Standard Method of Test for

Determining the Resilient Modulus of Soils and Aggregate Materials

AASHTO Designation: T 307-99 (2012)[1]

AASHTO

1. SCOPE

1.1. This method covers procedures for preparing and testing untreated subgrade soils and untreated base/subbase materials for determination of resilient modulus (M_r) under conditions representing a simulation of the physical conditions and stress states of materials beneath flexible pavements subjected to moving wheel loads.

1.2. The methods described are applicable to undisturbed samples of natural and compacted subgrade soils, and to disturbed samples of subgrade soils and untreated base/subbase prepared for testing by compaction in the laboratory.

1.3. In this method, stress levels used for testing specimens for resilient modulus are based upon the location of the specimen within the pavement structure. Samples located within the base and subbase are subjected to different stress levels as compared to those specimens that are from the subgrade. Generally, specimen size for testing depends upon the type of material based upon the gradation and the plastic limit of the material as described in a later section.

1.4. The value of resilient modulus determined from this procedure is a measure of the elastic modulus of untreated base and subbase materials and subgrade soils recognizing certain nonlinear characteristics.

1.5. Resilient modulus values can be used with structural response analysis models to calculate the pavement structural response to wheel loads, and with pavement design procedures to design pavement structures.

1.6. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 1—Test specimens and equipment described in this method may be used to obtain other useful and related information such as the Poisson's ratio and rutting characteristics of subgrade soils and base/subbase materials. Procedures for obtaining these are not covered in this standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop

- T 100, Specific Gravity of Soils
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 190, Resistance R-Value and Expansion Pressure of Compacted Soils
- T 191, Density of Soil In-Place by the Sand-Cone Method
- T 233, Density of Soil In-Place by Block, Chunk, or Core Sampling
- T 265, Laboratory Determination of Moisture Content of Soils
- T 296, Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression
- T 310, In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

2.2. *IEEE/ASTM Standard*:

- SI10, American National Standard for Metric Practice

3. TERMINOLOGY

3.1. *untreated granular base and subbase materials*—these include soil-aggregate mixtures and naturally occurring materials. No binding or stabilizing agent is used to prepare untreated granular base or subbase layers. These materials may be classified as either Type 1 or Type 2 as subsequently defined in Sections 3.3 and 3.4.

3.2. *subgrade*—subgrade soils are prepared and compacted before the placement of subbase and/or base layers. These materials may be classified as either Type 1 or Type 2 as subsequently defined in Sections 3.3 and 3.4.

3.3. *Material Type 1*—for the purposes of resilient modulus testing, Material Type I includes all untreated granular base and subbase material and all untreated subgrade soils that meet the criteria of less than 70 percent passing the 2.00-mm (No. 10) sieve and less than 20 percent passing the 75-µm (No. 200) sieve, and that have a plasticity index of 10 or less. Soils classified as Type 1 will be molded in a 150-mm diameter mold.

3.4. *Material Type 2*—for the purpose of resilient modulus testing, Material Type 2 includes all untreated granular base/subbase and untreated subgrade soils not meeting the criteria for material Type 1 given in Section 3.3. Thin-walled tube samples of untreated subgrade soils fall into this Type 2 category.

3.5. *resilient modulus of untreated materials*—the modulus of an untreated material is determined by repeated load triaxial compression tests on test specimens of the untreated material samples. Resilient modulus (M_r) is the ratio of the amplitude of the repeated axial stress to the amplitude of the resultant recoverable axial strain.

3.6. *haversine-shaped load form*—the required load pulse form. The load pulse is in the form $(1 - \cos\theta)/2$ as shown in Figure 1.

3.7. *maximum applied axial load* (P_{max})—the total load applied to the sample, including the contact and cyclic (resilient) loads.

$$P_{max} = P_{contact} + P_{cyclic} \quad (1)$$

3.8. *contact load* ($P_{contact}$)—vertical load placed on the specimen to maintain a positive contact between the specimen cap and the specimen.

$$P_{contact} = 0.1P_{max} \quad (2)$$

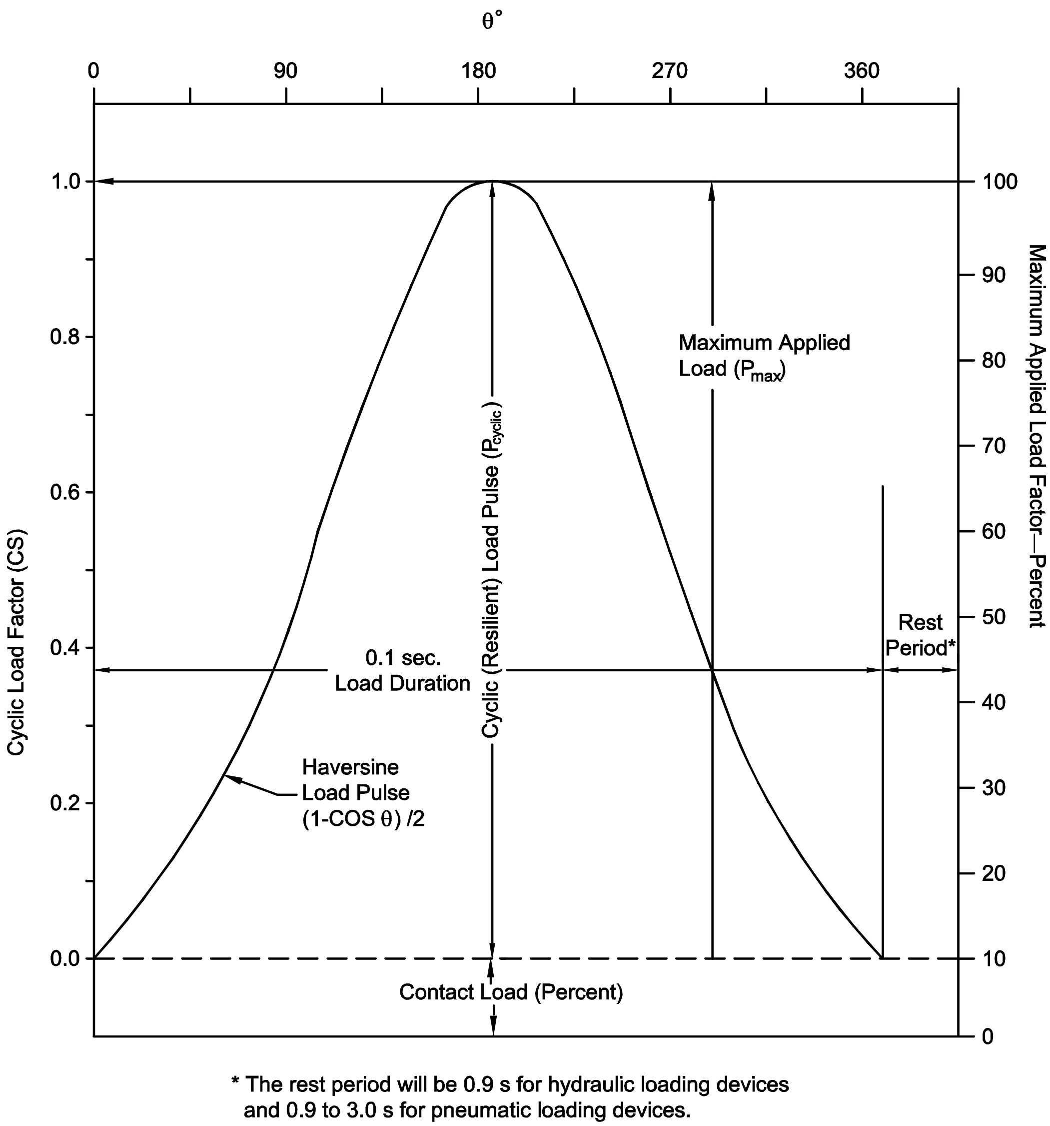


Figure 1—Definition of Resilient Modulus Terms Cyclic Axial Load (Resilient Vertical Load, P_{cyclic})—Repetitive Load Applied to a Test Specimen

$$P_{cyclic} = P_{max} - P_{contact} \quad (3)$$

3.9. *maximum applied axial stress* (S_{max})—the total stress applied to the sample including the contact stress and the cyclic (resilient) stress.

$$S_{max} = P_{max}/A \quad (4)$$

where:

A = initial cross-sectional area of the specimen.

3.10. *cyclic axial stress* (resilient stress, S_{cyclic})—Cyclic (resilient) applied axial stress.

$$S_{cyclic} = P_{cyclic}/A \quad (5)$$

3.11. *contact stress* ($S_{contact}$)—axial stress applied to a test specimen to maintain a positive contact between the specimen cap and the specimen.

$$S_{contact} = P_{contact} / A \quad (6)$$

Also,

$$S_{contact} = 0.1 S_{max} \quad (7)$$

3.12. S_3 is the total radial stress; that is, the applied confining pressure in the triaxial chamber (minor principal stress).

3.13. e_r is the resilient (recovered) axial deformation due to S_{cyclic}.

3.14. $\in_r$ is the resilient (recovered) axial strain due to S_{cyclic}.

$$\in_r = e_r / L \quad (8)$$

where:

L = original specimen length.

3.15. Resilient modulus (M_r) is defined as $S_{cyclic} / \in_r$.

3.16. Load duration is the time interval the specimen is subjected to a cyclic stress (usually 0.1 s).

3.17. Cycle duration is the time interval between the successive applications of a cyclic stress (usually 1.0 to 3.1 s, depending on type of loading device; see Section 6.2).

4. SUMMARY OF METHOD

4.1. A repeated axial cyclic stress of fixed magnitude, load duration (0.1 s), and cycle duration (1.0 to 3.1 s) is applied to a cylindrical test specimen. During testing, the specimen is subjected to a dynamic cyclic stress and a static-confining stress provided by means of a triaxial pressure chamber. The total resilient (recoverable) axial deformation response of the specimen is measured and used to calculate the resilient modulus.

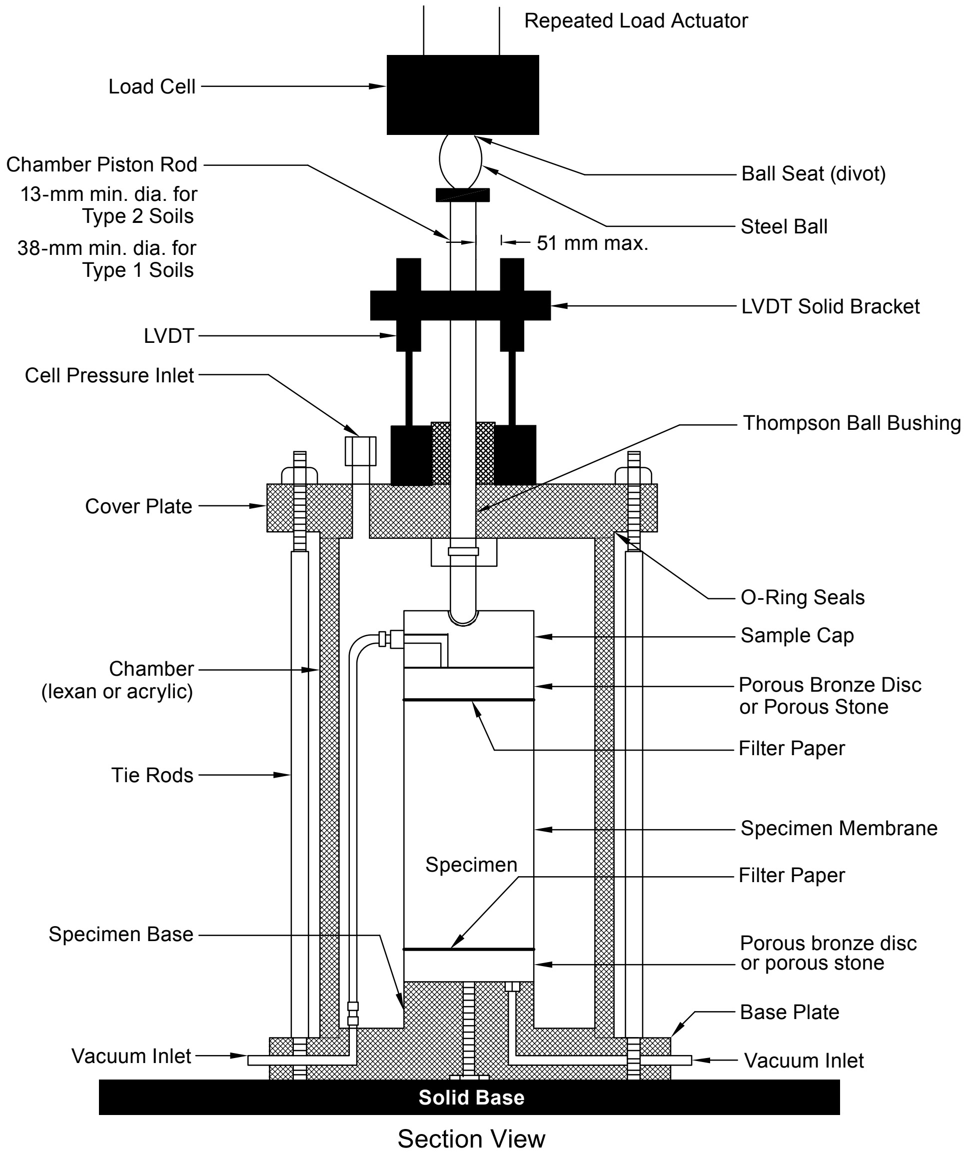
5. SIGNIFICANCE AND USE

5.1. The resilient modulus test provides a basic relationship between stress and deformation of pavement materials for the structural analysis of layered pavement systems.

5.2. The resilient modulus test provides a means of characterizing pavement construction materials, including subgrade soils, under a variety of conditions (i.e., moisture, density) and stress states that simulate the conditions in a pavement subjected to moving wheel loads.

6. APPARATUS

6.1. *Triaxial Pressure Chamber*—The pressure chamber is used to contain the test specimen and the confining fluid during the test. A typical triaxial chamber suitable for use in resilient testing of soils is shown in Figure 2. The deformation is measured *externally* with two spring-loaded linear variable differential transducers (LVDT) as shown in Figure 2.



Note: LVDT tips shall rest on the triaxial cell itself or on a plate/bracket that is rigidly attached to the triaxial cell.

Figure 2—Typical Triaxial Chamber with Eternal LVDTs and Load Cell (not to scale)

6.1.1. Air shall be used in the triaxial chamber as the confining fluid.

6.1.2. The chamber shall be made of polycarbonate, acrylic or other suitable "see through" material to facilitate the observation of the specimen during testing.

6.2. *Loading Device*—The loading device shall be a top-loading, closed loop, electrohydraulic or electropneumatic testing machine with a function generator that is capable of applying repeated cycles of haversine-shaped load pulse of the following durations.

Type of Loading Device	Load Pulse (s)	Rest Period (s)
Pneumatic	0.1	0.9 to 3.0
Hydraulic	0.1	0.9

6.2.1. The haversine-shaped load pulse shall conform to Section 3.6. All preconditioning and testing shall be conducted using a haversine-shaped load pulse. The system-generated haversine waveform and the response waveform shall be displayed to allow the operator to adjust the gains to ensure that they coincide during preconditioning and testing.

6.3. *Load and Specimen Response Measuring Equipment*:

6.3.1. The axial load-measuring device should be an electronic load cell located between the actuator and the chamber piston rod as shown in Figure 2. The following load-cell capacities are required:

Specimen Dia. (mm)	Max. Load Cap. (kN)	Req. Accuracy (N)
71	2.2	±4.5
100	8.0	±10.0
152	22.24	±22.24

The above requirements for load capacity and accuracy are approximately linear when plotted versus specimen cross-sectional area. Requirements for load cells used with other specimen diameters should be approximately on the same linear relationships.

Note 2—During periods of resilient modulus testing, the load cell shall be monitored and checked once every 2 weeks or after every 50 resilient modulus tests with a calibrated proving ring to assure that the load cell is operating properly. An alternative to using a proving ring is to insert an additional calibrated load cell and independently measure the load applied by the original load cell to ensure accurate loadings. Additionally, the load cell shall be checked at any time if the laboratory's in-house QA/QC testing indicates noncompliance or there is a suspicion of a load-cell problem. Resilient modulus testing shall not be conducted if the testing system is found to be out of calibration or if the load cell does not meet the manufacturer's tolerance requirements stated above for accuracy, whichever of the two is of the higher accuracy.

6.3.2. Test chamber pressures shall be monitored with conventional pressure gages, manometers, or pressure transducers accurate to 0.7 kPa.

6.3.3. *Axial Deformation*—Measuring system for all materials shall consist of 2 LVDTs fixed to opposite sides of the piston rod outside the test chamber as shown in Figure 2. These two transducers shall be located equidistant from the piston rod and shall bear on hard, fixed surfaces, which are perpendicular to the LVDT axis. Spring-loaded LVDTs are required. The following LVDT ranges are required:

Specimen Dia. (mm)	Range (mm)
71	±1
100	±2.5
152	±6

Both LVDTs shall meet the following minimum specifications:

- *Linearity*, ±0.25 percent of full scale
- *Repeatability*, ±1 percent of full scale
- *Minimum Sensitivity*, 2 mv/v (AC) or 5 mv/v (DC)

The above requirement for range is approximately linear when plotted versus specimen cross-sectional area. Requirements for LVDTs used with other specimen diameters are approximately on the same linear relationships. A digital or other type of deformation measurement system with equivalent linearity and repeatability specifications may be used in place of LVDTs.

6.3.3.1. A positive contact between the vertical LVDTs and the surface on which the tips of the transducers rest shall always be maintained during the test procedure. In addition, the two LVDTs shall be wired so that each transducer can be read and reviewed independently and the results averaged for calculation purposes.

Note 3—Misalignment or dirt on the shaft of the transducer can cause the "sticking" of the shafts of the LVDT. The laboratory technician shall depress and release each LVDT prior to each test to assure that there is no sticking. An acceptable cleaner/lubricant (as specified by the manufacturer) shall be applied to the transducer shafts on a regular basis.

6.3.3.2. The response of the LVDTs shall be checked daily with the laboratory's in-house QA/QC program. Additionally, the LVDTs shall be calibrated every 2 weeks, or after every 50 resilient modulus tests, whichever comes first, using a micrometer with compatible resolution or a set of specially machined gauge blocks. Resilient modulus testing shall not be conducted if the LVDTs do not meet the manufacturer's tolerance requirements for accuracy.

6.3.4. Suitable signal excitation, conditioning, and recording equipment are required for simultaneous recording of axial load and deformations. The signal shall be clean and free of noise. Use shielded cables for connections. If a filter is used, it shall have a frequency that cannot attenuate the signal. The LVDTs shall be wired separately so each LVDT signal can be monitored independently. A minimum of 200 data points from each LVDT shall be recorded per load cycle.

6.4. *Specimen Preparation Equipment*—A variety of equipment is required to prepare undisturbed samples for testing and to obtain compacted specimens that are representative of field conditions. Use of different methods of compaction is necessary to prepare specimens of different materials and to simulate desired field conditions. See Annexes A, B, and C for specimen preparation (Annex A), specimen compaction equipment and compaction procedures for Type 1 (Annex B), and Type 2 materials (Annex C or Appendix X1), respectively.

6.5. Equipment for trimming test specimens from undisturbed thin-walled tube samples of subgrade soils shall be as described in T 296.

6.6. *Miscellaneous Apparatus*—This includes calipers, micrometer gauge, steel rule calibrated to 0.5 mm, rubber membranes 0.25 to 0.79 mm thick, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones (subgrade), porous bronze discs (base/subbase), scales, moisture content cans, and report forms, as required.

6.7. *System Calibration and Periodic Checks*—The entire system (transducer, conditioning, and recording devices) shall be calibrated every 2 weeks or after every 50 resilient modulus tests using the laboratory's in-house QA/QC program. Daily and other periodic checks of the system shall also be performed in accordance with the laboratory's in-house QA/QC program.

7. PREPARATION OF TEST SPECIMENS

7.1. *Specimen Size*—The following guidelines, based on the sieve analysis test results, shall be used to determine the test specimen size.

7.1.1. Use 71-mm or 86-mm diameter specimens for tests on undisturbed cohesive specimens of Type 2 materials. For Type 1 materials, or compacted specimens of Type 2 materials, select mold sizes to fabricate specimens of a minimum diameter equal to five times the maximum particle size. If the maximum particle size exceeds 25 percent of the largest mold diameter available, these particles will be scalped. Length for all specimens will be at least two times the diameter.

7.2. *Undisturbed Subgrade Soil Specimens*—Undisturbed subgrade soil specimens are trimmed and prepared. The natural moisture content, *w,* of the tube sample shall be determined after triaxial resilient modulus testing following the procedure outlined in T 265, and recorded in the test report.

7.2.1. To be suitable for testing, a specimen of sufficient length, being at least twice the diameter of the specimen, shall be cut from the tube sample. The specimen shall be free from defects. Such defects include cracks in the specimen, broken corners that cannot be repaired during preparation, or presence of particles much larger than that typical for the material. For example, the presence of plus 19.0-mm stones in a fine-grained soil or presence of "foreign objects" such as large roots, wood particles, organic material, and gouges due to gravel hanging on the edge of the tube constitute damaged specimens that are unacceptable.

7.3. *Laboratory Compacted Specimens*—Reconstituted test specimens of both Type 1 and Type 2 materials shall be prepared to approximate the *in situ* wet density, γ_w, and moisture content, *w*. These laboratory-compacted specimens shall be prepared for all unbound granular base and subbase material and for all subgrade soils for which undisturbed tube specimens could not be obtained.

7.3.1. *Moisture Content*—The moisture content of the laboratory-compacted specimen shall be the *in situ* moisture content obtained in the field using T 310. If data are not available on *in situ* moisture content, then refer to Section 7.3.3. The moisture content of the laboratory-compacted specimen shall not vary by more than ±1.0 percent for Type 1 materials or ±0.5 percent for Type 2 materials from the *in situ* moisture content obtained.

7.3.2. *Compacted Density*—The density of the compacted specimen shall be the in-place wet density obtained in the field using T 310 or T 191. If these data are not available on *in situ* density, then refer to Section 7.3.3. The wet density of the laboratory-compacted specimen shall not vary by more than ±3 percent of the in-place wet density for that layer.

7.3.3. If either the *in situ* moisture content or the in-place density data are not available, then use the percentage of maximum dry density and the corresponding optimum moisture content by T 99 or T 180 as is specified by the individual testing or transportation agency. The moisture content of the laboratory-compacted specimen shall not vary by more than ±1.0 percent for Type 1 materials or ±0.5 percent for Type 2 materials from the target moisture content. Also, the wet density of the laboratory-compacted specimen shall not vary by more than ±3 percent of the target wet density.

Example: If the desired density is 1950 kg/m^3 and the desired moisture content is 8.0 percent for a Type 1 material, then a moisture content between 7.0 and 9.0 percent would be acceptable. For the same desired moisture content and density for a Type 2 material, acceptable moisture contents are between 7.5 and 8.5 percent. Acceptable densities for either material are between 1892 and 2009 kg/m^3.

7.3.4. *Sample Reconstitution*—Reconstitute the specimen for Type 1 and Type 2 materials in accordance with the provisions given in Annex A. The target moisture content and density to be used in determining needed material quantities are given in Section 7.3. Annex A provides guidelines for reconstituting the material to obtain a sufficient amount of material to prepare the appropriate specimen type at the designated moisture content and density. After this step is completed, specimen compaction can begin.

7.4. *Compaction Methods and Equipment for Reconstituting Specimens*:

7.4.1. *Compacting Specimens for Type 1 Materials*—The general method of compaction for Type 1 materials will be that of Annex B.

7.4.2. *Compacting Specimens for Type 2 Materials*—The general method of compaction for Type 2 materials will be that of Annex C or Appendix X1. If it is desired to investigate specimen density gradient, the method is that of Appendix B.

7.4.3. The prepared specimens shall be protected from moisture change by applying the triaxial membrane and testing within 5 days of completion. Prior to storage, and directly after removal from storage, weigh the specimen to determine if there was any moisture loss. If moisture loss exceeds 1 percent for Type 1 materials or 0.5 percent for Type 2 materials, then the prepared specimen will not be tested. However, a new specimen will be needed to be prepared for testing. Material from the specimens not tested may be reused.

8. PROCEDURE—RESILIENT MODULUS TEST FOR SUBGRADE SOILS

8.1. The procedure described in this section is used for undisturbed or laboratory-compacted specimens of subgrade soils. This can include specimens of 150-mm diameter or Type 2 specimens of 70-mm diameter.

8.2. *Assembly of Triaxial Chamber*—Specimens trimmed from undisturbed samples and laboratory-compacted specimens are placed in the triaxial chamber and loading apparatus in the following steps:

8.2.1. Place a moist porous stone and moist paper filter on the top of the specimen base of the triaxial chamber as shown in Figure 2.

8.2.2. Carefully place the specimen on the porous stone. Place the membrane on a membrane expander, apply vacuum to the membrane expander, then carefully place the membrane on the specimen and remove the vacuum and the membrane expander. Seal the membrane to the pedestal (or bottom plate) with an O-ring or other pressure seal.

8.2.3. Place a moist paper filter and the top platen containing a moist porous stone on the specimen, fold up the membrane, and seal it to the top platen with an O-ring or some other pressure seal.

8.2.4. If the specimen has been compacted or stored inside a rubber membrane and the porous stones and sample are already attached to the rubber membrane in place, Sections 8.2.1, 8.2.2, and 8.2.3 are omitted. Instead, the “specimen assembly” is placed on the base plate of the triaxial chamber.

8.2.5. Connect the specimen’s bottom drainage line to the vacuum source through the medium of a bubble chamber. Apply a vacuum of 7 kPa. If bubbles are present, check for leakage caused by poor connections, holes in the membrane, or imperfect seals at the cap of the base. The existence of an airtight seal ensures that the membrane will remain firmly in contact with the specimen. Leakage through holes in the membrane can frequently be eliminated by coating the surface of the membrane with liquid rubber latex or by using a second membrane.

8.2.6. When leakage has been eliminated, disconnect the vacuum supply and place the chamber on the base plate and the cover plate on the chamber. Insert the loading piston and obtain a firm connection with the load cell. Tighten the chamber tie rods firmly.

8.2.7. Slide the assembly apparatus into position under the axial loading device. Positioning of the chamber is extremely critical in eliminating all possible side forces in the piston rod. Couple the loading device to the triaxial chamber piston rod.

8.3. *Conduct the Resilient Modulus Test*—The following steps are required to conduct the resilient modulus test on a subgrade specimen that has been installed in the triaxial chamber and placed under the loading frame.

8.3.1. Open all drainage valves leading into the specimen to atmospheric pressure. This will simulate drained conditions. Simulation of undrained conditions will require saturation of specimens. Such procedures are not contained in this method.

8.3.2. If it is not already connected, connect the air pressure supply line to the triaxial chamber and apply the specified pre-conditioning confining pressure of 41.4 kPa to the test specimen. A contact stress of 10 percent ± 0.7 kPa of the maximum applied axial stress during each sequence number shall be maintained.

8.3.2.1. Loads applied to the top of the triaxial cell piston rod must be adjusted to apply stresses shown in Table 1 after accounting for a net upward or downward resultant calculated as follows:

$$F = (A \times P) - W \quad (9)$$

where:

F = resultant force;

A = piston rod cross-section area;

P = confining pressure; and

W = weight of piston rod and exterior-mounted specimen deformation measurement system.

Table 1—Testing Sequence for Subgrade Soil

Sequence	Confining Pressure, S_3		Max. Axial Stress, S_{max}		Cyclic Stress, S_{cyclic}		Constant Stress, $0.1S_{max}$		No. of
No.	kPa	psi	kPa	psi	kPa	psi	kPa	psi	Load Applications
0	41.4	6	27.6	4	24.8	3.6	2.8	0.4	500–1000
1	41.4	6	13.8	2	12.4	1.8	1.4	0.2	100
2	41.4	6	27.6	4	24.8	3.6	2.8	0.4	100
3	41.4	6	41.4	6	37.3	5.4	4.1	0.6	100
4	41.4	6	55.2	8	49.7	7.2	5.5	0.8	100
5	41.4	6	68.9	10	62.0	9.0	6.9	1.0	100
6	27.6	4	13.8	2	12.4	1.8	1.4	0.2	100
7	27.6	4	27.6	4	24.8	3.6	2.8	0.4	100
8	27.6	4	41.4	6	37.3	5.4	4.1	0.6	100
9	27.6	4	55.2	8	49.7	7.2	5.5	0.8	100
10	27.6	4	68.9	10	62.0	9.0	6.9	1.0	100
11	13.8	2	13.8	2	12.4	1.8	1.4	0.2	100
12	13.8	2	27.6	4	24.8	3.6	2.8	0.4	100
13	13.8	2	41.4	6	37.3	5.4	4.1	0.6	100
14	13.8	2	55.2	8	49.7	7.2	5.5	0.8	100
15	13.8	2	68.9	10	62.0	9.0	6.9	1.0	100

Note: Load sequences 14 and 15 are not to be used for materials designed as Type 1.

8.3.3. *Conditioning*—Begin the test by applying a minimum of 500 repetitions of a load equivalent to a maximum axial stress of 27.6 kPa and corresponding cyclic stress of 24.8 kPa using a haversine-shaped load pulse with durations as described in Section 6.2. If the sample is still decreasing in height at the end of the conditioning period, stress cycling shall be continued up to 1000 repetitions prior to testing as outlined in sequence No. 0, Table 1.

Note 4—The laboratory/technician shall conduct appropriate QA/QC comparative checks of the individual deformation output from the two vertical transducers during the conditioning phase of each resilient modulus test in order to recognize specimen misplacement and misalignment. During the preconditioning phase, the two vertical deformation curves shall be viewed to ensure that acceptable vertical deformation ratios are being measured. The vertical deformation ratio R_v is defined as $R_v = Y_{max}/Y_{min}$, where Y_{max} equals the larger of the two vertical deformations and Y_{min} equals the smaller of the two vertical deformations. Every effort shall be made to achieve R_v

values of 1.10 or less. Acceptable R_v values are 1.30 or less. If unacceptable vertical deformation ratios are obtained (i.e., R_v is greater than 1.30), then the test shall be discontinued and specimen placement/alignment difficulties alleviated. Once acceptable vertical deformation values are obtained, then the test shall be continued to completion. It is emphasized that the specimen alignment is critical for proper resilient modulus results. This note also applies to Section 9.3.3.

8.3.3.1. The above stress sequence constitutes sample conditioning; that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the sample cap and the test specimen.

8.3.3.2. If the total vertical permanent strain reaches 5 percent during conditioning, the conditioning process shall be terminated. For recompacted samples, a review shall be conducted of the compaction process to identify any reason(s) why the sample did not attain adequate compaction. If this review does not provide an explanation, the material shall be refabricated and tested a second time. If the sample again reaches 5 percent total vertical permanent strain during preconditioning, then the test shall be terminated and a notation added to the report form.

8.3.4. *Testing Specimen*—The testing is performed following the loading sequence shown in Table 1. Begin by decreasing the maximum axial stress to 13.8 kPa (Sequence No. 1, Table 1) and set the confining pressure to 41.4 kPa.

8.3.5. Apply 100 repetitions of the corresponding cyclic axial stress using a haversine-shaped load pulse with durations as described in Section 6.2. Record the average recovered deformations for each LVDT separately for the past five cycles on the Report Form C4.1 (Table C4.1).

8.3.6. Increase the maximum axial stress to 27.6 kPa (Sequence No. 2) and repeat Step 8.3.5 at this new stress level.

8.3.7. Continue the test for the remaining load sequences in Table 1 (3 to 15), recording the vertical recovered deformation. If at any time the permanent strain of the sample exceeds 5 percent, stop the test and report the result on the appropriate worksheet.

8.3.8. After completion of the resilient modulus test procedure, check the total vertical permanent strain the specimen was subjected to during the resilient modulus portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, and if strength information is desired, continue with the quick shear test procedure (Section 8.3.9). If the total vertical permanent strain exceeds 5 percent, the test is completed. No additional testing is to be conducted on the specimen, other than in Section 8.3.11.

8.3.9. *Quick Shear Test*—Apply a confining pressure of 27.6 kPa to the specimen. Apply a load so as to produce an axial strain at a rate of 1 percent per minute under a strain-controlled loading procedure. Continue loading until either (1) the load values decrease with increasing strain, (2) 5 percent strain is reached, or (3) the capacity of the load cell is reached. Data from the internally mounted deformation transducer in the actuator shaft and from the load cell shall be used to record specimen deformation and loads at a maximum of 3-s intervals.

8.3.10. At the completion of the triaxial shear test, reduce the confining pressure to zero and remove the sample from the triaxial chamber.

8.3.11. Remove the membrane from the specimen and use the entire specimen to determine moisture content in accordance with T 265.

8.3.12. Plot the stress–strain curve for the specimen for the triaxial shear test procedure.

9. PROCEDURE—RESILIENT MODULUS TEST FOR BASE/SUBBASE MATERIALS

9.1. The procedure described in this section applies to all unbound granular base and subbase materials. This can include specimens classified as Type 1 or Type 2 material.

9.2. *Assembly of the Triaxial Chamber*—When compaction is completed, place the porous bronze disc and specimen cap on the top surface of the specimen. Roll the rubber membrane off the rim of the mold and over the sample cap. If the sample cap projects above the rim of the mold, the membrane shall be sealed tightly against the cap with the O-ring seal. If it does not, the seal can be applied later. Install the specimen in the triaxial chamber as in Sections 8.2.1 through 8.2.7.

9.2.1. Connect the chamber pressure supply line and apply a confining pressure of 103.4 kPa.

9.2.2. Remove the vacuum supply from the vacuum saturation inlet and open the top and bottom head drainage ports to atmospheric pressure.

9.3. *Conduct the Resilient Modulus Test*—After the test specimen has been prepared and placed in the loading device as described in Section 8.2.1, the following steps are necessary to conduct the resilient modulus testing:

9.3.1. If not already done, adjust the position of the axial loading device or triaxial chamber base support as necessary to couple the load-generation device piston and the triaxial chamber piston. The triaxial chamber piston should bear firmly on the load cell. A contact stress of 10 percent ±0.7 kPa of the maximum applied axial stress during each sequence number shall be maintained.

9.3.1.1. Loads applied to the top of the triaxial cell piston rod must be adjusted to apply the stresses shown in Table 2 after accounting for a net upward or downward resultant calculated as follows:

$$F = (A \times P) - W \qquad (10)$$

where:

F = resultant force;

A = piston rod cross-sectional area;

P = confining pressure; and

W = weight of piston rod and exterior-mounted specimen deformation measurement system.

Table 2—Testing Sequences for Base/Subbase Materials

Sequence No.	Confining Pressure, S_3 kPa	psi	Max. Axial Stress, S_{max} kPa	psi	Cyclic Stress, S_{cyclic} kPa	psi	Constant Stress, $0.1S_{max}$ kPa	psi	No. of Load Applications
0	103.4	15	103.4	15	93.1	13.5	10.3	1.5	500–1000
1	20.7	3	20.7	3	18.6	2.7	2.1	0.3	100
2	20.7	3	41.4	6	37.3	5.4	4.1	0.6	100
3	20.7	3	62.1	9	55.9	8.1	6.2	0.9	100
4	34.5	5	34.5	5	31.0	4.5	3.5	0.5	100
5	34.5	5	68.9	10	62.0	9.0	6.9	1.0	100
6	34.5	5	103.4	15	93.1	13.5	10.3	1.5	100
7	68.9	10	68.9	10	62.0	9.0	6.9	1.0	100
8	68.9	10	137.9	20	124.1	18.0	13.8	2.0	100
9	68.9	10	206.8	30	186.1	27.0	20.7	3.0	100
10	103.4	15	68.9	10	62.0	9.0	6.9	1.0	100
11	103.4	15	103.4	15	93.1	13.5	10.3	1.5	100
12	103.4	15	206.8	30	186.1	27.0	20.7	3.0	100
13	137.9	20	103.4	15	93.1	13.5	10.3	1.5	100
14	137.9	20	137.9	20	124.1	18.0	13.8	2.0	100
15	137.9	20	275.8	40	248.2	36.0	27.6	4.0	100

9.3.2. Adjust the recording devices for the LVDTs and load cell as needed.

9.3.3. *Conditioning*—Set the confining pressure to 103.4 kPa and apply a minimum of 500 repetitions of a load equivalent to a maximum axial stress of 103.4 kPa and corresponding cyclic axial stress of 93.1 kPa according to sequence 0, Table 2, using a haversine-shaped load pulse with durations as described in Section 6.2. If the sample is still decreasing in height at the end of the conditioning period, stress cycling shall be continued up to 1000 repetitions prior to testing.

9.3.3.1. The above stress sequence constitutes sample conditioning; that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the sample cap and base plate and the test specimen. The drainage valves should be open to atmospheric pressure throughout the resilient modulus testing. This will simulate drained conditions. Simulation of undrained conditions will require saturation of specimens. Such procedures are not contained in this method.

9.3.3.2. If the total vertical permanent strain reaches 5 percent during conditioning, the conditioning process shall be terminated. A review shall be conducted of the compaction process to identify any reason(s) why the sample did not attain adequate compaction. If this review does not provide an explanation, the material shall be refabricated and tested a second time. If the sample again reaches 5 percent total vertical permanent strain during preconditioning, then the test shall be terminated and a notation added to the report form.

9.3.4. *Testing Specimen*—The testing is performed following the loading sequences in Table 2 using a haversine-shaped load pulse as described above. Decrease the maximum axial stress to 21.0 kPa and set the confining pressure to 21.0 kPa (Sequence No. 1, Table 2).

9.3.5. Apply 100 repetitions of the corresponding cyclic stress using a haversine-shaped load pulse with durations as described in Section 6.2. Record the average recovered deformations for each LVDT separately for the past five cycles on the report form.

9.3.6. Continue with sequence No. 2 increasing the maximum axial stress to 41.0 kPa and repeat the step in Section 9.3.5 at this new stress level.

9.3.7. Continue the test for the remaining load sequences in Table 2 (sequences 3 to 15), recording the vertical recovered deformation. If at any time the total vertical permanent strain deformation exceeds 5 percent, stop the test and make a notation on the report form.

9.3.8. After completion of the resilient modulus test procedure, check the total vertical permanent strain that the specimen was subjected to during the resilient modulus portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, and if strength information is desired, continue with the quick shear test procedure (Section 9.3.9). If the total vertical permanent strain exceeds 5 percent, the test is completed. No additional testing is to be conducted on the specimen, other than in Section 9.3.11.

9.3.9. *Quick Shear Tests*—Apply a confining pressure of 34.5 kPa to the specimen. Apply a load so as to produce an axial strain at a rate of 1 percent per minute under a strain-controlled loading procedure. Continue loading until either (1) the load values decrease with increasing strain, (2) 5 percent strain is reached, or (3) the capacity of the load cell is reached. Data from the internally mounted deformation transducer in the actuator shaft and from the load cell shall be used to record specimen deformation and loads at a maximum of 3-s intervals.

9.3.10. At the completion of the triaxial shear test, reduce the confining pressure to zero and remove the sample from the triaxial cell.

9.3.11. Remove the membrane from the specimen and use the entire sample to determine the moisture content in accordance with T 265.

9.3.12. Plot the stress–strain curve for the specimen for the triaxial shear test procedure.

10. CALCULATIONS

10.1. Perform the calculations to obtain resilient modulus values using the tabular arrangement shown on Report Form C4.1 (Table C4.1). The resilient modulus value is computed for each of the past five cycles of each load sequence. These values are subsequently averaged on the data sheet.

11. REPORT

11.1. *The report shall consist of the following*:

11.1.1. Report Form C4.1 (Table C4.1).

11.1.2. Report Form C4.2 (Table C4.2) (recompacted specimens) or Report Form C4.3 (Table C4.3) (thin-walled tube specimens).

11.2. *The following general information is to be recorded on all of the Report Forms*:

11.2.1. The specimen identification, the material type (Type 1 or Type 2), and test date.

11.3. *Report the following information on the appropriate data sheet*:

11.3.1. Report Form C4.2 (Table C4.2) shall be used to record general information concerning the specimen being tested. This form shall be completed only for those specimens that are recompacted from bulk samples. This form shall not be used to record information for thin-wall tube samples.

11.3.1.1. *Item 4*—Record a "Y" (Yes) or "N" (No) to denote whether the sample reached a 5 percent total vertical permanent strain during the conditioning stage of the test procedure (Sections 8.3.3 and 9.3.3). Also, note with a "Y" (Yes) or "N" (No) whether or not the sample reached 5 percent total vertical permanent strain during the testing sequence. Record the number of test sequences completed, either partially or completely, for the given sample.

11.3.1.2. *Item 5*—Record the specimen dimensions and perform the area and volume calculations.

11.3.1.3. *Item 6*—Record the compaction masses as outlined in Annex B (Type 1) or Annex C or Appendix X1 (Type 2).

11.3.1.4. *Item 7*—Record the *in situ* moisture content/density values used as the basis for compaction of the specimen as per Sections 7.3.1 and 7.3.2. These values were obtained from nuclear methods in the field. If these values are not available, record the optimum moisture content, maximum dry density, and 95 percent maximum dry density values used as the basis for compaction of the specimen as per Section 7.3.3.

11.3.1.5. *Item 8*—Record the moisture content of the compacted material as per Section B3.16 (Type 1) or Sections C3.12 or X1.6.3 (Type 2). Record the moisture content of the material after the resilient modulus test as per Section 8.3.11 (Subgrade) or Section 9.3.11 (Base/Subbase). Also, record the target density used for specimen recompaction.

11.3.1.6. *Item 9*—Record the results and accompanying information for the quick-shear test procedure as per Section 8.3.9 (Subgrade) or Section 9.3.9 (Base/Subbase).

11.3.2. Report Form C4.3 (Table C4.3) shall be used to record general information concerning the specimen being tested. This form shall be completed only for thin-walled tube specimens. This form shall not be used to record information for recompacted samples.

11.3.2.1. *Item 4*—Record the approximate distance from the top of the subgrade to the top of the specimen (if known).

11.3.2.2. *Item 5*—Record a "Y" (Yes) or "N" (No) to denote whether the sample reached 5 percent total vertical permanent strain during the preconditioning stage of the test procedure (Sections 8.3.3 and 9.3.3). Also, note with a "Y" (Yes) or "N" (No) whether or not the sample reached a 5 percent total vertical permanent strain during the testing sequence. Record the number of test sequences completed, either partially or completely, for the given sample.

11.3.2.3. *Item 6*—Record the specimen dimensions and perform the area and volume calculations. Record the mass of the specimen.

11.3.2.4. *Item 7*—Record the moisture content (*in situ*) prior to resilient modulus testing. Record the moisture content at the completion of resilient modulus testing as per Section 8.3.11. Record the wet and dry density of the thin-walled tube samples.

11.3.2.5. *Item 8*—Record the results and accompanying information for the quick-shear test procedure as per Section 8.3.9 (Subgrade).

11.3.3. Record the test data for each specimen in a format similar to Report Form C4.1 (Table C4.1) and attach with Report Form C4.2 (Table C4.2) or Report Form C4.3 (Table C4.3). The following information shall be recorded on Report Form C4.1 (Table C4.1):

11.3.3.1. *Column 1*—Record the chamber confining pressure for the testing sequence. Only one entry need be made for the past five load cycles. This entry should correspond exactly with the confining pressure levels shown in Table 1 (Subgrade) or Table 2 (Base/Subbase).

11.3.3.2. *Column 2*—Record the nominal axial cyclic stress for the testing sequence. Only one entry need be made for the past five load cycles. This entry should correspond exactly with the nominal axial cyclic stress required in Table 1 (Subgrade) or Table 2 (Base/Subbase).

11.3.3.3. *Columns 4 through 9*—Record the actual applied loads and stresses for each of the past five load cycles as shown on the worksheet.

11.3.3.4. *Columns 10 through 12*—Record the recoverable axial deformation of the sample for each LVDT independently for each of the past five load cycles. Average the response from the two LVDTs and record this value in Column 12. This value will be used to calculate the axial strain of the material.

11.3.3.5. *Column 13*—Compute the axial strain for each of the past five load cycles. This value is computed by dividing Column 12 by the original length of the specimen, Lo, which was recorded on Report Form C4.2 (Table A3.2) (recompacted specimens) or Report Form C4.3 (Table C4.3) (thin-walled tube specimens).

11.3.3.6. *Column 14*—Compute the resilient modulus for each of the past five load cycles. This value is computed by dividing Column 8 by Column 13.

11.3.3.7. *Average*—Compute the average of the past five load cycles for each column.

11.3.3.8. *Standard Deviation*—Compute the standard deviation of the values for each column for the past five load cycles using the equation:

$$s = \sqrt{\frac{\sum\left(x_i - \overline{x}\right)^2}{n-1}} = \sqrt{\frac{\sum x_i^2 - \frac{\left(\sum x_i\right)^2}{n}}{n-1}} \tag{11}$$

ANNEX A—SAMPLE PREPARATION

(Mandatory Information)

A1. SCOPE

A1.1. The following procedure provides guidelines for reconstituting the material to be tested so as to produce a sufficient amount of material needed to prepare the appropriate sample type (Type 1 or Type 2 sample) at the designated moisture content and density.

A1.1.1. *Sample Conditioning*—If the sample is damp when received from the field, dry it until it becomes friable. Drying may be in air or by use of a drying apparatus as long as the temperature does not exceed 60°C. Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles. Moderate pressure using a rubber-covered implement to push the particles through a 4.75-mm (No. 4) sieve has been found to be adequate to break down clay lumps.

A1.1.2. *Sample Preparation*—Determine the moisture content, w_1, of the sample as per T 265. The mass of the moisture content specimen shall be at least 200 g for samples with a maximum particle size smaller than the 4.75-mm (No. 4) sieve and at least 500 g for samples with a maximum particle size greater than the 4.75-mm (No. 4) sieve.

A1.1.2.1. Determine the appropriate total volume V of the compacted specimen to be prepared. The total volume must be based on a height of the compacted specimen slightly greater than that required for resilient testing to allow for trimming of the specimen ends, if necessary. Compacting to a height/diameter ratio of 2.1 to 2.2 will provide adequate material for this purpose.

A1.1.2.2. Determine the mass of oven-dry soil solids W_s required to obtain the desired dry density γd and moisture content w as follows:

$$W_s = 453.59\ \gamma_d\ V \qquad (A1.1)$$

where:

W_s = mass of oven-dry solids, g;

γ_d = desired dry density, lb/ft^3; and

V = total volume of compacted specimen, ft^3.

A1.1.2.3. Determine the mass of the dried sample, W_{ad}, with the moisture content, w_1, required to obtain W_s plus an additional amount, W_{as}, of at least 500 g to provide material for the determination of moisture content at the time of compaction.

$$W_{ad} = (W_s + W_{as})(1 + w_1/100) \qquad (A1.2)$$

where:

W_{ad} = mass of sample at water content w_1, g;

W_{as} = mass of moisture content specimen (usually 500 g), g; and

w_1 = water content of prepared material, percent.

A1.1.2.4. Determine the mass of water (W_{aw}) required to change the water content from the existing water content, w_1, to the desired compaction water content, w. (See Section 7.3.3)

$$W_{aw} = (W_s + W_{as})[(w - w_1)/100] \qquad (A1.3)$$

where:

W_{aw} = mass of water needed to obtain water content, w, g; and

w = desired water content of compacted material, percent.

A1.1.2.5. Place a sample of mass W_{ad} into a mixing pan.

A1.1.2.6. Add the mass of water (w_{aw}) needed to change the water content from w_1 to w, to the sample in small amounts and mix thoroughly after each addition.

A1.1.2.7. Place the mixture in a plastic bag. Seal the bag, place it in a second bag and seal it. Cure the sample for 16 to 48 h, determine the mass of the wet soil and container to the nearest gram and record this value on Report Form C4.2 (Table A3.2).

A1.1.2.8. The material is now ready for compaction.

ANNEX B—VIBRATORY COMPACTION OF TYPE 1 AND TYPE 2 SOILS

(Mandatory Information)

B1. SCOPE

B1.1. Soils will be recompacted using a split mold and vibratory compaction. Select mold sizes to fabricate specimens of a minimum diameter equal to five times the maximum particles size. If the maximum particle size exceeds 25 percent of the largest mold diameter available, these particles shall be scalped. Length of all specimens will be at least two times the diameter.

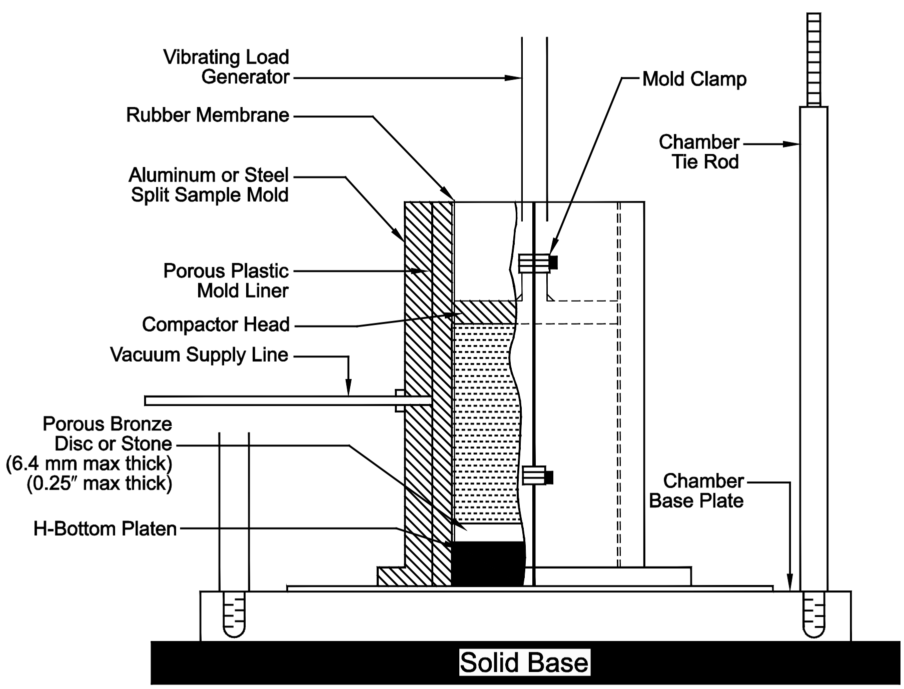
B1.2. Specimens shall be compacted in six lifts in a split mold mounted on the base of the triaxial cell as shown in Figure B2.1. Compaction forces are generated by a vibratory impact hammer without kneading action powered by air or electricity and of sufficient size to provide the required laboratory densities while minimizing damage to the sample membrane.

B2. APPARATUS

B2.1. A split mold, with an inside diameter of 152 mm, having a minimum height of 381 mm (or a sufficient height to allow guidance of the compaction head for the final lift).

B2.2. *Vibratory Compaction Device*—Vibratory compaction shall be provided using electric rotary or demolition hammers with a rated input of 750 to 1250 watts and capable of 1800 to 3000 blows per minute.

B2.3. The compactor head shall be at least 13 mm thick and have a diameter of not less than 146 mm.



Note: Compactor head should be 6.35 ± 0.5 mm (0.25 ± 0.02 in.) smaller than specimen diameter.

Figure B2.1—Typical Apparatus for Vibratory Compaction of Type 1 Untreated Materials

B3. PROCEDURE

B3.1. For removable platens, tighten the bottom platen into place on the triaxial cell base. It is essential that an airtight seal is obtained and that the bottom platen interface constitutes a rigid body because calculations of strain assume zero movement of the bottom platen under load.

B3.2. Place the two porous stones and the top platen on the bottom platen. Determine the total height of the top and bottom platens and stones to the nearest 0.25 mm.

B3.3. Remove the top platen and bronze disc, if used. Measure the thickness of the rubber membrane with a micrometer.

B3.4. Place the rubber membrane over the bottom platen and lower bronze disc. Secure the membrane to the bottom platen using an O-ring or other means to obtain an airtight seal.

B3.5. Place the split mold around the bottom platen and draw the membrane up through the mold. Tighten the split mold firmly in place. Exercise care to avoid pinching the membrane.

B3.6. Stretch the membrane tightly over the rim of the mold. Apply a vacuum to the mold sufficient to draw the membrane in contact. If wrinkles are present in the membrane, release the vacuum, adjust the membrane, and reapply the vacuum. The use of a porous plastic forming jacket line helps to ensure that the membrane fits smoothly inside the mold. The vacuum is maintained throughout the compaction procedure.

B3.7. Measure, to the nearest 0.25 mm, the inside diameter of the membrane-lined mold and the distance between the top of the lower porous stone and the top of the mold.

B3.8. Determine the volume, V, of the specimen to be prepared using the diameter determined in Step B3.7 and a value of height between 305 to 318 mm.

B3.9. Determine the mass of material, at the prepared water content, to be compacted into the volume, V, to obtain the desired density.

B3.10. For 152-mm diameter specimens (specimen height of 305 mm) six layers of 50 mm per layer are required for the compaction process. Determine the mass of wet soil, W_L, required for each layer.

$$W_L = W_t / N \tag{B3.1}$$

where:

W_t = total mass of test specimen to produce the appropriate density; and

N = number of layers to be compacted.

B3.11. Place the total required mass of soil for all lifts, W_{ad}, into a mixing pan. Add the required amount of water, W_{aw}, and mix thoroughly.

B3.12. Determine the mass of the wet soil and the mixing pan.

B3.13. Place the amount of wet soil, W_L, into the mold. Avoid spillage. Using a spatula, draw soil away from the inside edge of the mold to form a small mound at the center.

B3.14. Insert the vibrator and vibrate the soil until the distance from the surface of the compacted layer to the rim of the mold is equal to the distance measured in B3.7 minus the thickness of the layer selected in Step B3.10. This may require removal and reinsertion of the vibrator several times until experience is gained in gauging the vibration time that is required.

B3.15. Repeat Steps B3.13 and B3.14 for each new layer after first scarifying the top surface of the previous layer to a depth of 6.4 mm. The measured distance from the surface of the compacted layer to the rim of the mold is successively reduced by the layer thickness selected in Step B3.10. The final surface shall be a smooth horizontal plane. As a recommended final step where porous bronze discs are used, the top plate shall be placed on the sample and seated with the vibrator head. If necessary, due to degradation of the first membrane, a second membrane can be applied to the sample at the conclusion of the compaction process.

B3.16. When the compaction process is completed, determine the mass of the mixing pan and the excess soil. This mass subtracted from the mass determined in Step B3.12 is the mass of the wet soil used (mass of specimen). Verify the compaction water, W_c, of the excess soil using care in covering the pan of wetted soil during compaction to avoid drying and loss of moisture. The moisture content of this sample shall be conducted using T 265.

B3.17. Proceed with Section 9 of this method.

Note B1—As an alternative for soils lacking in cohesion, a mold with the membrane installed and held by vacuum, as in Appendix X2, may be used.

ANNEX C—COMPACTION OF TYPE 2 SOILS

(Mandatory Information)

C1. SCOPE

C1.1. This method covers the compaction of Type 2 soils for use in resilient modulus testing.

C1.2. The general method of compaction of Type 2 soils will be that of static loading (a modified version of the double plunger method). If testable thin-walled tubes are available, specimens shall not be recompacted.

C1.3. The process is one of compacting a known mass of soil to a volume that is fixed by the dimensions of the mold assembly. The minimum mold diameter shall be 71 mm. Select mold sizes to fabricate specimens of a minimum diameter equal to five times the maximum particle size. If the maximum particle size exceeds 25 percent of the largest mold diameter available, these particles shall be scalped. Length of all specimens will be at least two times the diameter. A typical mold assembly is shown in Figure C3.1. As an alternative for soils lacking in cohesion, a mold with the membrane installed and held by vacuum, as in Annex B, may be used. Several steps are required for static compaction, as follows in Section C3 of this Annex and as illustrated in Figures C3.2 to C3.6.

C2. APPARATUS

C2.1. The apparatus is as shown in Figure C3.1.

C3. PROCEDURE

C3.1. Five layers of equal mass shall be used to compact the specimens using this procedure. Determine the mass of wet soil, W_L, to be used per layer where $W_L = W_t/5$.

C3.2. Place one of the spacer plugs into the specimen mold.

C3.3. Place the mass of soil, W_L, determined in Step C3.1, into the specimen mold. Using a spatula, draw the soil away from the edge of the mold to form a slight mound in the center.

C3.4. Insert the second plug and place the assembly in the static loading machine. Apply a small load. Adjust the position of the mold with respect to the soil mass, so the distances from the mold ends to the respective spacer plugs are equal. Soil pressure developed by the initial loading will serve to hold the mold in place. By having both spacer plugs reach the zero volume change simultaneously, more uniform layer densities are obtained.

C3.5. Slowly increase the load until the plugs rest firmly against the mold ends. Maintain this load for a period of not less than 1 min. The amount of soil rebound depends on the rate of loading and load duration. The slower the rate of loading and the longer the load is maintained, the less the rebound (Figure C3.2).

Note C1—To obtain uniform densities, extreme care must be taken to center the first soil layer exactly between the ends of the specimen mold. Checks and any necessary adjustments should be made after completion of Steps C3.4 and C3.5.

Note C2—Use of compaction by measuring the plunger movements to determine that the desired volume has been reached for each layer is an acceptable alternative to the use of the spacer plugs.

C3.6. Decrease the load to zero and remove the assembly from the loading machine.

C3.7. Remove the loading ram. Scarify the top surface of the compacted layer to a depth of 3.2 mm and put the mass of wet soil, W_L, for the second layer in place and form a mound. Add a spacer plug of the height shown in Figure C3.3.

C3.8. Slowly increase the load until the plugs rest firmly against the top of the mold end. Maintain load for a period of not less than 1 min (Figure C3.3).

C3.9. Remove the load, flip the mold over, and remove the bottom plug keeping the top plug in place. Scarify the bottom surface of layer one and put the mass of wet soil W_L for the third layer in place and form a mound. Add a spacer ring of the height shown in Figure C3.4.

C3.10. Place the assembly in the loading machine. Increase the load slowly until the spacer plugs firmly contact the ends of the specimen mold. Maintain this load for a period of not less than 1 min.

C3.11. Follow the steps presented in Figures C3.5 and C3.6 to compact the remaining two layers.

C3.12. After compaction is completed, determine the moisture content of the remaining soil using T 265. Record this value on Report Form C4.2 (Table C4.2).

C3.13. Using the extrusion ram, press the compacted soil out of the specimen mold and into the extrusion mold. Extrusion should be done slowly to avoid impact loading the specimen.

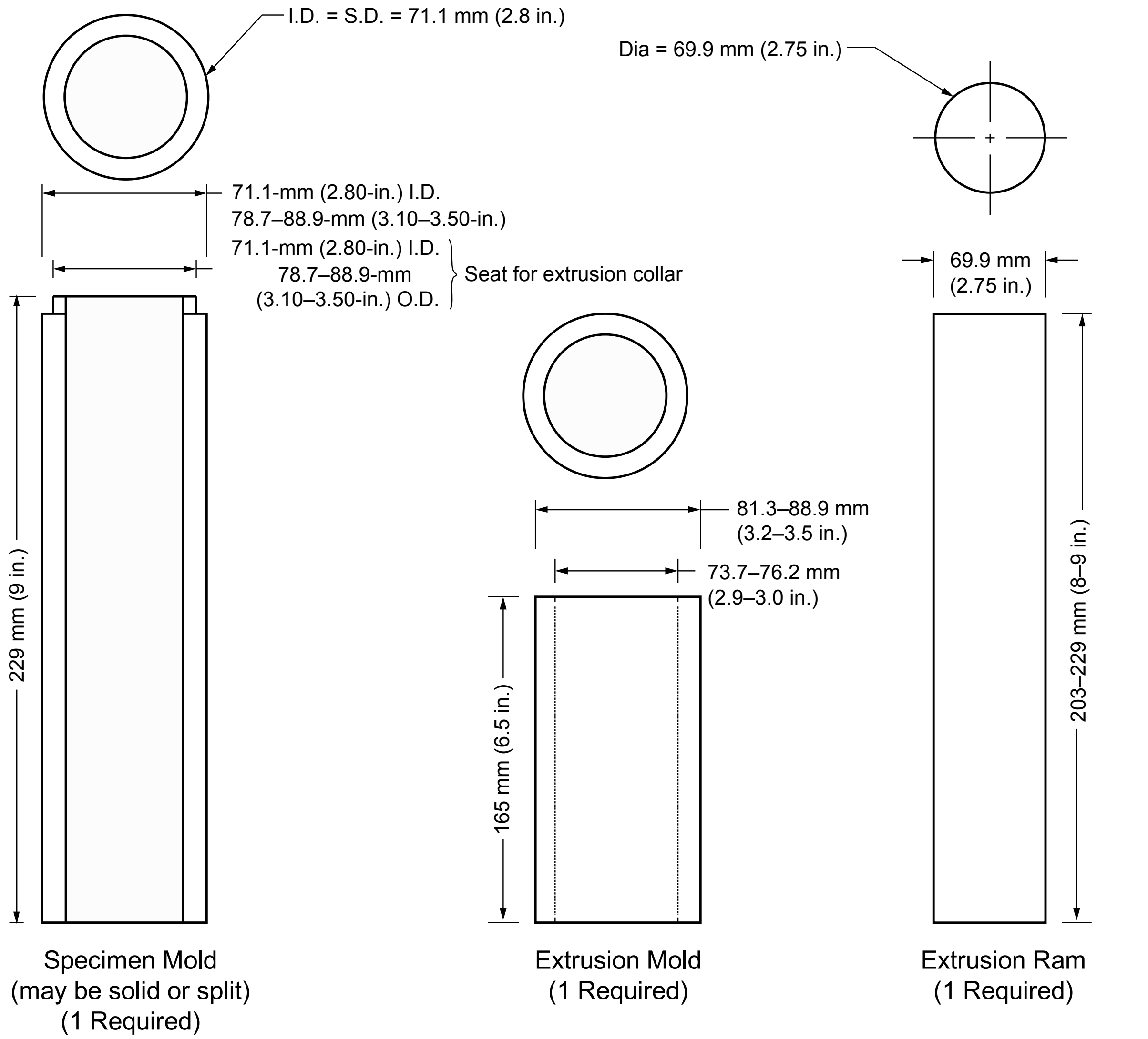
C3.14. Using the extrusion mold, carefully slide the specimen off the ram onto a solid end platen. The platen should be circular with a diameter equal to that of the specimen and have a minimum thickness of 13 mm. Platens shall be of a material that will not absorb soil moisture.

C3.15. Determine the mass of the compacted specimen to the nearest gram. Measure the height and diameter to the nearest 0.25 mm. Record these values on Report Form C4.1 (Table C4.1).

C3.16. Place a platen similar to the one used in Step C3.13 on top of the specimen.

C3.17. Using a vacuum membrane expander, place the membrane over the specimen. Carefully pull the ends of the membrane over the end platens. Secure the membrane to each platen using O-rings or other means to provide an airtight seal.

C3.18. Proceed with Section 8 of this method.



Not to scale

Note: S.D. = Specimen Diameter

All materials shall be stainless steel or aluminum (HI strength).

Note: This drawing is of a "typical" compaction device. Dimensions may vary due to availability of these pieces in the laboratory.

Spacer "Plugs" needed:

Quantity	Height
2	100.1-mm (3.940-in.)
2	71.6-mm (2.80-in.)
2	43.2-mm (1.700-in.)

H = dimensions as shown on Figures C3.2–C3.6 or as manufactured by laboratory to produce 28.4-mm (1.12-in.) lifts.

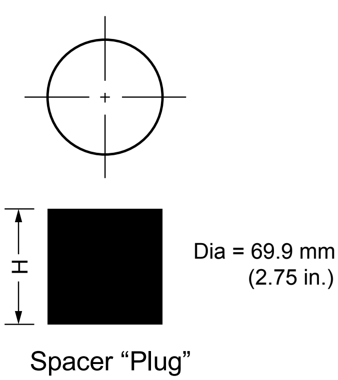
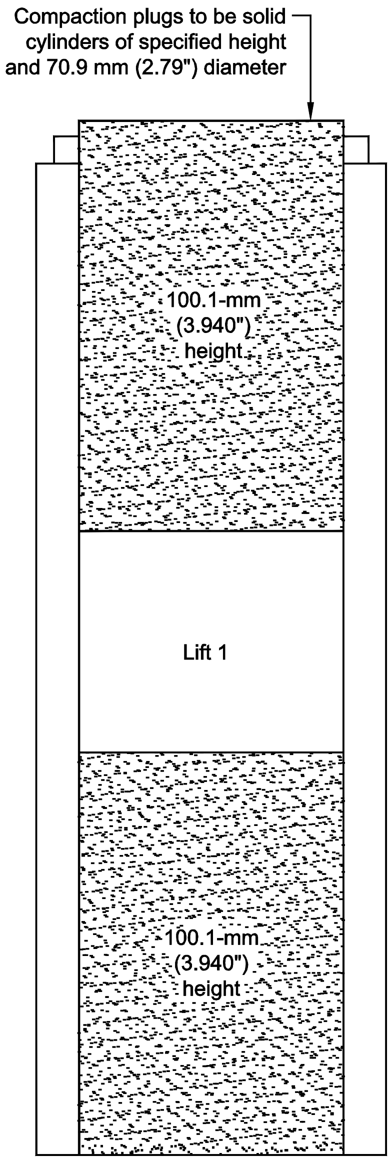


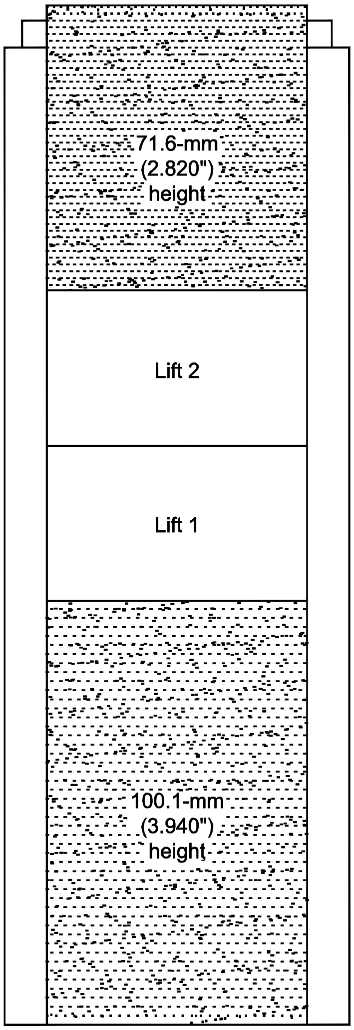
Figure C3.1—Typical Apparatus for Static Compaction of Type 2 Materials



Step 3.5—Lift 1:

- Measure correct wet weight of soil to use for a layer.
- Place in mold, spade.
- Insert plugs of given height.
- Double plunge until plugs are flush with top and bottom of mold.
- Remove top plug.
- Scarify the exposed surface of Lift 1.
- Proceed with next step.

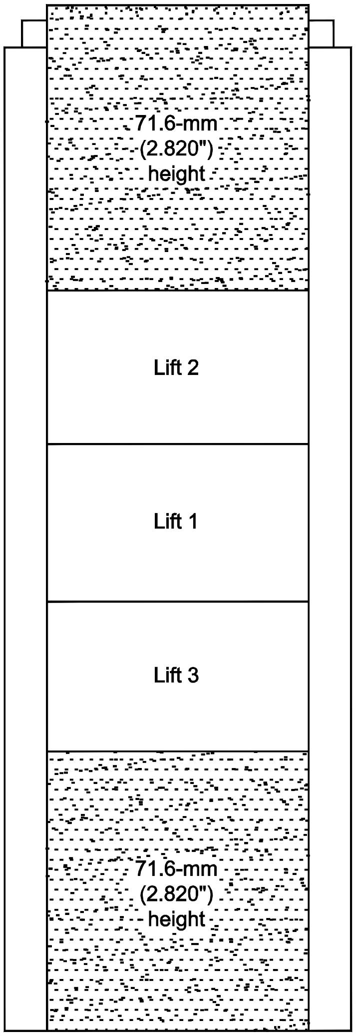
Figure C3.2—Compaction of Type 2 Soil, Lift 1



Step 3.7—Lift 2:

- Measure correct wet weight of soil to use for a layer.
- Place in mold, spade.
- Insert 71.6-mm (2.820") plug.
- Plunge until plugs are flush with top and bottom of mold.
- Flip mold over and remove 100.1-mm (3.940") plug, keeping the 71.6-mm (2.820") plug in place.
- Scarify the exposed surface of Lift 1.
- Proceed with next step.

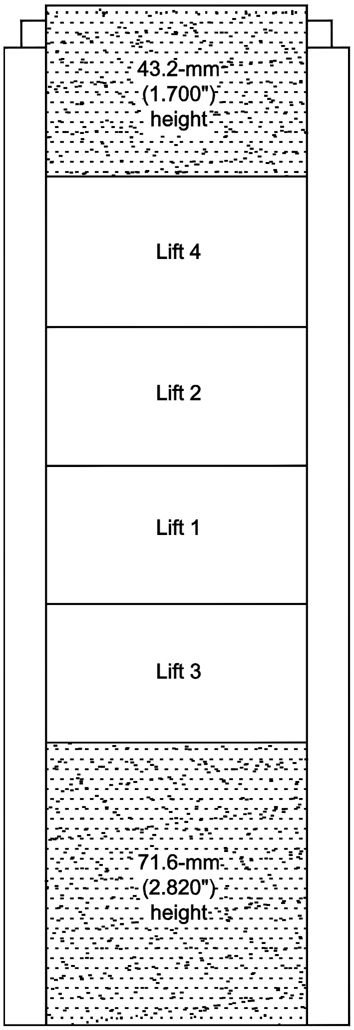
Figure C3.3—Compaction of Type 2 Soil, Lift 2



Step 3.9—Lift 3:

- Measure correct wet weight of soil to use for a layer.
- Place in mold, spade.
- Insert 71.6-mm (2.820") plug.
- Plunge until plugs are flush with top and bottom of mold.
- Flip mold over and remove 71.6-mm (2.280") plug from the top of Lift 2, keeping the 71.6-mm (2.820") plug (on Lift 3) in place.
- Scarify the exposed surface of Lift 2.
- Proceed with next step.

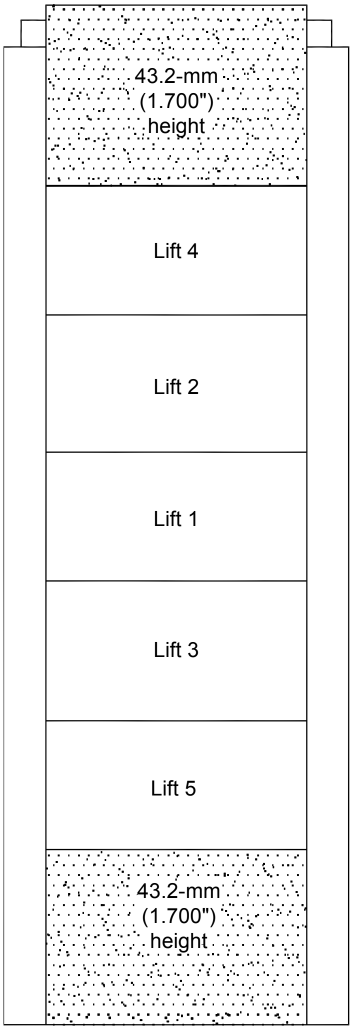
Figure C3.4—Compaction of Type 2 Soil, Lift 3



Step 3.11—Lift 4:

- Measure correct wet weight of soil to use for a layer.
- Place in mold, spade.
- Insert 43.2-mm (1.700") plug.
- Plunge until plugs are flush with top and bottom of mold.
- Flip mold over and remove 71.6-mm (2.820") plug, keeping the 43.2-mm (1.700") plug in place.
- Scarify the exposed surface of Lift 3.
- Proceed with next step.

Figure C3.5—Compaction of Type 2 Soil, Lift 4



Step 3.13—Lift 5:

- Measure correct wet weight of soil to use for a layer.
- Place in mold, spade.
- Insert 43.2-mm (1.700") plug.
- Plunge until plugs are flush with top and bottom of mold.
- Extrude compacted sample from mold using extruding apparatus or extrusion mold.
- Place in rubber membrane.
- Test for M_r.

Figure C3.6—Compaction of Type 2 Soil, Lift 5

C4. REPORT FORMS

(Nonmandatory Information)

Table C4.1—Report Form C4.1

Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials

1. SAMPLE NUMBER __ __ __ __
2. MATERIAL TYPE __ __ __ __
3. TEST DATE __ __-__ __-__ __
4. RESILIENT MODULUS TESTING

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PARAMETER	Chamber Confining Pressure	Nominal Maximum Axial Stress	Cycle No.	Actual Applied Max. Axial Load	Actual Applied Cycle Load	Actual Applied Contact Load	Actual Applied Max. Axial Stress	Actual Applied Cycle Stress	Actual Applied Contact Stress	Recov Def. LVDT #1 Reading	Recov Def. LVDT #2 Reading	Average Recov Def. LVDT 1 and 2	Resilient Strain	Resilient Modulus
DESIGNATION	S_3	S_{max}	c_1	P_{max}	P_{cyclic}	$P_{contact}$	S_{max}	S_{cyclic}	$S_{contact}$	H_1	H_2	H_{avg}	$\in_r$	M_r
UNIT	kPa	kPa	----	N	N	N	N	kPa	kPa	mm	mm	mm	mm/mm	MPa
PRECISION	_ _ _ ._	_ _ _._	_	_ _ _._	_ _ _._	_ _ _._	_ _ _._	_ _ _._	_ _._	_._ _ _ _ _	_._ _ _ _ _	_._ _ _ _ _	_._ _ _ _ _	_ _ _.
SEQUENCE 1			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

Note: Repeat the gray shaded area for Sequences 2 to 15.

Table C4.2—Report Form C4.2

Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials
(RECOMPACTED SAMPLES)

1. SAMPLING DATE: __ __-__ __ -20 __ __

2. SAMPLE NUMBER __ __ __ __

3. MATERIAL TYPE (Type 1 or Type 2) __

4. TEST INFORMATION
PRECONDITIONING – GREATER THAN 5 PERCENT PERM.STRAIN? (Y = YES OR N = NO) __
TESTING – GREATER THAN 5 PERCENT PERM. STRAIN? (Y = YES OR N = NO) __
TESTING – NUMBER OF LOAD SEQUENCES COMPLETED (0 – 15) __ __

5. SPECIMEN INFO.:
SPEC. DIAM., mm __ __ __.__
TOP __ __ __.__
MIDDLE __ __ __.__
BOTTOM __ __ __.__
AVERAGE __ __ __.__
MEMBRANE THICKNESS (1), mm __.__ __
MEMBRANE THICKNESS (2), mm __.__ __
NET DIAM, mm __ __ __.__
HEIGHT OF SPECIMEN, CAP AND BASE, mm __ __ __.__
HEIGHT OF CAP AND BASE, mm __ __ __.__
INITIAL LENGTH L_O, mm __ __ __.__
INITIAL AREA, A_O, mm^2 __ __ __ __ __ __ __ __.
INITIAL VOLUME, $A_O L_O$, mm^3 __ __ __ __ __ __ __ __.

6. SOIL SPECIMEN WEIGHT:
INITIAL WEIGHT OF CONTAINER AND WET SOIL, grams __ __ __ __ __.__ __
FINAL WEIGHT OF CONTAINER AND WET SOIL, grams __ __ __ __ __.__ __
WEIGHT OF WET SOIL USED, grams __ __ __ __ __.__ __

7. SOIL PROPERTIES:
IN SITU MOISTURE CONTENT (NUCLEAR), PERCENT __ __.__
IN SITU WEIGHT DENSITY (NUCLEAR), kg/m^3 __ __ __ __.__
or
OPTIMUM MOISTURE CONTENT, PERCENT __ __.__
MAX DRY DENSITY, kg/m^3 __ __ __ __.__
95 PERCENT MAX DRY DENSITY, kg/m^3 __ __ __ __.__

8. SPECIMEN PROPERTIES:
COMPACTION MOISTURE CONTENT, PERCENT __ __.__
MOISTURE CONTENT AFTER RESILIENT MODULUS TESTING, PERCENT __ __.__
COMPACTION DRY DENSITY, γ_d, kg/m^3 __ __ __ __.__

9. QUICK SHEAR TEST
STRESS–STRAIN PLOT ATTACHED (Y = YES OR N = NO) __
TRIAXIAL SHEAR MAXIMUM STRENGTH
(MAX. LOAD/X-SECTION AREA), kPa __ __ __ __.
SPECIMEN FAIL DURING TRIAXIAL SHEAR? (Y = YES, N = NO) __

10. TEST DATE __ __.__ __.__ __

GENERAL REMARKS:____
____

TESTED BY ___________________ DATE _______________

Table C4.3—Report Form C4.3

Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials
(THIN-WALL TUBE SAMPLES)

1. SAMPLING DATE: __ __-__ __ -20 __ __

2. SAMPLE NUMBER __ __ __ __

3. MATERIAL TYPE (Type 1 or Type 2) __

4. APPROX. DISTANCE FROM TOP OF SUBGRADE TO SAMPLE, m __.__ __

5. TESTING INFORMATION
PRECONDITIONING – GREATER THAN 5 PERCENT PERM. STRAIN? (Y = YES OR N = NO) __
TESTING – GREATER THAN 5 PERCENT PERM. STRAIN? (Y = YES OR N = NO) __
TESTING – NUMBER OF LOAD SEQUENCES COMPLETED (0 – 15) __ __

6. SPECIMEN INFO.:
SPEC. DIAM., mm
TOP __ __ __.__
MIDDLE __ __ __.__
BOTTOM __ __ __.__
AVERAGE __ __ __.__
MEMBRANE THICKNESS (1), mm __.__ __
MEMBRANE THICKNESS (2), mm __.__ __
NET DIAM, mm __ __ __.__
INITIAL LENGTH, L_O, mm __ __ __.__
INITIAL AREA, A_O, mm^2 __ __ __ __ __.
INITIAL VOLUME, $A_O L_O$, mm^3 __ __ __ __ __ __ __.
INITIAL WEIGHT, gram __ __ __ __ __.__

7. SOIL PROPERTIES:
IN SITU MOISTURE CONTENT, PERCENT __ __.__
MOISTURE CONTENT AFTER RESILIENT MODULUS TESTING, PERCENT __ __.__
WEIGHT DENSITY, γ_W, kg/m^3 __ __ __ __.__
DRY DENSITY, γ_d, kg/m^3 __ __ __ __.__

8. QUICK SHEAR TEST
STRESS-STRAIN PLOT ATTACHED (Y = YES OR N = NO) __
TRIAXIAL SHEAR MAXIMUM STRENGTH
(MAX. LOAD/X-SECTION AREA), kPa __ __ __ __
SPECIMEN FAIL DURING TRIAXIAL SHEAR? (Y = YES, N = NO) __

9. TEST DATE __ __.__ __.__ __

GENERAL REMARKS:____
____

TESTED BY __________________ DATE _______________

APPENDIXES

(Nonmandatory Information)

X1. KNEADING COMPACTION OF TYPE 2 SOILS

X1.1. *Scope*:

X1.1.1. This method covers kneading compaction of Type 2 soils for use in resilient modulus testing.

X1.1.2. Specimens shall be compacted in five lifts (layers) in a split mold. Either a pneumatic manual compactor or a hydraulic mechanical compactor provides the compactive effort. The number of tamps per lift and the compaction pressure are constant for all lifts. The compaction pressure is adjusted to achieve the required laboratory density.

X1.2. *Significance and Use*:

X1.2.1. Kneading compaction will yield a structure in Type 2 soils that is characteristically obtained by field compaction methods. Thus, when compacted dry of the optimum moisture content, the soil structure is mostly flocculated; and when compacted wet of the optimum, it is mostly dispersed.

X1.2.2. This procedure may result in a gradient of soil density within the specimen, which may affect the resilient modulus, M. Where it is important to achieve a uniform density in all specimen layers, the procedure described in Appendix X2 should be used.

X1.3. *Apparatus*:

X1.3.1. *Test Specimen Mold*—A split mold with a removable collar, as shown in Figure X1.1, shall be used. The minimum mold inside diameter shall be 71 mm. The mold shall have a minimum inside diameter not less than five times the maximum particle size. The trimmed length of all specimens shall be at least two times the diameter.

Note X1—As an alternative for soils lacking in cohesion, a mold with the membrane installed and held by vacuum, as described in Annex B, may be used.

X1.3.2. *Manual Compactor*—A pneumatic manual compactor, as shown in Figure X1.2, may be used. The volume of the air reservoir shall be a minimum of 200 times the volume of the compactor at full piston extension. The compactor rod shall be threaded to receive tamping feet of various diameters from 13 to 19 mm. The reservoir pressure regulator and gauge shall be capable of adjusting and reading air pressure from zero to 400 kPa. Calibration shall be checked annually using a calibrated proving ring or load cell.

Note X2—This device is modeled after the Harvard miniature compactor. A pneumatically operated compactor is preferred to a spring-loaded compactor due to the more consistent compactive effort and reduced operator variability.

X1.3.3. *Mechanical Compactor*—A hydraulic mechanical compactor capable of applying a foot pressure from 250 to 2000 kPa and meeting the requirements of T 190 may be used. When a mechanical compactor is used, the split mold inside diameter shall be chosen as required to work with the compactor, provided that the requirements of Section X1.3.1 are met.

X1.4. *Manual Compaction Procedure*:

X1.4.1. Specimen material shall be prepared in accordance with Annex A. If the maximum particle size exceeds 25 percent of the mold inside diameter, the oversize particles shall be scalped. The specimen will be fabricated 6 to 8 mm over height to allow trimming to a square end. Increase the quantity of material prepared to allow for the trimming.

X1.4.2. Specimens shall be compacted in five lifts of equal mass. Determine the mass of soil, W_L, required for each lift according to:

$$W_L = W_T/5 \quad (X4.1)$$

where:

W_T = total mass of test specimen to produce the target density, including the allowance for trimming.

Note X3—In most cases, the target density will be determined by field conditions. Where this is not the case, an appropriate target density can be determined by performing a laboratory moisture-density test according to the procedure of T 99 or T 180.

X1.4.3. Adjust the air reservoir pressure to the level to be used in the first trial. Thread the desired diameter tamper foot onto the compactor piston. Determine the required number of tamps for one coverage of each lift according to Table X1.1.

Table X1.1—Number of Tamps for One Coverage of a Lift-Manual Procedure

Specimen Diameter	Tamper Foot Diameter			
	13 mm	15 mm	17 mm	19 mm
71 mm	30	22	17	14
86 mm	44	33	26	20
102 mm	62	46	36	29
152 mm	137	103	80	64

Note X4—Maintaining a database of compaction variables, soil types, and moisture-density conditions will assist with selection of starting air pressure to achieve the desired specimen density.

X1.4.4. Place the mass of wet soil, W_L, for one lift in the mold. Using a spatula, draw the soil away from the edge of the mold to form a slight mound in the center.

X1.4.5. Holding the compactor vertically, apply the required number of tamps to the soil. Tamps should be distributed evenly over the specimen cross section. Each tamp should be applied slowly with just enough force to move the piston approximately 5 to 10 mm in the compactor.

Note X5—**Caution**: The piston should not be moved all the way to the end of the compactor, as this will cause an unregulated force to be applied.

X1.4.6. Lightly scarify the top surface of the compacted lift to a depth of 3 mm prior to placing soil in the mold for the next lift.

X1.4.7. Repeat steps in Sections X1.5.1 and X1.5.2 until five lifts have been compacted. Continue with Section X1.6.1.

X1.5. *Mechanical Compaction Procedure*:

X1.5.1. Specimen material shall be prepared and weighed in accordance with Sections X1.4.1 and X1.4.2.

X1.5.2. Adjust the foot pressure to the level to be used in the first trial.

X1.5.3. Place the mass of wet soil, W_L, for one lift in the mold. Using a spatula, draw the soil away from the edge of the mold to form a slight mound in the center.

X1.5.4. Apply one revolution of tamps to the first lift (normally five to seven tamps per revolution, according to T 190) to achieve one coverage over the specimen cross section.

X1.5.5. Lightly scarify the top surface of the compacted lift to a depth of 3 mm prior to placing soil in the mold for the next lift.

X1.5.6. Repeat Steps X1.5.3 through X1.5.5 until five lifts have been compacted.

X1.6. *Specimen Trimming and Calculations*:

X1.6.1. Remove the collar and carefully screed off the specimen to the top of the mold. Small depressions in the screeded surface, caused by removal of larger particles, shall be filled with fines. Remove the split mold from the base and the mold halves from the specimen.

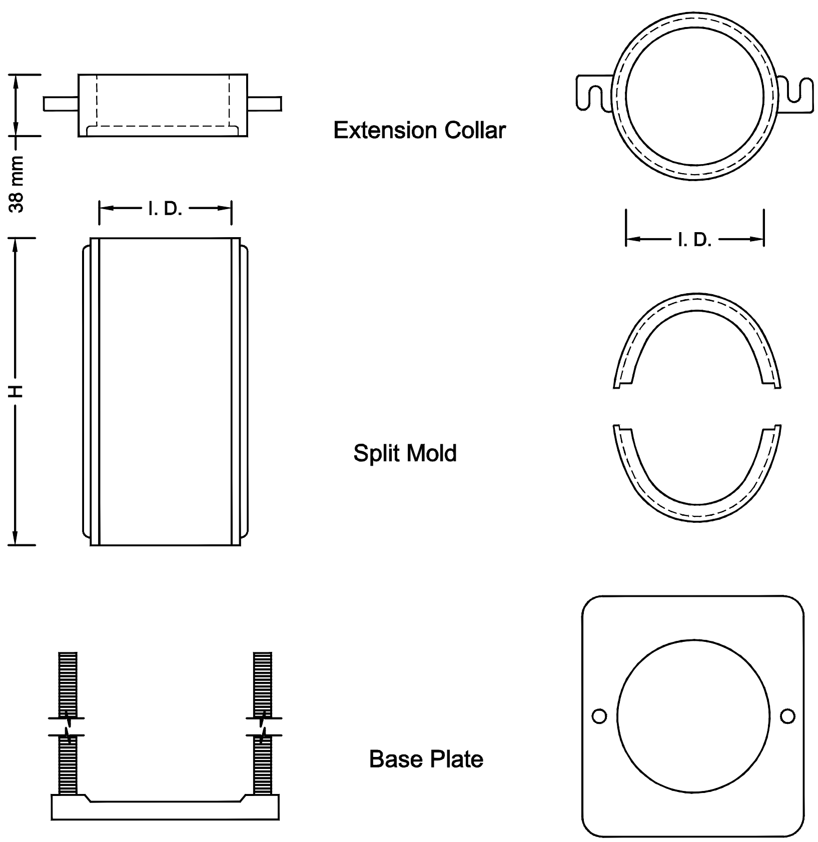
X1.6.2. Determine and record the mass of the entire specimen to the nearest gram. Use a tabular form, as in Figure X1.3, to record the data.

X1.6.3. Determine and record the moisture content of the remaining soil according to T 265.

X1.6.4. Calculate and record the average bulk (wet) density of the entire specimen, γ_s. If the average density differs from the target density by *less* than the tolerance allowed in Section 7.3.2 or 7.3.3, then proceed with Section 7.4.3 of this method.

X1.6.5. If the average density differs from the target density by *more* than the tolerance allowed in Section 7.3.2 or 7.3.3, then the compaction pressure shall be adjusted to increase or decrease the average density toward the target density. Repeat X1.4 or X1.5.

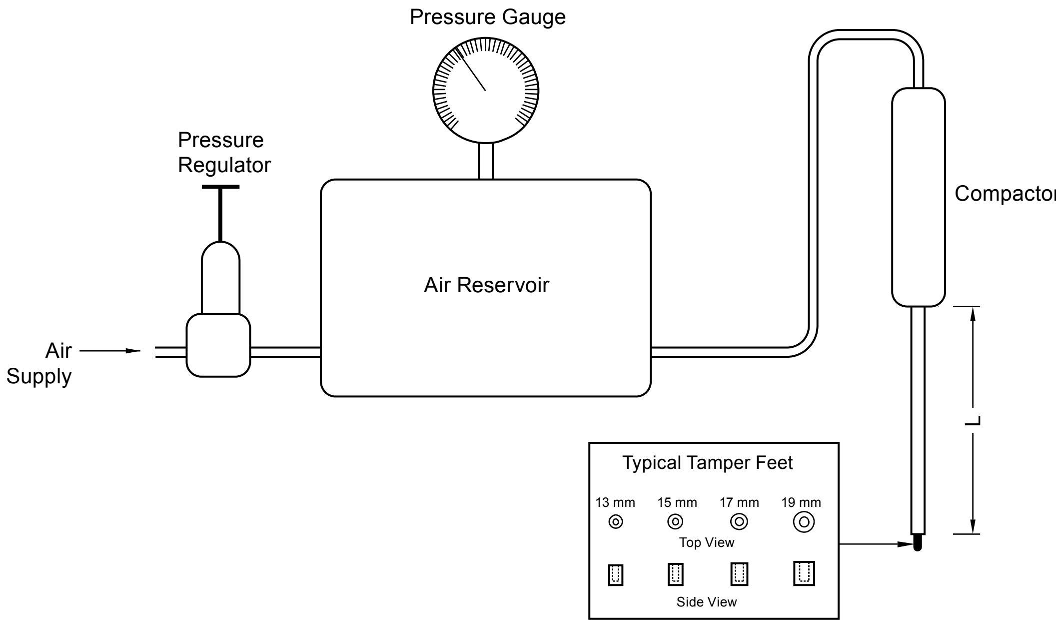
Note X6—If a sufficient quantity of material is available, it is preferable to use new material for each subsequent specimen. If the old material is reused, this will have an effect on the structure of subsequently compacted specimens.



Notes: 1. Mold halves are connected with 2 hose clamps.

2. H = I.D. × 2

Figure X1.1—Specimen Mold



Notes: 1. L = Specimen ht. + Collar ht. – Layer HL + 12 mm
2. Minimum Reservoir Volume = 200 × Compactor Volume
3. Minimum gauge accuracy is 0.5 kPa.
4. Compactor air cylinder is rolling diaphragm type.

Figure X1.2—Pneumatic Kneading Compaction System

KNEADING COMPACTION OF TYPE 2 SOILS

PROJECT	

Target Moisture (%)		Target Dry Density (kg/m^3)	

Mold Dimensions—diam × ht. (mm)		Mold Volume (cm)		Mold wt. (gm)	

Specimen No.				
Wt. of Scalped Soil (gm)				
No. Tamps per Layer				
Air or Tamper Foot Pressure (Pa)				
Wt. Specimen and Mold (gm)				
Wt. Mold Assembly (gm)				
Wt. Moist Soil (gm)				
Wt. Dry Soil (gm)				
Moisture Content (%)				
Dry Density (kg/m^3)				
Wet Density (kg/m^3)				

PERCENT DIFFERENCES

Target & Specimen Dry Density (%)				
Target & Specimen Moisture (%)				

Specimen No.	Soil Description

REMARKS

Figure X1.3—Kneading Compaction of Type 2 Soils

X2. OBTAINING A UNIFORM DENSITY IN TYPE 2 SOILS

X2.1. *Scope*:

X2.1.1. This method provides procedures for measuring and minimizing or eliminating density gradients in a specimen of Type 2 soil for use in resilient modulus testing.

X2.1.2. Specimens shall be compacted in five lifts (layers) in a density gradient mold. Kneading compaction (Appendix X1) shall be used. The number of tamps per lift shall be adjusted for each lift to avoid imparting a density gradient to the specimen.

X2.2. *Significance and Use*:

X2.2.1. A specimen fabricated in layers, with each lift receiving equal compactive effort, will typically exhibit a density gradient with the first lift compacted being more dense than the last. To measure this effect, the density gradient mold is used to determine the density of each lift. A trial-and-error process is used to adjust the compactive effort for each lift until the desired specimen density is obtained with a minimum gradient.

X2.2.2. Density gradients can occur with kneading (Appendix X1), static double plunger (Annex C), or vibratory (Annex B) compaction methods. The density gradient mold can be used in conjunction with any of the three compaction methods to measure density gradients from top to bottom within the specimen.

X2.2.3. For the most accurate characterization of resilient modulus, the density gradient within the test specimen should be minimized. The test specimen should have a structure that closely approximates the one that will be obtained in field compaction. The use of kneading compaction can help to achieve the proper structure.

X2.3. *Apparatus*:

X2.3.1. *Density Gradient Mold*—The density gradient mold is shown in Figure X2.1. This is a split mold with the inside milled to receive five interchangeable solid rings that have been permanently numbered from one through five. The ring I.D. shall be equal to the mold I.D. The mold height and diameter shall be the same as those used in preparing specimens for resilient modulus testing (Appendix X1).

X2.3.2. *Compactor*—To measure the density gradient (using Section X2.4), the same type of compactor shall be used as is used in preparing specimens for resilient modulus testing, as described in Annex B, Annex C, or Appendix X1. To minimize the density gradient (using Section X2.5), either a manual or a mechanical kneading compactor, as described in Appendix X1, shall be used.

X2.4. *Procedure for Compacting Specimens to Measure Density Gradients*:

X2.4.1. Specimen material shall be prepared in accordance with Annex A. If the maximum particle size exceeds 25 percent of the mold inside diameter, the oversize particles shall be scalped. The specimen will be fabricated 6 to 8 mm over height to allow trimming to a square end. Increase the quantity of material prepared to allow for the trimming.

X2.4.2. Specimens shall be compacted to the same diameter, and using the same apparatus and procedure, as is used in preparing specimens for resilient modulus testing, as described in Annex B, Annex C, or Appendix X1.

X2.4.3. Remove the collar and carefully screed off the specimen to the top of the mold. Small depressions in the screeded surface, caused by removal of larger particles, shall be filled with fines. Remove the split mold from the base and the mold halves from the specimen. Leave the five rings on the specimen.

X2.4.4. Determine and record the net mass of the entire specimen to the nearest gram. To do this, subtract the mass of the rings from the mass of the specimen with rings attached.

X2.4.5. Determine and record the moisture content of the remaining soil according to T 265.

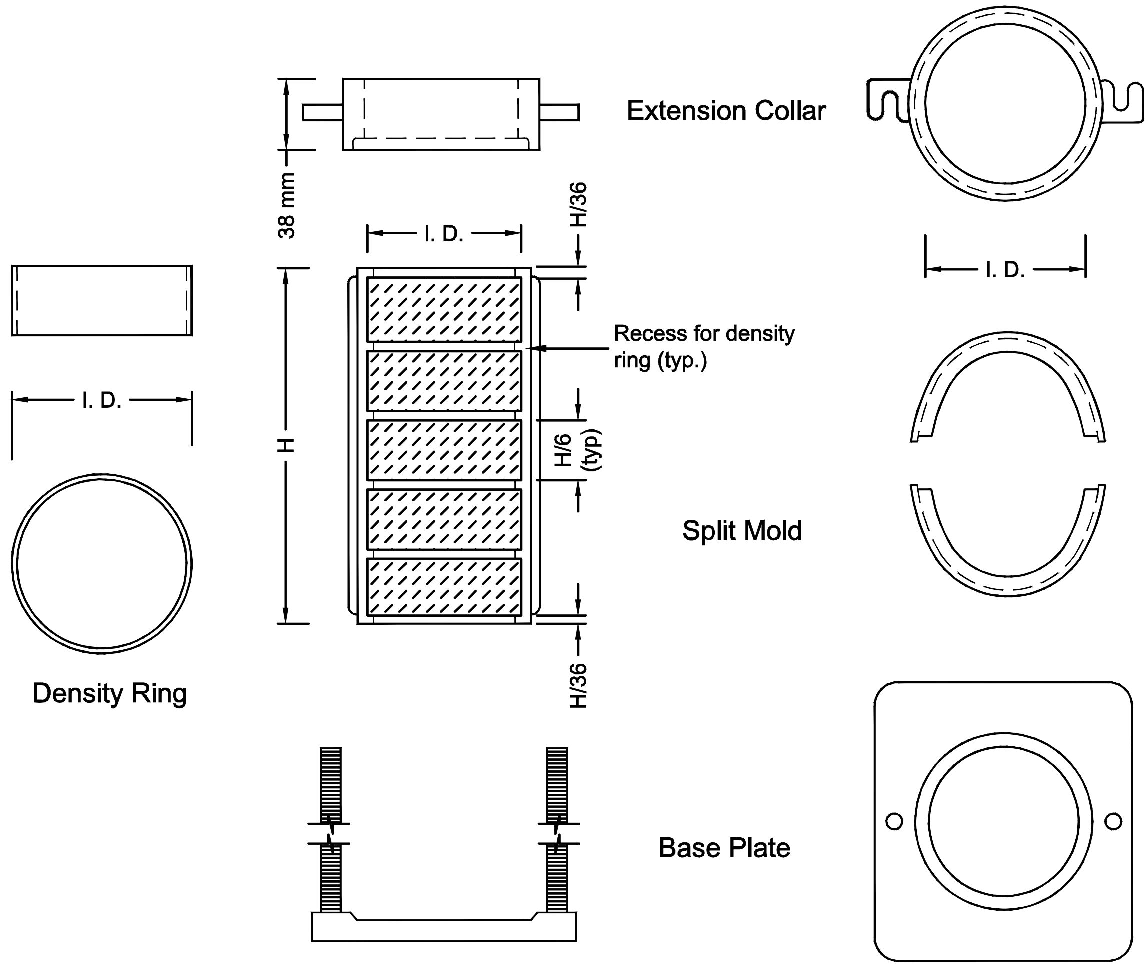
X2.4.6. Using a hacksaw or other abrasive device, carefully cut the specimen into five pieces. Each cut should be made midway between the rings. Screed off each piece to form square ends at the top and bottom of each ring. Small depressions in the screeded surface, caused by removal of larger particles, shall be filled with fines.

X2.4.7. Determine and record the net mass of each numbered piece to the nearest gram. Use a tabular form, as in Figure X2.2, to record the data.

X2.4.8. Determine and record the moisture content of each numbered piece.

X2.4.9. Calculate and record the average bulk (wet) density of the entire specimen, γ_s, and the densities of each of the five pieces, γ_1 to γ_5.

X2.4.10. If the maximum difference between the density of each individual piece and the average density is 1.0 percent or less, report the density gradient as being uniform. If the maximum difference between the density of each individual piece and the average density is more than 1.0 percent, report the density gradient as being nonuniform.



Notes: 1. L = Specimen ht. + Collar ht. – Layer HL + 12 mm
2. Minimum Reservoir Volume = 200 × Compactor Volume
3. Minimum gauge accuracy is 0.5 kPa.
4. Compactor air cylinder is rolling diaphragm type.

Figure X2.1—Density Gradient Mold

PROJECT	

Sample No.		Soil Description	

Target Moisture (%)	Target Density (kg/m^3)		*Air Tamper Foot Pressure (Pa)	

Was Sample Scalped?	Wt Scalped Soil (gm)		Mold Dimensions—diam. × ht. (mm)	

Ring Volume (cm^3)

				Weight (gm)							
Layer Position in Mold	Order of Compaction[a]	Ring No.	No. of Temps per Layer[b]	Ring	Ring + Soil (wet)	Soil (wet)	Soil (dry)	Water	Moisture (%)	Layer Dry Density (kg/m^3)	Percent Difference between Average Density and Layer Density (%)
1 (top)											
2											
3											
4											
5 (bottom)											

Average Layer Density (kg/m^3)	Average Moisture (%)	Percent Difference between Target Density and Average Density (%)	Percent Difference between Target Moisture and Average Moisture (%)

[a] For static compaction, middle layer is usually first. For kneading compaction, bottom layer is first.

[b] Required for kneading compaction (Annex A4).

REMARKS

Figure X2.2—Check for Density Gradient

X2.5. *Procedure for Compacting Test Specimens to Achieve a Uniform Density*:

X2.5.1. Follow the procedure in Sections X2.4.1 through X2.4.9, using either the manual or mechanical kneading compaction procedure (Appendix X1).

Note X7—The requirement in Appendix X1 that the number of tamps per lift be constant is waived. However, it is recommended that the number of tamps per lift be constant for each lift in the first trial specimen in order to establish that a density gradient does exist.

X2.5.2. If the average bulk density differs from the target density by more than the tolerance allowed in Section 7.3.2 or 7.3.3, then the compaction pressure shall be adjusted, holding the number of tamps per lift constant, to increase or decrease the average density toward the target density. Repeat Step X2.5.1.

X2.5.3. After the target average density is achieved, check the density uniformity according to Section X2.4. If the density is nonuniform, hold the compaction pressure constant and adjust the number of tamps per lift until a uniform density gradient is achieved.

Note X8—If a sufficient quantity of material is available, it is preferable to use new material for each subsequent specimen. If the old material is reused it will have an effect on the structure of subsequently compacted specimens.

X2.5.4. Use the compaction pressure and number of tamps per lift thus determined to prepare specimens for resilient modulus testing using the procedure in Appendix X1.

---

[1] Formerly AASHTO Provisional Standard TP 46. First published as a full standard in 1999.