} \ln(t_2/t_1)$

Where:

Q	=	$I^2 R/L = EI/L$
Q	=	Heat input
λ	=	Thermal conductivity [W/(m.K)]
T_1	=	Initial temperature(K)
T_2	=	Final temperature (K)
t_1	=	Initial time (s)
t_2	=	Final time (s)
I	=	Current flowing through heater wire (A)
R	=	Total resistance of heater wire (W)
L	=	Length of heater wire (m)
E	=	Measured voltage (V)

- $T = \frac{1}{A + B(\ln R) + C(\ln R)^3 - 273.2}$

Where:

A, B, and C = Steinhart-Hart coefficients, which vary depending on the specifications of the thermistor and temperature range

R = Resistance at T in ohms

Abstract

Land loss in South Louisiana is increasing at a fairly rapid rate. In an effort to reduce land loss and save the marshes of Louisiana, marsh creation projects have been proposed in carefully selected regions around the coast as part of the CPRA Coastal Master Plan 2017. Properties and characteristics of the soil obtained from soil borings were analyzed and used to determine the various design parameters that allow the marsh creation process to occur. Other properties that were taken into consideration for Louisiana coastal sediment are the geothermal properties.

This research analyses those different properties obtained from geotechnical reports from CPRA and other data bases, in order to find correlations between the different soil characteristics, specifically between the soil's compressive strength, consolidation properties, Atterberg Limits and moisture content. Furthermore, this research also studies the geothermal properties of selected Louisiana soils and the correlation between moisture content and thermal conductivity.

Keywords: Coastal, Geotechnical, Geothermal Energy, Correlation, Soil Properties

Chapter 1
Introduction

1.1 Introduction

Human and natural forces affecting the gulf coast region, are contributing greatly to the land loss of the Louisiana coast. Between 1932 and 2010, Louisiana's coast lost more than 1,800 square miles of land. From 2004 through 2008 alone, more than 300 square miles of marshland were lost to hurricanes Katrina, Rita, Gustav, and Ike (Louisiana Master Plan 2017).

Land loss reduces shorelines, marshes, and swamps that are a vital barrier and first line of defense against storm surge and flooding. Coastal flooding has become an all too common occurrence due to powerful storm surges associated with tropical events made worse over the years by subsidence, sea level rise, and coastal land loss. The master plan, in its purest sense, is a list of projects that build or maintain land and reduce risk to our communities. (Louisiana Master Plan 2017).

The Coastal Master Plan 2017 created by CPRA includes 124 projects that build or maintain more than 800 square miles of land and reduce expected damage by $8.3 billion annually by year 2050, which equates to more than $150 billion over the next 50 years and are expected to pay for themselves three times over the course of implementing the plan. The plan dedicates nearly $18 Billion to marsh creation using dredged sediments, $5 Billion to sediment diversions, and more than $2 Billion to other types of restoration projects-providing land building benefits of more than 800 square miles, compared to a future without action (Louisiana Master Plan 2017).

The objective of this research is to compile data found in Geotechnical design reports of completed marsh creation projects developed by CPRA and use the data to develop interrelationships between the soil properties specifically present in those areas. The soil relationships can be used by engineers, scientists, and researchers working in coastal restoration projects. A separate attempt was made to evaluate geothermal conductivity properties of some Louisiana coastal sediments.

1.2 History of the Coastal Area

Coastal Louisiana as shown in **Figure 1** below, was formed by the continual deposition of sediments from the Mississippi river. Weaving in and out of river alignments across the entire delta plain, the sediment-laden waters of the river overflowed and deposited minerals and nutrients effectively creating all of the south Louisiana deltaic plain with historical delta reaches spanning a range from as far west as the vermillion bay to as far as the St. Bernard parish Mississippi state line (Boudreaux, 2012). With each new course that the Mississippi River has taken it has deposited alluvial fans of sediment creating a deltaic plain (Deubert, 1982).

The coast of Louisiana is fringed by a band of marshland 10 to 80 miles in width. The western, narrower band of marsh—the chenier plain of southwest Louisiana--is characterized by stranded, marsh surrounded by beaches or cheniers. Gulfward-projecting, natural levee ridges bordering active and abandoned courses and distributaries of the Mississippi River typify the eastern marshes. This eastern region, which spans almost 200 miles of coastal Louisiana--from Vermilion Bay (about longitude 92°W) to the Chandeleur Islands --comprises the deltaic plain of the Mississippi River (Kolb, 1958) see Figure 1.

By 1920, developers were building on these former marshes, much of it at or slightly below sea level. By nature of the rapidity and environments within which the deltaic deposits were placed, most of the deposited soils are poorly consolidated. (Deubert, 1982).

The studies shown in this thesis cover the entire southern portion of the state of Louisiana. The parishes included in the study areas are Cameron, Iberia, Jefferson, Lafourche, Orleans, Plaquemines, St. Bernard, St. Charles, St. Mary, St. Tammany, Terrebonne, and Vermilion.

The objectives of the projects discussed in this paper are to restore marsh areas that are currently being degraded by the increased wave action, the lack of vegetation, and sea level rise. Other major contributors to land loss in these project areas include subsidence, compaction, and oxidation of marsh soils.

Marsh Creation establishes new wetlands in open water areas such as bays, ponds, and canals through sediment dredging and placement (Louisiana Master Plan 2017).

The design of these projects is such that dredged materials from the Gulf, Mississippi river and other rivers chosen by CPRA and other engineers, will be placed at the particular Marsh Creation project in order to restore the acres of previously lost land.

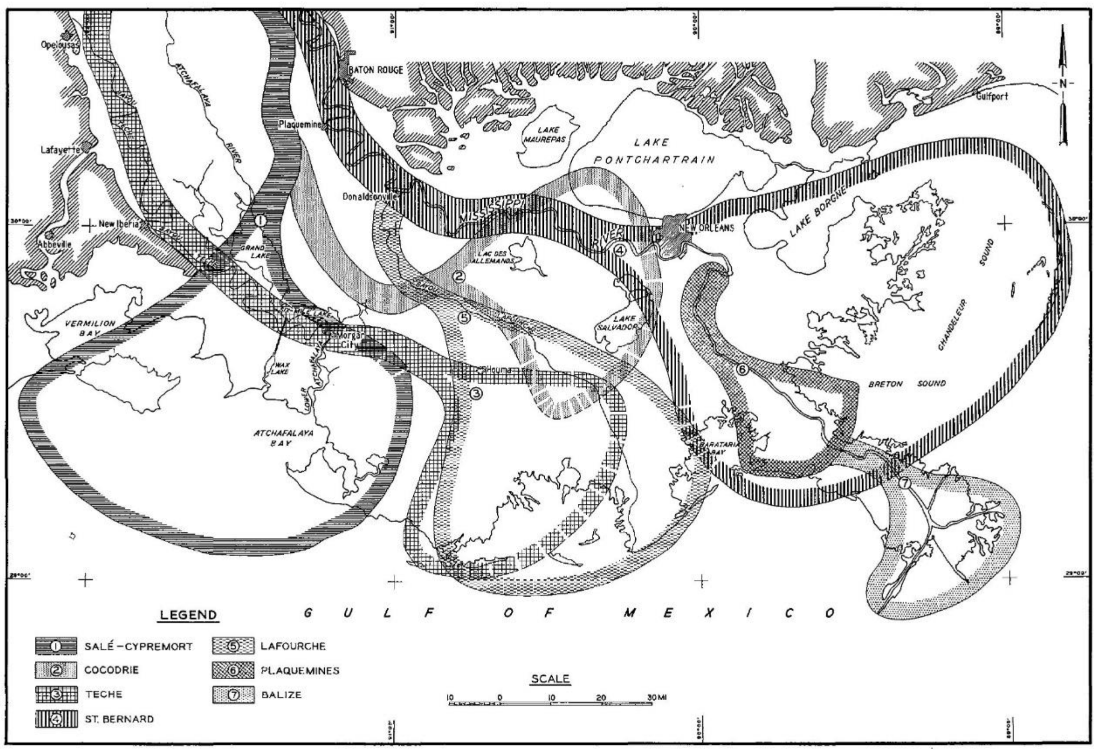


Figure 1 – Mississippi River Deltas (Kolb, 1958)

1.3 Louisiana Coastal Restoration

1.3.1 The Coastal Protection and Restoration Authority Formation

Prior to 2005, coastal protection and restoration efforts in Louisiana were handled by a number of local and state governmental entities with limited budgets and little or no coordination of efforts. As a result of the devastation of hurricanes Katrina and Rita, the federal government agreed to focus attention and money on our plight but had some requests. Rather than deal with a myriad of agencies, it wanted one central authority that would represent the state and be accountable for oversight of all activities and funds, and it wanted a coordinated plan of action with clear goals and achievable objectives. (Coastal 2013)

In December 2005, meeting in a special session to address recovery issues confronting the state following Katrina and Rita, the Louisiana Legislature restructured the State's Wetland Conservation and Restoration Authority to form the Coastal Protection and Restoration Authority otherwise known as CPRA. (Coastal 2013)

Act 8 expanded the membership, duties and responsibilities of the board and charged the new Authority with developing and implementing a comprehensive coastal protection plan, including both a Master Plan that would be revised every five years and an annual plan of action and expenditures to be submitted to the legislature every fiscal year for approval. (Coastal 2013)

1.3.2 Louisiana Coastal Master Plan

The first Coastal Master Plan was adopted by the Louisiana Legislature in 2007. Carrying over and building upon the objectives of this plan, the 2012 Coastal Master Plan was developed and approved on May 22, 2012. The 2017 Costal Master Plan was unanimously approved by the State House and Senate on June 2, 2017. This plan considers an array of new project ideas not evaluated in the 2012 Coastal Master Plan.

Figure 2 shows a map of the 124 projects included in the 2017 plan that build or maintain more than 800 Square Miles of land and reduce expected damage by $8.3 billion annually by year 50, which equates to more than $150 billion over the next 50 years and are expected to pay for themselves three times over the course of implementing the plan. The plan dedicates nearly $18 billion to marsh creation using dredged material, $5 billion to sediment diversions, and more than $2 billion to other types of restoration projects-providing land building benefits of more than 800 square miles, compared to a future without action. (Louisiana Master Plan 2017).

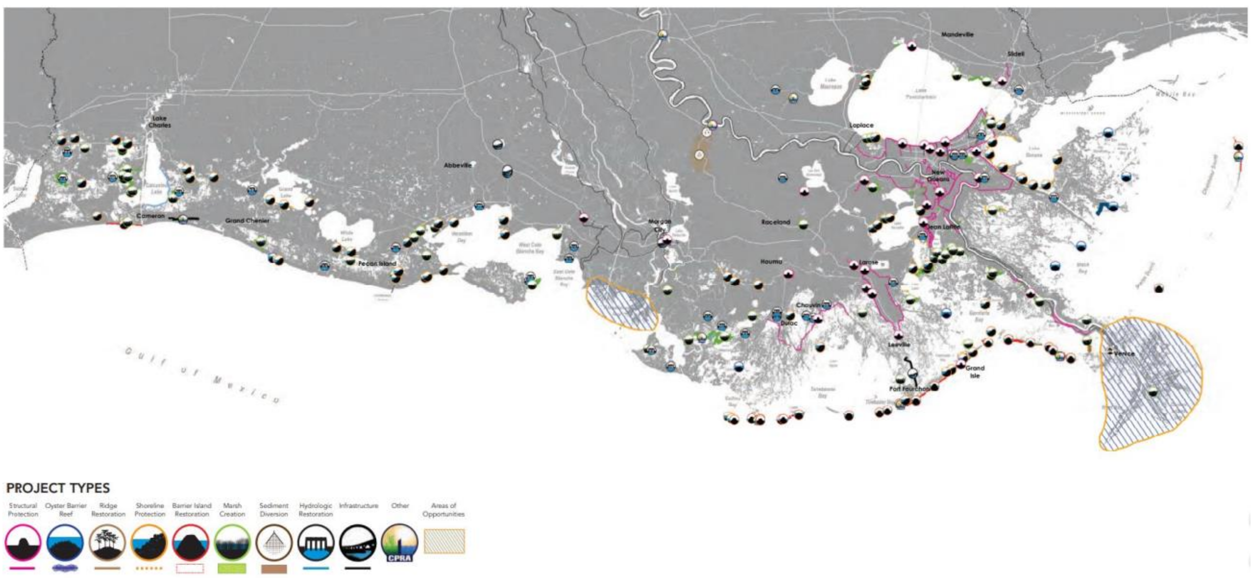


Figure 2 – CPRA Map of Projects (Louisiana Master Plan 2017)

In studying these projects and their benefits, CPRA also developed maps (**Figure – 3**) showing the medium scenario of negative effects that are projected to occur if these projects are not implemented. To capture this comparison, CPRA investigated what we called “Future without action” conditions for the next 50 years, meaning conditions that would be present throughout coastal Louisiana if we do nothing further without action conditions, our models included projects that are already constructed as well as projects that will be built in the near future because they have received construction funding (Louisiana Master Plan 2017).

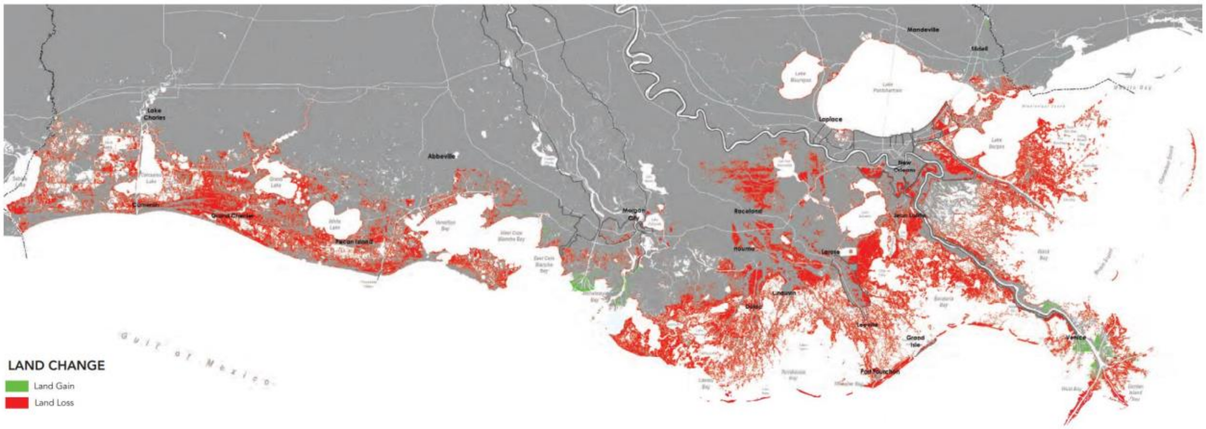


Figure 3 – Medium Scenario Future Without Action

Under the low environmental scenario, 1207 square miles could be lost over 50 years. Under the medium scenario, 2254 square miles could be lost. Under the high scenario, 4123 square miles could be lost. This predicted land loss is in addition to the nearly 1900 square miles of land area lost between 1932 and 2010 (Louisiana Master Plan 2017).

1.3.4 Marsh Creation and Land Creation

As many as 35 square miles of coastal marshland and other wetland ecosystem environments are being lost each year. (Barras, 1994). This equals to losing one football field size land loss every 38 minutes (Wheeler 2000).

The overall goal of the marsh creation projects is to create wetland habitat in typically degraded coastal marsh regions, in an effort to maximize ecological benefits for the project design life duration and restore the landscape and ecosystem that have been substantially distributed by human activities such as environmental pollution or land disturbance. (Mitsch et. al, 2004). Ecosystem restoration and restoration ecology refer to "the return of an ecosystem to a close approximation of its condition prior to disturbance" as defined by the national research council

(Boudreaux, 2012). The ultimate goal for restoring the coast and reducing risk is ultimately for the benefit of the people that live and work in those environmentally threatened areas.

1.3.4 The Dredging Process and its Benefits

Dredging as defined by CPRA, is an excavation activity conducted underwater for the purpose of removing marine bottom sediment. The dredging process often involves radical manipulation of in-situ sediments (Lee, 2004).

Dredging canals for energy exploration and pipelines provided our nation with critical energy supplies, but these activities also took a toll on the landscape, altering wetland hydrology and leading to land loss. Navigation canals provided our nation with critical infrastructure but also allowed salt water to invade deeper into coastal basins (Louisiana Master Plan 2017).

Although this type of dredging as well as dredging of oil and gas canals has caused land loss in the past, dredging for the purpose of creating marsh areas is proven to be a much more effective method. Not only is the dredged material used for creating marsh, but dredging occurring along distributary channels in order to direct flow into deteriorating marshes.

CPRA has used large-scale solutions involving extensive dredging and placement of materials, better management of the resources of the Mississippi and Atchafalaya Rivers, as well as improved hydrology to address root causes of land loss and reduce flooding risk (Louisiana Master Plan 2017).

As shown in the diagram in **Figure 4**, in order for a Marsh Creation Project to be implemented, the project area and the borrow area are selected. An earthen containment dike is then constructed around the perimeter of the project area typically using in-situ material, this will contain the slurry material. The borrow area is then hydraulically dredged, and the slurry material is pumped into the designated marsh creation areas. This slurry or dredged material goes through a de-watering and settlement process and eventually creates new marshland that is higher than the Mean Sea Level. The thickness of the dredged material will decrease overtime due to primary and secondary consolidation. Due to the overburden pressure caused by the dredged material, the existing subsurface soil beneath the containment areas will also experience additional consolidation settlement.

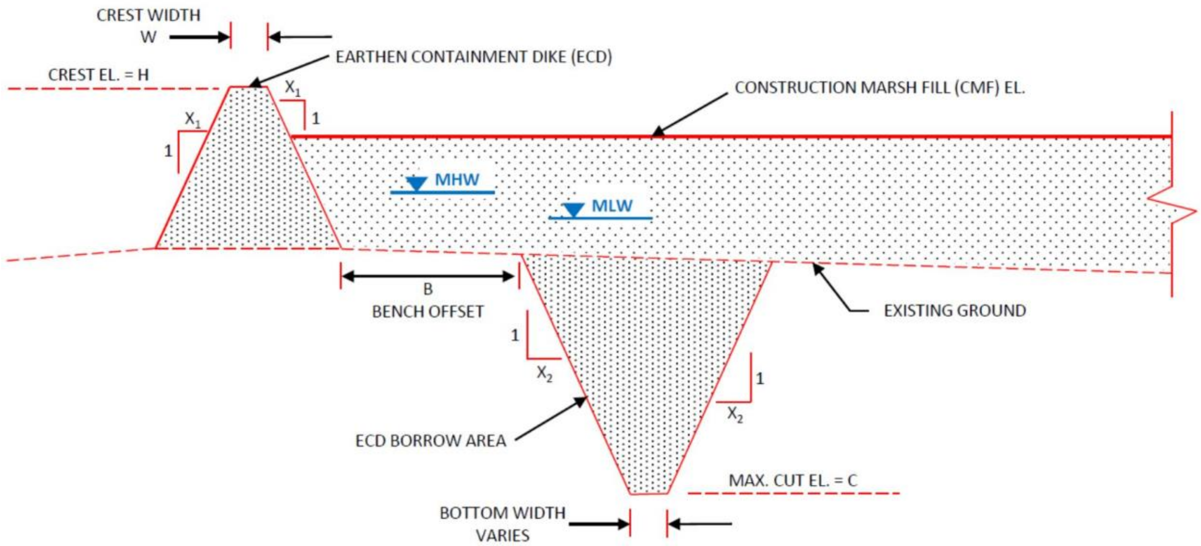


Figure 4 – Typical Marsh Creation Project Section with Earthen Containment Dike (Jaskaran, et. al, 2017)

The scope of this research is to evaluate engineering properties of coastal sediments from recently completed marsh creation projects in Louisiana. Geotechnical data from multiple marsh creation projects in multiple parishes were used to develop interrelationships between soil compressibility properties.

Chapter 2
Literature Review

2.1 Introduction

As the literature review during this research was done, it was found that many studies have been previously done in topics researching different correlations in soil properties and some have been successful. Although correlations have been previously observed, none have been made in areas related to Louisiana marsh land or specifically land that will be used to replenish the marshes. In most instances, these studies have been done for different soil types from other areas around the world, which are completely different from the types of soils available in south Louisiana.

Correlations to define relationships between soil properties has been of significant help to design a civil infrastructure project. Such correlations permit the engineer to make preliminary estimates and design calculations based on limited soils data with more assurance. Correlations also provide for a possible reduction in the amount of laboratory testing required when the economics of a project do not warrant extensive testing (Deubert, 1982).

The following sections give a brief review of the literature on correlations between different soil types and properties.

2.2 Established Correlations

2.2.1 Established Consolidation Index Correlations by previous studies

The following list and table 1 and 2 provide correlations that have been achieved by others as described by Deubert:

- Normally consolidated clay of low to medium sensitivity by Terzaghi and Peck:

$$Cc = 0.009(LL-10)$$

Where LL = Liquid limit

Cc = Compression Index

- Mississippi Valley alluvial soils by Sherman and Hadjidakis:

  $Cc = 0.011(LL)-0.176$

- Inorganic silty clay by Hough:

  $Cc = 0.30(e_0-0.27)$

  Where e_0 = Initial void ratio

- Marsh deposits near New York by Knapp:

  $Cc=0.6(e_0-1)$ for $e_0 < 6$

  $Cc=0.85(e_0-2)$ for $e_0 = 6$ to 14

- Organic soils and peats by MPMR (1958):

  $Cc = 0.010$ to 0.015 (w_n, %)

  Where w_n = Natural water content

- Organic soils and peats by Sowers

  $Cc = (0.5 \text{ to } 0.7)\ e_0$

Deubert found the following correlations:

Summary of General Correlations for Recent Deposits			
Line of Regression	**N**	**Sy**	**R^2**
$Cc = 0.014\ w_n - 0.16$	873	0.15	0.89
$Cc = 0.009\ LL - 0.09$	850	0.23	0.7
$Cc = 0.010\ PI + 0.07$ (Where PI=Plasticity Index)	799	0.23	0.65

Table 1 - Summary of General Correlations for Recent Deposits (Deubert, 1982)

Some Empirical Equations for Cc – Compression Index	
$Cc = 1.15(e_0 - 0.35)$	All Clays
$Cc = 17.66 \times 10^{-5}\ w_n^{\ 2} + 5.93 \times 10^{-3}\ w_n - 1.35 \times 10^{-1}$	Chicago Clays
$Cc = 0.01 w_n$	Chicago Clays
$Cc = 0.75\ (e_0 - 0.50)$	Soils to very low plasticity
$Cc = 1.15 \times 10^{-2}\ w_n$	Organic soils meadow mats, peats, and organic silt and clay

Table 2 - Some Empirical Equations for Cc: Table 3-1 (Deubert, 1982)

2.2.2 Established Coefficient of Consolidation Correlations

The following list provides correlations that have been achieved by others regarding the coefficient of consolidation (Cv) of soil:

- Coefficient of consolidation from liquid limit of soil:

  $Cv = ((10^8(w_L)^{-6.7591}) (cm^2/sec))(3.875 ft^2/day)$

  Where w_L = Liquid Limit

- The relationship can be expressed by the following equation (Al-tae's, et. la, 2011):

  $Cv = 4258 X^{(-1.75)} (3.875 ft^2/day)$

  Where X = liquid limit

An attempt has been made to correlate the coefficient of consolidation with index properties/ indices. Twenty soil samples of both fine grained and coarse grained are taken and empirical equations has been developed using Microsoft Excel (Jadhav, 2016). Only two relevant correlations were found using the SLRA and the MLRA models.

The correlations are as follows:

Cv Value and obtained from the shrinkage index (Is) (SLRA Model)

- Cv = 128.7/(Is)3.54 + 0.0002

  This correlation yielded a R^2 Value of 0.715

Cv Value and Plastic Limit (PL), Shrinkage Index (Is) (MLRA Model)

- Cv = 5.4*PL/(Is)3.54 + 0.0002

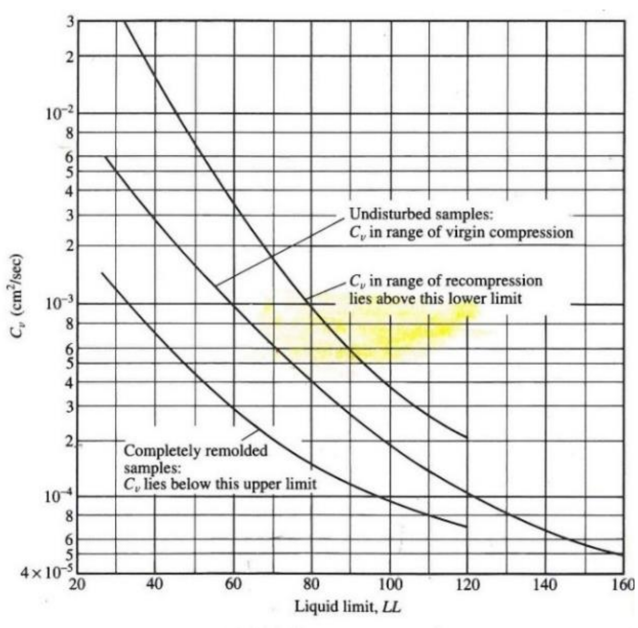
  This correlation Yielded a R^2 value of 0.79

An attempt was made to correlate the liquid limit and coefficient of consolidation (Cv) values of experimental results of soil sample collected for investigation. It is observed that the coefficient of consolidation (Cv) value decreases with increase in liquid limit. From SLRA correlation coefficient (R^2) is found to be 0.4081. It represents no significant relation exist between these two parameters to predict Cv from liquid limit (Jadhav, 2016).

2.3 Previous Studies

Different correlations of soil properties have been studied over many years. Some studies have achieved relative and effective correlations, while others seem to prove that some soil properties and characteristics do not have correlations.

In Establishing relationship between coefficient of consolidation and index properties/Indices of remolded soil samples, the author’s attempt is made to correlate the liquid limit and coefficient of consolidation (Cv) values of experimental results of soil sample collected for investigation. It is observed that the coefficient of consolidation (Cv) value decreases with increase in liquid limit (Jadhav, 2016). Figure 5 shows the range of different Cv correlations under different parameters.



▼ FIGURE 1.24 Range of C_v (after U.S. Department of the Navy, 1971)

Figure 5 – Range of Cv (after U.S. Department of the Navy, 1971)

During this literary review, it was found that the majority of the correlations previously studied showed positive correlations between Coefficient of Consolidation and Compression index Vs. Liquid Limit and Moisture Content; however; very few if any studies have been done for other correlations presented in this thesis including shear strength. The correlations described above are the correlations found thus far in this literature review.

2.4 Geothermal Properties of Soil

In recent studies of soil properties, the geothermal properties of soils are becoming more and more interesting to the engineering field. These studies are being used in order to test soil in areas where it remains at a constant temperature throughout the year and use it in the design of solar energy storage systems above ground. The ability of soil to efficiently conduct and store solar thermal energy is critical in the economic design of these systems. (Lutenegger, 2001)

In his study of thermal properties of soils, Lutenegger performed field and laboratory investigations to evaluate thermal conductivity by constructing a thermal needle probe and a field probe. Thermal conductivity values were obtained using a simple line heat sources analysis Weschler (1966) was used to reduce the measured temperature increase versus time data collected. (Lutenegger, 2001)

Thermal conductivity in the field using the field probe was obtained using the following:

$$k_t = \left(\frac{q}{4\pi(T_2 - T_1)}\right)\ln\left(\frac{t_2}{t_1}\right)$$

Where $q = I^2 x \frac{R}{L}$

I = applied current (amperes)

R = total resistance of heater element inside probe (ohms)

L = Length of probe (in)

T = Temperature (F)

t = Time (s)

Thermal conductivity in the laboratory using a thermal needle probe was calculated using the simple line heat source theory by Hillel (1982) and Ingersoll (1988):

$$k_c = \frac{(f_0 k_0 + k f_1 k_1)}{(f_0 - k f_1)}$$

Where f_0, f_1 = Volume fraction of water and solids respectively

k_0, k_1 = Thermal conductivity of water and solids

k_c = thermal conductivity of the composite medium

In this study, it was concluded that both approaches provide similar test results for estimating thermal conductivity. (Lutenegger, 2001)

In an attempt to gain background information on ground temperature and geothermal energy to be used for ground source heat pumps, ground temperature profiles were plotted in many areas in the United States. Dr. Olgun at Virginia Tech used this data to determine that after a certain depth in the ground generally after 30ft, the temperature of the soil remains relatively constant in Houston, TX. Although many of these ground temperature profiles have been done in many states, the closest one to New Orleans being in Houston, TX (figure 6), none have been done thus far in Louisiana.

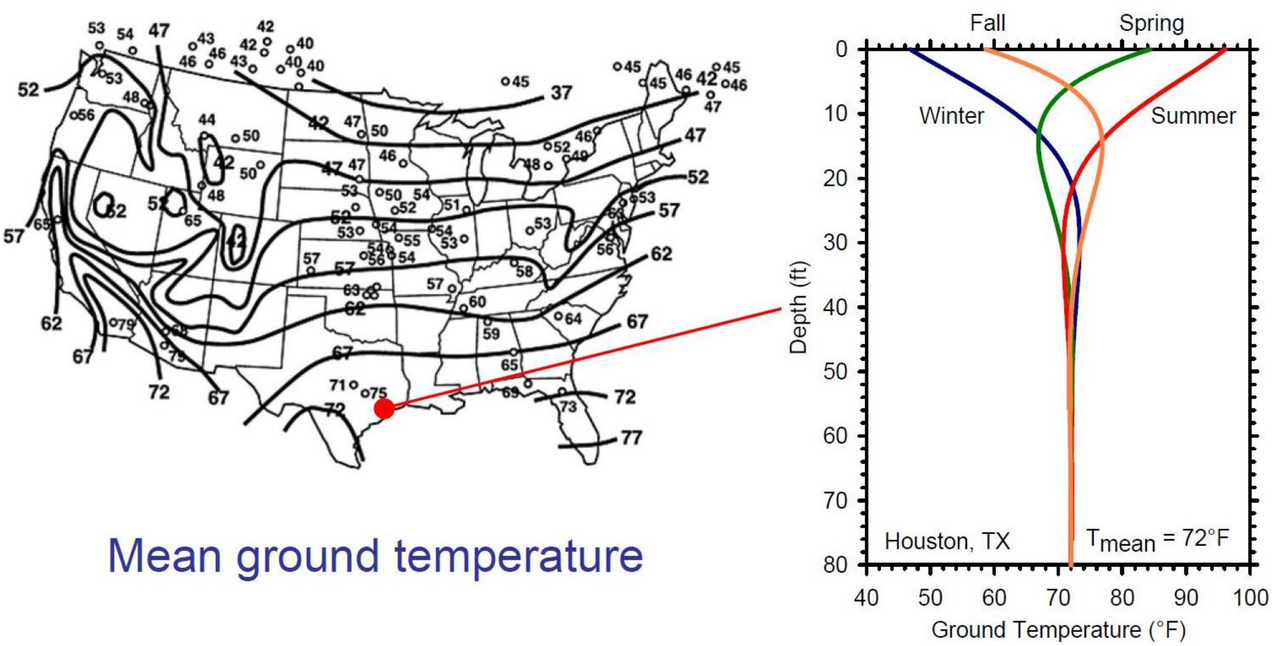


Figure 6 – Mean ground temperature in Houston, TX

Chapter 3
Scope

3.1 Research Objectives

The overall objective of this research was to evaluate soil properties obtained from the boring log information collected from different areas of on-going and recently completed marsh creation projects throughout the southern coast of Louisiana.

This research evaluates the following properties:

1. Coefficient of consolidation vs. moisture content
2. Coefficient of consolidation vs. liquid limit
3. Compression index vs. moisture content
4. Compression index vs. liquid limit
5. Undrained shear strength vs. moisture content
6. Undrained shear strength vs. liquid limit
7. Geothermal soil properties of Louisiana soil

3.2 Goals

The overall goal of this research is to find a correlation between the different soil properties listed in the objectives above, and verify the results using values of coefficient of determination (R^2) and check them with available equations previously developed for different types of soils. Additionally, geothermal properties of some coastal Louisiana soils were also evaluated.

3.3 Methodology

The data used in this thesis was obtained by multiple Geotechnical Engineering firms hired by CPRA, from the sites of actual projects that are on-going and ones that will be executed in the future according to the Coastal Master Plan 2017 and depending on funding sources. The studies will compare compressive stress with soil's moisture content liquid limits as well as the coefficient of consolidation and Compression Index vs. Liquid limit and Moisture Content obtained from the marsh creation projects boring logs.

The main purpose behind finding a correlation is to reduce the relatively time consuming and expensive geotechnical testing for future design efforts in marsh creation projects and the Coastal Engineering field.

A data set will be presented and analyzed to show the different types of soils present in the marsh creation project areas, it will study the characteristics described above of each type of soil and correlate the least expensive and time-consuming laboratory test performed with the lengthier and costly tests.

Although multiple attempts at finding a correlation between different soil characteristics and their shear strength have been attempted and have succeeded, the key differences between other work and this thesis are the types of soils tested, the types of projects that the parameters will be used to design, and the saturation amount in the various areas of Marshes.

Chapter 4
Laboratory Testing

4.1 Introduction

The geotechnical tests used in this study were performed by various Geotechnical Engineering firms. Soil classifications of the samples used were established in the laboratory in general using the Atterberg Method of determining the liquid Limit, Plastic Limit and Plasticity index.

The Geotechnical laboratory test typically conducted on the vibracore material for a proposed marsh creation borrow area generally include the USCS Classification, Gradation/Hydrometer, Moisture Content, Atterberg Limits, Unit Weight and Specific Gravity. These test results are utilized by the dredger and designer to estimate dredging production rates and marsh fill behavior (Jaskaran, et. al, 2017). The following chapter gives a brief description of some of the geotechnical test performed in order to obtain the data used in the analysis for this research.

4.2 Geotechnical Characterization Testing of Soils

Moisture content and USCS Classification were performed on all samples using ASTM D2216-10, D2487-11, and D2488-09a, Atterberg Limits were performed using ASTM D4318-10 method, Shear strength and consolidation tests were performed using ASTM D2166/D 2166M-10, ASTM D 2850-03a (2007), and ASTM D2435-11 Method. These methods include Consolidation Tests, Unconsolidated Undrained (UU or Q) Triaxial Tests, and Unconfined Compression Tests (UCT). The test data selected within the Marsh creation projects area included over 700 consolidation tests performed. A total of 2955 data points were used in developing the correlations shown in this study.

4.2.1 Moisture Content

Moisture content is defined as the ratio of the weight of water to the weight of solids in a given volume of soil. The moisture content of a soil sample is generally obtained by measuring the weight of a soil sample when it is retrieved from the ground, placing it in a small tin container, then placing the sample in an oven until it is completely dry, and weight remains constant. The soil sample is removed from the oven, and the moisture content is calculated by taking the ratio of wet to dry sample as expressed by the following formula:

$$MC(\%) = \frac{\boldsymbol{w_w - W_d}}{\boldsymbol{W_d - W_t}}$$

Where *Ww* = Weight of wet soil

Wd = Weight of dry soil

Wt = Weight of tin container

4.2.2 USCS Classification

Determination of soil type was done by using the Unified Soil Classification System, such that clay is defined as a soil having a liquid limit and plasticity index falling above the “A Line” and silty clay for those which fall below the “A Line” (Deubert, 1982). Basic geotechnical parameters need to be measured. The most basic parameter is the material’s physical property classification based on the grain size distribution of gravel, sand, silt, and clay. Other physical properties include water content, density, specific gravity, and percent solids (Lee, 2004)

4.2.3 Atterberg Limits

This method was developed by a Swedish scientist named Atterberg and later refined by Arthur Casagrande, to describe the consistency of the fine-grained soils with varying moisture contents. At a very low moisture content, soil behaves more like a solid. When the moisture content is very high, the soil and water may flow like a liquid. Hence, on an arbitrary basis, depending on the moisture content, the behavior of soil can be divided into four basic states: solid, semisolid, plastic, and liquid (Das, 2010).

The Atterberg limits include four parameters: shrinkage limit, plastic limit, liquid limit and plasticity index. The shrinkage limit is the moisture content, in percent, at which the volume of the soil mass ceases to change with continuing loss of moisture. It is a state of equilibrium reached at which more loss of moisture results in no further volume change. The plastic Limit is the moisture content at which the soil crumbles when rolled into threads of 1/8 in in diameter. It is the lower limit of the plastic stage of soil. This test is performed by repeatedly rolling of soil sample by hand on a glass plate. The liquid limit is a test performed using an apparatus called the Casagrande device, which consists of a brass cup and a hard rubber base. The test is performed by placing a soil paste in the brass cup as shown in **Figure 7**. A groove is then cut at the center of the soil with a grooving tool. By using the crank-operated cam, the cup is lifted and dropped. The moisture content required to close certain distance along the bottom of the groove after 25 blows is defined as the liquid limit.

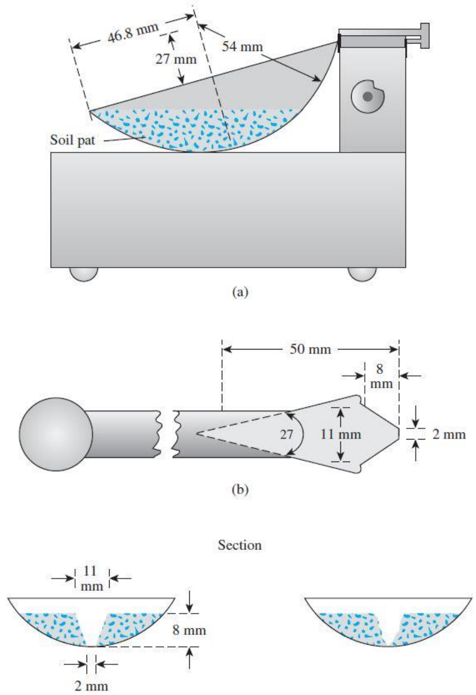


Figure 7 – Casagrande Device: Liquid Limit Test (Das, 2010)

4.2.4 Consolidation Test

Consolidation testing is a laboratory attempt to duplicate an in-situ consolidation by determining the stress-strain characteristics of a soil sample in compression. (Deubert, 1982)

The procedure for a one-dimensional laboratory consolidation test, consists of placing a soil specimen with a diameter of 2.4 in inside of a metal ring between two porous stones. A load is then applied on the specimen through a lever arm, with the load being applied for 24 hours, then doubled. The compression is measured by a micrometer dial gauge, and a plot of deformation against time is formed.

4.2.5 Shear Strength

Shear failure occurs when the stresses between the particles are such that they slide or roll past each other. Due to the particulate nature of soil, unlike that of a continuum, the shear strength depends on the interparticle interactions rather than the internal strength of the soil particles themselves (Coduto 2001).

Compressive strength is the maximum compressive load a body can bear prior to failure, divided by its cross-sectional area. Whereas: shear strength is the maximum shear load a body can withstand before failure occurs divided by its cross-sectional area.

In the laboratory, shear strength tests generally consist of unconfined compression test and unconsolidated-undrained triaxial tests. These tests are performed in order to determine the compressibility characteristics of the soils and the results are shown on a percent strain versus log pressure curve.

Compression of soils under a laterally constrained condition may be conveniently divided into primary compression observed during the increase in effective vertical stress, and secondary compression that follows at constant effective vertical stress (Mesri, et. al, 2007).

4.3 Geothermal Energy Testing of Soils

Geothermal Energy is energy available as heat contained or discharged from the earth's crust that can be used for generating electricity and providing direct heat for numerous applications such as space and district heating; water heating; water heating; aquaculture; horticulture; and industrial processes. In addition, the use of energy extracted from the constant temperatures of the earth at shallow depth by means of ground source heat pumps (GSHP) is also generally referred to as geothermal energy. (Renewable Energy 2012)

The overall objective of the geothermal energy research in Louisiana is to test the ground temperature and verify that after a certain depth the soil temperature remains constant year-round. This can lead to the ability to evaluate the feasibility of using conventional pile foundations as GEPs in Louisiana, characterizing and evaluating the hydro-thermal properties of subsurface soil, and eventually characterizing and evaluating thermo mechanical behavior of Geothermal Energy Pole foundation as alternate means for production and storage of energy. Through different field and laboratory research such as the ground temperature monitoring and determination of thermal conductivity of soil by thermal needle probe procedure, we can prove that this study is achievable.

4.3.1 Thermal Conductivity of Soil by Thermal Needle Probe

In order to determine the thermal conductivity of soil in the laboratory, a thermal needle probe (Figure 8) was built following the guidelines in ASTM Standard D 5334-08. The needle consists of a small hypodermic tube with nichrome heater element wire and glass braid type T thermocouple wire inserted into it. After the wires were inserted, the tube was filled with thermal epoxy. The thermocouple wires extruding from the top of the needle were connected to a thermocouple jack used for temperature reading, while the heater element wires were connected to the heat source input.

Figure 8 – Laboratory setup: thermal needle probe

4.3.2 Laboratory Testing Arrangement

The laboratory testing arrangement in Figure 9 was used as a guide to build the testing arrangement in Figure 10 includes a fixed piston setup that has a small opening at the top to allow the probe to be inserted into the sample. The needle will be attached to constant power supply, which will pass a constant current through it, allowing a variation of temperature to pass through the soil. On the other end of the needle, a thermocouple readout unit is attached in order for the temperature to be recorded.

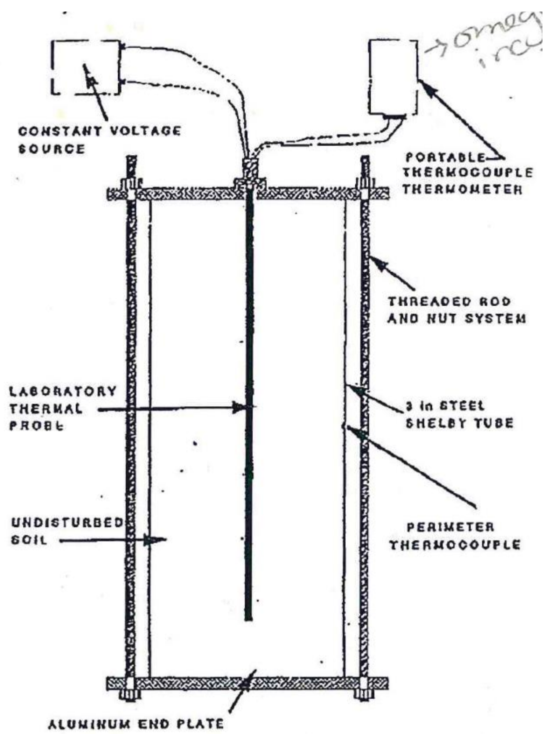


Figure 9 – Laboratory Test Arrangement (Lutenegger, 2001)

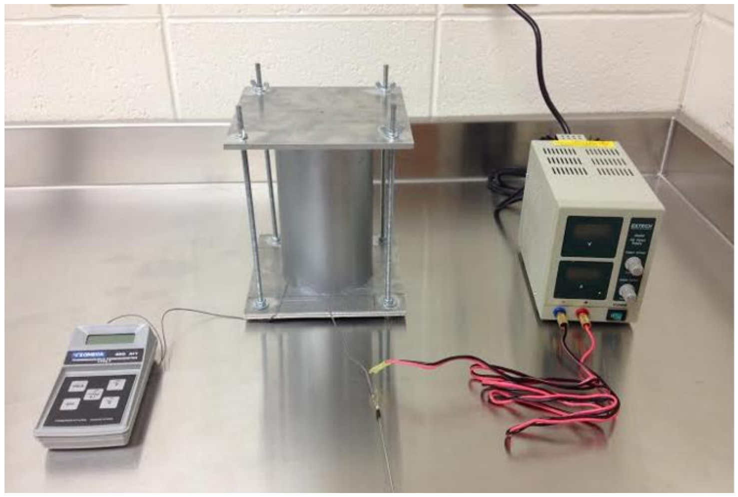


Figure 10 – Laboratory thermal conductivity setup

4.3.3 Laboratory Testing of Thermal Conductivity

The data obtained from the laboratory arrangement is recorded at different time intervals from 0-1200 seconds. The data is then graphed in order to find the slope of the steady state portion of the line. From the slope, we can determine initial and final temperature as well as the initial and final time to be used in the equation below.

Thermal conductivity can be computed using the following equation:

- $\lambda = \frac{2.30\ Q}{4\pi(T_2 - T_1)} \log_{10}(t_2/t_1) = \frac{Q}{4\pi(T_2 - T_1)} \ln(t_2/t_1)$

Where:

- Q = $I^2 R/L = EI/L$
- Q = Heat input
- λ = Thermal conductivity [W/(m.K)]
- T_1 = Initial temperature(K)
- T_2 = Final temperature (K)
- t_1 = Initial time (s)
- t_2 = Final time (s)
- I = Current flowing through heater wire (A)
- R = Total resistance of heater wire (W)
- L = Length of heater wire (m)
- E = Measured voltage (V)

4.3.4 Ground Temperature Monitoring Using Thermistor Strings

In order to measure the ground temperature to evaluate whether or not the temperature of the soil remains constant after a certain depth, field testing was performed using a Thermistor String. At a chosen location in New Orleans East (Figure 10), a 100 ft boring was excavated near the testing site, to evaluate the different soil layers present in the area. The thermistor string was then installed at 1 foot intervals to a depth of 49 ft below the surface and 1 ft above the ground.

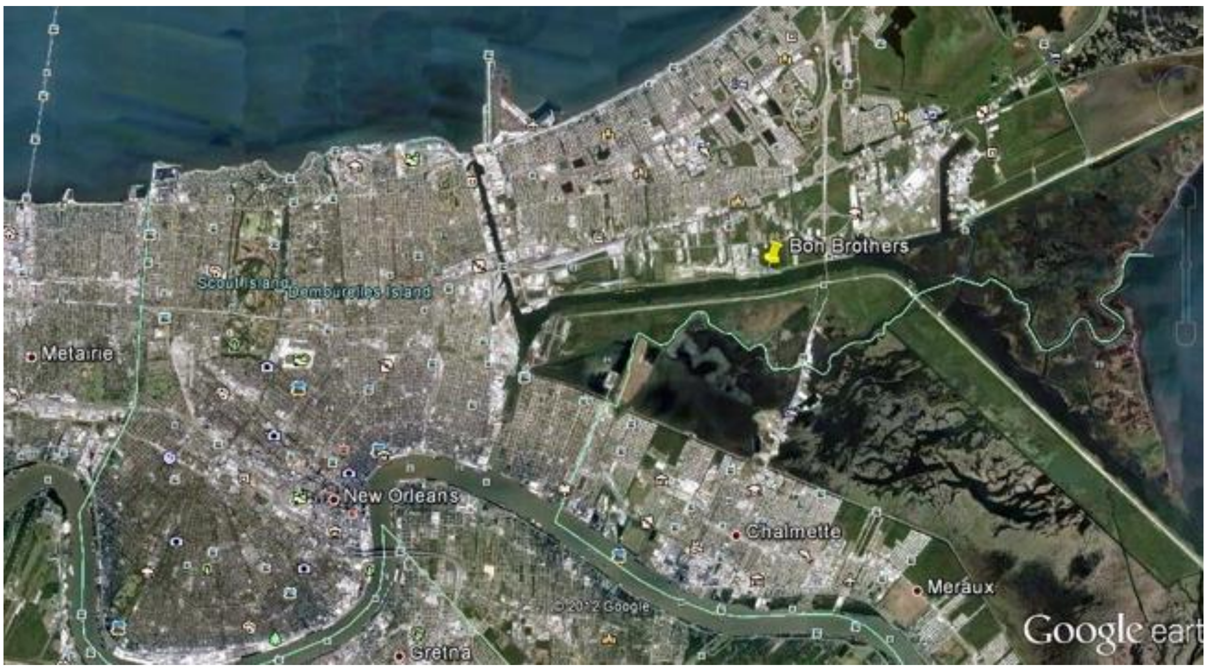


Figure 11 – Location of excavated boring and thermistor string installation

The field apparatus (figure 11) contains a series of temperature monitoring sensor, spaced according to the depths requested, at 1 ft intervals for this research's purpose. An autoranging multimeter is used to measure the resistance in Ohms, then this variable is used to find the temperature of the subsurface soil by the Steinhart-hart equation.

$$T = \frac{1}{A + B(\ln R) + C(\ln R)^3 - 273.2}$$

Where:

- A, B, and C = Steinhart-Hart coefficients, which vary depending on the specifications of the thermistor and temperature range
- R = Resistance at T in ohms

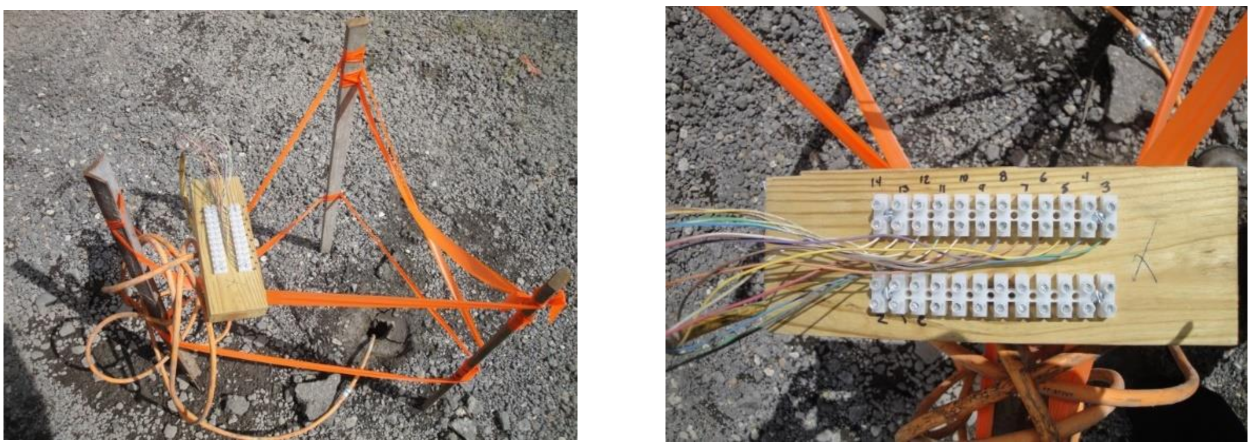


Figure 12 – Filed temperature monitoring setup

The ground temperature at the location mentioned above, was measured year-round at a once a week frequency. And a ground temperature profile was created to test the soil's temperature.

Chapter 5
Results and Discussions

5.1 Introduction

The main focus of this study is to find a correlation between the different properties of the soils in the marsh creation projects, and the effects of the weight/stress of the soil that is being dredged and placed in these areas on the existing subsurface soil whose properties are being evaluated. In addition to changes in geotechnical properties and engineering behavior in dredged materials, there are uncertainties in assigning property parameters based on possible alternate definitions of those parameters. The physical property of water content may be defined in two or three different ways, depending on the test or reporting method. The standard method for water content calculates the weight of water divided by the weight of dry solids. Alternate but commonly used methods calculate the weight of water divided by the total wet weight, or by a volumetric basis (Lee, 2004).

Accurate measurement of shear strength parameters, coefficient of consolidation, and compressibility can be difficult, time consuming and costly. As a result of this there is now a tendency in countries all over the world towards building up correlation equations between the above soil properties and the so-called soil indices in order to speed-up the design process. (pg-2)

This study focuses on finding a correlation between the above-mentioned soil parameters, specifically in areas of marsh creation projects in Southern Louisiana. The following chapter discusses the positive and negative results achieved during this research.

5.2 Discussion of Results (Geotechnical Properties)

The number of project sites for which data was available, for each parish studied is shown in table 3. From these samples, the points were plotted for compression index, shear strength, coefficient of consolidation, moisture content and liquid limit. The graphs below show the results and positive or negative regressions achieved after combining the available data for projects in the state of Louisiana.

Parish	**Number of Locations**
Cameron	2
Jefferson	3
Plaquemines	3
St. Charles	2
St. Tammany	2
Terrebonne	4
Vermillion	1

Table 3 - Number and location of project sites used in this paper

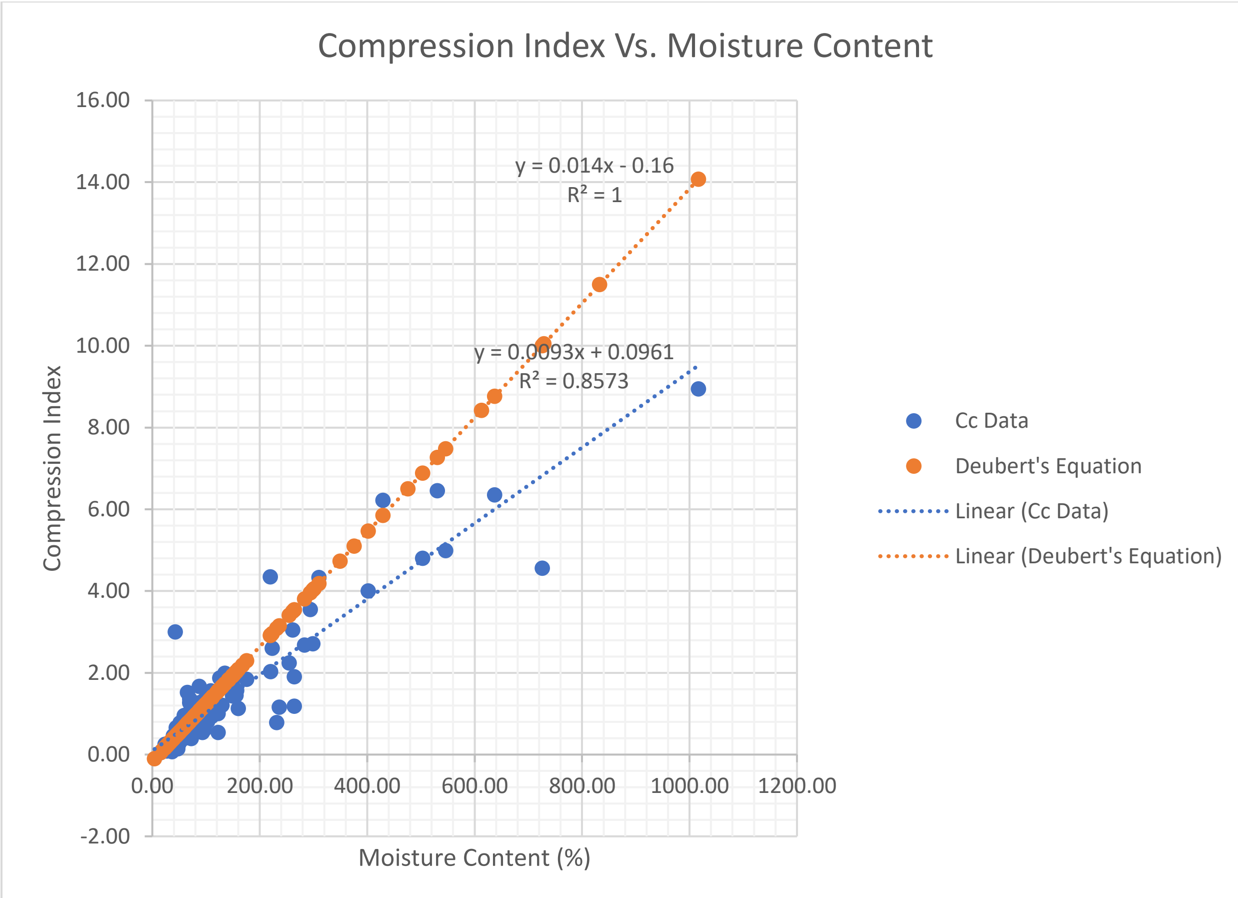


Figure 13 - Compression index vs. moisture content

The graph above shows experimental values of Compression Index. From SLRA correlation coefficient (R^2) is found to be 0.8573. It represents that a relation exists between these two parameters to predict compression index from moisture content

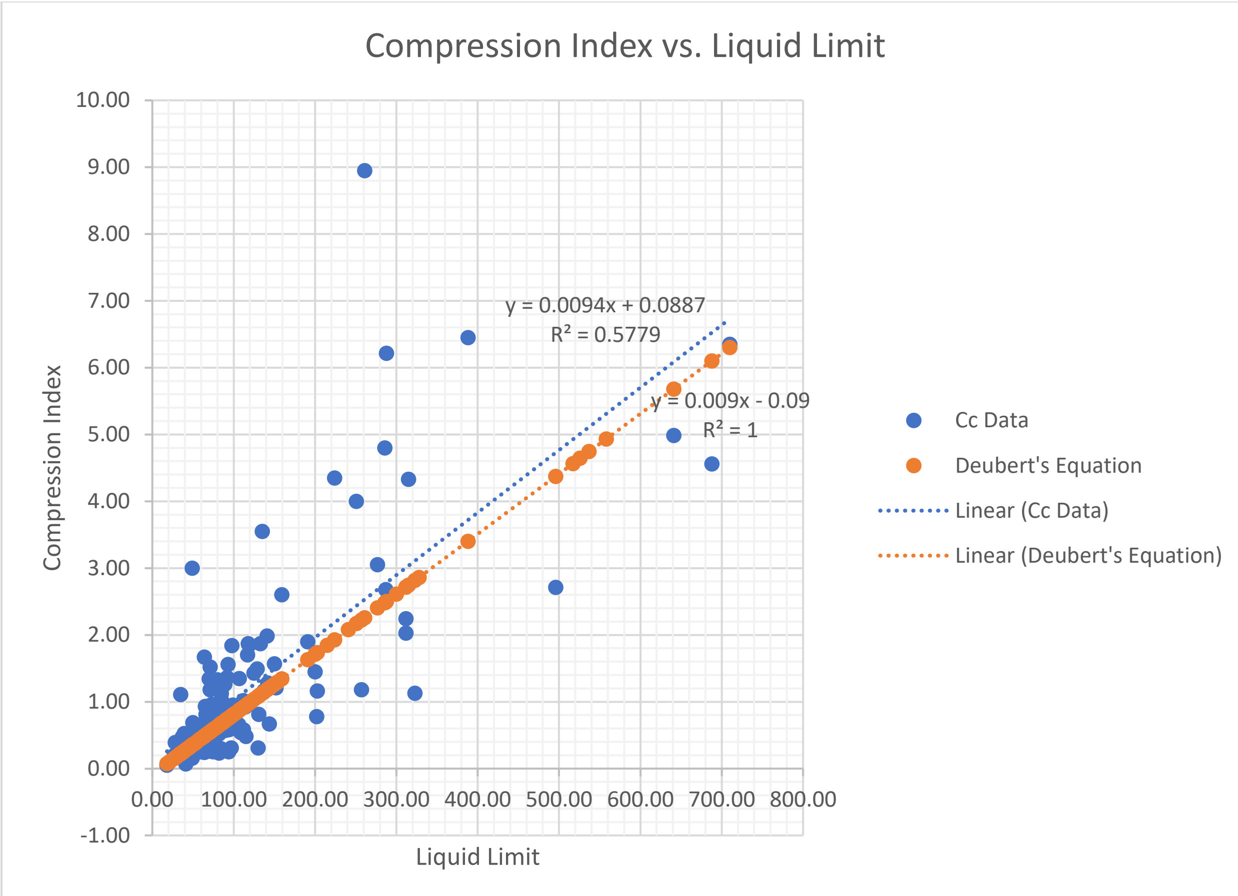


Figure 14 - Compression Index Vs. Liquid Limit

The graph above shows experimental values of Compression Index. From SLRA correlation coefficient (R^2) is found to be 0.5779. It represents that a relation possibly exists between these two parameters to predict Compression Index from Liquid Limit. When compared to Terzaghi's correlation Cc = 0.009 LL-0.10, similar results were found.

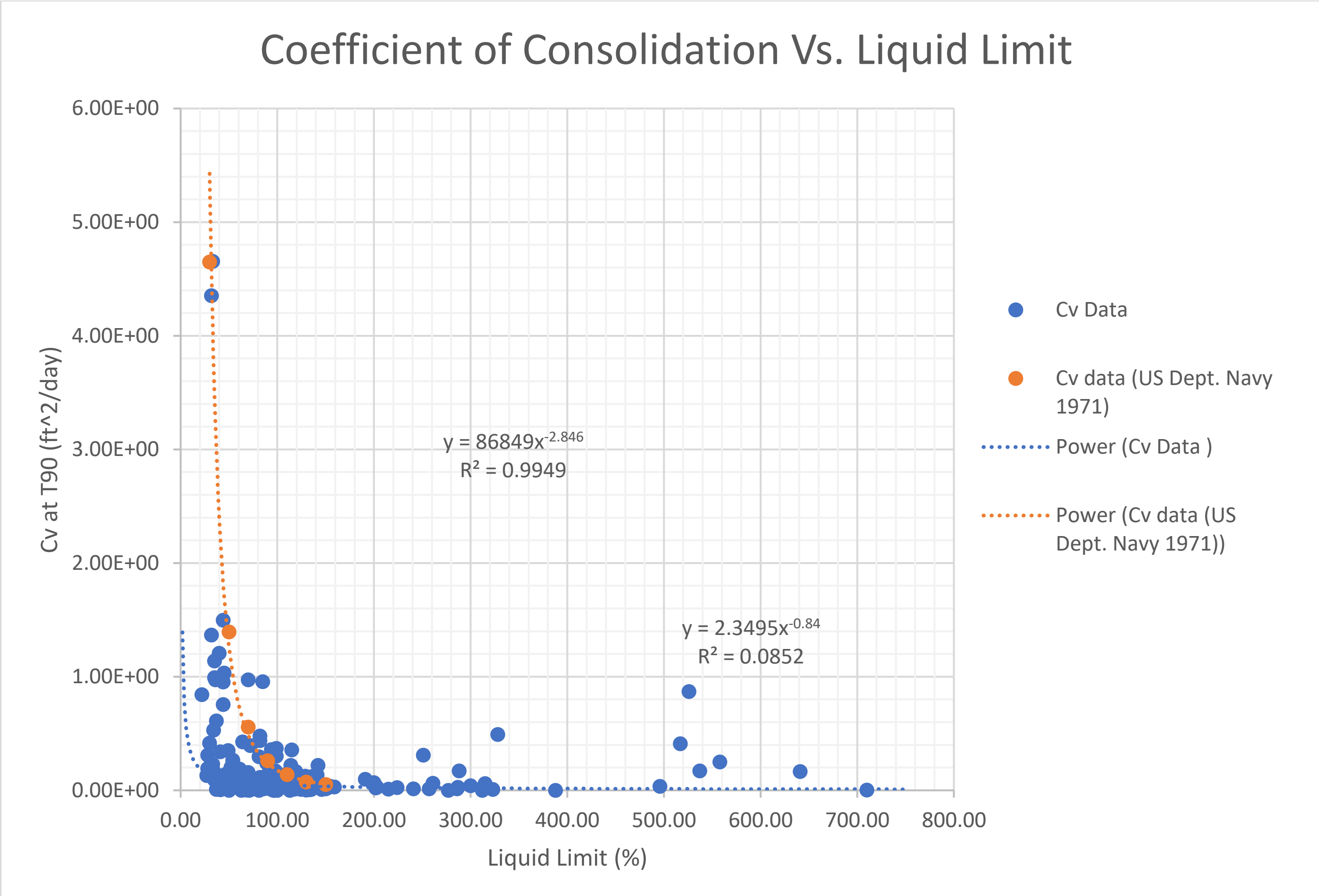


Figure 15 - Coefficient of Consolidation Vs. Liquid Limit

The graph above shows experimental values of coefficient of consolidation collected from all of the aforementioned projects. From the power regression shown on the graph in figure 15, the correlation coefficient (R^2) is found to be 0.0852. It represents that a relation does not exist between these two parameters to predict coefficient of consolidation from Liquid Limit. A power trendline was used to evaluate the data above due to the correlation coefficient being the highest from the different trendlines. The type of regression in this case did not make a difference, because a correlation could not be found between the two variables.

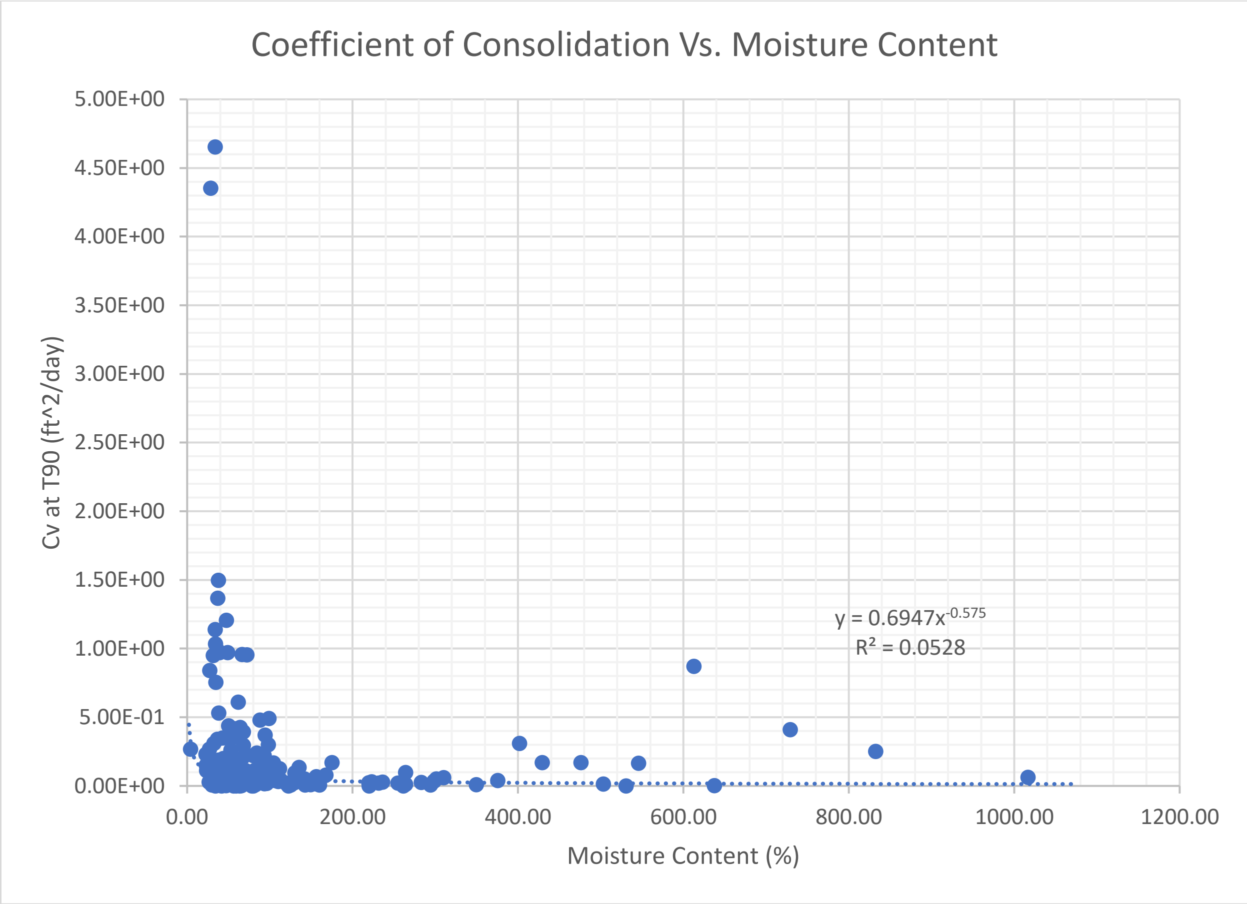


Figure 16 - Coefficient of Consolidation Vs. Liquid Limit

The graph above shows experimental values of coefficient of consolidation collected from all of the aforementioned projects. From the power regression shown on the graph in figure 16, the correlation coefficient (R^2) is found to be 0.0528. It represents that a relation does not exist between these two parameters to predict coefficient of consolidation from moisture content. A power trendline was used to evaluate the data above due to the correlation coefficient being the highest from the different trendlines. The type of regression in this case did not make a difference, because a correlation could not be found between the two variables.

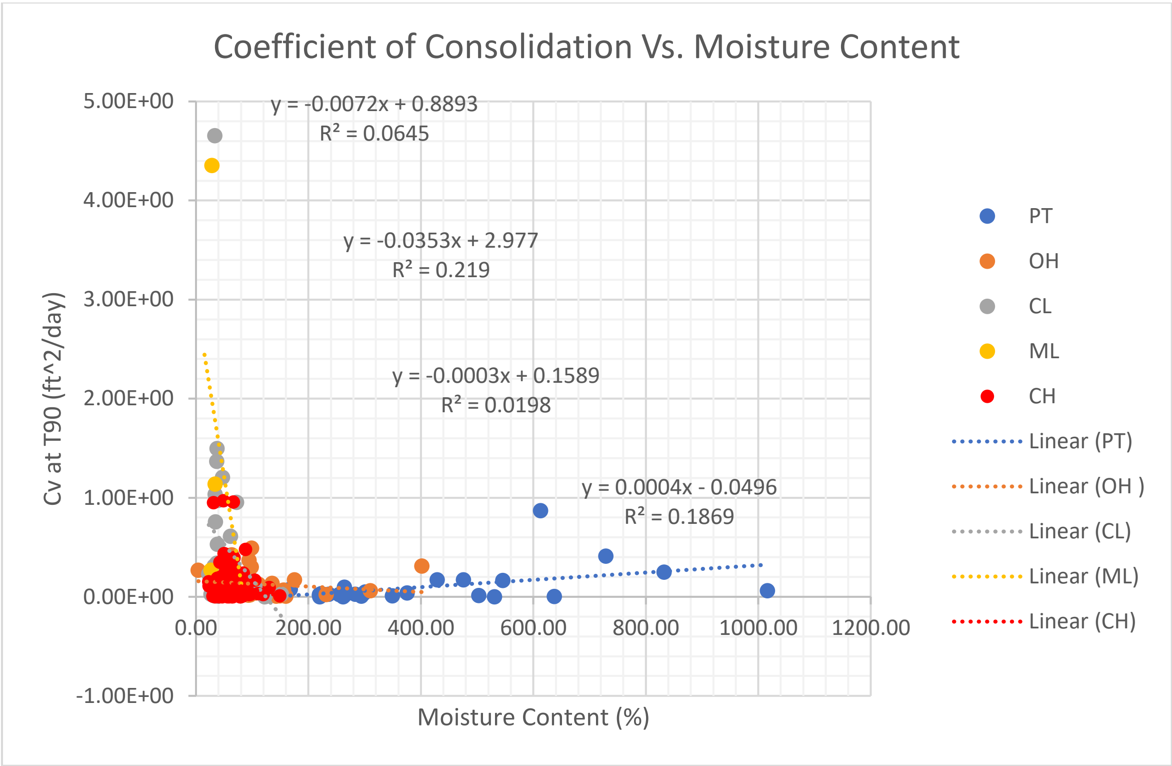


Figure 17 - Coefficient of Consolidation Vs. Moisture Content for Different Types of Soil

The graph above shows experimental values of coefficient of consolidation (Cv) collected. The data was separated into the different types of soils, in order to study how soil types affect the correlation between Cv and moisture content. The linear regressions observed in figure 17, did not achieve a positive result, with the correlation coefficient (R^2) being as follows:

Type of Soil	Correlation Coefficient
Peat (PT)	$R^2 = 0.1869$
Organic Clay (OH)	$R^2 = 0.0198$
Lean Clay (CL)	$R^2 = 0.0645$
Silt (ML)	$R^2 = 0.219$
Fat Clay (CH)	$R^2 = 0.0294$

Table 4 – Correlation coefficient for different soil types (Cv Vs. MC analysis)

These correlations represent that a relation does not exist between these two parameters to predict coefficient of consolidation from moisture content for the types of soils in Louisiana.

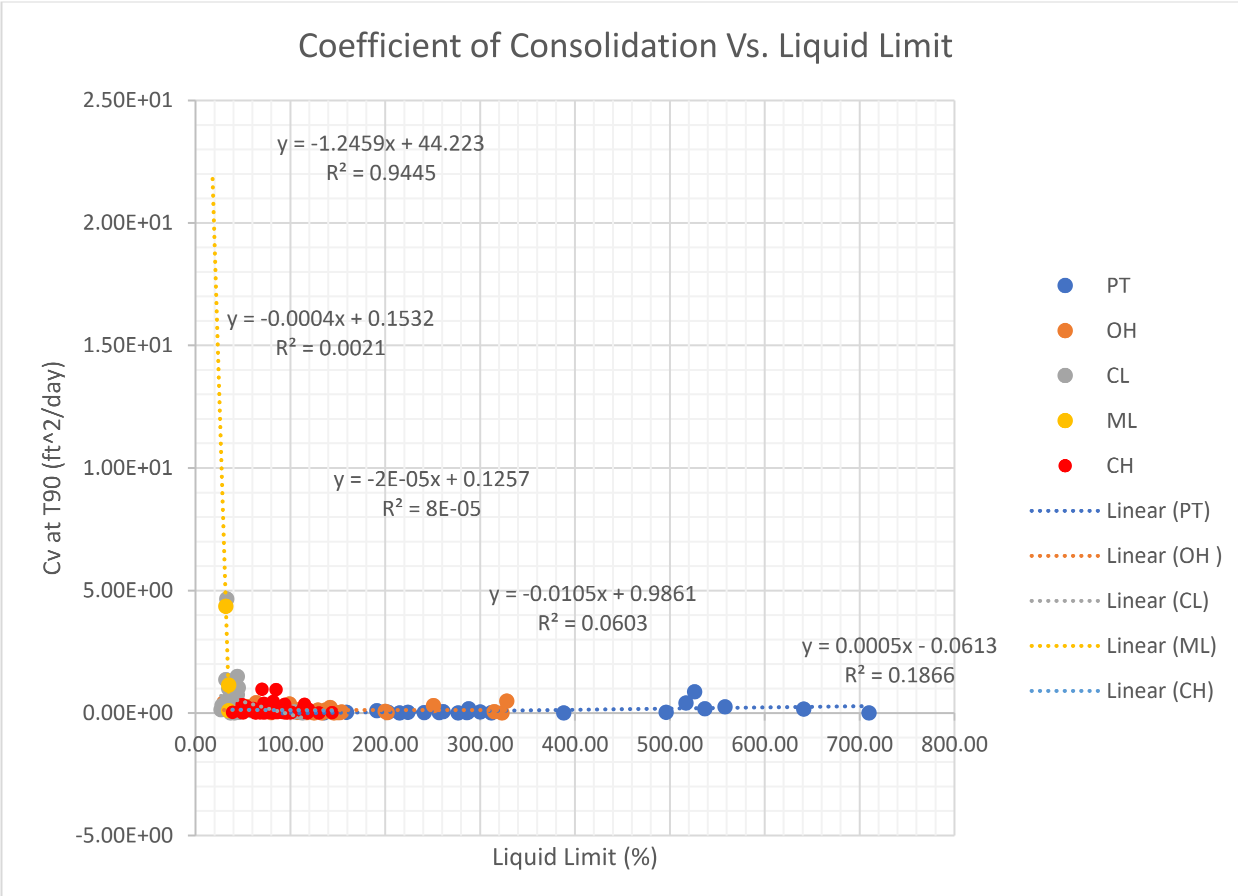


Figure 18 - Coefficient of Consolidation Vs. Liquid Limit for Different Types of Soil

The graph above shows experimental values of coefficient of consolidation (Cv) vs. liquid limit. The data was separated into the different types of soils, in order to study how soil types affect the correlation between Cv and liquid limit. The linear regressions observed in figure 18, only one type soil achieved a positive correlation result, and that is silt (ML)

The correlation coefficient (R^2) being are as follows:

Type of Soil	Correlation Coefficient
Peat (PT)	R^2 = 0.1866
Organic Clay (OH)	R^2 = 8E-05
Lean Clay (CL)	R^2 = 0.0603
Silt (ML)	R^2 = 0.9445
Fat Clay (CH)	R^2 = 0.0021

Table 5 – Correlation coefficient for different soil types (Cv vs. LL analysis)

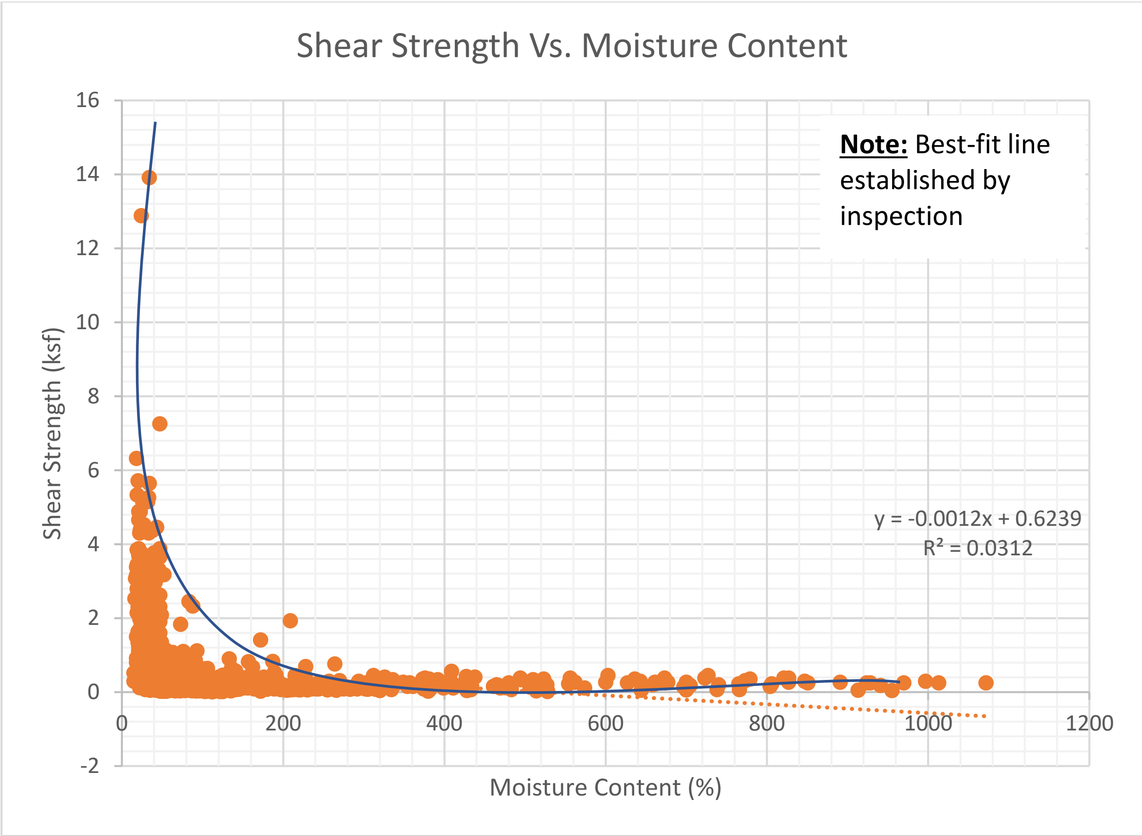


Figure 19 - Shear Strength Vs. Moisture Content

The graph above shows experimental values of Shear Strength. From SLRA correlation coefficient (R^2) is found to be 0.0312. It represents that no relation exists between these two parameters to predict Shear Strength from Moisture Content.

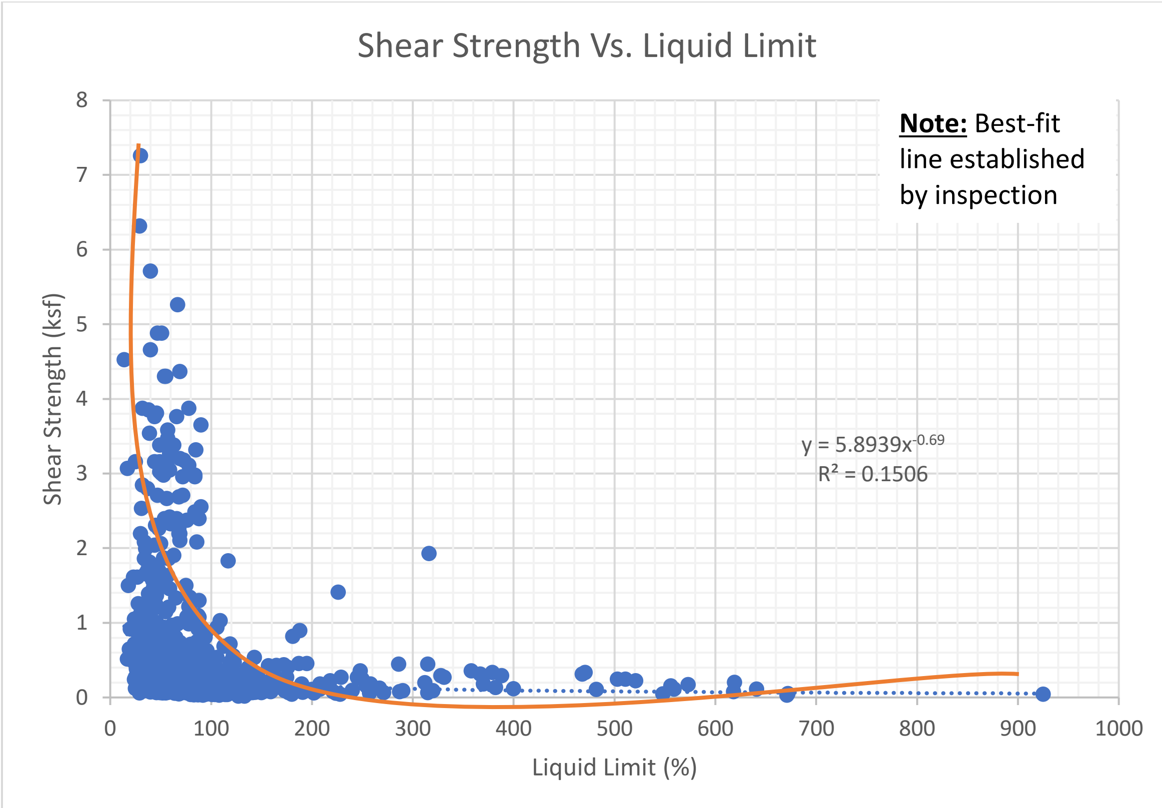


Figure 20 - Shear Strength Vs. Liquid Limit

The graph above shows experimental values of Shear Strength. From the trendline, the correlation coefficient (R^2) is found to be 0.1484. It represents that no relation exists between these two parameters to predict Shear Strength from Liquid Limit.

5.3 Field and Laboratory Results for Geothermal Energy Properties

5.3.1 Field Testing results

In order for geothermal energy piles to function properly, a constant heat source in the ground is needs to be available year-round. This study was performed to test whether that is an occurrence in the subsurface soil available in southern Louisiana. A thermistor string was installed and the temperature in the ground was measured for approximately 1 year to achieve a ground temperature profile for Louisiana similar to that for Houston, TX in figure 5.

The temperature profile in figure 21, shows that after a depth of 15-20 feet, the temperature remains relatively at a constant range between 70-75 degrees Fahrenheit.

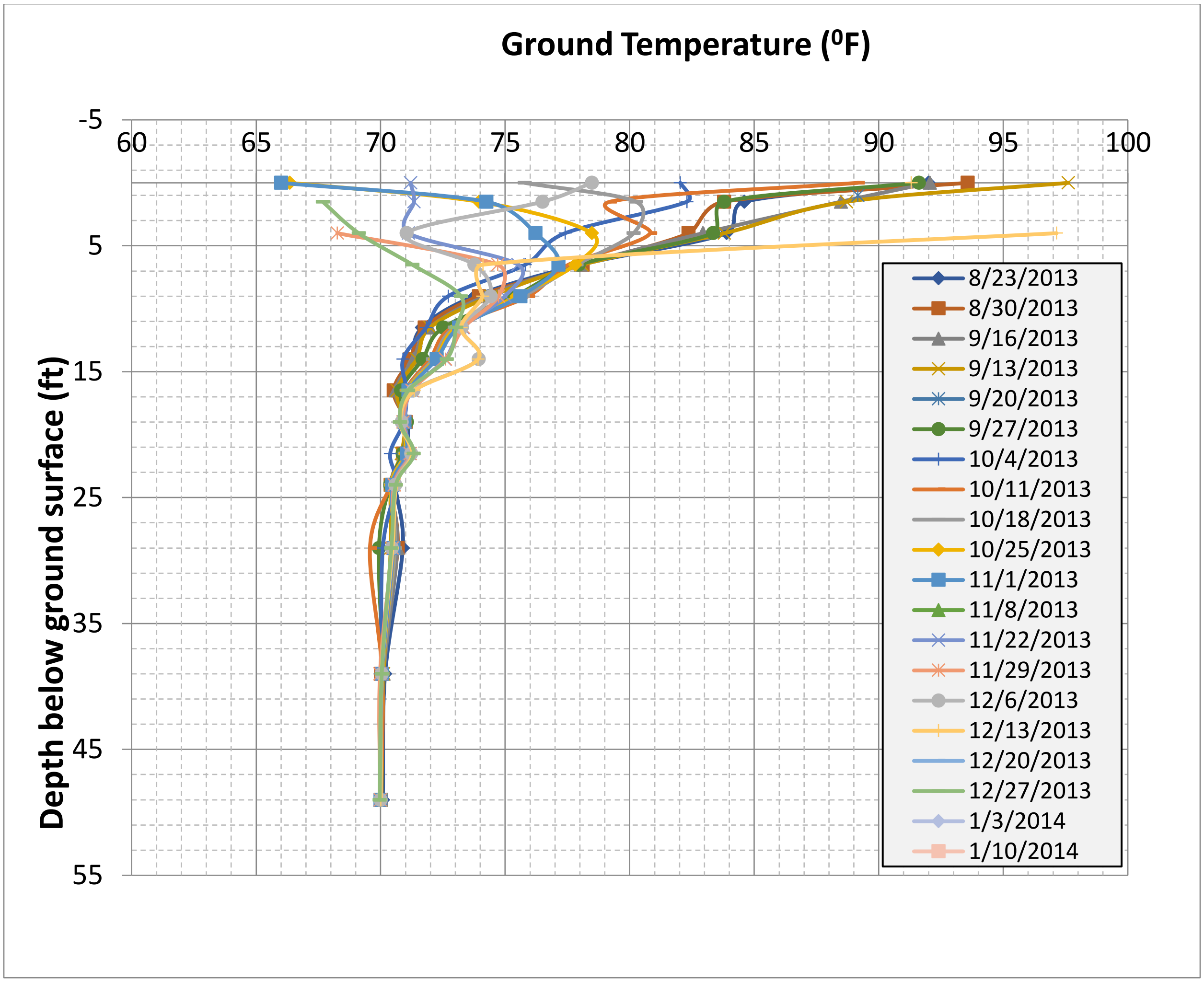


Figure 21 – New Orleans ground temperature profile

5.3.2 Laboratory results

Several types of soils were used in the laboratory to test the thermal conductivity of soils in the Louisiana area. The soil samples consisted of Ottawa Sand (used for calibration of the needle probe), coarse sand, hass pitt, red clay, grand isle sand and pumped river sand.

The thermal conductivity test was performed on the soils and the results are as follows:

Ottawa Sand Test 1			
Weight of apparatus			5.359
Weight of apparatus + sand			11.672
Weight of sand			6.313
Q	13.604823	I(A)	0.97
E (V)	5.7	L(m)	0.4064
Room temperature (F)		69.62	
Thermal Conductivity (W/m.K)			0.172512
Volume (in ^3)		120.2640938	
Density of Sand		0.052492808	

Ottawa Sand Test 2			
Weight of apparatus (lb)			5.359
Weight of apparatus + sand(lb)			11.992
Weight of sand			6.633
Q	10.12795	I(A)	0.84
E (V)	4.9	L(m)	0.4064
Room temperature (F)		70.5	
Thermal Conductivity (W/m.K)			0.15907
Volume (in ^3)		120.2640938	
Density of Sand		0.055153619	

Red Clay Sand Test 1			
Weight of apparatus (lb)			5.359
Weight of apparatus + sand(lb)			10.952
Weight of sand			5.593
Q	14.27165	I(A)	1
E (V)	5.8	L(m)	0.4064
Room temperature (F)		71.06	
Thermal Conductivity (W/m.K)			0.161575
Volume (in ^3)		120.2640938	
Density of Sand		0.046505984	

Red Clay Sand Test 2			
Weight of apparatus (lb)			5.359
Weight of apparatus + sand(lb)			11.316
Weight of sand			5.957
Q	14.61614	I(A)	0.99
E (V)	6	L(m)	0.4064
Room temperature (F)		71.24	
Thermal Conductivity (W/m.K)			0.169774
Volume (in ^3)		120.2640938	
Density of Sand		0.049532656	

Pumped River Sand Test 1			
Weight of apparatus (lb)			5.359
Weight of apparatus + sand(lb)			11.277
Weight of sand (lb)			5.918
Q	14.95325	I(A)	1.03
E (V)	5.9	L(m)	0.4064
Room temperature (F)		71.24	
Thermal Conductivity (W/m.K)			0.180783
Volume (in ^3)		120.2640938	
Density of Sand		0.04920837	

Pumped River Sand Test 2			
Weight of apparatus (lb)			5.359
Weight of apparatus + sand(lb)			11.444
Weight of sand			6.085
Q	14.12894	I(A)	0.99
E (V)	5.8	L(m)	0.4064
Room temperature (F)		65.66	
Thermal Conductivity (W/m.K)			0.180491
Volume (in ^3)		120.2640938	
Density of Sand		0.05059698	

Table 6a. – Thermal conductivity of different types of sands

Hass Pitt Sand Test 1			
Weight of apparatus (lb)			4.463
Weight of apparatus + sand(lb)			6.475
Weight of sand			2.012
Q	14.91142	I(A)	1.01
E (V)	6	L(m)	0.4064
Room temperature (F)		64.76	
Thermal Conductivity (W/m.K)			0.087848
Volume (in ^3)		48.92439975	
Density of Sand		0.041124674	

Hass Pitt Sand Test 2			
Weight of apparatus (lb)			4.463
Weight of apparatus + sand(lb)			6.51
Weight of sand			2.047
Q	14.51772	I(A)	1
E (V)	5.9	L(m)	0.4064
Room temperature (F)		64.94	
Thermal Conductivity (W/m.K)			0.164222
Volume (in ^3)		48.92439975	
Density of Sand		0.041840064	

Grand Isle Sand Test 1			
Weight of apparatus (lb)			5.359
Weight of apparatus + sand(lb)			11.3185
Weight of sand			5.9595
Q	13.98622	I(A)	0.98
E (V)	5.8	L(m)	0.4064
Room temperature (F)		65.12	
Thermal Conductivity (W/m.K)			0.124429
Volume (in ^3)		120.2640938	
Density of Sand		0.049553444	

Grand Isle Sand Test 2			
Weight of apparatus (lb)			5.359
Weight of apparatus + sand(lb)			11.375
Weight of sand			6.016
Q	14.22736	I(A)	0.98
E (V)	5.9	L(m)	0.4064
Room temperature (F)		64.94	
Thermal Conductivity (W/m.K)			0.139173
Volume (in ^3)		120.2640938	
Density of Sand		0.050023243	

Lowes Sand Test 1			
Weight of apparatus (lb)			5.359
Weight of apparatus + sand(lb)			11.986
Weight of sand			6.627
Q	14.12894	I(A)	0.99
E (V)	5.8	L(m)	0.4064
Room temperature (F)		65.3	
Thermal Conductivity (W/m.K)			0.175685
Volume (in ^3)		120.2640938	
Density of Sand		0.055103729	

Lowes Sand Test 2			
Weight of apparatus (lb)			4.463
Weight of apparatus + sand(lb)			11.916
Weight of sand			7.453
Q	14.12894	I(A)	0.99
E (V)	5.8	L(m)	0.4064
Room temperature (F)		65.48	
Thermal Conductivity (W/m.K)			0.229062
Volume (in ^3)		120.2640938	
Density of Sand		0.061971947	

Table 6b. – Thermal conductivity of different types of sands

Type of Soil	Thermal Conductivity Test 1 (W/m.K)	Thermal Conductivity Test 1 (W/m.K)
Ottawa Sand	0.17251	0.15907
Red Clay Sand	0.16157	0.16977
Pumped River Sand	0.18078	0.18049
Hass Pitt Sand	0.08784	0.16422
Grand Isle Sand	0.12442	0.13917
Lowes Sand	0.17568	0.22906

Table 7 – Thermal conductivity of different types of sands

The thermal conductivity for pumped river sand was also tested at different moisture contents. The sand was placed in an oven for 48 hours and allowed to completely dry, then a specific amount was used. The sample was weighed and waster was added to it at an amount of 25 and 50 percent by weight. The thermal conductivity was measured for the dry sample, the 25 percent moisture content, and the 50 percent moisture content. The results were as shown in figure 20.

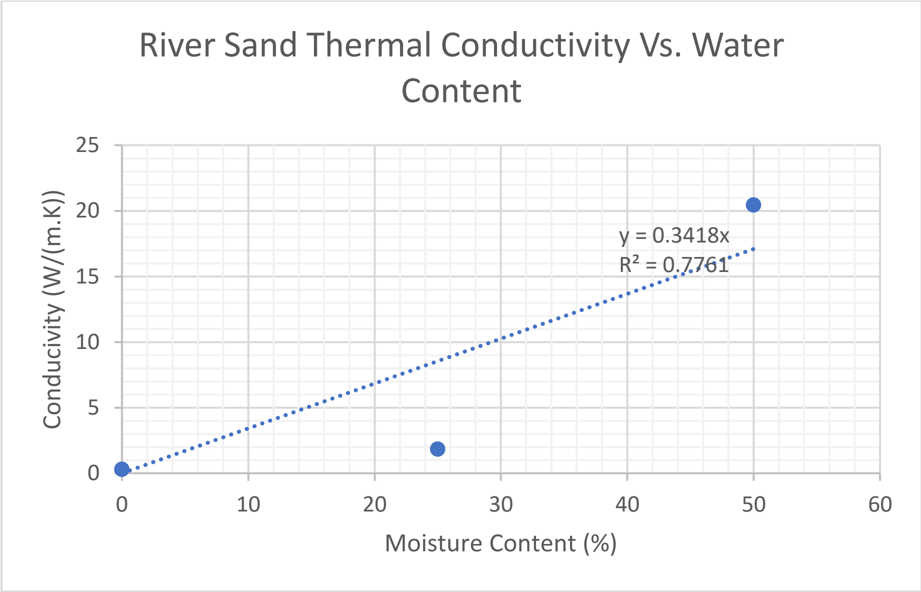


Figure 22 – Pumped River sand thermal conductivity vs. moisture content

From the above graph we can confirm that as the moisture content increases, so does the thermal conductivity of the soil. From the linear regression it is apparent that a correlation between the two variables is positive with an R^2 value of 0.807.

Chapter 6
Summary and Conclusion

Data was obtained from the CPRA CRIMS database for the geotechnical boring logs used in this research, in an attempt to find a correlation between different soil characteristics in south Louisiana. The following conclusion can be made regarding these correlations.

1. Based on limited data evaluated, the compression index and moisture content are related by the following relationship:

- Compression index and moisture content
  - Cc = 0.0093(w) + 0.0961 $R^2 = 0.8573$

    Where w = Moisture Content

    Cc = Compression Index
- Compression Index and Liquid Limit
  - Cc = 0.0094(LL) + 0.0887 $R^2 = 0.5779$

    Where LL = Liquid Limit
- Coefficient of consolidation and liquid limit (For ML – Silt)
  - Cv = -1.2459(LL) + 44.223 $R^2 =$

The equations listed above, showed a positive correlation between the different properties of soil. The remainder of the equations from the linear regressions did not achieve positive correlation. An additional property was taken into consideration that included the ratio of moisture content:liquid limit as a third party parameter between the different characteristics and was used to compare the shear strength; however; a positive correlation was not achieved and was therefore not included in this study.

2. The thermal conductivity of dry sand ranged from 0.08 to 0.22 W/m.K. Thermal conductivity of pumped river sand was tested at different moisture contents and the resulting relationship is as follows:

- Thermal Conductivity vs. moisture content of pumped river sand:
    - $y = 0.3418w$ $R^2 = 0.7761$

      Where w = Moisture Content

Chapter 7
Recommendations for Future Research

The results obtained from this study can be further used to manipulate and regroup the data for the purpose of finding more correlations. The data from this study, presents the available data from the soil borings, it does not further categorize the soils other properties. Soils can be classified per type and the same analysis can be studied using unit weight, organic content, etc. Furthermore, studying the geothermal energy of the soils and whether at certain depths the temperature remains constant or not in the field conditions. This data can also be used to find a correlation between the soil's physical and thermal properties.

The ability to predict undrained shear strength in dredged materials is important to the geotechnical engineer responsible for analyzing subaqueous slope stability or designing engineered structures built with dredged material (Lee, 2004). Therefore, this research can aid in further studies and correlations that will help with this prediction.

As far as the geothermal energy portion of this research, the methods, data and application can be used to answer many questions such as:

- What happens to the Louisiana soil properties subjected to cyclic heating and cooling?
- What happens to the pile frictional capacity at the interface of pile surface and soil?
- What happens to the pile load carrying capacity if heat is transferred in and out of the pile foundation?
- Does the pile and surrounding soils expand and contract due to heating and cooling?
- What type of piles is most suitable for use as a GEPs?
- Does the pile concrete crack due to cyclic heating and cooling?

- What is the amount of heat transfer and heat storage in the pile as well as in surrounding soils?
- Does excessive heating and cooling affect the heat balance of ground?
- How much does the Geothermal Energy Pile system cost in comparison to conventional GSHP system?
- What is the energy saving of using GEPs in comparison to conventional HVAC heating and cooling system?

This research will be developed further to complete the moisture content analysis for the remaining different types of soils, and will be used to test the thermal conductivity of soils on samples from the marsh creation project areas around southern Louisiana, which most definitely has soils with unique properties that are not seen anywhere else in the world.

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Vita

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