Designation: D7369 − 20

Standard Test Method for Determining the Resilient Modulus of Asphalt Mixtures by Indirect Tension Test[1]

This standard is issued under the fixed designation D7369; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for preparing and testing laboratory-fabricated or field-recovered cores of asphalt mixtures to determine resilient modulus values using a repeated-load indirect tension test.

1.2 The values stated in SI units are regarded as the standard. Values in parentheses are for informational use.

1.3 A precision and bias statement for this standard has not been developed at this time. Therefore, this standard should not be used for acceptance or rejection of a material for purchasing purposes.

1.4 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D8 Terminology Relating to Materials for Roads and Pavements
D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials
D6925 Test Method for Preparation and Determination of the Relative Density of Asphalt Mix Specimens by Means of the Superpave Gyratory Compactor
D6926 Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus
D6931 Test Method for Indirect Tensile (IDT) Strength of Asphalt Mixtures

2.2 *Other Document:*

NCHRP Project 1-28A Research Results Digest Number 285—Laboratory Determination of Resilient Modulus for Flexible Pavement Design, January 2004

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology D8.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *contact load ($P_{contact}$), n*—the vertical load placed on the specimen to maintain a positive contact between the loading strip and the specimen. The suggested contact load is 8 % of the maximum load (0.08 P_{max}). The contact load should be not less than 22.2 N (5 lb) and no more than 89.0 N (20 lb).

3.2.2 *core, n*—an intact cylindrical specimen of pavement material, which is removed from the pavement by drilling and sampling at the designated location. A core may consist of or include one, two, or more than two different layers.

3.2.3 *cyclic load (resilient vertical load, P_{cyclic}), n*—load applied to a specimen, which is directly used to calculate resilient modulus.

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

3.2.4 *haversine-shaped load form, n*—the required load pulse for the resilient modulus test. The load pulse is in the form (1-cos θ)/2 with the cyclic load varying from the contact load ($P_{contact}$) to the maximum load (P_{max}).

3.2.5 *instantaneous resilient modulus, n*—determined from the deformation-time plots (both horizontal and vertical) as described in Section 10.

3.2.6 *lift, n*—that part of the pavement produced with similar material and placed with similar equipment and techniques. The lift thickness is the thickness of the compacted

[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.26 on Fundamental/Mechanistic Tests.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

asphalt mixture that is achieved with one pass of the laydown machine and the subsequent compaction process and can be equal to or less than the core thickness or length.

3.2.7 *maximum applied load (P_{max}), n*—the maximum total load applied to the sample, including the contact and cyclic (resilient) loads. A P_{max} load of 400 N (89.9 lb) is suggested for testing.

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

3.2.8 *test specimen, n*—that part of the layer which is used for, or in, the specified test. The thickness of the test specimen can be equal to or less than the layer thickness.

3.2.9 *total deformation, n*—determined from the deformation-time plots (both horizontal and vertical) as described in Section 10.

4. Summary of Test Method

4.1 The repeated-load indirect tension resilient modulus test of asphalt mixtures is conducted through repetitive applications of compressive loads in a haversine waveform. The compressive load is applied along a vertical diametral plane of a cylindrical specimen of asphalt concrete. The resulting horizontal and vertical deformations of the specimen are measured. Values of resilient Poisson's ratio are calculated using recoverable vertical and horizontal deformations. The resilient modulus values are subsequently calculated using the calculated Poisson's ratio. Two separate resilient modulus values are obtained. One, termed *instantaneous* resilient modulus, is calculated using the instantaneous recoverable deformation that occurs during the unloading portion of one load-unload cycle. The other, termed *total* resilient modulus, is calculated using total recoverable deformation which includes both the instantaneous recoverable and the time-dependent continuing recoverable deformation during the unload or rest-period portion of one cycle.

5. Significance and Use

5.1 Resilient modulus can be used in the evaluation of materials quality and as input for pavement design, evaluation, and analysis. With this method, the effects of temperature and load on resilient modulus can also be investigated. This modulus test can be run on pavement cores because of specimen orientation.

NOTE 1—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 Specification D3666 are generally considered capable of competent and objective testing, sampling, inspection, etc. Users of this standard are cautioned that compliance with Specification D3666 alone does not completely ensure reliable results. Reliable results depend on many factors; following the suggestions of Specification D3666 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.

6. Apparatus

6.1 *Testing Machine*—Testing machine shall be a closed-loop, servo-electric, electro-hydraulic, or pneumatic testing machine with a function generator capable of applying a haversine-shaped load pulse over a range of load durations, load levels, and rest periods.

6.2 *Loading Device*—Loading device should be capable of testing 101.6 or 152.4 mm (4 or 6 in.) diameter specimens of thicknesses up to 63.5 mm (2.5 in.). The device should be compact enough to be used within an environmental chamber. It should have a fixed bottom loading plate and a moving upper loading plate. The movement of the upper plate should be guided by two columns, one on each side of the specimen and equidistant from the loading axis and the loading strips, to ensure it has minimal translational or rotational motion during loading of the specimen. The guide columns shall have a near frictionless bearing surface. The surface of the guide columns shall be frequently inspected for any grooves caused due to friction. Alignment of the device within the loading system shall be achieved so that such friction is limited. The upper plate shall be rigid enough to prevent excessive or undue deflection during loading. The loading strips shall be perpendicular to the line connecting the two guide columns, Fig. 1.

6.3 *Temperature-Control System*—The temperature-control system should be capable of maintaining a temperature of 5 to 45 °C (41 to 113 °F) ±1.0 °C (±2 °F). The system shall include a temperature-controlled cabinet large enough to house the loading device and space adequate to precondition specimens at a time prior to testing, as described in 8.3.

6.4 *Measurement and Recording System*—The measurement and recording system shall include sensors for measuring and simultaneously recording horizontal and vertical deformations and loads. The system shall be capable of recording horizontal and vertical deformations in the range of 0.00038 mm (0.000015 in.) of deformation. Load cells shall be accurately calibrated with a resolution of 8.9 N (2 lb) or better.

6.4.1 *Data Acquisition*—The measuring or recording devices must provide real-time deformation and should be capable of monitoring readings on tests conducted to 1 Hz.

FIG. 1 Specimen with Loading Strip Parts

Computer monitoring systems are recommended. The data acquisition system shall be capable of collecting 200 scans per second (a scan includes all deformation and load values at a given point of time). The capability to have real-time plots (simultaneous to the data collection by the computer monitoring system) shall also be provided to check the progress of the test. If strip-chart recorders are used without computer monitoring systems, the plotting scale shall be adjusted such that there is a balance between the scale reduction required as a result of the pen reaction time and the scale amplification needed for purposes of accurate measurement of values from a plot. Actual load values, and not the intended load values, shall be used for calculation purposes and so the data acquisition system shall also be capable of monitoring the load values continuously during testing.

NOTE 2—Tests at multiple frequencies can be done. The frequencies of 0.33 and 0.5 Hz are suggested.

6.4.2 *Deformation Measurement*—Both horizontal and vertical deformation shall be measured on the surface of the specimen by mounting LVDTs between gauge points along the horizontal and vertical diameters. The gauge length can be of three sizes in relation to the diameter of the specimen: ¼ of the diameter or 25.4 mm for a 101.6 mm diameter of the specimen (1 in. for a 4 in.) or 38.1 mm for a 152.4 mm diameter of the specimen (1.5 in. for a 6 in.); ½ of the diameter or 50.8 mm for a 101.6 mm diameter of the specimen (2 in. for a 4 in.) or 76.2 mm for a 152.4 mm diameter of the specimen (3 in. for a 6 in.); and one diameter or 101.6 for a 101.6 mm diameter of the specimen (4 in. for a 4 in.) or 152.4 mm for a 152.4 mm diameter of the specimen (6 in. for a 6 in.). It is required to have the two LVDTs on each face of the specimen, one horizontal and one vertical, resulting in a total of four LVDTs for deformation measurement.

NOTE 3—The results obtained with gauge length of ¼ of the diameter of the specimen have the best precision.

6.4.3 *Load Measurement*—The repetitive loads shall be measured with an electronic load cell with a capacity adequate for the maximum required loading and a sensitivity of 0.5 % of the intended peak load. During period of resilient modulus testing, the load cell shall be monitored and checked once a month with a calibrated proving ring to ensure that the load cell is operating properly. Additionally, the load cell shall be checked at any time that the QC/QA testing with in-house synthetic specimen (see 9.1) indicates a change in the system response or when there is a suspicion of a load cell problem.

6.5 *Loading Strip*—Steel loading strips, with concave sample contact surfaces, machined to the radius of curvature of a 101.60 ± 0.10 mm diameter specimen (4.000 ± 0.004 in.) or 152.40 ± 0.15 mm diameter specimen (6.000 ± 0.006 in.), are required to apply load to the test specimens. The contact areas of the loading strips shall be 12.7 mm (½ in.) and 19 mm (¾ in.) wide, respectively, for the 4 in. specimen and 6 in. specimen. The outer edges of the curved surface shall be filed lightly to remove sharp edges that might cut the specimen during testing. Thin lines should be drawn along the length of the strip at its center to help alignment. Also, appropriate marking should be made so as to center the specimen within the length of the strips. This could be done either by matching the center of specimen with a mark at the center of the strip or by positioning the specimen between two marks at the ends of the specimen thickness, or both.

6.6 *Marking and Alignment Devices:*

6.6.1 The LVDT alignment device should align the horizontal and vertical LVDTs simultaneously on the top and bottom faces of the specimen for gluing. If such a device is not used, then a marking device shall be used to mark mutually perpendicular axes on the top and bottom faces of the specimen through the center. The axes shall be simultaneously marked on the top and bottom faces of the specimen to ensure that the axes on the front and the back lie in a single plane.

6.6.2 An alignment device shall be used to position and place horizontal and vertical supports for gages or LVDTs along the horizontal and vertical diameter of the specimen and hold them there until the glue that holds the supports cures. It shall be easily removable, without disturbing the LVDT (once the glue cures), and shall not be destructively mounted on the specimen. The device shall be capable of mounting the LVDT at a gauge length of one quarter and one half of the diameter of the specimen. The LVDT shall be as close as possible to (but not touching) the surface of the specimen so as to minimize the bulging effect. To ensure uniform test results, a spacing of 5.08 mm (0.2 in.) is recommended. The axis of the LVDT shall not be at a distance greater than 6.35 mm (0.25 in.) from the surface of the specimen. Fig. 2 shows an example of alignment device.

7. Specimens

7.1 *Specimen Size*—Resilient modulus testing shall be conducted on 101.6 ± 3.8 mm (4 in.) or 152.4 ± 9 mm (6 in.) diameter specimens that are 38.1 mm (1.5 in.) to 63.5 mm (2.5 in.) in thickness. The test specimen can be obtained from field coring or from a Marshall-compacted specimen (Practice D6926) or from a gyratory-compacted specimen (Test Method D6925). Depending on the height of the gyratory-compacted specimen and the thickness of the test specimen, two or three specimens can be sawed from a compacted specimen.

7.2 *Core Specimens:*

7.2.1 Cores for test specimen preparation, which may contain one or more testable layers, must have smooth and uniform surfaces and must meet specimen diametric and thickness requirements summarized in 7.1. Cores that are obviously deformed or have any visible cracks must be rejected. Irregular top and bottom surfaces shall be trimmed as necessary, and individual layer specimens shall be obtained by cutting with a diamond saw using water or air as coolant. Additional specimens for each layer must be collected in the field in order to perform the pretest tensile strength.

7.2.2 If a core specimen has more than one layer, the layers shall be separated at the layer interface. Layers containing more than one lift of the same material may be tested as a single specimen. If sample layers de-bond during testing, the results are invalid and shall not be used.

7.2.3 In order to limit non-parallelism of the two flat sides, it is recommended to place the specimen on a level surface and measure the departure from perpendicularity. The displacement

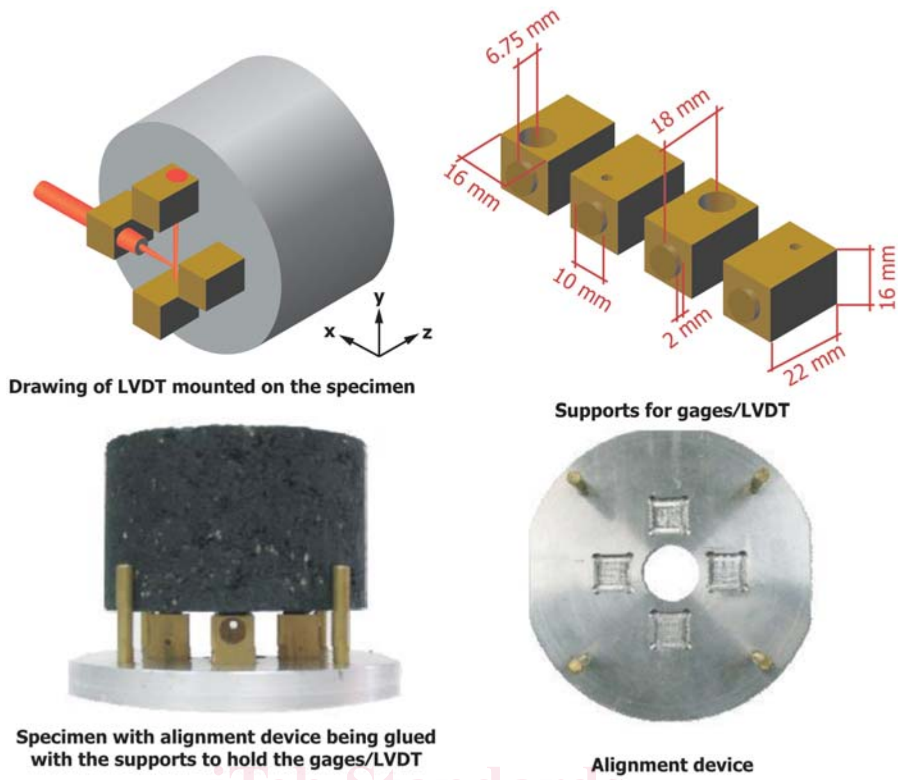

FIG. 2 Marking and Alignment Devices

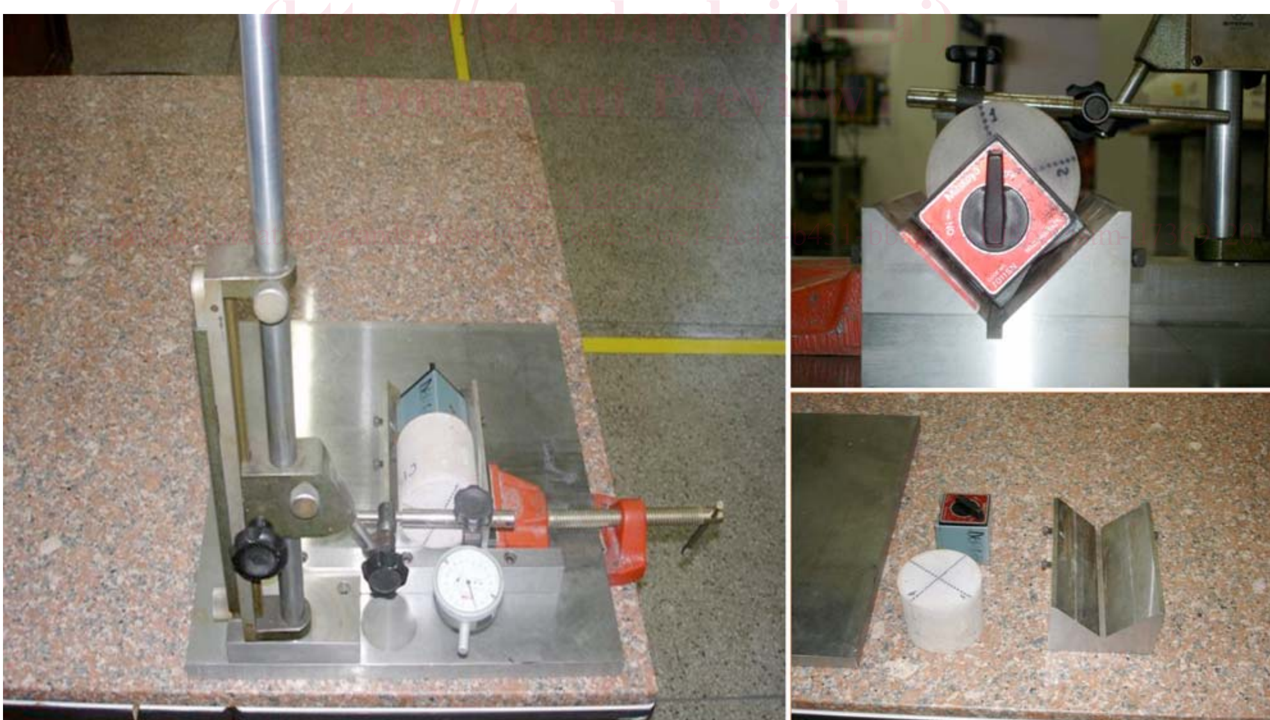

FIG. 3 Device to Measure Non-Parallelism

sensor should have a precision of 0.01 mm (0.0004 in.). The standard deviation of the two parallel surfaces shall be less than 0.56 mm (0.022 in.). The acceptable range of two test results used to determine the thickness of the sample is 2.04 mm (0.08 in.). Fig. 3 shows an example of device to measure non-parallelism.

7.3 *Laboratory-Molded Specimens*—Prepare the laboratory-molded specimens in accordance with acceptable compaction procedures such as Test Method D6925 and Practice D6926. The specimens' sizes must meet the requirements of 7.1.

7.4 *Diametral Axis*—Marking of the diametral axis to be tested shall be done using a suitable marking device as described in 6.6. This diametral axis location can be rotated slightly, if necessary, to avoid contact of the loading strips with abnormally large aggregate particles or surface voids or to avoid the mounting of the vertical LVDT over large surface voids. The second marking will be perpendicular to the first marked diametral axis. These markings are required for mounting horizontal and vertical LVDTs.

7.5 Thickness (*t*) of each test specimen shall be measured to the nearest 0.25 mm (0.01 in.) prior to testing. The thickness shall be determined by averaging four measurements located at ¼ points around the sample perimeter, and 12.7 mm (½ in.) to 25.4 mm (1 in.) in from the specimen edge.

7.6 Diameter (*D*) of each test specimen shall be determined prior to testing to the nearest 0.25 mm (0.01 in.) by averaging diametral measurements. Measure the diameter of the specimen at *(1)* mid-height, and *(2)* perpendicular (90°) to the axis measured in *(1)* above. The two measurements shall be averaged to determine the diameter of the test specimen.

7.7 *Replicates:*

7.7.1 The test procedure is applicable to both laboratory-compacted specimens and field cores. Three test specimens, each with a total thickness equal to 38.1 mm (1.5 in.) or 63.5 mm (2.5 in.), should be tested. It is recommended that both ends of the compacted specimen be sawed to obtain a smooth surface. This will result in three replicates from a given compacted specimen. In the case of field cores, three field specimens are needed from a homogeneous section.

7.7.2 Three test specimens will result in a total of twelve Poisson's ratio and resilient modulus values for both instantaneous and total (four values for each specimen).

7.8 *Specimen Preparation*—For deformation measurement in both the horizontal and vertical directions, mount the gauge points by gluing them to the test specimen. Wait until the gauge points are properly set and the glue is dry before removing the gluing jig. Attach the LVDTs on the two faces of the specimen, arranged as two horizontal and two vertical LVDTs. The electronic measuring system shall be adjusted and gains set as necessary for the four LVDTs. Prior to testing, zero the surface-mounted LVDTs (or extensometers, if used). An initial negative offset might be necessary if high gain is being used or there is a possibility of exceeding the range of voltage otherwise (or both).

8. Procedure

8.1 The procedure involves resilient modulus testing at defined load, loading frequency, and load duration at a temperature of 25 °C (77 °F).

8.1.1 Optionally for investigative purposes, the test series can be performed at different temperatures, for example, 5 °C (41 °F), 15 °C (59 °F), 20 °C (68 °F), and 25 °C (77 °F) at one specific loading frequency for each temperature. P_{max} and $P_{contact}$ would need to be tested and adjusted for the different temperatures.

8.2 *Testing Prerequisites*—Resilient modulus testing shall be conducted after system response has been verified by testing synthetic specimens, as outlined in 9.1.

8.3 *Pretest Tensile Strength*—Prior to performing the resilient modulus test, the indirect tensile strength shall be determined for one test specimen taken from the same layer and as close as possible to the location of the core specimen(s) to be tested for resilient modulus. For laboratory specimens, a sample having the same mix properties will be selected for indirect tensile strength testing. The indirect tensile strength test is performed as a basis for selecting the loading levels for the resilient modulus testing. The test shall be performed in accordance with Test Method D6931.

8.4 *Temperature Control*—The lab-compacted test specimens designated for resilient modulus testing shall be brought to the test temperature 25 ± 1 °C (77 ± 2 °F). Asphalt concrete field cores should also be placed in a controlled-temperature cabinet/chamber and brought to the specified test temperature. Unless the core specimen temperature is monitored in some manner and the actual temperature known, the cores' samples shall remain in the cabinet/chamber at 25 ± 1 °C (77 ± 2 °F) for a minimum of 4 h prior to testing. Inclusion of a dummy sample for temperature verification is also permissible.

8.4.1 If temperatures other than 25 °C are used, more time will be needed to equalize the temperature of the specimens as determined by the dummy specimen.

8.5 *Alignment and Specimen Seating:*

8.5.1 Position the test specimen so that the mid-thickness mark (cross mark for the two diametral axes) on the test specimen is located in the line of action of the actuator shaft or, alternatively, ascertain that the specimen is centered exactly between end markings on loading strips. The diametral markings are then used to ensure that the specimen is aligned from top to bottom loading strips. With the use of a mirror, the back face can be similarly aligned.

8.5.2 The contact surface between the specimen and each loading strip is critical for proper test results. Any projections or depressions in the specimen-to-strip contact surface, which leave the strip in non-contact condition over a length of more than 19.05 mm (0.75 in.) after completion of the load conditioning stage, shall be reason for rotating the test axis or rejecting the specimen. If no suitable replacement specimen is available, reject the specimen and document the situation.

8.6 *Preconditioning*—Preconditioning and testing shall be conducted while the specimen is located in a temperature-controlled cabinet meeting the requirements of 6.3.

8.6.1 Selection of applied loads for preconditioning and testing at the test temperature is based on the indirect tensile strength, determined as specified in Test Method D6931. Tensile stress levels from 10 to 20 % of the tensile strength measured at 25 °C (77 °F) are to be used in conducting the test at temperatures of 25 ± 1 °C (77 ± 2 °F). Specimen contact loads specified in 3.2.1 shall be maintained during testing.

8.6.2 The sequence of resilient modulus testing shall consist of initial testing along the first diametral axis followed by rotating the specimen 90°. The test specimen must be maintained at 25 ± 1 °C (77 ± 2 °F). The computer-generated waveform shall be as closely matched as possible to produce a haversine waveform by adjusting the gains. The number of load applications to be applied for each rotation for preconditioning cycles is 100. However, the minimum number of load applications for a given situation must be such that the resilient modulus deformations are stable (see 8.7). The minimal number of load cycles is that necessary to get five stable cycles, which means less than 1 % change in resilient modulus in five consecutive cycles. When using more preconditioning cycles, the number of preconditioning cycles shall be recorded and the reason documented. Also, if testing has to be stopped for any other reason, sufficient time should be given to the specimen for relaxation before resuming the test.

8.7 *Horizontal and Vertical Deformation*—Both the horizontal and the vertical deformations shall be monitored during preconditioning. If total cumulative vertical deformations greater than 0.025 mm (0.001 in.) occur, the applied load shall be reduced to the minimum value possible and still retain adequate deformations for measurement purposes. If the use of smaller load levels is not adequate for measurement purposes, discontinue preconditioning and generate ten load pulses for resilient modulus determination and so indicate on the test report.

8.8 *Testing*—At the end of preconditioning for each rotation, the resilient modulus testing shall be conducted as specified below:

8.8.1 Record the measured deformation individually from the four deformation measuring devices and the load sensor as soon as preconditioning is over (the load pulses are to be applied continuously through preconditioning and data collection for resilient modulus). The response is only recorded (deformation and load) for the last five loading cycles of the total applied load pulses. One loading cycle consists of one load pulse and a subsequent rest period. The resilient modulus will be calculated and reported for each cycle using the equation in Section 10. After 100 cycles of preconditioning, use the first five consecutive cycles for which the applied load does not exceed the maximum range shown in Table 1.

8.8.2 After the specimen has been tested along the first diametral plane, rotate the specimen 90° and repeat 8.8.1 after a minimum of 3 min of rest time.

8.8.3 After completion of the resilient modulus testing along the two perpendicular diametral planes, indirect tensile strength testing shall be performed at 25 ± 1.0 °C (77 ± 2 °F) in accordance with Test Method D6931. This test is performed to determine the tensile strength of the specific specimen actually used in resilient modulus testing. For this specimen, the loading axis shall be in the same orientation as the initial testing position.

TABLE 1 Maximum Range in Applied Load When Stable Conditions Have Been Reached

Estimated Modulus MPa (psi)	Maximal Range in Load Within Five Cycles
<3447.5 (<500 000)	44.5 N (10 lbf)
<6895 (<1 000 000)	90 N (20 lbf)

9. Quality Control / Quality Assurance (QC/QA)

9.1 Prior to the start of resilient modulus testing each week, the laboratory testing personnel shall perform testing on one or more in-house QC/QA synthetic specimens. The synthetic specimen should be selected for QC/QA to provide a response similar to the expected asphalt concrete specimen response at 25 °C (77 °F). Typically, materials such as polyethylene may be used to verify the system response. The synthetic specimens shall be tested at a temperature of 25 °C (77 °F), at a load time of 0.1 s, and a rest period of 0.9 s on both the axes at a load level expected for the AC samples. Any synthetic material can be used as long as it has a modulus similar to materials typically tested in a given environmental area. Checking the system with a known material or set of materials is the fastest and easiest way to make sure everything is working as expected. However, QC/QA testing shall be done whenever alignment of the loading system may have changed.

9.2 The specimens shall be tested as follows:

9.2.1 The specimen shall be located in a temperature-controlled cabinet meeting the requirements of 6.3 and at a temperature of 25 °C (77 °F). The applied loads for preconditioning and testing for the synthetic specimens are defined below. Use the load necessary to produce a deformation between 1 to 2.5 µm (50 to 100 µin.) on any given synthetic material. Use the above equation, deduced from the equation in 10.4.2, in order to give an estimative of the desired load:

$$\text{Load} = \frac{M_r \text{ of synthetic materials (deformation) (thickness)}}{(I3 - I2)\text{ (Poisson's Ratio)}} \quad (3)$$

9.2.2 The test specimen shall be preconditioned along the proper axis prior to testing by applying a minimum of 100 cycles of the specified haversine-shaped load pulse of 0.1 s duration with a rest period of 0.9 s. The computer-generated waveform shall be closely matched by adjusting gains and preconditioning until both horizontal and vertical deformations are stable and appear to be uniform. Adjust the equipment by tuning to get the best possible simulation of the desired haversine for the load and the desired time interval between loads.

9.2.3 The results from the QC/QA testing shall be stored as a permanent record of the system response to obtain the system fingerprint. This "fingerprint" is a record of the tuned equipment response and its fit to the requested mathematical waveform. If all the synthetic specimens have not been tested for each set of 100 resilient modulus cycles, QC/QA testing shall be performed on the remaining synthetic specimens in order to verify the system response.

9.3 Extensometers, LVDTs, and load cell shall be calibrated as recommended by the manufacturers of the equipment.

10. Calculations

10.1 *Instantaneous Deformation*—It is recommended to perform regression in three portions of deformation curve: the first (designated by "1") indicates the straight portion of the unloaded path; the second ("2") represents the curved portion that connects the unloading path to the recovery portion; and the third ("3") indicates the recovery portion, as illustrated in Fig. 4.

10.1.1 Linear regression in the straight portion of the unloading path between T_1 and T_2 from Fig. 5, related to T_m (displacement peak), T_a, and T_b from Table 2.

$$Y = a + b\,X \tag{4}$$

where:

Y = deformation value,
X = time, and
a, b = regression constants.

10.1.2 Regression in the curved portion that connects the unloading path and the recovery portion to yield the following hyperbolic equation, between T_2 and T_c (40 % rest period) from Table 2.

$$Y = a + \frac{b}{X} \tag{5}$$

where:

Y = deformation value,
X = time, and
a, b = regression constants.

10.1.3 Regression in the recovery portion between 40 and 90 % (recommended range) of the rest period to yield a hyperbolic equation. The recovery portion corresponds to the time from $\{(0.4 \cdot 0.9\ s) + 0.1\} = 0.46$ s until $\{(0.9 \cdot 0.9\ s) + 0.1\} = 0.91$ s, denoted by t_c and t_d, respectively, from Table 2.

$$Y = a + \frac{b}{X} \tag{6}$$

where:

Y = deformation value,
X = time, and
a, b = regression constants.

10.1.4 A tangent should be drawn to this hyperbola at the point corresponding to 55 % (recommended point) of the rest period (t_{55}) that corresponds to time of $\{(0.9 \cdot 0.55) + 0.1\} = 0.595$ s. The intersection of two linear equations is used to determine the time for the instantaneous deformation. The first equation is for the unloading path, which corresponds to half of the loading time (0.1 s · ½) = 0.05 s. This straight line occurs between the peak load time (T_m) plus 0.005 (t_a) and the peak load time + 0.05 s (t_b). The other linear equation is determined from the tangent of the hyperbola in the recovery period. Then the point on the hyperbolic curve corresponding to the time coordinate of the intersection, designated as Point A, is selected to determine the instantaneous deformation, as shown in Fig. 5, by subtracting the deformation on the curve corresponding to time of Point A from the peak deformation. With the definition of the straight portion of unloading path and straight recovery portion, the space between these two lines is the curved portion that connects the unloading path and the recovery portion.

10.2 Time recommendation for resilient displacement calculation:

10.2.1 The time recommendation for resilient displacement is shown in Table 2.

10.3 *Total Deformation*—Determined from the deformation-time plots (both horizontal and vertical) by subtracting the deformation obtained at the end of one load-unload cycle, as determined by taking the average of deformation

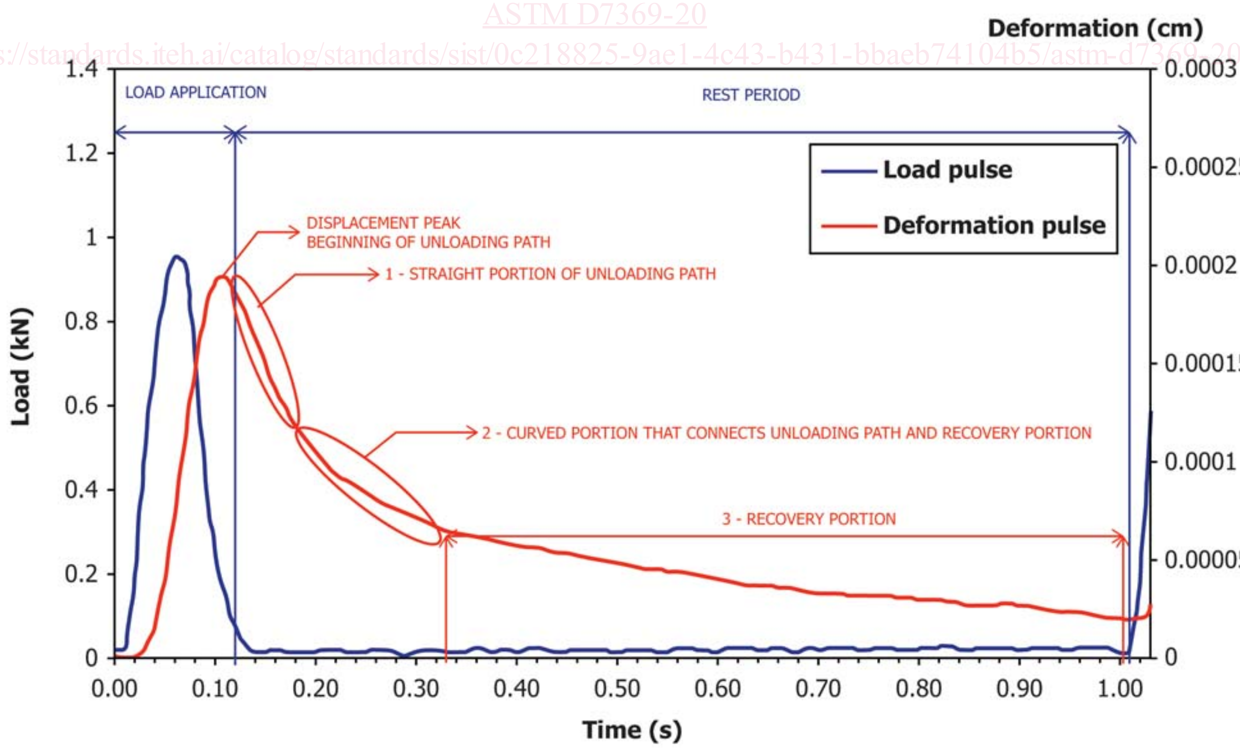

FIG. 4 Regression in Three Portions of Deformation Curve