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ASTM D2435 (2000) allows for both Teflon coated stacked rings and wire reinforced membranes to be used as confinement methods in direct simple shear (DSS) testing of soils. Although stacked rings were developed over 50 years ago, wire reinforced membranes have been used almost exclusively in practice. Over the past 10 years, however, stacked rings have become more popular and are now the dominant confinement system sold and used in the United States. Despite this change, no comprehensive testing program comparing both confinement methods has been published. The objective of this thesis is to perform a laboratory testing program to compare the results of using stacked rings and wire reinforced membranes as a confining system for direct simple shear tests. Tests were performed on samples of a high plasticity clay from the Gulf of Mexico, a low plasticity organic silt from Rhode Island, and a low plasticity sensitive clay from Portland, Maine. All soils were tested using both confinement types, with the only difference being the use of stacked rings or the wire reinforced membrane. Measured values of undrained shear strength for both normally consolidated and overconsolidated samples were very similar using both confining systems. Samples confined with the wire reinforced membrane exhibited more strain softening beyond the peak strength and more vertical strain to the effective consolidation stress than samples confined with stacked rings. These results show that both confining systems can be used with confidence for determination of the undrained shear strength.

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					19b. TELEPHONE NUMBER *(include area code)* (831) 656- 2319 civins@nps.edu

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COMPARISON OF DIRECT SIMPLE SHEAR CONFINEMENT METHODS ON CLAY AND SILT SPECIMENS.

BY

SETH T. McGUIRE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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OF

SETH T. McGUIRE

APPROVED:

Thesis Committee:

Major Professor: Chris Baxter

Aaron Bradshaw

Gopu Potty

Nasser H. Zawia

DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND
2011

Abstract

ASTM D2435 (2000) allows for both Teflon coated stacked rings and wire reinforced membranes to be used as confinement methods in direct simple shear (DSS) testing of soils. Although stacked rings were developed over 50 years ago, wire reinforced membranes have been used almost exclusively in practice. Over the past 10 years, however, stacked rings have become more popular and are now the dominant confinement system sold and used in the United States. Despite this change, no comprehensive testing program comparing both confinement methods has been published. The objective of this thesis is to perform a laboratory testing program to compare the results of using stacked rings and wire reinforced membranes as a confining system for direct simple shear tests. Tests were performed on samples of a high plasticity clay from the Gulf of Mexico, a low plasticity organic silt from Rhode Island, and a low plasticity sensitive clay from Portland, Maine. All soils were tested using both confinement types, with the only difference being the use of stacked rings or the wire reinforced membrane. Measured values of undrained shear strength for both normally consolidated and overconsolidated samples were very similar using both confining systems. Samples confined with the wire reinforced membrane exhibited more strain softening beyond the peak strength and more vertical strain to the effective consolidation stress than samples confined with stacked rings. These results show that both confining systems can be used with confidence for determination of the undrained shear strength.

Acknowledgments

A big thanks to Professor Chris Baxter for all of his help throughout each stage of this thesis. His help and guidance throughout this process were instrumental in the successful completion of this work.

Additionally, I’d like to thank my lab and office mates for their cooperation and assistance during the testing phase of this work; Alesandra Morales, Yaurel Guadalupe, and Sean Davis.

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1. Introduction

1.1 Direct Simple Shear Background

A direct simple shear test (DSS) is done on cylindrical or square samples, typically 50.8 mm to 63.5 mm in diameter with an approximate height of 25.4 mm. The specimen is confined by a wire reinforced membrane or stacked rings. Vertical stress is applied during a consolidation phase, followed by a shear phase consisting of application of a horizontal at constant volume. A DSS test has the same initial stress state as a direct shear test but avoids the stress concentration occurrences seen with direct shear (ASTM, 2000).

The first real shear strength test is thought to have been performed by Collin in 1846. It was called a double direct shear test. A soil was contained within a shear box as shown in Figure 1-1 and Figure 1-2. Weights were suspended from the bottom of the shear box. Weight was incrementally loaded until failure, allowing Collin to determine the weight to failure of the specimen (Sowers, 1963). Collins' specimen was confined in a 4 cm square box that allowed tranverse loading on the top and bottom (Young & Townsend, 1981).

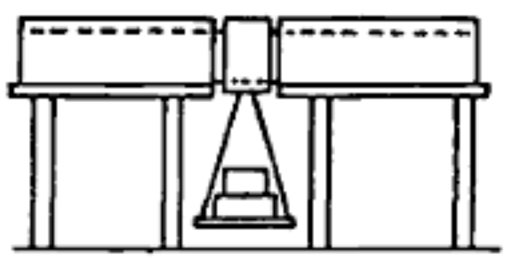


Figure 1-1 – Double Direct Shear as performed by Alexander Collin in 1846 (Sowers, 1963)

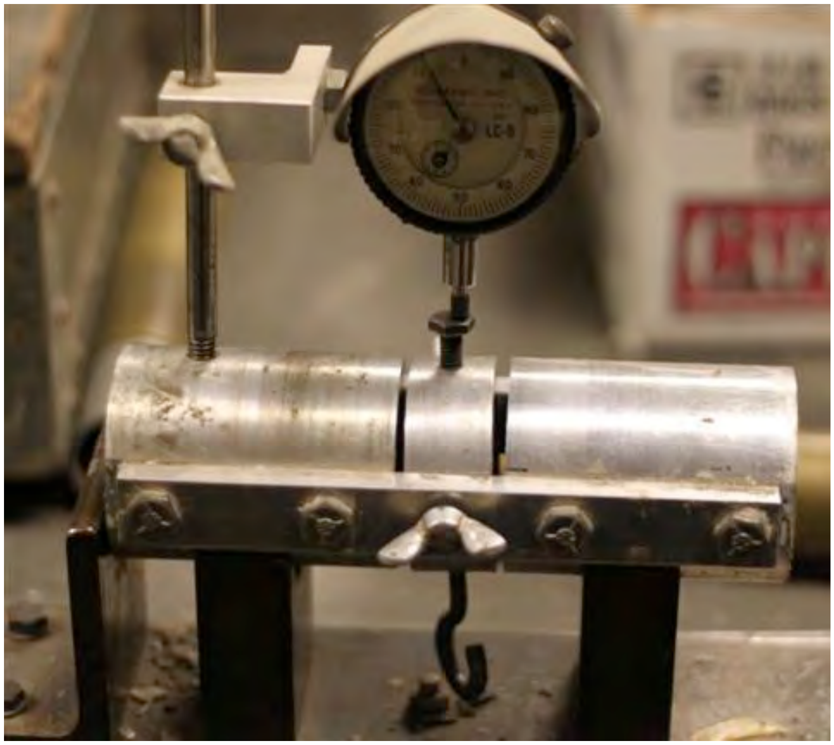


Figure 1-2 – Modern Day Double Direct Shear Device from the Michigan DOT (taken by Rachid Hankour 2011)

DSS testing in its current form is credited to Krey, Terzaghi, and Casagrande (Young & Townsend, 1981). The current method can be performed using circular or square sample and consists of a normal loading phase and a shear phase. The sample is confined on all sides, loaded with a normal force, and sheared while maintaining a constant sample volume. ASTM Standard D6235 was published in 2000, allowing use of both stacked metal rings and the wire reinforced membrane as confinement methods. (ASTM, 2000). The two primary methods of circular confinement are:

1) Metal rings stacked on top of each other along the entire specimen height.

2) A wire-reinforced rubber membrane constructed at the Norwegian Geotechnical Institute (NGI) (Figure 1-3).

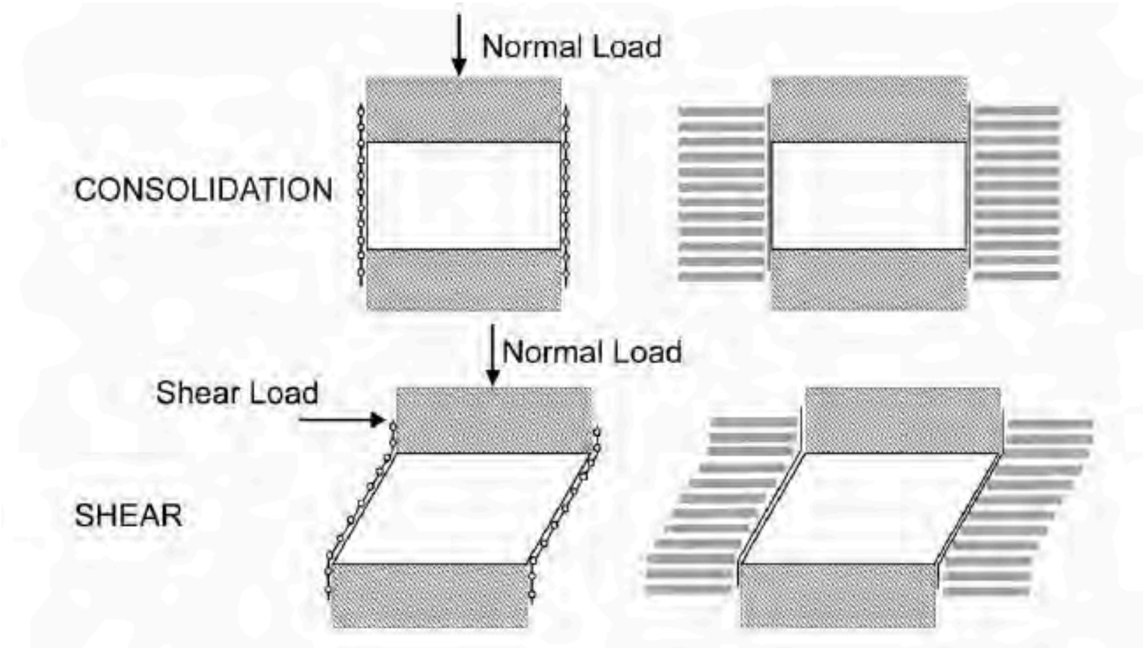


Figure 1-3 – Direct Simple Shear Confinement Types showing wire-reinforced membranes (left) and stacked rings (right) (Baxter et al, 2010)

Although stacked rings were developed over 50 years ago, wire reinforced membranes have been used almost exclusively in practice. Over the past 10 years automated testing systems such as the Geocomp Sheartrac-II have become readily available in the United States. These systems are tailor-made for DSS testing. Most of the manufacturers of these systems sell stacked rings as DSS test confinement types. Gecomp, Corp., GeoTac, and GDS Instruments are examples of companies selling stacked rings with automated shear systems. This has caused a significant increase in the popularity of stacked rings in the US. They have become the dominant confining system. Despite this change, no comprehensive testing program comparing both confinement methods has been published. The objective of this thesis is to perform a laboratory testing program to compare the results of using stacked rings and wire reinforced membranes as a confining system for direct simple shear tests.

Use of the two confining systems may produce slightly different results in terms of measured stiffness, strength, and stress-strain behavior. This may be due to differing rigidity of the two systems, or some other mechanism (Baxter et al 2010). This thesis will compare both confinement methods to quantify any difference in results (if any), explore the use of correction factors, and discuss where possible differences come from and their level of significance.

This will be accomplished through a laboratory testing program involving DSS tests using both wire reinforced membranes and stacked rings. Three soils will be tested: a high plasticity clay from the Gulf of Mexico, a low plasticity organic silt from Rhode Island, and a low plasticity sensitive clay from Portland, Maine. The effect of the confinement systems on both the consolidation and shear phases is evaluated.

1.2 Organization of Thesis

Chapter 2 consists of a literature review, in which the theory behind the direct simple shear test, historical test results of various soil types, and other tests that are used to measure shear strength is presented. Other shear strength tests are discussed in order to provide additional background on the concepts of shear strength in soils.The effects of strain rate, sample disturbance, and SHANSEP (Stress History and Normalized Soil Parameters) will also be discussed.

Chapter 3 will present the testing methods performed in the Marine Geomechanics Laboratory at the University of Rhode Island. In this chapter sample preparation, storage, equipment, and data analysis will be discussed in detail.

Chapter 4 will present the results of all DSS tests done on silts and clays. Results using both confinement systems (stacked rings and wire-reinforced membrane) will be compared to one another and correction factors will be detailed.

Chapter 5 will summarize test methods, results, recommendations, and any need for future work.

2. Literature Review

2.1 Historical Background

Strength testing of wood, metal, and glass began in the early 17th century. However, soil strength testing wasn't documented until the early 18th century by Belidor and was limited to observations or speculation of the shear surface behind a retaining wall. Surprisingly, Coulomb's paper introducing soil cohesion was based soil strength on observations of materials other than soil, such as mortar (Sowers, 1963).

According to Sowers in 1963 the first soil shear test was performed by Collin in 1846 causing sample failure in double direct shear. This was accomplished by loading the sample transversely until failure. In 1885 Leygue performed tests in a shear box, similar to today's shear box test (Sowers, 1963).

In 1936 the Swedish Geotechnical Institute (SGI) built the first direct simple shear device that was able to uniformly deform a soil specimen in pure shear. This device confined specimens using a rubber membrane and aluminum rings. The rings were packed tightly together and the sample was consolidated using lead weights. A picture of a typical sample using this equipment can be seen in Figure 3-1 below (Kjellam, 1951)

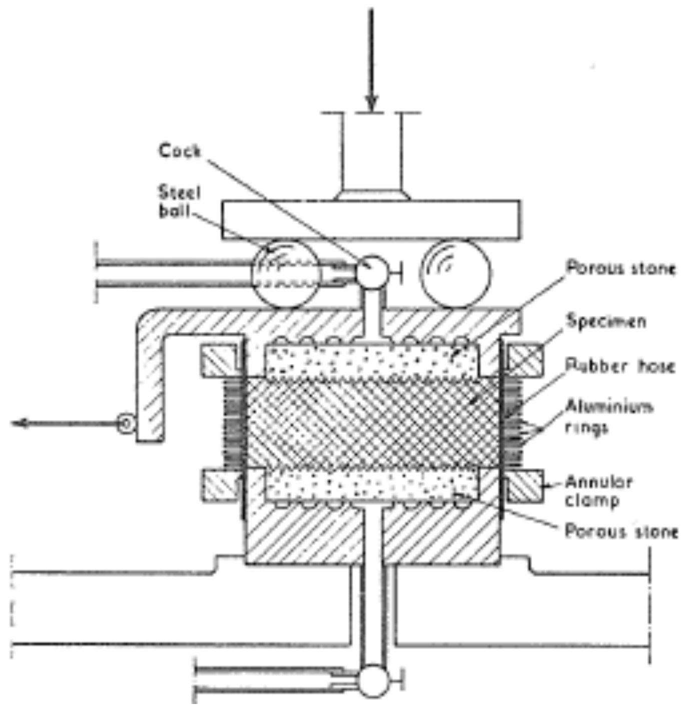
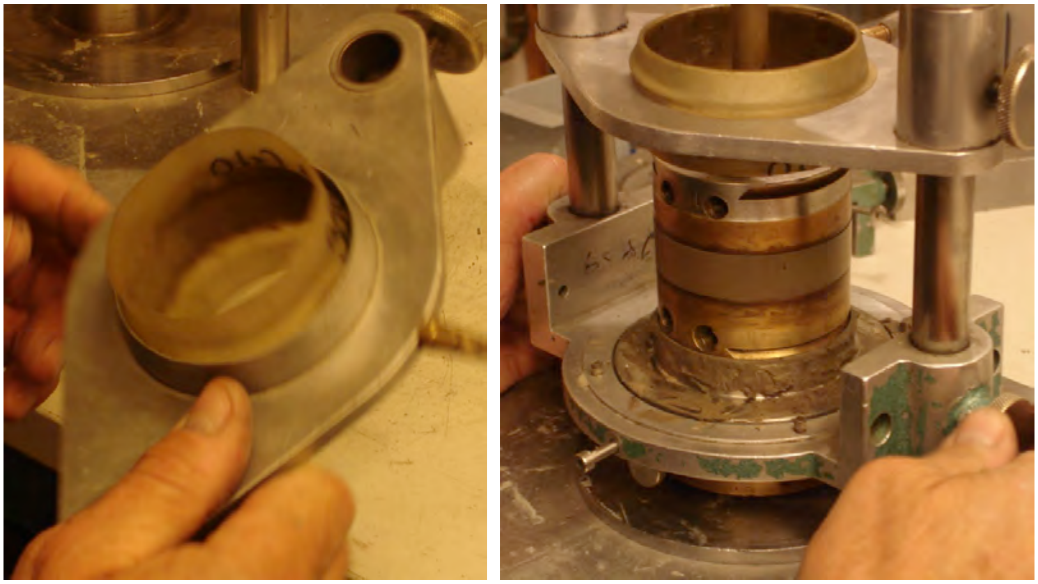


Figure 2-1 - SGI Simple Shear Device 1936 (Kjellam, 1951)

Since SGI's device was built in 1936 there have been many additional DSS devices. In 1953 a device was designed at the university of Cambridge using a square box for sand specimens. In the 1960's the Norwegian Geotechnical institute (NGI) created a device that was able to strain in simple shear after vertical loading using a rubber membrane reinforced with a wound wire encased by the rubber (DeGroot et al, 1992). NGI created the wire-reinforced membrane used in their DSS testing along with a special trimming apparatus allowing for minimal sample disturbance (Figure 2-2)



(a) **(b)**

Figure 2-2 – NGI DSS Membrane stretcher (a) and NGI DSS Set-up (b)

In the 1990's data acquisition and control systems became relatively inexpensive and several companies in the U.S. and the United Kingdom developed automated triaxial, direct simple shear, consolidation, and cyclic equipment. These companies sell direct simple shear equipment exclusively with stacked rings to avoid the high costs of wire reinforced membranes.

An example of one of these newer automated direct simple shear devices is a system created by the GEOCOMP Corporation called the 'Universal Shear Device.' This device is able to run monotonic and cyclic DSS tests under undrained conditions. The automated system dramatically reduces the labor involved in testing as the consolidation steps and shearing phases are pre-set before the test is started. This provides a rapid and precise control of the following operations (Marr, 2003):

- Application of constant vertical stress during consolidation;
- Maintenance of undrained conditions during shear by automatically adjusting the vertical stress to maintain constant specimen height;
- Application of a constant horizontal displacement rate during shear.
- Automatic acquisition of load, displacement, and pore pressure data.

Figure 2-3 – Geocomp Universal Shear Device (Marr, 2003)

2.2 Summary of ASTM Testing Requirements

According to ASTM D6528 the standard method for Consolidated Undrained Direct Simple Shear Testing of Cohesive Soils involves the following (ASTM, 2000):

" 1) A specimen of cohesive soil is constrained axially between two parallel, rigid platens and laterally, such that the cross sectional area remains constant.

2) The specimen is loaded axially and allowed to consolidate one-dimensionally. Each normal load increment is maintained until excess pore water pressures are essentially dissipated as interpreted from interpretation of the axial displacement rate. The maximum normal load is maintained until completion of one cycle of secondary compression or one day longer than the end of excess pore water pressure dissipation.

3) The specimen is sheared by displacing one platen tangentially relative to the other at a constant rate of displacement and measuring the resulting shear force. The platens are constrained against rotation and axial movement throughout shear.

4) The specimen volume is held constant during shear to simulate undrained conditions. Constant volume is achieved by changing the normal load applied to the specimen to maintain constant specimen height. Since the pore pressure is zero through shear, the change in normal stress is equal to the change in effective stress and assumed to be equal to the change in pore water pressure that would occur in a sealed specimen confined by a constant total stress."

Figure 2-4 provides a diagram outlining specimen set-up.

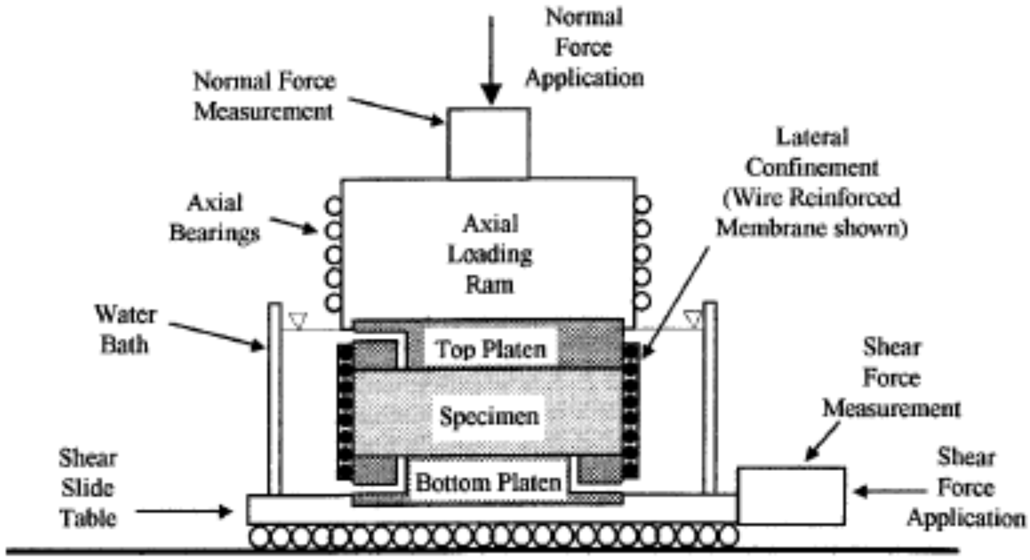


Figure 2-4 – Standard DSS Test Components (ASTM, 2000)

2.3 Shear Strength Determination from DSS Test

The term 'Simple Shear' is in reference to a state of strain. According to Degroot (1991) it is "a plane strain state where under constant volume condition an element deforms only in one direction. Through deformation the height remains constant, requiring the sides to elongate." The term 'Pure Shear' is said to occur when an element is under two equal and opposite principle stresses (DeGroot et al, 1992). Figure 2-5 shows the normal and shear stresses acting on the vertical and horizontal planes during a direct simple shear test.

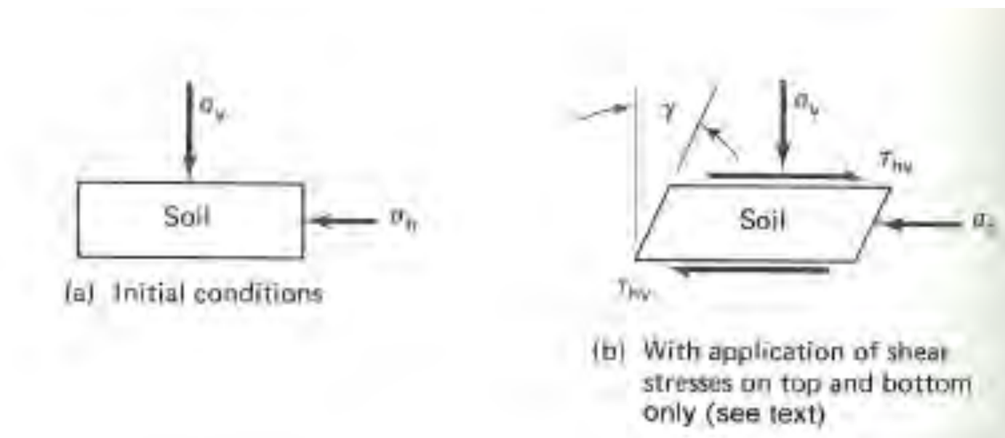


Figure 2-5 – Applied Stress during DSS Testing (Holtz & Kovacs, 1981)

The DSS test has been found to be a good overall representation of shear strength along a roughly horizontal failure plane, which is applicable to many loading conditions in situ (e.g. slope stability, bearing capacity, etc.). In addition, values of undrained shear strength from DSS tests are between values measured using triaxial compression and extension tests (Ladd and Degroot, 2003), as shown in Figure 2-6.

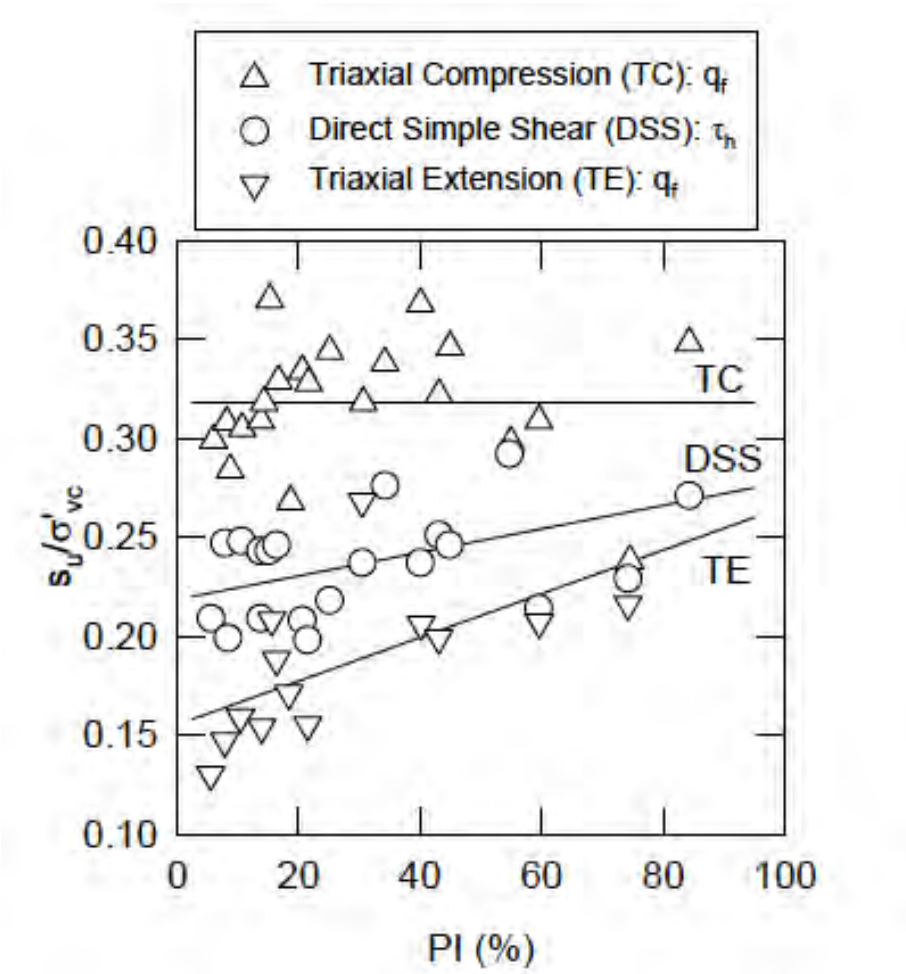


Figure 2-6 – Normalized undrained shear strengths for TC, DSS, and TE test results as a function of Plasticity Index (Ladd and Degroot, 2003)

Table 2-1 (Marr, 2003) also shows values of undrained shear strength normalized by the vertical effective consolidation stress (S_u/s_{vo}') for different modes of loading (compression, extension, simple shear). It reinforces the idea that DSS tests provides good average values of shear strength.

Table 2-1 – Summary of Shear Strength Results for different modes of loading (Marr, 2003)

Boston Blue Clay	
Stress Condition	**Value**
Triaxial Compression, Su / σ_{vc}	0.32
Triaxial Extension, Su / σ_{vc}	0.16
Direct Simple Shear, Su / σ_{vc}	0.22
Average of Compression and Extension	0.24
Average of Comp., Ext., and DSS	0.23

2.4 Pore Pressure Determination from DSS test

The DSS test is in principle comparable to a consolidated drained triaxial test, in that there is a consolidation stage (under 1-D conditions) followed by undrained shear (through application of shear stress in the horizontal direction. However, DSS tests are not typically back pressure saturated and pore pressures are not measured. Excess pore pressure during undrained shear is inferred from the change in total stress required to maintain constant volume (i.e. height) conditions. For example, if the total vertical stress decreases during shear to maintain constant volume, then that change in vertical stress is assumed to be equal to positive pore pressure development within the sample.. This was determined to be true through testing by Dyvik et al. (1988) on saturated cohesive soils. Dyvik et al. ran consolidated undrained DSS tests and constant volume DSS tests. In the cases of the constant volume tests pore pressure assumed to be equal to the change in vertical applied load, whereas the undrained tests measured pore pressure with a pore pressure transducer. Whether the pore pressure was measured through the use of a pore pressure transducer or the change in vertical applied load the results were in close agreement (Figure 2-7)

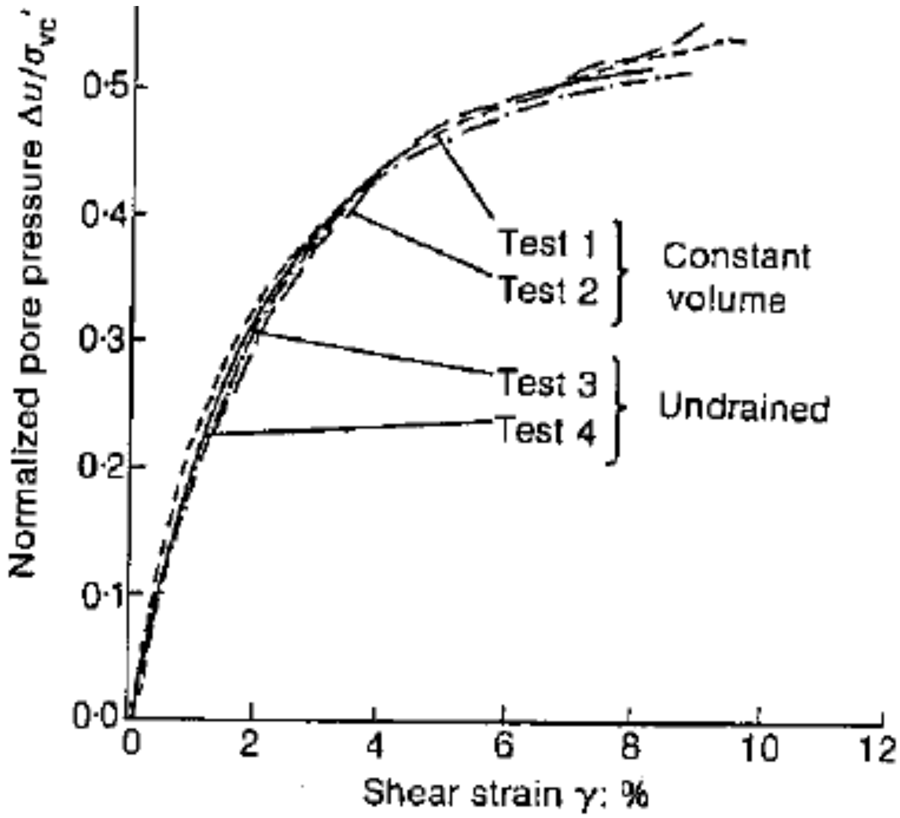


Figure 2-7 –Comparison of pore pressure from constant volume and undrained DSS test results (Dyvik et al. 1988)

2.5 Stress History and Normalized Soil Engineering Properties (SHANSEP)

‘Stress history and Normalized Soil Engineering Properties’ (SHANSEP) is an approach developed by Ladd and Foote (1974) for estimating the undrained shear strength based on the stress history of the soil. The premise behind SHANSEP is that undrained shear strength can be normalized by effective consolidation stress and is a function of the degree of overconsolidation. Performing undrained tests, such as DSS tests, at varying Over Consolidation Ratios allows for the construction of the curve found in Figure 2-8. For a given soil, the curves shown in Figure 2-9 can be expressed as:

$$S_u/\sigma'_{vc} = (Su/\sigma'_p)_{nc} \ \ x \ OCR^m \qquad \text{Equation [1]}$$

S_u = Undrained Shear Strength

$\boldsymbol{\sigma}'_{vc}$ = Vertical Effective Consolidation Stress

$\boldsymbol{\sigma}'_p$ = Preconsolidation Stress

OCR = Over Consolidation Ratio

m = slope of SHANSEP curve

Ladd and Foote (1974) stated that *"SHANSEP is strictly applicable only to mechanically overconsolidated and truly normally consolidated soils exhibiting normalized behavior*." For these soils, strength ratios, S_u/σ'_{vc}, of .225 for 16 normally consolidated clays and .26 for nine normally consolidated silts and organic soils were observed.

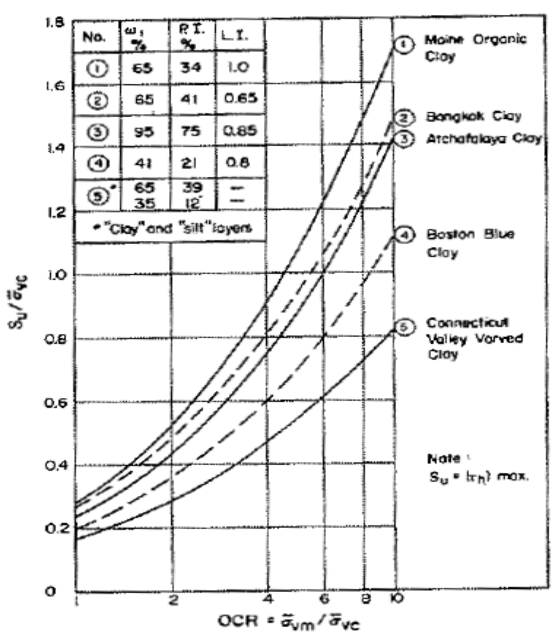


Figure 2-8 – Variation of Normalized CKoUDSS Strength Parameters with OCRs for 5 clays (Ladd & Foott, 1974)

2.6 Comparison of Specimen Confinement Methods in DSS

Two specimen confinement methods used in DSS as allowed by ASTM standard D6528 are stacked rings and a wire reinforced membrane. The following excerpt from ASTM D6528 outlines the two allowable methods of confinement:

"6.7 Lateral Confinement Device —The specimen shall be constrained laterally such that the cross-sectional area at any location does not change by more than 0.1 % during shear. In addition, the confinement must allow uniform shear deformation. Circular specimens are generally confined by a wire reinforced membrane or stacked rigid rings. Square specimens generally are confined by stacked hollow plates or hinged solid plates. The thickness of the individual stacked rings or plates must be less than 1⁄10 of the specimen thickness in order to allow relatively uniform shear deformation. When the confining device is within a water bath, it shall be constructed of corrosion resistant material."

A depiction of both the rings and wire-membrane is shown in Figure 2-9.

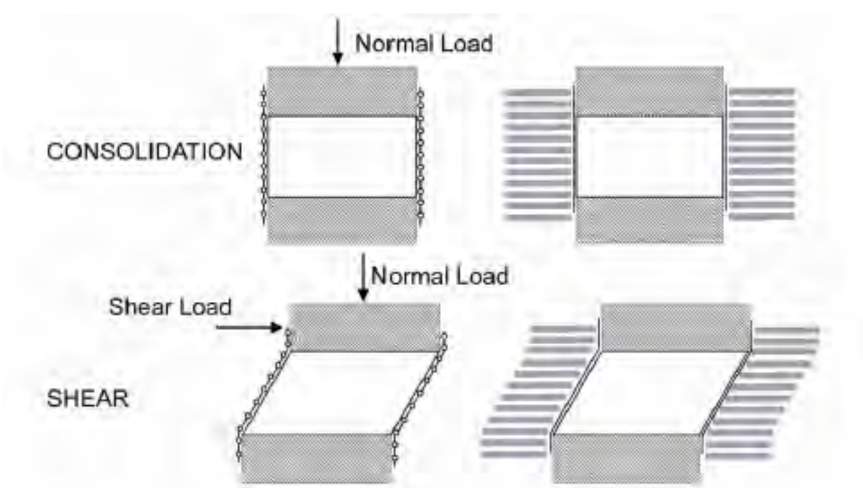


Figure 2-9 – Variation Schematic of wire-membrane (left) and metal rings (right) used in DSS testing (Baxter et al. 2010)

Baxter et al. (2010) compared the results of DSS tests using both the wire-reinforced membrane (WRM) and stacked rings. Figure 2-10 shows comparisons of DSS tests with aluminum rings directly compared to DSS tests performed with WRM's. The test results suggested that both confinging systems yielded comparable values of undrained shear strength, with the WRM exhibiting more strain softening after the peak strength than the stacked rings.

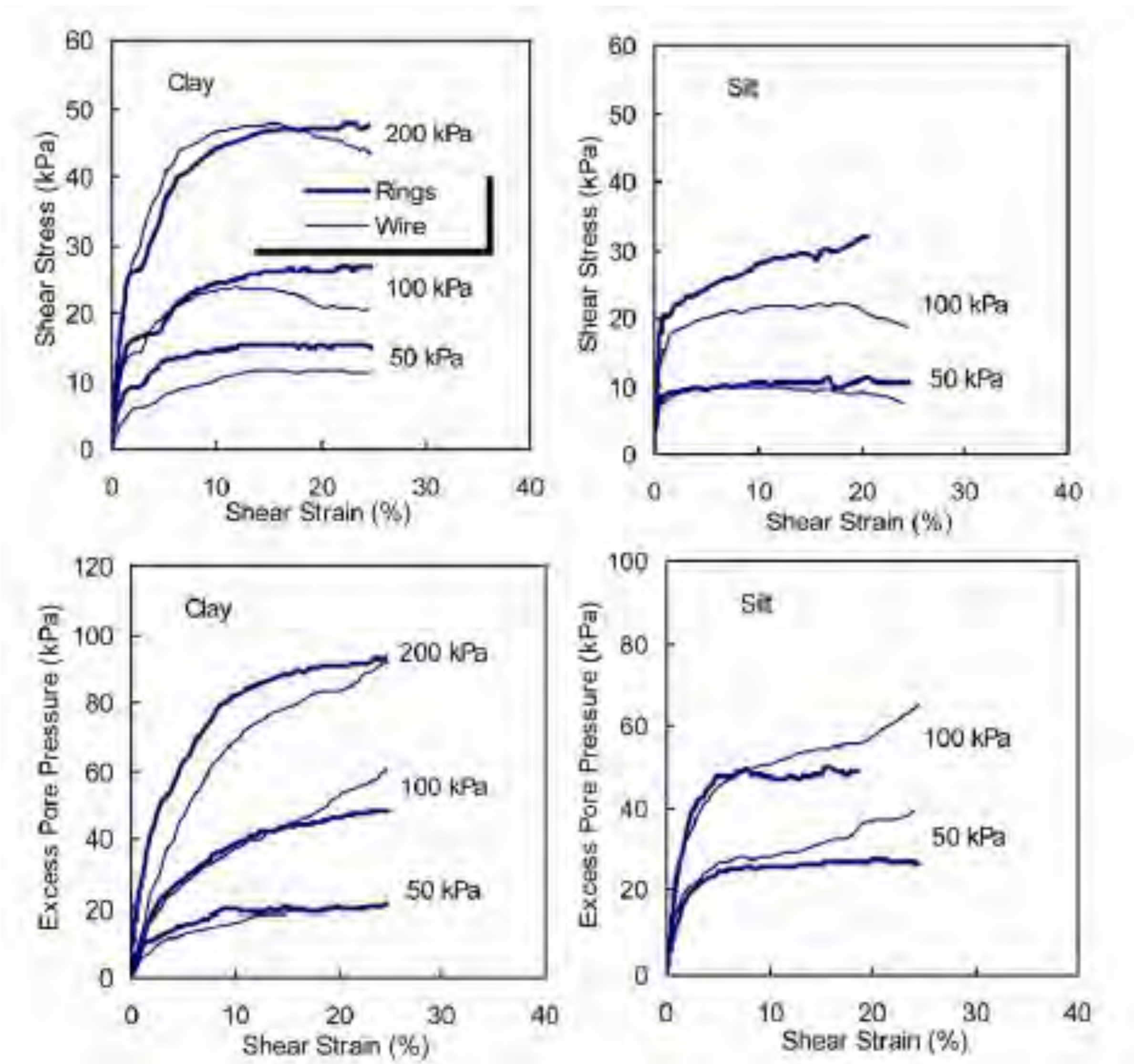


Figure 2-10 – Variation Shear Stress and pore pressure vs strain from DSS tests for a.) Gulf of Mexico Clay and b.) Organic Silt (Baxter et al, 2010).

The occurrence of strain softening in DSS tests is well documented. According to Ladd and Degroot (2003) all normally consolidated cohesive soils experience strain softening when tested in the Geonor device using WRM's. It has been hypothesized that some of the strain softening behavior observed is due to the equipment used rather than actual soil behavior. This hypothesized behavior is illustrated in Figure 2-11 (DeGroot et al, 1992).

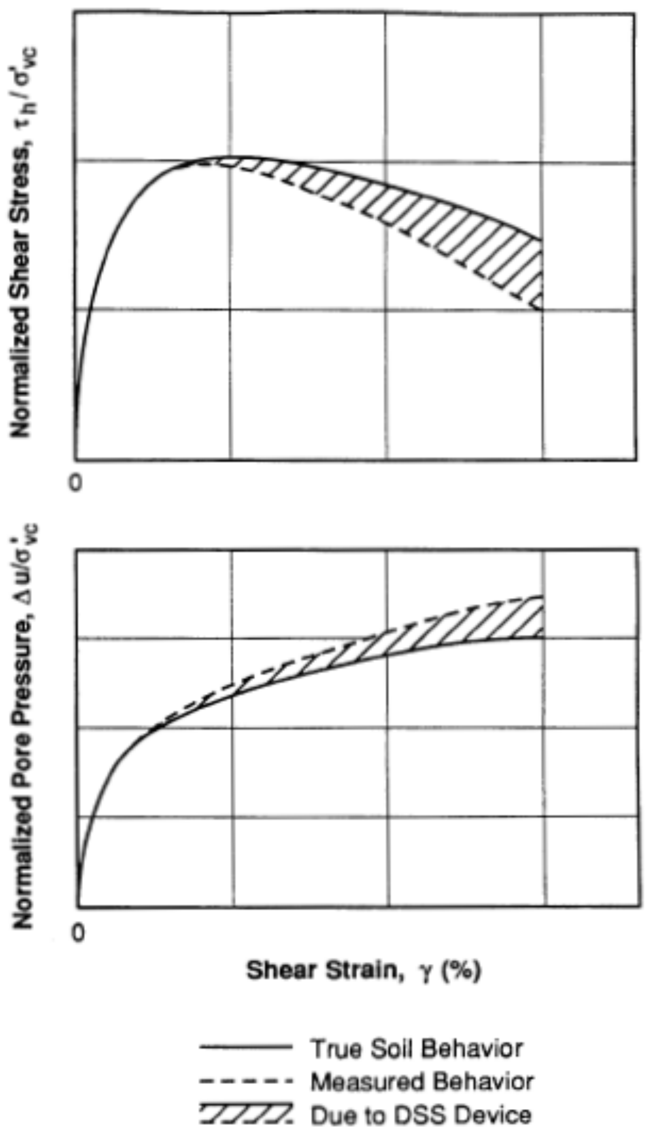


Figure 2-11 – Schematic of Hypotheis Showing Influence of DSS Apparatus on the Behavior of an OCR = 1 Speciment in an undrained DSS Test (DeGroot et al, 1992)

A potential drawback of the WRM is 'residual permanent stretching' of the membranes from continuous use. When using the WRM it is important not to use the membrane for loads higher than what they have been calibrated for. If the membrane experiences horizontal loads from the specimen it's confining (due to consolidation) greater than what it's calibrated for the membrane slowly yields creating a looser fit (Airey and Wood, 1984)

The importance of sample tightness using either confinement method is specifically addressed in ASTM standard D6528 which states that the cross sectional area of the specimen cannot change by more than 0.1% during DSS testing.

2.7 Stress Distributions in Circular Specimens

Lucks (1972) performed a three dimensional finite element analysis to analyze stress conditions within a specimen during a DSS test. It was found that 70% of the sample was found to be under uniform stress conditions and the horizontal shear stress was 80% uniform over the middle of the specimen. Based on this, Lucks concluded that DSS testing appropriately measured the horizontal shear stress in the soil (DeGroot et al, 1992).

A report done by Mladen Vucetic of NGI (Vucetic, 1981) showed there are non-uniform stress distributions along the edges of circularly confined specimens in DSS. Shorter samples with wider diameters were deemed to have less non-uniform stresses.

The stiffness of the vertical sides containing samples in DSS are of compared DSS results using both Geonor's and the Cambridge University DSS machine. WRM's are used in the Geonor apparatus while the Cambridge University apparatus used a metal rigid box. Budhu concluded the rigid set-up of the confinement system in Cambridge's system led to more uniform strain than the less rigid WRM used by the Geonor system at higher strains. He went on to say the type of rupture was dependent on the side stiffness. Finally, he concluded the stress ratio measured at the sample core was underestimated by both methods: 6% for NGI and 12% for Cambridge.

Cambridge stress transducers were used to calculate stress in a soil sample in three different places. The results of this test are shown in Figure 2-12. We see the greatest strength at the core, but the two edges and core do not agree with each other. This is consistent with uneven stress distributions in the sample and stresses. This does cast doubt on the efficacy of the DSS test, however these differences are typically minor in cohesive soils. Furthermore, when the sample core shear strength is compared to the measured shear strength of the 'entire' sample ultimate shear strength is under-estimated from 3%-7% which is acceptable in practice (Airey and Wood, 1984).

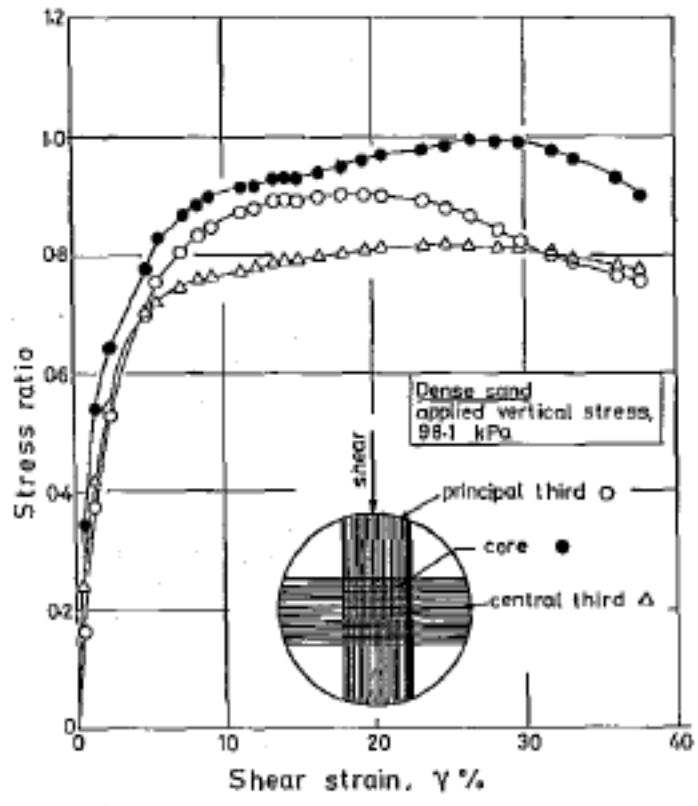


Figure 2-12 – Stress Ratio developed in Three Locations of Specimen (Airey & Wood, 1984)

DeGroot et al, (1992) presented test results of stress distributions in a rubber specimen tested in the Geonor DSS Device. When testing rubber specimens gaps in the rubber specimen resulted along the top and bottom due to the non-uniform stress. Obviously with a plastic soil these gaps aren't present, but the uneven stresses are. Figure 2-13 depicts this phenomenon.

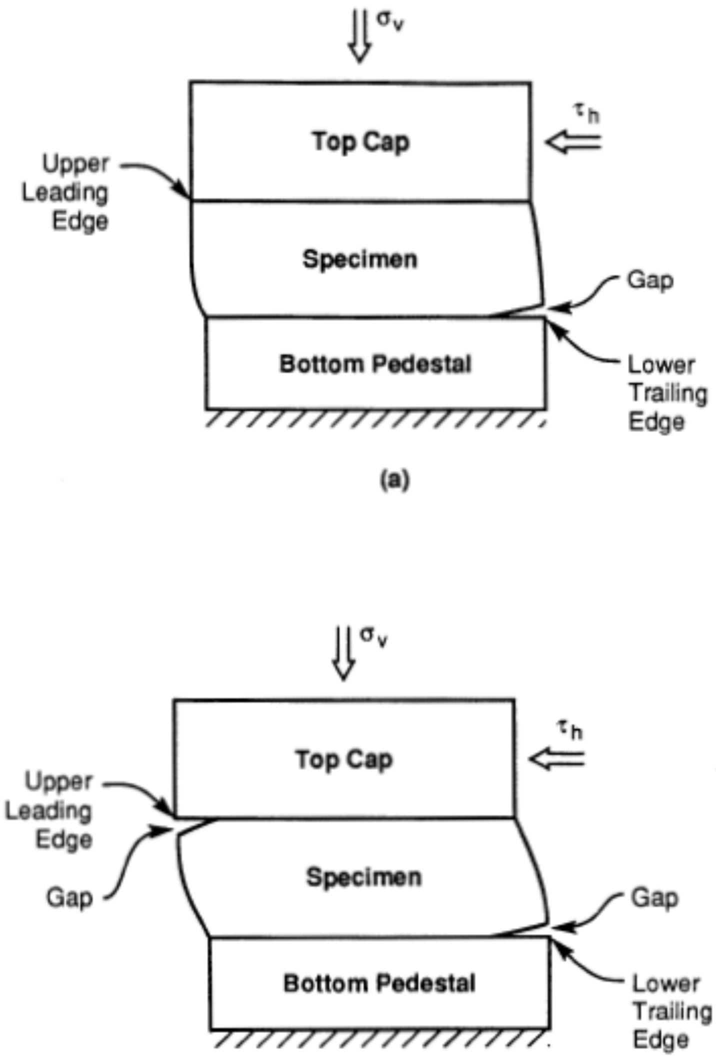


Figure 2-13 – Schematic of Deformed Shape of a Rubber Specimen Under Constant Height Direct Simple Shear Condition: (a) strain < 10%, (b) strain >10% (DeGroot et al, 1992).

2.8 Height to Diameter (H/D) Ratio

As imagined, if there are uniformities in circular specimens in the DSS test, the Height to Diameter ratio would be expected to have an impact on measured ultimate shear strength. The ASTM standard D6528 specifically states the Height to Diameter ratio cannot exceed 0.4 for DSS testing. The question of the affect of the

H/D ratio was researched by NGI in 1981. After over 30 tests on Haga clay of various H/D ratios and confinement strengths NGI determined the H/D ratio to have only a small affect on measured shear stress. The Haga clay was tested at H/D ratios of .32, .2, and .14. (Vucetic, 1981). This relative non-impact of the H/D ratio can be due to the elasticity of the Haga Clay (see Figure 2-14), or the relatively small H/D ratios used in their comparison (Airey and Wood, 1984).

In other soil types we see more of a disparity in Shear Strength of the same soil at different H/D ratios.

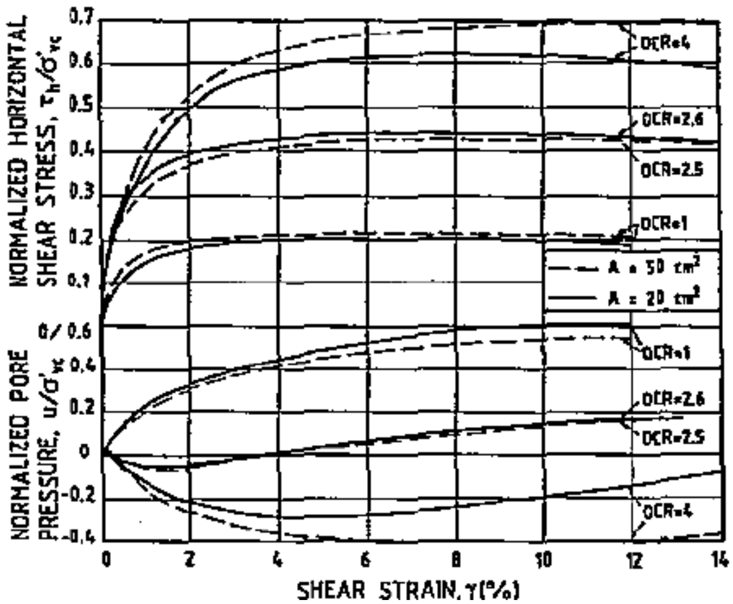


Figure 2-14 – Shear strength from DSS tests using specimen diameters of 50 scm and 20 scm with same height (Airey and Wood, 1984).

Figure 2-15 provides a comparison of both pore pressures and shear strength on Drammen Clay using different H/D ratios. The maximum difference in shear strength results measured was 12% (Airey & Wood, 1984). Ultimately, it may affect shear strength and is specifically limited in the ASTM standard.

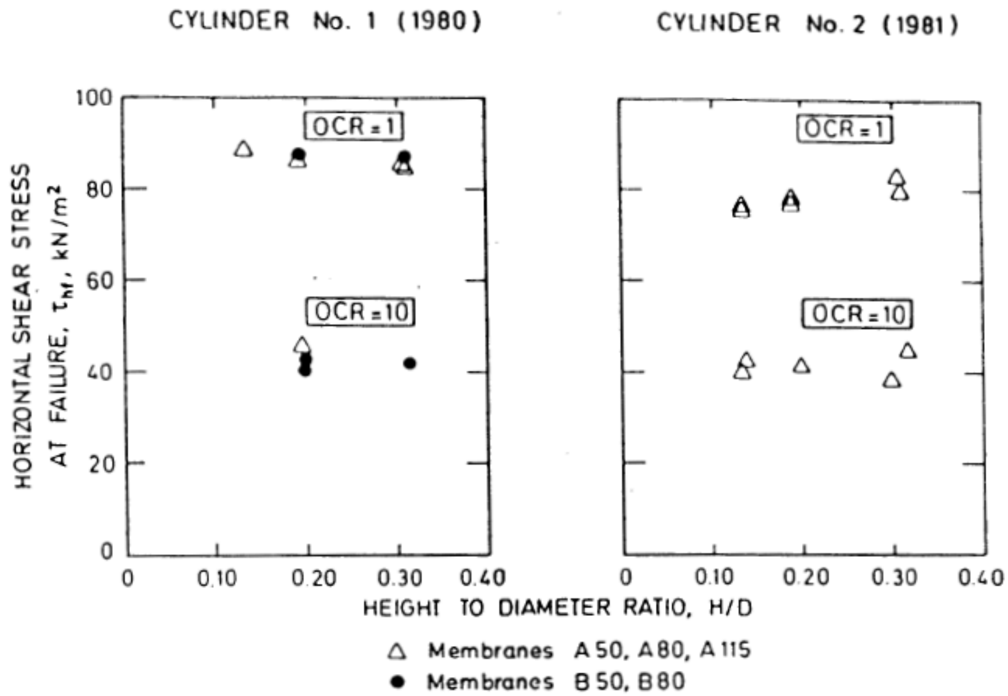


Figure 2-15 – Influence of Height to Diameter Ratio and Membrane Type on Measure Peak Horizontal Shear Stress from Geonor DSS Tests on Haga Clay (Vucetic, 1981) (DeGroot, Ladd, & Germaine, 1992)

2.9 Correction Factors

Baxter et al. (2010) evaluated running some tests with water instead of soil. This was done to calculate correction factors for both confinement systems. The assumption made was that the water has no shear strength, therefore any measurable shear strength is caused by the confinement system and should be subtracted from the data collected when testing soil specimens.

Figure 2-16 provides a nice representation of the effect both the WRM and Teflon rings have on shear strength. The plot on the right, showing the WRM data experienced buckling near 15% shear. A trend-line was used to approximate expected results to a strain of 30%. We see at strains close to 20% each method is near 1 kpa.

This means the added shear strength provided by the confinement methods isn't much of a factor at low strains. It's clear at higher strains the Teflon rings show a steep increase in the amount of strength provided. Baxter concluded this isn't a concern when testing max strength as that is usually reached in the neighborhood of 10-20% strain.

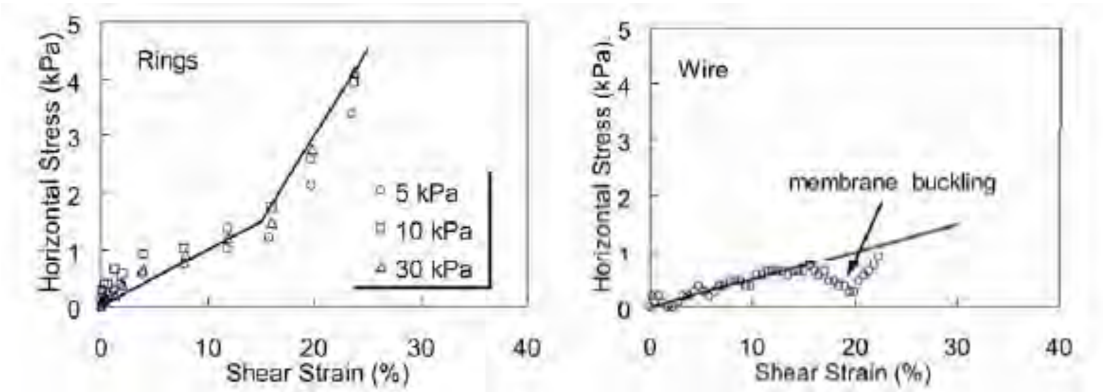


Figure 2-16 – Stress-strain relationship for samples of water used to correct the DSS results for the effect of teflon rings and WRM's (Baxter et al. 2010)

Similarly to Baxter's correction factors, researchers at MIT performed testing on WRM's and calculated a correction factor (Figure 2-17). They also concluded the correction factors for the WRM's were nearly negligible, and stated the correction was ~1 kPa for the range of normal stresses they were interested in. At normal loads higher than .3 kg/cm2 the O-rings experienced slipping, not allowing for good data (Ladd & Degroot, 2003).

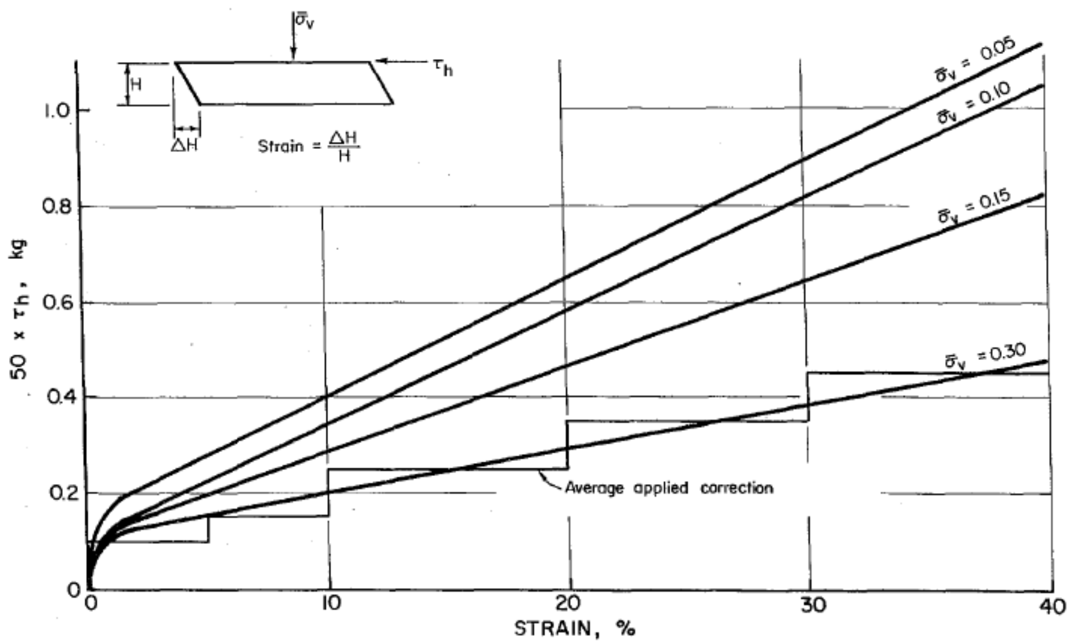


Figure 2-17 – Calibration of Membrane Resistance (Ladd & Degroot, Recommended Practice for Soft Ground Site Characterization, 2003)

The Norwegian Geotechnical Institute (NGI) performed a correction factor analysis on their WRM's. Their calculation takes both membrane thickness and size in to account. This is shown in Figure 2-18 and Table 2-2.

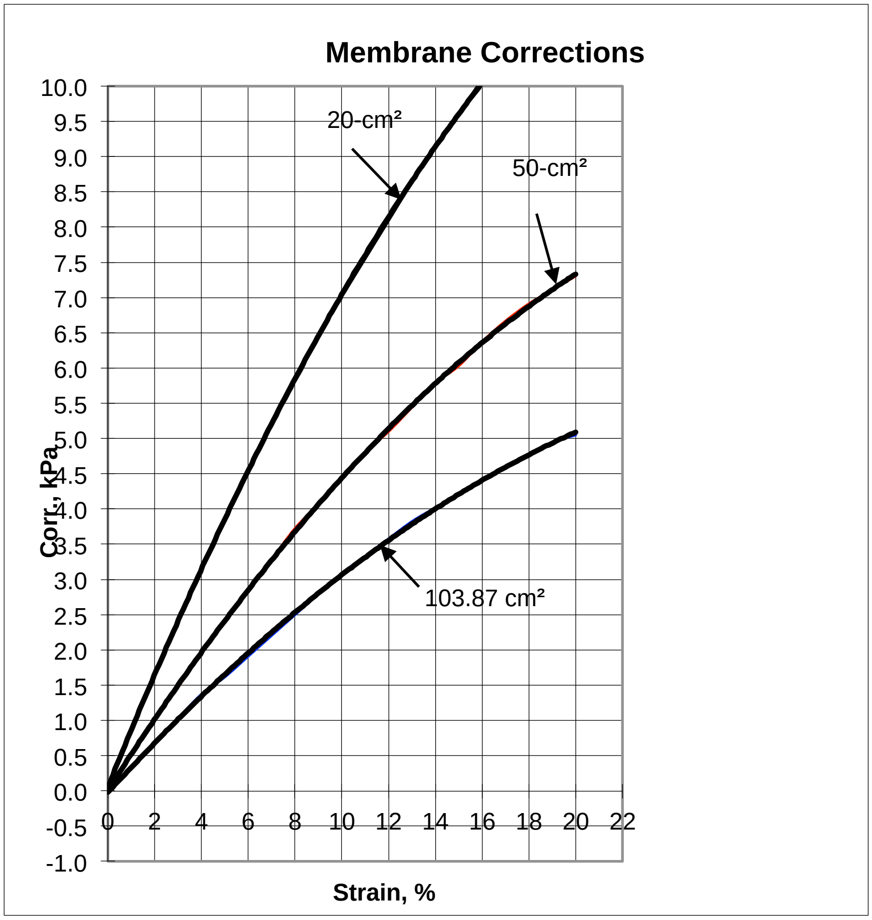


Figure 2-18 – NGI's Wire Reinforced Membrane chart by membrane size (Brylawski & Berre, 1992; rev 1997)

Table 2-2 – NGI's Wire Reinforced Membrane chart by membrane strength (Brylawski & Berre, 1992; rev 1997)

C	*f*
1.00	f = t / 0.6
1.25	f = (t + 0.0306) / 0.6
1.50	f = (t + 0.0696) / 0.6

Using Figure 2-18, Table 2-2, and the following calculations taken from Ed Brylawski's report (1997) NGI's Wire-Reinforced-Membrane correction factors can be determined (Brylawski & Berre, 1992; rev 1997).

<u>EXAMPLE CALCULATION</u>

Type of membrane____________________________C = 1.00
Amount of consolidation______________________ε_v = 10%
Area of sample_______________________________A = 50 cm²
Membrane correction from diagram_____________mem_{corr}= 4.45 kPa
Membrane thickness__________________________t = 0.65 mm
Factor_____________________________________ f = 0.65 / 0.6 = 1.083
Revised membrane correction ________________mem_{corr}^* = 4.45* 1.083 = 4.82 kPa
Actual measured vertical stress________________σ_{actual} = 50 kPa
Vertical consolidation stress___________________$\sigma_v = \sigma_{actual} - mem_{corr}^*$ =
50.00 - 4.82 = 45.18 kPa
Membrane corr. as a % of vert. stress___________$mem_{corr}^* / \sigma_{actual}$ = 4.82 / 50 =9.6%

2.10 Conclusion

It's clear there are some non-uniformities in specimens when performing DSS tests in either Teflon rings or WRM's. However, these non-uniformities are slight and do not affect the center of the specimen. Additionally, the DSS test provides a relatively average shear strength result when compared to other methods.

From the limited comparisons of Teflon rings vs. WRM's in the literature, it's apparent that they should produce a similar result, with somewhat different strain softening paths and potential variability at higher strains. This variability may cause correction factors to be calculated.

The Height to Diameter ratio does not appear to be a huge factor in Shear strength of cohesive soils, but should be limited to a value of 0.4 per ASTM and to ensure proper strength is measured as theoretically we would expect more non-uniformities in samples with smaller diameters.

3. Direct Simple Shear Experimental Methods

The laboratory testing program for this thesis involved direct simple shear (DSS) tests performed in the Marine Geomechanics Laboratory at the University of Rhode Island. Direct simple shear tests allow for the measurement of maximum horizontal shear stress of a specimen under undrained conditions by maintaining constant volume of during shear. In addition to undrained shear strength the DSS test allows for collection of consolidation data.

This chapter will provide a detailed description of the experimental program used for this research. This includes details of the equipment, sample preparation, testing procedures, soils tested, and software used.

3.1 Testing Equipment

The primary testing system used in this report was a direct simple shear device produced by Geocomp Corporation. The DSS device is Geocomp's Shear Track II system as shown in Figure 3-1. The Sheartrac II system is capable of running fully automated consolidated and shear phases of DSS and direct shear tests. The system consists of a computer controlled unit that uses micro-stepper motors to apply vertical and horizontal loads to the soil specimen. The system allows the tester to modify test parameters at any point during a test, and automatically saves and records data through the use of Geocomp's direct simple shear software (Geocomp, Inc).

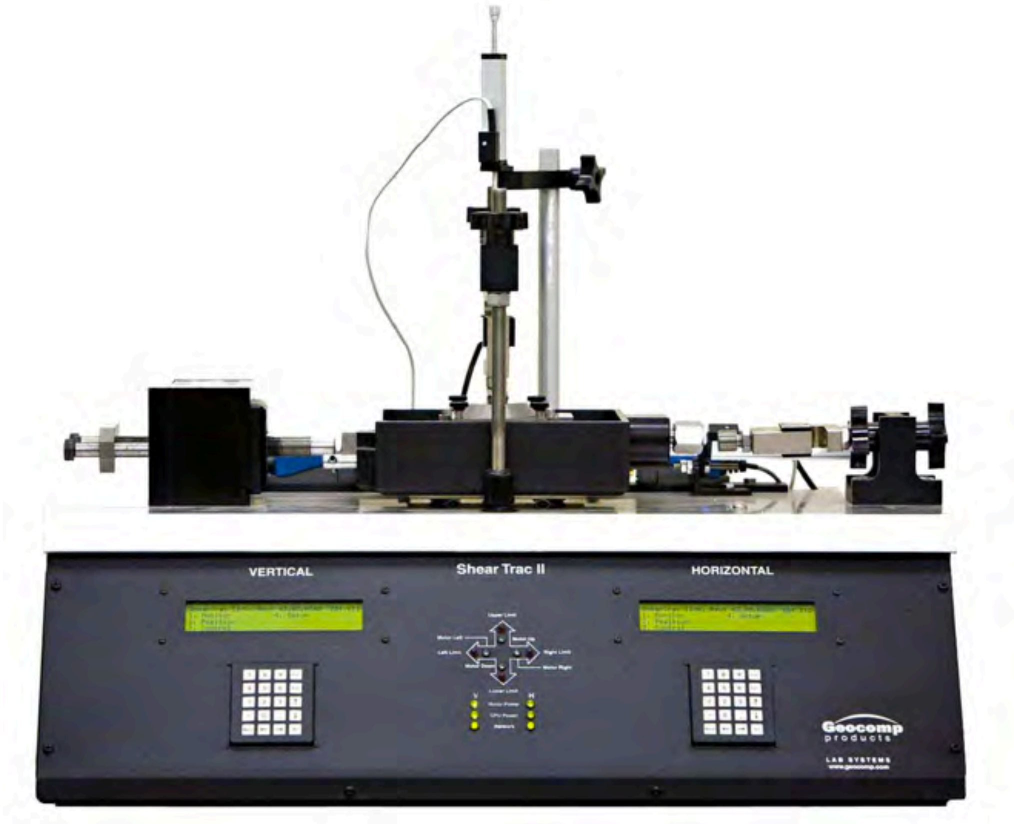


Figure 3-1 – Sheartrac II-DSS Testing Equipment (Geocomp, Inc)

In addition to the Sheartrac equipment, a general purpose load frame (Geocomp's Loadtrac II) was used to reconstitute a block sample of an organic silt from a slurry. The Loadtrac II system allows the user to run incremental load and constant rate of strain consolidation tests that are completely automated.

Figure 3-2 shows the LoadTrac set-up for a triaxial test. Later in this chapter detailed procedures will be presented regarding preparation of an organic silt block sample in the LoadTrac II.

Figure 3-2 - Geocomp's LoadTrac II set-up for Triaxial testing (Geocomp, Corp.)

Additional equipment used in the laboratory testing program included the following:

a) Denver instruments scale used to measure water content

b) Calipers

c) Geocomp Rubber Membrane used to hold the sample within the metal Teflon coated rings.

d) Geonor Wire Reinforced Membrane (Figure 3-3)

    a. Rated to 323 kPa vertical consolidation incrementally loaded.

    b. 65.79 mm diameter

e) Geocomp Teflon Rings (Figure 3-4)

   a. 63.5 mm diameter

f) Geocomp base plate used in Sheartrac II device

   a. Porous stone fixed to bottom of base-plate is held by 2 screws and was changed when testing with the Wire Reinforced Membrane vs. the Teflon rings.

g) Load Cells

   a. Model Artech Industries 20210 – 1k lb used for horizontal and vertical loads in DSS machine.

   b. Model Artech Industries 20210 – 5k used for vertical load in Geocomp's LoadTrac II.

   c. Load Cells calibrated using a proving ring.

h) Displacement Transducers

   a. Novotechnik TR-50 Displacement Transducers used to monitor displacement in both the horizontal and vertical directions when testing with the ShearTrac II machine.

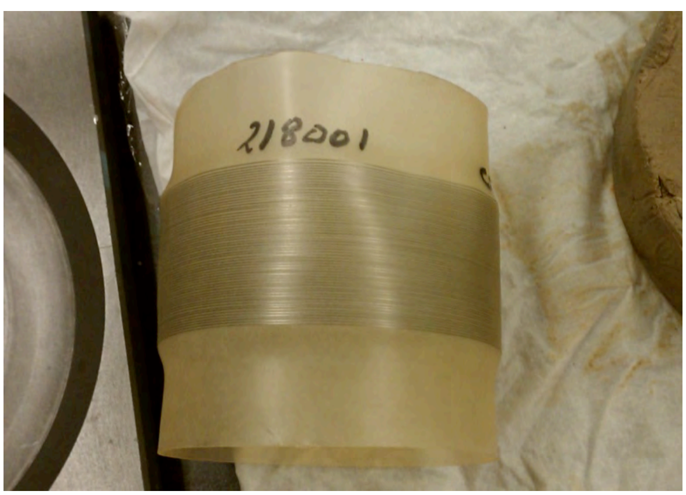


Figure 3-3 - Geonor Wire Reinforced membrane

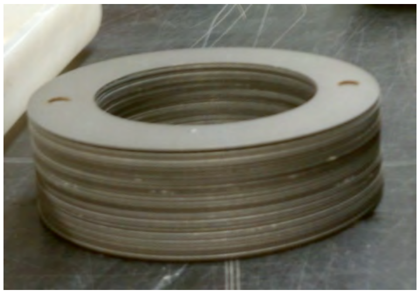


Figure 3-4 - Geocomp Teflon Rings used in DSS testing

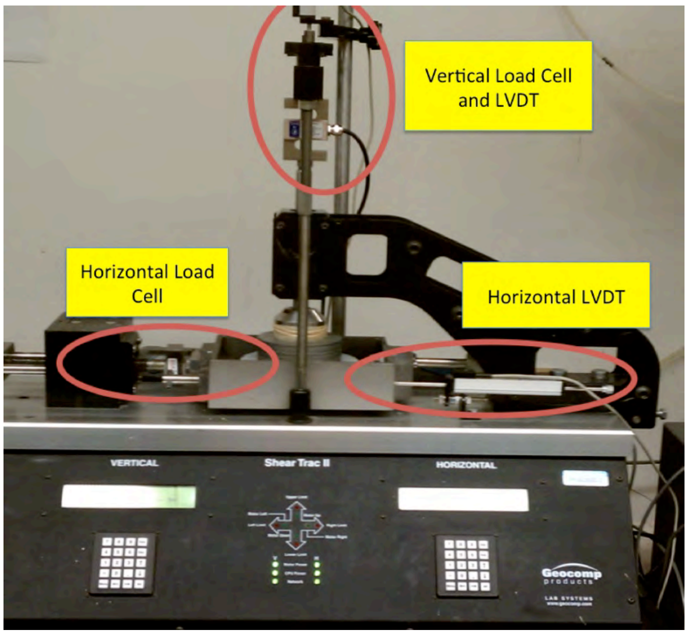


Figure 3-5 - Geocomp Sheartrach System highlighting load cells and LVDT's

3.2 Properties of Soils Tested

Samples of a high plasticity marine clay from the Gulf of Mexico, a low plasticity organic silt from Narragansett Bay, and highly sensitive Presumpscot Clay from a landfill in Maine were tested in this study. Properties of each soil are described below.

3.2.1 Gulf of Mexico Clay

The first type of clay tested was a high plasticity clay from the Gulf of Mexico taken from a Jumbo Piston Core (JPC-11). The sample was obtained in 1998 as part of a research cruise aboard the R/V Knorr (Knorr cruise 159). The soil tested in this study came from a depth of 1143 cm to 1279 cm It has been stored at the University of Rhode Island in the Rock and Core facility under refrigerated conditions for the last 13 years.

Index properties of the Gulf of Mexico clay from an adjacent Jumbo Piston Core were obtained by Bradshaw (1999):

Table 3-1 - Properties of Gulf of Mexico Clay (Bradshaw, 1999)

	W_P (%)	W_L (%)	I_p	I_L	G_S
JPC-20	36	93	57	0.96	2.66

Legend: W_P= plastic limit, W_L= liquid limit, I_L= liquidity index, I_p= plasticity index, G_s= specific gravity

Due to slight variation between Jumbo Piston Core testing sites testing was done in the lab to verify Liquid Limit (LL) and Plastic Limit (PL) of the Gulf of Mexico Clay in JPC-11.

Index test results obtained in this study indicated that the water content ranged from 70% to 80% before testing and approximately 65% post testing. The PL was calculated to 33% from an average 4 separate tests. LL was calculated to be 80% from an average of 4 tests. These values are consistent with the work of Bradshaw (1999).

3.2.2 Narragansett Bay Organic Silt

The second soil used in this study was an organic marine silt collected from Narragansett Bay. This silt was dried, reconstituted with distilled water, and consolidated to a stress of 100 kPa before being used for testing. Section 3.2.2.1 will detail the methods used to reconstitute the silt. The reconstituted silt had a water content of 35% before testing and 32% after DSS testing. The liquid limit of the organic silt was found to be 45% and the plastic limit was found to be 32%.

3.2.2.1 Narragansett Bay Silt Slurry Preparation

Reconstituted block samples of organic silt were prepared from slurry in a large slurry consolidometer. The following sample preparation methodology was taken from a prior Master's Thesis done at the University of Rhode Island (Page, 2004).

1) Air-dried silt from Narragansett Bay was soaked in distilled water for 7 days (Figure 3-6).

Figure 3-6 - Narr Bay Silt slurry step 1

2) Once fully saturated the silt was mixed in to a slurry using an electric drill (Figure 3-7).

Figure 3-7 - Mixing of Narr Bay Silt Slurry before sieving

3) The silt slurry was poured through a number 10 sieve (2 mm). The resulting sieved mix was allowed to settle (Figure 3-8).

Figure 3-8 - Narr Bay Silt Slurry after being poured through Number 10 (2mm) Sieve

4) After settling the excess water was siphoned from the top of the container.

5) In a slow circular motion the silt slurry was poured inside a confining steel cylinder. The diameter of the cylinder was 27.94 cm (Figure 3-9 and 3-10).

Figure 3-9 - Placing the sieved Narr Bay Silt in to consolidation mold

6) After filling the cylinder the top cap is placed on top of the silt slurry and the four bolts holding the cylinder to its base plate are checked for tightness.

Figure 3-10 - Narr Bay Silt Consolidation mold pre-placement of top cap

7) Finally, the silt slurry is placed inside the Geocomp Load frame and an incremental load consolidation test was performed with a load increment ratio of 1 to a vertical effective stress of 100 kPa (Figure 3-11).

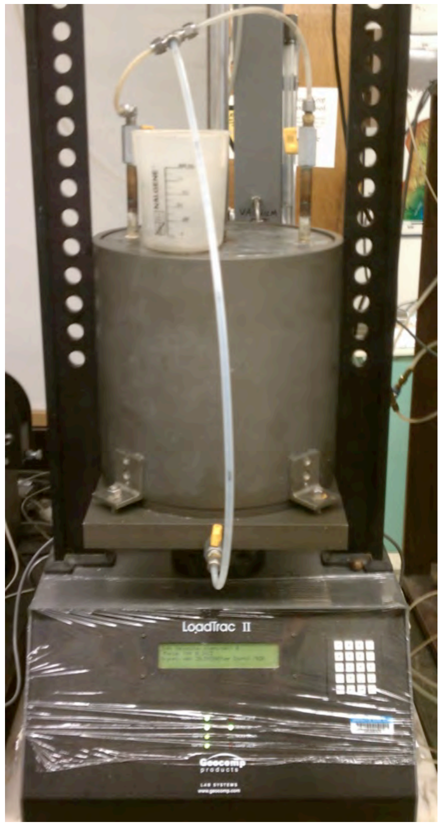
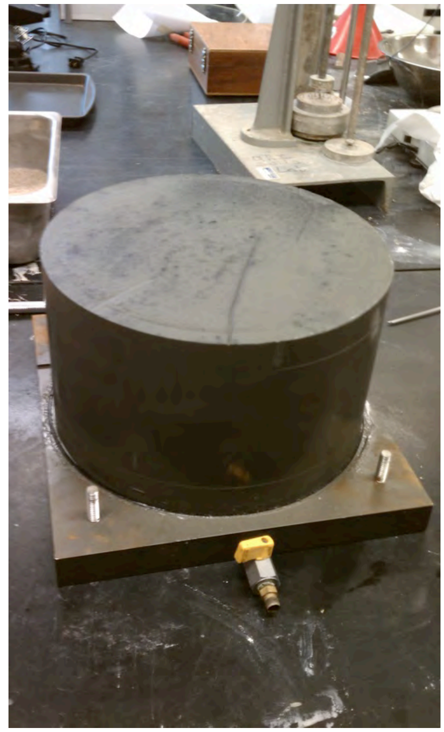


Figure 3-11 - Silt Slurry in Load frame (Note the drainage lines from the top and bottom

8) When Consolidation is complete the resulting silt ‘cake’ is carefully extracted by levering weights under the bottom edges of the cylindrical mold and slowly forcing the walls of the mold up while maintaining constant pressure on the sample (Figure 3-12).

(a)



(b)

Figure 3-12 - Beginning of silt cake extraction (a) and silt Block Sample after extraction (b)

9) After extraction the sample is sectioned using a wire cutter. After sectioning it is immediately wrapped in cheesecloth and sealed with wax to maintain water content (Figure 3-13).

Figure 3-13 - The resulting pieces of silt block ready for storage or testing

3.2.3 Sensitive Clay from Portland Maine (Presumpscot Formation)

The 3rd and final soil tested was a sensitive clay from Portland, Maine (Figure 3-14). This clay was collected using a hydraulic piston sampler in September, 2011. A constant rate of strain consolidation test performed by Geocomp (included in results section) indicated the sensitive nature of the clay.

Liquid and Plastic limit tests were run on the Presumpscot clay. The LL was calculated to be 46 and the PL was calculated to be 23. The natural water content of the Presumpscot clay was 50% before testing.

There was a limited amount of Presumpscot clay available for testing. For this reason testing was limited to one recompression DSS test using each confinement type. To minimize the significant change in strength of the clay vertical consolidation stresses past the pre-consolidation stress the samples were consolidated to approximately 90% the measured preconsolidation stress.

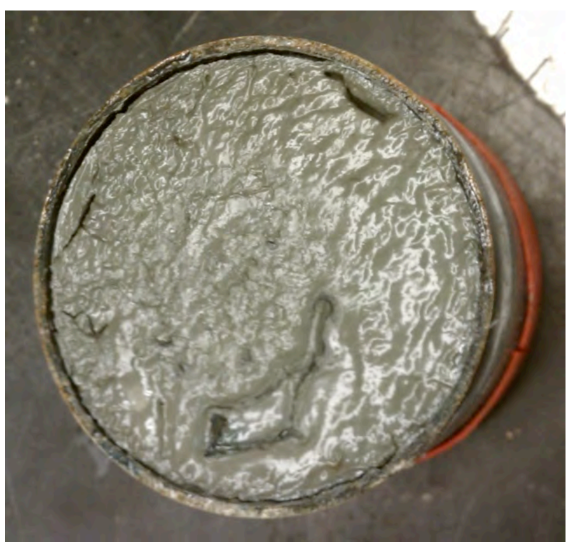


Figure 3-14 - Portland Maine Clay prior to extraction.

3.3 Test Procedures

This section outlines the testing procedures used for all DSS tests on both silt and clay specimens. Detailed steps used to perform the consolidation test are also presented. Emphasis was placed on replicating these test procedures for each test, ensuring reproducibility from test to test of the same soil and confinement type.

Figure 3-15 - Gulf of Mexico Clay extraction

3.3.1 Clay and Silt Direct Simple Shear Test

The following is a step-by-step procedure for preparing DSS tests:

1) Soil Extraction
    a. GoM Clay
        i. The Gulf of Mexico Clay was extracted from piston core tubes. 3 inch sections of the PVC tubes were cut using a table saw (Figure 3-15).

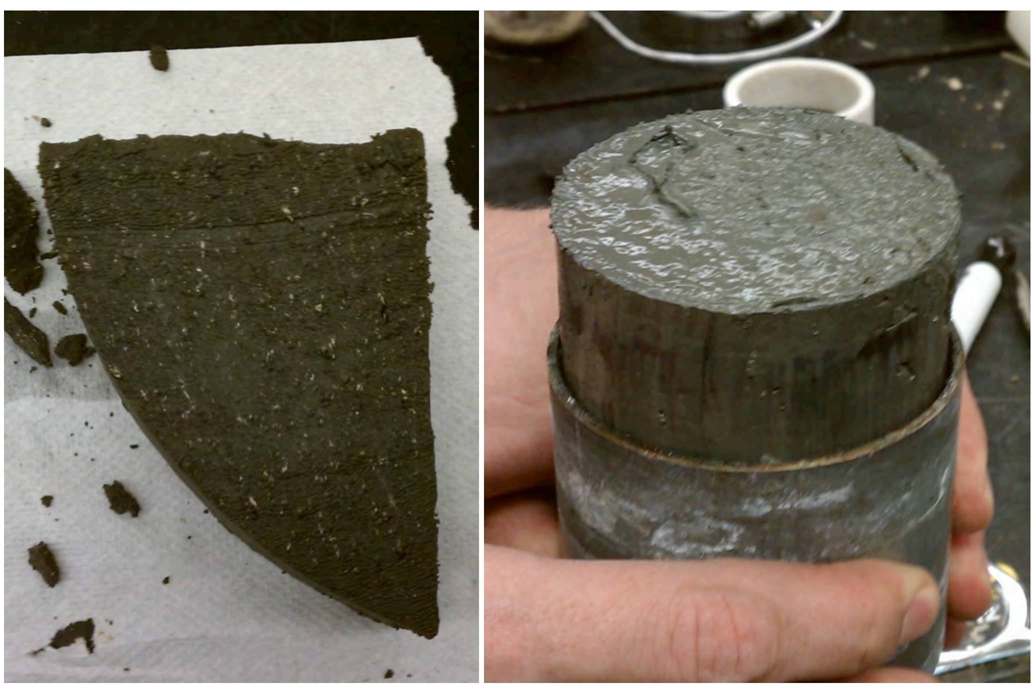
ii. After a section of soil has been cut it is extracted by pushing a plunger through the bottom of the PVC tube.

iii. After extracting the sample it is cut in two approximately 38.1 mm thick pieces.

b. Narragansett Bay Organic Silt

i. Extracted from a cheese cloth and wax covering using a razor and cut in to 38.1 mm high samples (Figure 3-16).

ii. The unused portion of the silt is covered in a damp towel and wrapped in plastic for later use.



(a) (b)

Figure 3-16 - Narragansett Bay Silt (a) and Presumpscot Clay (b)

c. Presumpscot Clay

   i. Due to the highly sensitive make-up of the Maine Clay it was extracted from the 76.3 mm diameter tube more carefully than the GoM Clay. The bond around the edge of the metal tube was broken with a wire membrane before the sample was extruded. This was done to preserve as much of the specimens in-situ integrity as possible (Figure 3-17).

Figure 3-17 - Maine Sensitive Clay edging

2) Trimming the samples

   a. When preparing a sample for the stacked rings a 63.5 mm diameter trimming ring is used to gently trim the clay (Figure 3-18).

b. Samples for the wire-reinforced membrane (WRM) were trimmed using a wire saw because the diameter was slightly larger than the 63.5 mm cutting ring (Figure 3-18).

(a) (b)

Figure 3-18 - Teflon Ring trimming ring (a) and WRM trimming apparatus (b).

After the sample has been 'trimmed' to the appropriate diameter it is cut to a height of exactly 1 inch.

a. The cutting ring is pushed over a metal block forcing exactly 1 inch of the clay sample out of the ring where it is cut.

b. When using a trimmed sample the specimen has a 76.2 mm wide, 25.4 mm tall ring placed around it. The portion of the sample that is above the 25.4 mm tall ring is trimmed using a wire saw.

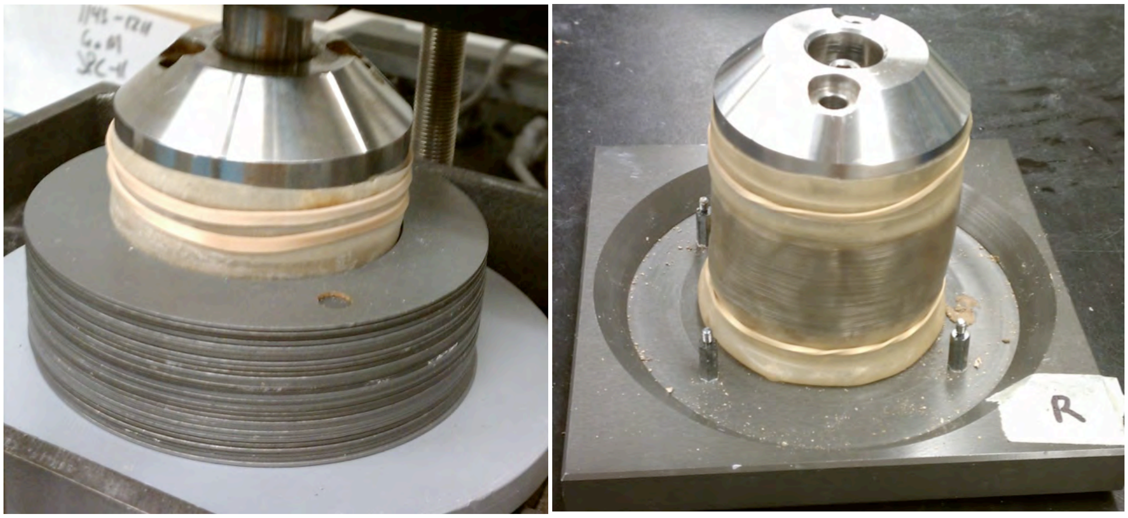
Figure 3-19 – Presumpscot Sensitive Clay trim

4.) A geogrid fabric is placed on the bottom porous stone of the DSS base plate to improve contact between the specimen and the porous stone. The specimen is then placed on top of the fabric.

a. For WRM tests the membrane is fit inside a membrane stretcher and gently slid over the sample until it reaches the porous stone.

b. For the Teflon Ring tests a thin rubber membrane is fit over the sample using the membrane stretcher. After the placement of the membrane the rings are slid over the specimen a few at a time.

5.) For both the Teflon Rings and WRM the top cap is place on top of the sample and rubber bands are used to seal the bottom and top of the sample to the bottom and top caps (Figures 3-20).



(a). (b)

Figure 3-20 – Metal stacked rings with top cap (a) and WRM with top cap (b).

6.) The base plate with the sample is placed in the Geocomp DSS machine and tightened using the horizontal screws.

7.) After placing the sample the Geocomp Sheartrac II is moved horizontally and vertically until the Shear Rod lines up in the center of the sample. After lining up the sample the rod is tightened to the specimen by holding the top cap firmly while screwing the rod in to it.

8.) All bolts are then tightened on the machine and the vertical LVDT is placed on the top cross bar.

9.) The consolidation and shear tables are input to the Geocomp Shear software and the test is run (see section 3.3.2 for settings.

10.) The final step of consolidation is allowed to run for 100 minutes past the end of primary consolidation and manually advanced to the shear phase after locking the vertical loading system.

3.4.2 Determination of Membrane Correction Factor.

A membrane correction factor testing was determined empirically using both the wire-membrane and the Teflon rings. This factor takes into account the resistance that each confining system adds to the measured shear stress. The methods used for Correction Factor testing followed the protocol used by Baxter et al. (2010), which was described in Section 2.5.

To determine the membrane correction factor, the bottom porous stone was first sealed and the WRM and inner membrane used with the Metal Rings was fixed to the sealed bottom porous stone with an O-ring. When testing the WRM the next step was to secure the top cap to the top of the WRM with another O-ring. A top cap with airtight valves was used, allowing water to be pumped into the WRM from the top cap. After filling with water a flexible tube connected to a pressure panel was screwed in to the valve located on the top cap. Once the sample was pressurized appropriately it was set up in the DSS device as if it were a normal test (Figure 3-21).

The stacked ring set-up was only slightly different than the WRM. The rings were stacked around the empty inner membrane, then the top cap was secured with an O-ring. The top cap was then held manually until the pressure was applied through the top cap.

For both confining systems, simple shear tests were performed on the water filled membranes at water pressures of 5, 7, and 10 kPa. The 7 kPa test was performed at the standard test speed of .02159 mm/min to directly compare how much resistance the different confinement methods add. The other tests were run at much higher strains to see how much role the backpressure played.

(a) (b)

Figure 3-21 - WRM Correction Factor testing set-up for WRM (a) and stacked rings (b).

Results of the correction factor tests are shown in Figures 3-22 and 3-23. Linear best fit lines were fit against the test run at the 7 kPa back-pressure at the strain rate of .02159 mm/min because. The correction factors were fit to that data because it represented the exact strain rate the DSS tests used. The results of all three tests were within .3 kPa of each other, suggesting that the strain rate and pore pressure did not play a significant role in the measured resistance. Figure 3-22 compares the results of the correction factors of both confinement methods side by side. The equation of the best fit lines for each are:

WRM: t = .6*g +.53
Rings: t = 1.24* g +.62

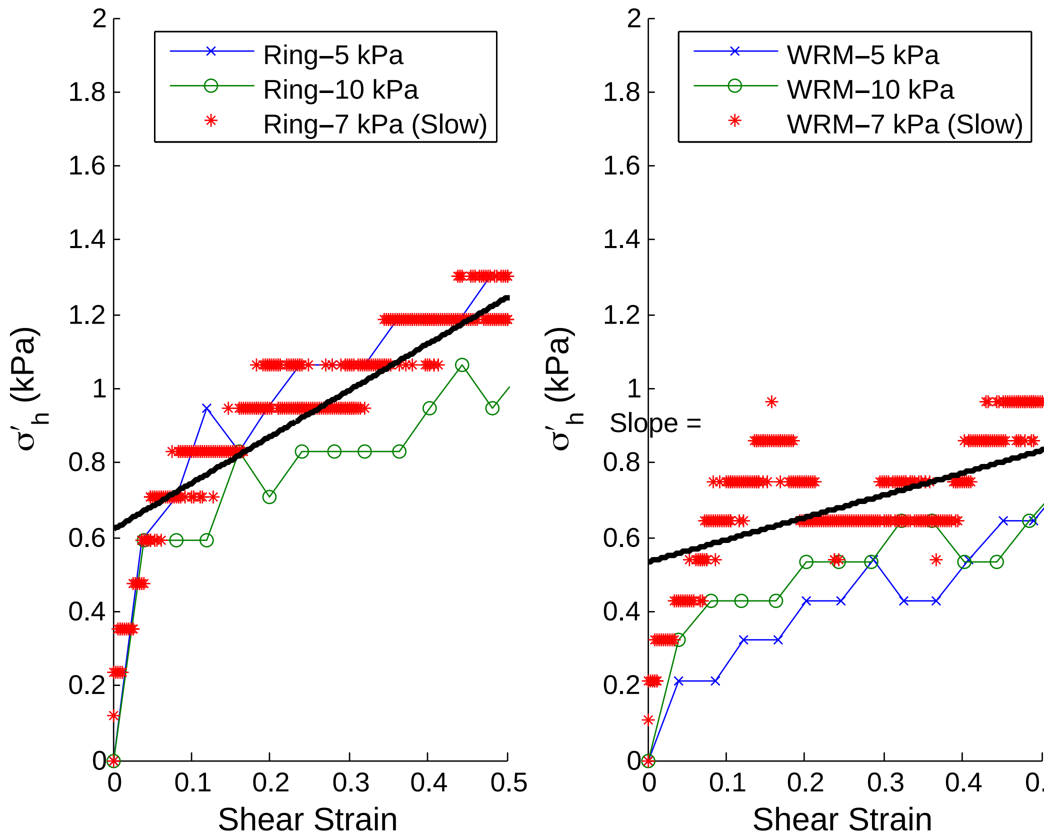


Figure 3-22 - WRM and Ring Correction Factor tests at varying strain rates

From figures 3-24 and 3-25 we see each method has similar results independent of strain rate or back pressure, with the exception of the WRM plot at .1 strain.

Figure 3-24 compares corrected and uncorrected data directly. As expected from the correction factors calculated during the test, the stacked ring data is altered slightly more than the WRM data. However, in both case the correction factors have a very slight effect on the results of the test (approximately 1 kPa). The results section of this thesis presents corrected data only.

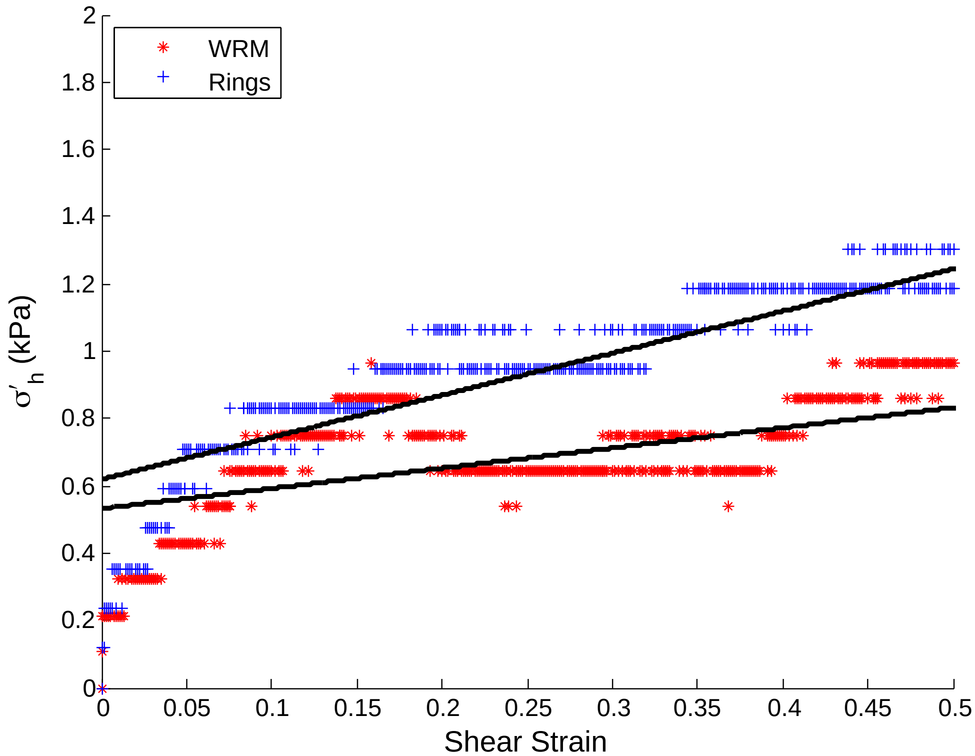


Figure 3-23 - WRM and Ring Correction Factor tests performed at .02159 mm/min strain rate

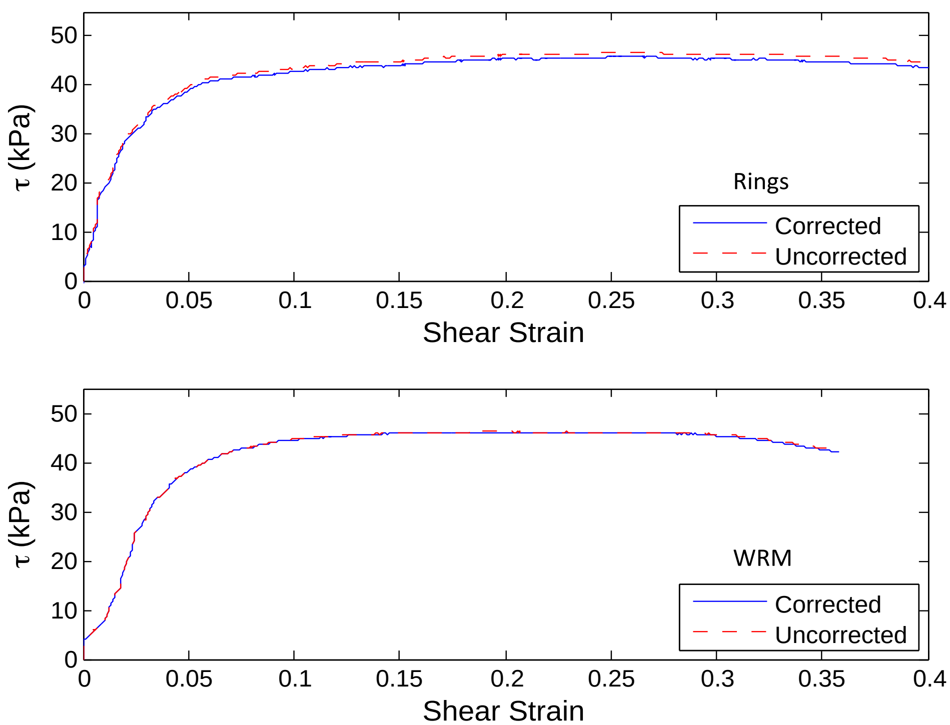


Figure 3-24 - Corrected vs. Uncorrected plots of Narragansett Bay Silt using the WRM and Rings.

The correction factors calculated in this thesis were compared to correction factors used by the Norwegian Geotechnical Institute (NGI) for WRM in their DSS apparatus (using 50 cm^2 samples) and the factors published by Baxter et al. (2010). This is shown in Figure 3-25. There is good agreement between the factors determined in this study and those of Baxter et al. (2010), however the correction factors are significantly lower than those found by NGI. The NGI correction includes the effect of a different DSS apparatus, whereas the other two corrections were performed on equipment from the same manufacturer.

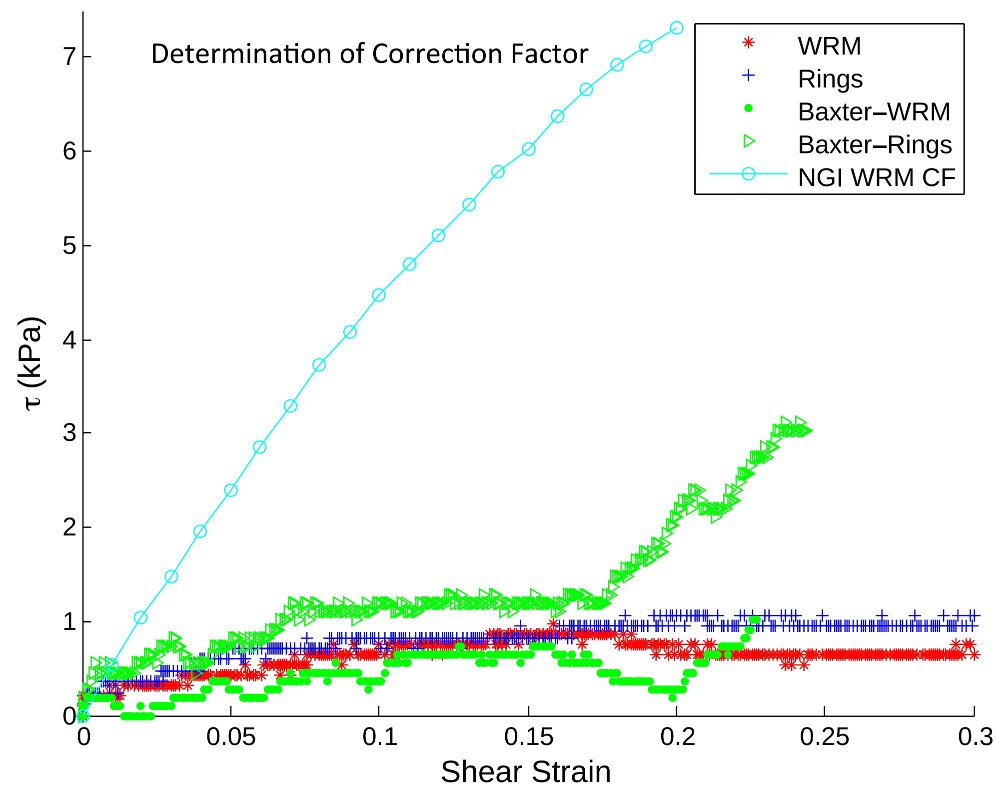


Figure 3-25 - Comparison Plot of all Correction Factor Methods (Brylawski & Berre, 1992; rev 1997) (Baxter et al. 2010)

3.4.3 Geocomp DSS Software PID Settings

The Geocomp software allows for a wide range of flexibility when inputting test parameters. Full control of consolidation load steps, duration, and percentage can be specified for manual or automated control. Shear rate speed and maximum strain can also be set.

In the options menu of the DSS Software is a field called PID. PID stands for Proportional-Integral-Derivative controller, which is a common feedback loop control system used in automated testing. This field controls the PID settings for both the horizontal and vertical phases of the DSS test. The entry fields are shown in Figure 3-26.

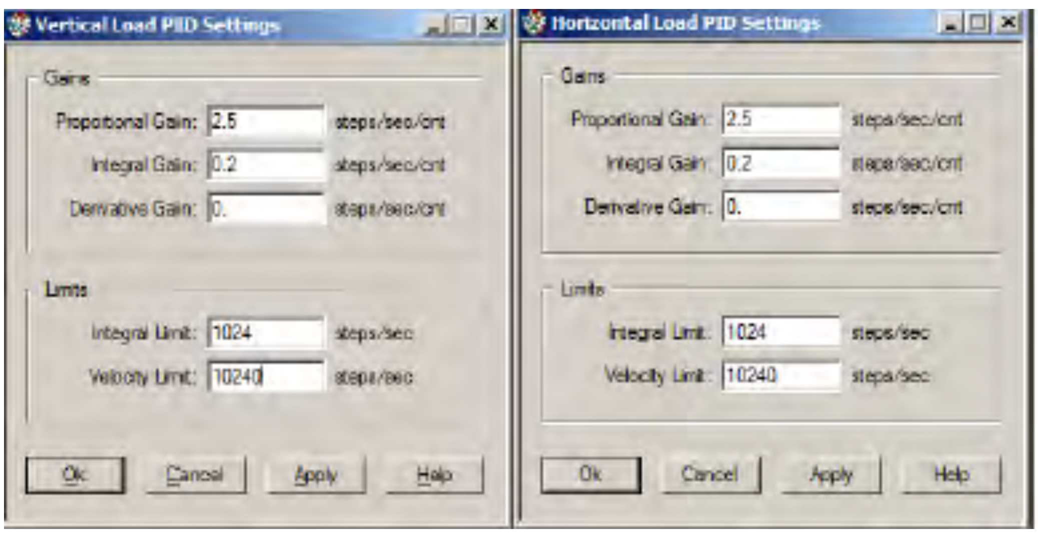


Figure 3-26 - PID Input Manual Geocomp Software (Geocomp, Inc, 1985-2005)

These values affect the smoothness of the measured data and must be varied to match the stiffness of the samples being tested. The PID Settings control the timing of the change in force in both directions.

During the shear phase of the DSS tests, the vertical stress was varied to maintain the constant volume conditions of the test. However, the data was not smooth because of the feedback control system, and the PID settings were varied over several tests to reduce this effect. Ultimately the variability in the vertical stress data was not reduced to an acceptable level and it was decided to maintain constant volume conditions for all tests by locking the vertical force to the value it read at the end of consolidation phase while monitoring axial strain making sure it never exceeded .05%. This procedure is an acceptable method by ASTM for maintaining constant sample volume during shear.

PID settings were left at P = 2.5, I = .2, and D = 0. These are the Geocomp recommended values. For extremely soft soil P could be increased. P would be decreased for very hard soils.

3.4.4 Consolidation Test

In addition to the DSS tests, incremental load consolidation tests were performed on each soil type. These tests provided a baseline consolidation curve used to compare the results of the consolidation data recorded during the DSS testing (ASTM, 2004). Consolidation data for the Presumpscot clay was run in accordance with ASTM D2435 (constant rate of strain test) and provided by Geocomp.

3.5 Testing Matrix

The test matrix in this study was designed to compare the results of the WRM and Teflon-coated metal rings compare in the Direct Simple Shear test. The primary variables used in this study to aid in this comparison were over-consolidation ratio and soil type. These variables along with the chosen strain rate are discussed in more detail here.

3.5.1 Strain Rate

A strain rate of .02159 mm/min was used for all DSS tests regardless of the consolidation state. This was approximately 5%/hour. According to ASTM D6528 most of the practical Direct Simple Shear experience is based on a strain rate of 5% per hour. The ASTM Standard also says the maximum strain shall result in specimen failure in a time exceeding twice the time for 90% consolidation. Based on our consolidation results for Gulf of Mexico clay this coincidentally worked out to be 5%/hour as well.

The importance of strain rate is highlighted in the Masters Thesis written by Jung (2005), in which the shear strength of the same soils was tested at different strain rates. When testing a highly plastic clay at 5%/hour and 50%/hour Jung calculated an 11% difference in shear strength. For this reason it's very important to maintain a consistent strain rate when comparing test methods.

3.5.2 Load Increment Ratio

A load increment ratio (LIR) of .5 was used on all samples. An LIR of 1 is a typical value, however for highly sensitive soils a ratio of less than 1 leads to a cleaner consolidation curve (ASTM, 2004). Due to the highly plastic nature of the Gulf of Mexico clay an LIR of less than 1 was deemed appropriate.

3.5.3 Stress History and Normalized Strength Engineering Parameters

In this study samples were tested in both their normally and over consolidated states. This was done in order to assess the results given by the two confinement methods on soils of different Over Consolidation Ratios (OCR). This comparison can be made by plotting the results on a traditional 'Su/σ'_{vc} vs OCR' curve (i.e. SHANSEP) as presented by Ladd and Foott (1974) and by direct comparison of the stress-strain curves.

Because soils react differently depending on consolidation state the addition of over consolidated tests adds a valuable point of comparison between DSS methods. This allows analysis of the soil in a state that may be more dilative than during a normally consolidated test.

3.5.4 Consolidation Stress

All samples were consolidated to 200 kPa. The normally consolidated samples were sheared at 200 kPa, whereas the overconsolidated samples were unloaded before the shear phase. 200 kPa was chosen because it guaranteed all soils were normally consolidated before testing. The Gulf of Mexico clay was from a depth of 11 meters and the organic silt had a lab set pre-consolidation stress of 100 kPa.

Table 3-3 summarizes the tests performed in this study.

Table 3-3 – Sample test log for all published tests

Test	Soil Type	Depth (cm)		Type	Strain rate	σ_p	σ_{vf}	OCR	w%	w%	H_o	e
#		from	to		mm/min	kPa	kPa		***Pre-Test***	***Post Test***	mm	
Test 19	GoM Clay	1201	1208	Rings	0.02159	200	200	1	80.95	65.24	25.4	2.19
Test 20	GoM Clay	1194	1201	Rings	0.02159	200	200	1	75.44	61.05	25.4	2.04
Test 23	GoM Clay	1189	1194	Rings	0.02159	200	25	8	76.95	61.49	25.4	2.08
Test 31	Narr Bay Silt	100 kPa σ'$_p$		Rings	0.02159	200	200	1	36.34	33.19	25.4	0.91
Test 34	Narr Bay Silt			Rings	0.02159	200	200	1	35.94	32.68	25.4	0.90
Test 35	Narr Bay Silt			Rings	0.02159	200	100	2	35.41	33.69	25.4	0.89
Test 36	Narr Bay Silt			Rings	0.02159	200	50	4	36.59	33.85	25.4	0.91
Test 37	Narr Bay Silt			Rings	0.02159	200	25	8	35.40	34.04	25.4	0.89
Test 39	GoM Clay	1162	1170	WRM	0.02159	200	200	1	78.51	64.53	25.4	2.12
Test 40	GoM Clay	1162	1170	WRM	0.02159	200	200	1	*no data*	63.57	25.4	*no data*
Test 41	GoM Clay	1155	1162	WRM	0.02159	200	100	2	78.59	65.54	25.4	2.12
Test 42	Narr Bay Silt	100 kPa σ'$_p$		WRM	0.02159	200	200	1	34.26	32.73	25.4	0.86
Test 43	Narr Bay Silt			WRM	0.02159	200	200	1	35.24	32.58	25.4	0.88
Test 44	Narr Bay Silt			WRM	0.02159	200	100	2	35.60	33.44	25.4	0.89
Test 45	Narr Bay Silt			WRM	0.02159	200	50	4	35.83	34.00	25.4	0.90
Test 46	Narr Bay Silt			WRM	0.02159	200	25	8	36.48	34.30	25.4	0.91
Test 47	GoM Clay	1155	1162	WRM	0.02159	200	50	4	80.47	67.13	25.4	2.17
Test 48	GoM Clay	1142	1155	WRM	0.02159	200	25	8	78.82	67.04	25.4	2.13
Test 51	GoM Clay	1012	1033	WRM	0.02159	200	25	8	78.63	67.94	25.4	2.12
Test 52	GoM Clay	1012	1033	Rings	0.02159	200	100	2	79.80	67.72	25.4	2.15
Test 53	GoM Clay	1012	1033	Rings	0.02159	200	25	4	80.25	67.82	25.4	2.17
Test 55	Maine Clay	71.5 ft		Rings	0.02159	105	105	1	58.58	50.02	25.4	---
Test 56	Maine Clay			WRM	0.02159	105	105	1	59.50	50.13	25.1	---

Table 3-4 – LL and PL for GoM Clay, Narragansett Bay Silt, and Portland Maine Clay

Soil Properties					
GoM Clay		**Narragansett Bay Silt**		**Maine Clay**	
LL	**PL**	**LL**	**PL**	**LL**	**PL**
80	33	45	25	46	23

4. Results and Discussion

Chapter 4 presents and discusses all consolidation and DSS test results for the lab tests performed for this thesis. All stacked ring and WRM data are plotted together, allowing for a clear comparison of both confinement methods. Sub-sections are organized by soil type. All shear data is normalized with the pre-consolidation stress. This is done to eliminate any discrepancies with data due to slight differences in consolidation stresses. For example, some of WRM tests were consolidated to 194 kPa while some of the stacked ring tests were consolidated to 205 kPa. The diameter of the end caps used with the WRM were 2.54 mm larger than that of stacked rings, tests were mistakenly run with the wrong sample diameter input into the Geocomp software, which resulted in changing consolidation stress by up to 10 kPa.

All non-normalized test data can be found in the Appendix.

4.1 DSS Consolidation Phase Results

The consolidation phase of each DSS test was compared to evaluate whether there is an effect of using either stacked rings or WRM. Specifically, the vertical strain to the vertical consolidation stress was compared between both confining systems and a standard incremental load consolidation test.

4.1.1 Gulf of Mexico Clay

Figure 4-1 compares multiple DSS consolidation test results using both the stacked rings and WRM. The extended starred line is from an incremental load consolidation test performed in a standard consolidometer as outlined in Chapter 3.

Based on these results it's difficult to see any clear differences between the two confinement methods. Going one step further, there aren't any clear differences between either method or the actual consolidation test.

The similarities in the tests are encouraging regarding the accuracy of both confinement methods. An ideal consolidation curve of an undisturbed soil will have a more clear transition from the top and bottom slope (recompression to virgin compression slopes). This transition point marks the pre-consolidation stress. Although it's not clearly defined, we see this transition around 80 kPa mark, which in the range of values we'd expect from Gulf of Mexico clay at a depth of approximately 12 meters.

It is reasonable to assume the Gulf of Mexico samples are somewhat disturbed if not remolded due to the highly plastic nature of the sample and the amount of handling the piston core tubes have received over a 10 year storage life. This assumption is consistent with the results shown in Figure 4-1.

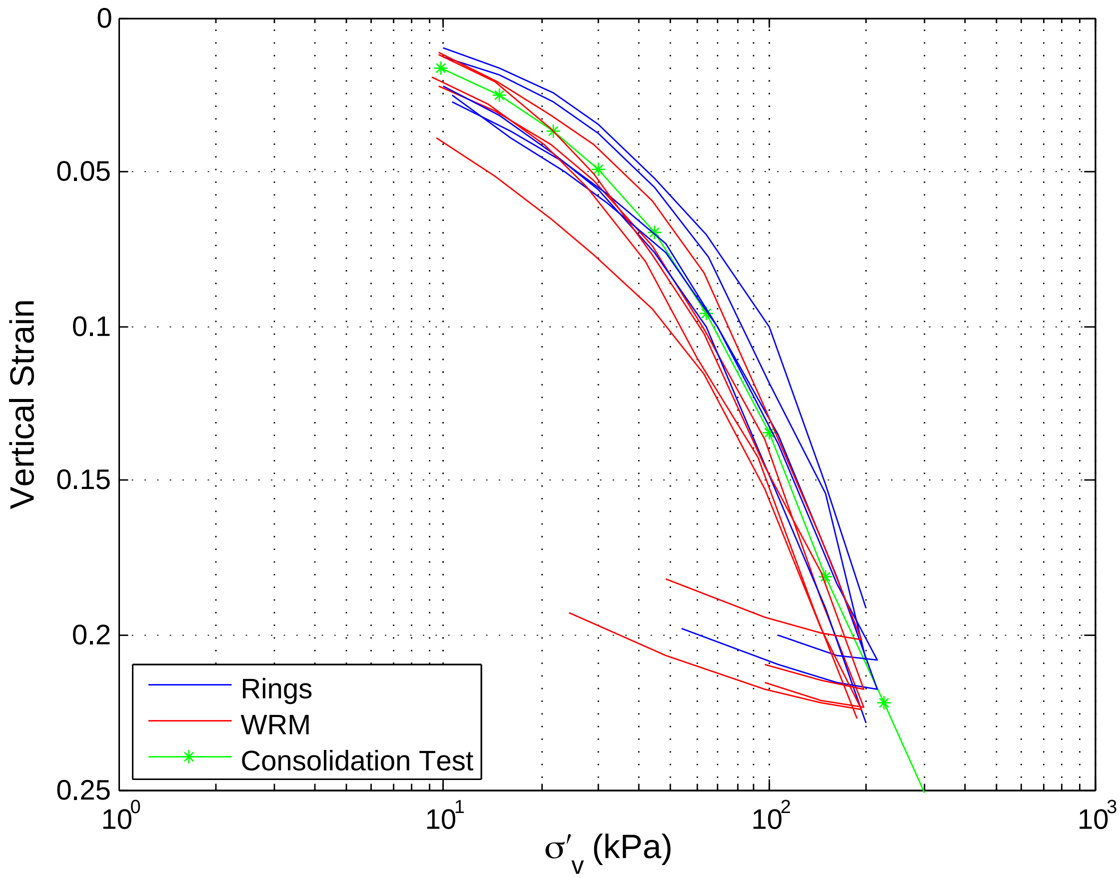


Figure 4-1 – Consolidation test results for samples of Gulf of Mexico clay using stacked rings, wire-reinforced membranes, and one traditional incremental load consolidation test.

4.1.2 Narragansett Bay Organic Silt

Figure 4-2 shows consolidation data for all the tests performed on samples of organic silt from Narragansett Bay using both DSS confinement methods along with a traditional incremental load consolidation test.

The organic silt used for this test was carved from a block sample reconstituted from a slurry and consolidated to exactly 100 kPa before testing. Because the pre-consolidation stress is known we would expect to see the transition point between the 'recompression' and 'virgin' compression portions of the graph to be very near 100 kPa. The preconsolidation stress is not clear from any of the data shown in Figure 4-2. By knowing the exact σ'$_p$ value a clearer consolidation curve was expected, however, the consolidation ring test shows similar results to the two DSS confinement methods.

The lack of a clear preconsolidation stress is attributed primarily to the fact that the soil is a low plasticity silt and some disturbance during trimming and testing. Regardless of the disturbance of the silt, it is clear that all consolidation data regardless of the confinement type resulted in very similar curves and magnitudes.

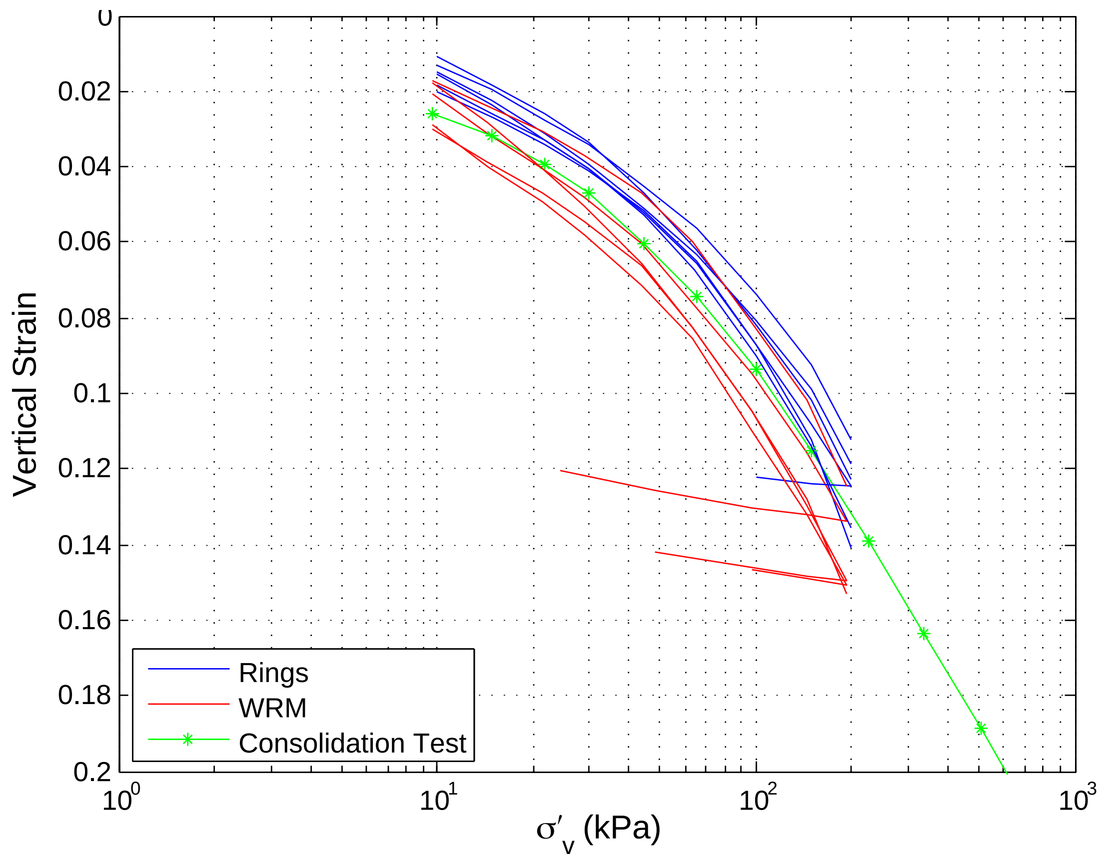


Figure 4-2 - Consolidation test results for samples of Narragansett Bay Organic Silt using stacked rings, wire-reinforced membranes, and one traditional incremental load consolidation test.

4.1.3 Presumpscot Clay

Figure 4-3 shows the results of a constant rate of strain consolidation test performed by Steven Rabasca of Soil Metrics, LLC on a high quality sample of Presumpscot clay. These results are included in this section to highlight the very unique and unstable properties of this sensitive clay. The sensitivity of the clay is evident by the significant loss of stiffness and increase in vertical strain as the preconsolidation stress was exceeded. This data was provided by the Geocomp Corp., which also supplied the remainder of the Shelby tube for DSS testing. Two DSS tests were performed on this clay, and both samples were consolidated to approximately 85% of the measured preconsolidation stress (90-105 kPa). This is traditionally called a recompression test.

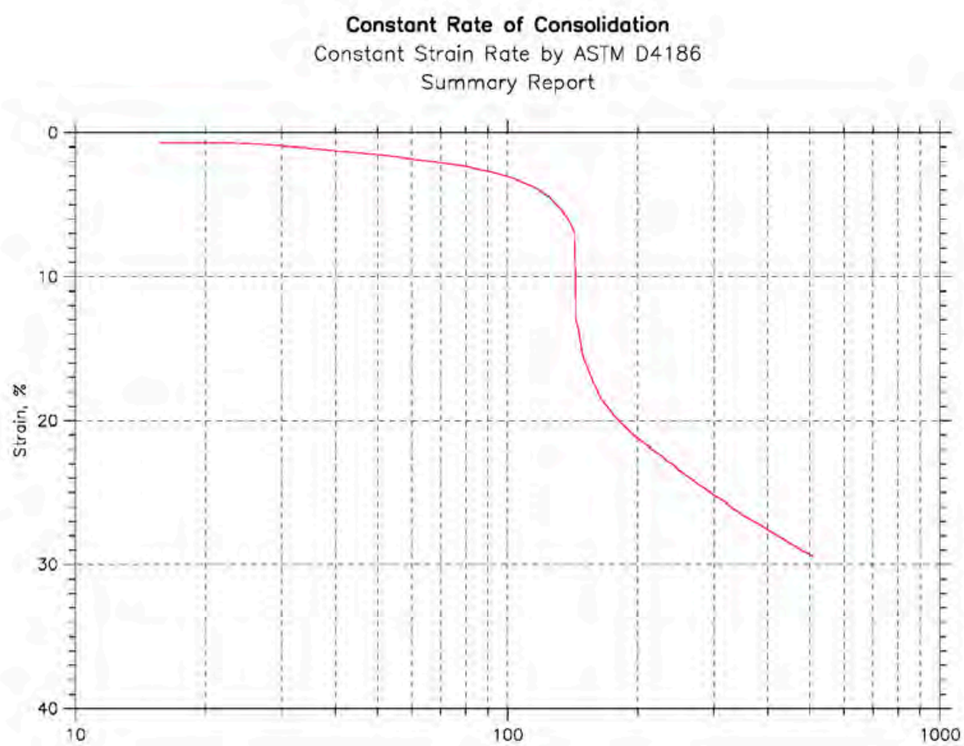


Figure 4-3 – Shear Stress & Pore Pressure vs. Strain (Geocomp, Corp.)

Figure 4-4 shows the consolidation data from the two DSS tests on Presumpscot clay. The vertical strain to the consolidation stress of 105 kPa exceeded 13%, indicating significant disturbance of the samples. The consolidation test (Figure 4-3) and DSS tests (Figure 4-4) were not performed at the same time and it is possible that the tube samples for the DSS tests were disturbed during transportation, extrusion, trimming, etc. The objective of this study, however, is to compare the DSS confinement methods and both tests yielded comparable strains under consolidation to 105 kPa.

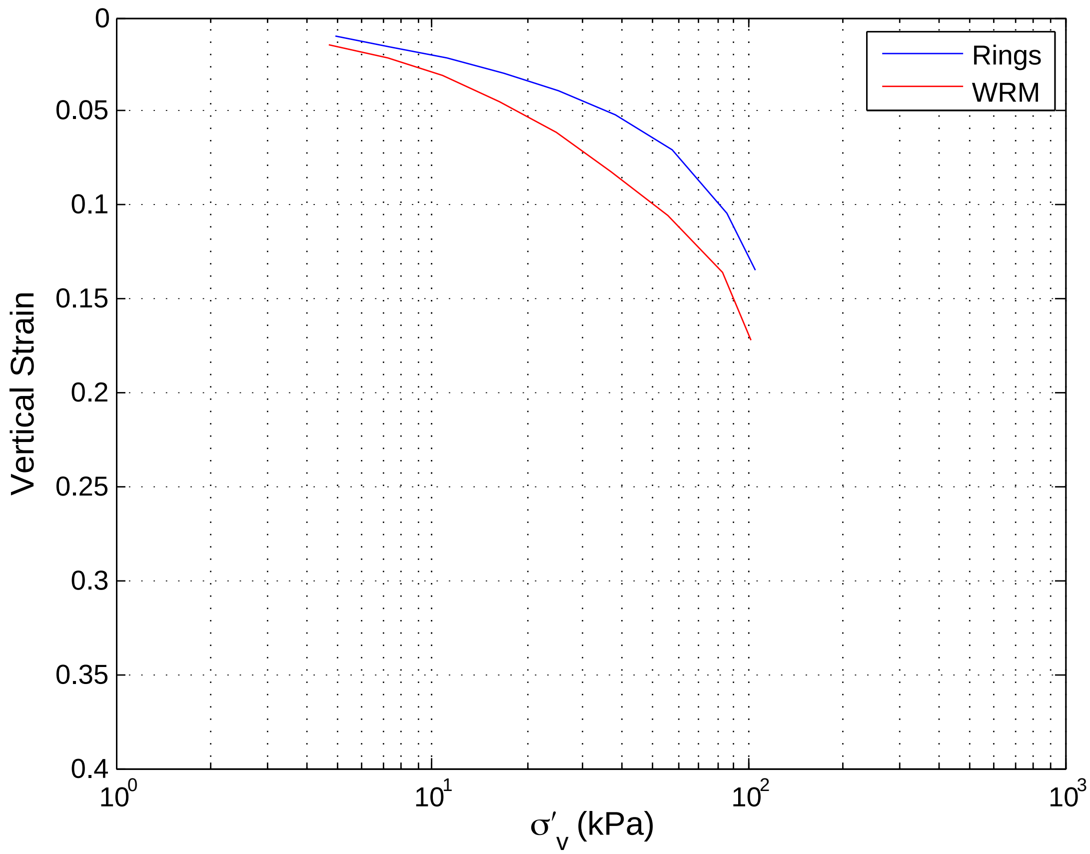


Figure 4-4 – DSS Consolidation Data from Sensitive Clay

4.1.4 Vertical Strain Comparison

Baxter et al. (2010) discussed the effect of the DSS confinement method on measured vertical strain. They concluded that stacked rings provide more rigid confinement compared to the WRM, resulting in slightly higher vertical strains than in the tests involving stacked rings. Table 2 shows average vertical strain rates for tests performed during this thesis. This data supports Baxter's claim, showing a 2-4 % increase in vertical strain when using the WRM instead of the stacked rings.

Table 4-5 – Comparison of Vertical Strain in WRM and Rings (*Presumpscot clay consolidated to 105 kPa)

Vertical Strain to 200 kPa					
Narragansett Bay Silt		**Gulf of Mexico clay**		**Presumpscot Clay**	
Rings	**WRM**	**Rings**	**WRM**	**Rings**	**WRM**
11.2	*15.3*	*20.8*	*24.1*	*13.5**	*17.2**
12.4	*12.45*	*21.7*	*20.2*		
12.2	*15.05*	*22.8*	*28.2*		
12.9	*15.0*	*19.1*	*22.7*		
11.8	*13.4*	*22.1*	*21.7*		
Average Vertical Strain %					
12.1	**14.2**	**21.3**	**23.4**	**13.5**	**17.2**

4.2 Shear Data

4.2.1 Gulf of Mexico Clay

Figure 4-5 shows the results of four DSS tests on Gulf of Mexico clay consolidated to a vertical effective stress of 200 kPa using both the WRM and stacked rings. The results show nearly identical peak shear strength and pore pressure response from both confining systems. The peak shear strength was mobilized at slighty lower shear strains with the WRM followed by noticeable strain softening not present with the stacked rings. This phenomenon was also observed by Baxter et al. (2010). Because the rings are more rigid they may be providing additional strength at higher strains not present when using the WRM. When testing the two confinement types with pressurized water there was slightly more strength present in the rings at higher strains, and a slight drop off in strength of the WRM at higher strains.

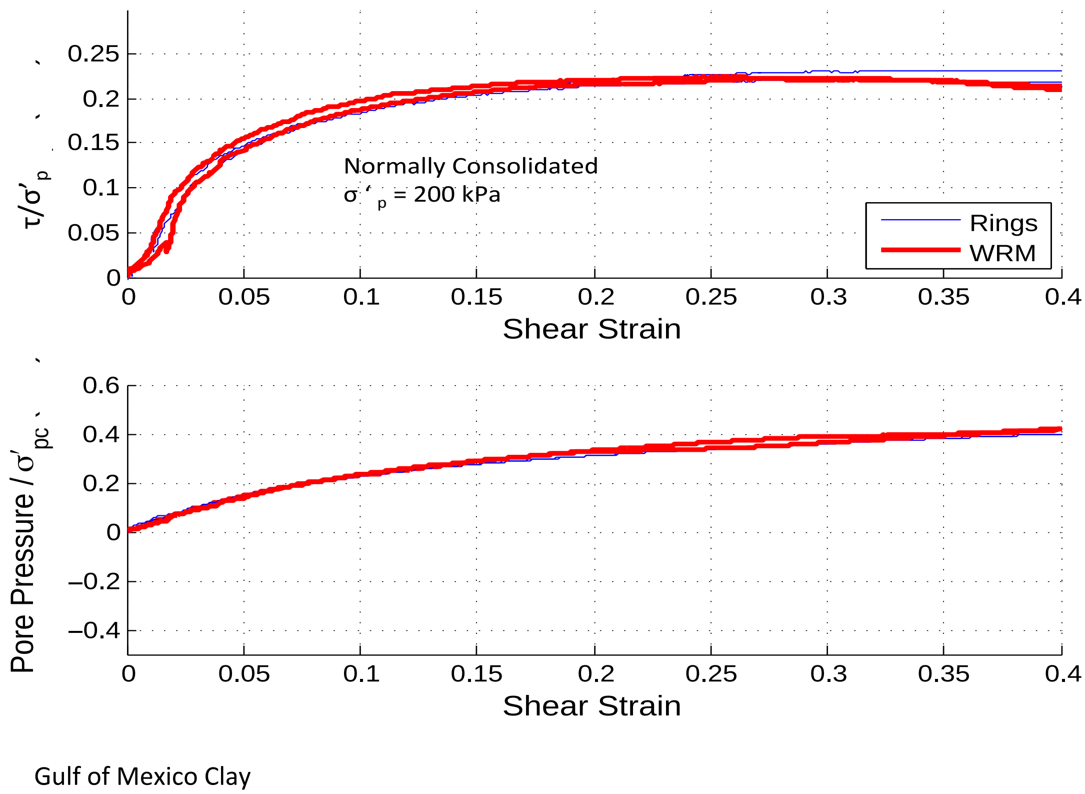


Figure 4-5 – Shear Stress & Pore Pressure vs. Strain

When analyzing the over-consolidated samples in figure 4-4 the differences in the two methods are more pronounced. As seen in the Normally consolidated tests there is significantly more strain softening present in the WRM tests compared to the Rings. It's seen even more clearly in the over-consolidated tests than in the normally-consolidated tests in figure 4-3.

With the exception of the test with an OCR of 2 the max shear strength of the over-consolidated tests seem to be very similar, however, at .2 strain the separation begins.

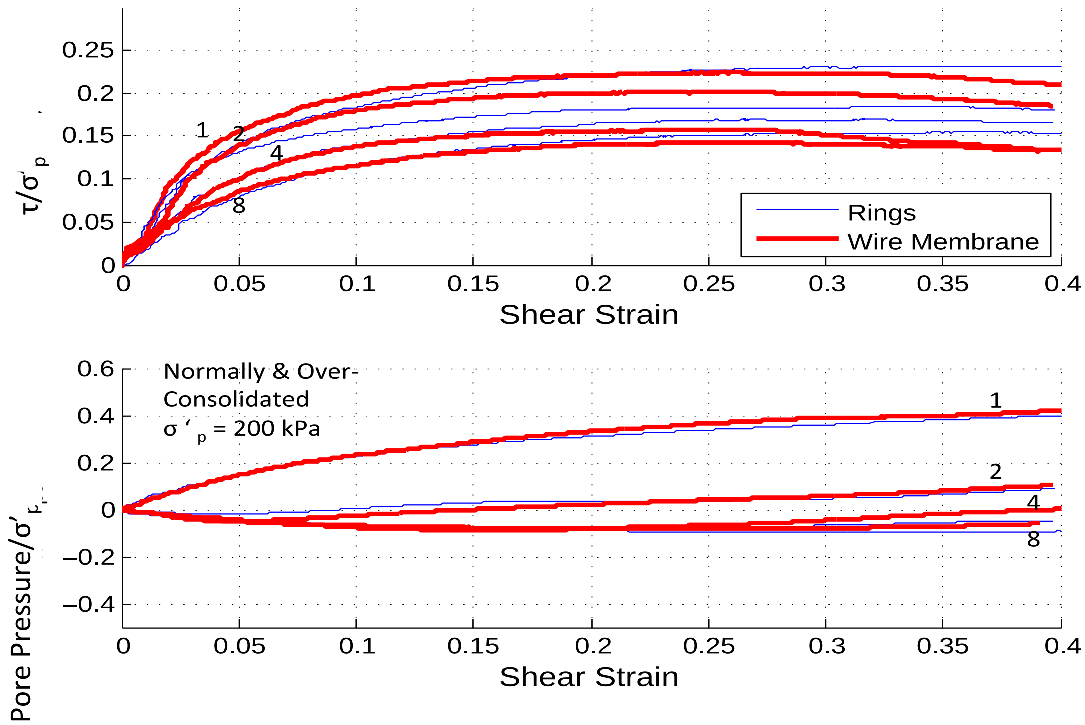


Figure 4-6 – Gulf of Mexico Clay Normally and Over Consolidated Shear and Pore pressure vs. strain.

Figures 4-7 and 4-8 show the stress paths in s’-t space for both normally and over-consolidated tests. From these figures it is clear that in all but the case of OCR=2 the stacked rings provide slightly more strength than the WRM’s.

The most consistency between the test confinement types is clearly observed in the normally consolidated tests.

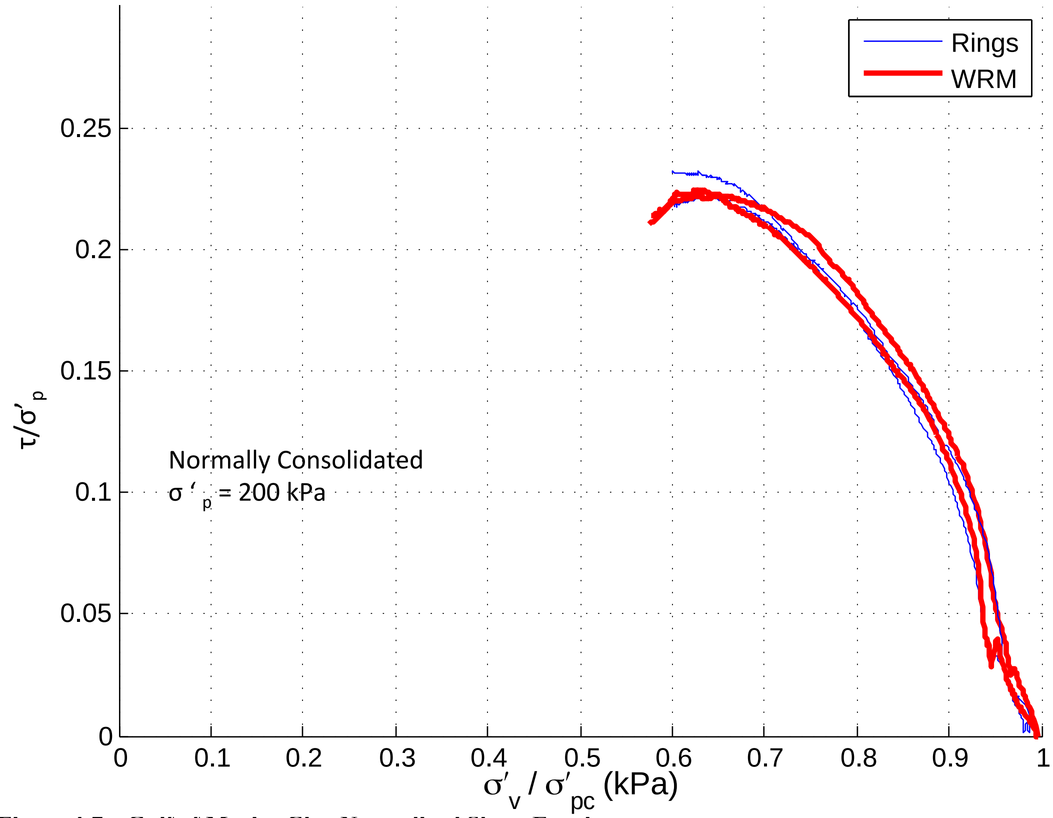


Figure 4-7 – Gulf of Mexico Clay Normalized Shear Envelope

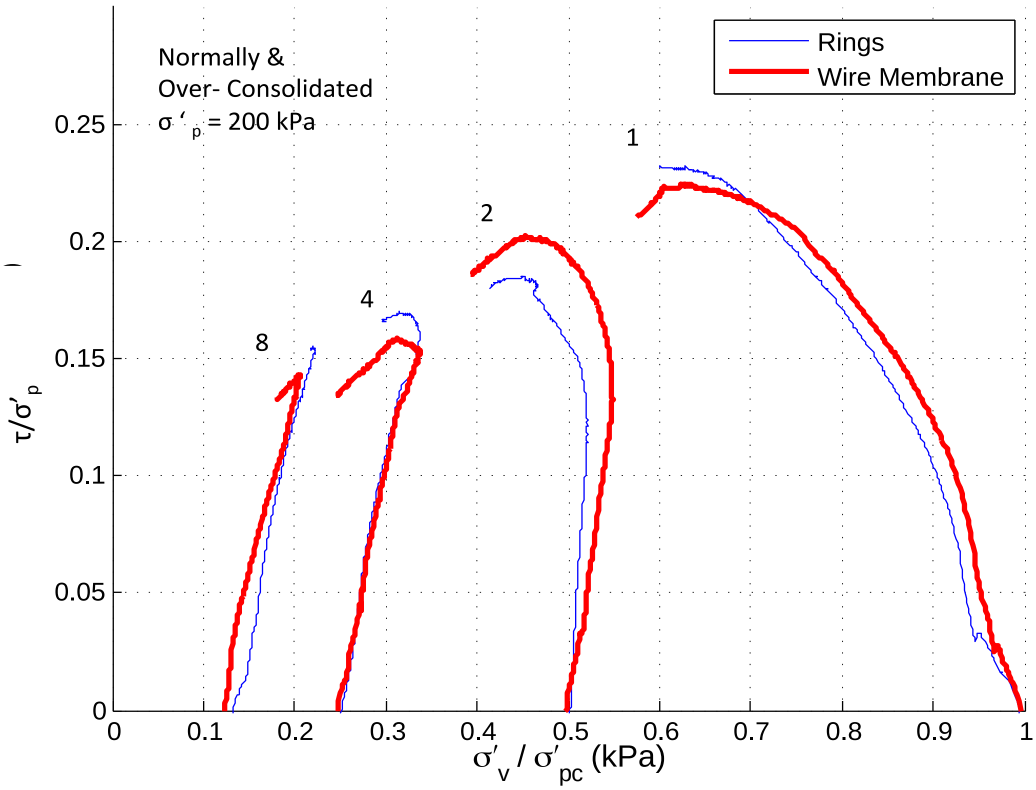


Figure 4-8 – Gulf of Mexico Clay varying OCR's Stress Paths

4.2.2 Narragansett Bay Silt

From figure 4-9 we see close resemblance between the two confinement types when testing Silty soil. As expected, there is more strain softening seen with the WRM, however it does not impact the maximum shear stress value. There does seem to be a slight increase in pore pressure at the tail end of the plots of the WRM tests not present in the Ring data that correlates with the softening in the Shear plots. This is also present in the Gulf of Mexico Results.

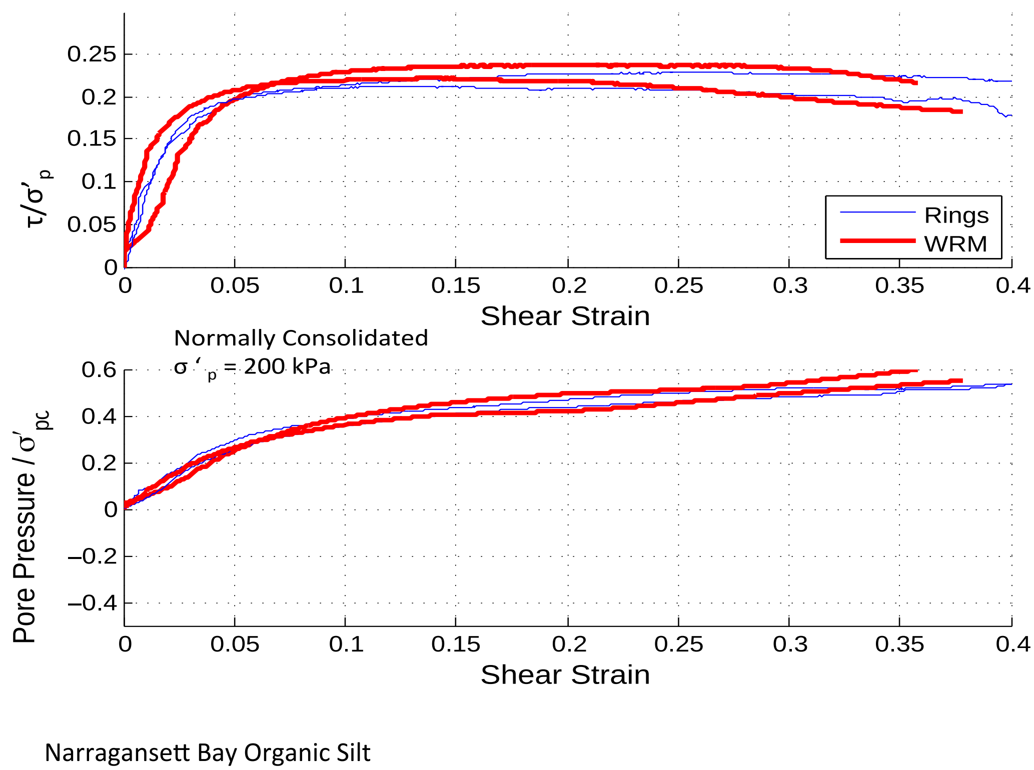


Figure 4-9 – Normally-Consolidated Narragansett Bay Silt Shear data

In figure 4-10 over consolidation ratio's of 1,2,4, and 8 were tested. When testing the silt there is a distinct amount of erratic data points in the Ring data past strain rates of .2 in all test with OCR's of 2 or more. This 'erratic' data is not seen in the normally consolidated test at the same strain rates.

The expected strain softening from the WRM and similar maximum shear values between both test types are present at the various OCR's. This data suggests the rings may not provide consistent results at higher strain in certain soil types.

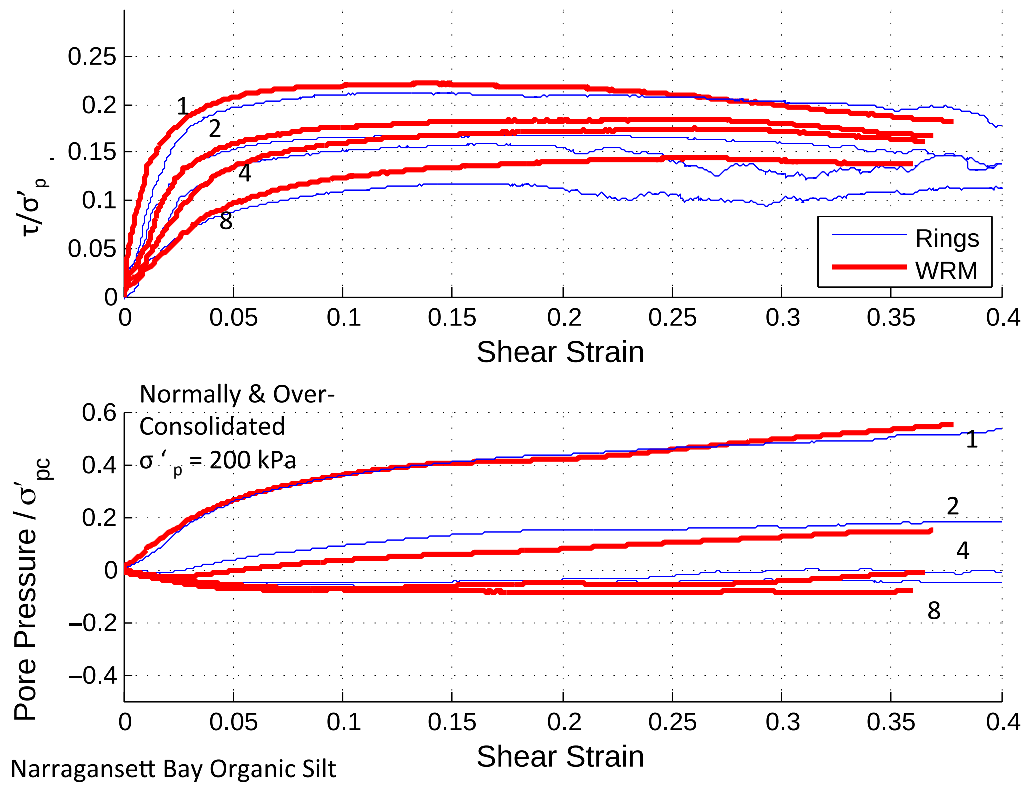


Figure 4-10 – Normally and Over-Consolidated DSS Shear phase data Narragansett Bay Silt

The shear envelopes of the normally-consolidated Narragansett Bay Silt are very similar, with slightly more strength seen in the WRM. This difference is slight, but is different from the Gulf of Mexico Clay data, where the slight strength increase was seen with the Rings.

When looking at the over-consolidated samples the erratic Ring data at high strain rates of the samples at 2,4, and 8 OCR's is clear, and seems to strike immediately following the max shear value. This raises the question, does the minimal decrease in strength of the Rings compared to the WRM at higher OCR's have to do with inconsistent data at higher strain rates? Because of the low magnitude of the strength differences it could also be due to normal error. The difference in the plasticity index of the Narragansett Bay Silt and Gulf of Mexico Clay may be a reason for the conflicting data regarding which confinement method results in the higher peak strength. The less plastic a soil is could lead to inconsistencies in the strength readings at higher strains in the Rings.

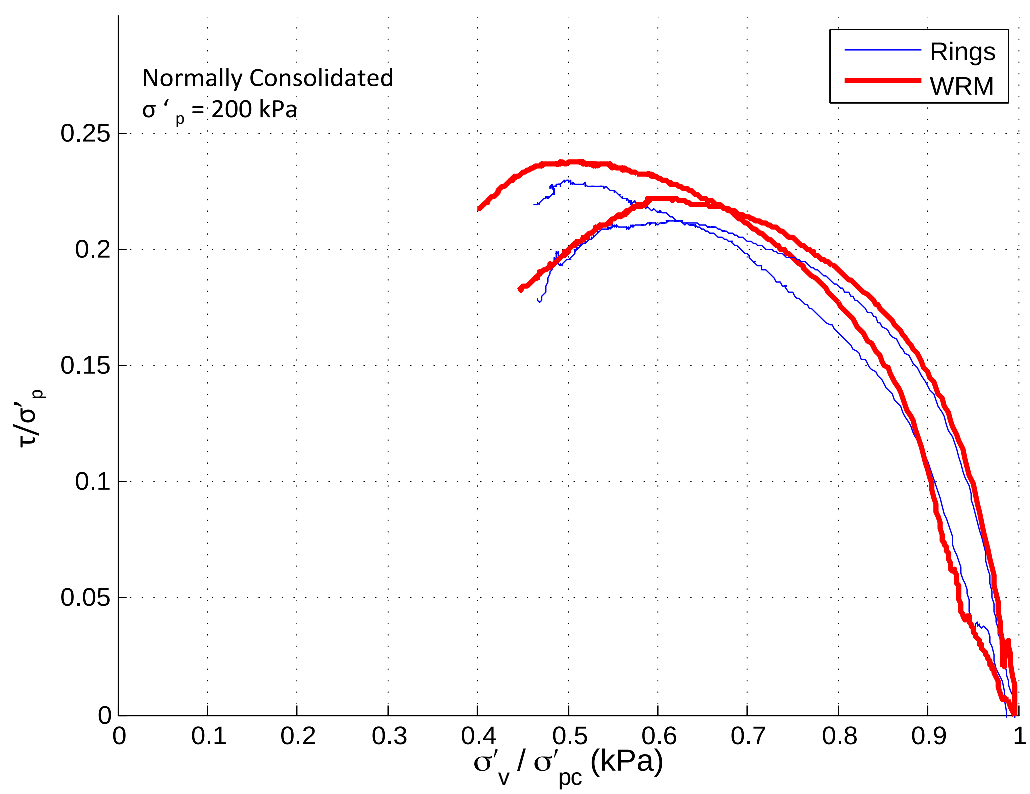


Figure 4-11 – Normally -Consolidated DSS Shear Envelope Narragansett Bay Silt

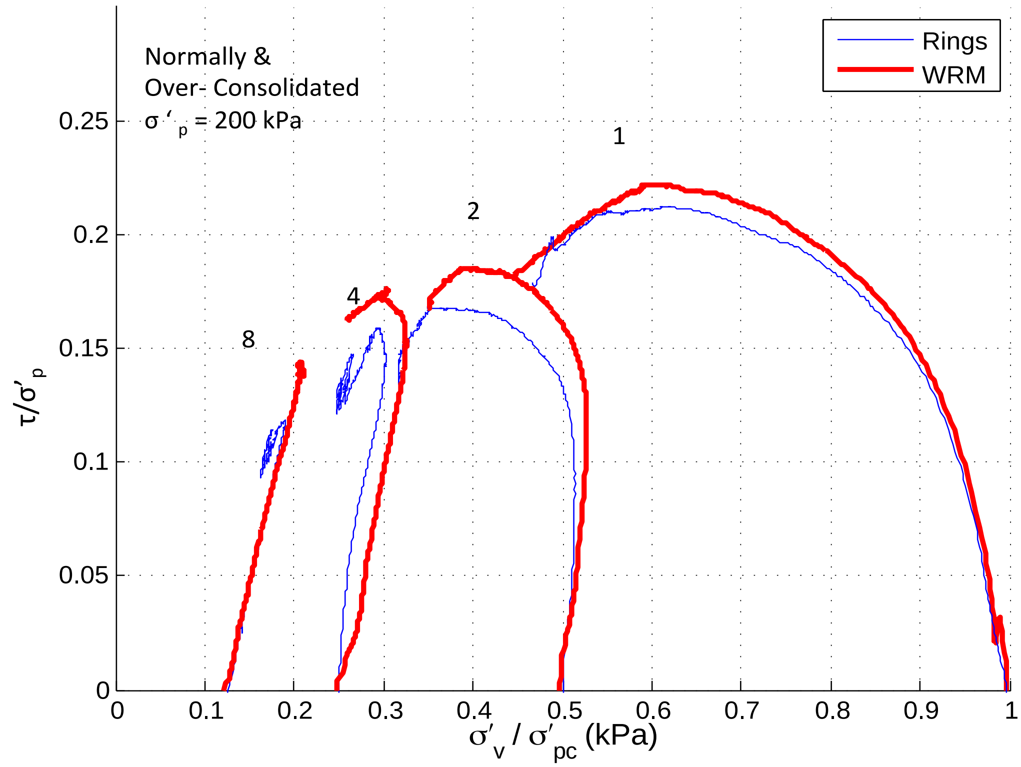


Figure 4-12 – Normally and Over-Consolidated DSS Shear Envelope data Narragansett Bay Silt

4.2.3 Presumpscot Clay

The highly sensitive nature of the Presumpscot Claylends itself to more significant strain softening behavior than was seen with the Gulf of Mexico clay or organic silt. This is seen clearly in Figure 4-13.

Again, there was slightly more strain softening present with the WRM results than with the stacked rings. This post-peak softening seems to have no bearing on the maximum shear stress reading for either method.

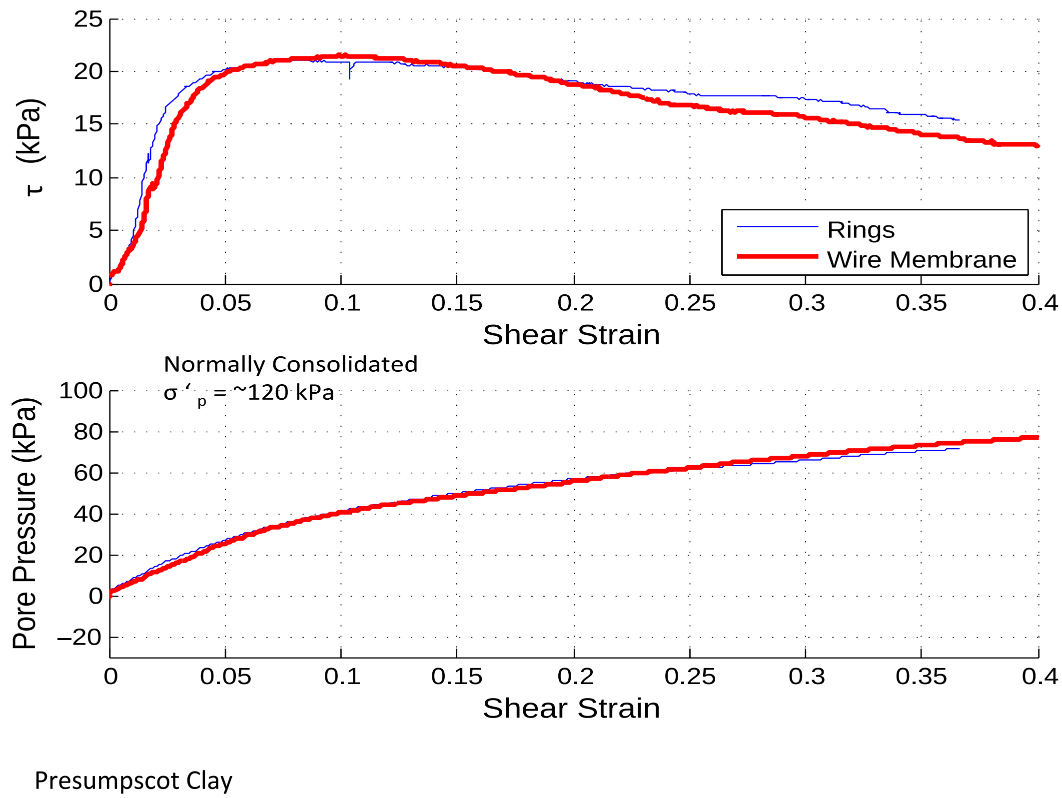


Figure 4-13 – Shear Stress and Pore Pressure vs. Strain Data for Presumpscot Clay.

The stress paths in s'-t space shown in Figure 4-14 clearly shows very similar strengths between the two tests. Interestingly a sharper peak is present with the WRM followed by a slightly quicker reduction in strength than seen in the stacked rings

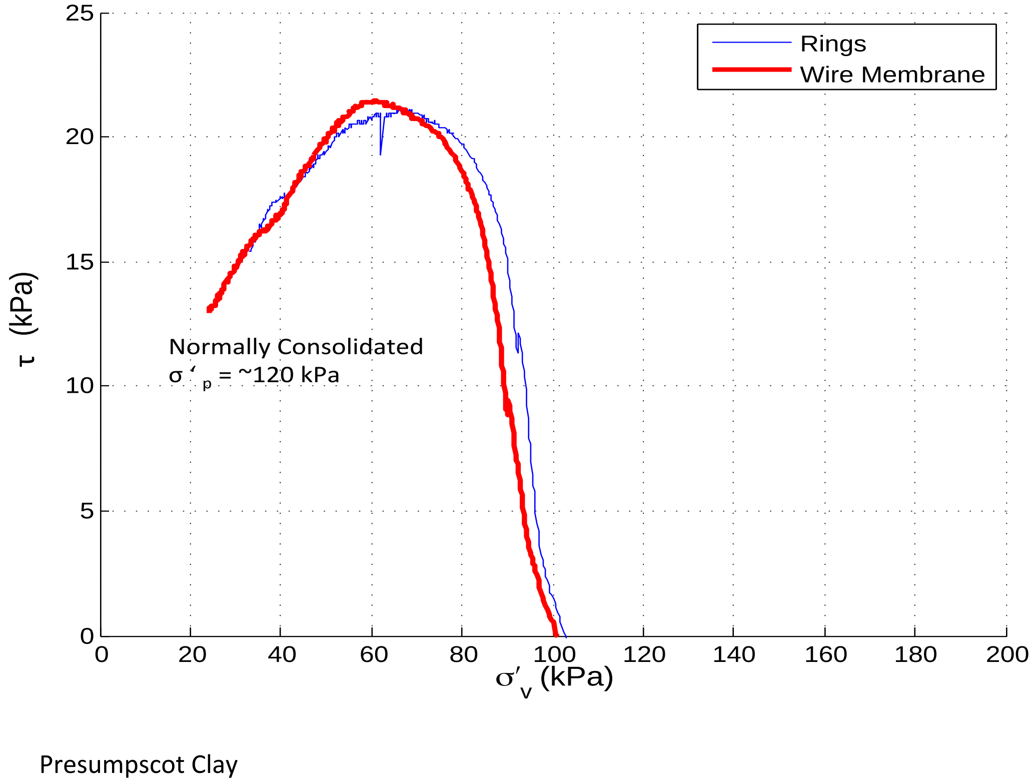


Figure 4-14 – Stress paths in s’-t space for DSS tests on normally consolidated samples of Presumpscot clay.

4.3 Stress History and Normalized Soil Engineering Properties (SHANSEP)

4.3.1 Gulf of Mexico Clay

Figures 4-15 and 4-16 compares the SHANSEP parameters obtained using both confinement methods for the Gulf of Mexico clay and the organic silt from Narragansett Bay. The relevant values from this plot are the abscissa (S) and slope (m). These values are used in the following equation as a method to determine shear strength based on stress history:

$$Su/\boldsymbol{\sigma}'_{vc} = (Su/\boldsymbol{\sigma}'_{p})_{nc} \text{ x } OCR^{m}$$

The m-value for the Gulf of Mexico clay for the metal rings is .78 and is .77 for the WRM. Based on the shear results already presented using the GoM clay this similarity is not surprising and is well within the margin for error. An agreement in values this close speaks to how similar the maximum shear strength results are using either confinement method on a disturbed plastic clay.

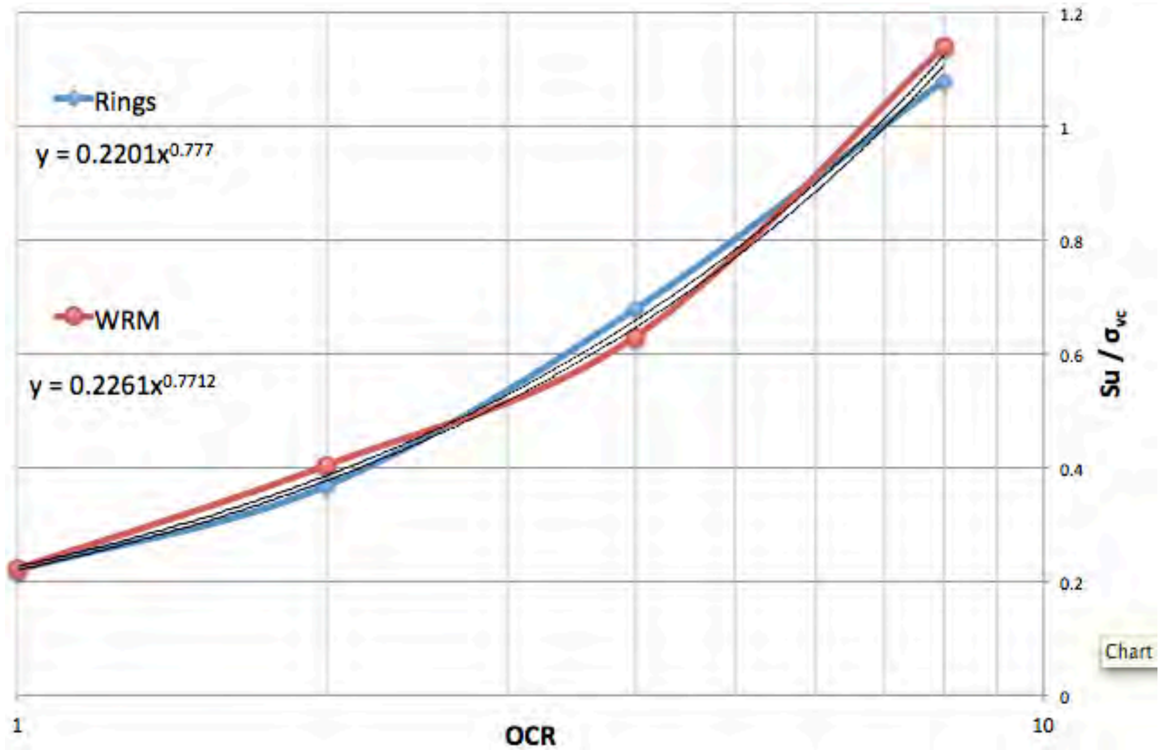


Figure 4-15 – Comparison of Su / σ_{vc} vs OCR data of Gulf of Mexico clay using stacked rings and WRM

4.3.2 Narragansett Bay Silt

The m-values for the organic silt tests show a more noticeable difference, with the strength ratio (Su / σ'_{vc}) becoming increasingly smaller in the stacked rings at each level of OCR. The m-value calculated from the stacked ring data is .74 vs. .81 calculated from the WRM data. The abscissa for each confinement method is nearly identical. This result is contrary to the Gulf of Mexico clay results and is counter-intuitive to expected strength differences. With the harder sides of the metal rings if there was a noticeable disparity in strength it would be expected to favor the strength ratio in the rings, not reduce it. While still minimal, it appears in slightly organic silts there is a more noticeable difference in strength calculated in the confinement methods at increasing OCR's.

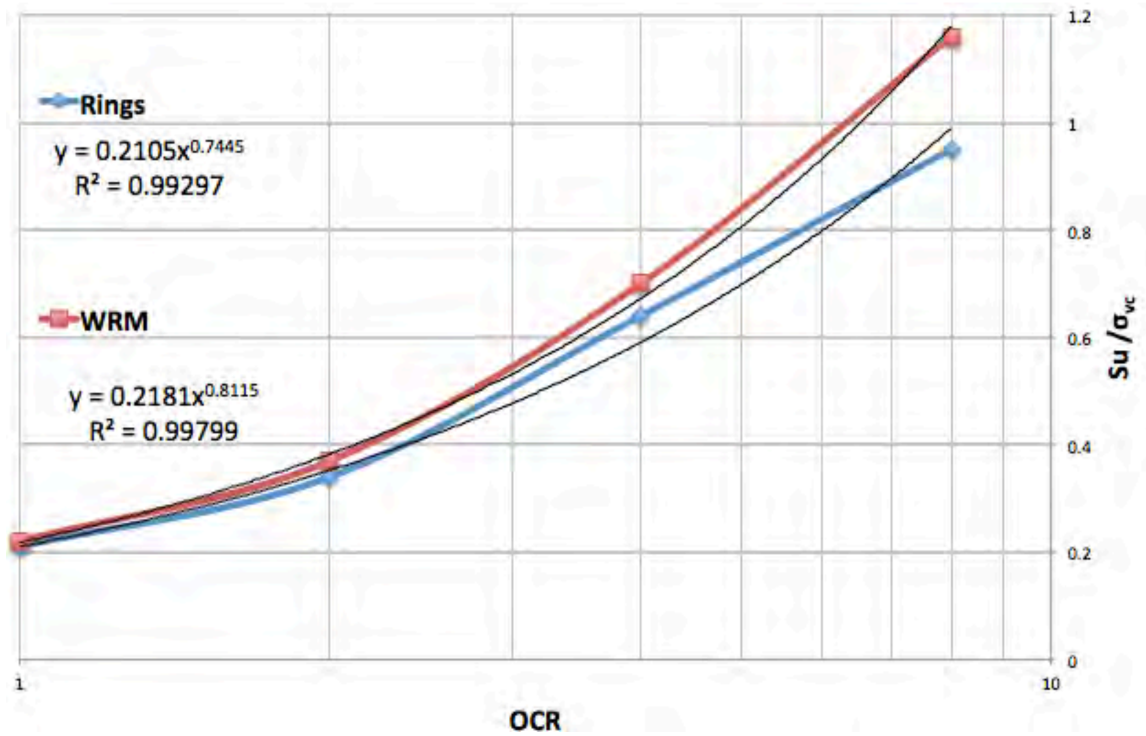


Figure 4-16 – Comparison Plot of Su / σ_{vc} vs OCR of Narragansett Bay Silt using Rings and WRM.

Table 4-6 summarizes the normalized shear stress values (τ/σ'_{vc}) used in the construction of Figures 4-15 and 4-16. The differences in values increases as the OCR increases. There is very close agreement between the values at OCR's of 1, 2, and 4 for both soil types. At an OCR of 8 the Silt shows a more appreciable difference between stacked rings and WRM.

Table 4-6 – Comparison strength ratios, τ/σ'_{vc}, at different OCR's for Organic Silt and GoM Clay as determined by DSS testing using metal stacked rings and WRM confinement methods.

	Silt (τ/σ'_{vc})			GoM (τ/σ'_{vc})		
OCR	Rings	WRM	Δ	Rings	WRM	Δ
1	0.21	0.22	*0.01*	0.23	0.22	*0.01*
2	0.34	0.37	*0.03*	0.37	0.40	*0.03*
4	0.64	0.70	*0.06*	0.68	0.63	*0.05*
8	0.95	1.16	*0.21*	1.08	1.14	*0.06*

5. Summary & Conclusions

The primary goal of this thesis was to compare the results of direct simple shear tests on different soil types under various stress conditions using a Wire Reinforced Membrane and Teflon-coated stacked rings as confinement methods. Both of these confinement methods have been approved in ASTM D2435, however there are almost no published studies comparing shear strengths obtained with each system. Comparisons were made of both consolidation and shear data for each soil and confining system.

The three soils tested were a high plasticity clay from the Gulf of Mexico, a low plasticity organic silt from Narragansett Bay in Rhode Island, and a sensitive clay from Portland, Maine called the Presumpscot Formation. The Gulf of Mexico Clay has been tested extensively at the University of Rhode Island, and 10.16 cm tube samples of intact clay were available for this study.

The organic silt was collected from 10.16 cm diameter gravity cores in Fall of 2010. In the spring of 2011, the organic silt was reconstituted into a slurry and consolidated to 100 kPa as a block sample. Following reconsolidation, the block was subsampled and stored in a refrigerator sealed with cheesecloth and wax until it was ready for testing.

A 6 inch section of a Shelby tube of the Presumpscot clay was provided by Steven Rabasca of Soil Metrics, LLC and the Geocomp, Corp. The sample had been collected from the field a month prior to laboratory testing.

Tests were performed on both normally consolidated and overconsolidated samples of the Gulf of Mexico clay and organic silt. There was not enough Presumpscot clay to run more than 2 recompression tests on undisturbed specimens.

From the test results, the following conclusions can be drawn regarding the comparison of wire-reinforced membranes and stacked rings in DSS testing:

- More vertical strain is present in the samples confined using the WRM during the consolidation phase than is seen with the stacked rings. This is likely due to reduced radial strain in the stiffer stacked ring system.. There was approximately 2-4% more vertical strain in all the WRM samples when compared to the test results using stacked rings. This finding is consistent with the results of a similar study performed by Baxter et al. (2010).
- Values of peak shear strength on normally consolidated samples were nearly equal using both confinement methods.
- There was a clear trend of increased strain softening in the tests performed with the WRM when compared to results of tests confined with the stacked rings. This phenomenon was thought to be due to increased resistance in the rings by Baxter et al. (2010).
- The normalized strengths of overconsolidated samples of organic silt obtained with the stacked rings were consistently smaller than the strengths obtained using the WRM. This was highlighted by the m-values calculated using the SHANSEP approach (Su/σ_{vc} vs. OCR). An m of .75 was calculated using the Rings vs a value of .81 for the WRM. It is not clear why this occurred or whether it is unique to the coarser-grained organic silt.

- Correction factors for both confinement systems were comparable and relatively small.
- Although there are differences between the two confinement types they are minimal in most cases and both methods can be used with confidence.

5.3 Recommendations for Future Work

The results of this thesis suggest that the effect of stacked rings or wire-reinforced membranes on measured values of undrained shear strength is minimal.

These results were obtained primarily on disturbed or reconstituted samples, and future study should focus on testing a range of high quality undisturbed samples. To add further validity to these findings additional tests could be run on an even wider range of soils, some of which should be undisturbed.

On most normally consolidated samples tested during this research they were consolidated to a stress that was greater than 2 times their previous consolidation stresses. Additional testing on normally consolidated samples at varying vertical stresses would be beneficial in verifying these results.

Appendix A Non-Normalized DSS Plots

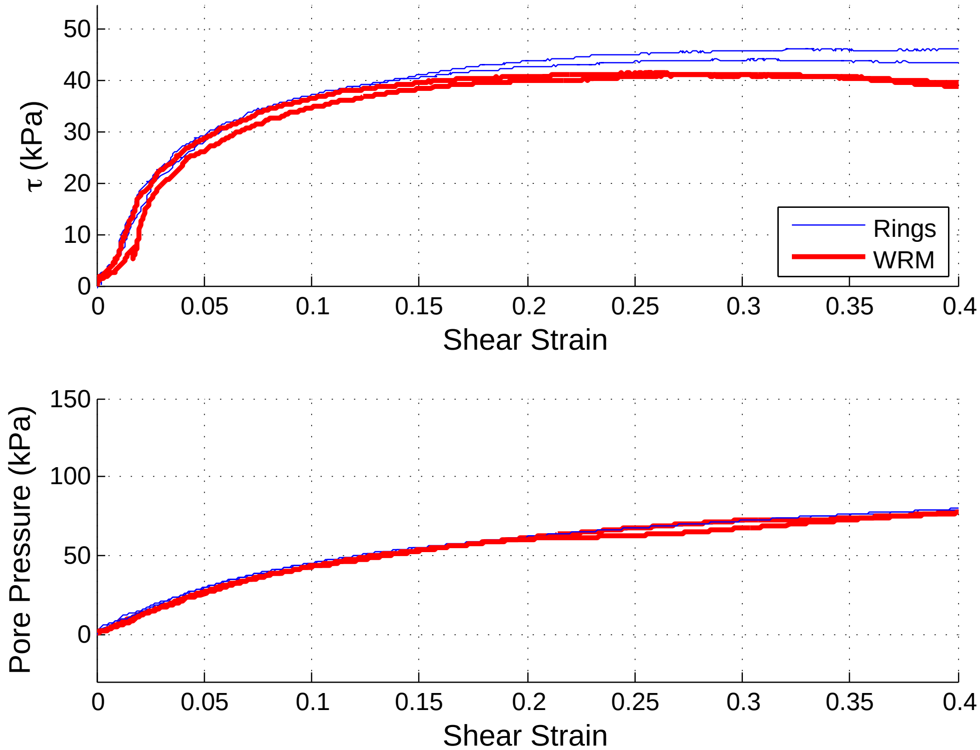


Figure A-1 – Gulf of Mexico Clay Normally Consolidated Comparison Plot

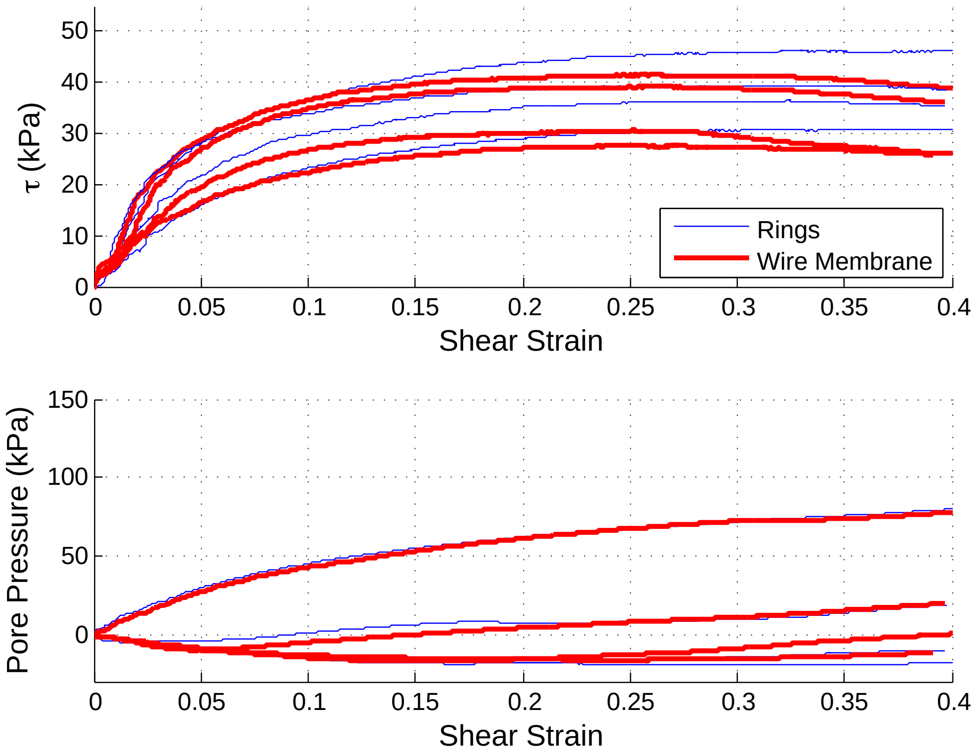


Figure A-2 – Gulf of Mexico Clay Over Consolidated Comparison Plot

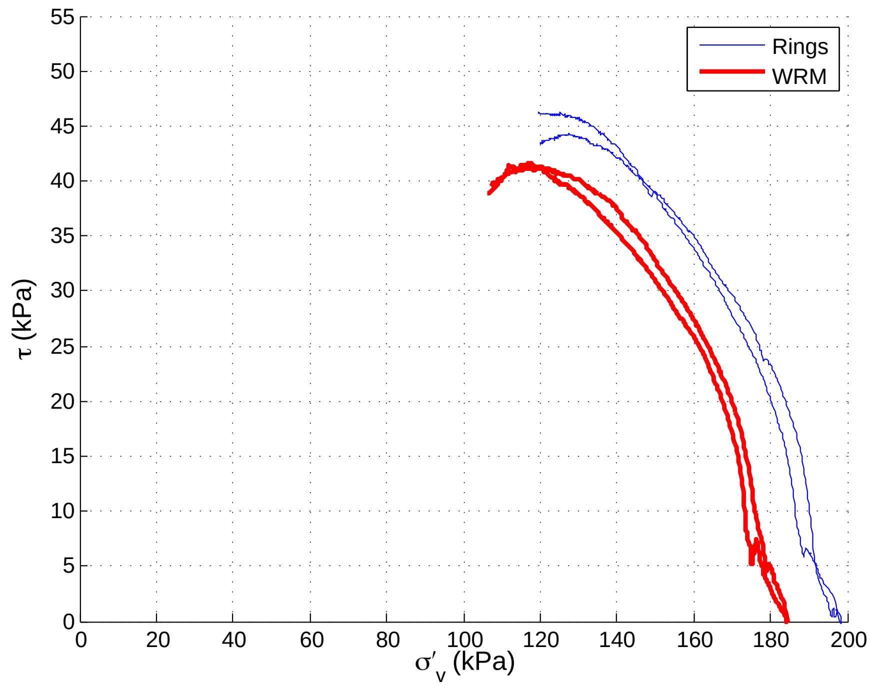


Figure A-3 – Gulf of Mexico Clay non-Normalized Shear Envelope

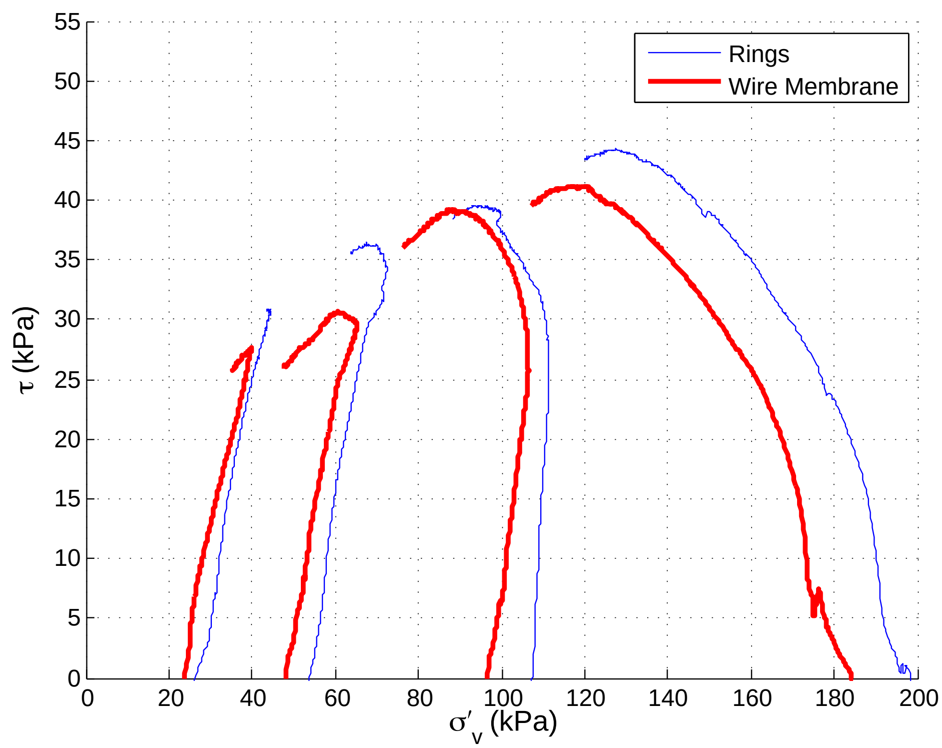


Figure A-4 – Gulf of Mexico Clay OCR Envelopes

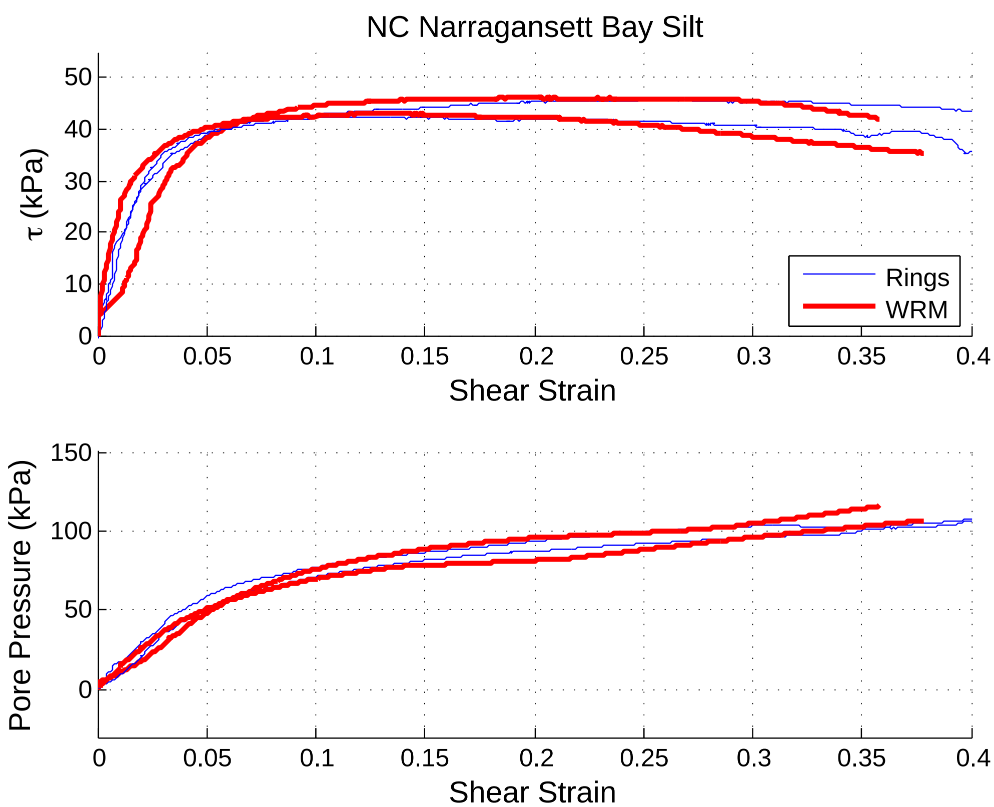


Figure A-5 – Narragansett Bay Organic Silt Normally Consolidated Comparison Plot

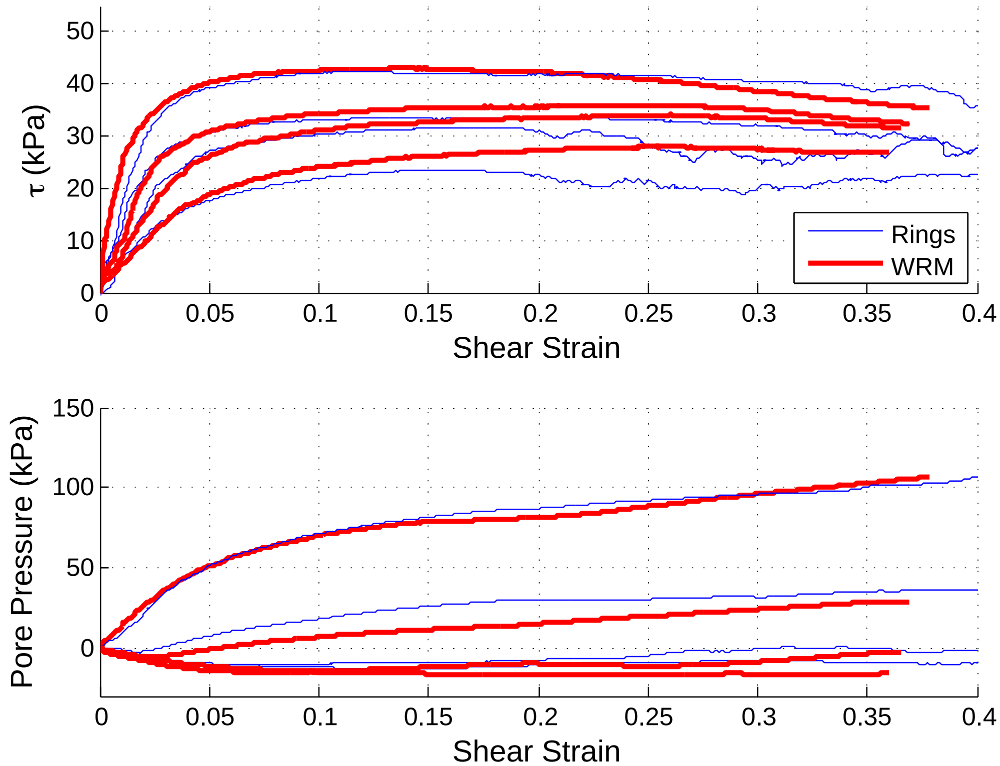


Figure A-6 – Narragansett Bay Organic Silt OCR Comparison Plot

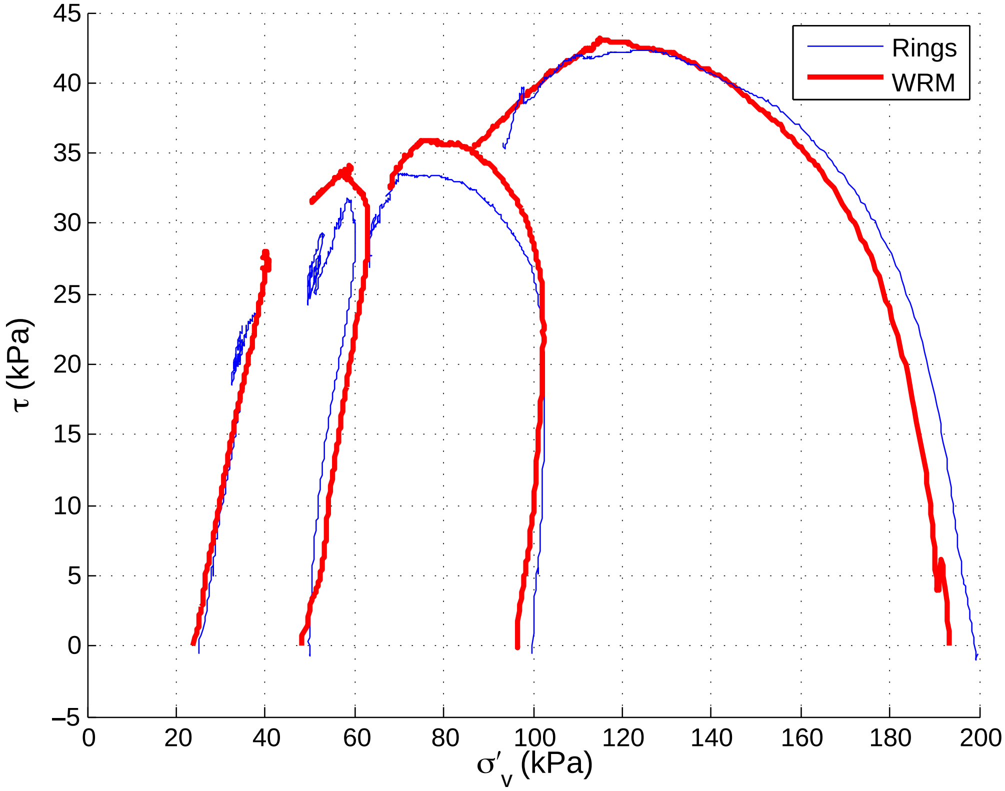


Figure A-7 – Narragansett Bay Organic Silt OCR Shear Envelope

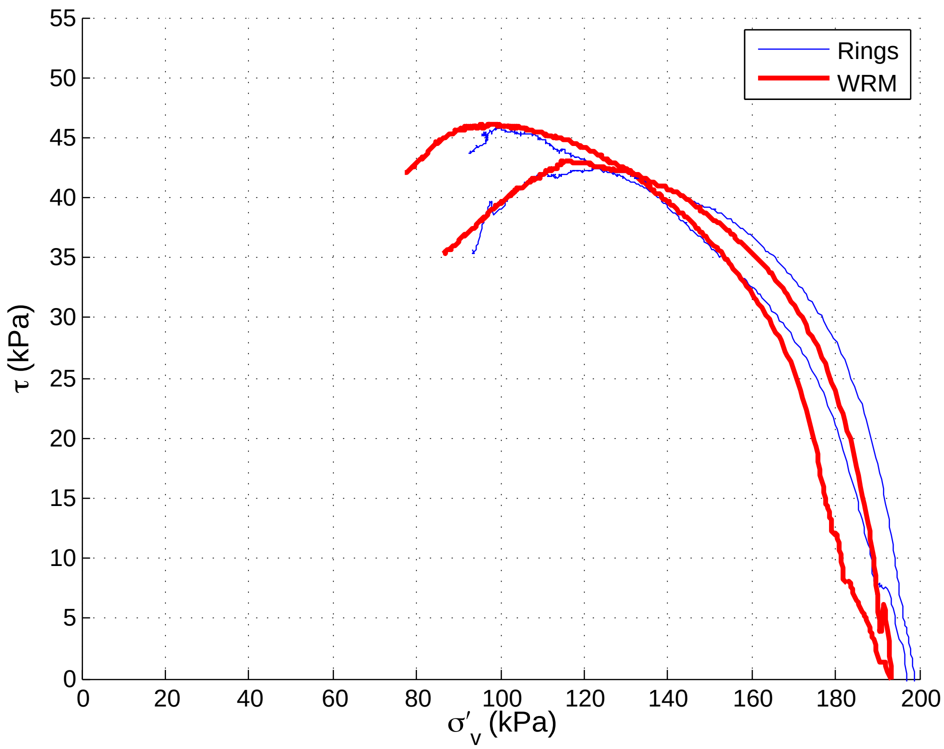


Figure A-8 – Silt NC Shear Envelope

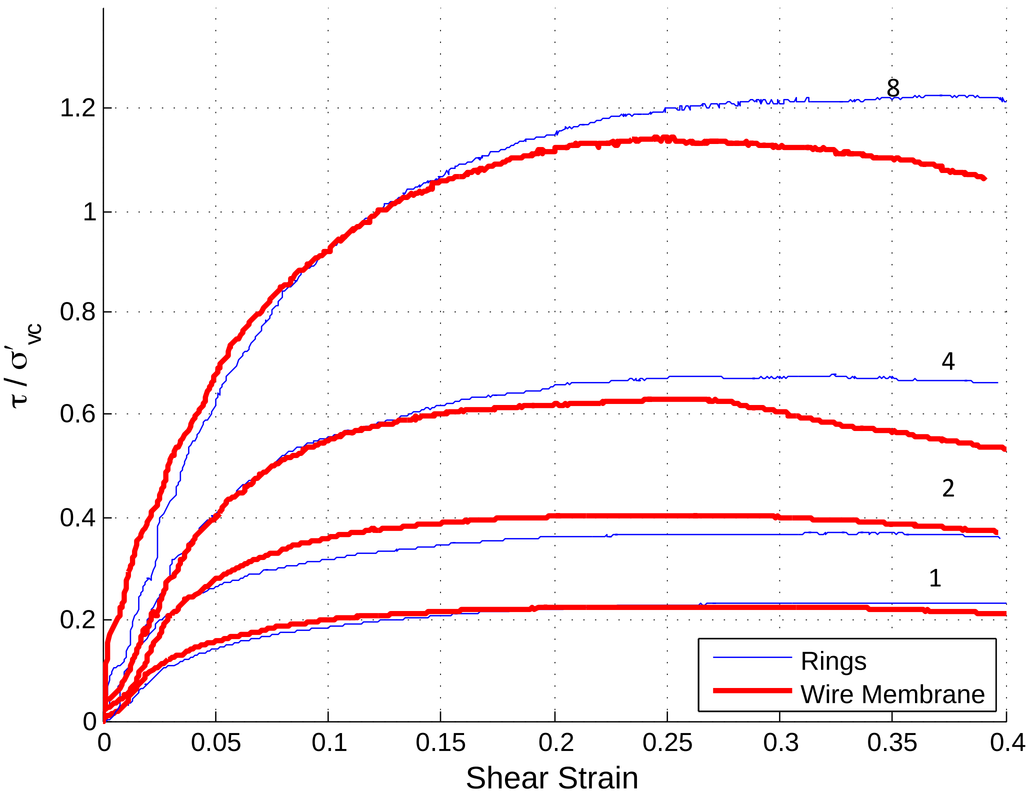


Figure A-9 – Gulf of Mexico Clay stress strain plot normalized by σ'$_{vc}$

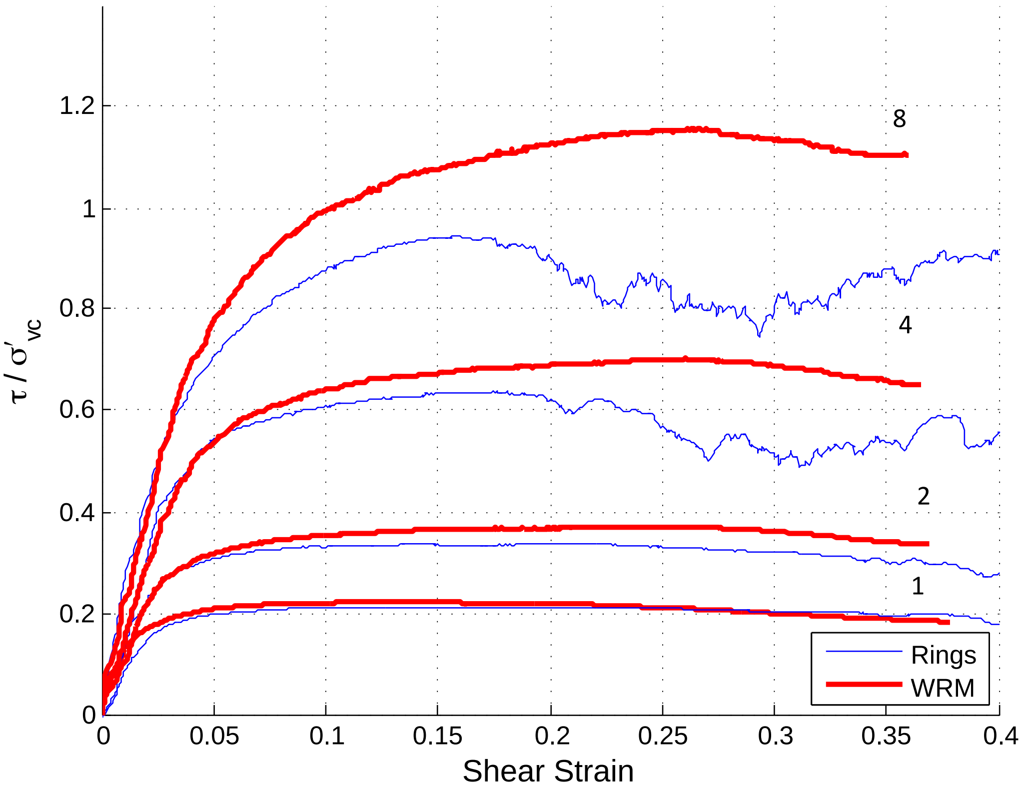


Figure A-10 – Narragansett Bay Organic Silt stress strain plot normalized by σ'$_{vc}$

Appendix B MATLAB Code

B1 – Data Files

```
%This script file is used to store test data and is called on in other
%functions and script files

area1 = .00317; %m2 area of Rings
area2 = .0035; %m2 area of WRM
area3 = .002; %m2 are of Chris Baxter et al correction factor testing

%initial heights in mm
%height5 = 25.4; %mm
height6 = 1.2*25.4; %mm - converted from 1.2 inches
height7 = 1.1*25.4; %mm
height8 = 25.4; %mm
height9 = 25.4; %mm
height10 = 25.4;
height11 = 25.4;
height12 = .9*25.4;
height13 = 25.4;
height14 = 25.4;
height15 = 25.4;
height16 = 25.4;
height17 = 25.4;
height18 = 25.4;
height19 = 25.4;
height20 = 25.4;
height21 = 25.4;
height22 = .94*25.4;
height23 = 25.4;
height24 = 25.4;
height25 = 25.4;
height26 = 25.4;
height27 = 25.4*1.03;
height28 = .75*25.4;
height29 = 1.04*25.4;
height30 = 25.4;
height31 = 25.4;
height33 = .75*25.4;
height32 = 1*25.4;
height34 = 1*25.4;
height35 = 1*25.4;
height36 = 1*25.4;
height37 = 1*25.4;
height38 = 1*25.4;
```

```
height39 = 1*25.4;
height40 = 1*25.4;
height41 = 1*25.4;
height42 = 25.4;
height43 = 25.4;
height44 = 25.4;
height45 = 25.4;
height46 = 25.4;
height47 = 25.4;
height48 = 25.4;
height49 = 25.4;
height50 = 25.4;
height51 = 25.4;
height52 = 25.4;
height53 = 25.4;
height54 = 25.4;
height55 = 25.4;
height56 = 30.58-6.33;


%Calls on all shear data file used in analysis
xlsread test5shear.xls; %calls on data file
test5shear = ans; %renames answer
xlsread test6shear.xls; %calls on data file
test6shear = ans; %renames answer
xlsread test7shear.xls; %calls on data file
test7shear = ans; %renames answer
xlsread test8shear.xls; %calls on data file
test8shear = ans; %renames answer
xlsread test9shear.xls; %calls on data file
test9shear = ans; %renames answer
xlsread test10shear.xls; %calls on data file
test10shear = ans; %renames answer
xlsread test11shear.xls; %calls on data file
test11shear = ans; %renames answer
xlsread test12shear.xls; %calls on data file
test12shear = ans; %renames answer
xlsread test13shear.xls; %calls on data file
test13shear = ans; %renames answer
xlsread test14shear.xls; %calls on data file
test14shear = ans; %renames answer
xlsread test15shear.xls; %calls on data file
test15shear = ans; %renames answer
xlsread test16shear.xls; %calls on data file
test16shear = ans; %renames answer
xlsread test17shear.xls; %calls on data file
```

```
test17shear = ans; %renames answer
xlsread test18shear.xls; %calls on data file
test18shear = ans; %renames answer
xlsread test19shear.xls; %calls on data file
test19shear = ans; %renames answer
xlsread test20shear.xls; %calls on data file
test20shear = ans; %renames answer
xlsread test21shear.xls; %calls on data file
test21shear = ans; %renames answer
xlsread test22shear.xls; %calls on data file
test22shear = ans; %renames answer
xlsread test23shear.xls; %calls on data file
test23shear = ans; %renames answer
xlsread test24shear.xls; %calls on data file
test24shear = ans; %renames answer
xlsread test25shear.xls; %calls on data file
test25shear = ans; %renames answer
xlsread test26shear.xls; %calls on data file
test26shear = ans; %renames answer
xlsread test27shear.xls; %calls on data file
test27shear = ans; %renames answer
xlsread test29shear.xls; %calls on data file
test29shear = ans; %renames answer
xlsread test30shear.xls; %calls on data file
test30shear = ans; %renames answer
xlsread test31shear.xls; %calls on data file
test31shear = ans; %renames answer
xlsread test32shear.xls; %calls on data file
test32shear = ans; %renames answer
xlsread test34shear.xls; %calls on data file
test34shear = ans; %renames answer
xlsread test35shear.xls; %calls on data file
test35shear = ans; %renames answer
xlsread test36shear.xls; %calls on data file
test36shear = ans; %renames answer
xlsread test37shear.xls; %calls on data file
test37shear = ans; %renames answer
xlsread test38shear.xls; %calls on data file
test38shear = ans; %renames answer
xlsread test39shear.xls; %calls on data file
test39shear = ans; %renames answer
xlsread test40shear.xls; %calls on data file
test40shear = ans; %renames answer
xlsread test41shear.xls; %calls on data file
test41shear = ans; %renames answer
xlsread test42shear.xls; %calls on data file
```

```
test42shear = ans; %renames answer
xlsread test43shear.xls; %calls on data file
test43shear = ans; %renames answer
xlsread test44shear.xls; %calls on data file
test44shear = ans; %renames answer
xlsread test45shear.xls; %calls on data file
test45shear = ans; %renames answer
xlsread test46shear.xls; %calls on data file
test46shear = ans; %renames answer
xlsread test47shear.xls; %calls on data file
test47shear = ans; %renames answer
xlsread test48shear.xls; %calls on data file
test48shear = ans; %renames answer
xlsread test49shear.xls; %calls on data file
test49shear = ans; %renames answer
xlsread test50shear.xls; %calls on data file
test50shear = ans; %renames answer
xlsread test51shear.xls; %calls on data file
test51shear = ans; %renames answer
xlsread test52shear.xls; %calls on data file
test52shear = ans; %renames answer
xlsread test53shear.xls; %calls on data file
test53shear = ans; %renames answer
xlsread test54shear.xls; %calls on data file
test54shear = ans; %renames answer
xlsread CF_ring_5kpa_1mm-min.xls; %calls on data file
ring5kpa = ans; %renames answer
xlsread CF_ring_10kpa_1mm-min.xls; %calls on data file
ring10kpa = ans; %renames answer
xlsread CF_wrm_5kpa_1mm-min.xls; %calls on data file
wrm5kpa = ans; %renames answer
xlsread CF_wrm_10kpa_1mm-min.xls; %calls on data file
wrm10kpa = ans; %renames answer
xlsread CF_wrm_7kpa_.02mm-min.xls; %calls on data file
wrm7kpa = ans; %renames answer
xlsread CF_ring_7kpa_.02mm-min.xls; %calls on data file
ring7kpa = ans; %renames answer
xlsread CF_ring_bax.xls; %calls on data file
ring7bax = ans; %renames answer
xlsread CF_wrm_bax.xls; %calls on data file
wrm7bax = ans; %renames answer
xlsread test55shear.xls; %calls on data file
test55shear = ans; %renames answer
xlsread test56shear.xls; %calls on data file
test56shear = ans; %renames answer
```

```
%Calls on all consolidation data files
xlsread test5comp.xls; %calls on data file
test5comp = ans; %renames answer
xlsread test6comp.xls; %calls on data file
test6comp = ans; %renames answer
xlsread test7comp.xls; %calls on data file
test7comp = ans; %renames answer
xlsread test8comp.xls;
test8comp = ans;
xlsread test9comp.xls;
test9comp = ans;
xlsread test10comp.xls;
test10comp = ans;
xlsread test11comp.xls;
test11comp = ans;
xlsread test12comp.xls;
test12comp = ans;
xlsread test13comp.xls;
test13comp = ans;
xlsread test14comp.xls;
test14comp = ans;
xlsread test15comp.xls;
test15comp = ans;
xlsread test16comp.xls;
test16comp = ans;
xlsread test17comp.xls;
test17comp = ans;
xlsread test18comp.xls;
test18comp = ans;
xlsread test19comp.xls;
test19comp = ans;
xlsread test20comp.xls;
test20comp = ans;
xlsread test21comp.xls;
test21comp = ans;
xlsread test22comp.xls;
test22comp = ans;
xlsread test23comp.xls;
test23comp = ans;
xlsread test24comp.xls;
test24comp = ans;
xlsread test25comp.xls;
test25comp = ans;
xlsread test26comp.xls;
test26comp = ans;
xlsread test27comp.xls;
```

```
test27comp = ans;
xlsread test28comp.xls;
test28comp = ans;
xlsread test29comp.xls;
test29comp = ans;
xlsread test30comp.xls;
test30comp = ans;
xlsread test31comp.xls;
test31comp = ans;
xlsread test33comp.xls;
test33comp = ans;
xlsread test32comp.xls;
test32comp = ans;
xlsread test34comp.xls;
test34comp = ans;
xlsread test35comp.xls;
test35comp = ans;
xlsread test36comp.xls;
test36comp = ans;
xlsread test37comp.xls;
test37comp = ans;
xlsread test38comp.xls;
test38comp = ans;
xlsread test39comp.xls;
test39comp = ans;
xlsread test40comp.xls;
test40comp = ans;
xlsread test41comp.xls;
test41comp = ans;
xlsread test42comp.xls;
test42comp = ans;
xlsread test43comp.xls;
test43comp = ans;
xlsread test44comp.xls;
test44comp = ans;
xlsread test45comp.xls;
test45comp = ans;
xlsread test46comp.xls;
test46comp = ans;
xlsread test47comp.xls;
test47comp = ans;
xlsread test48comp.xls;
test48comp = ans;
xlsread test49comp.xls;
test49comp = ans;
xlsread test50comp.xls;
```

```
test50comp = ans;
xlsread test51comp.xls;
test51comp = ans;
xlsread test52comp.xls;
test52comp = ans;
xlsread test53comp.xls;
test53comp = ans;
xlsread test54comp.xls;
test54comp = ans;
xlsread test55comp.xls;
test55comp = ans;
xlsread test56comp.xls;
test56comp = ans;

hfCF = .7*25.4; %height for correction factor testing

%Final heights of all samples must be input
%height after consolidation before shear
%hf5 = .86*25.4;
hf6 = height6 - abs(test6comp(1,8) - test6shear(1,3));
hf7 = height7 - abs(test7comp(1,8) - test7shear(1,3));
hf8 = height8 - abs(test8comp(1,8) - test8shear(1,3));
hf9 = height9 - abs(test9comp(1,8) - test9shear(1,3));
hf10 = height10 - abs(test10comp(1,8) - test10shear(1,3));
hf11 = height11 - abs(test11comp(1,8) - test11shear(1,3));
hf12 = height12 - abs(test12comp(1,8) - test12shear(1,3));
hf13 = height13 - abs(test13comp(1,8) - test13shear(1,3));
hf14 = height14 - abs(test14comp(1,8) - test14shear(1,3));
hf15 = height15 - abs(test15comp(1,8) - test15shear(1,3));
hf16 = height16 - abs(test16comp(1,8) - test16shear(1,3));
hf17 = height17 - abs(test17comp(1,8) - test17shear(1,3));
hf18 = height18 - abs(test18comp(1,8) - test18shear(1,3));
hf19 = height19 - abs(test19comp(1,8) - test19shear(1,3));
hf20 = height20 - abs(test20comp(1,8) - test20shear(1,3));
hf21 = height21 - abs(test21comp(1,8) - test21shear(1,3));
hf22 = height22 - abs(test22comp(1,8) - test22shear(1,3));
hf23 = height23 - abs(test23comp(1,8) - test23shear(1,3));
hf24 = height24 - abs(test24comp(1,8) - test24shear(1,3));
hf25 = height25 - abs(test25comp(1,8) - test25shear(1,3));
hf26 = height26 - abs(test26comp(1,8) - test26shear(1,3));
hf27 = height27 - abs(test27comp(1,8) - test27shear(1,3));
hf29 = height29 - abs(test29comp(1,8) - test29shear(1,3));
hf30 = height30 - abs(test30comp(1,8) - test30shear(1,3));
hf31 = height31 - abs(test31comp(1,8) - test31shear(1,3));
hf33 = height33 - abs(test33comp(1,8) - test33comp(end,3));
hf32 = height32 - abs(test32comp(1,8) - test32shear(1,3));
```

```
hf34 = height34 - abs(test34comp(1,8) - test34shear(1,3));
hf35 = height35 - abs(test35comp(1,8) - test35shear(1,3));
hf36 = height36 - abs(test36comp(1,8) - test36shear(1,3));
hf37 = height37 - abs(test37comp(1,8) - test37shear(1,3));
hf38 = height38 - abs(test38comp(1,8) - test38shear(1,3));
hf39 = height39 - abs(test39comp(1,8) - test39shear(1,3));
hf40 = height40 - abs(test40comp(1,8) - test40shear(1,3));
hf41 = height41 - abs(test41comp(1,8) - test41shear(1,3));
hf42 = height42 - abs(test42comp(1,8) - test42shear(1,3));
hf43 = height43 - abs(test43comp(1,8) - test43shear(1,3));
hf44 = height44 - abs(test44comp(1,8) - test44shear(1,3));
hf45 = height45 - abs(test45comp(1,8) - test45shear(1,3));
hf46 = height46 - abs(test46comp(1,8) - test46shear(1,3));
hf47 = height47 - abs(test47comp(1,8) - test47shear(1,3));
hf48 = height48 - abs(test48comp(1,8) - test48shear(1,3));
hf49 = height49 - abs(test49comp(1,8) - test49shear(1,3));
hf50 = height50 - abs(test50comp(1,8) - test50shear(1,3));
hf51 = height51 - abs(test51comp(1,8) - test51shear(1,3));
hf52 = height52 - abs(test52comp(1,8) - test52shear(1,3));
hf53 = height53 - abs(test53comp(1,8) - test53shear(1,3));
hf54 = height54 - abs(test54comp(1,8) - test54shear(1,3));
hfCF = .5*25.4;
hfCFbaxring = 22.8;
hfCFbaxwrm = 19.3;
hf55 = height55 - abs(test55comp(1,8) - test55shear(1,3));
hf56 = height56 - abs(test56comp(1,8) - test56shear(1,3));


%geo nor 50cm2 membrane correction


geo_shear = [0.0000
0.5394
1.0297
1.4711
1.9614
2.4027
2.8440
3.2853
3.7267
4.0699
4.4622
4.8054
5.0996
5.4429
5.7861
```

```
6.0313
6.3746
6.6688
6.9139
7.1101
7.3062];

geo_strain = [0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20]/100;
```

```
%This file will plot pore pressure and shear stress
%from Direct Simple Shear test Data using shear and consol functions.
%By Seth McGuire

clc; close all; clear all;


%Area the same for all samples
area1 = .00316692174; %m2

%calls on excel data and sample start and finish heights.
DATA;

%analyze data using shear function.
%[shear5,strain5,dpore5,max5] = shear(test5shear,hf5);
%[shear6,sh_strain6,dpore6,normal6,max6,maxpore6] = shear(test6shear,hf6);
%[shear7,sh_strain7,dpore7,normal7,max7,maxpore7] = shear(test7shear,hf7);
%[shear8,sh_strain8,dpore8,normal8,max8,maxpore8] = shear(test8shear,hf8);
```

```
%[shear9,sh_strain9,dpore9,normal9,max9,maxpore9] = shear(test9shear,hf9);
%[shear10,sh_strain10,dpore10,normal10,max10,maxpore10] =
shear(test10shear,hf10);
[shear11,sh_strain11,dpore11,normal11,max11,maxpore11] =
shear(test11shear,hf11,area1);
[shear12,sh_strain12,dpore12,normal12,max12,maxpore12] =
shear(test12shear,hf12,area1);
[shear13,sh_strain13,dpore13,normal13,max13,maxpore13] =
shear(test13shear,hf13,area1);
%[shear14,sh_strain14,dpore14,normal14,max14,maxpore14] =
shear(test14shear,hf14);
%[shear15,sh_strain15,dpore15,normal15,max15,maxpore15] =
shear(test15shear,hf15);
[shear16,sh_strain16,dpore16,normal16,max16,maxpore16] =
shear(test16shear,hf16,area1);
[shear17,sh_strain17,dpore17,normal17,max17,maxpore17] =
shear(test17shear,hf17,area1);
[shear18,sh_strain18,dpore18,normal18,max18,maxpore18] =
shear(test18shear,hf18,area1);
[shear19,sh_strain19,dpore19,normal19,max19,maxpore19] =
shear(test19shear,hf19,area1);
[shear20,sh_strain20,dpore20,normal20,max20,maxpore20] =
shear(test20shear,hf20,area1);
[shear21,sh_strain21,dpore21,normal21,max21,maxpore21] =
shear(test21shear,hf21,area1);
[shear22,sh_strain22,dpore22,normal22,max22,maxpore22] =
shear(test22shear,hf22,area1);
[shear23,sh_strain23,dpore23,normal23,max23,maxpore23] =
shear(test23shear,hf23,area1);
[shear24,sh_strain24,dpore24,normal24,max24,maxpore24] =
shear(test24shear,hf24,area2);
[shear25,sh_strain25,dpore25,normal25,max25,maxpore25] =
shear(test25shear,hf25,area2);
[shear26,sh_strain26,dpore26,normal26,max26,maxpore26] =
shear(test26shear,hf26,area2);
[shear27,sh_strain27,dpore27,normal27,max27,maxpore27] =
shear(test27shear,hf27,area2);
[shear29,sh_strain29,dpore29,normal29,max29,maxpore29] =
shear(test29shear,hf29,area1);
[shear30,sh_strain30,dpore30,normal30,max30,maxpore30] =
shear(test30shear,hf30,area1);
[shear31,sh_strain31,dpore31,normal31,max31,maxpore31] =
shear(test31shear,hf31,area1);
[shear32,sh_strain32,dpore32,normal32,max32,maxpore32] =
shear(test32shear,hf32,area1);
[shear34,sh_strain34,dpore34,normal34,max34,maxpore34] =
```

```
shear(test34shear,hf34,area1);
[shear35,sh_strain35,dpore35,normal35,max35,maxpore35] =
shear(test35shear,hf35,area1);
[shear36,sh_strain36,dpore36,normal36,max36,maxpore36] =
shear(test36shear,hf36,area1);
[shear37,sh_strain37,dpore37,normal37,max37,maxpore37] =
shear(test37shear,hf37,area1);
[shear38,sh_strain38,dpore38,normal38,max38,maxpore38] =
shear(test38shear,hf38,area2);
[shear39,sh_strain39,dpore39,normal39,max39,maxpore39] =
shear(test39shear,hf39,area2);
[shear40,sh_strain40,dpore40,normal40,max40,maxpore40] =
shear(test40shear,hf40,area2);
[shear41,sh_strain41,dpore41,normal41,max41,maxpore41] =
shear(test41shear,hf41,area2);
[shear42,sh_strain42,dpore42,normal42,max42,maxpore42] =
shear(test42shear,hf42,area2);
[shear43,sh_strain43,dpore43,normal43,max43,maxpore43] =
shear(test43shear,hf43,area2);
[shear44,sh_strain44,dpore44,normal44,max44,maxpore44] =
shear(test44shear,hf44,area2);
[shear45,sh_strain45,dpore45,normal45,max45,maxpore45] =
shear(test45shear,hf45,area2);
[shear46,sh_strain46,dpore46,normal46,max46,maxpore46] =
shear(test46shear,hf46,area2);
[shear47,sh_strain47,dpore47,normal47,max47,maxpore47] =
shear(test47shear,hf47,area2);
[shear48,sh_strain48,dpore48,normal48,max48,maxpore48] =
shear(test48shear,hf48,area2);
[shear49,sh_strain49,dpore49,normal49,max49,maxpore49] =
shear(test49shear,hf49,area2);
[shear50,sh_strain50,dpore50,normal50,max50,maxpore50] =
shear(test50shear,hf50,area2);
[shear51,sh_strain51,dpore51,normal51,max51,maxpore51] =
shear(test51shear,hf51,area2);
[shear52,sh_strain52,dpore52,normal52,max52,maxpore52] =
shear(test52shear,hf52,area1);
[shear53,sh_strain53,dpore53,normal53,max53,maxpore53] =
shear(test53shear,hf53,area1);
[shear54,sh_strain54,dpore54,normal54,max54,maxpore54] =
shear(test54shear,hf54,area1);
[shear55,sh_strain55,dpore55,normal55,max55,maxpore55] =
shear(test55shear,hf55,area1);
[shear56,sh_strain56,dpore56,normal56,max56,maxpore56] =
shear(test56shear,hf56,area2);
```

```
%Analyze consolidation data to be plotted with shear curves
%[sig6,strain6] = consol(test6comp,height6); %runs data file through function
%[sig7,strain7] = consol(test7comp,height7); %runs data file through function
%[sig8,strain8] = consol(test8comp,height8); %runs data file through function
%[sig9,strain9] = consol(test9comp,height9); %runs data file through function
%[sig10,strain10] = consol(test10comp,height10); %runs data file through function
%[sig11,strain11] = consol(test11comp,height11); %runs data file through function
%[sig12,strain12] = consol(test12comp,height12); %runs data file through function
%[sig13,strain13] = consol(test13comp,height13); %runs data file through function
%[sig14,strain14] = consol(test14comp,height14); %runs data file through function
%[sig15,strain15] = consol(test15comp,height15); %runs data file through function
[sig16,strain16,sigmax16] = consol(test16comp,height16,area1); %runs data file
through function
[sig17,strain17,sigmax17] = consol(test17comp,height17,area1); %runs data file
through function
[sig18,strain18,sigmax18] = consol(test18comp,height18,area1); %runs data file
through function
[sig19,strain19,sigmax19] = consol(test19comp,height19,area1); %runs data file
through function
[sig20,strain20,sigmax20] = consol(test20comp,height20,area1); %runs data file
through function
[sig21,strain21,sigmax21] = consol(test21comp,height21,area1); %runs data file
through function
[sig22,strain22,sigmax22] = consol(test22comp,height22,area1); %runs data file
through function
[sig23,strain23,sigmax23] = consol(test23comp,height23,area1); %runs data file
through function
[sig24,strain24,sigmax24] = consol(test24comp,height24,area2); %runs data file
through function
[sig25,strain25,sigmax25] = consol(test25comp,height25,area2); %runs data file
through function
[sig26,strain26,sigmax26] = consol(test26comp,height26,area2); %runs data file
through function
[sig27,strain27,sigmax27] = consol(test27comp,height27,area2); %runs data file
through function
[sig29,strain29,sigmax29] = consol(test29comp,height29,area1); %runs data file
through function
[sig30,strain30,sigmax30] = consol(test30comp,height30,area1); %runs data file
through function
[sig31,strain31,sigmax31] = consol(test31comp,height31,area1); %runs data file
through function
[sig32,strain32,sigmax32] = consol(test32comp,height32,area1); %runs data file
through function
[sig34,strain34,sigmax34] = consol(test34comp,height34,area1); %runs data file
through function
```

```
[sig35,strain35,sigmax35] = consol(test35comp,height35,area1); %runs data file through function
[sig36,strain36,sigmax36] = consol(test36comp,height36,area1); %runs data file through function
[sig37,strain37,sigmax37] = consol(test37comp,height37,area1); %runs data file through function
[sig38,strain38,sigmax38] = consol(test38comp,height38,area2); %runs data file through function
[sig39,strain39,sigmax39] = consol(test39comp,height39,area2); %runs data file through function
[sig40,strain40,sigmax40] = consol(test40comp,height40,area2); %runs data file through function
[sig41,strain41,sigmax41] = consol(test41comp,height41,area2); %runs data file through function
[sig33,strain33,sigmax33] = consol(test33comp,height33,area1);
[sig28,strain28,sigmax28] = consol(test28comp,height28,area1);
[sig42,strain42,sigmax42] = consol(test42comp,height42,area2); %runs data file through function
[sig43,strain43,sigmax43] = consol(test43comp,height43,area2); %runs data file through function
[sig44,strain44,sigmax44] = consol(test44comp,height44,area2);
[sig45,strain45,sigmax45] = consol(test45comp,height45,area2);
[sig46,strain46,sigmax46] = consol(test46comp,height46,area2);
[sig47,strain47,sigmax47] = consol(test47comp,height47,area2);
[sig48,strain48,sigmax48] = consol(test48comp,height48,area2);
[sig49,strain49,sigmax49] = consol(test49comp,height49,area2);
[sig50,strain50,sigmax50] = consol(test50comp,height50,area2);
[sig51,strain51,sigmax51] = consol(test51comp,height51,area2);
[sig52,strain52,sigmax52] = consol(test52comp,height52,area1);
[sig53,strain53,sigmax53] = consol(test53comp,height53,area1);
[sig54,strain54,sigmax54] = consol(test54comp,height54,area1);
[sig55,strain55,sigmax55] = consol(test55comp,height55,area1);
[sig56,strain56,sigmax56] = consol(test56comp,height56,area2);

%calls on data from 5 kPa pressure WRM CF Test
[shear_wrm1,strain_wrm1,max_shear_wrm1] = CF_shear(wrm5kpa,hfCF,area2);

%calls on data from 10 kPa pressure WRM CF Test
[shear_wrm2,strain_wrm2,max_shear_wrm2] = CF_shear(wrm10kpa,hfCF,area2);

%Calls on data from 7 kPa WRM CF Test with .0219 mm/min shear
[shear_wrm3,strain_wrm3,max_shear_wrm3] = CF_shear(wrm7kpa,hfCF,area2);

%Calls on data from 5 kPa metal ring test
[shear_ring1,strain_ring1,max_shear_ring1] = CF_shear(ring5kpa,hfCF,area1);
```

```
%Calls on data from 10 kPa metal ring test
[shear_ring2,strain_ring2,max_shear_ring2] = CF_shear(ring10kpa,hfCF,area1);

%Calls on data from 10 kPa metal ring test
[shear_ring3,strain_ring3,max_shear_ring3] = CF_shear(ring7kpa,hfCF,area1);



%%calls on data for correction Factor Testing from Chris Baxter et al's
%%work.

[shear_baxring,strain_baxring,max_shear_baxring] =
CF_shear(ring7bax,hfCFbaxring,area3);


[shear_baxwrm,strain_baxwrm,max_shear_baxwrm] =
CF_shear(wrm7bax,hfCFbaxwrm,area3);




%[SHANSEP_ratio_5] = SHANSEP_ratio(test5shear,test5comp,hf5,height5);
%[SHANSEP_ratio_6] = SHANSEP_ratio(test6shear,test6comp,hf6,height6);
%[SHANSEP_ratio_7] = SHANSEP_ratio(test07shear,test7comp,hf7,height7);
%[SHANSEP_ratio_8] = SHANSEP_ratio(test8shear,test8comp,hf8,height8);
%[SHANSEP_ratio_9] = SHANSEP_ratio(test9shear,test9comp,hf9,height9);
%[SHANSEP_ratio_10] = SHANSEP_ratio(test10shear,test10comp,hf10,height10);
%[SHANSEP_ratio_11] = SHANSEP_ratio(test11shear,test11comp,hf11,height11);
%[SHANSEP_ratio_12] = SHANSEP_ratio(test12shear,test12comp,hf12,height12);
%[SHANSEP_ratio_13] = SHANSEP_ratio(test13shear,test13comp,hf13,height13);
%[SHANSEP_ratio_14] = SHANSEP_ratio(test14shear,test14comp,hf14,height14);
%[SHANSEP_ratio_15] = SHANSEP_ratio(test15shear,test15comp,hf15,height15);
[SHANSEP_ratio_16] =
SHANSEP_ratio(test16shear,test16comp,hf16,height16,area1);
[SHANSEP_ratio_17] =
SHANSEP_ratio(test17shear,test17comp,hf17,height17,area1);
[SHANSEP_ratio_18] =
SHANSEP_ratio(test18shear,test18comp,hf18,height18,area1);
[SHANSEP_ratio_19] =
SHANSEP_ratio(test19shear,test19comp,hf19,height19,area1);
[SHANSEP_ratio_20] =
SHANSEP_ratio(test20shear,test20comp,hf20,height20,area1);
[SHANSEP_ratio_21] =
SHANSEP_ratio(test21shear,test21comp,hf21,height21,area1);
[SHANSEP_ratio_22] =
SHANSEP_ratio(test22shear,test22comp,hf22,height22,area1);
```

```
[SHANSEP_ratio_23] =
SHANSEP_ratio(test23shear,test23comp,hf23,height23,area1);
[SHANSEP_ratio_24] =
SHANSEP_ratio(test24shear,test24comp,hf24,height24,area2);
[SHANSEP_ratio_25] =
SHANSEP_ratio(test25shear,test25comp,hf25,height25,area2);
[SHANSEP_ratio_26] =
SHANSEP_ratio(test26shear,test26comp,hf26,height26,area2);
[SHANSEP_ratio_27] =
SHANSEP_ratio(test27shear,test27comp,hf27,height27,area2);
[SHANSEP_ratio_29] =
SHANSEP_ratio(test29shear,test29comp,hf29,height29,area1);
[SHANSEP_ratio_30] =
SHANSEP_ratio(test30shear,test30comp,hf30,height30,area1);
[SHANSEP_ratio_31] =
SHANSEP_ratio(test31shear,test31comp,hf31,height31,area1);
[SHANSEP_ratio_32] =
SHANSEP_ratio(test32shear,test32comp,hf32,height32,area1);
[SHANSEP_ratio_34] =
SHANSEP_ratio(test34shear,test34comp,hf34,height34,area1);
[SHANSEP_ratio_35] =
SHANSEP_ratio(test35shear,test35comp,hf35,height35,area1);
[SHANSEP_ratio_36] =
SHANSEP_ratio(test36shear,test36comp,hf36,height36,area1);
[SHANSEP_ratio_37] =
SHANSEP_ratio(test37shear,test37comp,hf37,height37,area1);

[SHANSEP_ratio_38] =
SHANSEP_ratio(test38shear,test38comp,hf38,height38,area2);
[SHANSEP_ratio_39] =
SHANSEP_ratio(test39shear,test39comp,hf39,height39,area2);
[SHANSEP_ratio_40] =
SHANSEP_ratio(test40shear,test40comp,hf40,height40,area2);
[SHANSEP_ratio_41] =
SHANSEP_ratio(test41shear,test41comp,hf41,height41,area2);
[SHANSEP_ratio_42] =
SHANSEP_ratio(test42shear,test42comp,hf42,height42,area2);
[SHANSEP_ratio_43] =
SHANSEP_ratio(test43shear,test43comp,hf43,height43,area2);
[SHANSEP_ratio_44] =
SHANSEP_ratio(test44shear,test44comp,hf44,height44,area2);
[SHANSEP_ratio_45] =
SHANSEP_ratio(test45shear,test45comp,hf44,height45,area2);
[SHANSEP_ratio_46] =
SHANSEP_ratio(test46shear,test46comp,hf46,height46,area2);
[SHANSEP_ratio_47] =
```

```
SHANSEP_ratio(test47shear,test47comp,hf47,height47,area2);
[SHANSEP_ratio_48] =
SHANSEP_ratio(test48shear,test48comp,hf48,height48,area2);
[SHANSEP_ratio_49] =
SHANSEP_ratio(test49shear,test49comp,hf49,height49,area2);
[SHANSEP_ratio_50] =
SHANSEP_ratio(test50shear,test50comp,hf50,height50,area2);
[SHANSEP_ratio_51] =
SHANSEP_ratio(test51shear,test51comp,hf51,height51,area2);
[SHANSEP_ratio_52] =
SHANSEP_ratio(test52shear,test52comp,hf52,height52,area1);
[SHANSEP_ratio_53] =
SHANSEP_ratio(test53shear,test53comp,hf53,height53,area1);
[SHANSEP_ratio_54] =
SHANSEP_ratio(test54shear,test54comp,hf54,height54,area1);
[SHANSEP_ratio_55] =
SHANSEP_ratio(test55shear,test55comp,hf55,height55,area1);
[SHANSEP_ratio_56] =
SHANSEP_ratio(test56shear,test56comp,hf56,height56,area2);
```

B2 – Functions

```
function [sig,strain,sigmax,OCR] = consol(test,height,area)
%This function analyzes a data set input to matlab from a .xls file.
%The script file that calls on it will input global height parameters
%The outputs are vertical stress and strain percentage.


%Create a new column with sigma in kPa
test(:,9) = (test(:,2)/1000)/area;

%Creat a new column for vertical strain %
test(:,10) = (test(:,3)-test(1,8))/height;

sig = test(:,9);
sig = [0;sig];
strain = test(:,10);
strain = [0;strain];
sigmax = max(sig);

OCR = max(sig)/sig(end);
```

```
end
```

```
function [shear,strain,dPore,normal,max_shear,maxpore] = shear(shear_data,hf,area)
%This function receives a data matrix. The matrix is an output from
%Geocomp Direct Simple Shear machine software (DSS).



if area < .00318;

shear_data(:,8) = (shear_data(:,4)-shear_data(1,4))/1000/area;

shear_data(:,9) = ((shear_data(:,5)-shear_data(1,5))/hf);
strain = shear_data(:,9);
if max(strain)>.4
   from = find(strain>.40);
else
   from = find(strain==max(strain));
end

shear = shear_data(:,8)-1.25*strain-.62;

shear_data(:,10) = shear_data(:,2)-shear_data(1,2);
dPore = -shear_data(:,10)/area/1000;


%Create a new column with sigma in kPa
shear_data(:,10) = ((shear_data(:,2)/1000)/area);
sig = shear_data(:,10); %Vertical stress in kPa
normal = sig(1:from(1)); %Vertical effective stress
strain = strain(1:from(1));
shear = shear(1:from(1));
dPore = dPore(1:from(1));

max_shear = find(shear==max(shear)); %finds the maximum used to plot max pt
max_shear = max_shear(1); %takes the first time maximum is reached
maxpore = find(dPore==max(dPore));
maxpore = maxpore(1);

else

shear_data(:,8) = (shear_data(:,4)-shear_data(1,4))/1000/area;

shear_data(:,9) = ((shear_data(:,5)-shear_data(1,5))/hf);
strain = shear_data(:,9);
```

```
if max(strain)>.4
    from = find(strain>0.40);
else
    from = find(strain==max(strain));
end

shear = shear_data(:,8)-.84*strain;

shear_data(:,10) = shear_data(:,2)-shear_data(1,2);
dPore = -shear_data(:,10)/area/1000;


%Create a new column with sigma in kPa
shear_data(:,10) = ((shear_data(:,2)/1000)/area)-.6*strain-.53;
sig = shear_data(:,10); %Vertical stress in kPa
normal = sig(1:from(1)); %Vertical effective stress
strain = strain(1:from(1));
dPore = dPore(1:from(1));
shear = shear(1:from(1));

max_shear = find(shear==max(shear)); %finds the maximum used to plot max pt
max_shear = max_shear(1); %takes the first time maximum is reached
maxpore = find(dPore==max(dPore));
maxpore = maxpore(1);

end
```

```
function [ratio] = SHANSEP_ratio(shear_data,compdata,hf,height,area)
%This function outputs Shear Stress / Normal Stress ratios as well as a data allowing
%user to plot the shear envelope.

[shear_,shstrain,dPore,normal,max_shear] = shear(shear_data,hf,area);
[sig,nstrain,sigmax,OCR] = consol(compdata,height,area);



ratio = shear_(max_shear)/(sigmax/OCR);
end
```

B3 – Plot Script Files

```
%This file plots all DSS data for both GoM and Silt specimens

%This data is:

%_______NOT NORMALIZED_______________%
```

```
%this file does not produce individual plots, it only demonstrates results
%of comparison plots


clc; close all; clear all;

DATA;

shear_analysis;

%__________________S I L
T___________________________%%%%%%%%%%%%%%%%%%%%%
%%
%__________________S I L T Over-Consolidated______________________________
figure
subplot(2,1,1)
hold on
p1 = plot(sh_strain35,shear35,'b')
p2 = plot(sh_strain42,shear42,'r','LineWidth',2)
p3 = plot(sh_strain36,shear36,'b',sh_strain37,shear37,'b',sh_strain34,shear34,'b')
p4 = plot(sh_strain44,shear44,'r',sh_strain45,shear45,'r',...
    sh_strain46,shear46,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
legend([p1,p2],'Rings','WRM','FontWeight','Bold','Location','SouthEast')
xlim([0 .4]);
ylim([0 55]);
grid

subplot(2,1,2)
hold on
p5 = plot(sh_strain35,dpore35,'b');
p6 = plot(sh_strain42,dpore42,'r','LineWidth',2);
p7 = plot(sh_strain36,dpore36,'b',sh_strain37,dpore37,'b',sh_strain34,dpore34,'b');
p8 =
plot(sh_strain44,dpore44,'r',sh_strain45,dpore45,'r',sh_strain46,dpore46,'r','LineWidth
',2);
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('Pore Pressure (kPa)','FontSize',12);
xlim([0 .4]);
ylim([-30 150]);
grid

%Now plot shear envelope for Silt
```

```
figure
hold on
p9 = plot(normal35,shear35,'b');
p10 = plot(normal42,shear42,'r','LineWidth',2);
p11 = plot(normal36,shear36,'b',normal37,shear37,'b',normal34,shear34,'b');
p12 =
plot(normal44,shear44,'r',normal45,shear45,'r',normal46,shear46,'r','LineWidth',2);
hold off
xlabel('\sigma\prime_v (kPa)','FontSize',12);
ylabel('\tau (kPa)','FontSize',12);
legend([p9,p10],'Rings','WRM');
xlim([0 200])
grid


%%
%___________________S I L T Normally-Consolidated_________________________

figure
subplot(2,1,1)
%Plot all stress vs strain on same plot for Silt
hold on
p13 = plot(sh_strain31,shear31,'b')
p14 = plot(sh_strain43,shear43,'r','LineWidth',2)
p15 = plot(sh_strain34,shear34,'b')
p16 = plot(sh_strain42,shear42,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
title('NC Narragansett Bay Silt','FontSize',12);
legend([p13,p14],'Rings','WRM','Location','SouthEast')
xlim([0 .4]);
ylim([0 55]);
grid

subplot(2,1,2)
%Plot all pore pressure vs strain on same plot for Silt
hold on
p17 = plot(sh_strain31,dpore31,'b')
p18 = plot(sh_strain43,dpore43,'r','LineWidth',2)
p19 = plot(sh_strain34,dpore34,'b')
p20 = plot(sh_strain42,dpore42,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('Pore Pressure (kPa)','FontSize',12);
xlim([0 .4]);
```

```
ylim([-30 150]);
grid


%Now plot shear envelope for Silt
figure
hold on
p21 = plot(normal31,shear31,'b')
p22 = plot(normal43,shear43,'r','LineWidth',2)
p23 = plot(normal34,shear34,'b')
p24 = plot(normal42,shear42,'r','LineWidth',2);
xlabel('\sigma\prime_v (kPa)','FontSize',12);
ylabel('\tau (kPa)','FontSize',12);
legend([p21,p22],'Rings','WRM')
xlim([0 200])
ylim([0 55])
grid



%%
%___________________________Silt Consolidation Comparison Plot_______

figure %comparison of all Silt plots
semilogx(sig29,strain29,'b',sig46,strain46,'r',sig33,strain33,'-
*g',sig30,strain30,'b',sig31,strain31,'b',sig32,strain32,'b',...

sig34,strain34,'b',sig35,strain35,'b',sig42,strain42,'r',sig43,strain43,'r',sig44,strain44,'r',
sig45,strain45,'r')
set(gca,'YDir','reverse')
xlabel ('\sigma\prime_v (kPa)','FontSize',12);
ylabel ('Vertical Strain','FontSize',12);
legend('Rings','WRM','Consolidation Test','location','SouthWest')
ylim([0 .20])
grid



%%
%Gulf of Mexico Results
%%
%_________________GoM Normally-Consolidated


%%%%%%%%%%%comparison of GoM data Normally
Consolidated%%%%%%%%%%%%%%%%%
```

```
figure
subplot(2,1,1)
%Plot all stress vs strain on same plot for GoM
hold on
p25 = plot(sh_strain19,shear19,'b')
p26 = plot(sh_strain20,shear20,'b')
p27 = plot(sh_strain40,shear40,'r','LineWidth',2)
p28 = plot(sh_strain39,shear39,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
legend([p25,p27],'Rings','WRM',...
    'location','SouthEast')
xlim([0 .4]);
ylim([0 55]);
grid

subplot(2,1,2)
%Plot all pore pressure vs strain on same plot for GoM
hold on
p29 = plot(sh_strain19,dpore19,'b')
p30 = plot(sh_strain40,dpore40,'r','LineWidth',2)
p31 = plot(sh_strain20,dpore20,'b')
p32 = plot(sh_strain39,dpore39,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('Pore Pressure (kPa)','FontSize',12);
xlim([0 .4]);
ylim([-30 150])
grid



%Now plot shear envelope for GoM
figure
hold on
p33 = plot(normal19,shear19,'b')
p35 = plot(normal40,shear40,'r','LineWidth',2)
p36 = plot(normal20,shear20,'b')
p34 = plot(normal39,shear39,'r','LineWidth',2);
hold off
xlabel('\sigma\prime_v (kPa)','FontSize',12);
ylabel('\tau (kPa)','FontSize',12);
legend([p33,p35],'Rings','WRM');
xlim([0 200])
```

```
ylim([0 55])
grid



%%
%_______________________GoM Over-Consolidated________________________

figure
subplot(2,1,1)
hold on
p35 = plot(sh_strain19,shear19,'b')
p36 = plot(sh_strain40,shear40,'r','LineWidth',2)
p37 = plot(sh_strain52,shear52,'b',sh_strain53,shear53,'b',sh_strain23,shear23,'b')
p38 =
plot(sh_strain41,shear41,'r',sh_strain47,shear47,'r',sh_strain51,shear51,'r','LineWidth',
2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
legend([p35,p36],'Rings','Wire Membrane','Location','SouthEast')
xlim([0 .4]);
ylim([0 55]);
grid

subplot(2,1,2)
%Plot all pore pressure vs strain for OCR Tests
hold on
p39 = plot(sh_strain19,dpore19,'b')
p40 = plot(sh_strain40,dpore40,'r','LineWidth',2)
p41 = plot(sh_strain52,dpore52,'b',sh_strain53,dpore53,'b',sh_strain23,dpore23,'b')
p42 =
plot(sh_strain41,dpore41,'r',sh_strain47,dpore47,'r',sh_strain51,dpore51,'r','LineWidth
',2);
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('Pore Pressure (kPa)','FontSize',12);
xlim([0 .4]);
ylim([-30 150]);
grid

%OCR shear envelope's
figure
hold on
p43 = plot(normal20,shear20,'b')
p44 = plot(normal39,shear39,'r','LineWidth',2)
```

```
p45 = plot(normal52,shear52,'b',normal53,shear53,'b',normal23,shear23,'b')
p46 =
plot(normal41,shear41,'r',normal47,shear47,'r',normal51,shear51,'r','LineWidth',2);
xlabel('\sigma\prime_v (kPa)','FontSize',12);
ylabel('\tau (kPa)','FontSize',12);
legend([p43,p44],'Rings','Wire Membrane',...
    'location','NorthEast');
xlim([0 200])
ylim([0 55])
grid

%%
%______________________GoM Consolidation Comparison Plot_______________

figure %comparison of all GoM plots
semilogx(sig18,strain18,'b',sig49,strain49,'r',sig28,strain28,'-
*g',sig19,strain19,'b',sig20,strain20,'b',sig52,strain52,'b',sig53,strain53,'b',sig41,strain
41,...
    'r',sig50,strain50,'r',sig51,strain51,'r',sig40,strain40,'r')
set(gca,'YDir','reverse')
xlabel ('\sigma\prime_v (kPa)','FontSize',12);
ylabel ('Vertical Strain','FontSize',12);
legend('Rings','WRM','Consolidation Test','location','SouthWest');
ylim([0 .25])
xlim([10^0 10^3])
grid
%%
%____________________Maine Clay Plots________________


figure
subplot(2,1,1)
hold on
p35 = plot(sh_strain55,shear55,'b')
p36 = plot(sh_strain56,shear56,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
legend([p35,p36],'Rings','Wire Membrane','Location','SouthEast')
xlim([0 .4]);
ylim([0 25]);
grid

subplot(2,1,2)
%Plot all pore pressure vs strain for OCR Tests
hold on
```

```
p39 = plot(sh_strain55,dpore55,'b')
p40 = plot(sh_strain56,dpore56,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('Pore Pressure (kPa)','FontSize',12);
xlim([0 .4]);
ylim([-30 100]);
grid

%OCR shear envelope's
figure
hold on
p43 = plot(normal55,shear55,'b')
p44 = plot(normal56,shear56,'r','LineWidth',2)
xlabel('\sigma\prime_v (kPa)','FontSize',12);
ylabel('\tau (kPa)','FontSize',12);
legend([p43,p44],'Rings','Wire Membrane',...
    'location','NorthEast');
xlim([0 200])
ylim([0 25])
grid
%%
%____________________Maine Clay Consolidation Plot_______________________

figure %comparison of all GoM plots
semilogx(sig55,strain55,'b',sig56,strain56,'r')%sig28,strain28,'-
*g',sig19,strain19,'b',sig20,strain20,'b',sig52,strain52,'b',sig53,strain53,'b',sig41,strain
41,...
    %'r',sig50,strain50,'r',sig51,strain51,'r',sig40,strain40,'r')
set(gca,'YDir','reverse')
xlabel ('\sigma\prime_v (kPa)','FontSize',12);
ylabel ('Vertical Strain','FontSize',12);
legend('Rings','WRM')%,'Consolidation Test','location','SouthWest');
ylim([0 .4])
xlim([10^0 10^3])
grid
%%
%_______________Corrected vs Uncorrected Plots

[ushear43,ush_strain43,udpore43,unormal43,umax43,umaxpore43] =
un_shear(test43shear,hf43,area2);
[ushear31,ush_strain31,udpore31,unormal31,umax31,umaxpore31] =
un_shear(test31shear,hf31,area1);
%above lines calculate corrected data

%Comparison of Silt Data corrected and uncorrected using ringss
```

```
figure
subplot(2,1,1)
plot(sh_strain31,shear31,'b',ush_strain31,ushear31,'--r')
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
legend('Corrected','Uncorrected','location','SouthEast')
xlim([0 .4]);
ylim([0 55]);

%Comparison of Silt data corrected and uncorrected using WRM

subplot(2,1,2)
plot(sh_strain43,shear43,'b',ush_strain43,ushear43,'--r')
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
legend('Corrected','Uncorrected',...
   'location','SouthEast')
xlim([0 .4]);
ylim([0 55]);

%%
%_________________Plots of CF Testing__________________

%%%%%WRM CF Tests Plot WRM
polyfit(strain_wrm3,shear_wrm3,1)
f1 = ans(1)
f2 = ans(2)

figure
subplot(1,2,2)
hold on
g1 = plot(strain_wrm1,shear_wrm1,'-x',strain_wrm2,shear_wrm2,'-
o',strain_wrm3,shear_wrm3,'*')
g2 = plot(strain_wrm3,f1*strain_wrm3+f2,'LineWidth',2);
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
ylim([0 2]);
xlim([0 .5]);
legend('WRM-5 kPa','WRM-10 kPa','WRM-7 kPa (Slow)')
set(g2,'Color','Black');



%%%%Ring CF Test Plots Ring
polyfit(strain_ring3,shear_ring3,1)
```

```
f3 = ans(1)
f4 = ans(2)

subplot(1,2,1)
hold on
g3 = plot(strain_ring1,shear_ring1,'-x',strain_ring2,shear_ring2,'-
o',strain_ring3,shear_ring3,'*')
g4 = plot(strain_ring3,f3*strain_ring3+f4,'bl','LineWidth',2);
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
ylim([0 2]);
xlim([0 .5]);
legend('Ring-5 kPa','Ring-10 kPa','Ring-7 kPa (Slow)')
set(g4,'Color','Black');
text(strain_ring3(end),f1*strain_ring3(end)+f2,['Slope =' f1])

%%%WRM and Ring CF Plots

figure
hold on
g1 = plot(strain_wrm3,shear_wrm3,'r*',strain_ring3,shear_ring3,'b+');
g2 = plot(strain_wrm3,f1*strain_wrm3+f2,'bl','LineWidth',2);
g4 = plot(strain_ring3,f3*strain_ring3+f4,'bl','LineWidth',2);

hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
ylim([0 2]);
xlim([0 .5]);
legend([g1],'WRM','Rings','Location','NorthWest')
set(g4,'Color','Black');
set(g2,'Color','Black');

%%
%This plot compares my CF data with Chris Baxter et al and NGI CF Plot

xlsread baxringdata.xls; %calls on data file
ringbax = ans; %renames answerxlsread CF_wrm_bax.xls; %calls on data file
xlsread baxwiredata.xls; %calls on data file
wrmbax = ans; %renames answer

strain_baxring = ringbax(:,7)/100;
strain_baxwrm = wrmbax(:,7)/100;
shear_baxring = ringbax(:,5);
shear_baxwrm = wrmbax(:,5);
```

```
figure
hold on
g1 = plot(strain_wrm3,shear_wrm3,'r*',strain_ring3,shear_ring3,'b+',...
    strain_baxwrm,shear_baxwrm,'g.',...
    strain_baxring,shear_baxring,'g>',geo_strain,geo_shear,'c-o');
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau (kPa)','FontSize',12);
ylim([0 7.5]);
xlim([0 .3]);
legend('WRM','Rings','Baxter-WRM','Baxter-Rings','NGI WRM
CF','Location','NorthEast')

%%
%_____________SHANSEP Plot_____________________%

ocr = [1,2,4,8];
gom_ring =
[SHANSEP_ratio_20,SHANSEP_ratio_52,SHANSEP_ratio_53,SHANSEP_ratio_48
]
gom_wrm =
[SHANSEP_ratio_39,SHANSEP_ratio_41,SHANSEP_ratio_47,SHANSEP_ratio_51
]


figure

p43 = semilogx(ocr,gom_ring,'b',ocr,gom_wrm,'r--')
xlabel ('OCR','FontWeight','Bold','FontSize',14);
ylabel ('S_u/\sigma_v_c (kPa)','FontWeight','Bold','FontSize',14);
title('SHANSEP Curve','FontWeight','Bold','FontSize',14);
grid
```

```
%This file plots all DSS data for both GoM and Silt specimens
%this file does not produce individual plots, it only demonstrates results
%of comparison plots


clc; close all; clear all;

DATA;

shear_analysis;
```

```
%________________S I L
T________________________%%%%%%%%%%%%%%%%%%%
%%
%________________S I L T Over-Consolidated___________________________
figure
subplot(2,1,1)
hold on
p1 = plot(sh_strain35,shear35/sigmax35,'b')
p2 = plot(sh_strain42,shear42/sigmax42,'r','LineWidth',2)
p3 =
plot(sh_strain36,shear36/sigmax36,'b',sh_strain37,shear37/sigmax37,'b',sh_strain34,s
hear34/sigmax34,'b')
p4 = plot(sh_strain44,shear44/sigmax44,'r',sh_strain45,shear45/sigmax45,'r',...
    sh_strain46,shear46/sigmax46,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\sigma\prime_h / \sigma\prime_p','FontSize',12);
legend([p1,p2],'Rings','WRM','FontWeight','Bold','Location','SouthEast')
xlim([0 .4]);
%ylim([0 .3]);
grid

subplot(2,1,2)
hold on
p5 = plot(sh_strain35,dpore35/sigmax35,'b');
p6 = plot(sh_strain42,dpore42/sigmax42,'r','LineWidth',2);
p7 =
plot(sh_strain36,dpore36/sigmax36,'b',sh_strain37,dpore37/sigmax37,'b',sh_strain34,
dpore34/sigmax34,'b');
p8 =
plot(sh_strain44,dpore44/sigmax44,'r',sh_strain45,dpore45/sigmax45,'r',sh_strain46,d
pore46/sigmax46,'r','LineWidth',2);
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('Pore Pressure / \sigma\prime_p','FontSize',12);
xlim([0 .4]);
ylim([-.5 .6]);
grid

%Now plot shear envelope for Silt
figure
hold on
p9 = plot(normal35/sigmax35,shear35/sigmax35,'b');
p10 = plot(normal42/sigmax42,shear42/sigmax42,'r','LineWidth',2);
p11 =
```

```
plot(normal36/sigmax36,shear36/sigmax36,'b',normal37/sigmax37,shear37/sigmax37
,'b',normal34/sigmax34,shear34/sigmax34,'b');
p12 =
plot(normal44/sigmax44,shear44/sigmax44,'r',normal45/sigmax45,shear45/sigmax45,
'r',normal46/sigmax46,shear46/sigmax46,'r','LineWidth',2);
hold off
xlabel('\sigma\prime_v / \sigma\prime_p','FontSize',12);
ylabel('\tau / \sigma\prime_p','FontSize',12);
legend([p9,p10],'Rings','WRM');
ylim([0 .3])
xlim([0 1])
grid

%Now plot silt shear vs strain normalizing by sig'vc instead of sig'p
figure
hold on
p1 = plot(sh_strain35,shear35/sig35(end),'b')
p2 = plot(sh_strain42,shear42/sig42(end),'r','LineWidth',2)
p3 =
plot(sh_strain36,shear36/sig36(end),'b',sh_strain37,shear37/sig37(end),'b',sh_strain34
,shear34/sig34(end),'b')
p4 = plot(sh_strain44,shear44/sig44(end),'r',sh_strain45,shear45/sig45(end),'r',...
   sh_strain46,shear46/sig46(end),'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau / \sigma\prime_v_c','FontSize',12);
legend([p1,p2],'Rings','WRM','FontWeight','Bold','Location','SouthEast')
xlim([0 .4]);
ylim([0 1.4]);
grid

%%
%___________________S I L T Normally-Consolidated_________________________

figure
subplot(2,1,1)
%Plot all stress vs strain on same plot for Silt
hold on
p13 = plot(sh_strain31,shear31/sigmax31,'b')
p14 = plot(sh_strain43,shear43/sigmax43,'r','LineWidth',2)
p15 = plot(sh_strain34,shear34/sigmax34,'b')
p16 = plot(sh_strain42,shear42/sigmax42,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau / \sigma\prime_p','FontSize',12);
legend([p13,p14],'Rings','WRM','Location','SouthEast')
```

```
xlim([0 .4]);
ylim([0 .3]);
grid

subplot(2,1,2)
%Plot all pore pressure vs strain on same plot for Silt
hold on
p17 = plot(sh_strain31,dpore31/sigmax31,'b')
p18 = plot(sh_strain43,dpore43/sigmax43,'r','LineWidth',2)
p19 = plot(sh_strain34,dpore34/sigmax34,'b')
p20 = plot(sh_strain42,dpore42/sigmax42,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('Pore Pressure / \sigma\prime_p','FontSize',12);
xlim([0 .4]);
ylim([-.5 .6]);
grid

%Now plot shear envelope for Silt
figure
hold on
p21 = plot(normal31/sigmax31,shear31/sigmax31,'b')
p22 = plot(normal43/sigmax43,shear43/sigmax43,'r','LineWidth',2)
p23 = plot(normal34/sigmax34,shear34/sigmax34,'b')
p24 = plot(normal42/sigmax42,shear42/sigmax42,'r','LineWidth',2);
xlabel('\sigma\prime_v / \sigma\prime_p_c','FontSize',12);
ylabel('\tau / \sigma\prime_p_c','FontSize',12);
legend([p21,p22],'Rings','WRM')
ylim([0 .3])
xlim([0 1])
grid



%%
%Gulf of Mexico Results
%%
%_________________GoM Normally-Consolidated


%%%%%%%%%%comparison of GoM data Normally
Consolidated%%%%%%%%%%%%%%%%%

figure
subplot(2,1,1)
%Plot all stress vs strain on same plot for GoM
```

```
hold on
p25 = plot(sh_strain19,shear19/sigmax19,'b')
p26 = plot(sh_strain20,shear20/sigmax20,'b')
p27 = plot(sh_strain40,shear40/sigmax40,'r','LineWidth',2)
p28 = plot(sh_strain39,shear39/sigmax39,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau / \sigma\prime_p','FontSize',12);
legend([p25,p27],'Rings','WRM',...
    'location','SouthEast')
xlim([0 .4]);
ylim([0 .3]);
grid

subplot(2,1,2)
%Plot all pore pressure vs strain on same plot for GoM
hold on
p29 = plot(sh_strain19,dpore19/sigmax19,'b')
p30 = plot(sh_strain40,dpore40/sigmax40,'r','LineWidth',2)
p31 = plot(sh_strain20,dpore20/sigmax20,'b')
p32 = plot(sh_strain39,dpore39/sigmax39,'r','LineWidth',2)
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('Pore Pressure / \sigma\prime_p','FontSize',12);
xlim([0 .4]);
ylim([-.5 .6])
grid


%Now plot shear envelope for GoM
figure
hold on
p33 = plot(normal19/sigmax19,shear19/sigmax19,'b')
p35 = plot(normal40/sigmax40,shear40/sigmax40,'r','LineWidth',2)
p36 = plot(normal20/sigmax20,shear20/sigmax20,'b')
p34 = plot(normal39/sigmax39,shear39/sigmax39,'r','LineWidth',2);
hold off
xlabel('\sigma\prime_v / \sigma\prime_p','FontSize',12);
ylabel('\tau / \sigma\prime_p','FontSize',12);
legend([p33,p35],'Rings','WRM');
xlim([0 1])
ylim([0 .3])
grid
%%
%____________________GoM Over-Consolidated____________________
```

```
figure
subplot(2,1,1)
%Plot all stress vs strain for OCR tests
hold on
p35 = plot(sh_strain19,shear19/sigmax19,'b')
p36 = plot(sh_strain40,shear40/sigmax40,'r','LineWidth',2)
p37 =
plot(sh_strain52,shear52/sigmax52,'b',sh_strain53,shear53/sigmax53,'b',sh_strain23,s
hear23/sigmax23,'b')
p38 =
plot(sh_strain41,shear41/sigmax41,'r',sh_strain47,shear47/sigmax47,'r',sh_strain51,sh
ear51/sigmax51,'r','LineWidth',2)
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau / \sigma\prime\_p','FontSize',12);
legend([p35,p36],'Rings','Wire Membrane','Location','SouthEast')
xlim([0 .4]);
ylim([0 .3]);
grid

subplot(2,1,2)
%Plot all pore pressure vs strain for OCR Tests
hold on
p39 = plot(sh_strain19,dpore19/sigmax19,'b')
p40 = plot(sh_strain40,dpore40/sigmax40,'r','LineWidth',2)
p41 =
plot(sh_strain52,dpore52/sigmax52,'b',sh_strain53,dpore53/sigmax53,'b',sh_strain23,
dpore23/sigmax23,'b')
p42 =
plot(sh_strain41,dpore41/sigmax41,'r',sh_strain47,dpore47/sigmax47,'r',sh_strain51,d
pore51/sigmax51,'r','LineWidth',2);
hold off
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau / \sigma\prime_p','FontSize',12);
xlim([0 .4]);
ylim([-.5 .6]);
grid

%OCR shear envelope's
figure
hold on
p43 = plot(normal19/sigmax19,shear19/sigmax19,'b')
p44 = plot(normal40/sigmax40,shear40/sigmax40,'r','LineWidth',2)
p45 =
plot(normal52/sigmax52,shear52/sigmax52,'b',normal53/sigmax53,shear53/sigmax53
,'b',normal23/sigmax23,shear23/sigmax23,'b')
p46 =
```

```
plot(normal41/sigmax41,shear41/sigmax41,'r',normal47/sigmax47,shear47/sigmax47,
'r',normal51/sigmax51,shear51/sigmax51,'r','LineWidth',2);
xlabel('\sigma\prime_v / \sigma\prime_p_c','FontSize',12);
ylabel('\tau / \sigma\prime_p_c','FontSize',12);
legend([p43,p44],'Rings','Wire Membrane',...
    'location','NorthEast');
xlim([0 1])
ylim([0 .3])
grid

%Now plot GoM dividing by final consolidation stress isntead of
%pre-consolidation stress

figure
hold on
p35 = plot(sh_strain19,shear19/sig19(end),'b')
p36 = plot(sh_strain40,shear40/sig40(end),'r','LineWidth',2)
p37 =
plot(sh_strain52,shear52/sig52(end),'b',sh_strain53,shear53/sig53(end),'b',sh_strain23
,shear23/sig23(end),'b')
p38 =
plot(sh_strain41,shear41/sig41(end),'r',sh_strain47,shear47/sig47(end),'r',sh_strain51,
shear51/sig51(end),'r','LineWidth',2)
xlabel ('Shear Strain','FontSize',12);
ylabel ('\tau / \sigma\prime_v_c','FontSize',12);
legend([p35,p36],'Rings','Wire Membrane','Location','SouthEast')
xlim([0 .4]);
ylim([0 1.4]);
grid
```

Appendic C NGI Correction Factor Data for WRM

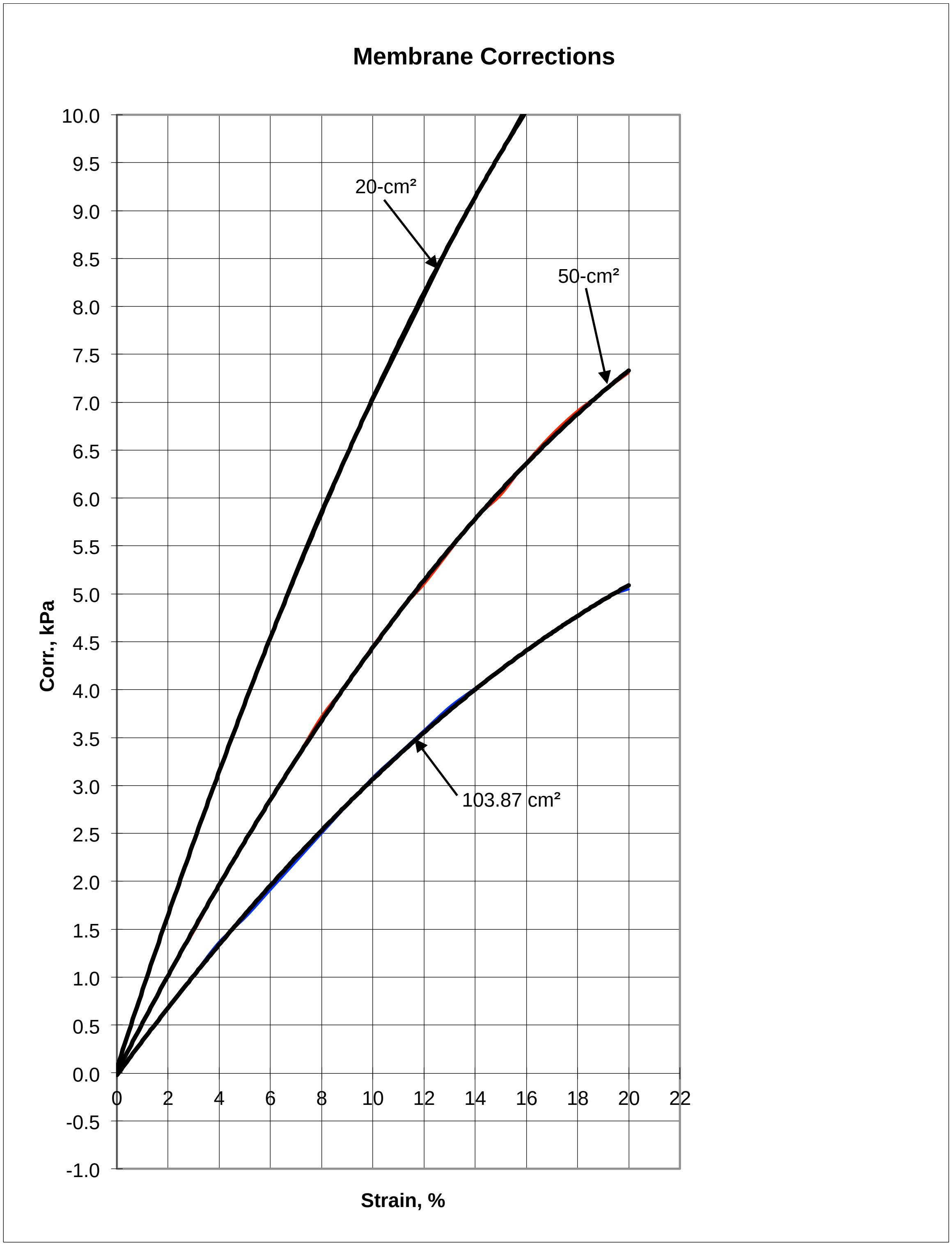


Figure C-1 –Geonor Correction Factor plot

GEONOR DSS MEMBRANES - ALLOWABLE AXIAL CONSOLIDATION STRESS - kPa

Item No.	218011	218010	218009	218001	218000	218002	217901	217900	217902
Specimen area	**20 cm2**			**35 cm2**			**50 cm2**		
C-value	1.0	1.25	1.5	1.0	1.25	1.5	1.0	1.25	1.5
Incremental consolidation (vertical stress capacity, doubling increments)*	363 kPa	961 kPa	1442 kPa	270 kPa	716 kPa	1079 kPa	226 kPa	598 kPa	903 kPa
Incremental consolidation (vertical stress capacity, last increment halved)*	435 kPa	1154 kPa	1730 kPa	323 kPa	859 kPa	1295 kPa	270 kPa	718 kPa	1083 kPa
Continuous consolidation (vertical stress capacity, monotonic drained loading)*	544 kPa	1442 kPa	2164 kPa	404 kPa	1074 kPa	1618 kPa	338 kPa	898 kPa	1354 kPa

* A membrane support ring may allow greater maximum consolidation vertical stress than these capacities, provided the final stress is below these limits and the resulting lateral stress is low enough. This should be evaluated for the specific test.
If a specimen dilates during shear (negative pore pressure), the membrane capacity may be exceeded even if starting below these consolidation capacities.

Figure C-2 –Geonor Correction Factor Table for Different Membrane thicknesses.

C	***f***
1.00	f = t / 0.6
1.25	f = (t + 0.0306) / 0.6
1.50	f = (t + 0.0696) / 0.6

Figure C-3 – Geonor Membrane correction factor chart

Appendic D Gulf of Mexico Clay Core Info

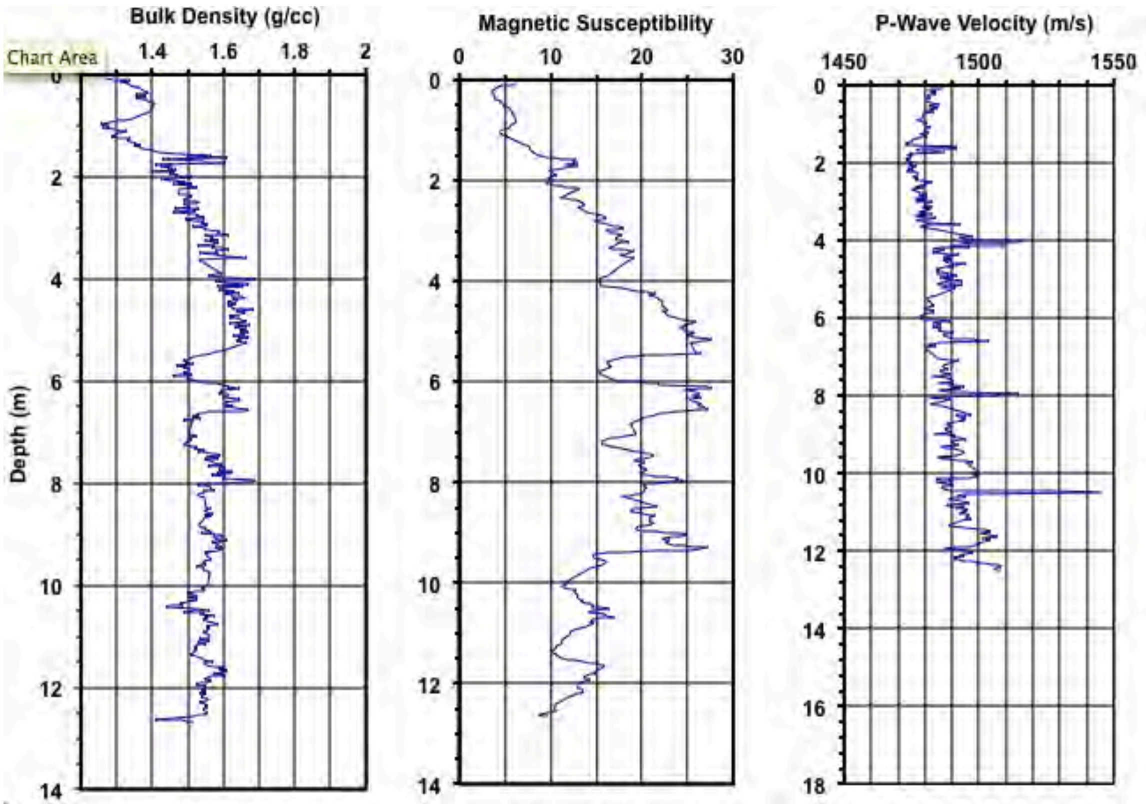


Figure D-1 – KN 159 JPC 11 Gulf of Mexico Clay Core Info

Appendix E Compilation of Typical Results

This section compiles a variety of shear strength test results.

E1 Clay DSS Tests

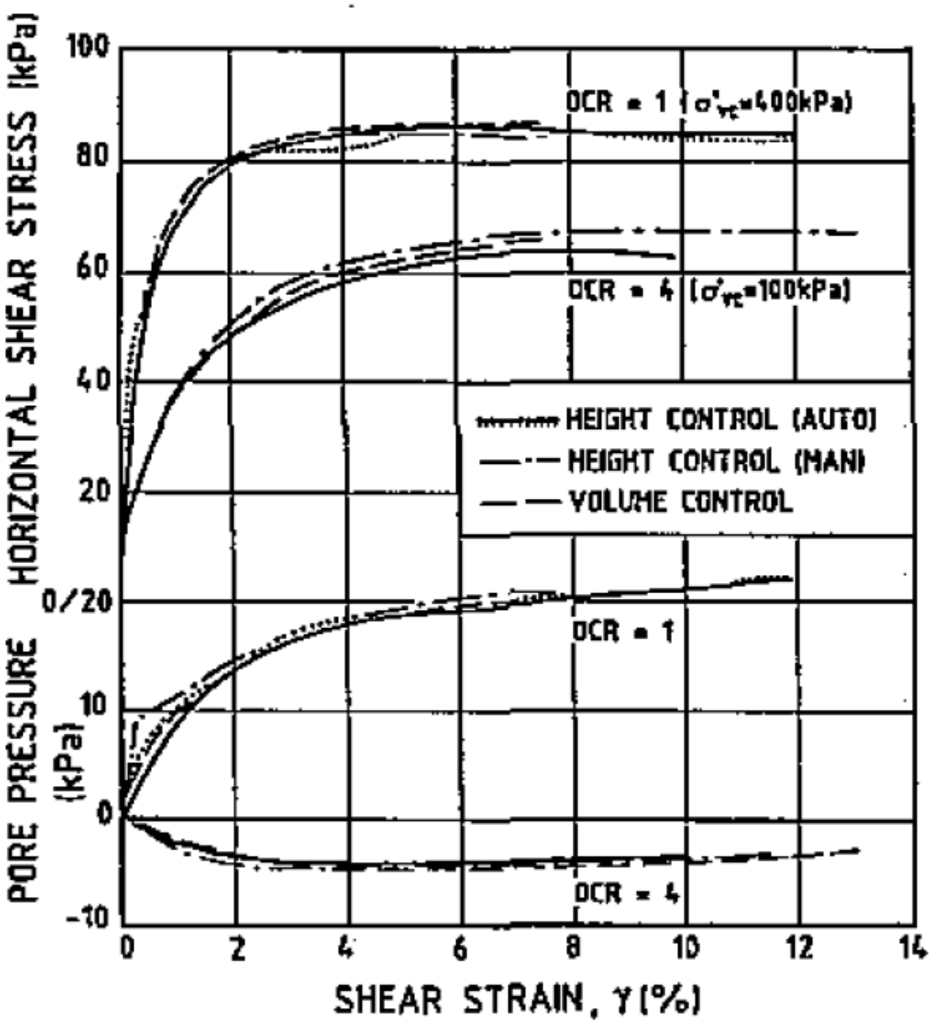


Figure E-1 – Direct Simple Shear Drammen Clay with Height Control OCR = 1 & 4, A = 50 cm2 (Airey & Wood, 1984)

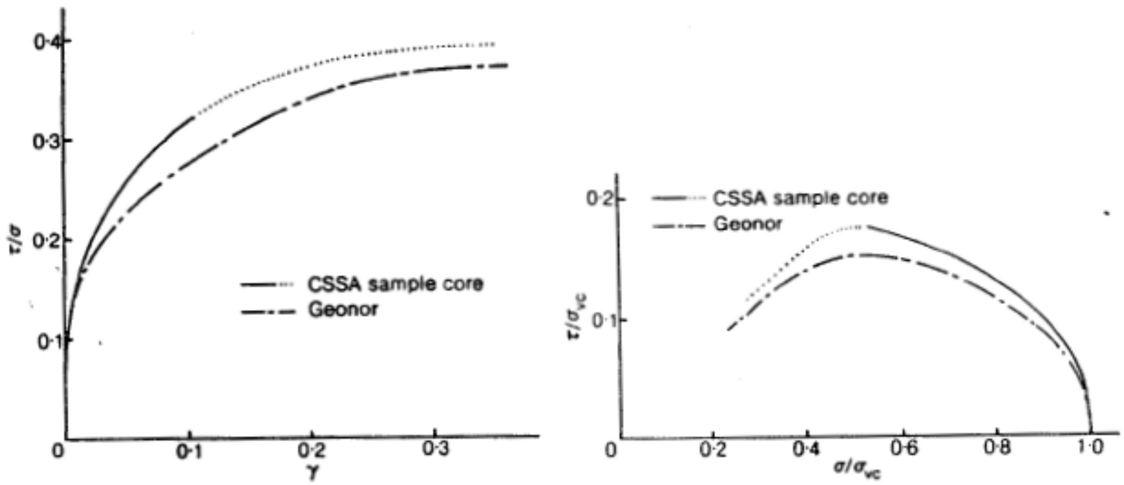


Figure E-2 – Constant Volume Simple Shear Tests on Kaolin (a) Shear Stress-Strain Curve; (b) Normalized Effective Stress Paths (Airey and Wood, 1987 via (DeGroot et al. 1992))

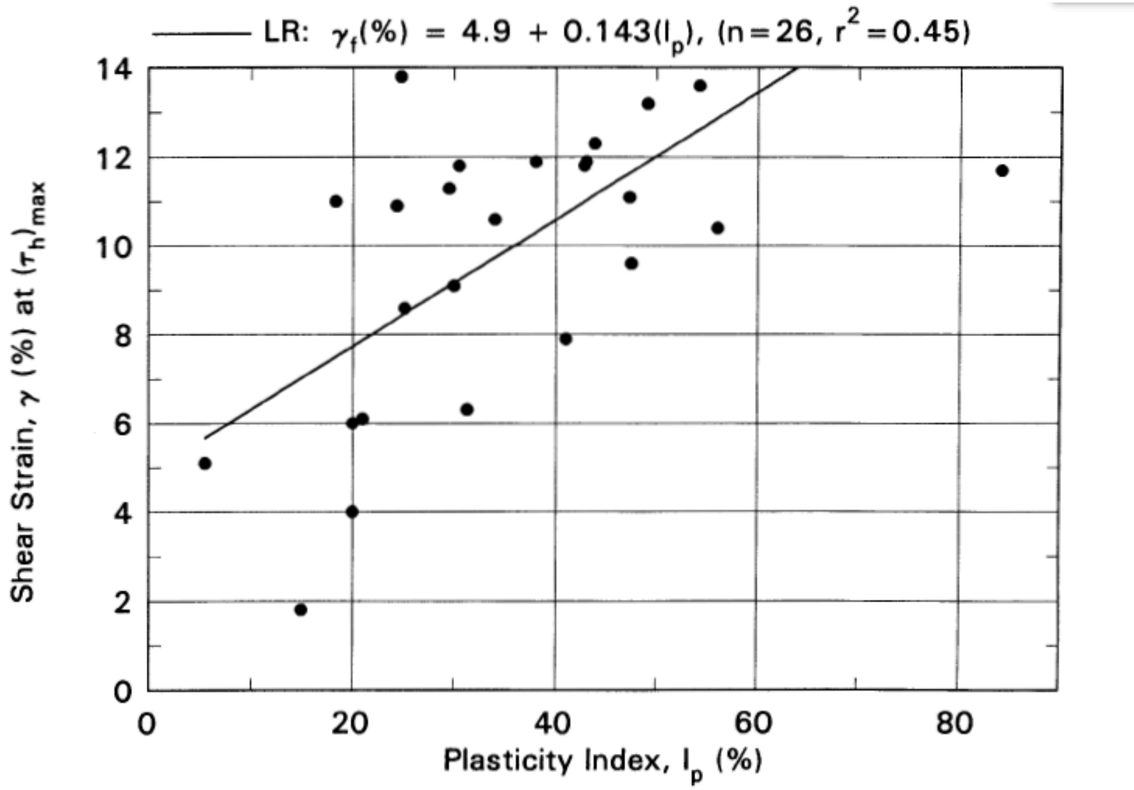


Figure E-3 – Shear Strain at Max Hor Shear Stress vs Plasticity index for NC Undrained DSS tests on Cohesive Soil (DeGroot et al. 1992)

Figure 20 highlights the role of the Plasticity Index on DSS testing. It's important to note the higher the plasticity index the higher strain rates reached before maximum Shear Stress is reached. (DeGroot, Ladd, & Germaine, 1992)

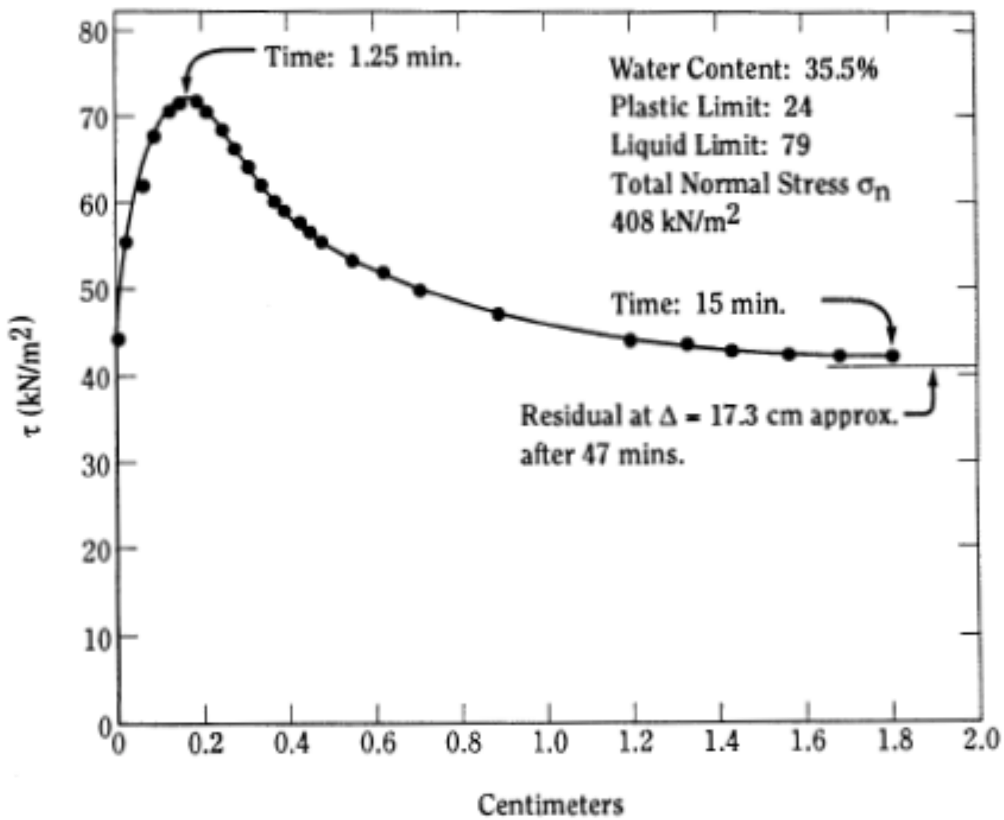


Figure E-4 – Stress -Displacement Relationship for "Rapid Undrained" Ring Shear Test on freshly remolded Blue London Clay (After Bishop, 1971 via DeGroot et al. 1992)

Rapid undrained test in figure 21 demonstrates prounounced strain softening. This can be attributed to the soil type and the rapid strain.

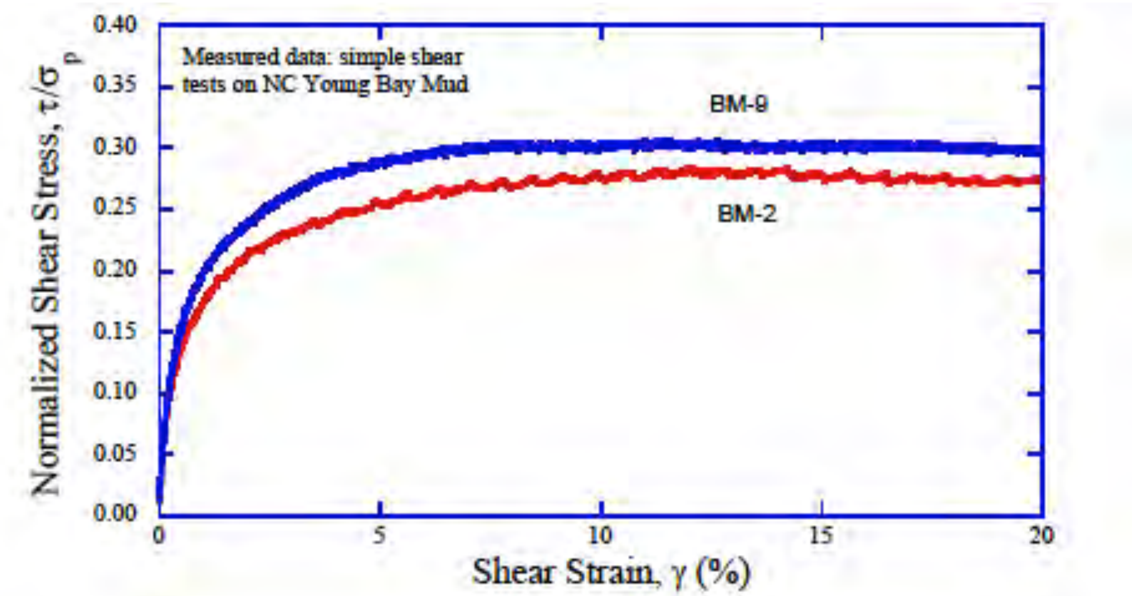


Figure E-5 – Test results of Clay with varying strain rate (Jung, 2005)

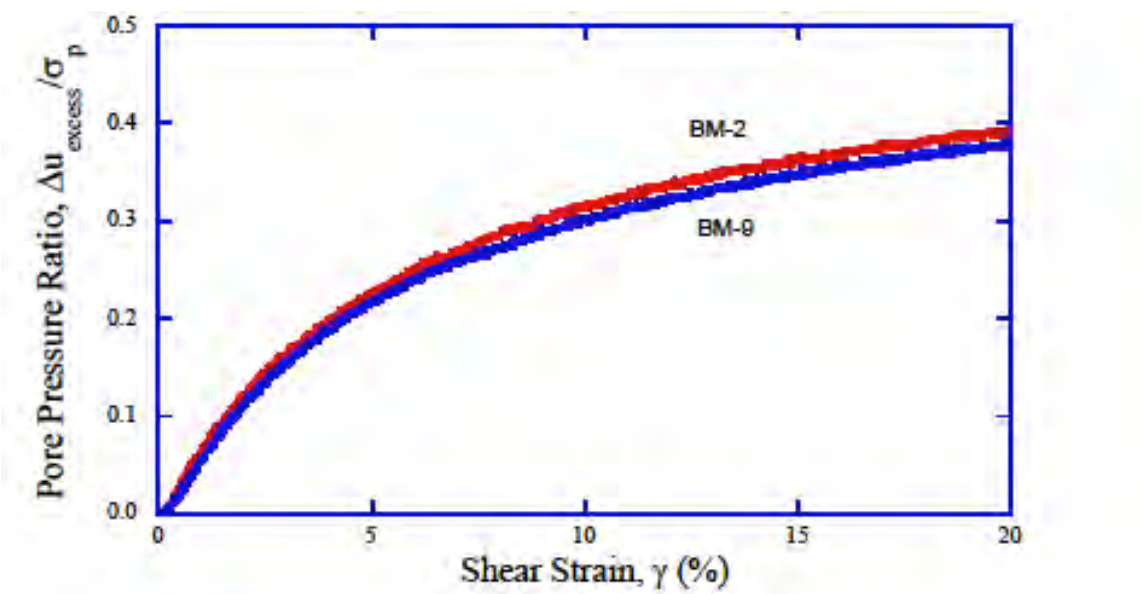


Figure E-6 – Pore pressure results of clay with varying strain rate (Jung, 2005)

2.9.2 Silt DSS Tests

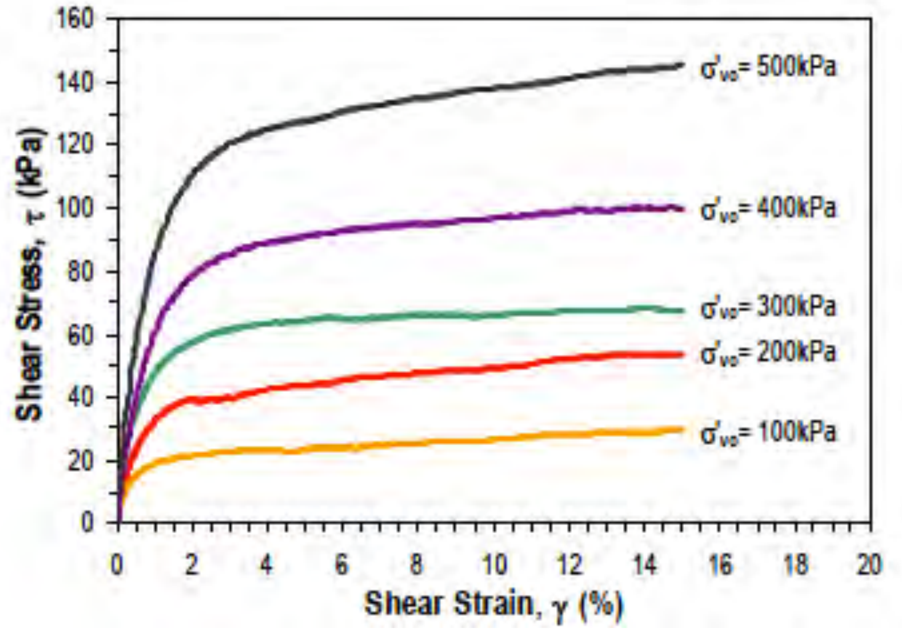


Figure E-7 – Stress Strain Curves from constant volume monotonic direct simple shear tests on NC Fraser River silt (Wijewickreme, 2006)

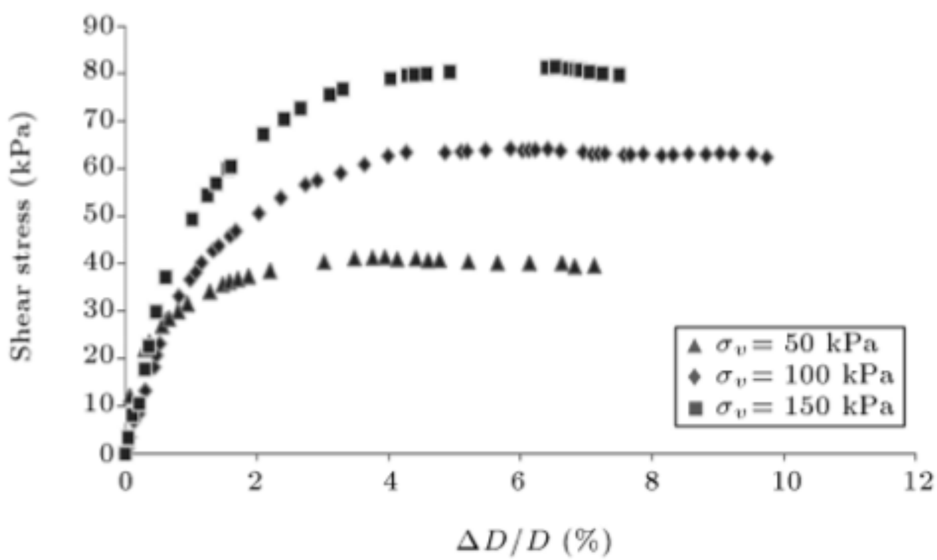


Figure E-8 – Results of saturated Direct Shear Test on Silt-Bentonite vs normalized horizontal strain (Ajdari et al, 2010)

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