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Standard Test Method for Determining Thermoplastic Pipe Wall Stiffness[1]

This standard is issued under the fixed designation F2433; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the load-deflection behavior of thermoplastic pipe wall sections under parallel plate loading conditions.

NOTE 1—These are not full pipe section tests, but pipe wall segment tests. The results of these tests will be different from pipe stiffness tests per Test Method D2412, although they may be proportional. This test provides quite different information, including , stress relaxation under constant strain, and comparisons of the function and stiffness of different pipe wall designs or materials.

1.2 This test method covers a loading test for determining the wall stiffness of a thermoplastic-pipe wall under a combined load of bending and compression. Changes in pipe wall profile geometry under load may also be determined.

1.3 This test method covers thermoplastic pipe.

1.4 The characteristics determined by this test method are wall stiffness and changes in profile wall dimensions at specific deformations.

1.5 The characteristics determined by this test method are wall stiffness, profile wall efficiency, and for some wall elements stability at specific Strain levels.

1.6 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.7 The text of this specification references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D695 Test Method for Compressive Properties of Rigid Plastics
D883 Terminology Relating to Plastics
D1600 Terminology for Abbreviated Terms Relating to Plastics
D2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
D2412 Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
F412 Terminology Relating to Plastic Piping Systems

2.2 *AASHTO Standards:*

M 252 Standard Specification for Corrugated Polyethylene Drainage Pipe[3]
M 294 Standard Specification for Corrugated Polyethylene Pipe, 300- to 1500-mm Diameter[3]

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology F412, and abbreviations are in accordance with Terminology D1600, unless otherwise specified.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *chord shortening, n*—the ratio of the reduction in pipe section chord shortening to the initial chord length expressed as a percentage.

3.2.2 Δy, *n*—measured change in chord length (in the direction of load application) expressed in millimeters (inches).

3.2.2.1 *compressive deformation, n*—the measured change of the inside diameter in the direction of load application expressed in millimeters (or inches).

3.2.3 *load (F), n*—the force applied to the wall section to produce or maintain a given percent chord length shortening at any given unit of time; expressed as Newtons per meter (pounds-force per linear inch).

[1] This test method is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.40 on Test Methods.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

3.2.4 *mean radius (r), n*—the mid-wall radius determined by subtracting the average wall thickness from the average outside diameter and dividing the difference by two; expressed in millimeters (or inches).

3.2.5 *time-independent pipe stiffness K(0), n*—the value obtained by dividing the force per unit length on the curved beam specimen by the resulting deflection in the same units at the % deflection prescribed and extrapolating the linear portion of the curve of stiffness versus % deflection to the moment of application of load.

3.2.6 *time-dependent residual curved beam stiffness K(t) and residual pipe stiffness K(t), n*—the value obtained by dividing the force per unit length on the curved beam specimen by the constant target deflection in the same units, at any time t, $t > 0$.

3.2.7 *modulus of relaxation, n*—the residual pipe stiffness versus log(time).

3.2.8 *residual pipe stiffness K(50y), n*—the value obtained by extrapolating values of residual pipe stiffness versus time to 50 years.

3.2.9 *compliance C(t), n*—the inverse of stiffness *K(t)*.

3.2.10 *liner cracking or crazing, n*—the occurrence of a break or network of fine breaks in the liner visible to the unaided eye.

3.2.11 *wall cracking, n*—the occurrence of a break in the pipe wall visible to the unaided eye.

3.2.12 *wall delamination, n*—the occurrence of any separation in the components of the pipe wall visible to the unaided eye.

3.2.13 *rupture, n*—a crack or break extending entirely or partly through the pipe wall.

4. Summary of Test Method

4.1 The test is conducted by applying a controlled, nearly instantaneous, load to the longitudinally cut edges of curved beam sections cut from short lengths of pipe until a prescribed shortening of the chord connecting the longitudinal edges is achieved and held constant for prescribed intervals. Load and deformation data establish the time-independent measure of curved beam wall stiffness at the instant of load application, the measure of efficiency of the profile wall geometry, stability of the profile wall, a modulus of relaxation and long-term estimates of residual pipe wall stiffness.

4.2 A length of a 10 to 120° arc segment of a pipe wall, from one diameter length to one meter long is loaded across its chord length between two freely rotating end plates at a controlled rate of approach to one another. Load-deflection data of the wall section in combined bending and compression are obtained. Change in pipe wall thickness at the center of the section (springline) is determined. If cracking, crazing, delamination, rupture, or buckling occurs, the corresponding load, deflection, and/or time are recorded.

NOTE 2—If this test method is incorporated in a product standard it would be necessary to define the arc length to be tested. There are, however, many reasons various arc lengths might be tested, especially as a research or product development tool. Large arc lengths are primarily in bending, while short arc lengths are primarily in compression.

5. Significance and Use

5.1 The performance under bending and compression load of a thermoplastic plastic pipe wall design obtained by this method can be used for the following:

5.1.1 To determine the stiffness of the pipe wall section. This is a function of the pipe dimensions, the wall design, the arc length tested, and the physical properties of the material of which the pipe is made.

5.1.2 To compare the characteristics of various thermoplastic pipe wall designs.

5.1.3 To compare the characteristics of various plastics in pipe form.

5.1.4 To study the interrelations of dimensions, materials, and deformation properties of thermoplastic pipe designs.

5.1.5 To measure the deformation and load-resistance at any of several significant events which may occur during the test.

5.1.6 To provide a reasonable quality control/quality assurance test for very large diameter plastic pipes.

5.2 The time-dependent pipe wall stiffness of a thermoplastic pipe obtained by this test method may used for the following:

5.2.1 To predict the residual stiffness of the pipe wall in bending and compression at all times after initial loading.

5.2.2 For purposes of design, to determine a modulus of relaxation under sustained loads.

5.2.3 To quantify the influence of material formulations of thermoplastics on the modulus of relaxation.

5.2.4 To study the influence of geometric patterns of wall profiles on the modulus of relaxation.

5.3 The time-independent reduction of wall thickness at springline may be used for the following:

5.3.1 For pipe wall stiffness, to quantify the efficiency of all wall profiles of any material composition and a given geometry with that of a solid uniform thickness wall.

6. Apparatus

6.1 *Testing Machine*—A properly calibrated compression testing machine of the constant-rate-of-crosshead movement type meeting the requirements of Test Method D695 shall be used to make the tests. The rate of head approach shall be 63.5 ± 2.5 mm (2.5 ± 0.1 in.)/s. The machines must be capable of holding a required percent chord shorting for an extended period of time.

6.2 *Loading Grips*—The load shall be applied to the specimen through two parallel-axis grips. These assemblies shall be flat, smooth, and clean. Specimen contact surfaces of platen shall be coated with a PTFE spray lubricant. The thickness of the platens shall be sufficient so that no bending or deformation occurs during the test, but it shall not be less than 12 mm (0.5 in.). The nominal length of each grip shall equal or exceed the specimen length but shall not be less than 1040 mm (41 in.). Upper and lower grips shall be free to rotate about an axis in the plane of the applied and reacting line loads. Recommended arrangement of loading frame, upper and lower grips with test specimen are shown in Fig. 1.

6.3 *Deformation Indicator*—The change in total wall (major wall for profile wall pipe) thickness at springline, shall be

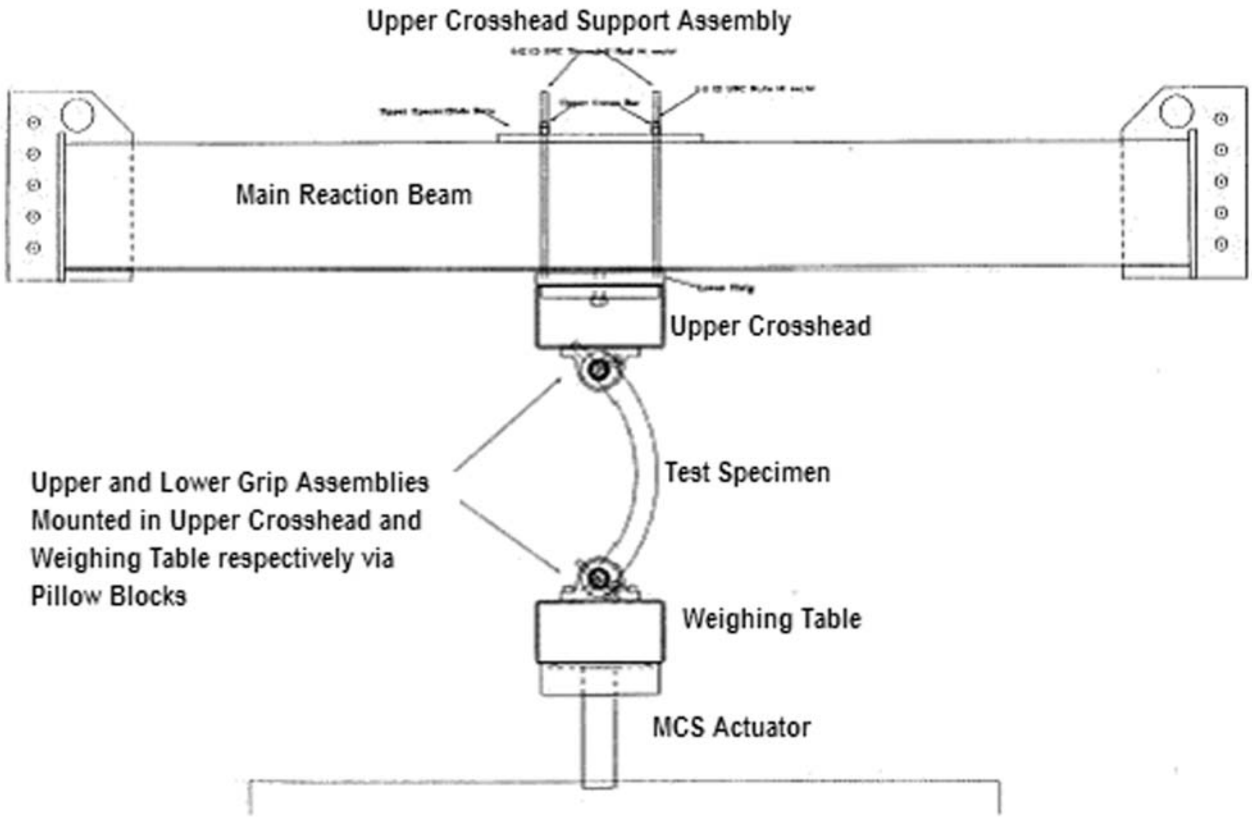

FIG. 1 Recommended Arrangement of Loading Frame, Upper & Lower Grips, and Test Specimen

measured with a suitable instrument meeting the requirements of 4.1.2 of Test Method D695, except that the instrument shall be accurate to the nearest 0.025 mm (0.001 in.). The instrument shall not affect in any way the load-deflection measurements.

6.4 *Load Sensor*—The change of load with time during the periods of displacement (loading) and during the period of constant displacement shall be digitally recorded with a precision of no less than 4 significant figures and at time intervals as noted in 9.3. The sensing element shall have a precision of ±2 % of maximum recorded value.

6.5 *Temperature Recorder*—Ambient temperature shall be continuously recorded using a sensor capable of recording to 1°C (1.8°F).

6.6 *Reaction Frame*—The reaction frame shall be sufficiently rigid such that the movement of the stationery platen shall not exceed 0.05 % of the displacement of the moving platen.

7. Test Specimens

7.1 Test specimens shall be cut from the pipe wall, with the cuts through the wall radial and parallel through the sample length. Test specimens may be the required arc length in degrees ±1° arc sections of the wall, as agreeable to the manufacturer and the purchaser, but not less than 10 degrees nor greater than 120 degrees. Test specimens should be a minimum of 600 mm (24 in.) long, and may be as much as 900 mm (36 in.), and for corrugated or profile pipe should be squarely cut in the corrugation or profile valley.

NOTE 3—Standard arc lengths for specimens should be 120°, 90°, and 30°, though other arc lengths may be used within the range of 120° to 10°, as determined by the needs of the owner, researcher, or testing laboratory.

8. Conditioning

8.1 Condition the pipe wall section for at least 24 h in air at a temperature of 23 ± 2°C (73.4 ± 3.6°F), and 50 ± 5 % relative humidity and conduct the test in a room maintained at the same temperature.

8.2 When a referee test is required, condition specimens for at least 40 h at 23 ± 2°C (73.4 ± 3.6°F), and 50 ± 5 % relative humidity per Practice D618 Procedure A and conduct the test under the same conditions.

9. Procedure

9.1 Before placing each test specimen in the test apparatus make the following measurements:

9.1.1 Measure, to the nearest 1 mm (0.04 in.), the longitudinal length with equally spaced parallel measurements at mid and quarter points of the arc of the curved beam. Determine the longitudinal length by averaging the three measurements.

9.1.2 For specimens prepared from AASHTO M 252M and AASHTO M 294M Type C pipes, at each of three points approximately located on a mid-longitudinal line of the corrugated wall, one point located at mid-length and two points

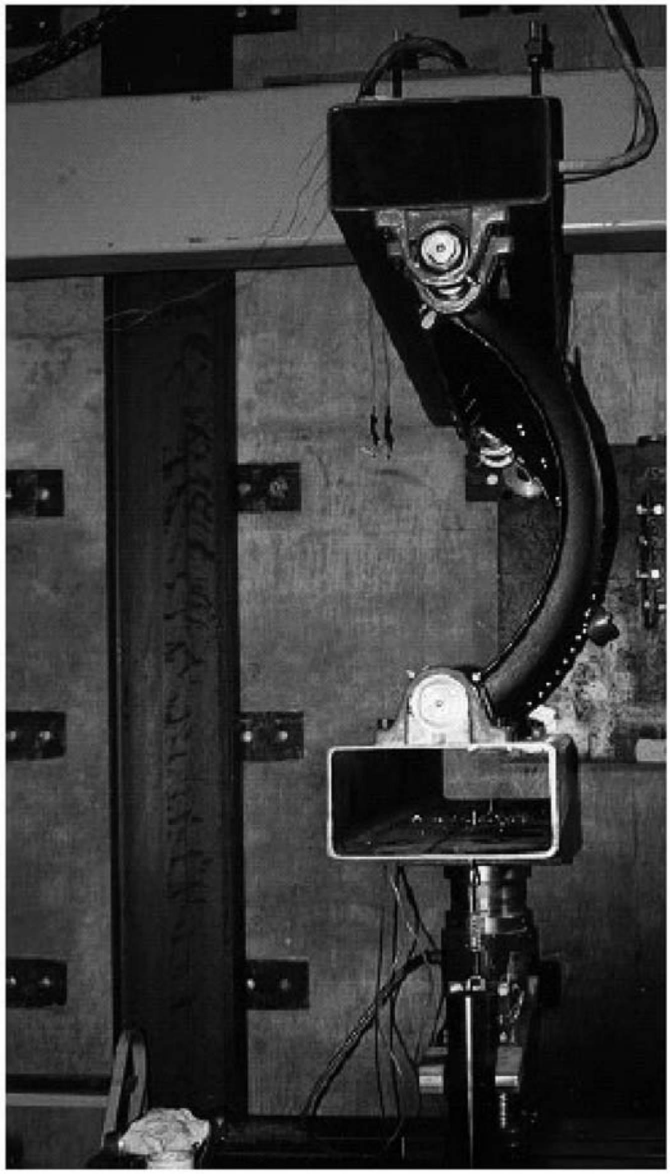

FIG. 2 Photographs of Specimen in Load Frame

located at one-quarter and three-quarter lengths, determine the out-to-out distance, to the nearest 1 mm (0.04 in.), from the center of the crest to a projection of the center of an adjacent valley on a line perpendicular to the tangent at the center of the crest. Determine the wall thickness by averaging the three measurements.

9.1.3 For specimens prepared from AASHTO M 252M and AASHTO M 294M Type S pipes measure the total wall thickness, to the nearest 1 mm (0.04 in.), at the center of the crests of the outer wall corrugations, located at approximately half and quarter points along the mid-longitudinal line of the curved beam. Determine the thickness by averaging the three measurements.

9.1.4 For specimens prepared from ASTM F894 pipes measure the total wall thickness, to the nearest 1 mm (0.04 in.), at the approximate midpoint between lap welds of the wall at locations approximately half and quarter lengths along the mid-longitudinal line of the curved beam. Determine the thickness by averaging the three measurements.

9.1.5 For specimens prepared from AASHTO M 294M Type D pipes measure the total wall thickness, to the nearest 1 mm (0.04 in.), from the outermost point of the circular web to the closest point on the inner surface of the pipe wall. Determine the thickness by averaging the three measurements.

9.2 The test is conducted by applying a nearly instantaneous load to the longitudinally cut edges of an arc section of test pipe until 10 % shortening of the chord connecting the longitudinal edges is achieved. For purposes of design and quality control and quality assurance, as determined by time independent stiffness, the sample shall be held in a shortened shape for intervals noted in 9.3 (time-independent pipe stiffness *K(0)*).

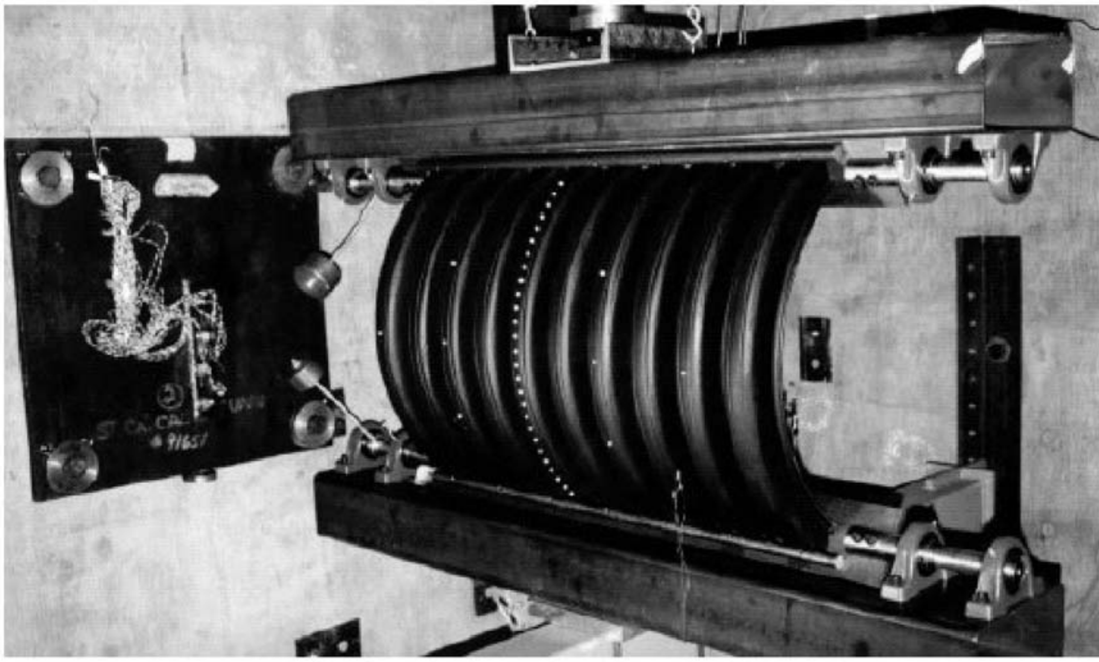

FIG. 2 Photographs of Specimen in Load Frame *(continued)*

For tests of the relaxation modulus the sample shall be held at a constant deformation for a minimum of 24 h. The displacement rate of load application is 65 ± 5 mm/s (2.5 ± 0.2 in./s). Load and displacement readings should be recorded at not greater than the following schedule:

Schedule A—Sampling Rate Schedule for Test Durations Greater than 12 Hours (except as noted)

Test Duration	Sampling Rate
>10 seconds	0.1 seconds
10 seconds to 2 minutes	1 second
2 minutes to 1 hour	10 seconds
1 to 12 hours	1 minute
12 to 17 hours	2.5 minutes
17 to 24 hours	10 minutes
24 hours to 72 hours	60 minutes
72 hours to 10 days	6 hours
10 days to 60 days	24 hours
>60 days	Every 7 days

9.3 *Time-independent Pipe Stiffness K(0)*—Load and displacement data shall be obtained at a sampling rate of no less than noted in the following schedule:

9.3.1 For curved beams cut from pipes with diameters of 600 mm (24 in.) or less:

0.01 seconds for no less than 2 seconds

9.3.2 For curved beams cut from pipes with diameters greater than 600 mm (24 in.) up to and including 1200 mm (48 in.):

0.02 seconds for no less than 2 seconds

9.3.3 For curved beams cut from pipes with diameters greater than 1200 mm (48 in.) up to and including 1800 mm (72 in.):

0.03 seconds for no less than 3 seconds,
additional data according to Schedule A

9.3.4 For curved beams cut from pipes with diameters greater than 1800 mm (72 in.) up to and including 2400 mm (96 in.):

0.04 seconds for no less than 4 seconds

9.3.5 For curved beams cut from pipes with diameters greater than 2400 mm (96 in.) up to and including 3000 mm (120 in.):

0.05 seconds for no less than 5 seconds

9.4 *Residual Pipe Wall Stiffnesses K(50y) and K(100y)*—Load and displacement data shall be obtained at a sampling rate of no less than noted in the following schedule:

9.4.1 For curved beams cut from pipes with diameters of 600 mm (24 in.) through 3000 mm (120 in.) pipes:

As required in 9.3.1 – 9.3.5, plus
0.1 seconds for no less than 10 seconds,
1 second for no less than 2 minutes,
10 seconds for no less than 1 hour,
1 minute for no less than 6 hours, and
2.5 minutes for no less than 17 hours.

10. Calculation

10.1 Calculate the time-independent pipe wall stiffnesses, *K(0)* and *K(t)* as follows:

10.1.1 For all load-deflection data calculate the time-dependent residual curved beam stiffness:

$$K(t) = F(t)/\Delta y(t) \quad (1)$$

where:

K(t) = time-dependent residual curved beam stiffness,
F(t) = the force applied to the wall section to produce or maintain a given percent chord length shortening at any given unit of time; expressed as Newtons per meter (pounds-force per linear inch), and
Δy = measured change in chord length (in the direction of load application) expressed in millimeters (inches).

NOTE 4—Immediately after the moment of initiation of continuous application of load, the load of record incorporates the influences of the continuing application of load and the relaxation of previously applied load. The net load at any time t, $t > 0$, is characterized as the residual load; the quantity, load per unit length divided by the associated displacement is characterized as the residual stiffness. These definitions also apply during the extended period when displacements are held constant without further application of load.

10.1.2 For the interval beginning at the instant of load application and ending when the deflection of the curved beam reaches 10 % shortening of the chord, plot, on cartesian coordinates, curved beam stiffness, *K(t)* versus % deflection.

10.1.3 Through the points between 2 % deflection and 8 % deflection fit a least squares estimate of a straight line.

10.1.4 Calculate the intercept, *K(0)* at time $t = 0$.

NOTE 5—Stiffness versus deflection is typically a smooth curve. The effective zero point of zero time is established by deleting the stiffness-time record prior to, and immediately after, the application of load recorded and extrapolating the initial straight line portion of the curve backwards to zero load.

10.2 Estimate the residual pipe wall stiffness, *K(t)*, of 300 mm (12 in.) diameter solid wall pipes after 50 years, *K(50y)*, and after 100 years, *K(100y)*.

10.2.1 Calculate and plot the residual stiffness, *K(t)* versus 1/log*(t)*, t = time in seconds, for all points beginning at the time of 10 % displacement of the curved beam extending through a period of no less than six (6) weeks.

10.2.2 Using the method of least squares linear regression calculate the parameters of the best line fitting the data points.

10.2.3 Evaluate *K(50y)* and *K(100y)*.

10.2.4 Calculate the stress relaxation factors:

$$SRF(50y) = K(50y)/K(0) \tag{2}$$

$$SRF(100y) = K(100y)/K(0) \tag{3}$$

NOTE 6—Stiffness is essentially a force per unit length by divided by an associated deflection. In SI units, with the force expressed in newtons per meter of length and the deflection in millimeters, pipe stiffness is expressed in kilopascals (kPa). Although stiffness units are dimensionally the same as those for pressure and stress, all are different quantities.

11. Report

11.1 Report the following information:

11.1.1 Complete identification of the material tested; including type, source, manufacturing code, previous history (if any), and product identification by standard number.

11.1.2 Dimensions of each specimen, including average outside diameter, average wall thickness, average inside diameter, liner thickness (if applicable), reinforcement thickness (if applicable), average inside chord length, outside chord length, arc length in degrees, and average specimen length.

11.1.3 Reduction of chord length in millimeters (or inches) and percent, reduction in wall thickness at springline in millimeters (or inches) and percent.

11.1.4 Wall section stiffness (or stiffnesses) at the prescribed % chord shortening at the prescribed unit (or units) of time. A plot on Cartesian coordinates of load in Newtons per meter (or pounds-force per inch) versus time in seconds at the prescribed chord shortening in millimeters (or inches) for each specimen tested.

11.1.5 Conditioning temperature, time, and environment.

11.1.6 The deflection, load, and time at which liner cracking, wall cracking, wall delamination, wall buckling, wall element buckling, and/or rupture occurs (if applicable). Any of these events should also be noted on the plot required in 11.1.4, wall section stiffness (or stiffnesses).

11.1.7 Date of test.

12. Precision and Bias

12.1 *Precision—*Only three laboratories have thus far run sufficient tests using this method. No statement of precision is yet available. Repeatability is within ±15 %.

12.2 *Bias—*Test results obtained from this test method are believed to be reliable since accepted techniques of analysis are used. However, no bias statement is made.

13. Keywords

13.1 buckling; modulus of relaxation; moment of inertia; pipe stiffness; residual pipe stiffness