4/10/97
3/98 & 3/99

II B SAMPLE DISTURBANCE

(Mini-Problem No. 2)

Page No.

1. Perfect Sampling 1
 1.1 Definition
 1.2 Effects on Undrained Stress-Strain Behavior

2. Ideal Tube Sampling
 2.1 Strain Path for ℄ Element 2
 2.2 Typical stress-strain-ESP Data for NC Clay 2
 2.3 Results from M. Santagata 3

3. Actual Sampling
 3.1 Hypothetical ESP (low OCR) 5
 3.2 Explanation & Comments 5
 3.3 Stress Relief due to Drilling Hole 6
 3.4 Measurements of σ'_s 6
 3.5 Typical Values of σ'_s 7

4. Correcting UUC Data for Effects of Sample Disturbance (or Incorrect σ'_{vc} for CK₀U testing)
 4.1 Introduction 8
 4.2 Corrected su Values Using SHANSEP Equation 8
 4.3 Experimental Data on Boston Blue Clay (BBC) 10
  - RBBC - induced & tube sampling - Natural BBC - tube samples
 4.4 Concluding Remarks 13

Old notes updated:
5. SHANSEP 14
6. Recompression 15
7. Comparison of Recompression vs SHANSEP 16
8. Summary & Conclusions 18

A Ideal Tube Sampling
B1,2 Study of Ideal Tube Sampling (Santagata 5/98)
C1,2 Values of σ'_s
D1,2 UUC data on resedimented & natural BBC
BBC1-9 Recompression vs SHANSEP for Natural BBC

Review Questions on IIB: Sample Disturbance = Mini Problem No. 2

1) Should a lab UUC test (à la ASTM) run on a perfect sample give a good estimate of $c_u = s_u$ for use in a stability analysis for the UU Case? Ans = NO, but explain why.

Sect 2 2) For Ideal Tube Sampling with a Shelby tube meeting ASTM specs, can one obtain samples where σ'_s is reasonably close to σ'_{vo} [and hence get reasonable values of s_u (UUC)] at

a) OCR ≤ 1 – 2 ?

b) OCR = 4 – 8 ?

Sect 3 3) What are the principal sources of additional disturbance that can occur when run UUC tests on actual tube samples (of ASTM specs)?

What steps can be taken to reduce this additional disturbance?

Sect 3 & 4 4) What are typical values of σ'_s/σ'_{ps} (or σ'_s/σ'_{vo}) in low to moderate OCR clays?

Is σ'_s/σ'_{ps} a good measure of the degree of disturbance for a naturally cemented clay?

5) Calculate q_{ps} and q_o for a clay with σ'_{vo} = 5.00 TSM and m = 0.80 for the following conditions:

	In situ	Measured in UUC	q_{ps}	q_o
			(PA)	
a)	OCR = 1, K_o = 0.6, A_u = 0.1	σ'_s = 0.40, q_s = 1.10		(1.825)
b)	OCR = 3, K_o = 0.9, A_u = 0.25	σ'_s = 2.30, q_s = 3.76	(4.325)	

6) For the SHANSEP technique (Assuming precise values of σ'_{vo} & σ'_p)

a) Are there conditions where it should give near perfect predictions of the in situ undrained shear behavior?

b) Under what conditions would it give serious underestimates of the in situ s_u and E_u?

7) Why is it desirable or necessary to know the in situ OCR profile when conducting Recompression CK_oU tests?

9) How do you decide to select SHANSEP vs Recompression → s_u for the UU Case (have fixed piston samples of appropriate γ_m) & access to MIT testing facilities)

No.	USCS	z (m)	Approx. SH	I_L
1	CL	2-10	$\sigma'_p = 15$ TSM	≈2
2	CL	10-40	OCR = 5 → 1.2	0.3 → 0.9
3	CH	5-10	$\sigma'_p \approx 50$ TSM	≈0.1
4	CL-CH	0-10	$\sigma'_p = 90 \pm 30$ TSM	0.2 ± 0.2
5	CH	5-40	OCR = 1	0.9 → 0.4

8) Recompression CK_oUC testing gave s_u = 5.92 TSM at a depth with σ'_{vo} = 10.0 TSM and σ'_p = 30.0 TSM. The site will be excavated, leading to σ'_{vc} = 5.0 TSM at that depth. Estimate the new (reduced) value of s_u assuming that the clay is similar to natural BBC (data on Sheet D2)

SAMPLE DISTURBANCE

1. PERFECT SAMPLING

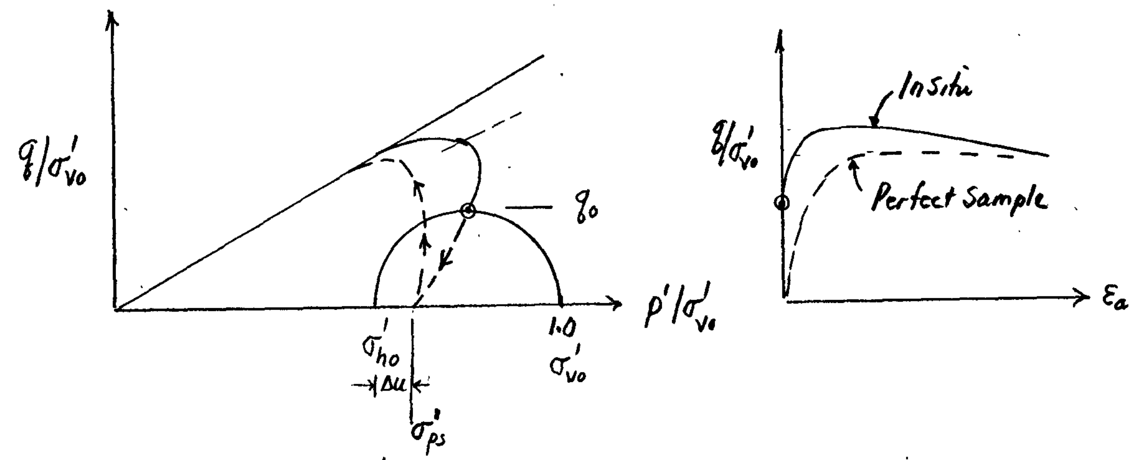
1.1 Definition

- Undrained release of in situ shear stress $q_o = \frac{\sigma'_{vo}}{2}(1-K_o)$

1.2 Effects on Undrained Stress-Strain Behavior

- Reference: Ladd & Lambe (1963) ASTM STP 361, 342-371
- Illustrated for OCR ≈ 1

——— In situ: CK_oUC
- - - - Lab Perfect Sample: CK_o-UUC



1) Estimation of σ'_{ps}:

- $\sigma'_{ps} = \sigma'_{vo}[K_o + A_u(1-K_o)]$, where $A_u = \frac{(\Delta u - \Delta\sigma_h)}{(\Delta\sigma_v - \Delta\sigma_h)} = \frac{\sigma'_{ps} - K_o\sigma'_{vo}}{\sigma'_{vo}(1-K_o)}$ for $\Delta\sigma_h = 0$

- Low OCR $K_o \simeq 0.4 - 0.7$, $A_u \simeq 0.1 \pm 0.2$ } $\sigma'_{ps}/\sigma'_{ho} \simeq 1.0 \pm 0.15$

- High OCR $K_o \simeq 2 \pm 0.5$, $A_u \simeq 1/3 - 1/2$ } $\sigma'_{ps}/\sigma'_{ho} \simeq 0.8 - 0.9$

2) Results of Perfect Sampling (at low OCR) →

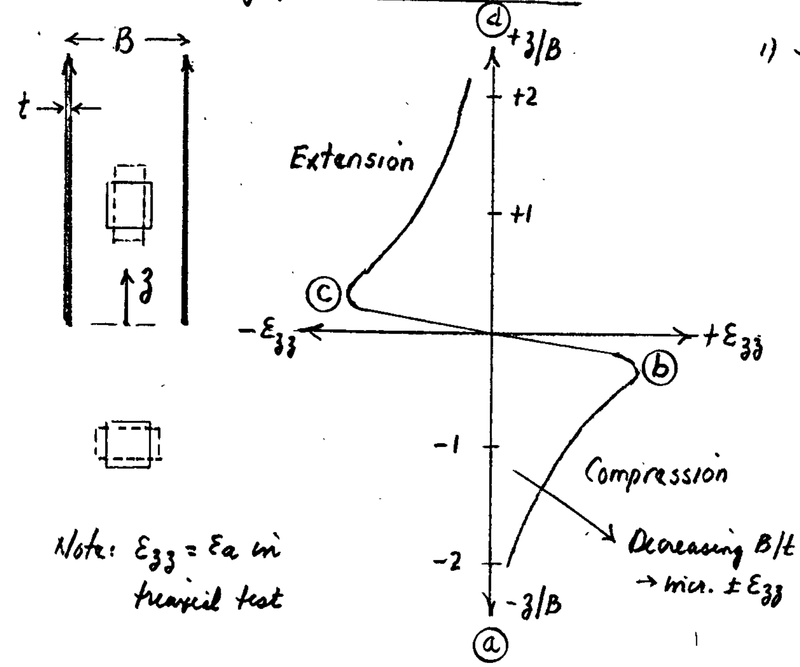
- Decrease in s_u by $10 \pm 5\%$
- Increase in ε_f and large decrease in E_u at $\Delta q/\Delta q_f = 0.5$

3) Conclusion: For low OCR clay, even perfect block sample cannot → reliable stress-strain data via UU testing. Therefore need CK_oU testing à la Sections 5 & 6

2. IDEAL TUBE SAMPLING

2.1 Strain Path for ℄ Element

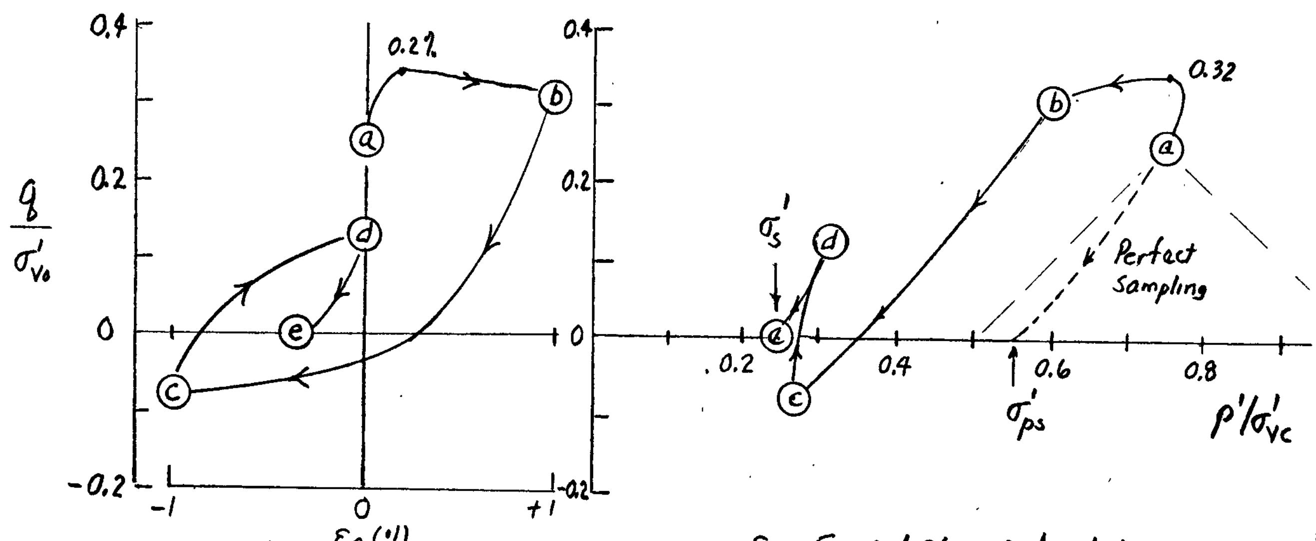
- Apply Baligh's (1985) "Strain Path Method" for tube penetration starting from in situ stresses



1) See Fig. 4 of Sheet A for details showing ε_{zz} vs z/B as function of B/t
   - Large compression strain in front of tube
   - Large extension strain within bottom of tube

2) ASTM thin walled Shelby tube with $B/t \approx 40 \rightarrow \varepsilon_{zz} = \pm 1\%$

2.2 Typical Stress-Strain-ESP Data for NC Clay (For $\varepsilon_{zz} = \varepsilon_a = \pm 1\%$)



- See Fig. 5 of Sheet A for data on NC resedimented BBC from Baligh et al. (1987) JGE, 113(7)

ⓐ Insitu condition; $\varepsilon_a = 0$, $q = q_0$
ⓑ $\varepsilon_a = +1\%$ compression
ⓒ $\varepsilon_a = -1\%$ extension
ⓓ $\varepsilon_a = 0$ in tube
ⓔ $q \rightarrow 0$ during extrusion from tube $\rightarrow \sigma'_s$ at start of UU test

2.3 Results from M. Santagata (SM, 5/94)

1) Test program on batches of resedimented BBC ($\sigma'_{vm} = 1 \rightarrow \sigma'_{vc} = 0.25$ ksc)

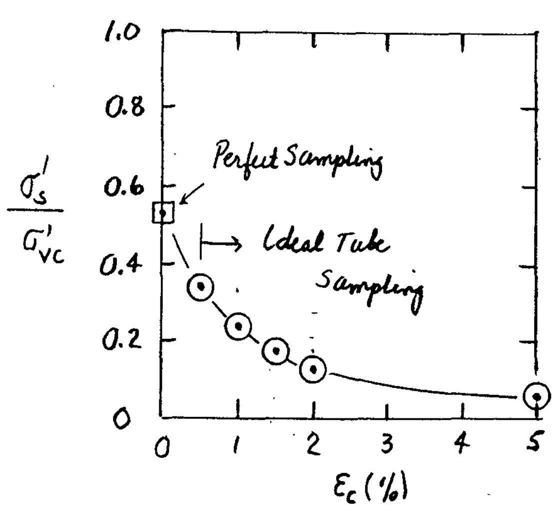
- CK_o consolidation to VCL → in situ OCR = 1, plus swelling to obtain in situ OCR = 2, 4 & 8
- Simulated Perfect Sampling via CK_o-UUC (= PSA = Perfect Sampling Approach)
- Simulated Ideal Tube Sampling (= ISA = Ideal Sampling Approach) via undrained shear along paths a – e → σ'_s
- Finally UUC test starting from σ'_s

Note: all shearing at $\dot{\varepsilon} = 0.5\%/hr$.

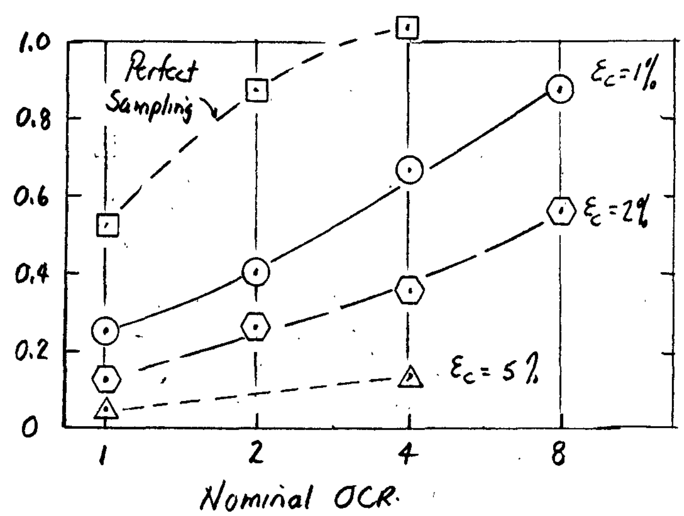
OCR	$\varepsilon_c = \pm\varepsilon_a$ (%)
1	0.5, 1, 1.5, 2, 5
2	1, 2
4	1, 2, 5, 8
8	1, 2

2) Effect of sampling on pre-shear values of σ'_{ps} and σ'_s normalized to σ'_{vc}

Effect of ε_c at OCR = 1



Effect of OCR



- Increasing ε_c (decreasing tube diameter to tube thickness ratio) causes large reduction in σ'_s due to sampling (as would expect since shearing beyond ε_f)

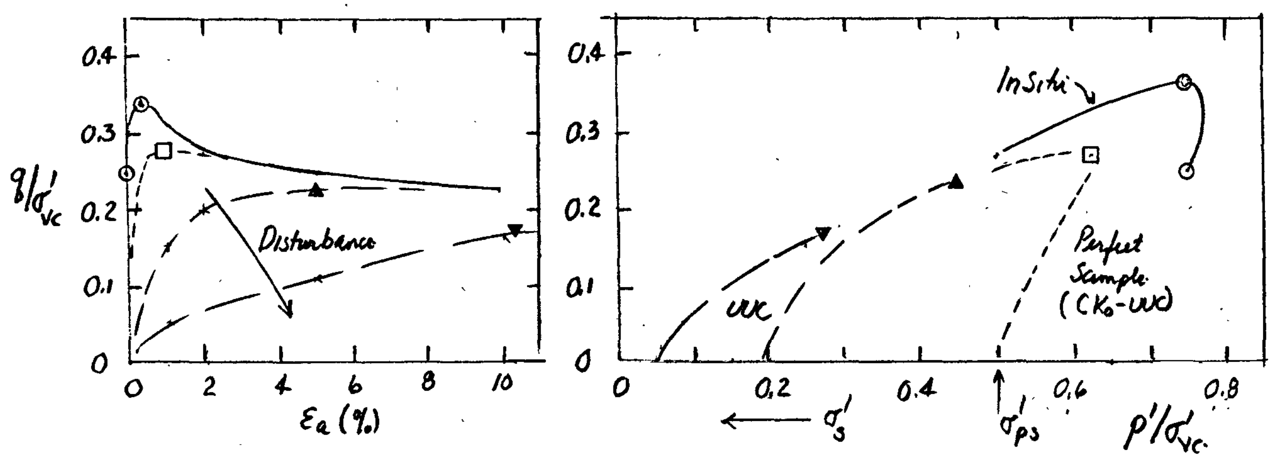
- Increasing OCR causes much less reduction in σ'_s due to sampling since increasing OCR →
  - increase in ε_f (0.2 to 5%)
  - change from contractive (+Δu) to dilatant (−Δu) behavior

2.3 <u>Continued</u>

3) Effect of sampling on stress-strain-ESP behavior at OCR=1

NOTE: See Sheet B1 for actual data from CK_0UC, CK_0-UUC and UUC tests

Normally Consolidated RBBC



Increasing sample disturbance (due to larger ε_c) leads to reduction in preshear σ'_s. Reduction in σ'_s →

- Change from contractive to dilatant ESP
- Lower s_u at higher ε_f
- Much lower initial stiffness (See Fig. 6.16, Sheet B2) (E_{u50} = E_u at $\Delta q/\Delta q_f = 0.5$)

4) Effects of OCR on sample disturbance: Increasing OCR →

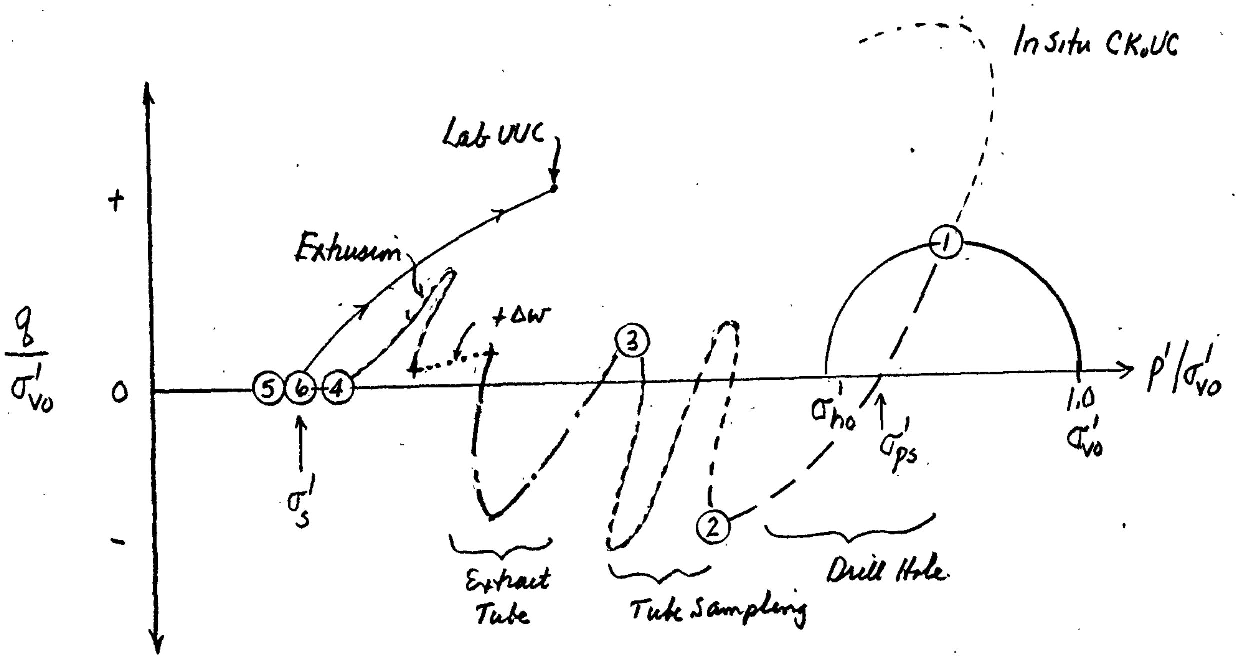
- Less reduction in σ'_s/σ'_{vc} for same ε_c (see p3)
- Less reduction in E_{u50}/σ'_{vc} (see Fig. 6.17, Sheet B2)
- Less reduction in s_u (see Section 4.3)

5) Conclusion

- Sample disturbance due to cyclic compression-extension strain (caused by insertion of tube sample) is much more important at low OCR than at high OCR.

3. ACTUAL SAMPLING

3.1 Hypothetical ESP (Illustrated for low OCR clay after Ladd (Lambe 1963)



3.2 Explanation and Comments

①② Make boring (drill hole) → stress relief. Can get failure in undrained extension (See Section 3.3)

②③ Tube sampling → compression-extension-compression à la Section 2. Can minimize via large B/t or eliminate via Sherbrooke block sampler [Lefebvre & Poulin, 1979, CGJ 16(1)]

③④ Extract tube → significant "suction" at bottom of tube. Use of Fixed Piston and prior rotation helps

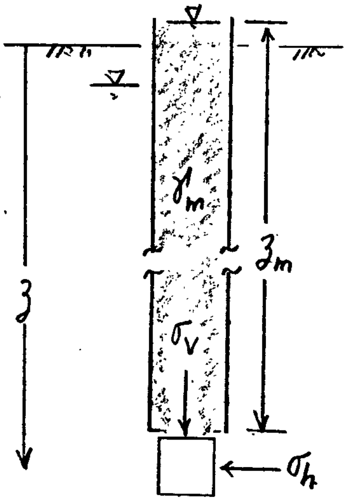
Transportation & Storage } → potential shocks, freezing (air transport), drying (if poor seal), corrosion (steel tube), etc.
→ internal movement of water → $+\Delta w$ (t) soft, sensitive
$-\Delta w$ (t) high OCR

Extrusion from tube → can produce very severe disturbance. Recommend: radiography, cut tube for specimen, wire around perimeter to break bonding (developed by JTG)

④⑤ Trim and set-up in triaxial cell for UUC test

⑤⑥ Apply cell pressure, $\sigma_c \rightarrow \Delta\sigma' = (1-B)\sigma_c$ for S<100%

3.3 Stress Relief Due to Drilling Hole



1) Shear stress (q_b) at bottom of hole

$\sigma_v = z_m \gamma_m$; $\sigma_h \approx \sigma_{ho} = K_o \sigma'_{vo} + u_s$

$\therefore q_b = \frac{1}{2}(\sigma_v - \sigma_{ho})$

2) Example calculation for OCR=1 (TSM) : WT at OGS

- $z = z_m = 10m$; $\gamma_t = 1.8$, $\gamma_m = 1.1 TCM$, $K_o = 0.5$
- $\sigma_v = (10)(1.1) = 11.0$; $\sigma_{ho} = (0.5)(10)(0.8) + (10)(1) = 14.0$

$\rightarrow q_b = \frac{1}{2}(11-14) = -1.5$ vs $q_f(E) = (-0.15)(8.0) = -1.2$

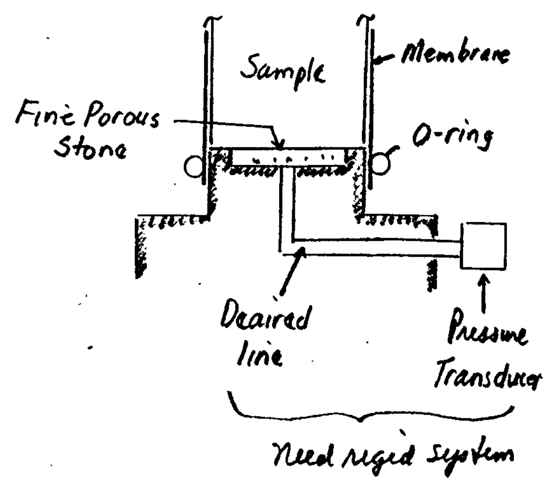
$\therefore$ Undrained shear failure in extension prior to sampling

3) Recommendation:

- Specify $z_m \cdot \gamma_m \rightarrow q_b \approx 0$
  - have $z_m > z$
  - use heavy weight drilling mud
- Most important at depth in low OCR cohesive soils

3.4 Measurement of σ'_s

1) Sketch of triaxial cell fitted with fine porous stone having $u_b > 1$-2 atm.



- Why need high u_b?

2) $\sigma'_s = \sigma_c - u$; check $B = \Delta u / \Delta \sigma_c$

For in situ S=100%, use $\sigma_c \rightarrow B = 1.0$

3) Value of σ'_s / σ'_{ps} (or simply σ'_s / σ'_{vo}) should reflect level of disturbance, except for cemented soils

4/97
3/30/99

3.5 Typical Values of σ_s'

1) Historic data (30 yr. ago) on BBC, MIT Campus: Student Center & Bldg 9
(Mostly 3" ϕ fixed piston with $\gamma_m \approx 75$-80 pcf (1.2-1.3 TCM)) (Sheet C1)

- OCR > 1.5 (above El. -50): $\sigma_s'/\sigma_{ps}' \approx 0.27 \pm 0.11$ (SD), n=9
- OCR < 1.5 : " $\approx 0.093 \pm 0.099$, n=9

∴ Lower OCR & greater depth → much lower σ_s'/σ_{ps}'

- Variation in s_u(UUC) followed variation in σ_s'

2) Recent data from U.K. special test site (Sheet C2)

- See remarks regarding importance of type of sampler, testing on-site (vs. transport to off-site labs) and quality of specimen trimming.

3) Tube sampling of batches of resedimented BBC (Santfield, SM thesis 5/94)

- OCR ≈ 1.0-1.3 → $\sigma_s'/\sigma_{vc}' = 0.06 \pm 0.06$ (SD) with significant increase in w of specimens.

4) Conclusions for reasonable to best quality 3" ϕ fixed piston samples in low-moderate OCR "ordinary" clays

- $\sigma_s'/\sigma_{ps}' \approx 0.2 - 0.4$ upper limit (shallow depth and/or moderate OCR)
- " $\approx 0.1 \pm 0.1$ lower limit (large depths and low OCR)
- Also see Section 4.3.3 (p12-13) for data from UUC tests at CA/T SB site
  $\sigma_s'/\sigma_{vo}' \approx 0.83 \pm 0.44$ within top 30' of crust
  " $\approx 0.16 \pm 0.04$ for deep, low OCR clay

3.5 Typical Values of σ'_s

1) Historic data (30 yr. ago) on BBC, MIT Campus: Student Center & Bldg. 9 (Mostly 3"ϕ fixed piston with $\gamma_m \approx$ 75-80 pcf (1.2-1.3 TCM)) (Sheet C1)

   - OCR > 1.5 (above El. -50): $\sigma'_s/\sigma'_{ps} \approx 0.27 \pm 0.11$ (SD), n=9
   - OCR < 1.5 : " $\approx 0.093 \pm 0.099$, n=9

   ∴ Lower OCR & greater depth → much lower σ'_s/σ'_{ps}

   - Variation in s_u(UUC) followed variation in σ'_s

2) Recent data from U.K. special test site (Sheet C2)

   - See remarks regarding importance of type of sampler, testing on-site (vs. transport to off-site labs) and quality of specimen trimming.

3) Tube sampling of batches of resedimented BBC (Seifield, SM thesis 5/94)

   - OCR ≈ 1.0-1.3 → $\sigma'_s/\sigma'_{VC} = 0.06 \pm 0.06$ (SD) with significant increase in w of specimens.

4) Conclusions for reasonable to best quality 3"ϕ fixed piston samples in low-moderate OCR "ordinary" clays

   - $\sigma'_s/\sigma'_{ps} \approx 0.2 - 0.4$ upper limit (Shallow depth and/or moderate OCR)
   - " $\approx 0.1 \pm 0.1$ lower limit (large depths and low OCR)

Also see Sect. 4.3.3 (p[illegible]) for data from UUC tests at CA/T [illegible]

4. CORRECTING UUC DATA FOR EFFECTS OF SAMPLE DISTURBANCE (Or Incorrect σ'_{vc} from CK_0U testing)

4.1 Introduction

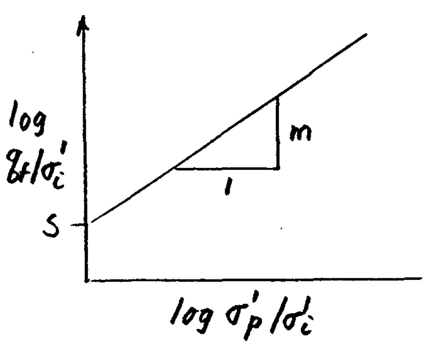
1) Prior sections suggest that values of σ'_s/σ'_{ps} (or σ'_s/σ'_{vo}) reflect the degree of disturbance and that lower values of σ'_s/σ'_{ps} (or σ'_s/σ'_{vo}) translate into lower values of s_u/σ'_{vo} from UUC tests (for same σ'_p).

2) Will first go through a method of correcting s_u(UUC) for decreases in σ'_s (due to disturbance) assuming that log s_u/σ'_s vs log "OCR" follows the SHANSEP equation. Can also use this technique to adjust CU data.

3) Will then look at results from several test programs on Boston Blue Clay (BBC), both resedimented & natural

4.2 Corrected s_u Values Using SHANSEP Equation

1) Theoretical considerations for linear $\log q_f/\sigma'_i$ vs $\log \sigma'_p/\sigma'_i$



- Definitions $q_f = s_u$, σ'_i = preshear σ'
  σ'_p = preconsolidation pressure
  "OCR" = σ'_p/σ'_i

- $q_1 = s_u$ at $\sigma'_i = \sigma'_1$ } both specimens
  $q_2 = s_u$ at $\sigma'_i = \sigma'_2$ } have same σ'_p

- $q_1 = \sigma'_1 S(\sigma'_p/\sigma'_1)^m$
  $q_2 = \sigma'_2 S(\sigma'_p/\sigma'_2)^m$

$$\frac{q_2}{q_1} = \frac{\sigma'_2}{\sigma'_1}\left(\frac{\sigma'_p}{\sigma'_2}\cdot\frac{\sigma'_1}{\sigma'_p}\right)^m = \frac{\sigma'_2}{\sigma'_1}\left(\frac{\sigma'_1}{\sigma'_2}\right)^m = \left(\frac{\sigma'_2}{\sigma'_1}\right)^{1-m}$$

$$\therefore\ q_2 = q_1(\sigma'_2/\sigma'_1)^{1-m} \quad \text{Eq. 4.2.}$$

2) Applications of Eq. 4.2 for samples having same σ'_p

a) UUC data on disturbed samples at given depth (constant σ'_p)

- q_s = measured s_u on specimen with $\sigma'_i = \sigma'_s$
- q_{ps} = computed s_u for perfect sample with $\sigma'_i = \sigma'_{ps}$
- $q_{ps} = q_s \left(\frac{\sigma'_{ps}}{\sigma'_s} \right)^{1-m}$

Note: If desire q_0 = computed s_u for in situ $\sigma'_i = \sigma'_{vo}$, then

$$q_0 = q_s \left(\frac{\sigma'_{vo}}{\sigma'_s} \right)^{1-m}$$

b) Adjustment of Recompression CK_0U data at given depth (constant σ'_p)

- q_m = measured s_u on specimen with $\sigma'_i = \sigma'_{vc}$
- q_0 = computed s_u for specimen with $\sigma'_i = \sigma'_{vo}$
- $q_0 = q_m \left(\frac{\sigma'_{vo}}{\sigma'_{vc}} \right)^{1-m}$ (this m may not equal m for UUC data)

c) adjustment of SHANSEP CK_0U data unloaded from constant σ'_{vm}

- q_m = measured s_u from test with $\sigma'_i = \sigma'_{vcm}$
- q_c = corrected s_u at $\sigma'_i = \sigma'_{vcc}$
- $q_c = q_m \left(\frac{\sigma'_{vcc}}{\sigma'_{vcm}} \right)^{1-m}$ (this m may not equal m for Recompr. data)

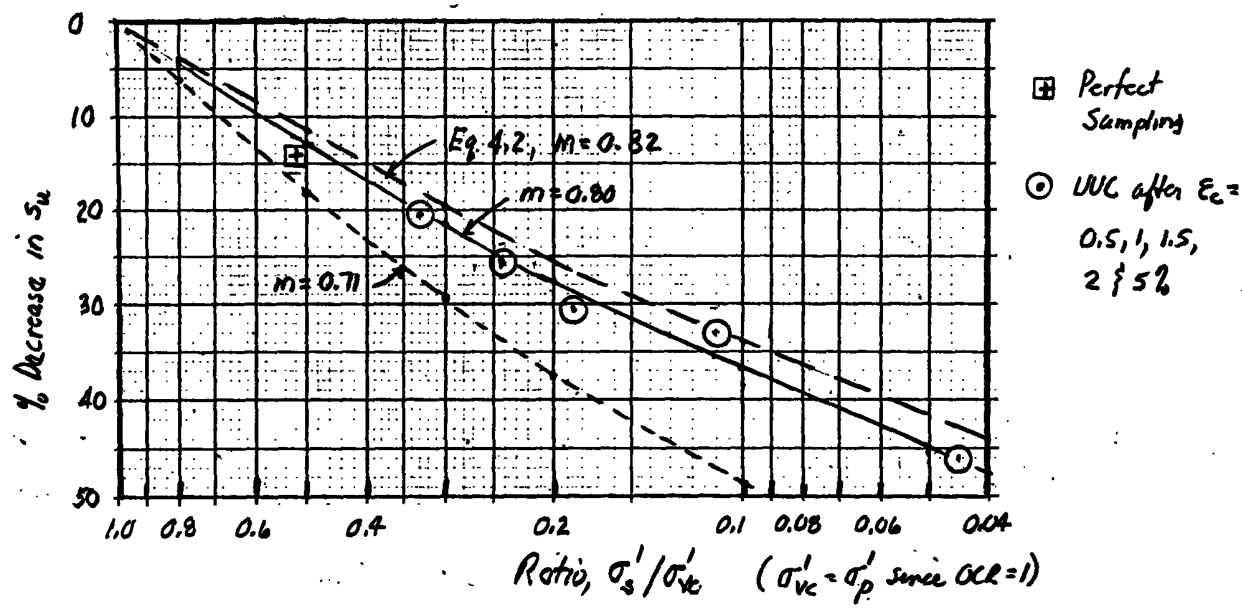
4.3 Experimental Data on Boston Blue Clay (BBC)

4.3.1 Data on RBBC with Induced Disturbance (Santagata 5/94)

(Same program as presented in Section 2.3)

1) Data at OCR = 1 from UUC tests ($\dot{\varepsilon}$ = 0.5%/hr) run after cyclic straining

a) Measured decrease in s_u versus σ_s'/σ_{vc}'



b) Modeling of above data using "Inducted OCR" = IOCR = σ_{vc}'/σ_s'

- Sheet 01, Fig. 6.12: log q_f(UUC)/σ_s' vs. log σ_{vc}'/σ_s' → S = 0.33 & m = 0.82
  Compared to SHANSEP CK_0UC → S = 0.33 & m = 0.71
- Predicted Decrease in s_u (%) = $100\left[1-(\sigma_s'/\sigma_{vo}')^{1-m}\right]$ from Eq. 4.2
- Predictions plotted above for m = 0.82 (Fig 6.12) & m = 0.71 (CK_0UC data), plus m = 0.80 (CCL best fit to data)

c) Correction of above UUC data to obtain in situ s_u/σ_{vo}' = 0.33 (from CK_0UC tests)

- $q_0 = q_s(\sigma_{vo}'/\sigma_s')^{1-m}$. Given: σ_{vo}' = 1; q_s = 0.22 & σ_s' = 0.11 as an example
- For m = 0.80 (best fit to data): $q_0 = 0.22\,(9.1)^{0.20} = 0.34$ → close to 0.33 (correct answer)
  " m = 0.71 (CK_0UC data) : " = " $(9.1)^{0.29} = 0.415$ → 26% too high

∴ Corrected s_u values very sensitive to assumed value of m for high degrees of disturbance (i.e., low values of σ_s'/σ_{vo}')

4.3.1 (Cont)

2) Data at OCR = 2, 4 & 8 from UUC tests after cyclic straining

a) Data on p3 show increasing σ_s'/σ_{vc}' with incr. OCR of clay, i.e., less disturbance for given value of $\pm \varepsilon_c$.

b) Unfortunately, UUC data are limited & not very consistent. However, data at OCR = 4 & 8 indicate little decrease in Su for $\sigma_s'/\sigma_{vc}' \geq 0.3$ (even thought m = 0.8 predicts ≈ 20% decr. at $\sigma_s'/\sigma_{vc}' = 0.3$)

4.3.2 Data on RBBC after Actual Tube Sampling (Sinfield 5/94)

1) Ran UUC tests on specimens taken from small tube samples pushed into batches of RBBC. Varied tube geometry → varying degrees of disturbance

2) Sheet D1, Fig 5.17 shows (for batch OCR = 1.0 & 1.27)

a) Extremely low values of σ_s'/σ_c' → IOCR = 5 to 500!
∴ actual tube sampling → more disturbance than predicted from Ideal Tube Sampling (perhaps in part because clay experienced increases in water content).

b) Values of q_y/σ_s' (q_y = yield stress) vs IOCR → m = 0.87 ± 0.01, i.e., slightly higher than shown in Sheet D1, Fig 6.12
Note: Use of q at ε = 10% → m = 0.825 (for S = 0.33)

3) Conclusions

- Actual tube sampling in low OCR clay (even under controlled lab conditions) → more disturbance than predicted from Sec. 2
- More research is needed to investigate influence of OCR and relationship between m from UUC data and m for SHANSEP CK_0UC tests

4.3.3 UUC Data from Tube Samples of Natural BBC
(Data by MIT and H&A from CA/T SB STP)

1) See Sheet BBC-2 for stress history (Elev. vs σ'_{vo} & σ'_p)
UUC tests run at $\dot{\varepsilon} \approx 5\%/hr$ to measure s_u vs ASTM $\dot{\varepsilon} = 60\%/hr = 1\%/min$

2) Sheet D2(a) compares s_u from UUC & SHANSEP CK$_0$UC testing.
a) Shaded zone shows SHANSEP q_f(C) computed using $S = 0.28$ & $m = 0.68$ for mean $\sigma'_p \pm 1 SD$
b) UUC data show • s_u slightly < SHANSEP at top, but much lower at depth.
($LR \to q_s = 2.3$ & 0.73 at El. $= 70$ & -20, $r^2 = 0.53$)

• Values of σ'_s that also generally decrease with depth, e.g.
El. 70-40 → $\sigma'_s/\sigma'_{vo} = 0.83 \pm 0.44$
El. -10±10 → " $= 0.16 \pm 0.04$
} σ'_s is preshear value after applying $\sigma_c = 0.67 \times \sigma'_{vo}$ w/ $B = 0.25-0.85$
∴ Increasing depth & lower OCR → more disturbance (as expected)

3) Sheet D2(b) shows UUC q_f/σ'_s vs σ'_p/σ'_s data scattered about the SHANSEP CK$_0$UC relationship. Note: σ'_p is mean value from Sheet BBC-2, which contributes to the scatter since actual σ'_p varies at any given El. (esp. in crust)

4) Corrected UUC data used $q_0 = q_s(\sigma'_{vo}/\sigma'_s)^{0.32}$, i.e. for $m = 0.68$ from CK$_0$UC testing
These corrected s_u data generally plot within the SHANSEP shaded zone
($LR \to q_0 = 2.4$ & 1.8 at El. $= 70$ & -20)

5) Conclusions:
• Measured s_u(UU) becomes much too low within deep, low OCR clay due to increasing sample disturbance
• Measurements of σ'_s and use of $m = 0.68$ from SHANSEP CK$_0$UC tests → corrected values of s_u that generally agreed quite well w/ SHANSEP (even tho UUC tests run w/ $\dot{\varepsilon} \approx 10 \times \dot{\varepsilon}$ for CK$_0$UC tests)

4.4 Concluding Remarks

1) If engineer in charge wants to run alot of UUC tests, then:

- Measurements of σ'_s are worthwhile in order to assess variations in the degree of disturbance, especially in low OCR clays
- However, spending same $ on consolidation tests → σ'_p profile would be more cost effective (i.e, don't run alot of UUC tests)

2) Correction of s_u(UUC) data for disturbance requires selection of a value of m to use in $q_0 = q_s (\sigma'_{vo}/\sigma'_s)^{1-m}$

- More research is needed to determine if m $\gtreqless$ m from SHANSEP CK_0UC testing
- I would select $m \approx 0.75 \pm 0.05$ based on current, very limited knowledge

3) s_u(UUC) on high quality samples (or corrected data) are UNSAFE for design for stability analyses since:

- Fast $\dot{\varepsilon}$ → s_u too high
- TC ($\delta = 0$) → " " "

4) Reliable undrained stress-strain-strength data require CK_0U testing via SHANSEP Section 5

Recompression " 6

5 SHANSEP

5.1 References = Ladd & Foott (1974), Ladd et al (1977) & Section 2.3.3 of SF for procedure (assumed known by 1.322 class) + TL = CCL (91)

5.2 Inherent assumptions needed for "perfect" results

- Perfect normalized behavior not affected by prior disturbance
- Known in situ OCR due to mechanical unloading (unless include some reloading tests)

5.3 Clay deposits where NOT applicable

- High I_L & S_t → "highly structured"
- Naturally cemented

also Fig 16(b) of CCL (91) { See Fig. 4 of SF for example James Bay B-6 Marine Clay, i.e. reconsolidation to $\sigma'_{vc} > \sigma'_p$ destroys brittle behavior of OC intact clay

5.4 Clay deposits where application is difficult

- Weathered crusts → highly scattered σ'_p : need in situ testing for spatial variability
- V. High σ'_p → requires v. high lab σ'_{vm} to get NC data

But in both cases, sample disturbance usually should not be a major problem

5.5 SHANSEP is only technique to use if clay deposit is truly NC, i.e. $\sigma'_{vo} = \sigma'_p$

- Waste ponds
- Recent river deltas
- Recent filling

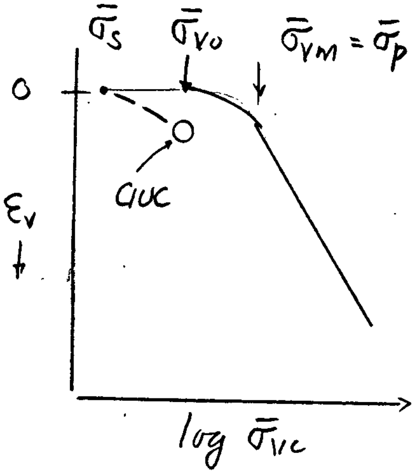
NOTE: Deposits may be Underconsolidated ($u > u_{equilibrium}$)

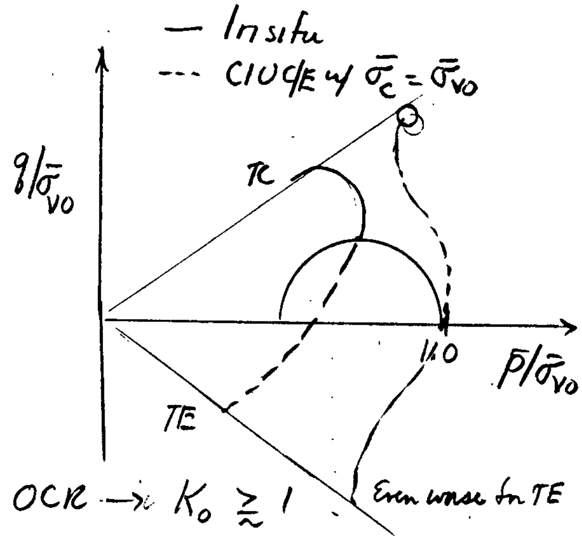
6. RECOMPRESSION

6.1 Reference = Section 2.3.3 of SF + Section 4.4 of CCL('91) = TL

6.2 CIU Testing - $\bar{\sigma}_c = \bar{\sigma}_{vo}$

- Not recommended for low OCR clays - Why?





- Probably ok for OCR → $K_o \gtrsim 1$

- Example from Ladd & Azzouz (1983 - ASCE Offshore Conf)

North of Paria Boring D1 (Venezuela)

d (ft)	OCR	$c_u/\bar{\sigma}_{vo}$ ≈ $q_f \cos\phi'$ CIUC	SHANSEP TC
90	~4.2	0.6	0.6
290	~1.2	0.325 (+23%)	0.265

- Example CK₀UC from Santagata (5/94) NC RBBC

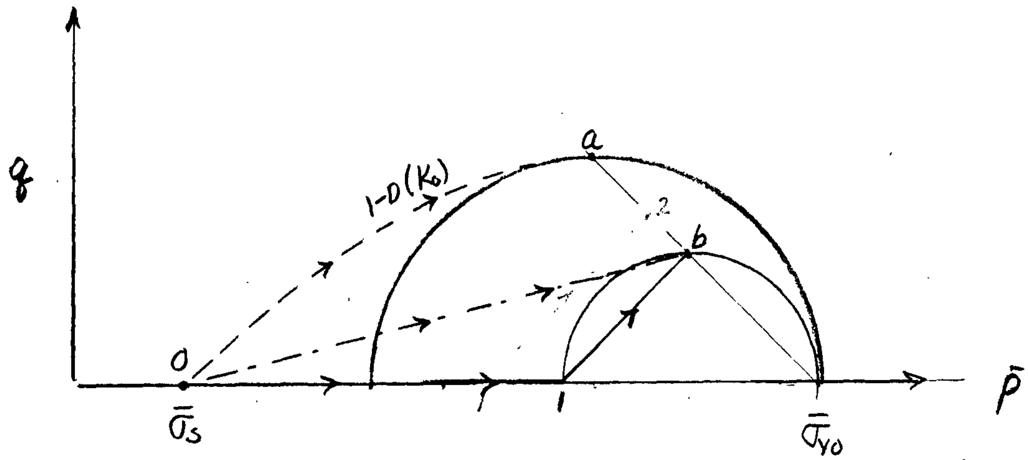
$\sigma'_{vc} = \sigma'_{vo}$ → s_u/σ'_{vo} too high by ≈ 8% for $\sigma'_s/\sigma'_{vo} = 0.24$

" " " " ≈ 20% " " = 0.11

- However CIUC (& CK_oUC) → SHANSEP $q_f(C)$ for CA/T SB STP below El. 18, even tho in situ OCR ≈ 1.15 ± 0.05 (CCL was surprised by this)

6.3 CK₀U Testing (Only for in situ OCR > 1)

1) Main problem is estimating in situ K_0 since 1-D reconsolidation to σ'_{v0} → K_0 much too low (for $\sigma'_{v0} < \sigma'_p$)



Stress path: 0a = K_0 recompression → K_0 too low
0b = specified stress path to obtain estimated (correct) in situ K_0
01b = simplified method to "estimated" K_0

2) Other than above problem, is much simpler and faster than SHANSEP

7. COMPARISON OF RECOMPRESSION vs SHANSEP

. See BBC1-9 for most extensive comparison on any clay. (Values of S ¦ m are summarized below)

CK₀U	Procedure	S	m	n	r^2	Remarks
TC	SHANSEP	0.279⁵	0.681	24	0.99	
	Recomp.	0.298	0.676	23	0.92⁵	← Higher by ≈ 5%
TE	SHANSEP	0.142	0.830	17	0.99	
	Recomp.	0.144	0.978	9	0.98⁵	← Much higher m → +29% at OCR = 5

• See p 17 for summary comparison of pros & cons of Recompression & SHANSEP

CK_0U Test Procedures to Predict In Situ Stress-Strain-Strength

SAMPLE/SOIL TYPE	Recompression	SHANSEP
1) Block on any soil type (except OCR=1)	• Recommended • Need to est. K_0	
2) Highly Structured (High I_L & S_t; cemented	• Recommended • Still need high quality samples	
3) Weathered crusts with highly scattered σ'_p	• Need in situ testing to get spatial σ'_p variation with some SHANSEP tests → S & m • OR rely on many on s_u index (TV, MV, etc)	
4) Truly OCR=1	• UNSAFE	• Required
5) Mechanically OC Low-moderate S_t	• May need for better E_u data	• Preferred for s_u (especially for multiple projects on same deposit)
6) Very high σ'_p (but uniform OCR profile)	• Preferred since SHANSEP testing requires $\sigma'_{vc} \geq 2\sigma'_p$ to get OCR=1 behavior.	

OTHER FACTORS		
1) Determination of Stress History (SH) & Use of NSP (i.e., values of S & m)	• MUST get SH to obtain NSP & plan location of tests • MUST get NSP – are they reasonable? – to interpolate/extrapolate point data	• ESSENTIAL • Automated CK_0-TX → σ'_p data (great advantage)
2) K_0 consolidation	• Need to estimate insitu K_0 as Recompression $K_0 \neq$ in situ value	• Automated CK_0-TX → K_0 vs OCR relationship (another advantage)

8. SUMMARY & CONCLUSIONS

8.1 Recompression CK₀U

- Easiest to use if not overly concerned about value of K_0 & how get there since → s_u directly
- Preferred with block samples (but also need $\bar{\sigma}'_p$ data)
- Clearly superior with highly structured clays (but need good quality samples → good data)
- Also preferred with high $\bar{\sigma}'_p$ clays (say > 5 atm) since difficult to get SHANSEP CK_0U tests into truly NC range
- Can seriously overpredict s_u with OCR near 1
- Should always measure $\bar{\sigma}'_p$ in order to obtain log $s_u/\bar{\sigma}'_{vo}$ vs log OCR → values of S & m + check that have representative results + interpolate/extrapolate throughout deposit

Tied Together.

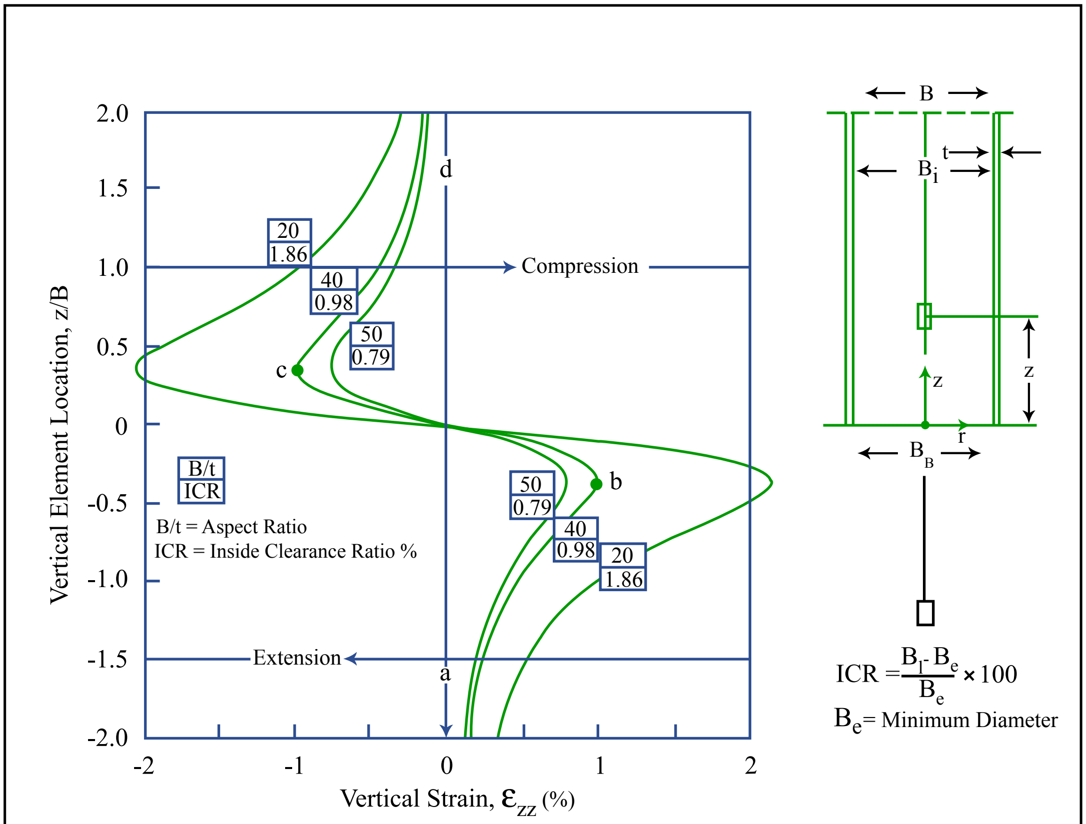
8.2 SHANSEP CK_0U

- Must use with truly OCR=1 deposits
- Even if don't use, at least evaluate/present results in terms of NSP
- Remember that stress history (OCR) is single most important variable + NSP can be used on subsequent jobs
- Use with "highly structured" clays probably → conservative s_u values if equate $s_u/\bar{\sigma}'_{vc}$ NC = $s_u/\bar{\sigma}'_p$

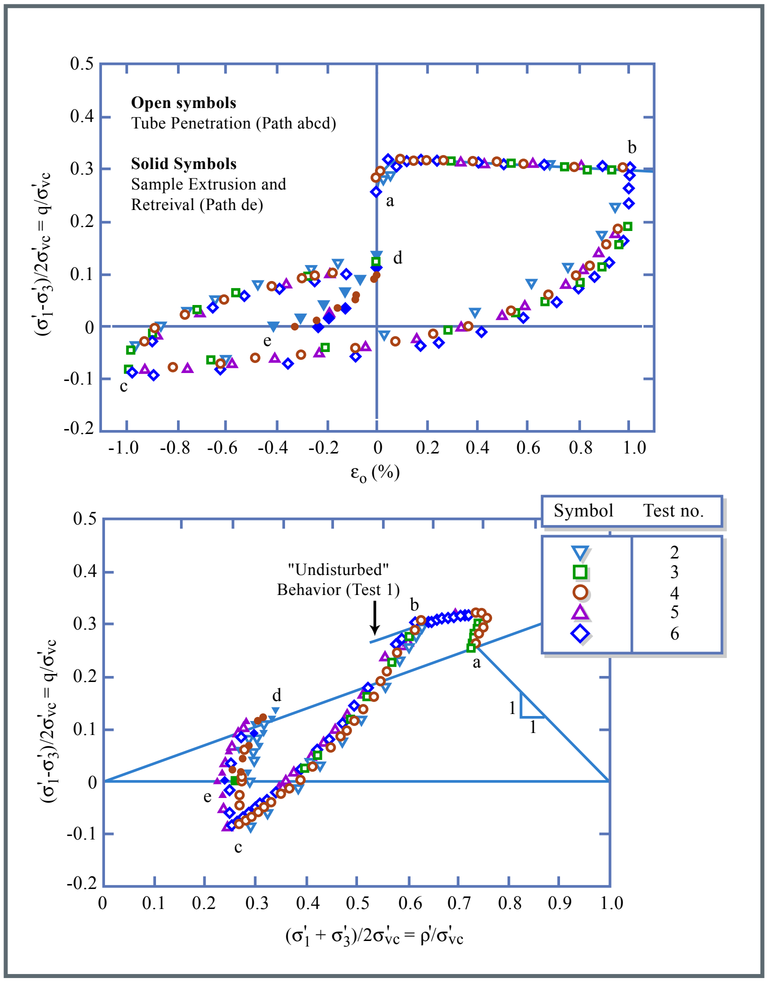
- With major jobs involving moderate to high OCR, try both techniques.
- Uncertainty in SHANSEP predicted s_u (assuming $\bar{\sigma}'_{vo}$ known)

$$Cov^2[s_u] = Cov^2[S] + m^2 Cov^2[\bar{\sigma}'_p] + \ln^2(OCR)\, V[m]$$

Adapted From Baligh et al. (1987) JGE, ASCE 113(7), 739-757

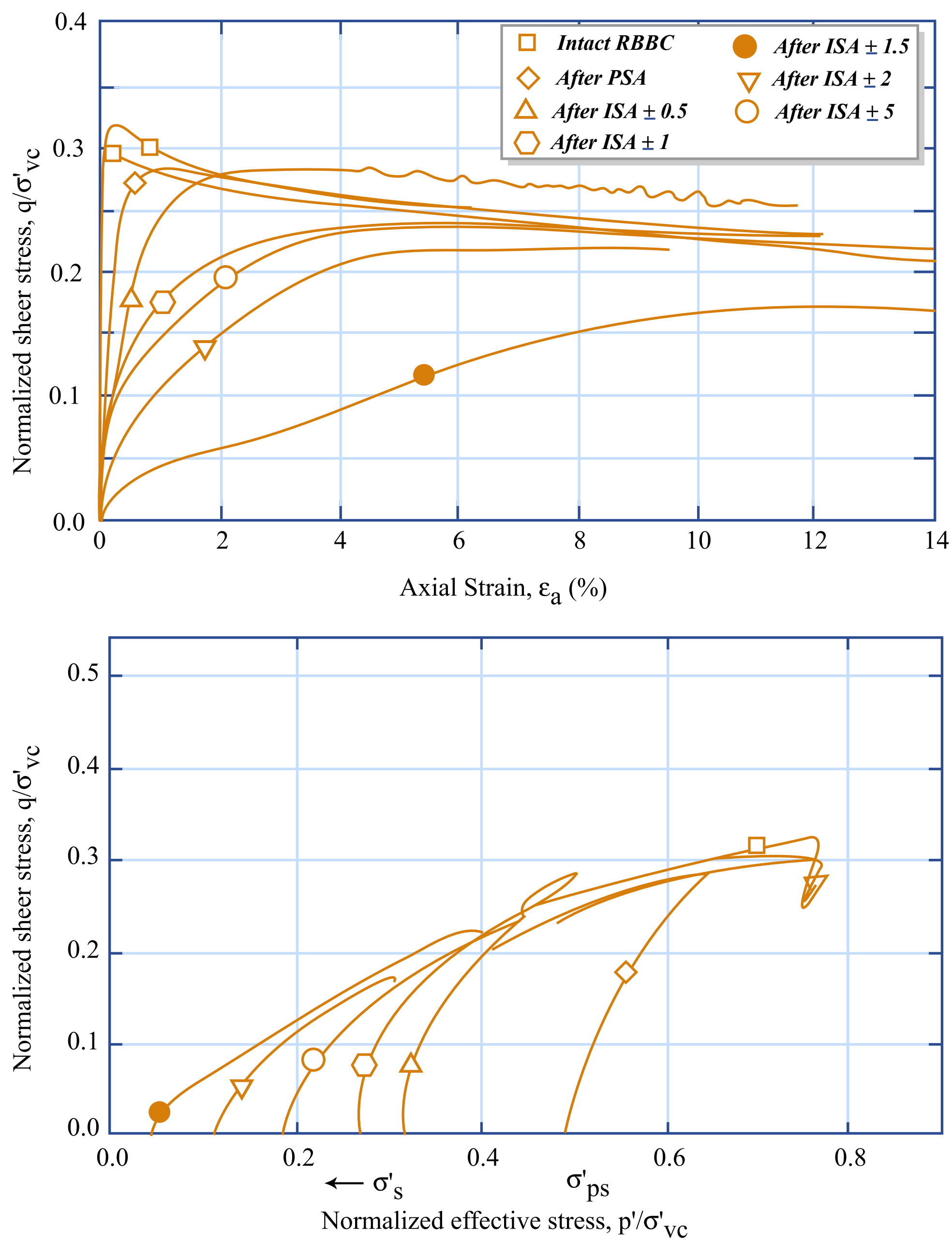


Straining history at the centerline of the simple samplers



Figures by MIT OCW.

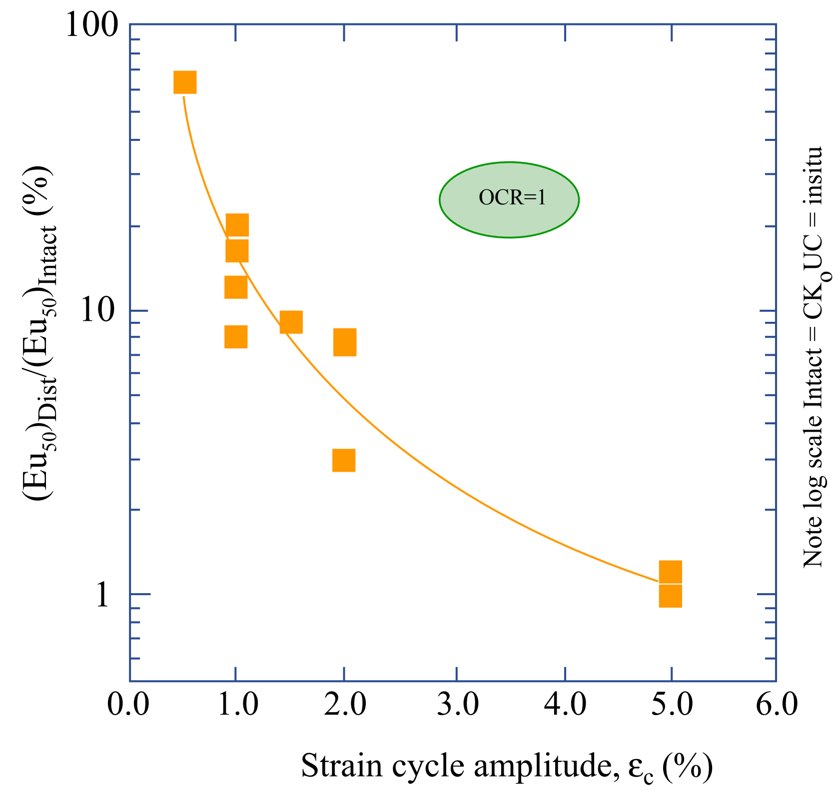
Adapted from M. Santagata, SM thesis, MIT 5/94



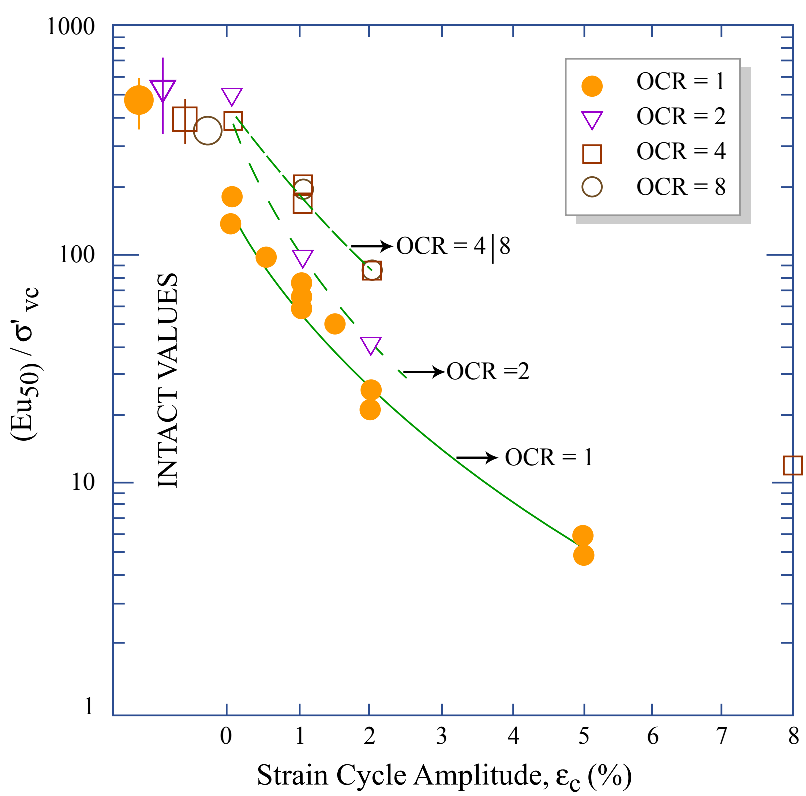
Effective of PSA and ISA disturbance on (a) The stress strain curves and (b) on the stress paths of normally consolidated RBBC

Figure by MIT OCW.

Adapted from *M. Santagata (5/94)*



Effect of ISA Disturbance on $Eu_{(50)}$ for NC

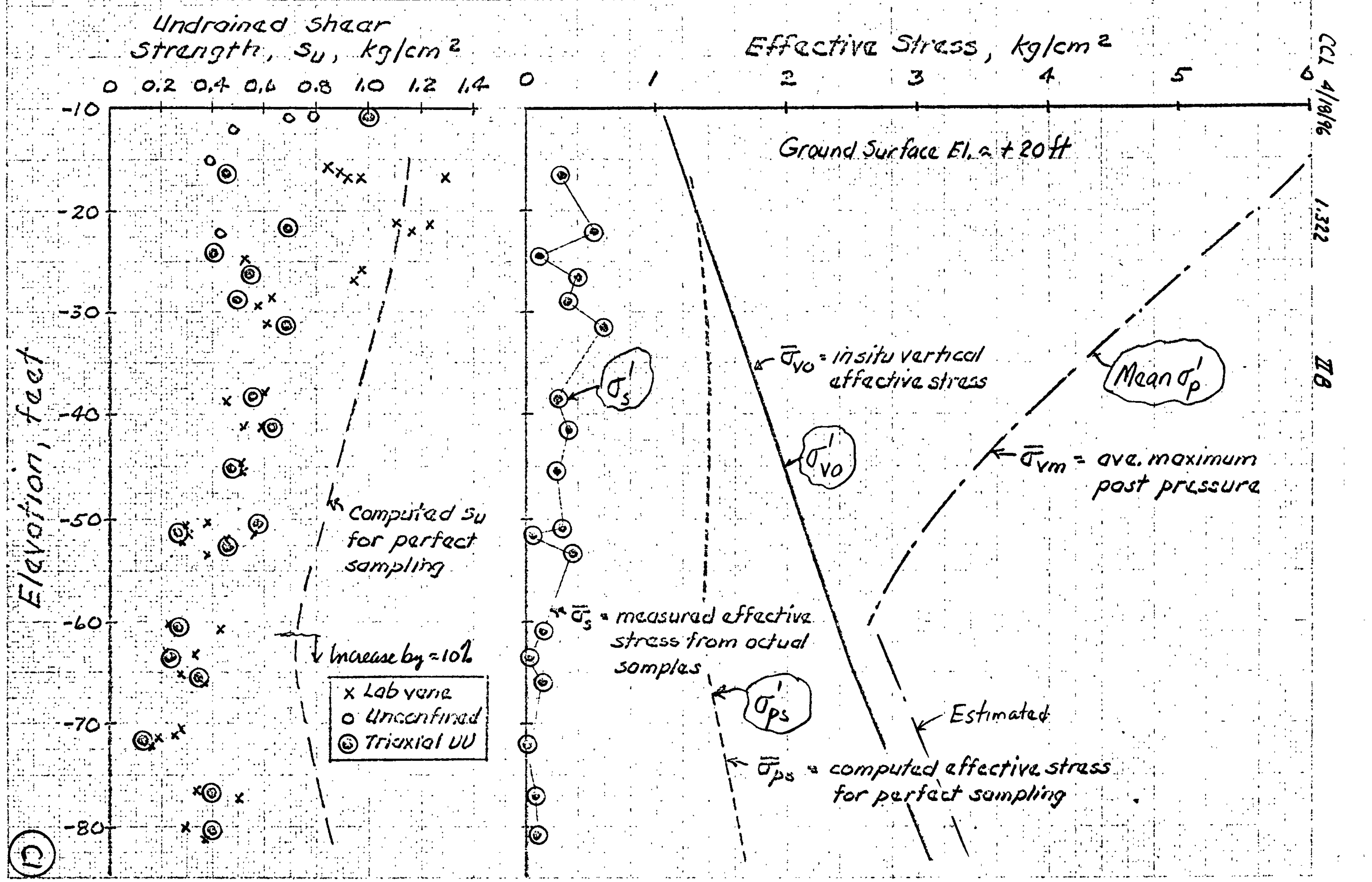


Decrease of Eu_{50} due to disturbance in RBBC

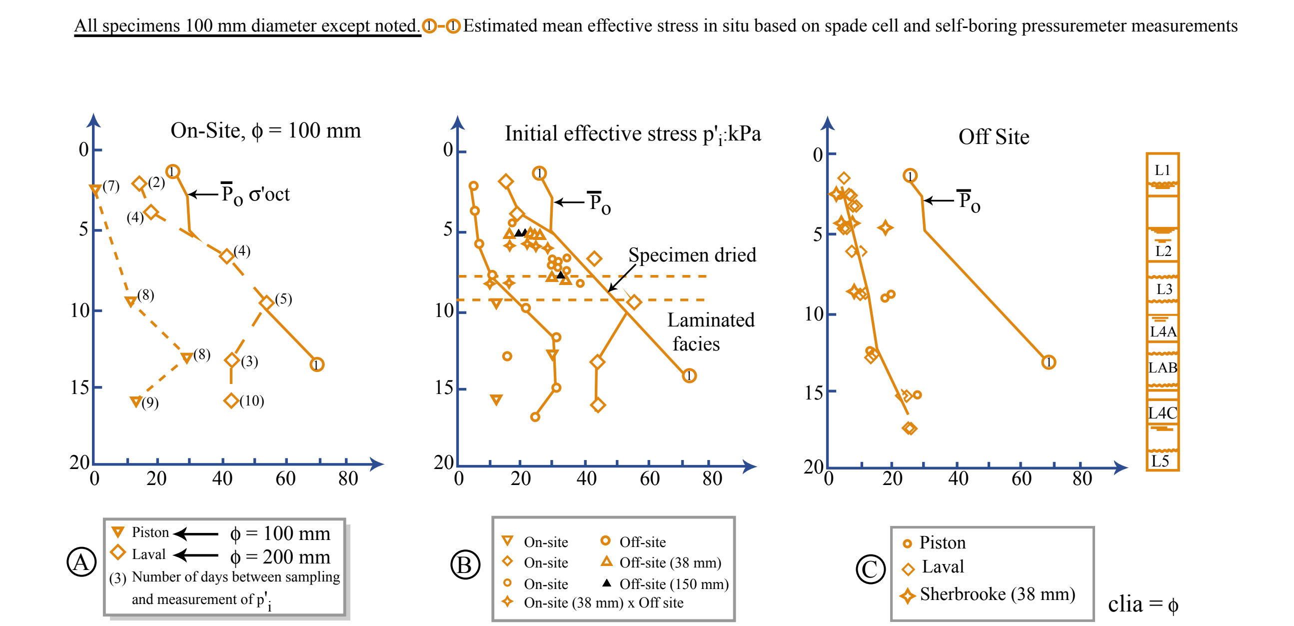
Figures by MIT OCW.

Undrained Strength and Effective Stress Data from Tests on Boston Blue Clay - M.I.T. Campus

CCL 1968



Adapted from Hight et al. (1992) Geot. 42(2) Bothkennar Plastic Clay



Measurements of initial effective stress p'_i : (a) Laval and piston samples - on-site laboratory (b) Laval, Sherbrooke and piston samples-on-and off-site laboratories (c) Laval, Sherbrooke and piston samples-off-site laboratory after preparation by tubing and trimming

Figure by MIT OCW.

Principal Conclusions from Comparing $P_i' = \sigma_s'$ vs. Mean In Situ $\sigma'_{oct} = \bar{P}_o$

1) Piston sampler σ_s' = 50% of Laval sampler σ_s'
2) Immediate tests on Laval samples → $\sigma_s' \approx \bar{P}_o$ ($\approx \sigma'_{ps}$) above z = 10 m } (a)
3) Transport of samples → reduced σ_s' [(b) vs (a)]
4) Poorer specimen trimming → reduced σ_s' (c)

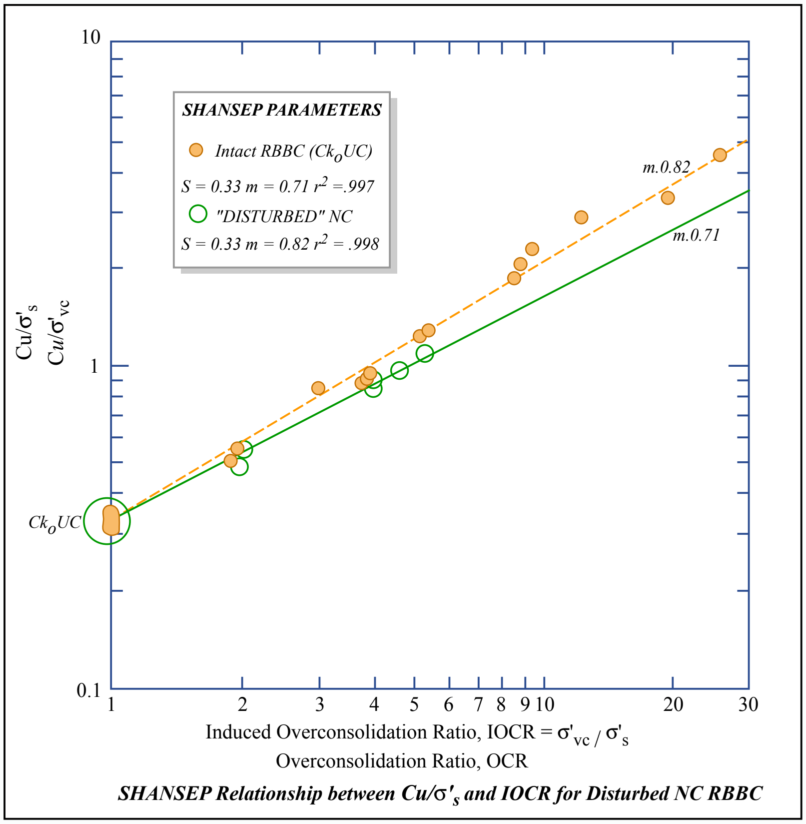


Figure by MIT OCW.

Santagata (5/94)
RBBC

$CK_0UC \rightarrow m = 0.71$

Induced disturbance (ε_c)
& UUC $\rightarrow m = 0.82$
for NC clay

Induced OCR = 2-25

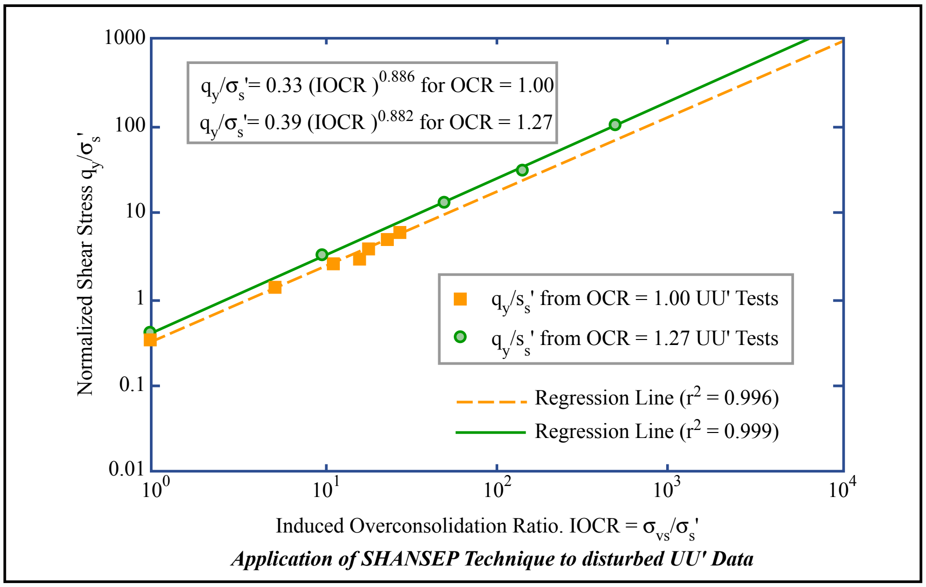


Figure by MIT OCW.

Sinfield (5/94)
NC RBBC
UUC tests on disturbed tube samples
Batch OCR = 1
$\rightarrow m = 0.86$
Batch OCR = 1.27
$\rightarrow m = 0.88$

Induced OCR = 5-500!

UUC & SHANSEP CK_0UC Data on Resedimented BBC

(a)

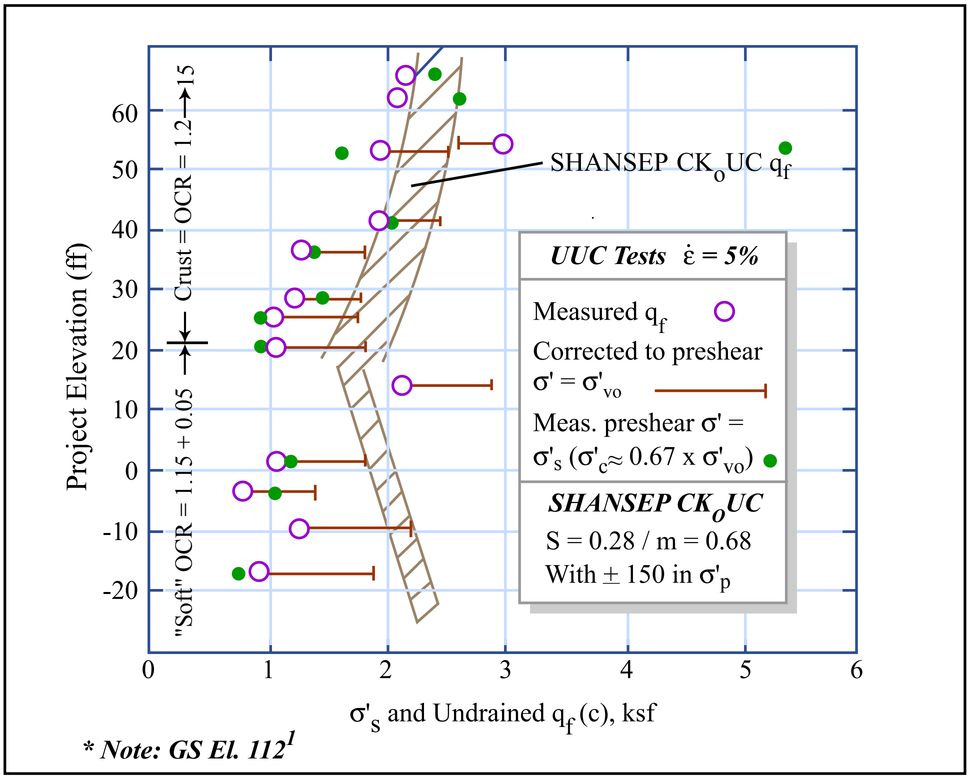


Figure by MIT OCW.

(b)

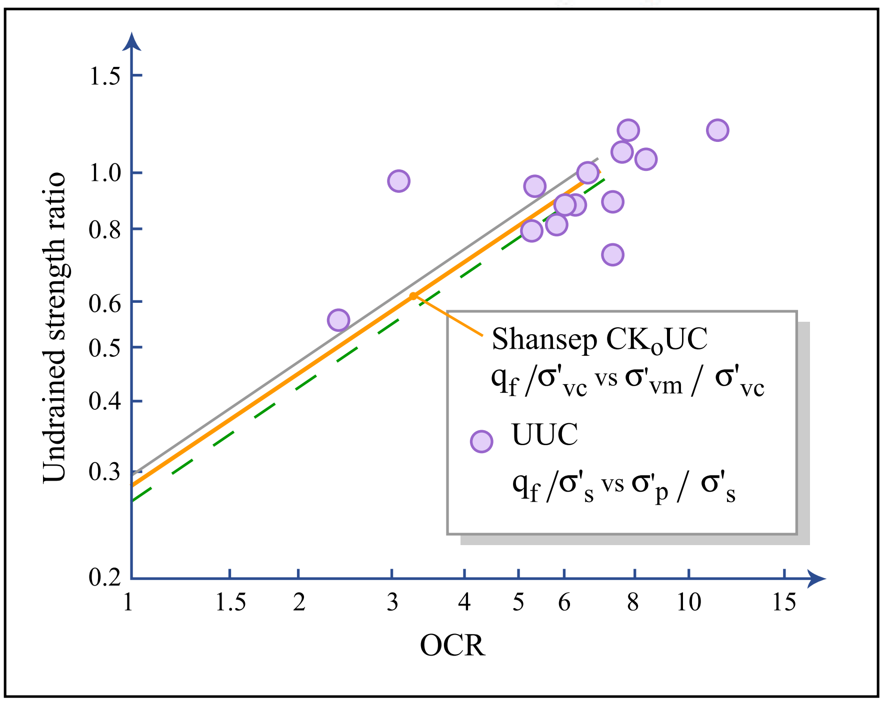


Figure by MIT OCW.

UUC and SHANSEP CK$_0$UC Data: SB STP on BBC (Data by MIT and HSA)
(a) Elev vs q_f and σ'_s
(b) Undrained Strength Ratio vs OCR

CCL 4/12/92 1.322
4/13/96

BBC-1

Supplement to Section 7 of IIB Sample Disturbance

Comparison of SHANSEP and Recompression CK_oUC/E Test Data on Natural Boston Blue Clay From Haley & Aldrich CAIT Special Test Program. MIT Performed Automated CK_oU Triaxial Tests → SM Theses by De La Beaumelle (1991) & Estabrook (1991)

- BBC-2 South Boston Stress History & Location of Block Samples
- -3 Log q_f/σ'_{vc} vs log OCR, CK_oUC (R → higher S)
- -4 " " ", CK_oUE (R → higher m)
- -5 ε_f vs. log OCR, CK_oUC/E (R → much lower ε_f, especially for TE)
- -6 A_f " " ", " (R → less difference between TC & TE)
- -7 E_{50}/σ'_{vc} " ", " (R → large increase in E_{50}/σ'_{vc} with OCR & much higher values at high OCR, esp. for TE)
- -8, -9 Comparison of normalized stress paths and stress-strain curves at moderate OCR, CK_oUC/E (R → generally to larger post peak strain softening).

ESE at Peak Strength (OCR>1)

Shear	Reconsolidation	c'/σ'_{vm} & σ'_p	$\sin\phi'$	ϕ'	q_f/σ' ± SD
TC	SHANSEP	0.064	0.335	19.6	0.005
	Recomp.	0.078	0.374	22.0	0.022
TE	SHANSEP	0.055	0.323	18.8	0.010
	Recomp.	0.074	0.225	13.0	0.015

CCL 4/12/92 1.322

BBC-2

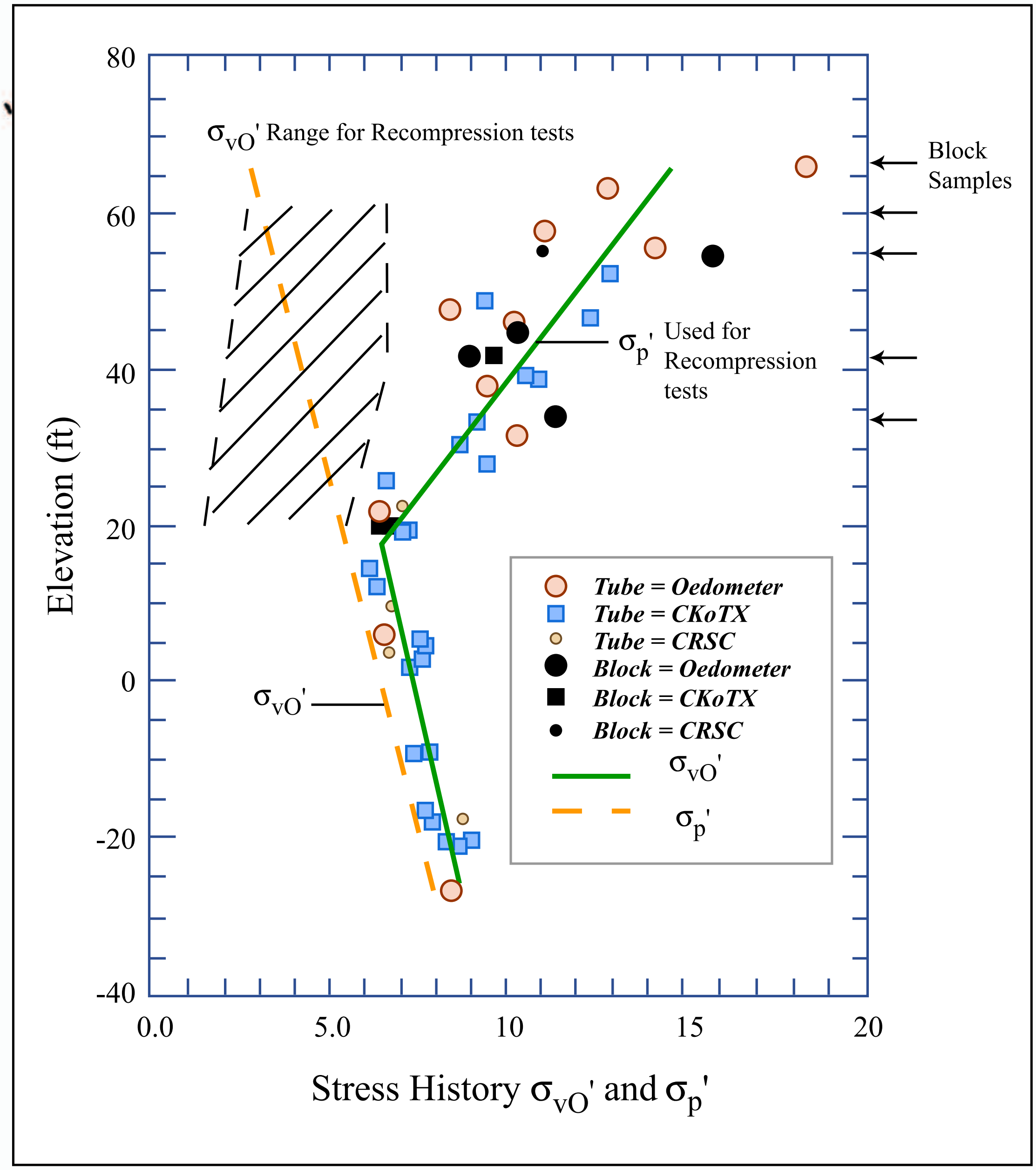


Figure by MIT OCW.

Figure 5-10: South Boston Stress History

CCL 4/12/92 1.322

BBC-3

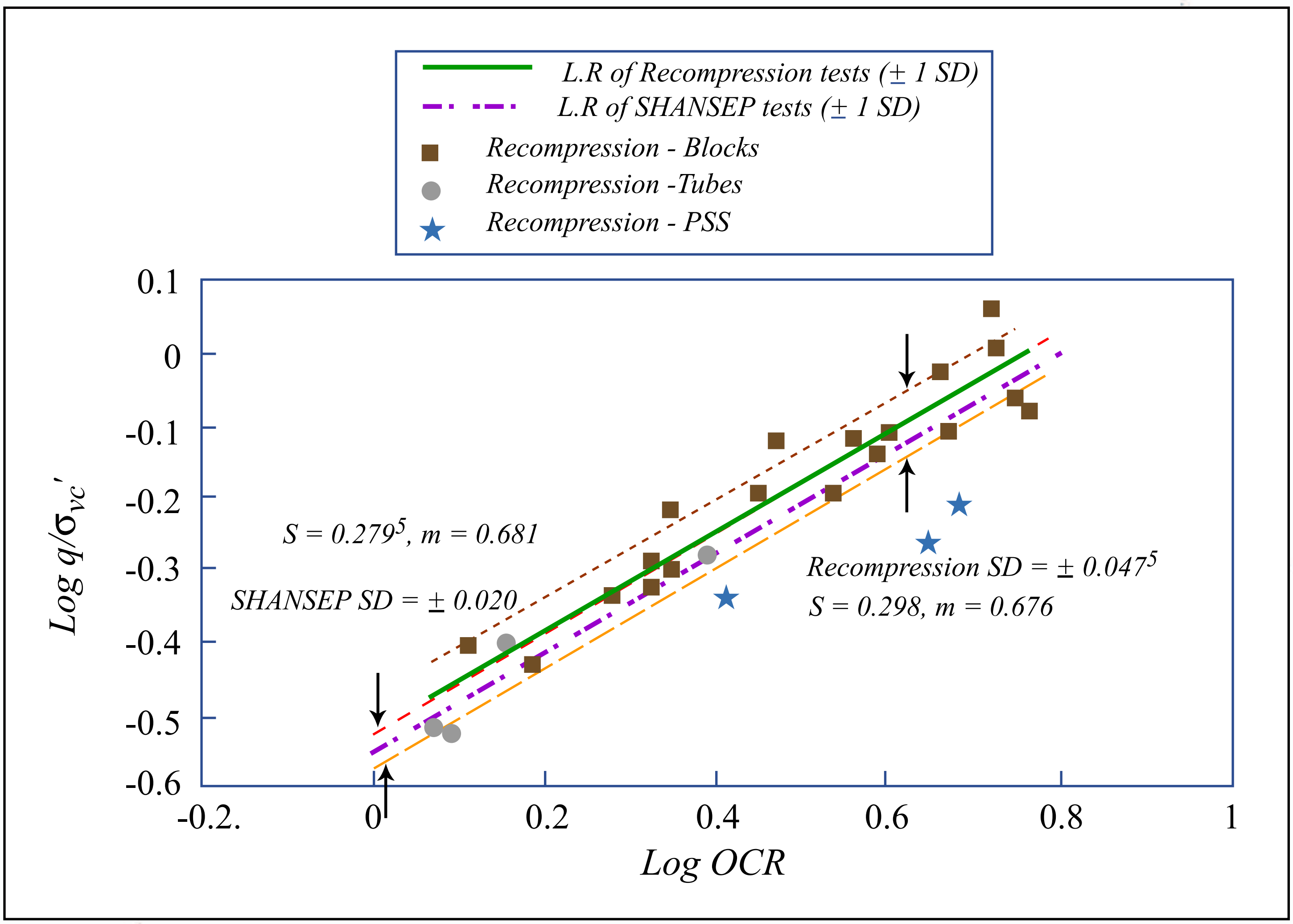


Figure by MIT OCW.

$OCR = \sigma'_{vm}/\sigma'_{vc}$ SHANSEP
$= \sigma'_p/\sigma'_{vc}$ Recomp.

Figure 7-4: Undrained Strength Ratio vs. OCR Comparison of SHANSEP and Recompression Triaxial Compression Tests

CCL 4/12/92 1.322

BBC-4

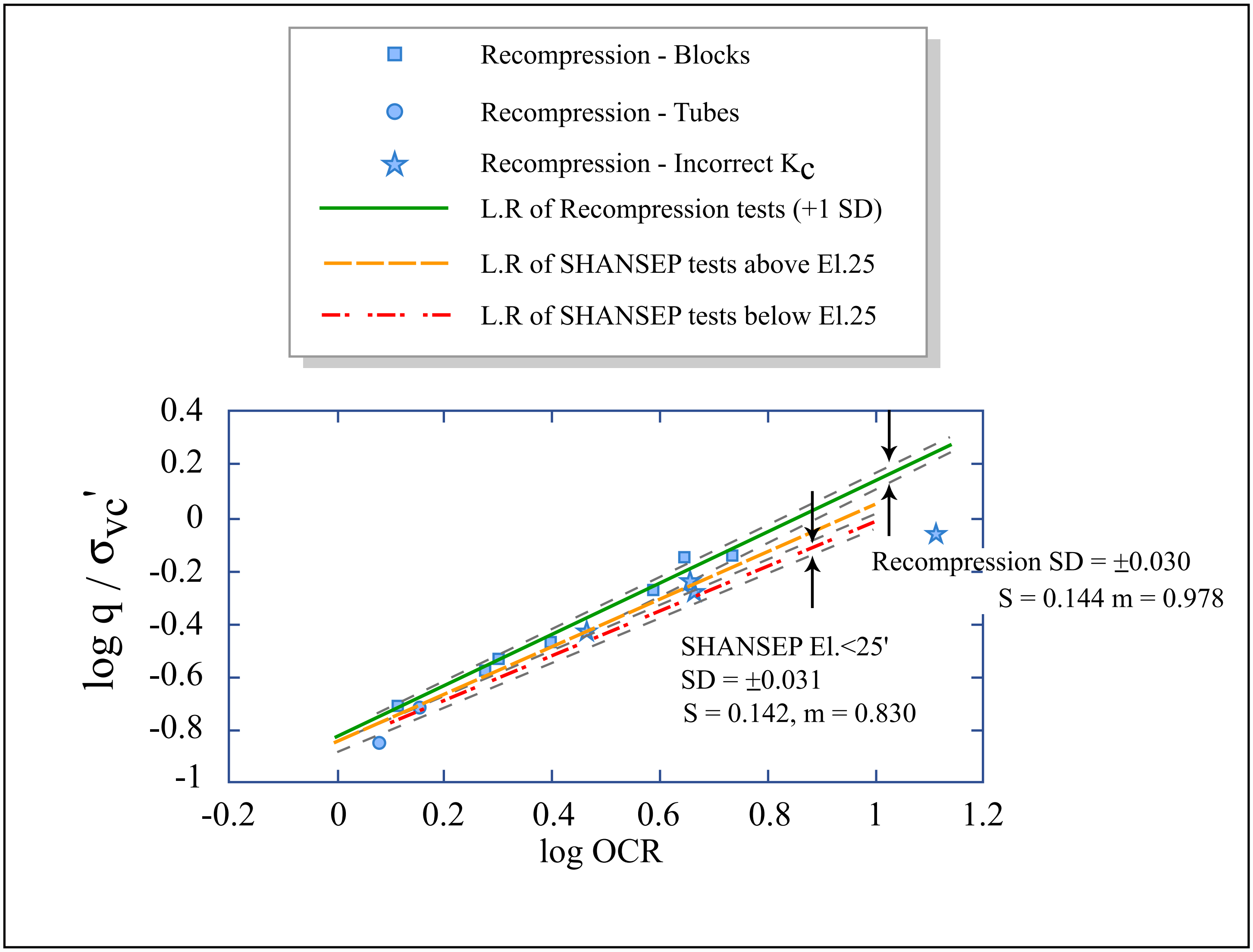
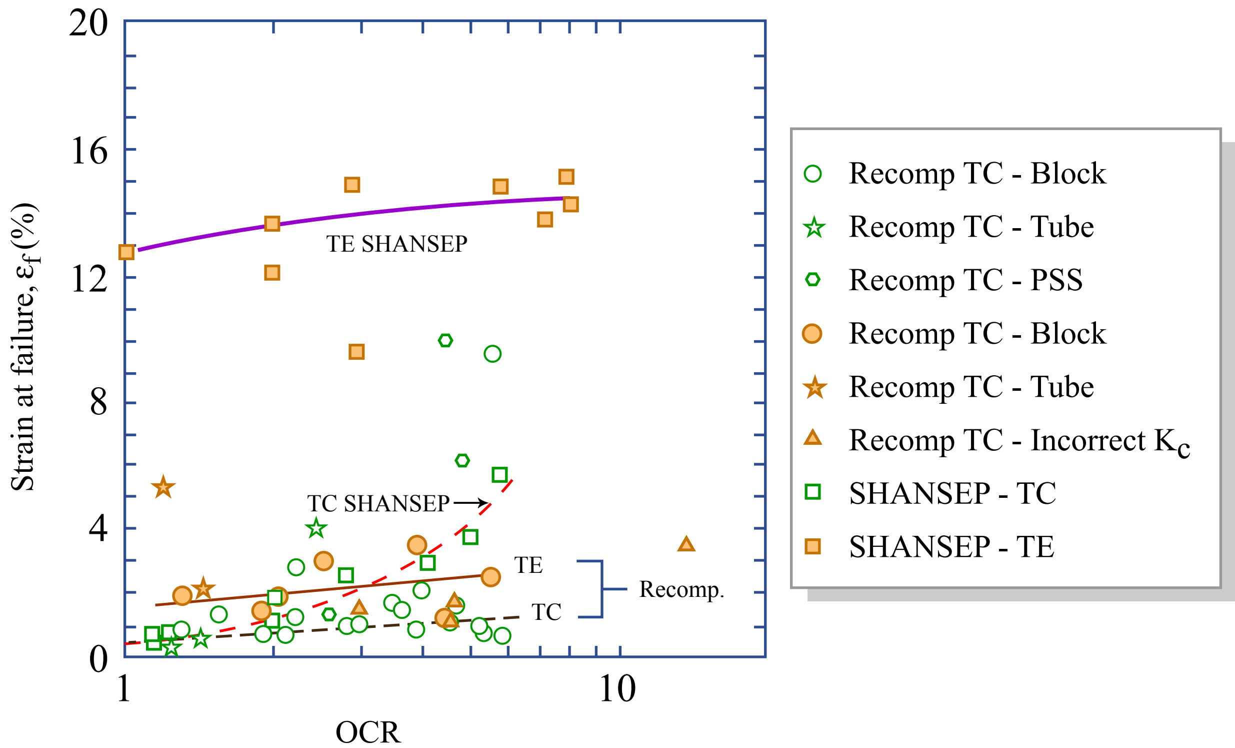


Figure by MIT OCW.

Figure 7-13: Undrained Strength Ratio vs. OCR Comparison of SHANSEP and Recompression Triaxial Extension Tests

CCL 4/12/92 1,322

BBC-5



Strain at failure vs. OCR for SHANSEP and recompression triaxial compression and extension tests on tube and block samples

Figure by MIT OCW.

CCL 4/12/92 1.322

BBC-6

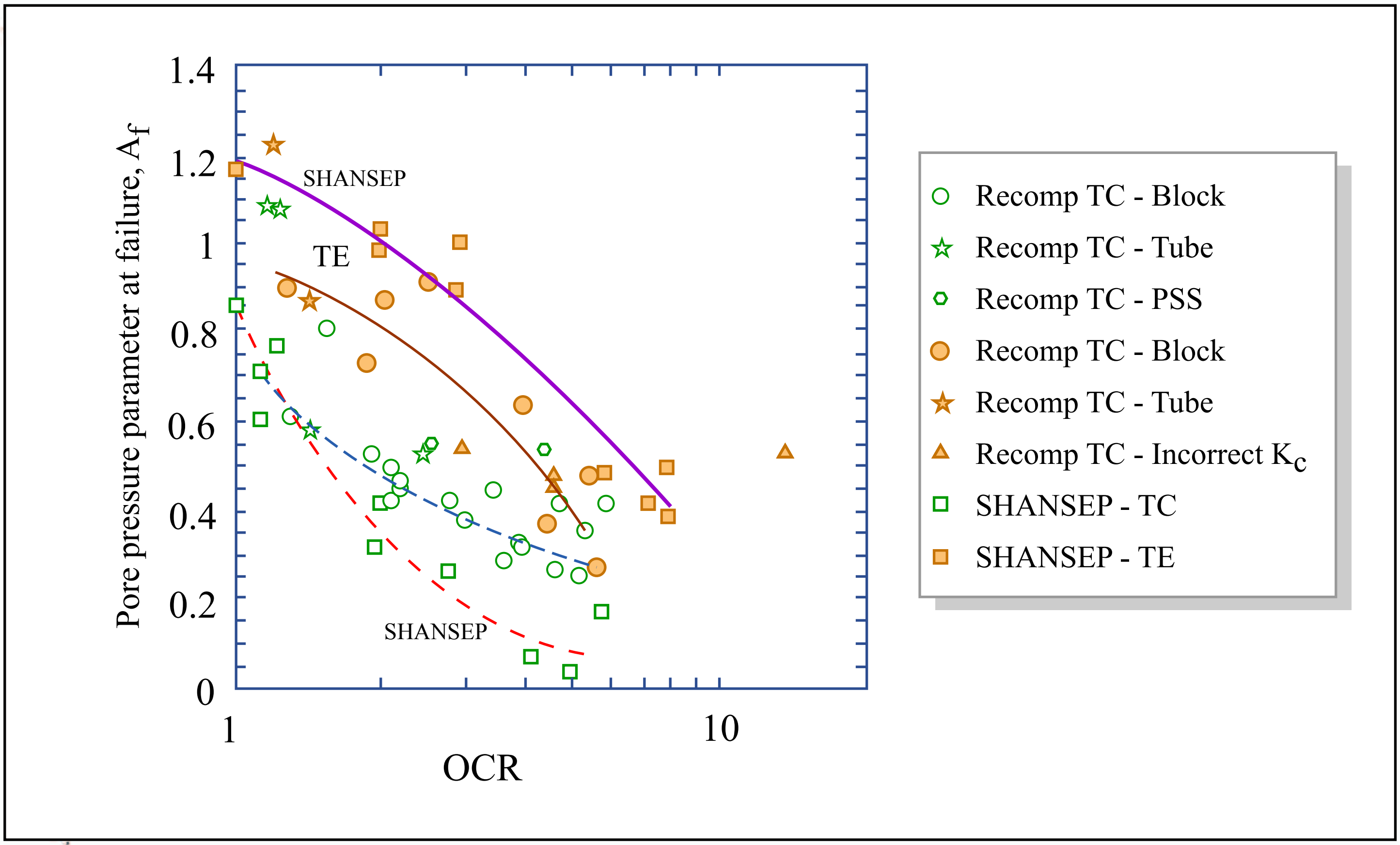
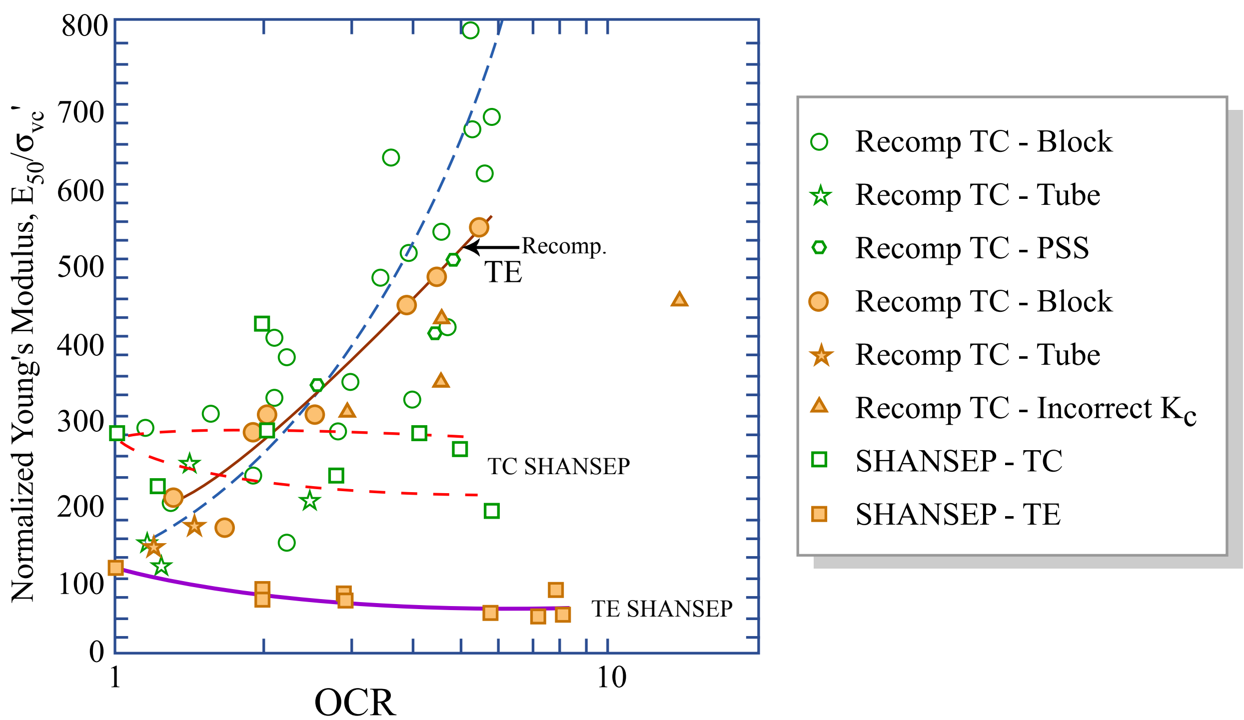


Figure by MIT OCW.

Figure 7-8: Pore Pressure Parameter at Failure vs. OCR for SHANSEP and Recompression Triaxial Compression and Extension Tests on Tube and Block Samples

CCL 4/12/92 1,322

BBC-7

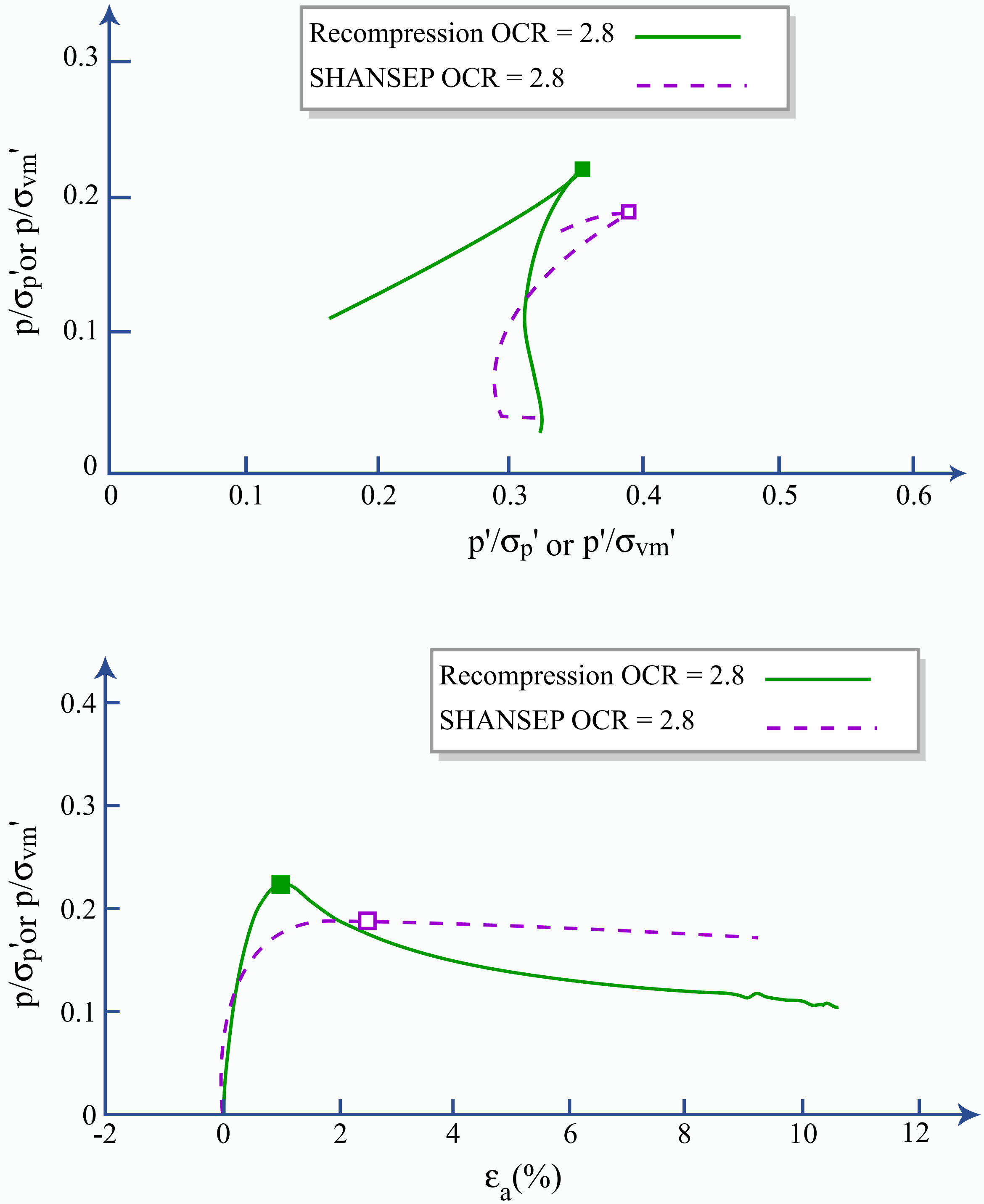


Normalized Young's Modulus vs. OCR for SHANSEP and recompression triaxial compression and extension tests a on tube and block samples.

Figure by MIT OCW.

CCL 4/12/92 1.322

BBC-8

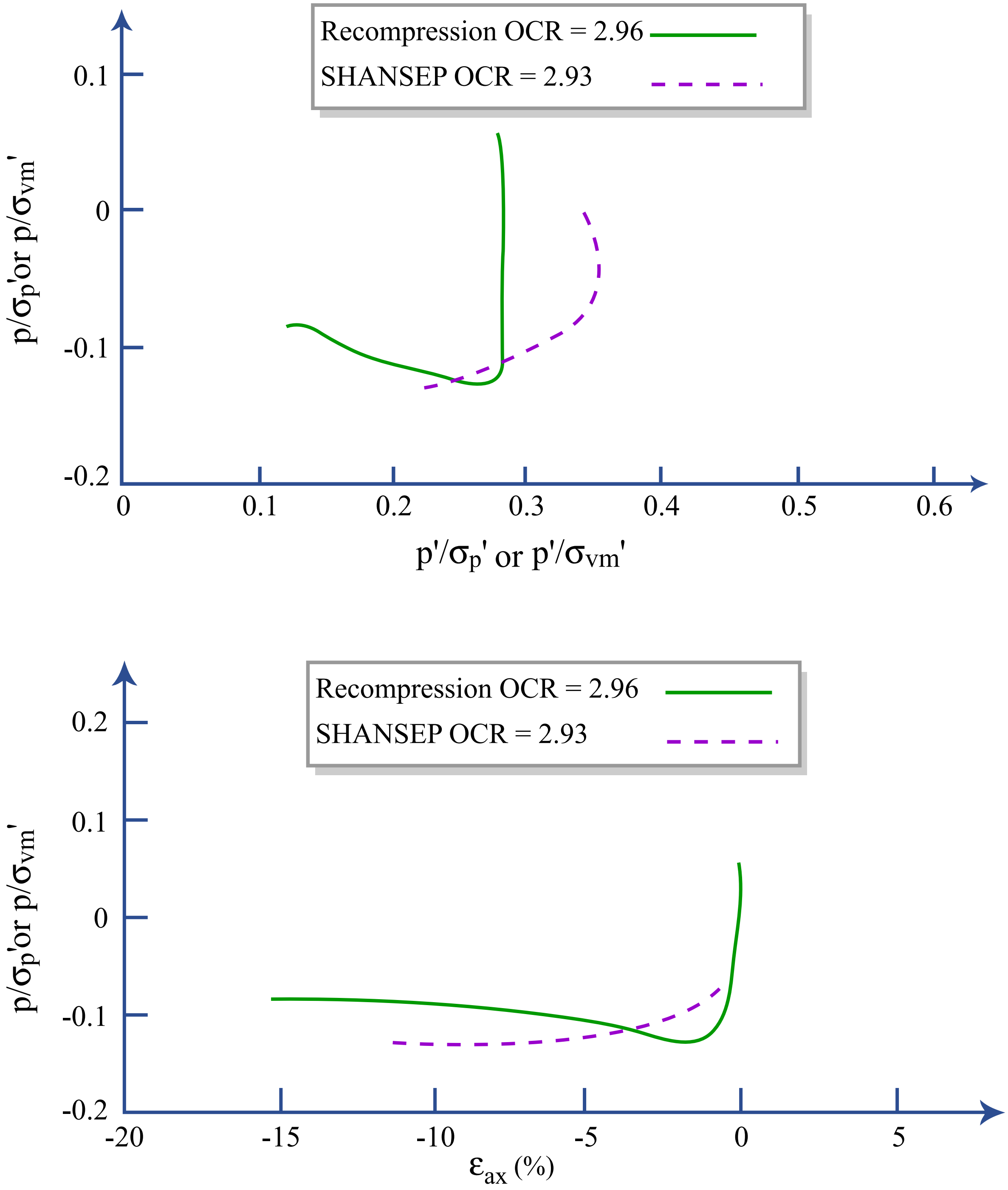


Comparison of SHANSEP and Recompression triaxial compression test stress paths and stress- strain curves at moderate OCR

Figure by MIT OCW.

CCL 4/12/92 1.322

BBC-9



Comparison of SHANSEP and Recompression triaxial extension test stress paths and stress-strain curves at moderate OCR.

Figure by MIT OCW.