Designation: D7460 – 10

Standard Test Method for Determining Fatigue Failure of Compacted Asphalt Concrete Subjected to Repeated Flexural Bending[1]

This standard is issued under the fixed designation D7460; 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 procedures for determining a unique failure point for estimating the fatigue life of 380 mm (14.96 in.) long by 50 mm (1.97 in.) thick by 63 mm (2.48 in.) wide asphalt concrete beam specimens sawed from laboratory or field compacted asphalt concrete, which are subjected to repeated flexural bending.

1.2 The between-laboratory reproducibility of this test method is being determined and will be available on or before June 2013. Therefore, this test method should not be used for acceptance or rejection of a material for purchasing purposes.

1.3 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.

1.4 *Units*—The values stated in SI units are to be regarded as standard. Other units of measurement included in this standard are for information only.

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D75 Practice for Sampling Aggregates

D140 Practice for Sampling Bituminous Materials

D979 Practice for Sampling Bituminous Paving Mixtures

D2041 Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

D3203 Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures

D3549 Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens

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

D5361 Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *AASHTO Standards:*[3]

T 321 Standard Method of Test for Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending

PP 3 Preparing Hot-Mix Asphalt (HMA) Specimens by Means of the Rolling Wheel Compactor

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

3. Terminology

3.1 *Definitions:*

3.1.1 *beam modulus*—Flexural Beam Stiffness, as determined in 10.1.3.

3.1.2 *failure point*—the number of cycles to failure, N_f, which corresponds to the maximum or peak Normalized Modulus × Cycles (Fig. 13) when plotted versus Number of Cycles.

3.1.3 *initial beam modulus*—Flexural Beam Stiffness determined at approximately 50 load cycles.

3.1.4 *normalized modulus × cycles*—see Rowe and Bouldin (**1**):[4]

$$\frac{(\text{Beam Stiffness} \times \text{Cycle Number})}{(\text{Initial Beam Modulus} \times \text{Cycle of Initial Beam Modulus})}$$

4. Summary of Test Method

4.1 The four-point flexural bending test method is conducted on compacted beam specimens to evaluate the fatigue

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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.

Current edition approved June 1, 2010. Published July 2010. Originally approved in 2008. Last previous edition approved in 2008 as D7640–08. DOI: 10.1520/D7460-10.

[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.

[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.

properties of an asphalt concrete mixture. A cyclic haversine (displaced sine wave with full amplitude on tension side of zero) displacement is applied at the central H-frame third points of a beam specimen, while the outer third points are held in an articulating fixed position. The frequency rate ranges from 5 to 10 Hz. This produces a constant bending moment over the center third (L/3) span (118.5 to 119 mm (4.66 to 4.69 in.)) between the H-frame contact points on the beam specimen. The level of desired strain is pre-calculated and an input for the displacement control. The deflection at the mid-length position (L/2) of a beam specimen is regulated by the closed loop control system.

5. Significance and Use

5.1 The laboratory fatigue life determined by this standard for beam specimens have been used to estimate the fatigue life of asphalt concrete pavement layers under repeated traffic loading. Although the field performance of asphalt concrete is impacted by many factors (traffic variation, speed, and wander; climate variation; rest periods between loads; aging; etc.), it has been more accurately predicted when laboratory properties are known along with an estimate of the strain level induced at the layer depth by the traffic wheel load traveling over the pavement.

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 assure 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 *Test System*—The test system shall consist of a load frame, an environmental chamber (temperature control system) and a closed loop control and data acquisition system. The test system shall meet the minimum requirements specified in Table 1. This standard specifically describes the systems of two primary suppliers (Cox and Sons, Inc. [Cox] and Industrial Process Controls, Ltd. [IPC]); however, other similar equipment could also be used.

TABLE 1 Test System Minimum Requirements

Load Measurement and Control	Range: 0 to 5 kN (0 to 1124 lbf) Resolution: 2.5 N (0.56 lbf) Accuracy: 5 N (1 lbf)
Displacement Measurement and Control	Range: 0 to 5 mm (0 to 0.2 in.) Resolution: 2.5 μm (9.8 × 10^5 in.) Accuracy: 5 μm (2.0 × 10^4 in.)
Frequency Measurement and Control	Range: 5 to 10 Hz Resolution: 0.005 Hz Accuracy: 0.01 Hz
Temperature Measurement and Control	Resolution: ±0.25°C (±0.45°F) Accuracy: ±0.5°C (±0.9°F)
Displacement Sensor	Linear Variable Differential Transducer (LVDT), Extensometer, or similar device

6.1.1 *Loading Device*—The test system shall include 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 (and resulting strain) during each load cycle. The loading device shall be capable of *(1)* providing cyclic haversine (= SIN^2(degrees/2)) loading at a frequency range of 5 to 10 Hz, *(2)* subjecting specimens to 4-point bending with free rotation and horizontal translation at all load and reaction points, and *(3)* forcing the specimen back to its original position (that is, zero deflection) at the end of each loading cycle. Fig. 1 illustrates the haversine waveform. Figs. 2 and 3 show the movements of the Cox and IPC loading devices, respectively; the Cox device loads in a downward direction and the IPC loads in an upward direction. The early version of the IPC device does not have free translation at the inner clamps; however, the newer model allows free rotation and translation at all four clamps.

6.1.2 *Environmental Chamber (Temperature Control System)*—The environmental chamber shall enclose the entire specimen and maintain the specimen at the desired test temperature. The temperature shall be within ±0.5°C (±0.9°F) 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.

6.1.3 *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 stiffness at load cycle intervals specified by the user.

6.2 *Miscellaneous Apparatus and Materials*—For the Cox device, an aluminum, wedge-shaped target for connecting the displacement sensor to the neutral axis of the specimen and cyanoacrylate (super glue) or equivalent is needed for attaching the target to the specimen. With both the Cox and the IPC equipment, an alignment fixture and a solid aluminum beam are needed for setting the proper clamp spacing and a saw suitable for cutting the beams with parallel faces to the proper tolerance.

7. Hazards

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

8. Sampling and Test Specimen Preparation

8.1 *Laboratory-Mixed and Compacted Specimens*—Sample asphalt binder in accordance with Practice D140 and sample aggregate in accordance with Practice D75. If a complete

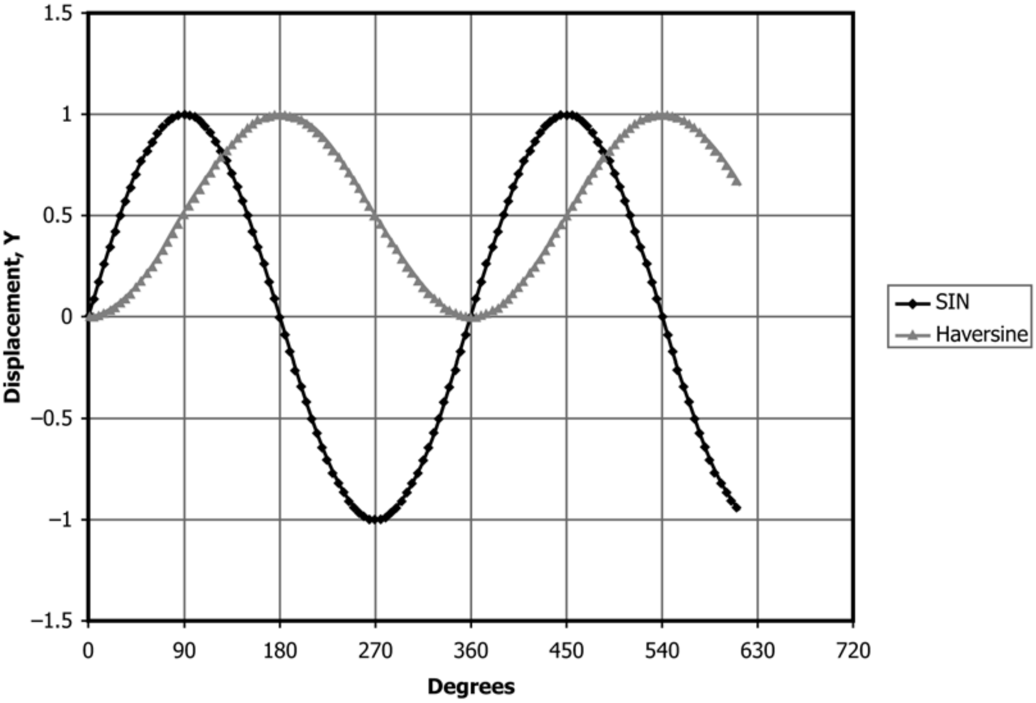


FIG. 1 Illustration of Haversine Wave Form Relative to Sine Wave

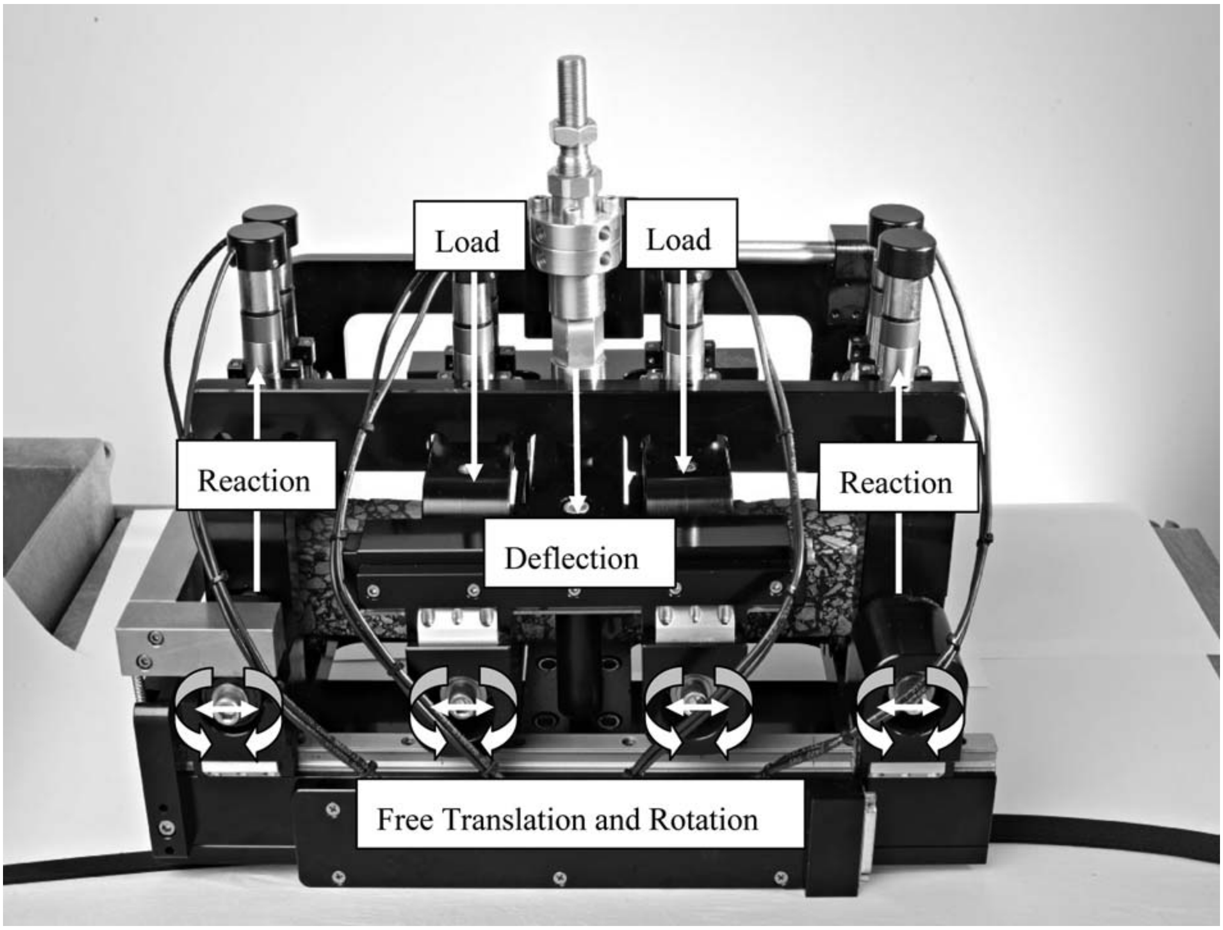
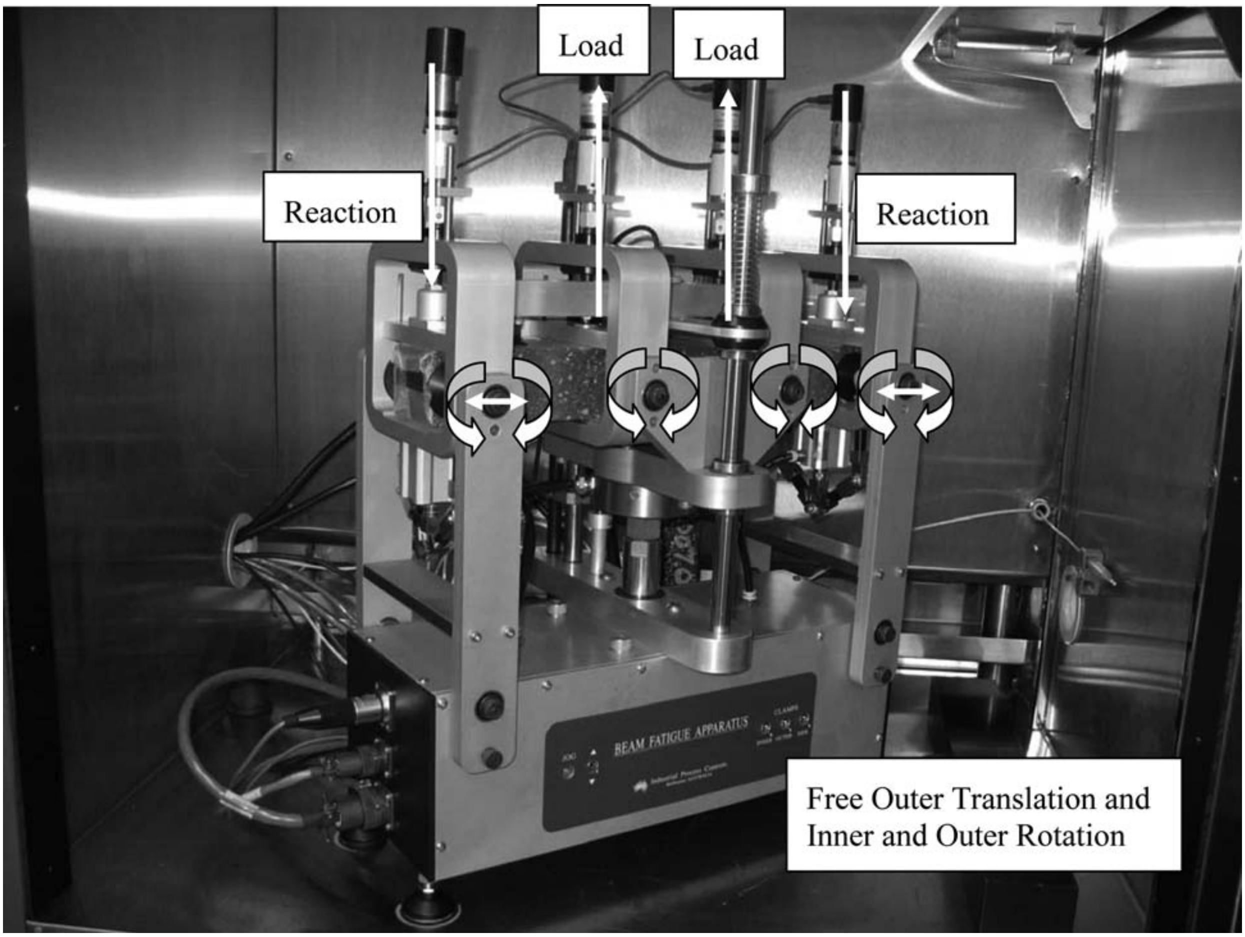


FIG. 2 Load and Freedom Characteristics of Fatigue Test Apparatus (Cox)



NOTE 1—Early model shown; the newer model allows free rotation and translation at all four clamps.

FIG. 3 Load and Freedom Characteristics of IPC Fatigue Test Apparatus

fatigue curve is desired, prepare nine replicate asphalt concrete beam specimens, from slab(s) or beam(s) compacted in accordance with AASHTO PP 3. Otherwise, prepare as many specimens as desired for individual beam test results. Laboratory prepared mixtures are typically conditioned with a short-term aging process, such as defined in AASHTO R 30. Test at least six replicate asphalt concrete beam specimens at different strain levels in order to develop a fatigue curve, as shown in Fig. 4. The extra specimens may also be tested as desired, if the data appears to include an outlier, or if a beam failure occurs directly at a clamp. A linear relationship on a log-log plot exists between N_f and the level of strain (με, microstrain = strain × 10^6).

NOTE 2—The type of compaction device (linear kneading, rolling wheel, vibratory) may influence the test results, relative to representing actual construction.

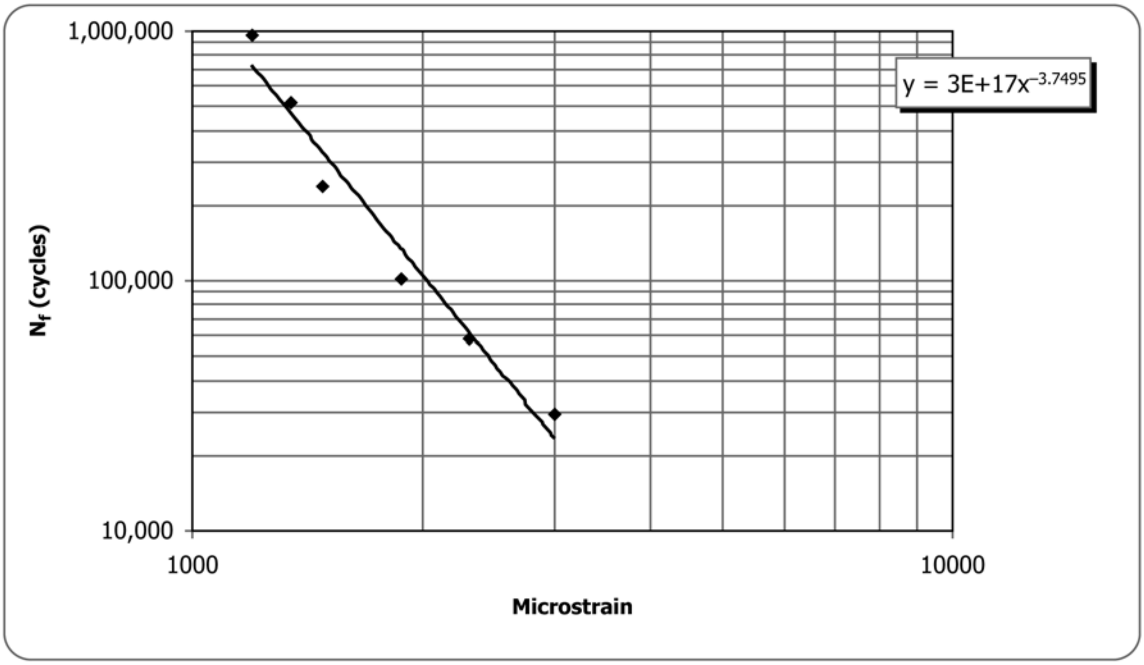
NOTE 3—Normally test specimens are compacted using a standard compactive effort. However, the standard compactive effort may not reproduce the air voids of roadway specimens measured according to Test Method D3203. If specimens are to be compacted to a target air void content, the compactive effort should be determined experimentally.

8.2 *Plant-Mixed, Laboratory Compacted Specimens*—Obtain asphalt concrete samples in accordance with Practice D979. If a complete fatigue curve is desired, prepare nine replicate asphalt concrete beam specimens, from slab(s) or beam(s) compacted in accordance with AASHTO PP 3. Otherwise, prepare as many specimens as desired for individual beam test results. See Notes 2 and 3. Test at least six replicate asphalt concrete beam specimens at different strain levels in order to develop a fatigue curve, as shown in Fig. 4. The extra specimens may also be tested as desired, if the data appears to include an outlier, or if a beam failure occurs directly at a clamp.

8.3 *Roadway Specimens*—Obtain compacted asphalt concrete samples from the roadway in accordance with Practice D5361.

8.4 *Specimen Trimming*—Saw at least 6 mm from all sides of each compacted specimen to provide smooth, parallel (saw-cut) surfaces for mounting the measurement gages. The final required dimensions of the test specimen, after sawing, are 380 ± 6 mm (14.96 ± 0.24 in.) in length, 50 ± 2 mm (1.96 ± 0.08 in.) in height, and 63 ± 2 mm (2.48 ± 0.08 in.) in width. To minimize specimen variability, it is recommended that the beams be immediately labeled to ensure consistent orientation (top and sides) during testing, relative to the compaction process.

8.5 *Specimen Storage*—The specimens should be stored on a 12.7 mm (½ in.) steel plate with a flatness of 0.127 mm (0.005 in.) across the surface of the plate from end to end. This



NOTE 1—Strain levels should be adjusted for the material.

FIG. 4 Example Fatigue Curve

flat surface keeps the beam specimens from being pre-strained before testing. Limit stacking of specimens to two high on storage racks.

9. Procedure

9.1 *Fixture Alignment*—A solid aluminum beam, having dimensions specified in 8.4 with tolerances to a flatness of 0.051 mm (0.002 in.) across the length of the aluminum beam (measured using a straight edge and feeler gauges), is used to ensure proper alignment of the beam fixture prior to testing. Insert the aluminum beam into the fixture, clamping the side clamps on the outside frame first. Clamp the top clamps on the outside frames followed by the top clamps on the inside frames. Place the actuator in load control and remove the load. Verify that the clamps are fully seated on the aluminum beam. On the Cox frame, apply the side clamps to the inside frames. After returning to displacement control, adjust the load to the positive side of zero; make a note of the actuator displacement sensor location and start cycling from this position. Once this zero load position is located and used as a guide, the bottom of all the clamps will be aligned. If the top and bottom sides of the beam test specimen are not parallel, it should not be an issue with the clamping. The saw cuts are typically straight on all sides of the beam even if these are not parallel to each other; the top clamps will compensate for the lack of parallelism, since the clamps are all independent of each other. The Cox fixture is designed to use the 3.175 mm (⅛ in.) tensile bar coupler for facilitating 360° movement without creating an eccentric moment, as shown in Fig. 5. The two spent 3.175 mm (⅛ in.) tensile bars pictured on the right-hand side of Fig. 5 show the deformation that can occur due to years of fatigue testing; any shortening of the shaft changes the stroke location. If the fixture uses this type of coupler, this initial sensor location should be checked after every seven testing days to evaluate the condition of the coupler. If the fixture is hard coupled, as with the IPC device, this alignment check can be performed less frequently.

9.2 *Specimen Measurement*—Measure the height and width of the specimen to the nearest 0.01 mm (3.94×10^{-4} in.) at three or more different points along the middle 100 mm (3.94 in.) of the specimen length in accordance with applicable sections of Test Method D3549, Determine the average of the measurements for each dimension and record the averages to the nearest 0.1 mm (0.004 in).

9.3 *Attaching the Target to the Neutral Axis of Specimen (Required with the Cox Fixture)*—Locate the center of a specimen on one of its 50 mm (1.97 in.) high lengthwise sides (i.e., mid-height and mid-length of the beam). Apply cyanoacrylate (super glue) or equivalent in a circle around this point and place the target on the glue such that the top of the target is at the center point of the beam. Allow the glue to cure before moving the specimen. Fig. 6 illustrates the target attached to the neutral axis of the specimen.

9.4 Place the specimen on a stiff flat surface in an environment holding the desired test temperature for two hours to ensure that the specimen has equilibrated to the desired test temperature prior to beginning the test. Based on past experience, approximately 1.5 to 2 hours is sufficient to equilibrate the temperature of a beam that was stored near room temperature to its testing environment. The temperature shall be within ±0.5°C (±0.9°F) throughout the conditioning and testing times.

NOTE 4—A common temperature used for this test method is 20°C (68°F), since it is near the critical temperature level for most of the U.S. Another method that has been used to determine the effective test

FIG. 5 Tensile Bar Coupler Connecting the Actuator to the H-frame (Inner Clamps)

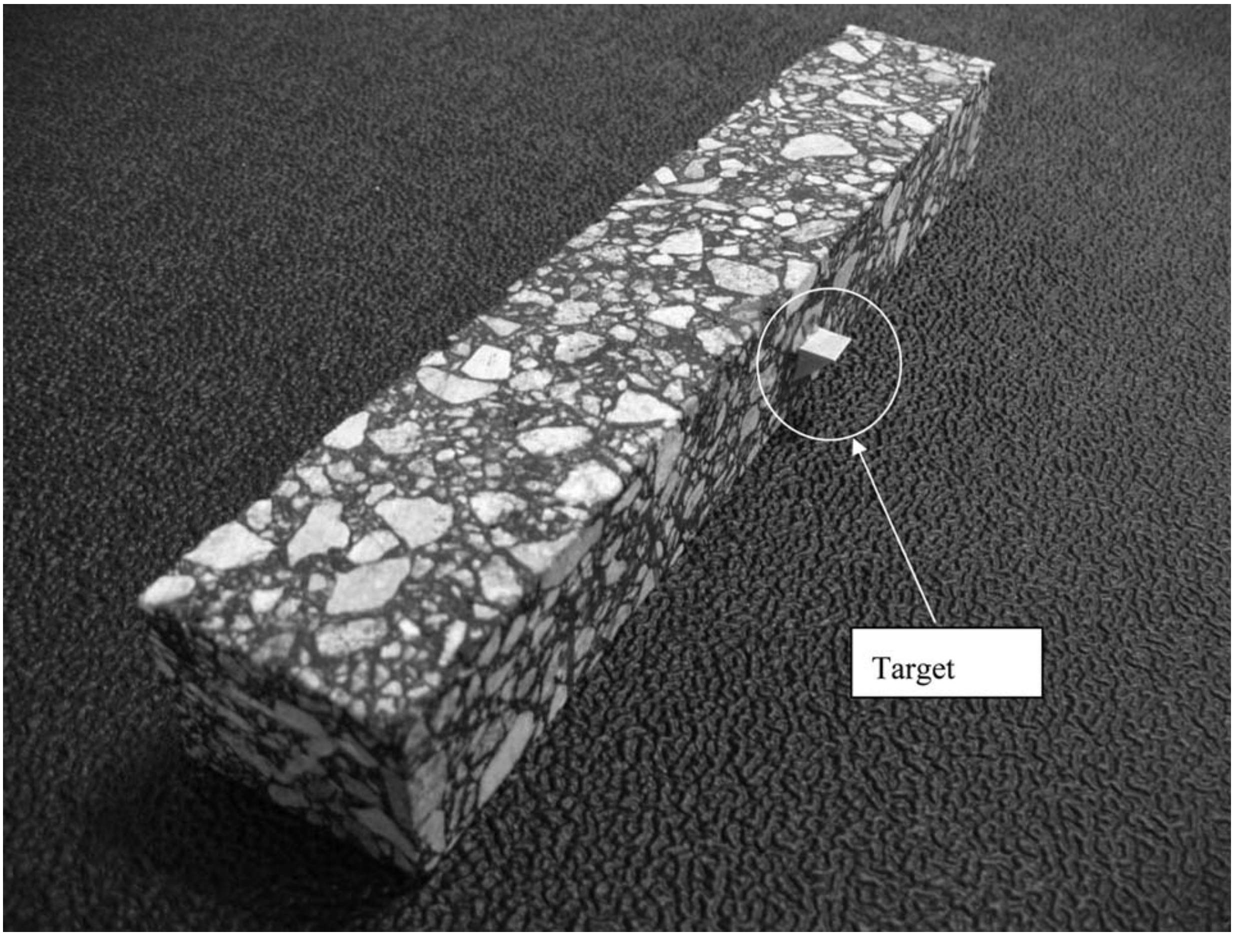


FIG. 6 Target Attached to the Beam Neutral Axis (Mid-Height, Mid-Length) (Cox)

temperature for equivalent pavement fatigue damage is the following equation developed during the Strategic Highway Research Program (SHRP):

$$T_{eff.Fatigue} = 0.8(MAPT) - 2.7 \tag{1}$$

where:

MAPT = mean annual pavement temperature (°C),

MAPT =

$$T_{20mm} = T_{air} - 0.00618(lat^2) + 0.2289(lat) + 42.2(0.9545) - 17.78, \tag{2}$$

T_{20mm} = temperature at 20 mm depth from pavement surface (°C),

T_{air} = mean annual air temperature (°C), and

lat = latitude of project location (degrees).

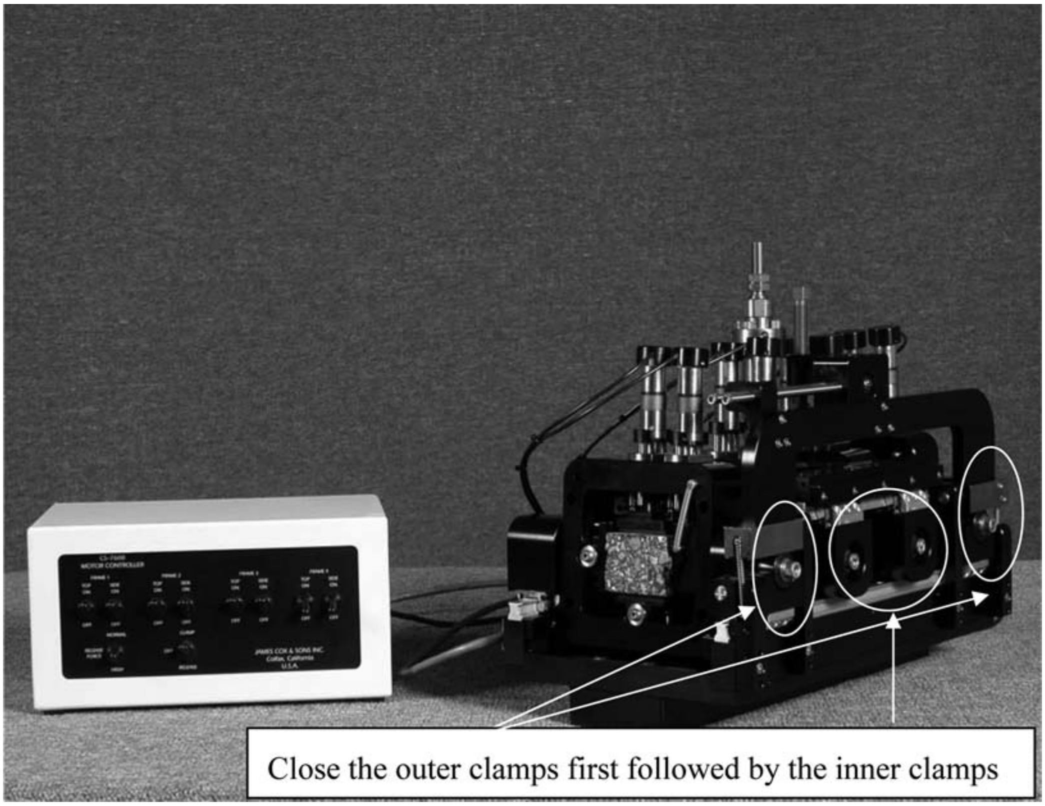
9.5 Open the clamps and slide the specimen into position (Figs. 7-10). With both the Cox and the IPC equipment, use the alignment fixture to ensure proper horizontal spacing of the clamps, (Cox: 119 mm (4.69 in.); IPC: 1 18.5 mm (4.66 in.)) center-to-center. When the specimen and clamps are in the proper positions, apply the side clamps to the outside frames, then apply the top clamps to the outside frames. Next, apply the top clamps to the inside frames. With the Cox, apply the side clamps of the inside frames. Check for adequate clamping pressure by toggling (lightly shaking) each frame with the spacing fixture in place and make sure that all clamps are seated properly, flat against the specimen.

9.6 Set the displacement amplitude to the desired strain rate by manually adjusting the sensor and the parameters in the test control software while lowering the displacement sensor onto the proper specimen contact position. Fig. 8 illustrates the Cox fixture with the displacement sensor resting on the target, such that beam displacement will be measured at the neutral axis. With the IPC fixture (Figs. 11 and 12), the beam displacement is measured on the tensile reaction side (top) of the beam. Clamp the displacement sensor into position so that it rests on top of the flat surface of the contact position and check that the displacement sensor will not over extend its designed length of travel.

9.7 Select the desired initial strain (50 to 3000 με; typically 200 to 800 με for conventional asphalt concrete; 70 to 150 με for evaluating severely high-repetition but low strain conditions; 1500 to 3000 με for some interlayer materials) and loading frequency, and the load cycle intervals at which test results are to be recorded and computed. The load cycle intervals to be recorded are typically spread out to adequately cover each decade on a log scale (that is, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 cycles) for the entire expected length of test. Enter these values into the specific template for this testing program in the Control and Data Acquisition System. Typically, the loading frequency is set within a range of 5 to 10 Hz (10 Hz is the most commonly used frequency) for simulating highway repetitive loading conditions.

NOTE 5—Selection of load cycle intervals at which test results are computed and recorded may be limited by the amount of memory available for storing data.

9.8 Within the load cycles to be recorded, include an interval near the point of 50 cycles. Determine the specimen stiffness at the 50th load cycle; this stiffness is the recommended estimate of the initial beam stiffness.



Close the outer clamps first followed by the inner clamps

FIG. 7 Order of Specimen Clamping Procedure

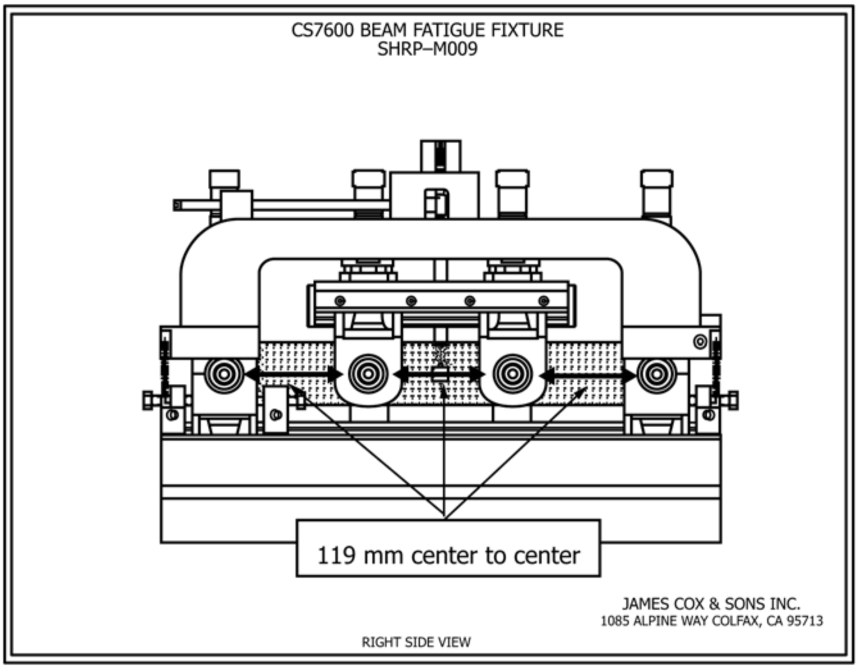


FIG. 8 Schematic of Cox Flexural Beam Fatigue Test Apparatus, Side View

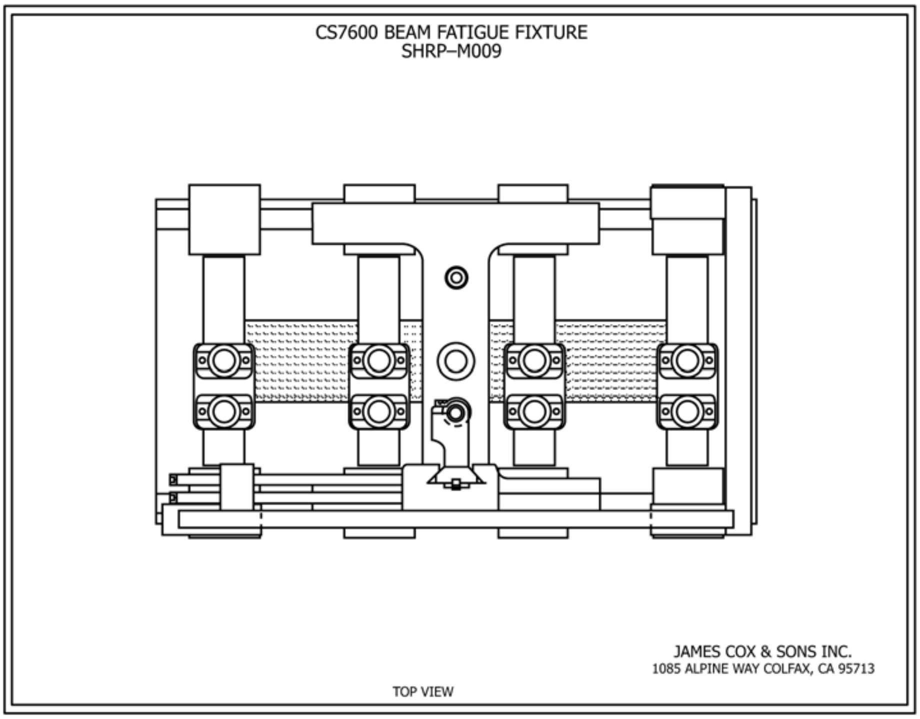


FIG. 9 Schematic of Cox Flexural Beam Fatigue Test Apparatus, Top View

9.9 Select a displacement level (strain level) near the mid-range initially for the specific material based on trial and error or experience, such that the specimen will undergo a minimum of 10 000 load cycles prior to failure. A minimum of 10 000 load cycles ensures that the specimen does not decrease in stiffness too rapidly. For establishing a fatigue curve, adjust the strain up and down on additional replicate beams to evaluate performance of the material over a range of strain levels.

9.10 After selecting 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. Ideally, the test should be terminated some time after the peak value has been achieved on a graphical plot of normalized complex modulus × cycles versus cycles, as shown in Fig. 13. To extend beyond this failure point, it is suggested that the test be terminated after the beam flexural stiffness

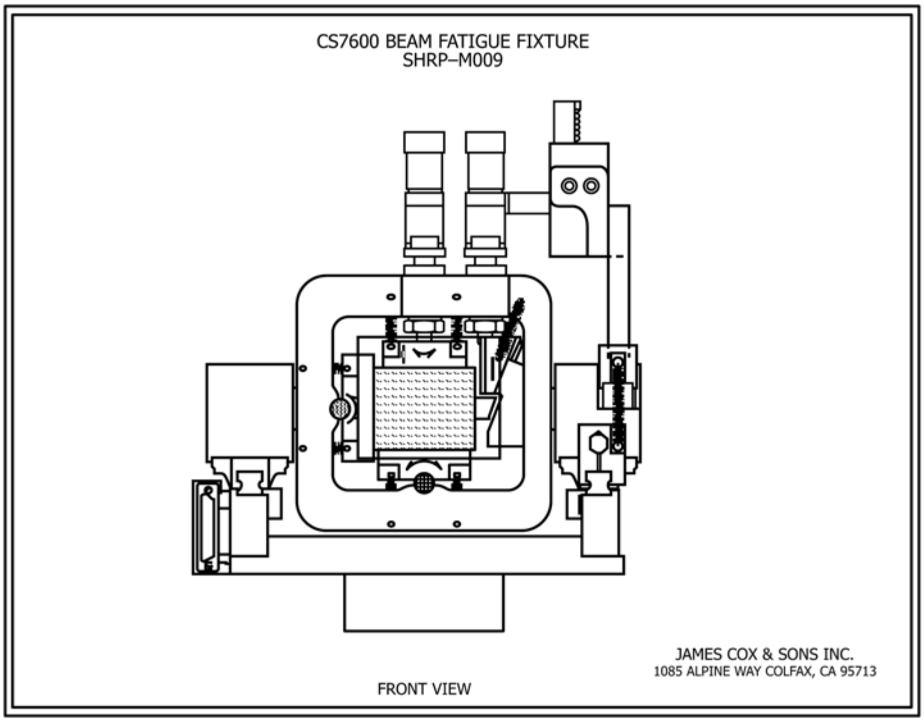


FIG. 10 Schematic of Cox Flexural Beam Fatigue Test Apparatus, End View

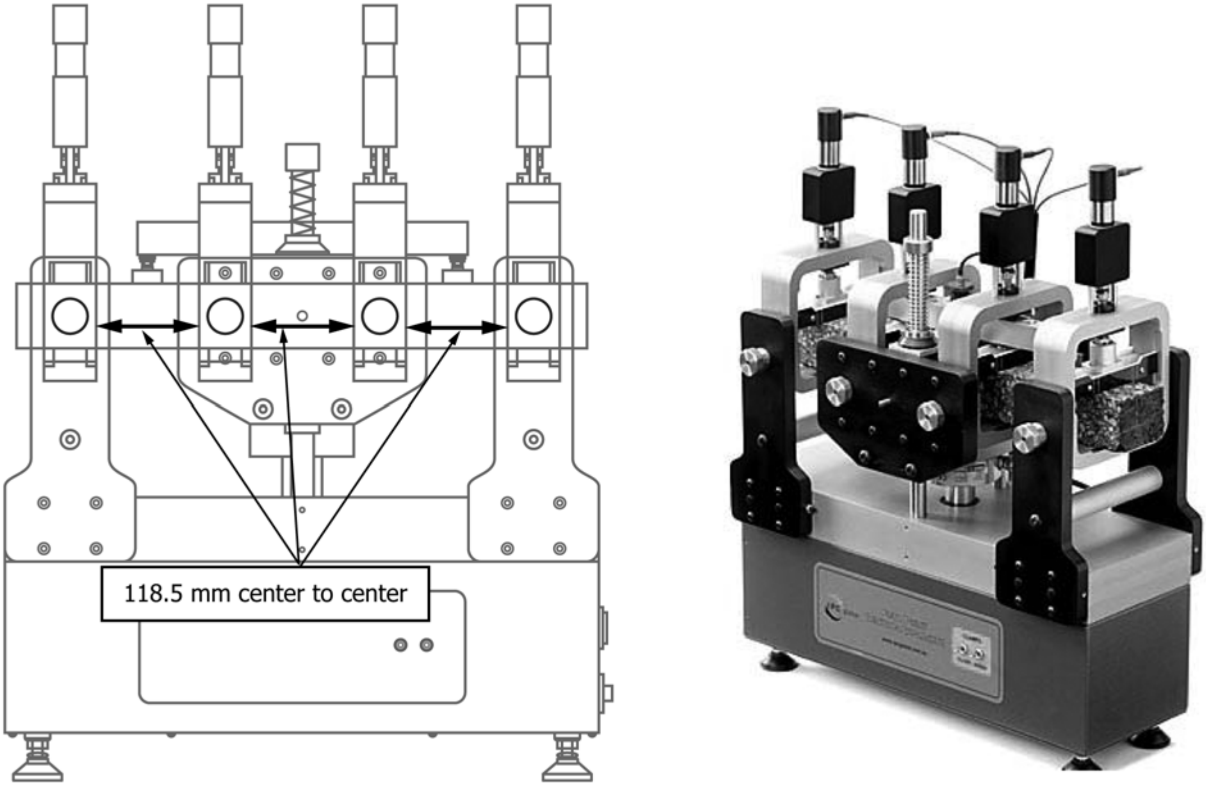


FIG. 11 Schematic and Photo of IPC Flexural Beam Fatigue Test Apparatus (newer model), Side View

reduces to about 40 percent of the initial beam stiffness. With low-strain testing, it may be impractical to reach this desired failure point; in this case, the failure point may be estimated using the extrapolation procedure described in 10.1.7.

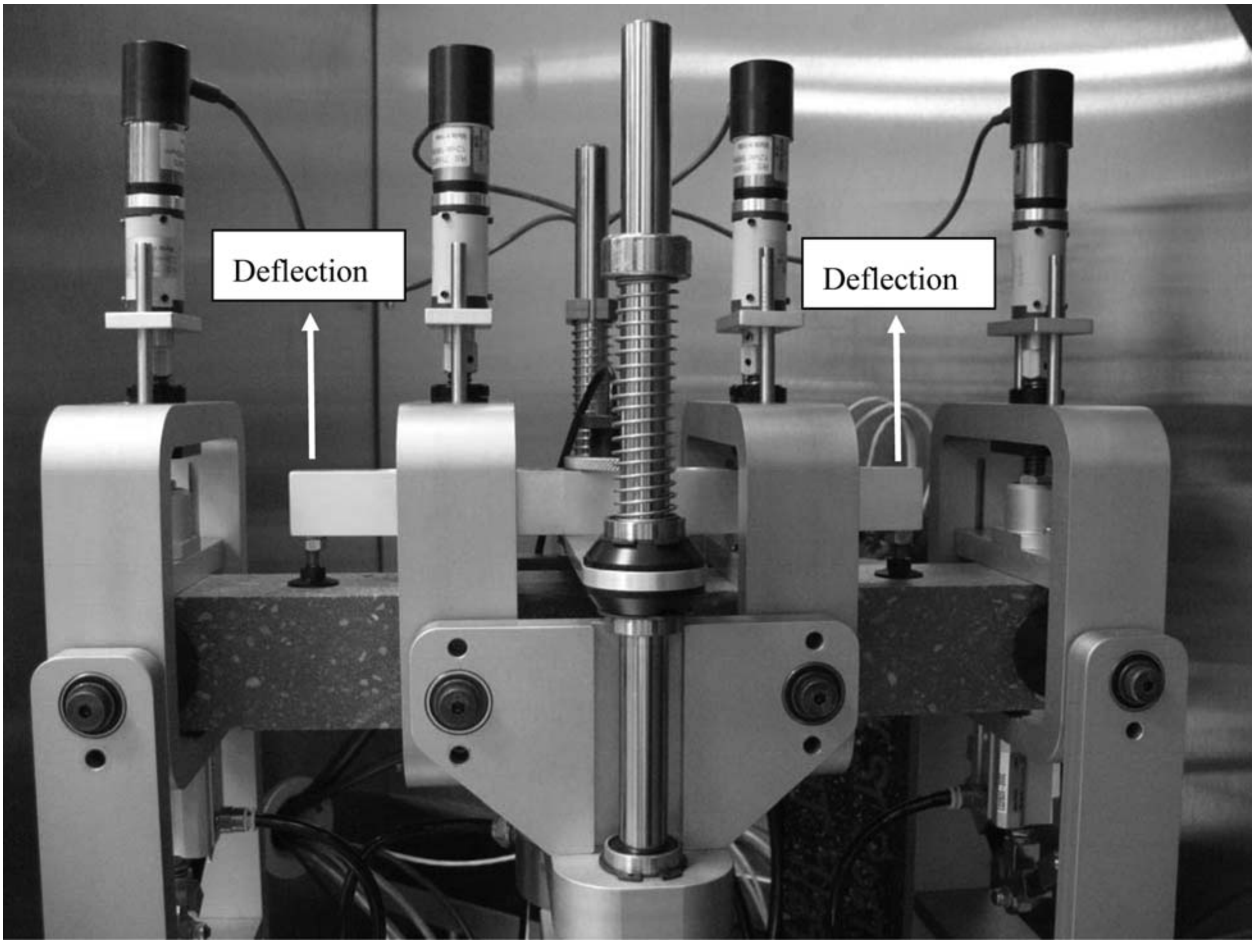
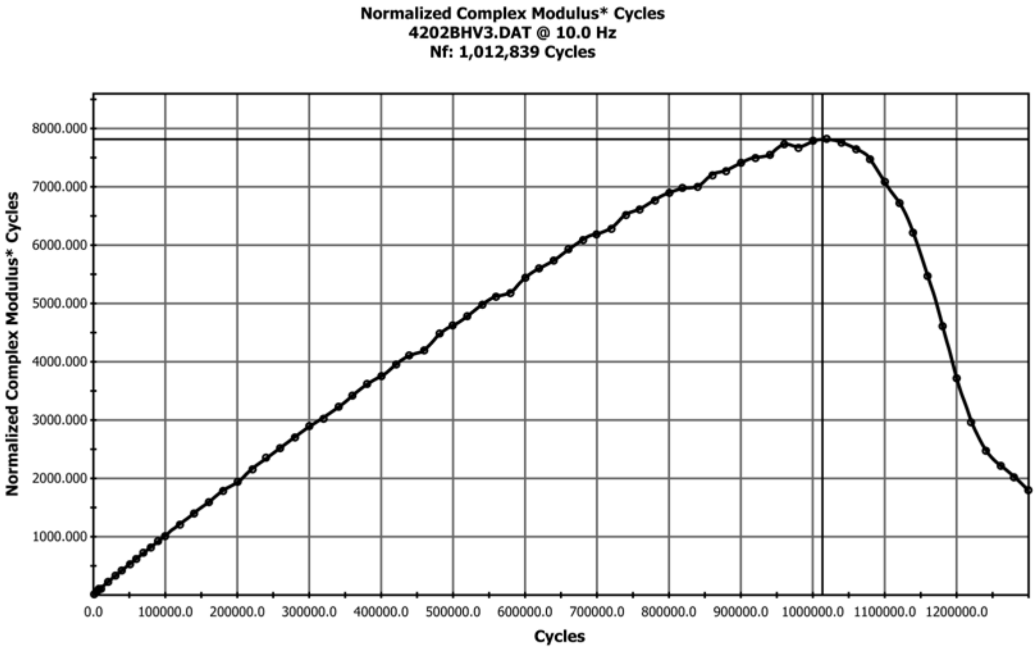


FIG. 12 Displacement in the IPC Apparatus (early model shown) is Measured With a Sensor Located on Top of Specimen



Solid Crosshair (1012839.00 Cycles, 7827.833)

FIG. 13 Normalized Complex Modulus × Cycles versus Cycles

NOTE 6—The point of failure can also be continually evaluated by monitoring the cyclic stress versus strain plot on the scope for the point at which the hysteresis loop (continuous plot of stress versus strain during loading) collapses, loses its shape, appears horizontal, or combinations thereof.

10. Calculation or Interpretation of Results

10.1 Perform the following calculations at the operator-specified load cycle intervals:

10.1.1 *Maximum Tensile Stress (Pa):*

$$\sigma_t = \frac{3 \times a \times P}{b \times h^2} \tag{3}$$

where:

a = center to center spacing between clamps (Cox: 0.1190 m; IPC: 0.1185 m),
P = load applied by actuator (N),
b = average specimen width (m), and
h = average specimen height (m).

10.1.2 *Maximum Tensile Strain (m/m):*

$$\varepsilon_t = \frac{12 \times \delta \times h}{(3 \times L^2) - (4 \times a^2)} \tag{4}$$

where:

δ = maximum deflection at center of beam (m),
a = space between inside clamps, L/3, (Cox: 0.1190 m; IPC: 0.1185 m); and
L = length of beam between outside clamps, (Cox: 0.3570 m; IPC: 0.3555 m).

10.1.3 *Flexural Beam Stiffness (Pa):*

$$S = \frac{\sigma_t}{\varepsilon_t} \tag{5}$$

10.1.4 *Phase Angle (deg):*

$$\varphi = 360 \times f \times s \tag{6}$$

where:

f = load frequency (Hz), and
s = time lag between P_{max} and δ_{max}, (s).

NOTE 7—When automated testing software is used in the control and data acquisition system, φ is approximated by an algorithm contained in the automated testing software.

10.1.5 *Normalized Modulus × Cycles (Pa/Pa)*—See Refs (**1-3**):

$$NM = \frac{S_i \times N_i}{S_o \times N_o} \tag{7}$$

where:

NM = normalized modulus × cycles,
S_i = flexural beam stiffness at cycle i (Pa),
N_i = cycle i,
S_o = initial flexural beam stiffness (Pa), estimated at approximately 50 cycles, and
N_o = actual cycle number where initial flexural beam stiffness is estimated.

10.1.6 *Failure Point (N_f, Number of Cycles to Failure)*—Occurs at the maximum or peak value of Normalized Modulus × Cycles (Fig. 13) when plotted versus Number of Cycles (**1-3**). A portion of the data is shown in Table 2 to show how the beam fatigue data is processed. The approximate maximum value can be easily read from the calculated data in the table. In addition, the raw calculated Normalized Modulus data can also be fit statistically to a best-fit polynomial curve, for more easily selecting the peak of the curve and determining N_f; mathematically, the peak is found where the second-order differential of the curve equation is equal to zero. In this example, the beam failure point is determined to be approximately 1 000 000 cycles.

TABLE 2 Beam Fatigue Data Processing

Cycle Number	Beam Modulus MPa	Beam Modulus (ksi)	Normalized Modulus × Cycles	Curve Fit Normalized Modulus × Cycles
49	2,845.63	(412.73)	1.00	1.00
59	2,807.98	(407.27)	1.19	1.19
69	2,784.96	(403.93)	1.38	1.38
79	2,763.79	(400.86)	1.57	1.56
89	2,750.69	(398.86)	1.76	1.72
99	2,738.07	(397.13)	1.94	1.94
199	2,599.42	(377.02)	3.71	3.71
299	2,518.00	(365.21)	5.40	5.40
399	2,454.15	(355.95)	7.02	7.04
–	–	–	–	–
639,999	1,235.18	(179.15)	5669.41	5739.15
659,999	1,242.14	(180.16)	5879.60	5939.54
679,999	1,230.69	(178.50)	6001.87	6083.25
699,999	1,220.77	(177.06)	6128.54	6197.14
719,999	1,224.56	(177.61)	6323.17	6282.33
739,999	1,219.59	(176.89)	6472.51	6525.92
759,999	1,202.43	(174.40)	6553.89	6626.00
779,999	1,198.08	(173.77)	6701.97	6777.35
799,999	1,190.15	(172.62)	6828.41	6904.06
819,999	1,172.30	(170.03)	6894.02	6982.29
839,999	1,169.54	(169.63)	7045.86	7009.76
859,999	1,154.78	(167.49)	7122.23	7211.63
879,999	1,142.93	(165.77)	7213.18	7279.26
899,999	1,136.51	(164.84)	7335.90	7413.91
919,999	1,125.55	(163.25)	7426.54	7503.34
939,999	1,107.49	(160.63)	7466.30	7559.20
959,999	1,112.04	(161.29)	7656.28	7750.53
979,999	1,095.22	(158.85)	7697.81	7684.28
999,999	1,071.08	(155.35)	7681.79	7796.08
1,019,999	1,049.57	(152.23)	7677.64	7821.54
1,039,999	1,026.61	(148.90)	7657.07	7759.67
1,059,999	984.21	(142.75)	7482.08	7642.30
1,079,999	948.63	(137.59)	7347.61	7491.58
1,099,999	896.24	(129.99)	7070.20	7102.10
1,119,999	811.02	(117.63)	6514.41	6736.92
1,139,999	724.70	(105.11)	5924.85	6232.63
1,159,999	617.83	(89.61)	5139.73	5487.98

10.1.7 *Extrapolating a Failure Point (based on One-Stage Weibull Survivor Function)*—Used for those fatigue test results obtained especially at low strain levels, where the peak value of the Normalized Modulus × Cycles when plotted versus Number of Cycles exceeds the duration of the test. This procedure, per Tsai, Harvey, and Monismith (**4, 5**), uses the following equation:

$$\mathrm{Ln}(-\mathrm{Ln}(\mathrm{SR})) = \gamma \times \mathrm{Ln}(\mathrm{N}) + \mathrm{Ln}(\lambda) \tag{8}$$

where:

Ln(–Ln(SR)) = the natural logarithm of the negative of the natural logarithm of SR,
SR = flexural beam stiffness ratio, beam stiffness at cycle i / initial beam stiffness,
N = number of cycles,

γ = the slope of the linear regression (Fig. 14) of the Ln(–Ln(SR)) versus Ln(N), and
Ln(λ) = the intercept of the linear regression of the Ln(–Ln(SR)) versus Ln(N).

10.1.7.1 The failure point is estimated by solving this equation for the value of N where SR is equal to 0.500 [Ln(–Ln(SR)) = –0.3675], or 50 % initial beam stiffness.

11. Report

11.1 *Asphalt Concrete Description*—Report the binder type, binder content, aggregate gradation, and air void percentage.

11.2 *Specimen Dimensions*—Report the specimen length, average specimen height, and average specimen width in meters, to four significant digits.

NOTE 8—See Practice E29 for information on determination of significant figures in calculations.

11.3 Report the average test temperature to the nearest 0.2°C (0.36°F).

11.4 Report the following test results for each load cycle interval selected by the operator to three significant figures: Applied Load (N), Beam Deflection (m), Tensile Stress (Pa), Tensile Strain (m/m), Flexural Stiffness (MPa), and Normalized Modulus × Cycles (MPa).

11.5 Report the initial flexural stiffness (MPa).

11.6 Report the measured or estimated cycles to failure.

11.7 Prepare a plot of Normalized Complex Modulus × Cycles versus Cycles as shown in Fig. 13.

12. Precision and Bias

12.1 *Precision*—The within-laboratory repeatability standard deviation on log scale has been determined to be 0.278, based on testing in one laboratory, three test replicates at each strain level (ranging from 200 to 2000 με), and eleven different types of mixture specimens. Therefore, the results of two properly conducted tests by the same operator on similar replicate beam specimens in the same equipment at the same strain level should not differ by more than 0.787 on a log scale. Table 3 shows a summary of the data used to generate the within-laboratory standard deviation. This estimate of precision is a combination of both replicate specimen preparation variability and testing variability. The between-laboratory reproducibility of this test method is being determined and will be available on or before June 2013. Therefore, this test method should not be used for acceptance or rejection of a material for purchasing purposes.

12.2 *Bias*—No information can be presented on the bias of this method for measuring fatigue life because this is a destructive test and no material having an accepted reference value is available.

13. Keywords

13.1 asphalt concrete fatigue; asphalt concrete flexural testing; asphalt concrete stiffness; asphalt concrete tensile testing; fatigue life; flexural bending

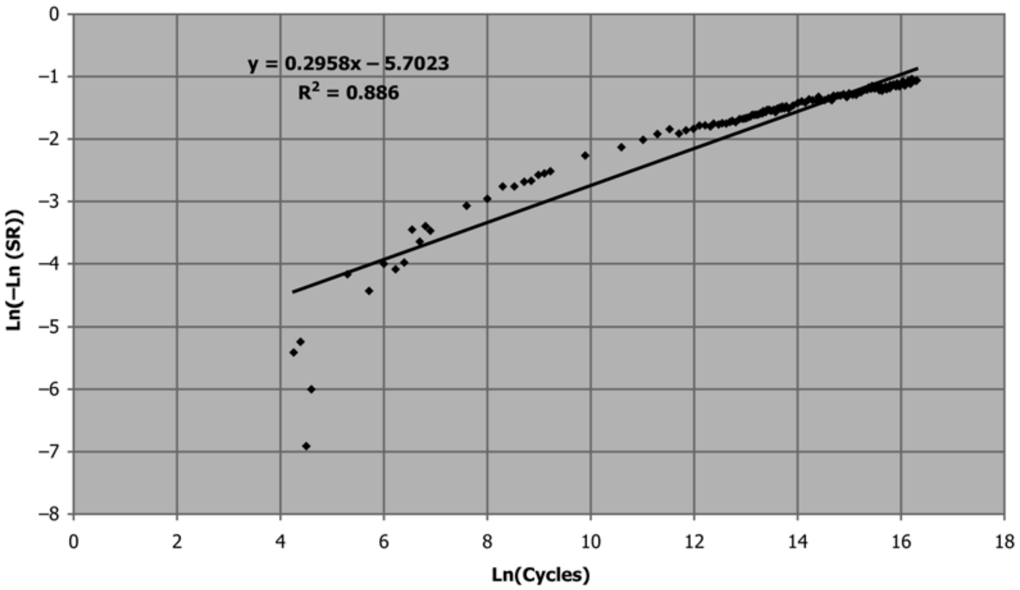


FIG. 14 Example of Linear Regression of Ln(–Ln(SR)) versus Ln(N)

TABLE 3 Single Laboratory Precision Data

Asphalt Concrete Mixture ID	Controlled Strain (micro)	Number of Cycles to Failure	Standard Deviation Number of Cycles to Failure	Log Number of Cycles to Failure	Standard Deviation Log Number of Cycles to Failure
1	300	85 790		4.933	
	300	165 560		5.219	
	300	54 682	57 191	4.738	0.242
2	300	39 392		4.595	
	300	197 160		5.295	
	300	241 360		5.383	
	200	805 800		5.906	
	200	1 190 120	106 172	6.076	0.431
	200	408 320	390 918	5.611	0.235
3	300	192 480		5.284	
	300	24 278		4.385	
	300	48 176		4.683	
	200	966 160		5.985	
	200	1 105 600	91 001	6.044	0.458
	200	306 759	426 693	5.487	0.306
4	300	75 670		4.879	
	300	12 290		4.090	
	300	43 782		4.641	
	200	287 000		5.458	
	200	456 200	31 690	5.659	0.405
	200	179 833	139 339	5.255	0.202
5	800	21 310		4.329	
	800	8780		3.943	
	800	20 674		4.315	
	400	250 960		5.400	
	400	36 656	7058	4.564	0.219
	400	105 440	109 418	5.023	0.418
6	350	222 920		5.348	
	350	555 240		5.744	
	350	582 440	200 180	5.765	0.235
7	2000	417 039		5.620	
	2000	294 039		5.468	
	2000	556 799	131 469	5.746	0.139
8	2000	437 999		5.641	
	2000	218 839		5.340	
	2000	181 479	138 582	5.259	0.202
9	2000	482 559		5.684	
	2000	487 719		5.688	
	2000	281 600	117 542	5.450	0.136
10	2000	186 439		5.271	
	2000	32 737		4.515	
	2000	52 479	83 625	4.720	0.391
11	2000	115 359		5.062	
	2000	210 839		5.324	
	2000	112 299	56 030	5.050	0.155
Average:			139 127		0.278

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