
Standard Method of Test for

Determining the Resilient Modulus of Soils and Aggregate Materials

AASHTO Designation: T 307-99 (2021)¹

Adopted: 1999

Reviewed but Not Updated: 2021

Editorially Revised: 2021

Technical Subcommittee: 1a, Soil and Unbound Recycled Materials



**American Association of State Highway and Transportation Officials
555 12th Street NW, Suite 1000
Washington, DC 20004**

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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 on 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 on the type of material based on 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.
- 1.7. *The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of R 18 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with R 18 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of R 18 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*

- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
- 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)

3. TERMINOLOGY

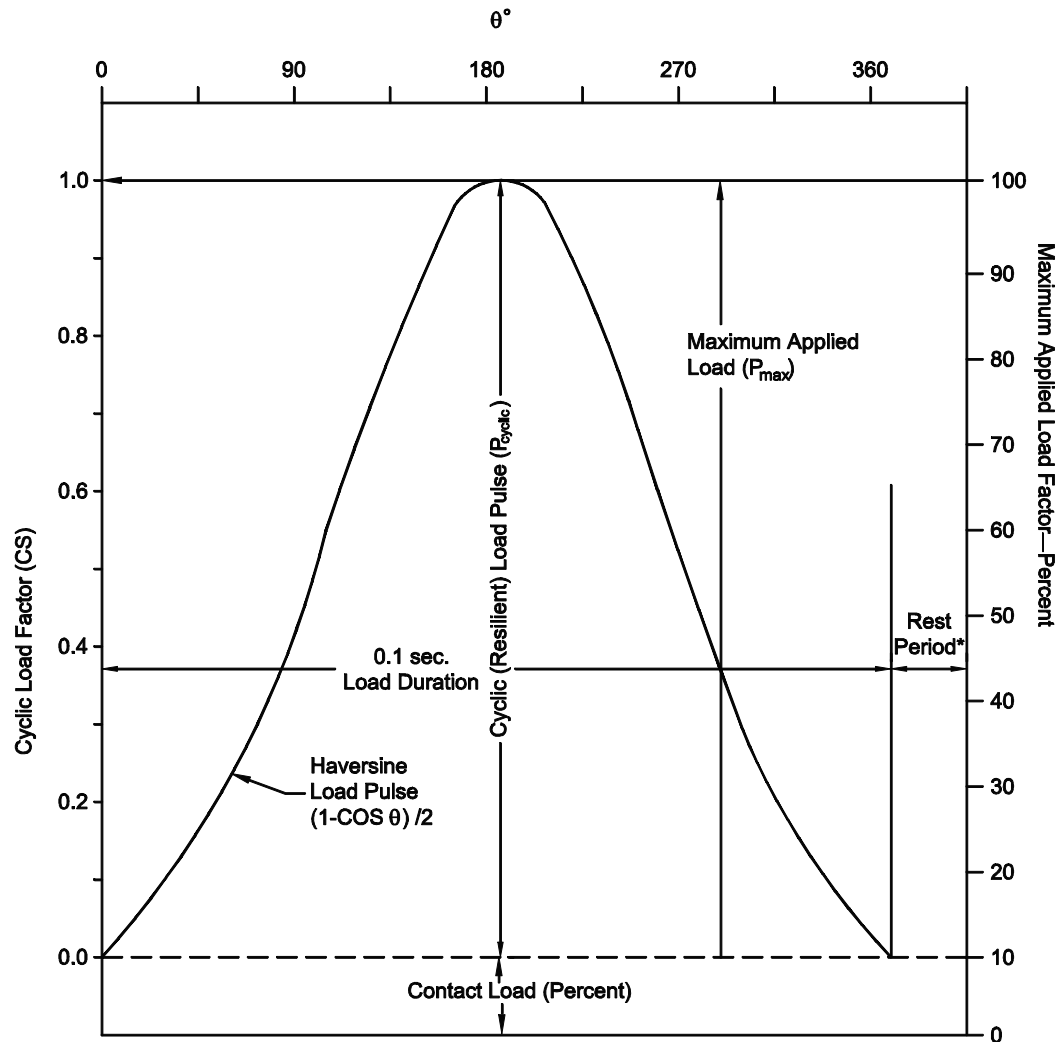
- 3.1. *untreated granular base and subbase materials*—these include soil-aggregate mixtures and naturally occurring materials. No binding or stabilizing agent is used to prepare untreated granular base or subbase layers. These materials may be classified as either Type 1 or Type 2 as subsequently defined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

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

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

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



* The rest period will be 0.9 s for hydraulic loading devices and 0.9 to 3.0 s for pneumatic loading devices.

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

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

- 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.

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

- 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.

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

Also,

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

- 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. ϵ_r is the resilient (recovered) axial strain due to S_{cyclic} .

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

where:

L = original specimen length.

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

- 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

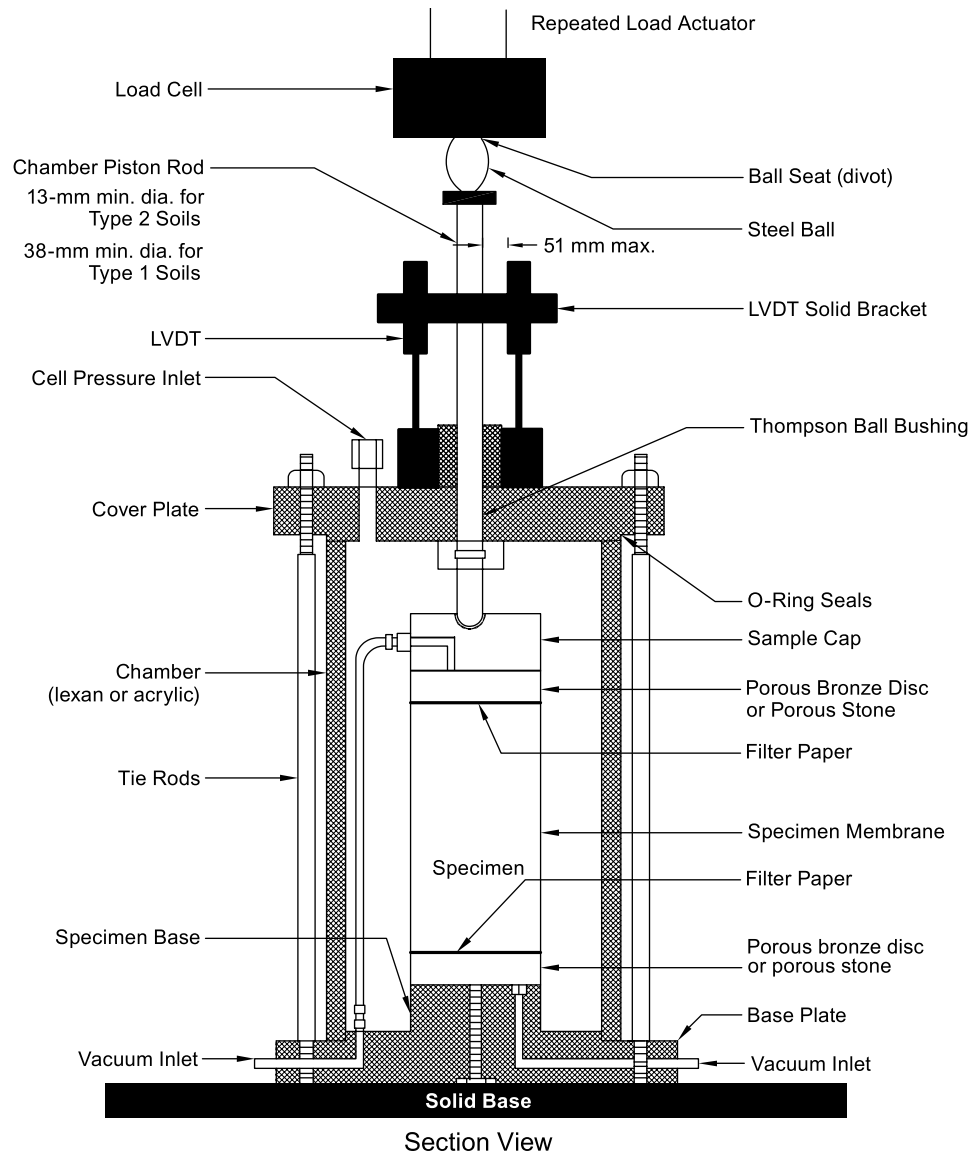
- 4.1. A repeated axial cyclic stress of fixed magnitude, load duration (0.1 s), and cycle duration (1.0 to 3.1 s) is applied to a cylindrical test specimen. During testing, the specimen is subjected to a dynamic cyclic stress and a static-confining stress provided by means of a triaxial pressure chamber. 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. Such material characterization may also be correlated with results from other tests such as T 88, T 89, T 90, T 100, and T 233.

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 External 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_{ws} , 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 $\pm$ 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 No.	Confining Pressure, S_3		Max. Axial Stress, S_{max}		Cyclic Stress, S_{cyclic}		Constant Stress, $0.1S_{max}$		No. of Load Applications
	kPa	psi	kPa	psi	kPa	psi	kPa	psi	
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, 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:
$$F = (A \times P) - W \tag{10}$$
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.