Standard Method of Test for

Determining the Fatigue Life of Compacted Asphalt Mixtures Subjected to Repeated Flexural Bending

AASHTO Designation: T 321-14

AASHTO

1. SCOPE

1.1. This standard provides procedures for determining the fatigue life and fatigue energy of 380 mm long by 50 mm thick by 63 mm wide asphalt mixture beam specimens sawed from laboratory- or field-compacted asphalt mixtures and subjected to repeated flexural bending until failure.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- PP 3, Preparing Hot Mix Asphalt (HMA) Specimens by Means of the Rolling Wheel Compactor[1]
- R 66, Sampling Asphalt Materials
- T 2, Sampling of Aggregates
- T 168, Sampling Bituminous Paving Mixtures
- T 247, Preparation of Test Specimens of Hot Mix Asphalt (HMA) by Means of California Kneading Compactor
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures

2.2. *ASTM Standards*:

- D3549/D3549M, Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D5361/D5361M, Standard Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing
- E29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. TERMINOLOGY

3.1. *Definition*:

3.1.1. *failure point*—the load cycle at which the specimen exhibits a 50 percent reduction in stiffness relative to the initial stiffness.

4. SIGNIFICANCE AND USE

4.1. The fatigue life and failure energy determined by this standard can be used to estimate the fatigue life of asphalt mixture pavement layers under repeated traffic loading. The performance of asphalt mixtures can be more accurately predicted when these properties are known.

5. APPARATUS

5.1. *Test System*—The test system shall consist of a loading device, an environmental chamber (optional), and a control and data acquisition system. The test system shall meet the minimum requirements specified in Table 1.

Table 1—Test System Minimum Requirements

Load measurement and control	Range:	0 to 5 kN
	Resolution:	2 N
	Accuracy:	5 N
Displacement measurement and control	Range:	0 to 5 mm
	Resolution:	2 µm
	Accuracy:	5 µm
Frequency measurement and control	Range:	5 to 10 Hz
	Resolution:	0.005 Hz
	Accuracy:	0.01 Hz
Temperature measurement and control	Range:	–10 to 25°C
	Resolution:	0.25°C
	Accuracy:	±0.5°C

5.1.1. *Loading Device*—The test system shall include a closed-loop, computer-controlled loading component that, 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 strain during each load cycle. The loading device shall be capable of (1) providing repeated sinusoidal loading at a frequency range of 5 to 10 Hz; (2) subjecting specimens to four-point bending with free rotation and horizontal translation at all load and reaction points; and (3) forcing the specimen back to its original position (i.e., zero deflection) at the end of each load pulse. (Figure 1 illustrates the loading conditions.)

5.1.2. *Environmental Chamber (Optional)*—The environmental chamber shall enclose the entire specimen and maintain the specimen at 20.0 ± 0.5°C during testing. An environmental chamber is not required if the temperature of the surrounding environment can be maintained within the specified limits.

5.1.3. *Control and Data Acquisition System*—During each load cycle, the control and data acquisition system shall be capable of measuring the deflection of the beam specimen, computing the strain in the specimen, and adjusting the load applied by the loading device such that the specimen experiences a constant level of strain on each load cycle. In addition, it shall be capable of recording load cycles, applied loads, and beam deflections and computing and recording the maximum tensile stress, maximum tensile strain, phase angle, stiffness, dissipated energy, and cumulative dissipated energy at load cycle intervals specified by the user.

5.2. *Miscellaneous Apparatus and Materials*—A suitable saw for cutting the beams and a mechanism for setting proper clamp spacing. For loading devices that require a glued nut for deformation measurement, a screw, nut (suggested size M 8 by 1) and block assembly for referencing the linear variable differential transducer (LVDT) to the neutral axis of the specimen, and epoxy for attaching the nut to the specimen are also needed.

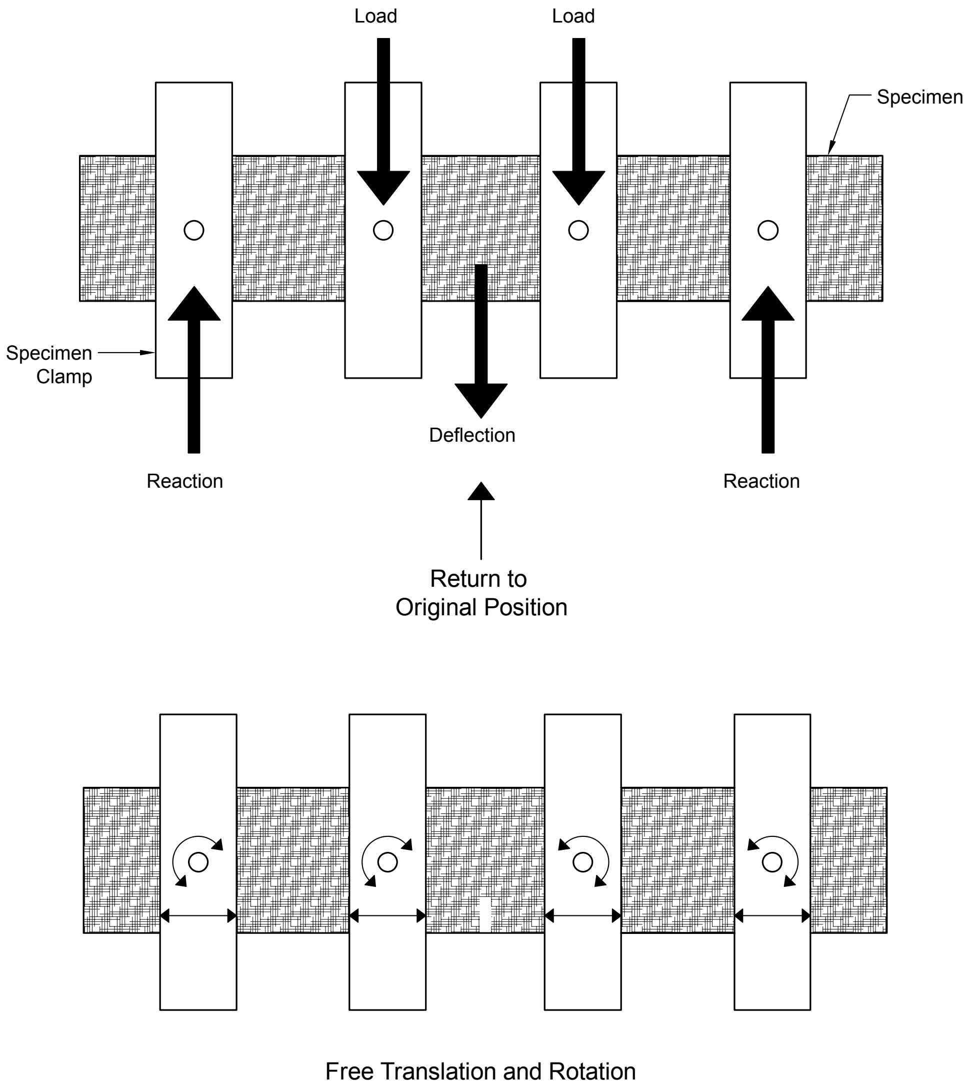


Figure 1—Load and Freedom Characteristics of Fatigue Test Apparatus

6. HAZARDS

6.1. Observe standard laboratory safety precautions when preparing and testing HMA specimens.

7. SAMPLING AND SPECIMEN PREPARATION

7.1. *Laboratory-Mixed and Compacted Specimens*—Sample asphalt binder in accordance with R 66 and sample aggregate in accordance with T 2. Prepare three replicate asphalt mixture beam specimens, from slab(s) or beam(s) compacted in accordance with PP 3 or T 247.

Note 1—The type of compaction device may influence the test results. It is recommended to cut beams from a large slab compacted by a vibratory roller.

Note 2—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 T 269. If specimens are to be compacted to a target air void content, the compactive effort to be used should be determined experimentally.

7.2. *Plant-Mixed, Laboratory-Compacted Specimens*—Obtain asphalt mixture samples in accordance with T 168. Prepare three replicate asphalt mixture beam specimens, from slab(s) or beam(s) compacted in accordance with PP 3 or T 247. (See Notes 1 and 2.)

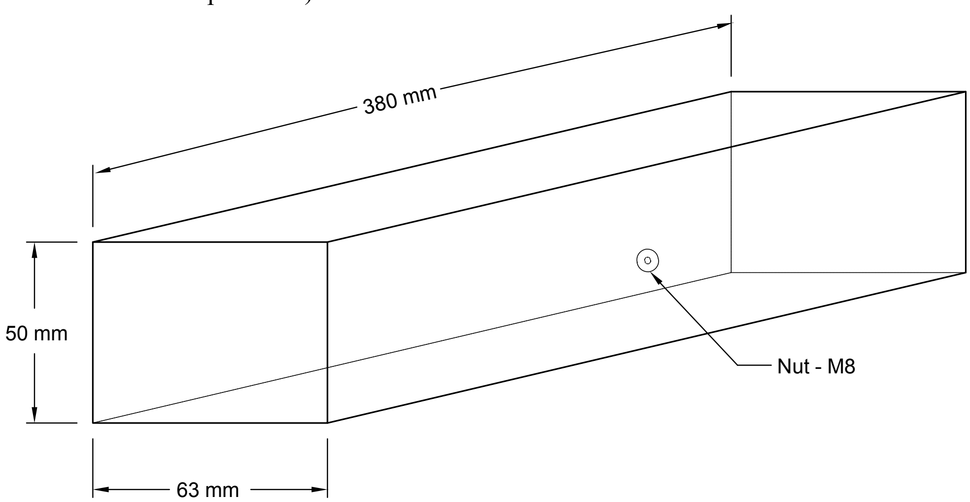
7.3. *Roadway Specimens*—Obtain compacted asphalt mixture samples from the roadway in accordance with ASTM D5361/D5361M.

7.4. Saw at least 6 mm from both sides of each test specimen to provide parallel (saw-cut) surfaces to eliminate high air void sections on the specimen surface. For loading devices that require gluing a nut for deformation measurement, these cut surfaces provide smooth surfaces for mounting the measurement gauges. The final required dimensions, after sawing, of the specimens are 380 ± 6 mm in length, 50 ± 6 mm in height, and 63 ± 6 mm in width.

8. PROCEDURE

8.1. *Specimen Measurement*—Measure the height and width of the specimen to the nearest 0.01 mm at three different points along the middle 100 mm of the specimen length in accordance with applicable sections of ASTM D3549/D3549M. Determine the average of the three measurements for each dimension and record the averages to the nearest 0.1 mm.

8.2. *Epoxying Nut to Neutral Axis of Specimen*—Locate the center of a specimen side. Apply epoxy in a circle around this center point and place the nut on the epoxy such that the center of the nut is over the center point. Avoid applying epoxy such that it fills the center of the nut. Allow the epoxy to cure before moving the specimen. (Figure 2 illustrates a nut epoxied to the neutral axis of the specimen.)



Note: Not to scale

Figure 2—Nut Epoxied to the Neutral Axis

8.3. Place the specimen in an environment that is at 20.0 ± 0.5°C for 2 h to ensure the specimen is at the test temperature prior to beginning the test.

8.4. Open the clamps and slide the specimen into position (Figures 3, 4, and 5). Use the jig to ensure proper horizontal spacing of the clamps, 119 mm center-to-center. When the specimen and clamps are in the proper positions, close the outside clamps by applying sufficient pressure to hold the specimen in place. Next, close the inside clamps by applying sufficient pressure to hold the specimen in place.

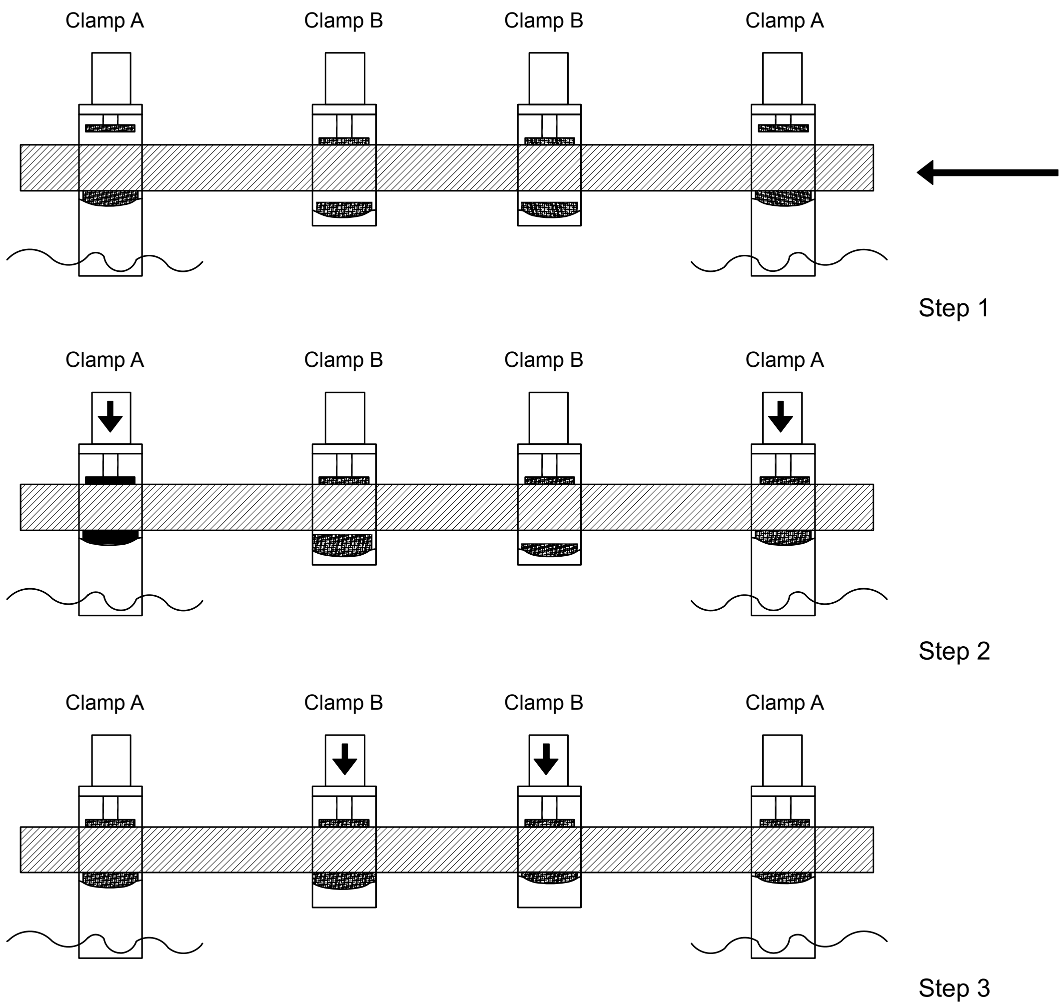


Figure 3—Specimen Clamping Procedure

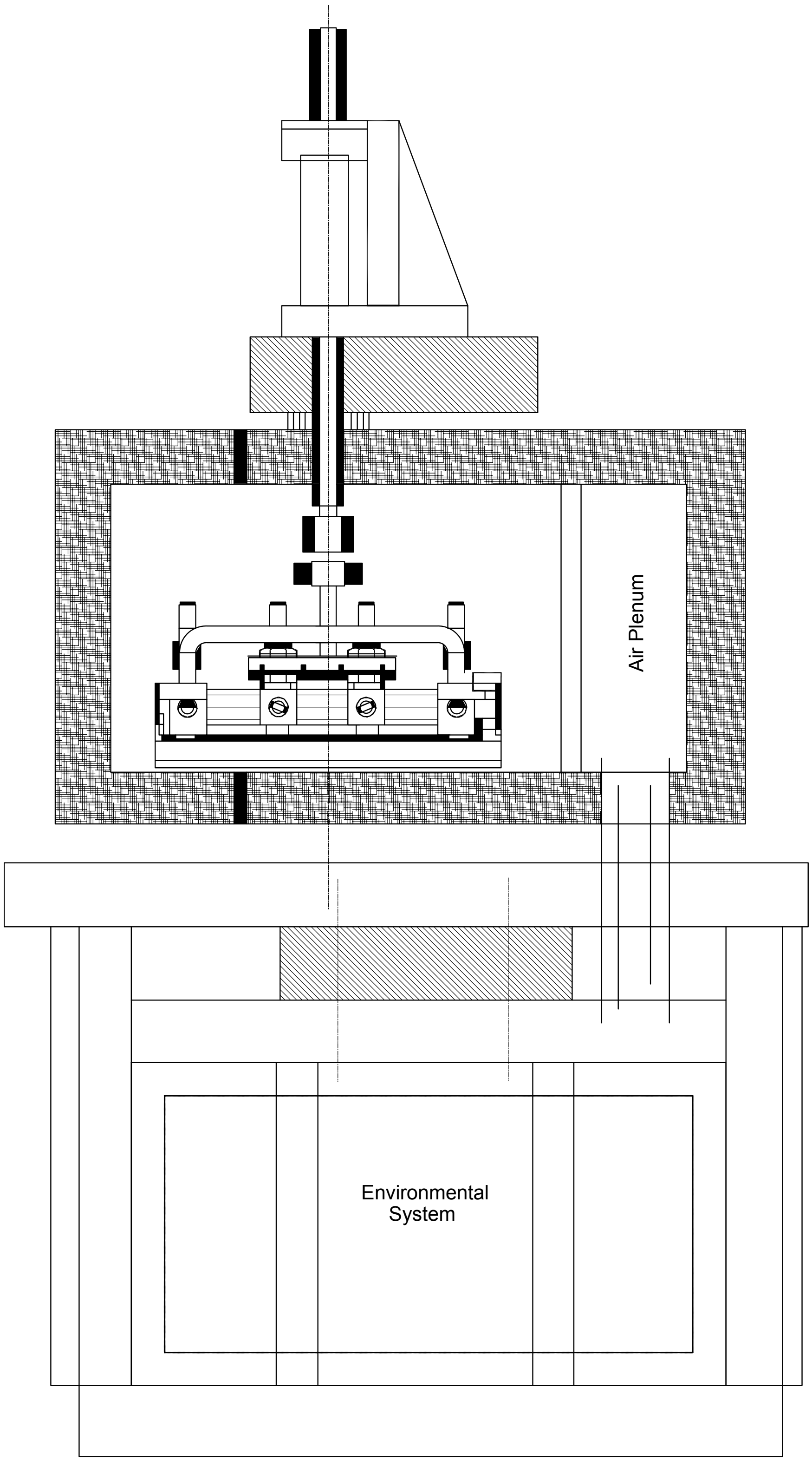


Figure 4—Schematic of Flexural Beam Fatigue Test Apparatus, Side View

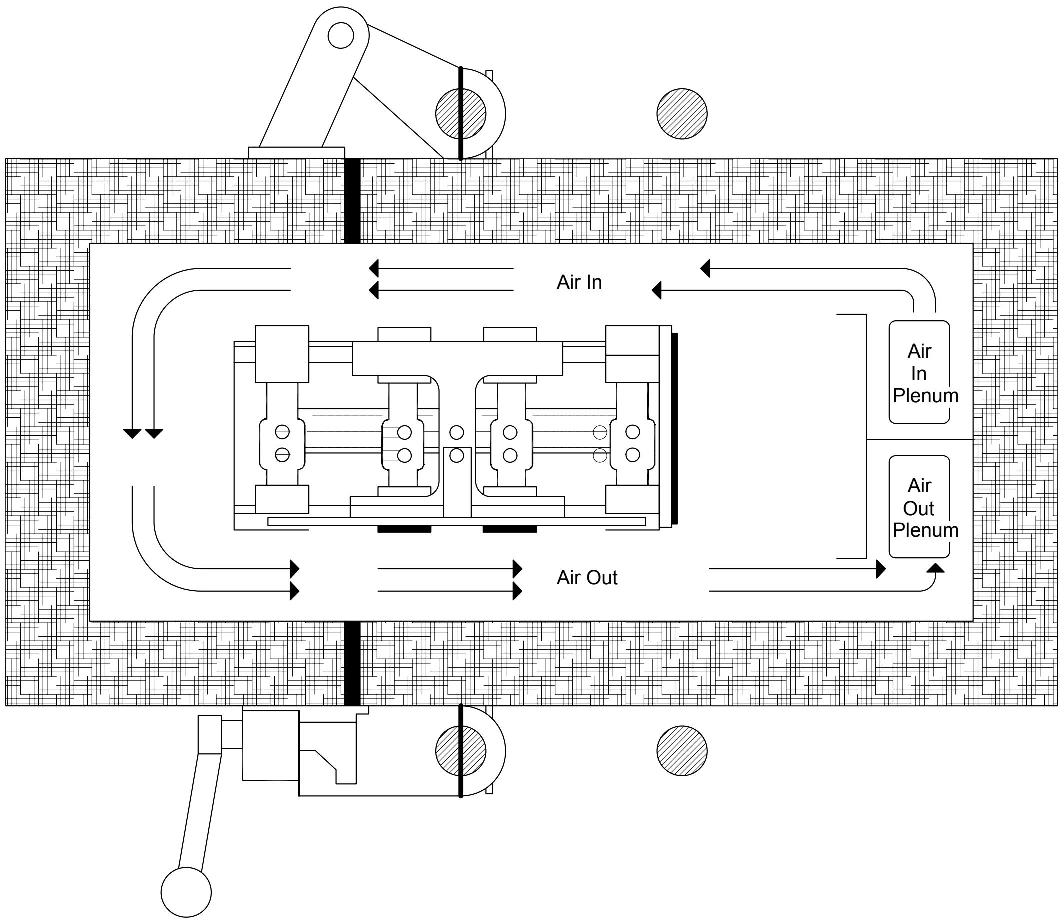


Figure 5—Schematic of Flexural Beam Fatigue Test Apparatus, Top View

8.5. Attach the LVDT block to the specimen by screwing the screw into the nut epoxied on the specimen (see Figure 4). Clamp the LVDT into position such that the LVDT probe rests on top of the block and the LVDT is reading close to zero.

8.6. Select the desired initial peak-to-peak strain (generally in the 250 to 750 microstrain for conventional asphalt mixtures) and loading frequency, and the load cycle intervals at which test results are recorded and computed, and enter them into the recording and control component's test program. In some instances, with highly modified materials for specialized applications, testing has been conducted with initial peak-to-peak strains as high as 2000 microstrain. Set the loading frequency within a range of 5 to 10 Hz.

Note 3—The data collection sequence should ensure that at least 200 data points are captured within each log decade of loading and that these should enable a smooth curve of flexural stiffness versus load cycles to be obtained. The collection sequence shall include data capture at cycle 50.

8.7. Select a deflection level (peak-to-peak strain level) such that the specimen will undergo a minimum of 10,000 load cycles before its stiffness is reduced to a condition that represents specimen failure. A minimum of 10,000 load cycles ensures that the specimen does not decrease in stiffness too rapidly.

Note 4—A test of 10,000 load cycles at 10 Hz will take 17 min to conduct once the test is started. A practical upper limit on the test time would correspond to around 1 day, during which approximately 1 million load applications can be achieved (around 28 h). Data in this range can be used to produce a relationship between strain and life to failure. Some trial and error may be required to estimate the strain levels to achieve these testing times. If an estimation of endurance limit is required, then additional testing beyond 1 million cycles is needed. Some methods suggest that tests as long as 10 million cycles may be required.

8.8. After selecting the appropriate test parameters, begin the test. Activate the recording and control components so that the test results at the selected load cycle intervals are monitored and recorded, ensuring that the test system is operating properly.

8.9. Determine at all load cycles the flexural stiffness and phase lag at each load cycle throughout the test while the test is being performed as follows:

8.9.1. *Maximum Peak-to-Peak Stress (Pa)*:

$$\sigma_t = (0.357P)/(bh^2) \quad (1)$$

where:

P = peak-to-peak load applied by actuator, N;

b = average specimen width, m; and

h = average specimen height, m.

8.9.2. *Maximum Peak-to-Peak Strain (m/m)*:

$$\epsilon_t = (12\delta h)/(3L^2 - 4a^2) \quad (2)$$

where:

δ = maximum peak-to-peak deflection at center of beam, m;

a = space between inside clamps, 0.357/3 m, (0.119 m); and

L = length of beam between outside clamps, 0.357 m.

8.9.3. *Flexural Stiffness (Pa)*:

$$S = \sigma_t / \epsilon_t \quad (3)$$

8.9.4. *Phase Angle (deg)*:

$$\varphi = 360fs \quad (4)$$

where:

f = load frequency, Hz; and

s = time lag between P_{max} and δ_{max}, s.

Note 5—When automated testing software is used in the recording and control component of the test system, φ is approximated by an algorithm contained in the automated testing software.

8.10. For each load cycle at which data are collected, compute the product of the flexural stiffness and load cycles ($S \times n$).

8.11. Terminate the data collection and stop the test after a point where the computed $S \times n$ has reduced from a peak value by 15 percent

9. CALCULATIONS

9.1. *Cycles to Failure*—Failure is defined as the point at which the product of the specimen stiffness and loading cycles is a maximum.

Note 6—The use of appropriate data smoothing methods, such as fitting six-order polynomials and cubic splines to the $S \times n$ curve, have been used to smooth out any irregularities in the data collection.

10. REPORT

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

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

Note 7—See ASTM E29 for information on determination of significant figures in calculations.

10.3. Report the average test temperature to the nearest 0.2°C.

10.4. Report the test results listed in Table 2 for each load cycle interval selected by the operator to three significant figures.

Table 2—Test Results

Load Cycle	Applied Load	Beam Deflection	Peak-to-Peak Stress	Peak-to-Peak Strain	Flexural Stiffness	Phase Angle	$S \times n$
	N	m	Pa	m/m	MPa	degree	

10.5. Report the flexural stiffness at cycle 50 in MPa.

10.6. Report the cycles to failure.

10.7. Report the flexural stiffness at the failure cycle.

10.8. Prepare a plot of stiffness versus load cycles as shown in Figure 6 and the $S \times n$ versus load cycles as shown in Figure 7.

10.9. When multiple test results are conducted at a single strain level, the average of the results shall be calculated by averaging the logarithm (base 10) of the numbers.

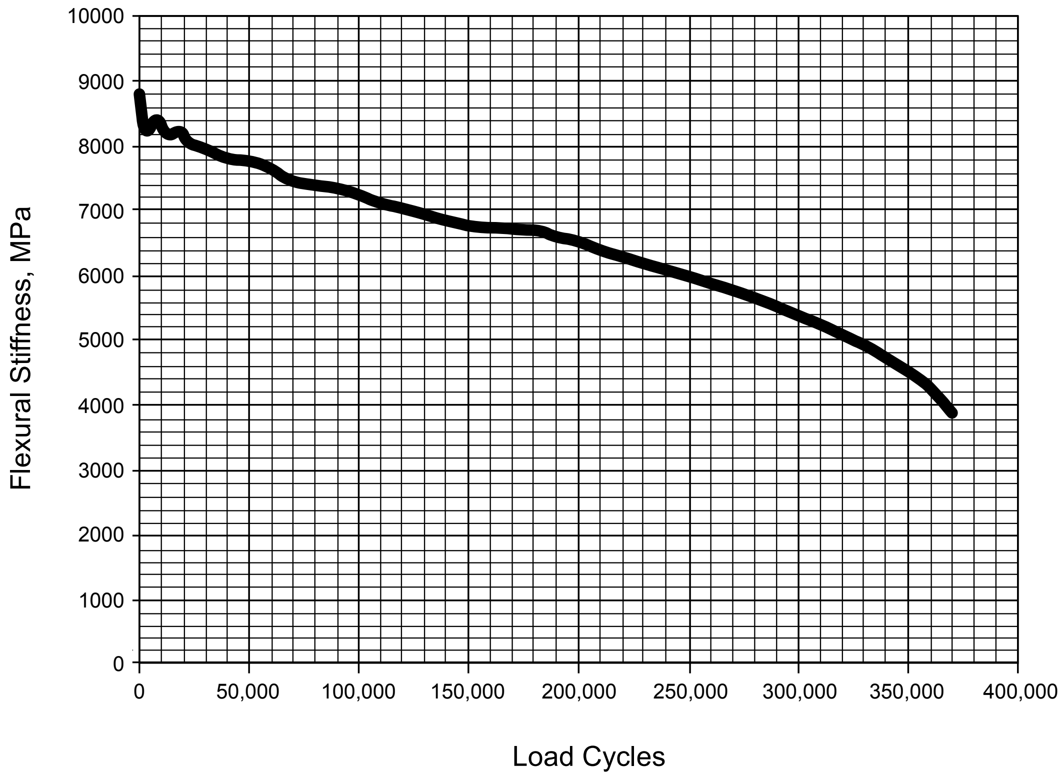


Figure 6—Stiffness versus Load Cycles

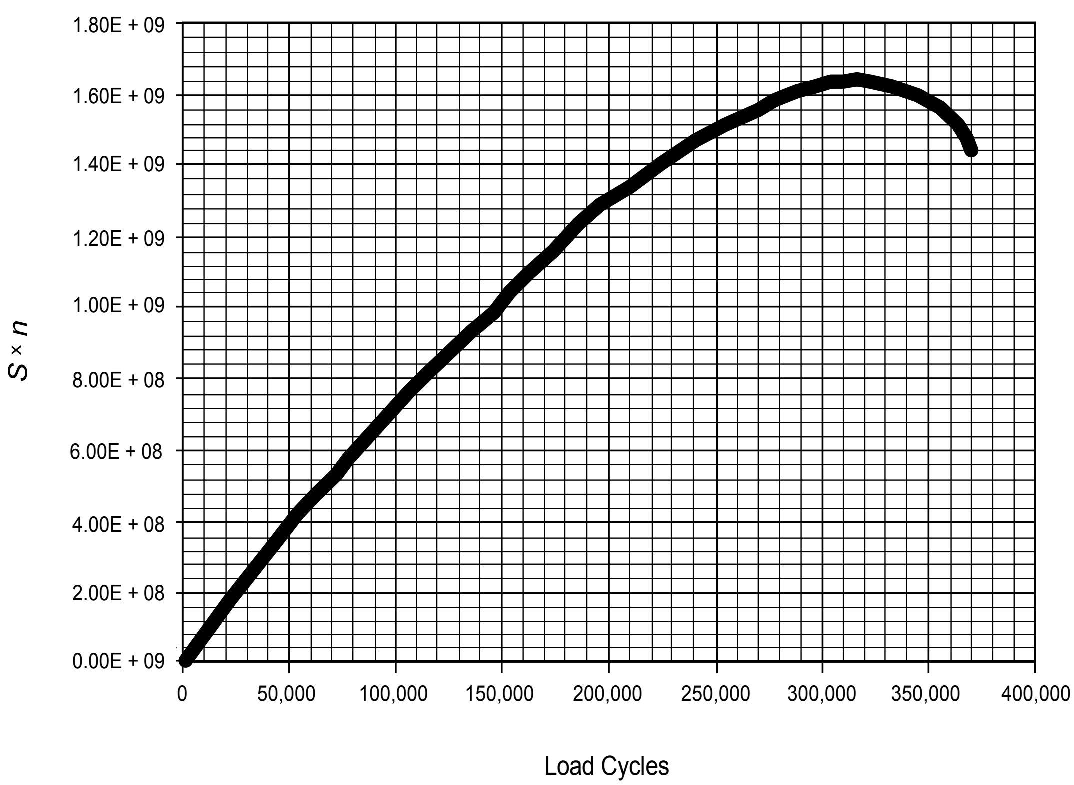


Figure 7—$S \times n$ versus Load Cycles

11. PRECISION AND BIAS

11.1. *Precision*—The research required to develop precision values has not been conducted.

11.2. *Bias*—The research required to establish the bias of this method has not been conducted.

12. KEYWORDS

12.1. Asphalt mixtures energy dissipation; asphalt mixtures fatigue; asphalt mixtures flexural testing; asphalt mixtures stiffness; asphalt mixtures tensile testing; fatigue life; flexural bending.