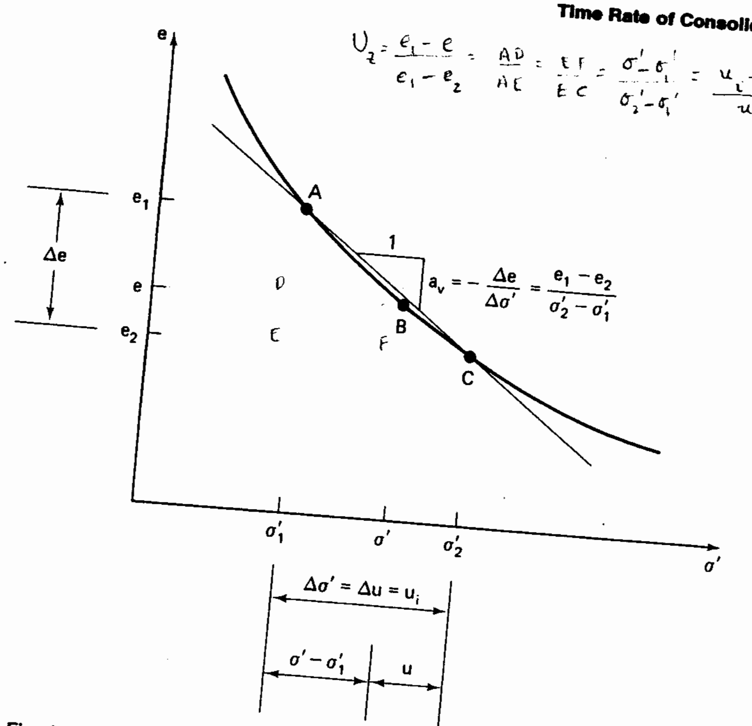

Fig. 9.2 Laboratory compression curve. Note: $\sigma' - \sigma_1' = (\sigma_2' - \sigma_1') - u = u_i - u$.

consolidation ratio, Eq. 9-8, or

$$U_z = 1 - \sum_{n=0}^{\infty} f_1(Z) f_2(T) \tag{9-9}$$

The solution to this equation is shown graphically in Fig. 9.3 in terms of the dimensionless parameters already defined. The tedious calculations involved in solving Eq. 9-9 are no longer necessary. From Fig. 9.3 it is possible to find the amount or degree of consolidation (and therefore u and σ') for any real time after the start of loading and at any point in the consolidating layer. All you need to know is the c_v for the particular soil deposit, the total thickness of the layer, and boundary drainage conditions. With these items, the time factor T can be calculated from Eq. 9-5. It is applicable to any one-dimensional loading situation where the soil properties can be assumed to be the same throughout the compressible layer.

Figure 9.3 also is a picture of the *progress of consolidation*. The *isochrones* (lines of constant T) in Fig. 9.3 represent the degree or percent

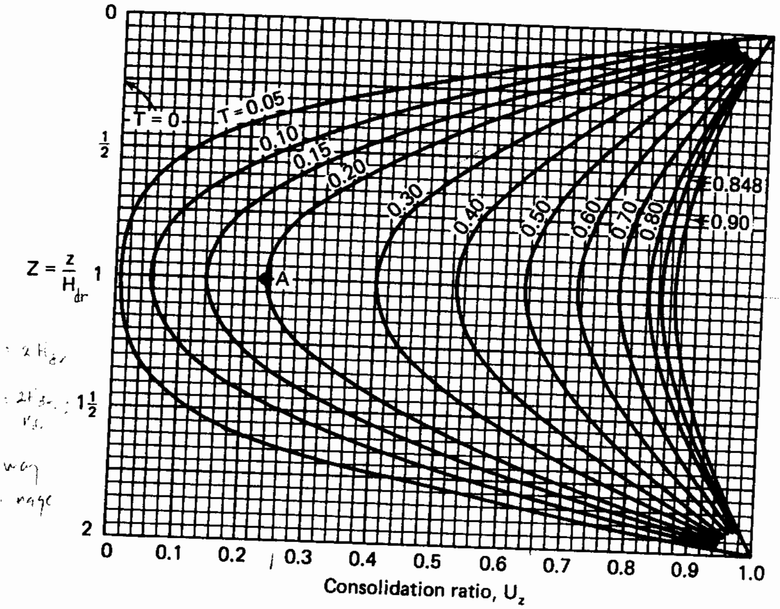

Fig. 9.3 Consolidation for any location and time factor in a doubly drained layer (after Taylor, 1948).

consolidation for a given time factor throughout the compressible layer. For example, the percent consolidation at midheight of a doubly drained layer (total thickness = $2H$) for a time factor equal to 0.2 is approximately 23% (see point A in Fig. 9.3). However at the same time (and time factor) at other locations within the soil layer, the degree of consolidation is different. At 25% of the depth, for example, $z/H = \frac{1}{2}$ and $U_z = 44\%$. Similarly, near the drainage surfaces at $z/H = 0.1$, for the same time factor, because the gradients are much higher, the clay is already 86% consolidated, which means that at that depth and time, 86% of the original excess pore pressure has dissipated and the effective stress has increased by a corresponding amount.

EXAMPLE 9.1

Given:

A 12 m thick layer of Chicago clay is *doubly drained*. (This means that a very pervious layer compared to the clay exists on top of and under the 12 m clay layer.) The coefficient of consolidation $c_v = 8.0 \times 10^{-8}$ m²/s.

Required:

Find the degree or percent consolidation for the clay 5 yr after loading at depths of 3, 6, 9, and 12 m.

Solution:

First, compute the time factor. From Eq. 9-5,

$$T = \frac{c_v t}{H_{dr}^2}$$

$$= \frac{8.0 \times 10^{-8}\ \text{m}^2/\text{s}\ (3.1536 \times 10^7\ \text{s/yr})\ (5\ \text{yr})}{(6)^2} = 0.35$$

Note that $2H = 12$ m and $H_{dr} = 6$ m since there is double drainage.
Next, from Fig. 9.3 we obtain (by interpolation) for $T = 0.35$:

At $z = 3$ m,	$z/H = 0.50$,	$U_z = 61\%$
At $z = 6$ m,	$z/H = 1.0$,	$U_z = 46\%$
At $z = 9$ m,	$z/H = 1.50$,	$U_z = 61\%$
At $z = 12$ m,	$z/H = 2.0$,	$U_z = 100\%$

EXAMPLE 9.2

Given:

The soil conditions of Example 9.1.

Required:

If the structure applied an average vertical stress increase of 100 kPa to the clay layer, estimate the excess pore water pressure remaining in the clay after 5 yr for the depths in the clay layer of 3, 6, 9, and 12 m.

Solution:

Assuming one-dimensional loading, the induced excess pore water pressure at the beginning of consolidation is 100 kPa. From Eq. 9-8,

$$U_z = 1 - \frac{u}{u_i}$$

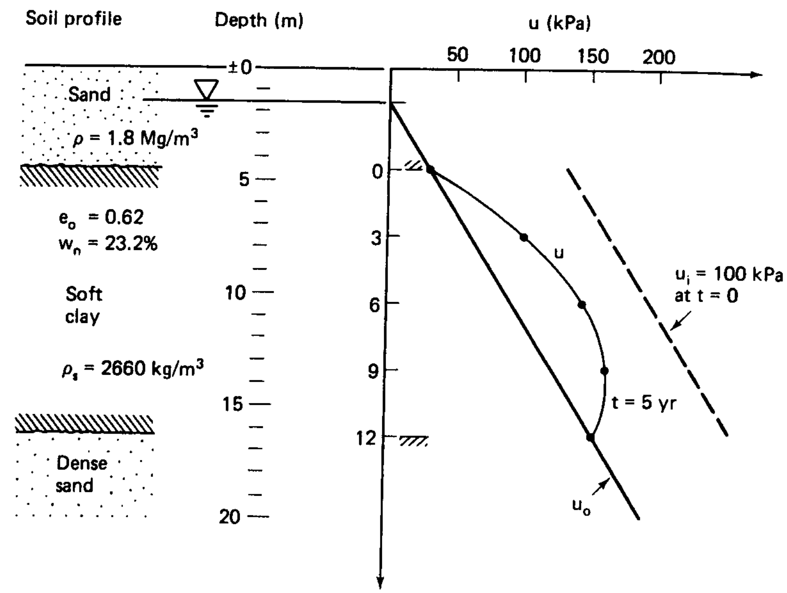

Fig. Ex. 9.2

or

$$u = u_i(1 - U_z)$$

From the solution in Example 9.1 we obtain:

At $z = 3$ m,	$U_z = 61\%$,	$u = 39$ kPa
At $z = 6$ m,	$U_z = 46\%$,	$u = 54$ kPa
At $z = 9$ m,	$U_z = 61\%$,	$u = 39$ kPa
At $z = 12$ m,	$U_z = 100\%$,	$u = 0$ kPa

Figure Ex. 9.2 shows these values versus depth. Note that they are *excess* pore pressures, that is, they are above the hydrostatic water pressure.

In most cases, we are not interested in how much a given point in a layer has consolidated. Of more practical interest is the *average degree or percent consolidation* of the entire layer. This value, denoted by U or U_{avg}, is a measure of how much the entire layer has consolidated and thus it can be directly related to the *total settlement* of the layer at a given time after loading. Note that U can be expressed as either a decimal or a percentage.

To obtain the average degree of consolidation over the entire layer corresponding to a given time factor we have to find the area under the T

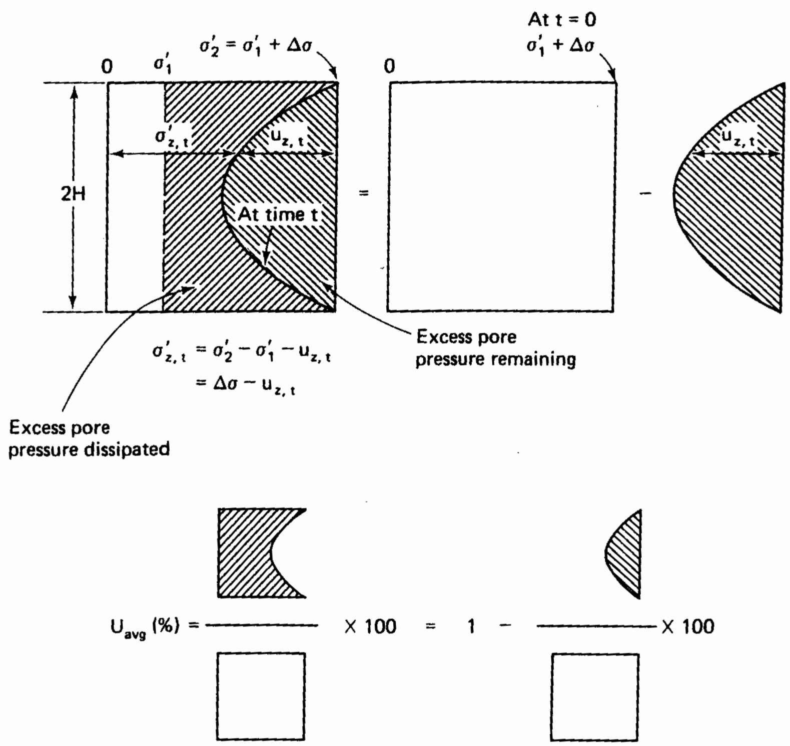

Fig. 9.4 Average degree of consolidation, U_{avg}, defined.

curve of Fig. 9.3. (Actually we obtain the area outside the T curve as shown in Fig. 9.4.) How the integration is done mathematically is shown in Appendix B-2. Table 9-1 presents the results of the integration for the case where a *linear* distribution of excess pore water pressure is assumed.

The results in Table 9-1 are shown graphically in Fig. 9.5. In Fig. 9.5a the relationship is shown arithmetically, whereas in Fig. 9.5b, the relationship between U and T is shown semilogarithmically. Another form of the relationship is found in Fig. 9.5c, where U is plotted versus $\sqrt{T}$. As discussed in the next section, Figs. 9.5b and 9.5c have been found to show certain characteristics of the theoretical U-T relationship to better advantage than Fig. 9.5a. Note that as T becomes very large, U asymptotically approaches 100%. This means that, theoretically, consolidation never stops but continues infinitely. It should also be pointed out that the solution for U versus T is dimensionless and applies to all types of problems where $\Delta\sigma = \Delta u$ varies *linearly* with depth. Solutions for cases

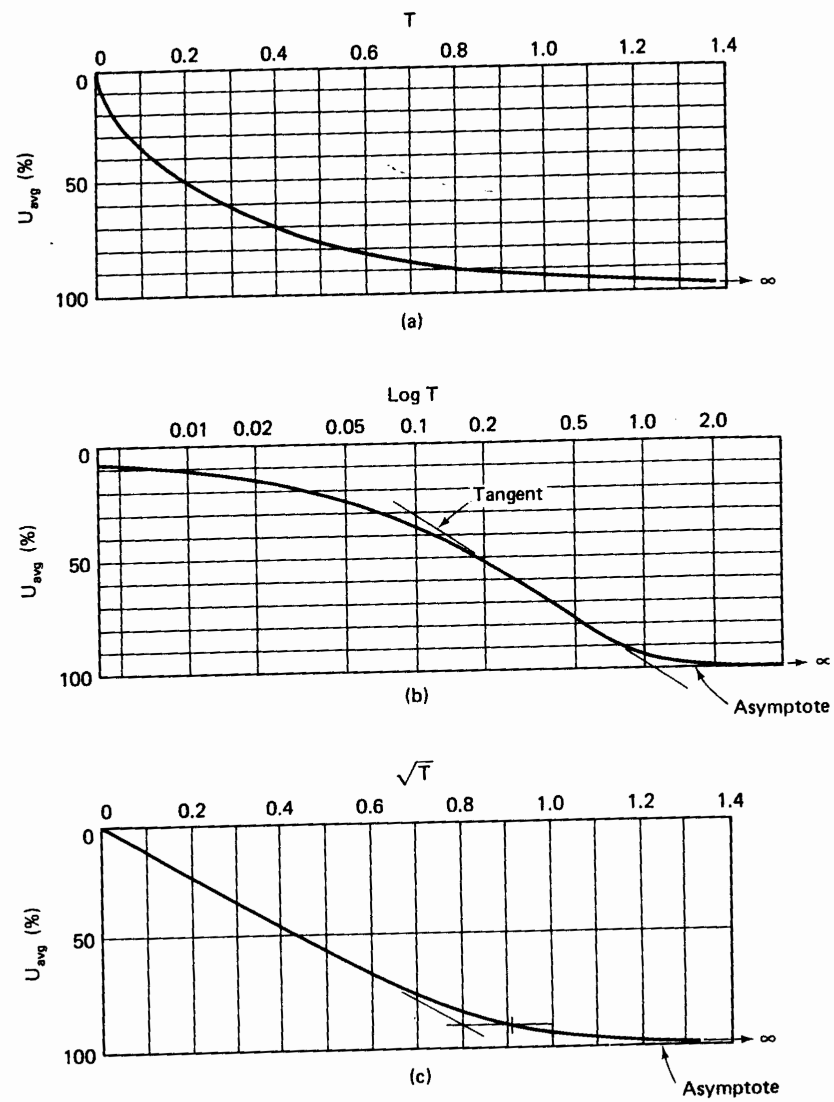

Fig. 9.5 U_{avg} versus T: (a) arithmetic scale; (b) log scale; (c) square root scale.

TABLE 9-1

U_{avg}	T
0.1	0.008
0.2	0.031
0.3	0.071
0.4	0.126
0.5	0.197
0.6	0.287
0.7	0.403
0.8	0.567
0.9	0.848
0.95	1.163
1.0	∞

where the initial pore pressure distribution is sinusoidal, half sine, and triangular are presented by Leonards (1962).

Casagrande (1938) and Taylor (1948) provide the following useful approximations:

For $U < 60\%$,

$$T = \frac{\pi}{4}U^2 = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2 \tag{9-10}$$

For $U > 60\%$,

$$T = 1.781 - 0.933 \log (100 - U\%) \tag{9-11}$$

EXAMPLE 9.3

Given:

$T = 0.05$ for a compressible clay deposit.

Required:

Average degree of consolidation and the percent consolidation at the center and at $z/H = 0.1$.

Solution:

From Table 9-1 and Fig. 9.5, $U_{avg} = 26\%$. Therefore the clay is 26% consolidated, on the average. From Fig. 9.3 you can see that the center of

the layer is less than 0.5% consolidated, while at the "10%" depth ($z/H = 0.1$) the clay is 73% consolidated. But, *on the average* throughout the layer, the clay is 26% consolidated.

What does the average consolidation mean in terms of settlements? U_{avg} can be expressed as

$$U_{avg} = \frac{s(t)}{s_c} \tag{9-12}$$

where $s(t)$ is the settlement at any time, and s_c is the final or ultimate consolidation (primary) settlement at $t = \infty$.

EXAMPLE 9.4

Given:

The data of Example 9.3.

Required:

Find the settlement when U_{avg} is 26%, if the final consolidation settlement is 1 m.

Solution:

From Eq. 9-12, $s(t) = U_{avg}(s_c)$. Therefore

$$s(t) = 26\% \text{ (1 m)} = 0.26 \text{ m}$$

EXAMPLE 9.5

Given:

The soil profile and properties of Examples 9.1 and 9.2.

Required:

Compute the time required for the clay layer to settle 0.25 m.

Solution:

To compute the average degree of consolidation, you first must estimate the consolidation settlement s_c, as you did in Chapter 8. For Chicago clay, a reasonable value of C_c is about 0.25 (Tables 8-2 and 8-3). From Fig. Ex. 9.2, $H_o = 12$ m and $e_o = 0.62$. Determine ρ for the soft clay and calculate σ'_{vo} at the middepth of layer from Eqs. 7-14c and 7-15. Assume the clay is normally consolidated. So

$$\begin{aligned}\sigma'_{vo} &= 1.8 \times 9.81 \times 1.5 + (1.8 - 1) \times 9.81 \times 3 \\ &\quad + (2.02 - 1) \times 9.81 \times 6 \\ &= 110 \text{ kPa}\end{aligned}$$

From Eq. 8-11,

$$s_c = 0.25 \frac{12 \text{ m}}{1 + 0.62} \log \frac{110 + 100}{110} = 0.52 \text{ m}$$

The average degree of consolidation U_{avg} when the clay layer settles 0.25 m is (Eq. 9-12):

$$U_{avg} = \frac{s(t)}{s_c} = \frac{0.25 \text{ m}}{0.52 \text{ m}} = 0.48, \text{ or } 48\%$$

To obtain T we can use either Table 9-1 or Fig. 9.5. Or since $U_{avg} < 60\%$, we can use Eq. 9-10.

$$T = \frac{\pi}{4}(0.48)^2 = 0.182$$

From Eq. 9.5, $t = TH_{dr}^2/c_v$, where $H_{dr} = 6$ m for double drainage; or

$$\begin{aligned} t &= \frac{0.182 \times (6 \text{ m})^2}{8 \times 10^{-8} \text{ m}^2/\text{s} \times 3.1536 \times 10^7 \text{ s/yr}} \\ &= 2.6 \text{ yr}\end{aligned}$$

EXAMPLE 9.6

Given:

The data of Examples 9.1 and 9.5.

Required:

How much time would be required for a settlement of 0.25 m to occur if the clay layer were singly drained?

Solution:

Use Eq. 9-5 directly.

$$c_v = 8 \times 10^{-8} \text{ m}^2/\text{s} \times 3.1536 \times 10^7 \text{ s/yr} = 2.523 \text{ m}^2/\text{yr}$$

$$t = \frac{TH_{dr}^2}{c_v}$$

where $H_{dr} = 12$ m for single drainage.

$$t = \frac{0.182 \times (12 \text{ m})^2}{2.523 \text{ m}^2/\text{yr}} = 10.4 \text{ yr}$$

or *four times as long* as with double drainage.

EXAMPLE 9.7

Given:

A 10 m thick clay layer with *single* drainage settles 9 cm in 3.5 yr. The coefficient of consolidation for this clay was found to be 0.544×10^{-2} cm^2/s.

Required:

Compute the ultimate consolidation settlement, and find out how long it will take to settle to 90% of this amount.

Solution:

From Eq. 9-5 solve for T:

$$\begin{aligned} T &= \frac{tc_v}{H^2} \\ &= \frac{3.5 \text{ yr } (0.544 \times 10^{-2}) \text{ cm}^2}{(100 \text{ m}^2) \text{ s}} \left(\frac{1 \text{ m}^2}{10\,000 \text{ cm}^2}\right)\left(3.1536 \times 10^7 \frac{\text{s}}{\text{yr}}\right) \\ &= 0.6 \end{aligned}$$

From Table 9-1 we see that the average degree of consolidation is between 0.8 and 0.9. Therefore we can use either Eq. 9-11 or Fig. 9.5a, or we can interpolate from Table 9-1. Using Eq. 9-11, we have

$$0.6 = 1.781 - 0.933 \log (100 - U\%)$$

$$1.27 = \log (100 - U\%)$$

or

$$U = 81.56\%, \text{ or } 82\%$$

Thus if 9 cm of settlement represents 82% of the total settlement, then the total consolidation settlement is (Eq. 9-12):

$$s_c = \frac{s(t)}{U_{avg}} = \frac{9 \text{ cm}}{0.82} = 11 \text{ cm}$$

For the time for 90% settlement to occur, find $T = 0.848$ for $U_{avg} = 0.9$, from Table 9-1. Using Eq. 9-5 and solving for t, we find that:

$$t = \frac{TH_{dr}^2}{c_v} = \frac{0.848\,(10 \text{ m})^2}{0.544 \times 10^{-2} \text{ cm}^2/\text{s}} \frac{10\,000 \text{ cm}^2}{\text{m}^2}$$

$$= 1.559 \times 10^8 \text{ s} \frac{\text{yr}}{3.1536 \times 10^7 \text{ s}}$$

$$= 4.94 \text{ yr}$$

EXAMPLE 9.8

Given:

The data of Example 9.7.

Required:

Find the variation in the degree of consolidation throughout the layer when $t = 3.5$ yr.

Solution:

When $t = 3.5$ yr, the corresponding time factor = 0.6, from Example 9.7. Find the curve for $T = 0.6$ in Fig. 9.3. (For a layer with single drainage, we use the top half or bottom half, depending on where the layer is drained. Assume for this problem that the layer is drained at the *top*.) The curve for $T = 0.6$ represents the degree of consolidation at any depth z. Since $T = 0.6$ and using Eq. 9-5 we find that this isochrone shows the variation of U_z for $t = 3.5$ yr. It can be seen that at the bottom of the layer, where $z/H = 1$, $U_z = 71\%$. At midheight of the 10 m thick layer, where $z/H = 0.5$, $U_z = 79.5\%$. Thus the degree of consolidation varies through the depth of the clay layer, but the *average* degree of consolidation for the entire layer is 82% (Example 9.7). Another interesting point about Fig. 9.3 is that the area to the left of the curve $T = 0.6$ represents 82% of the area of the entire graph, $2H$ versus U_z, whereas the area to the right of the curve $T = 0.6$ represents 18%, or the amount of consolidation yet to take place. (See also Fig. 9.4.)

9.4 DETERMINATION OF THE COEFFICIENT OF CONSOLIDATION c_v

How do we obtain the coefficient of consolidation c_v? This coefficient is the only part of the solution to the consolidation equation that takes into account the soil properties which govern the rate of consolidation. In Chapter 8 we described the procedure for performing consolidation or oedometer tests to obtain the compressibility of the soil. We mentioned that each load increment usually remains on the test specimen an arbitrary length of time, until (we hope) essentially all of the excess pore pressure has dissipated. Deformation dial readings are obtained during this process, and the coefficient of consolidation c_v is determined from the time-deformation data.

The curves of actual deformation dial readings versus real time for a given load increment often have very similar shapes to the theoretical U-T curves shown in Fig. 9.5. We shall take advantage of this observation to determine the c_v by so-called "curve-fitting methods" developed by Casagrande and Taylor. These empirical procedures were developed to fit approximately the observed laboratory test data to the Terzaghi theory of consolidation. Many factors such as sample disturbance, load increment ratio (LIR), duration, temperature, and a host of test details have been found to strongly affect the value of c_v obtained by the curve-fitting procedures (Leonards and Ramiah, 1959; Leonards, 1962). But research by Leonards and Girault (1961) has shown that the Terzaghi theory is applicable to the laboratory test if large LIR's (Eq. 8-20), usually around unity, are used.

The curve-fitting procedures outlined in this section will enable you to determine values of the coefficient of consolidation c_v from laboratory test data. In addition, the procedures will allow you to separate the secondary compression from the primary consolidation.

Probably the easiest way to illustrate the curve-fitting methods is to work with time-deformation data from an actual consolidation test. We will use the data for the load increment from 10 to 20 kPa for the test shown in Fig. 8.5. This data is shown in Table 9-2 and plotted in Figs. 9.6a, b, and c. Note how similar the shapes of these curves are to the theoretical curves of Figs. 9.5a, b, and c.

TABLE 9-2 Time-Deformation Data for Load Increment 10 to 20 kPa (Fig. 8.5)

Elapsed Time (min)	$\sqrt{t}$ ($\sqrt{\text{min}}$)	Dial Reading, R (mm)	Displacement (mm)
0	0	6.627	0
0.1	0.316	6.528	0.099
0.25	0.5	6.480	0.147
0.5	0.707	6.421	0.206
1	1.0	6.337	0.290
2	1.41	6.218	0.409
4	2.0	6.040	0.587
8	2.83	5.812	0.815
15	3.87	5.489	1.138
30	5.48	5.108	1.519
60	7.75	4.775	1.852
120	10.95	4.534	2.093
240	15.5	4.356	2.271
480	21.9	4.209	2.418
1382	37.2	4.041	2.586

(a) Casagrande's Logarithm of Time Fitting Method

In this method, the deformation dial readings are plotted versus the *logarithm of time*, as shown in Fig. 9.6b and to larger scale in Fig. 9.7. The idea is to find R_{50} and thus t_{50}, which is the time for 50% consolidation, by approximating R_{100}, the dial reading corresponding to the time for 100% primary consolidation, t_{100} or t_p. Refer to Fig. 9.5b, the theoretical *U-T* curve, for a moment. Note that the intersection of the tangent and the asymptote to the theoretical curve defines $U_{avg} = 100\%$. The time for 100% consolidation, of course, occurs at $t = \infty$. Casagrande (1938) suggested that R_{100} could be approximated rather arbitrarily by the intersection of the two corresponding tangents to the laboratory consolidation curve (Fig. 9.7). Later research (for example, Leonards and Girault, 1961) has shown this procedure defines to a good approximation the dial reading at which the excess pore water pressure approaches zero, especially when the LIR is large and the preconsolidation stress is exceeded by the applied load increment. Once R_{100} is defined, then it is fairly easy to determine R_{50} and t_{50}, once we find R_o, the initial dial reading.

How do we determine R_o, the dial reading corresponding to zero percent consolidation, on a semilog plot? Since T is proportional to U_{avg}^2 up to $U = 60\%$ (Eq. 9-10), the first part of the consolidation curve must be a parabola. To find R_o, choose any two times, t_1 and t_2, in the ratio of 4 to 1, and note their corresponding dial readings. Then mark off a distance above R_1 equal to the difference $R_2 - R_1$; this defines the corrected zero

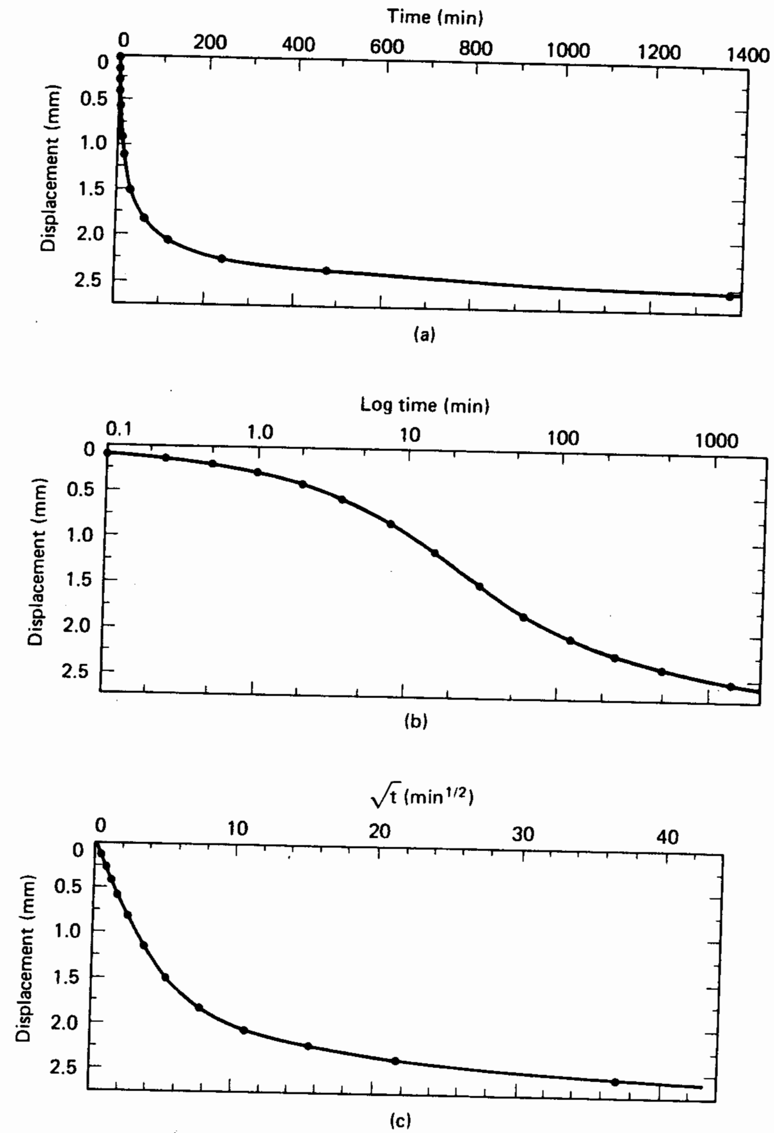

Fig. 9.6 Deformation-time curves for data from Table 9-2: (a) arithmetic scale; (b) log time scale; (c) square root of time scale.

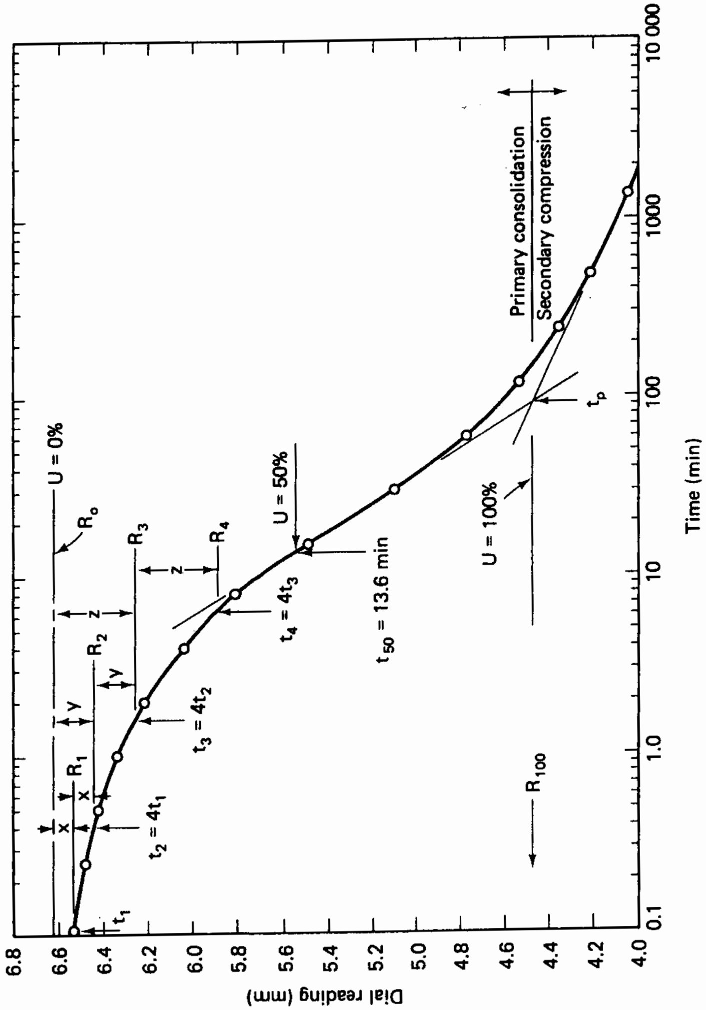

Fig. 9.7 Determination of t_{50} by the Casagrande method; data from Table 9-2.

point R_o. In equation form,

$$R_o = R_1 - (R_2 - R_1) \tag{9-13a}$$

Several trials are usually advisable to obtain a good average value of R_o, or

$$R_o = R_2 - (R_3 - R_2) \tag{9-13b}$$

and

$$R_o = R_3 - (R_4 - R_3) \tag{9-13c}$$

In Fig. 9.7, three different trials are shown for determining R_o from R_1, R_2, R_3, and R_4. The distances x, y, and z are marked off above the ordinates corresponding to times t_2, t_3, and t_4, respectively. You should satisfy yourself that both the graphical procedure and using Eqs. 9-13 (a, b, c) indicate about the same value for R_o (6.62 mm in this case).

Once the initial and 100% primary consolidation points have been determined, find t_{50} by subdividing the vertical distance between R_o and R_{100} [or $R_{50} = \frac{1}{2}(R_o - R_{100})$]. Then t_{50} is simply the time corresponding to the dial reading R_{50}. In Fig. 9.7, $t_{50} = 13.6$ min. To evaluate c_v, we use Eq. 9-5 with $T_{50} = 0.197$ (Table 9-1). We also need the average height of the specimen during the load increment. At the beginning of this increment, H_o was 21.87 mm. From the data of Table 9-2,

$$H_f = H_o - \Delta H = 21.87 - 2.59 = 19.28 \text{ mm}$$

Thus the average height of specimen during the increment is 20.58 mm (2.06 cm). Remember that in the standard oedometer test the specimen is doubly drained, so use $H_{dr} = 2.06/2$ in Eq. 9-5. Thus we have

$$c_v = \frac{TH_{dr}^2}{t} = \frac{T_{50}H_{dr}^2}{t_{50}}$$

$$= \frac{0.197\left(\frac{2.06}{2}\right)^2 \text{cm}^2}{13.6 \text{ min}\left(60 \frac{\text{s}}{\text{min}}\right)}$$

$$= 2.56 \times 10^{-4} \frac{\text{cm}^2}{\text{s}}\left(3.1536 \times 10^7 \frac{\text{s}}{\text{yr}}\right)\left(\frac{\text{m}^2}{10^4 \text{ cm}^2}\right)$$

$$= 0.81 \text{ m}^2/\text{yr}$$

Recall that the Casagrande fitting procedure found R_{50} and thus t_{50} by approximating R_{100}. This procedure did not find t_{100} since the time for any other degree of consolidation must be obtained from the classical consolidation theory in which $t_{100} = \infty$. But the procedure does define a t called t_p (for "primary") which is a practical time required to obtain a

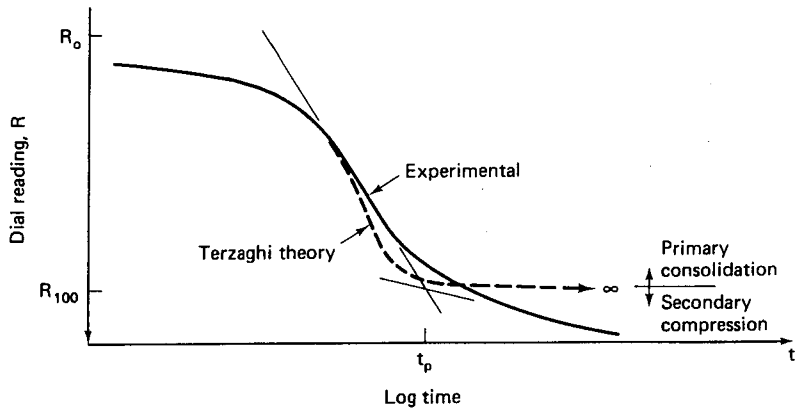

Fig. 9.8 Terzaghi consolidation theory and a typical experimental curve used to define t_p.

good usable value of R_{100}. Often, in practice, t_p is called t_{100}. The deviation of the experimental curve from the theoretical curve is shown in Fig. 9.8. Differences in the curves are the result of secondary compression and other effects such as the rate of effective stress increase (Leonards, 1977) not considered by the Terzaghi theory.

(b) Taylor's Square Root of Time Fitting Method

Taylor (1948) also developed a procedure for evaluating c_v, using the square root of time. As with Casagrande's fitting method, the procedure is based on the similarity between the shapes of the theoretical and experimental curves when plotted versus the square root of T and t. Refer to Fig. 9.5c and compare it with Fig. 9.6c. Note that in Fig. 9.5c the theoretical curve is a straight line to at least $U \simeq 60\%$ or greater. Taylor observed that the abscissa of the curve at 90% consolidation was about 1.15 times the abscissa of the extension of the straight line (Fig. 9.5c). He thus could determine the point of 90% consolidation on the laboratory time curve.

We will use the same data as before (Table 9-2) to illustrate the $\sqrt{t}$ fitting method. These data are plotted in Fig. 9.9. Usually a straight line can be drawn through the data points in the initial part of the compression curve. The line is projected backward to zero time to define R_o. The common point at R_o may be slightly lower than the initial dial reading (at zero time) observed in the laboratory due to immediate compression of the specimen and apparatus. Draw a second line from R_o with all abscissas 1.15 times as large as corresponding values on the first line. The intersection of this second line and the laboratory curve defines R_{90} and is the point of 90% consolidation. Its time is, of course, t_{90}.

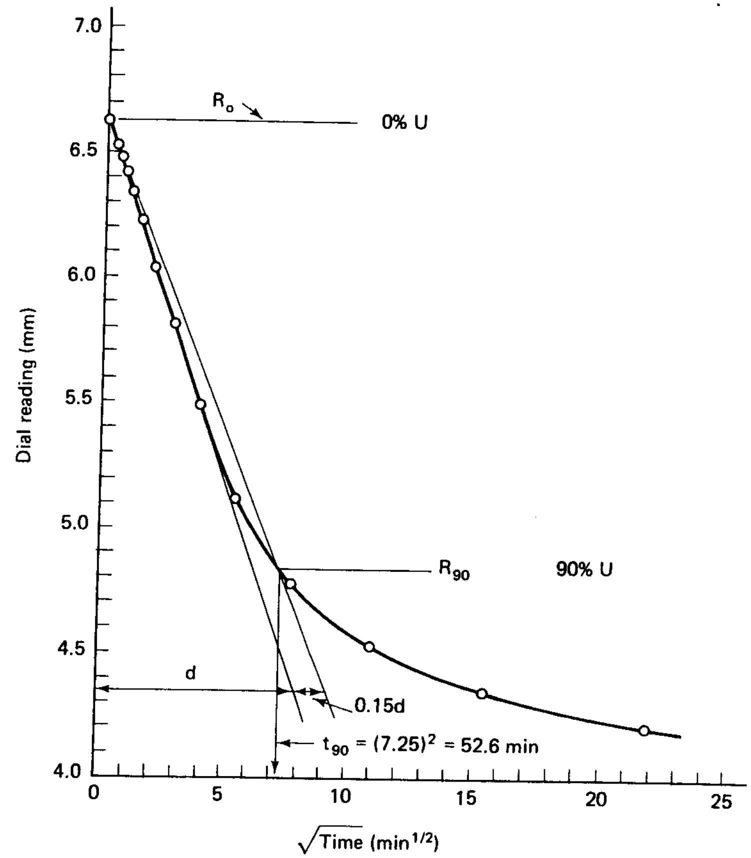

Fig. 9.9 Determination of c_v, using Taylor's square root of time method; data from Table 9-2.

The coefficient of consolidation is, as before, determined by using Eq. 9-5. From Table 9-1, $T_{90} = 0.848$. The average height of specimen is also used, as before. Therefore

$$c_v = \frac{0.848\,(2.06/2)^2\ \text{cm}^2}{52.6\ \text{min}\ (60\ \text{s/min})}$$

$$= 2.85 \times 10^{-4}\ \text{cm}^2/\text{s or } 0.90\ \text{m}^2/\text{yr}$$

This value is reasonably close to the value obtained using the Casagrande method. Because both fitting methods are approximations of theory, you should not expect them to agree exactly. Often c_v as determined by the $\sqrt{t}$ method is slightly greater than c_v by the log t fitting method.

You should also note that c_v is not a constant for a test on a given soil, but it depends greatly on the load increment ratio and whether the preconsolidation stress has been exceeded or not (Leonards and Girault, 1961). For load increments less than the preconsolidation stress, consolidation occurs quite rapidly, and c_v values can be rather high. However, determinations of t_p for these increments is often difficult because the time-settlement curves do not have the "classical" shapes of Figs. 9.7 and 9.9. For undisturbed clays c_v is usually a minimum for increments near the preconsolidation pressure (Taylor, 1948). For design, this minimum value is often used. However, for some situations it may be more appropriate to use the c_v for the anticipated load increment in the field.

A strong advantage of the $\sqrt{t}$ fitting method is that t_{90} can be determined without going too far beyond t_p. If dial readings are plotted as you go during the test, then it is possible to add the next increment of load as soon as t_{90} is reached. Not only is the time for testing significantly reduced compared to when the conventional 24 h increments are used, but also the contribution of secondary compression to the e versus log σ' curve can be effectively minimized (see Leonards, 1976).

By now you should have noticed that the data do not exactly coincide with the initial starting point in either of Figs. 9.7 or 9.9; that is, R_o does not equal exactly the initial reading of Table 9-2. The reason for the difference between the initial laboratory dial reading and R_o, the "corrected dial reading" corresponding to 0% consolidation, is due to several factors. These may include:

1. Vertical elastic compression of the soil specimen, porous stones, and apparatus.
2. Lateral expansion of the soil specimen if it is not trimmed exactly to the diameter of the ring.
3. Deformation associated with lateral expansion of the oedometer ring.

You will have the opportunity to use the two curve-fitting methods to determine c_v in the problems at the end of this chapter.

9.5 DETERMINATION OF THE COEFFICIENT OF PERMEABILITY

You may recall from Fig. 7.6 that the coefficient of permeability, k, of the soil may also be obtained indirectly from the consolidation test. If you take Eq. 9-3 and solve for k, you obtain

$$k = \frac{c_v \rho_w g a_v}{1 + e_o} \tag{9-14}$$

The value of e_o is the void ratio at the start of the time rate readings for a given load increment.

EXAMPLE 9.9

Given:

The time-deformation data for the load increment 10 to 20 kPa of the test in Fig. 8.4. From Table 9-2 and Fig. 9.7, a c_v value of 0.81 m^2/yr (2.56×10^{-4} cm^2/s) can be determined.

Required:

Compute the coefficient of permeability, assuming the temperature of the water is 20°C.

Solution:

It is first necessary to compute the coefficient of compressibility from Eq. 8-5 and using Fig. 8.4b:

$$a_v = \frac{e_1 - e_2}{\sigma_2' - \sigma_1'} = \frac{2.12 - 1.76}{(20 - 10)\ \text{kPa}}$$

$$= 0.036/\text{kPa} = 3.6 \times 10^{-5}\ \frac{\text{m}^2}{\text{N}}$$

From Eq. 9-14,

$$k = \frac{c_v \rho_w g a_v}{1 + e_o}$$

$$= \frac{2.56 \times 10^{-4}\ \dfrac{\text{cm}^2}{\text{s}} \times 1000\dfrac{\text{kg}}{\text{m}^3} \times 9.81\ \dfrac{\text{m}}{\text{s}^2} \times 3.6 \times 10^{-5}\ \dfrac{\text{m}^2}{\text{N}}\ \dfrac{1\ \text{m}}{100\ \text{cm}}}{1 + 2.12}$$

$$= 2.9 \times 10^{-7}\ \frac{\text{cm}}{\text{s}} = 2.9 \times 10^{-9}\ \frac{\text{m}}{\text{s}}$$

Note that the e used in the equation is the void ratio at the start of the load increment rather than the original or in situ void ratio.