26 3/01
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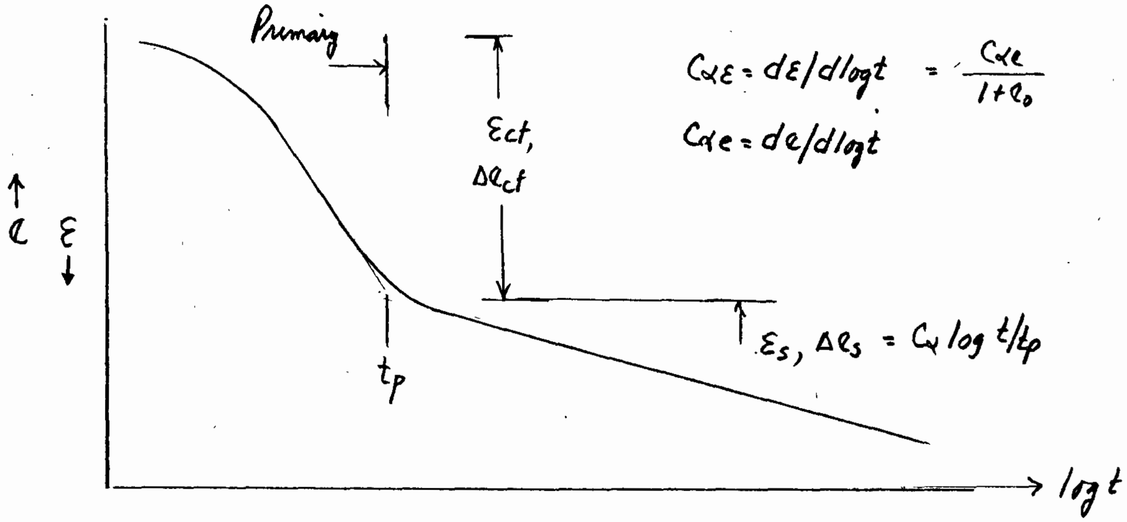
IV SECONDARY COMPRESSION

Sheets	A1-4	C_α/C Uniqueness & C_α vs t
"	B	Lab data to Support Hyp. A
"	C1-4	Laval " " " Hyp. B
"	D1-4	Surcharging to Reduce C_α
"	E1,2	Case history of shopping mall on varved clay
Sheets	F1-5	C_α/CR & surcharging data on SLC Clay
Sheet	F6	New correlation for C_α'/C_α & $\log(t_s/t_r) = f(AAOS)$

SECONDARY COMPRESSION

1. INTRODUCTION

1.1 Definitions (Incremental oedometer, NC, large LIR)



$$C_{\alpha\varepsilon} = d\varepsilon/d\log t = \frac{C_{\alpha e}}{1+e_0}$$

$$C_{\alpha e} = de/d\log t$$

1) Primary consolidation: Increasing σ'_v wherein rate of volume change is governed by "hydrodynamic time lag" (Terzaghi theory)

2) Secondary compression: occurs at ≃ constant σ'_v = 1-D drained creep that occurs after end of primary consolidation

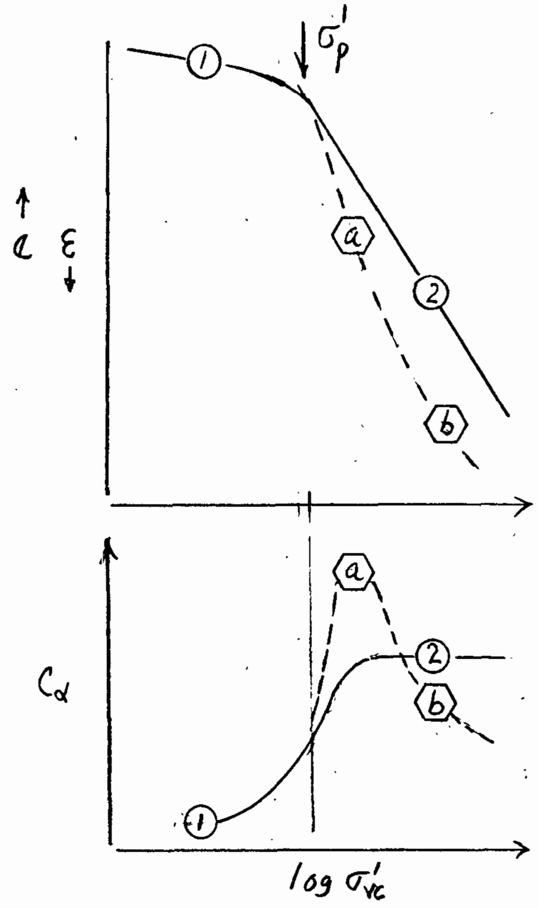
Note: Will later discuss whether or not creep also occurs during primary

1.2. Coverage

- Factors affecting C_α
- Uniqueness of C_α/C (C = slope of ε or e vs $\log \sigma'_{vc}$ curve)
- Hypothesis A vs Hypothesis B
  (does creep occur during primary → large effect of H_d (t_p) on σ'_p and e_{cf})
- Reduction in C_α due to surcharging

2. FACTORS AFFECTING RATE OF SECONDARY COMPRESSION

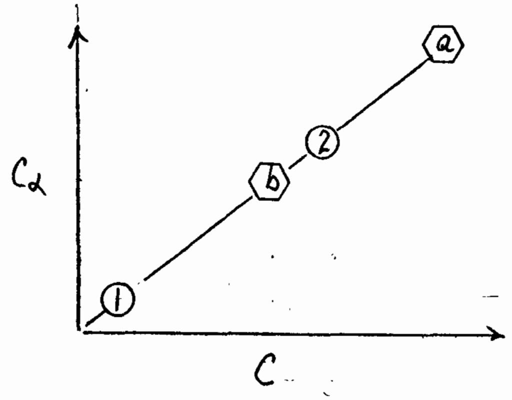
2.1 Effects of Stress History and Virgin Compressibility: Conceptual



EOP Compression Curves
—— Constant VCL
- - - S-shaped VCL

C = slope of compression curve

$C_e = -de/d\log\sigma'_{vc}$
$C_\varepsilon = d\varepsilon/d\log\sigma'_{vc}$ } both OC & NC



Unique $C_{\alpha e}/C_e = C_{\alpha\varepsilon}/C_\varepsilon$ ratio → C_α
Controlled by slope of compression curve

2.2 Values of C_α/C

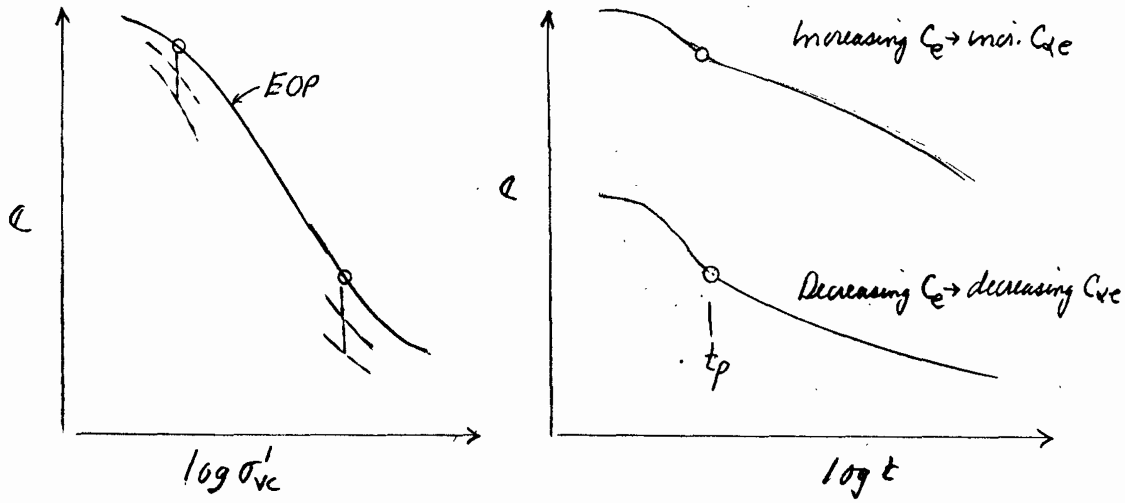
1) Sheets A1 & 2: Data on 7 clays
- Wide variation in soil types
- Both K_0 and $K_c = 1$ consolidation

2) Mesri & Choi [1985, JGE 111(4)]

	C_α/C	
• Majority of inorganic soft clays :	0.04 ± 0.01	$0.04^5 \pm 0.01^5$
• Highly organic plastic clays	0.05 ± 0.01	
• All soils (sands → peats)	$0.02 - 0.10$	

2.3 Variation in C_α with Time

1) Basic concept à la Mesri & Castro [1987, JGE, 113(3)] Sheet A3



NOTE: C_e = slope at start of each log cycle of secondary compression, i.e. at $t/t_p = 1, 10, 100$ etc.

2) See Sheet A4 for extreme example of increasing C_α with time from test with σ'_{vc} slightly less than σ'_p of highly structured, cemented clay, e.g.

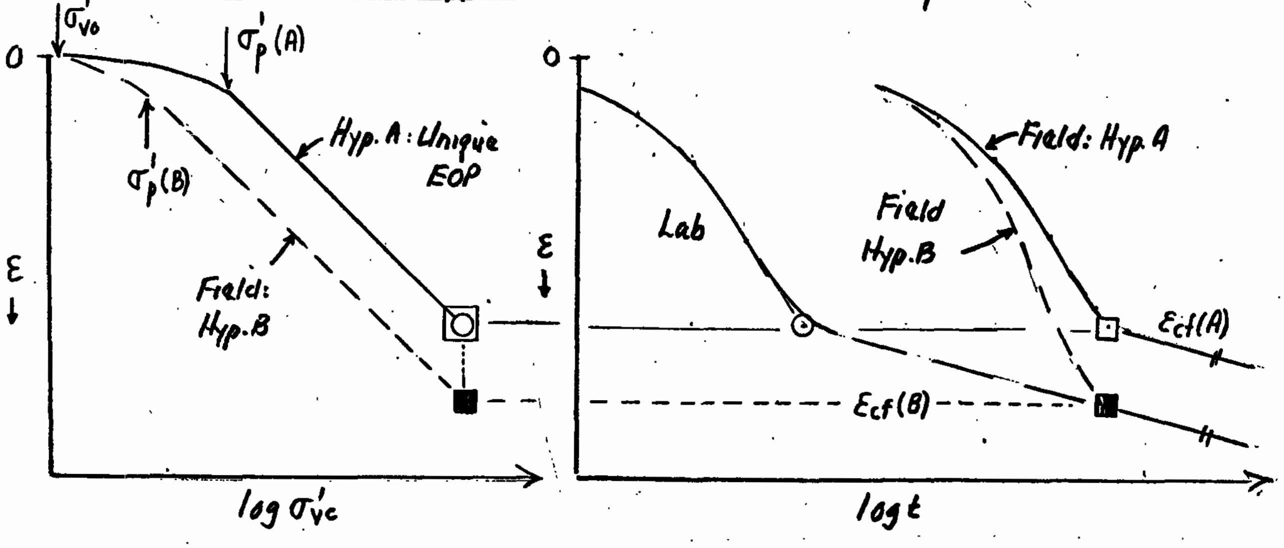
- $u_e \to \approx 0$ in 10 min
- Very large increase in $C_{\alpha e}$ at $t > 100$ min

3. HYPOTHESIS A vs HYPOTHESIS B

3.1 Physical "Mechanisms": Primary vs. Secondary (CCL opinion)

Primary Consolidation	Causes Creep?
1) Elastic deformation of particles	• Only if Δ interparticle stress
2) Particle reorientation	
• Slippage at contacts	• For sure
– breaking cementation bonds	• Are bonds "viscous"?
– displacing adsorbed H_2O	• Is water "viscous"?
3) Change in closest spacing	
• DL compression	• Unlikely
• Displace adsorbed H_2O	• Is water viscous?
4) Particle crushing	• Certainly continues in granular soils at high stresses

3.2 Overview of Hypotheses A and B : Effect of $t_p \propto H_d^2$



1) Hypothesis A: Creep due to continuation of same mechanisms → primary*; occurs mainly after primary → unique EOP; therefore field σ'_p (large t_p) = lab σ'_p (small t_p) and ε vs log t is simply displaced to right in proportion to H_d^2 → same ε_{cf}.

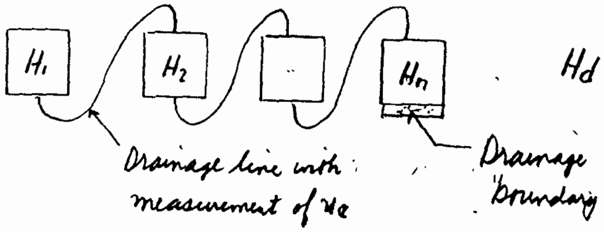
* that is, particles not in equilibrium at EOP and hence continue to get deformation (creep) at constant σ'_{vc}

2) Hypothesis B: Creep is due to some type of "structural viscosity" that also occurs during primary. Hence much larger field $t_p \rightarrow$ decrease in field σ_p' and increase in EOP ε_{cf} that lies on extension of lab ε_s vs log t.

3.3 Evidence to Support Hypothesis A

3.3.1 Laboratory Experiments (Mainly by Mesri et al.)

- Vary H_d (hence t_p) and compare e vs log σ_{vc}' at EOP



$$H_d = \sum_{n=1}^{n} H_i$$

- See Sheet B for data on SFBM with H_d = 7.6 to 50.8 cm $\rightarrow$ variation in $t_p = (50.8/7.6)^2 \approx \times 45 \rightarrow$ unique EOP e vs $\log \sigma_{vc}'$
However, results have been criticized for using $K_c = 1$ rather than K_0 (but Sec. 2.2 $\rightarrow$ Same C_α/C_c for $K_c = 1$ & $K_c = K_0$ à la A1 & A2)

3.3.2 Comparison of Predicted ε_{cf} from Hyp. A vs B

1) Selected parameters: CH clay, $c_v = 2\,m^2/yr \sim 6.3 \times 10^{-4}\,cm^2/sec.$
$CR = 0.3$, $C_{\alpha\varepsilon}/CR = 0.04 \rightarrow C_{\alpha\varepsilon} = 1.2\%$

2) t_p values: Lab. $H_d = 1\,cm$ & $T = 1 \rightarrow t_p = 26$ min $= 0.018$ day
Field $H_d = 5\,m$ & " $\rightarrow t_p > 12.5$ yr. $= 4563$ day

3) Magn. $\varepsilon_s = C_\alpha \log t_{p\,field}/t_{p\,lab} = 1.2 \log 253{,}500 = 6.5\%$

4) Predicted values of ε_{cf}

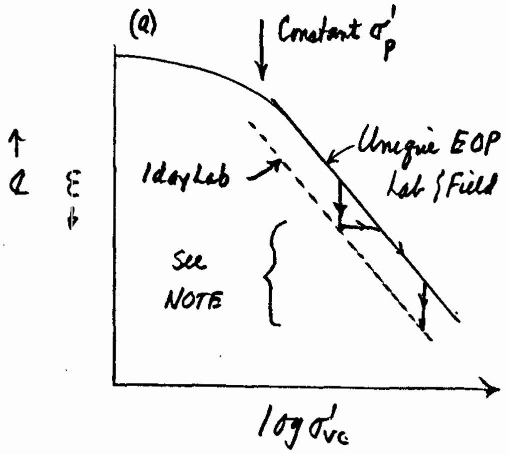
L/R	Hyp. A ε_{cf}	Hyp. B ε_{cf}	Ratio B/A
1	0.3 log 2 = 9.0%	+6.5 = 15.5%	→ 1.75
0.5	0.3 log 1.5 = 5.3%	" = 11.8%	→ 2.2

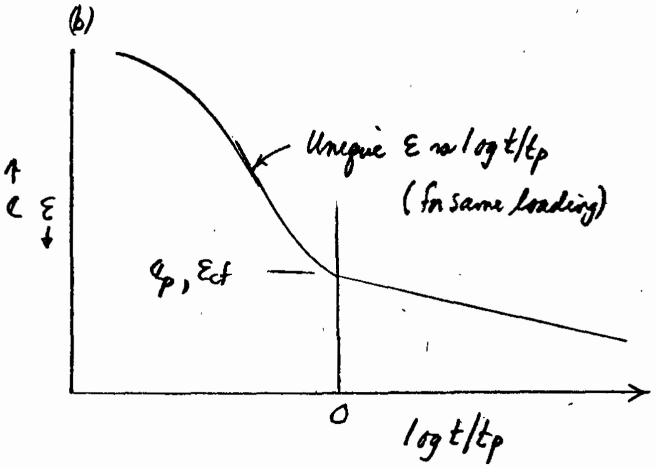
} Does not agree with general experience from case histories on "ordinary" clays

3.4 Predicted Behavior for Hypothesis A

1) Assumption of unique EOP compression curve that is independent of t_p (H_d) → very simple model of behavior

2) Examples





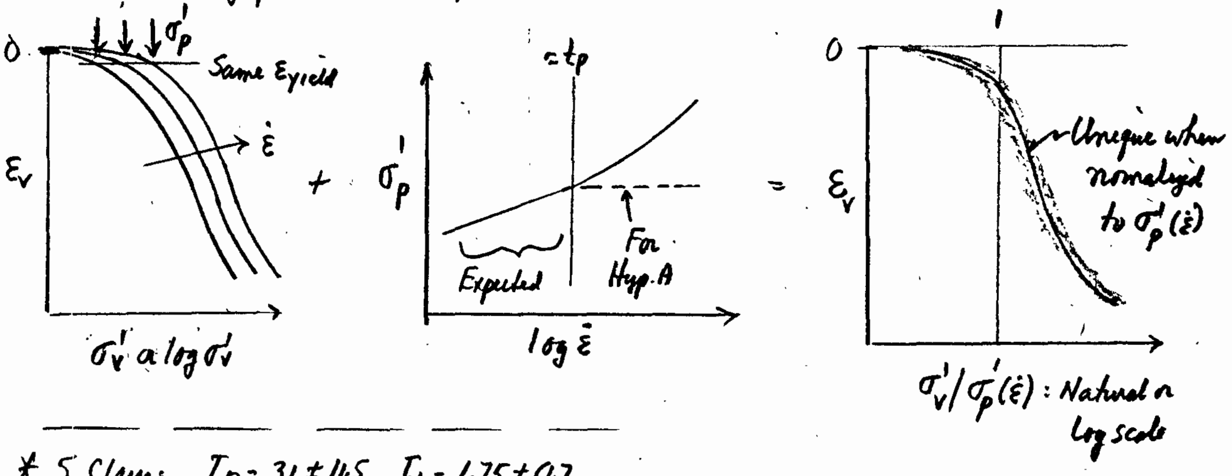
(c) NOTE: Illustration of e vs $\log \sigma'_{vc}$ during standard 24 hr. incremental oedometer test (lab).

3.5 Laval Univ. Lab Data Used to Support Hypothesis B

3.5.1 General approach [Leroueil et al. 1985, Geot. 35(2)]

1) Essentially all test materials were highly structured (hence probably cemented) clays from eastern Canada*; mainly CRS tests, plus incremental oed. where plotted ε at varying values of $\dot{\varepsilon}$

2) Big picture → unique ε vs $\sigma'_v/\sigma'_p(\dot{\varepsilon})$



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* 5 Clays: $I_p = 31 \pm 11.5$, $I_L = 1.75 \pm 0.7$,
(mean ± SD) $S_t = 65 \pm 45$, $\sigma'_p = 145 \pm 75$ kPa

3.5.2 Examples of Cited Data

1) Batiscan clay ($w_N \approx 80$, $w_L \approx 43$, $I_p = 21$, $I_L \approx 2.7$)

- Sheet C1 Fig 1 & 4: ε_v vs σ'_v as $f(\dot\varepsilon)$ Fig. 7: σ'_p vs $\log \dot\varepsilon$
  Fig 8 & 9: ε_v vs $\sigma'_v/\sigma'_p(\dot\varepsilon)$

2) Other data

- Sheet C2 – Fig. 20 $\sigma'_p/\sigma'_p(\text{ref.}\ \dot\varepsilon)$ vs $\log \dot\varepsilon$
  – Bottom: Data from Mesri's test with $H_d = 20''$ on sensitive clay showing that distance from drainage boundary → different compression curves during primary consolidation (hence refutes Hyp. A)

3.6 Laval Univ. Field Data Used to Support Hypothesis B

- Data from test fills: Kabbaj et al [1988, Geot 38(2)]; Leroueil et al. (1986)

	Case	z (m)	Typical		Measured Field			Lab EOP	Field
			w_N (%)	w_L	σ'_p (kPa)	σ'_{vc}	ε_v (%)	ε_v (%) at σ'_{vc}	Lab
Sensitive, brittle	Berthierville	3.0-3.9	62	43	58	72	12.5	9	1.4
	"	3.9-4.8	55	38	60	80	10.5	4	2.6
	St. Alban D	3.1-4.9	65	40	54	65	10.5	1.3	8.1
	Gloucester	2.4-4.9	80±10	55	56	61	5.8	1.0	5.8
	Vasby (Sweden)	4.3-7.3	100	95	43	51	16	1.7	9.4
					$\underbrace{\quad\quad}_{\sigma'_{vc}/\sigma'_p \approx 1.2 \pm 0.1}$				5.5 ±3.4

- Sheet C3: Compares field vs lab EOP compression curves → greatly reduced σ'_p and increased ε_v (Note natural scale)

- Sheet C4: Plots σ'_v @ $\varepsilon_v = 10\%$ vs $\log \dot\varepsilon$ → field data consistent with extrapolation of lab data.

3.7 Discussion of Laval Data

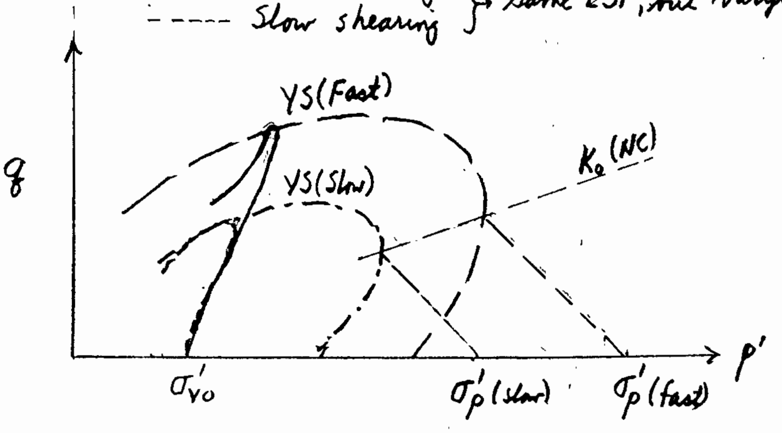
3.7.1 Nature of Their Clays

- Except for Vasby (which Mesri & Choi (1985) used as a case history to support Hypothesis A via ILLICON analyses), all are highly structured clays that are probably cemented.
- Materials are so compressible that plot ε_v vs σ'_v (not vs log σ'_v)

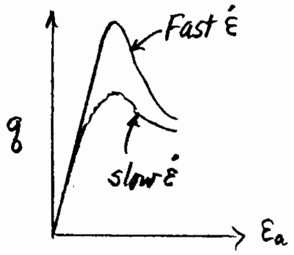
3.7.2 Evidence That Cementation Bonds Exhibit Viscous Behavior

- Lefebvre & Le Boeuf [1987: JGE 113(5)] data from CIUC/CK₀UC tests with varying $\dot{\varepsilon}$ on 5 similar Canadian clays, e.g, $I_p = 7\text{-}40\%$, $I_L = 2.3 \pm 0.6$ & $\sigma'_p = 140 \pm 45$ kPa
- CCL interpretation of Recompression tests, i.e., $\sigma'_{vc} \approx \sigma'_{vo}$

—— Fast shearing
---- Slow shearing
} → same ESP, but varying yield stress = failure



YS = yield surface



- That is, slower $\dot{\varepsilon}$ → weaker cementation bonds → smaller Yield Surface → lower σ'_p that is consistent with Laval data

3.7.3 CCL Conclusions

(viscous bonds = "structural viscosity")

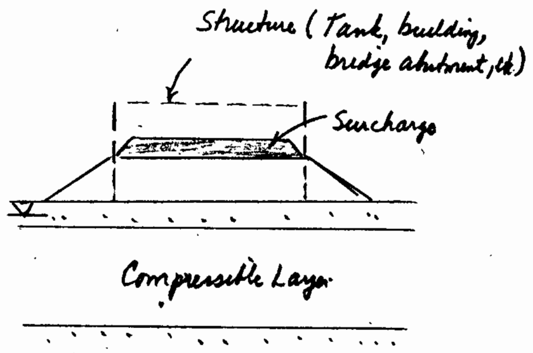
1) For Canadian cemented clays, Hypothesis B is closer to truth;

2) All cohesive soils probably exhibit some sort of "structural viscosity" at high strain rates, say $\dot{\varepsilon} > \dot{\varepsilon}$ at EOP in typical lab oedometer tests

3) But see 3.3.2 (i.e., general literature → meas. $P_{cf} \gg$ predicted via Hyp. A)

4. REDUCTION IN C_α WITH SURCHARGE

4.1 Introduction

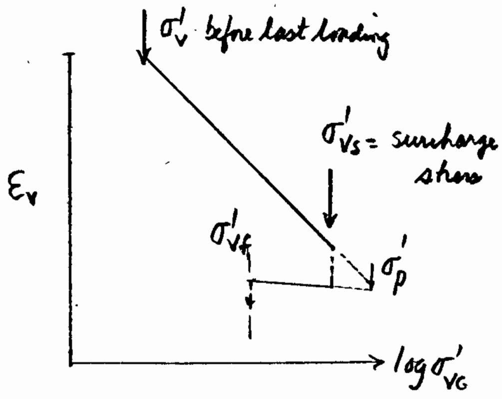


1) Preloading (e.g., with fill) is frequently used to reduce the settlement of structures, i.e., to reduce or eliminate significant settlements due to primary consolidation

2) In cases where long term settlements due to secondary compression will cause excessive total/differential settlements (e.g. approach fill at bridge abutment), the preloading can include a surcharge (i.e., consolidation to stresses > final stress → OC soil) to reduce C_α

3) Section 4 presents a rational design methodology

4.2 Basic Concepts and Definitions (Sheets D1 & D2)

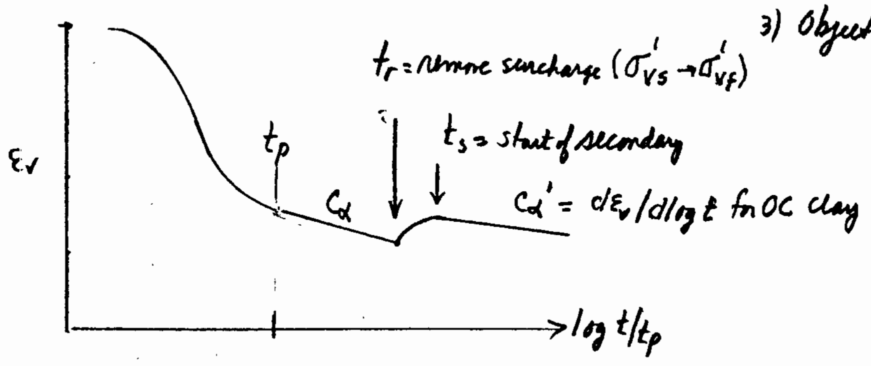


Notes

1) In field, σ'_{vs} would correspond to EOP (i.e., no secondary before unloading)

2) However, most lab testing includes some secondary before unloading → $\sigma'_p > \sigma'_{vs}$

3) Objective: How to predict C_α'



4.3 Comments on Experimental Data From Lab Tests

1) Most lab testing used $t_r > t_p$

2) Sheet D3: CCL's 1st evaluation of data using conventional approach in terms of

$$\text{Amt of Surcharge (AOS)} = (\sigma'_{vs} - \sigma'_{vf})/\sigma'_{vf} = \text{"OCR"} - 1$$

that did not use actual OCR

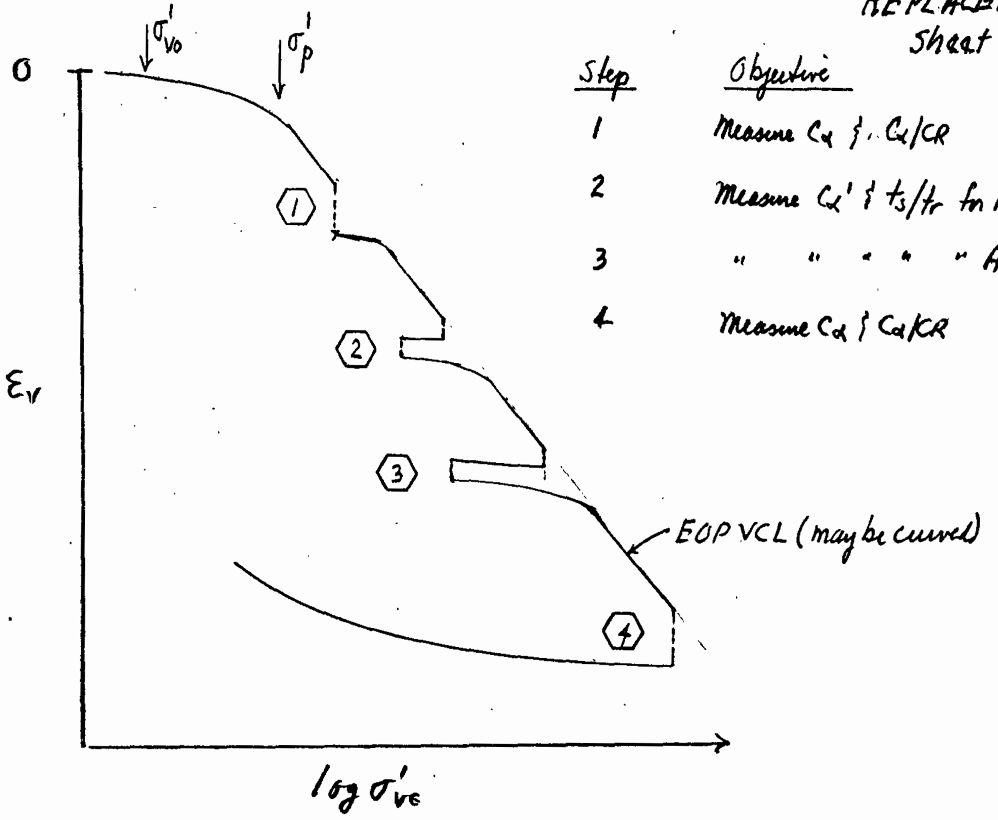
3) Sheet D4: CCL's better evaluation using actual OCR

$$\text{Adjusted Amt. of Surcharge (AAOS)} = (\sigma'_p - \sigma'_{vf})/\sigma'_{vf} = \text{OCR} - 1$$

that was developed for large shopping mall on deep varved clay in upper state NY

4.4 Recommended Lab Testing to Check / Supplement Fig. 3 (Sheet D4)

REPLACED BY
Sheet F6



Step	Objective
1	Measure C_α & C_α/C_R
2	Measure C_α' & t_s/t_r for AOS ≈ 10-15%
3	" " " " " AOS ≈ 20-30%
4	Measure C_α & C_α/C_R

Note: For Steps 2 & 3, need to also estimate induced σ'_p in order to calculate AAOS

4.5 Design of Surcharge (Preliminary)

1) Select design life (t) and acceptable ρ_s and estimate t_p

2) Determine σ'_{vf} & C_α profiles

3) For trial preload + surcharge geometry (plus possible variations in U_z with depth), determine σ'_{vs} profile

4) Estimate t_r/t_p for each layer (Typically will use vertical drains and design with $t_r \rightarrow \bar{U} \geq 90 \pm 5\%$)

5) For each layer:
   - Calculate AAOS (= AOS for $t_r/t_p \leq 1$)
   - Use Sheet F6 (preferably with some actual data for site cohesive soils)
     $\rightarrow C_\alpha'/C_\alpha$ & hence C_α' (Assuming no site data) · Calculate for both upper & mean lines
     $\rightarrow \log t_s/t_r$ & hence t_s · Use mean line
   - Calculate $\varepsilon_s = C_\alpha' \log t/t_s$, where t = design life

6) Predicted $\rho_s = \Sigma H_i \cdot \varepsilon_s$

7) Repeat until ρ_s is within acceptable limits

8) Evaluate uncertainty in 7) and discuss with client before selecting final design

9) Insist on field instrumentation (settlement pts. & piezometers) to check field rate of consolidation and hence when can safely remove surcharge

4.6 Data on Salt Lake City (SLC) Clays*

Nicky Si Yan Ng (6/98) SM thesis
"Characterization of Consolidation & Creep Properties of SLC Clays"

1) Sheet F1 • Plasticity chart → CL & CH clay

• Min-Max CR vs w_N → increasingly S-shaped VCL with incr. w_N
(Note that incr. old → lower CR_{max} than CRSC tests at higher w_N)

2) Sheet F2 • Fig 5.1 NC C_α vs CR → Mean $C_\alpha/CR \approx 0.043$

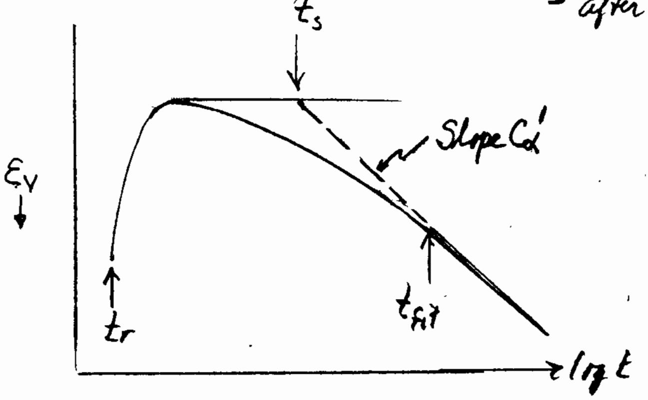
• Fig 5.2 NC C_α/CR increases with increasing w_N (0.03 → 0.05)

3) Sheet F3 • Fig 6.1 Special test procedure à la p10

- NC C_α Ⓐ
- OC data Ⓑ
- NC C_α Ⓒ
- OC data
- NC C_α

• Fig 6.2 d vs log t for Ⓐ, Ⓑ & Ⓒ

4) Sheet F4 • Fig 6.3 def vs log t - full increment
- after removing surcharge to enlarged scale



t_s = "start" of secondary with slope C_α'

t_{fit} = time for actual settlement to "fit" (match) prediction

• Fig 6.4 = $\log(t_{fit}/t_r)$ vs AAOS

5) Sheet F5 • F6.5 AAOS vs C_α'/C_α & $\log t_s/t_r$

Note linear C_α'/C_α vs log AAOS → $C_\alpha'/C_\alpha = 1.285 - 0.733 \log(\text{AAOS}, \%)$
$r^2 = 0.91$ & $SD = \pm 0.056$

6) Sheet F6 • F6.7 Above plots for SLC clays plus data in Sheet D4

Collective Data
n = 30

$$\boxed{\begin{aligned} C_\alpha'/C_\alpha &= 1.847 - 1.083 \log(\text{AAOS}, \%) \quad r^2 = 0.82,\ SD = \pm 0.12 \\ \log t_s/t_r &= 0.0206(\text{AAOS}, \%) \quad r^2 = 0.66,\ SD = \pm 0.156 \end{aligned}}$$

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* For design of reconstructed I-15 through Salt Lake City for 2002 Winter Olympics (we didn't get any bribes)

CCL 3/86 1.322
3/87 3/89

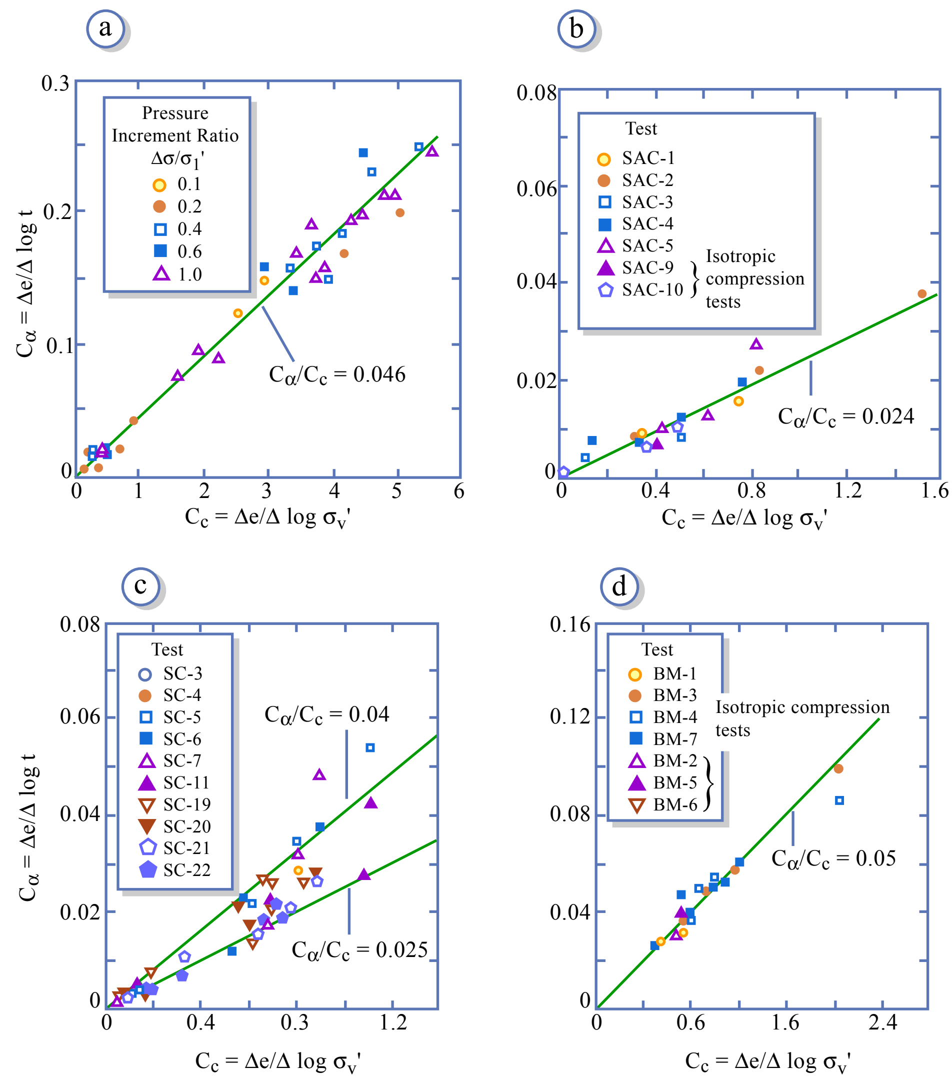
$C_\alpha - C_c$ Uniqueness (p1/2)

Discussion by Mesri & Choi (1984) Geotechnique, V34, No. 3

Data on uniqueness of C_α/C_c for a given clay independent of σ'_{vc}/σ'_p values & K_o vs $K_c = 1$

Table 2. Natural soft clays

	Location	Soil type	w: %	w_L: %	w_P: %	σ_p'/σ_{vo}'
a)	Mexico City	Lacustrine	311–340	361	91	1·4
b)	St Alban, Canada	Marine	48–54	31	18	1·9–2·7
c)	Singapore	Marine	38–79	54–86	19–32	—
d)	San Francisco	Coastal marine	86–97	89	37	1·2
e)	Olga, Canada	Glacio-lacustrine	85–94	67	29	2·2–2·5
f)	Broadback, Canada	Glacio-lacustrine	48	36	25	2·6–3·2
g)	Louiseville, Canada	Marine	64–71	65	28	2·6–2·9



C_α/C_c = data for natural soft clays: (a) Brown Mexico City Clay; (b) St. Alban Clay; (c) Singapore Clay; (d) San Francisco Bay mud.

Figure by MIT OCW.

A1

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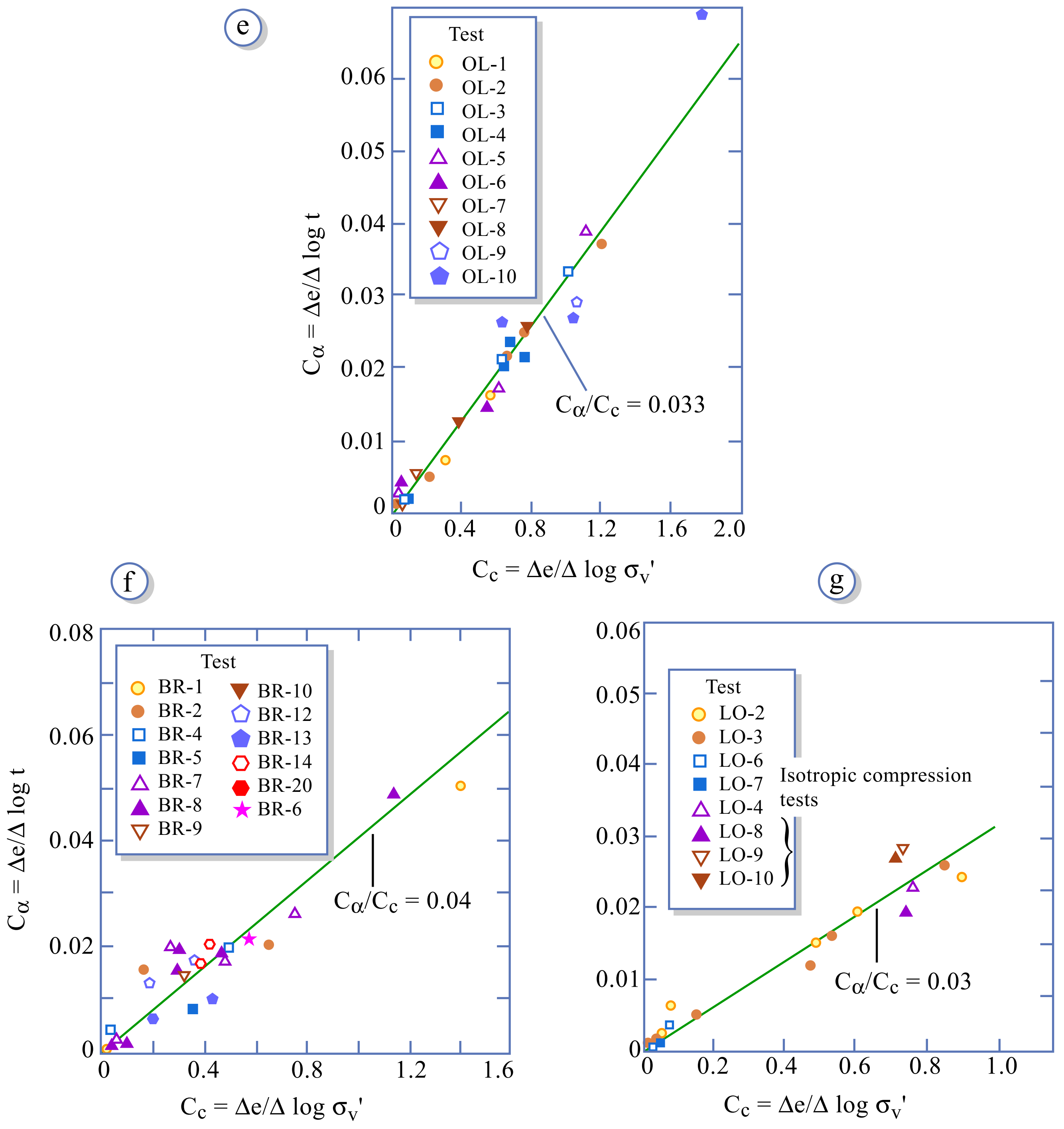
Adapted from Mesri & Choi (1984) continued



Contd:
(e) Olga clay; (f) Louiseville clay

Figure by MIT OCW.

Note: Also see Mesri & Castro (1987) JGE March

A2

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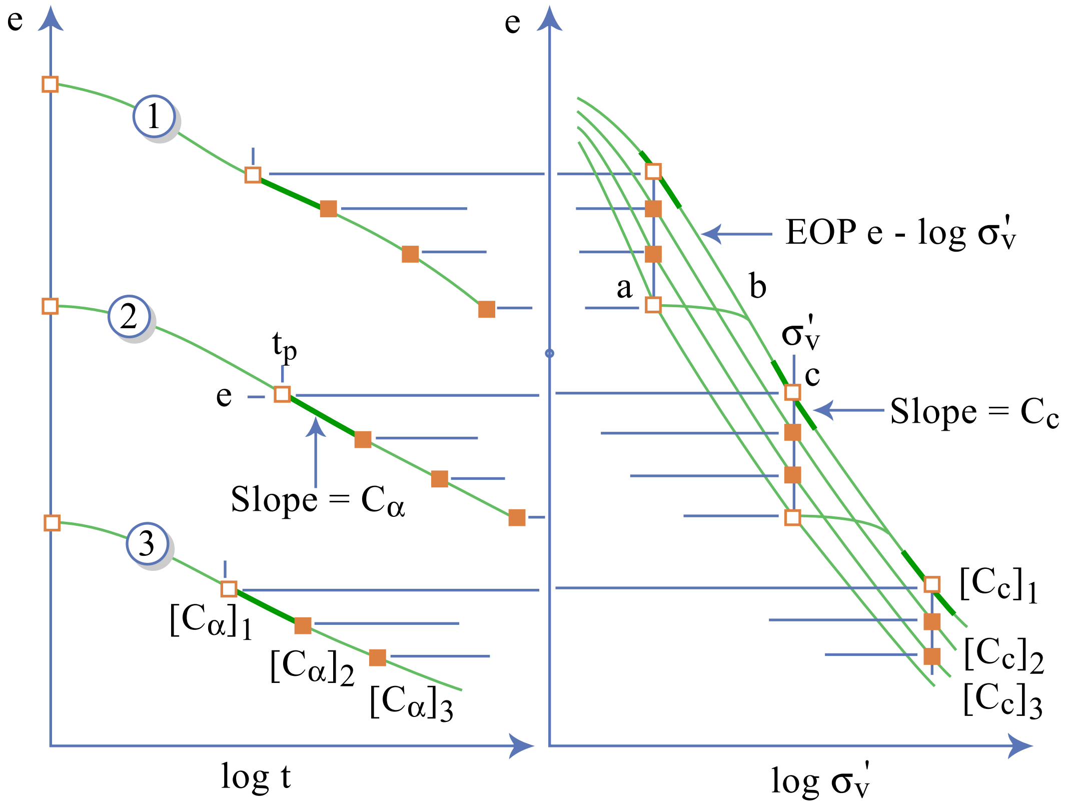
Variation in C_α with Time



Corresponding values of C_α and C_c at any instant (e, σ'_v, t) during secondary compression.

Figure by MIT OCW.

Adapted from Mesri & Castro (1987) JGE

Ⓐ3

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Example of C_α Increasing with Time

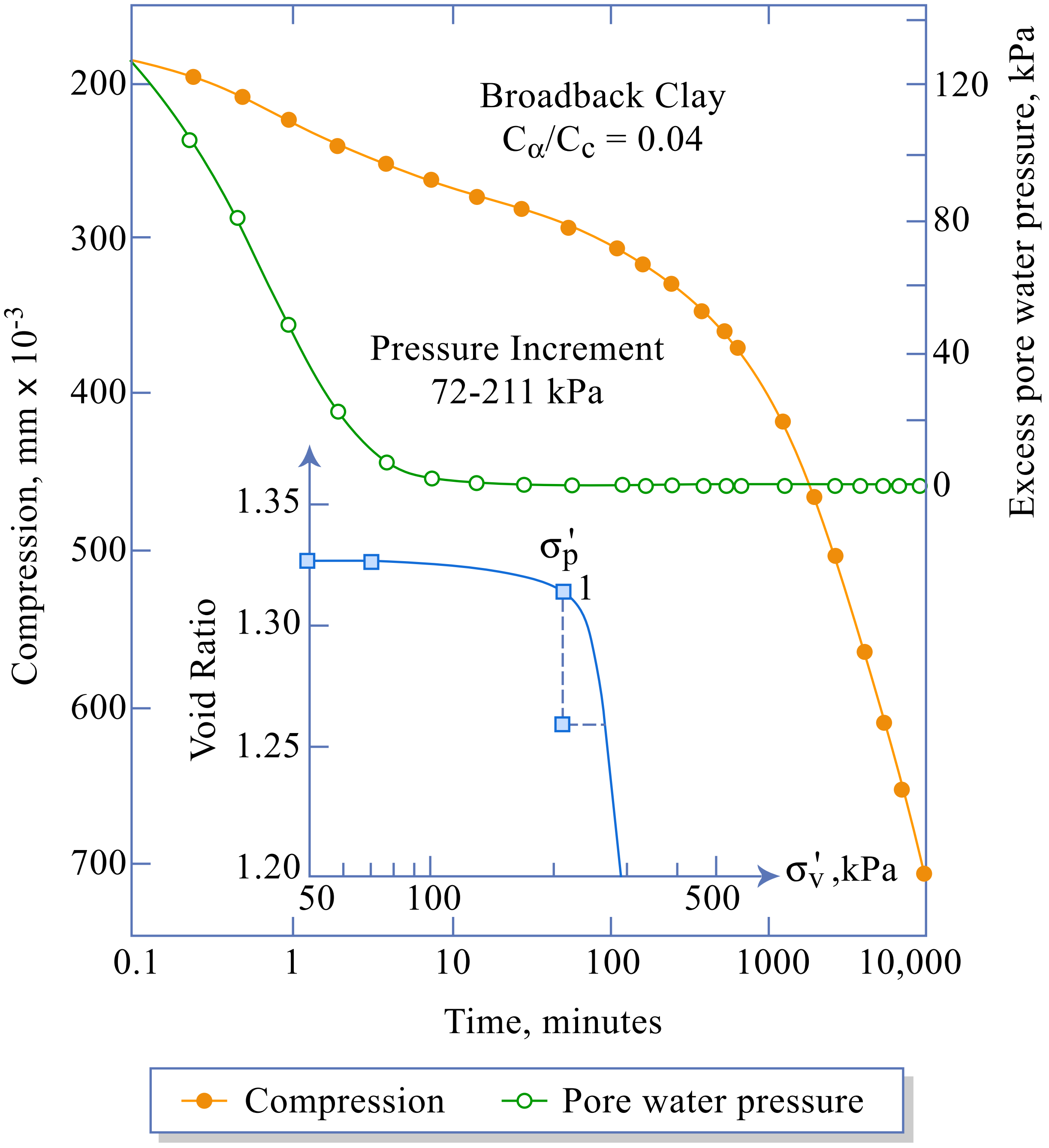

Figure by MIT OCW.

Adapted From Mesri & Castro (1987)

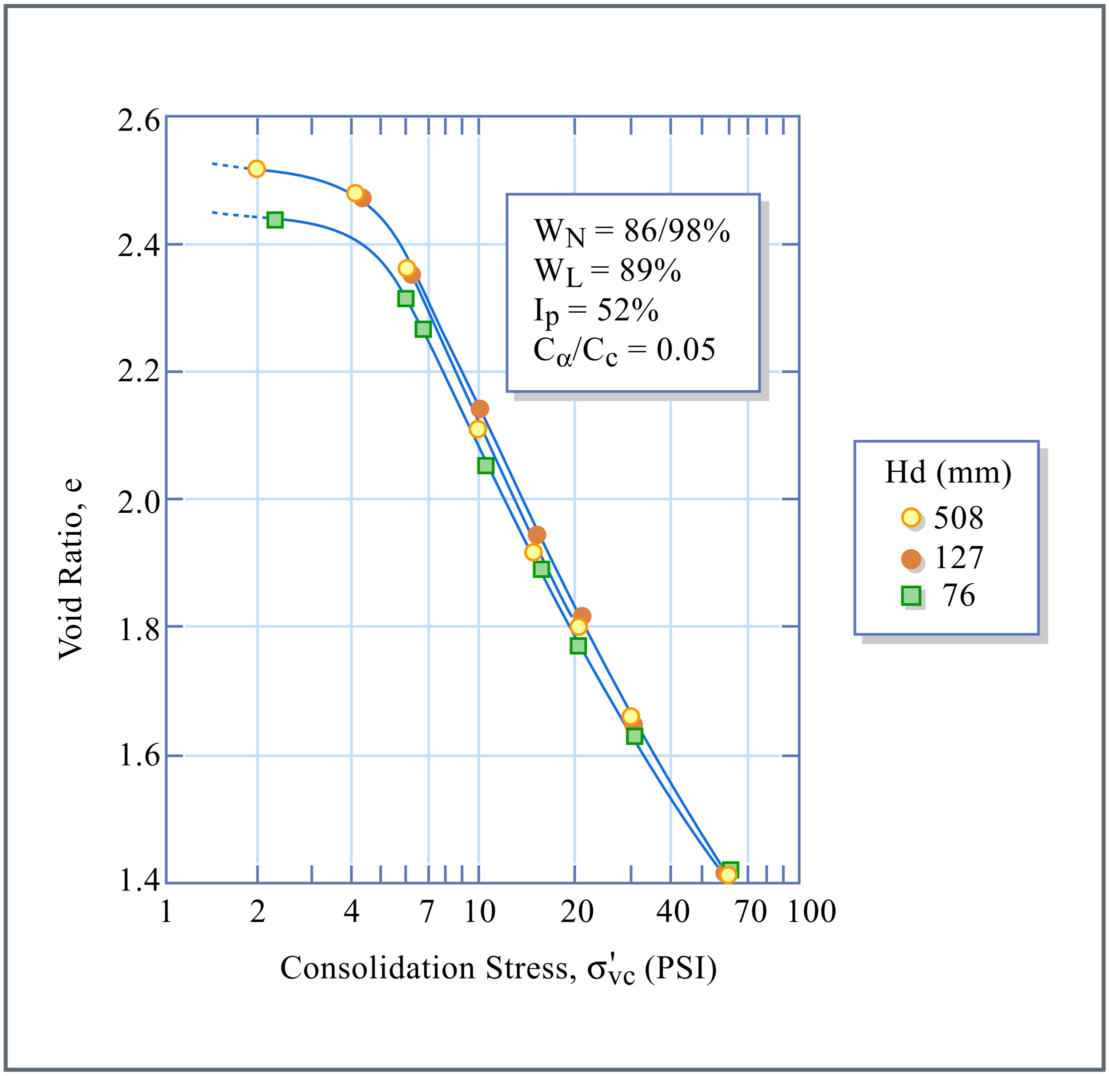

Figure by MIT OCW.

San Francisco Bay Mud from Mesri & Choi (1985) - 11th ICSMFE

$$\Delta e = \int_0^{t_p} \left[\left(\frac{\partial e}{\partial \sigma'} \right)_t \frac{d\sigma'}{dt} + \left(\frac{\partial e}{\partial t} \right)_{\sigma'} \right] dt + \int_{t_p}^{t} \left(\frac{\partial e}{\partial t} \right)_{\sigma'} dt$$

Clay	w_N(%)	w_L(%)	I_p(%)	k_o (cm/sec)	C_k	$C_{\alpha e}/C_c$
St. Alban	39-57	31	13	3×10^{-7}	0.51	0.024
Louiseville	64-71	65	37	6×10^{-8}	0.87	0.03
SFBM	86-98	89	52	3×10^{-7}	0.77	0.05

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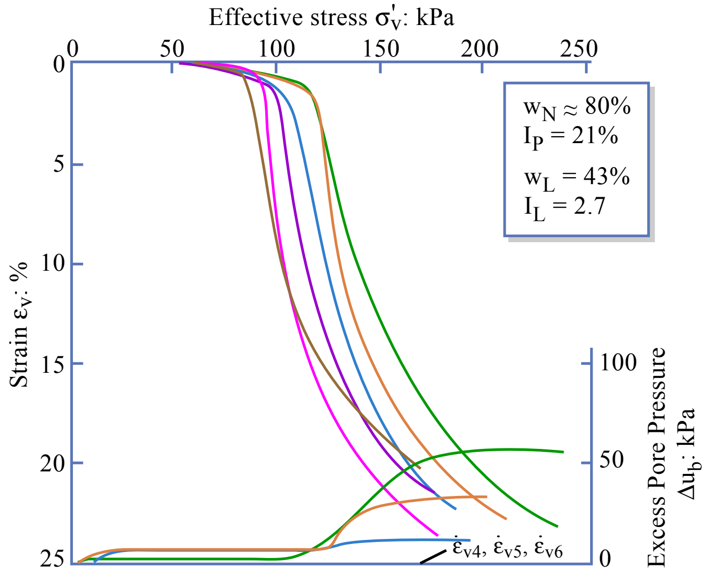
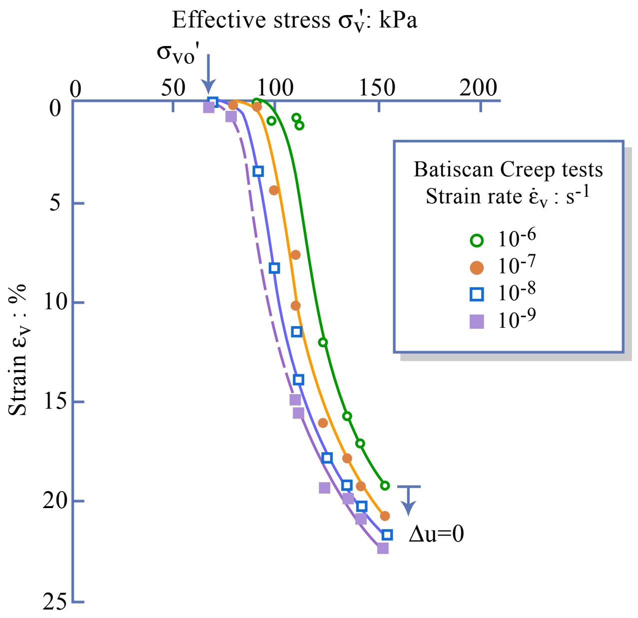
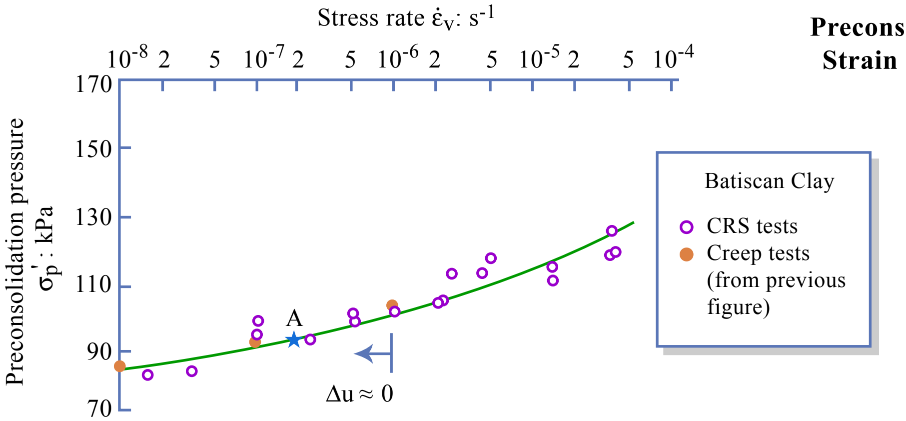
3/90



Typical CRS oedometer tests on Batiscan Clay



Constant $\dot\varepsilon_v$ Curves Deduced from Creep Tests on Batiscan Clay



Variation in Preconsolidation Pressure with Strain Rate for Batiscan Clay

Figure by MIT OCW.

C1

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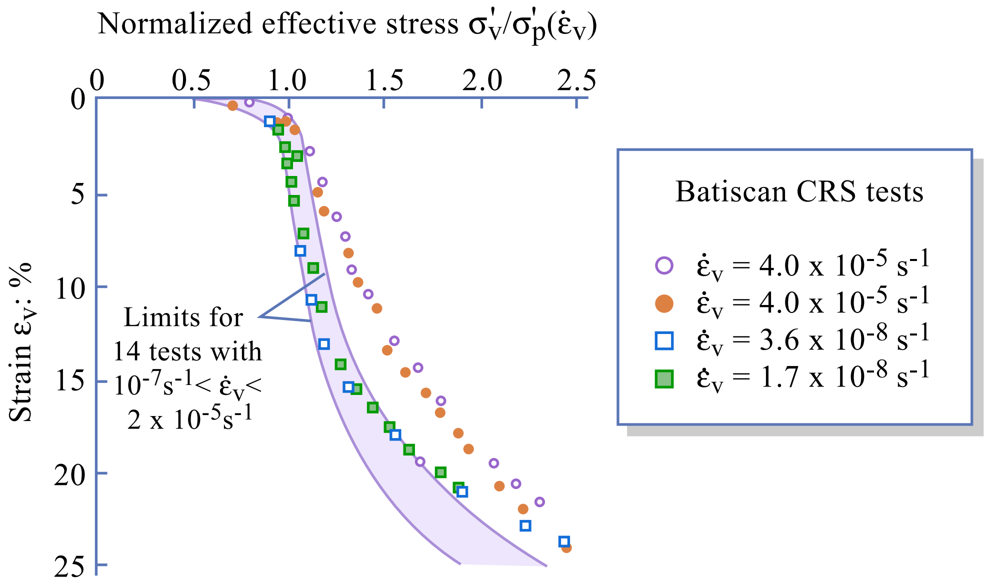
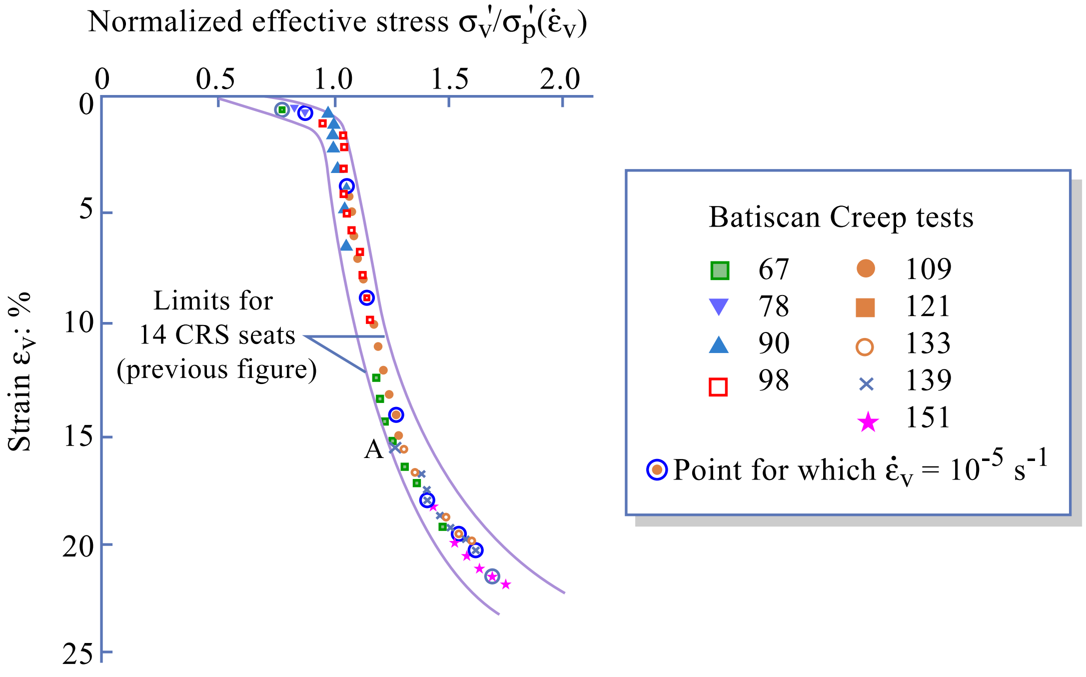
3/90



Normalized effective stress-strain relationship deduced from CRS oedometer tests on Batiscan clay

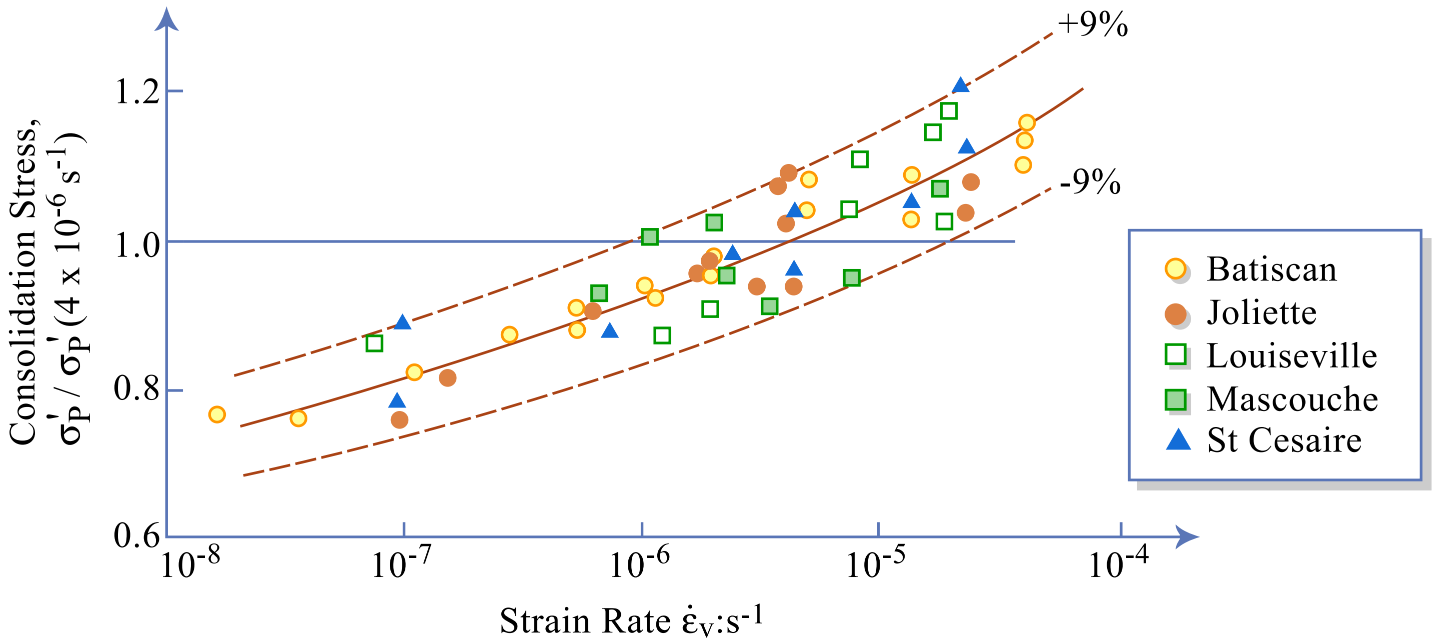


Normalized effective stress-strain relationship deduced from creep oedometer tests on Batiscan clay

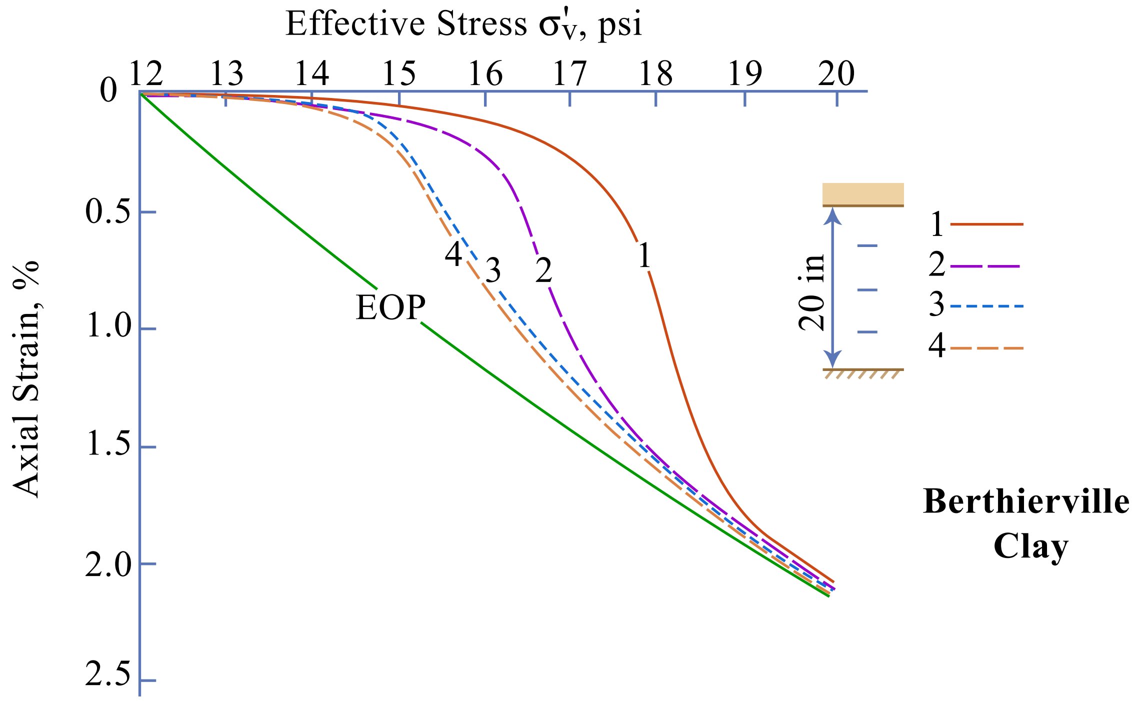
Figure by MIT OCW.

C1

CCL 3/86 1.322
3/90



Normalized Preconsolidation Pressure-Strain Rate Relationship for Champlain Sea Clays



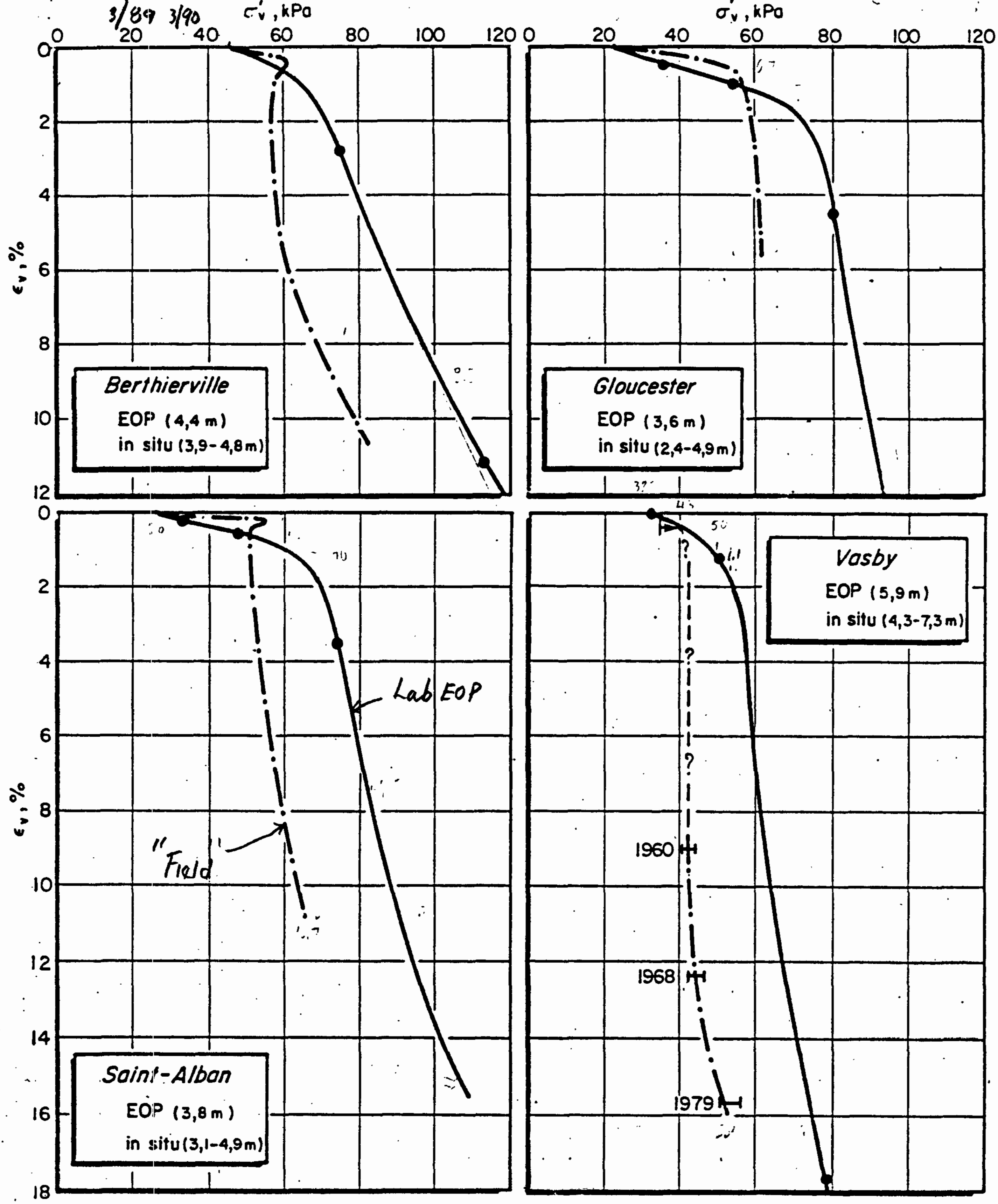
Berthierville Clay

Figure by MIT OCW.

Adapted from Berthierville Clay
Data from Mesri & Feng (1986)
Geotechnique Closure to Leroueil et al (1985)
Geol. V35 No 2

C2

CCL 3/86 1.322
3/89 3/90



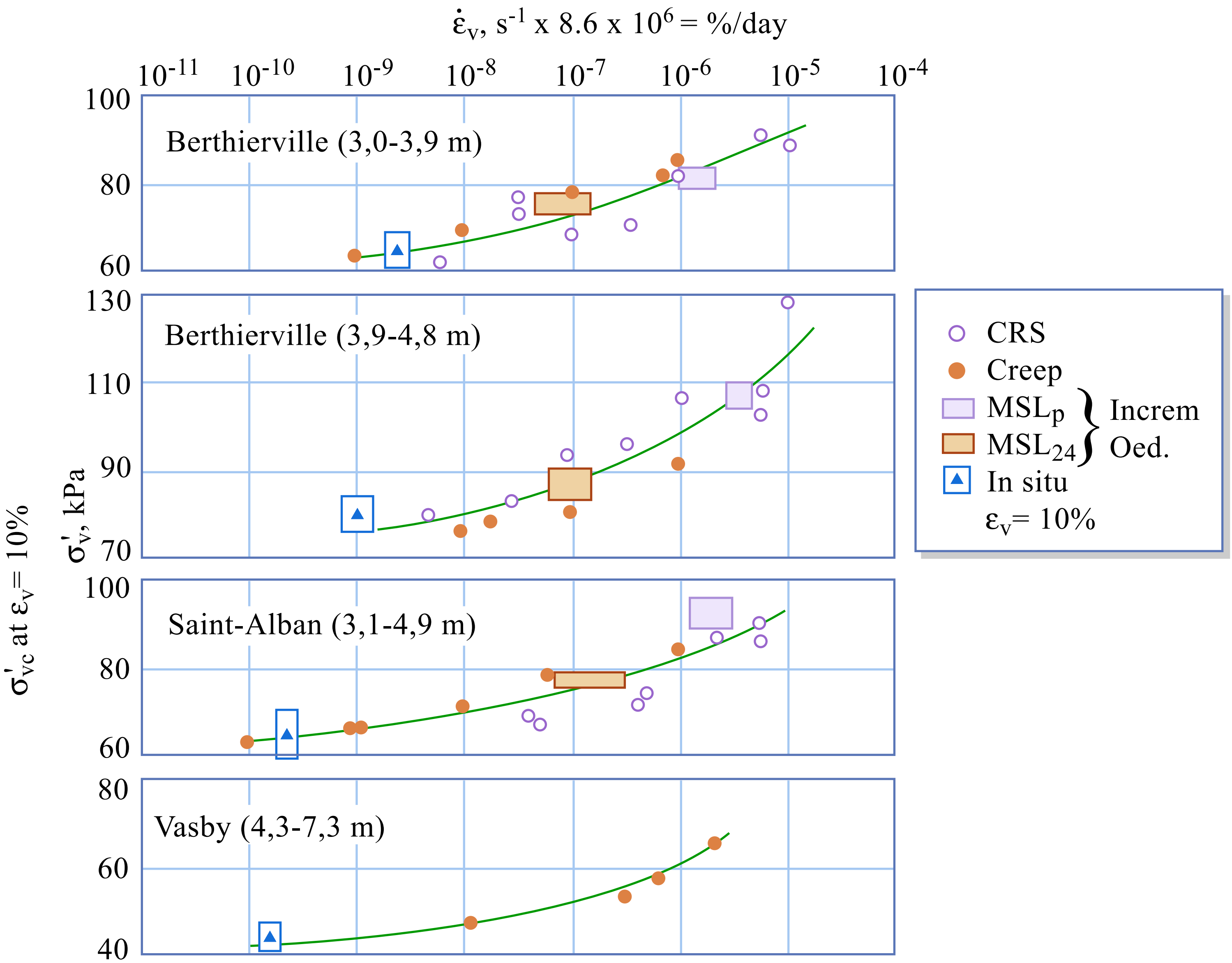
From Leroueil (1986) Seminar at MIT

Detailed presentation by Kabbaj, Tavenas & Leroueil (1988), Géotechnique 38(1), 83-100

17

C3

Field Data Used to Support Hypothesis B



Effective stress-strain rate relations observed in laboratory and in situ at a vertical strain of 10%. (after Leroueil et al., 1986-b)

Figure by MIT OCW.

CCL 3/13/90 1.322 Set D

3/96

REDUCTION IN C_α WITH SURCHARGE

1. CCL Methodology (See Fig. 1 = D2)

Eq. 1 $\rho_s = \Sigma (H_i C_\alpha' \log t/t_s)$, where H_i = original layer thickness

- Times: $t = 0$ when final staged surcharge is applied
  - t_p = end of primary consolidation under σ_{vs}'
  - t_r = removal of surcharge, i.e., from σ_{vs}' to σ_{vf}'
  - t_s = start of secondary compression under final stress, σ_{vf}'
- Stresses: σ_{vs}' = surcharge stress at center of layer
  - σ_p' = equivalent preconsolidation pressure $= \sigma_{vs}' \, (t_r/t_p)^{C_\alpha/C_R}$ (for $t_r > t_p$)
  - σ_{vf}' = final stress at center of layer
- Amount of Surcharge = AOS = $(\sigma_{vs}' - \sigma_{vf}')/\sigma_{vf}' = \sigma_{vs}'/\sigma_{vf}' - 1$
- Adjusted Amt. of Surcharge = AAOS = $(\sigma_p' - \sigma_{vf}')/\sigma_{vf}' = \sigma_p'/\sigma_{vf}' - 1$
- Rate of Secondary Compression ($d\varepsilon_v/d\log t$) : C_α for normally consolidated soil
  - C_α' for overconsolidated soil after surcharging

2. Experimental Results

- See Fig. 2 (D3) for CCL 1st summary of data using AOS, i.e., did not consider increased σ_p' for $t_r > t_p$
- See Fig. 3 (D4) for CCL more complete summary (plus reinterpretation of original data) using Adjusted AOS → more consistent relationship
- ~~See D5 for data from Mesri (1986) on MEC (more "precise" but complex treatment)~~

3. Other

- ~~See D6 for Johnson (1970) equation & explanation~~
- ~~See D7 for Fig. 11 of Ladd (1987) "Precompression Notes" giving former C_α'/C_α vs AOS data ("old" data before developed Fig. 3)~~

D1

CCL 1/1-2/89 GZA
3/7/89 Stopen
6/89 12/89 1.322

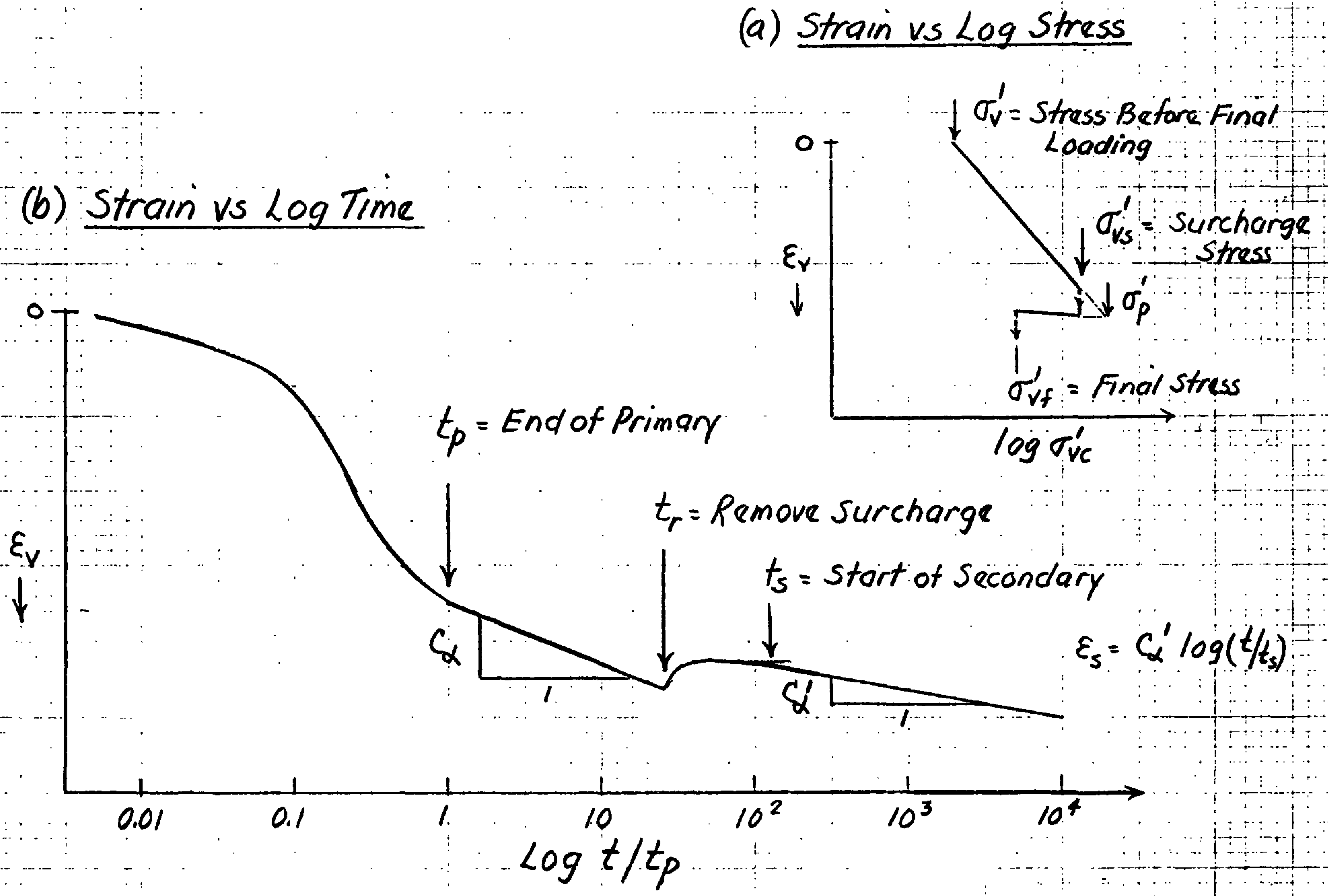
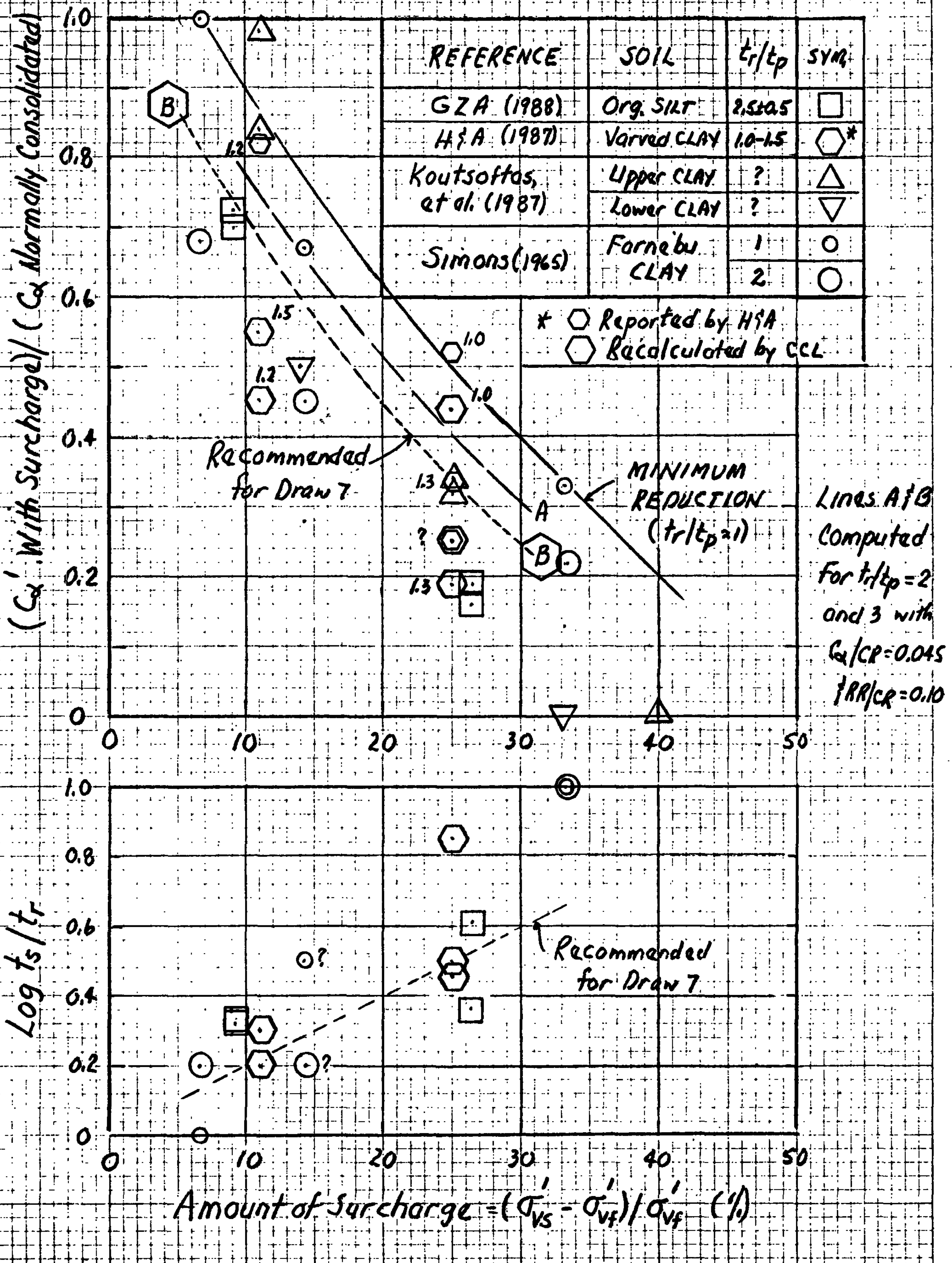


Fig. 1 Effect of Surcharge on Secondary Compression : Basic Concepts

CCL 12/30/88 GZA 3/89 1.322
3/7/89 Stopen

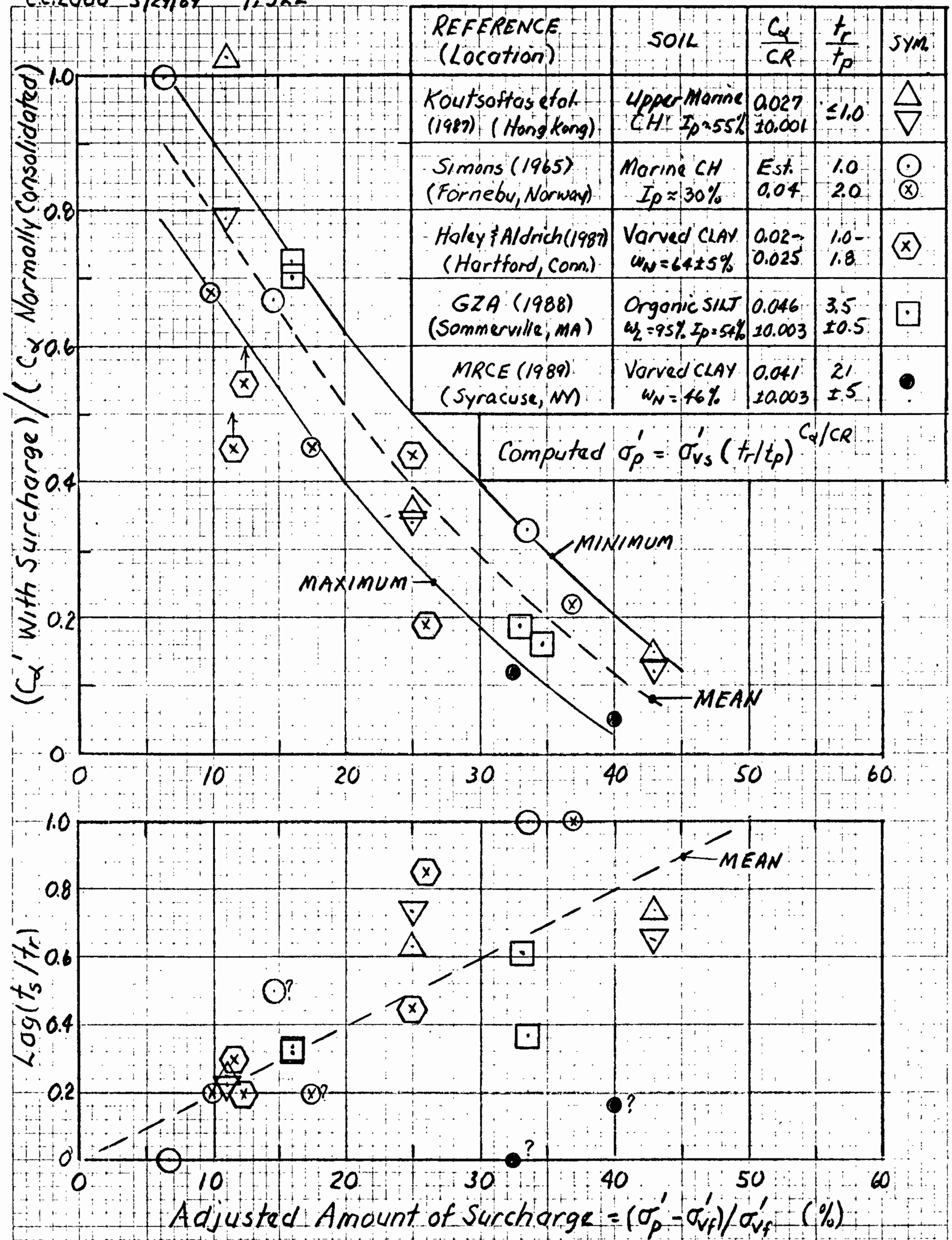


REFERENCE	SOIL	t_r/t_p	SYM
GZA (1988)	Org. SILT	2.5 to 3.5	□
H&A (1987)	Varved CLAY	1.0-1.5	⬡*
Koutsoftas, et al. (1987)	Upper CLAY	?	△
	Lower CLAY	?	▽
Simons (1965)	Fornebu CLAY	1	○
		2	◯

* ⬡ Reported by H&A
⬡ Recalculated by CCL

Fig. 2 Reduction in Rate of Secondary Compression Due to Surcharging

C.C.Ladd 5/29/89 1,322



REFERENCE (Location)	SOIL	$\frac{C_\alpha}{CR}$	$\frac{t_r}{t_p}$	SYM.
Koutsoftas et al. (1987) (Hong Kong)	Upper Marine CH $I_p \approx 55\%$	0.027 ±0.001	≤1.0	△ ▽
Simons (1965) (Fornebu, Norway)	Marine CH $I_p \approx 30\%$	Est. 0.04	1.0 2.0	⊙ ⊗
Haley & Aldrich (1987) (Hartford, Conn.)	Varved CLAY $w_N = 64 \pm 5\%$	0.02–0.025	1.0–1.8	⬡
GZA (1988) (Sommerville, MA)	Organic SILT $w_L = 95\%$ $I_p = 54\%$	0.046 ±0.003	3.5 ±0.5	⊡
MRCE (1989) (Syracuse, NY)	Varved CLAY $w_N = 46\%$	0.041 ±0.003	21 ±5	●

Computed $\sigma_p' = \sigma_{vs}' (t_r/t_p)^{C_\alpha/CR}$

Fig. 3 Reduction in Rate of Secondary Compression Due To Surcharging (Data adjusted to unloading at $t_r = t_p$)

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SETTLEMENT OF LARGE MAT ON DEEP COMPRESSIBLE SOIL

ASCE Settlement '94

James P. Stewart,[1] Hugh S. Lacy,[2] Members, ASCE,
and Charles C. Ladd,[3] Fellow, ASCE

Plan area = 65,000 m² for 2-3 story shopping center with 6-story tower.
Design: On piles → floating with added basement

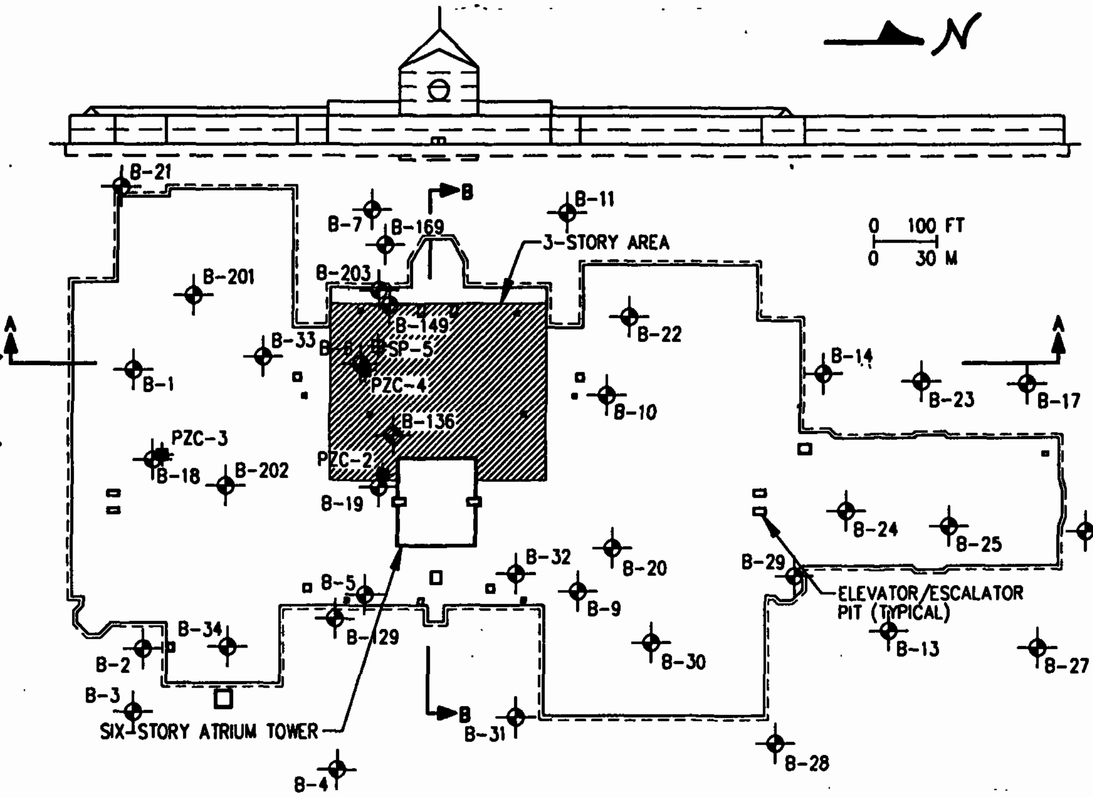


FIG. 1. Building Plan, Elevation and Selected Borings

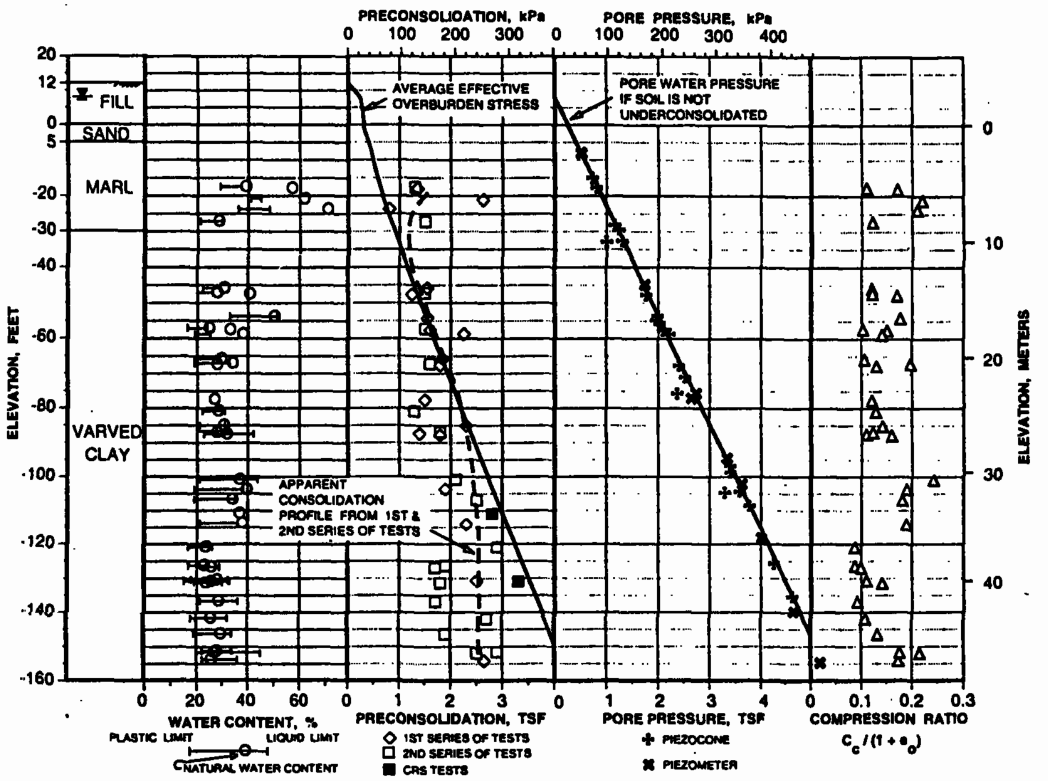
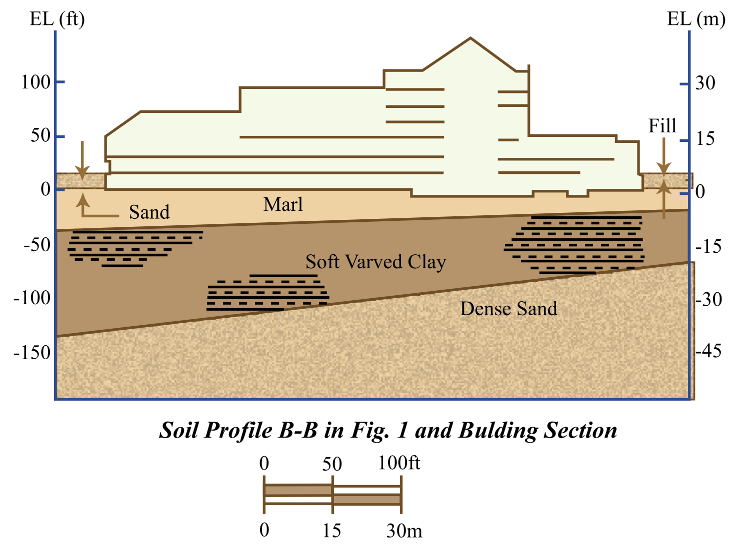


FIG. 4. Soil Properties Profile

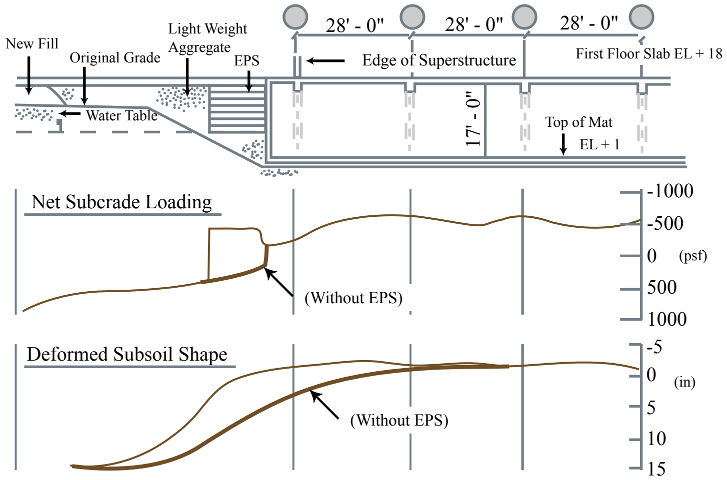
E1



Soil Profile B-B in Fig. 1 and Building Section

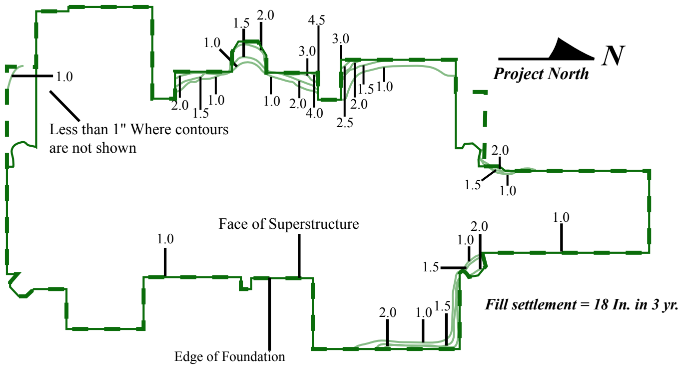
Large variation in clay thickness across site

Complex prediction of P_s [illegible]



Edge Conditions with predicted stress and deformations.

Extremely large variations in net stress along edge of building → EPS & lightweight fill



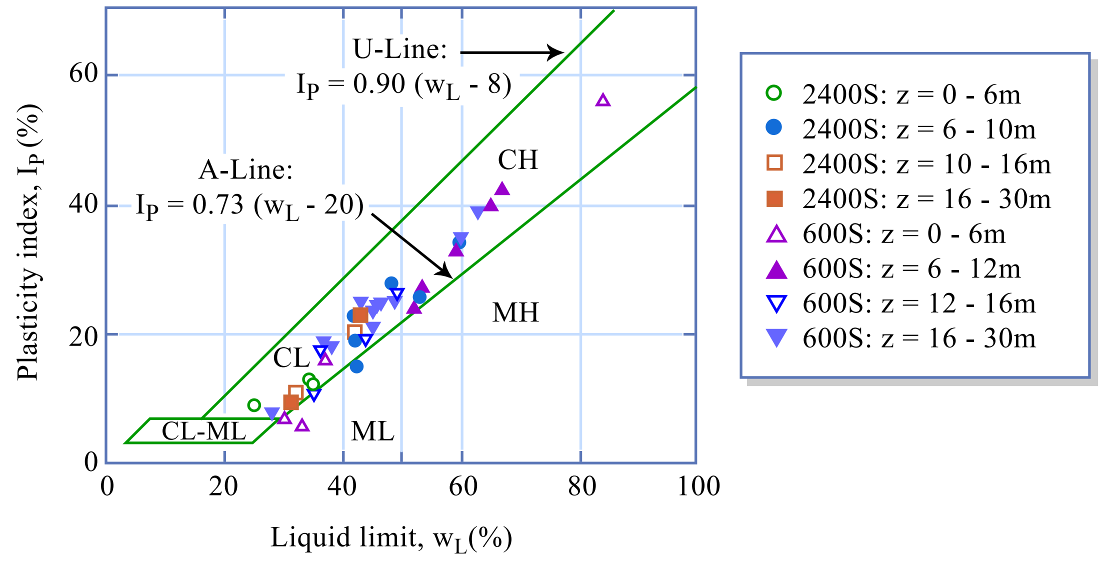
Note: Contours in inches. (1 inch = 25.4 mm)

Building settlement plan, January 1993

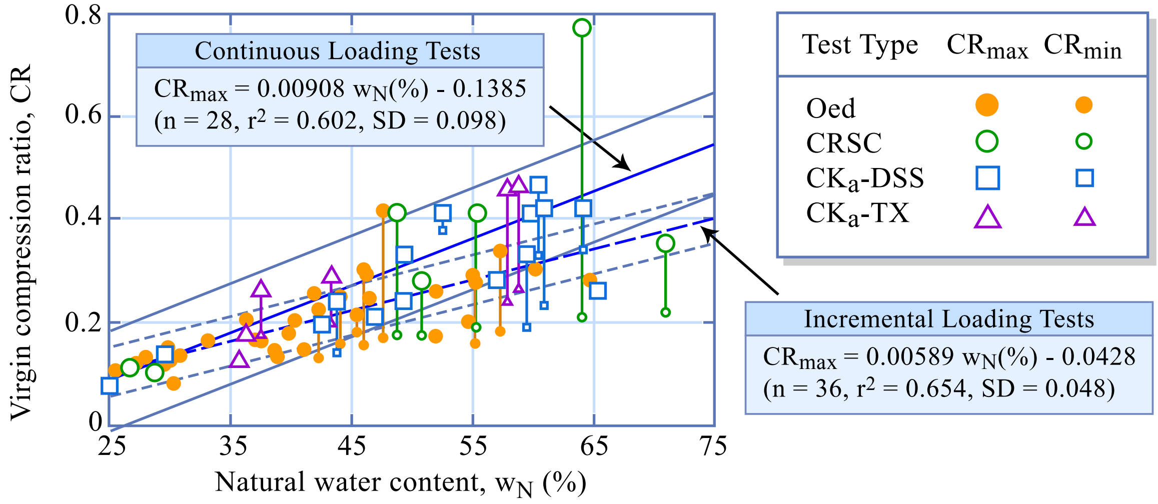
Measured building settlements 2.1 years after mat construction.

(Jacks in all columns)

Figures by MIT OCW.



Arthur Casagrande's Plasticity Chart for Cohesive Soils at 2400S & 600S

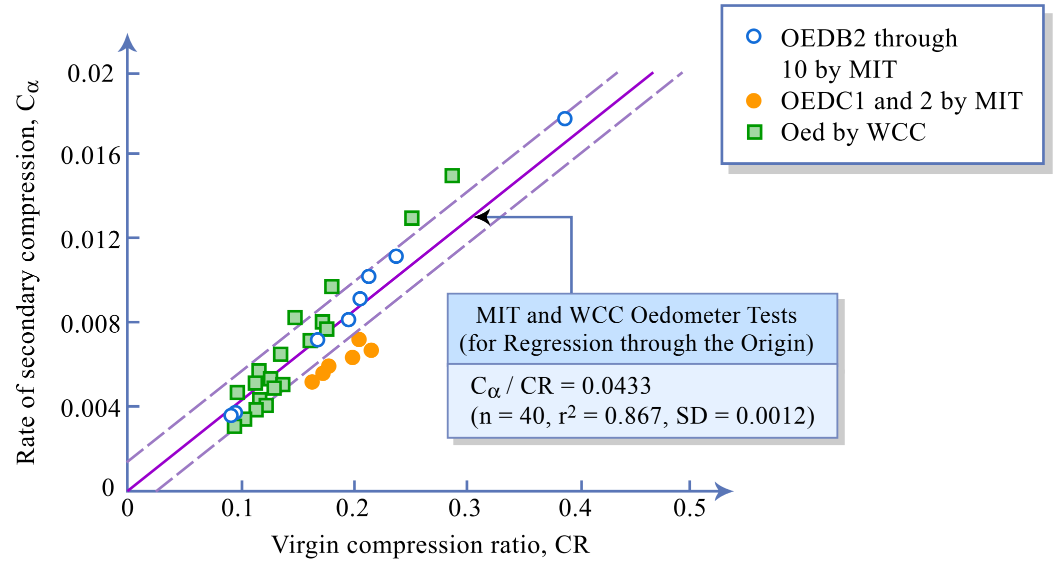


Virgin Compression Ratio vs. Natural water Content

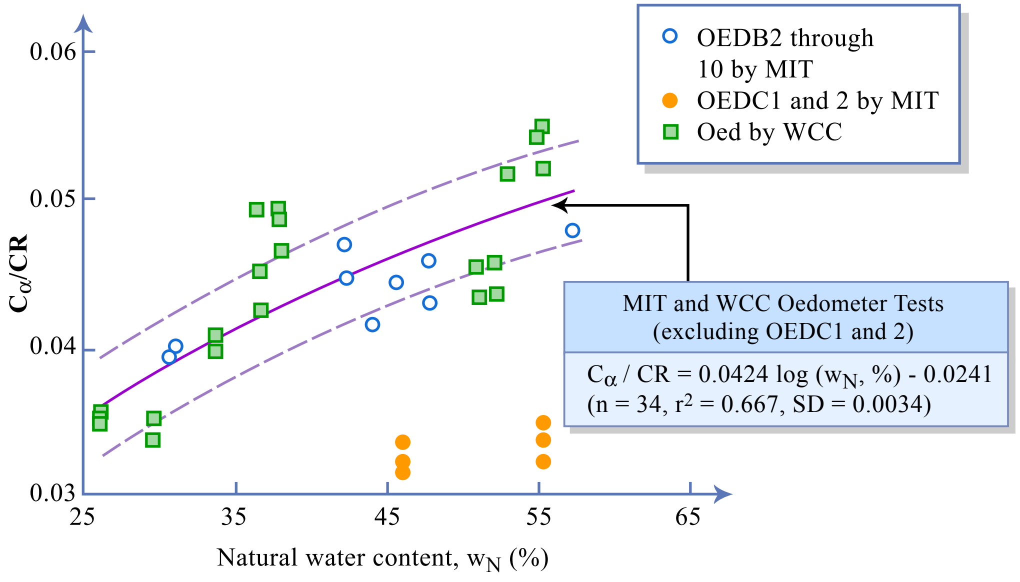
Figure by MIT OCW.

A

Cα vs CR →
mean = 0.043



Normally Consolidated Rate of Secondary Compression vs. Virgin Compression Ratio



C_α/CR vs. Natural Water Content

Figure by MIT OCW.

Cα/CR increases with increasing w_N (new finding?)

F2

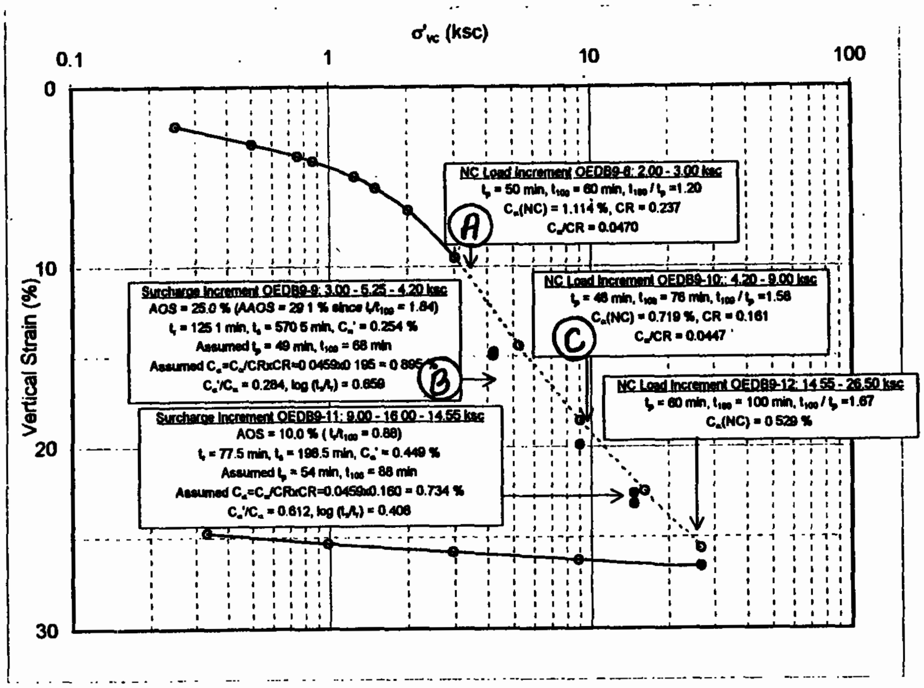
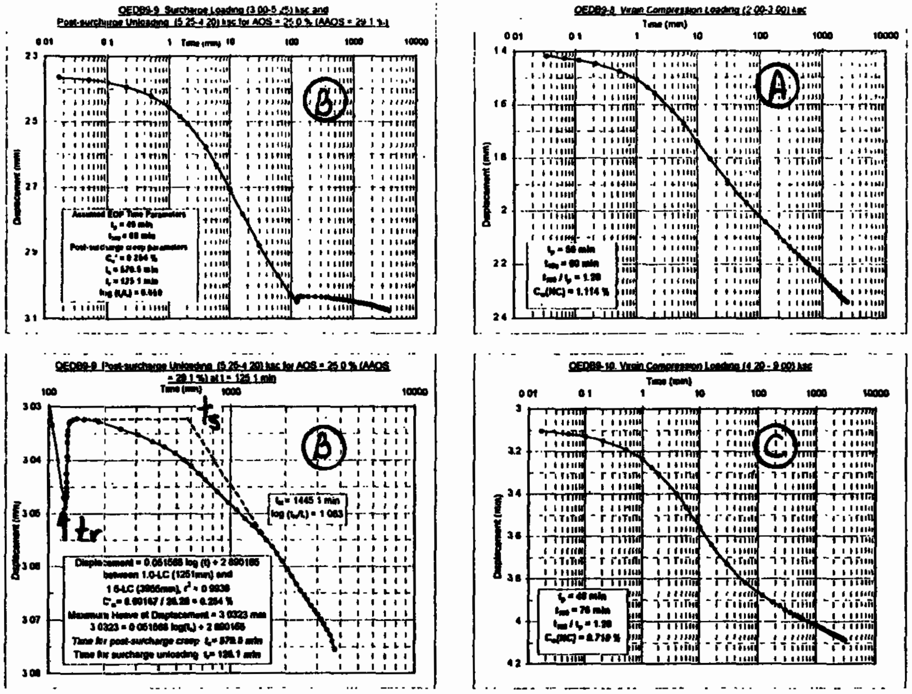


Figure 6.1: Compression Curve for OEDB9 Illustrating Information Obtained from Five Increments of a Type B Oedometer Test

Steps in Special Oedometer Test to Measure C_α/CR and Effect of Surcharging



Displacement vs. Log t Data

Figure 6.2: Compression - log t Curves for Surcharge Load Increment (OEDB9-9) and Normally Consolidated (without Surcharge) Load Increments (OEDB9-8 and OEDB9-10)

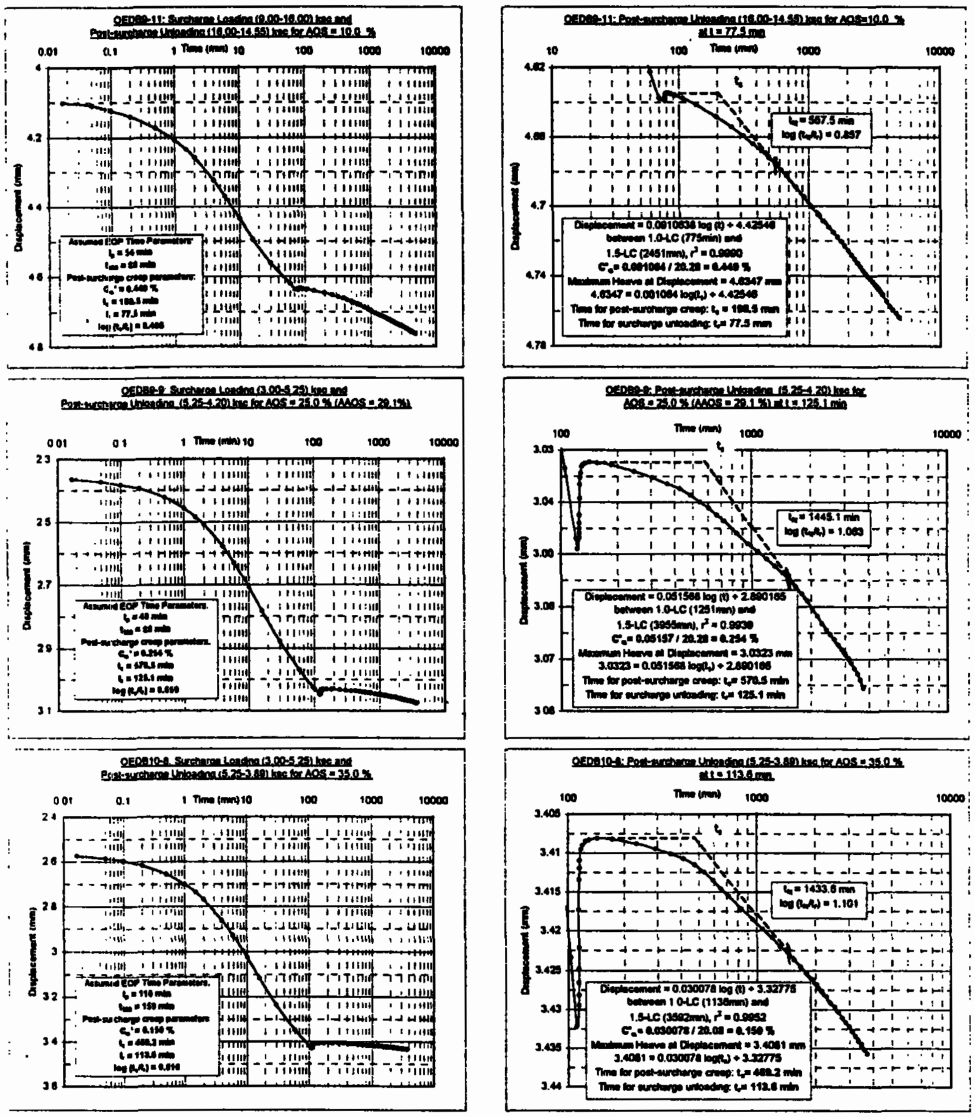


Figure 6.3: Non-linear Post-surcharge Creep Behavior at Low AOS = 10 %, Medium AOS = 25 % and High AOS = 35 %

Fitting Non-linear d vs log t with two lines:

#1: $\Delta d = 0 \rightarrow t = t_s$

#2: Secondary Comp. at reduced rate C_α' for $t > t_s$

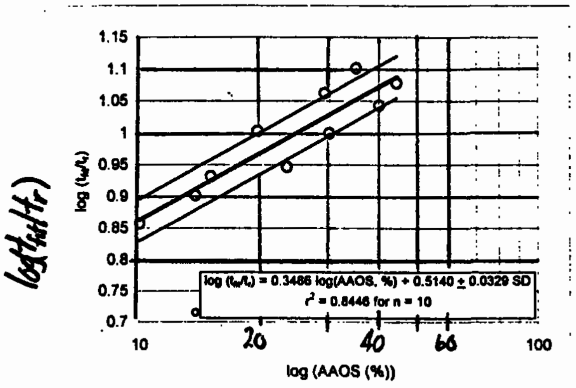


Figure 6.4: Correlation to Predict Time t_{fit} for the Settlement Predicted from Parameters using Ladd's Methodology to Match the Actual Settlement

Time for Predicted Creep to Catch up with Actual Data = t_{fit}

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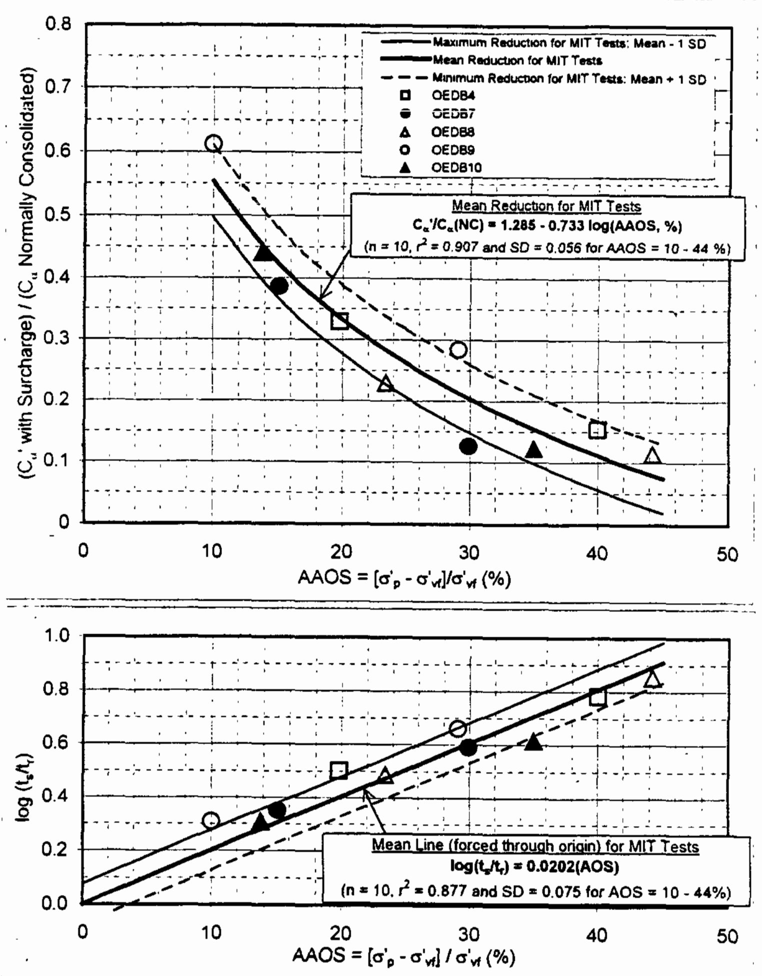

Figure 6.5a: Reduction in Rate of Secondary Compression due to Surcharge for MIT Data on Salt Lake City Clay

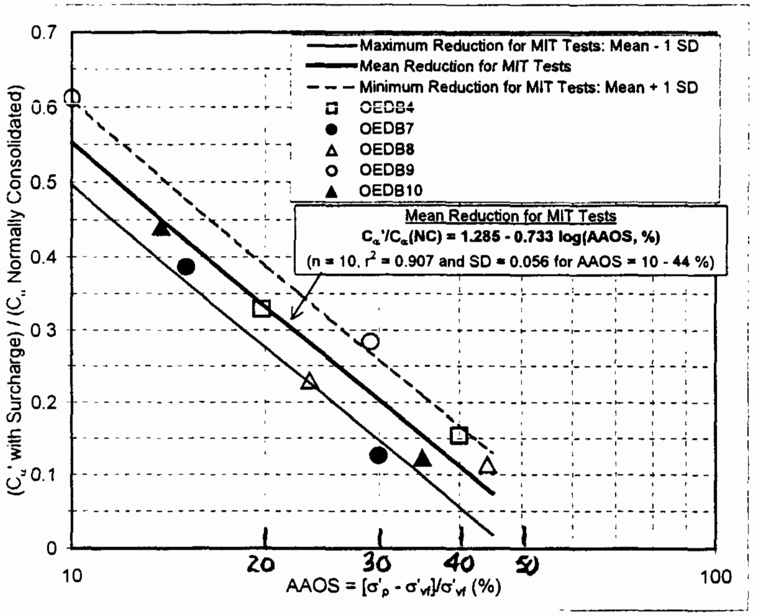

Figure 6.5b: Reduction in Rate of Secondary Compression due to Surcharge for MIT Data on Salt Lake City Clay

(vs log AAOS → linear relationship)

C_α'/C_α and $\log(t_s/t_r)$ vs AAOS for Salt Lake City Clays

F5

SYN (2/98)

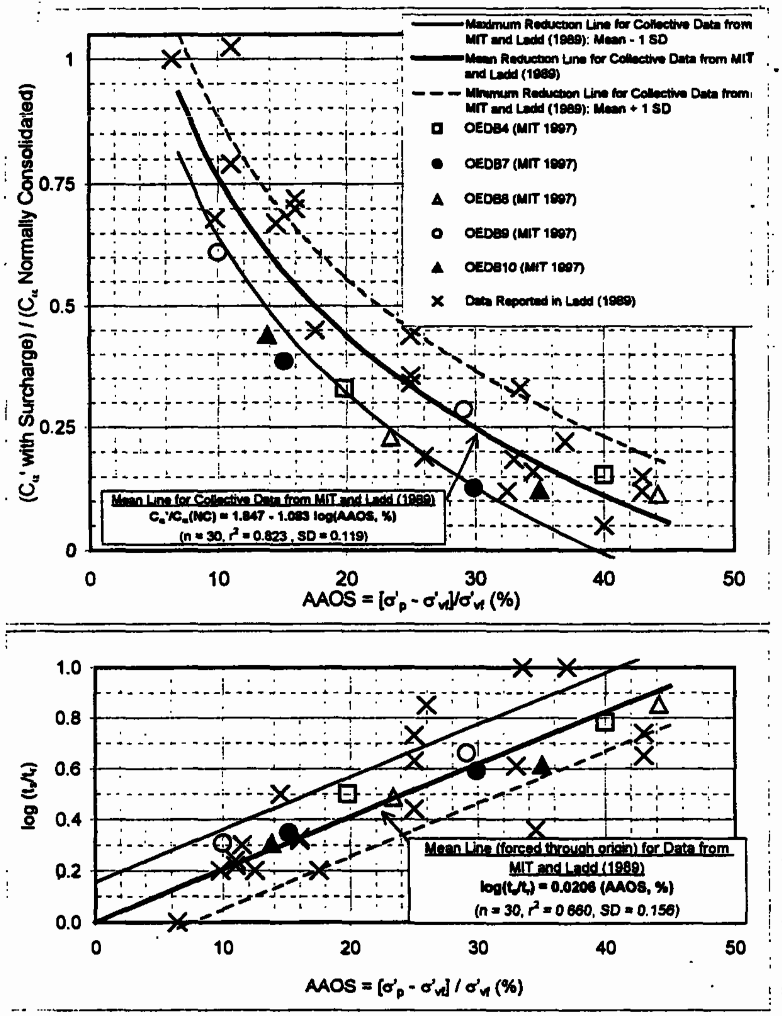

Figure 6.7a: Reduction in Rate of Secondary Compression due to Surcharge from MIT Data on SLC Clay and Ladd (1989)

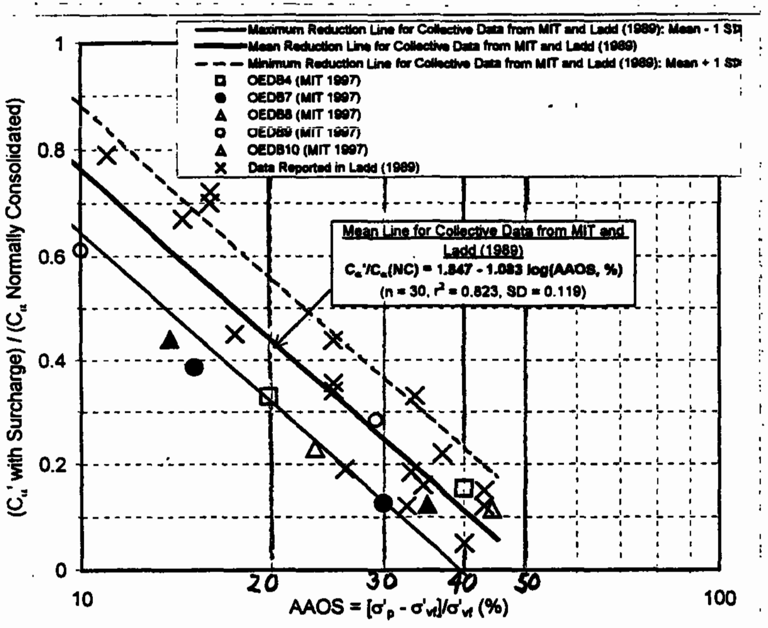

Figure 6.7b: Reduction in Rate of Secondary Compression due to Surcharge from MIT Data on SLC Clay and Ladd (1989)

$$\boxed{C_\alpha'/C_\alpha = 1.847 - 1.083 \log(AAOS, \%) \quad n = 30, \; SD = \pm 0.119}$$

C_α'/C_α and $\log(t_s/t_r)$ vs AAOS for Collective Data

F6