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Designation: D8458 − 22

Standard Test Method for Evaluation of Fatigue Performance of Asphalt Mixtures Using the Three-Point Bending Cylinder (3PBC) Test[1]

This standard is issued under the fixed designation D8458; 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 provides a procedure to determine the fatigue life (number of cycles to failure, N_f) of asphalt mixtures, and also the reduction in dynamic modulus (|E*|) with loading cycles, using cylindrical samples subjected to three-point cyclic bending. The results obtained from this test can be used to calibrate Viscoelastic Continuum Damage (VECD) models to obtain a damage characteristic curve, which in turn can be used to obtain fatigue lives (N_f) at a variety of temperatures, strain levels, and frequencies (a separate standard practice is being drafted for this procedure). Even though this test method is intended primarily for displacement (strain) controlled fatigue testing, certain sections may provide useful information for force-controlled tests.

1.2 The test method describes the testing apparatus, instrumentation, specimen fabrication, and analysis procedures required to determine the number of cycles to failure of asphalt concrete.

1.3 The text of this test method 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 test method.

1.4 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this 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

D979/D979M Practice for Sampling Asphalt Mixtures

D3549/D3549M Test Method for Thickness or Height of Compacted Asphalt Mixture Specimens

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

D5361/D5361M Practice for Sampling Compacted Asphalt Mixtures for Laboratory Testing

D6373 Specification for Performance-Graded Asphalt Binder

2.2 *AASHTO Standards:*[3]

R 30 Practice for Mixture Conditioning of Hot Mix Asphalt (HMA)

R 83 Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)

T 378 Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)

M 320 Standard Specification for Performance-Graded Asphalt Binder

M 332 Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test

3. Terminology

3.1 *Definitions:*

3.1.1 *dynamic modulus, |E*|*—the amplitude of the complex modulus that defines the relationship between the stress and strain of viscoelastic materials. The |E*| is simply the peak-to-peak stress divided by peak-to-peak strain in a cyclic test run at a constant frequency.

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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] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

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3.1.2 *initial dynamic modulus,* $|E^*|_0$—initial undamaged dynamic modulus determined at approximately 50 load cycles.

3.1.3 *Poisson's ratio*—the ratio of transverse to longitudinal strains of a loaded specimen.

3.1.4 *Timoshenko beam theory*—the theory which considers the bending and shear effects when subjected to loading, and commonly used in low aspect ratio beams (that is, when length-to-diameter ratio of a beam is <6).

3.2 For definitions of other terms used in this standard, refer to Terminology D8.

4. Summary of Test Method

4.1 A cylindrical specimen is clamped using C-shaped clamps in a three-point bending setup and subjected to sinusoidal actuator displacement-controlled loading with zero mean. While the loading is applied at the central clamp, the side clamps hold the sample in a fixed position. The actuator displacement is set such that the initial strain ranges from 200 to 800×10^{-6} mm/mm. The recommended loading frequency rate is from 5 Hz to 10 Hz. The load and deflection at the central clamp are measured during the entire duration of the test to be later analyzed by Timoshenko beam theory formulations to calculate the change in dynamic modulus ($|E^*|$) per loading cycle.

5. Significance and Use

5.1 This test method can be utilized to determine the fatigue resistance of asphalt mixtures. The test method is generally valid for specimens that are tested at intermediate temperatures. The three-point bending cylinder test samples are obtained by coring a 68 mm diameter cylinder from the center of a 150 mm diameter gyratory compacted sample, or horizontal coring from field cores or slabs cut from field sections. After coring, the sample is ready for testing and no further sample preparations steps are required. The two ends of the 68 mm diameter three-point bending cylinder sample do not need to be sliced.

5.2 The Timoshenko beam theory is used to calculate the reduction in dynamic modulus for each loading cycle. The test can be used to investigate the fatigue behavior of asphalt mixtures at various strain levels, temperatures, and frequencies. The results can be used to compare the fatigue life (N_f) for different asphalt mixtures. The N_f value can be calculated as the 50 % reduction in dynamic modulus. The N_f value is an indicator of fatigue performance of asphalt mixtures containing various mix design properties, asphalt binder types and modifications, gradations, and recycled materials. Typically, a higher N_f value indicates better fatigue performance. The N_f value may be used to identify crack-prone mixtures in performance-based mix design or in construction acceptance procedures, or both.

NOTE 1—The quality of the results produced by this test method 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 test method are cautioned that compliance with Specification D3666 alone does not completely ensure reliable results. Reliable results may 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 *Test System*—The test system consists of a three-point bending cylinder test setup, a load frame capable of providing cyclic load and displacement, an environmental chamber (temperature control system), and closed-loop control and data acquisition system. Fig. 1 illustrates the details of the three-point bending cylinder setup. The side clamps shall hold the asphalt sample fixed with no sliding, rotation, or combination thereof. High-strength steel shall be used in the production of the fixture. The test system's minimum requirements are specified in Table 1.

6.2 *Three-Point Bending Cylinder (3PBC) Test Fixture*—The test fixture is composed of a 175 mm solid base, two fixed 95 mm end supports used to clamp the sample, and a 95 mm central clamp for application of cyclic (zero-mean) vertical load. Supports and loading clamps are composed of two C-shaped pieces, which are screwed together to hold the asphalt sample in place. The lower C-shaped pieces are welded to the base plate. The distance between two supports is 125 mm and the inner diameters of clamps are 68 mm each. Top bars are placed on side clamps to prevent any potential deflection of the side clamps (see Fig. 1). All the parts (except the LVDT holders) are made of high-strength steel to prevent any undesirable deformation during the test. It is noted that dimensional tolerances shown in Fig. 1 are mandatory.

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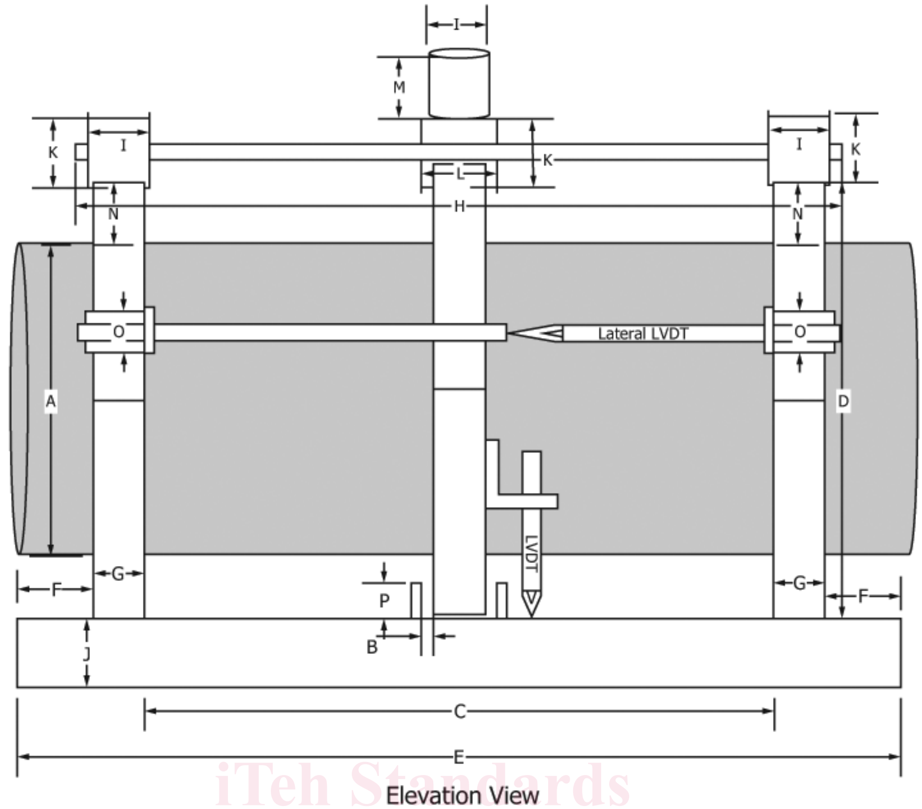
6.3 *Loading Device*—The test system includes a closed-loop, computer-controlled loading component which, during each load cycle in response to commands from the data processing and control component, adjusts and applies a load such that the specimen experiences a constant level of displacement during each loading cycle. The loading device should be capable of providing peak-peak sinusoidal loading with zero mean at a frequency range of 5 Hz to 10 Hz. Fig. 2(a) and Fig. 2(b) show the three-point bending cylinder setup with a mounted specimen in a material testing system and asphalt mixture performance tester, respectively.

6.4 *Environmental Chamber (Temperature Control System)*—The environmental chamber shall enclose the entire specimen and the fixture and maintain the specimen at the desired test temperature within ±0.5 °C throughout the conditioning and testing times. An environmental chamber is not required if the temperature of the surrounding environment can be maintained within the specified limits.

6.4.1 *Control and Data Acquisition System*—During each load cycle, the control and data acquisition system shall be capable of measuring the displacement of the beam specimen, and adjusting the load applied by the loading device such that the specimen experiences a constant level of displacement on each load cycle. In addition, it shall be capable of recording load cycles, applied loads, beam displacements, and temperature while computing and recording the maximum tensile stress, maximum tensile strain, phase angle, and dynamic modulus at load cycle intervals specified by the user.



A	68 ± 0.5 mm	G	10 to 12 mm	M	13 ± 0.5 mm
B	2.5 to 3.5 mm	H	152 ± 0.5 mm	N	13.5 ± 0.5 mm
C	125 ± 0.5 mm	I	12 ± 0.5 mm	O	10 ± 0.5 mm
D	95 ± 0.5 mm	J	15 ± 0.5 mm	P	8 ± 1 mm
E	175 ± 0.5 mm	K	15 ± 0.5 mm		
F	15 ± 0.5 mm	L	15 ± 0.5 mm		

A diameter of sample
B distance between orienting knob to central clamp
C distance between inner edges of side clamps
D height of side and central clamps
E length of base support
F distance between outer edge of side clamp to base support end
G width of clamps
H length of top bar
I diameter of cylindrical rod attached to load cell
J height of base support
K height of a clamp supporting on the central clamp
L length of a clamp supporting on the central clamp
M length of cylindrical rod attached to load cell
N distance of outer surface of mixture to side clamps' top edge
O height of stud to attach lateral LVDT
P height of orienting knob

FIG. 1 General Schematic View of the Three-Point Bending Cylinder Test Setup with a Loaded Specimen: (a) Elevation View; (b) Side View; and (c) Plan View

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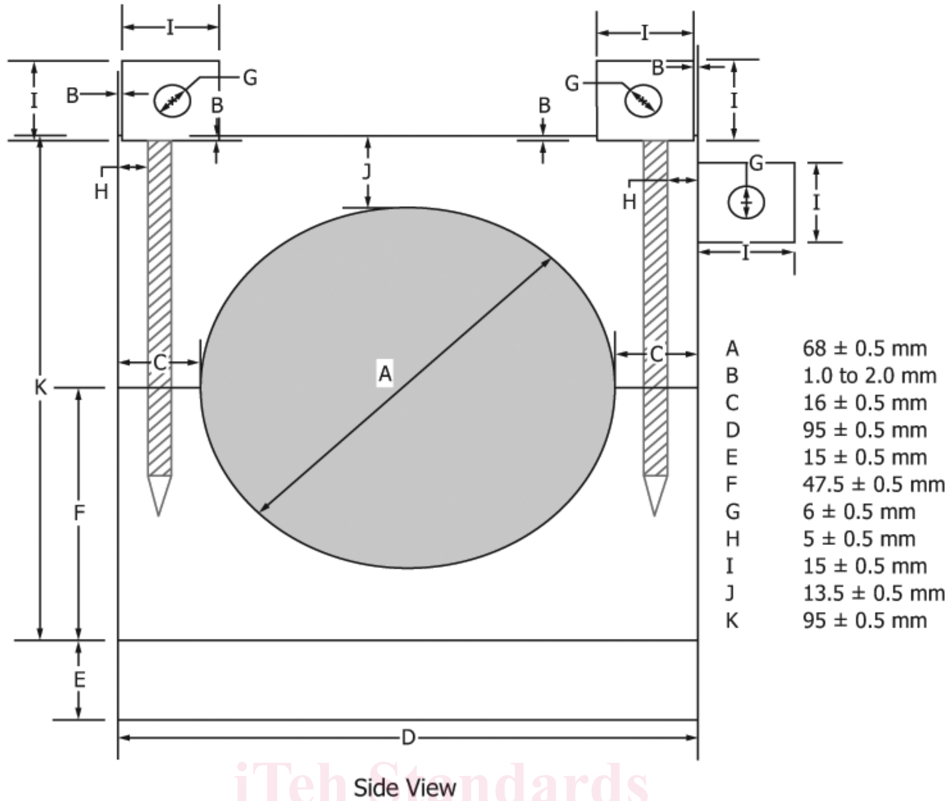
6.5 *Deformation Measurements*—Mid-span deformation shall be measured using sensors mounted on two sides of the central clamp as shown in Fig. 2. Also, it is encouraged to use a lateral LVDT to monitor the lateral movement of the side clamps, if applicable. Spring-loaded linear variable differential transducers (LVDTs) are recommended but not specified. The same LVDT type can be used to perform dynamic modulus tests according to AASHTO T 378.

6.6 Caliper or ruler accurate to ±0.05 mm for specimen diameter measurement.



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A diameter of sample
B distance of top bar clamp from two sides of fixed end support
C distance of outer surface of mixture to end support wall
D width of the base support
E height of the base support
F height of a C-shaped piece
G diameter of the top bar
H distance of end support wall to screws used to attach top bar clamp
I width of top bar clamp
J distance of upper outer surface of mixture to end support wall
K height of the fixed end support

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FIG. 1 General Schematic View of the Three-Point Bending Cylinder Test Setup with a Loaded Specimen: (a) Elevation View; (b) Side View; and (c) Plan View *(continued)*

6.7 The temperature measurements shall be performed using a calibrated digital thermometer with a tolerance range of no more than ±0.2 °C.

6.8 *Data Quality*—Accept only test data meeting the data quality statistics given in Table 2. Calculation steps and all the formulations for these data quality statistics are provided in Annex A2.

7. Hazards

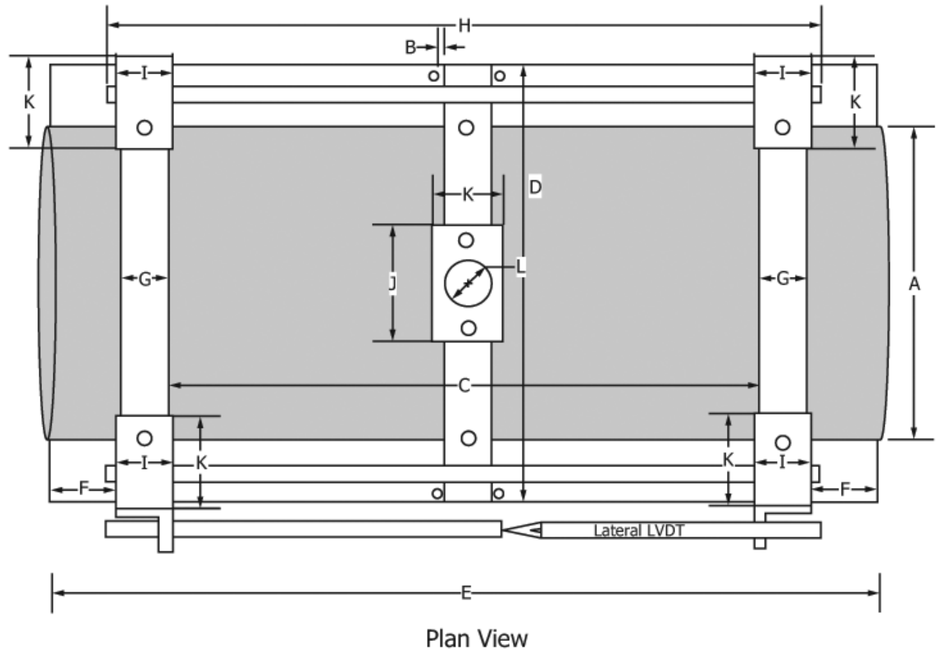
7.1 Observe standard laboratory safety precautions when preparing and testing asphalt concrete specimens.

8. Sampling and Test Specimen Preparation

8.1 The three-point bending cylinder test may be conducted on laboratory-prepared test specimens and/or field cores with NMAS less than or equal to 19 mm.

8.2 If the testing is run for the purpose of ranking multiple asphalt mixtures, a minimum of two replicates per testing condition is recommended. If a complete fatigue curve is needed for use in the viscoelastic continuum damage (VECD) analysis, a minimum of four replicates are recommended, where two replicates will be tested at one temperature and the other two will be tested at another temperature. Otherwise, prepare as many samples as required.

8.3 *Laboratory-Mixed and Laboratory Compacted (LMLC) Specimens*—The 3PBC specimen shall have a diameter of 68 ± 0.5 mm and a minimum length of 150 mm. LMLC specimens shall be short-term conditioned before the compaction as defined in AASHTO R 30. Prepare the asphalt concrete specimens in general accordance with AASHTO R 83 (it takes approximately 16 h for the specimens to be fully cooled down to room temperature). Then, core the compacted sample to



A	68 ± 0.5 mm	G	10 to 12 mm
B	2.5 to 3.5 mm	H	152 ± 0.5 mm
C	125 ± 0.5 mm	I	12 ± 0.5 mm
D	95 ± 0.5 mm	J	25 ± 0.5 mm
E	175 ± 0.5 mm	K	15 ± 0.5 mm
F	15 ± 0.5 mm	L	10 ± 0.5 mm

A	diameter of sample
B	distance between orienting knob to central clamp
C	distance between inner edges of side clamps
D	height of side and central clamps
E	length of base support
F	distance between outer edge of side clamp to base support end
G	width of clamps
H	length of top bar
I	width of top bar clamp
J	length of a clamp supporting on the central clamp
K	length of top bar clamp
L	diameter of cylindrical rod attached to load cell

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FIG. 1 General Schematic View of the Three-Point Bending Cylinder Test Setup with a Loaded Specimen: (a) Elevation View; (b) Side View; and (c) Plan View *(continued)*

TABLE 1 Test System Minimum Requirements

Measurement	Range	Accuracy	Resolution
Load measurement and control	0 to 5 kN	5 N	≤0.0012 kN
Displacement measurement and control	0 to 5 mm	5 μm	0.0025 mm
Frequency measurement and control	5 to 10 Hz	0.01 Hz	Not specified
Temperature measurement and control	5 to 35 °C	±0.5 °C	Not specified
Minimum number of data samples for each cycle	40	N/A	Not specified

obtain 68 mm diameter samples with an air void level of the operator's choice (for example, 7 % ± 0.5 %). Cored samples can also be rapidly dried by automatic drying machines (for example, CoreDry). In this process, a 3PBC sample can be tested within an hour of conditioning. Otherwise, traditional drying using a fan can be used which needs 24 to 48 h of conditioning prior testing.

8.4 *Plant-Mixed, Laboratory Compacted (PMLC) Specimens*—Obtain asphalt concrete samples in accordance with Practice D979/D979M. The 3PBC specimen shall have a diameter of 68 ± 0.5 mm and a minimum length of 150 mm. PMLC specimens shall not be short-term aged and prepared in general accordance with AASHTO R 83. The gyratory specimen will then be cored to obtain 68 mm diameter samples with an air void level of the operator's choice (for example, 7 % ± 0.5 %). Cored samples can also be rapidly dried by automatic drying machines (for example, CoreDry). In this process, a 3PBC sample can be tested within an hour of conditioning. Otherwise, traditional drying using a fan can be used which needs 24 to 48 h of conditioning prior testing.

8.5 *Field-Cored Specimens*—Obtain compacted asphalt concrete samples from the roadway in general accordance with

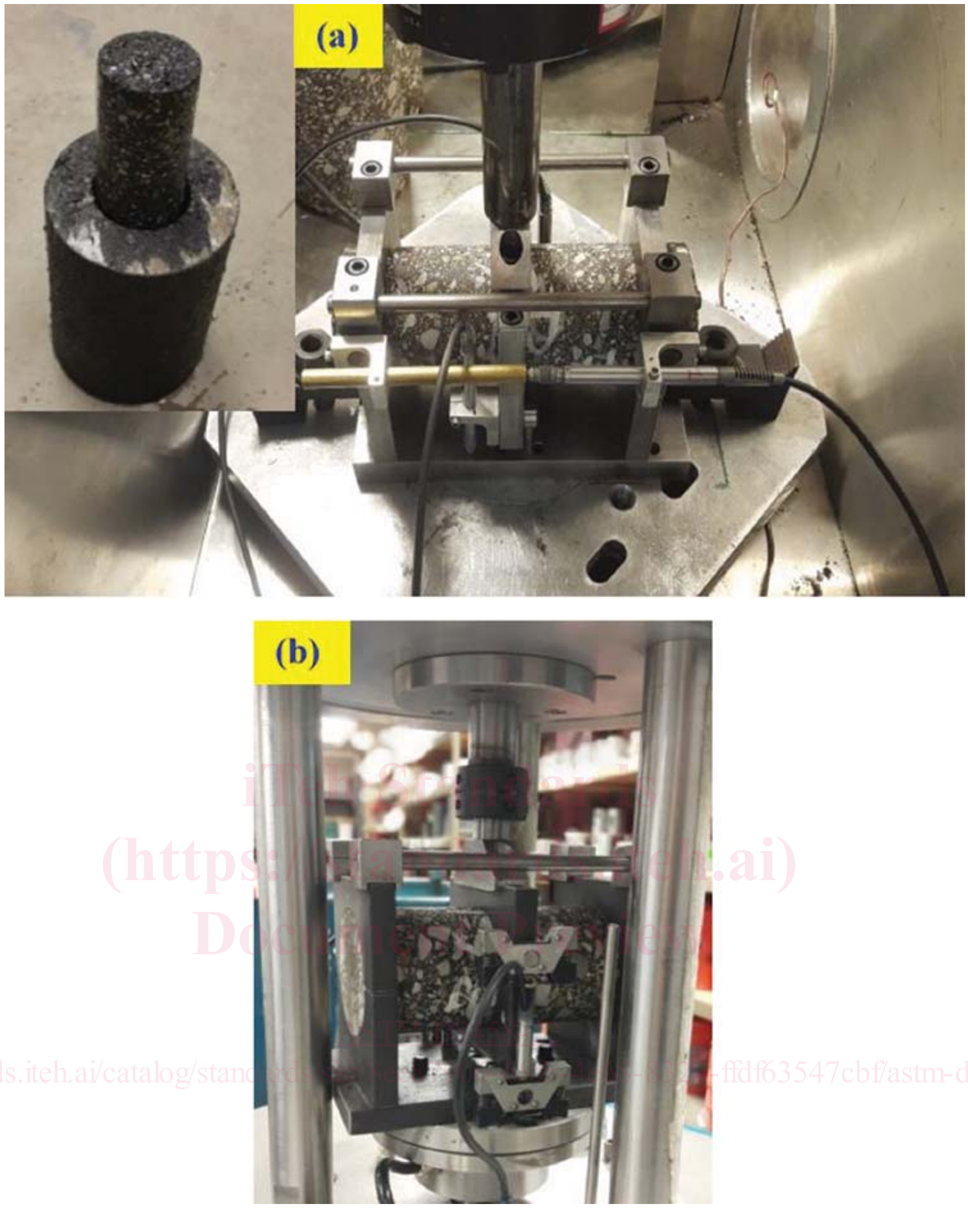

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FIG. 2 Three-Point Bending Cylinder Test Setup with a Loaded Specimen in the (a) Material Testing System (MTS) and (b) Asphalt Mixture Performance Tester (AMPT)

TABLE 2 Test System Limits for Data Quality Indicators

Indicator	Symbol	Equation	Limit
Standard error of the applied load	*se*(P)	Eq A2.9	≤10 %
Average standard error of the measured displacements	*se*(δ)	Eq A2.21	≤10 %
Uniformity coefficient for the displacement measurements	U_δ	Eq A2.22	≤30 %
Uniformity coefficient for the phase angle measurements	U_θ	Eq A2.23	≤3 degrees

Practice D5361/D5361M. The 3PBC specimen shall be cored horizontally (perpendicular to the direction of traffic) and shall have a diameter of 68 ± 0.5 mm and a minimum length of 150 mm. Field coring is only applicable to asphalt concrete layers thicker than 75 mm. Do not use this method if a homogeneous asphalt concrete layer with thickness greater than 75 mm does not exist in the field.

8.6 *Measurement of Specimen Dimensions*—Measure the height and diameter of the specimen to the nearest 0.1 mm at three different points at 120° apart in accordance with applicable sections of Test Method D3549/D3549M, determine the average of the measurements for each dimension, and record the averages to the nearest 0.1 mm.

8.7 *Specimen Preconditioning*—Place the specimen in an environmental chamber at a target test temperature ± 1.0 °C for a minimum of 2 h prior to beginning the test. Exact conditioning time should be determined by using a thermocouple placed at the center of a dummy sample and recording the time required to reach the target temperature.

8.8 *Testing Temperatures*—Recommended test temperature is the PG IT defined in Specification D6373, AASHTO M 320, or AASHTO M 332 and provided in the following equation:

$$T_1 = PG_{IT} = \frac{PH_{HT}+PG_{LT}}{2}+4 \quad (1)$$

where:

T_1 = first testing temperature (°C),
PG_{IT} = intermediate performance grade temperature (°C),
PH_{HT} = climatic high-performance grade temperature (°C), and
PG_{LT} = climatic low-performance grade temperature (°C).

NOTE 2—If the data will be analyzed using the simplified viscoelastic continuum damage theory (VECD), test should be repeated at another temperature. This is needed to determine if the pseudo stiffness (C) versus damage parameter (S) relationship is unique, regardless of the temperature of testing. Recommended second testing temperature is 10 °C lower than the T_1:

$$T_2 = T_1 - 10\ °C \quad (2)$$

where:

T_2 = second testing temperature (°C).

8.9 *Specimen Load*—Open the clamps and place the specimen into position (Fig. 2). Center the specimen. Once the specimen is in position, attach the center clamp first. Then lower the actuator (or raise the actuator, depending on the position of the actuator) so that base plate with two side clamps close to the specimen. Apply a seating load of 40 N (in load control) so that the specimen is seated against the two side clamps. Make sure the bottom plate is free to move so that the sample can be centered manually in two directions (in the direction of diameter and direction of its height). This centering process is extremely important. Once centered, tighten the side C-clamps while in load control mode. Once all clamps are tightened, tighten the bottom clamp to the testing equipment, again while in load control mode. If there is a gap between the sample and any of the three clamps, use painter's masking tape (for example, 3M Scotch Blue 2080 paper tape) to fill in the gap.

8.10 Once the tightening operation is completed, attach the two linear variable differential transducers (LVDTs) to the central clamp. Clamp the LVDTs into position so that it rests on top of the flat surface of the contact position and check that the displacement sensor will not overextend its designed length of travel. A third lateral LVDT can be used to monitor the lateral movement of the side clamps, if applicable. Finally, the top bars are placed to prevent any potential deflection of the side clamps.[4]

8.11 Set the displacement amplitude based on the desired strain rate by manually adjusting the sensor and the parameters in the test control software. Select the desired initial strain (for example, 200 to 800 × 10^{-6} mm/mm) and loading frequency (for example, 5 Hz) and the load cycle intervals at which test results are to be recorded and computed. Use the following equation to compute the target displacement based on the desired strain at the bottom of the 3PBC sample in the mid-span:

$$\delta_z = K\frac{\pi d^3}{4L}(\varepsilon_y)_{max} \quad (3)$$

8.11.1 The parameters of Eq 3 are defined in Section 9, and therefore are not repeated here for brevity.

8.12 Within the load cycles to be recorded, include an interval near the point of five cycles. Average the specimen dynamic modulus at the fifth load cycle; this dynamic modulus is the recommended estimate of the initial beam dynamic modulus.

8.13 Select a displacement level (strain level) near 200 × 10^{-6} mm/mm initially for the specific material based on trial and error or experience. If a complete fatigue curve is needed for use in the viscoelastic continuum damage (VECD) analysis, adjust the strain up and/or down on additional replicate beams to evaluate the performance of the material over a range of strain levels.

8.14 Upon selection of the appropriate test parameters, begin the test. Activate the control and data acquisition system so that the test results at the selected load cycle intervals are monitored and recorded, ensuring that the test system is operating properly. With low-strain testing, it may be impractical to reach this desired failure point; in this case, the test can be terminated at 100 000 loading cycles or after the specimen dynamic modulus reduces to about 20 % of the initial dynamic modulus.

NOTE 3—With some modified materials (for example, polymer-modified mixtures, fiber-reinforced asphalt concrete, etc.), lower termination criteria (for example, when dynamic modulus reduces to less than 20 % of the initial dynamic modulus) can be defined.

[4] The clamping procedure for the MTS unit is performed in the following order: after the three-point bending cylinder setup is attached to the MTS and the specimen is loaded, apply a contact load of 40 N such that the central clamp aligns on the surface at mid-span length of the specimen. Then tighten the screws as described above. For the AMPT unit, initially, the three-point bending cylinder setup is attached. The specimen is loaded in the setup and a sliding shaft is used to connect the central clamp of the setup to the top platen of the AMPT. Once the central clamp aligns on the surface of the specimen, tighten the screws as described above then tighten the sliding shaft.

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