
Standard Method of Test for

Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials

AASHTO Designation: T 292-97 (2000)



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 materials prepared for testing by compaction in the laboratory. Methods of compaction include kneading, impact, static and vibratory.
- 1.3. The values of resilient modulus determined with these procedures can be used to calculate the physical response of pavement structures.
- 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 any such optional information are, however, beyond the scope of this method.
- 1.4. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
 - T 88, Particle Size Analysis 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 296, Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression

3. SUMMARY OF METHOD

- 3.1. A repeated axial deviator stress of fixed magnitude, duration and frequency is applied to an appropriately prepared and conditioned cylindrical test specimen. During and between the dynamic deviator stress applications, specimens are subjected to a static all-around stress provided by means of a triaxial pressure chamber. The resilient (recoverable) axial strain response of the specimen is measured and is used to calculate the M_r .

4. SIGNIFICANCE AND USE

- 4.1. The resilient modulus test provides a relationship between stress and deformation of pavement construction materials and subgrade soils for use in pavement design and structural analysis of layered pavement systems.
- 4.2. The resilient modulus test provides a means of evaluating subgrade soils and untreated base/subbase materials over a range of stress states.

5. DEFINITIONS

5.1. *Description of Symbols:*

- 5.1.1. S_1 is the total axial stress (major principal stress).
- 5.1.2. S_3 (minor principal stress) and S_2 (intermediate principal stress) are assumed equal and are the total radial stress; that is, the applied confining pressure in the triaxial chamber.
- Note 2**—For tests which involve measurement of pore pressures of saturated specimens, the principal stresses referred to in this section are actually effective principal stresses, that is, the principal stress minus the back pressure.

- 5.1.3. $S_d = S_1 - S_3$ is the deviator stress, i.e., the repeated axial stress.

- 5.1.4. E_1 is the total axial strain due to S_d .

- 5.1.5. E_r is the resilient (recoverable) axial strain due to S_d .

- 5.1.6. $M_r = S_d/E_r$ is the resilient modulus.

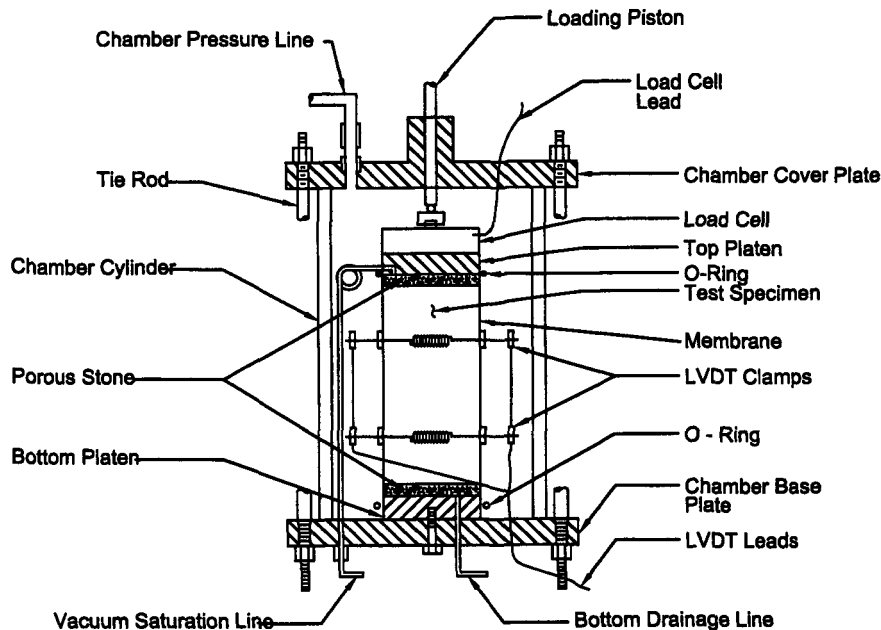
5.2. *Terminology:*

- 5.2.1. Load duration is the time interval the specimen is subjected to a deviator stress.
- 5.2.2. Cycle duration is the time interval between successive applications of a deviator stress.

- 5.2.3. Shear strength is the maximum resistance of a material to shearing stresses. When required for this procedure it is determined from the results of T 296.
- 5.2.4. Critical stress ratio is the numeric value of the principal stress ratio, S_1/S_3 , at which failure of a test specimen occurs. For tests involving measurement of pore pressures of saturated specimens, this is actually an effective critical stress ratio.
- 5.2.5. Viscoelasticity is the property of materials whose strain is at least partly dependent on time and magnitude of stress.
- 5.2.6. For purposes of this method specimens or soils will be designated granular or cohesive as follows:
- 5.2.6.1. Granular specimens or soils are those which meet the criteria of the AASHTO Soil Classification System group or subgroup Nos. A-1, A-2-4, A-2-5 and A-3. Materials that meet criteria of groups A-4 and A-5 and have a maximum plasticity index of 6 shall be considered granular.
- 5.2.6.2. Cohesive specimens or soils are those which meet the criteria of the AASHTO Soil Classification System group nos. A-2-6, A-2-7, A-6 and A-7. Materials that meet the criteria of group Nos. A-4 and A-5 and have a plasticity index greater than 6 shall be considered cohesive.
- Note 3**—Cohesive and granular designations used in this test method differ from those of M 145 and are made with regard to the material's potential for viscoelastic behavior. Materials of Section 5.2.6.2 are considered viscoelastic while those of Section 5.2.6.1 are not.
- 5.2.7. "Base/subbase" refers to the untreated layer or layers of specified materials placed between the concrete or asphalt pavement and the subgrade. It should be noted that different agencies may use the terms "base" or "subbase" in reference to the same material used in the same pavement layer. Other agencies may, however, apply these terms to different materials used in separate pavement layers.
- 5.2.8. "Subgrade" refers to the natural foundation or embankment soil, which has been prepared to support a pavement system.

6. APPARATUS

- 6.1. **Triaxial Pressure Chamber**—The pressure chamber is used to contain the specimen and confining fluid during the test. A triaxial chamber suitable for resilience testing of soils is shown in Figure 1.



Note: Internal LVDT mounting position shown. External mounting may be necessary. See Section 6.

Figure 1—Triaxial Chamber with Internal LVDTs and Load Cell

- 6.1.1. The chamber may require additional outlets for electrical leads if internal electric measuring devices are used.
- 6.1.2. The chamber must be of sufficient size to accommodate the specimen and possible internally mounted axial deformation measurement devices.
- 6.1.3. Air is used as the chamber confining fluid to avoid detrimental effects of water on electronic measuring equipment.
- 6.2. **Loading Device**—The external loading source may be any device capable of providing varying repeated loads in fixed cycles of load and release.
- 6.2.1. The loading device shall be capable of producing fixed load durations of 0.1, 0.15, 1.0 and preferably 0.05 seconds and a fixed cycle duration of between 1.0 and 3.0 seconds.
- 6.2.2. Load wave forms of approximate haversine, rectangular or triangular shapes may be used.
- 6.3. **Specimen Axial Deformation Measuring Equipment**—Two linear variable differential transformers (LVDT) are used to monitor specimen deformation. Recommended specifications for LVDTs are given in Table 1.

Table 1—Recommended Response Characteristics for Data Acquisition Devices**Analog Recorders**

Recording Speeds: 5 to 500 mm/s (0.2 to 20 in./s)

System Accuracy (include linearity and hysteresis): 0.5 percent^a

Frequency Response: 100 Hz

Characteristics	Measurement Transducers	
	Load Cell	LVDT ^b
Minimum Sensitivity, mv/v	2	0.2 mv/0.25 mm/v (AC LVDT) 5 mv/0.25 mm/v (DC LVDT)
Nonlinearity, percent FS	0.25	0.25
Hysteresis, percent FS	0.25	0.0
Repeatability, percent FS	0.10	0.01
Thermal effects on zero shift or sensitivity, percent FS/F(C)	0.005 (0.025)	
Maximum deflection at full rated load, mm (in.)	0.125 (0.005)	
Maximum capacity/Minimum Range, kg/mm (lb/in.)		
Specimen Diameter, mm (in.):		
71 (2.8)	135 (300)	± 5 (0.2)
102 (4.0)	270 (600)	± 7 (0.24)
152 (6.0)	680 (1500)	± 13 (0.50)

^a System frequency response, sensitivity, and linearity are functions of the electronic system interfacing, the performance of the signal conditioning system used and other factors. It is therefore a necessity to check and calibrate the above parameters as a total system and not on a component basis.

^b LVDTs, unlike strain gages, cannot be supplied with meaningful calibration data. System sensitivity is a function of excitation frequency, cable loading, amplifier phase characteristics, and other factors. It is necessary to calibrate each LVDT-cable-instrument system after installation using a known input standard.

- 6.3.1. The LVDTs are mounted 180° diametrically opposed about the specimen's axis. The preferred mounting location is on the specimen by use of clamps (see Figure 2). If the specimen is soft enough to be damaged by clamps, if slippage of clamps is suspected or if internal mounting of LVDTs is not possible, LVDTs may be mounted on the loading piston. External mounting will require that deflections occurring to the test equipment under dynamic loading be accounted for in the calculations.
- 6.3.2. It is recommended that the LVDTs have a range between two percent and 10 percent of the specimen height if externally mounted and between one percent and five percent of the distance between the clamps if internally mounted.
- 6.3.3. If the test system includes computer data storage hardware, signals from each LVDT may be stored individually. If data is recorded by a two-channel strip chart recorder, LVDTs should be wired so that the average signal is recorded.

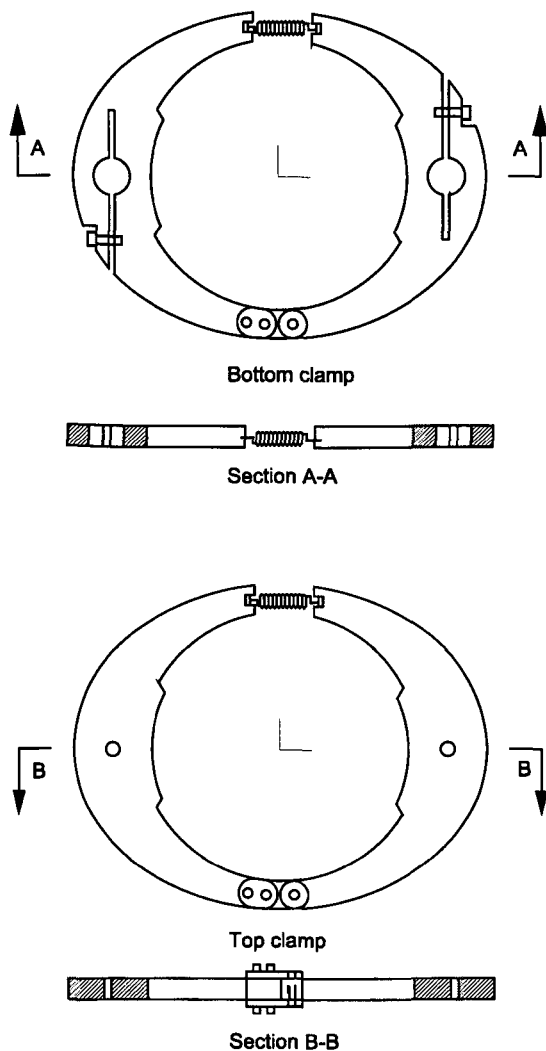


Figure 2—LVDT Clamp Detail

- 6.4. *Specimen Axial Load Measurement Device*—An electronic load cell is used to monitor the repeated load. Recommended specifications for load cells are given in Table 1.
- 6.4.1. The preferred location of the load cell is on top of the specimen cap. Load cells may be mounted outside the test chamber provided that corrections are made for any dynamic friction between the loading piston and test chamber.
- 6.5. *Data Acquisition*—It is necessary to maintain suitable signal excitation and conditioning and to have recording equipment and measuring devices for simultaneous measurement and recording of axial load and deformations. No data acquisition equipment will contain filters that may attenuate signals.
- 6.5.1. Recording systems may include high-speed strip chart recorders or computer data storage hardware. Recommended response characteristics for strip chart recorders are given in Table 1.
- 6.6. *Calibration*—LVDTs and load cells should be calibrated at the start of every test program and weekly thereafter. If the system's calibration record indicates consistency, periods between

calibrations may be extended but shall not exceed 30 days. Calibration may be accomplished by use of a high quality load ring and dial gage mounted in the test system as shown in Figure 3. Dial gage readings are compared to the deflections measured by the LVDTs. The loads generated by the test system are calculated using the load ring's force-displacement relationship and are compared to the load cell's output.

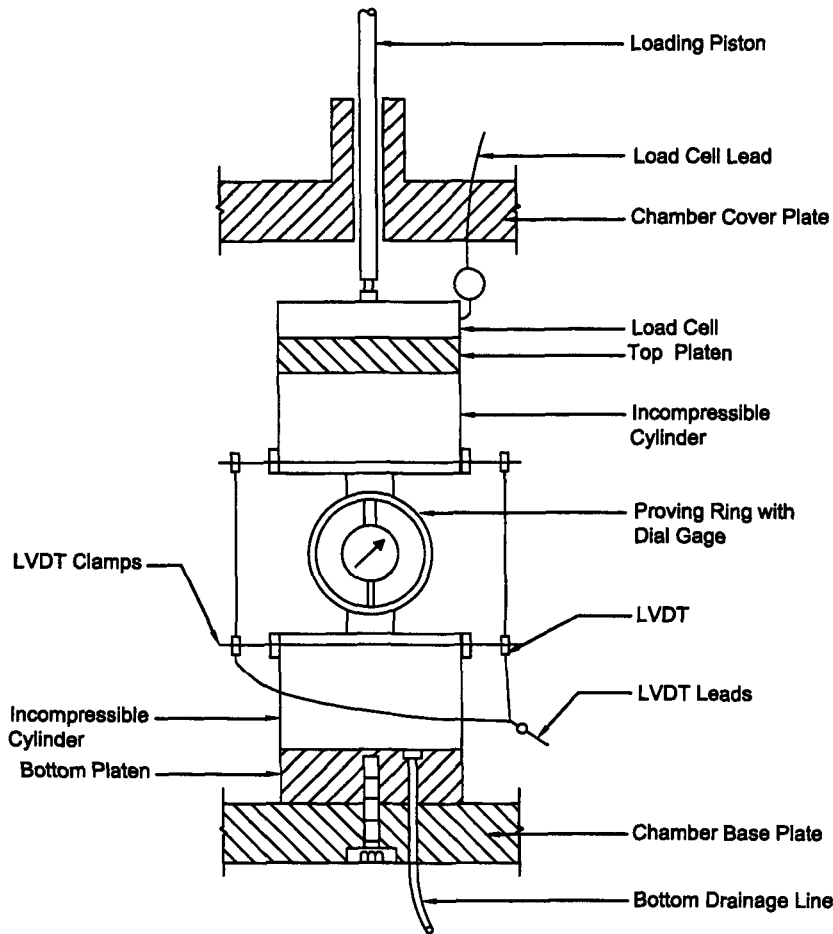


Figure 3—Proving Ring Calibration System

Note 4—To reduce inter-laboratory variation in test results the entire test system, including data acquisition equipment, may be calibrated after independent calibration of the load cell and LVDTs. This is accomplished by testing synthetic specimens to determine if the system can reproduce known moduli. It is recommended that at least five system calibrations be performed and the mean and coefficient of variation (CV) be calculated. The mean should not differ more than ± 5 percent of the specimen modulus and the CV should not be greater than five. Calibration of the entire system should be done considering that some synthetic specimen materials are sensitive to temperature and load duration.

- 6.7. *Test Chamber Pressure Measurement and Control Devices*—Chamber pressure is adjusted by a pressure regulator with a capacity of at least 207 kPa (30 psi) and capability of control to 1 kPa (0.1 psi). Chamber pressure is monitored by conventional gages or pressure transducers. A range of at least 207 kPa (30 psi) and accuracy of 1 kPa (0.1 psi) are required.

- 6.8. *Specimen Preparation Equipment:*
- 6.8.1. Equipment for trimming specimens from undisturbed samples is as described in T 296. Alternate trimming methods and equipment may be used provided they do not cause increased specimen disturbance.
- 6.8.2. Equipment for impact compaction is as described in T 99 or T 180.
- 6.8.3. Apparatus for kneading compaction is as described in T 190, or other apparatus, which utilize kneading methods of compaction.
- 6.8.4. Apparatus for static compaction. A typical mold is shown in Figure 7.
- 6.8.5. Split mold and hand-held air-operated vibratory compactor as shown in Figure 8.
- 6.9. *Rubber Membranes*—The rubber membrane used to encase the specimen shall provide reliable protection against leakage. Membranes shall be carefully inspected prior to use, and if any flaws or pinholes are evident, the membrane shall be discarded. In order to offer minimum restraint to the specimen, the unstretched membrane diameter shall be between 90 and 95 percent of the specimen. The membrane thickness shall not exceed 1 percent of the diameter of the specimen. The membrane shall be sealed to the base and cap by any method that will produce a positive seal.
- Note 5**—If the specimen contains angular material, application of two membranes may be necessary to prevent leakage. For these specimens the total membrane thickness shall not exceed 2 percent of the specimen diameter.
- 6.10. *Miscellaneous Apparatus*—This includes calipers, micrometer gage, steel rule (calibrated to 0.5 mm (0.02 in.)), rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones, scales, moisture content cans, and data sheets as required.

7. PREPARATION OF TEST SPECIMENS

- 7.1. *Specimen Size*—Specimen length should not be less than two times the diameter. Minimum specimen diameter is 71 mm (2.8 in.).
- 7.2. *Maximum Particle Size*—For laboratory compacted specimens, a minimum of 90 percent, by mass, of the material used to prepare the specimen shall have a maximum particle size finer than $\frac{1}{6}$ the specimen's diameter. The maximum particle size of the remaining material shall be no larger than $\frac{1}{4}$ of the specimen's diameter. T 88 is used with the appropriate U.S. Standard sieves to determine if the material meets these criteria.
- 7.3. *Undisturbed Specimens*—Undisturbed specimens are trimmed and prepared as described in T 296. Alternate methods may be used provided that they do not cause increased specimen disturbance.
- 7.4. *Preparation of Soil for Laboratory Compacted Specimens*—The following procedure is used to prepare soil samples for laboratory compaction.
- 7.4.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of drying apparatus such that the temperature does not exceed 60°C (140°F). Thoroughly pulverize the aggregations in such a manner as to avoid reducing the natural size of individual particles.

- 7.4.2. Sieve an adequate quantity of the pulverized soil using an appropriate sieve size to meet the maximum particle size criteria of Section 7.2. Discard any coarse material retained on the sieve. Note the sieve size and if material was discarded on the appropriate calculation form.
- 7.4.3. Determine the moisture content (w_1) of the material dried in Section 7.4.1. The moisture sample shall have a mass no less than 200 g (0.44 lb) for soils with a maximum particle size which passes the U.S. Standard Sieve Series 4.75-mm (No. 4) sieve, and no less than 500 g (1.10 lb) for soils with a maximum particle size which is retained on a 4.75-mm U.S. Standard Sieve.
- 7.4.4. Determine the volume (V) of the specimen to be prepared. For other than static methods, the height of the compacted specimen must be slightly greater than that required for resilience testing to allow for trimming of the specimen ends. An excess of 13 mm (0.5 in.) is generally adequate for this purpose.
- 7.4.5. Determine the mass of oven-dry soil solids M_s and water M_c required to obtain the desired dry density Y_d and water content w_c as follows:

$$M_s \text{ (kg)} = Y_d \text{ (kg/m}^3\text{)} \times V \text{ (m}^3\text{)}$$

$$M_c \text{ (kg)} = M_s \text{ (kg)} \times w_c \text{ (percent/100)}$$
OR

$$M_s \text{ (lb)} = Y_d \text{ (lb/ft}^3\text{)} \times V \text{ (ft}^3\text{)}$$

$$M_c \text{ (lb)} = M_s \text{ (lb)} \times w_c \text{ (percent/100)}$$
- 7.4.6. Determine the mass of air-dried soil (M_{ad}) required to obtain M_s . An additional amount (M_{as}) of at least 500 g should be allowed to provide material for the determination of water content at the time of compaction.

$$M_{ad} \text{ (g)} = (M_{as} + M_s) \times (1 + (w_1/100))$$
- 7.4.7. Determine the mass of water (M_{aw}) required to increase the existing water content to the desired compaction water content (w_c).

$$M_{aw} \text{ (g)} = (M_s + M_{ad}) \times ((w_c - w_1)/100)$$
- 7.4.8. Determine the wet mass of soil (M_t) to be compacted.

$$M_t \text{ (g)} = M_s \times (1 + w_c/100)$$
- 7.4.9. Place the mass of soil (M_{ad}) determined in Section 7.4.6 into a mixing container.
- 7.4.10. Add the water (M_{aw}) to the soil in small amounts and mix thoroughly after each addition.
- 7.4.11. Place the mixture and container in a plastic bag. Seal the bag and store it in an atmosphere of at least 75 percent relative humidity for 24 hours. Ensure a complete seal by using two or more bags.
- 7.4.12. After the storage period, determine the mass of the wet soil and container to the nearest gram and record this value on the appropriate forms as shown in Figures 4 and 5.