9. ONE DIMENSIONAL CONSOLIDATION TEST

Consolidation is the process of time-dependent settlement of saturated clay soil when subjected to an increased loading. In this chapter, the procedure of a one-dimensional laboratory consolidation test will be described, and the methods of calculation to obtain the void ratio pressure curve (e vs.log p), the reconsolidation pressure (Pc), and the coefficient of consolidation (cv) will be outlined. Test method **-ASTM D 2435**.

When structures are built on saturated soil, the load is presumed to be carried initially by incompressible water with in the soil. Because of additional load on the soil, water will tend to extrude from the void in the soil, causing a reduction in void volume and settlement of a structure. The phenomenon of this compression due to very slow extrusion of water from the void in a fine-grained soil as a result of increased loading (such as the weight of a structure on the soil) is known as **consolidation**. Associated settlement is referred to as **consolidation settlement.**

In soils of high permeability (coarse-grained soils), consolidation requires a short time interval for completion, with the result that almost all of the settlement has occurred by the time of construction is complete. However, in soils of low permeability (fine-grained soils particularly clayey soils), the process requires a long time interval for completion, with the result that strain occurs very slowly.

The method presents in this practice cover a procedure for determining the rate and the magnitude of consolidation of soil when it is restrained laterally and loaded and drained axially (known as one-dimension consolidation test). The data from the consolidation test can be used to develop an estimate of both the rate and the amount of both differential and total settlement of a structure or a landfill. Estimates of this type are often of key importance in first selecting a foundation type and secondly in evaluating its adequacy.

Apparatus

Load device, Consolidometer, Porous stone, Specimen ring, Extensometer (dial gauge) of sensitivity 0.0025mm, specimen trimming equipment (wire saw, sharp-edged knife), Balance(sensitive to 0.01g), Drying oven, stop watch, moisture can, and etc.

Specimen Preparation

1. Trim the specimen from an undisturbed sample of soil, taken from either from a sample tube or as an excavated block sample, to the inside diameter of the Consolidometer forcing it directly into the ring during trimming. Trim it flush with the plane surface of the ring. For soft to medium soils, a wire saw should be used for trimming the top and the bottom of the

specimen to minimize smearing. A straightedge with a sharp cutting edge may be used for the final trim after the excess soil has first been removed with a wire saw. For stiff soil, a sharpened straightedge alone may be used for trimming the top and bottom. If desired, the specimen height may be made less than the ring height by partial extrusion and trimming, provided the minimum specimen thickness requirement is used. The minimum specimen height should be 13mm but should not less than 10 times the maximum particle diameter. The minimum specimen diameter-to-height ratio should be 2.5.

2. Specimen measurement

- Determine the initial wet mass of the specimen, M_O, in the consolidation ring by measuring the mass of the ring with the specimen and subtracting the tare mass of the ring.
- Determine the initial height H_o, of the specimen to the nearest 0.025mm.
- Compute the initial volume V_o, of the specimen to the nearest 0.25cm^3 from diameter of the ring and initial specimen height.

3. Obtain two or three water content determination of the soil from the material trimmed adjacent to the test specimen if sufficient material is available.

4. When index properties are required store the remaining from the trimming taken from around the specimen.

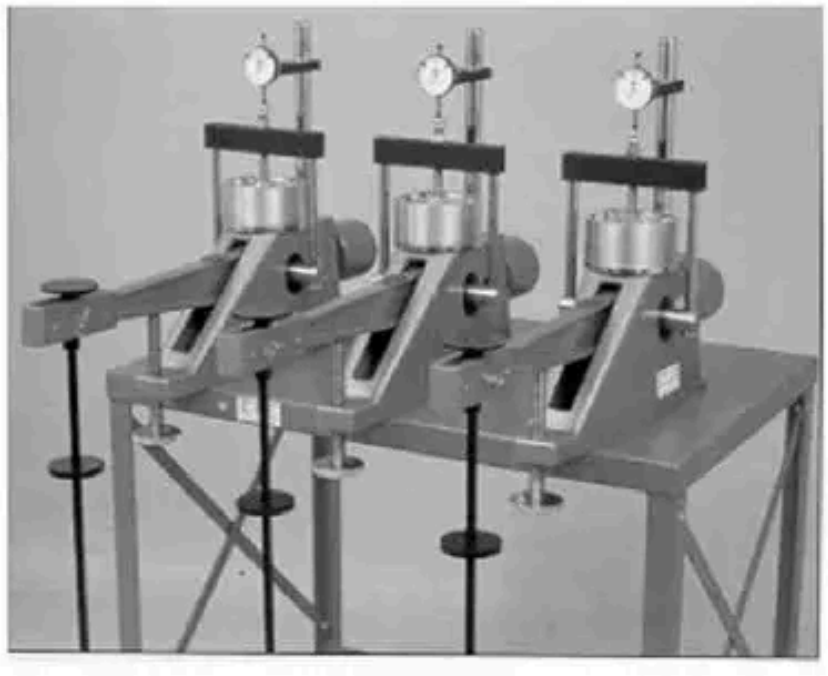

Figure 9:1 - Consolidation frame with Dial Gauge (with three gangs)

Soil index property determination

The determination of index properties is an important adjunct to but not a requirement of the consolidation test. When required all index tests such as: specific gravity, Atterberg limits, and particle size distribution may be performed on adjacent trimmings collected in specimen preparation.

Procedure

1. Porous plates. Before using the porous plate in a test they should be prepared as follows:

1.1. Clean the surfaces a natural bristle or nylon brush.

1.2. If the specimen is saturated, saturate the porous by boiling in distilled water for at least 20min, until the time of their contact with the specimen. If the specimen is very dry, highly expansive soil, place it on dry stone, but if it is partially saturated, place it on stones that have simply been damped.

2. Assembly of consolidation cell

2.1. Place the bottom porous plate, which is prepared as in step 1.

2.2. Place the specimen contained in its ring centrally on top of the porous plate.

2.3. Assemble the cell components so that the consolidation ring is laterally confined and in correct alignment.

2.4. Place the top porous plate and loading cap centrally on top of specimen.

3. Assembly in load frame

1) Place the consolidation cell in position on the bed of the loading apparatus.

2) Adjust the counter balanced loading beam so that when the load-transmitting members just make contact with the loading cap the beam is slightly above the horizontal position.

3) Add a small weight to the beam hanger, sufficient to maintain contact between the load-transmitting members while final adjustments are made. The resulting seating pressure should not exceed 5Kpa.

4) Within 5min after application of setting load, arrange the gauge to allow for measurement of a small amount of swelling of the specimen, while the greater part of the range of travel allows for compression. Record the initial reading of the gauge, di.

4. Loading sequence. Arrange of pressure selected from the following sequence has been found to be satisfactory. 6,12,25,50,100,200,400,etc Kpa

5. Record the gauge reading for the load increment stage, di.

6. Apply the required pressure to the specimen at a convenient moment by adding the appropriate weight to the beam hanger without jolting. Remove the weight used for the seating load.

7. Fill the consolidation cell with water (i.e inundate the specimen) after applying the pressure. If the specimen begins to swell, or if compression virtually ceases with short time, proceed to the next higher pressure to prevent swelling. Alternatively, if required, determine the swelling pressure.

8. Take readings of the compression gauge at suitable interval of time. The following approximate periods of elapsed time from zero are convenient.

   - 0.1,0.25,0.5,1,2,4,8,15,and 30min, 1,2,4,8,etc h if displacement versus log of time plot is required.
   - 0.09, 0.25, 0.49, 1, 4, 9, etc. min if displacement versus square root of time plot is required.

9. Plot the dial gauge readings against log of time, or square root of time, while the test is in progress.

10. Maintain the pressure until the plotted readings indicate that primary consolidation (see calculation and plotting part of this Lab Practice) has been completed. For soils that have slow primary consolidation, pressures should be applied for at least 24h. In extreme cases, or where secondary compression must be evaluated, they should be applied much longer.

11. Record the time and compression gauge reading at the termination of load increment stages. This reading becomes the initial reading for the next stage.

12. Increase the pressure to the next value in the selected sequence.

13. Repeat step 12 for further stages of the sequence of loading, making at least four stages in all (BS 1377). The maximum pressure to the specimen should be greater than the effective pressure, which will occur in situ due to the overburden and proposed construction.

14. Rebound (Unloading)

1) On completion of the recording of the compression gauge readings, in accordance with step10 under the maximum required pressure, unload the specimen as follows if the unloading curve is required. Otherwise proceed at step 15. The unloading portion of the log pressure versus void ratio curve is required in some methods of analysis for estimating the reconsolidation pressure (which is the largest effective stress undergone by the soil, see Calculation and Plotting section) for the soil.

2) The standard rebound or unloading, schedule should be selected by halving the pressure on the soil (i.e use the same increments of step 4, but in reverse order). However, if desired, each successive load can be only one fourth as large as the preceding load; that is, skip a decrement.

3) Record readings of the compression gauge at convenient intervals such as those indicated in step 8.

4) Plot the readings so that the completion of swell can be identified.

5) Record the final reading of the compression gauge.

6) Repeat 14.2-14.5, finishing with an applied pressure equal to the swelling pressure (if applicable) or to the initial applied pressure.

7) When the compression gauge indicates that equilibrium under the final pressure has been reached proceed to step 15.

15. Dismantling

1. To minimize swell during disassembly, rebound the specimen back to the seating load. Once height change has ceased (usually overnight), remove the load from the specimen and remove the consolidation cell from the apparatus and wipe any free water from the ring and specimen.

2. Determine the mass of the specimen in the ring and subtract the tare mass of the ring to obtain the final wet specimen mass.

2.1 Transfer the entire specimen on moisture can to oven maintained at 105°c to 110°c to get the final dry mass and water content.

Calculation and plotting

1. Specimen parameters

1.1 Initial wet density, ρ_o (in g/cm^3)

$$\rho_o = \frac{m_o}{v_o}$$

Where

m_o= the initial mass of the specimen in ring

v_o= the initial volume

1.2 Initial dry density, ρ_{do} (in g/ cm^3)

$$\rho_{do} = \frac{\rho_o}{1+w_o}$$

Where w_o = the initial water content (in decimal)

1.3 Initial void ratio, e_o

$$e_o = \frac{G\rho_w}{\rho_{do}} + 1$$

Where

G = the specific gravity of the soil

ρ_w = density of water (1g/cm^3)

1.4 Initial degree of saturation, So (this value can be used to indicate whether the test specimen is fully saturated initially)

$$S_O = \frac{GW_o}{e_o}$$

1.5 The water content and void ratio after the consolidation test are calculated similarly to the initial quantities by the sample height and weight of wet sample after the test.

2. Coefficient of consolidation, c_v

It relates to how long it will take an amount of consolidation to take place. Two curve fitting methods are recognized for evaluating the coefficient of consolidation, namely logarithm-of-time curve-fitting method and the square root time curve-fitting method.

2.2 Log time curve- fitting method

2.2.1 From those increments of load where time-versus-deformation readings are obtained, plot deformation readings versus logarithm of time (in minute) for each increment of load or pressure as the test progresses and for any increments of rebound where time-versus-deformation data have been obtained.

2.2.2 Find the deformation representing 100% primary consolidation for each load increment. First, draw straight line through the points representing final readings that exhibit a straight line trend and flat slop. Then, draw a second straight line tangent to the steepest part of the curve. The intersection of these two lines represents the deformation corresponding to 100% primary consolidation. Compression that occurs subsequent to 100% primary consolidation is defined as secondary compression.

2.2.3 Find the deformation representing 0% primary consolidation by selecting deformation at any two times that have a ratio of 1:4. The deformation corresponding to the larger of the two times should be greater than one-fourth but less than one-half of the total change in deformation for the load increment. The deformation corresponding to 0% primary consolidation equal to the deformation corresponding to the smaller time interval less the difference in deformations for the two selected times.

2.2.4 The deformation corresponding to 50% primary consolidation (d50) for each load increment is equal to the average of the deformations corresponding to the 0 and 100% deformations. The time required for 50% consolidation under any load increment may be found graphically from the curve for that load increment by observing the time that corresponds to 50% of the primary consolidation of the curve.

2.2.5 Determine the sample height, H, at 50% consolidation

$$H = H_o - (d_{50} - d_i)$$

Where H_o = initial height of specimen at the beginning of test

d_{50} = deformation reading @50% consolidation

d_i = deformation reading @ the beginning of the test

2.2.6 Calculate the coefficient of consolidation, cv (in m^2/year), for each load increment from the equation

$$C_v = 0.05 \frac{H^2}{t_{50}}$$

Where C_v= coefficient of consolidation, in m^2/year

H= sample height for doubly drained sample @50%

Consolidation for singly drained H equals twice the sample height

$H=2[H_0-(d_{50}- d_i)]$, in m

t_{50}=time for 50% consolidation, in year

2.2.7 Repeat 2.1.1 - 2.1.6 for each of the applied load.

2.3 Square root time curve -fitting method

2.3.1 From those increments of load where time-versus-deformation readings are obtained, plot deformation readings versus the square of time in minute for each increment of load.

2.3.2 Draw a straight line of best fit to the early portion of the curve (usually within the first 50% of compression) and extend it to intersect the ordinate of zero time. The corresponding deformation ordinate do represents 0% primary consolidation.

2.3.3 Draw second straight line through do point which at all points has abscissa 1.15 times as great as those on the first straight line. The intersection of this line with the deformation -square root time curve gives 90% primary consolidation.

2.3.4 The deformation at 100% primary consolidation is 1/9 more than the difference in deformation between 0 and 90% consolidation. Similarly,

the deformation at 50% consolidation is 5/9 of the difference between that at 0 and 90%.

2.3.5 Determine the sample height ,H, at 90% consolidation

$$H = H_o - (d_{90} - d_i)$$

Where

H_o = initial height of specimen at the beginning of test

d_{90} = deformation reading @90% consolidation

d_i = deformation reading @ the beginning of the

2.3.6 Calculate the coefficient of consolidation, cv, in m2/year from the time of 90% consolidation by the equation

$$C_v = 0.21\frac{H^2}{t_{90}}$$

Where

c_v= coefficient of consolidation, in m2/year

H= sample height for doubly drained sample @90% Consolidation, in m

t_{90}=time for 90% consolidation, in year

2.3.7 Repeat 2.2.1-2.2.6 for each of the applied load

2.4 Coefficient of secondary compression

The coefficient of secondary compression, if requires, is derived from log of time curve as follows

2.4.1 Extend the linear portion of the secondary compression portion of the curve, obtain as described in 2.1.2, so that it covers one complete cycle of log time. It may be necessary to prolong the duration of the load increment to establish a linear relationship.

2.4.2 Read off the compression dial gauge readings at the beginning and end of the cycle, e.g. at 1000min and 10000min, and calculate the difference , δH_s (in mm), between them.

2.4.3 Calculate the coefficient of secondary compression, c_{sec}, from the equation

$$C_{sec} = \frac{\delta H_s}{H_o}$$

Where H_o = the initial height of the specimen.

2.4.4 Repeat 2.3.1-2.3.3 for each of the applied loading stage.

3. Compression and swelling indices, Coefficient of compressibility, m_v, and Preconsolidation pressure

3.1 First prepare plot of void ratio versus log of pressure curve following steps

3.1.1 Compute void ratio corresponding to 100% primary consolidation for each load.

$$e = e_o - \Delta e$$

$$\Delta e = G\rho_w A \frac{d_{100} - d_i}{M_s}$$

But

Where d_{100}= dial gauge reading @ 100% pre consolidation

d_i= dial reading at the beginning of the test

G = specific gravity of the soil

ρ_w = density of water

A =c/s area of specimen

M_s = mass of entire dry specimen at end of test

3.1.2 Plot values of void ratio (computed in3.1.1) as ordinate against the corresponding applied pressure on logarithmic scale as abscissa

3.1.3 Indicate the position of e_o on the plot.

3.2 Compression index (C_c) and Swelling index (C_s)

First plot the field consolidation line [Refer to Soil and Foundations, by Liu and Evett, how to prepare this.] From this plot:

C_c = the slop of the virgin consolidation line (VCL) or Field consolidation line

$$C_c = \frac{e_B - e_c}{\log(P_c/P_B)}$$

Where B and C are two points on the VCL

Cs = the slope of a swelling curve (Rebound line)

$$C_s = \frac{e_D - e_c}{\log(P_c/P_D)}$$

Where C and D are two points on a swelling line.

3.3 **Coefficient of compressibility** ,*mv*

Within the small stress interval from p_1 to p_2 , the e-log p curve is characterized by the coefficient of compressibility as:

$$m_v = \left(\frac{e_1 - e_2}{1 + e_1}\right)\frac{1}{P_2 - P_1}$$

Where e_1 and e_2 are the void ratio at p_1 and p_2 respectively.

Note: mv varies with the stress level and loading direction (i.e., loading or unloading). m_v is generally used to calculate the vertical settlement s of a layer of initial thickness ho subjected to the increased Δp in pressure

$$S = m_v h_o \Delta p$$

(This equation applied provided that the soils in the laboratory and field undergo a similar stress load, stress increment, and loading direction).

3.4 Determination of Preconsolidation pressure (Casagrande Method)

3.4.1 Choose the point P1 of minimum curvature on the consolidation curve(e-log p curve)

3.4.2 Draw horizontal line through P1

3.4.3 Draw tangent line to the curve at P1

3.4.4 Divide the angle formed by lines drawn at 3.4.2 and 3.4.3 by a line l.

3.4.5 The intersection between the line formed by 3.4.4 and the extension of VCL give the point of preconsolidation pressure.

4. Prepare a graph of pressure along the abscissa on a logarithmic scale versus coefficient of consolidation along the ordinate on arithmetic scale to see the variation of coefficient of consolidation with pressure.

Table 9:1: Consolidation of Soils

Mansoura High Institute of Eng. &Tech.		
Civil Engineering Department		
Soil Testing Laboratory	**Consolidation of Soils**	
Project	Location	Depth
Client	Lab. no.	Date
Responsible Technician	Checked by	Approved by
Test Method		

[A] Specimen Data

At Beginning of Test

(1) Type of specimen (check one) ……. Undisturbed …… Remolded

(2) Area of Specimen, A ……..

(3) Initial height of specimen, H_0 ……

(4) Initial volume of specimen [i.e., (2) x (3)]…….

(5) Mass of specimen ring …….. g

(6) Mass of specimen ring + specimen …….. g

(7) Initial wet mass of specimen [i.e., (6)-(5)] …….. g

(8) Initial wet unit weight, ρ_0

(9) Initial moisture content

a. Can No. ……..

b. Mass of wet soil + can …….. g

c. Mass of dry soil + can …….. g

d. Mass of can …… g

e. Mass of water [i.e., b-c] ..…… g

f. Mass of dry soil [i.e., c-d] ……. g

g. Initial moisture content …… %

(10) Initial dry unit weight, ρ_{d0} ……..

(11) Specific gravity of soil ……...

(12) Initial void ratio [i.e., $e_0 = (G\rho_w/\rho_{d0})-1$] ……..

(13) Initial degree of saturation [i.e., $s_0 = Gw_0/e_0$] …….. %

At End of Test

(14) Can No. ……

(15) Mass of can + wet specimen removed from Consolidometer …… g

(16) Mass of can + oven-dried specimen ……. g

(17) Final mass of water in the specimen [i.e., (15)-(16)]…….. g

(18) Final dry mass of specimen [i.e., (16)-(14)]…… g

(19) Final Moisture content ……. %

(20) Final degree of saturation ……. %

[B] Time-verses-Deformation Data

(1) Pressure increment from …… Kpa to …… Kpa

Elapsed Time (min)	Deformation Dial Reading (mm)

[C] Void Ratio

(1) Initial void ratio, e_0= ……

(2) Height of solid in specimen [i.e. $H_s=M_s/AG\rho_w$] …….

(3) Initial Deformation Dial Reading at Beginning of the test …….

Pressure (Kpa)	Deformation Dial reading representing 100% primary consolidation	Change in Thickness of Specimen, ΔH	Change in Void Ratio [Δe=ΔH/Hs]	Void Ratio [e=e_0-Δe]
(4)	(5)	(6)=(5)-(3)	(7)=(6)/(2)	(8)=(1)-(7)

[D] Coefficient of Consolidation

(1) Initial Height of specimen at the beginning of the test, H_0

Pressure P (Kpa)	Deformation dial reading at 50% consolidation	Thickness of specimen at 50% consolidation	Half-thickness of specimen at 50% consolidation.	Time for 50% consolidation (min)	Coefficient of consolidation, Cv (m^2/year)
(2)	(3)	(4)=(3)-(1)	(5)=(4)/2	(6)	(7)=0.2x(5)2 / (6)