Designation: D7369 – 11

Standard Test Method for Determining the Resilient Modulus of Bituminous 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 bituminous 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 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D3387 Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine (GTM)

D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials

D4013 Practice for Preparation of Test Specimens of Bituminous Mixtures by Means of Gyratory Shear Compactor (Withdrawn 2013)[3]

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 Bituminous Specimens Using Marshall Apparatus

D6931 Test Method for Indirect Tensile (IDT) Strength of Bituminous 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:*

3.1.1 *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 contact load is 4 % of the maximum load (0.04 P_{max}) and is not less than 22.2 N (5 lb), but not more than 89.0 N (20 lb).

3.1.2 *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.

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

$$P_{cyclic} = P_{max} - P_{contact} \tag{1}$$

3.1.4 *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}).

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

3.1.6 *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 bituminous 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.

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

$$P_{max} = P_{contact} + P_{cyclic} \tag{2}$$

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[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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

3.1.8 *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.

3.1.9 *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 bituminous 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.

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 Practice D3666 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with D3666 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of 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 top loading, closed loop, 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 heights 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. A picture of the loading strip parts is presented in Fig. 1. The loading strips shall be perpendicular to the line connecting the two guide columns.

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 pre-condition at least three 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. 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

FIG. 1 Sample with Loading Strip Parts

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 either done 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 or from a gyratory-compacted specimen. 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:*

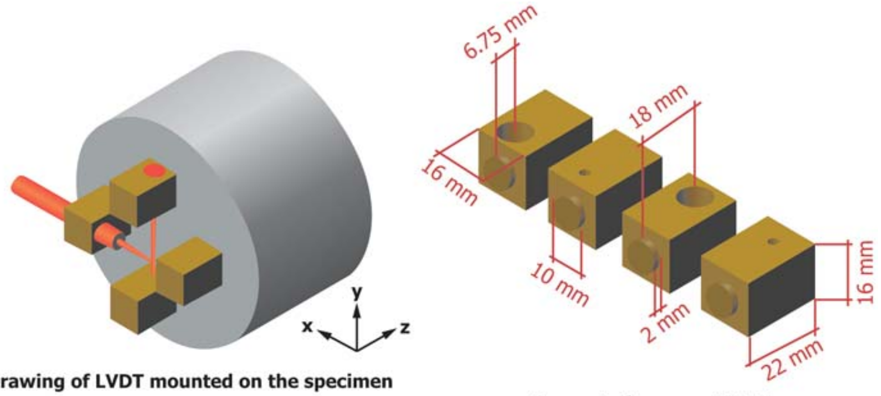
7.2.1 Cores for test specimen preparation, which may contain one or more testable layers, must have smooth and uniform surfaces and must meet specimen diametric and thickness requirements summarized in 7.1. Cores that are obviously deformed or have any visible cracks must be rejected. Irregular top and bottom surfaces shall be trued 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. Traffic direction shall be marked on each layer after cutting, to maintain the correct orientation.

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 measuring the departure from perpendicularity. The displacement 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 Methods D3387, D4013, D6925 and D6926. The specimens size 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



Drawing of LVDT mounted on the specimen

Supports for gages/LVDT

Specimen with alignment device being glued with the supports to hold the gages/LVDT

Alignment device

FIG. 2 Marking and Alignment Devices

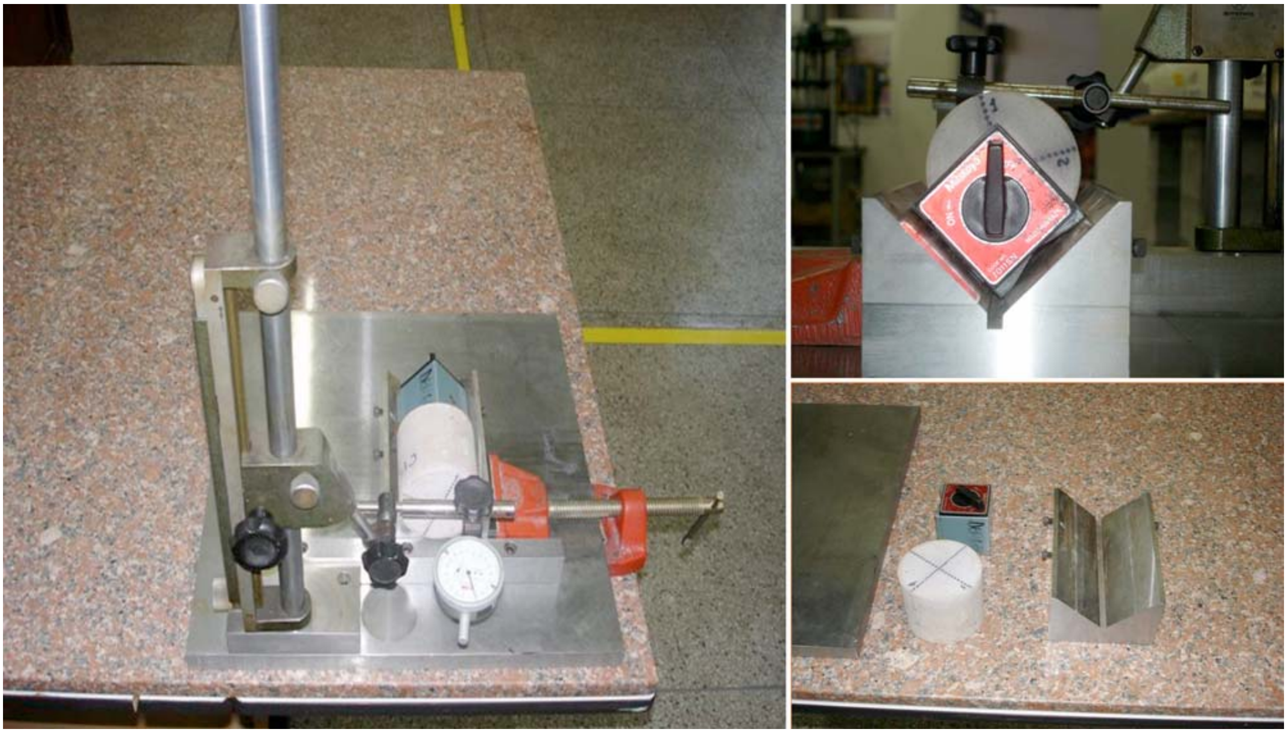


FIG. 3 Device to Measure Non-Parallelism

described in 6.6. The axis shall be parallel to the traffic direction symbol (arrow) marked during the field coring operations. 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 mid-height along *(1)* the axis parallel to the direction of traffic and *(2)* the axis 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 50.8 mm (2.0 in.) can be obtained from a specimen compacted to a height of 127 mm (5 in.) or 178 mm (7 in.) respectively. 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 extensometers and the surface-mounted LVDTs. 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). Optionally, 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.

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. Calculate the indirect tensile strength as follows:

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 6 hours prior to testing. Inclusion of a dummy sample for temperature verification is also permissible.

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 3.1.1 shall be maintained during testing.

8.6.2 The sequence of resilient modulus testing shall consist of initial testing along the first diametral axis (or along the traffic direction for the field cores) followed by rotating the specimen 90°. The test specimen must be maintained at 25°C (77°F). The computer-generated waveform shall be as closely matched as possible to produce a haversine waveform by adjusting the gains. No rest period is required between the initial test and the test performed after rotation. 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 10 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 5 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.

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.

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 second and a rest period of 0.9 second 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.

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

Estimated Modulus MPa (psi)	Maximal Range in Load within 5 Cycles
< 3447.5 (< 500 000)	44.5 N (10 lbf)
< 6895 (< 1 000 000)	90 N (20 lbf)

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 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 10.3.2 in order to give an estimative of the desired load:

$$\text{Load} = \frac{M_R \text{ of synthetic material } (\text{deformation})\,(\text{thickness})}{(I3 - I2)\,(\text{Poisson's ratio}_{\text{synthetic}})} \qquad (3)$$

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 second duration with a rest period of 0.9 second. The computer generated wave form 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, LVDT 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.

$$Y = a + b\,X \qquad (4)$$

where:

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

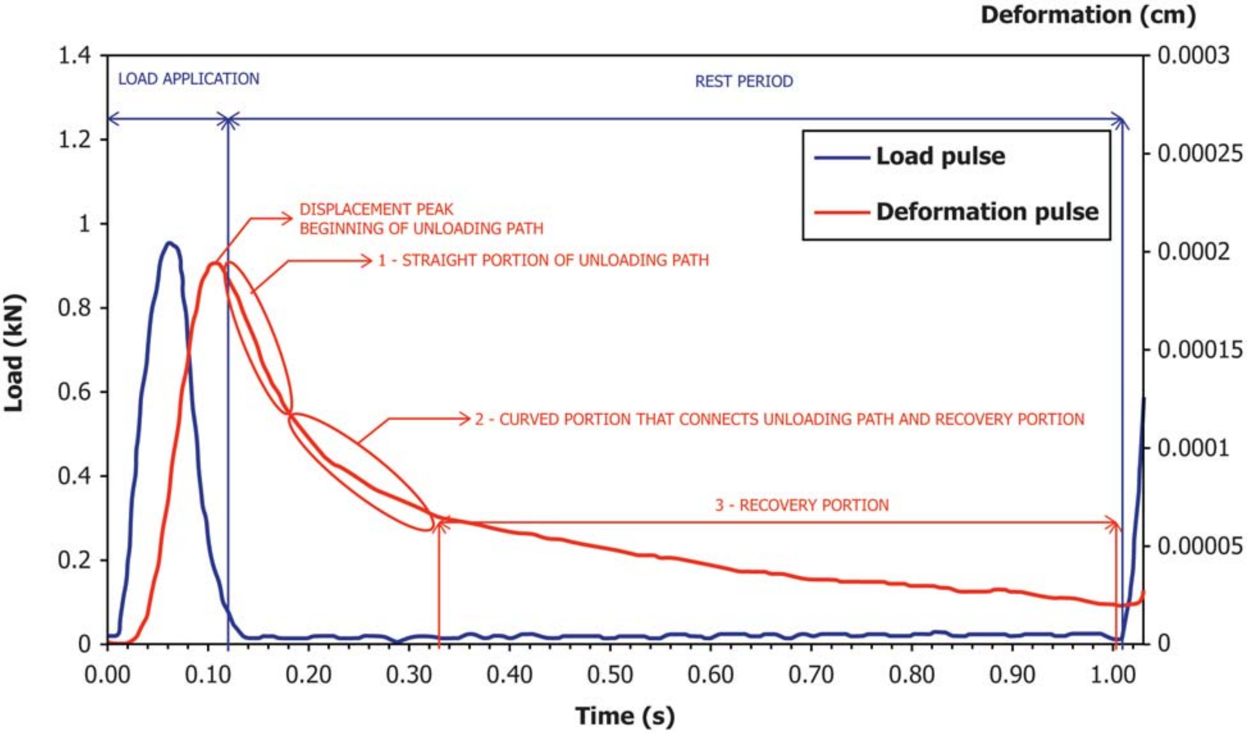


FIG. 4 Regression in Three Portions of Deformation Curve

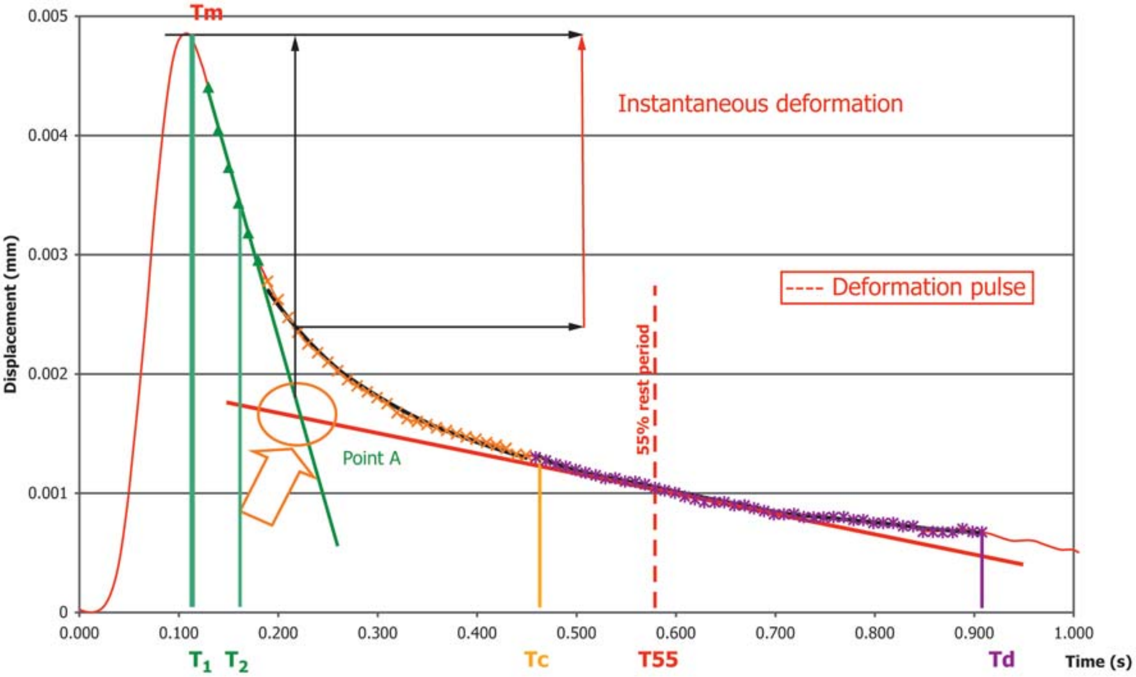


FIG. 5 Determination of Instantaneous Deformation

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

TABLE 2 Constant Values for Resilient Modulus and Poisson's Ratio Calculation

Gauge Length as a Fraction of Diameter Specimen	*I1*	*I2*	*I3*	*I4*
0.25	0.144357	–0.450802	0.155789	–0.488592
0.50	0.233936	–0.780056	0.307445	–1.069463
0.75	0.265925	–0.952670	0.430875	–1.934486
1.00	0.269895	–1.000000	–0.062745	–3.587913

hyperbolic equation. The recovery portion corresponds to the time from $\{(0.4 \cdot 0.9\ \text{s}) + 0.1\} = 0.46$ s until $\{(0.9 \cdot 0.9\ \text{s}) + 0.1\} = 0.91$ 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 ($0.1\ \text{s} \cdot ½$) = 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 *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 values obtained for the time period between 85 % completion and 95 % completion of the rest period from the peak deformation values, as described in Fig. 6. They correspond to the following times $\{(0.9 \cdot 0.85) + 0.1\} = 0.865$ s, and $\{(0.9 \cdot 0.95) + 0.1\} = 0.955$ s, denoted by (t_e) and (t_f) respectively from Table 2, according Fig. 6. This value includes both the instantaneous recoverable deformation and the time-dependent continuing recoverable deformation during the rest period portion of one cycle.

10.3 The following equations are intended for the calculation of either instantaneous or total values, depending on whether instantaneous or total deformation values are used. Consider horizontal deformation as positive and vertical deformation as negative. The load value is assumed to be positive.

10.3.1 *Poisson's Ratio*—Poisson's ratio shall be calculated from the vertical and horizontal deformation values by the use of the following equation. According Zhang et al (1997),[4] if the relation ship between the width of the loading strip and the

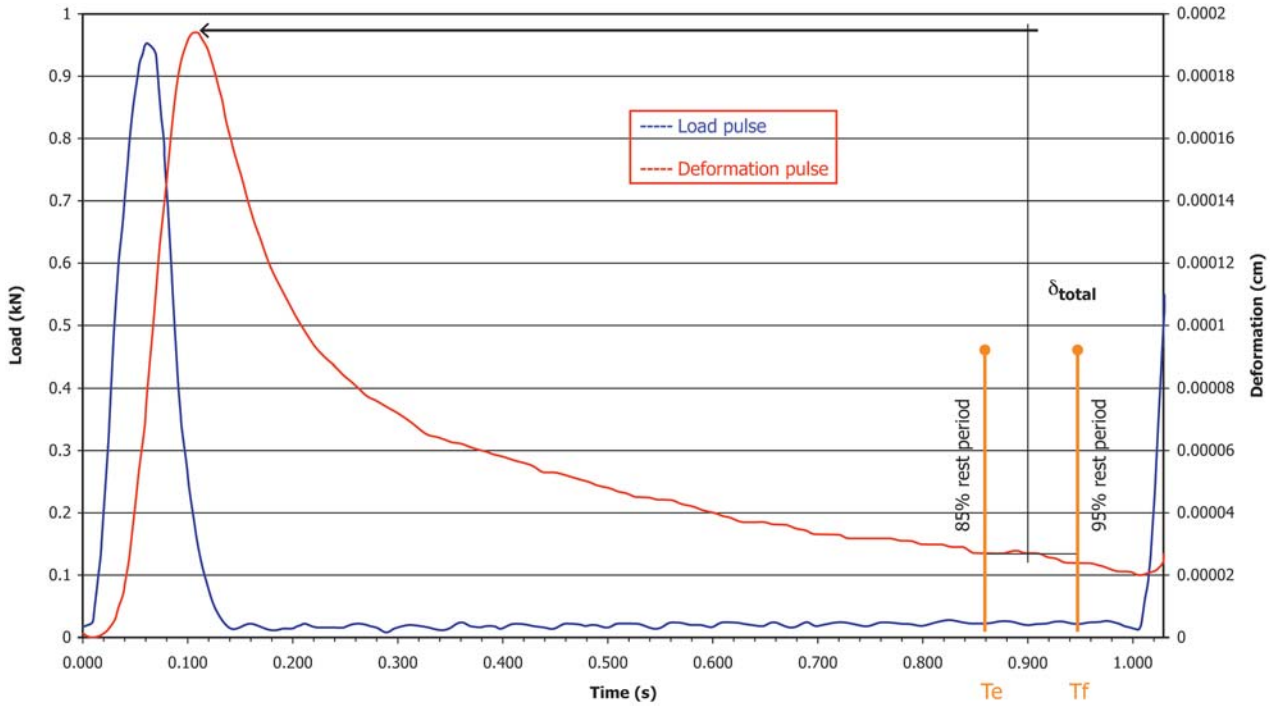


FIG. 6 Determination of Total Deformation

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[4] Zhang, W., Drescher, A., and Newconb, D.E., "Viscoelastic Analysis of Diametral Compression of Asphalt Concrete," *Journal of Engineering Mechanics*, Vol 123 , No. 6, 1997, pp. 596–603.

diameter of specimen is ⅛ the Poisson's ratio will be independent of the diameter of specimen, nevertheless it is dependent of the gauge length in accordance with the constants designed by "*I*1, *I*2, *I*3 and *I*4", presented in Table 2:

$$\mu = \frac{I4 - I1 \times \left(\frac{\delta_v}{\delta_h}\right)}{I3 - I2 \times \left(\frac{\delta_v}{\delta_h}\right)} \qquad (7)$$

where:

μ = instantaneous or total Poisson's ratio,

δ_v = the recoverable (instantaneous or total) vertical deformation measured over the vertical diameter of the specimen, mm (in.), and

δ_h = the recoverable horizontal (instantaneous or total) deformation measured over the horizontal diameter of the specimen, mm (in.).

10.3.1.1 The expected range for the Poisson's ratio is 0.25 to 0.45. When the calculated Poisson's ratio is outside this range, the calculated values shall be reported and a visual inspection of the specimen should be made to study the deformation shape, presence of cracks due to damage, or both, and so reported.

10.3.1.2 The Poisson's ratio must be calculated for each set of LVDTs (horizontal and vertical). That is, for the first diametral plane, two Poisson's ratio values are estimated. These are obtained from the two faces of the specimen. Another set of Poisson's ratio values are obtained after rotation, resulting in a total of four Poisson's ratio values for a single specimen.

10.3.2 *Resilient Modulus*—The resilient modulus can then be calculated from the Poisson's ratio, as obtained from 10.3.1, and the recoverable horizontal deformation (instantaneous or total) according to Zhang (1997):

$$M_R = \frac{P_{cyclic}}{\delta_h t}\left(I1 - I2 \cdot \mu\right) \qquad (8)$$

where:

M_R = instantaneous or total resilient modulus of elasticity, MPa (psi),

δ_h = recoverable horizontal (instantaneous or total) deformation, mm (in.),

μ = instantaneous or total Poisson's ratio,

t = thickness of specimen, mm (in.),

P_{cyclic} = $P_{max} - P_{contact}$ = cyclic load applied to specimen, N (lb),

P_{max} = maximum applied load, N (lb) and

$P_{contact}$ = contact load, N (lb).

10.3.2.1 For each horizontal deformation, the corresponding Poisson's ratio value must be used, resulting in a total of four resilient modulus values (two faces × two axes or rotations) for a single specimen.

10.4 A flow chart for determination of instantaneous deformation is shown in Fig. 7.

NOTE 4—The flow charts presented in 10.4 and 10.5 for determination of instantaneous and total displacement, the typical displacement pulse, presented in 10.5 and time recommendation for resilient displacement calculation, presented in 10.6 were developed by Brito, L., Evaluation and Parametric Analysis of Resilient Modulus of Bituminous Mixtures Using Repeated Load Indirect Tension, Master Thesis in Civil Engineering of Federal University of Rio Grande do Sul, Brazil, 2006 according to NCHRP Research Results Digest, January 2004, No. 285 Project 1-28A.

10.5 A flow chart for determination of total deformation is shown in Fig. 8.

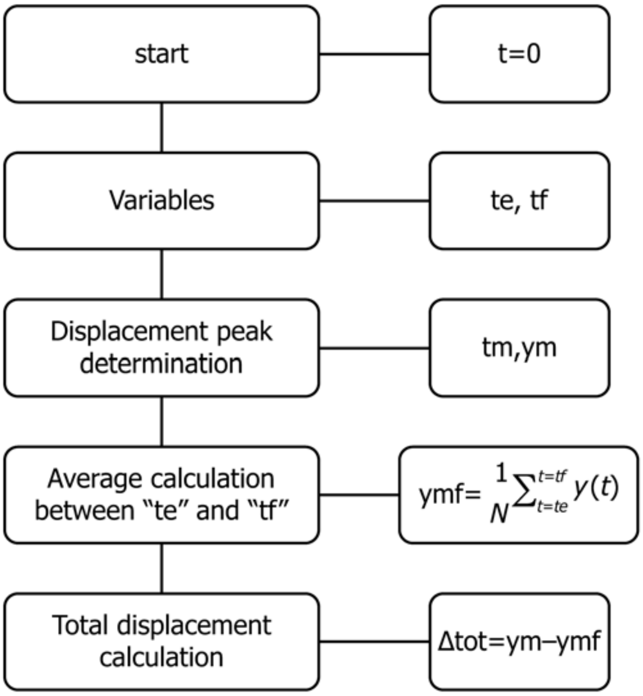

FIG. 7 Flow Chart for Determination of Instantaneous Deformation

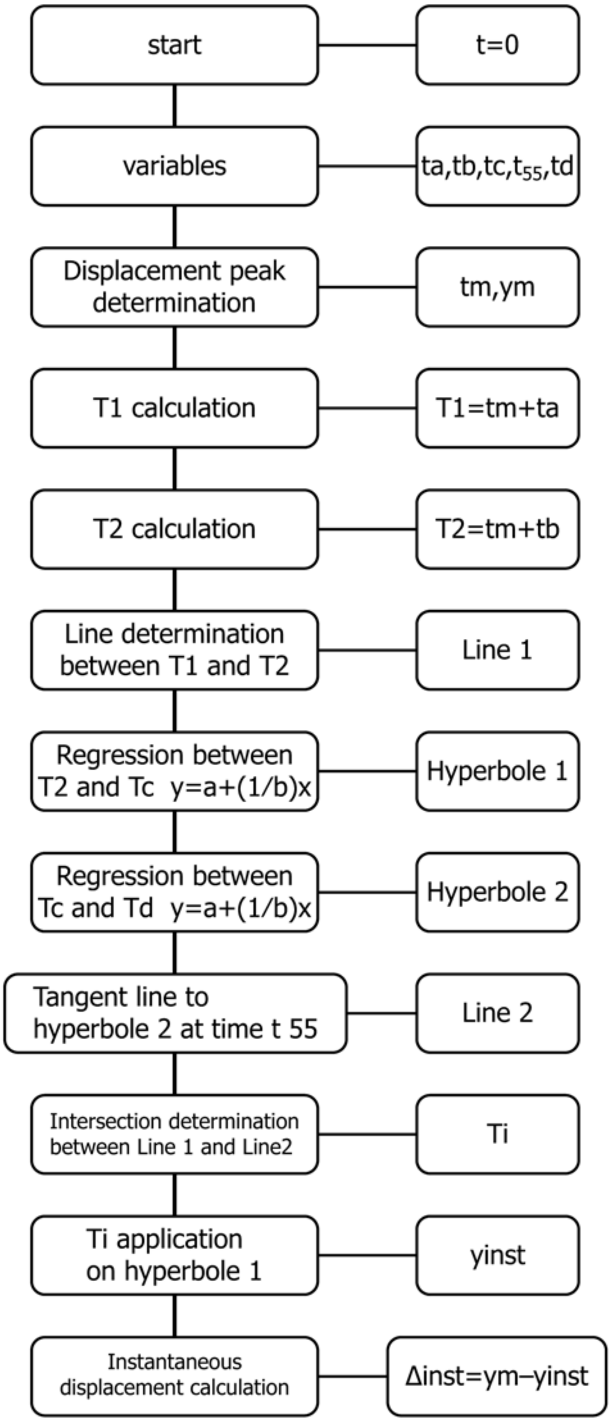

FIG. 8 Flow Chart for Determination of Total Deformation

10.6 Time recommendation for resilient displacement calculation:

10.6.1 The time recommendation for resilient displacement is shown in Table 3.

11. Report

11.1 The following general information shall be recorded:

11.1.1 Sample identification.

TABLE 3 Time Recommendation for Resilient Displacement

NCHRP Research Results Digest January 2004, No. 285 Project 1-28A recommendations		Considering a load pulse of 0.1 s and a rest time of 0.9 s, the total cycle time for curve estimative are	
t_c	40% rest period	t_c	0.46 s
t_d	90% rest period	t_d	0.91 s
t_{55}	55% rest period	t_{55}	0.595 s
t_e	85% rest period	t_e	0.865 s
t_f	95% rest period	t_f	0.955 s
T_1	Tm + Ta	t_a	0.005
T_2	Tm + Tb	t_b	½ $t_{load\ pulse}$ (when $t_{load\ pulse}$ equal to 0,1 s, t_b = 0.05)

11.1.2 Average thickness of the test specimen (*t*), to the nearest 0.254 mm (0.01 in.).

11.1.3 Average diameter of the test specimen (*D*) to the nearest 0.254 mm (0.01 in.).

11.1.4 Indirect tensile strength (initial), to the nearest MPa (psi); from a comparable test specimen used to select the stress (or load) level for the testing.

11.1.5 Indirect tensile strength (final), to the nearest MPa (psi); for the test specimen after resilient modulus test has been completed.

11.1.6 The following (and additional, if so required) comments should be recorded, when relevant:

11.1.6.1 If sawing was required for core specimens.

11.1.6.2 If the specimen was skewed (either end of the specimen departed from perpendicularity to the axis by more than 0.5° or 3.175 mm (1⁄8 in.) in 304.8 mm (12 in.), as observed by placing the specimen on a level surface and measuring the departure from perpendicularity.

11.1.6.3 If a "dummy" specimen was used to monitor the temperature. If not, the time that the specimen was maintained at the test temperature in the environmental chamber.

11.1.6.4 If tests could not be completed due to damage/failure of the test specimen.

11.1.6.5 If the projections/depressions on the test surface were higher or deeper than 1.59 mm (1⁄16 in.) and the specimen was tested because no replacement was available. Record the projections/depressions in such a case.

11.1.6.6 If, for core specimens, no traffic direction was marked, or if the test was not performed on the marked axis for some reason.

11.2 The following information shall be recorded:

11.2.1 Instantaneous resilient modulus for each specimen:

11.2.1.1 The vertical load levels (P_{cyclic}).

11.2.1.2 The contact load ($P_{contact}$) used over the last five loading cycles.

11.2.1.3 Instantaneous recoverable horizontal and vertical deformations measured over the last five cycles.

11.2.1.4 The calculated instantaneous Poisson's ratio (μ_i) over the last five cycles.

11.2.1.5 The calculated instantaneous resilient modulus (M_{ri}) over the last five cycles.

11.2.1.6 The average and standard deviation of calculated instantaneous Poisson's ratio and instantaneous resilient modulus for all the replicates used for a given mix type.

11.2.2 Total resilient modulus for each specimen:

11.2.2.1 The vertical load levels (P_{cyclic}).

11.2.2.2 The contact load ($P_{contact}$) used over the last five loading cycles.

11.2.2.3 Total recoverable horizontal and vertical deformations measured over the last five cycles.

11.2.2.4 The calculated total Poisson's ratio (μ_t) over the last five cycles.

11.2.2.5 The calculated total resilient modulus (M_{rt}) over the last five cycles.

11.2.2.6 The average and standard deviation of calculated total Poisson's ratio and instantaneous resilient modulus for all the replicates used for a given mix type.

11.2.3 A total of 24 results will be obtained, considering three replicates, two faces, two rotations and two times of recovery (Instantaneous or Total).

12. Precision and Bias

12.1 *Precision:*

12.1.1 The within-laboratory repeatability standard deviation has been determined to be 7 %, based on one laboratory, 3 test replicates, and 6 different samples. The between-laboratory reproducibility of this test method is being determined and will be available on or before June 2013. Therefore, this Standard should not be used for acceptance or rejection of a material for purchasing purposes.

12.1.2 For the synthetic specimen selected for QC/QA, two results obtained by the same operator at different times should be considered suspect if they differ by more than 5 %.

12.2 *Bias*—No information can be presented on the bias of this procedure for measuring resilient modulus because no material having an accepted reference value is available.

NOTE 5—The precision of this test method depends on the ability of the personnel who are conducting the test and the capability, calibration and maintenance of the equipment used. Suggested ways of maintaining the testing quality are contained in Specification D3666.

13. Keywords

13.1 indirect tension test; Poisson's ratio; recoverable deformation; resilient modulus

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