Colorado Procedure – Laboratory 3101-14

Standard Method of Test for

Resistance R-Value and Expansion Pressure of Compacted Soils or Aggregates by Means of Hveem Stabilometer

(AASHTO T 190-09 & ASTM D 2844-07 were the reference documents used to develop this procedure.)

1. SCOPE

1.1 This method covers the procedure for testing both treated and untreated laboratory compacted soils or aggregates with the stabilometer and expansion pressure devices to obtain results indicative of performance when placed in the base, subbase, or subgrade of a road subjected to traffic.

2. APPARATUS

2.1 Kneading Compactor capable of applying an average contact pressure of 350 ± 16 psi (2413 ± 110 kPa) to the tamper foot shown in Figure 1 and with provisions for maintaining this pressure during changes in sample height. The load-time trace shall be free of “chatter” or evidence of impact-associated changes in slope. The rise time for application of foot pressure, in the range from 35 to 300 psi (241 to 2068 kPa), shall not be less than 0.07 nor more than 0.20 seconds. The dwell time, measured at 300 psi (2068 kPa) foot pressure, shall not be less than 0.15 nor more than 0.45 seconds. The pressure-release or removal time shall not be greater than 0.60 seconds.

2.1.1 The compactor shall include a counter or timer for measuring the number of tamps applied to a specimen and a mold holder for use in compacting specimens that rotates equally between tamps to give 5 to 7 tamps per revolution of the mold. The holder shall firmly restrain the mold during compaction. The base of the mold holder shall have a metal plate 3 31/32 inches (100.8 mm) in diameter and 0.5 inches (12.7 mm) high. The plate shall be an integral part of the base of the mold holder. A steel disk shall be placed inside the mold on the base of the mold holder.

The disk shall be approximately 2 inches (50.8 mm) in height and 3 15/16 inches (100 mm) in diameter with a rubber disk of the same diameter by 1/8 inch (3.2 mm) thick cemented to the disk. A mold collar as supplied by the manufacturer shall be placed on the mold during compaction. The compactor shall include a trough for feeding the sample into the mold in 20 increments.

2.2 Compression Testing Machine, Figure 1, with a minimum capacity of 45 kN (10,000 lbf) and satisfying the requirements of ASTM E 4.

Figure 1 - Compactor with Sample Feed Trough

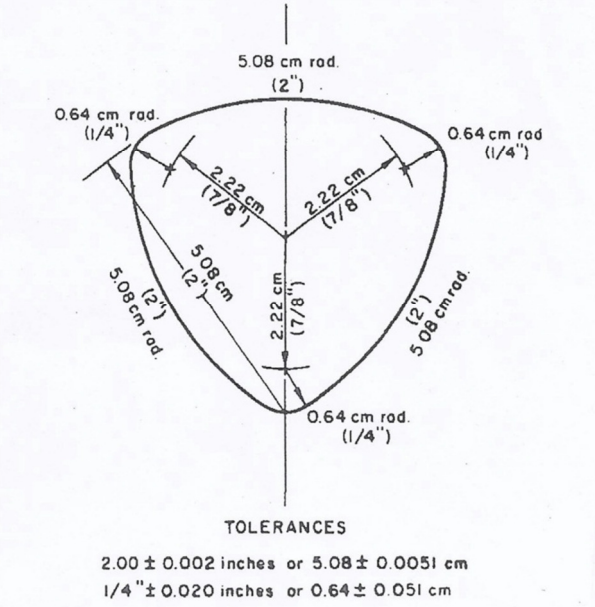

Figure 2 - Tamper Foot for Kneading Compactor

Dimensional Limits, in, (cm)

	Min	**Max**
Distance Across Foot		
3 Measurements	2.042	2.082
120° Apart	(5.189)	(5.289)

2.3 Mold, commercially purpose built 4 ± 0.002 in. (101.6 ± 0.05 mm) inside diameter by 5 ± 0.008 in. (127.00 ± 0.20 mm) high.

(See Note 1 for surface roughness.)

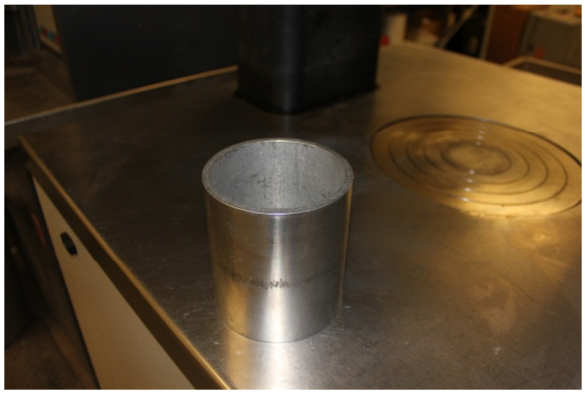

Figure 3 – Mold on Table Stand

NOTE 1: Inside roughness is obtained by smooth machining inside to required diameter of 4.000 ± 0.002 in. (101.60 ±0.05 mm) diameter followed on final operation with a boring tool ground to a 90 degree point with sharp point ground flat measuring 0.001 to 0.003 in. (0.02 to 0.08 mm) across. Depth of cut is 0.002 in. (0.05 mm) with 0.010 in. (0.25 mm) feed using sulfur-based oil coolant.

2.4 Rubber Disks, 3-5/16 in. (100 mm) in diameter by 1/8 in. (3.2 mm) thick and having a durometer hardness of 60 ± 15.

2.5 Metal Follower, solid-walled, metal specimen follower 3.95± 0.005 in. (100.33 ± 0.13 mm) in outside diameter by 5 in. (127 mm) long.

2.6 Exudation-Indicator Device, as shown in Figure 4.

2.7 Phosphor Bronze Disk, as shown in Figure 5.

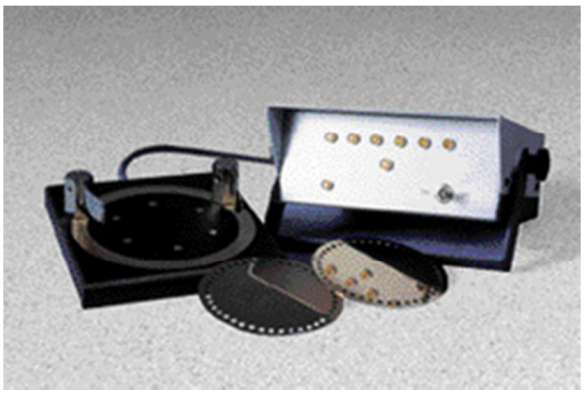

Figure 4 - Exudation-Indicator Device

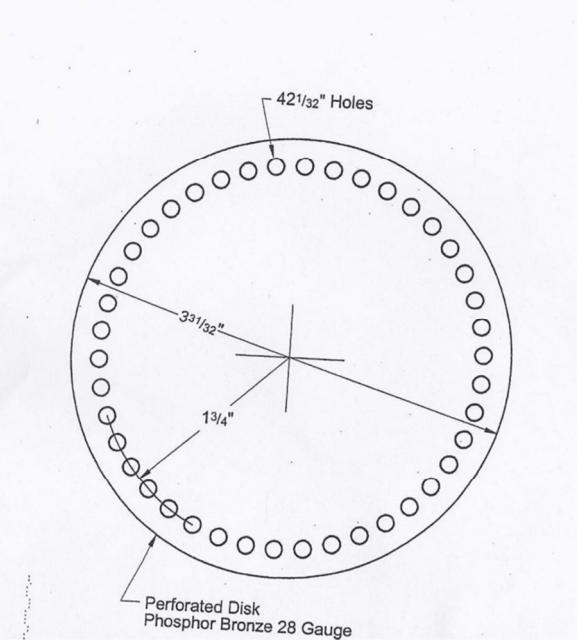

Figure 5 - Phosphor-Bronze Disk

2.8 Round Filter Paper, 4 in. (100 mm) diameter and 0.006 in. (0.15 mm) thick, medium filtering speed, medium retention.

2.9 Expansion-Pressure Device, with accessories as shown in Figure 6. There should be at least three of these devices for each sample to be tested within a day's time.

2.10. Deflection Gauge, with divisions of 0.0001 in. (0.002 mm) and an Allen wrench as shown in Figure 6.

2.11 Stabilometer, with accessories, as shown in Figures 7 and 8.

2.12 Standard Metal Specimen, 4 in. (101.60 mm) in outside diameter by 6 in. (152.4 mm) high as shown in Figure 8.

2.13 Balance, of sufficient capacity, conforming to the requirements of M 231, Class G 5.

2.14 Sieves, 1-in. (25.0-mm), 3/4-in. (19.0-mm) and No. 4 (4.75-mm) conforming to the requirements of M 92 for Wire-Cloth Sieves for Testing Purposes.

2.15 Miscellaneous equipment, including mixing pans, spoons, spatulas, and approximately gallon sized containers with close fitting lids.

2.16 Tamping Rod, a metal rod, 1.5 in. to 2.0 in. (38 to 51 mm) in diameter.

2.17 Expansion pressure calibration equipment, a suitable hanger and weights, and a calibrated proving ring.

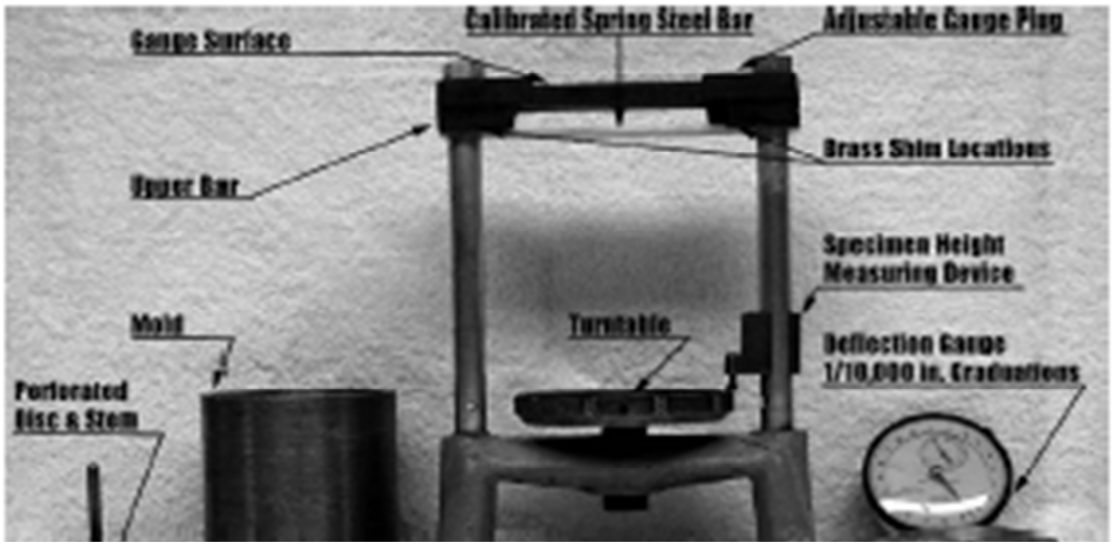

Figure 6 - Expansion-Pressure Device and Accessories

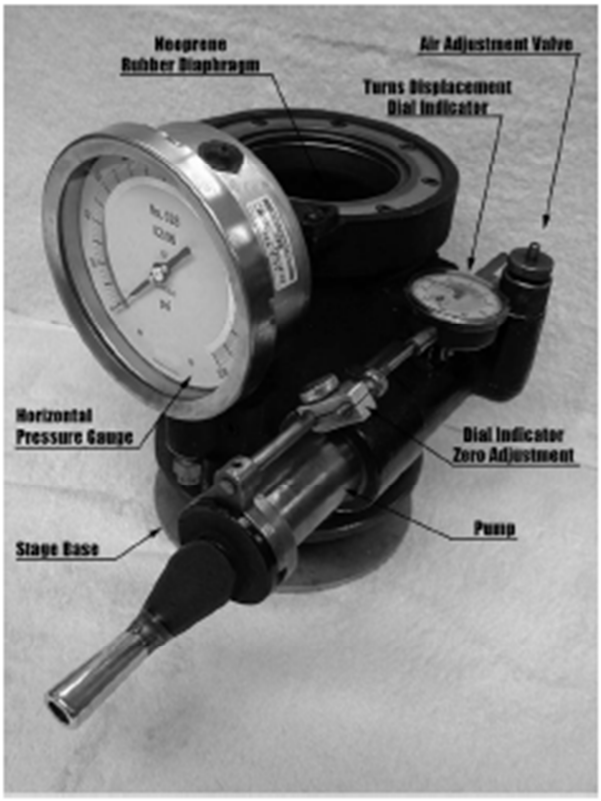

Figure 7 - Stabilometer

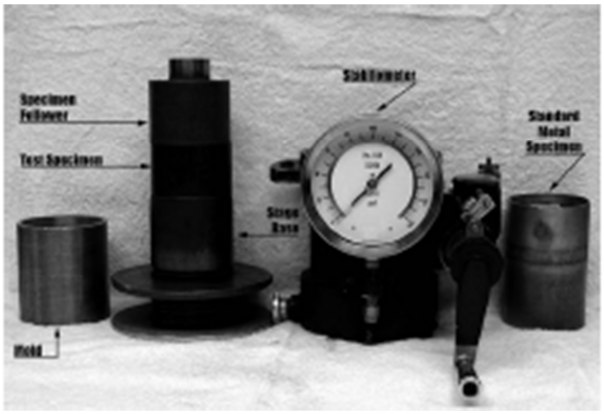

Figure 8 - Stabilometer Accessories

3. SOIL PREPARATION

3.1 Remove any coatings from coarse aggregate and break clay lumps to pass the No. 4 sieve (4.75-mm).

3.2 Adjust the soil graduation when any percentage of the material is retained on the 3/4-in. (19.0-mm) sieve by use of rock correction formula for building R value samples (see appendix X2) or by physically scalping the material at the ¾ inch screen and performing a new gradation on the -3/4 inch material. When 75 percent or more of the sample passes the 3/4-in. (19.0-mm) sieve, then use that part of the sample passing the 3/4-in. (19.0-mm) sieve. If less than 75 percent of the sample passes the 3/4-in. (19.0-mm) sieve, use that part of the sample passing the 1-in. (25.0-mm) sieve.

4. PREPARATION OF SOIL SPECIMENS

4.1 Thoroughly mix four or more 1200-g samples of soil with the amount of water estimated to equal one-half to two-thirds of the water required to produce saturation as defined in Sections 4.3 and 4.4. Place the samples in covered containers and allow them to stand overnight. Just prior to compaction, mix the samples with the final amount of water required to produce saturation. The first sample is used as a pilot specimen to assist in determining the final amount of water required.
(Appendix X1)

NOTE 2: 11 lbs. of -#4 material is needed to develop Four (4) 1200 gram samples.

4.2 Weigh out enough material to fabricate a compacted sample 4 inches (101.6 mm) in diameter by approximately 2.5 inches (63 mm) in height. Compacted specimens having heights from 2.3 to 2.7 inches (58.4 to 68.6 mm) are acceptable. Sample heights between 2.450 and 2.449 inches do not require correction. Those outside of this range should be corrected using a chart equivalent to Figure 9 in Appendix X6. Compact the soil into the mold by means of the kneading compactor as follows: Place the mold in the mold holder. Place inside the mold the steel and rubber disk combination with the rubber disk toward the sample. Adjust the mold for approximately 1/8 inch (3 mm) clearance between the lower edge of the mold and base of the mold holder by placing a shim under the mold and tighten the set screw on the mold holder. The space between the top of the rubber disk on the top edge of the mold should not exceed 2 5/8 inches (67 mm). Place the collar (as supplied by the manufacturer) on the mold. With the compactor-foot pressure set at 250 ± 25 psi (1724 ± 172 kPa), feed 3 inches (76.2 mm) of the soil into the mold. Feed the balance of the soil into the mold in 20 equal increments with one application of the ram after each increment. Apply 10 additional tamps to level the soil, and then place a rubber disk on top of the specimen. Apply 100 additional tamps with a foot pressure of 350 psi (2410 kPa). Stop

compacting the soil at any time before 100 tamps if water appears around the bottom of the mold.

NOTE 3: Use lower compaction pressures, when necessary, to limit the penetration of the ram into the soil by not greater than a 1/4 inch (6 mm). The top of the 2.5 inches (63 mm) compacted specimen should not be more than 1/8 inch (3mm) from the top of the mold. For those sample types for which a 1200 gram sample produces excessive waste material, samples may be batched at a lower mass to reduce the amount of waste material per point.

4.3 Place a metal disk 3-15/16 inches (100 mm) in diameter on the compacted soil and apply 10 additional tamps at a foot pressure sufficient to level the specimen. Place a phosphor-bronze disk on the compacted surface of the soil and place a filter paper on top of the bronze disk. Invert the mold and place it on the exudation device so that the filter paper is on the bottom. Using the compression testing machine, apply a uniformly increasing pressure to the soil at the rate of 2000 lbs. (8900 N) / min. Water should be exuded from the soil between 100 (690) and 800 psi (5520 kPa). Stop loading and record the exudation pressure when either five or six outer lights on the exudation device are lighted or three outer lights are lighted and free water is visible around the bottom of the mold.

4.4 Mold at least two more specimens with different amounts of moisture so that a range of exudation pressures from 100 to 800 psi (690 to 5520 kPa) is obtained which bracket the 300 psi (2070 kPa) value.

NOTE 4A: Occasionally, material from very plastic, clay test-specimens will extrude from under the mold and around the follower ram during the loading operation. If this occurs before the 800 psi (5520 kPa) point is reached and fewer than five lights are illuminated, the soil should be reported as less than 5 R-value.

NOTE 4B: In some cases coarse granular materials and clean sands may require the use of paper baskets to permit testing. When baskets are employed in compaction, the steel disk is removed and the specimen is compacted in the half of the mold nearest the base of the mold holder. A 1/8 inch rubber disk with a magnetic backing is attached to the metal plate of the mold holder referenced in Subsection 2.1.1. A blotter paper and extra filter paper should be placed on the rubber disk to absorb excess water extruded during the compaction process. Since baskets already utilize a phosphor-bronze disk in their construction, the phosphor-bronze disk referred to in Subsection 4.3 is not needed. The sample shall not be inverted as stated in Subsection 4.3. Only a filter paper needs to be added to the bottom of the specimen before testing.

NOTE 4C: The sample surface nearest the exudation plate shall be free of moisture before the filter paper is added.

NOTE 4D: No stabilometer mold collar tolerances are given as the mold collar need only fit the molds supplied by the manufacturer.

5. STANDARDIZATION OF EXPANSION-PRESSURE APPARATUS

5.1 Standardize the spring steel bar of the expansion-pressure device (Figure 6) by applying upward measured loads at the center of the bar and measuring the respective deflections of the bar with the deflection gauge. (See Appendix X1 for standardization procedure.)

5.2 The spring steel bar is considered to be in calibration when the deflections are within the following tolerances:

Applied Load, lbf (N)	Dial Reading (in.)	(mm)
8 (36)	0.0021 ± 0.0002	(0.053 ± 0.005)
16 (71)	0.0042 ± 0.0002	(0.107 ± 0.005)
24 (107)	0.0063 ± 0.0002	(0.160 ± 0.005)
32 (142)	0.0084 ± 0.0002	(0.213 ± 0.005)

5.3 If the deflection gauge does not check the above readings, loosen the top frame bar and adjust the position of the shims, between the frame and the spring steel bar, until the required readings are obtained.

NOTE 5: Some models of the expansion-pressure apparatus have set screw adjustments in lieu of shims.

6. EXPANSION-PRESSURE TESTING

6.1 Allow the test specimen to rebound in a covered mold for at least 30 minutes after determination of the exudation pressure and the compacted specimen height to the nearest 2.5 mm (0.1 in.).

6.2 Place the deflection gauge in position on the expansion-pressure device with the single-bearing end of the gauge base resting on the adjustment ring.

6.3 Place the perforated disk with stem firmly on the face of the compacted specimen in the mold and place the mold in the expansion-pressure device after placing surface filter paper on the turntable.

6.4 Seat the perforated disk firmly on the specimen with pressure applied by the fingers. Raise the turntable on the expansion device until the deflection gauge reading increases by 0.001 inches.

6.5 Put approximately 200 mL of water into the mold and allow pressure from expansion of the specimen to develop for 16 to 24 hours.

NOTE 6: The test specimen shall not be left unconfined by the expansion-pressure device while there is free water on top of the specimen in the mold.

7. ADJUSTMENT OF STABILOMETER

7.1 Adjust the bronze nut on the stabilometer stage base so that the top of the stage is 3-1/2 in. (89 mm) below the bottom of the upper tapered ring of the stabilometer. Perform all tests at this setting.

7.2 Adjust the amount of air in the stabilometer cell so that 2 ± 0.05 turns of the pump handle increase the liquid pressure from 5 to 100 psi (34.4 to 689 kPa) with the standard metal specimen in the stabilometer chamber.

8. RESISTANCE-VALUE TESTING OF SPECIMENS

8.1 After testing for expansion pressure, pour water off the top of the specimen (Note 5) and place the mold with the specimen on top of the stabilometer. Place the follower on top of the specimen and force the specimen from the mold into the stabilometer. Lower the testing machine head until it just engages the follower.

NOTE 7: If all the water has drained through the specimen, add water to the top and allow it to stand for 15 minutes. Pour off any excess water and continue to test.

8.2 Apply a horizontal pressure of 5 psi (34.5 kPa) to the specimen by means of the displacement pump, then apply a vertical load using a uniform rate of movement of 0.05 in./minute (1.3 mm/minute).

8.3 Record the horizontal pressure when the vertical load is 2000 lbf (8896 N) and stop loading. Reduce the vertical load to 1000 lbf (4448 N). With the displacement pump, adjust the horizontal pressure to 5 psi (34.5 kPa).

NOTE 8: This will result in a further reduction in the applied load and should be ignored.

8.4 Turn the stabilometer pump handle at approximately two turns per second and measure the number of turns of the pump handle (using the turns-displacement dial indicator on the stabilometer) to raise the horizontal pressure from 5 to 100 psi (34.5 to 689 kPa). This is the turns displacement, *D*, of the specimen.

8.5. Determine the resistance, *R*, as follows:

$$R = 100 - \left[\frac{100}{\left(\frac{2.5}{D}\right)\left(\frac{160}{Ph} - 1\right) + 1}\right] \quad \text{English Units}$$

$$R = 100 - \left[\frac{100}{\left(\frac{2.5}{D}\right)\left(\frac{1100}{Ph} - 1\right) + 1}\right] \quad \text{Metric Units}$$

where:

Ph = horizontal pressure, kPa (psi), and
D = turns displacement reading.

8.6 This is the R-value for specimens with compacted heights from 2.45 to 2.55 in. (62 to 65 mm). If the height of the specimen is between 2.3 and 2.45 in. or 2.55 and 2.7 in. (0.58 and 62 mm or 65 and 68 mm respectively) use the chart (Figure 10) for correcting R-values to a specimen height of 2.5 in. (63 mm).

NOTE 9: If the R-value is desired at a specific exudation pressure, for example, 300 psi (2068 kPa), within the range of pressures measured in tests of three specimens, it is convenient to construct a graph of R-value versus exudation pressure and then interpolate.

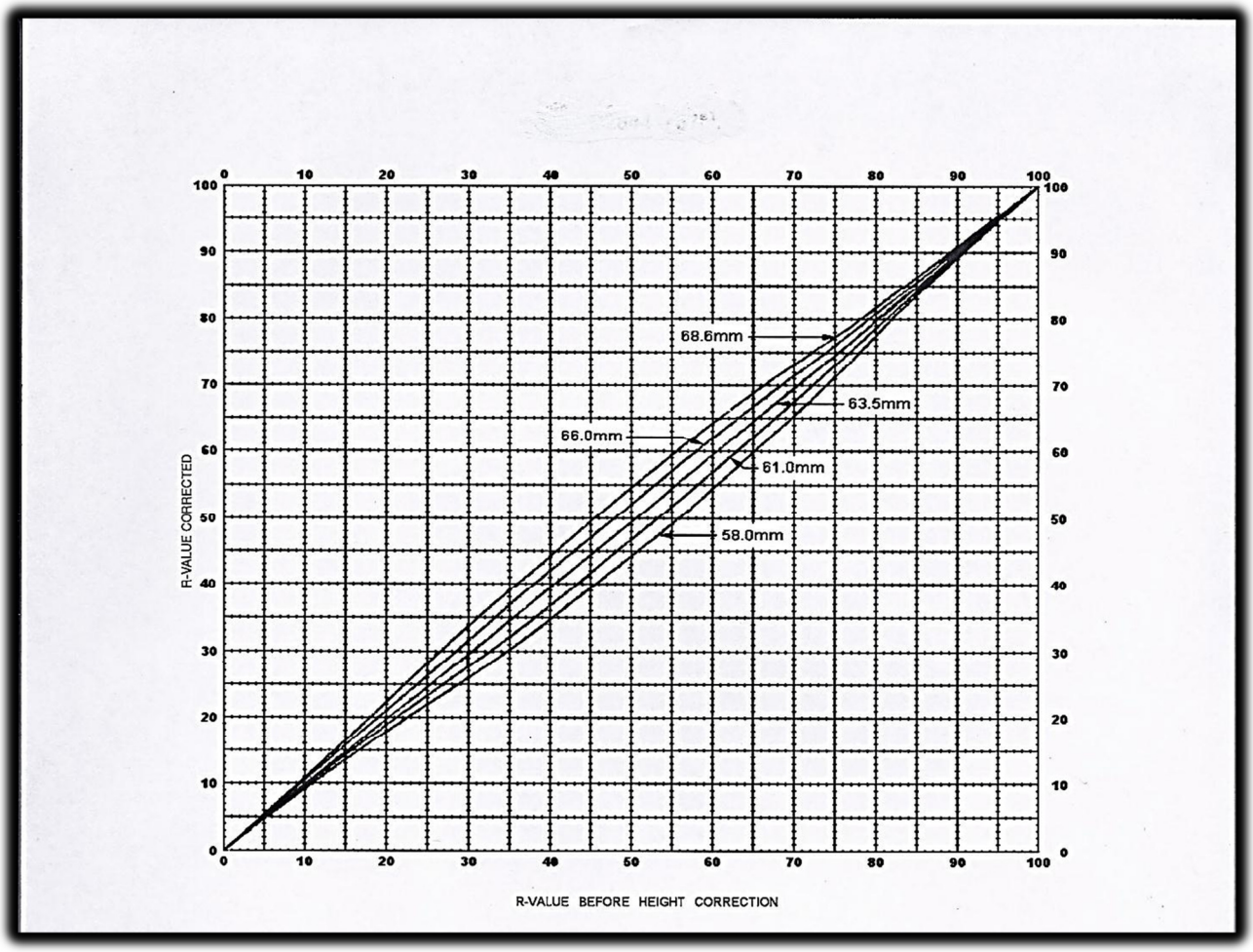

Figure 9 - R value Height Correction Chart

(See Appendix X4.)

APPENDIX

(Non-mandatory Information)

X1. STANDARIZING HEIGHT MEASUREMENT ON THE EXPANSION PRESSURE DEVICE

1. Place a specimen of known height (preferably 2.500 inches) on the turntable of the expansion pressure device.
2. Place the *perforated disc and stem* (see figure 6) on top of the specimen.
3. With the dial gauge in place on top of the expansion pressure device, rotate the turntable until the top of the perforated disc and stem contacts the bottom of the *calibrated spring steel bar*.
4. Place a load on the calibrated steel bar which displaces it by 10/10,000 of an inch (0.00010").
5. Raise the *specimen height measuring device* and rotate it so that it rests on the edge of the turntable.
6. Read the height indicated and record.
7. If the height indicated differs from the measured height of the standardization specimen, either adjust the level of the calibrated spring steel bar (if possible on the device in use) or adjust the specimen height measuring device, and make note of the difference to be used as a correction factor during testing.

X2. R Value Specimen Building Worksheet Example

1. Remove any coatings from the coarse aggregate and break clays lumps to pass the No. 4 (4.75 mm) sieve.

Note: This is a mathematical correction using the ¾" sieve as 100% passing rather than a physical "scalping" of the ¾" sieve.

Sieve Size **A**	Percent Passing **B**	Calculation **C**	Cumulative Weight Passing (1200) gram sample **D**	Cumulative Weight 1200-D **E**
1½"	100			
1"	100			
3/4"	96	96/96 x 1200	1200	0
1/2"	88	88/96 x 1200	1100	100
3/8"	73	73/96 x 1200	913	287
No. 4	45	45/96 x 1200	563	637
- No. 4			0	1200

X3. Determination of Resistance Value at Equilibrium
(Criteria for determination of "Unstable" Material)

1. SCOPE

1.1 This procedure will be used to determine the R-value of a material by the Hveem Stabilometer at 300 psi exudation pressure, and to evaluate stability.

1.2 Determine the R-value by Hveem Stabilometer in accordance with Sections 4, Preparation of Soil Specimens.

2. CALCULATION: R-VALUE BY STABILOMETER AND EXUDATION PRESSURE

2.1 Determine the R-value by the stabilometer and exudation pressure method by plotting the R-values of the three specimens against their respective exudation pressures.

2.2 Connect the plotted points using a smooth curve. The R-value by stabilometer is the point at which the curve crosses the 300 psi exudation pressure.

3. CALCULATION: EVALUATION OF STABILITY

3.1 Calculate and plot moisture content at the respective exudation pressures, as determined above.

3.2 Compare the moisture at 300 psi exudation moisture vs. the optimum moisture (AASHTO T 99 or T 180).

3.3 Determine the decrease in R-value from the 400 psi to 300 psi exudation pressure points.

3.4 Compare moisture at 300 psi exudation moisture to the optimum moisture (AASHTO T 99 or T 180).

3.5 Material will be considered "unstable" if the optimum moisture is greater than the 300 psi exudation moisture and the decrease in R-value from 400 psi to 300 psi exudation pressure is 10 or greater.

4. CALCULATION OF EXUDATION MOISTURE

4.1 Calculate the water added percent to the nearest 0.01 percent for each specimen using the following formula:

$M2 = W(100+M1)/W1$

Where:
M2 = Water added, in percent
W = Water added, in grams (total)
M1 = Hygroscopic moisture*, in percent
W1 = Original specimen batch mass, in grams

* *Hygroscopic moisture*: Water which is so tightly held by the attraction of soil particles that it cannot be removed except as a gas, by raising the temperature above the boiling point.

4.2 Calculate the exudation moisture in percent for each specimen using the following formula:

M = M1 + M2

Where:

M = Exudation moisture, in percent
M1 = Hygroscopic moisture, in percent
M2 = Water added, in percent

Example

W1 = 1100
W = 65 70 76
M1 = 4.52
M2 = 6.18 6.65 7.22

M = M1 + M2

M = 4.52 + 6.18 = 10.70%
M = 4.52 + 6.65 = 11.17%
M = 4.52 + 7.22 = 11.74%

5. REPORT

5.1 Use CDOT Form #323 and Form #1003 for reporting / recording information for this CP-L.

X4. RESISTANCE R-VALUE SAMPLE DATA SHEET AND R-VALUE GRAPH

CDOT SOILS GENERIC
EXAMPLE WORK SHEET

Set-Up Weights
(cumulative)

+ 3/4" _____

+ 1/2" _____

300 psi R = (0.1) _____ + 3/8" _____

+ #4 _____

	1	2	3	4	- #4 _____ Total Setup
Cylinder NO					
C.C. H2O added					
% H2O added					

EXUDATION

Exudation Pressure, psi				
Exudation Pressure, lbs				

STABILOMETER

2000 160 (psi)				
Turns Displacement				
"R" Value				
Corrected "R" Value				

PROPERTIES

Height of Sample				
Wt. Of Cyl. & Sample				
Cylinder Tare Weight				
Wet Weight of Sample				
Original Weight				
Dry Weight				
Percent Hygro				

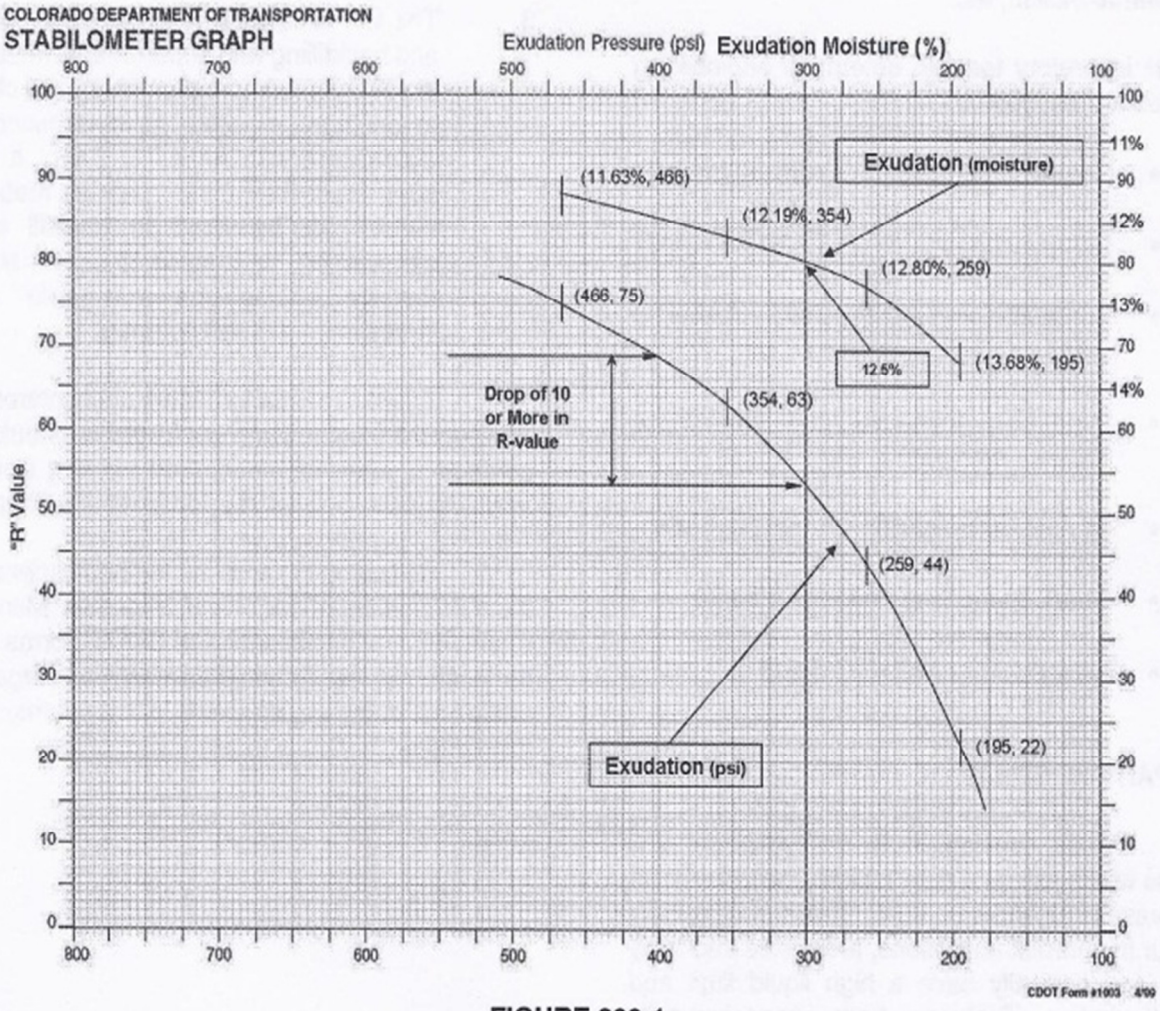

FIGURE 200-1

R VALUE GRAPH EXAMPLE

X5. TABLE FOR R VALUE CONVERSION TO RESILIENT MODULUS

CDOT RESILIENT MODULUS OF SOIL

	Mr	
R	psi	MPa
5	3,025	20.859
6	3,126	21.552
7	3,230	22.268
8	3,337	23.008
9	3,448	23.772
10	3,562	24.562
11	3,681	25.378
12	3,803	26.221
13	3,929	27.092
14	4,060	27.992
15	4,195	28.922
16	4,334	29.883
17	4,478	30.876
18	4,627	31.902
19	4,781	32.962
20	4,940	34.057
21	5,104	35.189
22	5,273	36.358
23	5,448	37.566
24	5,629	38.814
25	5,816	40.103
26	6,010	41.436
27	6,209	42.812
28	6,416	44.235
29	6,629	45.704
30	6,849	47.223
31	7,077	48.792
32	7,312	50.413
33	7,555	52.088
34	7,806	53.818
35	8,065	55.606
36	8,333	57.454
37	8,610	59.363
38	8,896	61.335
39	9,191	63.373
40	9,497	65.478
41	9,812	67.654
42	10,138	69.901
43	10,475	72.224
44	10,823	74.623
45	11,183	77.103
46	11,554	79.664
47	11,938	82.311

	Mr	
R	psi	MPa
48	12,335	85.046
49	12,745	87.872
50	13,168	90.791
51	13,606	93.807
52	14,058	96.924
53	14,525	100.144
54	15,007	103.472
55	15,506	106.909
56	16,021	110.461
57	16,553	114.131
58	17,103	117.923
59	17,672	121.841
60	18,259	125.889
61	18,865	130.072
62	19,492	134.393
63	20,140	138.858
64	20,809	143.472
65	21,500	148.238
66	22,214	153.164
67	22,953	158.252
68	23,715	163.510
69	24,503	168.943
70	25,317	174.556
71	26,158	180.355
72	27,027	186.347
73	27,925	192.538
74	28,853	198.935
75	29,812	205.545
76	30,802	212.374
77	31,826	219.430
78	32,883	226.720
79	33,975	234.253
80	35,104	242.036
81	36,271	250.077
82	37,476	258.386
83	38,721	266.970
84	40,007	275.840
85	41,336	285.005
86	42,710	294.474
87	44,129	304.257
88	45,595	314.366
89	47,110	324.810
90	48,675	335.602

$Mr_{psi} = 10^{((S1 + 18.72) / 6.24)}$ where $S1 = [(R-5) / 11.29] + 3$ 1 psi = 0.0068947572931 MPa

X6. TABLE FOR R – VALUE HEIGHT CORRECTION

Initial Value	2.3 Inches	2.4 Inches	2.5 Inches	2.6 Inches	2.7 Inc
5	5	5	5	5	5
6	5	6	6	6	7
7	6	7	7	7	8
8	7	8	8	8	9
9	8	8	9	10	10
10	9	9	10	11	11
11	10	10	11	12	13
12	11	11	12	13	14
13	11	12	13	14	15
14	12	13	14	15	16
15	13	14	15	16	17
16	14	15	16	17	18
17	15	16	17	18	20
18	16	17	18	19	21
19	17	18	19	20	22
20	17	19	20	22	23
21	18	20	21	23	24
22	19	20	22	24	25
23	20	21	23	25	26
24	21	22	24	26	27
25	22	23	25	27	28
26	23	24	26	28	30
27	24	25	27	29	31
28	25	26	28	30	32
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