INTERNATIONAL

Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings[1]

This standard is issued under the fixed designation D 2992; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice establishes two procedures, Procedure A (cyclic) and Procedure B (static), for obtaining a hydrostatic design basis (HDB) or a pressure design basis (PDB) for fiberglass piping products, by evaluating strength-regression data derived from testing pipe or fittings, or both, of the same materials and construction, either separately or in assemblies. Both glass-fiber-reinforced thermosetting-resin pipe (RTRP) and glass-fiber-reinforced polymer mortar pipe (RPMP) are fiberglass pipe.

NOTE 1—For the purposes of this standard, polymer does not include natural polymers.

1.2 This practice can be used for the HDB determination for fiberglass pipe where the ratio of outside diameter to wall thickness is 10:1 or more.

NOTE 2—This limitation, based on thin-wall pipe design theory, serves further to limit the application of this practice to internal pressures which, by the hoop-stress equation, are approximately 20 % of the derived hydrostatic design stress (HDS). For example, if HDS is 5000 psi (34 500 kPa), the pipe is limited to about 1000-psig (6900-kPa) internal pressure, regardless of diameter.

1.3 This practice provides a PDB for complex-shaped products or systems where complex stress fields seriously inhibit the use of hoop stress.

1.4 Specimen end closures in the underlying test methods may be either restrained or free, leading to certain limitations.

1.4.1 *Restrained Ends*—Specimens are stressed by internal pressure only in the hoop direction, and the HDB is applicable for stresses developed only in the hoop direction.

1.4.2 *Free Ends*—Specimens are stressed by internal pressure in both hoop and longitudinal directions, such that the hoop stress is twice as large as the longitudinal stress. Th practice may not be applicable for evaluating stresses induc by loadings where the longitudinal stress exceeds 50 % of t HDS.

1.5 The values stated in inch-pound units are to be regard as the standard. The values in parentheses are given f information purposes only.

NOTE 3—There is no similar or equivalent ISO standard.

1.6 *This standard does not purport to address all of t safety concerns, if any, associated with its use. It is t responsibility of the user of this standard to establish appr priate safety and health practices and determine the applic bility of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 618 Practice for Conditioning Plastics for Testing

D 883 Terminology Relating to Plastics

D 1598 Test Method for Time-to-Failure of Plastic Pi Under Constant Internal Pressure

D 1599 Test Method for Resistance to Short-Time Hydra lic Pressure of Plastic Pipe, Tubing, and Fittings

D 1600 Terminology for Abbreviated Terms Relating Plastics

D 2143 Test Method for Cyclic Pressure Strength of Rei forced, Thermosetting Plastic Pipe

D 3567 Practice for Determining Dimensions of "Fib glass" (Glass-Fiber-Reinforced Thermosetting Resin) P and Fittings

F 412 Terminology Relating to Plastic Piping Systems

F 948 Test Method for Time-to-Failure of Plastic Pipi Systems and Components Under Constant Internal Pr sure With Flow

[1] This practice 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.or contact ASTM Customer Service at service@astm.org. For *Annual Book of A Standards* volume information, refer to the standard's Document Summary pag the ASTM website.

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

2.2 *ISO Standard:*

3 Preferred Numbers—Series of Preferred Numbers[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *General*—Definitions are in accordance with Terminologies D 883 and F 412, and abbreviations are in accordance with Terminology D 1600, unless otherwise indicated.

3.1.2 *closure, free-end*—a sealing device or mechanism fastened to the end of the test specimen so that internal pressure produces longitudinal tensile stresses in addition to hoop and radial stresses in the test specimen.

3.1.3 *closure, restrained-end*—a sealing device or mechanism which relies on a rod through the test specimen or an external structure to resist the end thrust produced by internal pressure, thereby limiting the stresses in (straight) specimens to the hoop and radial directions only.

3.1.4 *failure*—the transmission of the test fluid through the body of the specimen in any manner, whether it be a wall fracture, localized leaking, or weeping at a distance greater than one diameter from the end closure.

NOTE 4—For this practice, specimens which have not failed may be included as failures under the specific conditions given in 6.3, 9.3, and 12.2.

3.1.5 *fiberglass pipe*—a tubular product containing glass fiber reinforcement embedded in or surrounded by cured 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.

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

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

3.1.8 *hoop stress*—the tensile stress in the wall of the piping product in the circumferential direction due to internal pressure; hoop stress will be calculated by the ISO equation, as follows:

$$S = P(D - t_r)/2t_r \quad (1)$$

where:

S = hoop stress, psi (kPa),
D = average reinforced outside diameter, in. (mm),
P = internal pressure, psig (kPa), and
t_r = minimum reinforced wall thickness, in. (mm).

NOTE 5—Hoop stress should only be determined on straight hollow cylindrical specimens. Product evaluation of more complex shapes may be based on pressure.

3.1.9 *hydrostatic design basis (HDB)*—a hoop stress developed for fiberglass pipe by this practice and multiplied by a service design factor to obtain an HDS.

3.1.10 *hydrostatic design pressure (HDP)*—the estimated maximum internal hydrostatic pressure that can be applied cyclically (Procedure A) or continuously (Procedure B) to a piping component with a high degree of certainty that failure of the component will not occur.

3.1.11 *hydrostatic design stress (HDS)*—the estimated maximum tensile stress in the wall of the pipe in the hoop direction due to internal hydrostatic pressure that can be applied cyclically (Procedure A) or continuously (Procedure B) with a high degree of certainty that failure of the pipe will not occur.

3.1.12 *long-term hydrostatic strength (LTHS)*— the estimated tensile stress in the wall of the pipe in the hoop direction due to internal hydrostatic pressure that, when applied cyclically, will cause failure of the pipe after a specified number of cycles by Procedure A or a specified number of hours by Procedure B.

NOTE 6—The time for determination of LTHS or LTHP is specified by the product standard. Typically, the time is 150×10^6 or 657×10^6 cycles for Procedure A and 100 000 or 438 000 h for Procedure B.

3.1.13 *long-term hydrostatic pressure (LTHP)*—the estimated internal pressure of the piping product that, when applied cyclically, will cause failure of the product after a specified number of cycles by Procedure A or a specified number of hours by Procedure B.

3.1.14 *pressure design basis (PDB)*—an internal pressure developed for fiberglass piping product by this practice and multiplied by a service design factor to obtain an HDP.

3.1.15 *pressure rating (PR)*—the estimated maximum pressure in the pipe or fitting that can be exerted continuously with a high degree of certainty that failure of the piping component will not occur.

3.1.16 *service design factor*—a number equal to 1.00 or less that takes into consideration all the variables and degree of safety involved in a fiberglass piping installation so that when it is multiplied by the HDB, an HDS and corresponding pressure rating is obtained, or when it is multiplied by the PDB, a pressure rating is obtained directly, such that in either case a satisfactory and safe piping installation results when good quality components are used and the installation is made properly.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *average outside diameter*—a measurement obtained in accordance with Practice D 3567 less any veil-reinforced and nonreinforced exterior coating thicknesses.

3.2.2 *minimum reinforced wall thickness*—a measurement obtained in accordance with Practice D 3567, excluding veil-reinforced and nonreinforced coating and lining thicknesses; wall thickness of fittings is determined at the thinnest section of the fitting body.

4. Summary of Practice

4.1 Procedure A consists of exposing a minimum of 18 specimens of pipe or fittings, or both to cyclic internal pressures at a cycle rate of 25 cycles/min and at several different pressures. Elevated test temperatures are obtained by circulating a hot liquid through the specimens or by testing in an air environment where the temperature is controlled.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

4.1.1 The cyclic LTHS or cyclic LTHP of a pipe or fitting is obtained by an extrapolation of a log-log plot of the linear regression line for hoop stress or internal pressure versus cycles to failure.

4.1.2 The experimental basis for Procedure A shall be in accordance with Test Method D 2143, which forms a part of this practice. When any part of the procedure is not in agreement with Test Method D 2143, the provisions of this practice shall be used.

4.1.3 Joints between pipe and fitting specimens shall be typical of those normally used for the kind of piping being tested.

4.2 Procedure B consists of exposing a minimum of 18 specimens of pipe or fittings, or both, to constant internal hydrostatic pressures at differing pressure levels in a controlled environment and measuring the time to failure for each pressure level. Test temperatures are obtained by immersing the specimens in a controlled-temperature water bath, by testing in an air environment where the temperature is controlled, or by circulating a temperature-controlled fluid through the specimen.

NOTE 7—Testing in a water bath precludes the detection of weeping failure, (see 3.1.4) by either visual or electronic means.

4.2.1 The static LTHS or static LTHP of a pipe or fitting is obtained by an extrapolation of a log-log linear regression line for hoop stress or internal pressure versus time to failure.

4.2.2 The experimental basis for Procedure B shall be in accordance with either Test Method D 1598 or Test Method F 948, or both, which form a part of this practice. When any part of this practice is not in agreement with the selected method, the provisions of this practice shall be used.

4.2.3 Joints between pipe and fitting specimens shall be typical of those normally used for the kind of piping being tested.

4.3 The HDB category is obtained by categorizing the LTHS in accordance with Section 7 or Section 10.

4.4 The PDB category is obtained by categorizing the LTHP in accordance with Section 8 or Section 11.

4.5 Hydrostatic design stresses for pipe are obtained by multiplying the HDB values by a service design factor.

4.6 *Reconfirmation of HDB or PDB for Altered Constructions*—When a product already has an HDB or PDB determined in accordance with this practice and a change of process or material is made, a reconfirmation of the original HDB or PDB may be attempted in accordance with Section 12. At least six specimens must be tested and meet the specified criteria.

5. Significance and Use

5.1 This practice is useful for establishing the hoop stress or internal pressure versus time-to-failure relationships, under selected internal and external environments which simulate actual anticipated product end-use conditions, from which a design basis for specific piping products and materials can be obtained. This practice defines an HDB for material in straight, hollow cylindrical shapes where hoop stress can be easily calculated, and a PDB for fittings and joints where stresses are more complex.

5.1.1 An alternative design practice based on initial stra versus time-to-failure relationships employs a strain basis HD instead of the stress basis HDB defined by this practice. Th strain basis HDB is most often used for buried pipe desig with internal pressures ranging from 0 to 250 psig (1.72 MPa

5.2 To characterize fiberglass piping products, it is nece sary to establish the stress versus cycles or time to failure, o pressure versus cycles or time to failure relationships ov three or more logarithmic decades of time (cycles or hour within controlled environmental parameters. Because of th nature of the test and specimens employed, no single line ca adequately represent the data. Therefore, the confidence limi should be established.

5.3 Pressure ratings for piping of various dimensions at ea temperature may be calculated using the HDS determined b testing one size of piping provided that the same speci process and material are used both for test specimens and t piping in question.

5.4 Pressure ratings at each temperature for componen other than straight hollow shapes may be calculated using t HDP determined by testing one size of piping provided that (the specific materials and manufacturing process used for t test specimens are used for the components, (*2*) for joints, t joining materials and procedures used to prepare the te specimens are used for field joining, and (*3*) scaling of critic dimensions is related to diameter and pressure rating of t component.

NOTE 8—Scaling of fittings and joints should be further verified short-time testing in accordance with Test Method D 1599.

5.5 Results obtained at one set of environmental conditio should not be used for other conditions, except that high temperature data can be used for design basis assignment f lower application temperatures. The design basis should b determined for each specific piping product. Design an processing can significantly affect the long-term performan of piping products, and therefore should be taken into consi eration during any evaluation.

5.6 This practice is valid for a given pipe or fitting only s long as the specimens are truly representative of that mater and manufacturing process.

5.6.1 Changes in materials or manufacturing processes w necessitate a reevaluation as described in Section 12.

PROCEDURE A

6. Long-Term Cyclic Hydrostatic Strength or Long-Term Cyclic Hydrostatic Pressure

6.1 Select either free-end or restrained-end closures bas on the tensile stresses induced by internal pressure and the typ of joint in the intended piping system (see 1.4).

6.2 Obtain a minimum of 18 failure stress-cycle points f each selected temperature in accordance with Test Meth D 2143 except as follows:

6.2.1 Determine the average outside diameter and the min mum reinforced wall thickness in accordance with Practi D 3567.

NOTE 9—Because of the need to cut the specimen, this determinat may be made on the failed test specimen. A corrected hoop stress is th calculated for use in the analysis.

6.2.2 Elevated test temperatures are obtained by circulating a heated test liquid through the specimens or by testing in a hot air environment. In either case the test liquid shall be maintained within ±5°F (3°C) of the selected temperature.

NOTE 10—Where elevated test temperatures are maintained by applying heat to the circulating test liquid, work to date indicates that the ambient air temperature need not be controlled.

6.2.3 The stress or pressure values for test shall be selected to obtain a distribution of failure points as follows:

Cycles to Failure	Failure Points
1 000 to 10 000	at least 3
10 000 to 100 000	at least 3
100 000 to 1 000 000	at least 3
1 000 000 to 10 000 000	at least 3
After 15 000 000	at least 1
Total	at least 18

6.3 Analyze the test results by using, for each specimen, the logarithm of the stress or pressure in Section 6 and the logarithm of the cycles to failure, as described in Annex A1.

NOTE 11—It is the custom of those testing fiberglass pipe to plot stress or pressure on the vertical (*y*) axis and time or cycles on the horizontal (*x*) axis.

6.3.1 A specimen which leaks within one diameter of an end closure may be: (*1*) included as a failure point if it lies above the 95 % lower confidence limit curve; (*2*) repaired and testing resumed provided the new leak is more than one diameter from a test joint, or (*3*) discarded and no data point recorded.

6.3.2 Those specimens that have not failed after more than 15 000 000 cycles may be included as failures in establishing the regression line. Use of such data points may result in a lower or higher cyclic LTHS or cyclic LTHP. In either case, the lower confidence value requirements of Section 6 must be satisfied.

NOTE 12—Non-failed specimens may be left under test and the regression line recalculated as failures are obtained.

6.3.3 Determine the final line for extrapolation by the method of least squares using the failure points along with those nonfailure points selected by the method described in 6.3.1 and 6.3.2. Do not use failure points for stresses or pressures that cause failure in less than 500 cycles on the average; determine these points by averaging the number of cycles-to-failure of tests made at the same stress or pressure level, that is, a stress within ±200 psi (1380 kPa) or a pressure within ±20 psig (138 kPa). Include in the report all failure points excluded from the calculation by this operation and identify them as being in this category.

NOTE 13—Since this procedure is for pipe or fittings, or both, it is recommended that the pipe specimen and fitting be tested at the same time as one specimen, using the normal joining procedures to join them together, with the fitting being at one end of the specimen. If the fitting fails first, it can be cut off, and the test can be continued using the unfailed pipe with a mechanical end closure replacing the fitting. Should the pipe fail first, it can be recorded and repaired and the test continued until the fitting fails. If this recommendation is followed, it may enable the tester to obtain failure points for both the pipe and the fitting while testing only one specimen.

7. Cyclic Hydrostatic Design Basis

7.1 Calculate the cyclic LTHS at the specified time (150×10^6 or 657×10^6 cycles) as described in Annex A1.

7.2 If $Sxy > 0$ (see A1.4) consider the data unsuitable.

7.3 Calculate r in accordance with A1.4.3. If r is less than the applicable minimum value given in Table A1.1, consider the data unsuitable.

7.4 If required, determine the cyclic HDB category in accordance with Table 1.

8. Cyclic Pressure Design Basis

8.1 Use the procedures in 7.1, 7.2, and 7.3, using pressure in place of stress.

8.2 If required, determine the cyclic PDB category in accordance with Table 2.

PROCEDURE B

9. Long-Term Static Hydrostatic Strength

9.1 Select either free-end or restrained-end closures based on the tensile stresses induced by internal pressure and the type of joint in the intended piping system (see 1.4).

9.2 Obtain a minimum of 18 failure points for each selected temperature in accordance with Test Method D 1598 or Test Method F 948 except as follows:

9.2.1 Determine the average outside diameter and the minimum reinforced wall thickness in accordance with Practice D 3567 (Note 9).

9.2.2 The inside environment for the pipe or fitting, test specimens, or both, shall be water. The outside environment shall be air or a controlled temperature water bath (See 7). Other media may be used, but the environment shall be given in the test report. The test liquid shall be maintained within ±5°F (3°C) of the test temperature (Note 10).

9.2.3 The stress or pressure values for test shall be selected to obtain a distribution of failure points as follows:

TABLE 1 Hydrostatic Design Basis Categories by Procedure A or Procedure B

Hydrostatic Design Basis Category		Range of Calculated Values	
psi[A]	(kPa)	psi	(kPa)
2 500	(17 200)	2 400 to 3 010	(16 500 to 20 700)
3 150	(21 700)	3 020 to 3 820	(20 800 to 26 300)
4 000	(27 600)	3 830 to 4 790	(26 400 to 33 000)
5 000	(34 500)	4 800 to 5 990	(33 100 to 40 900)
6 300	(43 400)	6 000 to 7 590	(41 000 to 52 900)
8 000	(55 200)	7 600 to 9 590	(53 000 to 65 900)
10 000	(68 900)	9 600 to 11 990	(66 000 to 82 900)
12 500	(86 200)	12 000 to 15 290	(83 000 to 105 900)
16 000	(110 000)	15 300 to 18 990	(106 000 to 130 900)
20 000	(138 000)	19 000 to 23 990	(131 000 to 169 900)
25 000	(172 000)	24 000 to 29 990	(170 000 to 209 900)
31 500	(217 000)	30 000 to 37 990	(210 000 to 259 900)
40 000	(276 000)	38 000 to 47 000	(260 000 to 320 000)

[A] Standard stress levels chosen in accordance with ISO 3, Series R10

TABLE 2 Pressure Design Basis Categories by Procedure A or Procedure B

Pressure Design Basis Category			Range of Calculated Values	
psi	(bar)[A]	(kPa)	psi	(kPa)
91	(6.3)	(630)	87 to 110	(605 to 760)
116	(8)	(800)	111 to 143	(765 to 990)
150	(10)	(1 000)	144 to 172	(995 to 1 180)
180	(12.5)	(1 250)	173 to 220	(1 190 to 1 510)
230	(16)	(1 600)	221 to 287	(1 520 to 1 980)
300	(20)	(2 000)	288 to 345	(1 990 to 2 380)
360	(25)	(2 500)	346 to 438	(2 390 to 3 020)
460	(31.5)	(3 150)	439 to 556	(3 030 to 3 830)
580	(40)	(4 000)	557 to 695	(3 840 to 4 790)
725	(50)	(5 000)	696 to 876	(4 800 to 6 040)
910	(63)	(6 300)	877 to 1 110	(6 050 to 7 680)
1 160	(80)	(8 000)	1 115 to 1 380	(7 690 to 9 580)
1 450	(100)	(10 000)	1 390 to 1 720	(9 590 to 11 800)
1 800	(125)	(12 500)	1 730 to 2 220	(11 900 to 15 300)

[A] Standard pressures chosen in accordance with ISO 3, Series R10.

Hours to Failure	Failure Points
10 to 1 000	at least 4
1 000 to 6 000	at least 3
After 6 000	at least 3
After 10 000	at least 1
Total	at least 18

9.2.4 Maintain the internal test pressure in each specimen within ±1 % of this pressure. Measure the time to failure to within ±2 % or 40 h, whichever is smaller.

9.3 Analyze the test results by using, for each failure point, the logarithm of the stress or pressure in pound-force per square inch or pound-force per square inch gage (kilopascals) and the logarithm of the time-to-failure in hours as described in Annex A1 (Note 9).

9.3.1 A specimen which leaks within one diameter of an end closure may be: (*1*) included as a failure point if it lies above the 95 % lower confidence limit curve; (*2*) repaired and testing resumed provided the new leak is more than one diameter from a test joint, or (*3*) discarded and no failure point recorded.

9.3.2 Those specimens that have not failed after more than 10 000 h may be included as failures in establishing the regression line. Use of such data points may result in a lower or higher static LTHS or static LTHP. In either case, the lower confidence value requirements of 9.4.2 must be satisfied.

NOTE 14—Non-failed specimens may be left under test and the regression line recalculated as failures are obtained.

9.3.3 Determine the final line for extrapolation by the method of least squares using the failure points along with those nonfailure points selected by the method described in 9.3.1 and 9.3.2. Do not use failure points for stresses or pressures that cause failure in less than 0.3 h on the average; determine these points by averaging the times-to-failure of tests made at the same stress or pressure level, that is, a stress within ±200 psi (1380 kPa) or a pressure within ±20 psi (138 kPa). Include in the report all failure points excluded from the calculation by this operation and identify them as being in this category (Note 12).

10. Static Hydrostatic Design Basis

10.1 Calculate the static LTHS at the specified time (100 000 or 438 000 h) as described in Annex A1.

10.2 If $Sxy > 0$ (see A1.4), consider the data unsuitable.

10.3 Calculate r in accordance with A1.4.3. If r is less th the applicable minimum value given in Table A1.1, consid the data unsuitable.

10.4 If required, determine the static HDB category i accordance with Table 1.

11. Static Pressure Design Basis

11.1 Use the procedures in 10.1, 10.2, and 10.3, usi pressure in place of stress.

11.2 If required, determine the static PDB category i accordance with Table 2.

12. Reconfirmation of HDB or PDB

12.1 When a piping product has an existing HDB or PD determined in accordance with Procedure A or Procedure any change in material, manufacturing process, constructi or liner thickness will necessitate a screening evaluation a described in 12.2, 12.3, 12.4, 12.5, and 12.6.

12.2 Obtain failure points for at least two sets of specimen each set consisting of 3 or more specimens tested at the sam stress or pressure level, that is, a stress within ±200 psi (13 kPa) or a pressure within ±20 psi (138 kPa), as follows:

12.2.1 For Procedure A:

Cycles to Failure (Average of Set)	Failure Points
15 000 to 300 000	at least 3
More than 1 500 000	at least 3
Total	at least 6

Include as failures those specimens which have not faile after 4 500 000 cycles provided they exceed the existing HD or PDB regression line.

12.2.2 For Procedure B:

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 which have not faile after 3000 h provided they exceed the existing HDB or PD regression line.

12.3 Calculate and plot the 95 % confidence limits and t 95 % prediction limits of the original regression line i accordance with A1.4 using only data obtained prior to t change.

NOTE 15—Prediction limits define the bounds for single observatio whereas confidence limits define the bounds for the regression line.

NOTE 16—For 95 % confidence limits, there is a 2.5 % probability t 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 t LCL. For 95 % prediction limits, there is a 2.5 % probability t individual data points may fall above the UPL and a 2.5 % probability t individual data points may fall below the LPL.

12.4 Consider any changes in the material or manufacturi process minor and permissible if the results of 12.2 meet t following criteria.

12.4.1 The average failure point for each stress or pressure level falls on or above the 95 % lower confidence limit of the original regression line.

12.4.2 The earliest individual failure point at each stress or pressure level falls on or above the 95 % lower prediction limit of the original regression line.

12.4.3 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.

12.5 Alternatively to 12.4, consider any changes in the material or manufacturing process permissible if the results of 12.2 meet the following:

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

12.5.2 At least two points exceed 4.5×10^{6} cycles or 3000-h failure time.

12.6 Data meeting the criteria of 12.4 or 12.5 may be assumed to be part of the original data set and a new regression line and HDB or PDB determined using all failure points.

12.7 If the data fails to satisfy the criteria of 12.4 or 12.5, the changes are considered major and a new regression line must be established. While the new test program is being conducted, an interim HDB or PDB for the material or process change may be taken as the lower of the following:

12.7.1 The 95 % lower confidence limit of the value obtained by extrapolating the failure points of 12.2.1 to 657 000 000 cycles (50 years) by the procedure in 7.2, or the failure points of 12.2.2 to 438 000 h (50 years) by the procedure in Annex A1.

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

13. Hydrostatic Design Stress or Hydrostatic Design Pressure

13.1 Obtain the HDS or HDP by multiplying the HDB or PDB as determined by Procedure A or Procedure B by a service design factor selected for the application on the basis of two general groups of conditions. The first group considers the manufacturing and testing variables, specifically normal variations in the material, manufacture, dimensions, good handling techniques, and in the evaluation procedures in this method. The second group considers the application or use, specifically installation, environment, temperature, hazard involved, life expectancy desired, and the degree of reliability selected.

NOTE 17—It is not the intent of this practice to give service design factors. The service design factor should be selected by the design engineer after evaluating fully the service conditions and the engineering properties of the specific plastic pipe material under consideration. Recommended service design factors will not be developed or issued by ASTM.

14. Pressure Rating

14.1 For data based on hoop stress calculate the pressure rating from the HDS by means of the ISO equation in 3.1.8 for each diameter and wall thickness of pipe made from the specific materials and constructions tested.

14.2 For data based on internal pressure, establish the pressure rating directly from the HDP for products made from the specific materials and constructions tested.

15. Report

15.1 Report the following information:

15.1.1 Complete identification of the specimen including material type, source, manufacturer's name and code number, and previous significant history, if any.

15.1.2 Specimen dimensions including nominal size, average and minimum reinforced wall thickness, and average outside diameter, and liner material and liner thickness if product is lined.

15.1.3 Fitting dimensions, including all items listed in 15.1.2 and the type of fitting.

15.1.4 Procedure used, (Procedure A or Procedure B), and the ASTM designation of the underlying test method.

15.1.5 End closure type, free-end, or restrained-end.

15.1.6 Test temperature.

15.1.7 Test environment inside and outside of the pipe.

15.1.8 A table of stresses or pressures in pound-force per square inch or pound-force per square inch gage (kilopascals) and the number of cycles to failure (Procedure A) or time-to-failure in hours (Procedure B) of all the specimens tested; the nature of the failures, and the part that failed, that is, fitting or pipe. Specimens that are included as failures after they have been under stress or pressure for more than 15 000 000 cycles or more than 10 000 h shall be indicated.

15.1.9 The estimated LTHS or LTHP.

15.1.10 The value for r.

15.1.11 The HDB or HDP.

15.1.12 The source of the HDB or PDB (7.1 or 7.2 for Procedure A or 10.1 or 10.2 for Procedure B), and the categorized value in accordance with Table 1 or Table 2.

15.1.13 Any unusual behavior observed in the tests.

15.1.14 Dates of tests.

15.1.15 Name of laboratory and supervisor of tests.

16. Precision and Bias

16.1 The precision and bias of this practice for obtaining the HDB or PDB are as specified in Test Methods D 1598, D 2143, and F 948. This practice includes a statistical basis for evaluating the suitability of the data in Sections 6 and 9.

17. Keywords

17.1 closure; cyclic pressure; design basis; fiberglass pipe; reconfirmation; static pressure

ANNEX

(Mandatory Information)

A1. LEAST SQUARES CALCULATIONS FOR LONG-TERM HYDROSTATIC STRENGTH OR LONG-TERM HYDROSTATIC PRESSURE

A1.1 General

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

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

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 (or cycles), and let y be $\log_{10}V$, where V is the stress (or pressure) 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 stress (or pressure) 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:

$$= \frac{1}{n}\Sigma y_i \quad (A1.2)$$

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

$$= \frac{1}{n}\Sigma x_i \quad (A1.3)$$

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

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

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

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

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

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

A1.4.3 *Correlation of Data:*

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

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

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

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:

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

and then let:

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

and then:

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

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

NOTE A1.1—In general, b takes the sign of S_{xy}.

NOTE A1.2—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:

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

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, for x using Eq A1.12, Eq A1.13, and Eq A1.14, respectively:

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

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

$$\sigma_\delta^2 = \{\Sigma(y_i - Y_i)^2 + \lambda\Sigma(x_i - \xi_i)^2\}/\{\lambda(n - 2)\} \quad (A1.14)$$

A1.4.5.3 Calculate the following quantities:

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

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

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

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

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

the variance, A, of a using the formula:

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

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

$$\sigma_n^{\,2} = A + 2Bx_L + Cx_L^{\,2} \quad (A1.20)$$

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

$$\sigma_\epsilon^{\,2} = \lambda\sigma_\delta^{\,2} \quad (A1.21)$$

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

$$\sigma_y^{\,2} = \sigma_n^{\,2} + \sigma_\epsilon^{\,2} \quad (A1.22)$$

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

$$\sigma_y = (\sigma_n^{\,2} + \sigma_\epsilon^{\,2})^{0.5} \quad (A1.23)$$

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

$$y_L = a + bx_L \quad (A1.24)$$

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:

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

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:

$$V_{L\,0.95} = 10^{Y_{L\,0.95}} \quad (A1.26)$$

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

$$V_L = 10Y^L \quad (A1.27)$$

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.

APPENDIXES

(Nonmandatory Information)

X1. DATA ANALYSIS

X1.1 *Hoop Stress versus Cycles-to-Failure or Time-to-Failure:*

X1.1.1 Hoop stress is a more convenient parameter to use when attempting to predict long-term hydrostatic strength of a material. Its use reduces scatter in the data by compensating for varying dimensions in the test specimens. It effectively normalizes pressure for variations in specimen geometry, and reduces the variable to a material parameter. For this particular reason it has been widely used for evaluating the long-term hydrostatic properties of plastic materials. Essentially, once a value for HDS has been determined for a particular material and construction, that value can be used to effectively predict the long-term working pressure of tubular products by compensating for the various product geometries.

X1.1.2 The main limitation of the use of hoop stress is that it can only be applied to simple tubular-shaped specimens. Therefore, its application has been mainly limited to materials and a few products such as pipe and simple fittings like couplings.

X1.2 *Internal Pressure versus Cycles-to-Failure or Time-to-Failure*—The use of internal pressure rather than stress extends the application of this practice to the prediction of service life for many products of complex geometries which do not permit the calculation of hoop stress. The logarithm of internal pressure is used in place of the logarithm of hoop stress in the calculations.

X2. EXAMPLE CALCULATION

X2.1 *Basic Data*—The example data given in Table X2.1, together with the example analysis given in this appendix, can be used to validate statistical packages 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 X2.5.

X2.2 *Sums of Squares:*
S_{xx} = 0.798109
S_{yy} = 8.78285 x 10^{-4}
S_{xy} = −0.024836

X2.3 *Coefficient of Correlation:*
r = 0.938083

X2.4 *Functional Relationships:*

λ = 1.100457 x 10^{-3}
b = −3.31731 x 10^{-2}
a = 3.782188

X2.5 *Calculated Variances:*
D = 4.84225 x 10^{-6}
B = −1.46896 x 10^{-5}
C (variance of b)= 5.01271 x 10^{-6}
A (variance of a)= 4.66730 x 10^{-5}
σ_n^2(error variance for) x = 4.046696 x 10^{-5}
σ_ϵ^2(error variance for) y = 5.80057 x 10^{-5}

X2.6 *Confidence Limits*—For N = 32 and Student's t of 2.0423, the estimated mean and confidence and prediction intervals are given in Table X2.2.

TABLE X2.1 Example Data for Example Calculation

Data Point	Time, h	Stress, psi	Log Time, *h*	Log Stress, *f*	Data Point	Time, h	Stress, psi	Log Time, *h*	Log Stress, *f*
1	9.	5500.	0.95424	3.74036	17	1301.	4700.	3.11428	3.67210
2	13.	5500.	1.11394	3.74036	18	1430.	4800.	3.15534	3.68124
3	17.	5500.	1.23045	3.74036	19	1710.	4800.	3.23300	3.68124
4	17.	5500.		3.74036	20	2103.	4800.	3.32284	3.68124
5	104.	5200.	2.01703	3.71600	21	2220.	4500.	3.34635	3.65321
6	142.	5200.	2.15229	3.71600	22	2230.	4400.	3.34830	3.64345
7	204.	5200.	2.30963	3.71600	23	3816.	4700.	3.58161	3.67210
8	209.	5200.	2.32015	3.71600	24	4110.	4700.	3.61384	3.67210
9	272.	5000.	2.43457	3.69897	25	4173.	4600.	3.62043	3.66276
10	446.	5000.	2.64933	3.69897	26	5184.	4400.	3.71466	3.64345
11	466.	5000.	2.66839	3.69897	27	8900.	4600.	3.94939	3.66276
12	589.	4800.	2.77012	3.68124	28	8900.	4600.	3.94939	3.66276
13	669.	4700.	2.82543	3.67210	29	10900.	4500.	4.03743	3.65321
14	684.	5000.	2.83506	3.69897	30	10920.	4500.	4.03822	3.65321
15	878.	4600.	2.94349	3.66276	31	12340.	4500.	4.09132	3.65321
16	1299.	4800.	3.11361	3.68124	32	12340.	4500.	4.09132	3.65321

TABLE X2.2 Confidence Limits

Time, h	Mean	Lower Confidence Interval	Lower Prediction Interval
1	6056	5864	5771
10	5611	5487	5379
100	5198	5129	5003
1000	4816	4772	4641
10 000	4462	4398	4293
100 000	4133	4037	3960
438 000	3936	3820	3756

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D 2992–01) that may impact the use of this standard.

(*1*) RPMP and RTRP acronyms in 3.1.6 and 3.1.7were corrected.
(*2*) Note 7 was added.
(*3*) 9.2.2 was revised.
(*4*) 11.1 was revised.
(*5*) 12.3 was revised.