Standard Method of Test for

Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)

AASHTO Designation: T 313-12

AASHTO

1. SCOPE

1.1. This test method covers the determination of the flexural creep stiffness or compliance of asphalt binders by means of a bending beam rheometer. It is applicable to material having a flexural stiffness value from 20 MPa to 1 GPa (creep compliance values in the range of 50 nPa–1 to 1 nPa–1) and can be used with unaged material or with material aged using T 240 (RTFOT) or R 28 (PAV), or both. The test apparatus is designed for testing within the temperature range from –36 to 0°C.

1.2. Test results are not valid for beams of asphalt binder that deflect more than 4 mm, or less than 0.08 mm, when tested in accordance with this method.

1.3. *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*:

- M 320, Performance-Graded Asphalt Binder
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- R 66, Sampling Asphalt Materials
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)

2.2. *ASTM Standards*:

- C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C802, Standard Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials
- E77, Standard Test Method for Inspection and Verification of Thermometers
- E220, Standard Test Method for Calibration of Thermocouples By Comparison Techniques

2.3. *Deutsche Industrie Norm (DIN) Standard*:

- 43760, Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors

2.4. *NCHRP Document*:

- NCHRP Web-Only Document 71 (Project 09-26), Precision Estimates for AASHTO Test Method T 308 and the Test Methods for Performance-Graded Asphalt Binder in AASHTO Specification M 320

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of nonparticulate organic modifiers.

3.1.2. *physical hardening*—a time-dependent stiffening of asphalt binder that results from the time-delayed increase in stiffness when the asphalt binder is stored at low temperatures. The increase in stiffness due to physical hardening is reversible when the temperature is raised.

3.2. *Descriptions of Terms Specific to This Standard*:

3.2.1. *flexural creep*—a test in which a simply supported asphalt binder prismatic beam is loaded with a constant load at its midpoint and the deflection of the beam is measured with respect to loading time.

3.2.2. *measured flexural creep stiffness,* $S_m(t)$—ratio obtained by dividing the maximum bending stress in the beam by the maximum bending strain.

3.2.3. *estimated creep stiffness,* $S(t)$—the creep stiffness obtained by fitting a second-order polynomial to the logarithm of the measured stiffness at 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 s and the logarithm of time.

3.2.4. *flexural creep compliance,* $D(t)$—ratio obtained by dividing the maximum bending strain in the beam by maximum bending stress. $D(t)$ is the inverse of $S(t)$. $S(t)$ has been used historically in asphalt technology, while $D(t)$ is commonly used in studies of viscoelasticity.

3.2.5. *m-value*—absolute value of the slope of the logarithm of the stiffness curves versus the logarithm of the time.

3.2.6. *contact load*—load required to maintain positive contact between the beam and the loading shaft; 35 ± 10 mN.

3.2.7. *seating load*—load of 1-s duration required to seat the beam; 980 ± 50 mN.

3.2.8. *test load*—load of 240-s duration required to determine the stiffness of material being tested; 980 ± 50 mN.

3.2.9. *testing zero time, s*—time at which the signal is sent to the solenoid valve to switch from zero load regulator (contact load) to the testing load regulator (test load).

4. SUMMARY OF TEST METHOD

4.1. The bending beam rheometer measures the midpoint deflection of a simply supported beam of asphalt binder subjected to a constant load applied to the midpoint of the beam. The device operates only in the loading mode; recovery measurements are not obtained.

4.2. A test beam is placed in the controlled temperature fluid bath and loaded with a constant load for 240 s. The test load (980 ± 50 mN) and the midpoint of deflection of the beam are monitored versus time using a computerized data acquisition system.

4.3. The maximum bending stress at the midpoint of the beam is calculated from the dimensions of the beam, the span length, and the load applied to the beam for loading times of 8, 15, 30, 60, 120, and 240 s. The maximum bending strain in the beam is calculated for the same loading times from the dimensions of the beam and the deflection of the beam. The stiffness of the beam for the loading times specified above is calculated by dividing the maximum stress by the maximum strain.

4.4. The load and deflection at 0.0 and 0.5 s are reported to verify that the full-testing load (980 ± 50 mN) during the test is applied within the first 0.5 s. They are not used in the calculation of stiffness and *m*-value and should not be considered to represent material properties. The rise time of the load (time to apply full load) can be affected by improper operation of the pressure regulators, improper air bearing pressure, malfunctioning air bearing (friction), and other factors. By reporting the 0.0- and 0.5-s signals, the user of the test results can determine the conditions of the loading.

5. SIGNIFICANCE AND USE

5.1. The test temperature for this test is related to the temperature experienced by the pavement in the geographical area for which the asphalt binder is intended.

5.2. The flexural creep stiffness or flexural creep compliance, determined from this test, describes the low-temperature, stress–strain–time response of asphalt binder at the test temperature within the linear viscoelastic response range.

5.3. The low-temperature thermal cracking performance of paving mixtures is related to the creep stiffness and the slope of the logarithm of the creep stiffness versus the logarithm of the time curve of the asphalt binder contained in the mix.

5.4. The creep stiffness and the slope of the logarithm of the stiffness versus the logarithm of the time curve are used as performance-based specification criteria for asphalt binders in accordance with M 320.

6. APPARATUS

6.1. *Bending Beam Rheometer (BBR) Test System*—A bending beam rheometer (BBR) test system consisting of (1) a loading frame that permits the test beam, supports, and the lower part of the test frame to be submerged in a constant temperature fluid bath; (2) a controlled-temperature liquid bath that maintains the test beam at the test temperature and provides a buoyant force to counterbalance the force resulting from the mass of the beam; (3) a computer-controlled automated data acquisition component; (4) specimen molds; and (5) items needed to calibrate and/or verify the BBR.

6.1.1. *Loading Frame*—A frame consisting of a set of sample supports, a blunt-nosed shaft that applies the load to the midpoint of the test specimen, a load cell mounted on the loading shaft, a means for zoering the load on the test specimen, a means for applying a constant load to the loading shaft, and a deflection measuring transducer attached to the loading shaft. A schematic of the device is shown in Figure 1.

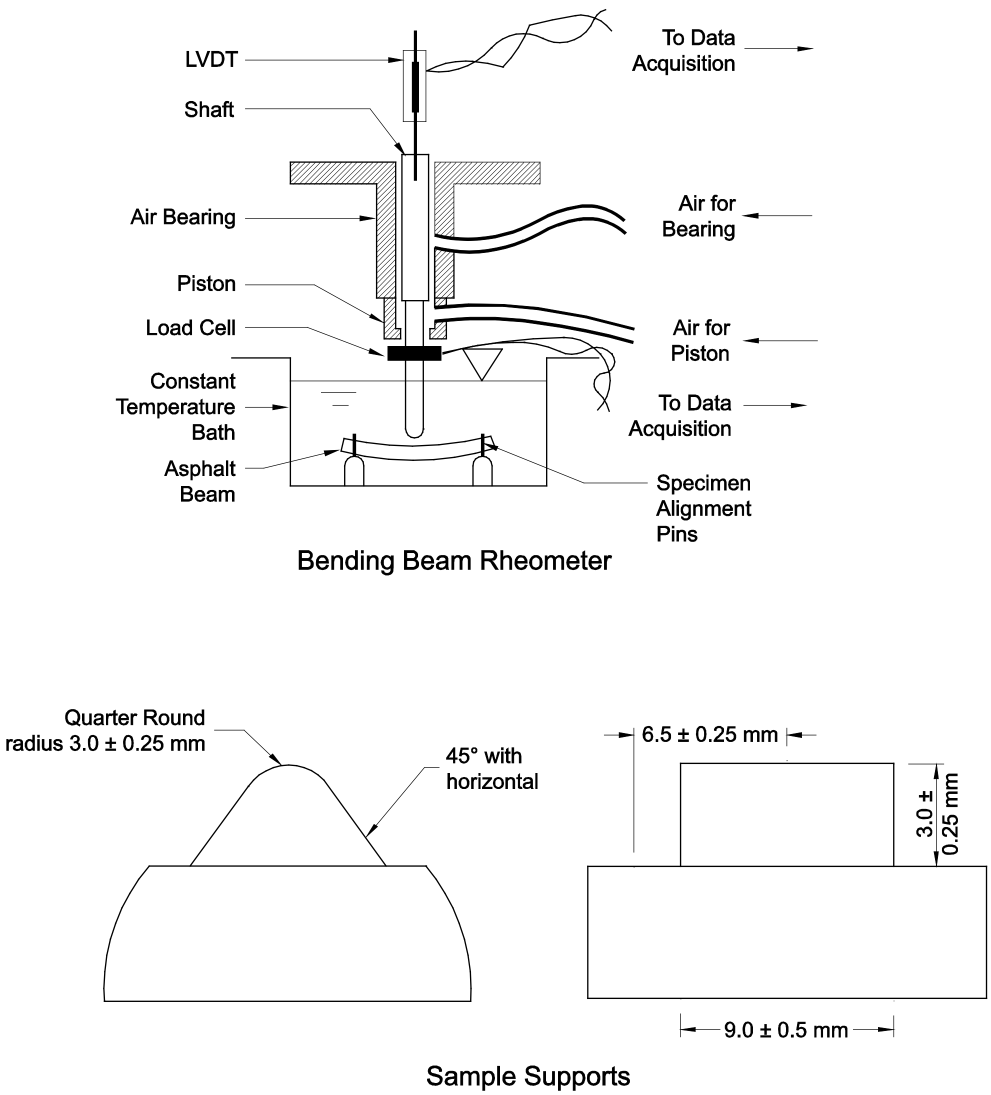

Figure 1—Schematic of the Bending Beam Rheometer

6.1.1.1. *Loading System*—A loading system that is capable of applying a contact load of 35 ± 10 mN to the test specimen and maintaining a test load of 980 ± 50 mN.

6.1.1.2. *Loading System Requirements*—The rise time for the test load shall be less than 0.5 s. The rise time is the time required for the load to rise from the 35 ± 10 mN contact load to the 980 ± 50 mN test load. During the rise time, the system shall dampen the test load to 980 ± 50 mN. Between 0.5 and 5.0 s, the test load shall be within ±50 mN of the average test load, and thereafter shall be within ±10 mN of the average test load.

6.1.1.3. *Sample Supports*—Sample supports with specimen support strips 3.0 ± 0.30 mm in top radius and inclined at an angle of 45 degrees with the horizontal (see Figure 1). The supports, made of stainless steel (or other corrosion-resistant metal), are spaced 102.0 ± 1.0 mm apart. The width of the supporting area of the supporting strips shall be 9.5 ± 0.25 mm. This is required to ensure that the edges of the specimen, resulting from the molding procedure, do not interfere with the mid-span deflection of the specimen measured during testing. The supports shall also include vertical alignment pins 2 to 4 mm in diameter placed at the back of each sample supports at 6.75 ± 0.25 mm from the center of the supports. These pins should be placed on the back side of the support to align the specimen on the center of the supports. See Figure 1 for details.

6.1.1.4. *Loading Shaft*—A blunt-nosed loading shaft (with a spherical contact point 6.25 (±0.30) mm in radius) continuous with a load cell and a deflection measuring transducer that is capable of applying a contact load of 35 ± 10 mN and maintaining a test load of 980 ± 50 mN. The rise time for the test load shall be less than 0.5 s where the rise time is the time required for the load to rise from the 35 ± 10 mN preload to the 980 ± 50 mN test load. During the rise time, the system shall dampen the test load after the first 5 s to a constant ±10-mN value.

6.1.1.5. *Load Cell*—A load cell with a minimum capacity of 2000 mN, having a minimum resolution of 2.5 mN mounted in-line with the loading shaft and above the fluid to measure the contact load and the test load.

6.1.1.6. *Linear Variable Differential Transducer (LVDT)*—A linear variable differential transducer or other suitable mounted device mounted axially above the loading shaft capable of resolving a linear movement ≤ 2.5 μm with a range of at least 6 mm to measure the deflection of the test beam.

6.1.2. *Controlled-Temperature Fluid Bath*—A controlled-temperature liquid bath capable of maintaining the temperature at all points within the bath between –36 and 0°C within ±0.1°C. Placing a cold specimen in the bath may cause the bath temperature to fluctuate ±0.2°C from the target test temperature; consequently, bath fluctuations of ±0.2°C during isothermal conditioning shall be allowed.

6.1.2.1. *Bath Agitator*—A bath agitator for maintaining the required temperature homogeneity with agitator intensity such that the fluid current does not disturb the testing process, and mechanical noise caused by vibrations is less than the resolution specified in Sections 6.1.3 and 6.1.3.1.

6.1.2.2. *Circulating Bath (Optional)*—A circulating bath unit separate from the test frame that pumps the bath fluid through the test bath. If used, vibrations from the circulating system shall be isolated from the bath test chamber so that mechanical noise is less than the resolution specified in Sections 6.1.3 and 6.1.3.1.

6.1.3. *Data Acquisition System*—A data acquisition system that resolves loads to the nearest 2.5 mN, beam deflection to the nearest 2.5 μm, and bath fluid temperature to the nearest 0.1°C. The system shall sense the point in time when the signal is sent to the solenoid valve(s) to switch from zero load regulator (contact load) to the testing load regulator (test load). This is zero time. Using this time as a reference, the system shall provide a record of load and deflection measurements relative to this time. The system shall record the load and deflection at the loading times of 0.0, 0.5, 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 s. All readings shall be an average of three or more points within ±0.2 s from the loading time, e.g., for a loading time of 7.8, 7.9, 8.0, 8.1, and 8.2 s.

6.1.3.1. *Signal Filtering*—Digital or analog smoothing of the load and the deflection data may be required to eliminate electronic noise that could otherwise affect the ability of the second-order polynomial to fit the data with sufficient accuracy to provide a reliable estimate of *m*-value. The load and deflection signals may be filtered with a low-pass analog or digital filter that removes signals of greater than 4-Hz frequency. The averaging shall be over a time period less than or equal to ±0.2 s of the reporting time.

6.2. *Temperature Measuring Equipment*—A calibrated temperature transducer capable of measuring the temperature to 0.1°C over the range of –36 to 0°C mounted within 50 mm of the midpoint of the test specimen supports.

Note 1—Required temperature measurement can be accomplished with an appropriately calibrated platinum resistance thermometer (RTD) or a thermistor. Calibrations of an RTD or thermistor can be verified as per Section 6.6. An RTD meeting DIN Standard 43760 (Class A) is recommended for this purpose. The required precision and accuracy cannot be obtained unless each RTD is calibrated as a system with its respective meter or electronic circuitry.

6.3. *Test Beam Molds*—Test beam molds of suitable dimensions to yield demolded test beam 6.35 ± 0.05 mm thick by 12.70 ± 0.05 mm wide by 127 ± 2.0 mm long, fabricated from aluminum flat stock as shown in Figure 2.

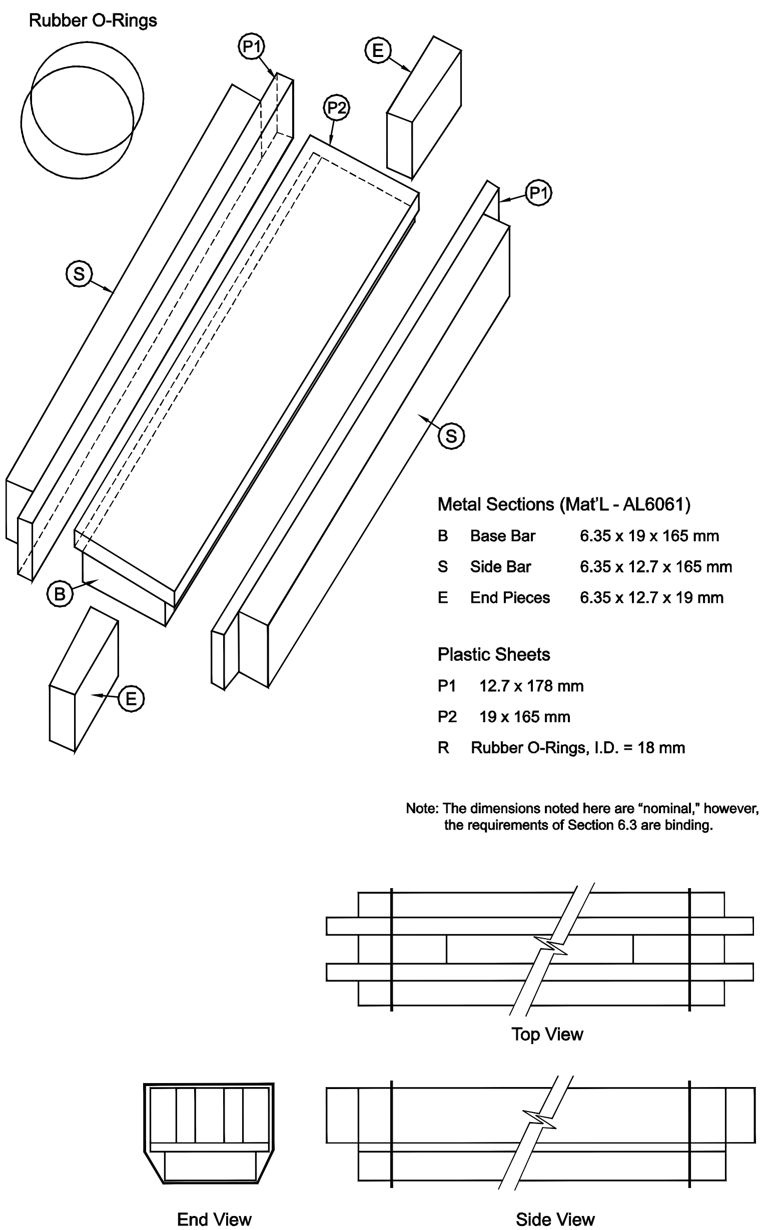

Figure 2—Dimensions and Specifications for Aluminum Molds

6.3.1. The thickness of the two spacers used for each mold (small end pieces used in the metal molds) shall be measured with a micrometer and shall not vary from each other in thickness by more than 0.05 mm.

Note 2—Small errors in the thickness of the test specimen can have a large effect on the calculated modulus because the calculated modulus is a function of the thickness, *h*, raised to the third power.

6.4. *Items for Calibration or Verification*—The following items are required to verify and calibrate the BBR.

6.4.1. *Stainless Steel (Thick) Beam for Compliance Measurement and Load Cell Calibration*—One stainless steel beam, 6.4 ± 0.1 mm thick by 12.7 ± 0.25 mm wide by 127 ± 5 mm long, for measuring system compliance and calibrating the load cell.

6.4.2. *Stainless Steel (Thin) Beam for Overall System Check*—One stainless steel beam, 1.3 ± 0.3 mm thick by 12.7 ± 0.1 mm wide by 127 ± 5 mm long, with an elastic modulus reported to three significant figures by the manufacturer. The manufacturer shall measure and report the thickness of this beam to the nearest 0.01 mm and the width to the nearest 0.05 mm. The dimensions of the beam shall be used to calculate the modulus of the beam during the overall system check. See Section 10.1.2.1.

6.5. *Standard Masses*—One or more standard masses are required as follows:

6.5.1. *Verification of Load Cell Calibration*—One or more masses totaling 100.0 ± 0.2 g and two masses of 2.0 ± 0.2 g each (see Note 3) for verifying the calibration of the load cell.

Note 3—Any suitable object may be used if the mass is confirmed to be 2.0 ± 0.2 g.

6.5.2. *Calibration of Load Cell*—Four masses, each of known mass ±0.2 g, and equally spaced in mass over the range of the load cell.

6.5.3. *Daily Overall System Check*—Two or more masses, each of known mass to 0.2 g, for conducting overall system check as specified by the manufacturer.

6.5.4. *Accuracy of Masses*—Accuracy of the masses in Section 6.5 shall be verified at least once each every three years.

6.6. *Calibrated Thermometers*—Calibrated liquid-in-glass thermometers for verification of the temperature transducer of suitable range with subdivisions of 0.1°C. These thermometers shall be partial immersion thermometers with an ice point and shall be calibrated in accordance with Test Method E77 at least once per year. A suitable thermometer is designated 133C. An electronic thermometer of equal accuracy and resolution may be used.

6.7. *Thickness Gauge*—A stepped thickness gauge for verifying the calibrations of displacement transducer as described in Figure 3.

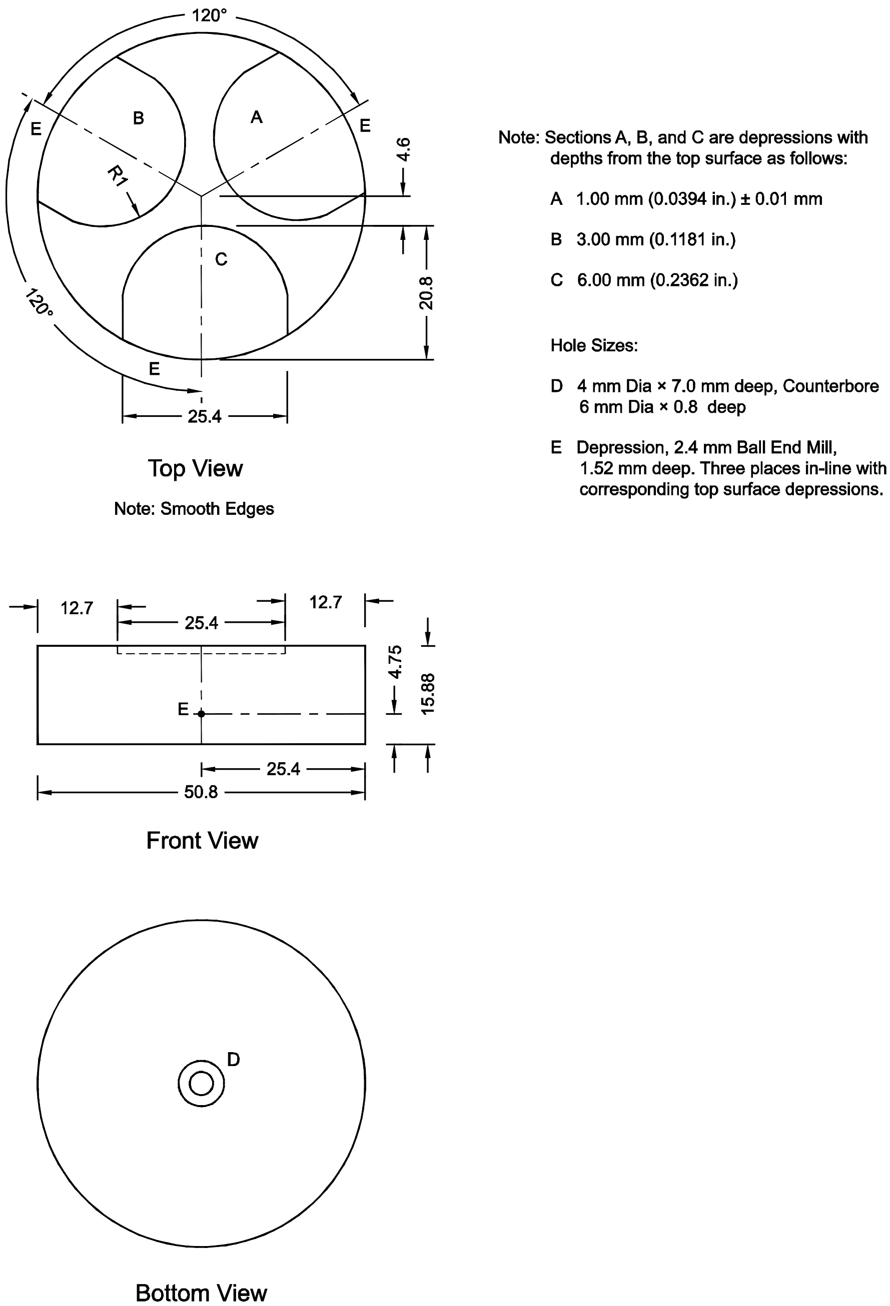

Figure 3—Typical Thickness Gauge Used to Calibrate Deflection Detector

7. MATERIALS

7.1. *Plastic Sheeting*—Clear plastic sheeting, 0.12 ± 0.04 mm thick, for lining the interior faces of the three long aluminum mold sections. Sheeting should not be distorted by hot asphalt binder.

Note 4—Transparency film sold for use with laser printers has been found suitable.

7.2. *Petroleum-Based Grease*—A petroleum-based grease used to hold the plastic strips to the interior faces of the three long aluminum mold sections.

Note 5—**Warning**: Do not use any silicone-based products.

7.3. *Glycerol-Talc Mixture*—Used to coat the end pieces of aluminum molds.

Note 6—A mixture of 50 percent by weight USP grade glycerin and 50 percent USP grade talc or kaolin (china clay) is suitable for this purpose.

7.4. *Bath Fluid*—A bath fluid that is not absorbed by or does not affect the properties of the asphalt binder tested. The mass density of the bath fluid shall not exceed 1.05 g/cm^3 at testing temperatures. The bath fluid shall be optically clear at all testing temperatures. Silicone fluids or mixtures containing silicones shall not be used.

Note 7—Suitable bath fluids include ethanol, methanol, and glycol–methanol mixtures (e.g., 60 percent glycol, 15 percent methanol, 25 percent water).

8. HAZARDS

8.1. Observe standard laboratory safety procedures when handling hot asphalt binder and preparing test specimens.

8.2. Alcohol baths are flammable and toxic. Locate the controlled temperature bath in a well-ventilated area away from sources of ignition. Avoid breathing alcohol vapors and contact of the bath fluid with the skin.

8.3. Contact between the bath fluid and skin at the lower temperatures used in this test method can cause frostbite.

9. PREPARATION OF APPARATUS

9.1. Clean the supports, loading head, and bath fluid of any particulates and coatings as necessary.

Note 8—Because of the brittleness of asphalt binder at the specified test temperatures, small fragments of asphalt binder can be introduced into the bath fluid. If these fragments are present on the supports or the loading head, the measured deflection will be affected. The small fragments, because of their small size, will deform under load and add an apparent deflection of the beam. Filtration of the bath fluid will aid in preserving the required cleanliness.

9.2. Select the test temperature and adjust the bath fluid to the selected temperature. Wait until the temperature stabilizes and then allow the bath to equilibrate to the test temperature ±0.1°C prior to conducting a test.

9.3. Activate the data acquisition system and load the software as explained in the manufacturer's manual for the test system.

10. STANDARDIZATION

10.1. Verify the calibration of the displacement transducer, load cell, and temperature transducer as described in Sections 10.1.1 through 10.1.6. As a minimum, each of the verification steps and their frequency of performance shall be performed as described in this section. Additional verification steps may be performed at the recommendation of the manufacturer. Calibration procedures are described in the Annex. At the option of the manufacturer, the verification and calibration steps may be combined.

10.1.1. *Verification of Temperature Transducer*—On each day, before conducting tests, and whenever the test temperature is changed, verify calibration of the temperature detector by using a calibrated thermometer as described in Section 6.6. With the loading frame placed in the liquid bath, immerse the thermometer in the liquid bath close to the temperature transducer, and compare the temperature indicated by the thermometer to the temperature displayed by the data acquisition system. If the temperature indicated by the data acquisition system does not agree with the thermometer within ±0.1°C, calibration is required.

10.1.2. *Verification of Freely Operating Air Bearing*—On each day, before conducting tests, verify that the air bearing is operating freely and is free of friction. Sections 10.1.2.1 and 10.1.2.2 shall be used to verify that the shaft is free of friction. If the requirements of Sections 10.1.2.1 and 10.1.2.2 are not satisfied, friction is present in the air bearing. Clean the shaft, and adjust the clearance of the displacement transducer as per the manufacturer's instructions. If this does not eliminate the friction, discontinue use of the BBR and consult the manufacturer.

Note 9—Friction may be caused by a poorly adjusted displacement transducer core that rubs against its housing, an accumulation of asphalt binder on the loading shaft, by oil or other particulates in the air supply, and other causes.

10.1.2.1. Place the thin steel beam (Section 6.4.2) on the sample supports, and apply a 35 ± 10-mN load to the beam using the zero load regulator. Observe the reading of the LVDT as indicated by the data acquisition system. Gently grasp the shaft, and lift it upward approximately 5 mm by observing the reading of the LVDT. When the shaft is released, it shall immediately float downward and make contact with the beam.

10.1.2.2. Remove any beams from the supports. Use the zero load regulator to adjust the loading shaft so that it is free-floating at the approximate midpoint of its vertical travel. Gently add a 2-g mass to the loading shelf. The shaft shall slowly drop downward under the mass.

10.1.3. *Verification of Displacement Transducer*—On each day, before conducting tests, verify the calibration of the displacement transducer using a stepped gauge block of known dimensions similar to the one shown in Figure 3. With the loading frame mounted in the bath at the test temperature, remove all beams from the supports, and place the gauge block on a reference platform underneath the loading shaft according to the instructions supplied by the instrument manufacturer. Apply a 100.0 ± 0.2-g mass to the loading shaft, and measure the rise of the steps with the displacement transducer. Compare the measured values as indicated by the data acquisition system with the known dimensions of the gauge. If the known dimensions as determined from the gauge block and the dimensions indicated by the data acquisition system differ by more than ±5 μm, calibration is required. Perform the calibration, and repeat Section 10.1.1. If the requirements of Section 10.1.1 cannot be met after calibration, discontinue use of the device, and consult the manufacturer.

10.1.4. *Daily Overall System Check*—On each day, before conducting tests and with the loading frame mounted in the bath, perform a check on the overall operation of the system. Place the 1.3 ± 0.3-mm-thick stainless steel (thin) beam of known modulus as described in Section 6.4.2 on the sample supports. Following the instructions supplied by the manufacturer, place the beam on the supports and apply a 50.0 or 100.0 ± 0.2-g initial mass (491 or 981 mN ± 2 mN) to the beam to ensure that the beam is seated and in full contact with the supports. Following the manufacturer's instructions, apply a second additional load of 100.0 to 300.0 ± 0.2 g to the beam. The software provided by the manufacturer shall use the change in load and associated change in deflection to calculate the modulus of the beam to three significant figures. The modulus reported by the software shall be within 10 percent of the modulus reported by the manufacturer of the beam; otherwise, the overall operation of the BBR shall be considered suspect and the manufacturer shall be consulted.

10.1.5. *Verification of Load Cell*—Verify the calibration of the load cell as follows:

10.1.5.1. *Contact Load*—On each day, verify the calibration of the load cell in the range of the contact load. Place the 6.4-mm-thick stainless steel compliance beam (Section 6.4.1) on the supports. Apply a 20 ± 10-mN load to the beam using the zero load pressure regulator. Add the 2.0 ± 0.2-g mass as specified in Section 6.5.1 to the loading platform. The increase in the load displayed by the data acquisition system shall be 20 ± 5 mN. Add a second 2.0 ± 0.2-g mass to the loading platform. The increase in the load displayed by the data acquisition system shall be 20 ± 5 mN. If the increases in displayed load are not 20 ± 5 mN, calibration is required. Perform the calibration. If the requirements for the contact load cannot be met after calibration, discontinue use of the device and consult the manufacturer.

10.1.5.2. *Test Load*—On each day, before conducting tests, verify the calibration of the load cell in the range of the test load. Place the 6.4-mm-thick stainless steel compliance beam (Section 6.4.1) on the supports. Use the zero load regulator (contact load) to apply a 20 ± 10-mN load to the beam. Add the 100.0-g mass to the loading platform. The increase in the load displayed by the data acquisition system shall be 981 ± 5 mN. Otherwise, calibrate the load cell. If the requirements for the test load cannot be met after calibration, discontinue use of the device and consult the manufacturer.

10.1.6. *Verification of Front-to-Back Alignment of Loading Shaft*—Every 6 months, check the alignment of the loading shaft with the center of the sample supports with an alignment gauge supplied by the manufacturer or by measurement as follows: Cut a strip of white paper about 25 mm in length and slightly narrower than the width of the compliance beam. Stick the paper strip to the center of the compliance beam with tape. Move the frame out of the bath, place the compliance beam on the supports, and place a small section of carbon paper over the paper. With the air pressure applied to the air bearing, push the shaft downward, causing the carbon paper to make an imprint on the white paper. Remove the beam, and measure the distance from the center of the imprint to each edge of the beam with a pair of vernier calipers. The difference between the two measurements shall be 1.0 mm or less. If this requirement is not met, contact the manufacturer of the device.

11. PREPARATION OF MOLDS AND TEST SPECIMENS

11.1. To prepare molds, spread a very thin layer of petroleum-based grease, only sufficient to hold the plastic to the aluminum, on the interior faces of the three long aluminum mold sections. Place the plastic strips over the aluminum faces and rub the plastic with firm finger pressure. Assemble the mold as shown in Figure 2 using the rubber O-rings to hold the pieces of the mold together. Inspect the mold and press the plastic film against the aluminum to force out any air bubbles. If air bubbles remain, disassemble the mold and recoat the aluminum faces with grease. Cover the inside faces of the two end pieces with a thin film of glycerol and talc to prevent the asphalt binder from sticking to the aluminum end pieces. After assembly, keep the mold at room temperature until pouring the asphalt binder.

Note 10—Thickness of the specimen is controlled by the end pieces. The thickness of the end pieces should be measured periodically to make sure that it meets the requirements of Section 6.3. The stiffness is proportional to the third power of the thickness.

11.2. If unaged binder is to be tested, obtain test sample according to R 66.

11.3. *Degassing Prior to Testing*—If the asphalt binder is also being tested according to T 314 (DT) and has been conditioned according to T 240 (RTFO) and R 28 (PAV), degas the asphalt binder as described in R 28 prior to testing. Otherwise, degassing of the asphalt binder sample is not required.

11.4. Heat the material in an oven set at the minimum temperature and for the minimum time necessary for it to be sufficiently fluid to pour.

Note 11—Minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. In all cases, heating time should be minimized. These precautions will help avoid oxidative hardening and volatile loss that will further harden the sample. During the heating process, the sample should be covered and stirred occasionally to ensure homogeneity.

11.5. *Molding*—Pour the binder from the one end of the mold and move toward the other end, slightly overfilling the mold. When pouring, hold the sample container 20 to 100 mm from the top of the mold and pour continuously toward the other end in a single pass. Allow the mold to cool 45 to 60 min to room temperature after pouring, and trim the exposed face of the cooled specimens flush with the top of the mold using a hot knife or heated spatula.

11.6. Store all test specimens in their molds at room temperature prior to testing. Schedule testing so that it is completed within 4 h after specimens are poured.

Note 12—Time-dependent increases in stiffness can occur when asphalt binders are stored at room temperature for even short periods of time. This increase in stiffness is the result of molecular associations and is referred to as steric hardening in the literature.

11.7. Just prior to testing, cool the aluminum mold containing the test specimen in a freezer or ice bath at –5°C ± 7°C for 5 to 10 min, only long enough to stiffen the asphalt binder beam so that it can be readily demolded without distortion (Note 8). Some softer grades may require lower temperatures. Do not cool the molds containing the specimens in the test bath because it may cause temperature fluctuations in the bath to exceed ±0.2°C.

Note 13—Excessive cooling may cause unwanted hardening of the beam, thereby causing increased variability in the test data.

11.8. Immediately demold the specimen when it is sufficiently stiff to demold without distortion by disassembling the aluminum mold. Discard the plastic sheeting (lining the mold sections) if they become distorted.

Note 14—Minimize distortion of the specimen during demolding. If the plastic sheeting does not fully separate from the testing beam, you may remove the final portion of the sheeting as the beam is being immersed in the test bath to avoid distortion. Full contact at specimen supports is assumed in the analysis. A warped test beam yields a measured stiffness less than the actual stiffness.

12. PROCEDURE

12.1. When testing a specimen for compliance with M 320, select the appropriate test temperature from Table 1 of M 320. After demolding, immediately place the test specimen in the testing bath and condition it at the testing temperature for 60 ± 5 min.

Note 15—Asphalt binders may harden rapidly when held at low temperatures. This effect, which is called physical hardening, is reversible when the asphalt binder is heated to room temperature or slightly above. Because of physical hardening, conditioning time must be carefully controlled if repeatable results are to be obtained.

12.2. *Checking Contact Load and Test Load*—Check the adjustment of the contact load and test load prior to testing each set of test specimens. The 6.35-mm-thick stainless steel beam shall be used for checking the contact load and test load.

Note 16—Do not perform these checks with the thin steel beam or an asphalt test specimen.

12.2.1. Place the thick steel beam in position on the beam supports. Using the test load regulator valve, gently increase the force on the beam to 980 ± 50 mN.

12.2.2. Switch from the test load to the contact load, and adjust the force on the beam to 35 ± 10 mN. Switch between the test load and contact load four times.

12.2.3. When switching between the test load and contact load, watch the loading shaft and platform for visible vertical movement. The loading shaft shall maintain contact with the steel beam when switching between the contact load and test load while maintaining these loads at 35 ± 10 mN and 980 ± 50 mN, respectively.

12.2.4. *Corrective Action*—If the requirements of Sections 12.2.1 to 12.2.3 are not met, the device may require calibration as per the manufacturer's instructions or the loading shaft may be dirty or require alignment (see Section 10.1.2). If the requirements of Sections 12.2.1 to 12.2.3 cannot be met after calibration, cleaning, or other corrective action, discontinue use of the device and consult the equipment manufacturer.

12.3. Enter the specimen identification information, test load, test temperature, time the specimen is placed in the bath at the test temperature, and other information as appropriate into the computer which controls the test system.

12.4. After conditioning, place the test beam on the test supports, and initiate the loading sequence of the test. Maintain the bath at the test temperature ±0.1°C during testing; otherwise, the test shall be rejected.

12.5. Manually apply a 35 ± 10-mN contact load to the beam to ensure contact between the beam and the loading head for no more than 10 s. The specified contact load is required to ensure continuous contact between the loading shaft and support, and the specimen. Failure to establish continuous contact within the required load range gives misleading results. The contact load shall be applied by gently increasing the load to 35 ± 10 mN. While applying the contact load, the load on the beam shall not exceed 45 mN, and the time to apply and adjust the contact load shall be no greater than 10 s.

12.6. *Activate the automatic test system that is programmed to proceed as follows*:

12.6.1. Immediately after the application of the 35-mN contact load, increase the load from 35 ± 10 mN to the 980 ± 50-mN seating load for 1.0 ± 0.1 s.

Note 17—The seating loads described in Sections 12.6.1 and 12.6.2 are applied and removed automatically by the computer-controlled loading system and are transparent to the operator. Data are not recorded during the initial loading.

12.6.2. Reduce the load to 35 ± 10 mN and allow the beam to recover for 20.0 ± 0.1 s.

12.6.3. Apply a test load ranging as specified in Section 6.1.1.2.

Note 18—The actual load on the beam as measured by the load cell is used in calculating the stress in the beam. The 980 ± 50-mN initial seating and test load includes the 35 ± 10-mN preload.

12.6.4. Remove the test load and terminate the test.

12.6.5. At the end of the initial seating load, and at the end of the test, monitor the computer screen to verify that the load on the beam returns to 35 ± 10 mN in each case. If the beam does not return to 35 ± 10 mN, the test is invalid and the rheometer should be calibrated.

12.7. Remove the specimen from the supports and proceed to the next test.

13. CALCULATION AND INTERPRETATION OF RESULTS

13.1. See Annex.

14. REPORT

14.1. *Report data as shown in Figure 4 that describes individual test, including*:

14.1.1. Maximum and minimum temperature of the test bath measured during the 240 s of testing measured at 1.0-s intervals to the nearest 0.1°C;

14.1.2. Date and time when test load is applied;

14.1.3. File name of test data;

14.1.4. Name of operator;

14.1.5. Sample identification number;

Test Information

Project:	Testing	Target Temp:	23.0°C	Conf. Test	2.199e + 008
Operator:	JSY	Actual Temp:	14.8°C	Date:	09/17/93
Specimen:	Plastic Beam B	Soak Time:	0.0 s	Load Const:	0.24
Time:	11:47:03	Beam Width:	12.70 mm	Defl Const:	0.0024
Date:	09/18/93	Thickness:	6.35 mm	Date:	09/17/93
File:	0818934.DAT				

Results

t Time (s)	P Force (N)	d Defl (mm)	Measured Stiffness (kPa)	Estimated Stiffness (kPa)	Difference (%)	*m*-value
8	0.9859	0.9126	87030.0	87060.0	0.03532	0.176
15	0.9894	1.022	77990.0	77930.0	–0.08120	0.175
30	0.9913	1.158	68690.0	68990.0	0.04809	0.175
60	0.9910	1.308	61110.0	61110.0	0.004487	0.174
120	0.9908	1.475	54150.0	54150.0	–0.001551	0.174
240	0.9906	1.664	48010.0	48000.0	–0.005077	0.174
Regression Coefficients:						
a = 5.100	*b* = –0.1784	*c* = 0.001020	*R*^2 – 0.999996			
– Cannon bending beam rheometer –			P to print – ESC to continue			

Figure 4—Typical Test Report

14.1.6. Time beam in bath;

14.1.7. Time test started;

14.1.8. Any flags issued by software during test;

14.1.9. Correlation coefficient, R^2, for log stiffness versus log time, expressed to nearest 0.000001;

14.1.10. Anecdotal comments (maximum 256 characters);

14.1.11. Report constants A, B, and C to three significant figures; and

14.1.12. Difference between measured and estimated stiffness calculated as:
(Estimated – Measured) × 100 percent/Measured.

14.2. Report load and deflection as for times 0.0 and 0.5 s.

14.3. Report data as shown in Figure 4 for time intervals of 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 s, including:

14.3.1. Loading time, nearest 0.1 s;

14.3.2. Load, nearest 1.0 mN;

14.3.3. Beam deflection, nearest 1 μm;

14.3.4. Measured Stiffness Modulus, MPa, expressed to three significant figures;

14.3.5. Estimated Stiffness Modulus, MPa, expressed to three significant figures;

14.3.6. Difference between measured and estimated Stiffness Modulus in percent;

14.3.7. Estimated *m*-value, nearest 0.001; and

14.3.8. Regression Coefficients and least square fit R^2 value.

15. PRECISION AND BIAS

15.1. *Precision*—Criteria for judging the acceptability of creep stiffness and slope results obtained by this method are given in Table 1.

15.1.1. *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

15.1.2. *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

Table 1—Precision Estimates

Condition	Coefficient of Variation (1s%)[a]	Acceptable Range of Two Test Results (d2s%)[a]
Single-Operator Precision:		
Creep Stiffness (MPa)	2.5	7.2
Slope (*m*-value)	1.0	2.9
Multilaboratory Precision:		
Creep Stiffness (MPa)	6.3	17.8
Slope (*m*-value)	2.4	6.8

[a] These values represent the 1s% and d2s% limits described in ASTM C670.

Note 19—The precision estimates given in Table 1 are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 174 to 196 laboratories for each of the eight pairs of samples. The analysis included five binder grades: PG 52-34, PG 64-16, PG 64-22, PG 70-22, and PG 76-22 (SBS modified). Average creep stiffness results ranged from 125.4 MPa to 236.8 MPa. Average slope results ranged from an *m*-value of 0.308 to 0.374. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note 20—As an example, two tests conducted on the same material yield creep stiffness results of 190.3 MPa and 200.7 MPa, respectively. The average of these two measurements is 195.5 MPa. The acceptable range of results is then 7.2 percent of 195.5 MPa or 14.1 MPa. As the difference between 190.3 MPa and 200.7 MPa is less than 14.1 MPa, the results are within the acceptable range.

15.2. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

16. KEYWORDS

16.1. Flexural; creep stiffness; flexural creep compliance; bending beam rheometer.

ANNEX

(Mandatory Information)

A1.1. *Calibration of Displacement Transducer*—Calibrate the displacement transducer using a stepped gauge block of known dimensions similar to the one shown in Figure 3. With the loading frame mounted in the bath at the test temperature, remove all beams from the supports, and place the stepped gauge block on a reference platform underneath the loading shaft according to the instructions supplied by the instrument manufacturer. Apply a 100-g mass on the loading shaft, and follow the manufacturer's instructions to obtain a displacement transducer reading on each step. The software provided by the manufacturer shall convert the measurements to a calibration constant in terms of µm/bit to three significant figures and shall automatically enter the new constant into the software. The calibration constant should be repeatable within 10 percent from one calibration to another; otherwise, the operation of the system may be suspect.

A1.2. *Calibration of Load Cell*—Calibrate the load cell in accordance with the manufacturer's instructions using a minimum of four masses evenly distributed over the range of the load cell. The software provided by the manufacturer shall convert the measurements to a calibration constant in terms of mN/bit to three significant figures and shall automatically enter the new constant into the software. The calibration constants should be repeatable within 10 percent from one calibration to another; otherwise, the operation of the system may be suspect. Repeat the process for each test temperature.

A1.3. *Calibration of Temperature Transducer*—Calibrate the temperature detector by using a calibrated thermometer of suitable range meeting the requirements of Section 10.1.5. Immerse the thermometer in the liquid bath close to the thermal detector, and compare the temperature indicated by the calibrated thermometer to the detector signal being displayed. If the temperature indicated by the thermal detector does not agree with the thermometer within ±0.1°C, follow the manufacturer's instructions for correcting the displayed temperature to agree with the thermometer temperature.

A1.4. *Determine the System Compliance*—Determine the system compliance in accordance with the manufacturer's instructions using a minimum of four masses evenly distributed over the range of the load cell. The data acquisition software shall measure the position of the displacement transducer at each load. The compliance shall be calculated as the measured deflection per unit load. The software provided by the manufacturer shall convert the measurements to a compliance in terms of µm/N to three significant figures and shall automatically enter the compliance into the software. The compliance measurement may be performed as part of the load cell calibration or as a separate operation. The compliance measurement shall be performed each time the load cell is calibrated. The compliance value should be repeatable within 10 percent from one determination to another; otherwise, the operation of the system may be suspect. Repeat the process for each test temperature.

A1.5. *Typical Test Result*—A typical test result is shown in Figure 4. Disregard measurements obtained and the curves projected on the computer screen during the initial 8 s of the application of the test load. Data from a creep test obtained immediately after the application of the test load may not be valid because of dynamic loading effects and the finite rise time. Use only the data obtained between the 8- and 240-s loading time for calculating $S(t)$ and m.

A1.6. *Deflection of an Elastic Beam*—Using the elementary bending theory, the midspan deflection of an elastic prismatic beam of constant cross section loaded in three-point loading can be obtained by applying Equations A1.1 and A1.2 as follows:

$$\delta = \frac{PL^3}{48EI} \tag{A1.1}$$

where:

δ = deflection of beam at midspan, mm;

P = load applied, N;

L = span length, mm;

E = modulus of elasticity, MPa; and

I = moment of inertia, mm^4.

and:

$$I = \frac{bh^3}{12} \tag{A1.2}$$

where:

I = moment of inertia of cross section of test beam, mm^4;

b = width of beam, mm; and

h = thickness of beam, mm.

Note A1—The test specimen has a span-to-depth ratio of 16:1 and the contribution of shear to deflection of the beam can be neglected.

A1.7. *Elastic Flexural Modulus*—According to elastic theory, calculate the flexural modulus of a prismatic beam of constant cross section loaded at its midspan using the following equation:

$$E = \frac{PL^3}{4bh^3\delta} \quad (A1.3)$$

where:

E = time-dependent flexural creep stiffness, MPa;

P = constant load, N;

L = span length, mm;

b = width of beam, mm;

h = thickness of beam, mm; and

δ = deflection of beam, mm.

A1.8. *Maximum Bending Stress*—The maximum bending stress in the beam occurs at the midspan at the top and bottom of the beam. Calculate σ thus:

$$\sigma = \frac{3PL}{2bh^2} \quad (A1.4)$$

where:

σ = maximum bending stress in beam, MPa;

P = constant load, N;

L = span length, mm;

b = width of beam, mm; and

h = thickness of beam, mm.

A1.9. *Maximum Bending Strain*—The maximum bending strain in the beam occurs at the midspan at the top and bottom of the beam. Calculate Є using the following equation:

$$\epsilon = \frac{6\delta h}{L} \quad \text{(mm/mm)} \quad (A1.5)$$

where:

ϵ = maximum bending strain in beam, mm/mm;

δ = deflection of beam, mm;

h = thickness of beam, mm; and

L = span length, mm.

A1.10. *Linear Viscoelastic Stiffness Modulus*—According to the elastic-viscoelastic correspondence principle, it can be assumed that if a linear viscoelastic beam is subjected to a constant load applied at $t = 0$ and held constant, the stress distribution is the same as that in a linear elastic beam under the same load. Further, the strains and displacements depend on time and are derived from those of the elastic case by replacing E with $1/D(t)$. Since $1/D(t)$ is equivalent to $S(t)$, rearranging the elastic solution results in the following relationship for the stiffness:

$$S(t) = \frac{PL^3}{4bh^3\delta(t)} \tag{A1.6}$$

where:

$S(t)$ = time-dependent flexural creep stiffness, MPa;
P = constant load, N;
L = span length, mm;
b = width of beam, mm;
h = thickness of beam, mm;
$\delta(t)$ = deflection of beam, mm; and
$\delta(t)$ and $S(t)$ indicate that the deflection and stiffness, respectively, are functions of time.

A1.11. *Presentation of Data*:

A1.11.1. Plot the response of the test beam to the creep loading as the logarithm of stiffness with respect to the logarithm of loading time. A typical representation of test data is shown in Figure 4. Over the limited testing time from 8 to 240 s, the plotted data shown in Figure A1.1 can be represented by a second-order polynomial as follows:

$$\log S'(t) = A + B[\log(t)] + C[\log(t)]^2 \tag{A1.7}$$

and, the slope, m, of the logarithm of stiffness versus logarithm time curve is equal to (absolute value):

$$|m(t)| = \frac{d\left[\log S'(t)\right]}{d\left[\log(t)\right]} = B + 2C\left[\log(t)\right] \tag{A1.8}$$

where:

$S'(t)$ = time-dependent flexural creep stiffness estimated using Equation A1.7, MPa;
t = time in seconds; and
A, B, and C = regression coefficients.

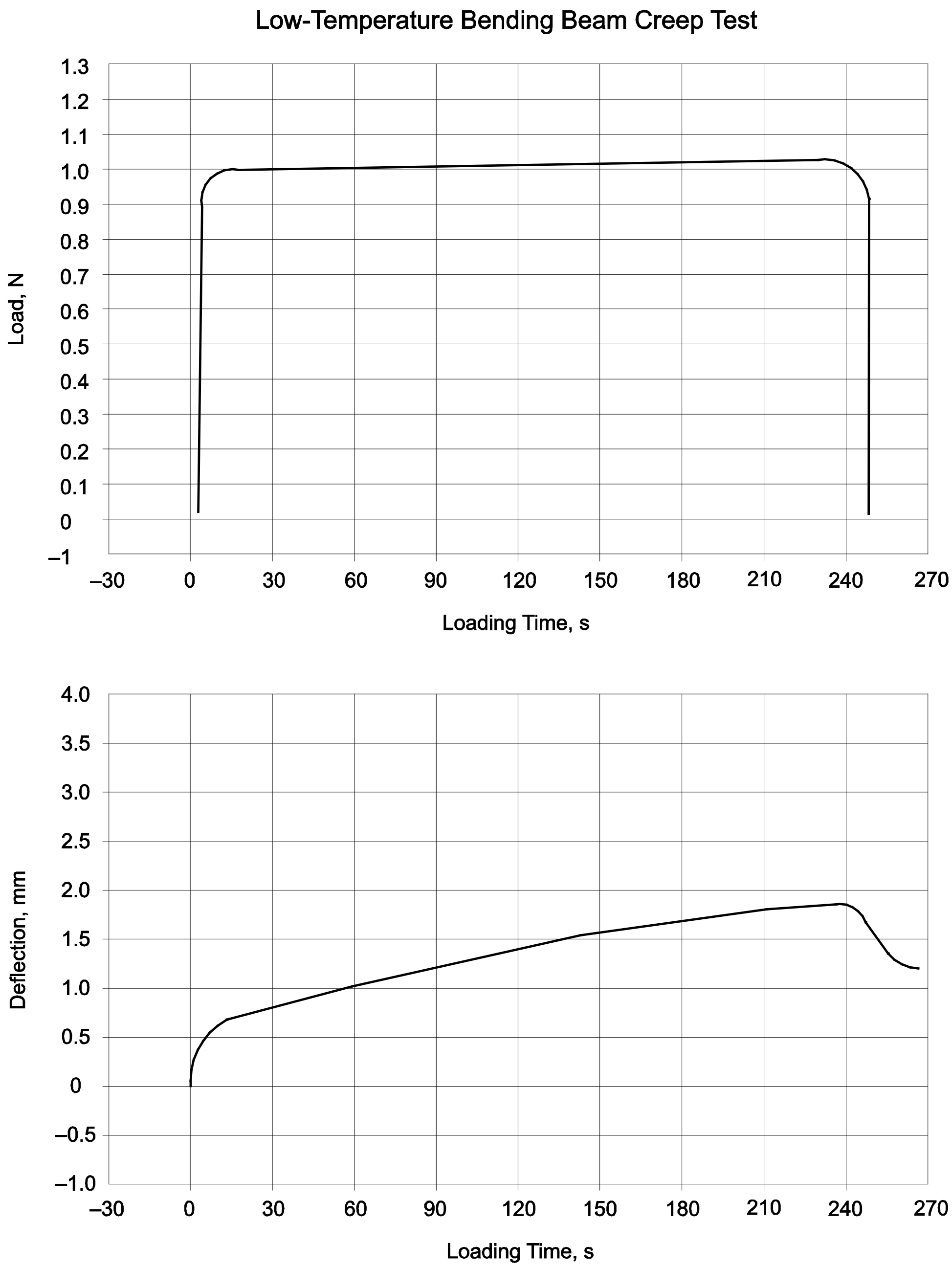

Figure A1.1—Typical Load and Deflection Plots

A1.11.2. Smoothing the data may be required to obtain smooth curves for the regression analysis as required to determine an *m*-value. This procedure can be performed by averaging five readings taken at the reported time ±0.1 and ±0.2 s.

A1.11.3. Obtain the constants *A*, *B*, and *C* from the least squares fit of Equation A1.7. Use data equally spaced with respect to the logarithm of time to determine the regression coefficients in Equations A1.7 and A1.8. Determine experimentally the stiffness values used for the regression to derive the coefficients *A*, *B*, and *C* and to, in turn, calculate values of *m* after loading times of 8, 15, 30, 60, 120, and 240 s.

A1.12. Calculation of regression coefficients, estimated stiffness values, and m:

A1.12.1. Calculate the regression coefficients A, B, and C in Equations A1.7 and A1.8 and the denominator D as follows:

$$A = \frac{S_y(S_{x2}S_{x4} - S_{x3}^2) - S_{xy}(S_{x1}S_{x4} - S_{x2}S_{x3}) + S_{xxy}(S_{x1}S_{x3} - S_{x2}^2)}{D} \quad (A1.9)$$

$$B = \frac{6(S_{xy}S_{x4} - S_{xxy}S_{x3}) - S_{x1}(S_yS_{x4} - S_{xxy}S_{x2}) + S_{x2}(S_yS_{x3} - S_{xy}S_{x2})}{D} \quad (A1.10)$$

$$C = \frac{6(S_{x2}S_{xxy} - S_{x3}S_{xy}) - S_{x1}(S_{x1}S_{xxy} - S_{x3}S_y) + S_{x2}(S_{x1}S_{xy} - S_{x2}S_y)}{D} \quad (A1.11)$$

$$D = 6(S_{x2}S_{x4} - S_{x3}{}^2) - S_{x1}(S_{x1}S_{x4} - S_{x2}S_{x3}) + S_{x2}(S_{x1}S_{x3} - S_{x2}{}^2) \quad (A1.12)$$

where, for loading times of 8, 15, 30, 60, 120, and 240 s:

S_{x1} = log 8 + log 15 + ... log 240;
S_{x2} = $(\log 8)^2 + (\log 15)^2 + \ldots (\log 240)^2$;
S_{x3} = $(\log 8)^3 + (\log 15)^3 + \ldots (\log 240)^3$;
S_{x4} = $(\log 8)^4 + (\log 15)^4 + \ldots (\log 240)^4$;
S_y = log S(8) + log S(15) + ... log S (240);
S_{xy} = log S(8)(log (8)) + log S(15) log (15) + ... log S(240) log (240); and
S_{xxy} = $[\log (8)]^2 \log S(8) + [\log (15)]^2 \log S(15) + \ldots [\log (240)]^2 \log S(240)$.

A1.12.2. Calculate the estimated stiffness $S'(t)$ at 8, 15, 30, 60, 120, and 240 s as follows:

$$\log S'(t) = A + B[\log(t)] + C\,[\log(t)]^2 \quad (A1.13)$$

A1.12.3. Calculate the estimated m-value at 8, 15, 30, 60, 120, and 240 s as the absolute value of

$$|m| = B + 2C\,[\log(t)] \quad (A1.14)$$

A1.12.4. Calculate $\overline{S}$ the average of the stiffness values at 8, 15, 30, 60, 120, and 240 s as:

$$\log \overline{S} = \frac{[\log S(8) + \ldots \log S(240)]}{6} \quad (A1.15)$$

A1.12.5. Calculate the fraction of the variation in the stiffness explained by the quadratic model as:

$$R^2 = 1.00 - \left[\frac{[\log S(8) - \log S'(8)] + \ldots [\log S(240) - \log S'(240)]}{\left[\log S(8) - \log(\overline{S})\right]^2 + \ldots \left[\log S(240) - \log(\overline{S})\right]^2} \right] \quad (A1.16)$$

A1.12.6. Use the estimated values of the stiffness and m at 60 s for specification purposes. Measured and estimated stiffness values should agree to within 2 percent. Otherwise, the test is considered suspect.