EXPERIMENT 11
CONSOLIDATION TEST

Purpose:

This test is performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. From the measured data, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the preconsolidation pressure (or maximum past pressure) of the soi. In addition, the data obtained can also be used to determine the coefficient of consolidation and the coefficient of secondary compression of the soil.

Standard Reference:

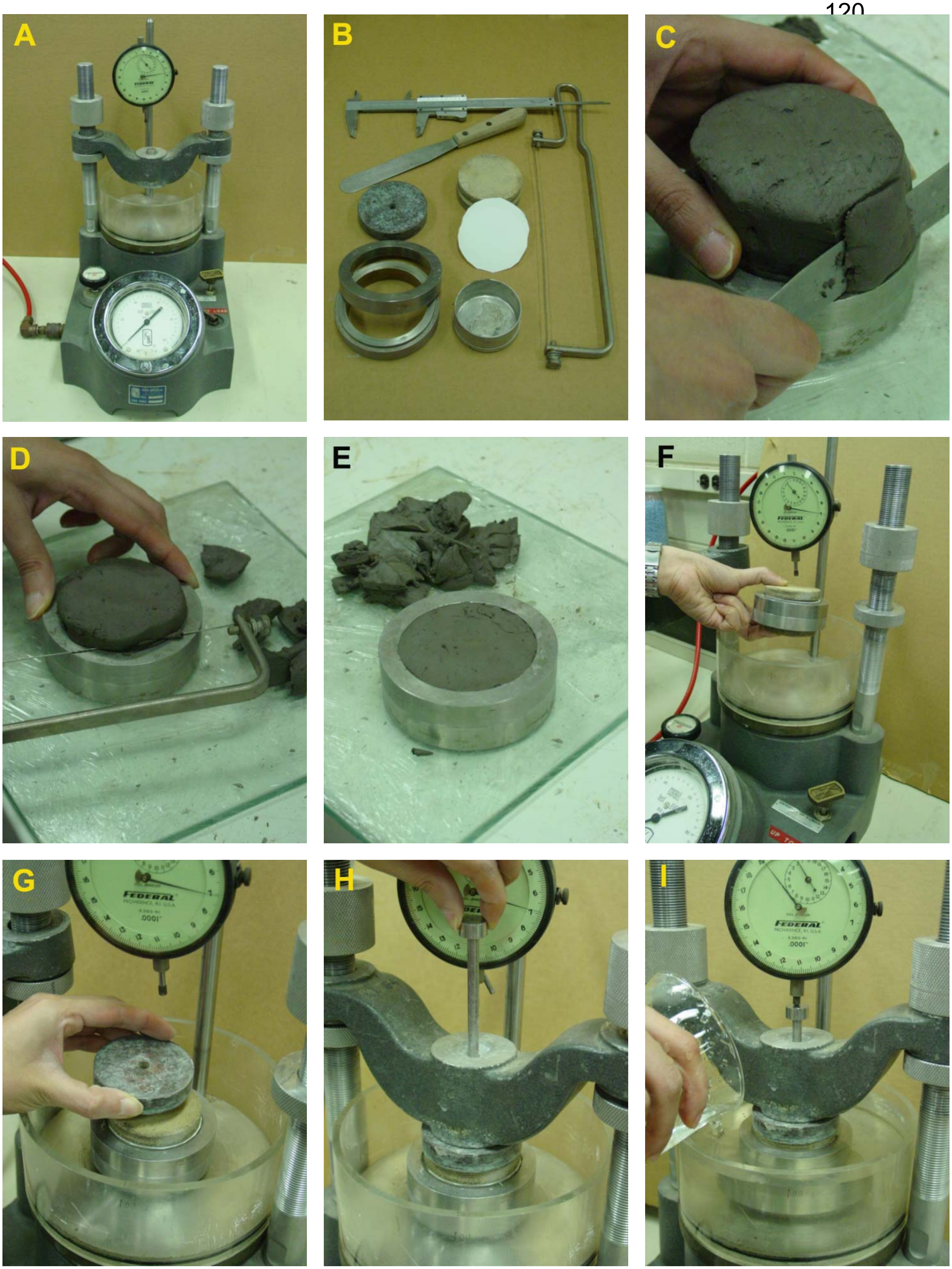
ASTM D 2435 - Standard Test Method for One-Dimensional Consolidation Properties of Soils.

Significance:

The consolidation properties determined from the consolidation test are used to estimate the magnitude and the rate of both primary and secondary consolidation settlement of a structure or an earthfill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

Equipment:

Consolidation device (including ring, porous stones, water reservoir, and load plate), Dial gauge (0.0001 inch = 1.0 on dial), Sample trimming device, glass plate, Metal straight edge, Clock, Moisture can, Filter paper.


A
B
C
D
E
F
G
H
I
FEDERAL

Test Procedure:

(1) Weigh the empty consolidation ring together with glass plate.

(2) Measure the height (h) of the ring and its inside diameter (d).

(3) Extrude the soil sample from the sampler, generally thin-walled Shelby tube. Determine the initial moisture content and the specific gravity of the soil as per Experiments 1 and 4, respectively (Use the data sheets from these experiments to record all of the data).

(4) Cut approximately a three-inch long sample. Place the sample on the consolidation ring and cut the sides of the sample to be approximately the same as the outside diameter of the ring. Rotate the ring and pare off the excess soil by means of the cutting tool so that the sample is reduced to the same inside diameter of the ring. It is important to keep the cutting tool in the correct horizontal position during this process.

(5) As the trimming progresses, press the sample gently into the ring and continue until the sample protrudes a short distance through the bottom of the ring. Be careful throughout the trimming process to insure that there is no void space between the sample and the ring.

(6) Turn the ring over carefully and remove the portion of the soil protruding above the ring. Using the metal straight edge, cut the soil surface flush with the surface of the ring. Remove the final portion with extreme care.

(7) Place the previously weighed Saran-covered glass plate on the freshly cut surface, turn the ring over again, and carefully cut the other end in a similar manner.

(8) Weigh the specimen plus ring plus glass plate.

(9) Carefully remove the ring with specimen from the Saran-covered glass plate and peel the Saran from the specimen surface. Center the porous stones that have been soaking, on the top and bottom surfaces of the test specimen. Place the filter papers between porous stones and soil specimen. Press very lightly to make sure that the stones adhere to the sample. Lower the assembly carefully into the base of the water reservoir. Fill the water reservoir with water until the specimen is completely covered and saturated.

(10) Being careful to prevent movement of the ring and porous stones, place the load plate centrally on the upper porous stone and adjust the loading device.

(11) Adjust the dial gauge to a zero reading.

(12) With the toggle switch in the down (closed) position, set the pressure gauge dial (based on calibration curve) to result in an applied pressure of 0.5 tsf (tons per square foot).

(13) Simultaneously, open the valve (by quickly lifting the toggle switch to the up (open) position) and start the timing clock.

(14) Record the consolidation dial readings at the elapsed times given on the data sheet.

(15) Repeat Steps 11 to 13 for different preselected pressures (generally includes loading pressures of 1.0, 2.0, 4.0, 8.0, and 16.0 tsf and unloading pressures of 8.0, 4.0, 2.0, 1.0 and 0.5 tsf)

(16) At the last elapsed time reading, record the final consolidation dial reading and time, release the load, and quickly disassemble the consolidation device and remove the specimen. Quickly but carefully blot the surfaces dry with paper toweling. (The specimen will tend to absorb water after the load is released.)

(17) Place the specimen and ring on the Saran-covered glass plate and, once again, weigh them together.

(18) Weigh an empty large moisture can and lid.

(19) Carefully remove the specimen from the consolidation ring, being sure not to lose too much soil, and place the specimen in the previously weighed moisture can. Place the moisture can containing the specimen in the oven and let it dry for 12 to 18 hours.

(20) Weigh the dry specimen in the moisture can.

Analysis:

(1) Calculate the initial water content and specific gravity of the soil.

(2) For each pressure increment, construct a semilog plot of the consolidation dial readings versus the log time (in minutes). Determine D_0, D_{50}, D_{100}, and the coefficient of consolidation (c_v) using Casagrande's logarithm of time fitting method. See example data. Also calculate the coefficient of secondary compression based on these plots.

(3) Calculate the void ratio at the end of primary consolidation for each pressure increment (see example data). Plot log pressure versus void ratio. Based on this plot, calculate compression index, recompression index and preconsolidation pressure (maximum past pressure).

(4) Summarize and discuss the results.

EXAMPLE DATA

Consolidation Test

Data Sheets

Date Tested: October 05, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: GB-08-ST-13'-15'

Visual Classification: Gray silty clay

Before test

Consolidation type	= Floating type
Mass of the ring + glass plate	= 465.9 g
Inside diameter of the ring	= 6.3 cm
Height of specimen, H_i	= 2.7 cm
Area of specimen, A	= 31.172 cm^2
Mass of specimen + ring	= 646.4 g
Initial moisture content of specimen, w_i (%)	= 19.5 %
Specific gravity of solids, G_s	= 2.67

After test

Mass of wet sample + ring + glass plate	= 636.5 g
Mass of can	= 59.3 g
Mass of can + wet soil	= 229.8 g
Mass of wet specimen	= 170.50 g
Mass of can + dry soil	= 208.5 g
Mass of dry specimen, M_s	= 149.2 g
Final moisture content of specimen, w_f	= 14.27 %

<u>Calculations</u>

Mass of solids in specimen, M_s = 149.2 g
(Mass of dry specimen after test)

Mass of water in specimen before test, M_{wi} = w_i x M_s
= 0.195*149.2 = 29.094 g

Mass of water in specimen after test, M_{wf} (g) = w_f x M_s
= 0.1427*149.2 = 21.29 g

Height of solids, H_s = $\frac{M_s}{A \times G_s \times \rho_w} = \frac{149.2}{31.172 \times 2.67 \times 1}$ = 1.792 cm
(same before and after test and note ρ_w = 1 g/cm^3)

Height of water before test, H_{wi} = $\frac{M_{wi}}{A \times \rho_w} = \frac{29.09}{31.172 \times 1}$ = 0.933 cm

Height of water after test, H_{wf} = $\frac{M_{wf}}{A \times \rho_w} = \frac{21.29}{31.172 \times 1}$ = 0.683 cm

Change in height of specimen after test, $\Sigma\Delta H$ = 0.257 cm
($\Sigma\Delta H$ for all pressures – see t vs Dial Reading plots)

Height of specimen after test, H_f = H_i - $\Sigma\Delta H$ = 2.7-0.257 = 2.443 cm

Void ratio before test, e_o = $\frac{H_i - H_s}{H_s} = \frac{2.7 - 1.792}{1.792}$ = 0.506

Void ratio after test, e_f = $\frac{H_f - H_s}{H_s} = \frac{2.443 - 1.792}{1.792}$ = 0.3617

Degree of saturation before test, S_i = $\frac{H_{wi}}{H_i - H_s} = \frac{0.933}{2.7 - 1.792} \times 100$
= 102.7 %

Degree of saturation after test, S_f = $\dfrac{H_{wf}}{H_f - H_s} = \dfrac{0.683}{2.443 - 1.792} \times 100$

$= 105.08\%$

Dry density before test, ρ_d = $\dfrac{M_s}{H_i \times A} = \dfrac{149.2}{2.7 \times 31.172}$ = $1.77\ g/cm^3$

$= (110.6\ pcf)$

Table 1: Time - Settlement Data (1 unit on dial guage = 0.0001 inches)

loading= ¼ tsf	
time	dail reading
0	0
0.1	0
0.25	0
0.5	0
1	
2	
4	
8	
15	
30	
60	
120	

loading=1/8 tsf	
time	dail reading
0	0
0.1	0
0.25	0
0.5	0
1	
2	
4	
8	
15	
30	
60	
120	

loading=1/2 tsf	
time	dail reading
0	0
0.1	13
0.25	18
0.5	25
1	34
2	40
4	54
8	77
15	90
30	126
60	144.5
130	160
300	162
1380	169

loading=1 tsf	
time	dail reading
0	0
0.1	6
0.25	8
0.5	11.5
1	15
2	20.5
4	27
10	42
15	46
31	58
60	79
121	81
240	85
562	86

loading=2 tsf	
time	dail reading
0	255
0.1	255.5
0.25	256
0.5	256.5
1	257
2	257.5
4	258
8	258.5
15	262.5
30	283
60	286
128	292.5
240	297
335	299
390	300
678	303
1380	303.5
1520	304

loading=4 tsf	
time	dail reading
0	313
0.06	319
0.15	328
0.3	336
1	357
2	375
4	398
8	428
15	453
30	464
60	472.5
120	479.5
290	486
395	488
1230	496

loading=2 tsf (unloading)	
time	dail reading
0	496
0.1	496
0.25	496
0.5	495.5
1	495
2	494
4	493.5
8	493
15	492.5
30	492.5
70	492.5
140	492.5
215	492.5

loading=1 tsf (unloading)	
time	dail reading
0	492.5
0.1	492.5
0.25	492.5
0.5	492
1	490.5
2	486.5
4	481.5
8	477.5
15	474.5
44	472.5
60	471.5
218	470.5

loading=1/2 tsf (unloading)	
time	dail reading
0	470.5
0.06	469.5
0.5	466
1	464.5
2	461.5
4	458.5
8	454
15	450.5
30	447
60	444.5
110	443.5
930	440.5

loading=1 tsf (reloading)	
time	dail reading
0	440.5
0.1	440.7
0.25	441
0.5	441.2
1	441.5
2	441.6
4	441.8
8	442
15	442.1
30	442.4
60	442.4
120	442.4

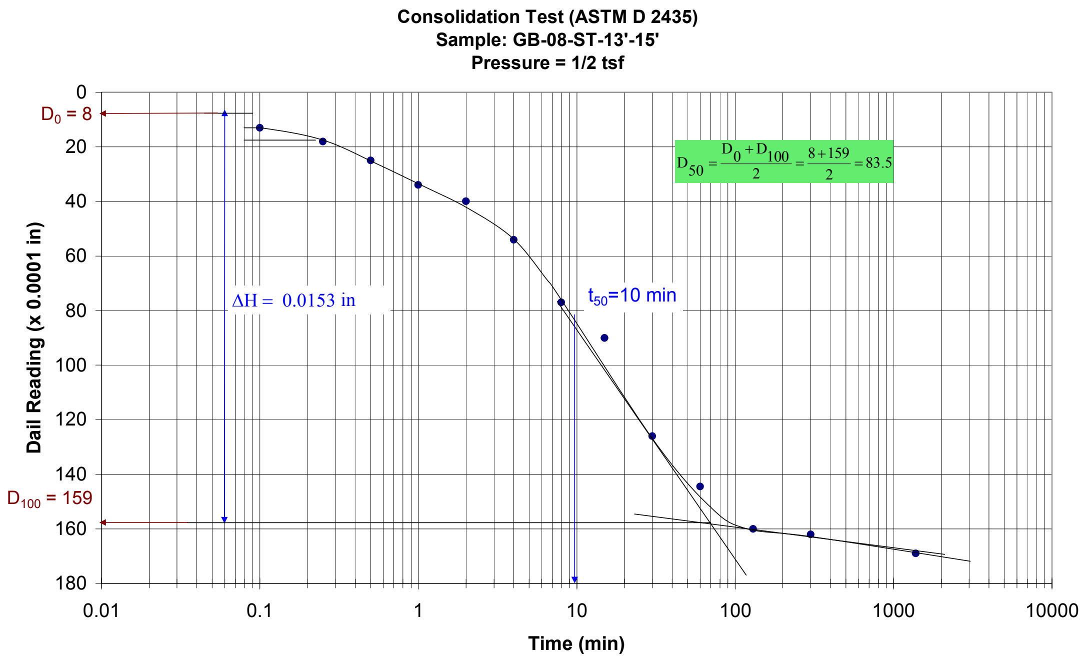
loading=2 tsf (reloading)	
time	dail reading
0	442.4
0.1	442.9
0.25	443.4
0.5	444.4
1	445.1
2	445.3
4	445.4
8	445.9
15	446.3
30	446.4
60	446.5
120	446.5

loading=4 tsf (reloading)	
time	dail reading
0	446.5
0.1	446.5
0.25	446.6
0.5	449.5
1	456.5
2	465.5
4	473.5
8	481
17	485.5
30	488
108	490.5
947	500

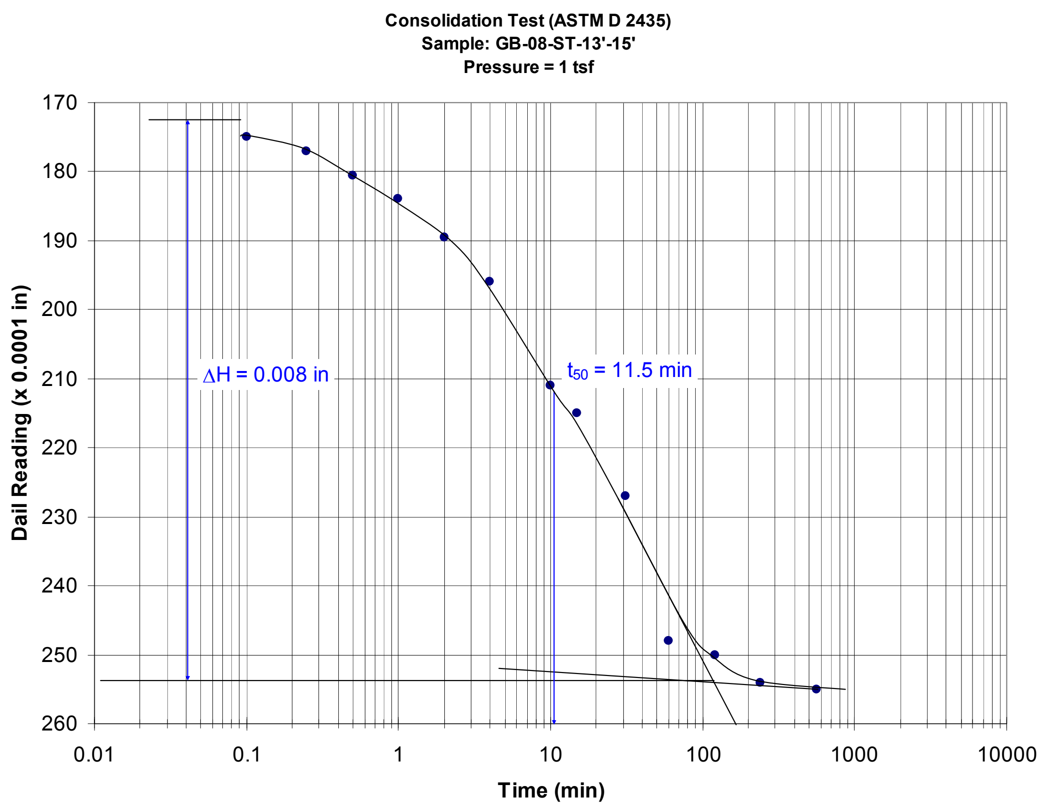
loading=8 tsf	
time	dail reading
0	500
0.1	510
0.25	518
0.5	528
1	542
2	561.5
4	580
8	604
15	619.5
30	631.8
60	640
127	642
205	651
228	652

loading=16 tsf	
time	dail reading
0	652
0.1	672
0.25	687
0.5	702
1	727
2	754
4	800.5
8	816
15	836.5
30	850
60	860
115	867

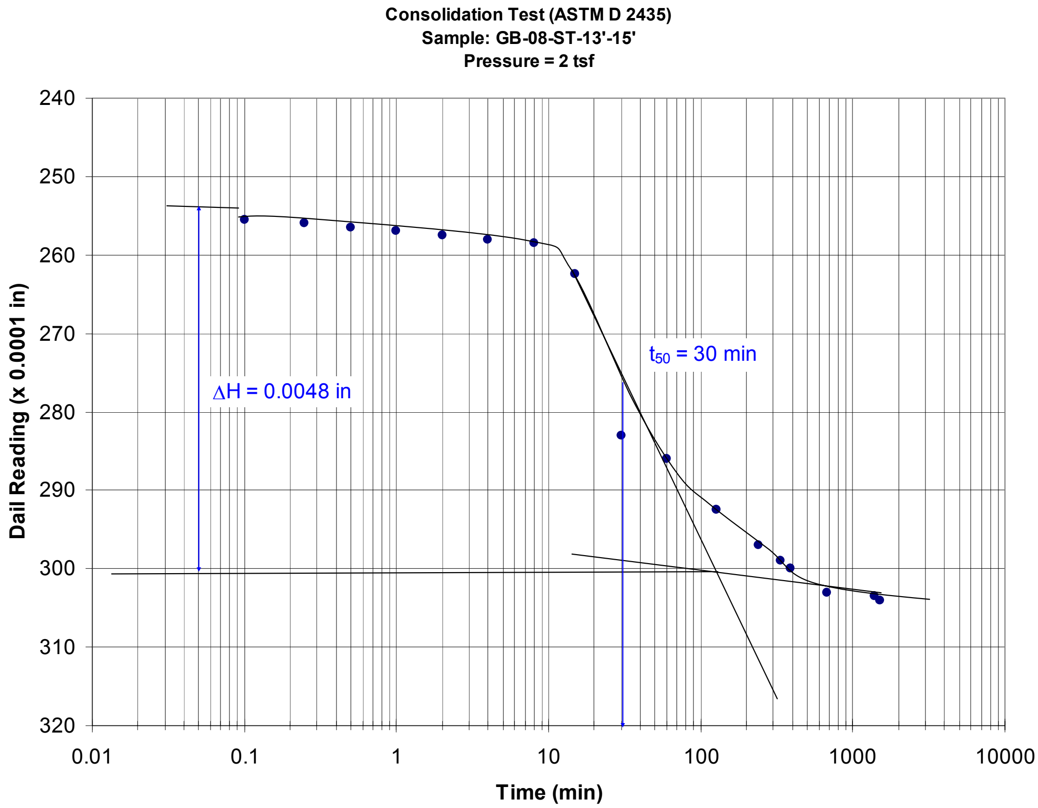
loading=32 tsf	
time	dail reading
0	867
0.1	877
0.25	893
0.5	908
1	928
2	953
4	983
8	1012
15	1027
30	1040
50	1047.5
76	1052.5
138	1060
240	1063

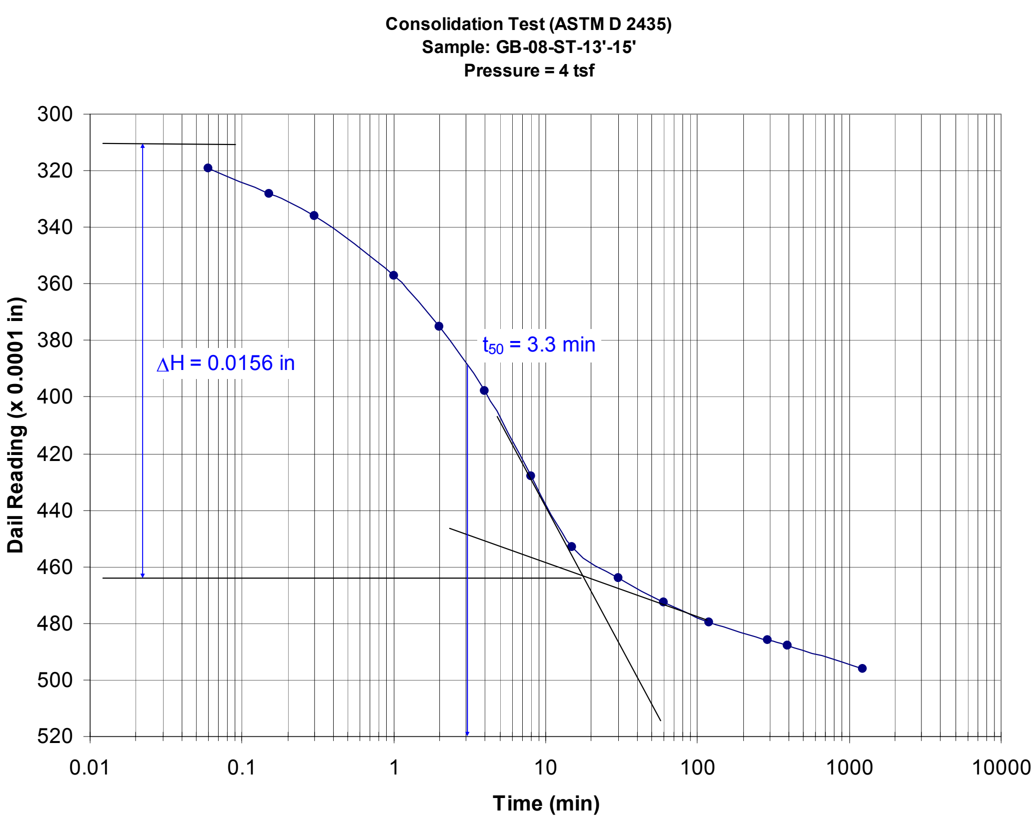


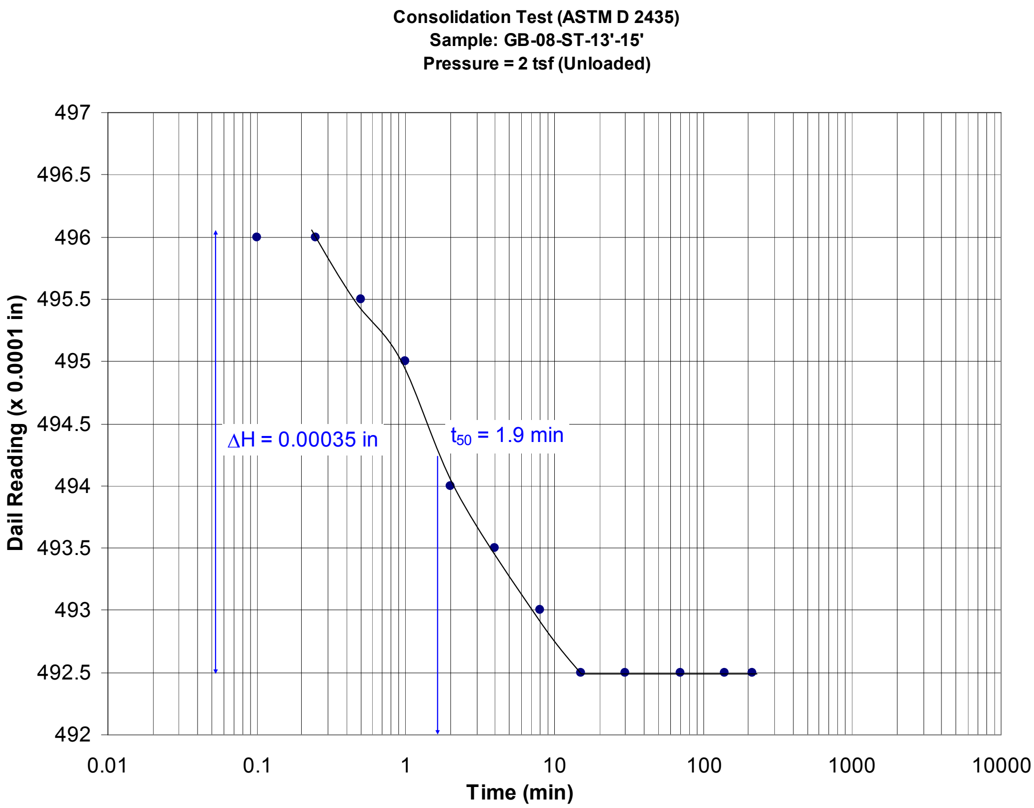
Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1/2 tsf
D0 = 8
D100 = 159
D50 = (D0 + D100)/2 = (8+159)/2 = 83.5
ΔH = 0.0153 in
t50=10 min
Dail Reading (x 0.0001 in)
Time (min)
0
20
40
60
80
100
120
140
160
180
0.01
0.1
1
10
100
1000
10000

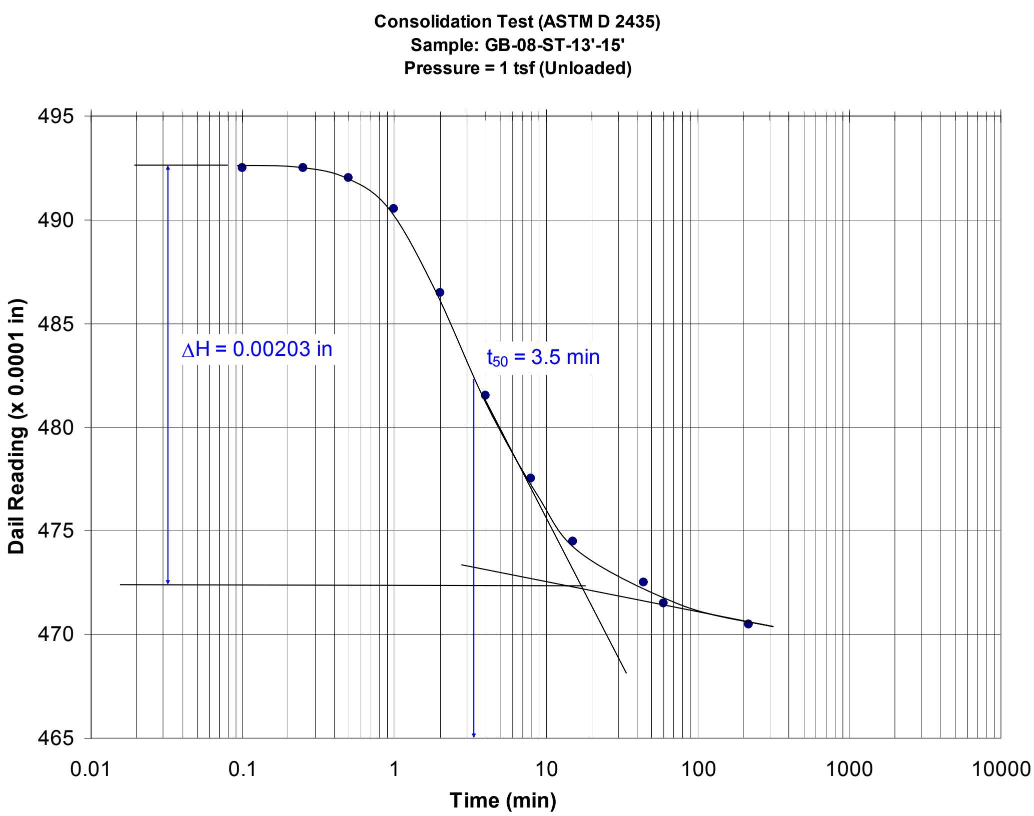


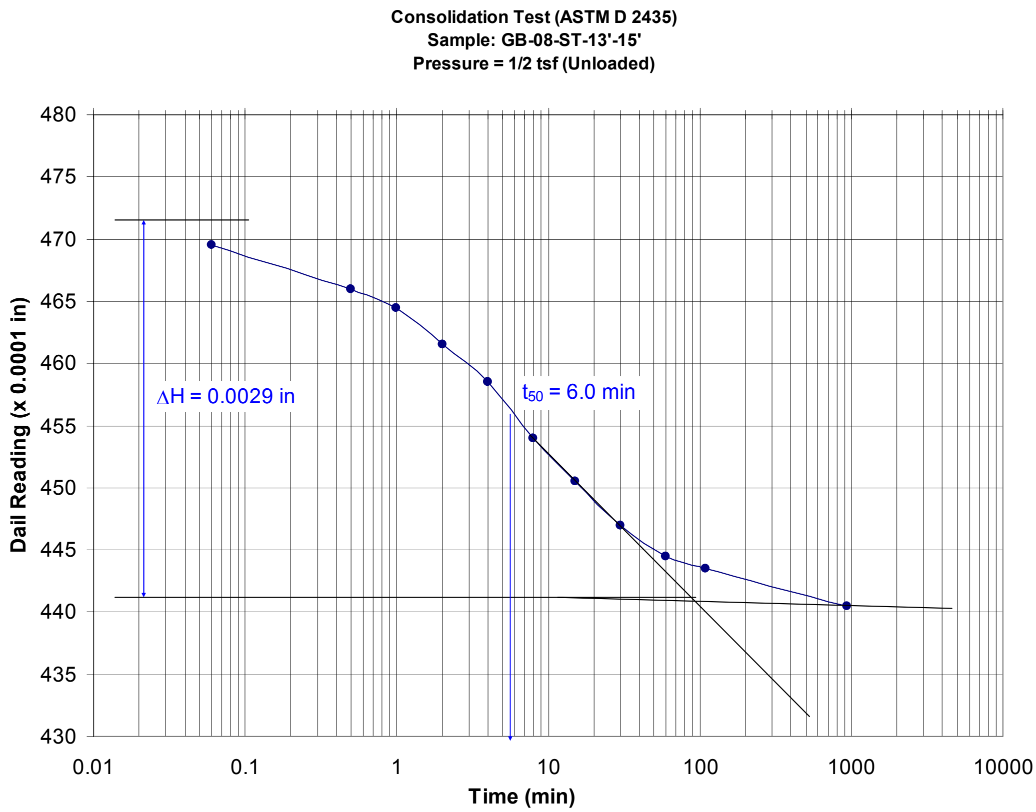
Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1 tsf
ΔH = 0.008 in
t50 = 11.5 min
Dail Reading (x 0.0001 in)
Time (min)
170
180
190
200
210
220
230
240
250
260
0.01
0.1
1
10
100
1000
10000

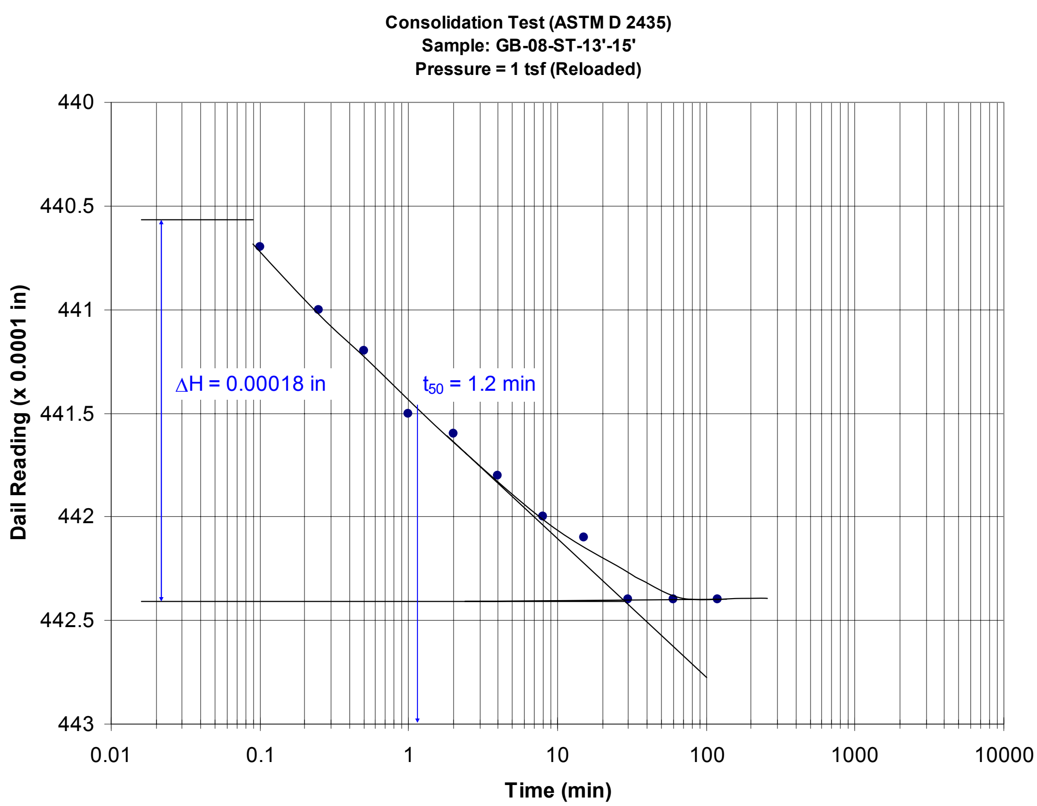

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 2 tsf
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.0048 in
t_{50} = 30 min
240
250
260
270
280
290
300
310
320
0.01
0.1
1
10
100
1000
10000

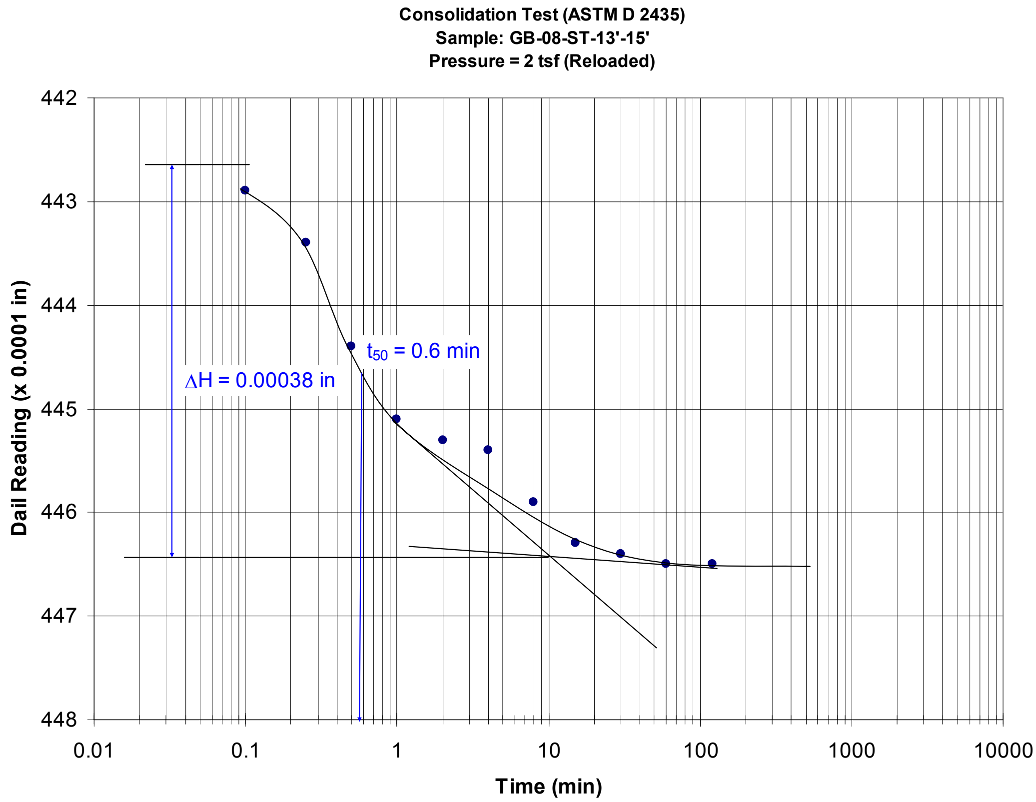

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 4 tsf
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.0156 in
t_{50} = 3.3 min
300
320
340
360
380
400
420
440
460
480
500
520
0.01
0.1
1
10
100
1000
10000

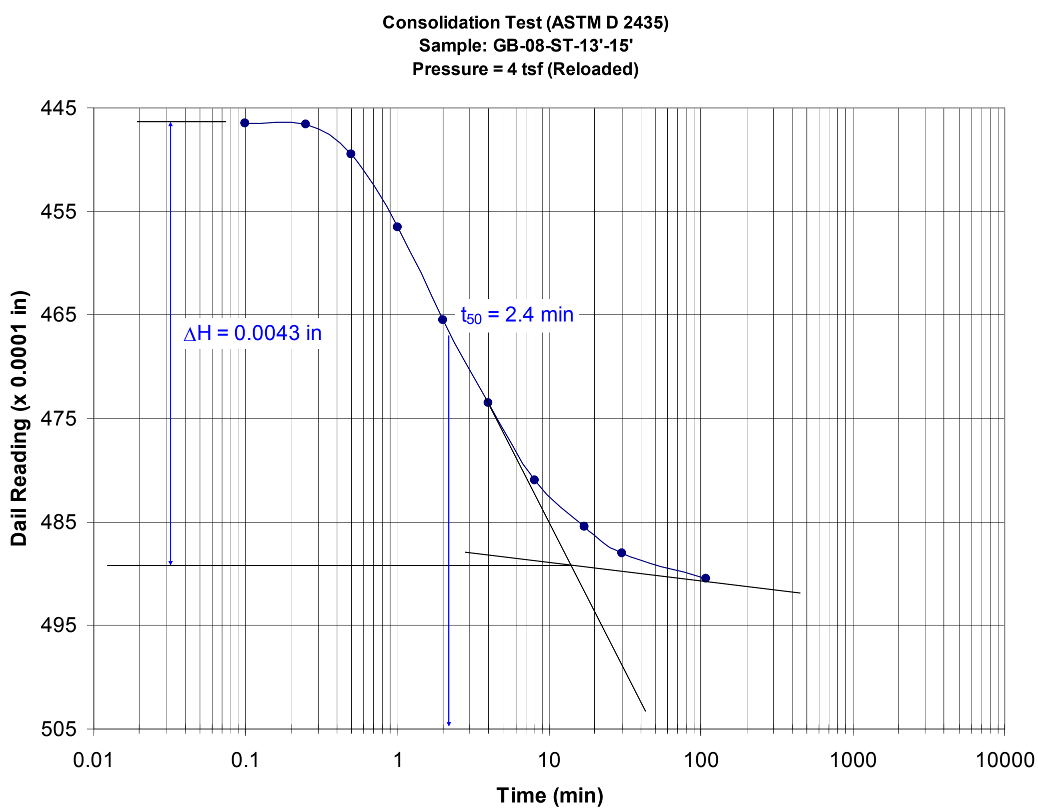

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 2 tsf (Unloaded)
Dail Reading (x 0.0001 in)
497
496.5
496
495.5
495
494.5
494
493.5
493
492.5
492
0.01
0.1
1
10
100
1000
10000
Time (min)
ΔH = 0.00035 in
t50 = 1.9 min

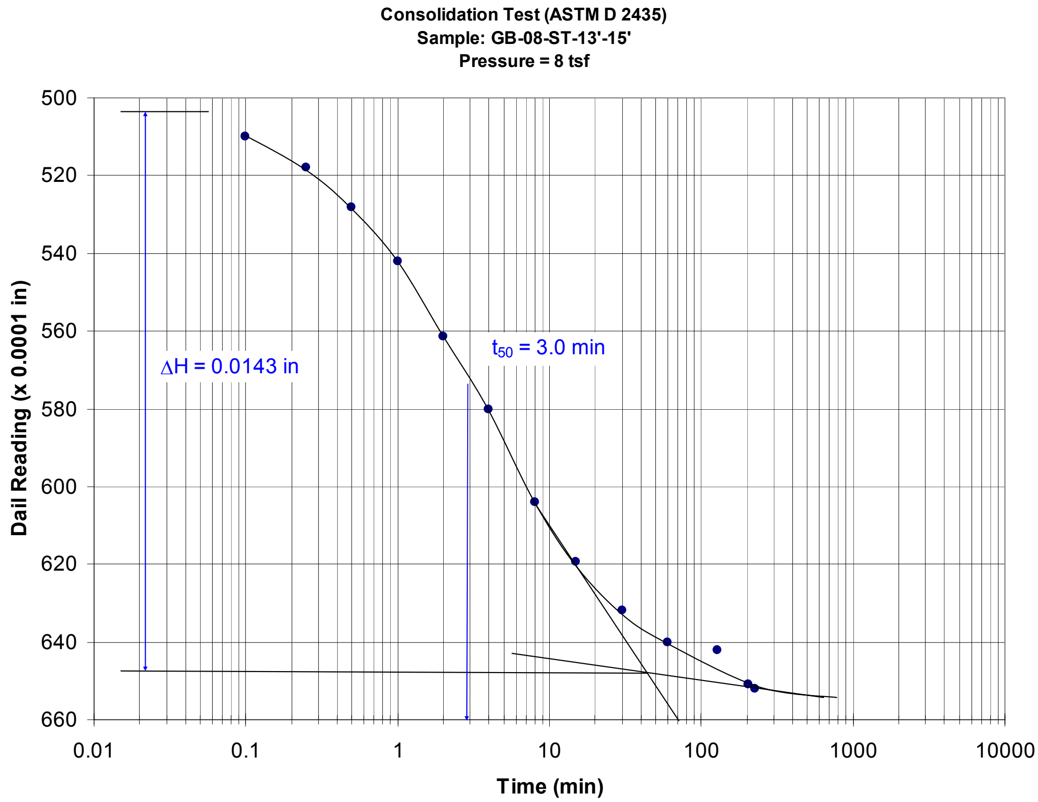

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1 tsf (Unloaded)
Dail Reading (x 0.0001 in)
495
490
485
480
475
470
465
0.01
0.1
1
10
100
1000
10000
Time (min)
ΔH = 0.00203 in
t50 = 3.5 min

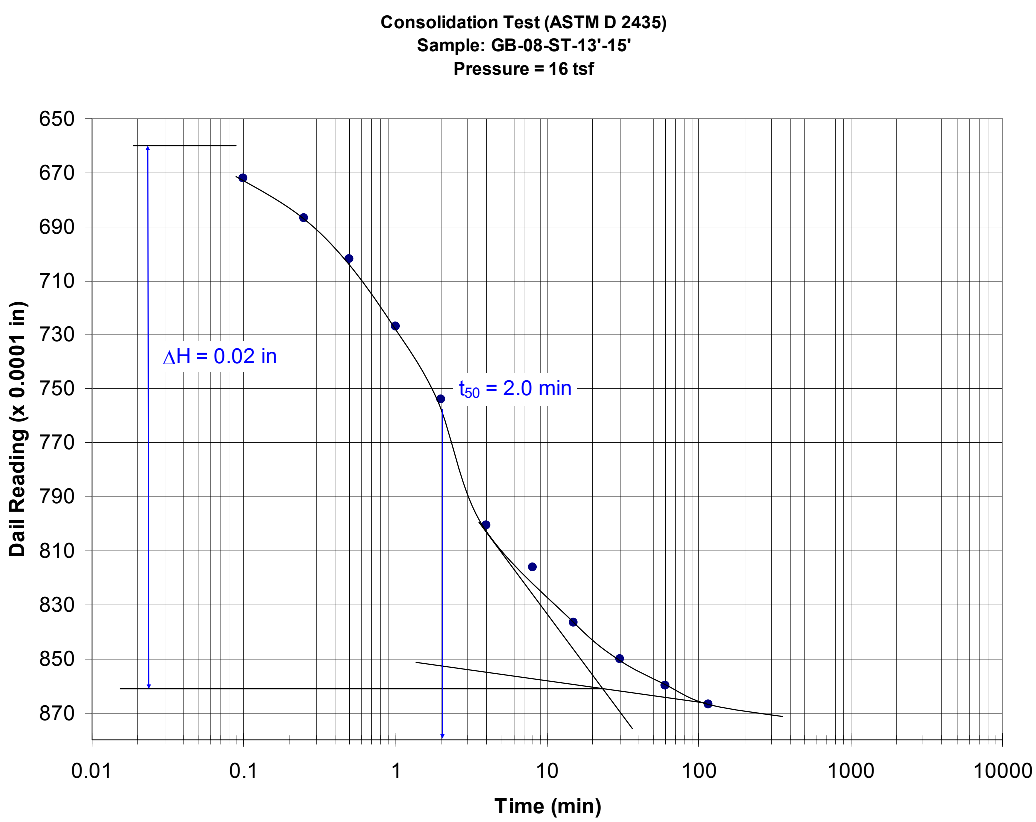

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1/2 tsf (Unloaded)
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.0029 in
t50 = 6.0 min
480
475
470
465
460
455
450
445
440
435
430
0.01
0.1
1
10
100
1000
10000


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1 tsf (Reloaded)
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.00018 in
t50 = 1.2 min
440
440.5
441
441.5
442
442.5
443
0.01
0.1
1
10
100
1000
10000


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 2 tsf (Reloaded)
Dail Reading (x 0.0001 in)
Time (min)
442
443
444
445
446
447
448
0.01
0.1
1
10
100
1000
10000
ΔH = 0.00038 in
t50 = 0.6 min


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 4 tsf (Reloaded)
Dail Reading (x 0.0001 in)
Time (min)
445
455
465
475
485
495
505
0.01
0.1
1
10
100
1000
10000
ΔH = 0.0043 in
t50 = 2.4 min


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 8 tsf
Dail Reading (x 0.0001 in)
500
520
540
560
580
600
620
640
660
ΔH = 0.0143 in
t50 = 3.0 min
0.01
0.1
1
10
100
1000
10000
Time (min)


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 16 tsf
Dail Reading (x 0.0001 in)
650
670
690
710
730
750
770
790
810
830
850
870
ΔH = 0.02 in
t50 = 2.0 min
0.01
0.1
1
10
100
1000
10000
Time (min)

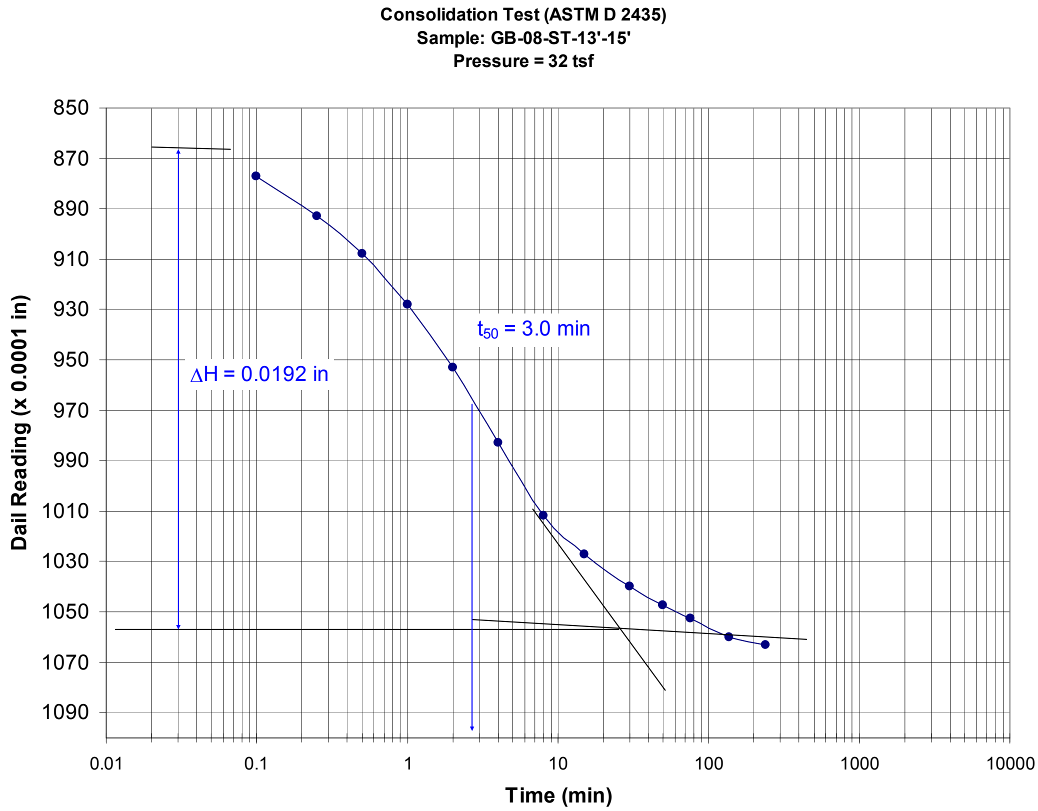

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 32 tsf
Dail Reading (x 0.0001 in)
850
870
890
910
930
950
970
990
1010
1030
1050
1070
1090
0.01
0.1
1
10
100
1000
10000
Time (min)
ΔH = 0.0192 in
t50 = 3.0 min

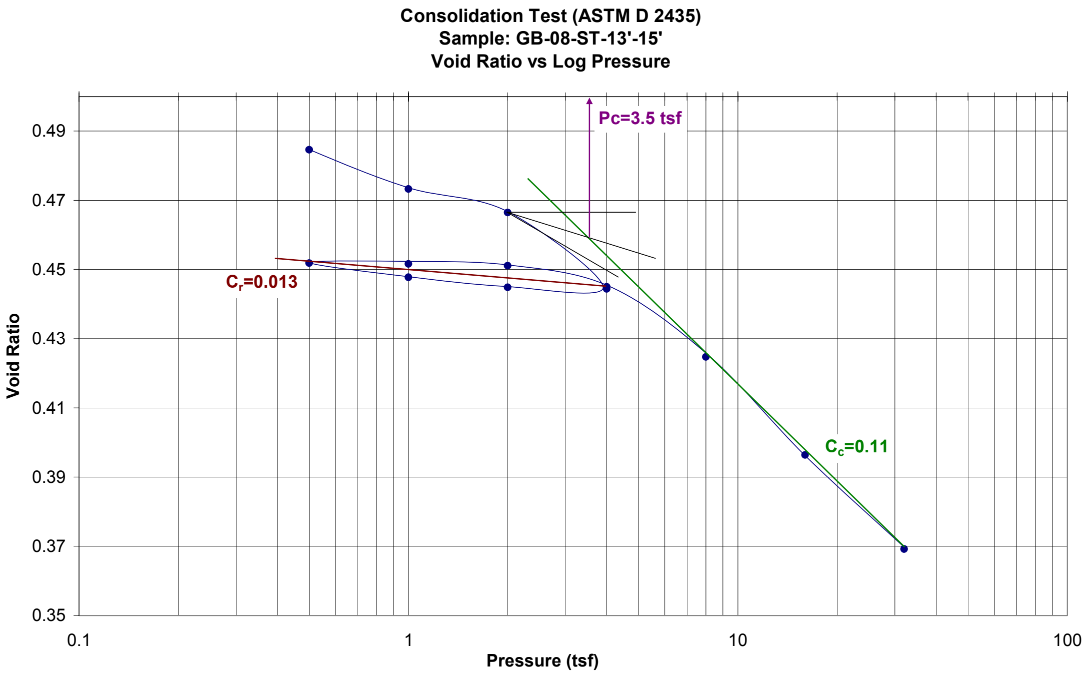
Table 2: Analysis of Consolidation Test Data

Pressure (tsf)	Time for 50% consolidation t_{50} (min)	D_0 (from graph)	D_{100} (from graph)	$D_{50} = (D_0+D_{100})*0.5$	$H_j = D_{50} * 0.0001$	ΔH (from graph)	$\Sigma \Delta H^{*}$	H^{**}	H_d^{**}	Coefficient of consolidation C_v (in^2/min)***	H_v^{***}	e^{***}
0								1.06299				
0.5	10	8	159	83.5	0.00835	0.0153	0.0153	1.04769	0.52593	5.45E-03	0.34	0.48
1	11.5	173	254	213.5	0.02135	0.008	0.0233	1.03969	0.52518	4.72E-03	0.33	0.47
2	30	254	301	277.5	0.02775	0.0048	0.0281	1.03489	0.52438	1.81E-03	0.33	0.47
4	3.3	310	362	336	0.03360	0.0156	0.0437	1.01929	0.51805	1.60E-02	0.31	0.44
2	1.9	496	492.5	494.25	0.04943	0.0004	0.04335	1.01964	0.52218	2.83E-02	0.31	0.44
1	3.5	493	472.5	482.5	0.04825	0.002	0.04132	1.02167	0.52290	1.54E-02	0.32	0.45
0.5	6	472	442	457	0.04570	0.0029	0.03842	1.02457	0.52371	9.01E-03	0.32	0.45
1	1.2	441	442.4	441.5	0.04415	0.0002	0.0386	1.02439	0.52323	4.49E-02	0.32	0.45
2	0.6	443	446.5	444.55	0.04446	0.0004	0.03898	1.02401	0.52312	8.98E-02	0.32	0.45
4	2.4	446	489	467.5	0.04675	0.0043	0.04328	1.01971	0.52154	2.23E-02	0.31	0.44
8	3	504	650	577	0.05770	0.0143	0.05758	1.00541	0.51713	1.76E-02	0.30	0.42
16	2	660	861	760.5	0.07605	0.02	0.07758	0.98541	0.51172	2.58E-02	0.28	0.40
32	3	869	1060	964.5	0.09645	0.0192	0.09678	0.96621	0.50722	1.69E-02	0.26	0.37

* $\Sigma\Delta H$ for applied pressure = $\Sigma\Delta H$ of all previous pressures + ΔH under applied pressure

** $H_{dj} = \dfrac{H_j}{2} \pm \dfrac{\Delta H_j}{4}$ and $H_j = H_i \pm \Delta H_{j-1}$ (- for Loading and + for Unloading)

*** $C_v = 0.197 \times \dfrac{H_d^2}{t_{50}}$, $H_v = (H_i - H_s) - \Sigma\Delta H$ and $e = \dfrac{H_v}{H_s}$



Final Results:

Compression Index (C_c) = 0.11

Recompression Index (C_r) = 0.013

Preconsolidation pressure (P_c) or Maximum past pressure (σ_{vmax}) = 3.5 tsf

Coefficient of consolidation (C_v)= 1.54×10^{-2} to 9.01×10^{-3} in^2/min
(depends on the pressure)

Coefficient of secondary compression ($C\alpha$) = 0.001
(It is the slope of time vs settlement curve beyond the end of primary consolidation)

BLANK DATA SHEETS

Consolidation Test

Data Sheets

Date Tested:

Tested By:

Project Name:

Sample Number:

Sample Description:

Before test

Consolidation type	=
Mass of the ring + glass plate	=
Inside diameter of the ring	=
Height of specimen, H_i	=
Area of specimen, A	=
Mass of specimen + ring	=
Initial moisture content of specimen, w_i (%)	=
Specific gravity of solids, G_s	=

After test

Mass of wet sample + ring + glass plate	=
Mass of can	=
Mass of can + wet soil	=
Mass of wet specimen	=
Mass of can + dry soil	=
Mass of dry specimen, M_s	=
Final moisture content of specimen, w_f	=

<u>Calculations</u>

Mass of solids in specimen, M_s =
(Mass of dry specimen after test)

Mass of water in specimen before test, M_{wi} = $w_i \times M_s$=

Mass of water in specimen after test, M_{wf} (g) = $w_f \times M_s$=

Height of solids, $H_s = \dfrac{M_s}{A \times G_s \times \rho_w}$ =
(same before and after test and note $\rho_w = 1\ g/cm^3$)

Height of water before test, $H_{wi} = \dfrac{M_{wi}}{A \times \rho_w}$ =

Height of water after test, $H_{wf} = \dfrac{M_{wf}}{A \times \rho_w} =$ =

Change in height of specimen after test, $\Sigma\Delta H$ =
($\Sigma\Delta H$ for all pressures – see t vs Dial reading plot)

Height of specimen after test, $H_f = H_i - \Sigma\Delta H$ =

Void ratio before test, $e_o = \dfrac{H_i - H_s}{H_s}$ =

Void ratio after test, $e_f = \dfrac{H_f - H_s}{H_s}$ =

Degree of saturation before test, $S_i = \dfrac{H_{wi}}{H_i - H_s}$ =

Degree of saturation after test, $S_f = \dfrac{H_{wf}}{H_f - H_s}$ =

Dry density before test, $\rho_d = \dfrac{M_s}{H_i \times A}$ =

Time - Settlement Data

Conversion: 0.0001 inch = 1.0 on dial reading (confirm this before using)

LOADING = _____ tsf	
ELAPSED TIME, min	**DIAL READING**
0	
0.1	
0.25	
0.5	
1	
2	
4	
10	
15	
30	
60	
120	
240	

LOADING = _____ tsf	
ELAPSED TIME, min	**DIAL READING**
0	
0.1	
0.25	
0.5	
1	
2	
4	
10	
15	
30	
60	
121	
240	

LOADING = _____ tsf	
ELAPSED TIME, min	**DIAL READING**
0	
0.1	
0.25	
0.5	
1	
2	
4	
10	
15	
30	
60	
120	
240	

Analysis of Consolidation Test Data

Pressure (tsf)	Time for 50% consolidation t_{50} (min)	D_0 (from graph)	D_{100} (from graph)	$D_{50} = (D_0+D_{100})*0.5$	$H_j = D_{50} * 0.0001$	ΔH (from graph)	$\Sigma\,\Delta H^*$	H^{**}	H_d^{**}	Coefficient of consolidation C_v (in^2/min)	H_v^{***}	e^{***}

* $\Sigma\Delta H$ for applied pressure = $\Sigma\Delta H$ of all previous pressures + ΔH under applied pressure

** $H_{dj} = \frac{H_j}{2} \pm \frac{\Delta H_j}{4}$ and $H_j = H_i \pm \Delta H_{j-1}$ (- for Loading and + for Unloading)

*** $C_v = 0.197 \times \frac{H_d^2}{t_{50}}$, $H_v = (H_i - H_s) - \Sigma\Delta H$ and $e = \frac{H_v}{H_s}$

Engineering Properties of Soils Based on Laboratory Testing
Prof. Krishna Reddy, UIC