PROBLEM SOILS

Sheets

1. Highly Structured and Sensitive — S1-S3
   - S1 Summary of material covered in Consolid. IV
   - S2 Laval field data
   - S3 DM7.1 I_L vs $\sigma'_p = f(S_t)$

2. Peats and Highly Organic Soils — P1-P5
   - P1, 2 "text"
   - P3, 4, 4a Correlations
   - P5 Fundamentals of decrease in σ'_{vc} due to settlement

3. Collapsing and Expansive Soils — C/E1-C/E4
   - C/E1 Overview
   - C/E1, 2 Collapsing soils
   - C/E3, 4 Expansive clays

   ES1-4 Effects of changes in climate on behavior of expansive soils
   ES5 Fdn. design on " "

   Note: Limitations of double oedometer testing and influence of stress level on collapse/swell behavior will be covered under Part G (Compacted Clays)

4. Tropical Residual Soils — R1-R6
   - R1 "text"
   - R2-4 Backup information
   - R5, 6 Sowers (1994)

   Note: CCL has very little experience with residual soils

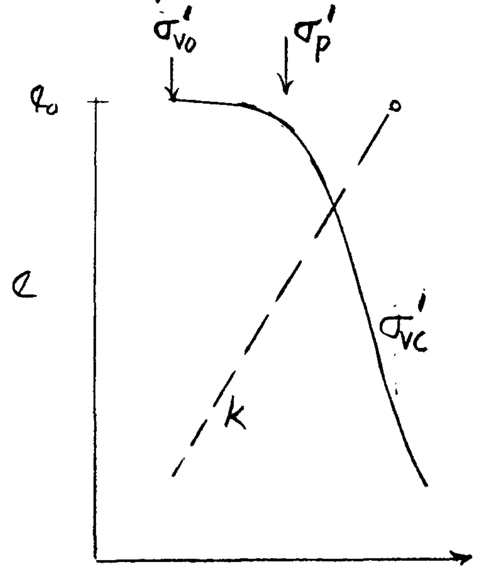
5. Varved Clays — V1-V12
   - V1, 2 "text"
   - V3-12 Backup information

6. References (Outdated) — Ref1

Highly Structured & Sensitive Clays

V. high I_L vs σ_p'
Often cemented & leached
See S3

Mesri - Hypothesis A



ILLICON

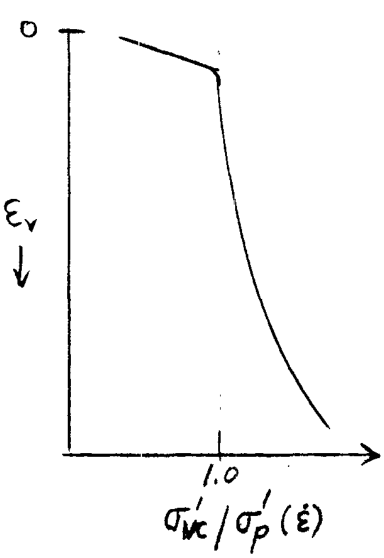
- Assumes unique EOP → in situ = lab
- Input e vs log σ_{vc}' & log k

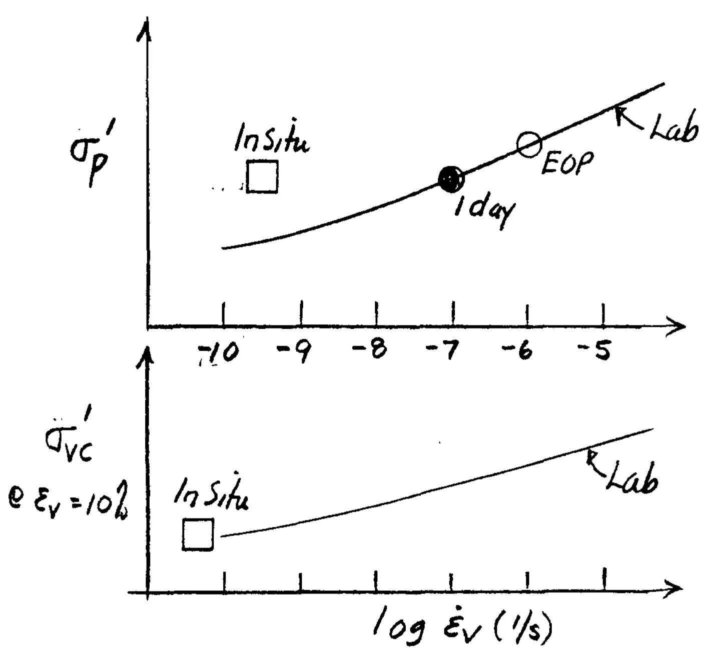
NOTE: Either case, often get CR → 1 ± 0.5

Laval - Hypothesis B

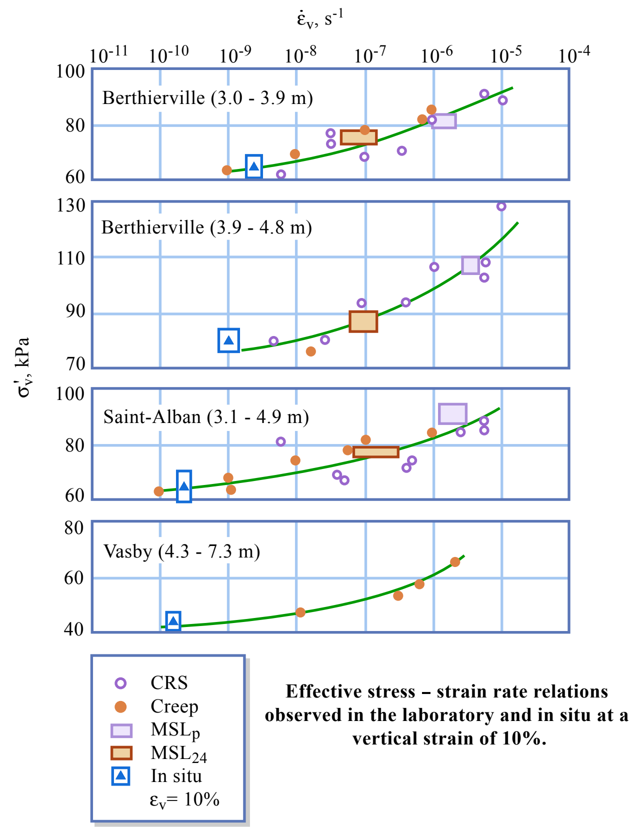
Leroueil (1988) CGJ 25(1)

- Lab → unique $\sigma_{vc}' - \varepsilon_v - \dot{\varepsilon}_v$
- Insitu → ε_v > lab EOP See S2

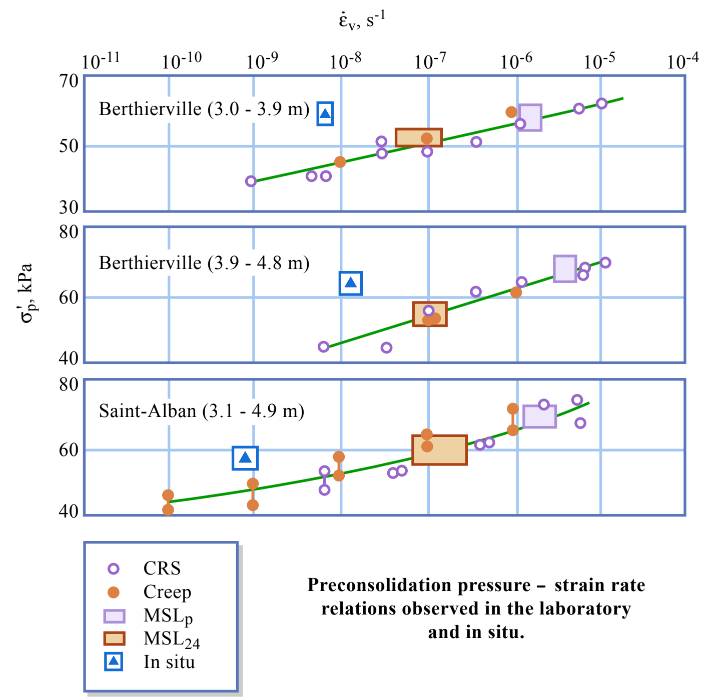




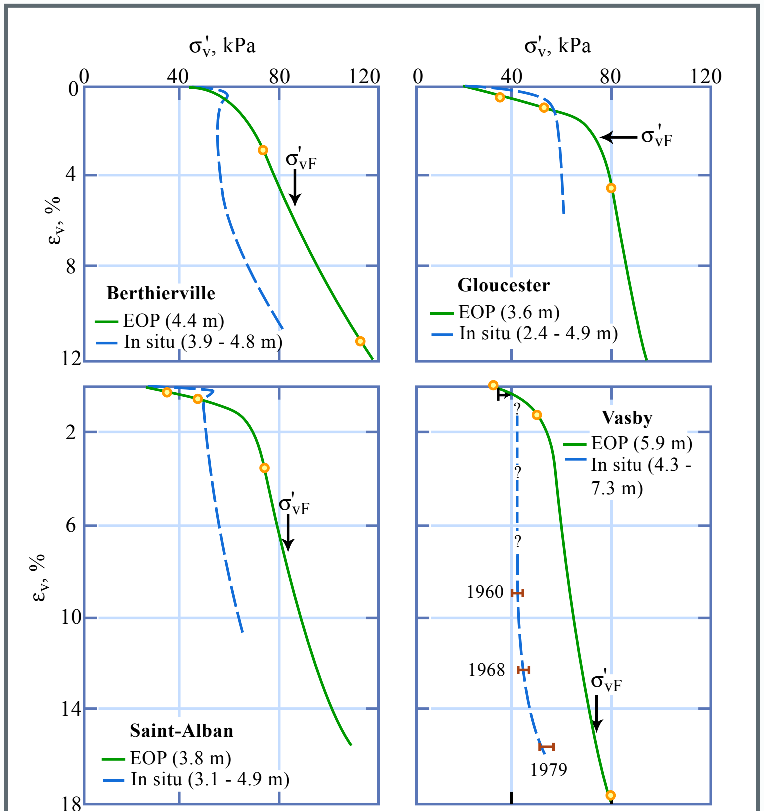
CCL would use Hyp. B for Champlain clays



Effective stress – strain rate relations observed in the laboratory and in situ at a vertical strain of 10%.



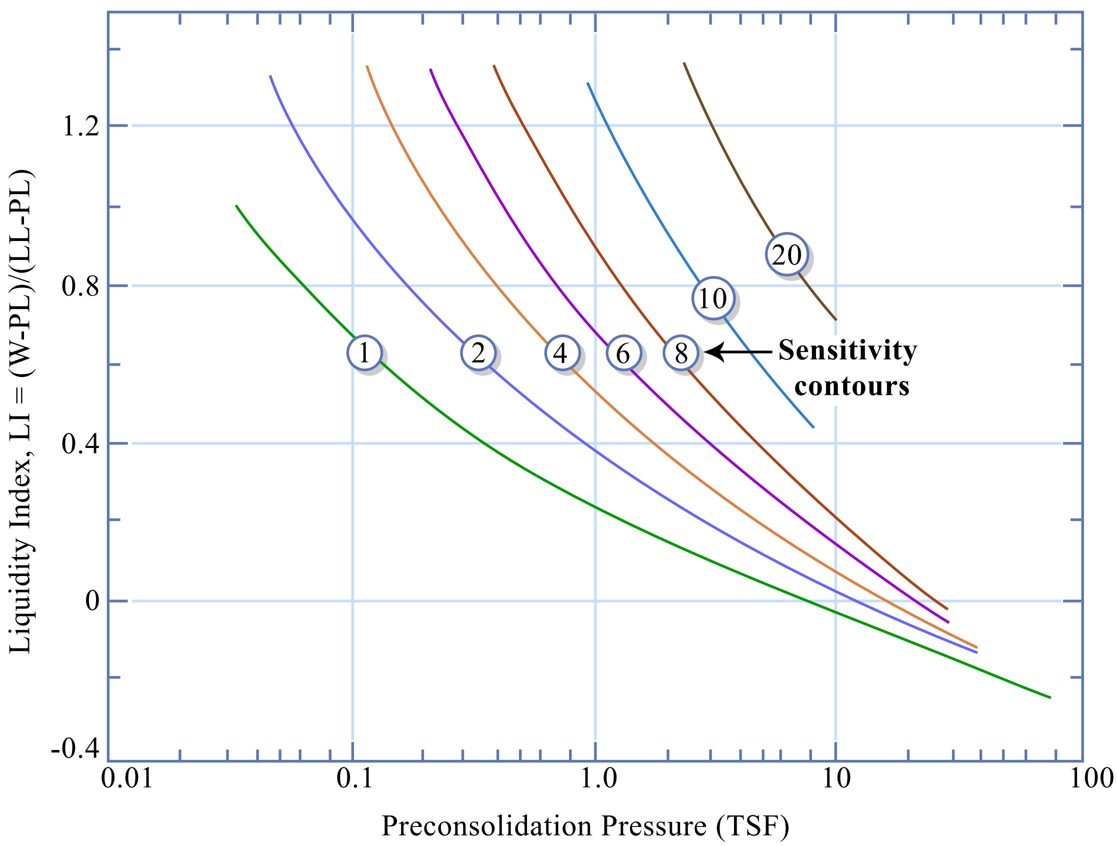
Preconsolidation pressure – strain rate relations observed in the laboratory and in situ.



Comparison of in situ stress-strain curves & laboratory end-of-primary compression curves

Figures by MIT OCW.

(after Leroueil *et al.* 1988b).



Preconsolidation Pressure vs. Liquidity Index

Figure by MIT OCW.

Adapted from: NAVFAC DM 7.1 Soil Mechanics May 1982

1) CCL has no idea of the reliability of this correlation

2) Most Champlain clays plot above this correlation, e.g. Lefebvre et al (1987) JGE, 113(5), 476-489 for 5 clays

Clay	I_L	σ'_p (bar)	S_t
GB #12	2.85	1.1	>300
" #39	2.85	1.9	500
NBR B6	1.8	1.45	100
" B6	2.5	1.75	450
St J.V.	1.4	9.4	100

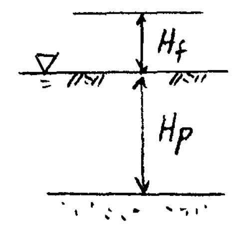
1. Introduction

- Characterized by: (Often) Low σ_p' & c_u
  Low E_u & highly creep susceptible
  High compressibility, CR
  $C_\alpha / CR \simeq 0.07 \pm 0.02$ (P4a, Table 1 & Fig 10)

- Example - Typical NC deposit

  $\rho > H_f$ for $H_f \le \frac{1}{2} H_p$

  e.g. 20' peat, 5' fill → ρ below WT



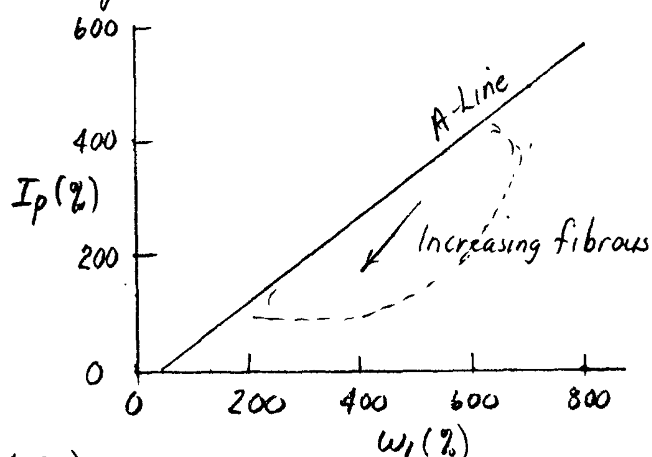
2. Classification & Index Properties

1) Types (Muskeg Eng. Handbook, 1969)

Fine Fibrous (grassy)	↑ w_N	400 - 1500%
Course Fibrous (woody)		
Amorphous - granular		200 - 500%

2) Plasticity Chart

Difficult to obtain w_p

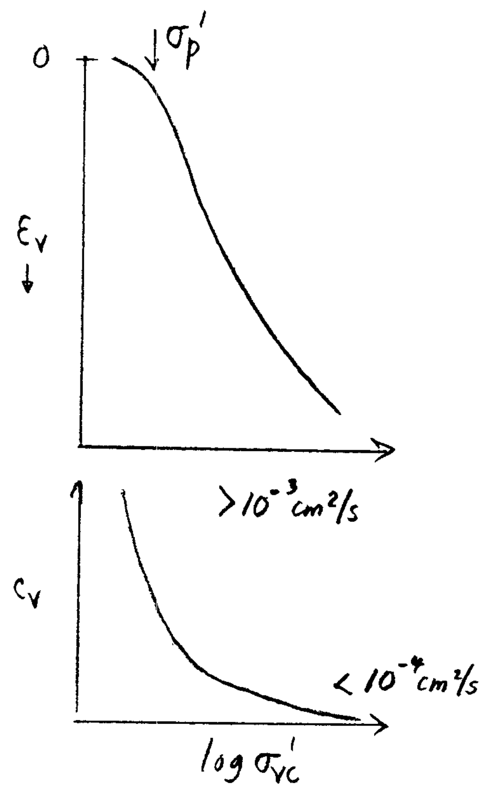


3) Correlations with w_N (P3)

- Increasing w_N corresponds with increasing OM - best via chemical analysis
  - burn at 440 or 750°C (ASTM D 2974) → higher values
- Increasing OM → decreasing G_s
- Typical unit weights

w_N (%)	γ_t (TCM)	σ_{v0}' at $z = 5$ m
300	1.15	0.75 TSM = 155 psf = 7.5 kPa
1000	1.03	0.15 " = 30 psf = 1.5 kPa

3. Consolidation (1-D): General Behavior



Compressibility

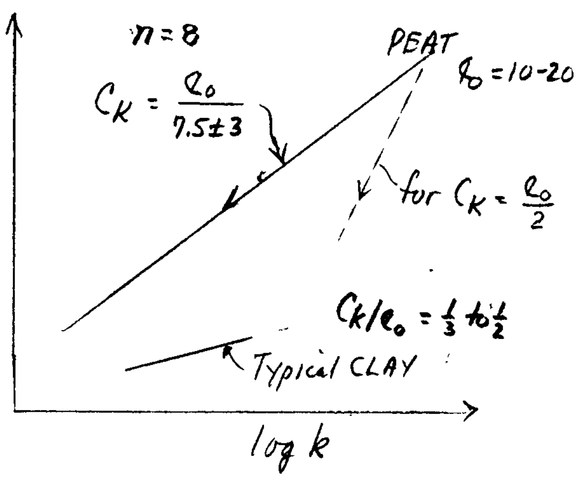
- Often low σ_p'
- See P4 for w_N vs CR → 0.5 ± 0.1 typical (top) (Also P4a, Fig. 1) w_N = 200-1000%
- Usually S-shaped

Coefficient of Consolidation (DM-7 NG)

- c_v decreases substantially (often 1-2 orders of magnitude) (see P4 bottom)

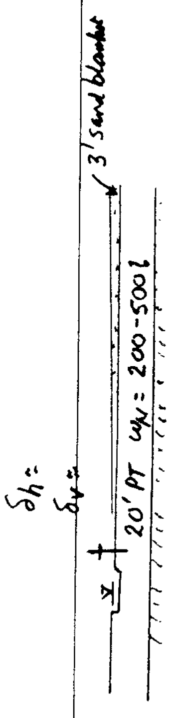
Coefficient of Permeability

Lefebvre et al. (1984)



* k decreases more rapidly with decreasing e than for inorganic clay

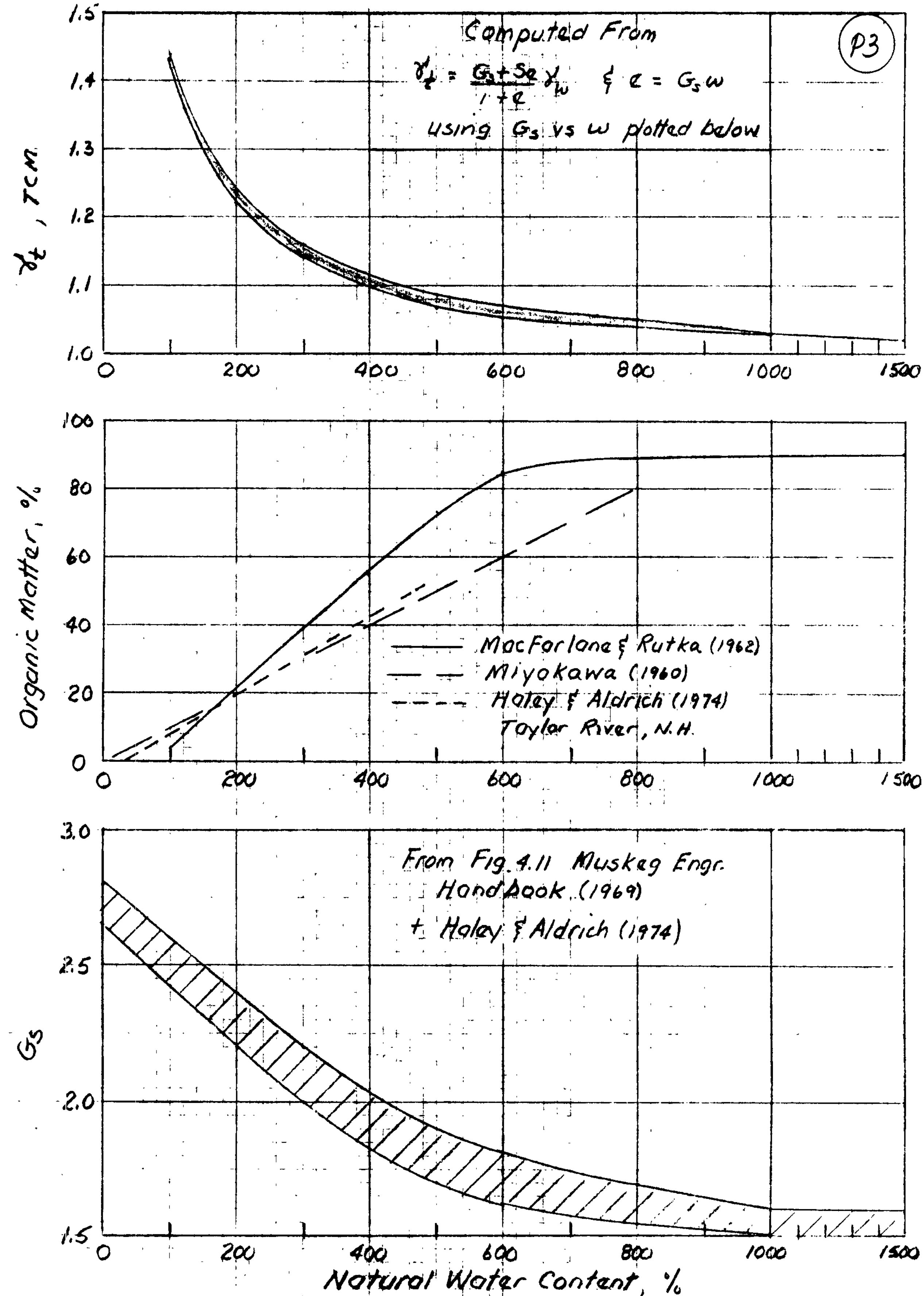
e ≈ 15 $k = 10^{-5}$ cm/s non-plastic SILT
≈ 3 " 10^{-8} " CH CLAY



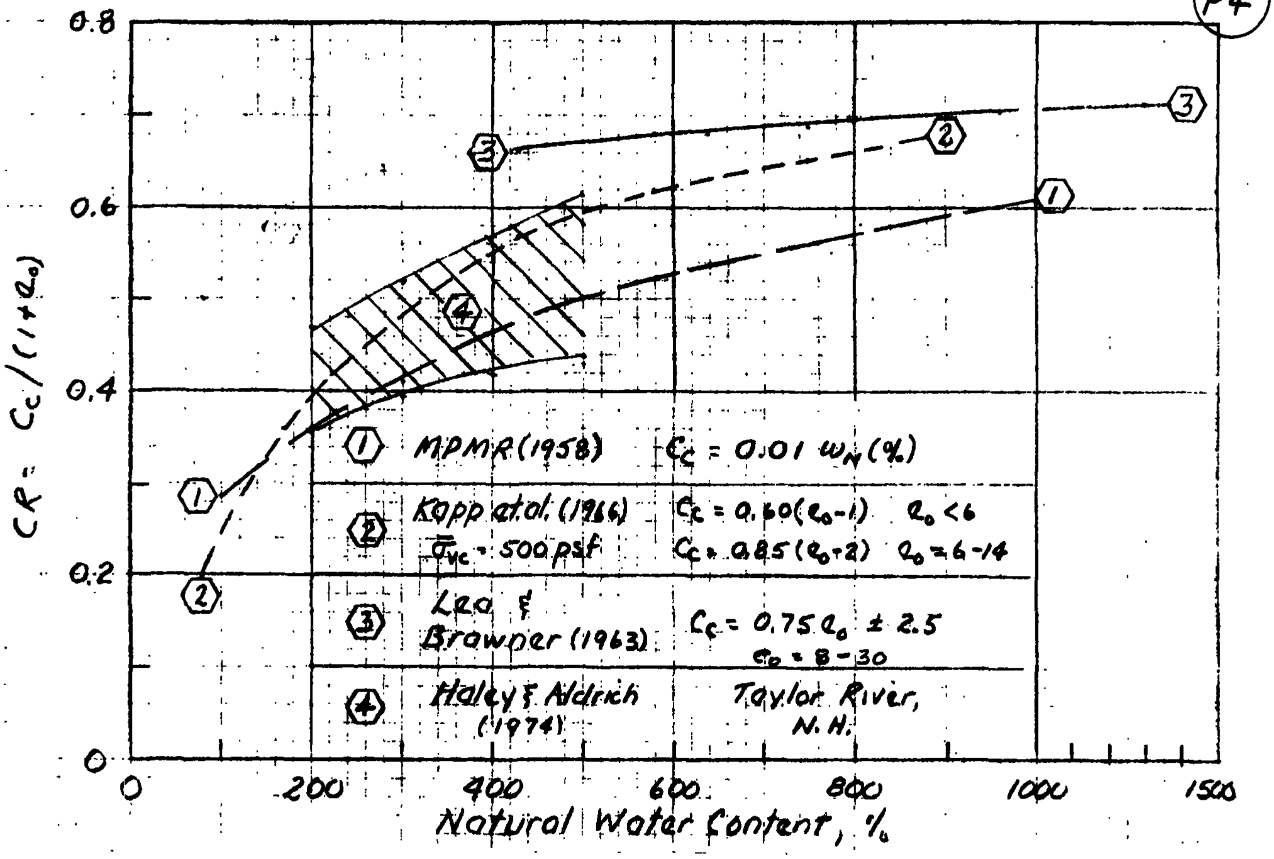
4. Estimating Field Settlements

See P4a for data on e_c vs w_N, C_k vs e_0 & C_α/C_c

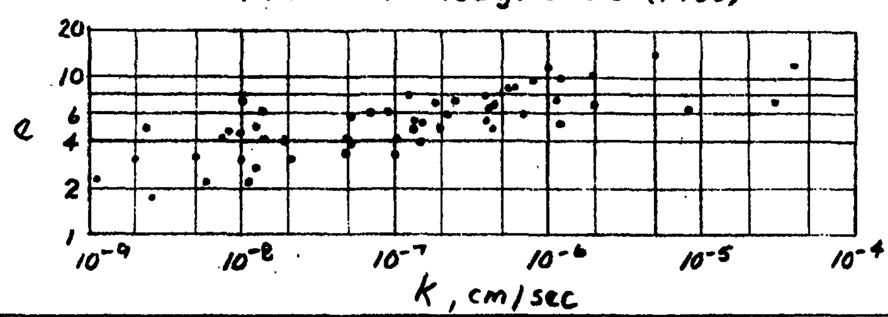
1) V. rapid consolidation at very low σ_{vc}' ∴ ρ_s can be very important
2) Major jobs warrant non-linear, finite strain (due to large ΔH_d) (input $e - \log \sigma_{vc}' - \log k$)
3) Simplified approach $t_f = t_e \left(\frac{H_f}{H_e}\right)^n$ $n \approx 1.3 \pm 0.2$ (vs. Terzaghi n=2)
4) See P5 for reduction in σ_{vc}' due to 1-D settlement
5) WATCH OUT FOR LARGE LATERAL DEFORMATIONS (Taylor River)

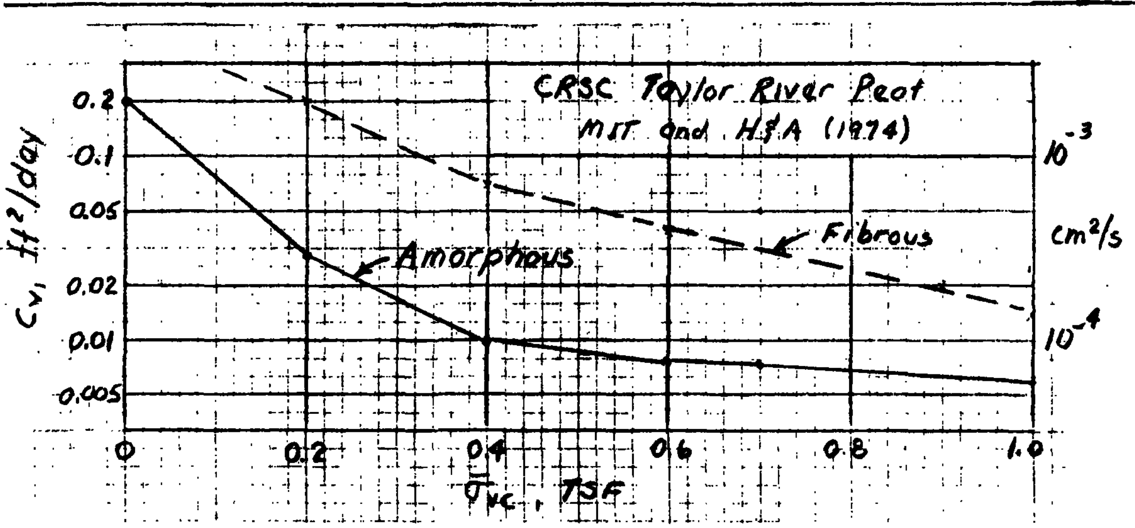


INDEX PROPERTIES OF PEAT M.I.T. 1.322 3/74



From L. Casagrande (1966)

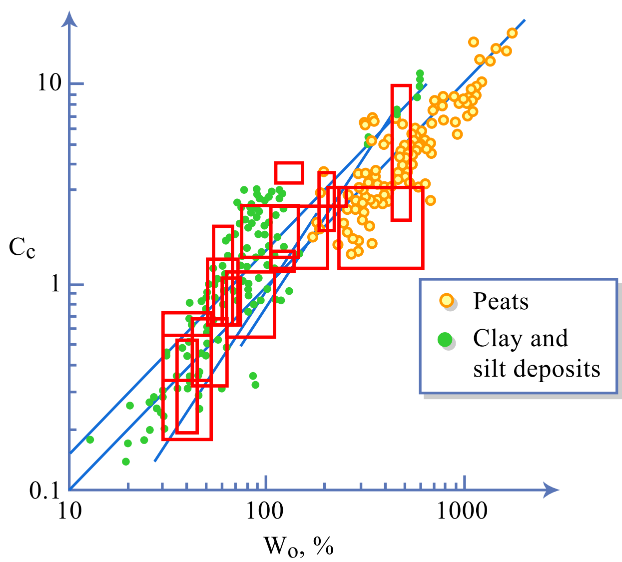




ENGINEERING PROPERTIES OF PEAT

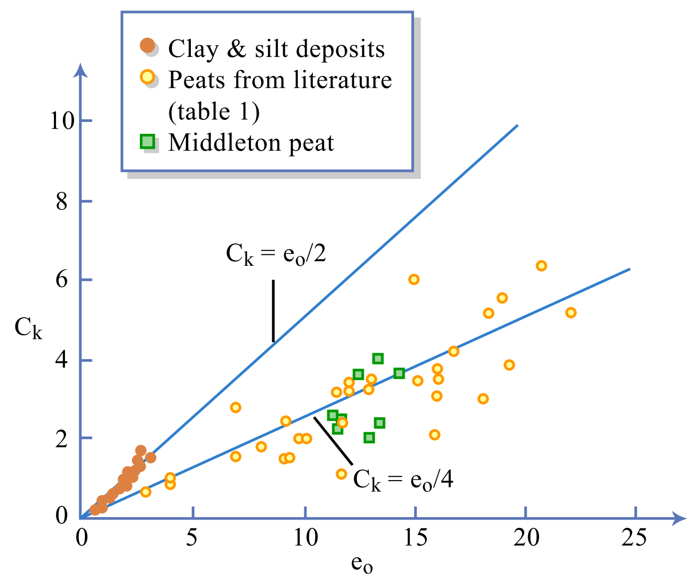
TABLE 1. Values of Natural Water Content, w_o, Initial Vertical Coefficient of Permeability, k_{vo}, and C_α/C_c for Peat Deposits

Peat (1)	w_o % (2)	k_{vo} m/s (3)	C_α/C_c (4)	Reference (5)
Fibrous peat	850	4×10^{-6}	0.06–0.10	Hanrahan (1954)
Peat	520	—	0.061–0.078	Lewis (1956)
Amorphous and fibrous peat	500–1,500	10^{-7}–10^{-6}	0.035–0.083	Lea and Brawner (1963)
Canadian muskeg	200–600	10^{-5}	0.09–0.10	Adams (1965)
Amorphous to fibrous peat	705	—	0.073–0.091	Keene and Zawodniak (1968)
Peat	400–750	10^{-5}	0.075–0.085	Weber (1969)
Fibrous peat	605–1,290	10^{-6}	0.052–0.072	Samson and LaRochell (1972)
Fibrous peat	613–886	10^{-6}–10^{-5}	0.06–0.085	Berry and Vickers (1975)
Amorphous to fibrous peat	600	10^{-6}	0.042–0.083	Dhowian and Edil (1981)
Fibrous peat	660–1,590	5×10^{-7}–5×10^{-5}	0.06	Lefebvre et al. (1984)
Dutch peat	370	—	0.06	Den Haan (1994)
Fibrous peat	610–850	6×10^{-8}–10^{-7}	0.052	Present study (1997)



Values of natural water content and compression index for peats as compared to those of soft clay and silt deposits.

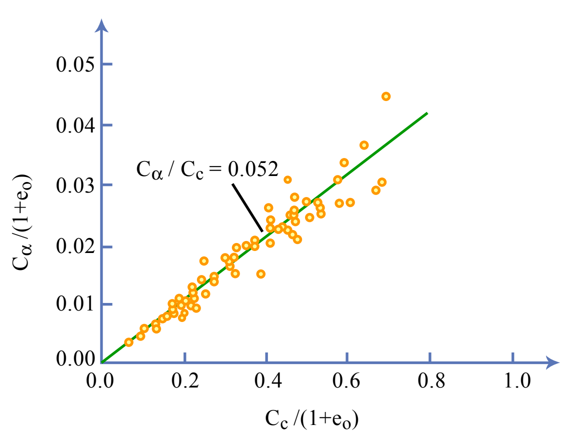
Figure by MIT OCW.



Values of C_k for peats as compared to those of soft clay and silt deposits.

Figure by MIT OCW.

Adapted from: **Mesri and Rokhsar (1974); Mesri et al. (1994); Watanabe (1977)**



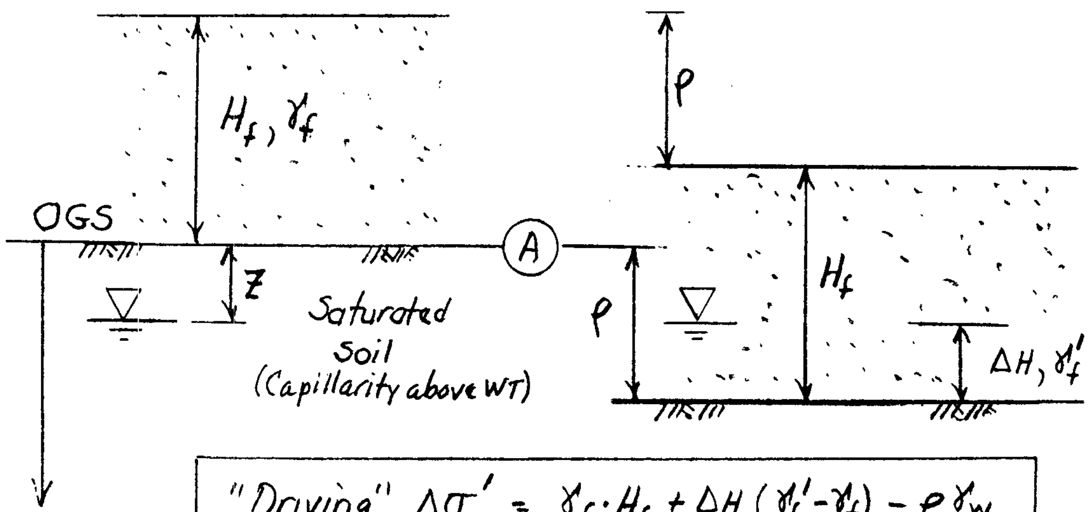
Relationship between secondary compression index and compression index for Middleton peat.

Most comprehensive study of secondary compression behavior of peat (NC & OC), plus other "goodies"

Figure by MIT OCW. Adapted from: Mesri et al (1997) JGGE 123(5)

Influence of Large Settlement on Consolidation Stress

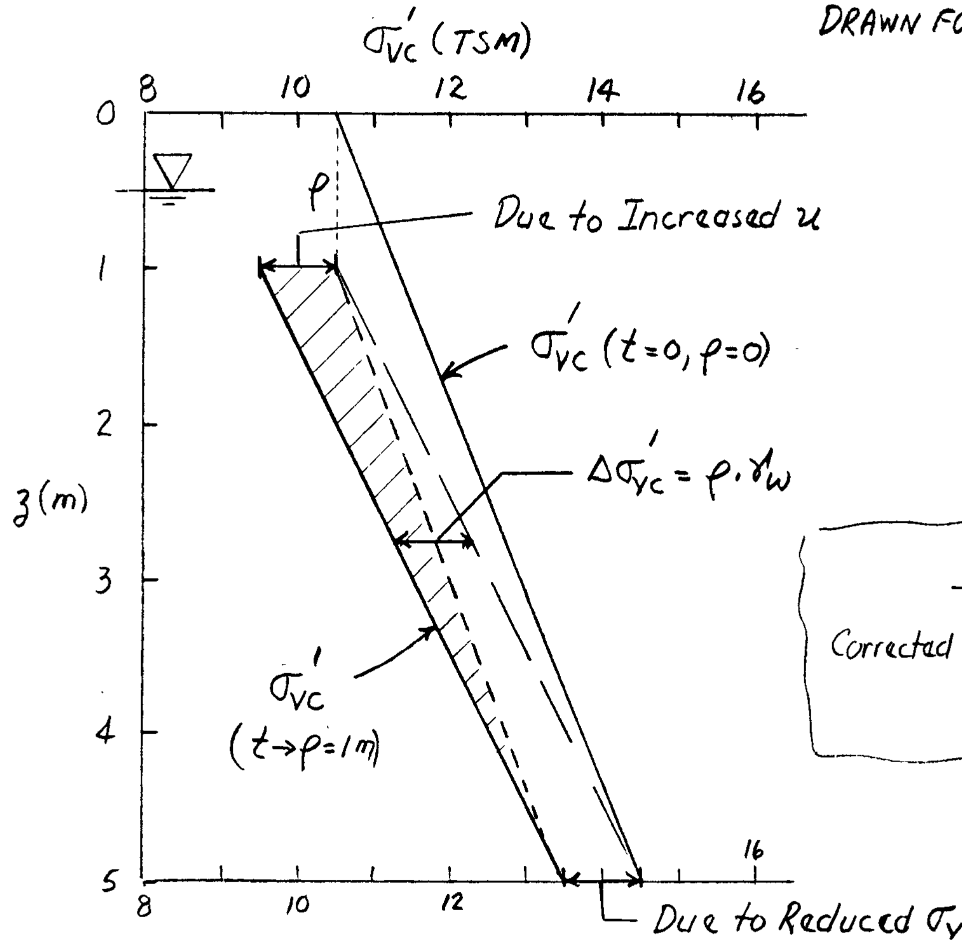
INITIAL CONDITION (t=0) — WITH SETTLEMENT ρ



$$\text{"Driving"}\ \Delta\sigma_{vc}' = \underbrace{\gamma_f \cdot H_f + \Delta H(\gamma_f' - \gamma_f)}_{\Delta\sigma_v \text{ at (A) = bottom of fill}} - \rho\,\gamma_w$$

$$\text{"}\ \Delta\sigma_v - \Delta u$$

DRAWN FOR: $H_f = 5m$
$\gamma_f = \gamma_f' = 2TCM$
$z = 0.5m$
$\rho = 1.0m$
$\gamma_b = 0.8TCM$

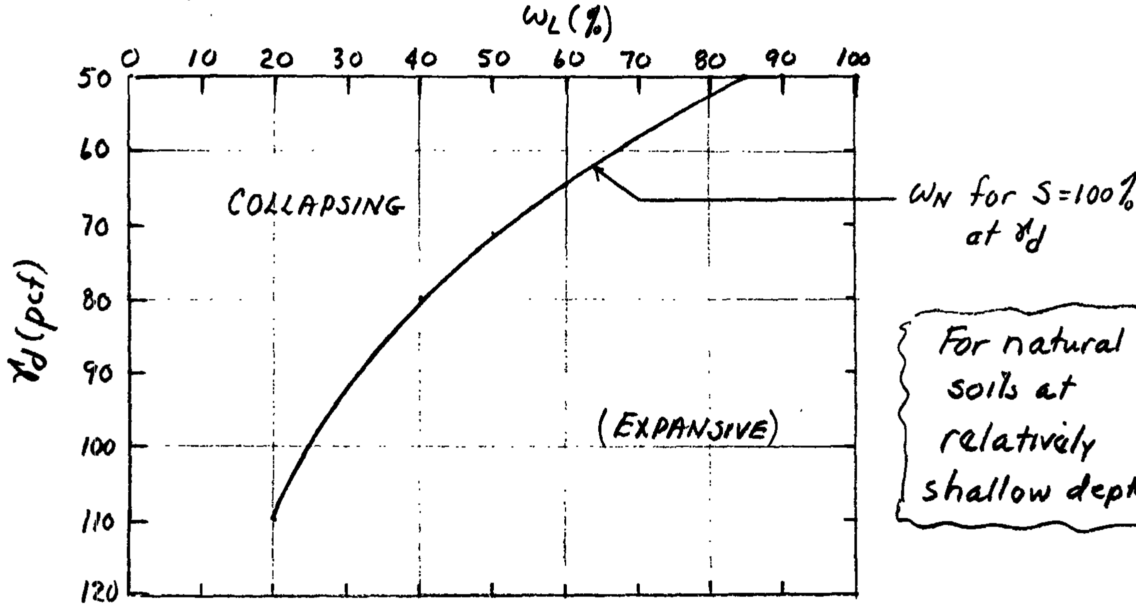


Constant m_v

$$\text{Corrected } \rho_{cf} = \frac{\rho_{cfo}}{1 + \rho_{cfo}\frac{\gamma_w}{\Delta u}}$$

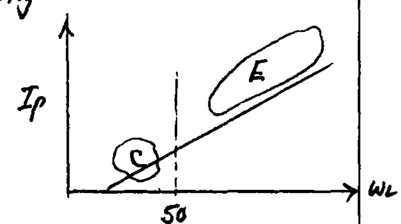
1. Introduction

- Occurs when some <u>partially saturated</u> soils have "free" access to water ((Say $S < 50\text{-}75\%$))
- Holtz & Hilt (1961)



For natural soils at relatively shallow depth.

- Low γ_d & low I_p : $w(S=100\%) > w_L \rightarrow$ collapsing
- High γ_d & high I_p : $\rightarrow$ expansive

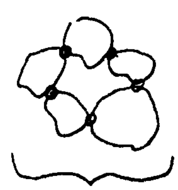


2. Collapsing

1) Index properties → ML, CL-ML & CL (all low I_p)

   LOESS (wind blown silty soil) + sometimes mudflows, alluvial, residual

2) Structure o = "bonding"



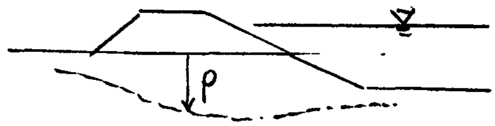
Natural "dry" state

- Carbonates
- dry clay
- capillarity

} adding H_2O weakens/destroys bonding

3) For cuts in Loess - use <u>vertical</u>, because sloping will → alot erosion

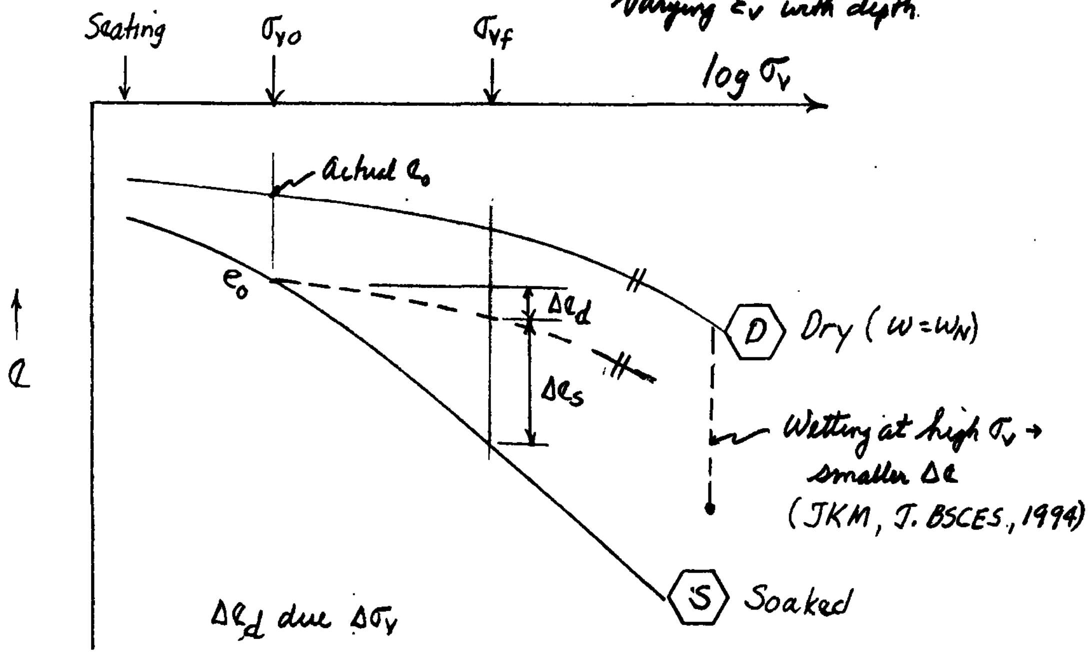
3) Example : San Joaquin Valley, CA : $\rho \rightarrow 15'$! (Dudley, 1970)



Canal for water supply

4) Estimating Settlements

- Boring with undisturbed sampling : MUST USE ___ HOLE
- "Double Oedometer" (Clemence & Finbarr 1981)
  ↑ For homogeneous deposit, one pair to tests can be used to predict varying ε_v with depth.



Δe_d due $\Delta\sigma_v$

Δe_s due saturation = "collapse"

$$\rho = \Sigma\left[H_i \left(\frac{\Delta e_d + \Delta e_s}{1+e_0} \right) \right]$$

(Paper used soaked e_0 to be conservative; also use of D & S curves tends to overpredict ρ)

"Environmental Stress Path Testing"

↓

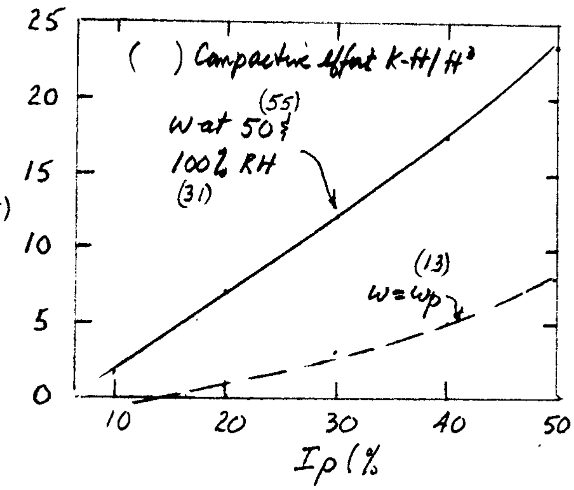
Better procedure is to load dry & then add H_2O at each depth

3. Expansive Clays

1) General Conditions & Scope of Problem

- CH Clays (usually significant smectite content) in climate where rate of evaporation greatly exceeds rate of rainfall, i.e. clay starts out in desiccated condition with low degree of saturation

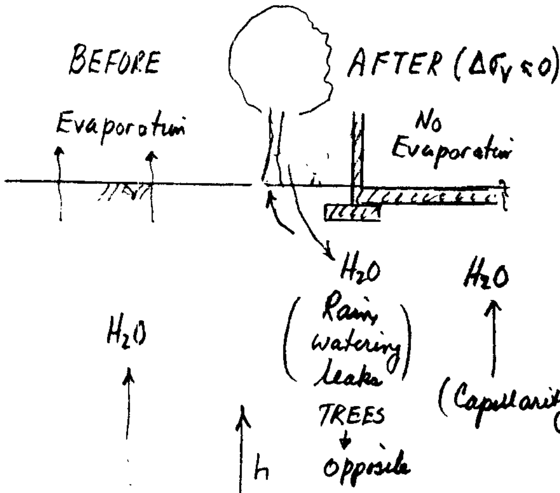
- Ladd & Lambe (1961): Fig. 1

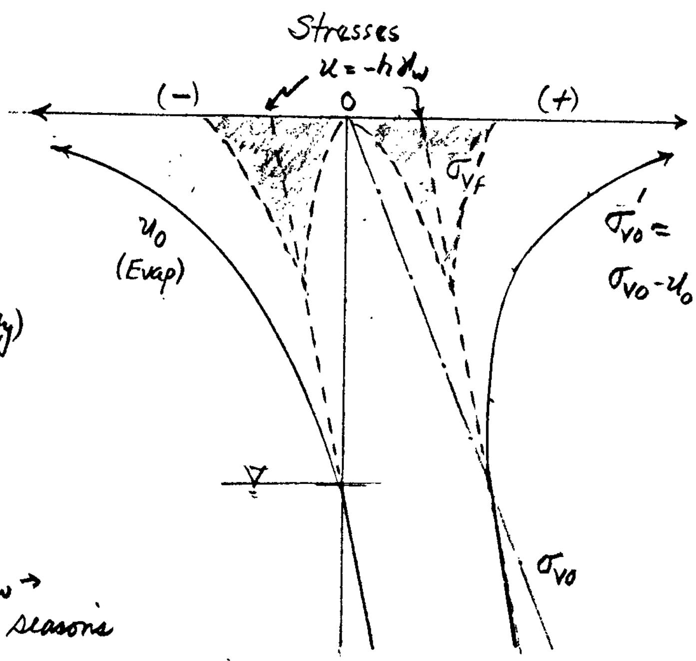


NRC (1984) Comm. Ground Failure Hazards

- \$5-10 B/yr damage in US to homes, buildings, roads & utilities (several times > than Σ floods + hurricanes + tornadoes + earthquakes!)
- In 20% of US, 10% of new homes suffer severe damage due to poor or no geot. engr.

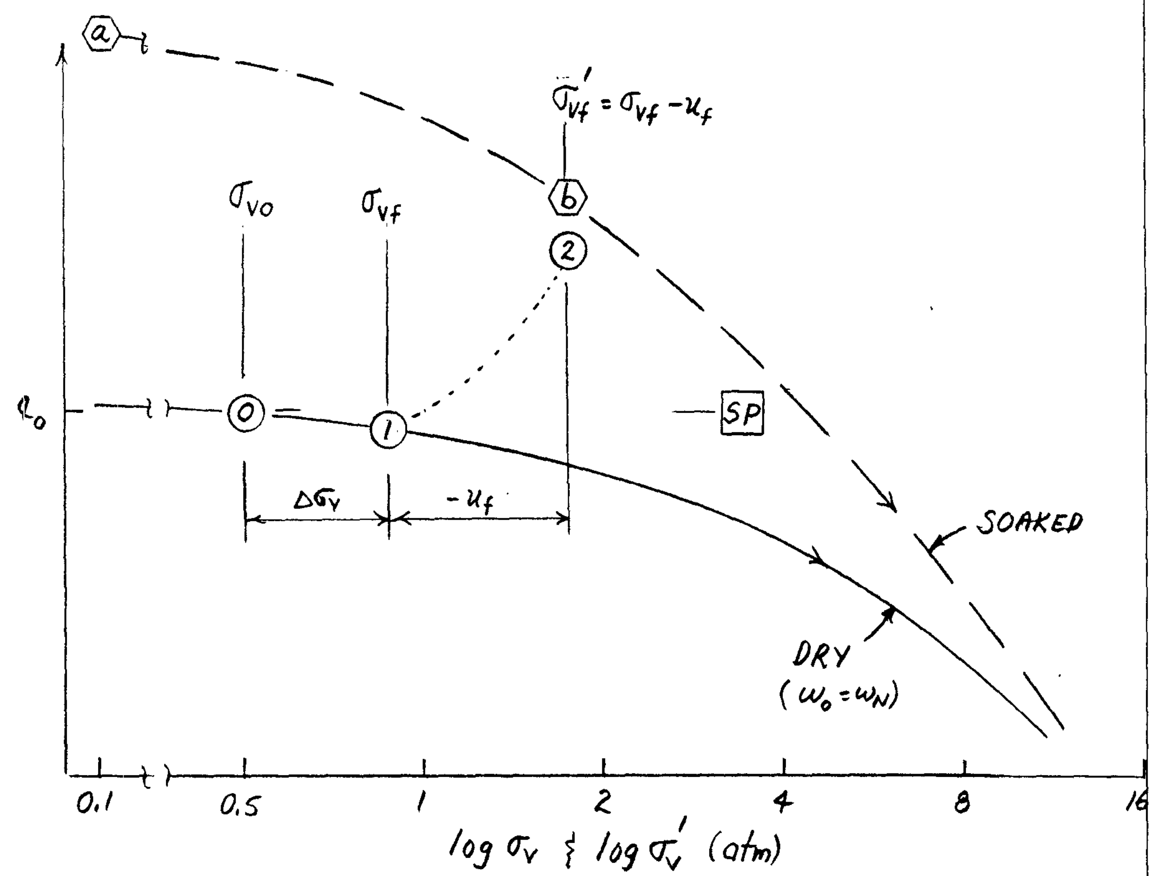
2) Illustration of $\Delta\sigma'$ Due to Construction





NOTE: Varying $u_f \gtrless -h\gamma_w$ → shaded zone due to seasons

3) "Environmental Stress Path Testing" (Sampling in DRY hole)



Steps (At each depth)

- Start with DRY sample ($w = w_N$)
- Apply σ_{vo} & σ_{vf} : $e_1 - e_0 = -\Delta e$ due to applied load
- Add water plus increase stress to σ'_{vf} : $e_2 - e_1 = +\Delta e$ due to swelling

(• SP = Swell Pressure to prevent swelling at e_0) Heave $\varepsilon_v = \dfrac{e_2 - e_1}{1 + e_1}$

4) Double Oedometer (Jennings & Knight, 1957, 4[th] ICSMFE)

- Duplicate samples: use results at varying depth
- One loaded DRY to get $-\Delta e$ due to $+\Delta\sigma_v$
- Other SOAKED at seating stress → ⓐ (≈ 0.1 atm)
- Predicted final e at ⓑ

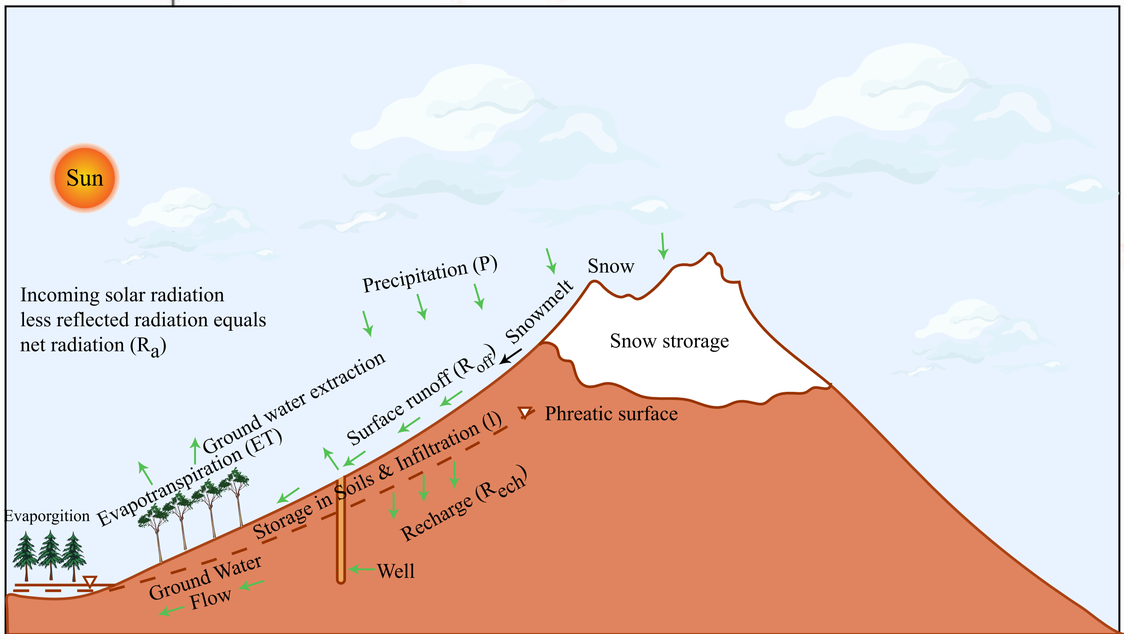
NOTE: Estimation of u_f a problem with both methods.
Assuming $u_f = 0$ → most unfavorable condition → maximum heave, but neglects seasonal Δu_f that can cause increased damage

A EFFECTS OF CHANGES IN CLIMATE (Seasonal Wetting & Drying)

1. Climatic Changes

Blight (1997) Rankine Lecture
Geot. 47(4)

a) Components of water balance



Components of the soil water balance.

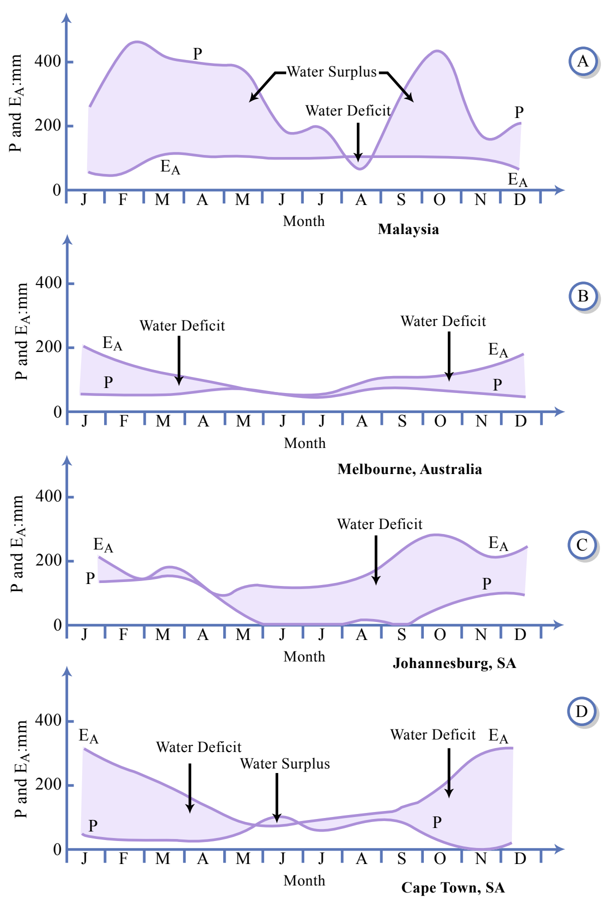
- Complex
- * Precipitation (P) − (Intercepted + Runoff) } Input

"

- * Evapotranspiration (E_A) + Recharge (flow to W.T.) + Change Soil Water Storage } Output

b) Examples: Rainfall vs Evaporation

Worse case = wet season with alot of rain and very dry season (hot & dry).



Illustrations of different types of atmospheric water balance: (A) Kuala Tahan, Malaysia, 1984; (B) Melbourne, Australia, 30-year average; (C) Johannesburg, South Africa, 1987; (D) Cape Town, South Africa, 1992. E_A, A-pan evaporation; P, precipitation.

Figures by MIT OCW.

Adapted from: (Blight 1977)

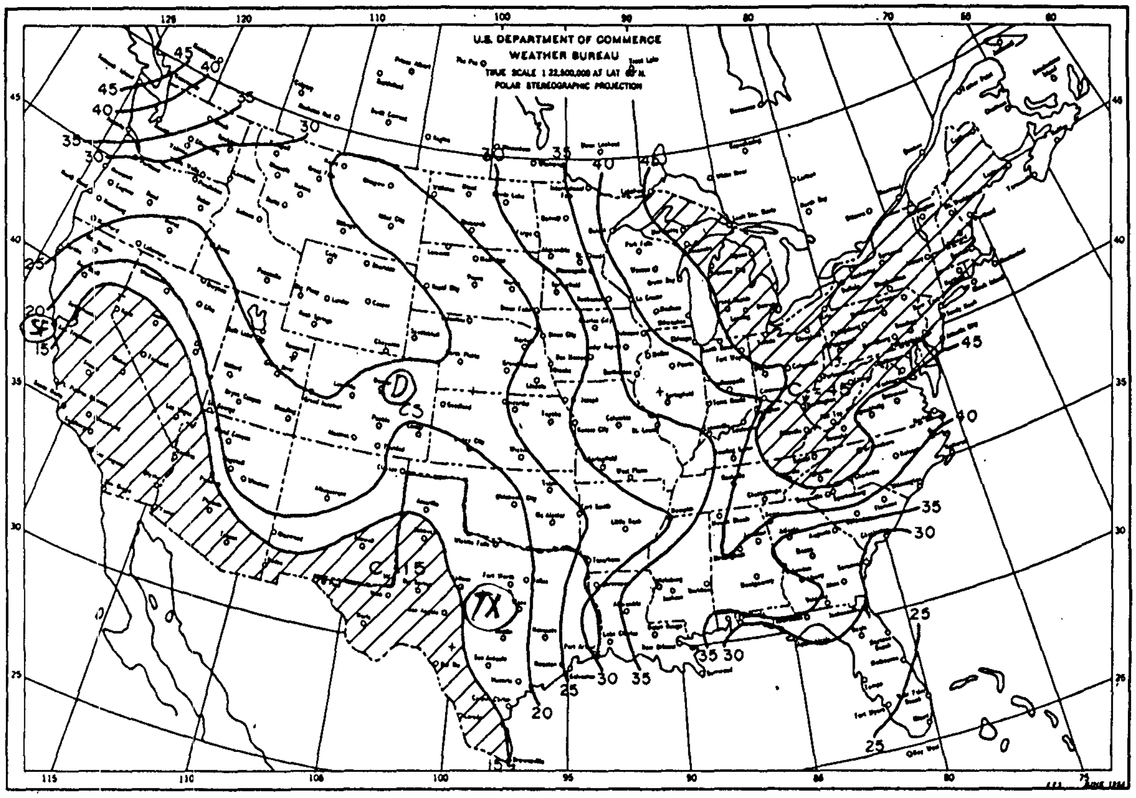
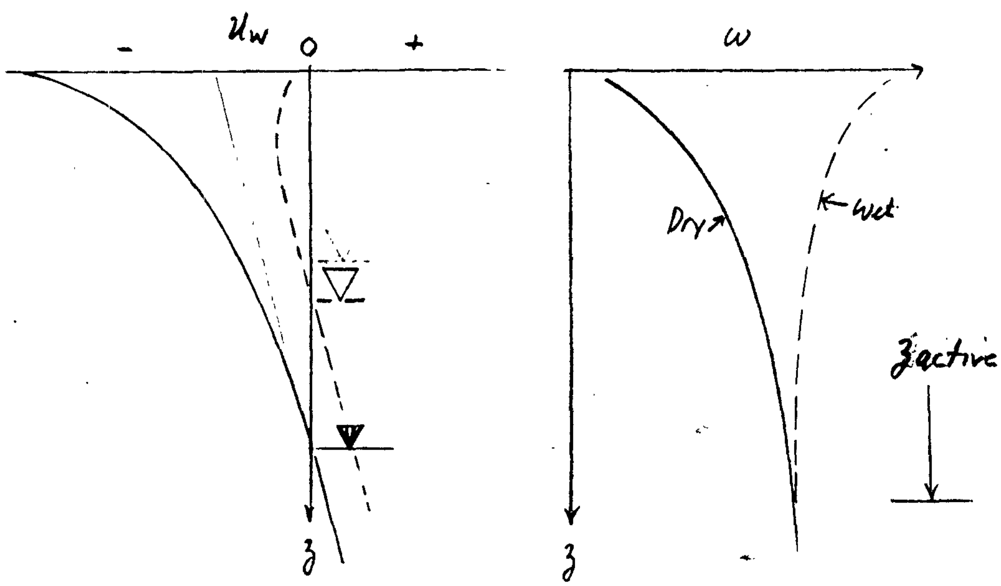


FIG. 1 Climatic Ratings (C_w) for Continental United States (NRC Report 1968)

Severe problems: San Francisco area, Denver, Texas, etc.
Increasing $C_w \Rightarrow$ high P/E_A ; $C_w \approx 20 \pm 5 \rightarrow$ seasonal damage

2. Active Zone = Depth of "seasonal" change in water content → cycles of swelling & shrinkage

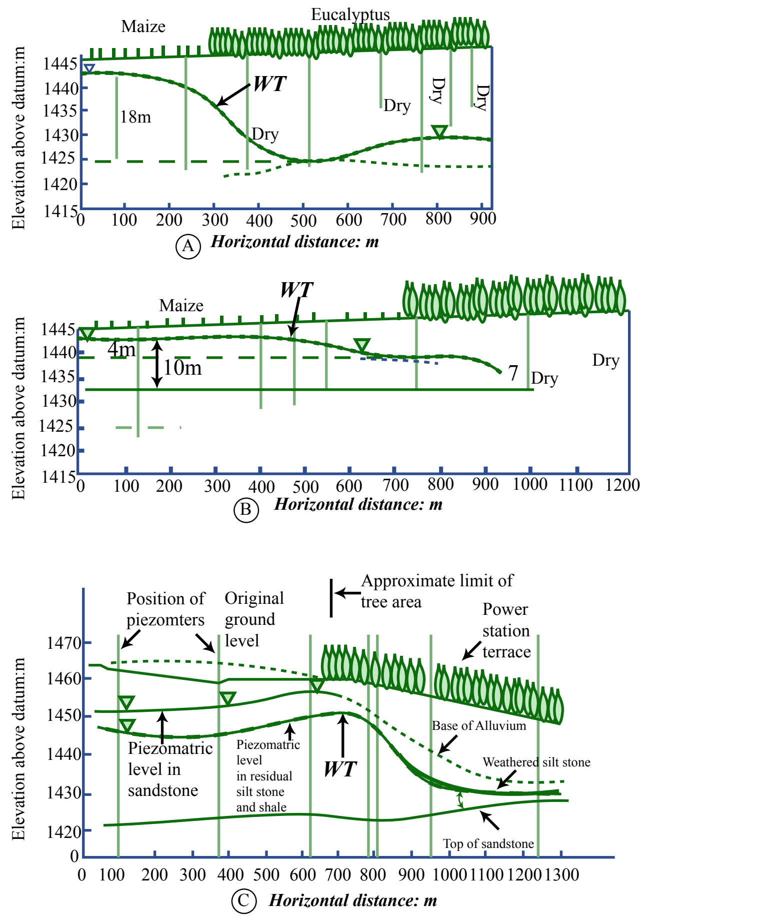
▼—— Dry
▽- - - Wet



3. Some Examples (Blight 1997)

a) Trees → depressed water table
+ also increase amt of drying during dry season

- Effect extends to 3/4 ± 1/4 × tree height horizontally
- Depth >> depth of roots
- Why trees do this?



(>20m)

(≈10m)

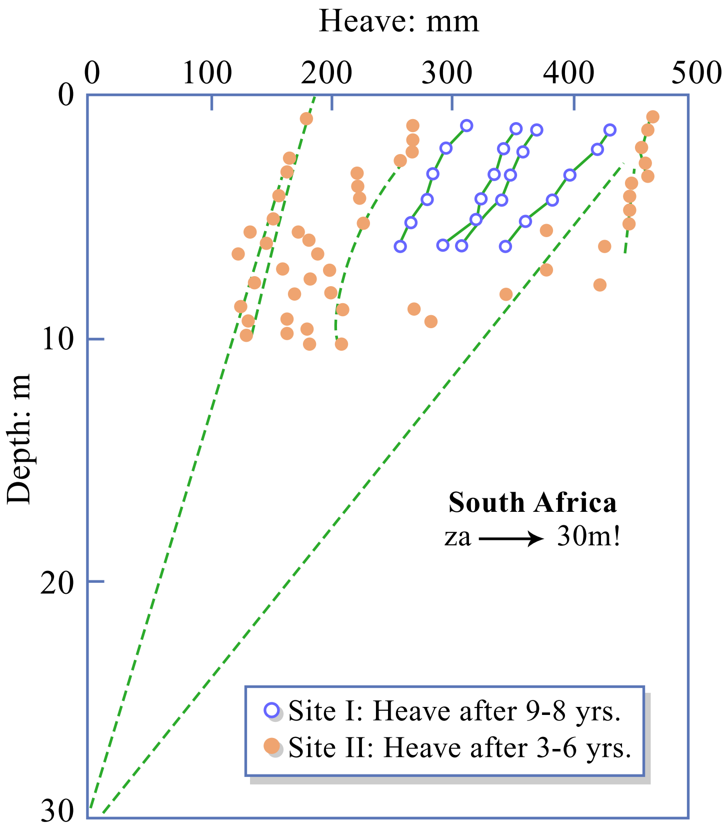
(≈15m)

Water table depression beneath eueatyptus plantations: (a, b) near Johannesburg; (c) at the site of a power station near Johannesburg.

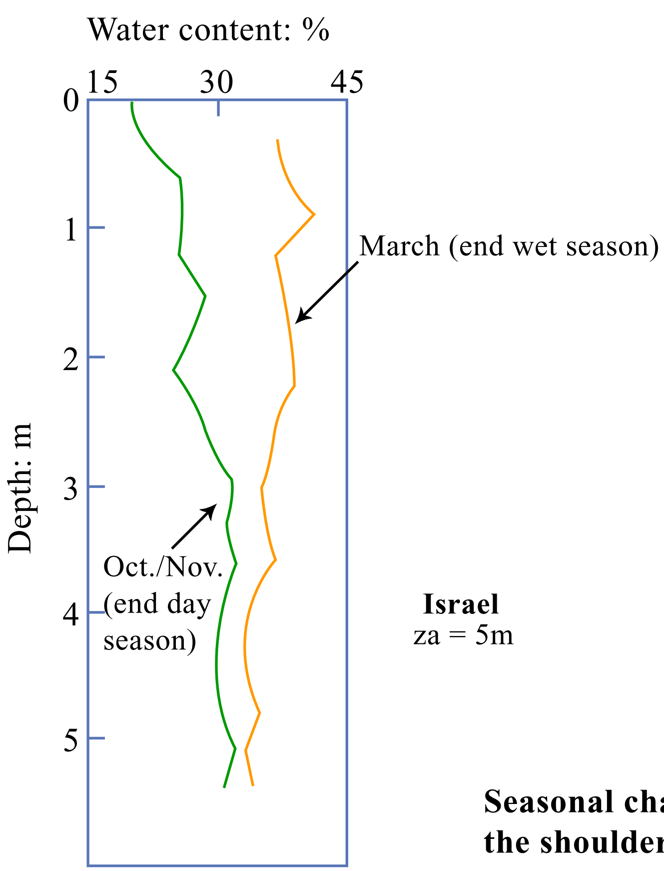
- - - Plazometers
...... Bedrock
▽ Water cable

Figure by MIT OCW.
Adapted from: (Blight 1977)

b) Depth of Active Zone (z_a)



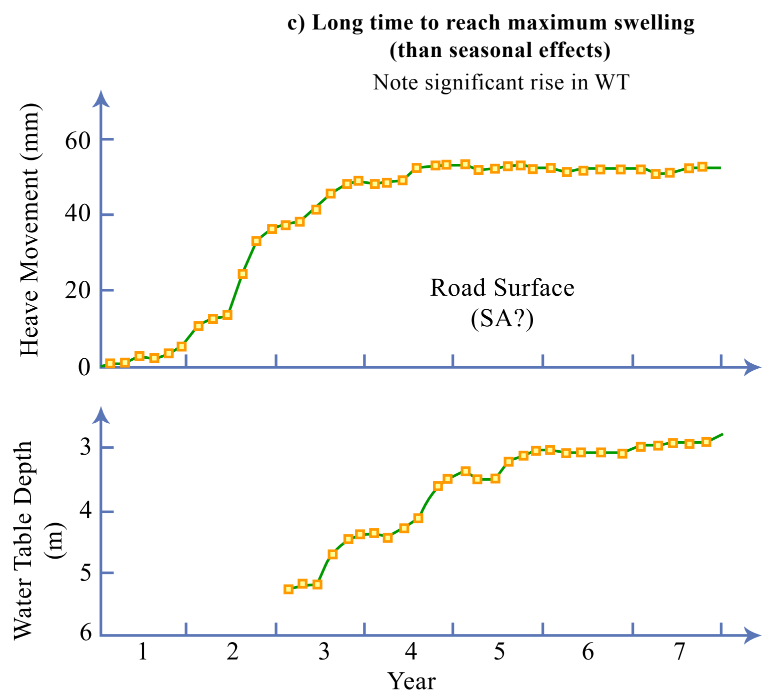
Measurements of heave with depth, indicating a depth of active zone of about 30m.



Seasonal changes in water content observed under the shoulders of an airport pavement in Israel.

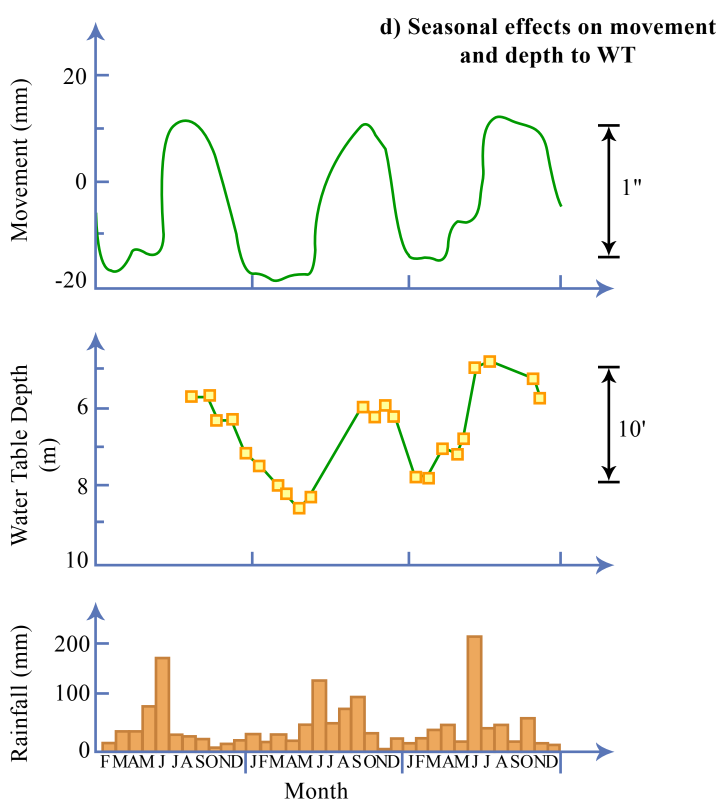
Figure by MIT OCW.

c) Long time to reach max. swelling (than seasonal effects)
. Note significant rise in WT



Surface heave movements and a rise of the water table that occurred as a new water balance was established in a recently urbanized area

d) Seasonal effects on movement and depth to WT

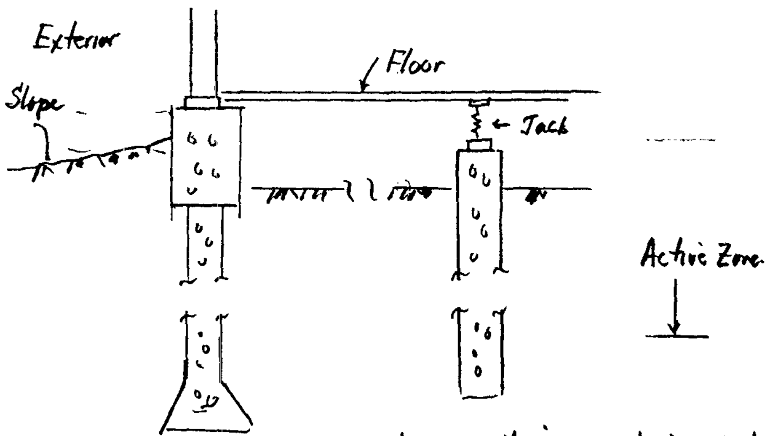


Seasonal variations in surface movement and water table depth for an old building in Cap Town

Figures by MIT OCW.

B. FOUNDATION DESIGN ON EXPANSIVE SOILS

1. Best Solution = Isolate Bldg from Active Zone → Piers + Grade Beams



NOTE: Do NOT attach structures to bldg such as fences, patios, etc.

Must have sufficient embedment to resist uplift forces due to swelling soil around piers

2. Partial Solutions

a) Prewet fdn soils – but will not help with seasonal wetting/drying
⇒ poor practice

b) Prestressed slab – at minimum, replace upper soils with granular fill
– add cut-off wall around perimeter to reduce seasonal effects

Reference: Book by Nelson & Miller (1992) Expansive Soils: .... J. Wiley

1. Background

1) Residual Soil = in situ weathering of rock → soil (see R5,6)

2) Composition in WARM-WET climates (see R2)

- Crystalline rock + poor drainage → smectile
- " " + good " → red laterites (iron oxides)
  - Usually cemented
  - Considered "good" ML-MH soil
- Volcanic ash & rock → andisols
  - Generally high $w_N - I_p$ → "poor" MH soil

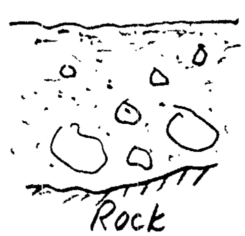
Saprolite: retains structure of parent rock

2. Comments on Engineering Practice

1) Index Properties (see R2,3)

- Can't use empirical correlations based on sedimentary clays
- Results = f(preparation method)

2) Structure & Resultant Problems (R3, 5 & 6)



- Extremely heterogeneous: fine grained at top → mostly rocks at bottom
- Can't sample for meaningful lab testing
- Usually high in situ k

3) Estimates of Settlement

- Local experience
- In situ testing via SPT or Menard Pressuremeter (R4) or PLT (costly) or DMT (if can insert)

4) Slope Stability (R3)

- Increased %S during rainfall → failures   Hong Kong, California Bay area
- Definition of $\bar{\sigma} = f_1(\sigma - u_a) + f_2(u_a - u_w)$
  (For compacted clays, often use $f_1 = 1$, $f_2 = \chi$)

(R2)

TROPICAL RESIDUAL SOILS*

C.C. Ladd 1.322 3/82

1.0 DEFINITIONS AND SPECIAL COMPOSITION

1.1 Tropical = ±22° N-S

Residual soil = in situ weathering of rock to produce soil.

1.2 Composition of Tropical Residual Soils in Warm-Wet Climates

(1) Crystalline rock and poor drainage → smectite

(2) Crystalline rock and good drainage → Red Laterites (also called Oxisols)

- Kaolinite plus Fe/Al. oxides (reddish color)
- Low "activity" with a lot of cementation
- Considered "good" MH soil

(3) Weathering of volcanic ash/rock → Andisols

- Halloysite (tubes + spheres) plus amorphous alumina & silica (very high SSA but low surface charge) and maybe smectite (usually dark color)
- Generally high w_N and P.I.
- Considered "poor" MH soil

2.0 CHARACTERISTICS OF RED RESIDUAL SOILS (LATERITES) WHICH OFTEN REQUIRE DIFFERENT ENGINEERING PRACTICE (Compared to saturated sedimentary clays).

2.1 Index Testing and Correlations with Atterberg Limits (See Mitchell & Sitar, 1982, for examples).

(1) Halloysite

- Tubular structure → very low dry density
- Dehydration when dried

(2) Fe & Al. oxides plus silica gel act as strong cementing agents.

- Decreases effective SSA
- Highly variable in situ

---

* Panel discussions and Proceedings ASCE GED Spec. Conf. on Engr. and Construction in Tropical and Residual Soils, Honolulu, Hawaii, Jan. 1982 (Available from ASCE).

(R3)

(3) Drying soil generally increases amount of cementation and reduces plasticity.

(4) Amount of mechanical remolding can greatly affect measured Atterberg Limits (more remolding → increased plasticity).

(5) Conclusions

- Can't use empirical correlations developed for temperate clays
- Any correlation with index properties likely to be very scattered

2.2 Heterogeneity

(1) Profile characterized by differential weathering and cementation. See Brand (1982) for classification system for Hong Kong.

(2) Because of above, properties highly variable and

- Undisturbed sampling difficult to perform
- Conventional size samples don't reflect mass properties

(3) Conclusions

- Base design on local experience and/or large in situ testing

2.3 Saturation - Rainfall

(1) Strata of main interest usually occur above the water table and are characterized by:

- Partial saturation
- Generally high in situ permeability

(2) How to define $\bar{\sigma}$ in partially saturated soils?

- If $S \geq 80\%$, $\bar{\sigma} = \sigma - u_w$ probably reasonable (discontinuous air voids)
- Otherwise, must consider two components, i.e. $\bar{\sigma} = f_1(\sigma - u_a) + f_2(u_a - u_w)$

(3) Variation in u_w greatly affect slope stability

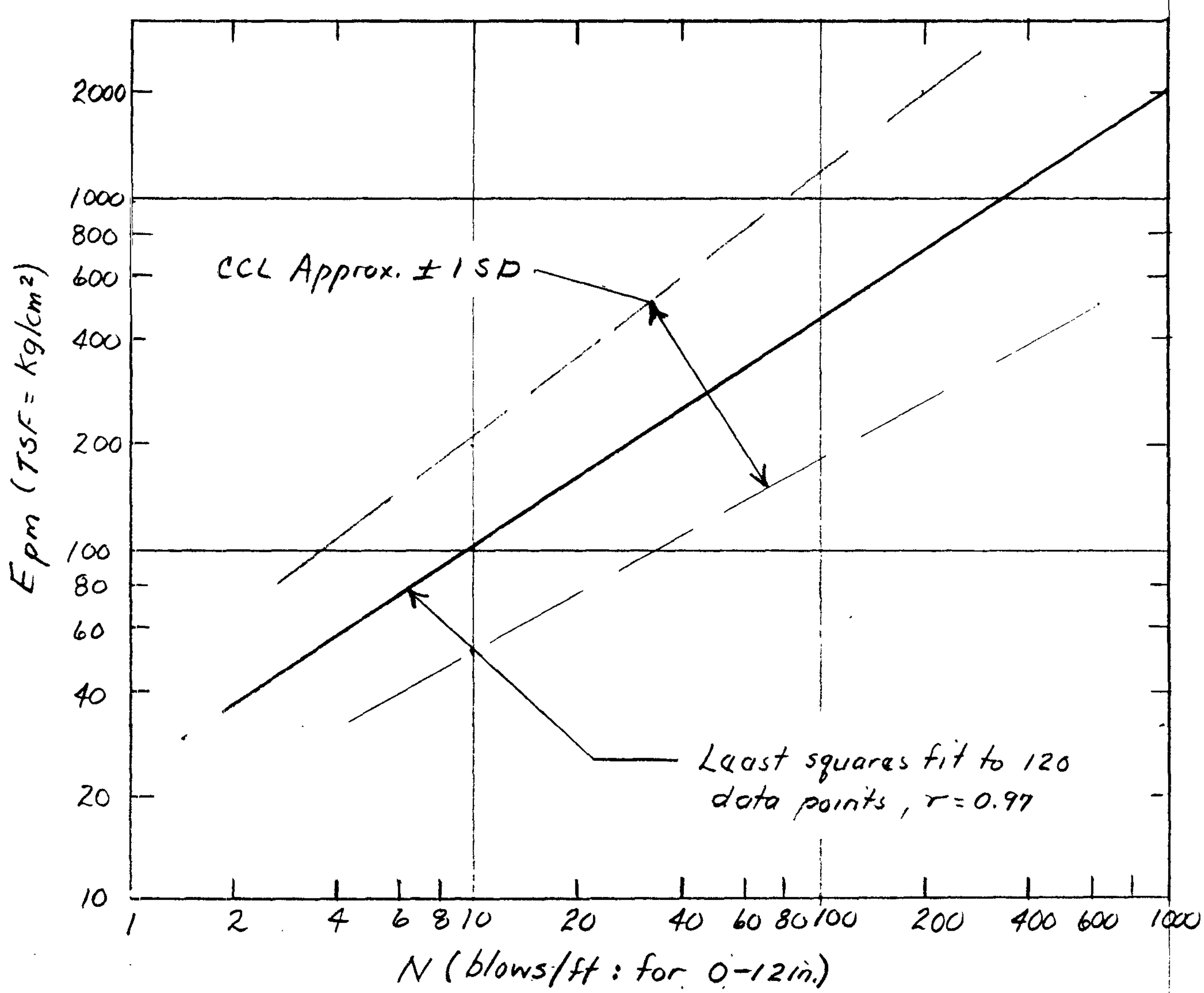
- Seasonable variations
- Effect of heavy rainfalls
- Influence of modifying drainage pattern

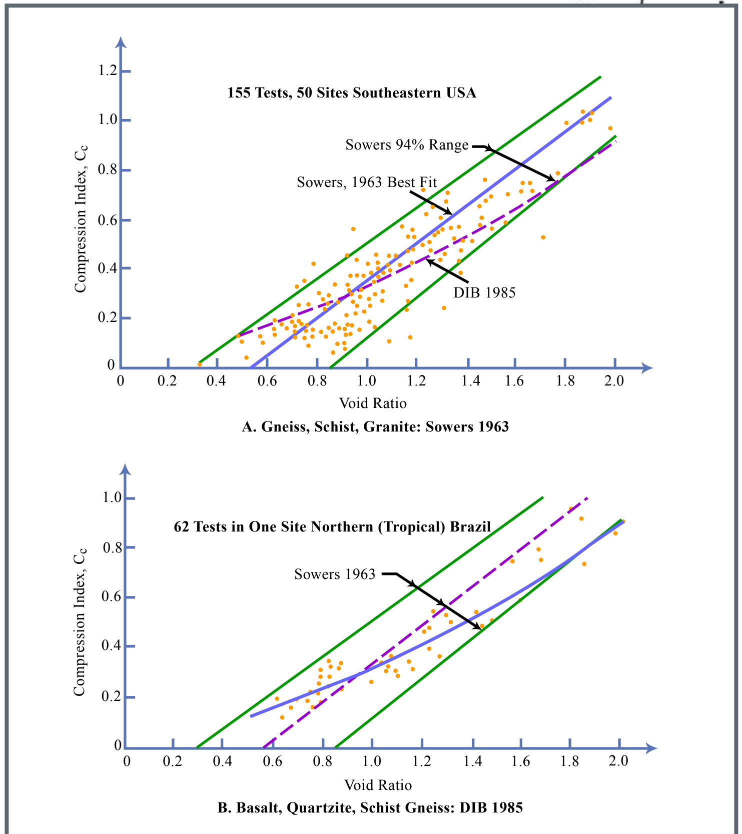
Martin, R.E. (1977) "Est. Fdn. Settlements in Residual Soils"
ASCE, JGED V103, GT3, pp. 197-212

- For residual soil developed from igneous & metamorphic rock, mostly SM to ML nonplastic materials with 30-70% fines.
- Recommends using Schmertmann method

$$\rho = C_1 C_2 \,\Delta q\, \Sigma\left(\frac{I_3}{E_s}\right)\Delta z \quad \text{with } E_s = E_{pm} \text{ (Menard Pressuremeter)}$$

- If E_{pm} not available, can use approx. N vs. E_{pm} correlation below
- Method supported by 5 case histories (but $\rho < 0.5''$ most cases) in greater Wash. D.C. area only

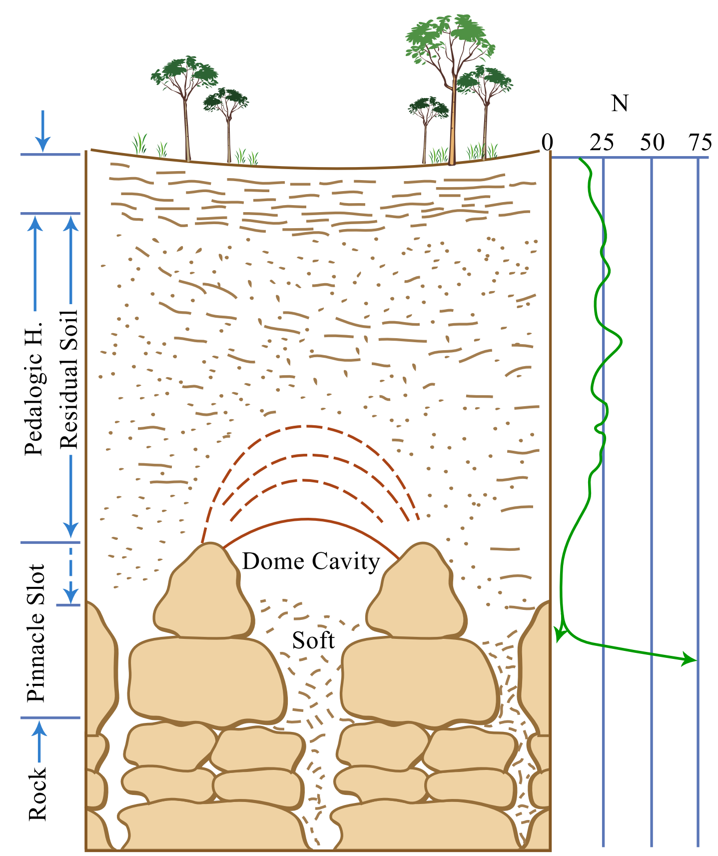




Relationship Between the Void Ratio and Compression Index in Residual Soils Derived from Crystalline (Igneous and Metamorphic) Rocks.

Figure by MIT OCW.

← MUST check for underground voids



Residual Soil Profile in Limestones

Residual Soil Settlement Related to the Weathering Profile

Figure by MIT OCW.
Adapted from:

MUST study when encounter residual soils

ASCE Geot. Spec. Publ. No. 40 "Settlement '94" V2, p 1689-1702

→ RESIDUAL SOIL SETTLEMENT RELATED TO THE WEATHERING PROFILE

George F. Sowers,[1] Honorary Member, ASCE

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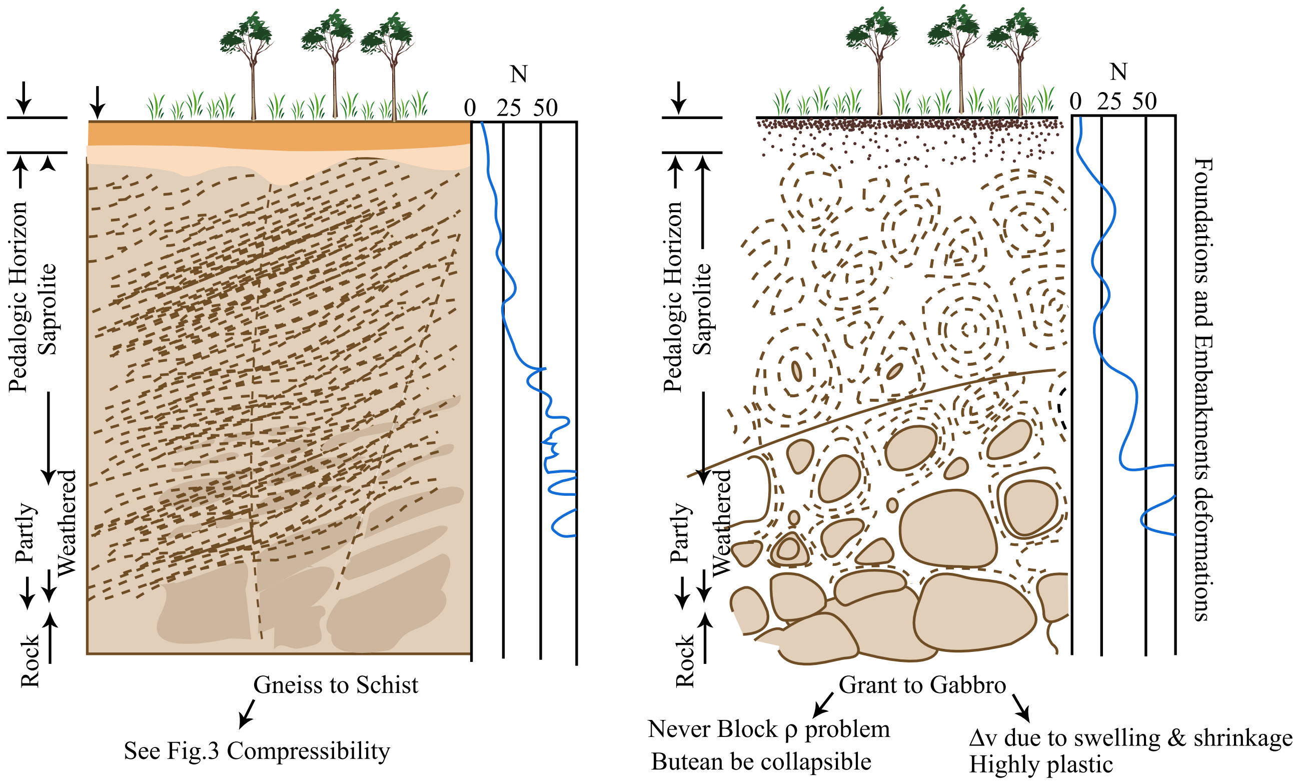
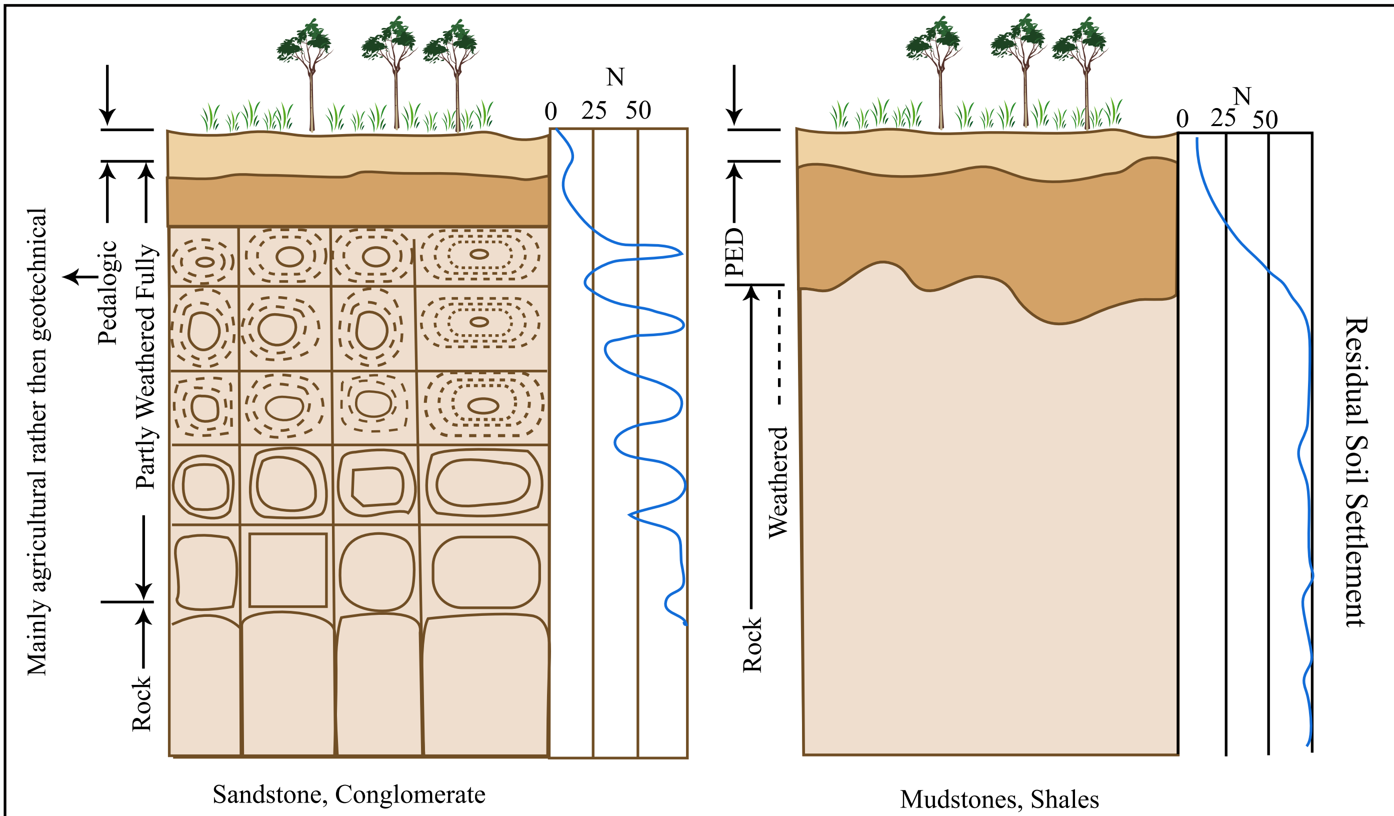
R6



Weathering profiles in crystalline Rock: Gneiss to Schist, Granite to Gabbro



Weathering Profiles in Clastic Sedimentary Rock: Sandstones and Shales

Figures by MIT OCW.

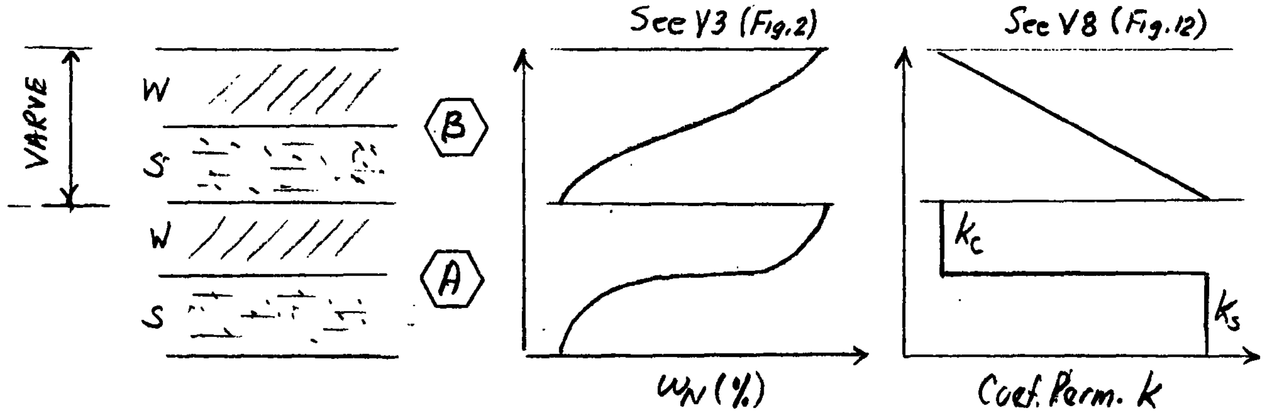
Adapted from: Sowers (1994)

1. Deposition & Composition

1) Deposition: rhythmically banded glacial lake deposit (fresh cold H_2O)

Summer: meltwater with heavy load → coarser grained fraction settling out

Winter: little flow & frozen over → finer fraction settling out



2) Composition (North America, esp. NE US; e.g. Conn. Valley, NJ Hackensack Valley and upper state NY)

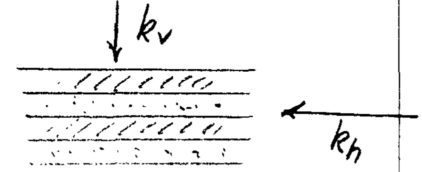
- Typical varve thickness = 2±1 cm
- Summer → "Silt" layer ML → CL } Plasticity Chart V4 (Fig. 3)
- Winter → "Clay" layer CH } Plasticity Chart V4 (Fig. 3)
- Can get thick (several ft) layer of <u>rockflour</u> (cohesionless silt size ground quartz, etc)
- Radiography BEST; drying alternative
- Transition within varve: A = abrupt; B = gradual
- Often find decreasing varve thickness at higher elevations (retreating glacier)

2. 1-D Consolidation

- Compression curves (V5) A = stiff → C & D = soft
- CR vs w_N (V6) w_N = 30 - 60 → CR = 0.05 - 0.4±0.1 (NJ)
- c_v(NC) vs w_N (V7) w_N = 30 - 70 → c_v (≈ >1 to <0.1 ft²/day (Mass & NJ)

NOTE: Oedometer specimen should include at least one varve

3. Anisotropic Flow



$r_k = k_h / k_v$

1) Importance

- Combined vertical & horizontal drainage

  See V9 (Fig. 13)

- Radial drainage to Vertical Drains

  See V10 (Fig. 14) Want $c_h = \frac{k_h}{m_v \cdot \gamma_w} = \frac{k_h}{k_v} c_v = r_k c_v$

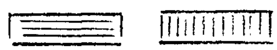
($H_d = 50'$, $c_v = 0.1\ ft^2/day \rightarrow t_{90} = 50\,yr$
Sand drain $s = 20'$, $c_h = 1.0 \rightarrow t_{90} = 1\,yr$)

2) Theoretical Relationship for $r_k = k_h/k_v$ (Kenney, 1963)

See V8 (Fig. 12) For $k_s/k_c = 100$ A (Abrupt) $\rightarrow r_k = 25$
B (gradual) $\rightarrow r_k = 2.5$

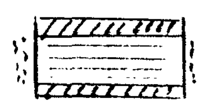
3) Methods to Measure c_h & r_k : V11 (Table C-1)

LAB a) V & H oedometer



} incorrect m_v

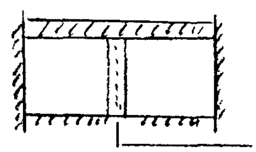
b) Oedometer w/ radial drainage :



Side friction & Smear

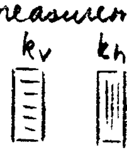
c) "Rowe" Cell with central drain

Need large diameter specimen

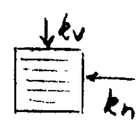


d) Separate measurements of k_v & k_h : TX

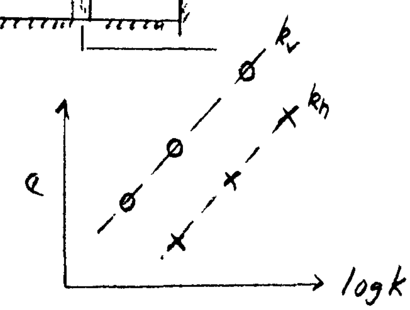
Cylinders



Cube



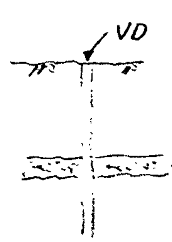
MIT 4" cube



FIELD a) Piezometers (Casagrande) – Falling/rising head

SF 50A b) Self-boring

c) Pumping from sand drain



4) Results V12 (Table C-2) All $k_v \approx 10 \pm 5 \times 10^{-8}$ cm/s

- New Liskeard Lab & field $\rightarrow r_k \approx 3 \pm 1$ 500±300 20±10
- Conn. Valley $r_k \approx 10 \pm 5$ .NJ Field >> Lab
  └ rockflour layer?

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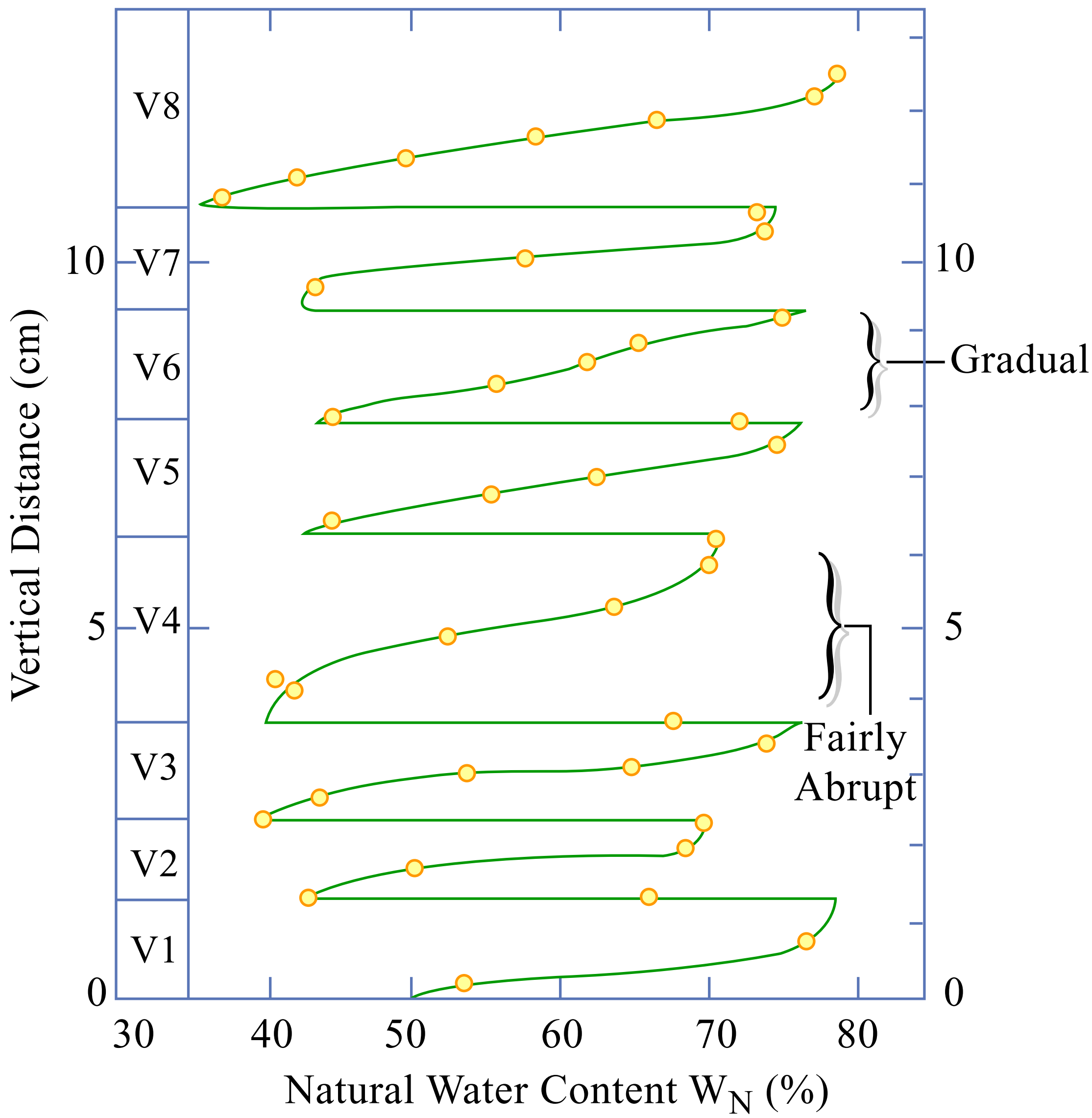
3/01

V3

Northeastern US Varved Clays



Notes:

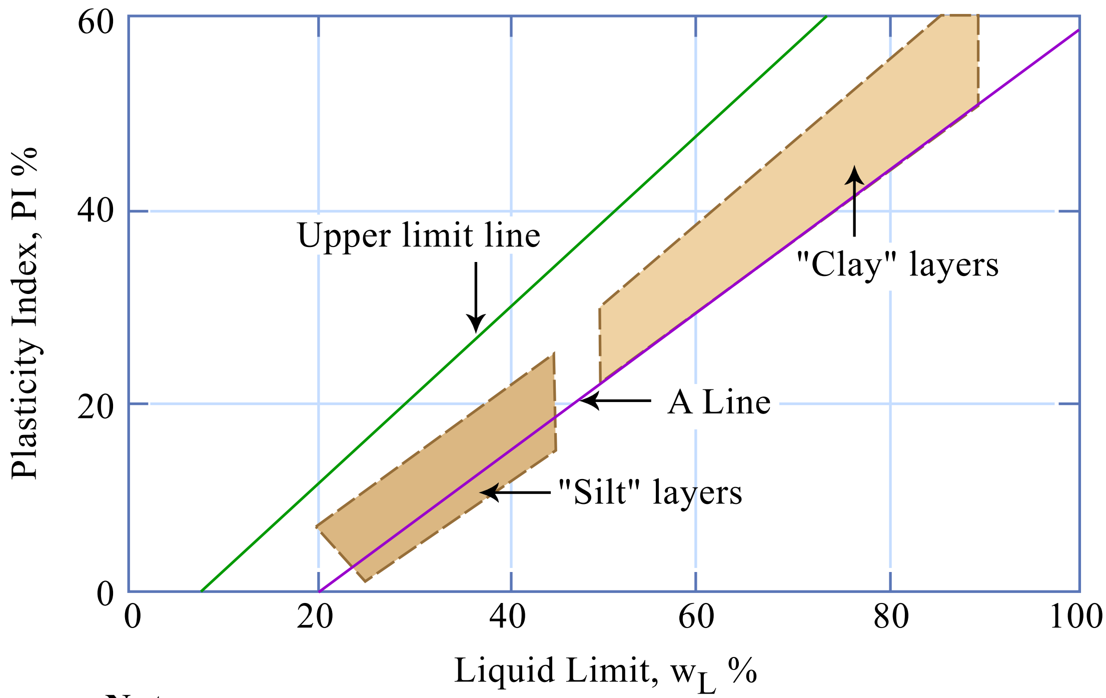
1) V1, V2, etc. refer to separate varves
2) Sample from Northampton, Ma., W_N = 56.7%
3) Data from Ladd and Wissa (1970)

Water Content Variation within a Varved Clay from the Connecticut Valley

Figure by MIT OCW.

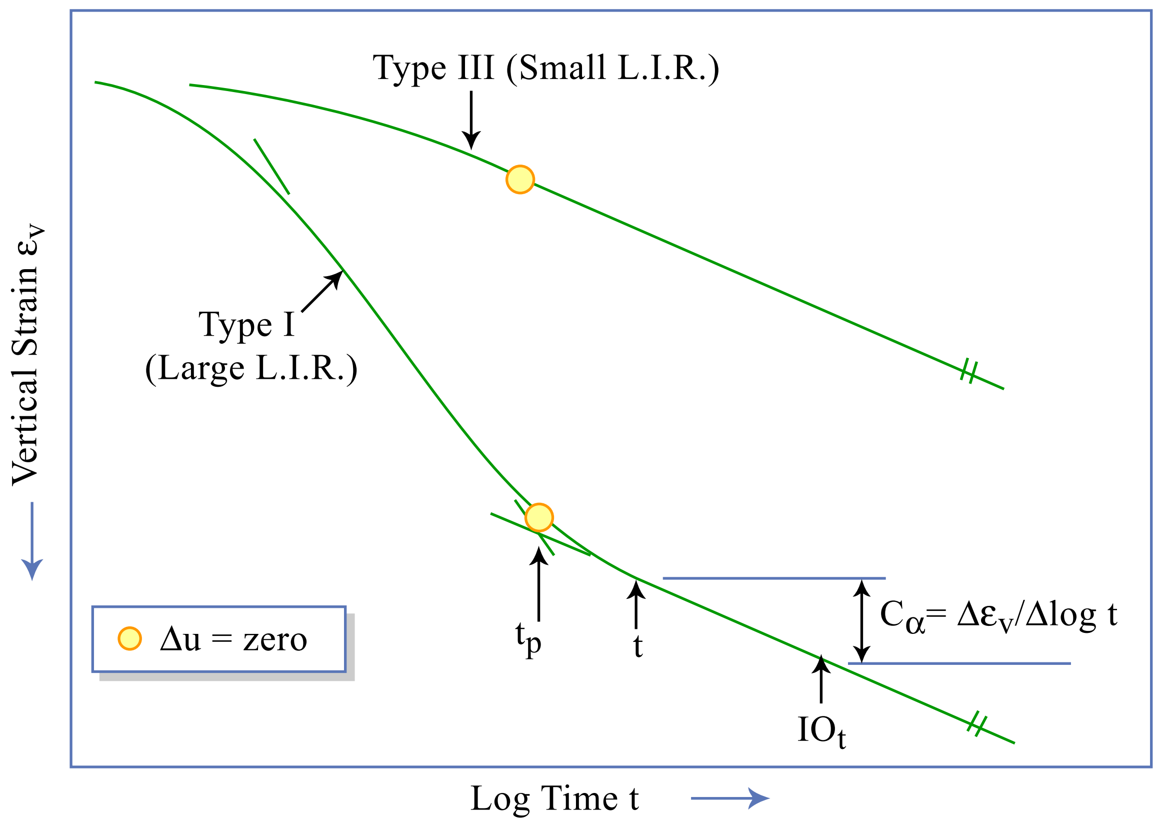
Adapted from: Ladd (1987) Lecture Notes. N.Y. ASCE Met. Section

V4



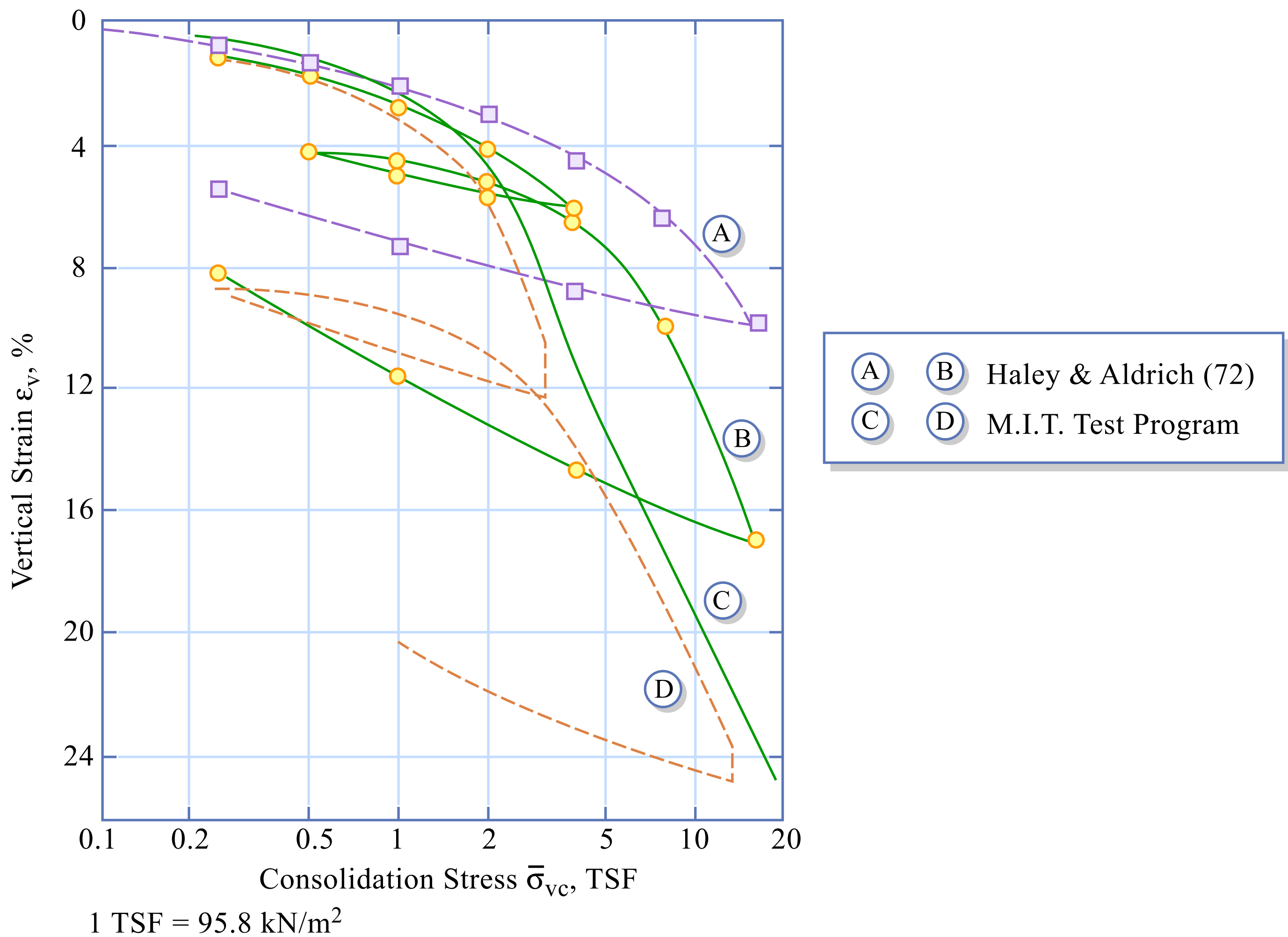
Note:
Range shown for varved clays having w_L >30 % for bulk material

Plasticity Chart for Typical varved clays from Northeastern United States.



Strain vs. Log Time from Incremental Consolidometer Test Showing Effect of Load Increment Ratio (N.C. Clay)

Figure by MIT OCW.



Curve	Type of Test	W_N (%)	$\bar{\sigma}_{vm}$ TSF	CR Max.	CR Min.	Location
A	24 hr. Incremental	36.2	8 *	0.11		Chicopee-Holyoke
B		50.2	6	0.23		
C	CRSC	61.9	2.5	0.30	0.20	Northampton
D		65.4	2	0.25	0.19	Amherst

Typical Compression Curves for Connecticut Valley Varved Clays

Figure by MIT OCW.

Adapted from: Ladd & Foott (1977)

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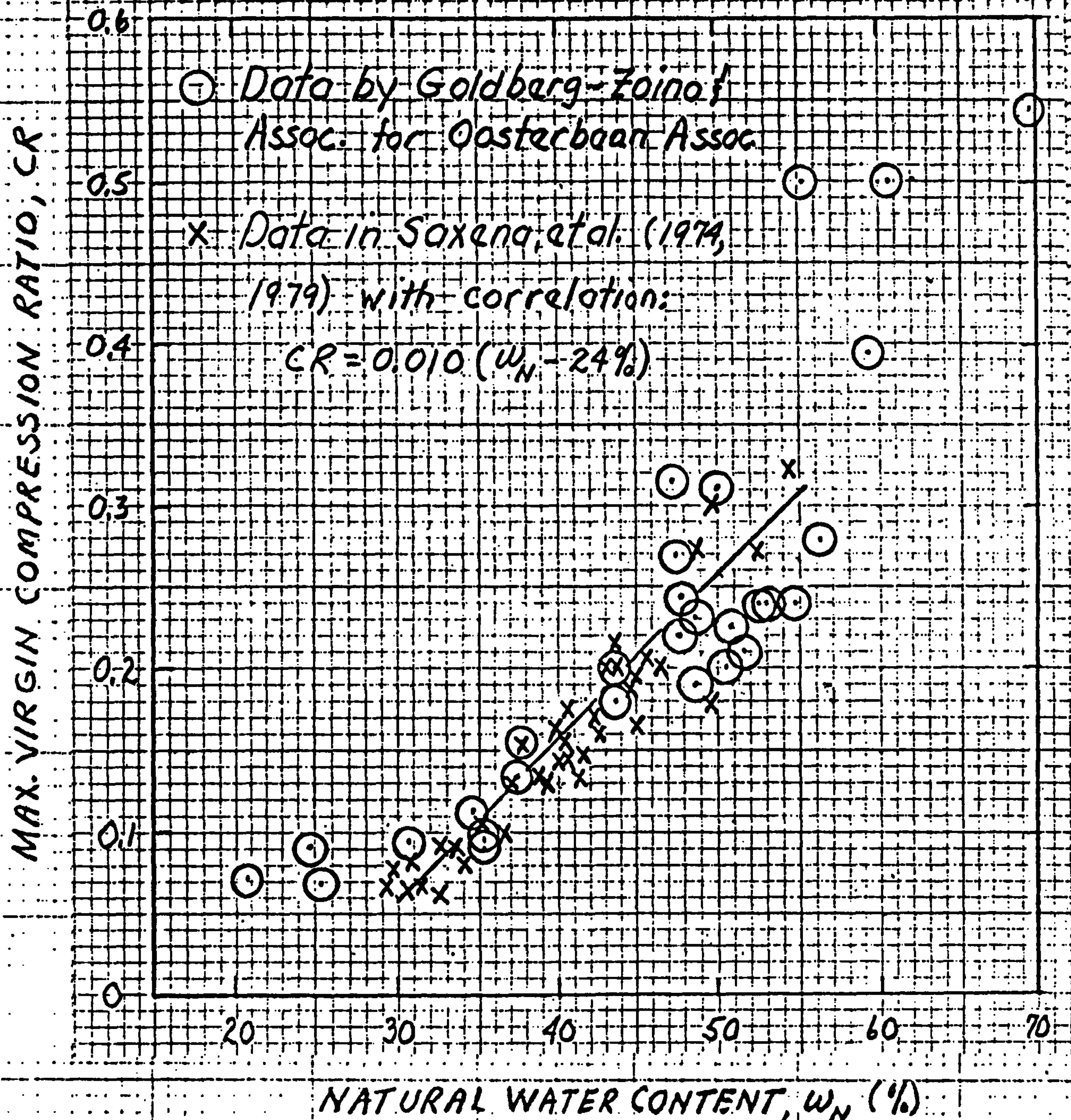
V6



NOTE: For sites near Newark Airport

FIGURE 6 VIRGIN COMPRESSION RATIO VS. NATURAL WATER CONTENT FOR HACKENSACK VALLEY VARVED CLAYS

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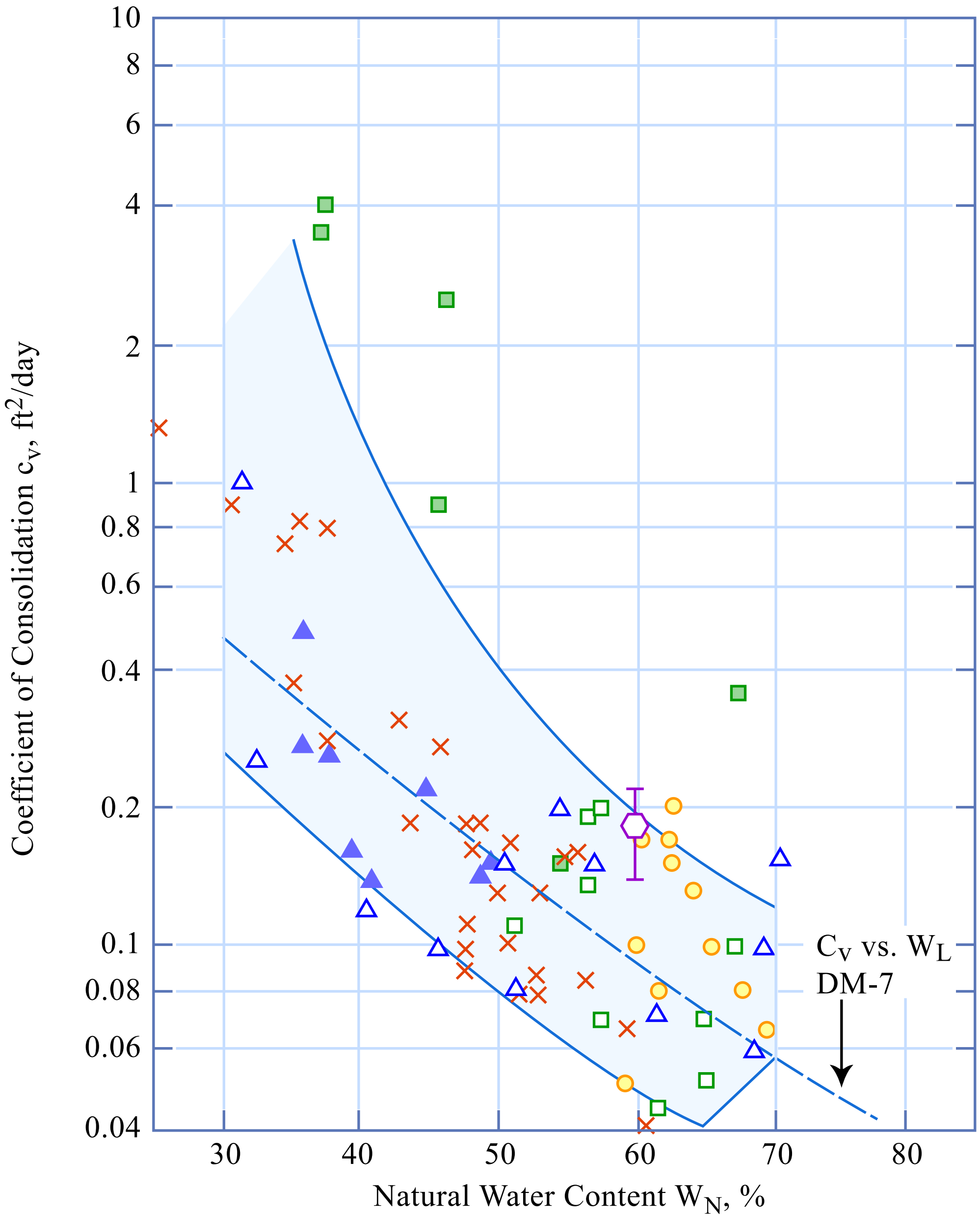
V7



Location*	Type of Test	Symbol
Amherst, MA.	CRSC & Increm.	○
Northampton, MA.	CRSC & Increm.	□ ■ **
E. Windsor, CT.	Increm.	⬡
Jersey City, N.J.	Increm.	△
Secaucus, N.J.	CRSC	▲
New Jersey	Increm. by GZA	× **

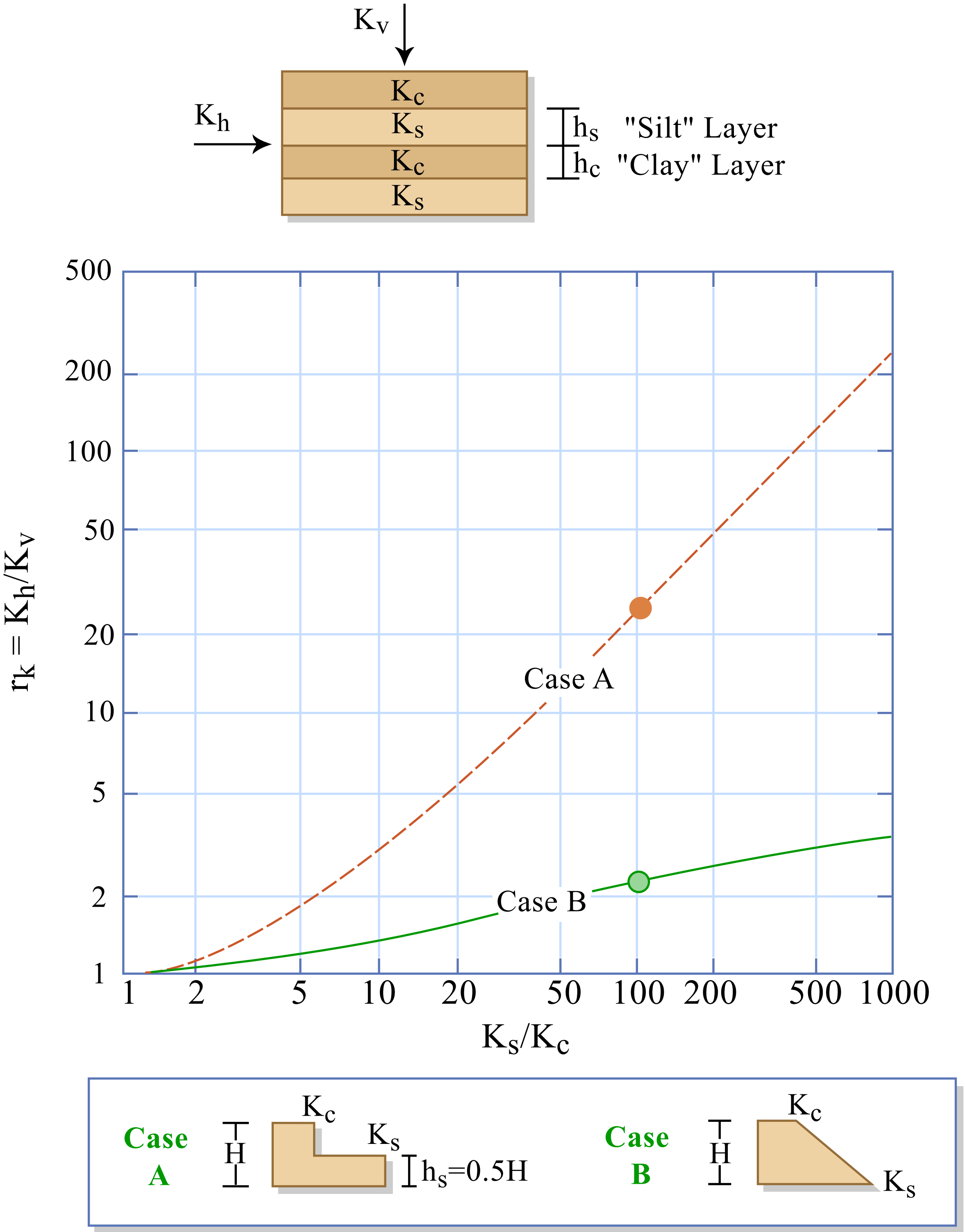
Coefficient of Consolidation (Vertical Drainage) vs. Natural Water Content for Normally Consolidated Varved Clays

* See Ladd (1975) for data sources

** From square root time method

1 ft^2/day = 0.093 m^2/day

Figure by MIT OCW.

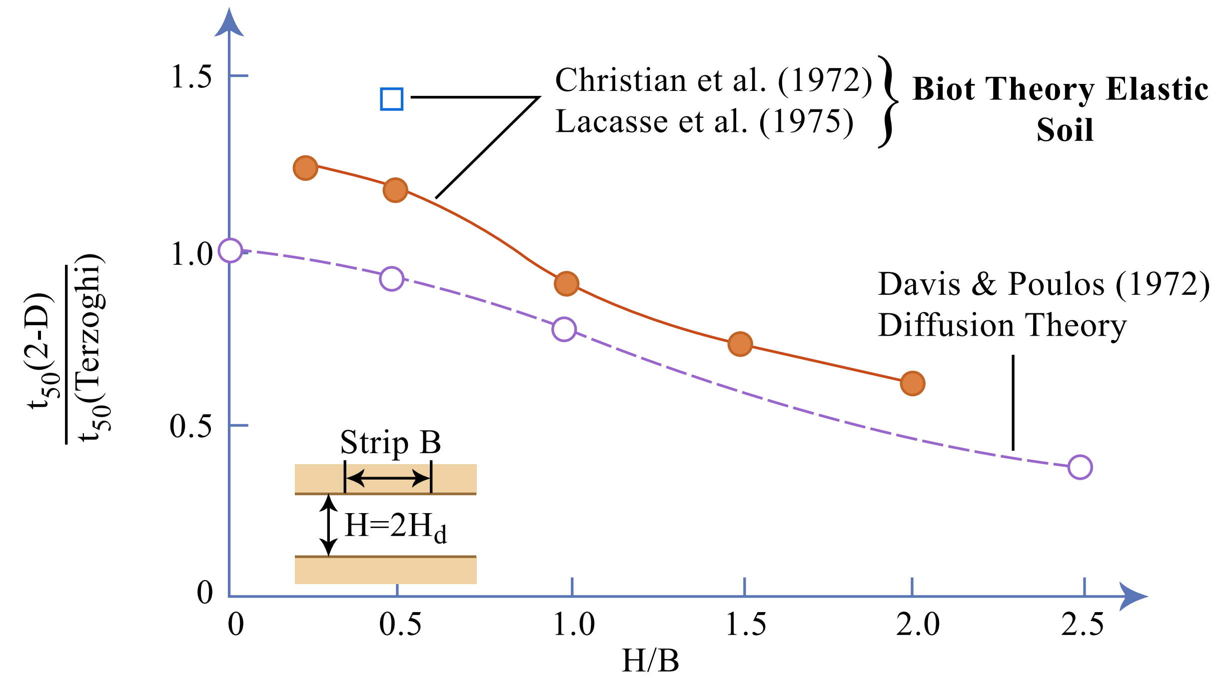


Relationship Between K_h/K_v Ratio and Permeability of the Silt and Clay Layers

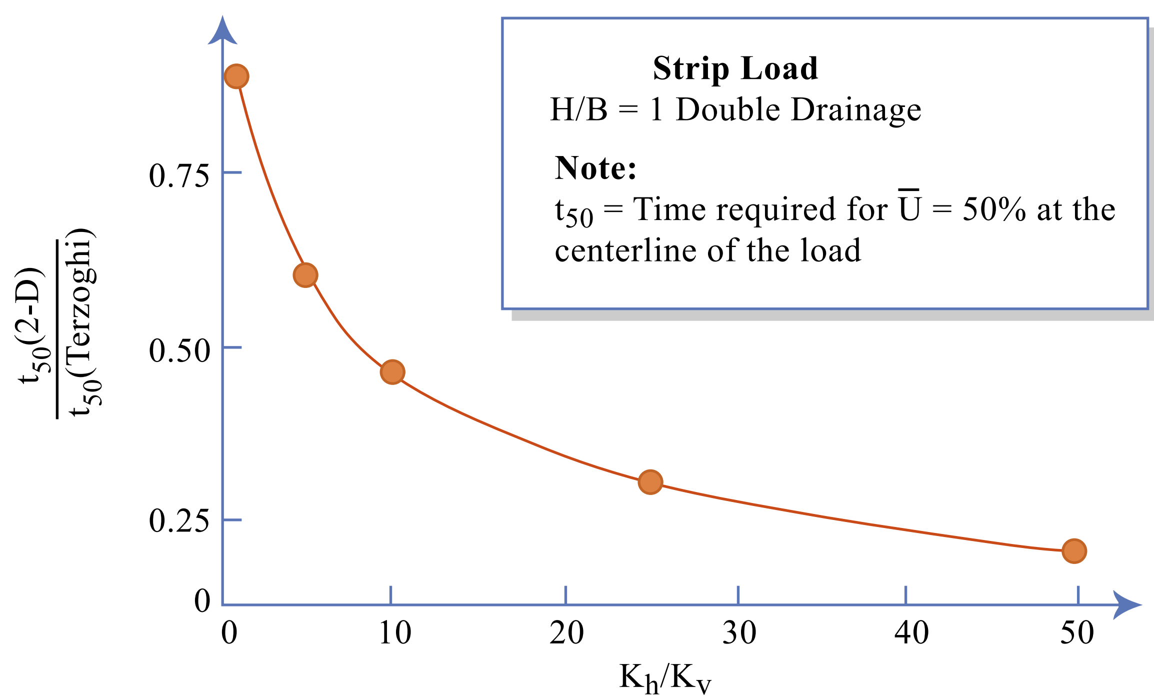
Figure by MIT OCW.

(After Kenney, 1963)

V9

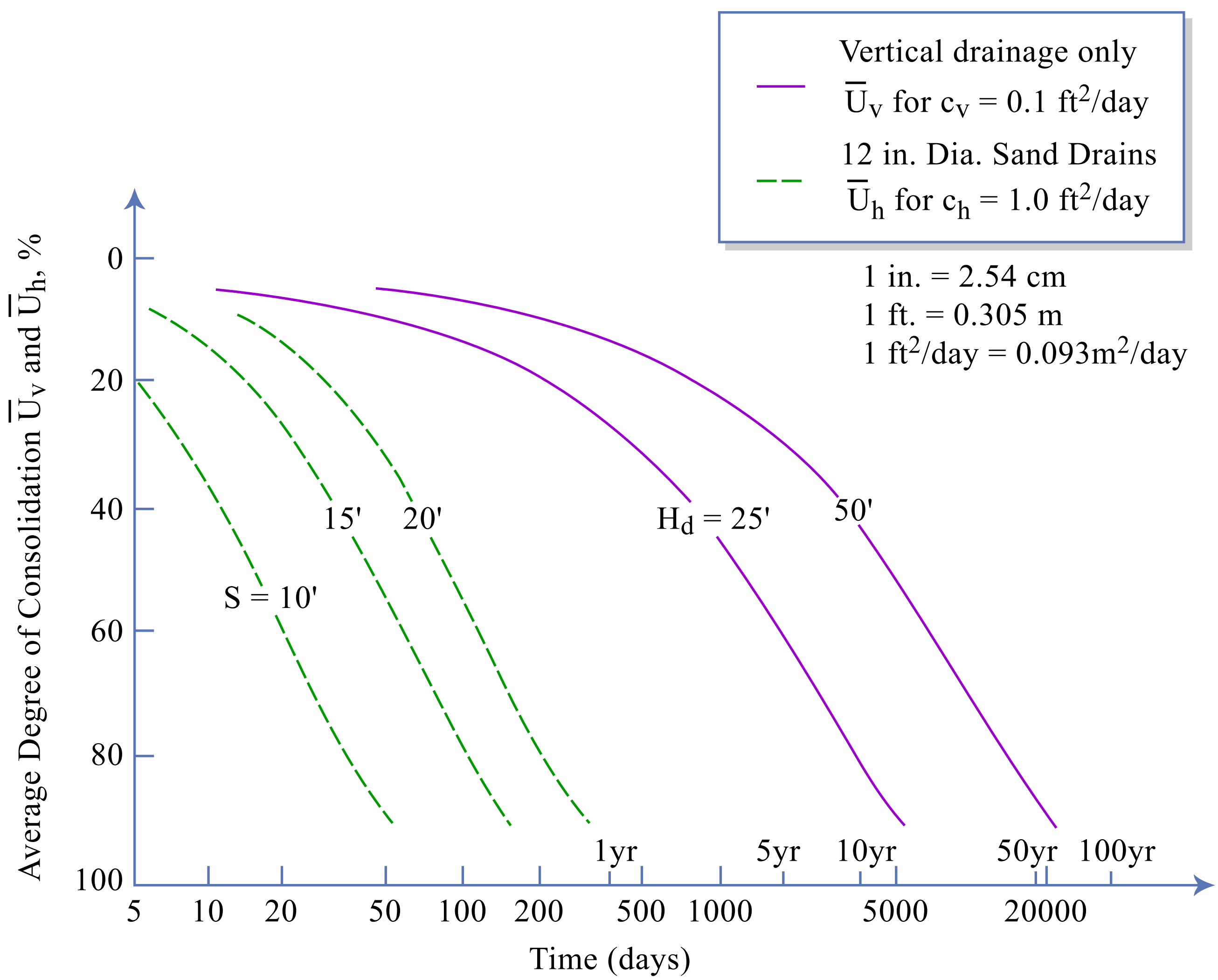


(a) Effect of Lateral Drainage on Rate of Consolidation from Different Theories with Isotropic Permeabilities



(b) Effect of Anisotropic Permeability Ratio on Rate of Consolidation for H/B =1 with Double Drainage

Figure by MIT OCW.



Effect of Sand Drains on Rate of Consolidation of Normally Consolidated Varved Clay with c_h/c_v = 10

Figure by MIT OCW.

METHODS FOR MEASUREMENT OF c_h AND k_h/k_v

NO.	METHOD AND PARAMETER	REMARKS	REFERENCE
1	Laboratory consolidometer test on horizontal ($\theta=90^o$) sample (c_h)	(1) Wrong m_v (2) Sample size influences results	Rowe (1959)
2	Laboratory consolidometer test with radial drainage to sides (c_h)	May have problems with side friction and scale effects	McKinley (1961)
3	Laboratory consolidometer test with radial drainage to vertical sand drain (c_h)	Large sample recommended to minimize scale effects	Rowe & Barden (1966) Shields & Rowe (1965)
4	Laboratory permeability tests on vertical and horizontal samples (c_h)	Problem with variability when using different samples	
5	Laboratory permeability tests on cubic sample (k_h/k_v)	Better than No. 4; large (10 cm) samples recommended	Chan & Kenney (1973) Ladd & Wissa (1970) Saxena et al. (1974)
6	Field constant head flow tests with hydraulic piezometer (c_h, k_h)	(1) Method of installation important (2) Need to consider length to diameter ratio	Mitchell & Gardner (1975)
7	Field pumping test from vertical sand drain (k_h)	(1) Method of installation important (2) Pervious layers can have important effect	Casagrande & Poulos (1969)

Table C-1

Ladd & Foott (1977)

VII

Table C-2

SUMMARY OF ANISOTROPIC PERMEABILITY RATIOS FOR VARVED CLAYS (Ladd, 1975)

LOCATION	LABORATORY k_v (10^{-8} cm/sec)	ANISOTROPIC PERMEABILITY RATIO			REFERENCE
		Method	k_h/k_v	Remarks	
1 New Liskeard Canada (Thick varve layer)	7 (5.2 - 9.5)	Lab: 2.5" Cube Field: Flow Pattern in Natural Slope	3.3 ± 0.4 < 5 3	6 Samples. Ave. Varve 1.6" Thick Upper Limit Best Estimate	Chan & Kenney (1973) Kenney & Chan (1973)
2 Amherst, Mass.	9	Lab: 4" Cube	4.5, 8, 11	Increase with depth d = 28,43,67'	M.I.T.
3 Northampton Mass.	6 ± 2	Lab: 2" Cube Lab: 4" Cube Field: Inferred from Settlement Data	5 (3.3-6.3) 14, 10 60 ± 30	4 Tests; El.79' 2 Tests; El.59',51' May be Questionable	Ladd & Wissa (1970) Connell et. al. (1973)
4 East Windsor, Conn.	20	Lab: k on Separate Samples Lab: c_h/c_v from Consolidometer Tests	6 - 7 4 - 6 ≤ 10	Quoted Est. by Writer Est. by Writer	Healy et. al.(1970)
5 Secaucus, N.J.	5 - 10	Lab: 4" Cube	5 ± 2.5	2 Samples Varves Inclined	Saxena et. al.(1974)
6 Section 7A, New Jersey Turnpike	17 ± 7 5 - 6	Lab: 2" Samples Field: Pumping Test from Instrumented Jetted Sand Drain	20 ± 10 10 ± 5 500 ± 300	d = 15 - 40' d = 50 - 75' d = 22 - 85' Values by Writer	Casagrande and Poulos (1969)

1 in. = 2.54 cm 1 ft = 0.305 m

V/2

CCL 3/30/86 3/87 3/88 4/89 3/92 3/99

1.322 VI Consolidation: PROBLEM SOILS

(Ref 1)

Some References on "Problem" Soils

Hypothesis B using unique $\sigma_v' - \varepsilon_v - \dot{\varepsilon}_v$ relationship

Highly Structured & Sensitive

1) Mesri & Choi (1985) ASCE, JGE #4 - Computer program
2) Leroueil et al (1983) CGJ #4 - Estimating σ_p'
3) Leroueil et al (1985) Geotechnique #2 - Lab compressibility
4) Kabbaj et al (1988) Geotechnique #1 } In situ compressibility
5) Leroueil et al (1988) Soils & Fdn #3 } Several case histories
6) Leroueil (1988) CGJ 25(1) State of the art
7) Liu & Carter (1999) "Virgin compression of structured soils" Geot 49(1)

Peats

1) MacFarlane, J.C (1969), Muskeg Eng. Handbook, U. Toronto Press
2) Skempton & Petley (1970), Geotechnique, #4 - Index properties
* 3) Lefebvre et al (1984), CGJ, #2 - Lab & field data NBR peats
4) ASTM (1983) SPT 820 Testing of Peats & Organic Soils
5) Mesri et al (1997) "Secondary compression of peat w/ & w/o surcharging" JGGE, 123(5)

Collapsing-Loess

1) Holtz & Gibbs (1961), 5th ICSMFE, Vol.1, p673 - Settlement
2) Clemence & Finbarr (1981), ASCE, JGED, #3 - Design & references
3) Houston, et al. (1988) ASCE, JGE, #1 - Case history

Expansive Clays

1) Ladd & Lambe (1961) 5th ICSMFE, Vol 1, p201 - Correlations
2) O'Neill et al. (1980) ASCE, JGED, #12 - Good references
3) Nelson & Miller (1992) Expansive Soils: Problems and Practice in Fdn & Pavement Eng., J. Wiley

Residual Soils

1) 1.322 handout with Martin (1977), ASCE, JGED, #3 - SPT-E
2) Townsend, F.C. (1985), ASCE, JGE #1 - Updated references

Varved Clays

1) Ladd (1987) Lecture Notes, NY ASCE Met. Section
2) Ladd & Foott (1977) "Fdn design emb. ...", FHWA TS-77-214, USDOT