LABORATORY TESTING

The coefficient of consolidation (c_v) can be evaluated using information obtained from the laboratory consolidation test if, each time you put a load increment on the sample, you monitor the change in the height of the sample over time.

As discussed in the last class, c_v transforms a plot of U as a function of T into a plot of settlement as a function of time since

$$U = \frac{s(t)}{s_c} \times 100 \quad \text{and} \quad T = \frac{c_v}{H_{dr}^2} t$$

Here H_{dr} is half the specimen height since most consolidation test specimens are doubly drained and s_c is the total consolidation settlement under the load increment. Therefore, it should be possible to derive a value for c_v from the settlement history of the specimen under a given load increment. Unfortunately, things are not that simple.

When you put each new load increment on the sample, the sample undergoes some small amount of immediate elastic settlement, then primary consolidation settlement, then secondary compression settlement.

It is very difficult to determine where each phase ends and the next begins, so it is very difficult to determine what settlements correspond to 0% and 100% consolidation. In other words, you really don't know s(t) or s_c very well.

Today we'll look at several methods for finding c_v from laboratory test data. Each method is designed to get around the uncertainty in determining where consolidation settlement begins and ends during the test.

Casagrande Method

Begin by plotting the change in specimen height (or dial gage reading) as a function of the logarithm of time.

To estimate the dial gage reading corresponding to 0% consolidation (R_0) you can make use of the fact that the plot of U as a function of T is parabolic for U < 60%.

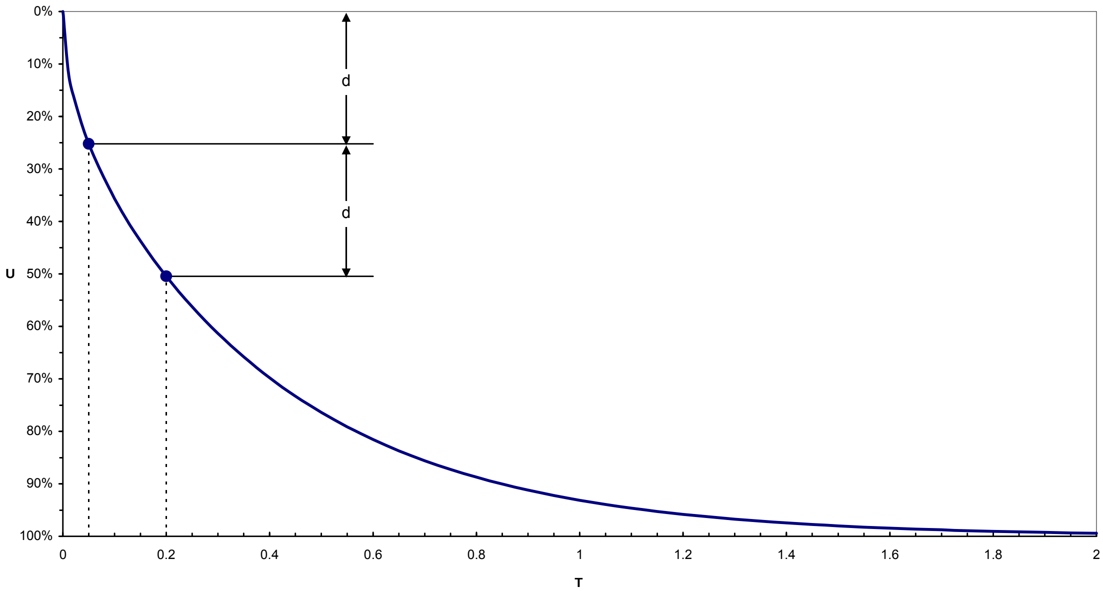
1. Pick two times t_1 and t_2 in the ratio of 4:1 and note the corresponding dial readings R_1 and R_2 (which represent the height of the sample at the two different times).

2. If the curve is parabolic and times t_1 and t_2 differ by a factor of 4, then R_1 and R_2 must differ by a factor of 2. If R_2 is exactly twice R_1, then

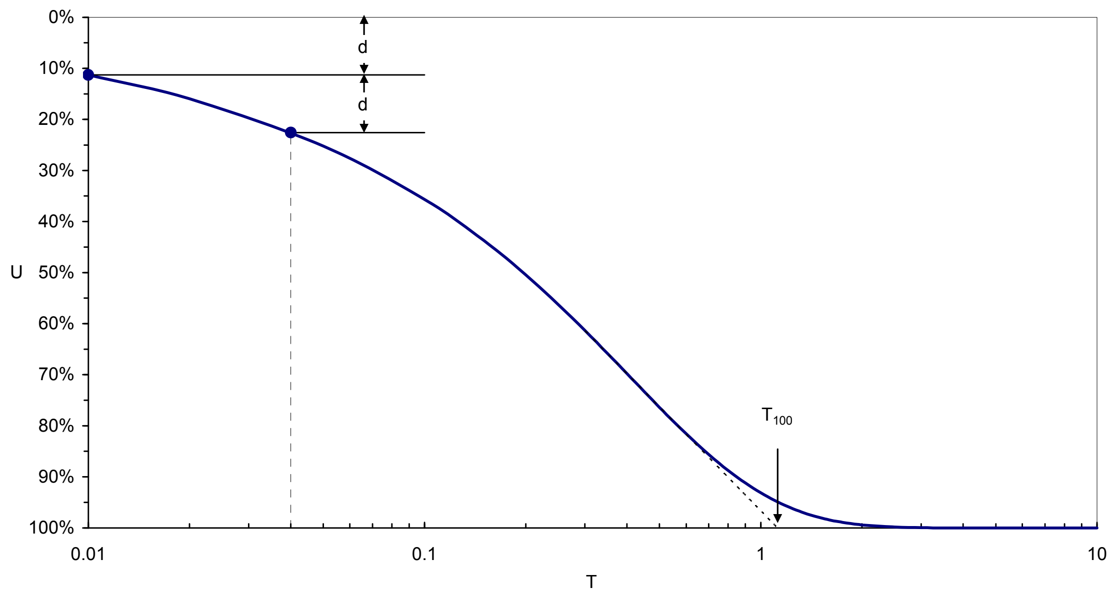
$$R_2 - R_1 = R_1 - R_0$$

   This means that R_0 is as far above R_1 as R_1 is above R_2. This lets you locate R_0 on the plot by scaling off the distance between R_1 and R_2.

Since we're dealing with laboratory data that contains some measurement error, it's a good idea to repeat Steps 1 and 2 a couple of times using different values of t_1 and average the results.



If we look at a plot of U log T, though (next page), we see that the curve is first concave downward, then roughly linear, then concave upward as it approaches the asymptote U=100%. In theory, it will take an infinite amount of time to reach 100% consolidation. However, we can approximate a finite value for T_{100} by extrapolating the linear middle portion of the curve until it hits the asymptote U=100%.



The laboratory consolidation curve will exhibit similar behavior, but it will be asymptotic to the secondary compression curve at U=100% rather than a horizontal line. Thus,

3. To determine R_{100}, draw a tangent to the primary consolidation curve and a tangent to the secondary consolidation curve and select their intersection as U=100%.

Having identified R_0 and R_{100} we next calculate R_{50}, the dial reading corresponding to 50% consolidation and, from that, determine t_{50}, the corresponding time. With that we can write

$$T_{50} = 0.197 = c_v \frac{t_{50}}{H_{dr}^{\ 2}} \quad \Rightarrow \quad c_v = 0.197\left(\frac{H_{dr}^{\ 2}}{t_{50}}\right)$$

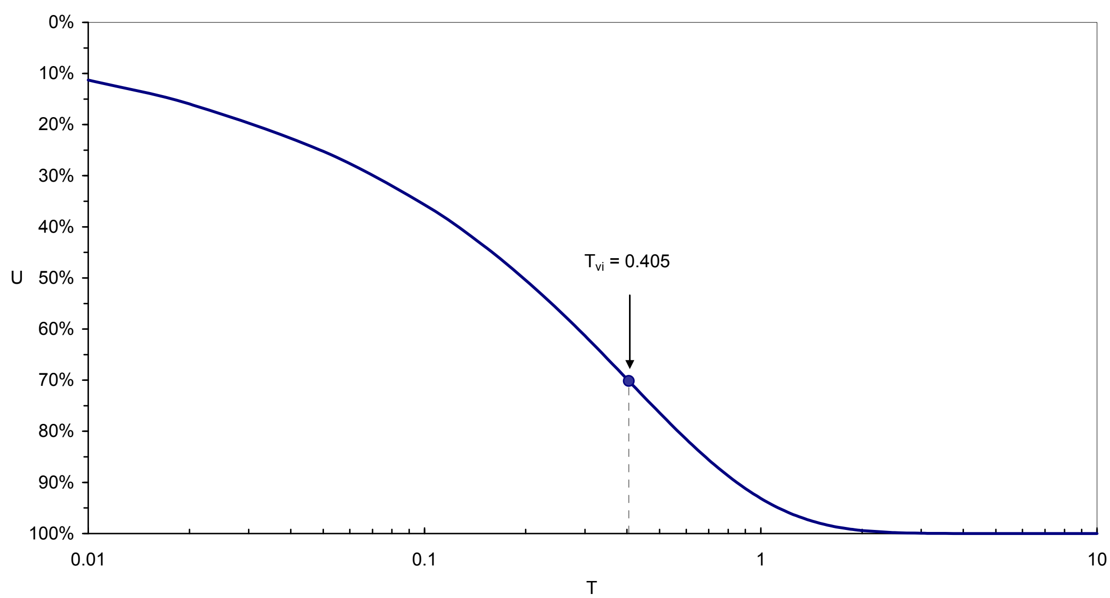
<u>Inflection Point Method</u>

The inflection point method avoids the hassle of having to identify R_0 by noting that a plot of U as a function of log(t) has an inflection point at T = 0.405 (next page).

In practice, you would plot sample height as a function of log(t) as you would with the Casagrande method, then simply locate the inflection point and read off t_i at that point. By definition then,

$$T_i = 0.405 = \frac{c_v}{H_{dr}^{\ 2}} t_i \quad \Rightarrow \quad c_v = 0.405\left(\frac{H_{dr}^{\ 2}}{t_i}\right)$$

This method has the advantage that you only need good data in the middle of the consolidation curve, well away from both the immediate elastic settlement at U → 0 and the secondary compression at U → 100%.



Professor Mesri at University of Illinois shows in his article that this method produces values of c_v that agree as well with those produced by both the Casagrande and Taylor methods as the values produced by those methods agree with each other.

Taylor Method

If you plot change in height (or dial gage reading) as a function of the square root of time, it should plot as a straight line as long as U < 60%.

If you extrapolate the linear portion of the laboratory consolidation curve back toward the origin, you can determine the dial reading R_0 corresponding to 0% consolidation (i.e., the dial reading after the immediate settlement has occurred).

Taylor noted that if you extrapolate the linear portion of the laboratory consolidation curve forward (beyond 60% consolidation) it gives you a T_{90} that's about 15% too low. That's because the parabolic approximation gives

$$T_{90} = \frac{\pi}{4}(0.9)^2 = 0.636$$

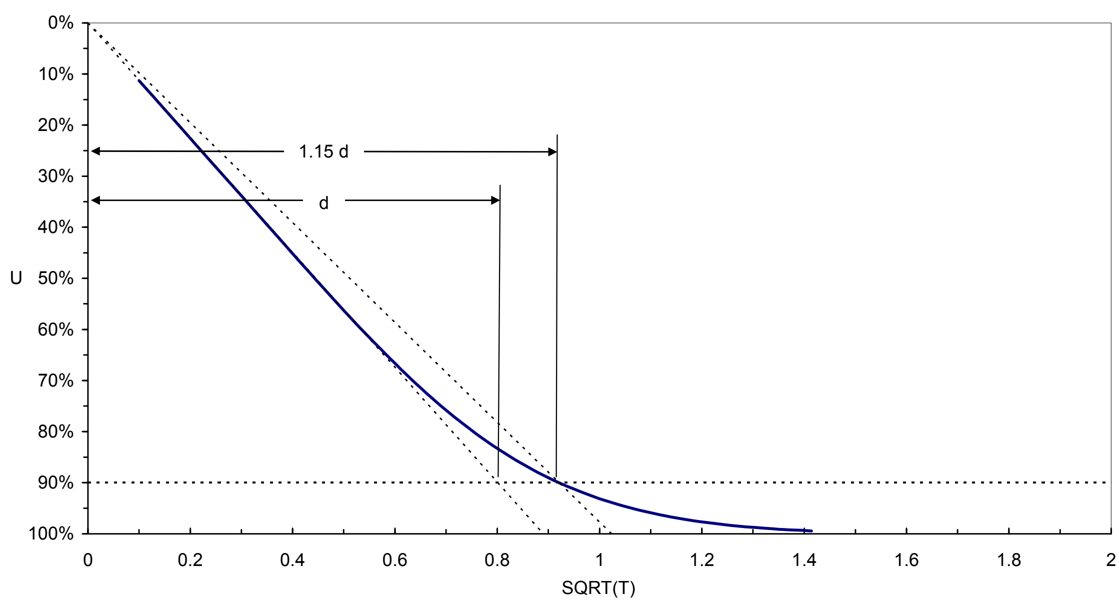
where the actual value is closer to

$$T_{90} = 1.781 - 0.933\log(10) = 0.848$$

Thus, on a plot of U as a function of the square root of T, the ratio of the correct value to the extrapolated value is

$$\frac{\sqrt{0.848}}{\sqrt{0.636}} = 1.1545$$

Thus, if you draw a line starting from (0, R_0) with a slope 15% shallower than the linear portion of the laboratory consolidation curve, its intersection with the nonlinear portion of the laboratory curve defines 90% consolidation.

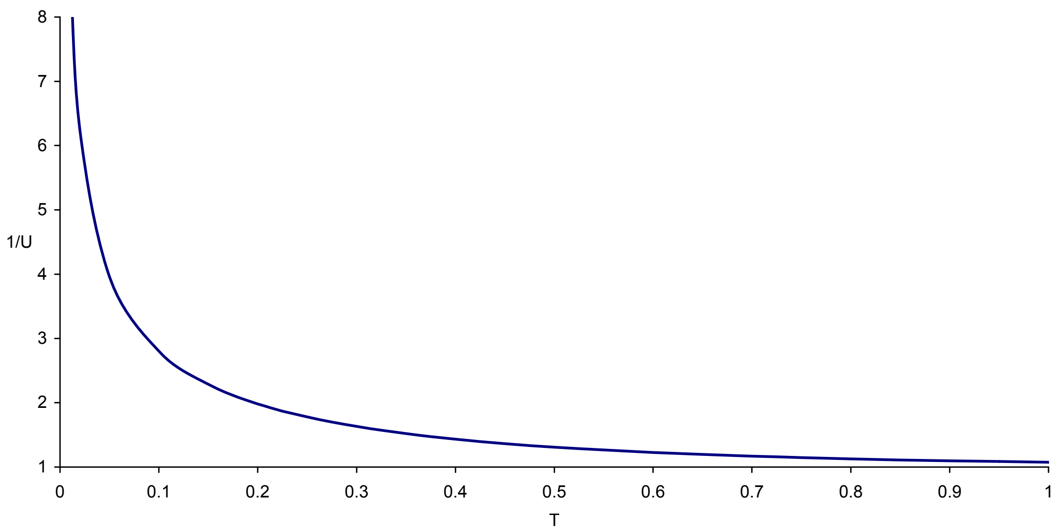


Once you've determined t_{90}, you can write

$$T_{90} = 0.848 = c_v \frac{t_{90}}{H_{dr}^2} \quad \Rightarrow \quad c_v = 0.848\left(\frac{H_{dr}^2}{t_{90}}\right)$$

Rectangular Hyperbola Method

The rectangular hyperbola method makes use of the fact that for U% > 60%, a plot of 1 / U vs. T is a rectangular hyperbola:



The definition of a rectangular hyperbola is a hyperbola whose asymptotes are mutually perpendicular. The equation for a rectangular hyperbola is

$$(x-h)(y-k) = c$$

where $x = h$ and $y = k$ are the asymptotes and c is a constant.

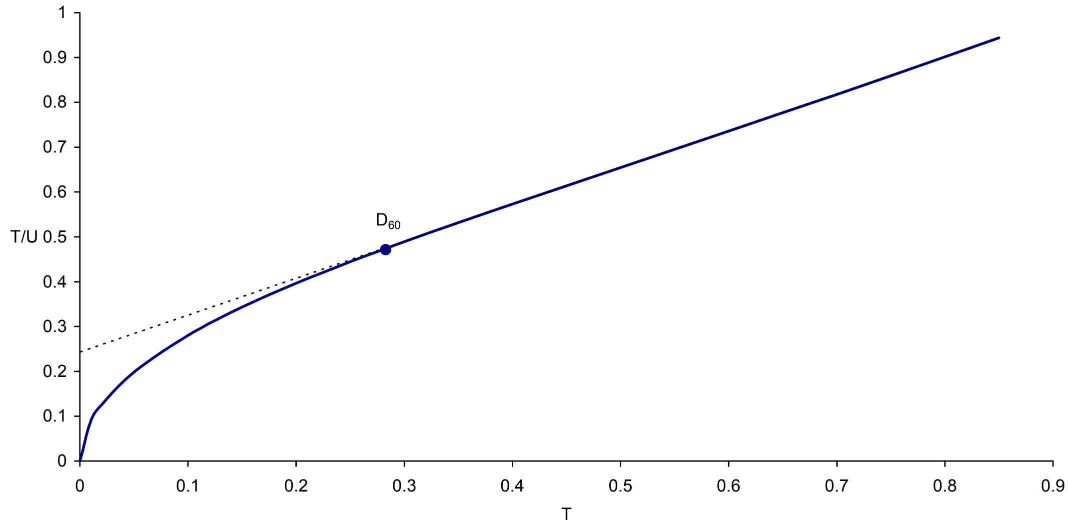
Because the average consolidation curve is a rectangular hyperbola for U > 60%, a plot of T / U vs. T is a straight line beyond 60% consolidation (see next page).

If you plot t / δ vs. t instead of T / U vs. T, you also get a straight line. The coefficient of consolidation can be calculated from the slope (m) and intercept (c) of that line as

$$c_v = 0.24\left(\frac{m}{c}\right)H_{dr}^2$$

Furthermore, the settlement corresponding to 100% consolidation (δ_{100}) can be found from the slope as

$$\delta_{100} = 0.859 / m$$



This is the only method for which δ_{100} can be identified at less than 90% consolidation, which has led the inventor to propose a method of consolidation testing in which a new load increment is applied as soon as δ_{100} is identified. This speeds the test from days to hours.