Designation: D5365 – 12

An American National Standard

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

This standard is issued under the fixed designation D5365; 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 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 and health 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.

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 D 20.23 that the log-log linear regression analysis of test data is a conservative approach and is representative of standard industry practice. However, a task group has been formed to evaluate alternative non-linear analysis methods.

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.

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.

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

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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 Plastic 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.

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 may 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 2).

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 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.

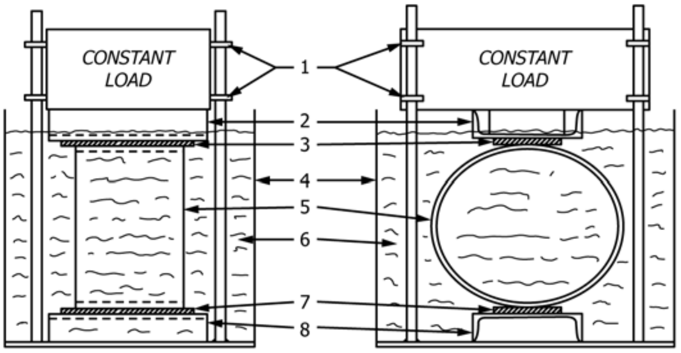
9.1.2 *Inside Diameter*—Determine in accordance with Test Method D3567 at both ends prior to deflection and average the measurements.

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 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.



Side View
1 Load-Application Guides
2 Load-Application Device
3 0.25 in (6 mm) Rubber Pad
4 Test Enclosure

Front View
5 Submerged Test Specimen
6 Test Solution
7 0.25 in. (6 mm) Rubber Pad
8 Load-Applicatiion Device

FIG. 1 Long-Term Ring Bending Test Apparatus

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. The solution may be added prior to loading the pipe ring and should 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 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 may 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 must 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 as described in 11.2, 11.3, 11.4, 11.5, and 11.6.

11.2 Obtain failure points 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

Include as failures those specimens that have not failed after 3000 h, provided they exceed the regression line.

11.3 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.

11.4 Consider any changes in material or manufacturing process minor and permissible if the results of 11.2 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 Alternatively to 11.4, consider changes in material or manufacturing process permissible if the results of 11.2 meet the following:

11.5.1 All data points fall above the 95 % lower confidence limit of the original regression line, and

11.5.2 At least two points exceed 3000-h failure time.

11.6 Data meeting the criteria of 11.4 or 11.5 may be assumed to be part of the original data set and a new regression line determined using all failure points.

11.7 If the data fails to satisfy the criteria of 11.4 or 11.5, 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:

11.7.1 The 95 % lower confidence limit of the value obtained by extrapolating the failure points of 11.2 to 438 000 h (50 years) by the procedure in Annex A1.

11.7.2 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:

$$y = a + bx \tag{A1.1}$$

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:

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, . . . n,
x_i = $\log_{10}$ of t_i, where t_i is the time to failure in hours of Observation i; i = 1, . . . n,
$\bar{y}$ = arithmetic mean of all y_i values:

$$= \frac{1}{n} \sum y_i \tag{A1.2}$$

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

$$= \frac{1}{n} \sum x_i \tag{A1.3}$$

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

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

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

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

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

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

A1.4.3 *Correlation of Data:*

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

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

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

A1.4.3.2 If the value of r is less than the applicable minimum value given in Table A1.1as 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:

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

and then let:

$$b = -\sqrt{\lambda} \tag{A1.9}$$

and then:

$$a = \bar{y} - b\bar{x} \tag{A1.10}$$

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:

$$x_L = \log_{10} t_L \tag{A1.11}$$

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, 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:

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

$$Y_i = a + b\xi_i \tag{A1.13}$$

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

A1.4.5.3 Calculate the following quantities:

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

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

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

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

$$C = D(1 + \tau) \tag{A1.18}$$

the variance, A, of a using the formula:

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

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

$$\sigma_n^2 = A + 2Bx_L + Cx_L^2 \tag{A1.20}$$

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

$$\sigma_\varepsilon^2 = 2\lambda\sigma_\delta^2 \tag{A1.21}$$

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

$$\sigma_y^2 = \sigma_n^2 + \sigma_\varepsilon^2 \tag{A1.22}$$

A1.4.5.5 Calculate the estimated standard deviation, σ_y, for y_L using the equation:

$$\sigma_y = (\sigma_n^2 + \sigma_\varepsilon^2)^{0.5} \tag{A1.23}$$

and the predicted value, y_L, for y at x_L using the relationship:

$$y_L = a + bx_L \tag{A1.24}$$

where a and b have the values obtained in accordance with Eq A1.9 and Eq A1.10.

A1.4.6 *Calculation and Confidence Intervals:*

A1.4.6.1 Calculate the lower 95 % prediction interval, $y_{L\,0.95}$, predicted for y_L using the equation:

$$y_{L\,0.95} = y_L - t_v \sigma_y \tag{A1.25}$$

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

(n – 2)	r minimum	(n – 2)	r minimum
11	0.6835	25	0.4869
12	0.6614	30	0.4487
13	0.6411	35	0.4182
14	0.6226	40	0.3932
15	0.6055	45	0.3721
16	0.5897	50	0.3541
17	0.5751	60	0.3248
18	0.5614	70	0.3017
19	0.5487	80	0.2830
20	0.5386	90	0.2673
21	0.5252	100	0.2540
22	0.5145	. . .	. . .
23	0.5043	. . .	. . .
24	0.4952	. . .	. . .

TABLE A1.2 Student's "*t*" Value (Two-Sided 0.05 Level of Significance)

Degrees of Freedom ($n - 2$)	Student's " *t*" Value, t_v	Degrees of Freedom ($n - 2$)	Student's " *t*" Value, t_v	Degrees of Freedom ($n - 2$)	Student's" *t*" Value, t_v
1	12.7062	46	2.0129	91	1.9864
2	4.3027	47	2.0117	92	1.9861
3	3.1824	48	2.0106	93	1.9858
4	2.7764	49	2.0096	94	1.9855
5	2.5706	50	2.0086	95	1.9853
6	2.4469	51	2.0076	96	1.9850
7	2.3646	52	2.0066	97	1.9847
8	2.3060	53	2.0057	98	1.9845
9	2.2622	54	2.0049	99	1.9842
10	2.2281	55	2.0040	100	1.9840
11	2.2010	56	2.0032	102	1.9835
12	2.1788	57	2.0025	104	1.9830
13	2.1604	58	2.0017	106	1.9826
14	2.1448	59	2.0010	108	1.9822
15	2.1315	60	2.0003	110	1.9818
16	2.1199	61	1.9996	112	1.9814
17	2.1098	62	1.9990	114	1.9810
18	2.1009	63	1.9983	116	1.9806
19	2.0930	64	1.9977	118	1.9803
20	2.0860	65	1.9971	120	1.9799
21	2.0796	66	1.9966	122	1.9796
22	2.0739	67	1.9960	124	1.9793
23	2.0687	68	1.9955	126	1.9790
24	2.0639	69	1.9949	128	1.9787
25	2.0595	70	1.9944	130	1.9784
26	2.0555	71	1.9939	132	1.9781
27	2.0518	72	1.9935	134	1.9778
28	2.0484	73	1.9930	136	1.9776
29	2.0452	74	1.9925	138	1.9773
30	2.0423	75	1.9921	140	1.9771
31	2.0395	76	1.9917	142	1.9768
32	2.0369	77	1.9913	144	1.9766
33	2.0345	78	1.9908	146	1.9763
34	2.0322	79	1.9905	148	1.9761
35	2.0301	80	1.9901	150	1.9759
36	2.0281	81	1.9897	200	1.9719
37	2.0262	82	1.9893	300	1.9679
38	2.0244	83	1.9890	400	1.9659
39	2.0227	84	1.9886	500	1.9647
40	2.0211	85	1.9883	600	1.9639
41	2.0195	86	1.9879	700	1.9634
42	2.0181	87	1.9876	800	1.9629
43	2.0167	88	1.9873	900	1.9626
44	2.0154	89	1.9870	1000	1.9623
45	2.0141	90	1.9867	. . .	1.9600

where:

y_L = value obtained in accordance with Eq A1.24 when x_L is, as applicable, the value in accordance with Eq A1.11 appropriate to a design life of, for example, 50 years (that is, x_L = 5.6415 (h)) or to a time at which it is desired to predict with 95 % confidence the minimum value for the next observation of V,

σ_y = value obtained in accordance with Eq A1.23, and

t_v = applicable value for Student's t for $v = n - 2$ df, as given in Table A1.2 for a two-sided 0.05 level of significance (that is, mean ±2.5 %).

A1.4.6.2 Calculate the corresponding lower 95 % prediction limit for V using the relationship:

$$V_{L\,0.95} = 10^{Y_{L\,0.95}} \tag{A1.26}$$

A1.4.6.3 The predicted mean value of V at time t_L, that is, V_L, is given by the relationship:

$$V_L = 10Y^L \tag{A1.27}$$

where:

Y_L = value obtained in accordance with Eq A1.24

A1.4.6.4 Setting $\sigma_y{}^2 = \sigma_n{}^2$ in Eq A1.22 will produce a confidence interval for the line rather than a prediction interval for a future observation.

A1.5 Example Calculation

A1.5.1 *Basic Data*—The example data given in Table A1.3, together with the example analysis given in this subsection, can be used to validate statistical packages or procedures. Because of rounding errors, it is unlikely that there will be exact agreement, but acceptable procedures should agree within ±0.1 % of the results given in A1.5.6.

A1.5.2 *Sums of Squares:*

TABLE A1.3 Example Data For Example Calculation

Observation Number	*x*(Time) Variable	LOG *x* Variable	*y*(Strain) Variable	LOG *y* Variable
1	5184	3.714641	1	0
2	2230	3.348283	1	0
3	2220	3.346331	1.03	1.283708E-02
4	12340	4.091289	1.03	1.283708E-02
5	10900	4.037401	1.03	1.283708E-02
6	12340	4.091289	1.03	1.283708E-02
7	10920	4.038197	1.03	1.283708E-02
8	8900	3.949365	1.05	2.118911E-02
9	4173	3.620425	1.05	2.118911E-02
10	8900	3.949365	1.05	2.118911E-02
11	878	2.943476	1.05	2.118911E-02
12	4110	3.613819	1.07	2.938355E-02
13	1301	3.114257	1.07	2.938355E-02
14	3816	3.581585	1.07	2.938355E-02
15	669	2.825408	1.07	2.938355E-02
16	1430	3.155316	1.09	3.742624E-02
17	2103	3.322818	1.09	3.742624E-02
18	589	2.770098	1.09	3.742624E-02
19	1710	3.232975	1.09	3.742624E-02
20	1299	3.113589	1.09	3.742624E-02
21	272	2.434553	1.14	5.690446E-02
22	446	2.649318	1.14	5.690446E-02
23	466	2.668369	1.14	5.690446E-02
24	684	2.835038	1.14	5.690446E-02
25	104	2.01702	1.18	7.188151E-02
26	142	2.152274	1.18	7.188151E-02
27	204	2.309615	1.18	7.188151E-02
28	209	2.320131	1.18	7.188151E-02
29	9	0.9542362	1.25	9.690937E-02
30	13	1.113936	1.25	9.690937E-02
31	17	1.230441	1.25	9.690937E-02
32	17	1.230441	1.25	9.690937E-02

$S_{xx} = 0.7981093$
$S_{yy} = 8.365498 \times 10^{-4}$
$S_{xy} = -0.024165$

A1.5.3 *Coefficient of Correlation:*

$$r = 0.935215$$

A1.5.4 *Functional Relationships:*

$\lambda = 1.048164 \times 10^{-3}$
$b = -3.237537 \times 10^{-2}$
$a = 0.1372625$

A1.5.5 *Calculated Variances:*

$D = 4.84063 \times 10^{-6}$
$B = -1.470945 \times 10^{-5}$
$C \text{ (variance of } b\text{)} = 5.01947 \times 10^{-6}$
$A \text{ (variance of } a\text{)} = 4.671877 \times 10^{-5}$
$\sigma_n^2 \text{ (error variance for } x\text{)} = 0.0515264$
$\sigma_\varepsilon^2 \text{ (error variance for } y\text{)} = 1.1157 \times 10^{-4}$

A1.5.6 *Confidence Limits*—For $N = 32$ and Student's t of 2.0423, the estimated mean and confidence and prediction intervals are given in Table A1.4.

TABLE A1.4 Confidence Limits

Time (hours)	Mean	Lower Confidence Interval	Lower Prediction Interval
1	1.37	1.33	1.29
10	1.27	1.25	1.20
100	1.18	1.17	1.12
1000	1.10	1.09	1.04
10000	1.02	1.00	0.97
100000	0.94	0.92	0.89
438000	0.90	0.87	0.85

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D5365 – 06) that may impact the use of this standard (April 1, 2012).

(1) Updated the ISO equivalency statement,
(2) Improved the presentation in Annex A1 and,
(3) Corrected a small error found in the data analysis Annex A1, equation A1.21.

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