The use and measurement of fully softened shear strength (FSSS)

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GeoVirginia 2013

A MAP OF VIRGINIA AND MARYLAND
A Scale of English Miles
John Brandon (1654)
John Brandon (1700)
Henrico C.
Surry C.
Isle of Weight C.
Lower Norfolk C.
Carotuk C.
Albemarle C.
Rappahanoc
Stafford C.
Anne Arundel
CHESEAPEAKE BAY
Cape Henry
Cape Charles
Acoomac C.
Calbot C.
Cæcil C.
LAND
Minquaas
Sasquahanoks
Tockwoghs
Sauwan
Delawar Bay
PART OF NEW IARSY
THE NORTH SEA

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Brandon Plantation, Halifax County
VIRGINIA.
Scale of Miles
John Brandon (1700)
Leroy Jackson Brandon (1862)
Francis Brandon (1746)
John Brandon (1654)
Longitude West 3 from Washington
Long. East from Washington
Engraved by G.W. Boynton.

Fully softened shear strength vs. lessons learned

- Analysis and testing method borne out of failures.
- Investigation of failures and back-analysis played critical roles in development of FSSS.
  - Long term failures in cuts in stiff clays
  - Long term failures in compacted clay embankments

Fully Softened Strength

- 80 year old concept
- Growing in importance
- Included in new Corps of Engineers levee manual
- Special session at San Diego ASCE conference
- ASCE EDS subcommittee
- VT workshop

2011 Workshop on Fully Softened Strength (FSS)

- Held at Virginia Tech – August 16 & 17, 2011
- Attended by 57 engineers and geologists

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Virginia Polytechnic Institute
And State University

The Charles E. Via, Jr.
Department of Civil Engineering

CENTER FOR
GEOTECHNICAL PRACTICE AND RESEARCH

Report of the Workshop on Shear Strength for
Stability of Slopes in Highly Plastic Clays

by

J. Michael Duncan
Thomas L. Brandon

Aad

Daniel R. VandenBerge

Report of a study performed by the Virginia Tech Center for
Geotechnical Practice and Research

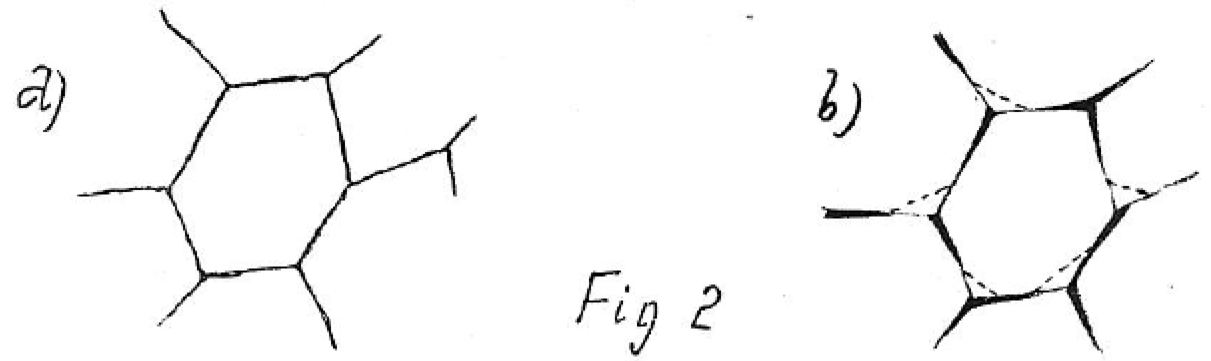
CGPR
Center for
Geotechnical Practice and Research
200 Patton Hall
Blacksburg, VA 24061

December 2011
CGPR #67

Virginia Tech

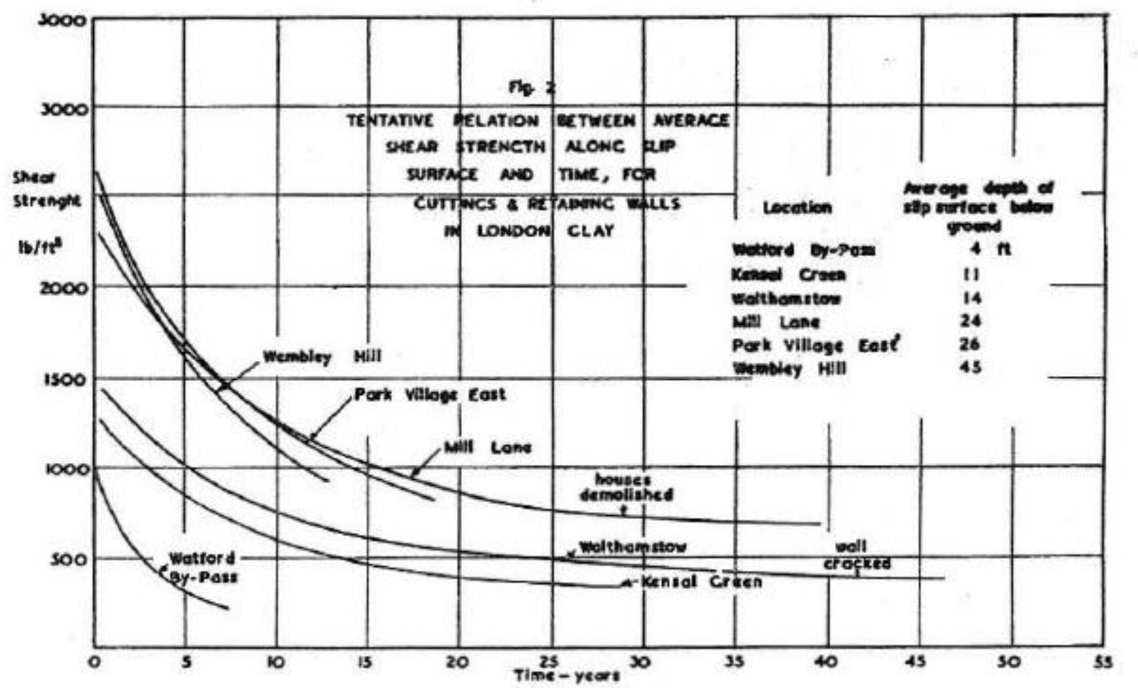
Background on FSSS

- Terzaghi observed softening in stiff fissured clays in 1936.



Background on FSS

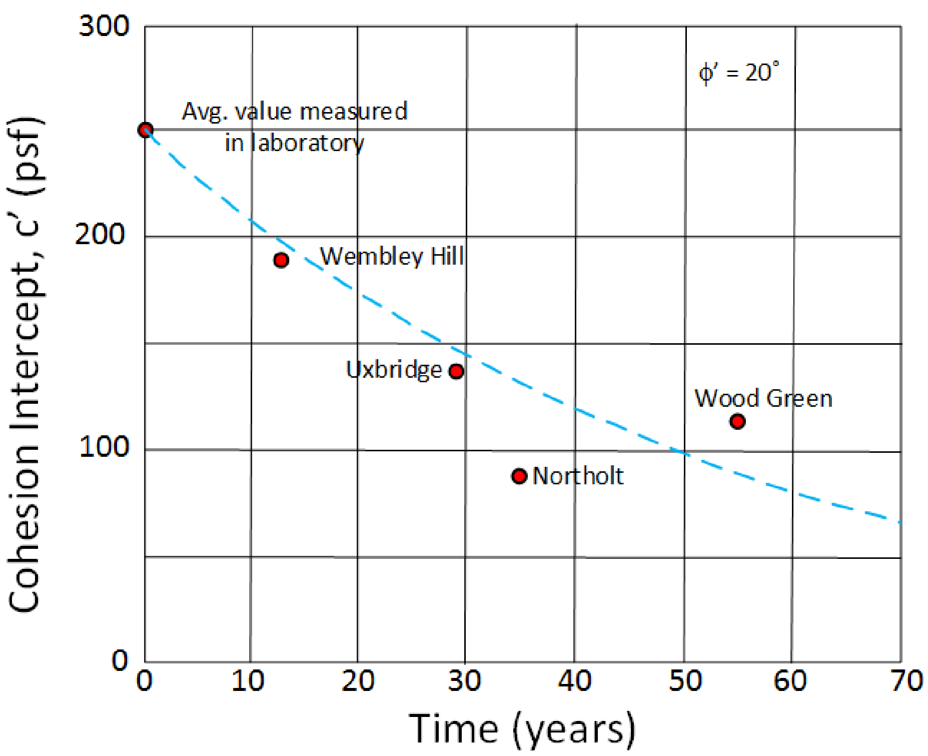
- Skempton (1948) coined the term "fully softened shear strength."



Tentative relation between average shear strength along slip surface and time, for cuttings & retaining walls in London clay.

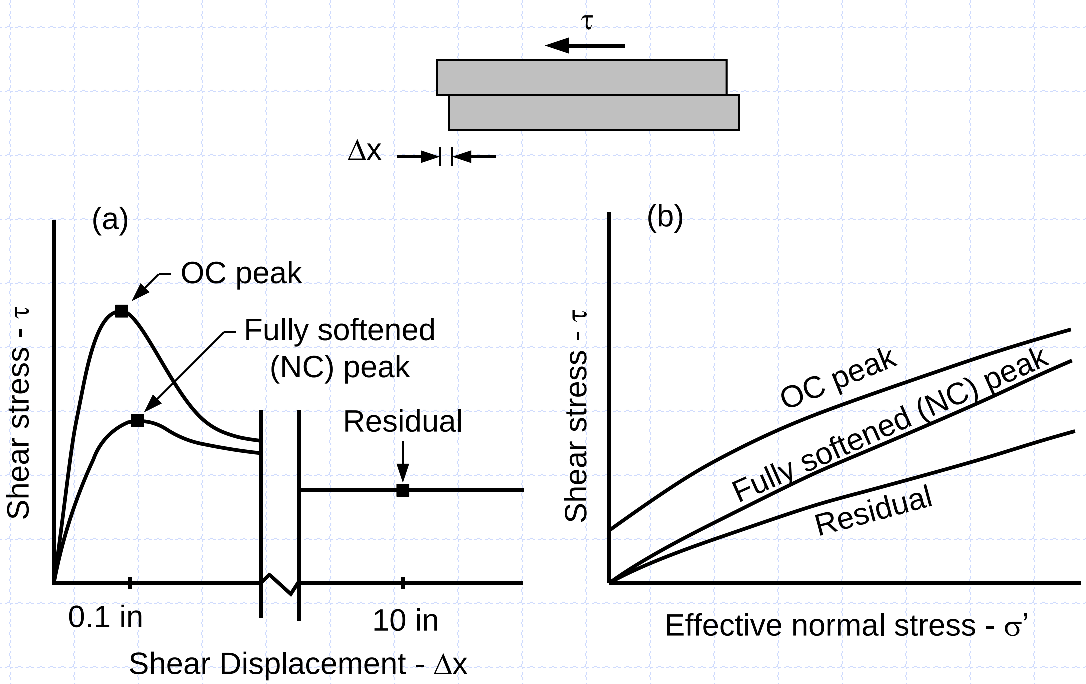
Background on FSS

- Henkel and Skempton (1954) and Henkel (1957) thought that c′ decreased with time.



Background on FSS

- Skempton (1970) equated FSS with the peak drained strength of normally consolidated clay.



Duncan et al. (2011)

Background on FSS

- S. Wright studied shallow slope failures in compacted highly plastic Texas clays.
  - Paris and Beaumont clays (CH)
  - Strengths from back analysis much higher than laboratory strengths on compacted clays.
  - Strength reduced from cycles of wetting and drying.

Workshop: the softening process

- Primary mechanisms
  - Around excavations – lateral stress relief
  - In compacted fills – desiccation & shrinkage
- Mostly occurs in highly plastic clays
- Local factors must be considered
  - Mineralogy
  - Climate

Vanden Berge et al. (2013)

Workshop: the softening process

- Likelihood of reaching FSS increases with:
  - Higher Plasticity Index
  - Presence of fissures or shrinkage cracks
  - w% above Shrinkage Limit
  - Higher clay size fraction
  - Lower sand and silt content
  - Higher activity

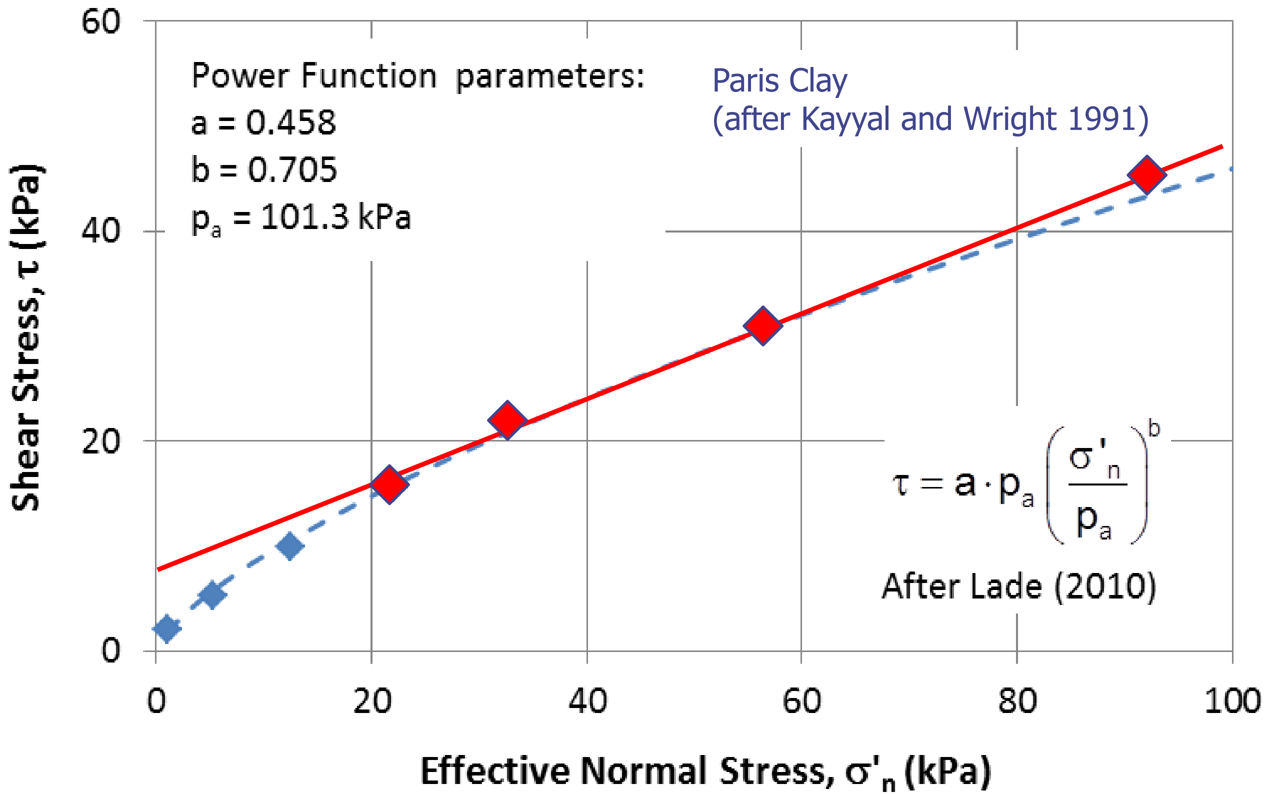
Vanden Berge et al. (2013)

Laboratory Measurement of FSSS

- FSSS has been measured by direct shear (DS), triaxial compression (TC), and ring shear (RS) tests
- Tests should be performed on specimens prepared near the LL
- FSSS envelope is usually curved
  - ϕ'_{sec} decreases with increasing stress.

Curved Strength Envelopes

- Can lead to significant error at low stresses
- Affects depth of predicted failure surface



Virginia Tech Study

- Partnered with ERDC
- Difference in test apparatus (DS, RS, and TC)
- Influence of sample preparation technique
  - Blenderized vs. "unmolested"
  - Initial liquidity index
- Low stress tests

Ring shear apparatus

- ASTM D7608 developed by Prof. Tim Stark at UI-CU

  "Standard Test Method for Torsional Ring Shear Test to Determine Drained Fully Softened Shear Strength and Nonlinear Strength Envelope of Cohesive Soils (Using Normally Consolidated Specimen) for Slopes with No Preexisting Shear Surfaces"

- Most labs use Bromhead RS

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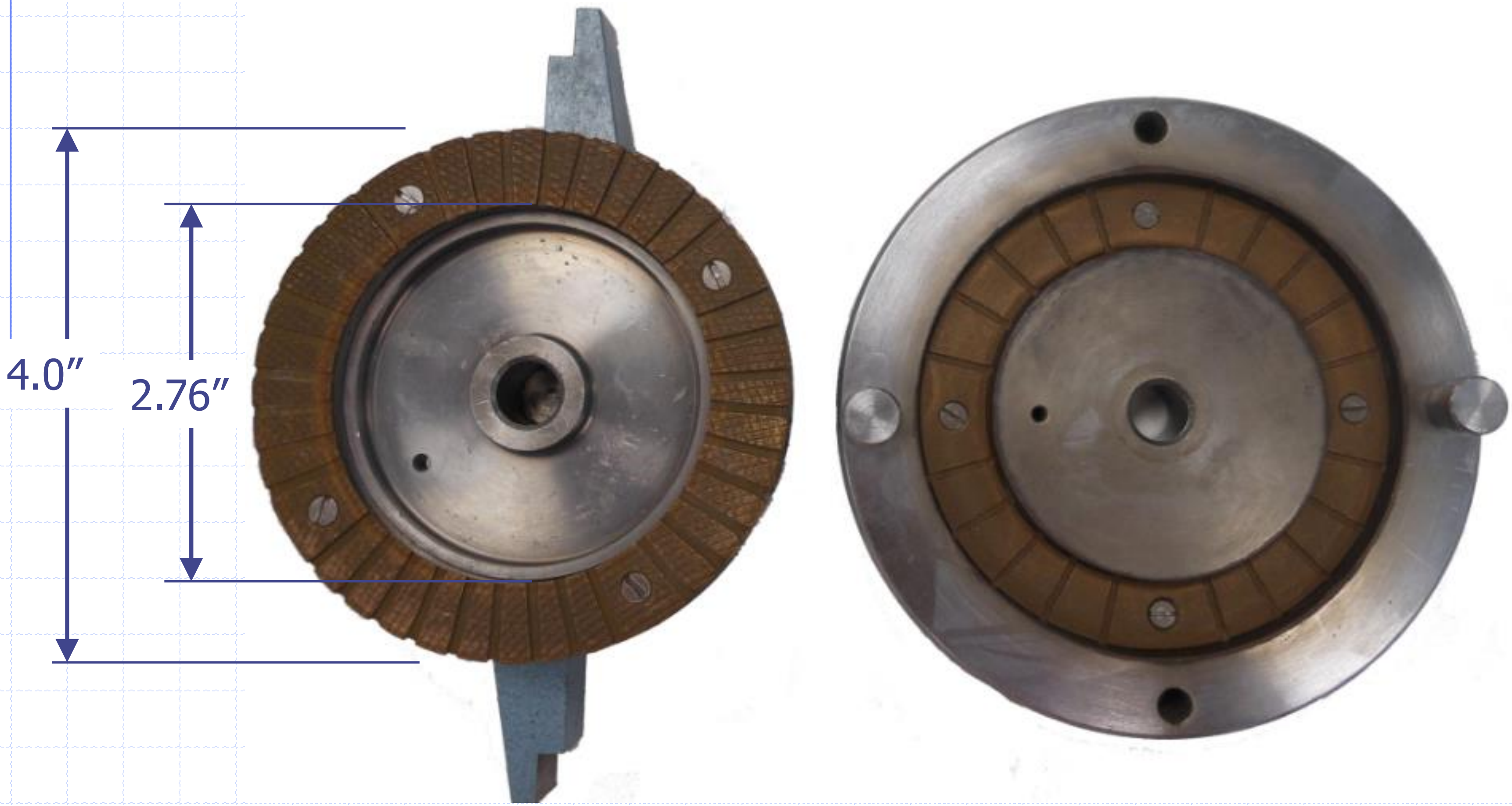
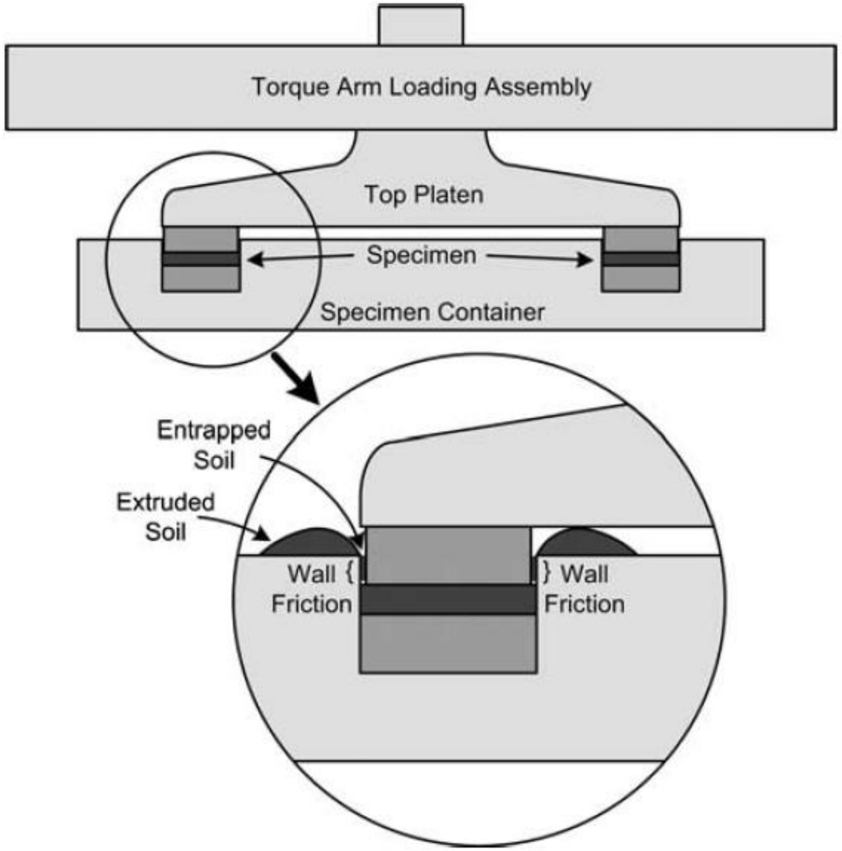
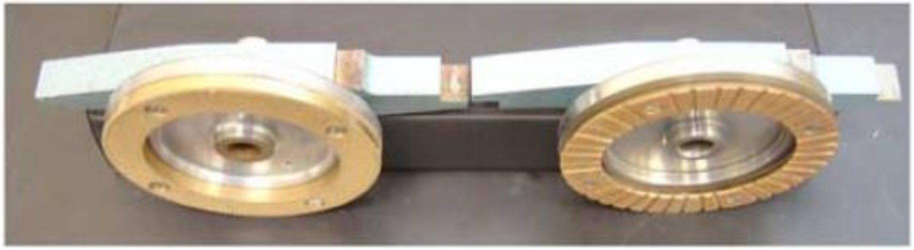
Bromhead Devices

Sample Container

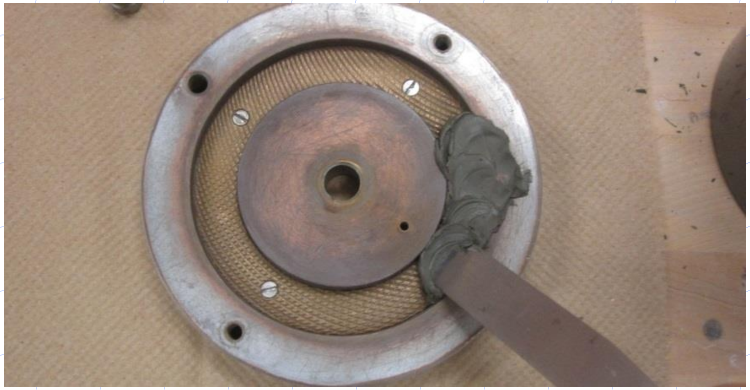


VT Modifications

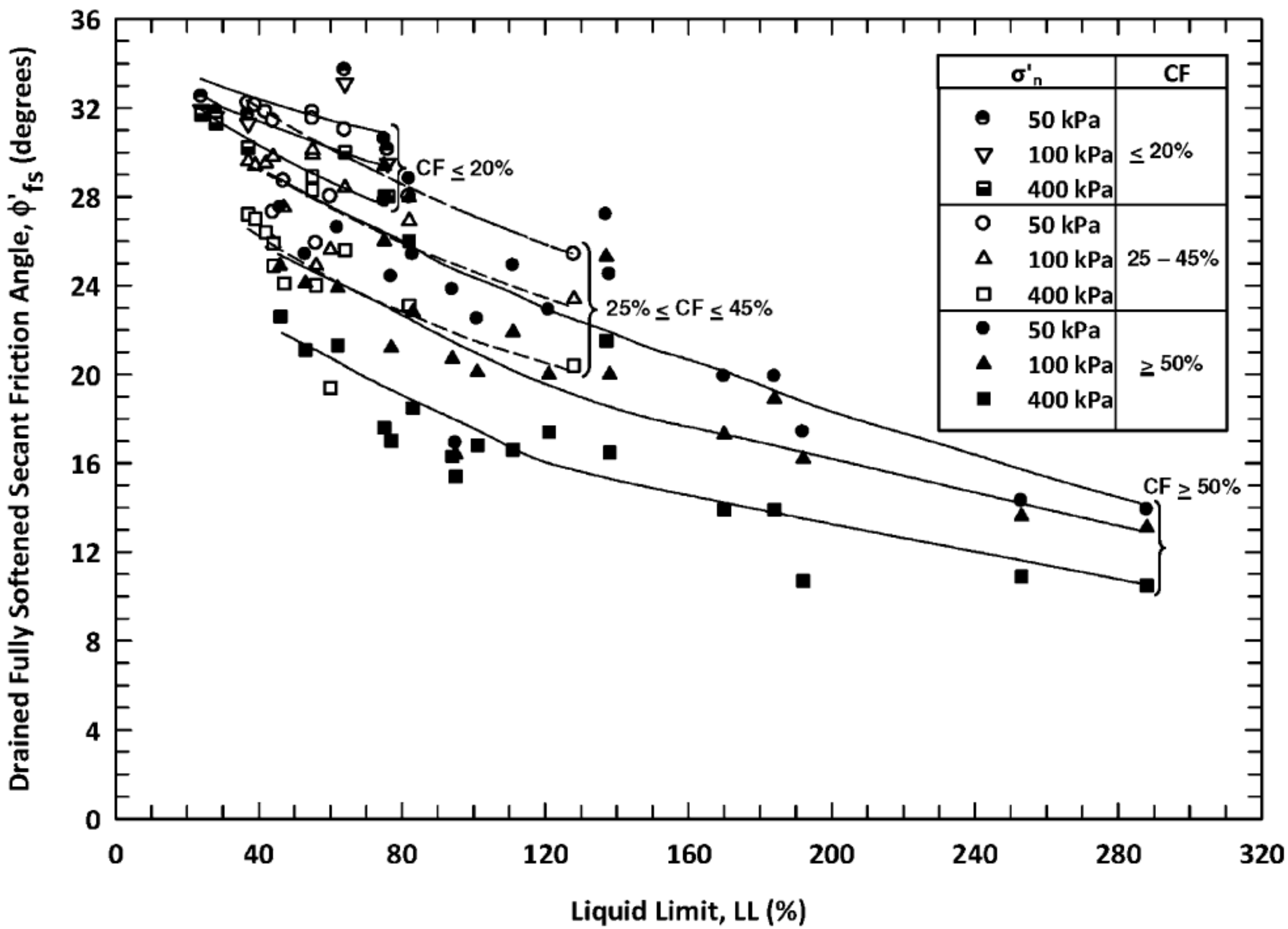




Sample Preparation



Fully softened correlation



Stark and Hussain (2013)

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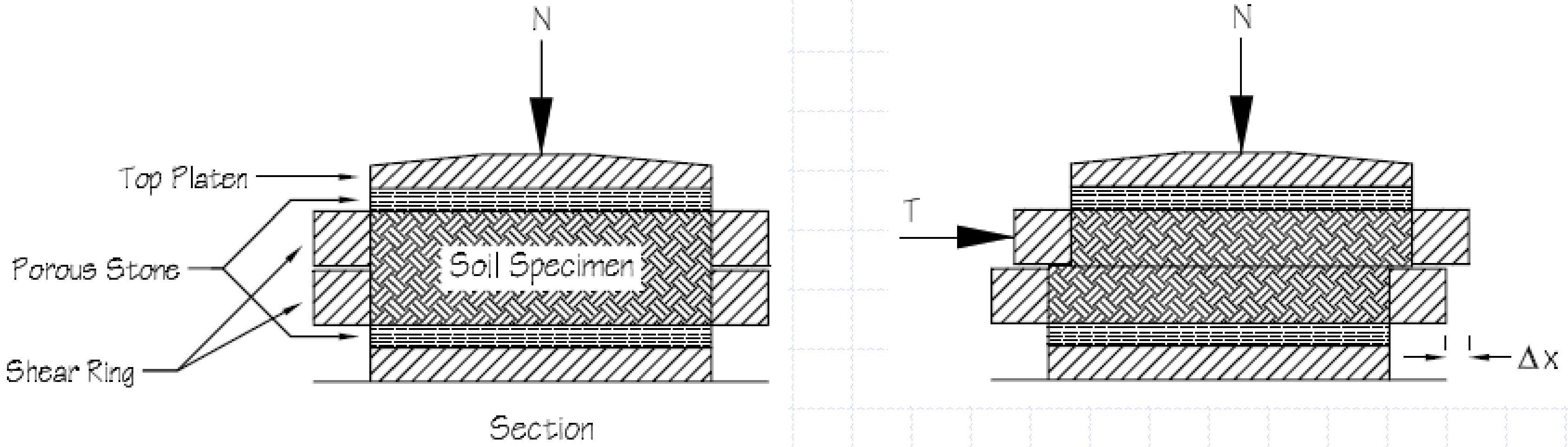
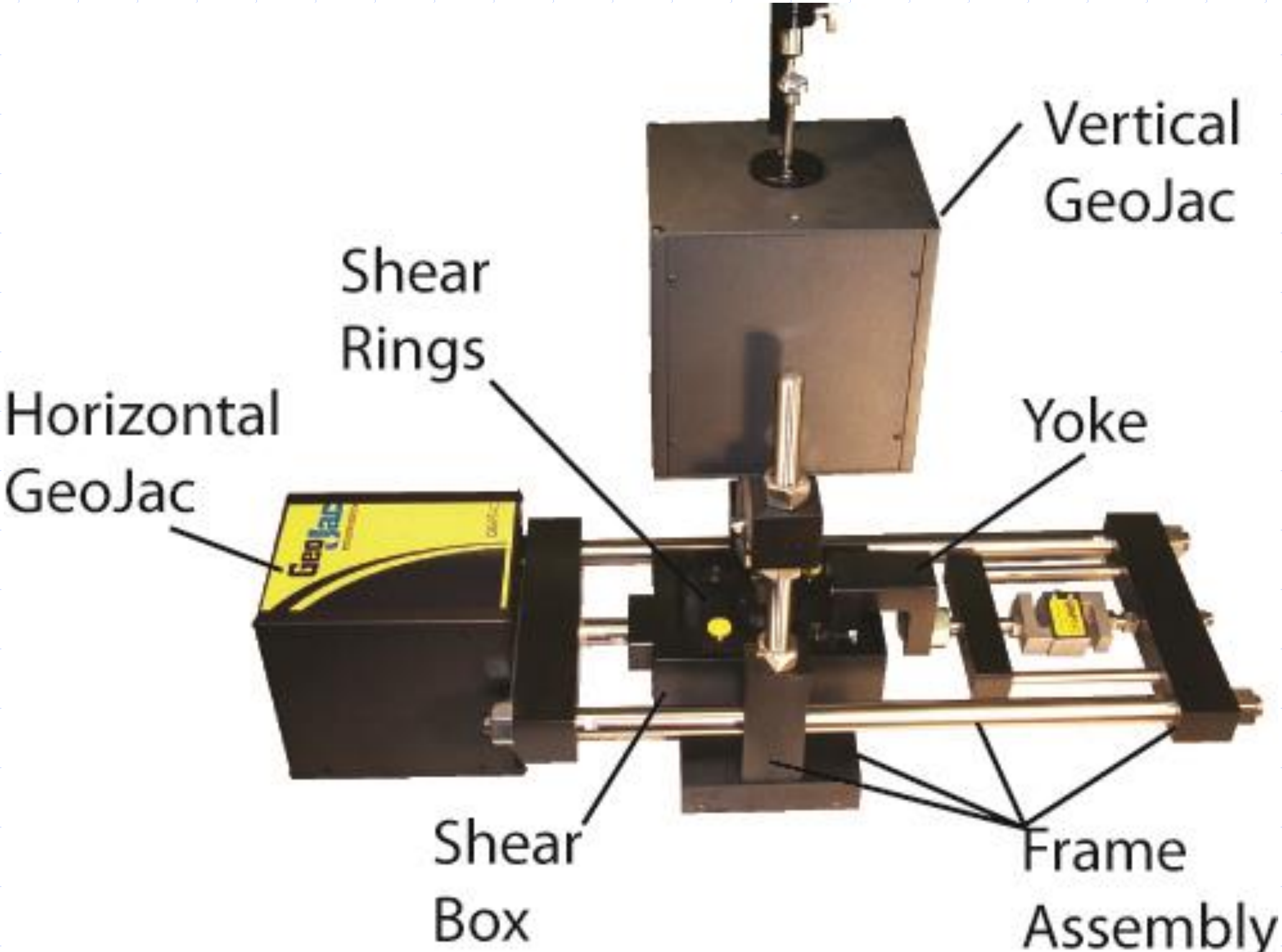
Direct Shear Apparatus

- ASTM D3080
- Historically popular for FSSS
- No spec for fully softened strength

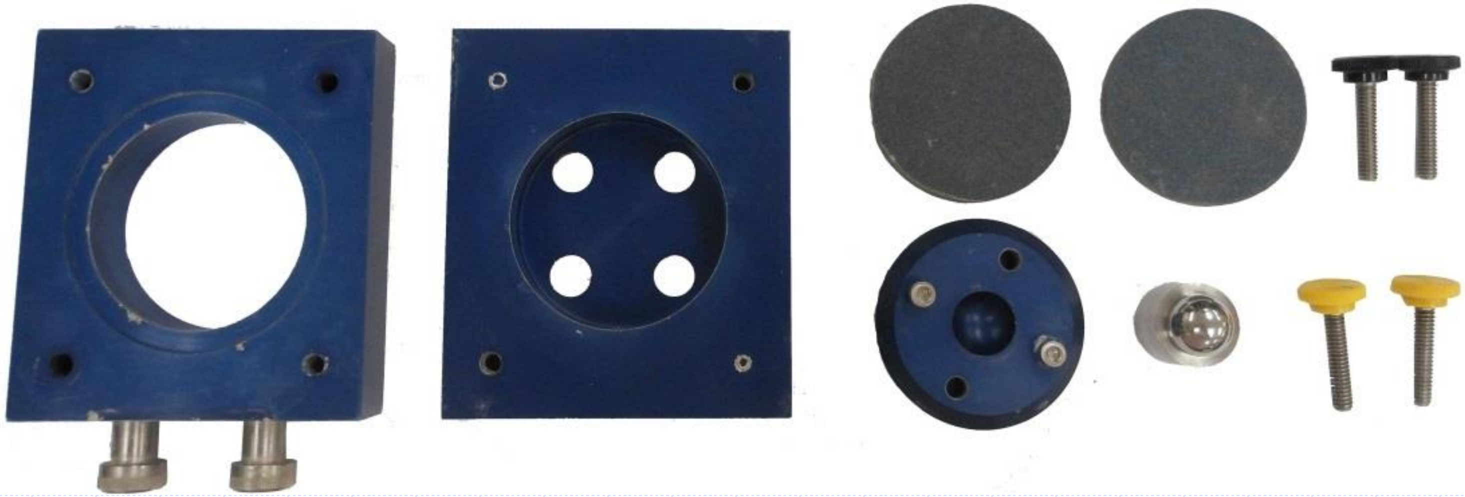


Direct Shear



Conventional Shearbox

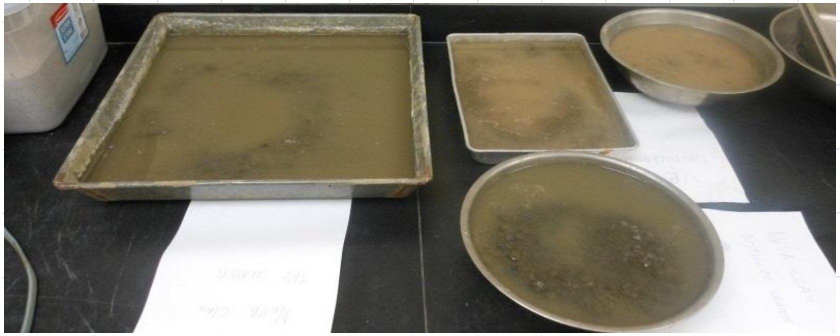
- Square and circular cross sections
- Aluminum top and bottom rings and platens



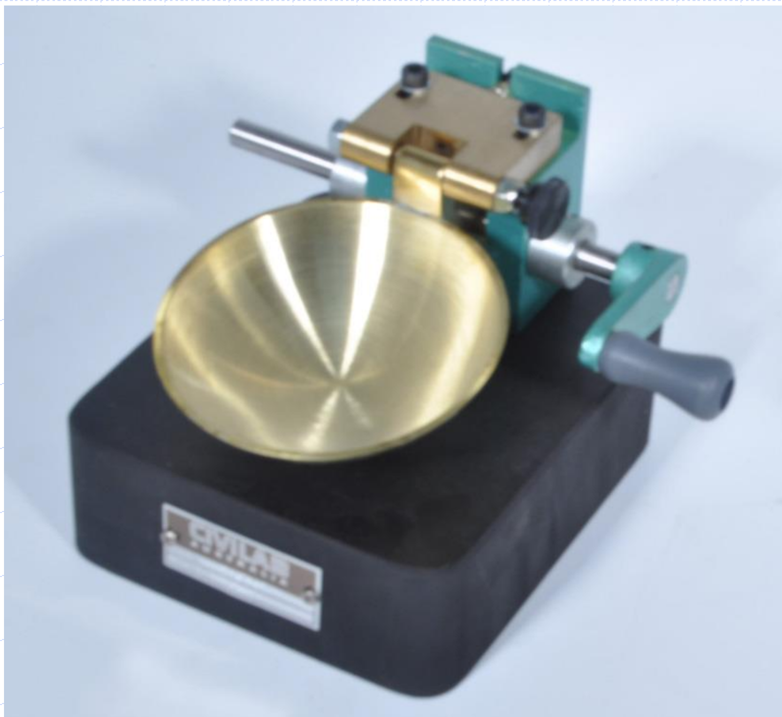
Low Stress Shearbox (< 500 psf)

- Plastic rings
- Aluminum yoke
- Low capacity load cells

Sample Preparation

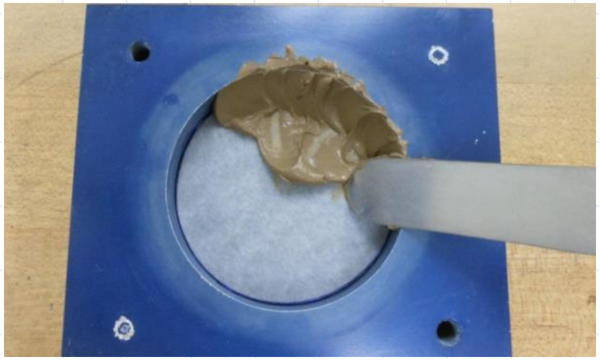


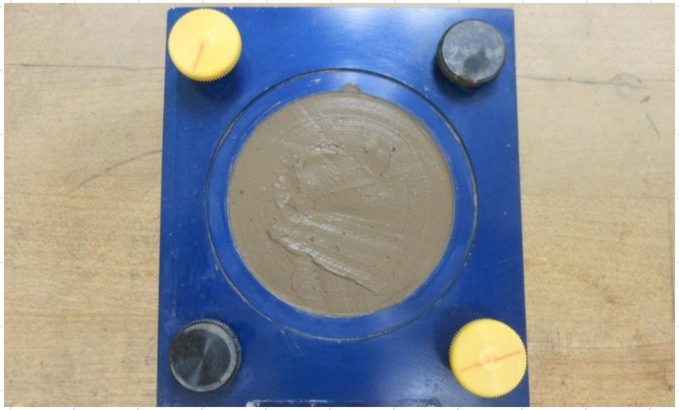
Specimen Preparation



- Liquid limit measured periodically
- Closure of groove at 25 blows is considered ideal.

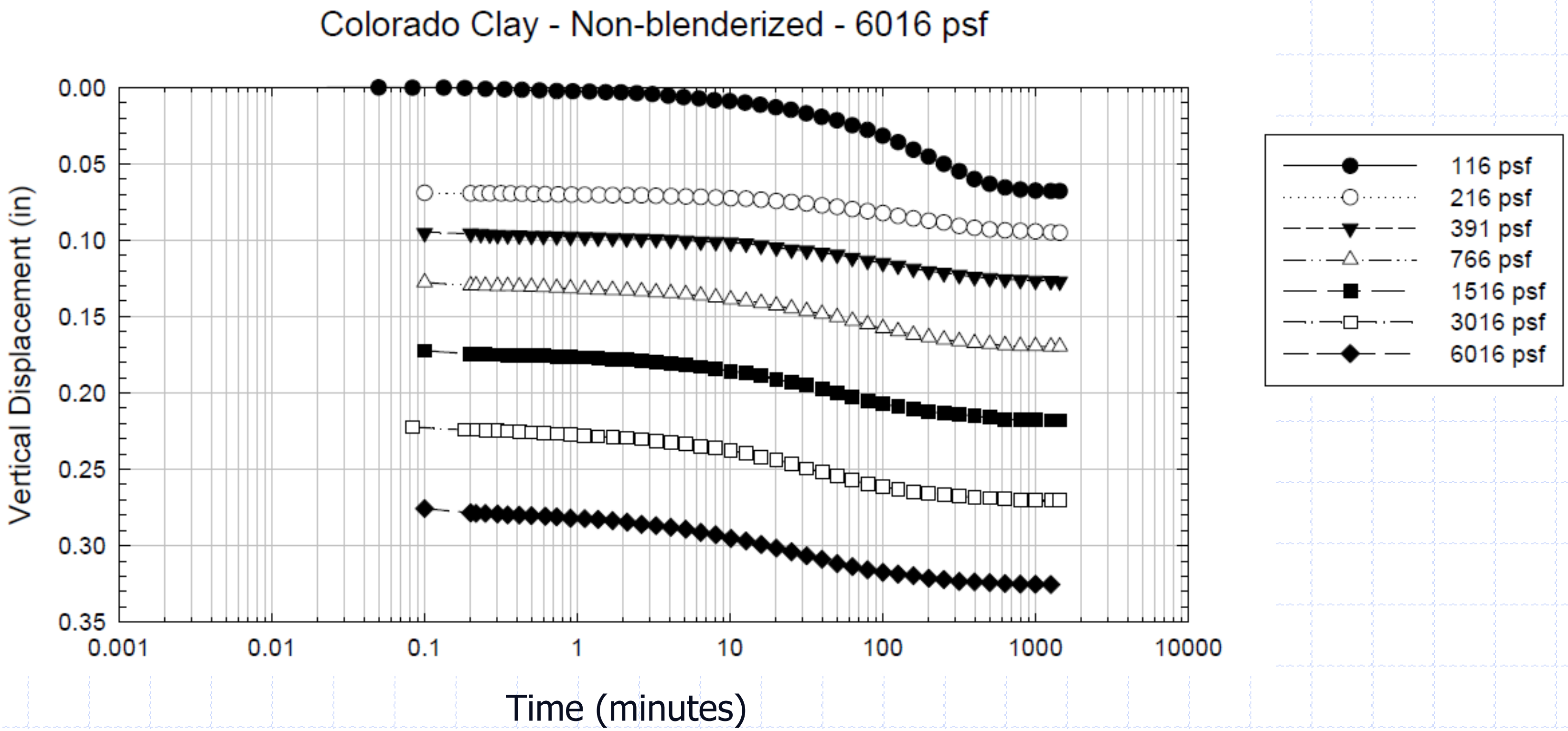
Direct Shear Sample Fabrication



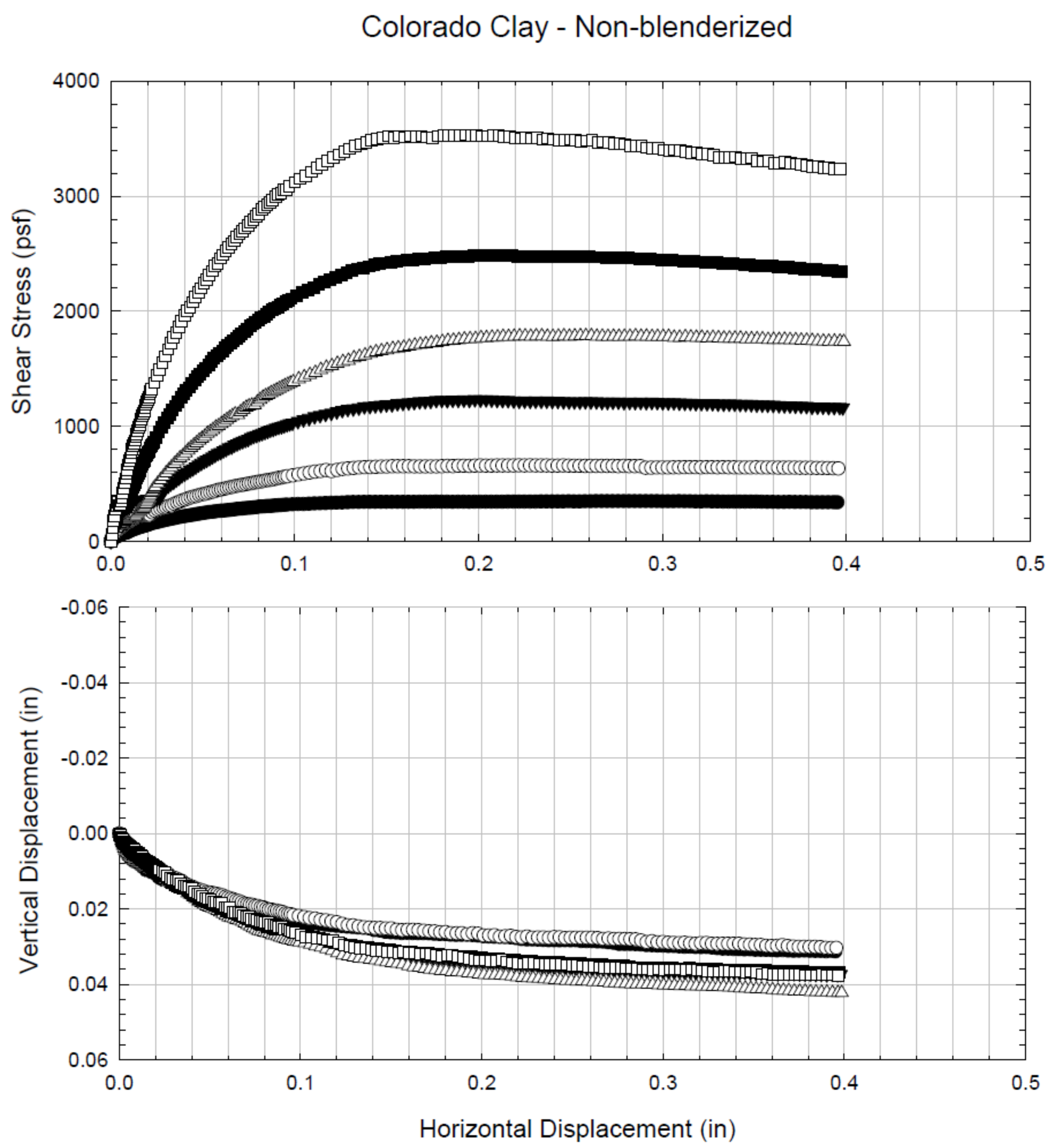


Test Procedure

- Consolidated in stages



Shear



Colorado Clay - Non-blenderized
Shear Stress (psf)
4000
3000
2000
1000
0
0.0
0.1
0.2
0.3
0.4
0.5
Vertical Displacement (in)
-0.06
-0.04
-0.02
0.00
0.02
0.04
0.06
0.0
0.1
0.2
0.3
0.4
0.5
Horizontal Displacement (in)

Triaxial Apparatuses

- Automated (high stress tests)

Triaxial Apparatuses

- Manual (low stress tests)

Difficulty with Triaxial Specimens

Going from this…

to this…

Batch Consolidometer

Batch Consolidometer

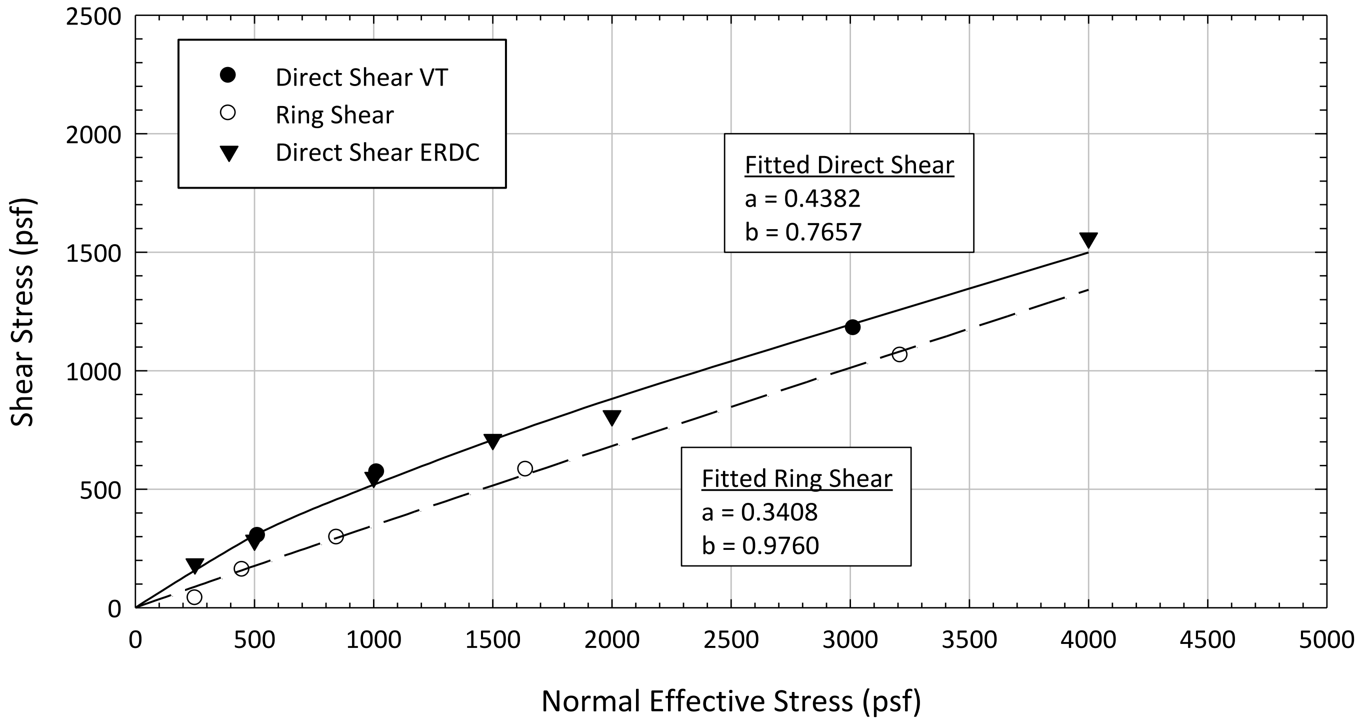
Soils Tested

Sample	Specific Gravity (ASTM D854)	USCS (ASTM D2487)		Atterberg Limits (ASTM D4318)			Clay-sized Fraction (< 2μm) (ASTM D422)
		Symbol	Group Name	LL	PL	PI	
Texas 1	2.78	CH	Fat Clay	68	25	43	63
Texas 2	2.78	CH	Fat Clay	66	23	43	58
Texas 3	2.82	CH	Fat Clay	65	21	44	55
Texas 4	2.81	CH	Fat Clay	66	24	42	67
Texas 5	2.86	CH	Fat Clay	76	28	48	59
Texas 6	2.85	CH	Fat Clay	73	26	47	51
Alabama 1	2.73	CL	Lean Clay	42	23	19	33
Alabama 2	2.72	CH	Sandy Fat Clay	51	26	25	40
Alabama 3	2.79	ML	Low Plasticity Silt	47	29	18	29
Alabama 4	2.71	CL	Lean Clay	43	23	20	37
Colorado Clay	2.78	CL	Lean Clay	42	22	20	24
NOVA	2.80	CH	Fat Clay	66	28	38	17
Oahe	2.88	CH	Fat Clay	74	24	50	50
Oak Harbor	2.82	CL	Lean Clay	47	22	25	47
VBC	2.79	CH	Fat Clay	78	26	52	69

Sample Locations

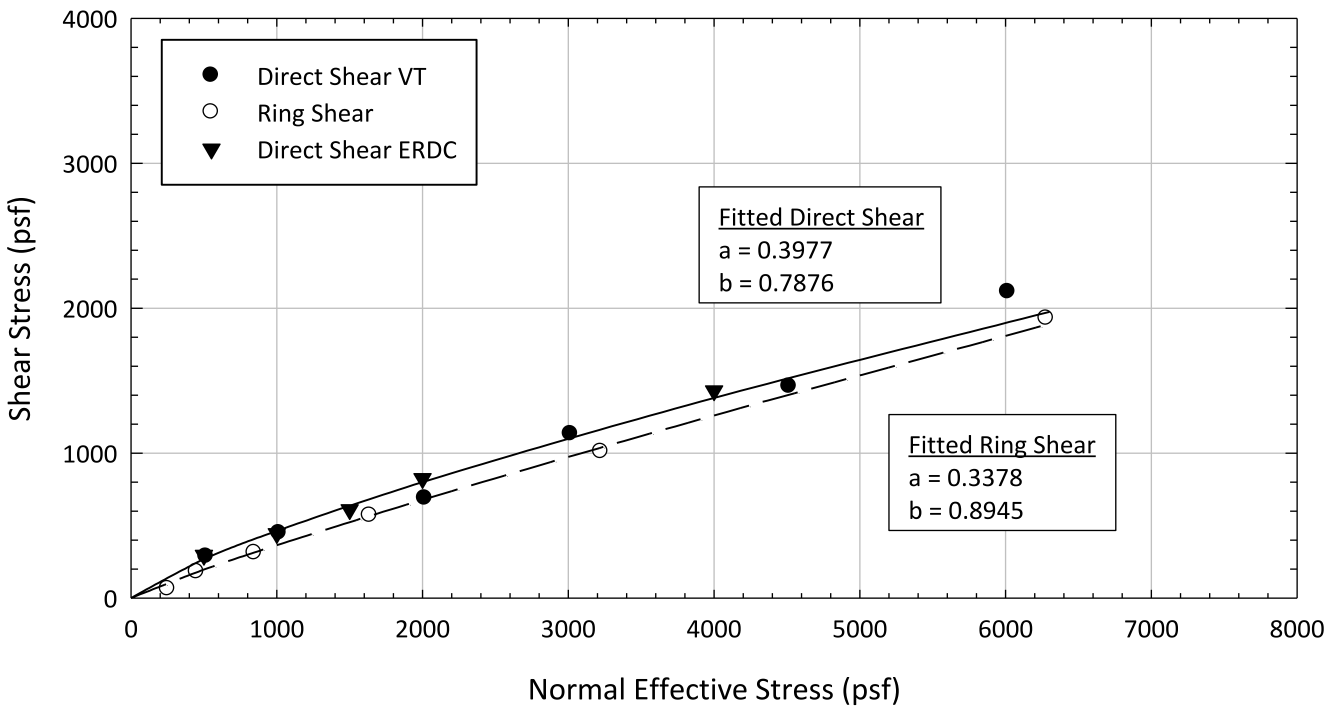
Results

- Direct shear device versus ring shear device
  - The direct shear fully softened failure envelope is higher and more curved than that measured with the ring shear device.

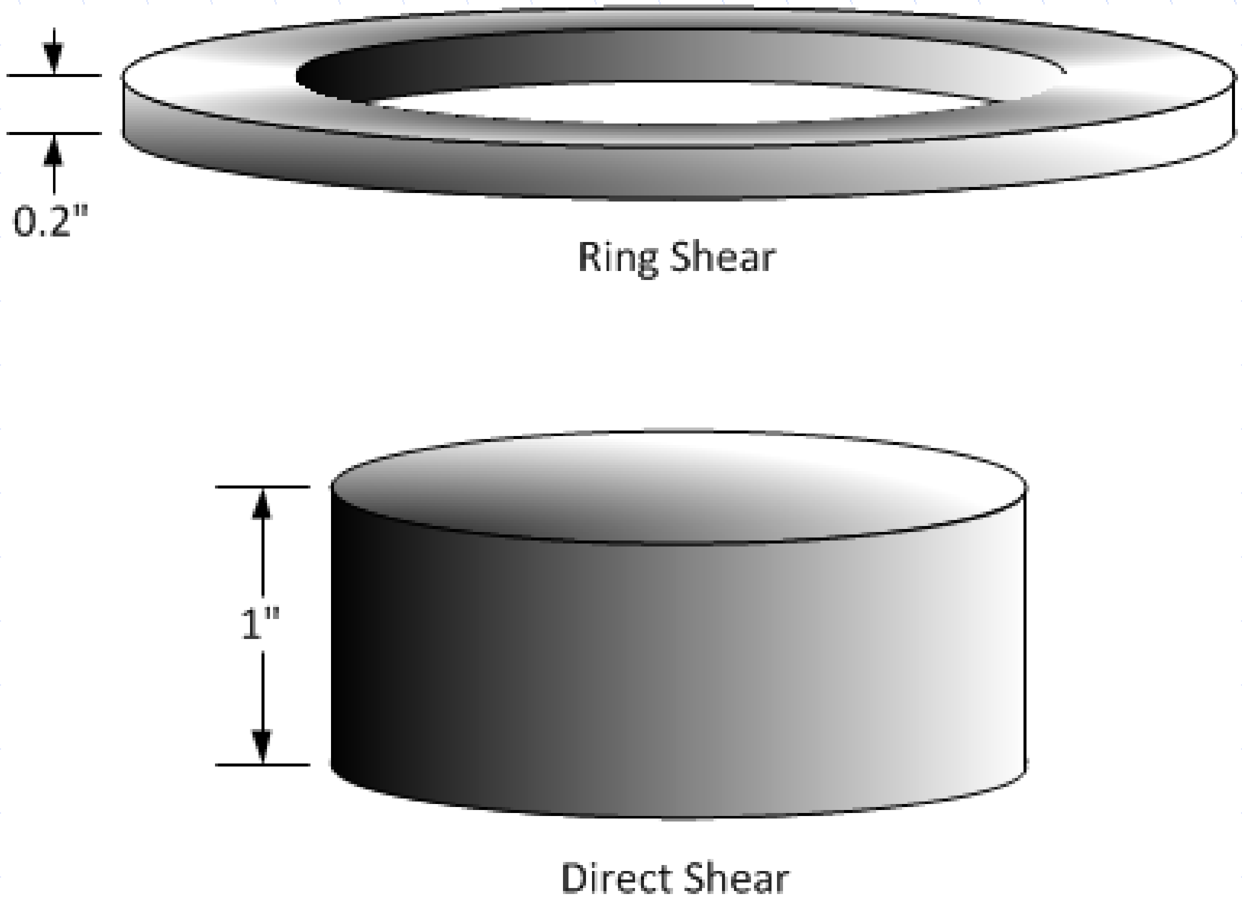


Results

- Direct shear device versus ring shear device
  - Some were closer, but all produced the same result.

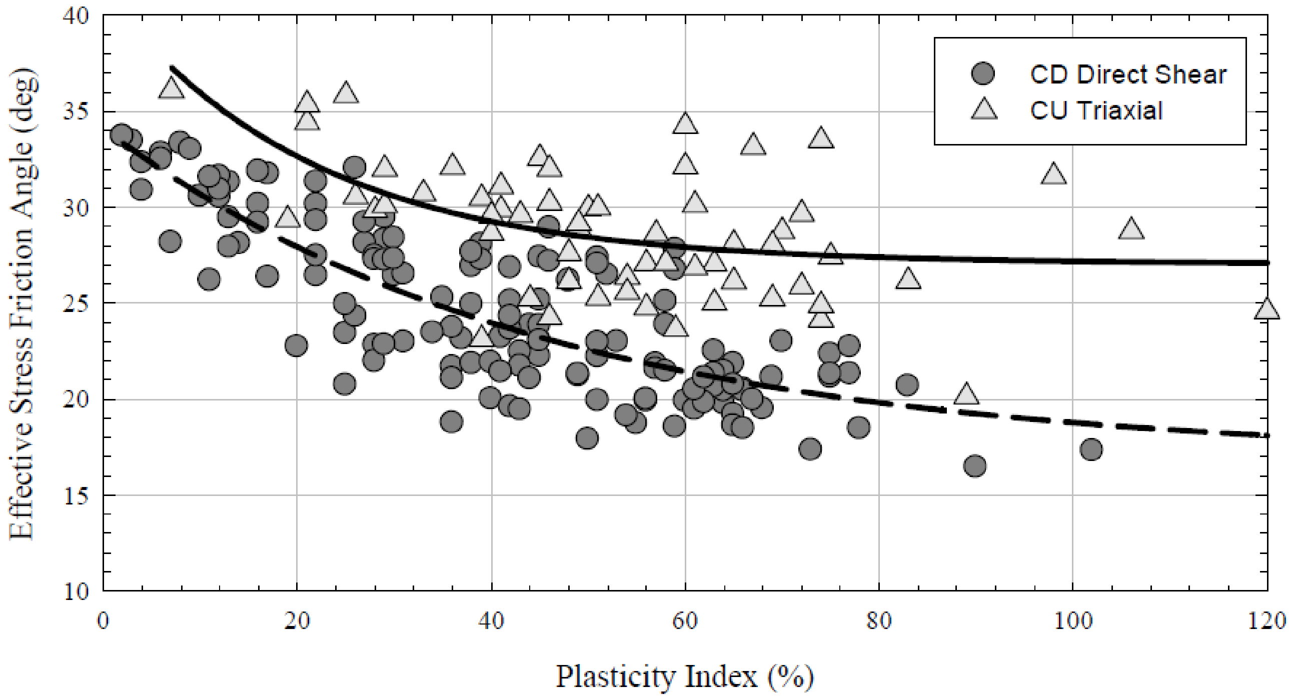


Differences in specimen size



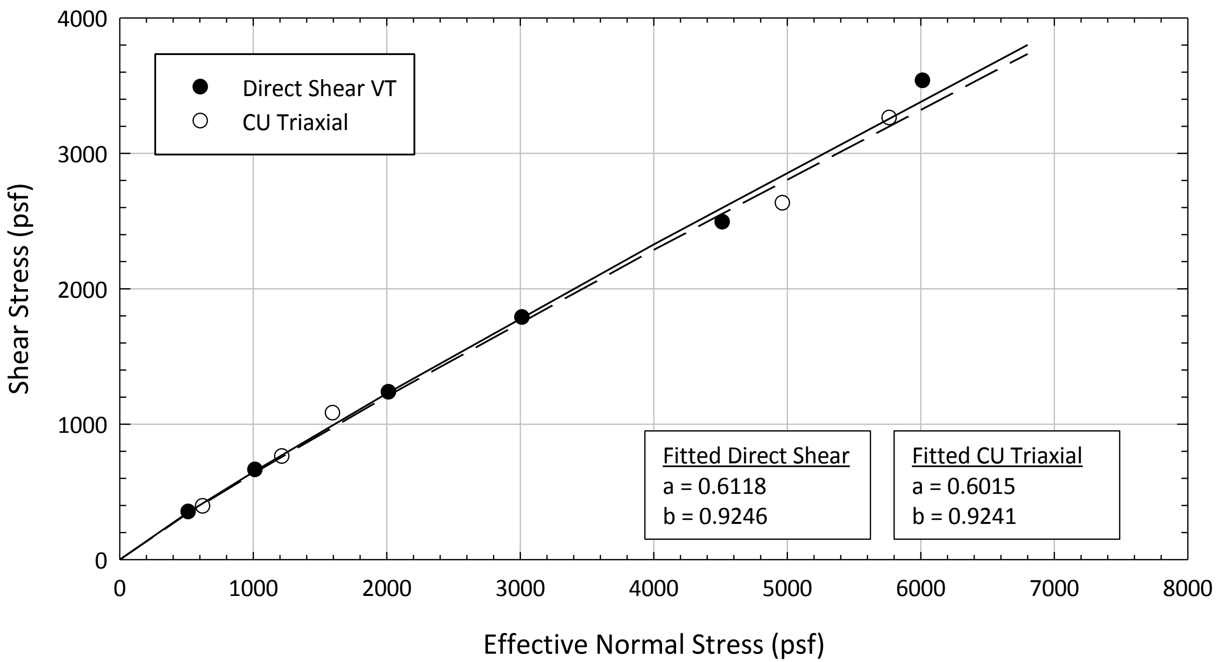
Results

- Direct Shear vs. Triaxial
  - Big difference in undisturbed riverine, lacustrine, and other alluvial clays.



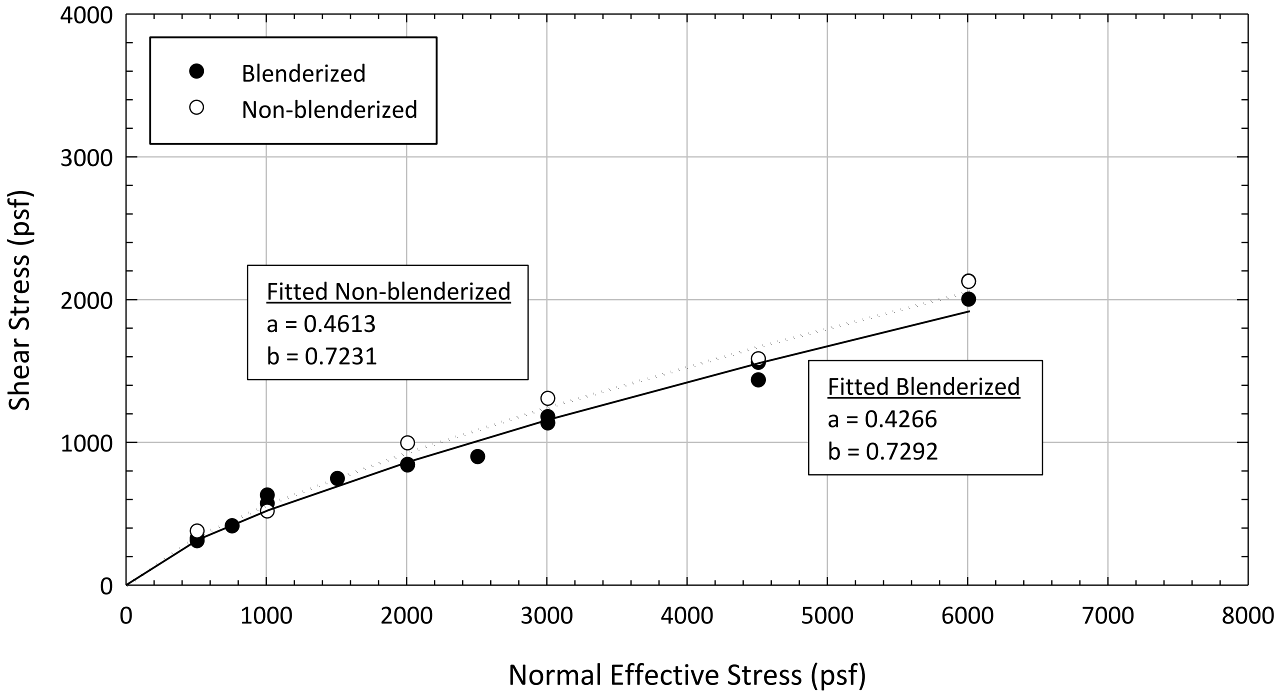
Results

- Direct Shear vs. Triaxial
  - Not a big difference for remolded clays
  - Fully softened strength can be measured by either DS or TC.



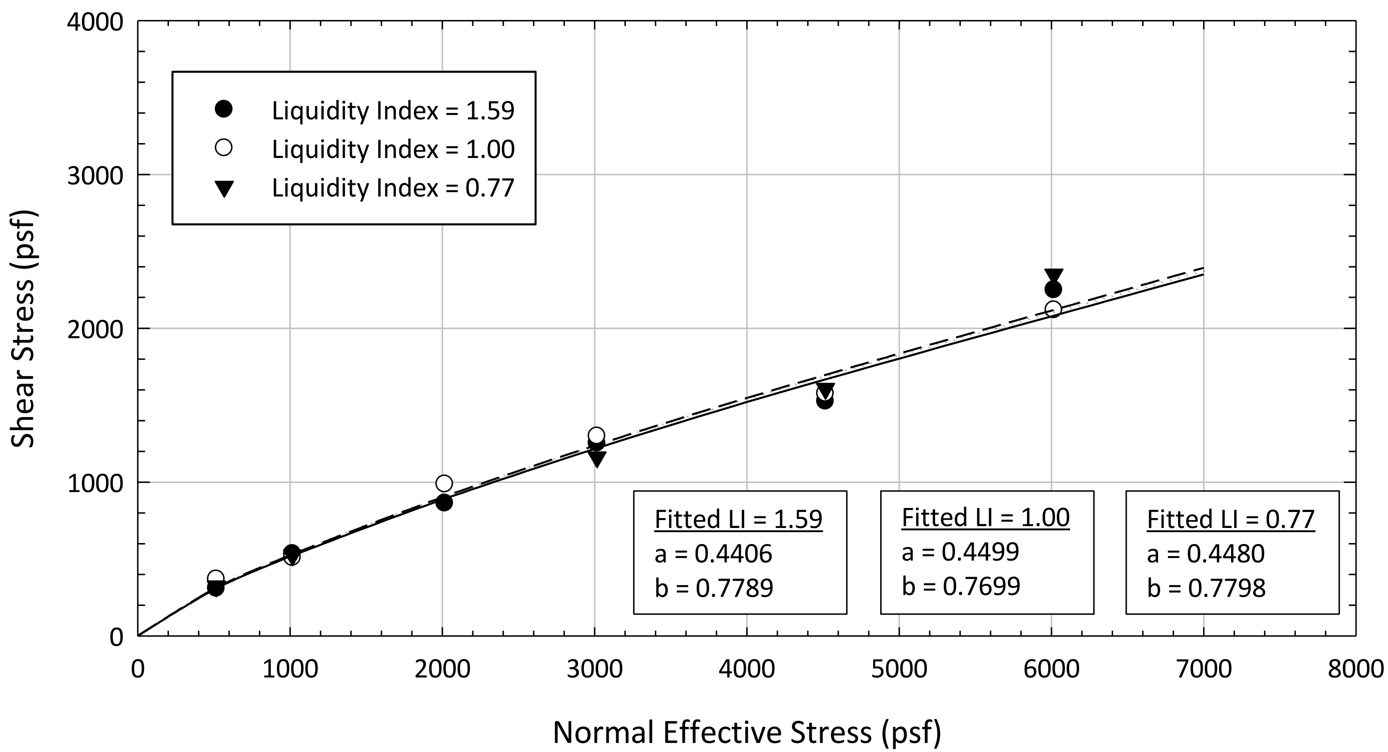
Results

- Blenderized vs. non-blenderized



Results

◆ Initial Liquidity Index



Summary

- Study of failures have led to the use of fully softened shear strengths for a variety of projects
  - Cuts in stiff fissured clays
  - Embankments of compacted fat clays in arid environments

Summary

- Curvature of the FS envelope important
  - Influences depth of sliding
  - Need tests conducted at low stresses
- Direct shear is the best apparatus to measure FS strengths
  - Ring shear results appear to be too low
  - Triaxial tests more complicated

Summary

- Blenderizing and ball-milling not important.
- FSSS not very sensitive to liquidity index, but w% = LL is suggested
  - Easy to test w%
  - Can insure no entrapped bubbles
  - Can accommodate settlement during consolidation.

Thanks!

Bernardo Castellanos
Prof. Mike Duncan
Daniel VandenBerge
US Army Corps of Engineers
Virginia Tech CGPR