CCL 2/97 2/98 3/2/99 3/1/01 1.322 Consolidation Part II

1-D CONSOLIDATION: MAGNITUDE OF FINAL SETTLEMENT

(Note: Raplace $\bar{\sigma}$ with σ')

Page No.

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1-D CONSOLIDATION: MAGNITUDE OF FINAL SETTLEMENT

1. ROLE OF OEDOMETER (1-D Consolidation Test)

1.1 Objectives of Test - 5 items

1) σ'_p = yield stress
2) CR, RR, SR = compressibility
3) c_v → rate of primary consolidation
4) C_α = rate of secondary compression
5) $K_0 = \sigma'_{hc}/\sigma'_{vc}$ for $\varepsilon_h = 0$ (special projects, e.g., using FE w/ GSM)

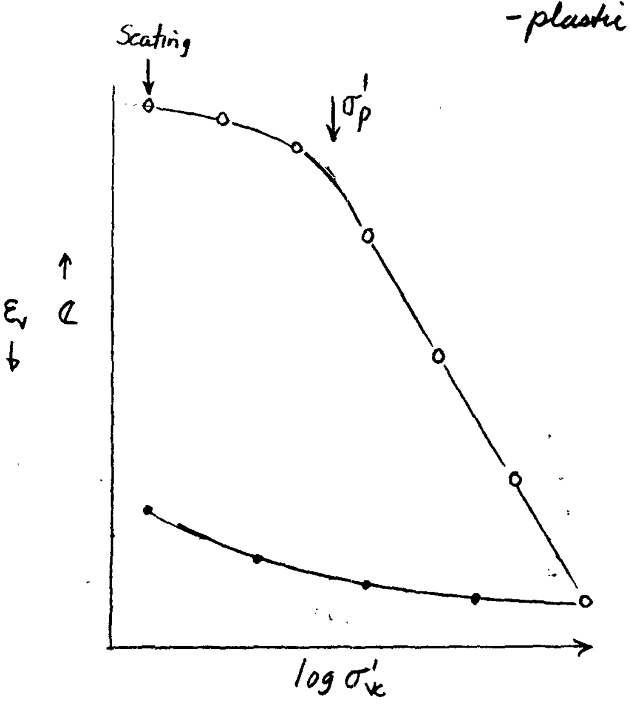
1.2 Std. Procedure - Incremental (ASTM D2435-90)

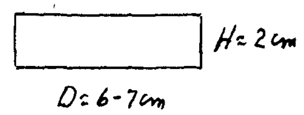
1) Seating $\sigma = 0.1$ atm. : when add water?

2) LIR = 1 (Standard)
When reduce? < a) b)

3) t_c = 24 hr. (Std) : How get EOP?

4) Misc -
- Max. stress to define VCL & σ'_p →
- S_i - always check
- Filter material - paper (cannot) - plastic





Why $D/H \geq 3$?

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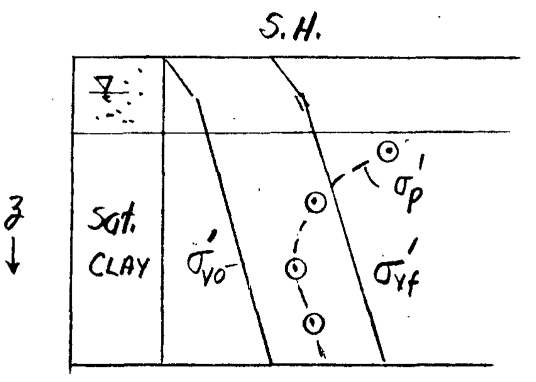
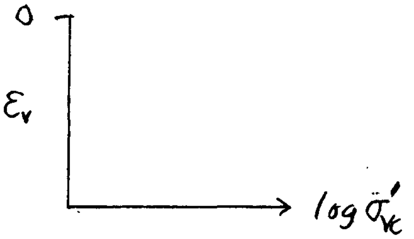
2, SETTLEMENT COMPUTATIONS

2.1 Problem



$RR = \frac{C_r}{1+e_o}$; $CR = \frac{C_c}{1+e_o}$

Have raw data from 4 oed. tests



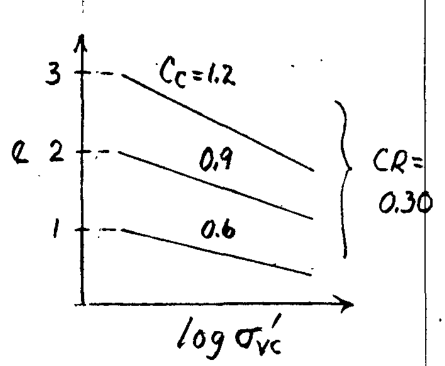
2.2 Questions (Ignoring effects of disturbance & creep)

1) Eqn for $\rho_{cf} = \Sigma H_i (RR \log \bar{\sigma}_p/\bar{\sigma}_{vo} + CR \log \bar{\sigma}_{vf}/\bar{\sigma}_p)$

2) How evaluate parameters?

3) Most important variable $= \sigma'_p$

2.3 Discussion



1) Plotting e (research) or ε (practice) vs $\log \sigma'_{vc}$

2) Typical values CR
(soft → med. stiff, low-mod. S_t)

CL → 0.25 ±0.1
CH → 0.35 ±0.1
} for non-structured → const. CR

3) Typical values of RR/CR ≤ 0.1-0.2 (unless significant "structure" = S-curve)

a) Collective evaluation of RR & CR

b) Supplemental information → σ'_p profile

(1) Geology → help explain/predict trends

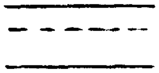
(2) In situ testing → spatial variability (Mini-problem)

3. MECHANISMS OF VOLUME CHANGE (Part A, V)

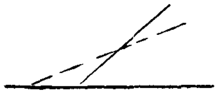
Rebound

1) Elastic particle deformation:
especially "bending" platy particles

2) Change in "closest" spacing (≈ constant orientation)



3) Change particle orientation & sliding at contacts



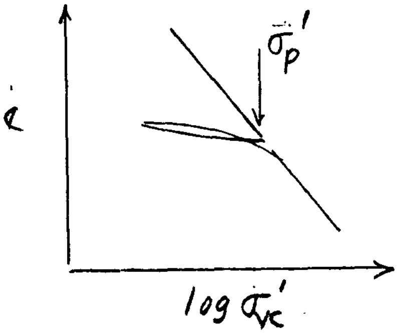
4) "Particle" crushing
- Clay floccs & aggregates
- Sand

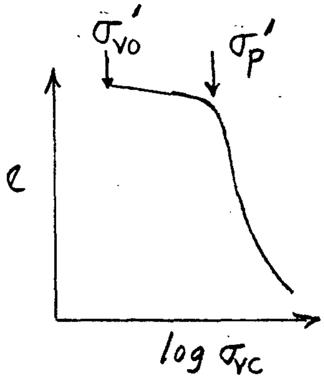
4. MECHANISMS CAUSING PRECONSOLIDATION PRESSURE

4.1 Physical Significance

$$\bar{\sigma}_p \equiv \sigma'_p \equiv \bar{\sigma}_{vm} \equiv P'_c$$

Yield Stress for 1-D loading separating
"elastic" behavior - small strains & ≈ recoverable
vs "plastic" behavior - large strains, mostly non-recoverable





4.2 *"Four" Principal Mechanisms*

TABLE V SF '85 p66

Preconsolidation Pressure Mechanisms (For Horizontal Deposits with Geostatic Stresses)

Category	Description	Stress History Profile	In situ Stress Condition	Remarks / References
A) Mechanical One Dimensional	1) Changes in total vertical stress (overburden, glaciers, etc.) 2) Changes in pore pressure (water table, seepage conditions, etc.)	Uniform with constant $\sigma'_p - \sigma'_{vo}$ (except with seepage)	K_o, but value at given OCR varies for reload vs. unload	Most obvious and easiest to identify
B) Desiccation	1) Drying due to evaporation vegetation, etc. 2) Drying due to freezing	Often highly erratic	Can deviate from K_o, e.g. isotropic capillary stresses	Drying crusts found at surface of most land deposits; can be at depth within deltaic deposits
C) Drained Creep (Aging)	1) Long term secondary compression	Uniform with constant σ'_p / σ'_{vo}	K_o, but not necessarily normally consolidated value	Leonards and Altschaeffl (1964); Bjerrum (1967)
D) Physico-Chemical	1) Natural cementation due to carbonates, silica, etc. 2) Other causes of bonding due to ion exchange, thixotropy, "weathering" etc.	Not Uniform	No Information	Poorly understood and often difficult to prove. Very pronounced in eastern Canadian clays, e.g. Sangrey (1972), Bjerrum (1973), Quigley (1980)

4.3 "*Mechanical*" $\Delta\sigma' = \Delta\sigma - \Delta u$

a) $\Delta\sigma$

Constant

$(\sigma'_p - \sigma'_{vo})$ σ'_p/σ'_{vo} Erratic

1) Overburden
2) Prior structures
3) Glaciation
4) Waves - $\Delta\tau$ (Madsen, 1978 geot)

NOTE: Also review 1.361 Notes Part IV-4

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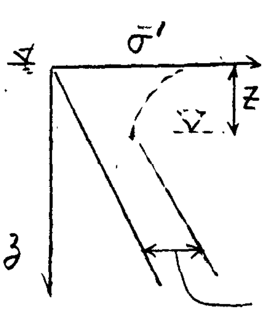
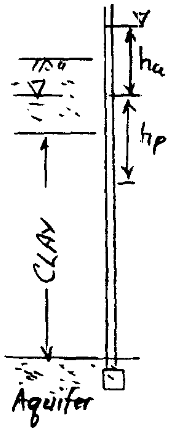
<u>$(\bar{\sigma}_p' - \bar{\sigma}_{vo}')$</u> <u>$\bar{\sigma}_p'/\bar{\sigma}_{vo}'$</u> <u>Erratic</u>

b) Δu at Boundaries

1) Δ Water Table

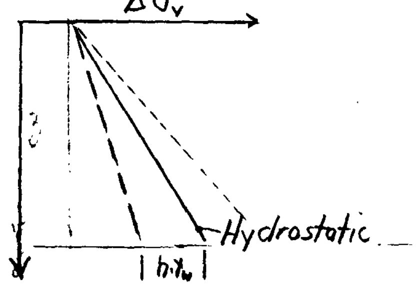


$\Delta\bar{\sigma}' = Z\gamma_w$ if $\bar{U} \to 100\%$
$\{$ $S_r \approx 100\%$ (within crust)



b) Artesian -- --

Pumping -----



$$\boxed{\Delta\bar{\sigma}_v' = 3(\gamma_b \pm j = i\gamma_w)}$$

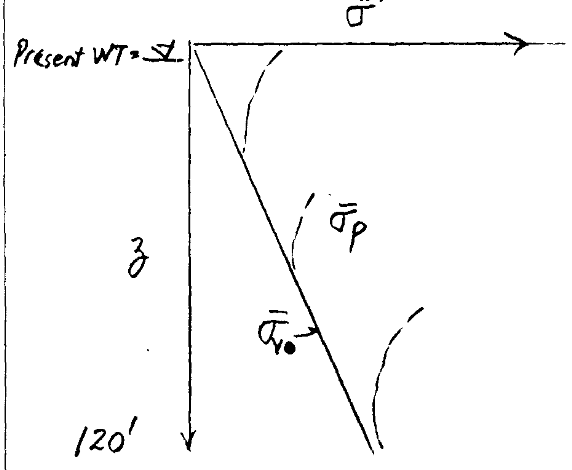
- Mexico City, Houston, Tokyo, Taipei, Bangkok

4.4 <u>Desiccation</u> (Drying crust)

1) Evaporation, vegetation, etc.
1 is very significant (esp. trees) } changes during seasons within "active" zone. Can reach 10±5 m!

2) Frost

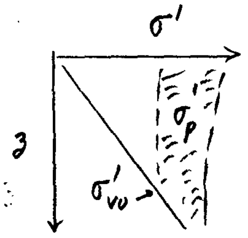
- Both can → v. high "soil suction"
- K_o or not



- Observed deltaic flood plain, e.g. Mississippi River.

How explain?

- Tidal mud flat deposits (Holocene)



How get OC?

See Kenney (1964) p5a & b

CCL 2/94 1.322 p.5a

SEA-LEVEL MOVEMENTS AND THE GEOLOGIC HISTORIES OF THE POST-GLACIAL MARINE SOILS AT BOSTON, NICOLET, OTTAWA AND OSLO

Geotechnique (1964)
14(3) 203-230

by

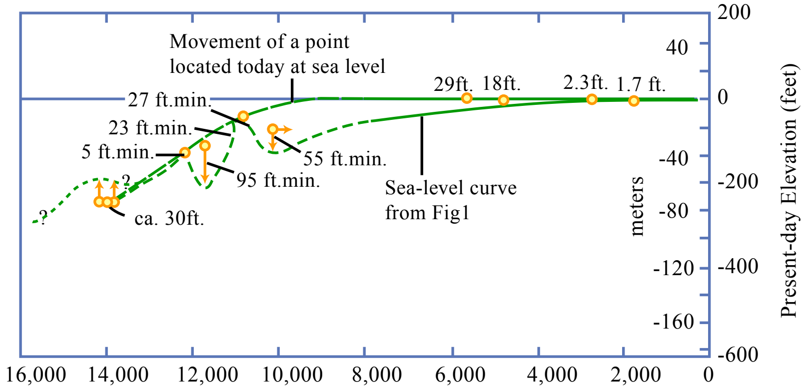
T. C. KENNEY*

SYNOPSIS

The Paper is divided into two separate parts; the first part deals with eustatic sea-level movements which have occurred during the past 20,000 years, and the second part concerns the geologic history of marine soil deposits at Boston, Nicolet, Ottawa, and Oslo.

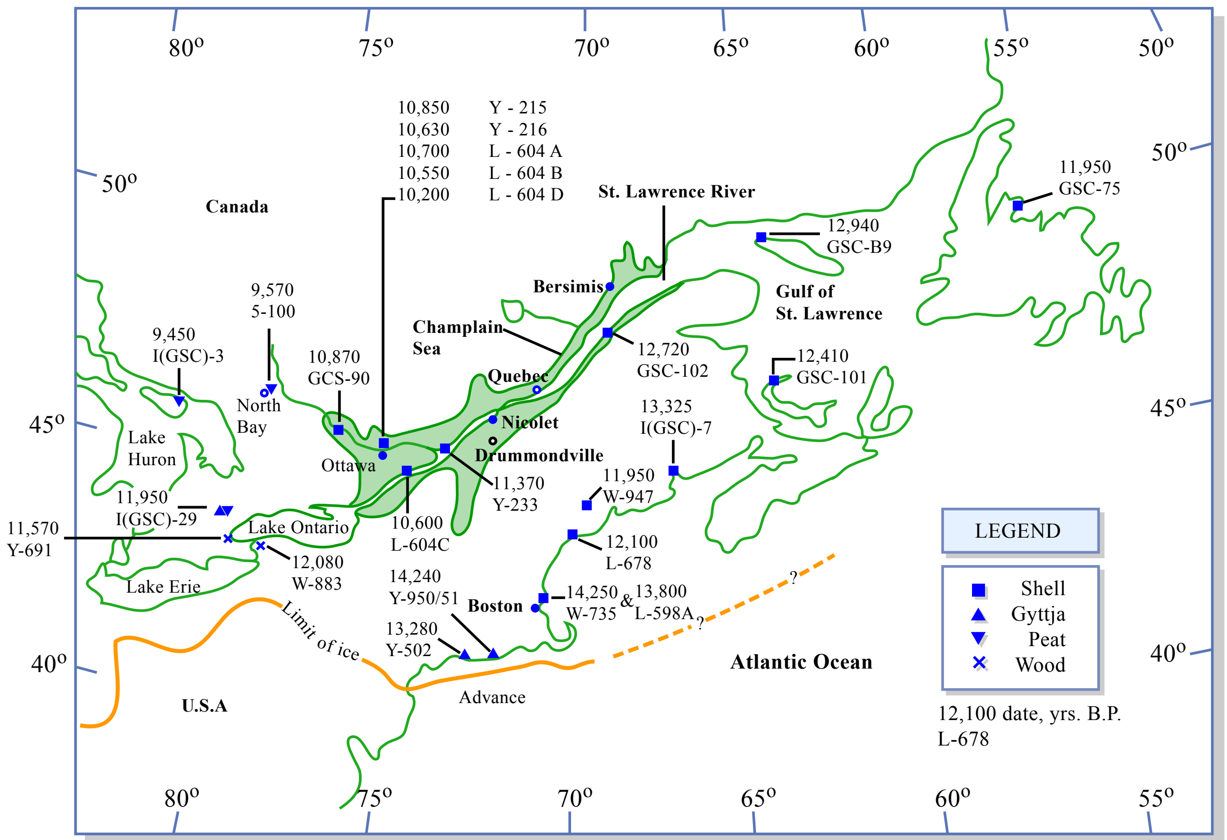
Eustatic sea-level movements are determined by synthesizing direct and indirect evidence concerning sea-level movements. Direct evidence consists of the ages and elevations of marine fossils and other materials, and elevations and ages of deposition and erosion surfaces which were controlled by sea-level movements. Indirect evidence consists of the dates of climate and temperature changes and the dates of major activity of the continental glaciers. From these data a provisional sea-level movement curve has been drawn for the period extending over the past 20,000 years.

Geologic histories of marine soil deposits are dependent on, among other things, sea-level and local crustal movements. For each of the above mentioned sites, time curves of sea-level and crustal movements are drawn, and from a study of these curves and other geological evidence, the general geologic history of the soils at each site is determined. Geotechnical data are presented in the form of boring profiles and results of laboratory tests, and these are discussed with respect to the previously determined geologic history. In certain cases there are apparent discrepancies between the geologic histories and the interpretations of geotechnical data, and these apparent discrepancies are commented upon.



Boston, Sea-level and Post-Glacial Crustal Movements

Figure by MIT OCW.



Extent of the "classical" Wisconsin glaciation of North America

Figure by MIT OCW.

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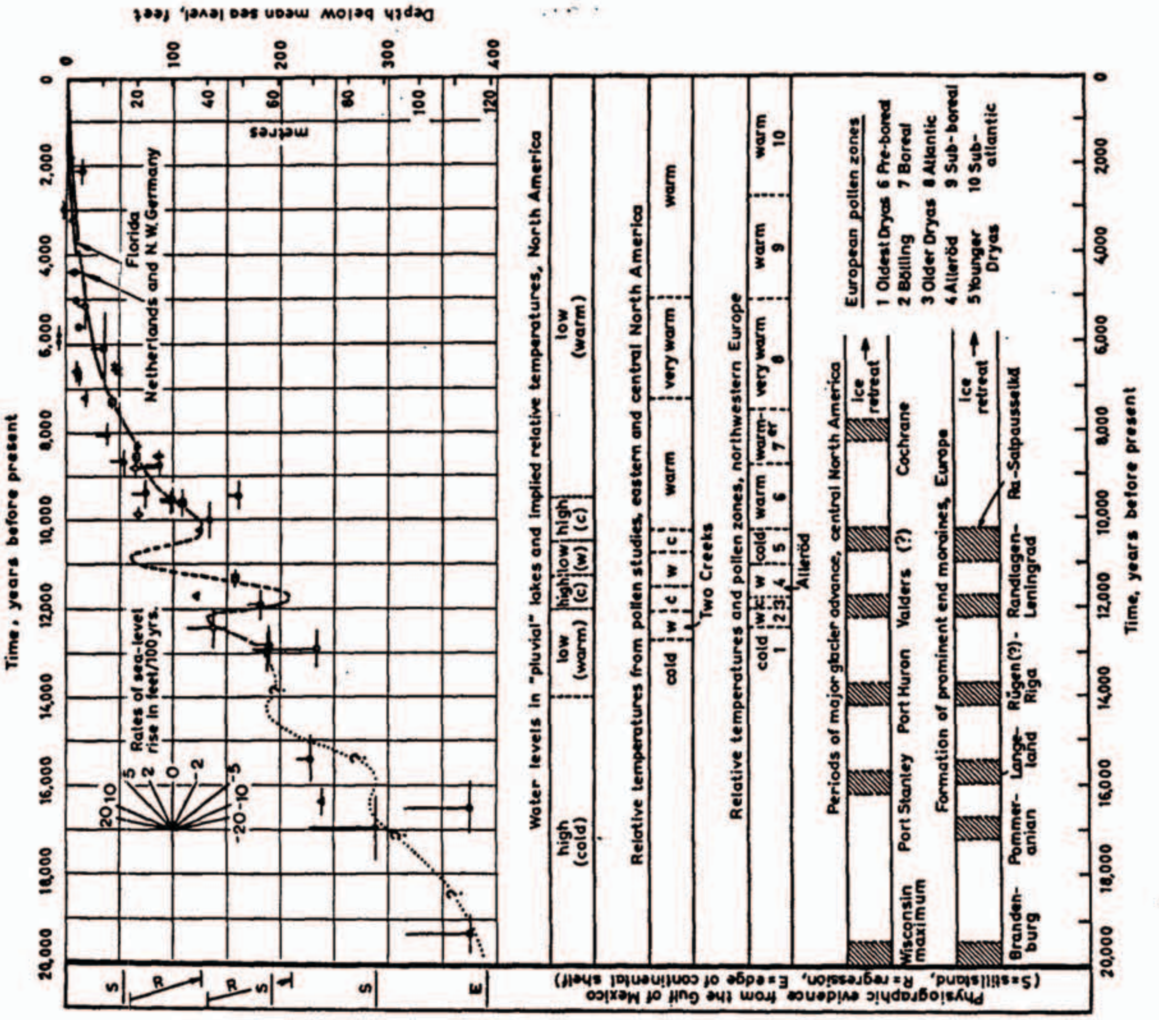
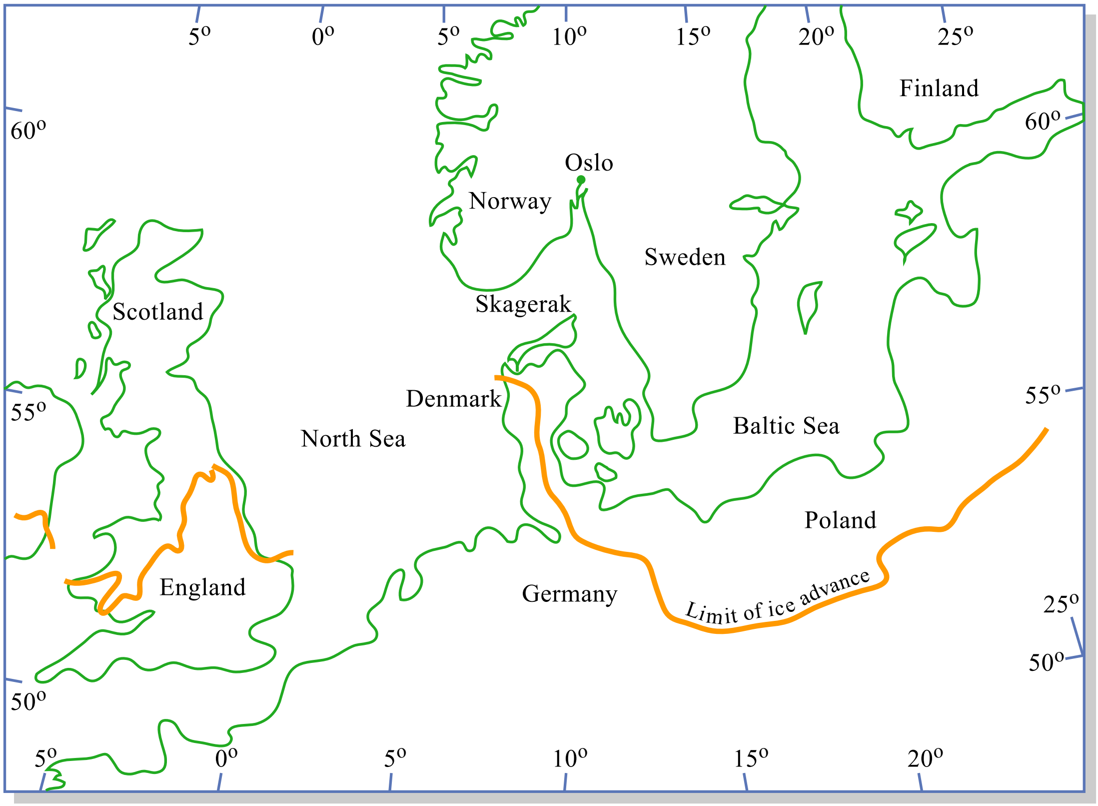


Fig. 1. Eustatic sea-level movement curve for the late Pleistocene period



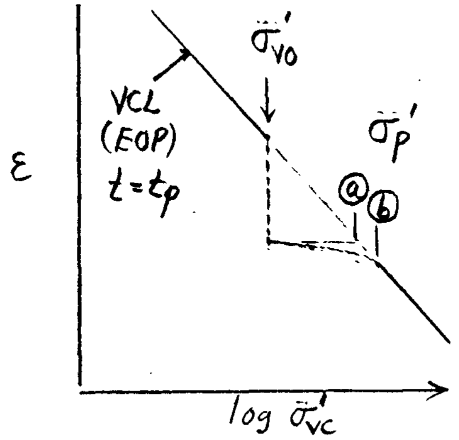
Extent of the Weichsel Glaciation of Europe

Figure by MIT OCW.

2/97 3/01

4.5 Drained Creep (Sec. Compr. = Aging*)

* Note: Some authors use term "aging" to include D = Physico-Chem



ⓐ $C_\alpha \log(t/t_p) = CR \log(\bar{\sigma}'_p/\bar{\sigma}'_{vo})$

$$\log OCR = \frac{C_\alpha}{CR} \log(t/t_p)$$

$$OCR = (t/t_p)^{C_\alpha/CR}$$

$C_\alpha/CR = 0.045 \rightarrow$

No. cycles	$m = 1$ OCR	$m = 0.8$ OCR
1	1.11	1.14
2	1.23	1.30
3	1.36^5	1.47^5

$\approx$ 10-15% / LC

ⓑ Mesri & Castro (JGE 3/87)

$$C_\alpha \log(t/t_p) + RR \log(\bar{\sigma}'_p/\bar{\sigma}'_{vo}) = CR \log(\bar{\sigma}'_p/\bar{\sigma}'_{vo})$$

$$OCR = (t/t_p)^{\frac{C_\alpha/CR}{m}} \quad \text{where } m = 1 - C_s/C_c = 1 - RR/CR$$

NOTE: No difference in predicted ε_{cf} if $\sigma'_{vf} > \sigma'_p$

Discussion

1) Does σ'_p lie on EOP? CCL believes it should if no physico-chemical cementation.

2) Tokyo Fig 39 à la Bjerrum (1972) → Incr. OCR with incr. I_p

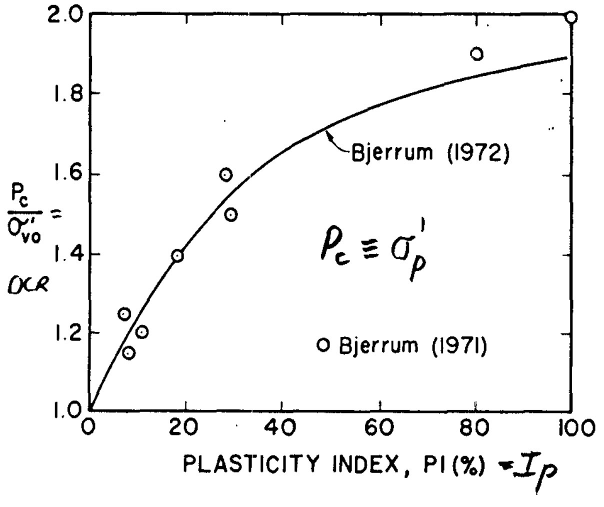


Fig. 39 Precompression of late glacial and post glacial clays attributed to aging.

Why is this plot suspect (CCL regrets including)?

Ans: if $C_\alpha/CR \approx$ constant & if deposits of same age, then OCR due to aging should not vary w/ I_p

3) Confusing terminology:

"Young" NC = little or no aging

"Old" NC = significant aging

↑ Should use "normally loaded"

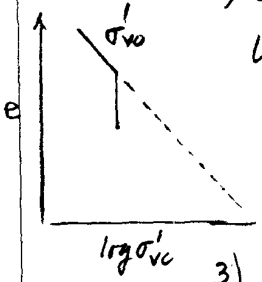
4.6 Physico-Chemical (see Table V, p4)

1) Discussion (Cementation & other causes of "bonding")

- Certain deposits do contain potential cementing agents like carbonates, Al-Fe oxides, silica, organic matter, etc.
- Other causes even less well documented
- CCL believes can be very significant in some deposits, but hard to prove

NOTE: If combination of high I_L + high σ'_p + brittle clay behavior! } then quite likely e.g. Champlain Clays

2) Example - James Bay B-6 (p8)

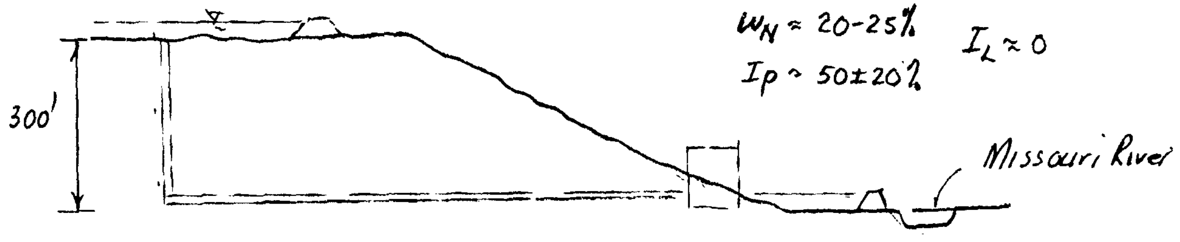


Why conclude Marine Clay had significant cementation?

- σ'_p inconsistent w/ mechanical, desiccation and aging
- Variable σ'_p on block samples
- 1-D → very compressible at $\sigma'_{vc} > \sigma'_p$
- CK_0UC → very brittle with v. high yield surface

3) Example - Nebraska Pumped Storage Project (p9)

Pierre Shale : up to 50% $CaCO_3$
$w_N \approx 20\text{-}25\%$
$I_p \sim 50 \pm 20\%$
$I_L \approx 0$



- Most oedometer data → $\sigma'_p = 160 \pm 20$ atm vs. Geology predicted only 80 atm vs ave. $\bar{\sigma}_{vo} \approx 10$ atm
- If mechanical σ'_p → v. high K_0 → significant impact on slope stability ("spalling") and tunnel lining design
- McGowen SM - is high σ'_p due to cementation?
  - leach with HCl → lower σ'_p?
  - correlation with % $CaCO_3$

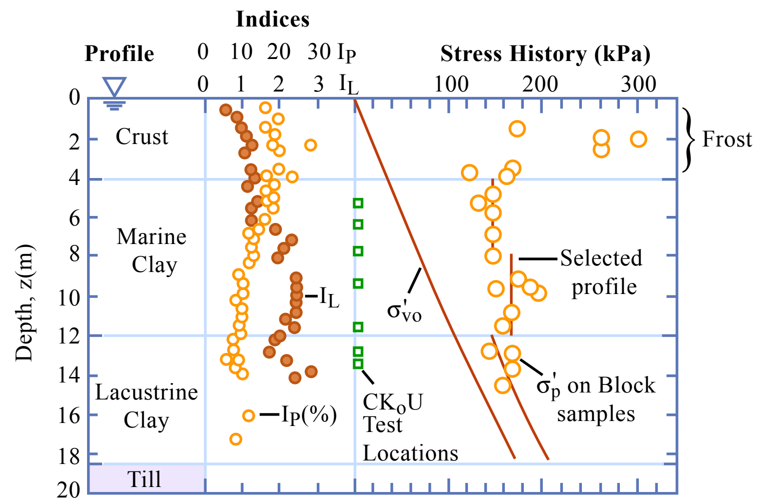
4) Examples - MIT Biology Bldg (p9a) ; EB CA/T (p11a)

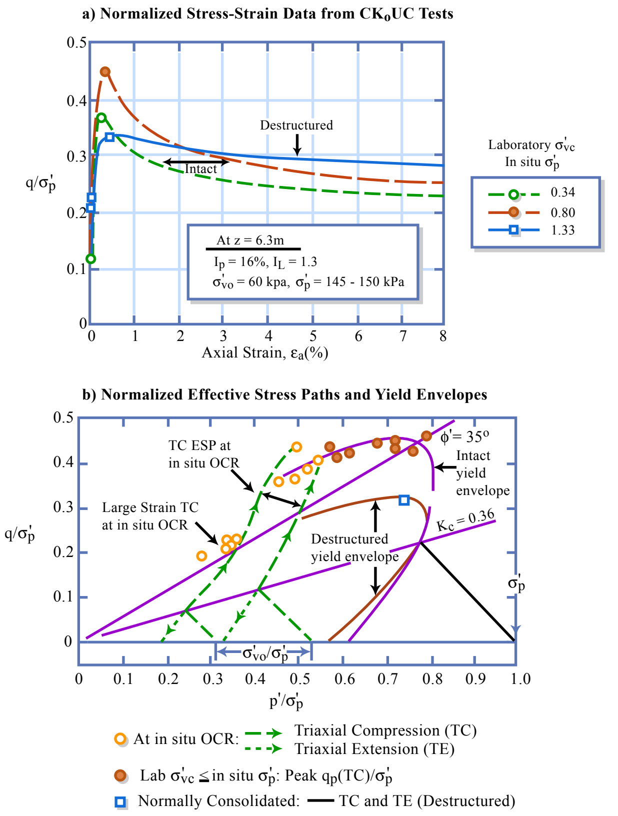
Soil profile, index properties & Stress history at James Bay B-6

∴ Marine Clay, $z = 4\text{-}12m$

$I_L \approx 2 \pm 1/2$

$\sigma'_p \approx 1.6 \pm 0.3$ bar

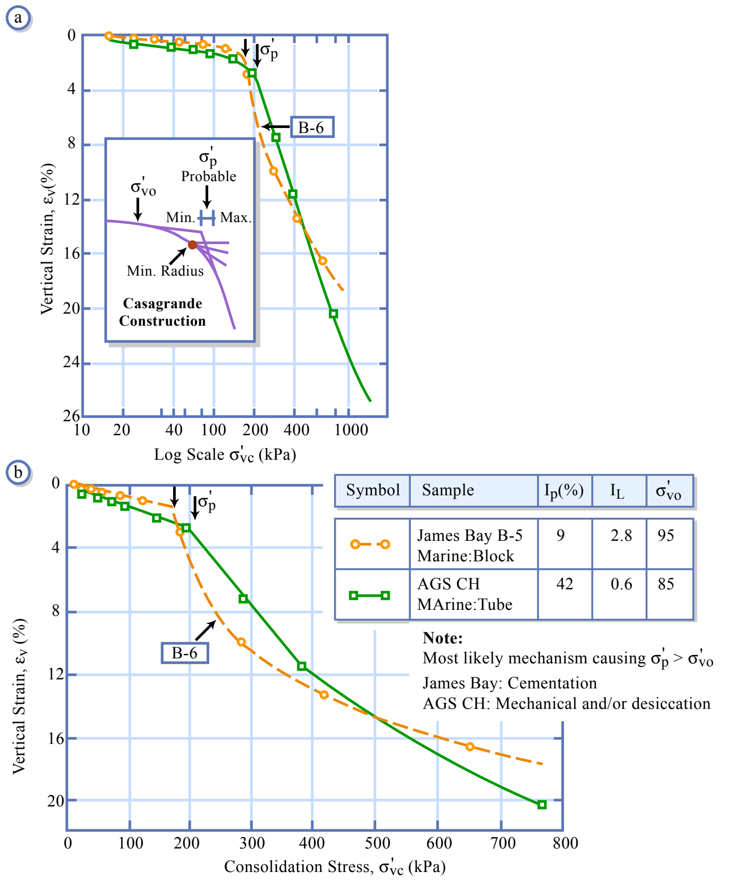




(a) Normalized Stress-Strain, (b) Effective Stress Paths and Approximate Yield Envelopes from CK$_0$U Tests on James Bay B-6 Marine Clay.

Data from Lefebvre et al. (1983).

1-D & CK$_0$UC data (from SF'85)



Symbol	Sample	Ip(%)	IL	σ'vo
-○-	James Bay B-5 Marine:Block	9	2.8	95
-□-	AGS CH MArine:Tube	42	0.6	85

Note:
Most likely mechanism causing $\sigma'_p > \sigma'_{vo}$
James Bay: Cementation
AGS CH: Mechanical and/or desiccation

Compression curves for clays having different preconsolidation pressure mechanisms
(a) Semi-Log scale; (b) Natural scale.

Figures by MIT OCW.

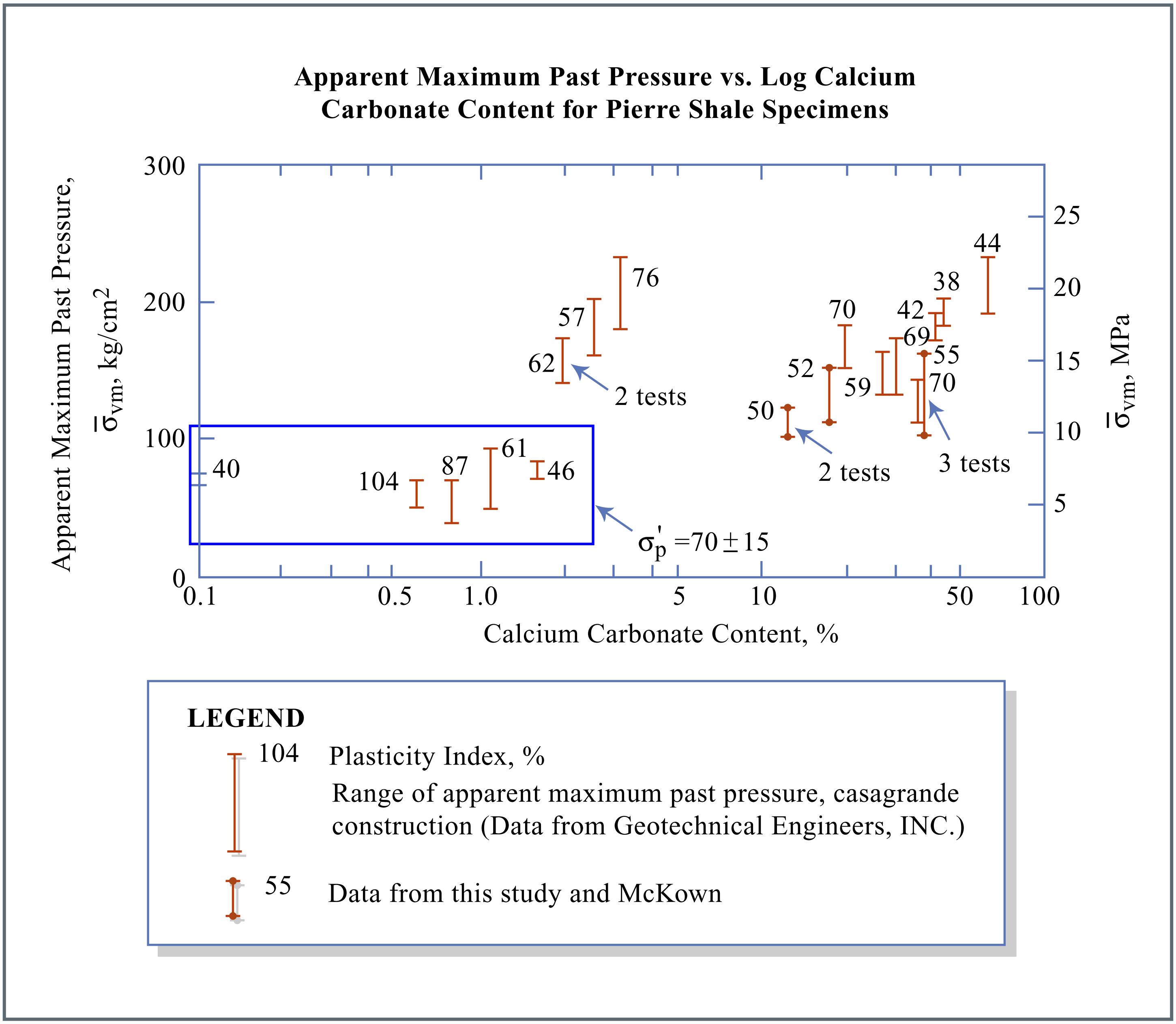


Figure by MIT OCW.

Adpated from: McGowen & Ladd (1982) ASTM STP 777

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Consolidation II

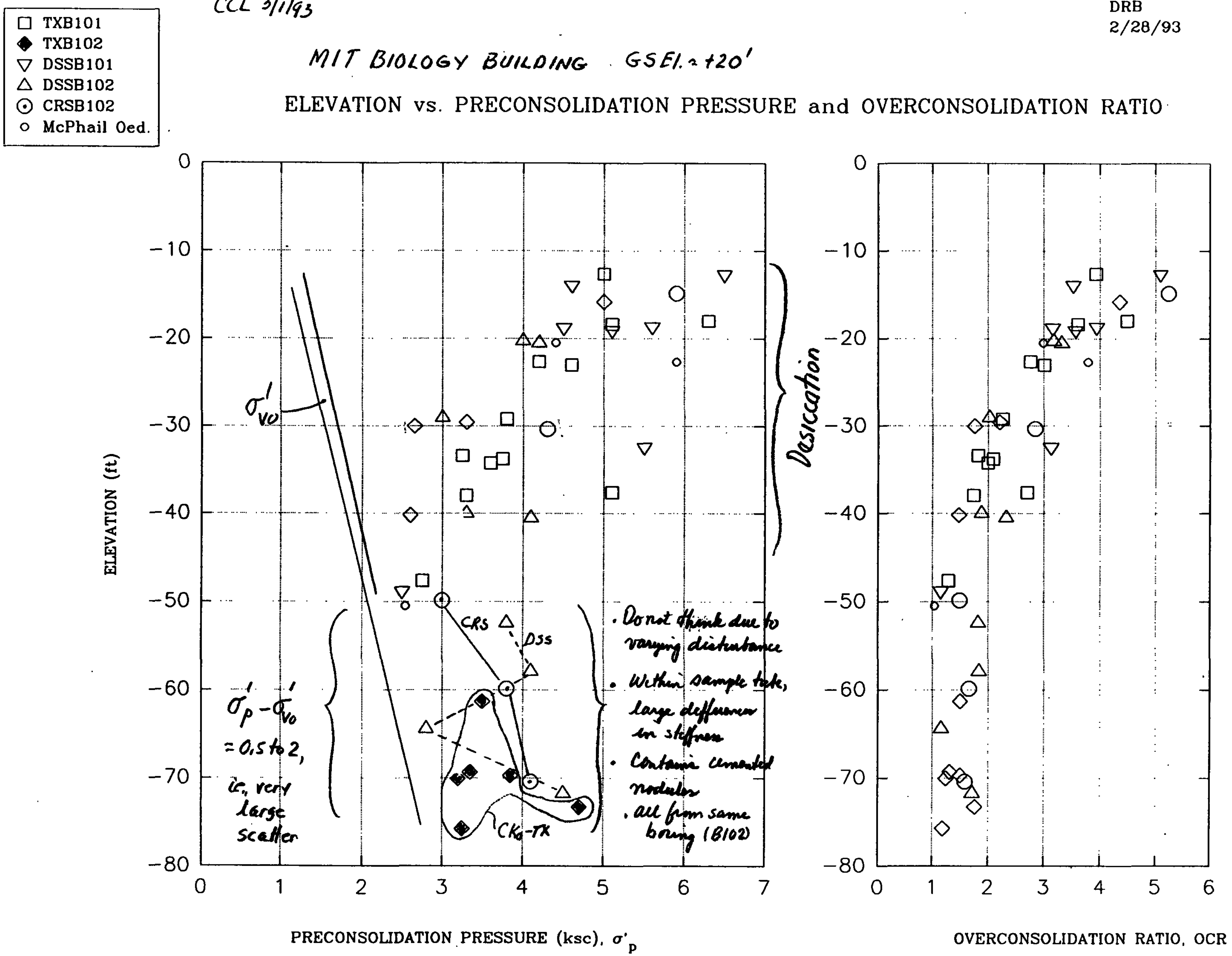
p9a

CCL 3/1/93

DRB
2/28/93

MIT BIOLOGY BUILDING GS El. ≈ +20'

ELEVATION vs. PRECONSOLIDATION PRESSURE and OVERCONSOLIDATION RATIO

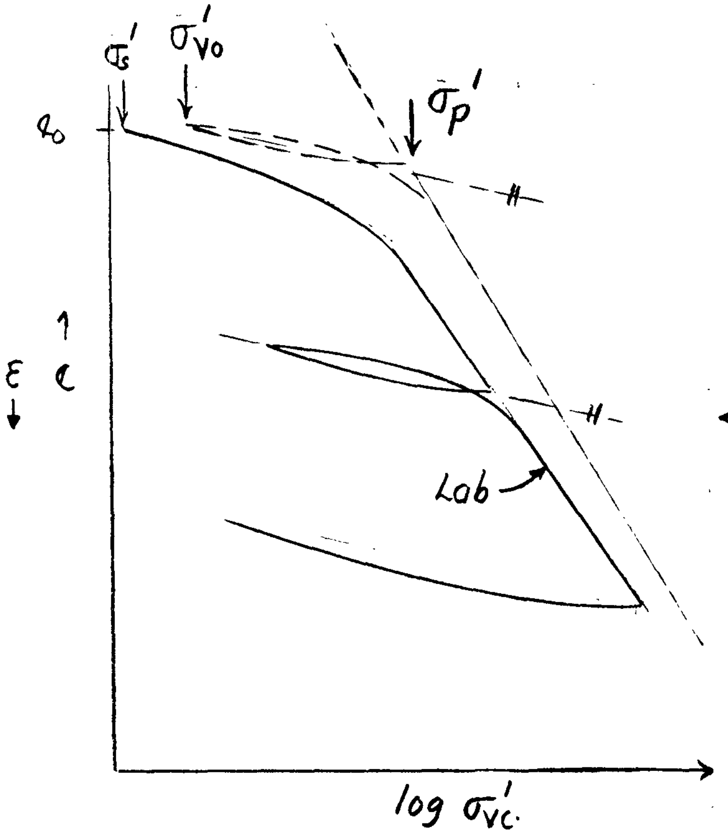


Desiccation

$\sigma'_p - \sigma'_{vo}$ = 0.5 to 2, ie, very large scatter

- Do not think due to varying disturbance
- Within sample tube, large difference in stiffness
- Contains cemented nodules
- All from same boring (B102)

5. SAMPLE DISTURBANCE (see Fig. 2-6, p10a)



5.1 Schematic

- Moderate quality
- Add severe disturbance

← Validity of parallel assumption vs Mechanisms → σ_p' ?
(Not for cementation)

5.2 Effects of Disturbance

1) Lower curve
2) Obscure & usually lower est. σ_p'
3) Signifance incr. recompression compressibility

   ∴ Should include?

4) May lower virgin compressibility
   (e Notes)

   - Table 2-2 - low-moderate S_t

     (using JHS) → Corr./meas. CR ≈ 1.15 ± 0.05 ← but can be much larger for S-shaped curves

     e.g., CA/T BBC 0.25 → 0.7 (p11b)
     Orinoco Clay 0.25 → 0.35 (p13a,b)

CCL 3/2/99

CCL 5/28/67

Reconstruction of In situ Compression Curve using Schmertmann's Method

JHS (1955) "The undisturbed consolidation of clay", 1955 Trans ASCE, 120, 1201-1233

NOTE: CCL recommends using linear (not curved) recompression and virgin compression lines to obtain Δe vs $\log \sigma'_{vc}$

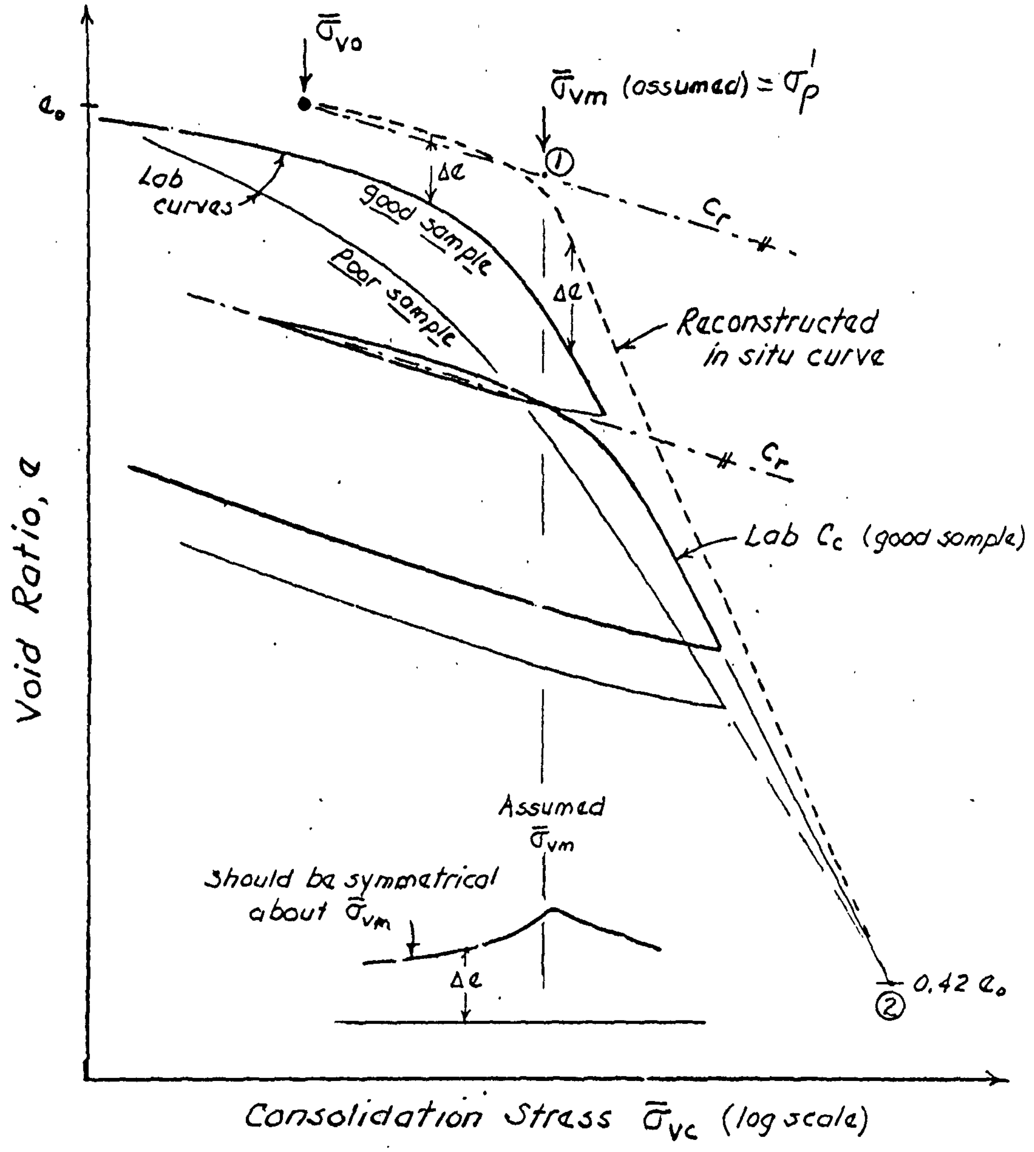


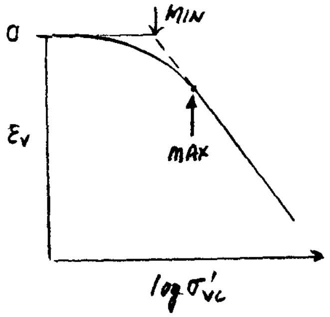
Figure 2-6

6 GRAPHICAL METHODS TO ESTIMATE σ'_p

6.2 Casagrande (AC)

- Most common
- Add min-max.

- Use standard size scale: CCL prefers 3 cycle $8\frac{1}{2}$ x 11 with $\Delta\varepsilon_v/\Delta LC = 10 \pm 2\%$



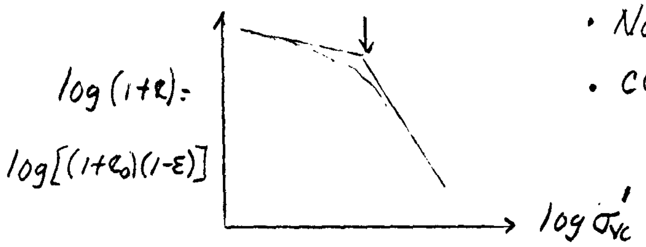
6.3 Schmertmann (Fig. 2-6 of Notes, p10a)

- No published update since 1955
- Advantage → "insitu" curve
- NOT APPLICABLE TO LOW OCR
- CCL prefers using linear (not curved) recompression - virgin compression lines to obtain Δe vs $\log \sigma'_{vc}$

6.1 Testing Soils with S-Shaped VCL

- p11a SB/EB CA/T Test Sites: Stress history
- p11b " " " " : Typical compression curves & values of CR

6.4 Butterfield (1979 geot. No. 4)



- Not much backup
- CCL - MIT experience → not valid (e.g. H.P. No. 4)

(NOTE: MIT-SI uses $\log e$ vs $\log \sigma'_{vc}$ to cover very large range in σ'_{vc})

6.5 Strain Energy = Work/Unit Volume (Covered 1.361)

- See p12 & p12a (Note: delete U/R data; must use max. CR for VCL)
- Use of linear scale → more precise σ'_p than via AC
- Need data at $\sigma'_{vc} < \sigma'_{v0}$ to define initial slope

6.6 Recommendations

1) Always use AC since std. practice & simple to apply
2) But SE preferred since more accurate, less judgement (esp. w/ rounded curves) and can automate, plus linear σ'_{vc} scale
3) See p12b for example of Comparing SE vs AC

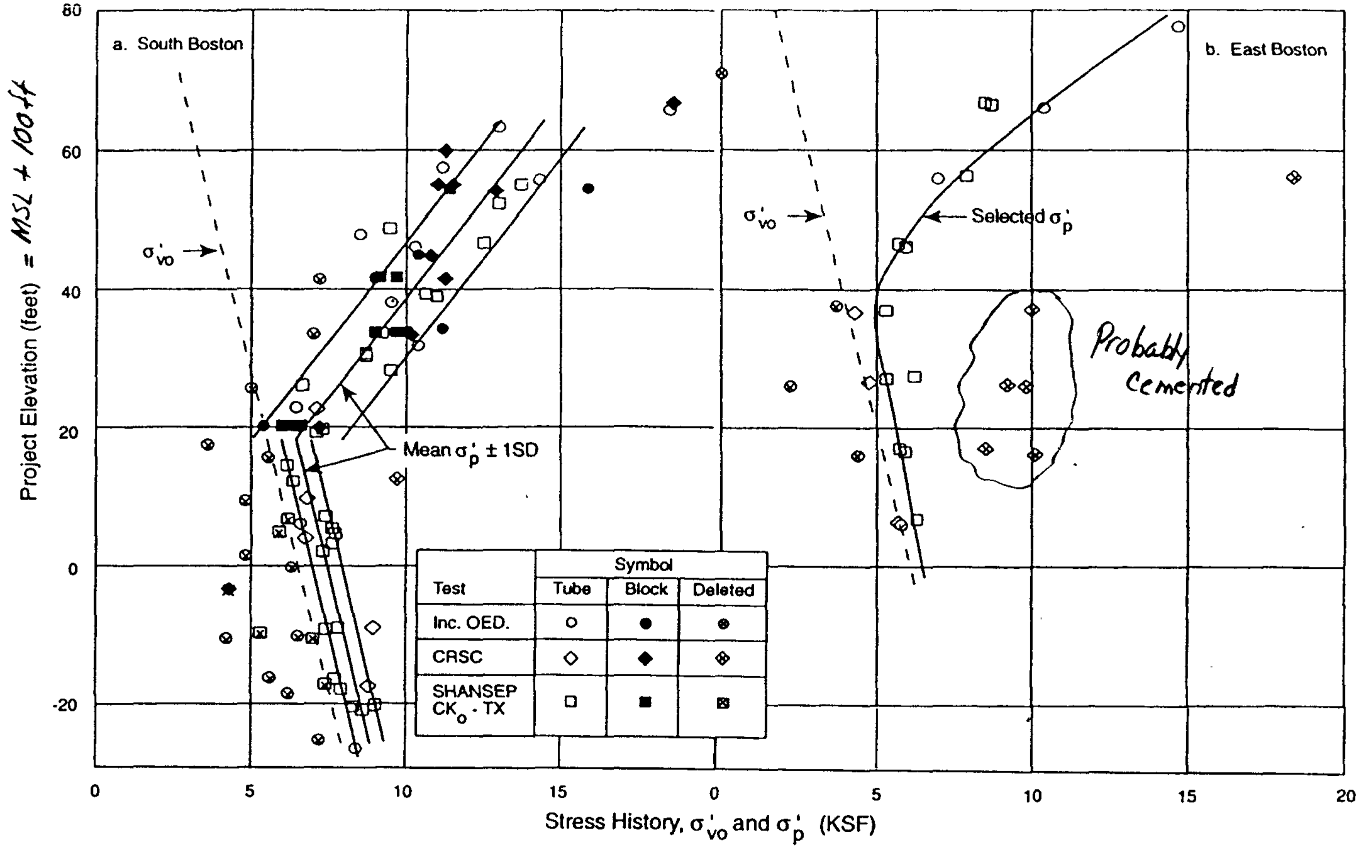
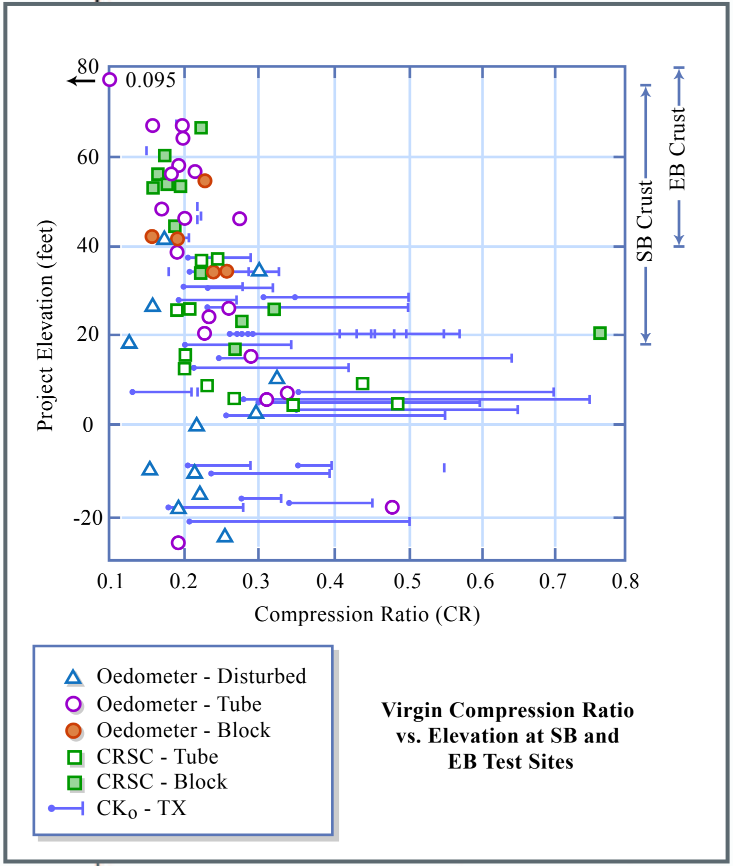


FIG. 6. Stress History from 1-D Consolidation Tests at SB and EB Test Sites (CA/T)

Notes: 1) Most of "good" σ_p' values from continuous loading tests (CRSC & SHANSEP CK_0-TX)

2) Deleted values due to excessive disturbance (ε_v @ σ_{v0}' too large for example) or σ_p' very high (probably localized cementation)

3) Used heavy weight mud → $\sigma_v = z\gamma_m \approx$ est. σ_{h0}; fixed piston sampler (3" ϕ) and Sherbrooke 30cm ϕ block sampler (at SB to El. 20)

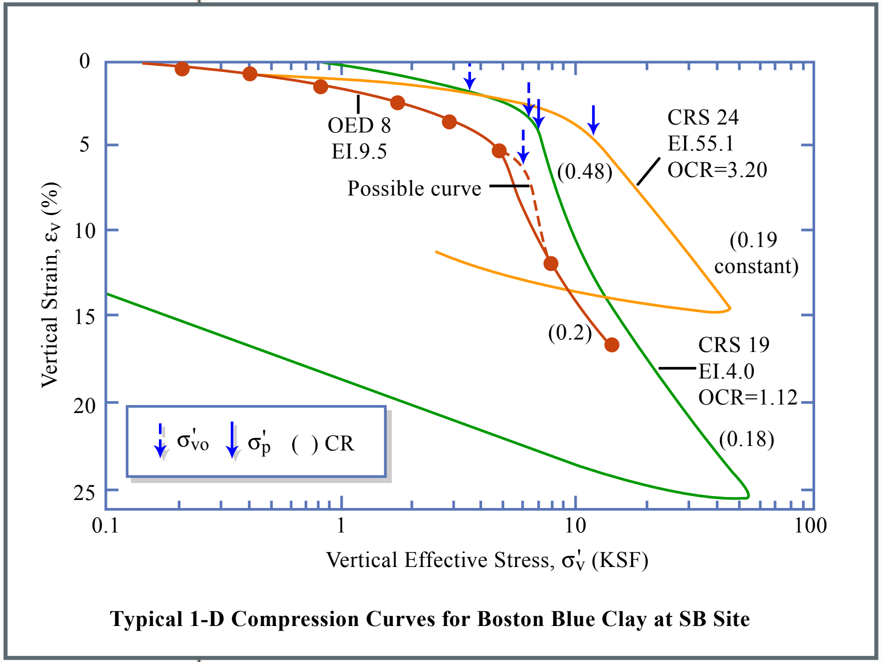


Virgin Compression Ratio vs. Elevation at SB and EB Test Sites

Figure by MIT OCW.

1) In upper crust, CRS, CK$_0$-TX & OED → same values of max. CR ≈ 0.2 (since similar compression curves).

2) At greater depths, need continuous loading tests to define max. CR ≈ 0.4 - 0.7. OED → much lower values of max. CR, partially due to more disturbance (tests run before used special extrusion technique)



Typical 1-D Compression Curves for Boston Blue Clay at SB Site

Figure by MIT OCW.

Adapted from: Ladd et al. (1998) Geo-Congress 98

1) CRS 24 in crust → linear VCL w/ CR ≈ 0.2.
- Oed = CRS
- SE better than AC

2) CRS 19 in low OCR clay → S-shaped VCL w/ CR decreasing at increasing σ'_{vc}/σ'_p

3) OED 8 in low OCR clay → ill-defined VCL. Can't define σ'_p and max. CR. Plus this specimen was moderately disturbed

2/97
3/99

STRAIN ENERGY ≡ WORK PER UNIT VOLUME

SE W

References

(1) Crooks & Graham (1976), geot. 26(2)

(2) Tavenas, et al. (1979), geot. 29(3)

(3) Becker, Crooks, Been & Jefferies (1987), Can. Geot. J., 24(4)

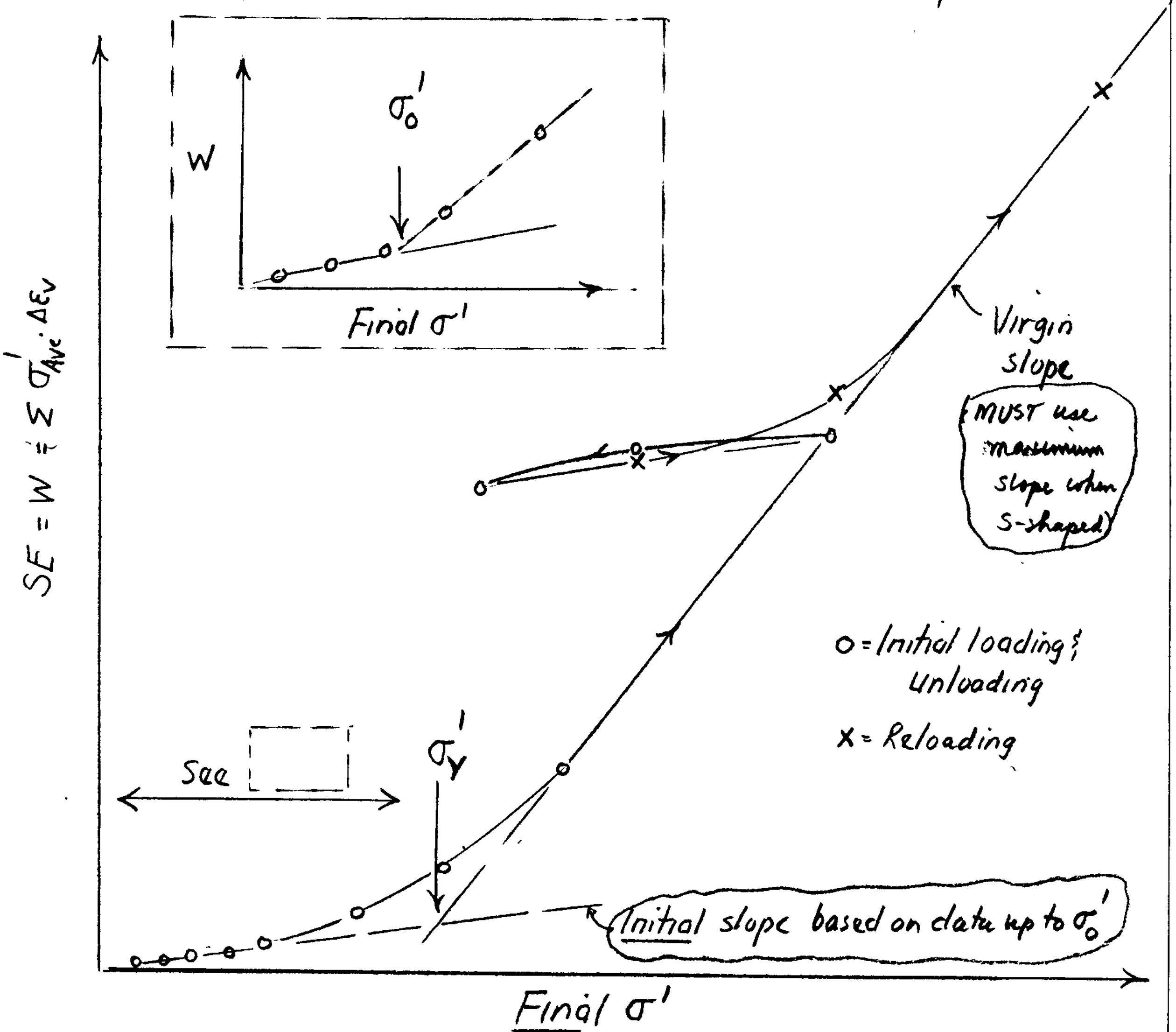
Definition

- Strain Energy = Work/Unit Volume = $\int(\sigma_1' d\varepsilon_1 + \sigma_2' d\varepsilon_2 + \sigma_3' d\varepsilon_3)$
- Oedometer (Ref. 3) $W = \int \sigma_v' d\varepsilon_v \approx \Sigma(\sigma'_{vc_{Ave}} \times \Delta\varepsilon_v)$ for each increment

  ↑ MUST be natural strain = $\Delta H/H = \Delta e/(1+e)$

Technique à la Ref(3) : Obtain both YIELD & INSITU Stresses, V & H!

σ_Y' σ_0' (see p 12a)



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12/a
1.322

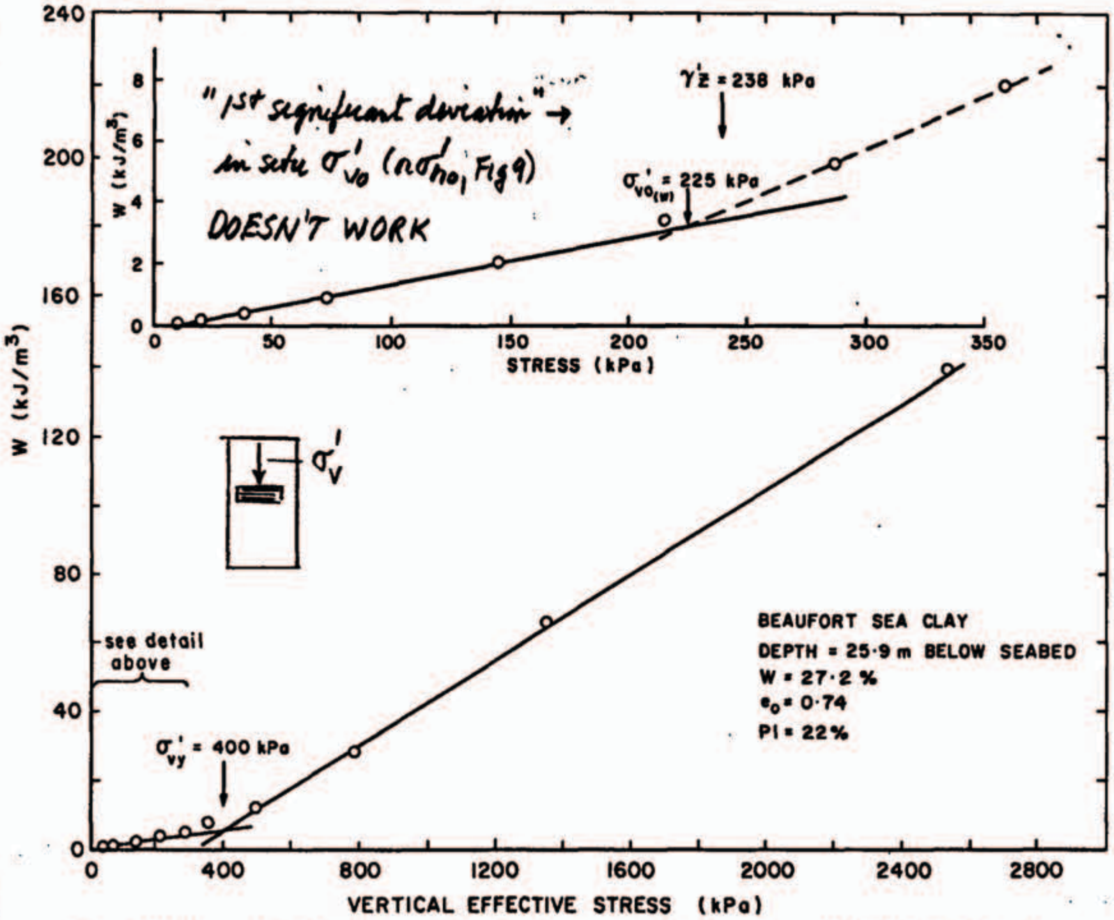
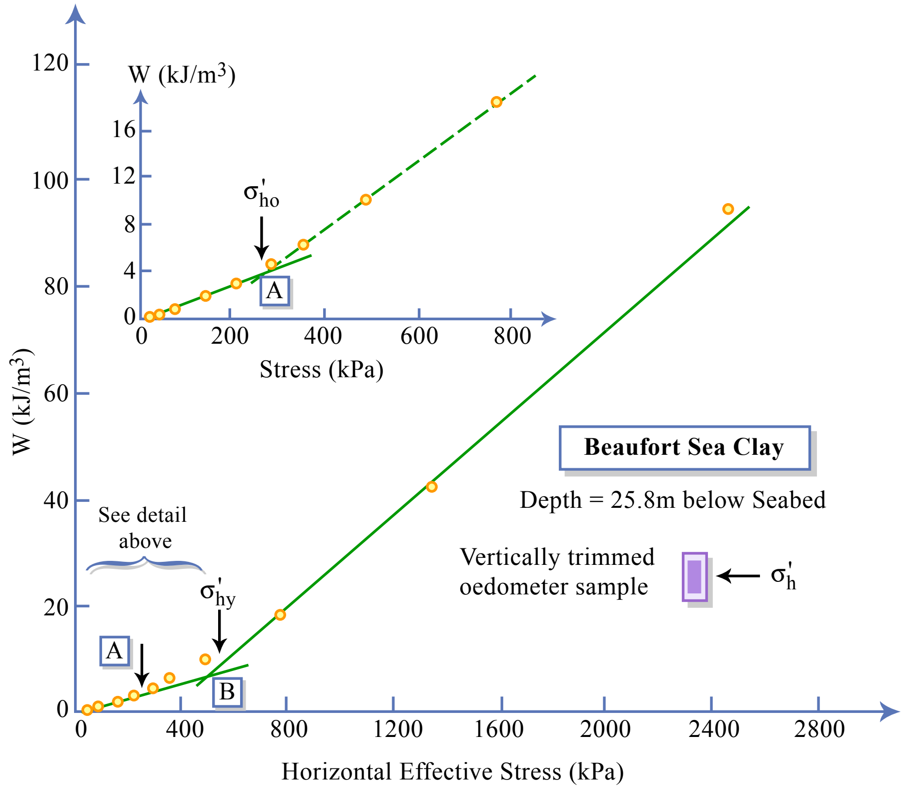


FIG. 6. Work per unit volume interpretation of oedometer test data for overconsolidated Beaufort Sea clay.



Work per unit volume interpretation of VTO test on overconsolidated Beaufort Sea clay.

Figure by MIT OCW.

Experimental data from Becker, et al. (1987) showing estimates of σ'vo, σ'ho,
σ'vy = σ'p & σ'hy obtained from Work Per Unit Volume = Strain Energy Technique

MHP
CCL 11/24/94

CCL 3/9/95 1.322 II p12b
2/97

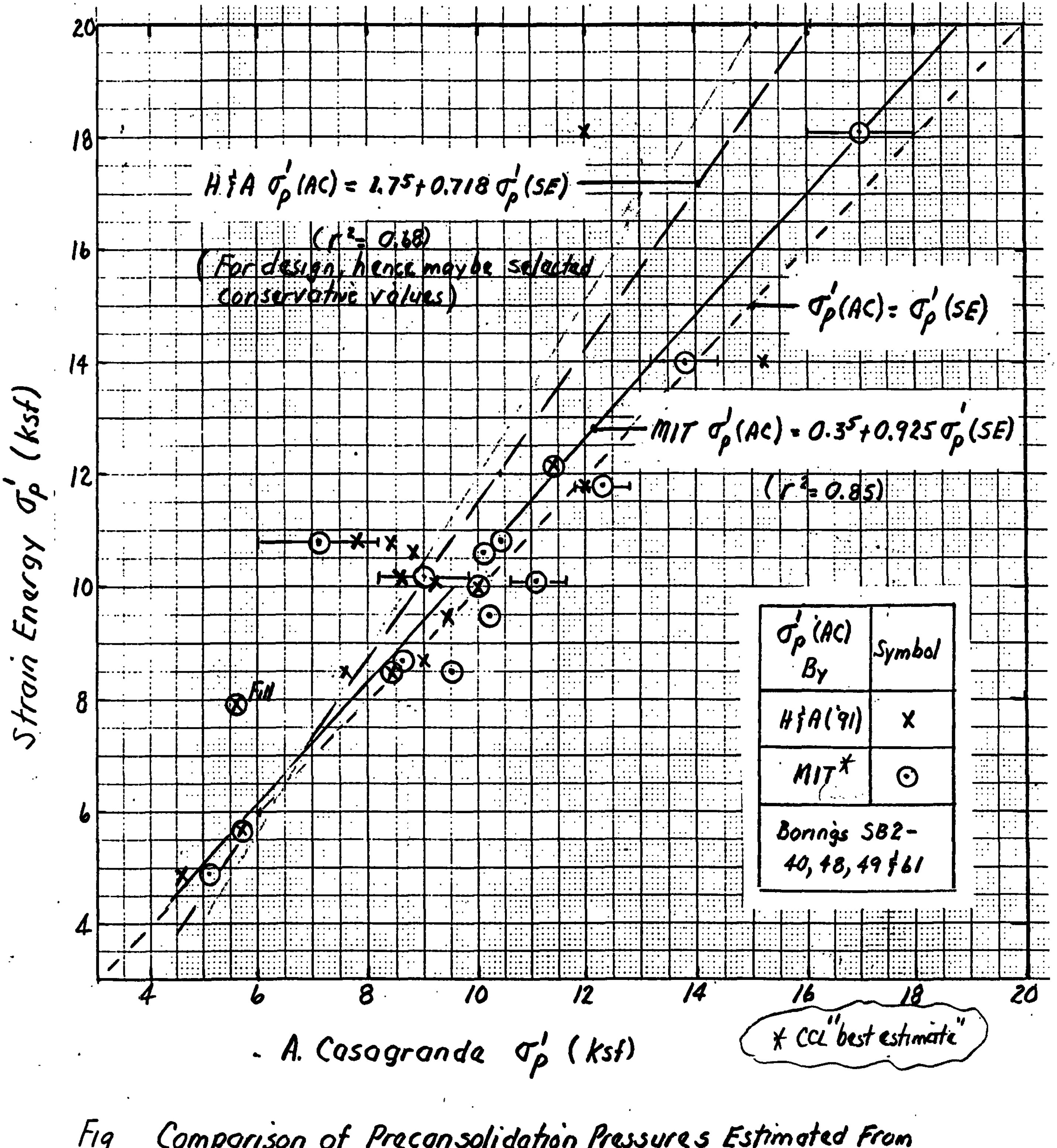


Fig. Comparison of Preconsolidation Pressures Estimated From Casagrande and Strain Energy Techniques for 17 Oedometer Tests on BBC (Fixed piston samples from SB 0004A)

7. ASSESSMENT OF EFFECTS OF SAMPLE DISTURBANCE ON σ'_p

7.1 General Guidance

1) Used mudded hole ($z \cdot \gamma_m \approx \sigma_{ho}$), FP samples & debond

2) Always use radiography whenever possible
   - Select best quality soil for testing, or, avoid more highly disturbed soil
   - Even best quality may show evidence of disturbance, e.g., rounded near edges

3) Always run s_u index above/below consolidation specimens to see if soil is weaker/stronger than typical (e.g., p 13a, b)

4) Measurements of σ'_s in companion UUC tests also helpful

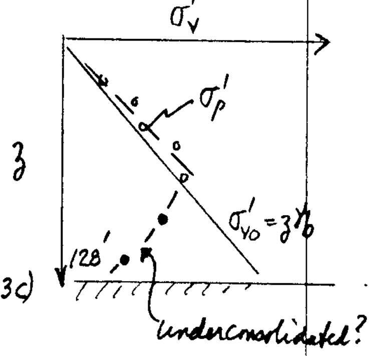
5) Always compare σ'_p profile with in situ testing data from FVT, CPTU, etc. (Mini-problem, Section 10)

7.2 Evidence of "Excessive" Disturbance

1) Increased ε_v at σ'_{vo} compared to typical data (goes with lower σ'_s/σ'_{vo})

2) Lower CR than typical and/or less S-shaped than typical and more rounded than typical near σ'_p

3) However, as of now, no definitive methodology to obtain corrected values of σ'_p



7.3 Examples

1) Offshore Venezuela, Orinoco Clay (p13a & b + Fig 10, p13c)
   - 1st test → "OCR" = 0.56 vs 2nd test → OCR = 1.15
   - Note very large increase in s_u with depth below top of tube (gross disturbance)
   - See Fig. 10 for correlation with ε_v at σ'_{vo}

2) Floating foundation on very thick varved clay (Fig. 4, p13c)

3) ε_v at σ'_{vo} data on BBC from CA/T SB STP (p13d)
   - New sample extrusion technique à la Dr. Germaine (developed for Arctic silts) uses piano wire around perimeter after pre-cut top/bottom based on X-ray

4) TPM ('96) Sample Quality Designation (A → E) for OCR < 4 ± 1 (plotted p13d)
   - What SQD needed for reliable σ'_p? • Incr. σ'_{vo} → incr. ε_v even with very high quality samples (p13d)

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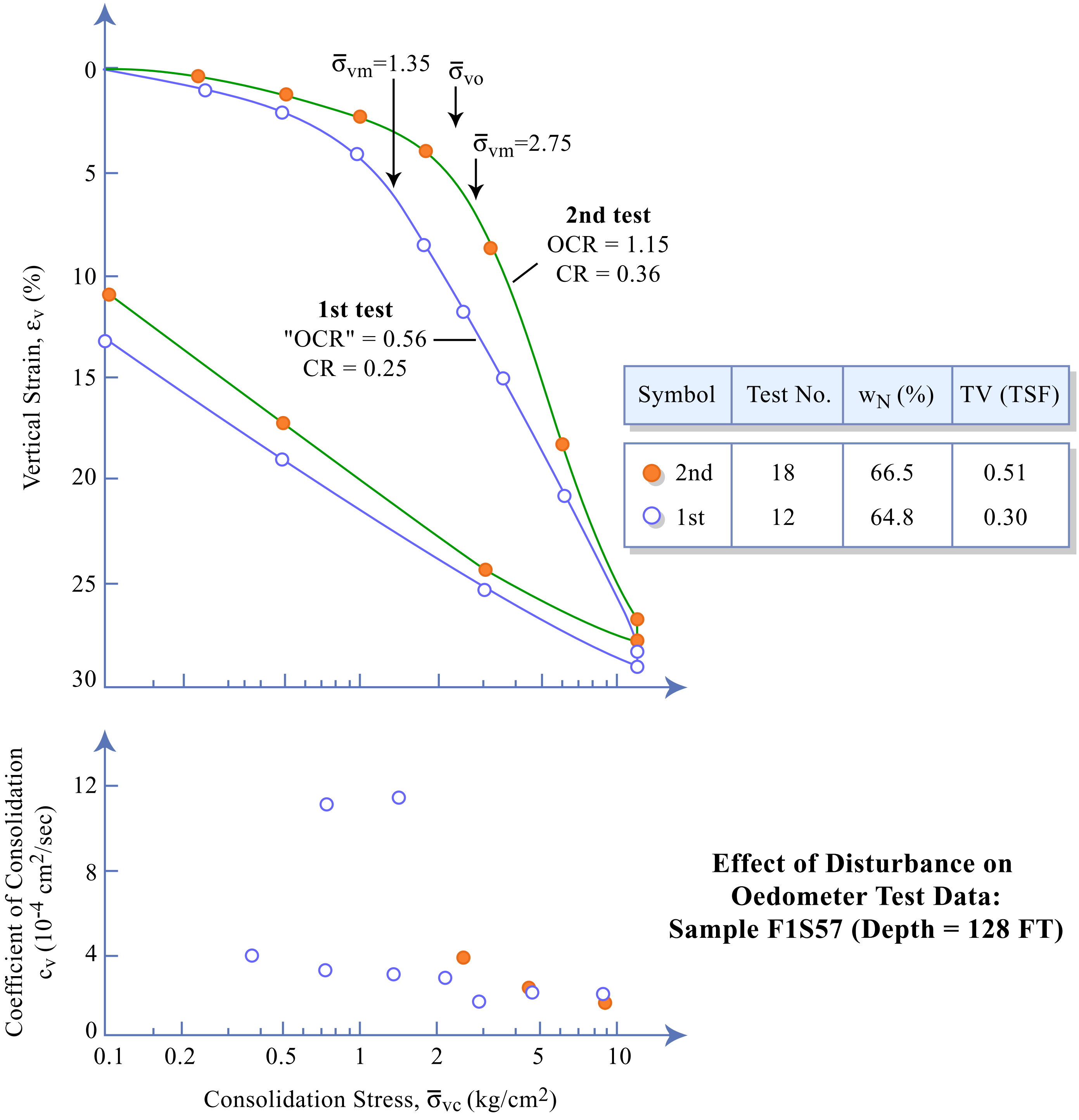

Symbol	Test No.	w_N (%)	TV (TSF)
● 2nd	18	66.5	0.51
○ 1st	12	64.8	0.30

Effect of Disturbance on Oedometer Test Data: Sample F1S57 (Depth = 128 FT)

Figure by MIT OCW.

Adapted from: Ladd et al. (1980)

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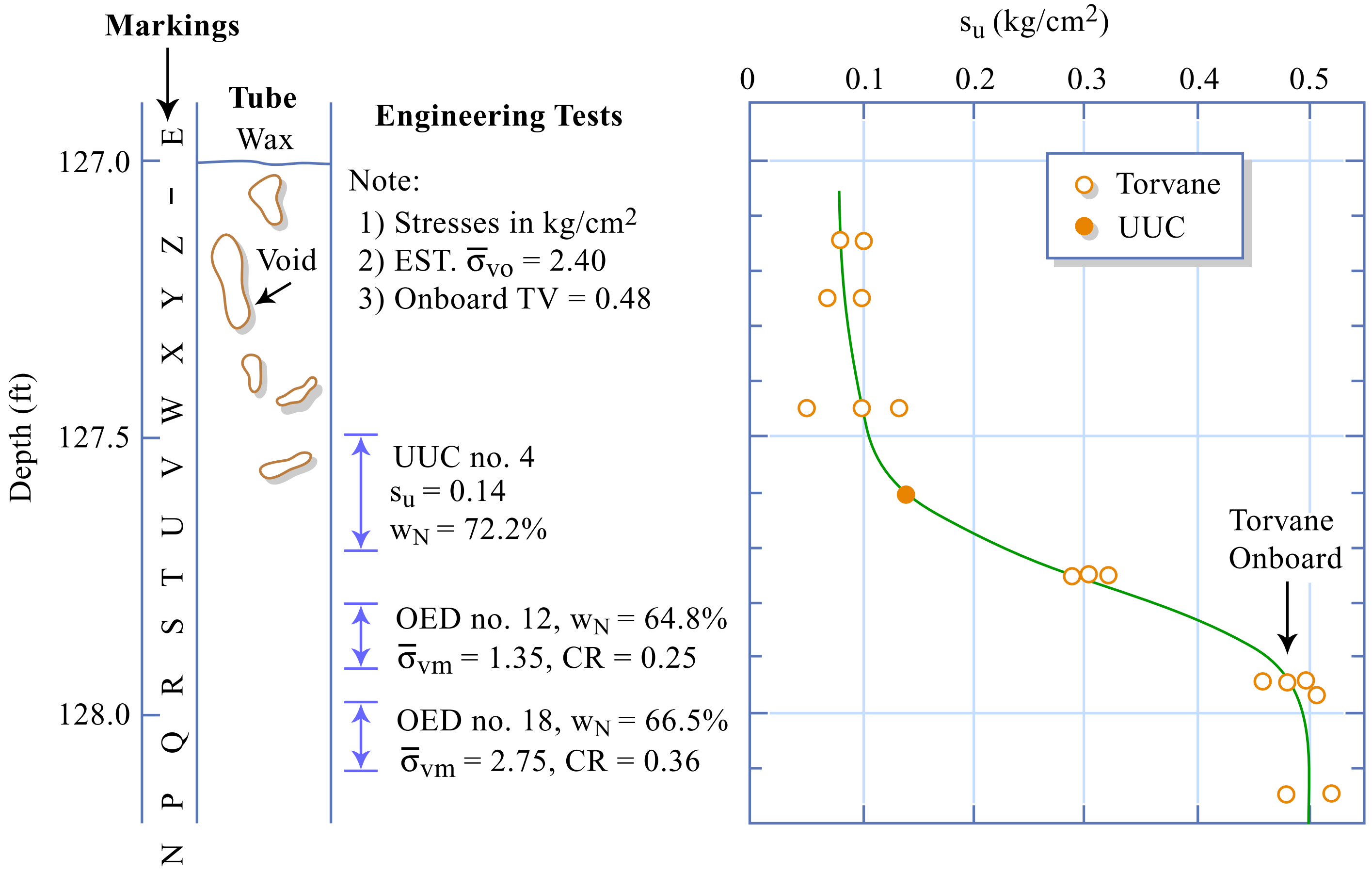
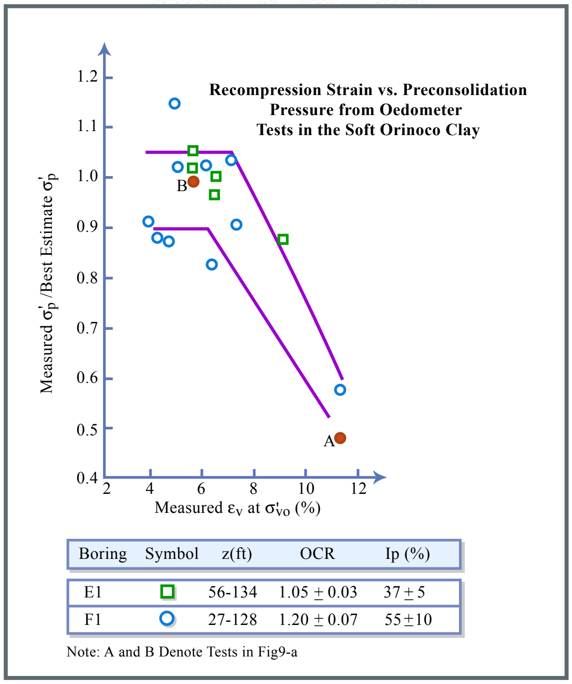


Comparison of Oedometer and Strength Data with Radiograph for Push Sample of Orinoco Clay

Figure by MIT OCW. Adapted from: Ladd et al. 1980.

From SF'85 SOA

Adapted [From Ladd et al. (1980)].



Boring	Symbol	z(ft)	OCR	Ip (%)
E1	☐	56-134	1.05 ± 0.03	37 ± 5
F1	○	27-128	1.20 ± 0.07	55 ± 10

Note: A and B Denote Tests in Fig9-a

Figure by MIT OCW.

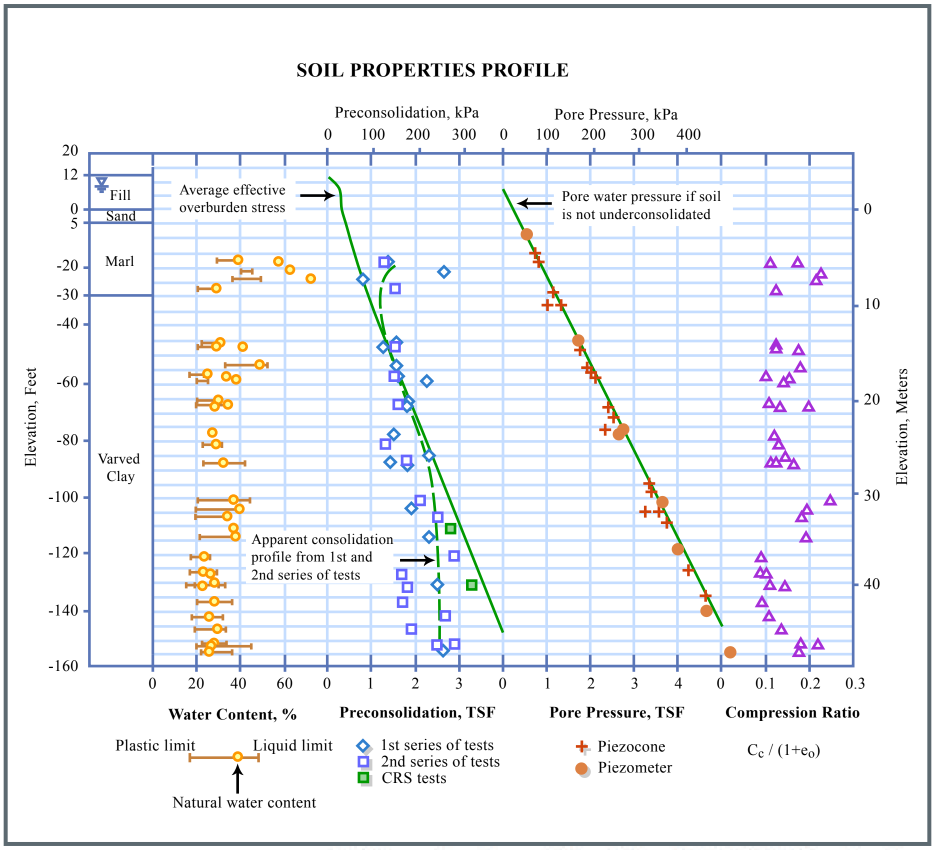


Figure by MIT OCW. Adapted from Steward, Lacy & Ladd : ASCE P'94 Conf

Large shopping mall with floating foundation on thick deposit of varved clay in upper state NY

1) Initial oedometer → "underconsolidated" near bottom 70'
(altho. CPTU dissipation & piezometer → hydrostatic u)

2) Subsequent CRSC at MIT on best quality clay from radiographs
→ 2 values of σ'_p slightly below hydrostatic σ'_{vo}

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3/1/01

13d

CCL 3/5/92 1.322 II Consol. Part II

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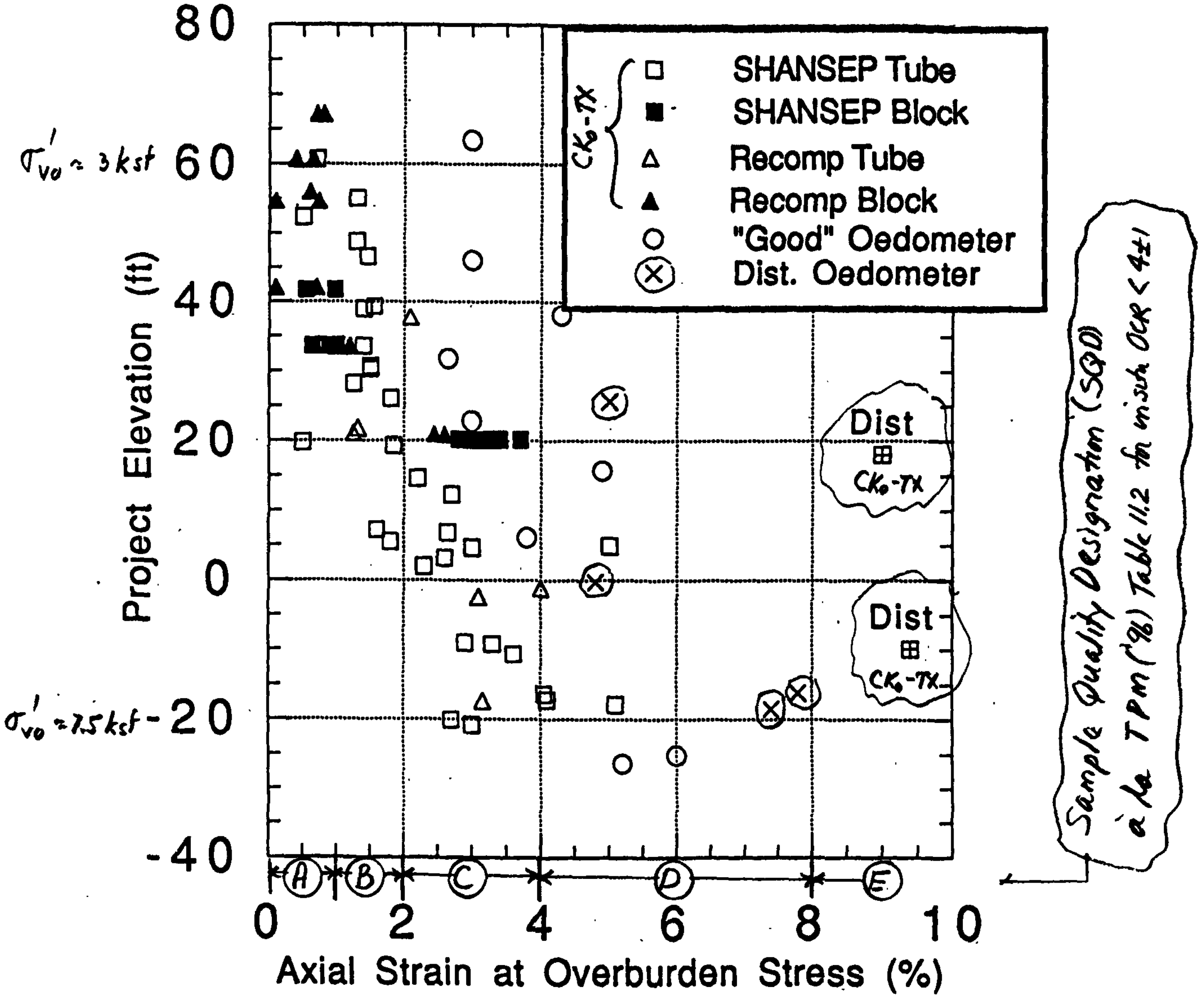
Note that CK_0-TX → smaller ε_v than oedometer tests
Also block → smaller ε_v than FP tube, except El. 20



Sample Quality Designation (SQD)
à la TPM ('96) Table 11.2 for in situ OCR < 4±1

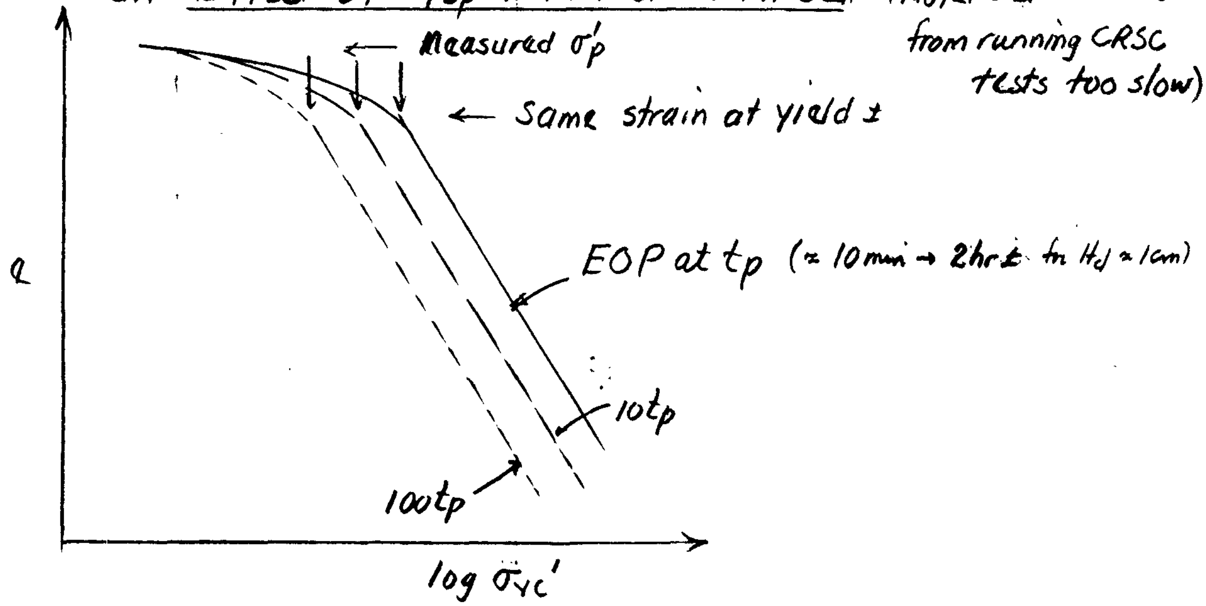
ⓧ Dist. oedometer: mainly occurred during extrusion → new technique where used piano wire to cut bond between BBC & Shelby tube

Figure 5-14: South Boston Elevation vs. Axial Strain at Overburden Stress from CK_0 and Typical Oedometer Tests

8. EFFECT OF TIME AND EOP

8.1 Effect of t/t_p with Incremental Oed.

(Note: Get same results from running CRSC tests too slow)



- Obtain above via different tests with varying t or same test with data plotted varying t, or CRSC with varying $\dot{\varepsilon}_v$
- Not controversial concept for $t \geq t_p$

8.2 How to Obtain EOP From Incremental Tests

1) See Fig. 2-11 & Notes (p14a)

2) Typical differences σ'_p EOP vs 1 day ≈ 15±5%

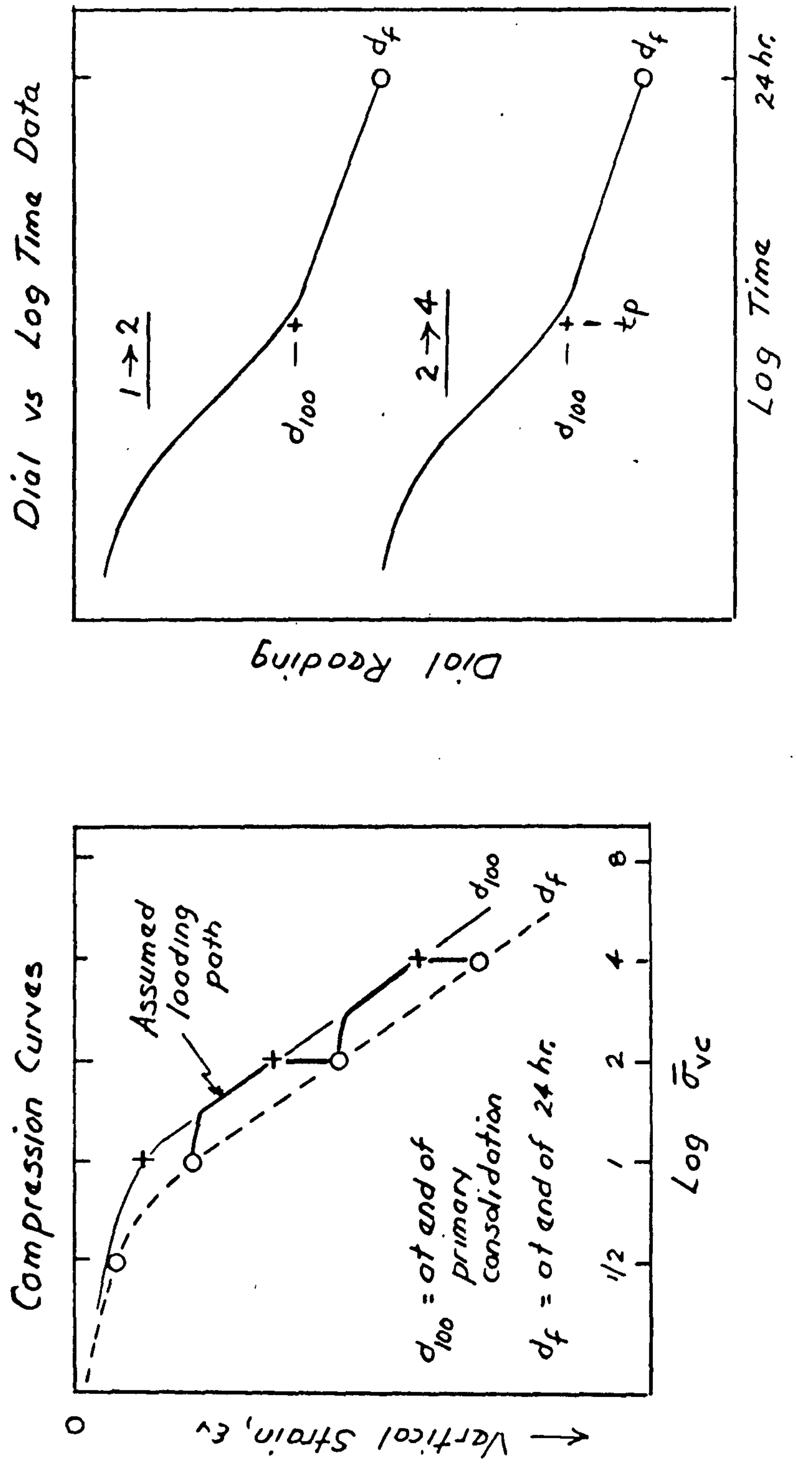
3) Std. practice (ASTM D2435-90 allows either t_p or constant t_c up to 24hr) - Most use t_c = 24hr (except U of I & MIT)

4) Problems in practical application
   - t_p varies OC→NC
   - Hard to define low-LIR & near σ'_p (true with both $\sqrt{t}$ & log t methods to estimate d_{100} at t_p

CCL recommendation.
- Get typical NC t_p & use throughout, e.g. $t \approx$ 10 min. low σ_v, $t \approx$ 2hr high σ_v

Very Important

CCL 3/10/73



CORRECTION OF OEDOMETER TEST DATA TO OBTAIN END OF PRIMARY CONSOLIDATION COMPRESSION CURVE

Figure 2-11

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ASTM D 4186-89

8.3 CRSC (Wahls et al + Wissa et al)

ASCE, JSMFD, 97(10)

1) Principle & how operate

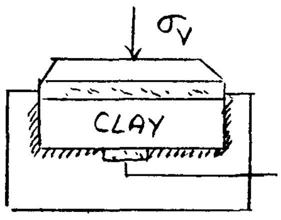


Fig 2-7 & Notes

PLUS BACKPRESSURE

$u_e \equiv u_b < 5\text{-}10\%\ \sigma_v$

Linear Theory

$$\bar{\sigma}_v' = \sigma_v - \frac{2}{3} u_b$$

$$k = \frac{\dot{\varepsilon} H_d^2 \gamma_w}{2 u_b}$$

$$c_v = \frac{H_d^2}{2 u_b}\left(\frac{\Delta\sigma_v}{\Delta t}\right) = \frac{\dot{\varepsilon} H_d^2}{2 u_b m_v} = \frac{k}{m_v \cdot \gamma_w}$$

2) Effects of $\dot{\varepsilon}$ on measured $\bar{\sigma}_p'$ - see p16

4) Advantages & limitations

- Cont. data
- 1/10th time
- Too fast $\dot{\varepsilon} \rightarrow \bar{\sigma}_p'$ too high
- No C_α
- Capital investment

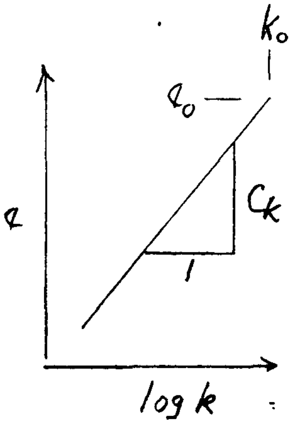
3) Mesri & Castro (3/87 JGE)

$$\dot{\varepsilon} = \frac{k_0}{2^{C_c/C_k} H_d^2} \times \frac{\bar{\sigma}_p'}{\gamma_w} \times \frac{C_{\alpha e}}{C_c}$$

(NOTE: $\dot{\varepsilon}$ to obtain EOP with $u_b \approx 1$ kPa ∴ too slow for CRSC tests to measure k_v & c_v)

$$\underbrace{}_{}$$
Cover in Part III

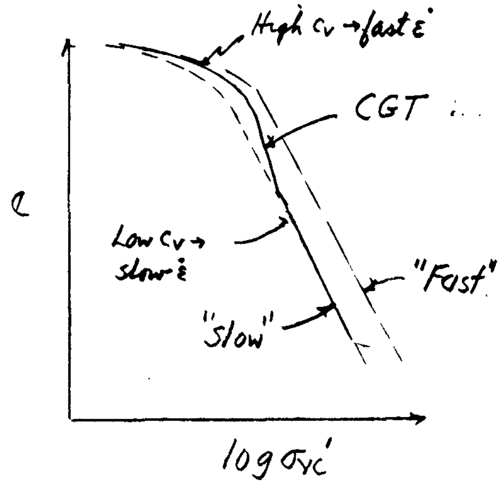
5) $k = k_0 (10)^{\left\{\frac{e - e_0}{C_k}\right\}}$



$C_k = de/d\log k$

8.4 CGT (Maintains constant $i = u_b/H_d$)

Why variable $\dot{\varepsilon}$ can → erroneous compression curve



8.3 Continued: 6) Discussion p16

- Most of data on high I_L - high S_t clays that are probably cemented
- Will later conclude that Champlain clays have cementation bonds → Yield envelope = $f(\dot{\varepsilon})$
- However, even more ordinary clays probably have a "structural viscosity" → $\bar{\sigma}_p' = f(\dot{\varepsilon})$ at v. high rates

Cover in Part IV

CCL 3/87 2/87 1,322 1-D Pcf Part II

Leroueil et al (1983) CGJ No4

TABLE 1. Geotechnical properties of clays Champlain Clays

Site	Number and symbol	Depth (m)	w (%)	w_L	I_P	I_L	S_t fall cone	C_u field vane (kPa)	σ'_{vo} (kPa)	$\sigma'_{p\,conv}$ (kPa)	Reference
Berthierville	1■	3.7	72	59	34	1.4	15	14	21	47	Samson *et al.* 1981 Morin *et al.* 1983
St-Césaire	2+	4.2	89	68	42	1.5	22	25	55	80	Samson *et al.* 1981
St-Césaire	2+	6.8	85	70	43	1.3	19	27	68	90	
Gloucester	3×	3.7	88	52	28	2.3	70	20	35	65	Samson *et al.* 1981 Leroueil *et al.* 1983
Gloucester	3×	4.1	76	53	29	1.8	35	20	38	67	
Gloucester	3×	7.5	93	53	29	2.4	88	25	58	87	
Varennes	4✳	8.9	62	65	39	0.9	28	60	64	216	Samson *et al.* 1981
Joliette	5★	6.7	65	41	19	2.3	108	29	40	110	Samson *et al.* 1981
Ste-Catherine	6●	3.8	88	60	35	1.8	30	18	20	60	Samson *et al.* 1981 Morin *et al.* 1983
Mascouche	7▽	3.8	65	55	30	1.3	52	70	34	270	Leahy 1980 Marchand 1982
St-Alban	8△	3.9	60	40	18	2.1		13	25	55	Leroueil *et al.* 1978*a* Leahy 1980
Fort Lennox	9□	6.1	60	45	22	1.7	30	30	54	105	Leahy 1980 Paquin 1983
Louiseville	10○	9.2	75	70	27	1.1	22	45	58	160	Leahy 1980 Leblond 1981
Batiscan	11◇	7.3	80	43	21	2.7	85	25	60	88	Bouchard 1982
Other sites	◆										Authors' files

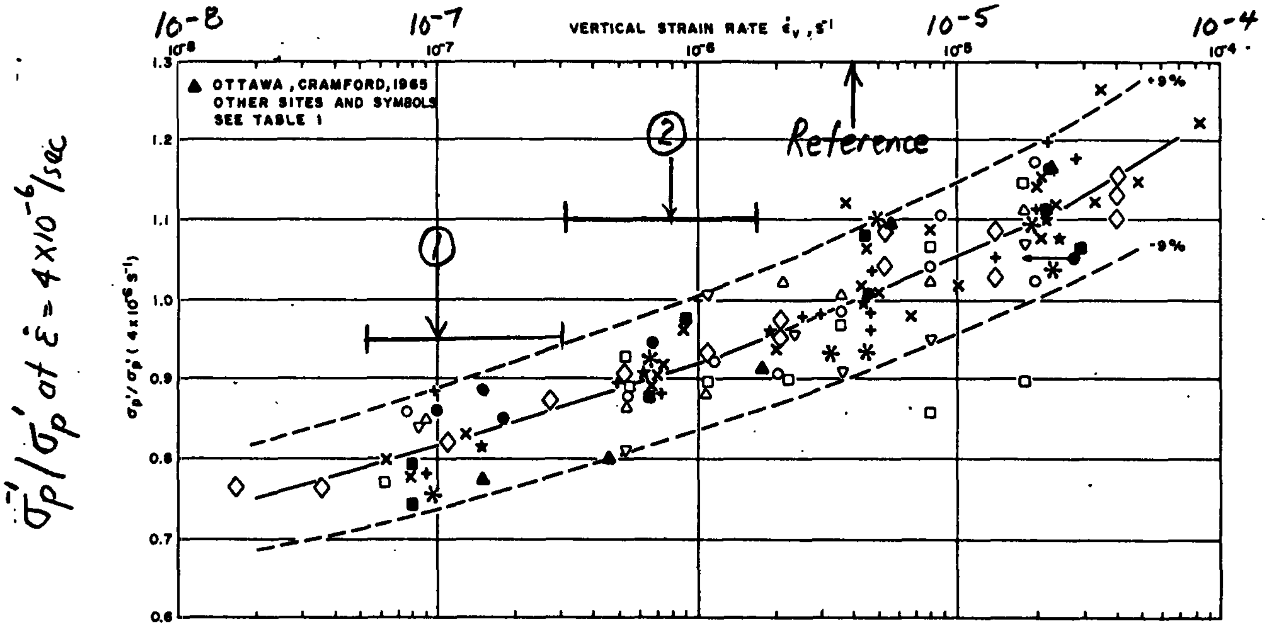


FIG. 7. Normalized preconsolidation pressure – strain rate relationship.

① Mean & range for $\dot{\varepsilon}$ typical oed. at t = 1 day

② " " " " " " " t = t_p or $u_b \approx 0$ in CRSC

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9. MISCELLANEOUS

9.1 Temperature [Also Baldi, et al. (1988), CGJ 25(4), 807-825]

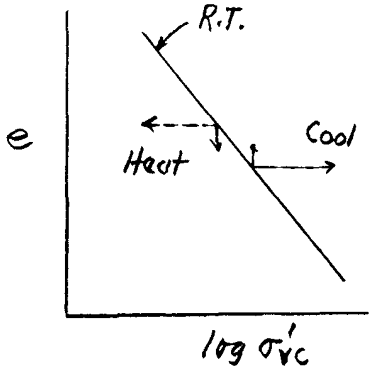
1) Results for Arctic Silt (see p17a)

2) Other results (see p17b & c)

Typical in situ T ≈ 10°C NC
≈ −2°C Arctic
≈ 5°C at great depth G. Mexico

$$\frac{[\sigma'_p(T) - \sigma'_p(20°)]}{\sigma'_p(20°)} \longrightarrow \frac{\%\ \text{Decr.}\ \sigma'_p}{\Delta T = +10°C} \approx 5\text{-}10\%$$

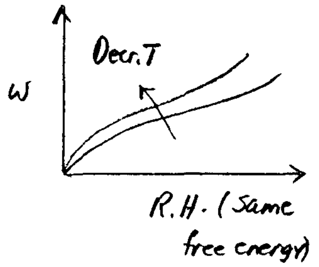
3) ΔT during test



$\Delta\sigma'_v >> \Delta e$ - Why?

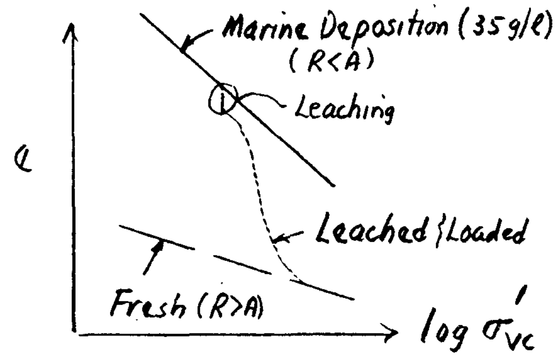
- Not $\Delta(R-A)$
- Contact stress

Incr. water adsorption with decr. T → incr. $\bar{\bar{\sigma}}_r$?



9.2 Pore Fluid (Covered Part A, VI)

1) Schematic - marine illitic clays



2) Other potential effects

$\bar{\bar{\sigma}}_a$ · Kaolinite: anything that changes + edge charge

R-A · Smectite: amt swelling = f(salt conc., cation valence & dielectric const.)

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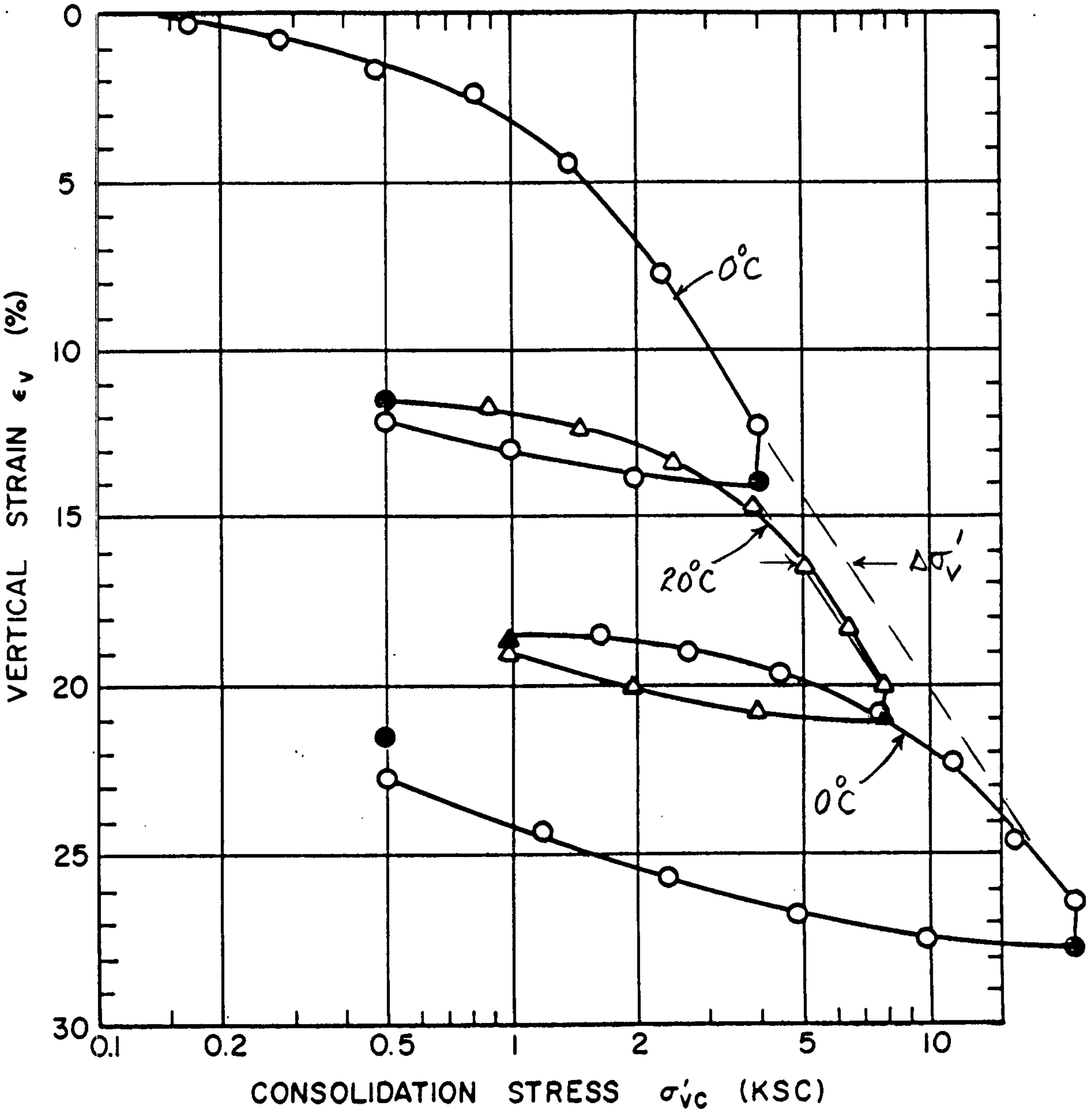
17a



Sample No.	MP - B2 - S7	W_N (%)	52.1	Estimated	
Depth	16.3'	W_L (%)	66.3	σ'_{vo} 0.402	σ'_p 1.7 KSC
Soil type	Gray Clayey Silt (MH)	W_p (%)	31.3	CR 0.168	RR 0.027
		I_p (%)	35.0	G_s 2.78	e_o 1.494
○ At t_p					S(%) 97.0
● At t_f		Remarks		Corrected for apparatus compressibility.	
COMPRESSION CURVE		TEST NO.		OED - B2 S7 TC - 1	

Figure 4-14 Compression Curve for Temperature Controlled Oedometer Test (OED-B2S7TC)

MIT Center Scientific Excellence in Offshore Engr.
SM Thesis, Yin (1985)

ARCTIC SILT
Harrison Bay, Alaska

2/97

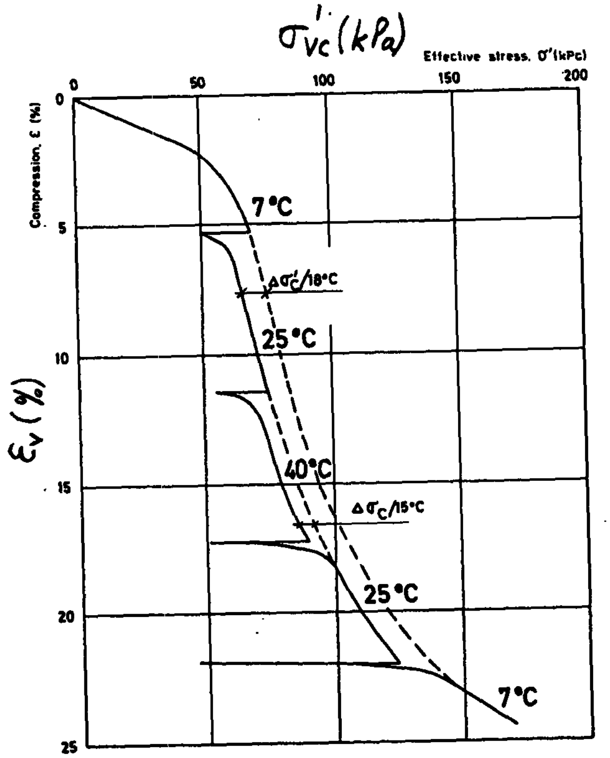


FIG. 5—*CRS test with varying temperature. Clay from Bäckebol.*

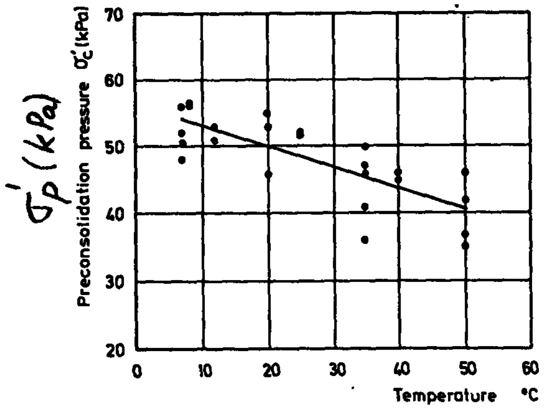
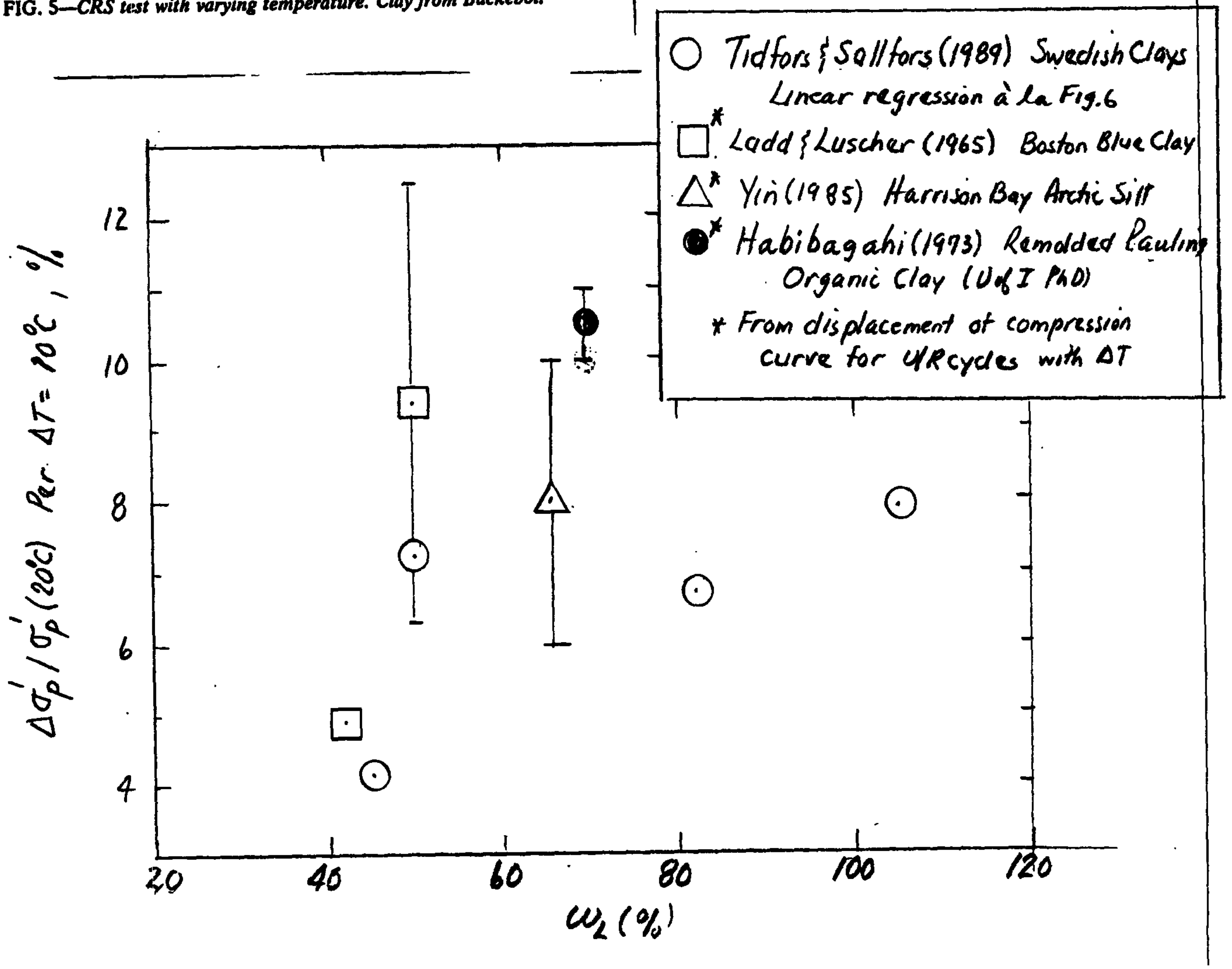


FIG. 6—*Preconsolidation pressure as a function of test temperature for specimens taken at 7 m depth at Bäckebol. Full line shows results of linear regression analysis.*

Tidfors & Sallfors (1989)
GTJ, ASTM 12(1)

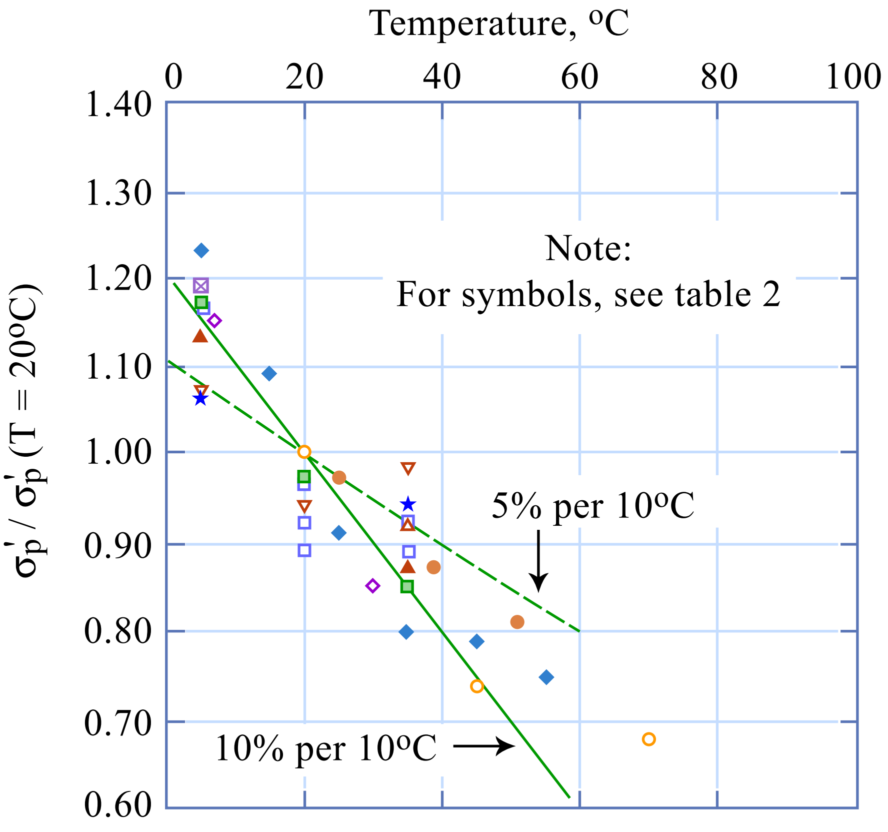
T Data for 4 Swedish Clays



Boudali, Leroueil & Murthy (1994) "Viscous behaviour of natural clays"
13th ICSMFE, New Delhi, Vol. 1, 411-416

Site	Depth (m)	I_p (%)	Type of oedometer test	σ'_p (20°C) (kPa)	Range of temperature, °C	Reference	Symbol used in Fig. 8
Berthierville	3.15-3.30	25	CRS, $\dot{\varepsilon}_v$=1.0 x $10^{-6}s^{-1}$	60.5	5-35	Present study	□
"	"	"	CRS, $\dot{\varepsilon}_v$=1.5 x $10^{-6}s^{-1}$	58	"	"	■
"	"	"	CRS, $\dot{\varepsilon}_v$=1.6 x $10^{-6}s^{-1}$	52.5	"	"	■
Louiseville	8.70-8.76	29	CRS, $\dot{\varepsilon}_v$=1.5 x $10^{-6}s^{-1}$	175	"	"	▴
"	8.76-8.82	29	"	190	"	"	▵
St-Jean-Vianney	4.44-4.54	14	"	980	"	"	★
"	5.60-5.72	14	"	1060	"	"	☆
Argile noire	---	32	Conventional	---	20-95	Despax, 1976	○
Illite	---	---	Isotropic consolidation	---	25-61	Campanella and Mitchell, 1968	●
Bäckebol	3.0-7.0	60	CRS, 0.0024mm/min	54	7-30	Tidfors and Sällfors, 1989	◇
Luleå	4.0	60	Conventional	50	5-55	Eriksson, 1989	◆

Table 2. Clays considered in Fig. 8



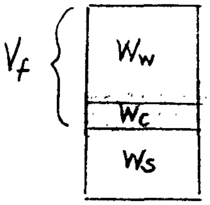
Variation of the Normalized Preconsolidation Pressure (σ'_p/σ'_p(20°C)) with Temperature

Figure by MIT OCW.

3) Check effect of Δ salt conc. on AL, esp. w_L

4) Effect of salt on measured w ($\underline{\underline{c = \text{salt}}}$)

- Measured $w = \dfrac{W_w}{W_s + W_c}$



- Salt G_c = specific gravity (≈ 2.3)

  C = conc. g/cc of solution

- Fluid $\gamma_f = \gamma_w + C\left(\dfrac{G_c - 1}{G_c}\right)$

- Corrected $w' = \dfrac{V_f \cdot \gamma_w}{W_s} = \dfrac{w}{1 - C\left(\frac{1}{\gamma_c} + w\right)}$

  = weight of voids if all pure H_2O

  → consistent $e = V_v/V_s$ & $G_s w' = S e$

{GSL $C = 0.150$ g/cc $w = 51.5\% \rightarrow w' = 60\%$}

- Potentially large affect on AL - Plasticity Chart - empirical correlations, but constant I_L (see p18a)

9.3 Side Friction Covered 1.37

10. PRACTICAL PROBLEM (Assuming Pcf = Poed)

- See p19 for problem - Class Discussion on ______
- For in situ consider : FVT
  CPTU
  DMT
- 2± sheets w/ answers + rationale

2/97
2/22/98

Supplement to Effect of Salt Conc. on Water Content (for $\gamma_w = 1.00 g/cc$)

Definitions

$$w = \frac{W_W}{W_S + W_C}$$

$$w' = \frac{V_f \cdot \gamma_w}{W_S}$$

$$C = \frac{W_C}{V_f}$$

$$G_c = \frac{\gamma_c}{\gamma_w}$$

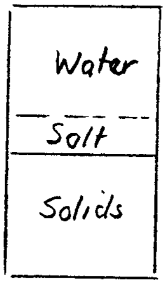
$$\gamma_c = \frac{W_C}{V_C}$$

Phase Relations

W_W

$W_C = C V_f$

$W_S = \frac{V_f \cdot \gamma_w}{w'} = \frac{V_f}{w'}$



$V_W = W_W \cdot \gamma_w = W_W$

$V_C = C V_f / \gamma_C$

V_S

$$V_f = W_W + \frac{C V_f}{\gamma_c} = \frac{W_W}{1 - C/\gamma_c}$$

$$\frac{W_C}{W_S} = \frac{C V_f}{V_f} w' = C w'$$

$$\gamma_f = \gamma_w + C\left(\frac{G_c - 1}{G_c}\right)$$

Derivation

$$w' = \frac{V_f \cdot \gamma_w}{W_S} = \frac{W_W}{(1 - C/\gamma_c) W_S} = \frac{w(W_S + W_C)}{(1 - C/\gamma_c) W_S} = \frac{w(1 + W_C/W_S)}{(1 - C/\gamma_c)} = \frac{w(1 + C w')}{(1 - C/\gamma_c)}$$

$$\rightarrow w' = w \Big/ \left[1 - C\left(\frac{1}{\gamma_c} + w\right)\right]$$

Application when Add/Substract water at Constant W_C

Change from w_0 to w_1, use $C_1 = C_0 (w'_0 / w'_1) \approx C_0 (w_0 / w_1)$

Example ($G_c = 2.33 = \gamma_c$ for $\gamma_w = 1.00$)

1) Initial condition: $C_0 = 0.150 g/cc$ $w_0 = 51.5\% \rightarrow w'_0 = \frac{51.5}{1 - 0.150(0.429 + 0.515)} = 60.0\%$
(at w_N)

2) Increase to $w_1 = 100\%$: $C_1 \approx 0.150\left(\frac{51.5}{100}\right) = 0.0773 \rightarrow w'_1 = \frac{100}{1 - 0.0773(0.429 + 1.00)} = 112.4\%$ vs 112.9%
(at w_L)

3) Decrease to $w_2 = 40\%$: $C_2 \approx 0.150\left(\frac{51.5}{40}\right) = 0.193 \rightarrow w'_2 = \frac{40}{1 - 0.193(0.429 + 0.40)} = 47.6\%$ vs 47.5%
(at w_P)

4) Plasticity Chart

Measured $w \rightarrow w_L = 100\%$, $I_p = 100 - 40 = 60\%$ → on A-line
Corrected $w' \rightarrow w_L = 112.4\%$, $I_p = 112.4 - 47.6 = 64.8\%$ → below A-line

5) Liquidity Index

Measured $w \rightarrow I_L = (51.5 - 40.0)/60 = 0.192$ } same
Corrected $w' \rightarrow I_L = (60.0 - 47.6)/64.8 = 0.192$