Designation: D 6648 – 01

Standard Test Method for
Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)[1]

This standard is issued under the fixed designation D 6648; 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 [2]

1.1 This test method covers the determination of the flexural-creep stiffness or compliance and m-value of asphalt binders by means of a bending-beam rheometer. It is applicable to material having flexural-creep stiffness values in the range of 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 materials aged using aging procedures such as Test Method D 2872, Test Method D 1754, or Practice D 6521. The test apparatus may be operated within the temperature range from -36°C to 0°C.

1.2 Test results are not valid for test specimens that deflect more than 4 mm or less than 0.08 mm when tested in accordance with this test method.

1.3 *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:*

C 802 Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials[3]

D 140 Practice for Sampling Bituminous Materials[4]

D 1754 Test Method for Effect of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)[4]

D 2872 Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)[4]

D 6521 Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)[4]

E 77 Test Method for Inspection and Verification of Thermometers[5]

2.2 *AASHTO Standard:*

AASHTO MP1 Standard Specification for Performance Graded Binder[6]

2.3 *DIN Standard:*[7]

43760

3. Terminology

3.1 *Definitions:*

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

3.1.2 *physical hardening, n*—a time-dependent, reversible stiffening of asphalt binder that typically occurs when the binder is stored below room temperature.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *contact load, n*—the load, P_c, required to maintain positive contact between the test specimen, supports, and the loading shaft; 35 ± 10 mN.

3.2.2 *flexural creep compliance, D(t), n*—the ratio obtained by dividing the maximum bending strain (see Eq X1.5) in a beam by the maximum bending stress (Eq X1.4). The flexural creep stiffness is the inverse of the flexural creep compliance.

3.2.3 *flexural creep stiffness, S(t), n*—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 (see Eq 4, section 14.4).

3.2.4 *measured flexural creep stiffness, S_m (t), n*—the ratio (see Eq 3, section 14.2) obtained by dividing the measured maximum bending stress (see X1.4) by the measured maximum bending strain (see Eq X1.5). Flexural creep stiffness has been used historically in asphalt technology while creep compliance is commonly used in studies of viscoelasticity.

3.2.5 *m-value, n*—the absolute value of the slope of the logarithm of the stiffness curve versus the logarithm of time (see Eq 5, section 14.5).

3.2.6 *test load, n*—the load, P_t, of 240-s duration used to determine the stiffness of the asphalt binder being tested; 980 ± 50 mN.

4. Summary of Test Method

4.1 The bending beam rheometer is used to measure the

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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 D04.44 on Rheological Tests.

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[2] This standard is based on SHRP Product 1002 and AASHTO TPI.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.03.

[5] *Annual Book of ASTM Standards*, Vol 14.03.

[6] Available from the American Association of State Highway and Transportation Officials, 444 N. Capitol St. NW, Washington, DC 20001.

[7] Deutsches Institut fuer Normung (German Standards Institute), Beuth Verlag GmbH, Burggrafenstrasse 6, 1000 Berlin 30, Germany.

mid-point deflection of a simply supported prismatic beam of asphalt binder subjected to a constant load applied to the mid-point of the test specimen. The device operates only in the loading mode; recovery measurements cannot be obtained with the bending beam rheometer.

4.2 A prismatic test specimen is placed in the controlled temperature fluid bath and loaded with a constant test load for 240.0 s. The test load (980 ± 50 mN) and the mid-point deflection of the test specimen are monitored versus time using a computerized data acquisition system.

4.3 The maximum bending stress at the midpoint of the test specimen is calculated from the dimensions of the test specimen, the span length, and the load applied to the test specimen for loading times of 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 s. The maximum bending strain in the test specimen is calculated from the dimensions of the test specimen and the deflection for the same loading times. The stiffness of the test specimen for the specific loading times is calculated by dividing the maximum bending stress by the maximum strain.

5. Significance and Use

5.1 The temperatures for this test are related to the winter 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 range of linear viscoelastic response.

5.3 The low-temperature thermal cracking performance of asphalt pavements is related to the creep stiffness and the m-value of the asphalt binder contained in the mix.

5.4 The creep stiffness and the m-value are used as performance-based specification criteria for asphalt binders in accordance with AASHTO Method of Practice MP1.

6. Interferences

6.1 Measurements for which the mid-point deflection of the test specimen is greater than 4.0 mm are suspect. Strains in excess of this value may exceed the linear response of asphalt binders.

6.2 Measurements for which the mid-point deflection of the test specimen is less than 0.08 mm are suspect. When the mid-point deflection is less than 0.08 mm, the test system resolution may not be sufficient to produce reliable test results.

7. Apparatus

7.1 A bending beam rheometer (BBR) test system consisting of the following: (*1*) a loading frame with test specimen supports, (*2*) a controlled temperature liquid bate which maintains the test specimen at the test temperature and provides a buoyant force to counterbalance the force resulting from the mass of the test specimen, (*3*) a computer-controlled data acquisition system, (*4*) test specimen molds, and (*5*) items for verifying and calibrating the system.

7.2 *Loading Frame*—A frame consisting of a set of sample supports, a blunt-nosed shaft to apply the load to the midpoint of the test specimen, a load cell mounted in line with the loading shaft, a means for zeroing the load applied to the test specimen, a means for applying a constant load to the test specimen and a deflection measuring transducer attached to the loading shaft. A schematic of the device is shown in Fig. 1.

7.3 *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 within ± 10 mN.

7.3.1 *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. Details of the loading pattern are shown in Fig. 2.

7.3.2 *Loading Shaft*—A loading shaft continuous and in line with the load cell and deflection measuring transducer with a spherically shaped end 6.3 ± 0.3 mm in radius.

7.3.3 *Load Cell*—A load cell to measure the contact load and the test load. It shall have a minimum capacity of no less than 2.00 N and a resolution of at least 2.5 mN. It shall be mounted in line with the loading shaft and above the fluid level in the controlled temperature bath.

7.3.4 *Linear Variable Differential Transducer (LVDT)*—A linear variable differential transducer or other suitable device to measure the deflection of the test specimen. It shall have a linear range of at least 6 mm, and be capable of resolving linear

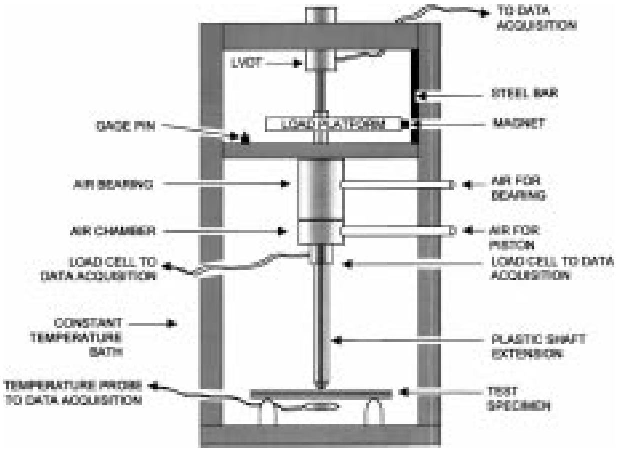


FIG. 1 Schematic of Test Device

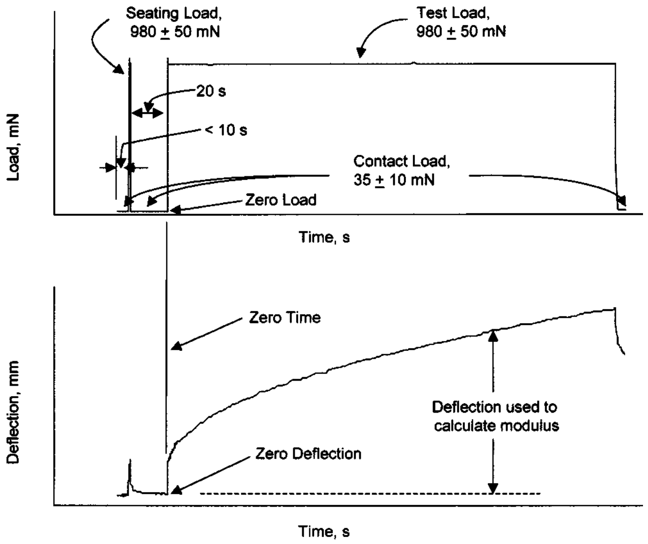


FIG. 2 Definition of Loading Pattern

movement of 2.5 µm. It shall be mounted axially with and above the loading shaft.

7.3.5 *Sample Supports*—Two stainless steel or other non-corrosive metal supports with a 3.0 ± 0.3 mm contact radius and spaced 102 ± 1.0 mm apart. The spacing of the supports shall be measured to ± 0.3 mm and the measured value shall be used in the calculations in Section 14. The supports shall be dimensioned to ensure that the test specimen remains in contact with the radiused portion of the support during the entire test. See Fig. 3.

7.3.5.1 The width of the test specimen support in contact with the test specimen shall be 9.50 ± 0.25 mm. See Fig. 3.

7.3.5.2 A vertical alignment pin 2 to 4 mm in diameter shall be provided at the back of each support to align the test specimen on the supports. The front face of the pins shall be 6.75 ± 0.25 mm from the middle of the support. See Fig. 3.

7.4 *Temperature Transducer*—A calibrated temperature transducer capable of measuring the temperature to 0.1°C over the range from -36°C to 0°C and mounted within 50 mm of the geometric center of the test specimen.

NOTE 1—The required temperature measurement can be accomplished with an appropriately calibrated platinum resistance thermometer (PRT) or a thermistor. Calibration of the PRT or thermistor can be verified as per section 11.5. A platinum resistance thermometer meeting DIN Standard 43760 (Class A) is recommended for this purpose.

7.5 *Controlled-Temperature Fluid Bath*—A controlled-temperature liquid bath capable of maintaining the temperature at all points in the bath to within ± 0.1°C of the test temperature in the range of -36°C to 0°C. Placing a test 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 iso-thermal conditioning shall be allowed.

7.5.1 *Bath Agitator*—A bath agitator for maintaining the required temperature homogeneity with agitation intensity such that the fluid currents do not disturb the testing process and mechanical noise caused by vibrations is less than the resolution specified in 7.3.3 and 7.3.4.

7.5.2 *Circulating Bath (Optional)*—A circulating bath unit separate from the test frame, which 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 7.3.3 and 7.3.4.

7.6 *Data Acquisition and Control Components*—A data acquisition system that resolves loads to the nearest 2.5 mN, test specimen deflection to the nearest 2.5 µm, and bath fluid temperature to the nearest 0.1°C. The data acquisition system shall sense the point in time when the signal to switch from the

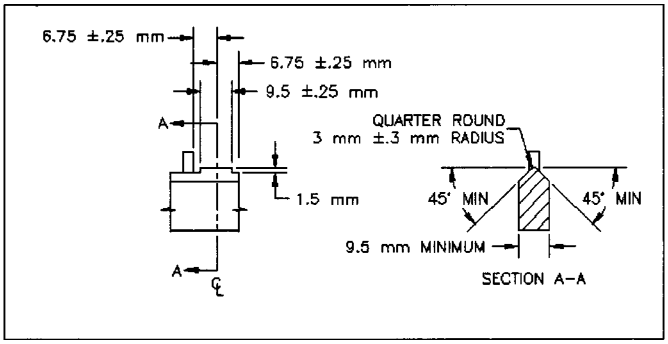


FIG. 3 Schematic of Specimen Supports

contact load to the test load is activated. This time shall be used as the zero loading time for the test load and deflection signals. Using this time as the reference for zero time, the data acquisition system shall provide a record of subsequent load and deflection measurements at 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 s.

7.6.1 *Filtering of Acquired Load and Deflection Signals*—The load and deflection signals shall be filtered with a low pass analog and/or digital filter that removes components with frequencies greater than 4 Hz from the load and deflection signals. Filtering may be accomplished by averaging five or more digital signals equally spaced in time about the time at which the signal is reported. The averaging shall be over a time period less than or equal to ± 0.2 s of the reporting time. For example, the load and deflection signals at 8.0 s may be the average of signals at 7.8, 7.9, 8.0, 8.1, 8.2 s.

7.7 *Test Specimen Molds*—Test specimen molds with interior dimensions of 6.35 ± 0.05 mm wide by 12.70 ± 0.05 mm deep by 127 ± 5 mm long fabricated from aluminum or stainless steel as shown in Fig. 4, or from silicone rubber as shown in Fig. 5.

7.7.1 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. (see Eq X1.3).

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

7.8.1 *Stainless Steel (Thick) Beam for Compliance Measurement and Load Cell Calibrations*—One stainless steel beam 6.4 ± 0.3 mm thick by 12.7 ± 0.3 mm wide by 127 ± 5 mm long for measuring system compliance and calibrating load cell. When this beam is used to measure the thickness of test specimens as per section 13.2, the thickness of this beam shall be measured to the nearest 0.01 mm. This measurement shall be used in the calculation of the thickness of the test specimens when using the equations in section 13.2.3.1.

7.8.2 *Stainless Steel (Thin) Beam for Overall System Check*—One stainless steel beam 1.0 to 1.6 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 of the BBR. The manufacturer of the BBR 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 11.3).

7.8.3 *Standard Masses*—Standard masses for verification and calibration as follows:

7.8.3.1 *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 for verifying the calibration of the load cell (see section 11.3).

7.8.3.2 *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 (see A1.2).

7.8.3.3 *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 (see section 11.4).

7.8.3.4 *Accuracy of Masses*—Accuracy of the masses in section 7.8.3 shall be verified at least once each every three years.

7.8.4 *Typical Gage Block*—A stepped gage block with thickness measured to ±5 µm for calibrating and for verifying the calibration of the displacement transducer (see Fig. 6 for typical design).

7.9 *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 E 77 at least once per year. A suitable thermometer is designated ASTM 133C-00.

8. Materials

8.1 *Plastic Sheeting for Metal Molds*—Clear plastic sheeting 0.08 to 0.15 mm thick for lining the interior faces of the

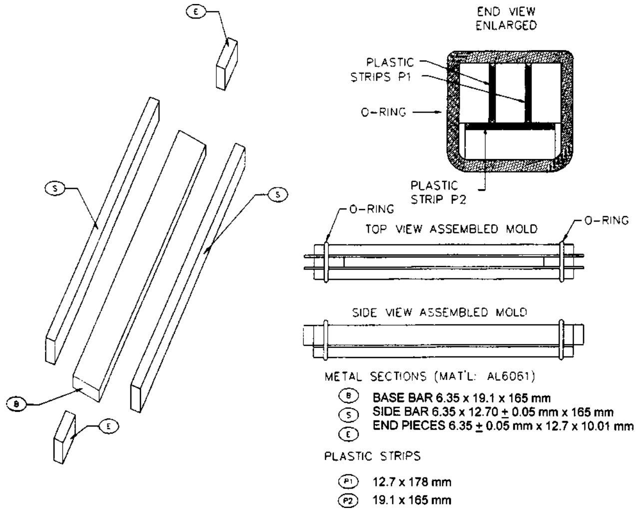


FIG. 4 Dimensions and Specifications for Aluminum Molds

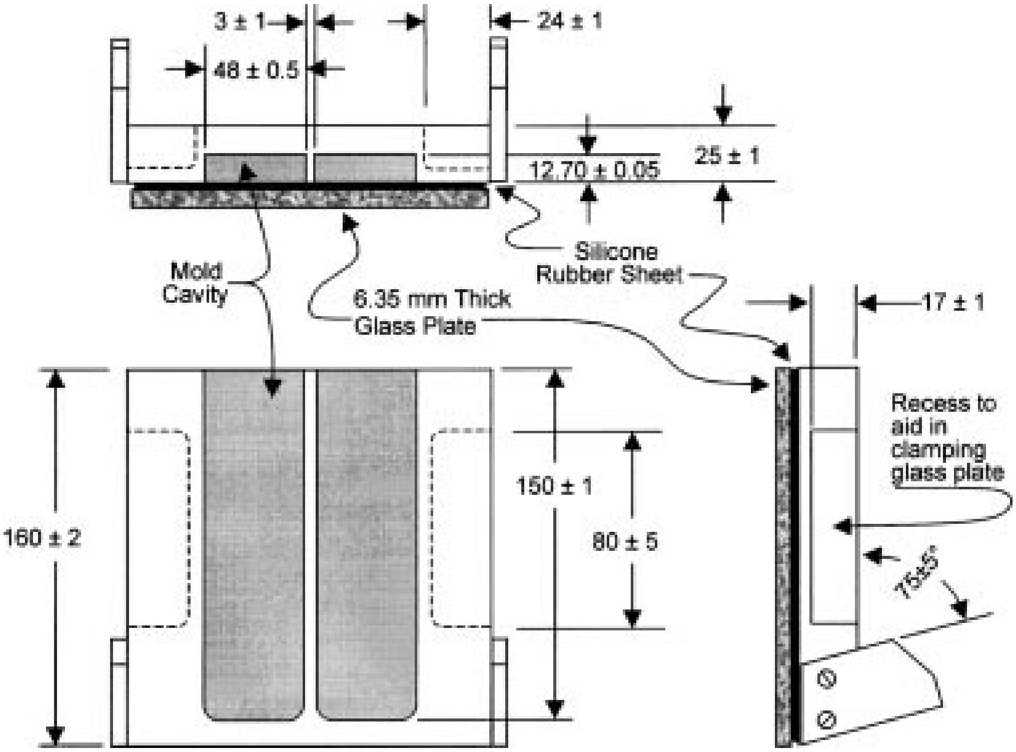
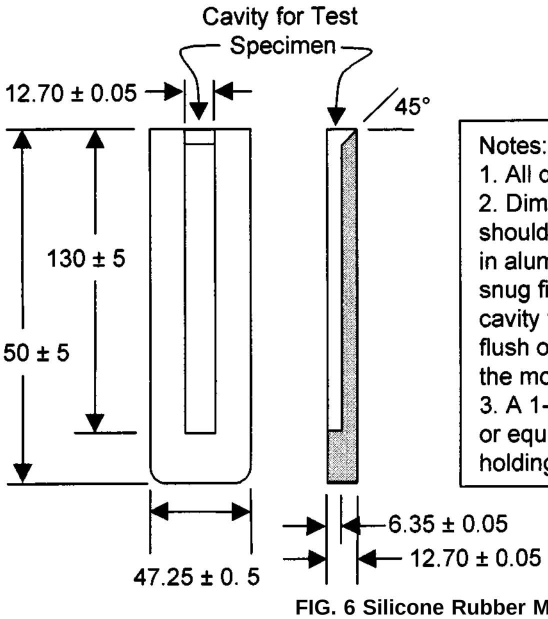


FIG. 5 Dimensions for Fixture for Silicone Molds



Notes:
1. All dimensions in mm.
2. Dimensions of silicone mold should match dimensions of cavity in aluminum mold holder to provide snug fit. When inserted into the cavity the silicone mold shall be flush or slightly above the surface of the mold holder.
3. A 1-in Binder Clip (ACCO 72100 or equivalent) is acceptable for holding the glass plate to the fixture.

FIG. 6 Silicone Rubber Mold

three long metal mold sections. Hot asphalt binder shall not distort sheeting. Transparency film sold for use with laser printers has been found suitable for this purpose.

8.2 *Sheeting for Silicone Molds*—Silicone rubber sheeting for lining the space between the glass plate and the silicone mold. Hot asphalt binder shall not distort the sheeting when the test specimen is prepared. The sheeting shall be sufficiently rigid so that the shrinkage of the asphalt binder does not distort the sheeting or pull the sheeting from the glass when the test specimen is cooled.

NOTE 3—Silicone rubber sheeting, 10 ± 0.5 mm thick, Shore A Hardness 60 has been found acceptable for this purposes.[8]

8.3 *Petroleum Based Grease*—A petroleum-based grease to hold the plastic strips to the interior faces of the three long metal mold sections. No silicone-based products shall be used.

8.4 *Glycerol-Talc Mixture*—Used to coat the vertical interior end faces of the metal molds. A mixture of 20 percent by

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[8] Available from McMaster-Carr Supply Company, P.O. Box 440, New Brunswick, NJ 08903, Silicone rubber sheeting, Part No. 863K43:Shore A Hardness 60.

weight USP-grade glycerin and 80-percent USP grade talc or kaolin (china clay) is suitable for this purpose.

8.5 *Bath Fluid*—A bath fluid that is not absorbed by or does not affect the properties of the asphalt binder being tested. The mass density of the fluid shall not exceed 1.05 g/cm^3 at the test temperature as measured with suitable hydrometers. The bath fluid shall be optically clear at the test temperature.

8.5.1 Suitable bath fluids include, but are not limited to ethanol, methanol, stabilized isopropanol, and glycol-methanol-water mixtures (for example, 60 % glycol, 15 % methanol, and 25 % water). Silicone fluids or mixtures containing silicones shall not be used.

9. Hazards

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

9.2 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.

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

10. Preparation of Apparatus

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

NOTE 4—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 may be affected. The small fragments, because of their small size, will deform under load and add an apparent deflection to the true deflection of the test specimen. Filtration of the bath fluid will aid in preserving the required cleanliness.

10.2 Select the test temperature and adjust the bath fluid to the selected temperature. Allow the bath to equilibrate to the test temperature ± 0.1°C before conducting a test.

10.3 Turn on the loading and data acquisition system and start the software as explained in the manufacturer's manual. Allow the data acquisition system and computer to warm up according to the manufacturer's instruction manual before operating the BBR.

11. Verification

Verify the calibration of the components of the BBR as required by Section 11.

NOTE 5—Additional verification steps may be performed at the option of the manufacturer. At the option of the manufacturer, the verification and calibration steps may be combined.

11.1 *Verification of Displacement Transducer*—On each day, before any tests are conducted, verify the calibration of the displacement transducer using a stepped-gage block of known dimensions similar to the one shown in Fig. 6. With the loading frame mounted in the bath at the test temperature remove all beams from the supports and place the gage block on a reference platform underneath the loading shaft according to the instructions supplied by the instrument manufacturer. Apply a 100 ± 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 gage. If the known dimensions as determined from the gage block and the dimensions indicated by the data acquisition system differ by more than ± 15 µm, calibration is required. Perform the calibration as per A1.1 and repeat section 11.1. If the requirements of section 11.1 cannot be met after calibration, discontinue use of the device and consult the manufacturer.

11.2 *Verification of Freely Operating Air Bearing*—On each day, before any tests are conducted, verify that the air bearing is operating freely and is free of friction. Sections 11.2.1 and 11.2.2 shall be used to verify that the shaft is free of friction. If the requirements of 11.2.1 and 11.2.2 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 6—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.

11.2.1 Place the thin steel beam (section 7.8.2) 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 upwards 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.

11.2.2 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 coin or other weight of approximately 2 g (for example, copper U.S. penny) to the loading shelf. The shaft shall slowly drop downward under the weight of the coin.

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

11.3.1 *Contact Load*—On each day before any tests are conducted, verify the calibration of the load cell in the range of the contact load. Place the 6.35 mm thick stainless steel compliance beam (section 7.8.1) 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 7.8.3 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 as per A1.2 and repeat section 11.3.1. If the requirements of section 11.3.1 cannot be met after calibration, discontinue use of the device and consult the manufacturer.

11.3.2 *Test Load*—On each day, before any tests are conducted, verify the calibration of the load cell in the range of the test load. Place the 6.35 mm thick stainless steel compliance beam (section 7.8.1) on the supports. Use the zero load regulator (contact load) to apply a 20 ± 10 mN load to the beam. Add the 100 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 in accordance with A1.2 and repeat section 11.3.2. If the requirements of section 11.3.2 cannot be met after calibration, discontinue use of the device and consult the manufacturer.

11.4 *Daily Overall System Check*—On each day, before any tests are conducted and with the loading frame mounted in the bath, perform a check on the overall operation of the system. Place the 1.0 to 1.6 mm thick stainless steel (thin) beam of known modulus as described in section 7.8.2 on the sample supports. Following the instructions supplied by the manufacturer, place the beam on the supports and apply a 50 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 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 BBR, otherwise the overall operation of the BBR shall be considered suspect and the manufacturer of the device shall be consulted.

11.5 *Verification of Temperature Transducer*—On each day before any tests are conducted, and whenever the test temperature is changed, verify calibration of the temperature detector by using a calibrated thermometer as described in section 7.9. 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 as per A1.3 is required.

11.6 *Verification of Front-to-Back Alignment of Loading Shaft*—When the instrument is installed or otherwise disturbed through handling such that the alignment of the loading shaft may be suspect, the alignment of the loading shaft with the center of the sample supports shall be checked with an alignment gage 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 Scotch 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 bond 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.

12. Preparation of Molds and Test Specimens

12.1 *Preparation of Molds*—Each time specimens are prepared, prior to filling the molds, prepare the molds as described in Section 12.1 or 12.2.2.

NOTE 7—Silicone molds may be used at the option of the user but metal molds shall be used for reference purposes.

12.1.1 *Preparation of Metal Molds*—Remove any deposits of asphalt binder, grease or other residue from the molds. To prepare the metal molds, spread a very thin layer of petroleum-based grease on the interior faces of the three long metal mold sections. Use only the amount of grease necessary to hold the plastic strips to the metal. Plastic strips that have become distorted from previous heating shall not be used. Place the plastic strips over the metal faces and rub the plastic with firm finger pressure. Assemble the mold as shown in Fig. 4 using the rubber O-rings to hold the pieces of the mold together. Inspect the mold and press the plastic film against the metal to force out any air bubbles. If air bubbles remain, disassemble the mold and recoat the metal faces with grease. Cover the inside faces of the two end pieces with a thin film of the glycerol and talc mixture to prevent the asphalt binder from sticking to the metal end pieces. After assembly, keep the mold at room temperature until pouring the asphalt binder.

12.1.2 *Preparation of Silicone Molds*—Remove asphalt binder, grease or other residue by wiping the molds with a clean, dry cloth. Do not use an organic solvent to clean the molds. Prepare silicone rubber molds by assembling the two mold sections as shown in Fig. 5.

12.2 *Preparation of Test Specimen*:

12.2.1 If unaged binder is to be tested, obtain test samples according to Practice D 140. Laboratory-aged samples or samples of asphalt binder recovered from mixtures shall be obtained in accordance with appropriate test methods or methods of practice.

12.2.2 Heat the asphalt binder in an oven set at no greater than 165°C until the asphalt binder is sufficiently fluid to pour. If the asphalt binder does not pour easily when heated in an oven set to 165°C, it may be heated in an oven set at 180°C until sufficiently fluid to pour.

NOTE 8—Minimum pouring temperatures (readily pours but not overly fluid) are recommended. Heating asphalt binders to temperatures above 165°C should be avoided, however, with some modified asphalts or aged binders a pouring temperature above 165°C may be required. Temperatures above 180°C should not be used. In all cases, heating time should be minimized. During the heating process the sample should be covered and stirred occasionally to ensure homogeneity. Use caution during stirring to avoid trapping air bubbles in the asphalt binder.

12.3 *Molding Test Specimens*—Mold test specimens according to section 12.3.1 or 12.3.2.

12.3.1 *Molding Test Specimens (Metal Mold)*—With the mold at room temperature, begin pouring the binder from one end of the mold and move toward the other end, slightly overfilling the mold. When pouring, hold the sample container 20 to 30 mm from the top of the mold, pouring continuously toward the other end in a single pass. Place the filled mold on the laboratory bench and allow the mold to cool for 45 to 60 min to room temperature. After cooling to room temperature, trim the exposed face of the cooled specimens flush with the top of the mold using a hot knife or a heated spatula.

12.3.2 *Molding Test Specimen (Silicone Rubber Mold)*—If the viscosity of the binder warrants, the operator, at his discretion, may preheat the silicone rubber mold in its aluminum fixture in a 135°C oven for up to 30 minutes prior to filling. Fill the mold from the top of the mold in a slow steady manner taking care not to entrap air bubbles. Fill the mold to the top with no appreciable overfilling. Allow the mold and its contents to cool to room temperature for at least 45 min after pouring.

12.4 *Storing and Demolding Test Specimens*:

12.4.1 Store all test specimens in their molds at room temperature prior to testing. Testing shall be completed within 4 h after specimens are poured.

NOTE 9—Time-dependent increases in stiffness can occur when an asphalt binder is stored at room temperature for even short periods of time.

12.4.2 Just prior to demolding, cool the metal or silicone mold containing the test specimen in a cold chamber or water bath for no longer than 5 min, but only long enough to stiffen the test specimen so that it can be readily demolded without distortion. In no case shall the sample be exposed to demolding temperatures that are within 10°C of the test temperature. 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 10—Excessive cooling may cause unwanted hardening of the asphalt binder, thereby causing increased variability in the test data.

12.4.3 Immediately demold the specimen when it is sufficiently stiff to demold without distortion by disassembling the metal mold or by removing the test specimen from the silicone rubber mold. To avoid distorting the specimen, demold the specimen by sliding the plastic strips and metal side pieces from the specimen.

NOTE 11—During demolding, handle the specimen with care to prevent distortion. Full contact at specimen supports is assumed in the analysis. A warped test specimen may affect the measured stiffness and m-value.

13. Procedure

13.1 When testing a specimen for compliance with AASHTO MP1, select the appropriate test temperature from Table 1 of AASHTO MP1. After demolding, immediately place the test specimen in the testing bath and condition it at the testing temperature. The seating load shall be applied to the test specimen within 60 ± 5 minutes after the test specimen is placed in the testing bath. The test specimen shall remain submerged in the bath fluid at the test temperature ± 0.1°C for the entire 60 ± 5 minutes.

NOTE 12—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.

13.2 *Test Specimen Thickness Measurement*—The thickness of the test specimen shall be taken as the measured thickness of the metal spacers used to mold the test specimen. (See section 7.7.1).

13.2.1 *Optional Methods for Measuring Test Specimen Thickness*—Two optional methods of thickness measurement (Sections 13.2.2 and 13.2.3) may be used at the discretion of the user. Measured insert thickness (section 13.2) shall be used as the reference method for the metal molds. Methods 13.2.2 or 13.2.3 must be used with the silicone molds.

NOTE 13—Measurement of the test specimen thickness in accordance with sections 13.2.2 or 13.2.3 may reduce the variability in the test results but this may be offset by the additional handling required. When using the procedure in section 13.2.2 or 13.2.3, use caution not to warp or distort the test sample.

13.2.2 *Direct Method*—In using this method, the thickness of the test specimen shall be measured with a thickness gage or similar apparatus. The specimen shall remain submerged at the test temperature ± 0.2°C during the measurement. The thickness shall be obtained at the midpoint of the test specimen to the nearest 2.5 µm and entered into the software by the operator for use in calculating the stiffness of the test specimen.

13.2.3 *Measurement with Displacement Transducer*—The thickness of the test specimen may be measured with the displacement transducer as described below. The thickness may be calculated by hand, using the displacement readings displayed by the instrument or may be entered into the software and calculated automatically. Calculate and report the thickness to the nearest 50 µm for use in calculating the stiffness of the test specimen.

13.2.3.1 Establish the displacement reading corresponding to the top of the supports by placing the 6.35-mm thick stainless steel beam (section 7.8.1) on the supports. Apply a 35 ± 10 mN contact load to the steel beam and record the reading of the displacement transducer as R_{s1}. Invert the steel beam and obtain a second reading, R_{s2}. Average the two readings and record the average as R_s. Calculate the displacement transducer reading that corresponds to the top of the supports (see Fig. 7):

$$R_o = R_s + t_s \quad (1)$$

where:

R_o = displacement transducer reading corresponding to top of supports,

R_s = average of two displacement transducer readings with displacement transducer in contact with top of the steel test specimen, and

t_s = measured thickness of steel beam (section 7.8.1).

13.2.3.2 Establish the thickness of the test specimen immediately before testing by placing the test specimen on the supports. Apply a 35 ± 10 mN contact load to the test specimen and record the reading of the displacement transducer as R_{a1}. Invert the test specimen and obtain a second reading, R_{a2} If the two readings agree within 1.0 mm, average them as R_a. If the two readings differ by more than 1.0 mm. the flatness of the test specimen is suspect, and it should be discarded. Calculate the thickness of the test specimen as (see Fig. 7):

$$t_a = R_o - R_a \quad (2)$$

where:

t_a = calculated thickness of test specimen,

R_o = displacement transducer reading corresponding to top of supports calculated as per Eq 1, and

R_a = average of two displacement transducer readings with displacement transducer in contact with top of the test specimen.

13.3 *Checking Contact Load and Test Load*—Check the adjustment of the contact load and test load prior to testing each set of tests specimens in accordance with section 13.4. The 6.35-mm thick stainless steel beam (section 7.8.1) shall be

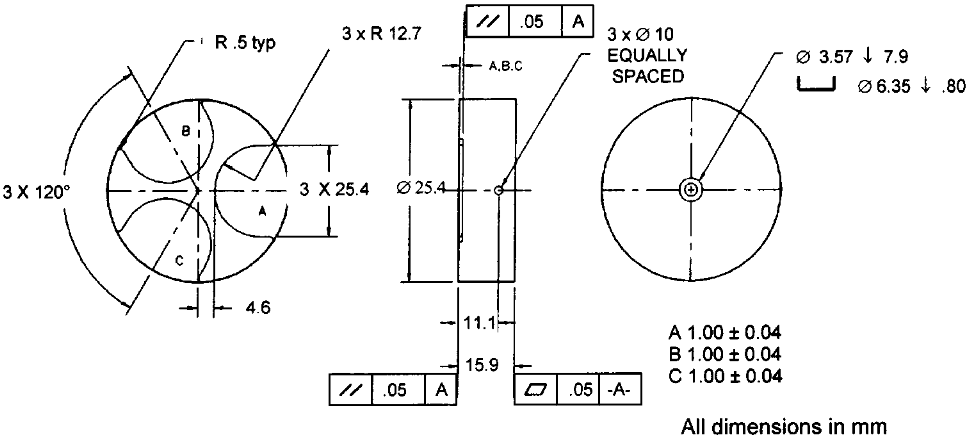

FIG. 7 Gage Block Used to Calibrate Displacement Transducer

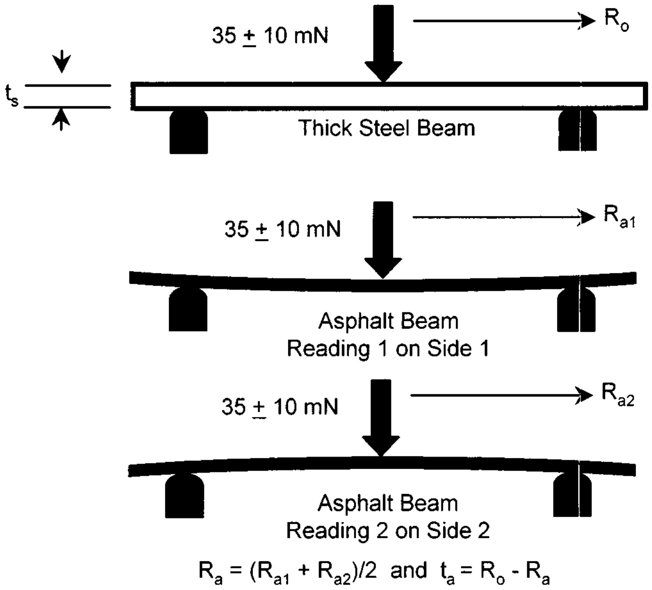

FIG. 8 Specimen Thickness Measured with Displacement Transducer

used for checking the contact load and test load.

NOTE 14—Do not perform these checks with the thin steel beam or an asphalt test specimen.

13.3.1 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.

13.3.2 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.

13.3.3 When switching between the test load and contact, 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 and the contact load and test load shall be maintained at 35 ± 10 mN and 980 ± 50 mN, respectively.

13.3.4 *Corrective Action*—If the requirements of sections 13.3.1-13.3.3 are not met, the device may require calibration as per A1.2 or the loading shaft may be dirty or require alignment (see section 11.2). If the requirements of sections 13.3.1-13.3.3 cannot be met after calibration, cleaning, or other corrective action, discontinue use of the device and consult the equipment manufacturer.

13.4 Enter the specimen identification information, elapsed time the specimen is conditioned in bath at the test temperature, and other information as appropriate into the computer that controls the test system (see Table A1.1).

13.5 After conditioning, place the test specimen on the test supports and gently position the back side of the test specimen against the alignment pins. Initiate the test as described in section 13.6. The bath temperature shall be maintained at the test temperature ± 0.1°C during the test otherwise the test shall be rejected.

13.6 Manually apply a 35 ± 10 mN contact load for no longer than 10 s to the test specimen to ensure contact between the test specimen and the loading head.

NOTE 15—The 35 ± 10 mN contact load is required to ensure continuous contact between the loading shaft, end supports, and the test specimen. Failure to establish continuous contact within the required load range gives misleading results. Holding the contact for an excessive amount of time can affect the reported stiffness and m-values.

13.7 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.

13.8 With the contact load applied to the test specimen, activate the automatic test system, which is programmed to proceed as follows:

13.8.1 Apply a 980 ± 50 mN seating load for 1 ± 0.1s.

NOTE 16—The seating load described in sections 13.8.1 and 13.8.2 is applied and removed automatically by the computer-controlled loading system.

13.8.2 Reduce the load to the 35 ± 10 mN contact load and allow the test specimen to recover for 20 ± 0.1 s. At the end of the seating load, the operator shall monitor the computer screen to verify that the load on the test specimen returns to 35 ± 10 mN. If it does not, the test shall be rejected.

13.8.3 Apply a 980 ± 50 mN test load to the test specimen. The software shall record the test load at 0.5 s intervals from 0.5 s to 240 s and calculate the average of the recorded load values. Between 0.5 and 5 s, the test load shall be within ± 50 mN of the average test load and for the remaining times within ± 10 mN of the average test load. The actual load on the test specimen as measured by the load cell shall be used to calculate the stress in the test specimen. The loading pattern is defined in Fig. 2.

13.8.4 Remove the test load and return to the 35 ± 10 mN contact load.

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

14. Reduction of Test Data

14.1 The data acquisition software shall generate a plot of the measured load and the measured deflection of the test specimen versus loading time at intervals of 0.5 s or less, starting with application of the seating load. Deflection shall be in units of mm and load in units of mN. A typical representation of the loading and deflection curves is shown in Fig. 2.

14.2 Calculate the measured stiffness of the test specimen at loading times of 8.0, 15.0, 30.0, 60.0, 120.0 and 240.0 s from the dimensions of the test specimen, the measured test load, and the test specimen deflection using:

$$S_m(t) = PL^3/4bh^3\delta(t) \qquad (3)$$

where:

$S_m(t)$ = flexural creep stiffness at time t, MPa,
P = measured test load, mN,
L = distance between supports, mm,
b = width of test specimen, mm,
h = depth of test specimen, mm, and
$\delta(t)$ = deflection of test specimen at time t.

14.2.1 Do not use values of load and deflection obtained before 8 s loading time to calculate the stiffness. Data from a creep test obtained immediately after application of the test load may not be valid because of dynamic loading effects and the finite rise time of the applied load.

14.3 *Calculation of S and m-Value*:

14.3.1 Fit the logarithm of the stiffness values versus the logarithm of the loading times using a second degree polynomial by calculating:

$$A = [S_y(S_{x2}S_{x4} - S_{x3}^{\ 2}) + S_{yx1}(S_{x2}S_{x3} - S_{x1}S_{x4}) + S_{yx2}(S_{x1}S_{x3} - S_{x2}^{\ 2})] / D$$

$$B = [S_y(S_{x2}S_{x3} - S_{x1}S_{x4}) + S_{yx1}(6S_{x4} - S_{x2}^{\ 2}) + S_{yx2}(S_{x1}S_{x2} - 6S_{x3})] / D$$

$$C = [S_y(S_{x1}S_{x3} - S_{x2}^{\ 2}) + S_{yx1}(S_{xl}S_{x2} - 6S_{x3}) + S_{yx2}(6S_{x2} - S_{x1}^{\ 2})] / D$$

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

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

S_y = $\log S_m(8) + \log S_m(15) + \ldots + \log S_m(240)$,
S_{x1} = $\log(8) + \log(15) + \ldots + \log(240)$,
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_{yx1} = $[\log S_m(8)][\log(8)] + [\log S_m(15)][\log(15)] + \ldots + [\log S_m(240)][\log(240)]$, and
S_{yx2} = $[\log S_m(8)][1\mathrm{og}(8)]^2 + [\log S_m(15)][\log(15)]^2 + \ldots + [\log S_m(240)][\log(240)]^2$.

14.3.2 Calculate the fraction of the variance in the stiffness explained by the quadratic model as:

$$R^2 = [6A\,S_y + 6B\,S_{yx1} + 6C\,S_{yx2} - S_y^{\ 2}] / [6\,S_{y2} - S_{y2}]$$

where:

S_{y2} = $[\log S(8)]^2 + [\log S(15)]^2 + \ldots + [\log S(240)]^2$

14.4 Calculate the stiffness values at loading times of 8.0, 15.0, 30.0, 60.0, 120.0 and 240.0 seconds using:

$$\log S_e(t) = A + B[\log(t)] + C[\log(t)]^2 \qquad (4)$$

where:

A, B, and C = the regression coefficients determined in 14.3.1, and
t = loading time.

14.4.1 Calculated and measured values of the stiffness should agree within 2 %. Otherwise, the test results are suspect.

14.5 Calculate the m-value for loading times of 8.0, 15.0, 30.0, 60.0, 120.0 and 240.0 seconds using:

$$m(t) = |d \log[S(t)] / d \log(t) = \|[B + 2C \log(t)]\| \qquad (5)$$

where:

B and C = the regression coefficients determined in 14.3.1, and
t = loading time.

14.6 Calculate the average load during the test by averaging the loads at 0.5 s and every 0.5 s thereafter up to 240 s.

14.7 For the time period between 0.5 s and 5.0 s calculate the maximum difference between the average load and the recorded loads at each 0.5 s interval.

14.8 For the time period between 5.0 and 240 s, calculate the maximum difference between the average load and the recorded loads at each 0.5-s interval.

NOTE 17—Report information which follows details data to generated by the BBR software. Actual communication of specific test result information by the user of this method is at the discretion of the user. Format of such communications are beyond the scope of this method.

15. Report

15.1 For each test, report the test information as shown in Table A1.1 including:

15.1.1 File name,

15.1.2 Test Specimen ID Number,

15.1.3 Project Identification No.,

15.1.4 Operator's name,

15.1.5 Date of test (dd/mm/yy),

15.1.6 Test specimen width (mm to nearest 0.01 mm),

15.1.7 Test specimen thickness (mm to nearest 0.01 mm),

15.1.8 Total elapsed time between first immersing test specimen in bath and applying the seating load [m],

15.1.9 Time test load applied (h,m),

15.1.10 Manufacture and Model Number of BBR,

15.1.11 Identification code that is unique to device. This is used to distinguish between multiple BBR's when more than one BBR is used in a laboratory,

15.1.12 Version of software used,

15.1.13 Maximum temperature during test (°C to 0.1°C),

15.1.14 Minimum temperature during test (°C to 0.1°C),

15.1.15 Maximum load recorded during test (mN nearest 1 mN),

15.1.16 Minimum load recorded during test (mN nearest 1 mN),

15.1.17 Date of last temperature calibration (dd/mm/yy),

15.1.18 Load cell calibration constant (mN/bit to three significant figures),

15.1.19 Date of last load cell calibration (dd/mm/yy),

15.1.20 LVDT calibration constant (µm/bit to three significant figures),

15.1.21 Date of last LVDT calibration (dd/mm/yy),

15.1.22 Modulus of steel beam measured during overall system check (GPa to three significant figures),

15.1.23 Compliance of loading system (µm/N to three significant figures),

15.1.24 Date of last compliance measurement (dd/mm/yy).

15.1.25 Two lines of 74 characters per line shall be provided for warnings generated by the software or for comments entered manually by the operator through the keyboard. Information in these lines shall be a permanent part of the test record.

15.2 Report the test results as shown in Table A1.1 for time intervals of 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 s including:

15.2.1 Loading time in seconds, nearest 0.1 s,

15.2.2 Test load in mN, nearest 1 mN,

15.2.3 Test specimen deflection in mm, nearest 1 µm,

15.2.4 Measured Stiffness Modulus, MPa, expressed to three significant figures,

15.2.5 Estimated Stiffness Modulus, MPa, expressed to three significant figures,

15.2.6 Difference between estimated and measured stiffness calculated as:

$$\{(Estimated - Measured) \times 100\ \%\}/\{Measured\}$$

15.2.7 Estimated m-value, nearest 0.001.

15.3 For each test, report the following summary data as shown in Fig. 1.

15.3.1 Regression coefficients and R^2 as per Section 8,

15.3.2 Contact load at t = 0, just prior to application of test load (mN to nearest 1 mN),

15.3.3 Test load after 0.5 s loading time (mN to nearest l mN),

15.3.4 Average load obtained by averaging the load at 0.5 s and every 0.5 s thereafter up to 240.0 s,

15.3.5 Maximum deviation of load from average load during interval from 0.5 to 5.0 s (mN),

15.3.6 Maximum deviation of load from average load during interval from 5.0 to 240.0 s (mN),

15.3.7 Deflection at zero time (mm),

15.3.8 Deflection at 0.5 s (mm).

15.4 *Data File*—The software shall generate a data file containing the load cell readings, LVDT readings, and temperature readings in units of mN, mm, and 0.1°C. The readings shall start at zero time and continue for 240 s at 0.5 s intervals. The file shall be in ASCII format. It shall not be a part of the report but shall be accessible at the option of the user.

16. Precision and Bias

16.1 *Precision*—Criteria for judging the acceptability of replicate measurements of flexural creep stiffness and m-value are given in Table 1. The criteria in Table 1 are based on several AMRL proficiency samples and several round robins involving more than 300 tests and different grades of binder.

16.2 *Single-Operator Precision (Repeatability)*—Duplicate results obtained by the same operator using the same equipment in the same laboratory shall not be considered suspect unless the difference in the duplicate results, expressed as a percent of their mean, exceeds the values given in Table 1 for single operator precision.

16.3 *Multi-laboratory Precision (Reproducibility)*—Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the results, expressed as a percent of their mean, exceeds the values given in Table 1 for multi-laboratory precision.

16.4 *Bias*—Since there is no acceptable reference value the bias for this test method cannot be determined.

17. Keywords

17.1 bending beam rheometer; flexural creep compliance; flexural creep stiffness

TABLE 1 Estimated Repeatability and Reproducibility

Condition	Coefficient of Variation (1 s %)[A]	Acceptable Range of Two Test Results (d2s %)[A]
Single-Operator Precision		
Creep Stiffness (MPa)	3.2	9.1
Slope	1.4	4.0
Multi-laboratory Precision		
Creep Stiffness (MPa)	9.5	26.9
Slope	4.6	13.0

[A] These values represent the 1s % and d2s % limits described in Practice C 670. These values are based on data from the AASHTO Materials Reference Laboratory Proficiency Testing Program and other regional round robin testing programs conducted with metal (aluminum) molds. Round robin testing conducted with metal and silicone rubber molds has shown that results obtained with the two different types of molds are not statistically different.

ANNEX

(Mandatory Information)

A1. CALIBRATION

Calibrate the components of the BBR as required by section 11.2 in accordance with the following instructions:

A1.1 *Calibration of Displacement Transducer*—Calibrate the displacement transducer using a stepped gage block of known dimensions similar to the one shown in Fig. 7. With the loading frame mounted in the bath at the test temperature, remove all beams from the supports and place the stepped gage 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 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 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 7.9. 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

TABLE A1.1 Typical Test Report

Test Conditions

File Name	AXX5M301#	Max temp during test (°C)	
Test Specimen ID No.[A]	AXB5PAV	Min. temp. during test (°C)	
Project ID No.[A]	XY DOT 45	Maximum Load during test (mN)	989
Operator's Name[A]	Joe Smith	Minimum Load during test (mN)	994
Date of test (mm/dd/yy)	03/22/97	Date last temperature calib. (mm/dd/yy)	03/22/97
Specimen width (mm)[B]	12.70	Load calib. Constant (mN/bit)	2.40
Specimen thick (mm)[B]	6.35	Date last load cell calib. (mm/dd/yy)	03/22/97
Elapsed time in bath (m)[A]	63	LVDT calib. Constant (µm/bit)	2.54
Time test load applied (h,m)	14:37	Date last LVDT calib. (mm/dd/yy)	03/22/97
Manf./Model of BBR	BB Tech-01	Modulus steel beam (GPa)	200
Device ID[A]	Unit No. 2	Compliance of loading system (µm/N)	2.57
Software Version	V 6.7.1	Date of last compliance check (mm/dd/yy)	03/22/97

Two lines of 74 characters per line for software-generated or operator-entered warnings and comments.

[A] Entered by technician.

[B] Entered at option of technician. Remaining data entered automatically by software.

Test Results

t Time (s)	P_t Test Load (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Stiffness Difference (%)	m-value
8.0	988	0.345	358	358	0.12	0.339
16.0	987	0.401	287	287	–0.23	0.362
30.0	987	0.482	222	222	0.10	0.387
60.0	988	0.597	168	168	–0.03	0.411
120.0	987	0.758	125	125	0.11	0.436
240.0	989	0.992	91.7	91.8	0.07	0.461

Calculated Parameters

Regression Coefficients:(A, B, C, R^2)	2.18	–0.195	0.00223	0.999981
Contact load when t = 0.0 s (mN)	31			
Average load from 0.5 to 240 s	998	Test load when t = 0.5 s (mN)		1021
Max. load deviation, 0.5 to 5.0 s (mN)	42	Max. load deviation, 5 to 240.0 s (mN)		2
Deflection at zero time, (mm)	0.000	Deflection at 0.5 s (mm)		1.237

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.

APPENDIX

(Nonmandatory Information)

X1. BEAM THEORY AND DATA INTERPRETATION

X1.1 *Deflection of an Elastic Beam*—Using elementary bending theory, the mid-span deflection of an elastic prismatic beam of constant cross-section loaded in three-point loading can be obtained by applying Eq X1.1 and X1.2 as follows:

$$\delta = PL^3/48EI \tag{X1.1}$$

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,

$$I = bh^3/12 \tag{X1.2}$$

where:
b = width of beam, mm, and
h = thickness of beam, mm.

NOTE X1.1—The test specimen has a span to depth ratio of 16 to 1, and the contribution of shear to deflection of the beam can be neglected.

X1.2 *Elastic Flexural Modulus*—According to elastic theory, calculate the flexural modulus of a prismatic beam of constant cross-section loaded at its midspan.

Therefore:

$$E = PL^3/4bh^3\delta \tag{X1.3}$$

where:
E = flexural creep stiffness, MPa,
P = load, N,
L = span length, mm,
b = width of beam, mm,
h = depth of beam, mm, and
δ = deflection of beam, mm.

X1.3 *Maximum Bending Stress*—The maximum bending stress occurs at the top and bottom of the beam at its midspan.

Therefore:

$$\sigma = 3PL/2bh^2 \tag{X1.4}$$

where:
σ = maximum bending stress in beam, MPa,
P = constant load, N,
L = span length, mm,
b = width of beam, mm, and
h = depth of beam, mm.

X1.4 *Maximum Bending Strain*—The maximum bending strain in the beam occurs at the top and bottom of the beam at its midspan.

Therefore:

$$\epsilon = 6\delta h/L^2 \; mm/mm \tag{X1.5}$$

where:
ϵ = maximum bending strain in beam, mm/mm,
δ = deflection of beam, mm,
h = thickness of beam, mm, and
L = span length, mm.

X1.5 *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 in the beam 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 numerically equivalent to S(t), rearranging the elastic solution results in the following relationship for the stiffness:

$$S(t) = PL^3/4bh^3\delta(t) \tag{X1.6}$$

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

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