Designation: D5365 – 23

Standard Test Method for
Long-Term Ring-Bending Strain of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe[1]

1. Scope*

1.1 This test method covers a procedure for determining the long-term ring-bending strain (S_b) of "fiberglass" pipe. Both glass-fiber-reinforced thermosetting-resin pipe (RTRP) and glass-fiber-reinforced polymer mortar pipe (RPMP) are "fiberglass" pipes.

1.2 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* A specific warning statement is given in 9.5.

NOTE 1—There is no known ISO equivalent to this standard.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D883 Terminology Relating to Plastics

D1600 Terminology for Abbreviated Terms Relating to Plastics

D3567 Practice for Determining Dimensions of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings

3. Terminology

3.1 *Definitions:*

3.1.1 *General*—Definitions are in accordance with Terminology D883 and abbreviations are in accordance with Terminology D1600 unless otherwise indicated.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *end point*—the failure of the test specimen. The failure mode may be catastrophic, characterized by a sudden fracture through the pipe wall in the area of greatest strain.

3.2.2 *fiberglass pipe*—tubular product containing glass-fiber reinforcements embedded in or surrounded by curing thermosetting resin. The composite structure may contain aggregate, granular or platelet fillers, thixotropic agents, pigments, or dyes; thermoplastic or thermosetting liners or coatings may be included.

3.2.3 *reinforced polymer mortar pipe (RPMP)*—fiberglass pipe with aggregate.

3.2.4 *reinforced thermosetting resin pipe (RTRP)*—fiberglass pipe without aggregate.

4. Summary of Test Method

4.1 This test method consists of subjecting submerged-pipe ring specimens to various increasing deflections induced by a constant load and monitoring the time to failure. A minimum of 18 samples are required. Test temperatures are obtained by testing in a fluid environment where the temperature is controlled.

4.2 The long-term ring-bending strain is obtained by an extrapolation to 50 years of a log-log linear regression line for failure strain versus time.

NOTE 2—It is the consensus of Subcommittee D20.23 that the log-log linear regression analysis of test data is a conservative approach and is representative of standard industry practice.

5. Significance and Use

5.1 This test method determines the long-term ring-bending strain of pipe when deflected under constant load and immersed in a chemical environment. It has been found that effects of chemical environments can be accelerated by strain induced by deflection. This information is useful and necessary for the design and application of buried fiberglass pipe.

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[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.23 on Reinforced Thermosetting Resin Piping Systems and Chemical Equipment.

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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.

*A Summary of Changes section appears at the end of this standard

NOTE 3—Pipe of the same diameter but of different wall thicknesses will develop different strains with the same deflection. Also, pipes having the same wall thickness but different constructions making up the wall may develop different strains with the same deflection.

6. Apparatus

6.1 *Loading Device*—The testing apparatus shall be suitable for maintaining a constant load on the test specimen.

6.2 *Load Application*—The load shall be applied to the test specimens using any of three alternative pairs of parallel loading surfaces; flat plates, rods or bars of a length at least as long as the pipe ring and of sufficient strength and stiffness to ensure a straight loading surface throughout the test. The same type of loading device shall be used for each specimen in a test series. In order to achieve uniform strain along the pipe, use 0.25-in. (6-mm) thick elastomeric pads between the parallel loading surfaces and the pipe ring (see Note 4).

6.2.1 *Flat Plates*—The plates shall have a minimum 6-in. (152-mm) width.

6.2.2 *Bars*—The bars shall have a flat contact surface of 0.75 ± 0.25 in. (19 ± 6 mm).

6.2.3 *Rods*—The rod diameter shall be 2 ± 0.25 in. (51 ± 6 mm) for pipe rings 12 in. (305 mm) and greater in diameter. For smaller pipes, the rod diameter shall be 1 ± 0.25 in. (25 ± 6 mm).

6.3 *Environment Containment*—A test enclosure of sufficient size to fully immerse the test specimens shall be used to contain the test solution. The enclosure shall not chemically affect the test solution.

NOTE 4—Elastomeric pads with a hardness of Shore A40 to 70 have been used successfully.

7. Test Specimens

7.1 The test specimens shall be ring sections taken from a sample(s) of pipe selected at random from a normal production run. The test specimens shall have a minimum length of one nominal pipe diameter or 12 in. (305 mm) ± 5 %, whichever is less. Treat the cut edges of the specimens by the same procedure as production products.

8. Test Conditions

8.1 The standard temperature shall be 23 ± 5°C (73.4 ± 9°F).

9. Procedure

9.1 *Test Specimen Measurements:*

9.1.1 *Wall Thickness*—Determine in accordance with Test Method D3567.

9.1.2 *Inside Diameter*—Determine in accordance with Test Method D3567 at both ends prior to deflection and average the measurements.

NOTE 5—It is recommended that the inside diameter be measured with the axis vertical.

9.2 Place the test apparatus into the test enclosure.

9.3 Place the pipe ring in the test apparatus (see Fig. 1) and apply force to deflect the specimen at a rate not to exceed 10 % of its diameter per minute while keeping the top and bottom
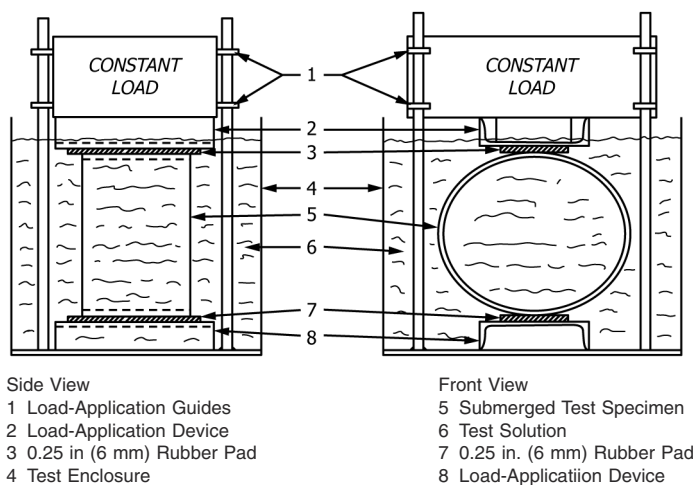

FIG. 1 Long-Term Ring Bending Test Apparatus

loading devices (plates, bars, or rods) of the apparatus as near parallel as practical. When the desired deflection is obtained cease adding load to the apparatus.

NOTE 6—Alignment of the specimen within the loading devices is critical. The loading devices should not only be parallel with the load points 180° opposite, but the pipe ring should also be centered between the load-application guides. Additionally, the load-application guides should permit complete vertical freedom of movement, so the specimen remains under constant load.

9.4 Measure the vertical inside diameter of the deflected pipe specimen at both ends to the nearest 0.01 in. (0.25 mm). Average the measurements and determine the initial deflection by subtracting the average vertical inside diameter after loading from the measurement determined in 9.1.2.

NOTE 7—Deflections in excess of 28 % of diameter may cause local flattening of the pipe and lead to erratic test results. For deflections approaching 28 %, improved accuracy is obtained by use of strain gages or by establishing, for each pipe product, a calibration of deflection versus measured strain. This calibration technique may also be useful at all deflection levels.

9.5 Introduce the test solution to completely submerge the pipe ring as quickly as possible after loading. The solution may be added prior to loading the pipe ring and shall be added within 30 min of loading the pipe ring. Testing time commences only after both specimen loading (deflection) and the addition of solution are complete. (**Warning**—Since the failure mode could be catastrophic, take precautions to prevent or contain splashing or spilling of the test solution or other damages resulting from the sudden collapse of the pipe specimen.)

9.6 Periodically check and maintain the test solution within ±5 % of the specified strength or concentration for the duration of the test. The test specimen must remain completely submerged.

NOTE 8—As some solutions become more concentrated with the evaporation of water, care must be exercised in replenishment to prevent a build-up in strength. It may be necessary, with some reagents, to periodically clean the deflected specimen and replace the test solution with a fresh mixture. The use of plastic film, cut carefully to fit around the test

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apparatus and floated on the top of the test solution, has been found helpful in reducing evaporation.

9.7 Continuously monitor the decreasing pipe-ring inside vertical diameter versus time or inspect the loaded specimen at least at the frequency given below and measure the pipe specimen inside vertical diameter:

Hours	Inspect at Least
0 to 20	Every hour
20 to 40	Every 2 h
40 to 60	Every 4 h
60 to 100	Every 8 h
100 to 600	Every 24 h
600 to 6000	Every 48 h
After 6000	Every week

Determine the deflection by subtracting the inside vertical diameter from the measurement determined in 9.1.2.

NOTE 9—Decreasing diameter of the pipe ring (deflection change) may be monitored with an appropriate indicator on the apparatus above the solution and submerged specimen.

9.8 Calculate the end point (failure time and failure deflection) in accordance with 10.1.

9.9 Record the following data:

9.9.1 Average pipe-wall thickness,

9.9.2 Average inside pipe diameter before deflection,

9.9.3 Average inside pipe diameter after deflection,

9.9.4 Initial deflection,

9.9.5 Type of loading device,

9.9.6 Type, location and time of any distress of the pipe wall,

9.9.7 Failure deflection and time at the end point, and

9.9.8 Type of failure.

9.10 To determine the regression line and the lower confidence level, a minimum of 18 samples is required. Distribution of data points shall be as follows:

Hours	Failure Points
10 to 1000	At least 4
1000 to 6000	At least 3
After 6000	At least 3
After 10 000	At least 1

9.10.1 Those specimens that have not failed after more than 10 000 h may be included as failures to establish the regression line. Use of these data points may result in a higher or lower extrapolated value.

NOTE 10—Non-failed specimens may be left under test and the regression line recalculated as failures are obtained.

10. Calculation

10.1 Determine the failure time and deflection:

10.1.1 The failure deflection and failure time shall be the last values noted prior to the fracture occurrence.

10.2 *Long-Term Ring-Bending Strain:*

10.2.1 Compute the failure strain for each failed specimen as given in 10.2.1.1 and 10.2.1.2.

10.2.1.1 Crown and invert failures:

$$\varepsilon_f = \frac{4.28(e)(\Delta_f)}{(D + \Delta_f/2)^2}$$

where:

ε_f = failure strain in inches per inch (millimetres per millimetre),

e = wall thickness in inches (millimetres) in accordance with 9.1.1 (see Note 11),

D = mean diameter in inches (millimetres) (ID in accordance with 9.1.2 plus e in accordance with 9.1.1 or OD minus e), and

Δ_f = failure deflection in accordance with 10.1.

10.2.1.2 Springline failures:

$$\varepsilon_f = \frac{2.44(e)(\Delta_f)}{(D + \Delta_f/2)^2}$$

NOTE 11—The S_b calculations assume that the neutral axis is at the pipe-wall midpoint. For pipe-wall constructions that produce an altered neutral-axis position, it shall be necessary to evaluate results by substituting $2\bar{y}$ for e. ($\bar{y}$ is the distance from the appropriate pipe surface to the neutral axis.) Neutral-axis position shall be determined with strain-gage couples.

10.2.2 Use for each specimen in the series, the log of the failure strain and the log of the failure time in hours as described in A1.4.1. Calculate S_b, the strain at 50 years (438 000 h).

10.2.3 If $Sxy > 0$ (see Annex A1.4.2.2), consider the data unsuitable.

10.2.4 Calculate r in accordance with A1.4.3.1. If r is less than the applicable minimum value given in Table A1.1, consider the data unsuitable.

10.2.5 Prepare a graph on a log-log diagram showing time to failure versus failure strain, with time plotted on the horizontal (x) axis and strain on the vertical (y) axis.

11. Reconfirmation of the S_b Regression Line

11.1 When a piping product has an existing S_b regression line, any change in material, manufacturing process, construction or liner will necessitate a screening evaluation (reconfirmation) as described in 11.2, 11.3, 11.4, and 11.5.

11.2 Calculate and plot the 95 % confidence limits and the 95 % prediction limits of the original regression line in accordance with A1.4.6.2 using only data obtained prior to the change.

NOTE 12—Prediction limits define the bounds for single observations, whereas confidence limits define the bounds for the regression line.

NOTE 13—For 95 % confidence limits, there is a 2.5 % probability that the mean value for the regression line may fall above the UCL and a 2.5 % probability that the mean value for the regression line may fall below the LCL. For 95 % prediction limits, there is a 2.5 % probability that individual data points may fall above the UPL and a 2.5 % probability that individual data points may fall below the LPL.

11.3 From the original regression line, select strain levels for at least two sets of specimens. Each specimen set shall consist of three or more specimens tested at the same initial strain level, as follows:

Hours to Failure (Average of Set)	Failure Points
10 to 200	At least 3
More than 1000	At least 3
Total:	At least 6

For the purposes of reconfirmation it is permitted to include as failures those specimens which have not failed after 1200 hours provided they exceed the existing regression line.

11.4 Consider any changes in material or manufacturing process minor and permissible if the results of 11.3 meet the following criteria:

11.4.1 The average failure point for each specimen set falls on or above the 95 % lower confidence limit of the original regression line.

11.4.2 The earliest individual failure point falls on or above the 95 % lower-prediction limit of the original regression line.

11.4.3 The failure points are distributed about the originally determined regression line. No more than two-thirds of the individual failure points may fall below the original regression line.

11.5 It is permitted to assume that data meeting the criteria of 11.4 are part of the original data set and to determine a new regression line using all failure points. Specimens which have not failed after 1200 hours are not suitable for establishing a new regression line; however, it is permitted to use these points for the purpose of reconfirmation.

11.6 If the data fails to satisfy the criteria of 11.4, the changes are considered major and a new regression line must be established. While the new test program is being conducted, an interim S_b value for the material or process change may be taken as the lower of the following calculations:

11.6.1 The 95 % lower confidence limit of the value obtained by extrapolating the failure points of 11.3 to 438 000 h (50 years) by the procedure in Annex A1.

11.6.2 The 95 % lower confidence limit of the original regression line at 50 years.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the pipe composition, manufacturers code, size, and minimum wall thickness,

12.1.2 Description of loading apparatus and monitoring system,

12.1.3 Data in 9.9,

12.1.4 Complete description of the test solution,

12.1.5 If used, the type of strain gage employed and method of mounting,

12.1.6 Temperature at which the test was run,

12.1.7 Graph of 10.2.5,

12.1.8 Calculations of 10.2.1, and

12.1.9 Strain at 50 years for the mean and the value for *r*.

13. Precision and Bias

13.1 No precision and bias statement can be made for this test method since controlled round-robin test programs have not been run. This test method is generally used to evaluate large-diameter fiberglass pipe.

14. Keywords

14.1 constant load; deflection; end point; fiberglass pipe; pipe-ring specimens; regression line; ring-bending strain

ANNEX

(Mandatory Information)

A1. LEAST SQUARES CALCULATION FOR LONG TERM RING-BENDING STRAIN

A1.1 General

A1.1.1 The analysis is based on the following relationship:

$$y = a + bx \qquad (A1.1)$$

where:
y = one variable,
x = other variable,
b = slope of the line, and
a = intercept on the y axis.

A1.1.2 A linear functional relationship analysis (sometimes called "covariance analysis") is used, subject to tests for the sign (that is, "+" or "−") of the slope and the coefficient of correlation for the quantity of data available. The relevant equations are given together with example data and results, on the basis of which any other statistical computing package may be used subject to validation by agreement with the example results to within the indicated limits.

A1.1.3 For the purposes of this annex, a design service life of 50 years has been assumed.

A1.2 Procedure for Analysis of Data

A1.2.1 Use a linear functional relationship analysis to analyze n pairs of data values (as y and x) to obtain the following information:

A1.2.1.1 The slope of line, b,

A1.2.1.2 The intercept on the y axis, a,

A1.2.1.3 The correlation coefficient, r, and

A1.2.1.4 The predicted mean and the lower 95 % confidence and prediction intervals on the mean value.

A1.3 Assignment of Variables

A1.3.1 Let x be $\log_{10}t$, where t is the time, in hours, and let y be $\log_{10}V$, where V is the stain value.

A1.4 Functional Relationship Equations and Method of Calculation

A1.4.1 *Basic Statistics and Symbols:*

A1.4.1.1 The following basic statistics and symbols are used:

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n = number of pairs of observed data values (V_i, t_i),

y_i = $\log_{10}$ of V_i, where V_i is the strain at failure of Observation i; $i = 1, \ldots n$,

x_i = $\log_{10}$ of t_i, where t_i is the time to failure in hours of Observation i; $i = 1, \ldots .n$,

$\bar{y}$ = arithmetic mean of all y_i values:

$$= \frac{1}{n} \sum y_i \qquad (A1.2)$$

$\bar{x}$ = arithmetic mean of all x_i values:

$$= \frac{1}{n} \sum x_i \qquad (A1.3)$$

A1.4.2 *Relevant Sums-of-Squares:*

A1.4.2.1 Calculate the following sums-of-squares and cross-products:

$$S_{xy} = \frac{1}{n} \sum (x_i - \bar{x})(y_i - \bar{y}) \qquad (A1.4)$$

A1.4.2.2 If $S_{xy} > 0$, consider the data unsuitable for evaluating the material; otherwise calculate also:

$$S_{xx} = \frac{1}{n} \sum (x_i - \bar{x})^2 \qquad (A1.5)$$

$$S_{yy} = \frac{1}{n} \sum (y_i - \bar{y})^2 \qquad (A1.6)$$

A1.4.3 *Correlation of Data:*

A1.4.3.1 Calculate the coefficient of correlation, r, from the following relationship:

$$r^2 = \frac{(S_{xy})^2}{(S_{xx} \times S_{yy})} \qquad (A1.7)$$

$$r = \sqrt{r^2}$$

A1.4.3.2 If the value of r is less than the applicable minimum value given in Table A1.1 as a function of n, reject the data; otherwise, proceed to A1.4.4.

A1.4.4 *Functional Relationships:*

A1.4.4.1 To find a and b for the functional relationship line, $y = a + bx$ (Eq A1.1), first set:

$$\lambda = \left(\frac{S_{yy}}{S_{xx}} \right) \qquad (A1.8)$$

and then let:

$$b = -\sqrt{\lambda} \qquad (A1.9)$$

and then:

$$a = \bar{y} - b\bar{x} \qquad (A1.10)$$

NOTE A1.1—Since $y = \log_{10}V$ and $x = \log_{10}t$, hence $V = 10^y$, $t = 10^x$ and the implied relationship for V in terms of t is therefore:

$$V = 10^{(a + b \times \log_{10} t)}$$

A1.4.5 *Calculation of Variances:*

A1.4.5.1 If t_L is the applicable time to failure, then set:

$$x_L = \log_{10} t_L \qquad (A1.11)$$

A1.4.5.2 Calculate, in turn, the following sequence of statistics. For $i = 1$ to $i = n$, the best fit, ξ_i, for true x, the best fit,

TABLE A1.1 Minimum Values for the Coefficient of Correlation, *r*, for Acceptable Data From *n* Pairs of Data

n Number of variables	n-2 Degrees of freedom	Minimum r
3	1	0.9999
4	2	0.9900
5	3	0.9587
6	4	0.9172
7	5	0.8745
8	6	0.8343
9	7	0.7977
10	8	0.7646
11	9	0.7348
12	10	0.7079
13	11	0.6835
14	12	0.6614
15	13	0.6411
16	14	0.6226
17	15	0.6055
18	16	0.5897
19	17	0.5751
20	18	0.5614
21	19	0.5487
22	20	0.5368
23	21	0.5256
24	22	0.5151
25	23	0.5052
26	24	0.4958
27	25	0.4869
32	30	0.4487
37	35	0.4182
42	40	0.3932
47	45	0.3721
52	50	0.3542
62	60	0.3248
72	70	0.3017
82	80	0.2830
92	90	0.2673
102	100	0.2540

Y_i, for true y and the error variance, σ_δ^2, for x using Eq A1.12, Eq A1.13, and Eq A1.14, respectively:

$$\xi_i = \{\lambda x_i + (y_i - a)b\}/2\lambda \qquad (A1.12)$$

$$Y_i = a + b\xi_i \qquad (A1.13)$$

$$\sigma_\delta^2 = \left\{ \sum (y_i - Y_i)^2 + \lambda \sum (x_i - \xi_i)^2 \right\} / \{\lambda(n - 2)\} \qquad (A1.14)$$

A1.4.5.3 Calculate the following quantities:

$$\tau = b\sigma_\delta^2 / 2S_{xy} \qquad (A1.15)$$

$$D = 2\lambda b\sigma_\delta^2 / nS_{xy} \qquad (A1.16)$$

$$B = -D\bar{x}(1 + \tau) \qquad (A1.17)$$

A1.4.5.4 Calculate the following variances: the variance, C, of b using the formula:

$$C = D(1 + \tau) \qquad (A1.18)$$

the variance, A, of a using the formula:

$$A = D \left\{ \bar{x}^2 (1 + \tau) + \frac{S_{xy}}{b} \right\} \qquad (A1.19)$$

the variance, σ_n^2, of the fitted line at x_L using the formula:

$$\sigma_n^2 = A + 2Bx_L + Cx_L^2 \qquad (A1.20)$$

the error variance, σ_ε^2, for y using the formula:

$$\sigma_\varepsilon^2 = 2\lambda \sigma_\delta^2 \qquad (A1.21)$$

the total variance, σ_y^2, for future values, y_L, for y at x_L using the formula:

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