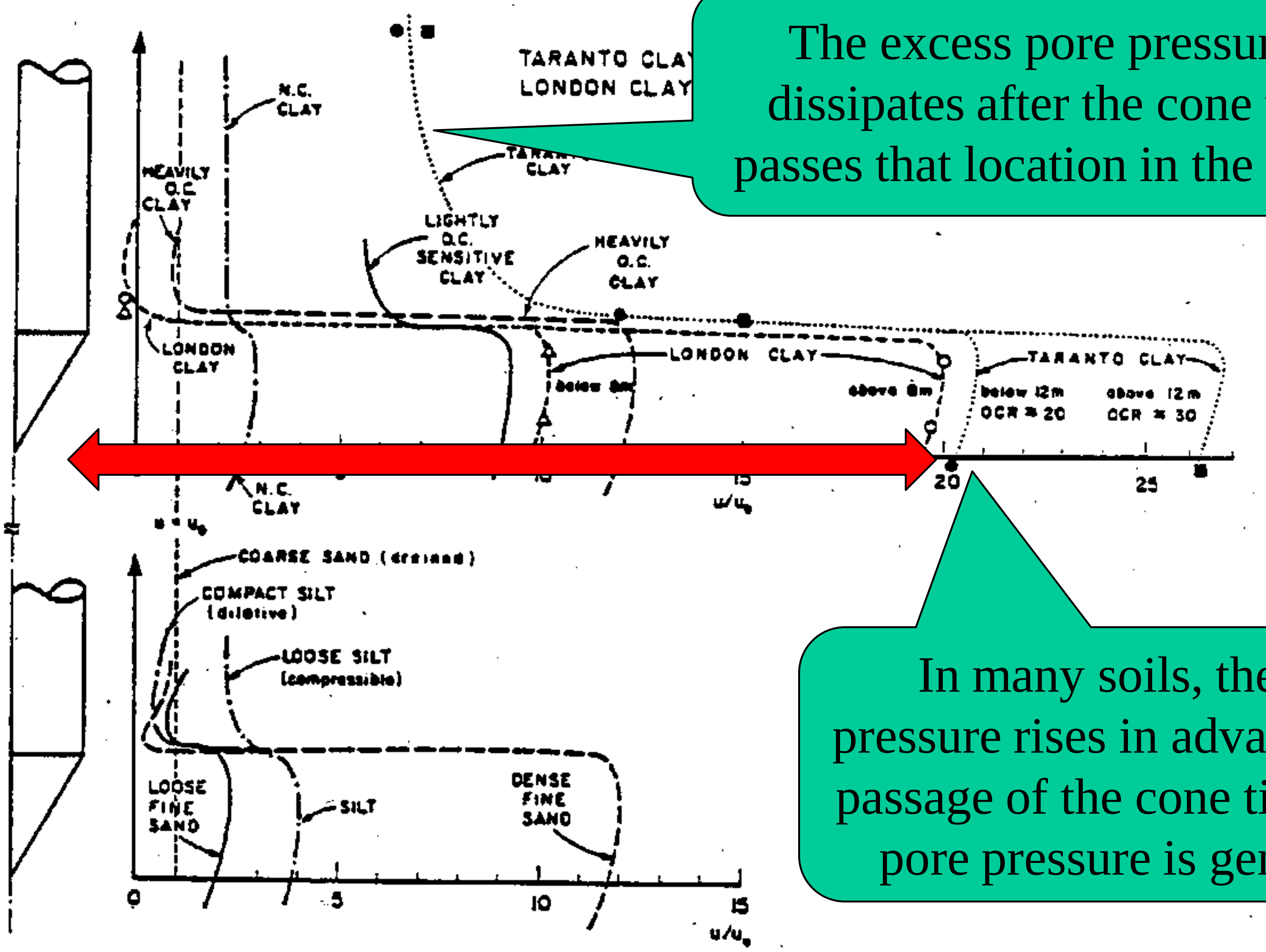
Pore pressure dissipation data and consolidation calculations

Pore pressure dissipation and consolidation calculaitons

1. Pore pressure terminology
2. Pore pressure distribution adjacent to a moving cone
3. Procedure for the pore pressure dissipation test
4. Typical pore pressure dissipation curves
5. Calculating t_{50} form dissipation graphs
6. Calculating c_{vh}, the coefficient of consolidation
7. Consolidation calculations

Pore pressure terminology

$u_t = u = u_2$	penetration pore pressure at a specific depth
u_o	static pore pressure or equilibrium pore pressure at a specific depth
$\Delta u = u_t - u_o$	excess pore pressure generated by the penetrating cone penetrometer tip
u_i	pore pressure measured at time i, during the pore pressure dissipation procedure
Δu_i	excess pore pressure calculated at time i, during the pore pressure dissipation procedure

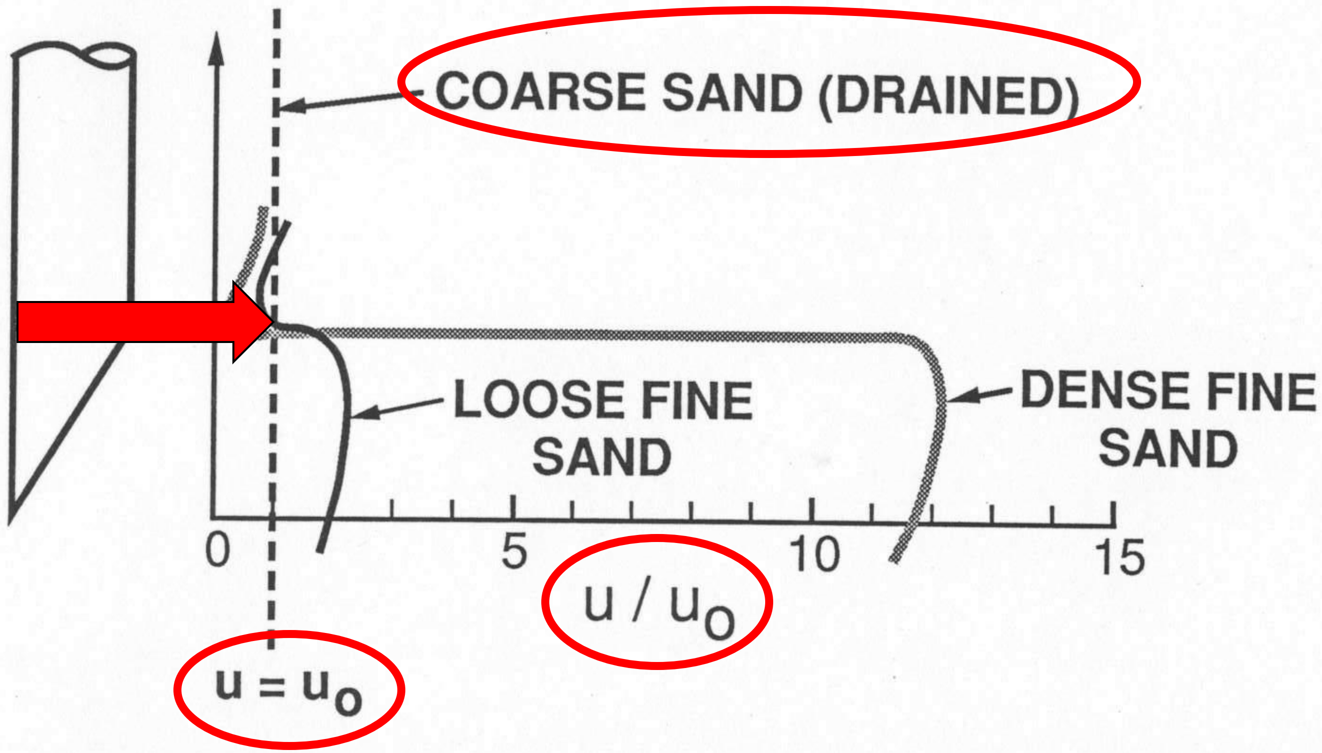


The excess pore pressure dissipates after the cone tip passes that location in the soil.

In many soils, the pore pressure rises in advance of the passage of the cone tip. Excess pore pressure is generated.

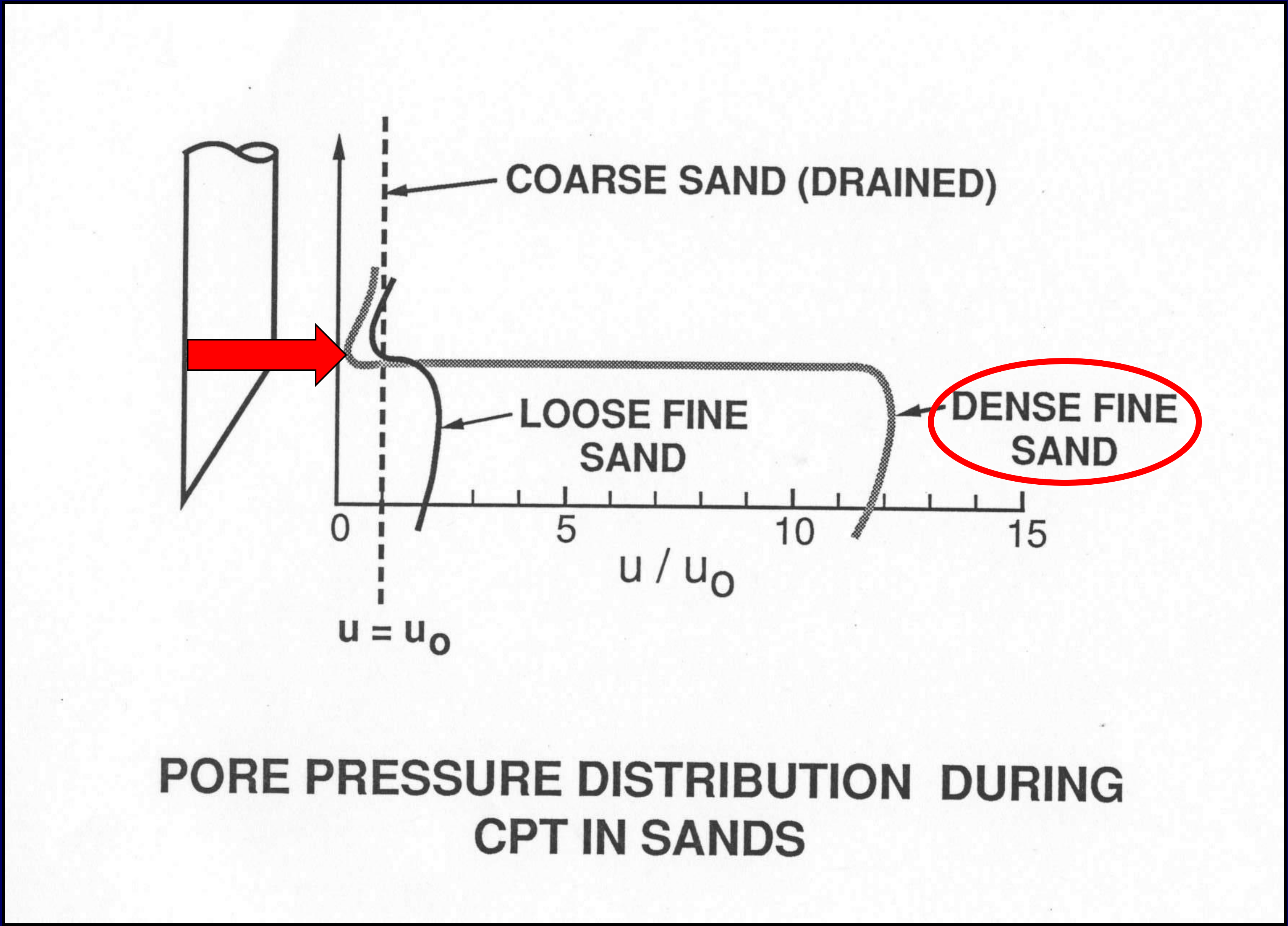
The magnitude and distribution of pore pressures adjacent to the cone tip during penetration

Pore pressures adjacent to the passing penetrometer in well drained coarse sand remain at static pore pressure levels

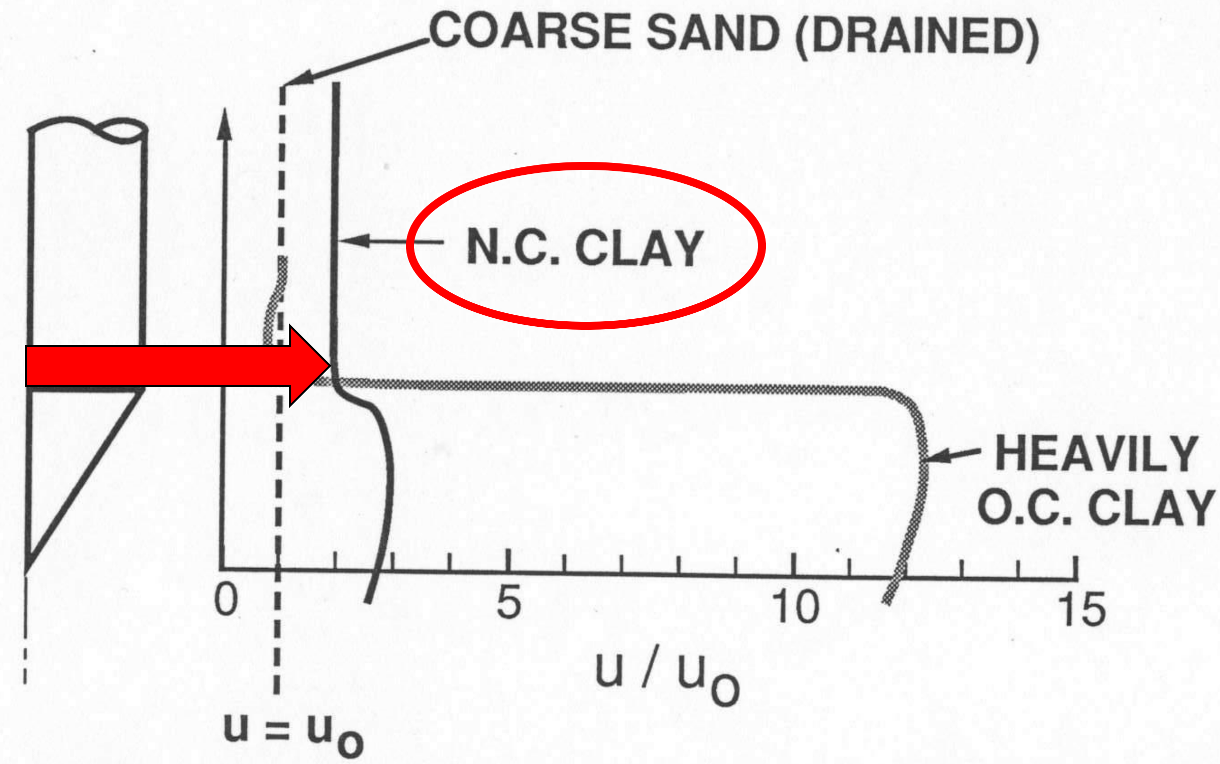


PORE PRESSURE DISTRIBUTION DURING CPT IN SANDS

Pore pressures less than the static value are generated in dense fine sands at the point of pore pressure measurement

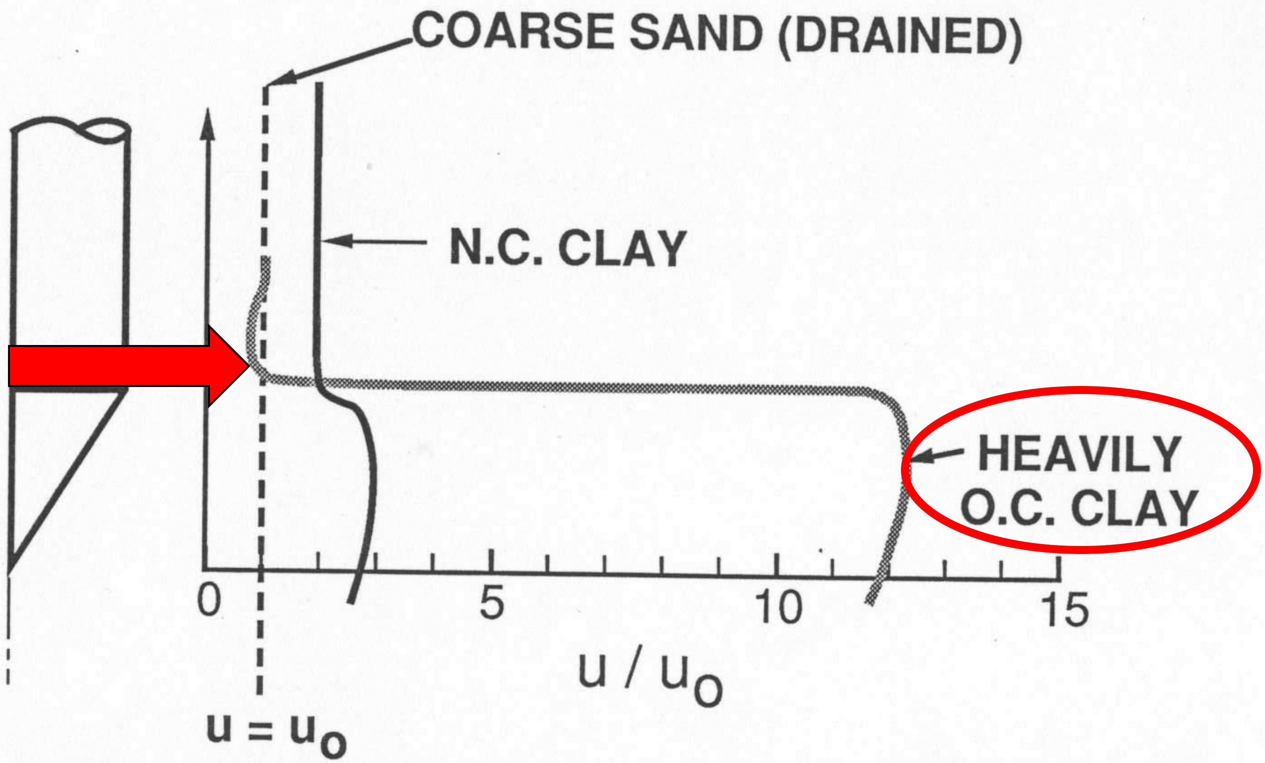


Pore pressures in excess of the static value are generated in normally consolidated clays at the point of pore pressure measurement



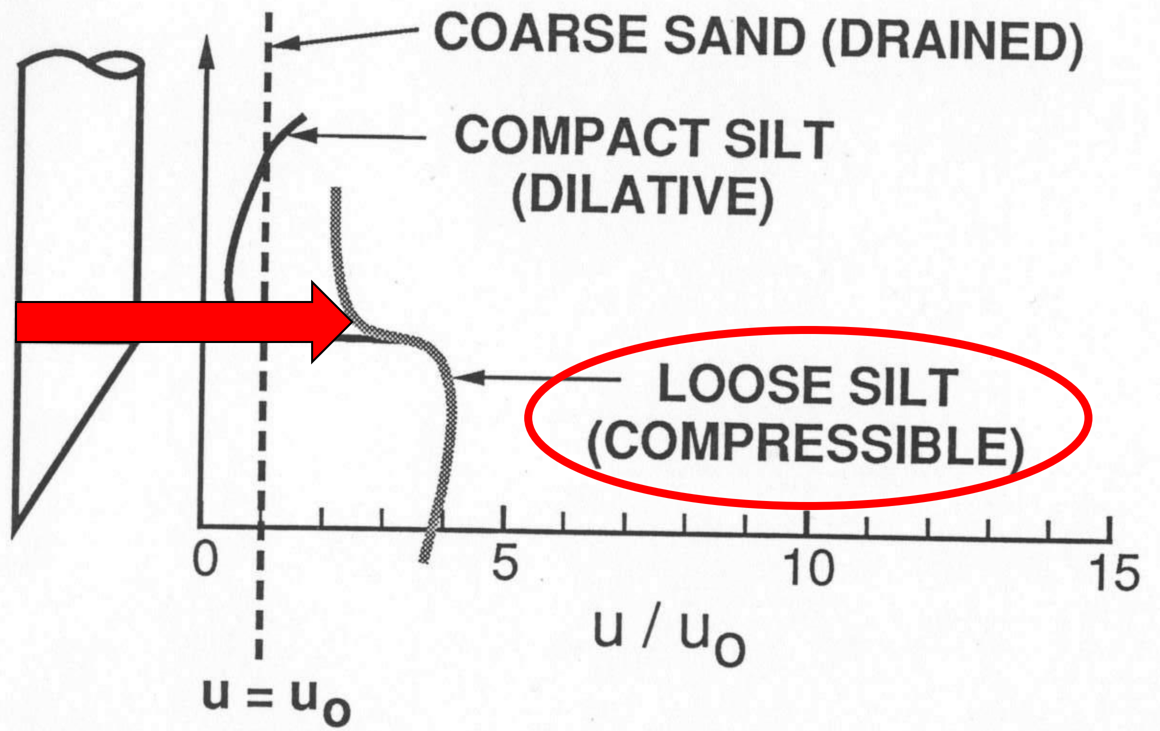
PORE PRESSURE DISTRIBUTION DURING CPT IN CLAYS

Pore pressures less than the static value are generated in over consolidated clays at the point of pore pressure measurement



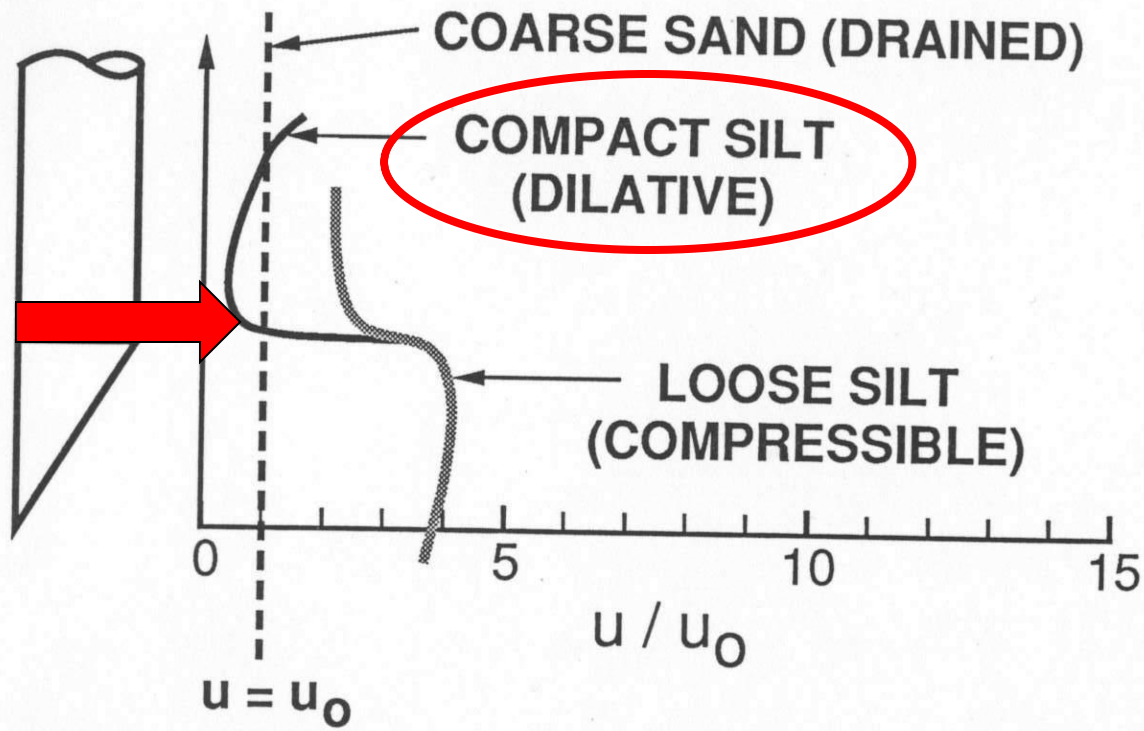
PORE PRESSURE DISTRIBUTION DURING CPT IN CLAYS

Pore pressures in excess of the static value are generated in loose silts at the point of pore pressure measurement



PORE PRESSURE DISTRIBUTION DURING CPT IN SILTS

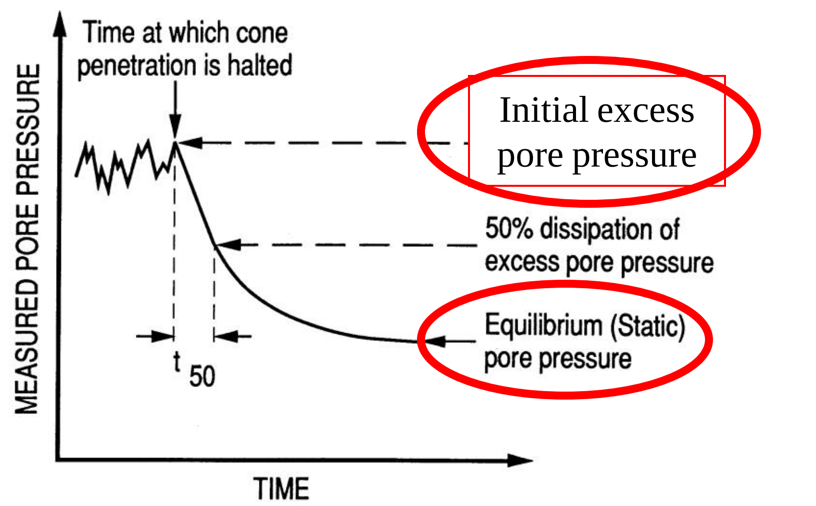
Pore pressures less than the static value are generated in compact silts at the point of pore pressure measurement



PORE PRESSURE DISTRIBUTION DURING CPT IN SILTS

The procedure for collecting pore pressure dissipation data for determining consolidation rate parameters

1. Stop advancement of the cone penetrometer. Do not release the load on the push rods.
2. The total pore pressure at the time of halting penetration is $u_t = u_i$. This is time $t = 0$. (Burns and Mayne, 1998)
3. Record the decrease or dissipation of the total pore pressure, u_i, until the excess pore pressure, Δu_i, has declined to a value equal to 50% of the difference between u_i and u_o. The magnitude of the static pore water pressure, u_0, is required.

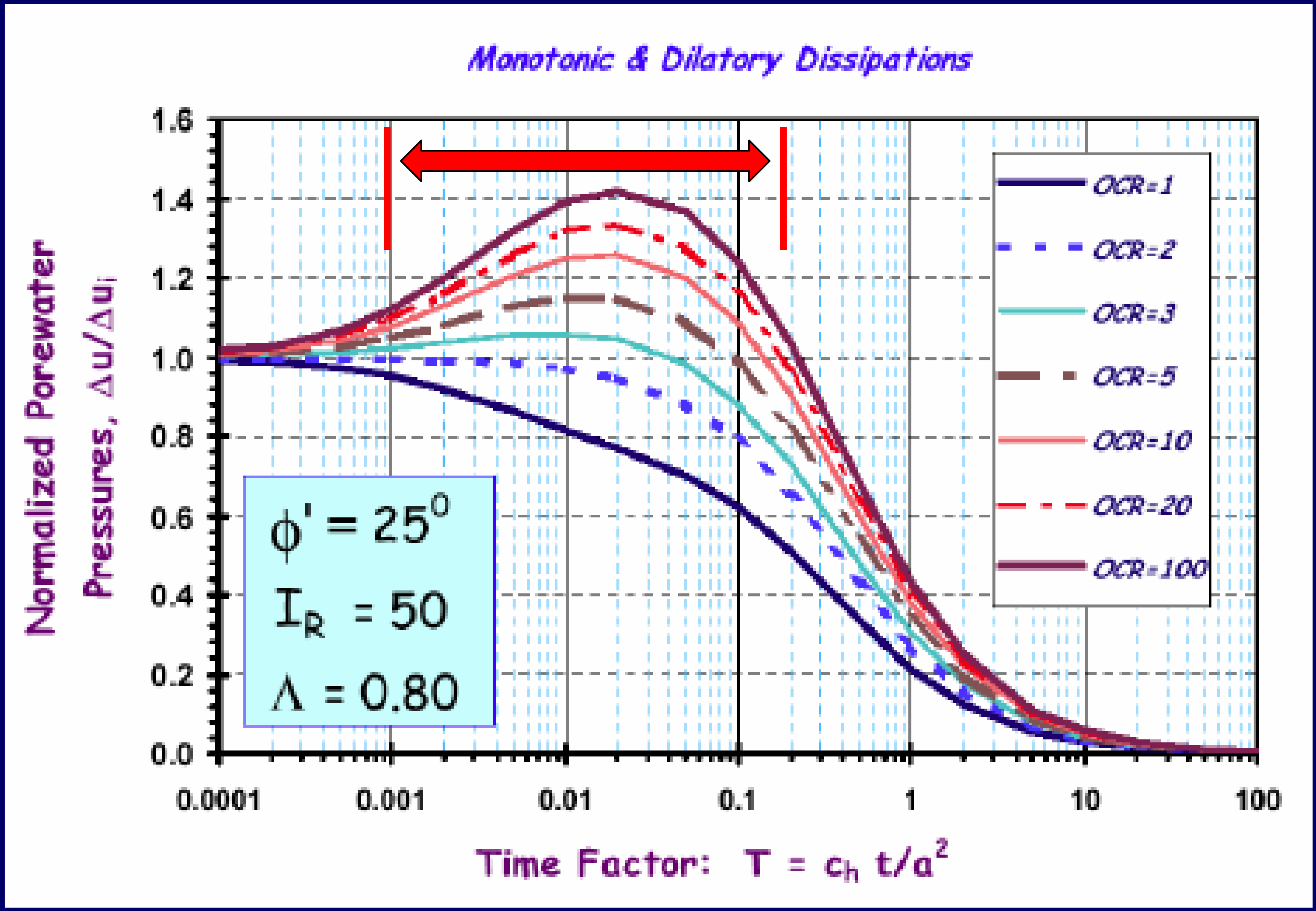


PIEZOMETER CONE DISSIPATION TIMES WITH PORE PRESSURE SENSOR BEHIND TIP

Determining the magnitude of the static pore pressure, u_0

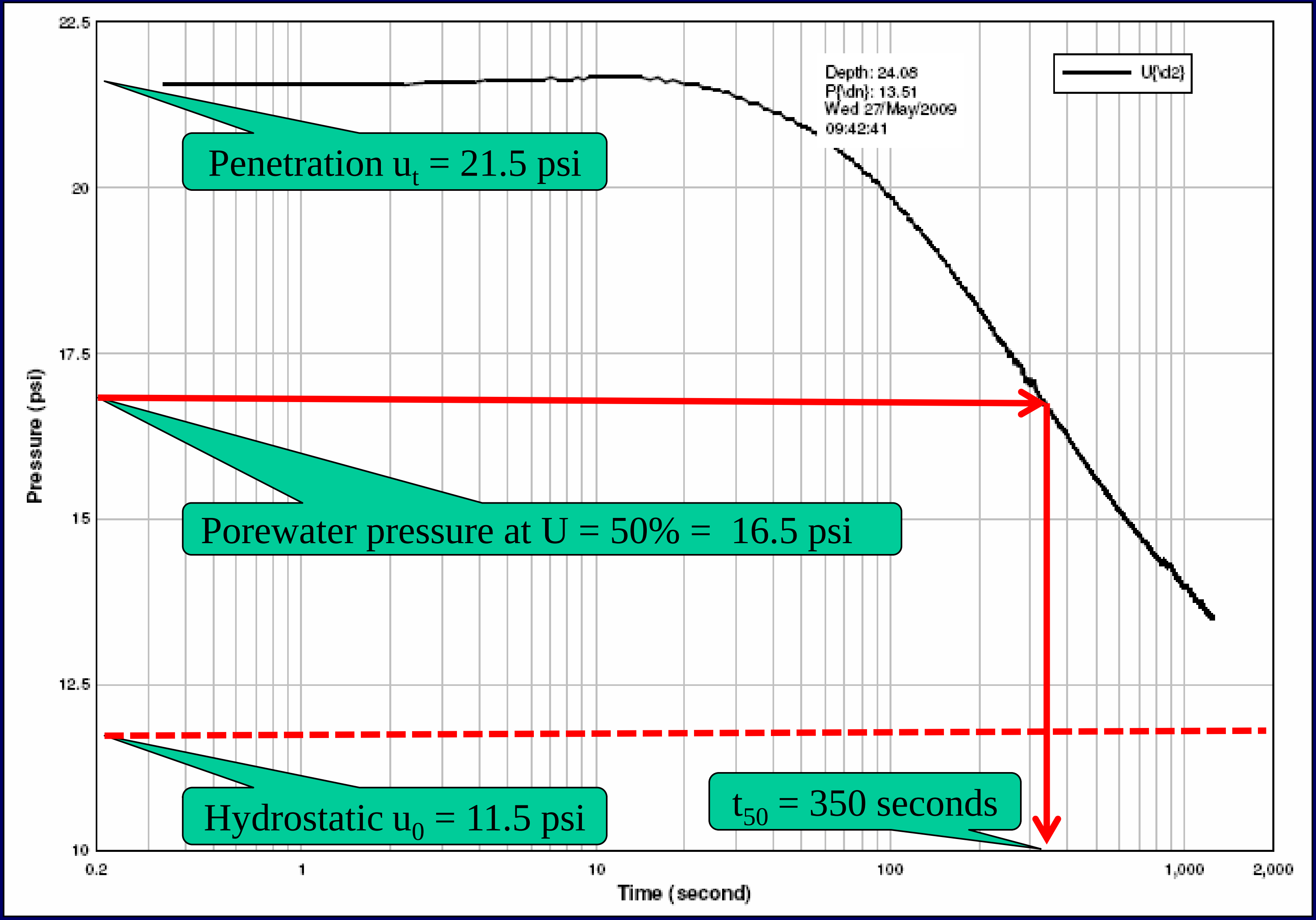
1. From nearby boreholes drilled not long before the cone penetrometer tests.
2. In CPTs, from observing the total pore pressure in clean coarse sand strata.
3. In CPTs, from pore pressure dissipation tests on relatively rapid draining (high hydraulic conductivity) soils. Time to total dissipation of excess pore pressure ($\Delta u = 0$) is reasonable (several minutes, not hours). These soils will have relatively low friction ratios.
4. In CPTs, carry out the pore pressure dissipation on strata of interest for consolidation to $\Delta u = 0$. This can take hours.
5. Determined from literature search including as-built LOTBs.

The shape of the pore pressure dissipation curve is related to OCR

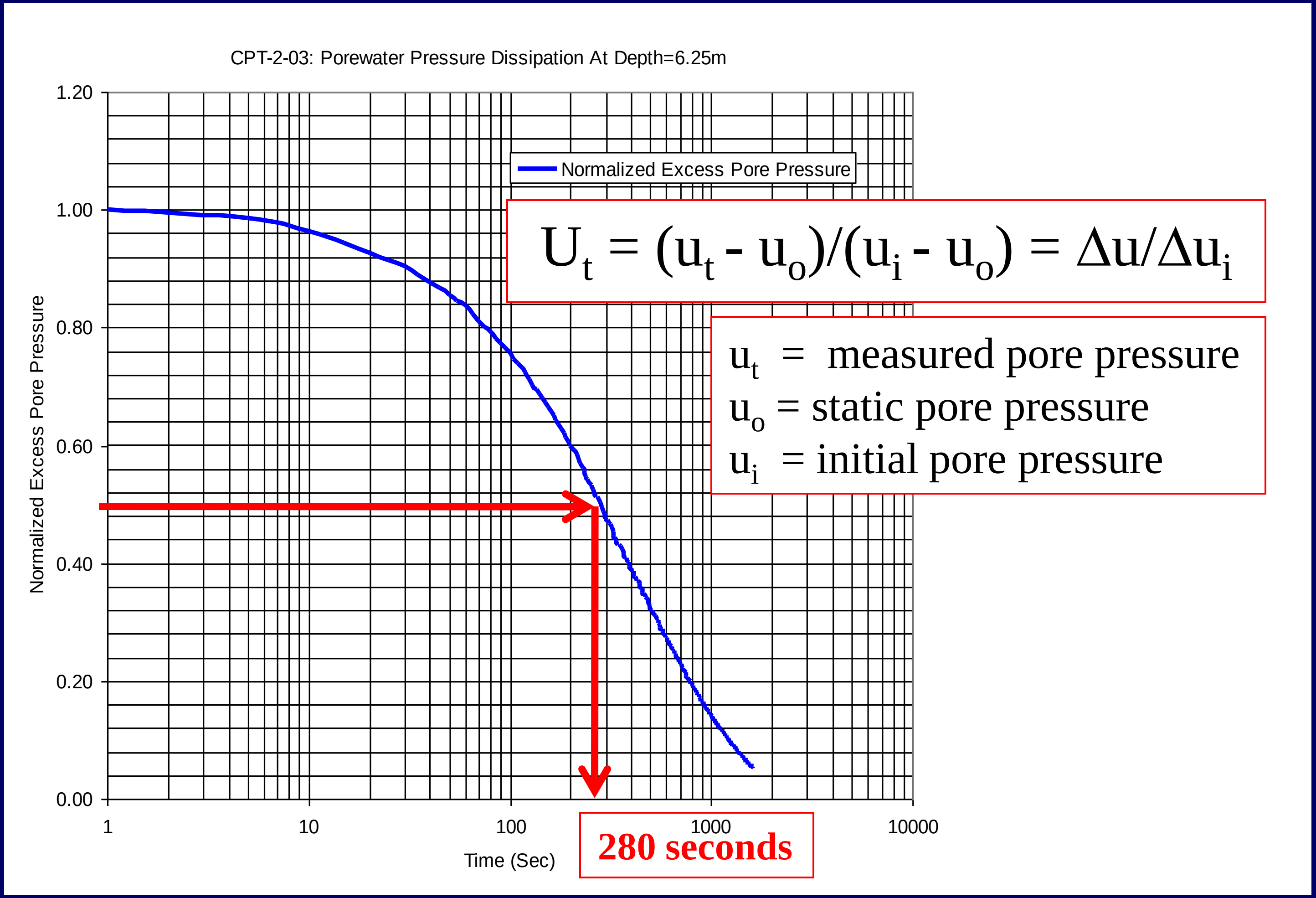


Pore pressure dissipation curves for very dense sand and overconsolidated clay can exhibit a post penetration increase.

Measuring t_{50} from a plot of the observed pore pressure data as a function of time.



An alternative method of plotting the pore pressure dissipation data and measuring t_{50}.



Plot the pore pressure or normalized excess pore pressure (U_t) as a function of time and measure t_{50}.

Application of CPT data to conventional consolidation theory in clay

- Coefficient of consolidation (c_{vh}) can be determined from pore pressure dissipation observations. This will permit calculation of the time-to-consolidate.
- Stratigraphy (drainage path distances) can be assessed by CPT profiles
- Coefficient of compression or the compression index (c_c) can not be determined from CPT data. The Coefficient of compression is needed to determine the magnitude of consolidation, which is the result of plastic deformation.

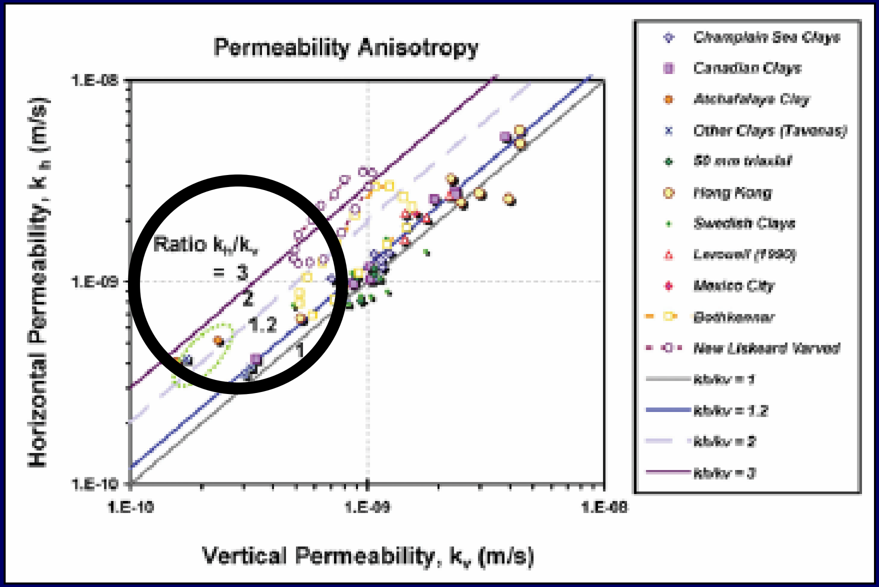
Ratio of horizontal to vertical permeability

The CPT measures the k_h, however the rate of consolidation is controlled by the k_v.

TABLE 3
PERMEABILITY ANISOTROPY IN NATURAL CLAYS

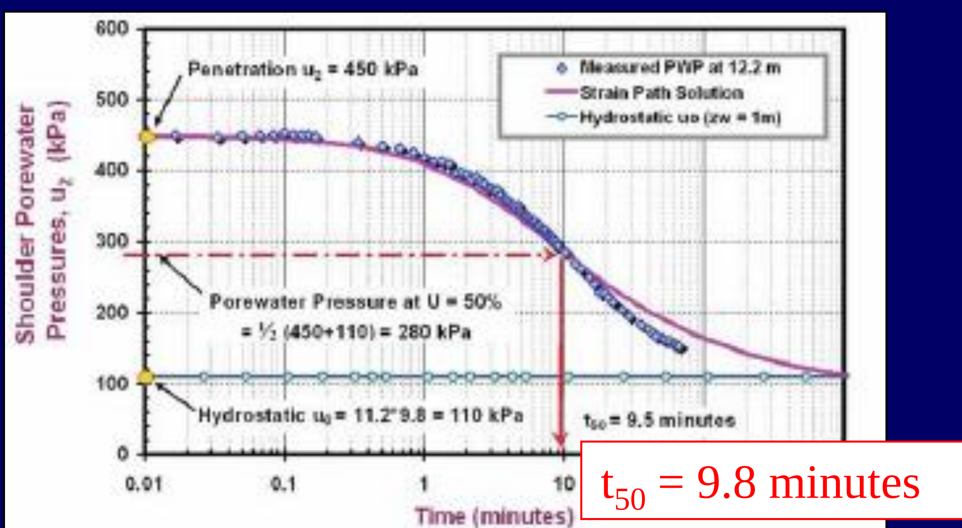
Nature of the Clay	Ratio k_h/k_v
Homogeneous Clays	1 to 1.5
Sedimentary Clays with Discontinuous Lenses and Layers, Well-Developed Macrofabric	2 to 4
Varved Clays and Silts with Continuous Permeable Layers	1.5 to 15

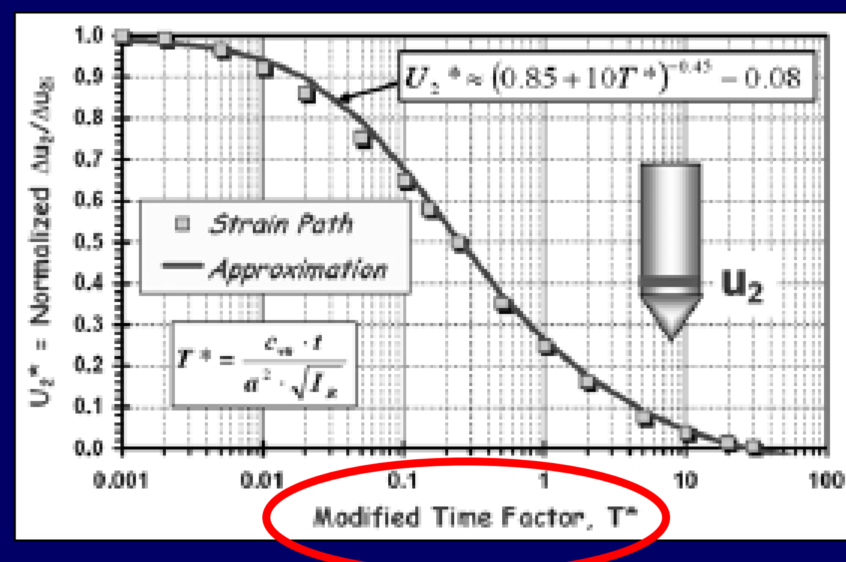
Adapted after Leroueil and Jamiolkowski (1991).
Note: k_h = horizontal hydraulic conductivity; k_v = vertical hydraulic conductivity.



Estimation of the coefficient of consolidation (c_{vh}) from pore pressure dissipation data and the rigidity index (Teh and Houlsby, 1991))

- This analysis is based on the strain path method (SPM).
- $c_{vh} = ((T_{50})\,(a_c)^2\,(I_R)^{0.5})/t_{50}$
- $T_{50} = 0.245$ for a 15 cm^2 cone tip.
- $a_c = 2.2$ cm for a 15 cm^2 cone tip

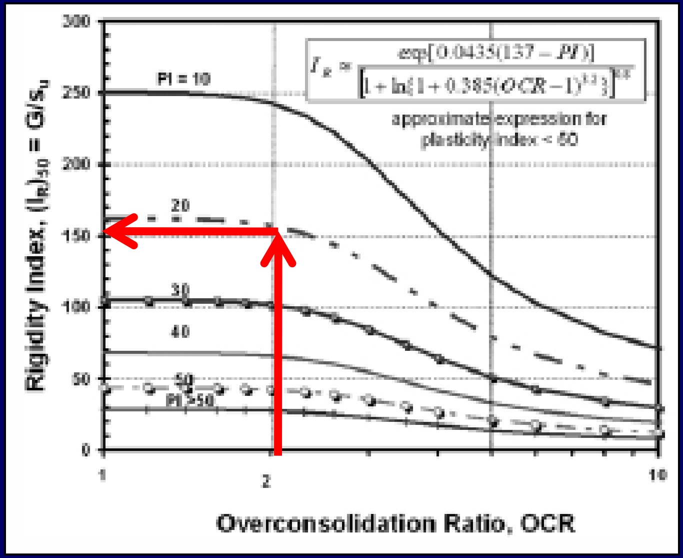




Estimation of the rigidity index (I_R) for clays and silts from the net tip resistance and the pore pressure (Mayne, 2001)

- I_R is used to calculate c_{vh}.
- $I_R = G/s_u$
  - where G is for undrained conditions and small strains
- $I_R = \exp(((1.5/M) + 2.925)\,((q_t - \sigma_{vo})/(q_t - u_2)) - 2.95)$
  - where $M = 6(\sin \phi')/(3 - \sin \phi')$

If plasticity index and OCR are known, this empirical correlation can be used.



Example of the calculation for c_{vh}

- $c_{vh} = ((T_{50})\ (a_c)^2\ (I_R)^{0.5})/t_{50}$
  - $T_{50} = 0.245$
  - $a_c = 2.2$ cm
  - $I_R = 155$ for OCR = 2 and PI = 20
  - $t_{50} = 9.8$ minutes
- $c_{vh} = ((0.245)\ (2.2\ \text{cm})^2\ (155)^{0.5})/9.8$ minutes
- $c_{vh} = (14.76\ \text{cm}^2)/9.8$ minutes
- $c_{vh} = 1.51\ \text{cm}^2/\text{min}$

Example of the calculation for c_{vh}

- $c_{vh} = ((T_{50})\ (a_c)^2\ (I_R)^{0.5})/t_{50}$
  - $T_{50} = 0.245$
  - $a_c = 2.2$ cm $= 0.0722$ feet
  - $I_R = 155$ for OCR = 2 and PI = 20
  - $t_{50} = 9.8$ minutes
- $c_{vh} = ((0.245)\ (0.0722\ \text{ft})^2\ (155)^{0.5})/9.8$ minutes
- $c_{vh} = (0.0159\ \text{ft}^2)/9.8$ minutes
- $c_{vh} = 1.16 \times 10^{-3}\ \text{ft}^2/\text{min} = 2.34\ \text{ft}^2/\text{day}$

An alternative method for the estimation of the coefficient of consolidation (c_{vh}) from pore pressure dissipation data and the rigidity index (Burns and Mayne, 1998))

- Refer to Geotechnical Engineering Circular No. 5, FHWA-IF-02-034.
- This is an iterative procedure based on matching the entire pore water pressure dissipation curve to a calculated curve.

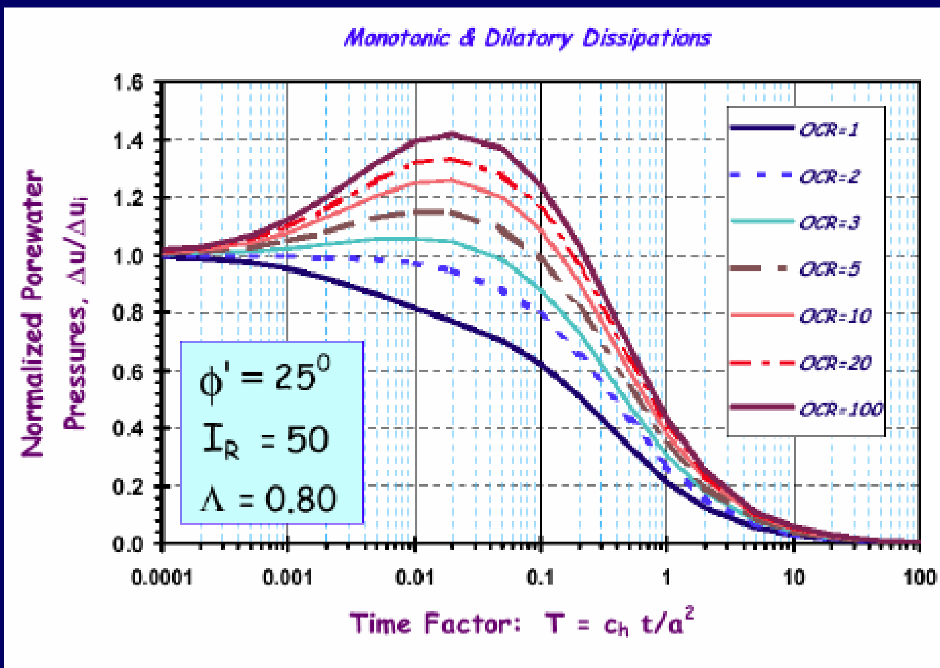
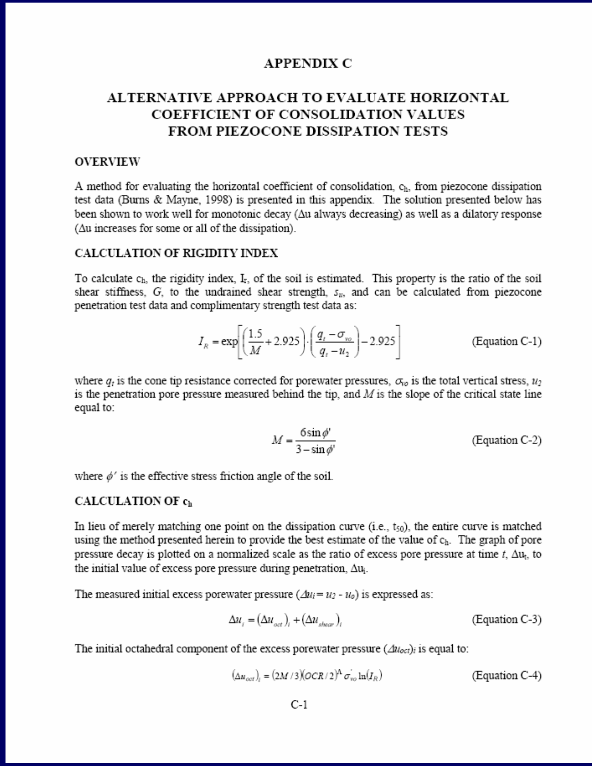


Figure C-1. Comparison of measured and predicted piezocone dissipation data.



APPENDIX C

ALTERNATIVE APPROACH TO EVALUATE HORIZONTAL COEFFICIENT OF CONSOLIDATION VALUES FROM PIEZOCONE DISSIPATION TESTS

OVERVIEW

A method for evaluating the horizontal coefficient of consolidation, c_h, from piezocone dissipation test data (Burns & Mayne, 1998) is presented in this appendix. The solution presented below has been shown to work well for monotonic decay (Δu always decreasing) as well as a dilatory response (Δu increases for some or all of the dissipation).

CALCULATION OF RIGIDITY INDEX

To calculate c_h, the rigidity index, I_r, of the soil is estimated. This property is the ratio of the soil shear stiffness, G, to the undrained shear strength, s_u, and can be calculated from piezocone penetration test data and complimentary strength test data as:

$$I_R = \exp\left[\left(\frac{1.5}{M}+2.925\right)\cdot\left(\frac{q_t-\sigma_{vo}}{q_t-u_2}\right)-2.925\right] \quad \text{(Equation C-1)}$$

where q_t is the cone tip resistance corrected for porewater pressures, σ_{vo} is the total vertical stress, u_2 is the penetration pore pressure measured behind the tip, and M is the slope of the critical state line equal to:

$$M = \frac{6\sin\phi'}{3-\sin\phi'} \quad \text{(Equation C-2)}$$

where ϕ' is the effective stress friction angle of the soil.

CALCULATION OF c_h

In lieu of merely matching one point on the dissipation curve (i.e., t_{50}), the entire curve is matched using the method presented herein to provide the best estimate of the value of c_h. The graph of pore pressure decay is plotted on a normalized scale as the ratio of excess pore pressure at time t, Δu_t, to the initial value of excess pore pressure during penetration, Δu_i.

The measured initial excess porewater pressure ($\Delta u_i = u_2 - u_o$) is expressed as:

$$\Delta u_i = (\Delta u_{oct})_i + (\Delta u_{shear})_i \quad \text{(Equation C-3)}$$

The initial octahedral component of the excess porewater pressure $(\Delta u_{oct})_i$ is equal to:

$$(\Delta u_{oct})_i = (2M/3)(OCR/2)^{\Lambda}\sigma'_{vo}\ln(I_R) \quad \text{(Equation C-4)}$$

C-1

Questions?