Designation: D7258 – 17

Standard Specification for Polymeric Piles[1]

1. Scope*

1.1 This specification addresses the use of round and rectangular cross-section polymeric piles in axial and lateral load-bearing applications, including but not limited to marine, waterfront, and corrosive environments.

1.2 This specification is only applicable to individual polymeric pile products. Sheet pile and other mechanically connected polymeric pile products using inter-locking systems, are not part of this specification.

1.3 The piling products considered herein are characterized by the use of polymers, whereby *(1)* the pile strength or stiffness requires the inclusion of the polymer, or *(2)* a minimum of fifty percent (50 %) of the weight or volume is derived from the polymer. The type classifications of polymeric piles described in Section 4 show how they can be reinforced by composite design for increased stiffness or strength.

1.4 This specification covers polymeric piles fabricated from materials that are virgin, recycled, or both, as long as the finished product meets all of the criteria specified herein. Diverse types and combinations of inorganic filler systems are permitted in the manufacturing of polymeric piling products. Inorganic fillers include such materials as talc, mica, silica, wollastonite, calcium carbonate, etc. Pilings are often placed in service where they will be subjected to continuous damp or wet exposure conditions. Due to concerns of water sensitivity and possible affects on mechanical properties in such service conditions, organic fillers, including lignocellulosic materials such as those made or derived from wood, wood flour, flax shive, rice hulls, wheat straw, and combinations thereof, are not permitted in the manufacturing of polymeric piling products.

1.5 The values are stated in inch-pound units as these are currently the most common units used by the construction industry.

1.6 Polymeric piles under this specification are designed using design stresses determined in accordance with Test Methods D6108, D6109, and D6112 and procedures contained within this specification unless otherwise specified.

1.7 Although in some instances it will be an important component of the pile design, frictional properties are currently beyond the scope of this document.

1.8 Criteria for design are included as part of this specification for polymeric piles. Certain Types and sizes of polymeric piles will be better suited for some applications than others. Polymeric piles designed and manufactured under the different Type classifications as defined within this specification will, as a whole, exhibit a wide-range of mechanical properties. For example, a 10-in. diameter Type II, chopped glass fiber reinforced high-density polyethylene (HDPE) pile will likely have an apparent stiffness much different than a 10-in. diameter Type V, glass fiber reinforced composite tube filled with concrete. Similarly, the ultimate moment capacity of these two example piles will also likely be significantly different from each other. Use of a licensed Professional Engineer is, therefore, highly recommended for designing and selecting polymeric piles in accordance with this specification.

1.9 *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.*

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D883 Terminology Relating to Plastics
D1141 Practice for the Preparation of Substitute Ocean Water
D2344/D2344M Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products
D5033 Guide for Development of ASTM Standards Relating

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[1] This specification is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.20 on Plastic Lumber.

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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**

to Recycling and Use of Recycled Plastics (Withdrawn 2007)[3]

D6108 Test Method for Compressive Properties of Plastic Lumber and Shapes

D6109 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber and Related Products

D6112 Test Methods for Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber and Shapes

D6341 Test Method for Determination of the Linear Coefficient of Thermal Expansion of Plastic Lumber and Plastic Lumber Shapes Between –30 and 140°F (–34.4 and 60°C)

D6662 Specification for Polyolefin-Based Plastic Lumber Decking Boards

E84 Test Method for Surface Burning Characteristics of Building Materials

2.2 *Other Documents:*

ASCE 7 Minimum Design Loads for Buildings and Other Structures[4]

AASHTO GSDPB-1 Standard Specification for Design of Pedestrian Bridges[5]

AASHTO HB-13 Standard Specification for Highway Bridges[5]

Department of Defense Unified Facility Criteria UFC 4-152-01 Design: Piers and Wharves, Naval Facilities Engineering Command, Washington DC

3. Terminology

3.1 *Definitions:*

3.1.1 *axial load-bearing pile, n*—a vertical or battered member driven into the ground to help support a load of any structure bearing upon it. Axial load-bearing piles are commonly divided into two kinds; point-bearing (end-bearing) and friction. A point-bearing pile derives practically all its support from the rock or soils near the point and much less from contact with soil along the pile shaft. A friction pile derives its support principally from the soil along the pile shaft through the development of shearing resistance between the soil and the pile.

3.1.2 *lateral load-bearing pile, n*—a vertical or battered member driven into the ground to resist lateral loads imposed upon it or a structure. A common application for a lateral load-bearing pile is to absorb lateral forces at points of impact and dissipate them horizontally into a structure and/or soil stratum. A fender pile is an example of a lateral load-bearing pile.

3.1.3 *combined axial and lateral load-bearing pile, n*—a vertical or battered member driven into the ground to resist both axial and lateral loads or applied external forces imposed upon it. Combined axial and lateral load-bearing piles are commonly divided into two kinds; point-bearing (end-bearing) and friction. A point-bearing pile derives practically all its support from the rock or soils near the point and much less from contact with soil along the pile shaft. A friction pile derives its support principally from the soil along the pile shaft through the development of shearing resistance between the soil and the pile.

3.2 Additional definitions of terms applying to this specification appear in Terminology D883 and Guide D5033.

4. Classification

4.1 Polymeric Piles contained in this specification are classified as following six (6) types:

4.1.1 *Type I*—Polymeric only.

4.1.2 *Type II*—Polymeric with reinforcement in the form of chopped, milled or continuous fiber or mineral.

4.1.3 *Type III*—Polymeric with reinforcement in the form of metallic bars, cages, or shapes.

4.1.4 *Type IV*—Polymeric with reinforcement in the form of non-metallic bars or cages.

4.1.5 *Type V*—Polymeric composite tube with a concrete core.

4.1.6 *Type VI*—Any other polymeric piling meeting the requirements in 1.3 and not otherwise described by Types I through V above.

5. Ordering Information

5.1 The purchaser shall state whether this specification is to be used, select the preferred options permitted herein, and include the following information in the invitation to bid and purchase order:

5.1.1 Title, number and date of this specification,

5.1.2 Type and composition,

5.1.3 Percent recycled content (if requested),

5.1.4 Flame spread index, if applicable,

5.1.5 Color,

5.1.6 Quantity in linear feet (meters), and minimum length without splices,

5.1.7 Cross-sectional dimensions,

5.1.8 Performance requirements including flexural strength, axial strength, and stiffness,

5.1.9 Required accessories including pile tips, splices and driving caps,

5.1.10 Special handling, packing, or shipping requirements,

5.1.11 Marking, if other than specified, and

5.1.12 Shop drawings and submittals.

6. Tolerances

6.1 *Sizes:*

6.1.1 *Circular Piles:*

6.1.1.1 Maximum deviation from a circular cross section shall be:

$$b = 0.98a \tag{1}$$

where:

$2a$ = major oval diameter, and
$2b$ = minor oval diameter.

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[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.

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

(1) For example, for 13 in. (330 mm) major diameter pile, maximum allowable difference between major and minor diameter would be 0.26 in. (7 mm).

6.1.1.2 *Diameter*—Tolerance against specified diameter = ±3 %.

6.1.2 *Rectangular Piles:*

6.1.2.1 *Squareness of Piles*—Measurements of the two opposing diagonals shall not differ by more than 3 %, calculated with the smaller diagonal denominator.

6.1.2.2 Dimensions shall not vary from specified dimension by more than 3 %.

6.1.3 *Cross-Section*—All piles, regardless of cross sectional shape shall remain consistent in cross-sectional area along the length of the pile, except that a tolerance of ±6 % is permitted against the nominal or specified area at any location along the length of pile.

6.1.4 Each pile shall be measured at a minimum of three locations at quarter points along its length, prior to shipment, to confirm compliance with this section.

6.1.5 Pile head tolerance from the plane perpendicular to the longitudinal axis of the pile shall be ¼ in. (6 mm) in 12 in. (305 mm) but not more than ½ in. over the whole pile length (12 mm).

7. Lengths

7.1 All piles shall be furnished in lengths specified, except that tolerances shall be plus 1 ft (0.3 m), minus 0 in. (0 mm) corrected to 73°F, and

7.2 Piles 41 ft or longer—plus 2 ft (0.6 m), minus 0 in (0 mm) corrected to 73°F.

8. Straightness

8.1 A straight line from the center of the head to the center of the tip shall lie entirely within the body of the pile when the pile is vertically suspended from the head.

8.2 Lateral load-bearing piles shall be free of short crooks that deviate more than 2½ in. (64 mm) from straightness in any 20 ft (1.5 m) length. See Fig. 1.

8.3 Axial load-bearing piles shall have no more than 1 in. (24 mm) bow or bend in 20 ft (6.5 m) of length.

8.4 Straightness as defined in 8.2 and 8.3 shall be interpreted as the as-built straightness.

9. Placement of Reinforcement for Pile Types III and IV only

9.1 Longitudinal reinforcement shall remain within 5 % of the specified radial location as measured from centroid of the cross-section of the pile.

9.2 Longitudinal reinforcement shall not twist more than 5° over any 20 ft (6.1 m) section of the pile.

10. Surface Condition

10.1 The pile surface will typically exhibit some roughness or corrugations due to manufacturing processes. However, the piles shall not have depressions or projections greater than ½ in. (13 mm) and the total surface area of any such depressions or projections shall not be greater than 9 in.^{2} (58 cm^2).

10.2 The surface of the pile shall contain no cracks or splits, in any orientation.

11. Performance Requirements

11.1 The cross-sectional dimensions of piles will be determined on the basis of the ability to perform satisfactorily under the physical loading and environmental conditions imposed as well as the energy absorption properties desired. Testing methods and procedures for analysis of results to define allowable values for the design of plastic piles are given below.

11.2 *Load Combinations*—Polymeric piles subject to multiple load types shall be checked for all applicable load combinations. Load factors and load reductions shall be determined in accordance with the applicable code or ASCE 7. Where allowed by the applicable code or ASCE 7, allowable stress increases are permitted. Each load type in combination shall be divided by the load duration factor corresponding to the load type's duration. See A2.1 for the procedure to determine the load duration factor. A sample calculation of the load duration factor is provided in Appendix X1.

NOTE 2—Applicable codes vary depending upon location and usage. Relevant codes may include, but are not limited to, American Association of State Highway and Transportation Officials (AASHTO) HB-13, Standard Specification for Highway Bridges, AASHTO GSDPB-1, Standard Specification for Design of Pedestrian Bridges, or Department of Defense Unified Facility Criteria (UFC) 4-152-01 Design: Piers and Wharves.

11.3 *Design Strength:*

11.3.1 All piles shall be designed such that for all load combinations:

$$f_a \leq F_n' \times C_D \tag{2}$$

where:

f_a = total applied stress in each combination (psi),
F_n' = allowable stress as calculated in 11.7.3, 11.8.2, 11.9.2, 11.9.3, or 11.12.2 (psi), and
C_D = Load Duration Factor for the material and considered load duration. Derivation of C_D is explained in Annex A2.

NOTE 3—Results from testing of plastic lumber decking boards after eleven years of outdoor exposure have shown that the boards had discolored and faded, but that both strength and stiffness were basically unchanged. Similar results are expected with polymeric piles made with similar materials. Introduction of carbon black and other additives can significantly reduce ultraviolet light degradation of polymers. Further details of this testing and results are given in Appendix X3 in Specification D6662.

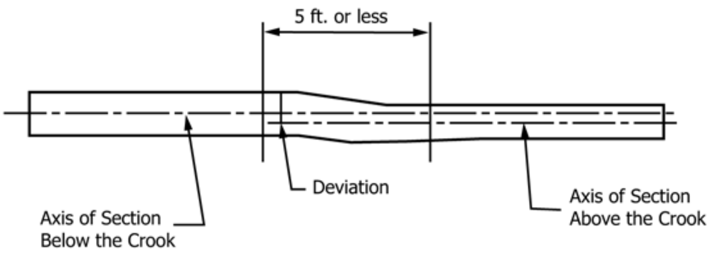
11.4 *Interpolation of Mechanical Properties:*

11.4.1 Interpolation of mechanical properties of a polymeric pile from other pile test data is permitted if the test results verify a logical progression of properties and the following conditions are met:

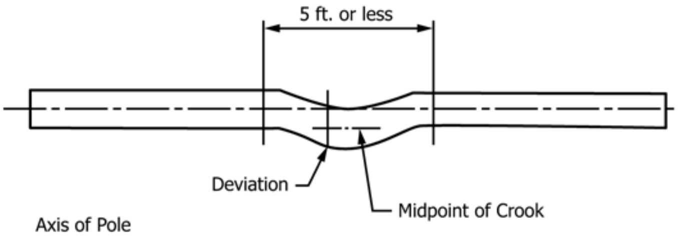
11.4.1.1 All specimens have the same and material composition.

11.4.1.2 Three or more tests are performed on specimens with varying width or diameter.

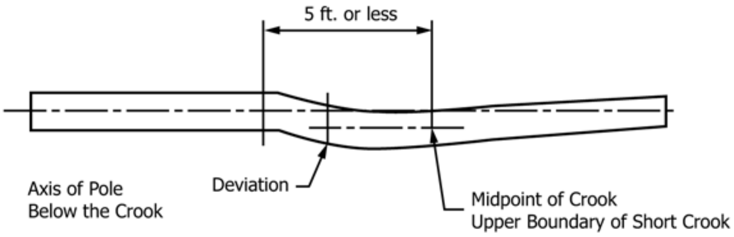
11.4.1.3 At least one test is performed on specimens with a width or diameter greater than that of the product whose properties are being interpolated.



Case 1: Where the Reference Axes are Approximately Parallel



Case 2: Where the Axis of Sections Above and Below the Crook Coincide or are Practically Coincident



Case 3 - Where Axis of Section Above Short Crook is not Parallel or Coincident with the Axis Below the Crook

The three cases shown are typical, and are intended to establish the principle of measuring short crooks. There may be other cases not exactly like those illustrated.

FIG. 1 Measurement of Short Crook N.T.S.

11.4.1.4 At least one test is performed on specimens with a width or diameter less than that of the product whose properties are being interpolated.

11.4.1.5 For rectangular piles all specimens have the same thickness.

11.5 *Creep Rupture:*

11.5.1 Creep rupture tests shall be performed for the intended use (that is, flexural test for a flexural member, compression test for a compression member) in accordance with the procedures outlined in Test Methods D6112 including the following modifications:

11.5.1.1 The stress in the outer fiber, as indicated in subsection 12.3.1 of Test Methods D6112, in flexural creep tests shall be modified to be calculated as follows:

$$F = \frac{M}{S} \tag{3}$$

where:

F = the stress in the outer fiber throughout load span, (psi),
S = section modulus (in.^{3}), and
M = Bending Moment.

11.5.1.2 The maximum strain, as indicated in subsection 12.3.2 of Test Methods D6112, in the outer fiber at the mid-span is calculated as follows:

$$\xi = 9.39 \cdot y \cdot \Delta / L^2 \tag{4}$$

where:

y = distance from the outer fiber to the centroid of the section, (in.),
Δ = maximum deflection at mid-span, (in.), and
L = support span, (in.).

11.5.2 F_{cr} shall be the stress required to cause creep rupture in ten years determined from the creep rupture curve calculated in Test Methods D6112.

11.6 *Serviceability:*

11.6.1 The maximum ten-year strain in any member shall not exceed 0.03 (3 %).

NOTE 4—Applicable codes or project specific requirements may require deflection limits that result in a maximum strain of less than 0.03.

11.6.2 Deflection shall be calculated using the apparent modulus of elasticity determined in 11.7.4. Calculated deflection shall not exceed building code or project specific deflection limits.

11.6.3 Laterally loaded piles (for example, fender piles) shall meet all project specific stiffness and energy absorption requirements.

11.7 *Flexural Properties (Lateral Load-bearing Piles):*

11.7.1 Test procedure shall be in accordance with Test Methods D6109 with the following modifications:

11.7.1.1 The minimum support span to depth ratio of each specimen shall be no less than 10:1.

11.7.1.2 The distance between the loading noses on the four-point test, shall be either one third of the specimen length or 4 ft, whichever is less.

11.7.1.3 *Specimens Tested*—A minimum of 28 specimens shall be tested at 23 ± 2°C (73.4 ± 4°F). Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

11.7.2 A minimum of ten specimens shall be cycled five times to 30 % of the flexural failure load and their load deflection output shall be reported. If there is more than a 10 % loss in flexural strength or stiffness modulus, the piling product shall not be used in load cycling applications such as fender piling.

11.7.3 *Allowable Flexural Stress*—The allowable flexural stress, F_b', of a product is given as follows:

$$F_b' = (F_b/FS)\cdot C_{TF}\cdot C_L \tag{5}$$

where:

F_b = the base flexural stress value at 23°C (73.4°F) for normal duration loading (ten-year duration), (psi) as defined as follows:

$$F_b = F_{bt}\cdot\beta \le F_{cr} \tag{6}$$

where:

F_{bt} = the nonparametric 5 % lower tolerance limit at 75 % confidence of the flexural stress at 3 % outer fiber strain (or failure if 3 % strain cannot be reached) determined from flexure tests conducted in accordance with 11.7.1 (psi). Statistical calculations shall be in accordance with Practice D2915.
F_{cr} = ultimate creep rupture stress for flexure calculated in accordance with 11.5, (psi),
β = stress-time factor to convert the test value, F_{bt}, to a ten year normal duration value. This value shall be determined in accordance with Annex A1,
FS = factor of safety = 2.0,
C_{TF} = temperature factor for flexure determined in accordance with Annex A3, and
C_L = beam stability factor defined as follows:

11.7.3.1 C_L = 1.0 for a beam with a thickness greater than or equal to its depth ($t \ge d$), round sections, or a beam with full lateral support. For all other beams:

$$C_L = \left(\frac{c\cdot C_b\cdot\pi}{I_x\cdot F_b\cdot L_u}\right)\cdot\sqrt{\frac{E'\,I_y\,G'\,J}{(1-I_y/I_x)}} \le 1.0 \tag{7}$$

where:

c = distance from outer compression fiber to the neutral axis, (in.), and
C_b = equivalent moment factor determined as follows:

$$C_b = \frac{12}{3\left(\frac{M_1}{M_{MAX}}\right)+4\left(\frac{M_2}{M_{MAX}}\right)+3\left(\frac{M_3}{M_{MAX}}\right)+2} \tag{8}$$

where:

M_1 = moment at the quarter point (in.-lb),
M_2 = moment at the half point (in.-lb),
M_3 = moment at the three quarter point (in.-lb), and
M_{MAX} = maximum moment (in.-lb).

(1) As an alternative, it is permissible to use C_b = 1.0 as a conservative value.

E' = apparent modulus of elasticity as defined in 11.7.4 (psi),
I_y = moment of inertia about the weak axis (in.^{4}),
I_x = moment of inertia about the strong axis (in.^{4}), and
G' = apparent shear modulus (psi), calculated as follows:

$$G' = G/\alpha \tag{9}$$

where:

G = shear modulus determined from tests performed in accordance with 11.8.1 (psi),
α = creep adjustment factor determined in accordance with Annex A1,
J = torsional constant, polar moment of inertia (in.^{4}),

F_b = base flexural stress defined above, (psi), and
L_u = effective unbraced length, (in.).

11.7.4 *Apparent Modulus of Elasticity and Adjustment for Creep*—The apparent modulus of elasticity, E', shall be determined as follows:

$$E' = E/\alpha \tag{10}$$

where:

E = modulus as determined from Test Method D6109, except that it represents the chord modulus values between 0.1 F_{bt} and 0.4 F_{bt}, (psi), and
α = creep adjustment factor determined in accordance with Annex A3.

NOTE 5—Values for α shall be provided by manufacturers for their specific products based on methodology presented in Annex A1.

11.8 *Shear Strength:*

11.8.1 *Test Procedure*—Test Method D2344/D2344M incorporating the following criteria and modifications:

11.8.1.1 *Specimen Size for Testing*—Specimens for test shall not be machined to reduce the cross-sectional thickness—only full-size cross sections shall be used. Also, in accordance with subsection 5.3 of Test Method D2344/D2344M, use span length-to-specimen thickness ratio of 4 for the specimen size.

11.8.1.2 *Specimens Tested*—A minimum of 28 specimens shall be tested. Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

11.8.1.3 An extension indicator shall be affixed to the specimen to record the displacement (strain) of the specimen below the upper loading nose as a function of applied stress. The recorded stress-strain data shall also be reported.

11.8.1.4 Use the short beam strength, F^{sbs}, as calculated in Eq. 1 of Test Method D2344/D2344M as the shear strength value F_v in Eq 11.

11.8.2 *Allowable Shear Stress*—The allowable shear stress of a product is given as follows:

$$F_v' = (F_v/FS) \cdot C_{TF} \tag{11}$$

where:

F_v = the base shear stress value at 23°C (73.4°F) for normal duration loading (ten-year duration), (psi) as defined below,
FS = factor of safety = 2.0, and
C_{TF} = temperature factor for flexure, determined in accordance with Annex A3.

11.8.2.1 F_v, the base shear stress value for the product is determined as follows:

$$F_v = F_{vt} \cdot \beta \leq F_{cr} \tag{12}$$

where:

F_{vt} = the nonparametric 5 % lower tolerance limit at 75 % confidence of the shear stress at 3 % fiber strain (or failure if 3 % strain cannot be reached) determined from shear tests conducted in accordance with 11.8.1 (psi). Statistical calculations shall be in accordance with Practice D2915.
F_{cr} = ultimate creep rupture stress for shear calculated in accordance with 11.5, (psi), and
β = stress-time factor to convert the test value, F_v, to a ten year normal duration value. This value shall be determined in accordance with Annex A1.

11.9 *Bearing:*

11.9.1 Tests shall be performed in accordance with Test Method D6108 with the following modifications:

11.9.1.1 *Specimens Tested*—A minimum of 28 specimens shall be tested at 23 ± 2°C (73.4 ± 4°F). Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

11.9.1.2 *Bearing Perpendicular to the Direction of Extrusion:*

(1) Test Method D6108 subsection 6.2: The standard test specimen shall take the form of the actual manufactured product cross-section with a length equal to half its height.

(2) Test Method D6108 subsection 10.2: Place the test specimen between the surfaces of the compression platens, taking care to align the center line of the surface perpendicular to the extrusion with the center line of the platens to ensure that the ends of the specimen are parallel with the surface of the platens. The proper positioning of a member with dimensions b×d is shown in Fig. 2. Adjust the crosshead of the testing machine until it just contacts the top of the compression platen.

11.9.1.3 *Bearing Parallel to the Direction of Extrusion:*

(1) Test Method D6108, subsection 6.2: The standard test specimen shall take the form of the actual manufactured product cross-section with a height equal to twice its length.

(2) Test Method D6108, subsection 10.2: Place the test specimen between the surfaces of the compression platens, taking care to align the center line of the surface parallel to the extrusion with the center line of the platens to ensure that the ends of the specimen are parallel with the surface of the platens. The proper positioning of a member with dimensions b×d is shown in Fig. 3. Adjust the crosshead of the testing machine until it just contacts the top of the compression platen.

11.9.2 *Bearing Perpendicular to Extrusion:*

11.9.2.1 *Allowable Bearing Stress*—The allowable bearing stress, $F_{C\perp}'$, of a product loaded in compression perpendicular to the extrusion direction is given as follows:

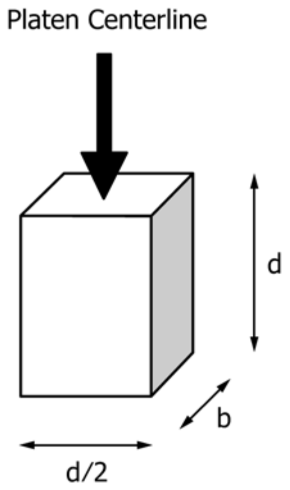


FIG. 2 Bearing Perpendicular to the Direction of Extrusion

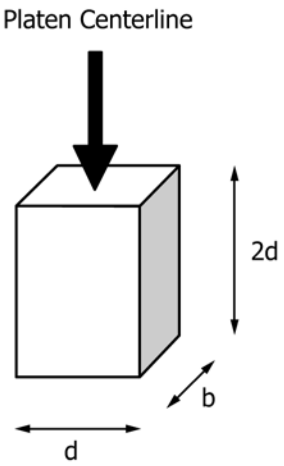


FIG. 3 Bearing Parallel to the Direction of Extrusion

$$F_{C\perp}' = (F_{C\perp}/FS)\cdot C_{TC} \tag{13}$$

where:

$F_{C\perp}$ = the base bearing stress value at 23°C (73.4°F), (psi) defined below,
FS = factor of safety = 2.0, and
C_{TC} = temperature factor for compression, determined in accordance with Annex A3,

(1) $F_{C\perp}$, the base bearing stress value for the product is determined as follows:

$$F_{C\perp} = F_{C\perp\ t}\cdot\beta \le F_{cr} \tag{14}$$

where:

$F_{C\perp\ t}$ = the nonparametric 5 % lower tolerance limit at 75 % confidence of the bearing stress perpendicular to the extrusion direction at 3 % fiber strain (or failure if 3 % strain cannot be reached) determined from bearing tests conducted in accordance with 11.9.1 (psi). Statistical calculations shall be in accordance with Practice D2915.
F_{cr} = the ultimate creep rupture stress for bearing perpendicular to the direction of extrusion calculated in accordance with 11.5, (psi), and
β = stress-time factor to convert the test value, $F_{C\perp\ t}$, to a ten year normal duration value. This value shall be determined in accordance with Annex A1.

11.9.3 *Bearing Parallel to Extrusion:*

11.9.3.1 *Allowable Bearing Stress*—The allowable bearing stress, $F_{C\|}'$, of a product loaded in compression parallel to the extrusion direction is given as follows:

$$F_{C\|}' = (F_{C\|}/FS)\cdot C_{T} \tag{15}$$

where:

$F_{C\|}$ = the base bearing stress value at 23°C (73.4°F), (psi) defined below,
FS = factor of safety = 2.0, and
C_{TC} = temperature factor for compression, determined in accordance with Annex A3.

(1) $F_{C\|}$, the base bearing stress value for the product is determined as follows:

$$F_{C\|} = F_{C\|\ t}\cdot\beta \le F_{cr} \tag{16}$$

where:

$F_{C\|\ t}$ = the nonparametric 5 % lower tolerance limit at 75 % confidence of the bearing stress parallel to the extrusion direction at 3 % fiber strain (or failure if 3 % strain cannot be reached) determined from bearing tests conducted in accordance with 11.9.1 (psi). Statistical calculations shall be in accordance with Practice D2915.
F_{cr} = ultimate creep rupture stress for compression parallel to the direction of extrusion calculated in accordance with 11.5, (psi), and
β = stress-time factor to convert the test value, $F_{C\|\ t}$, to a ten year normal duration value. This value shall be determined in accordance with Annex A1.

11.10 *Design Flexural Stiffness:*

11.10.1 The Design Flexural Stiffness, $(EI)_D$ of the pile is the product of the Modulus of Elasticity, E of the pile and the moment of inertia of the gross section, I. The Modulus of Elasticity, E, is the average value of the Chord Modulus at 1 % strain determined in accordance with Test Methods D6109. Use the value one standard deviation below the mean.

11.11 *Energy Absorption:*

11.11.1 *Specimens Tested*—A minimum of 28 specimens shall be tested in accordance with Test Methods D6109 at 23 ± 2°C (73.4 ± 4°F). The nonparametric 5 % lower tolerance limit with 75 % confidence as explained in Practice D2915 shall be used in calculations involving the measured force versus deflection at 0.25 % strain. Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

11.11.2 Test procedures shall conform to Test Methods D6109 with the following modifications:

11.11.2.1 The minimum support span to depth ratio of the specimen shall be no less than 10:1.

11.11.2.2 The distance between the loading noses on the four-point test, shall be either one third of the specimen length or 4 ft, whichever is less.

11.11.2.3 The rate of crosshead motion shall be as follows:

$$R = \lambda V L_t^2 \text{ (in./s)} \tag{17}$$

where:

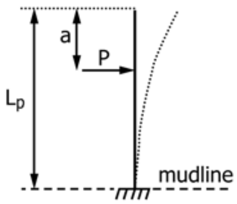
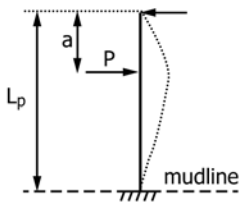
V = design vessel velocity (in./s),
L_t = length of the test specimen (in.), and
λ = adjustment coefficient as defined in Fig. 4.

(1) d

(2) For some design vessel velocities, the required rate of crosshead motion exceeds realistic testing speeds. In this case, testing at the maximum realistic crosshead speed shall be permitted. A scale factor, as determined in 11.11.3.1, shall be applied to the allowable energy absorption determined in 11.11.3.

11.11.2.4 An average Load-Deflection plot of the specimens tested shall be reported. An equation for the load-deflection curve shall be reported in the following form:

$$P(\Delta_t) = A\Delta_t^3 + B\Delta_t^2 + C\Delta_t \tag{18}$$

	Cantilever Pile	Restraint at Top of Pile	
			
	All values of a	$a \leq 0.414L_P$	$a > 0.414L_P$
λ	$\frac{1.11}{(L_P - a)(2L_p + a)}$	$\frac{0.278\cdot(a^2 - 3L_P^2)^2\cdot(a+2L_P)}{(a+L_P)^2\cdot(L_P^2 - a^2)\cdot L_P^3}$	$\frac{0.556\cdot(a+2L_P)}{L_P^3\cdot\sqrt{\frac{a}{a+2L_P}}}$
ψ	$\frac{108\cdot(L_P - a)^2\cdot(2L_P + a)}{23}$	$\frac{216\cdot a\cdot(L^2{}_P - a^2)^3}{23\cdot(3\ L^2{}_P - a^2)^2}$	$\frac{108\cdot a\cdot b^2}{23}\cdot\sqrt{\frac{a}{a+2L_P}}$
γ	$\frac{(L_P - a)\cdot(2L_P + a)}{6}$	$\frac{2L_P^3(L_P^2 - a^2)^3}{3(L_P - a)^2\cdot(a + 2\ L_p)\cdot(3\ L_P^2 - a^2)^2}$	$\frac{L_P^3}{3\cdot a+2L_P}\cdot\sqrt{\frac{a}{a+2L_P}}$

a = distance to point of vessel impact from top of pile
L_P = length of pile above the mudline

FIG. 4 Energy Absorption Coefficients

where:

P = force applied to the test specimen (lb), and
Δ_t = deflection of the test specimen (in.).

11.11.2.5 The load-deflection curve for the actual pile shall be calculated and reported in the form:

$$P(\Delta_p) = A\Delta_p{}^3 + B\Delta_p{}^2 + C\Delta_p \tag{19}$$

where:

A, B, and C = as calculated in 11.11.2.4, and
Δ_p = deflection of the pile calculated as:

$$\Delta_p = \psi\Delta_t / L_t{}^3 \text{ (in.)} \tag{20}$$

where:

ψ = adjustment coefficient as defined in Fig. 4.

11.11.3 *Allowable Energy Absorption*—Allowable pile energy absorption shall be taken as follows:

$$U = \int_0^{\Delta_f} P(\Delta_p)\, d\Delta \tag{21}$$

where:

Δ_f = deflection at defined failure strain calculated as:

$$\Delta_f = 2\gamma\varepsilon_f / d \text{ (in.)} \tag{22}$$

where:

γ = adjustment coefficient as defined in Fig. 4,
d = cross sectional depth in the direction of impact (in.), and
ε_f = defined failure strain, generally taken as 0.01, where:

$$\varepsilon_f \leq \varepsilon_r$$

where:

ε_r = strain at which the test specimen ruptured.

11.11.3.1 *Energy Absorption Scale Factor*—For piles tested at crosshead rates other than the rate determined in 11.11.2.3, the allowable energy absorption shall be scaled by the following factor:

$$\text{Scale Factor} = C_{D,t_b} / C_{D,t_a} \tag{23}$$

where:

$C_{D,ta}$ = load duration factor for time t_a, as determined in Annex A2,
$C_{D,tb}$ = load duration factor for time t_b, as determined in Annex A2,
t_a = ε_c / R_{dv},
t_b = ε_f / R_{test},
ε_f = strain at failure during test as determined in 11.11.3,
ε_c = $(\varepsilon_f/2)\cdot(1+ n_c)$,
n_c = creep coefficient as determined in Annex A1,
R_{dv} = crosshead rate based on design vessel velocity required by 11.11.2.3, and
R_{test} = actual crosshead rate used for test.

11.12 *Compressive Strength:*

11.12.1 Test procedures shall conform to Test Method D6108 with the following modifications:

11.12.1.1 *Specimens Tested*—A minimum of 28 specimens shall be tested at 23 ± 2°C (73.4 ± 4°F). Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

11.12.2 *Design of Compression Members*—Laterally unsupported portions of axially loaded piles shall meet the following slenderness ratio requirement:

$$S_r = K_e L_u / r < 28 \tag{24}$$

where:

S_r = slenderness ratio,

K_e = buckling length coefficient (greater than or equal to 1.0) that depends on the end constraint for the column,

L_u = unbraced length of the member, and

r = radius of gyration.

NOTE 6—The above slenderness ratio shall be checked for both principle bending axes of the member.

11.12.3 The allowable compressive stress of a product is given as follows:

$$F_c' = (F_c/FS) \cdot C_{TC} \cdot C_P \quad (25)$$

where:

F_c = base compressive stress value at 23°C (73.4°F) for normal duration loading (ten-year duration), (psi) as defined below:

$$F_c = \beta \cdot F_{ct} \leq F_{cr} \quad (26)$$

where:

F_{ct} = nonparametric 5 % lower tolerance limit at 75 % confidence of the compressive stress at 3 % fiber strain (or failure if 3 % strain cannot be reached) determined from compression tests conducted in accordance with 11.12.1 (psi). Statistical calculations shall be in accordance with Practice D2915,

F_{cr} = ultimate creep rupture stress for compression calculated in accordance with 11.5, (psi),

β = stress-time factor to convert the test value, F_{ct}, to a ten year normal duration value. This value shall be determined in accordance with Annex A1,

FS = factor of safety = 2.0,

C_{TC} = temperature factor for compression determined in accordance with Annex A3,

C_P = column stability factor defined below:

C_P = 1.0 for a column with lateral support throughout its length. For all other columns:

$$C_P = \frac{\pi^2 E' I}{2(KL)^2 A F_C} \leq 1.0 \quad (27)$$

where:

E' = apparent modulus of elasticity as defined in 11.7.4, (psi),

I = moment of inertia about the weak axis,

K = effective length factor determined by the condition of the end restraint,

L = unbraced member length, and

F_C = base compressive stress defined above.

11.13 *Combined Stresses:*

11.13.1 *Combined Stresses—Bending and Compression*—Plastic members subject to both axial compression and flexure shall be proportioned in accordance with the following interaction equation:

$$\frac{f_c}{F'_c} + \frac{f_{bx}}{F'_{bx}(1 - f_a/F'_{ex})} + \frac{f_{by}}{F'_{by}(1 - f_a/F'_{ey})} \leq 1.0 \quad (28)$$

where:

f_c = P/A = actual compressive stress (psi),

F'_c = allowable compressive stress under axial compression only (psi), in accordance with 11.12.3,

f_{bx} , f_{by} = flexural stress at service load due to primary bending moment about the respective axis (psi),

F'_{bx} , F'_{by} = allowable flexural stress about the respective axis (psi), in accordance with 11.7.3,

F'_{ex} , F'_{ey} = critical elastic buckling stress about the respective axis (psi), calculated as follows:

$$F'_{ex}, F'_{ey} = \frac{\pi^2 E' I C_{TF}}{2(KL_u)^2 A} \quad (29)$$

where:

E' = apparent modulus of elasticity as defined in 11.7.4 (psi),

I = moment of inertia about the axis in which buckling is induced (in.^{4}),

β = stress-time factor,

C_T = temperature factor, determined in accordance with Annex A3,

K = effective length factor determined by the condition of the end restraint,

L_u = unbraced member length (in.), and

A = cross sectional area (in.^{2}).

11.14 *Dimensional Stability—Thermal Expansion:*

11.14.1 Test procedures shall conform to Test Method D6341 with the following modifications:

11.14.1.1 *Specimens Tested*—A minimum of 15 specimens shall be tested. Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

11.14.1.2 *Criteria*—Report the measured thermal expansion coefficient in either the longitudinal or the transverse directions to two significant figures. Thermal expansion shall be considered for the design of expansion slots, where polymeric piles are used with dissimilar materials or any other case where movement due to thermal effects will cause structural or serviceability concerns.

11.15 *Hygrothermal Cycling:*

11.15.1 *Test Procedure*—Specimens shall also be prepared as described in Test Method D6108. Each specimen shall be weighed. Specimens will then be totally submerged in substitute ocean water created in accordance with Practice D1141 (using weights to hold down, if necessary) for a period of 24 hours. Each specimen shall then be dried with a dry cloth on the outside surfaces. Each specimen shall then be weighed again within 20 minutes of removal from the water. Specimens, which exceed a 1 % weight gain as compared to the unsoaked specimen shall be resoaked until such time as the weight changes less than 1 % per 24 hour period. Such specimens will then be considered to have reached moisture absorption equilibrium. Specimens will then be frozen to –20°F (–29°C) for 24 hours, then returned to room temperature. This process comprises one hygrothermal cycle. This process shall be repeated two more times, for a total of three cycles of water submersion, moisture absorption equilibrium, and freezing. After the completion of these steps, the specimens shall be returned to room temperature and tested as described in Test Method D6108.

11.15.2 *Specimen Tested*—A minimum of 15 specimens shall be prepared as in accordance with Test Method D6108 and tested. Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

11.15.3 *Criteria*—Any obvious physical changes that occur as a result of the hygrothermal cycling shall be noted. The compressive modulus and the greater of the stress level of the pile is product of the mean value minus one standard deviation at 3 % strain when tested without hygrothermal cycling.

11.16 *Flame Spread Index:*

11.16.1 The flame spread index of pile products shall be determined by testing in accordance with Test Method E84.

11.16.2 A minimum of five test specimens shall be tested.

11.16.3 The test specimens shall either be self-supporting by their own structural characteristics or held in place by added supports along the test specimen surface. The test specimen shall remain in place throughout the test duration. Test results are invalid if one of the following occurs during the test: (a) the test specimen sags from its position in the ceiling to such an extent that it interferes with the effect of the gas flame on the test specimen or (b) portions of the test specimen melt or drop to the furnace floor to the extent that progression of the flame front on the test specimen is inhibited.

11.16.4 Appendix X1 of Test Method E84 provides guidance on mounting methods.

11.16.5 Products shall have a flame spread index no greater than 200 when tested in accordance with Test Method E84.

NOTE 7—For combustible construction, codes often require fire performance at least equivalent to that of wood. A maximum flame spread index of 200 when tested in accordance with Test Method E84 is considered to be equivalent to that of wood. For outdoor applications, there is no requirement specified for smoke developed index.

NOTE 8—Fire retardants are available to increase the resistance to ignitability and flame spread of piles and shall be incorporated as needed.

12. Installation

12.1 Piles shall be capable of being driven by air/steam, diesel or hydraulic hammers. Axial load bearing piles must be capable of withstanding a striking energy from a hammer rated at a minimum of 10,000 ft-lb (13.6 KJ) per blow without damage to the pile anywhere along its length, with the exception of a sacrificial 2 ft at driving end.

13. Splicing of Piles

13.1 *Strength*—Splicing mechanisms must provide strength equal to or greater than the ultimate strength of the pile proper, in bending, compression, tension and torsion. Splices shall be tested in accordance with Test Methods D6108 and D6109 with the splice located at the mid-span. Failure shall not occur at the splice.

13.2 *Stiffness*—The stiffness of any splice, defined as the product E times I, must provide a minimum of 100 % of pile stiffness. For this purpose, E shall represent the Modulus of Elasticity as defined by Test Methods D6109 and I shall represent the moment of inertia of the cross section.

13.3 *Fender Piles*—If at all possible, avoid placing a splice in the region of possible contact with vessels. If splices cannot be avoided in the possible contact area, special considerations shall be taken to ensure acceptable performance and durability of the pile under these loading conditions.

14. Specimen Conditioning

14.1 *Conditioning of Specimens for Tests*—Unless specifically stated otherwise, all specimens shall be conditioned and tested in accordance with the appropriate test method.

15. Workmanship, Finish, and Appearance

15.1 The polymeric pilings furnished in accordance with this specification shall be an acceptable match to approved samples in pattern, color, and surface appearance. The products shall be free of defects that adversely affect performance or appearance. Such defects include, but are not limited to, blemishes, spots, indentations, cracks, blisters, and breaks.

16. Certification

16.1 When requested, a manufacturer's certification and any other documents required to substantiate certification shall be furnished stating that the product was manufactured to meet this specification.

17. Quality Assurance

17.1 This section presents a Quality Assurance program for the manufacturer to put into place to verify compliance with specific portions of this specification. The program shall include the following at a minimum:

17.1.1 Product Specification, including incoming product inspection and acceptance requirements.

17.1.2 Sampling and inspection frequencies shall be devised to encompass all variables that affect the quality of the finished product including lot-to-lot variations from different production runs. Increased frequencies shall be used in connection with new or revised facilities. A random sampling scheme shall generally be used for specimen selection.

NOTE 9—Increased sampling and test frequencies is a useful procedure when investigating apparent data trends or adjustments in process. It is desirable at times to deviate from a random sampling scheme while investigating effects of specific variables.

17.1.3 Procedures to be followed upon failure to meet specifications or upon out of control conditions shall be specified. Included shall be reexamination criteria for suspect product and product rejection criteria.

17.1.4 Finished product marking, handling, protection, and shipping requirements as they relate to the performance of the finished product shall be defined.

17.2 *Inspection Personnel*—All manufacturing personnel responsible for quality control shall have knowledge of the inspection and test procedures used to control the process of the operation and calibration of the recording and test equipment used and of maintenance and interpretation of quality control records.

17.3 *Record Keeping*—All pertinent records shall be maintained on a current basis and be available for review. Records shall include:

17.3.1 Inspection reports and records of test equipment calibration, including identification of personnel conducting tests.

17.3.2 All test data, including re-testing and data associated with rejection, production, and corrective actions taken.

17.4 *Testing Equipment*—Testing equipment shall be properly maintained, calibrated and evaluated for accuracy and adequacy at a reasonable frequency.

17.5 *Retest and Rejection*—If the results of any selected quality tests do not meet the requirements and if agreed upon between the purchaser and the seller, the test(s) shall be conducted again in accordance with statistically valid sampling techniques. There shall be no agreement to lower the minimum requirements or omitting tests that form a part of this specification, substituting or modifying a test method or by changing the specification limits. In retesting, the product requirements of this specification shall be met. If upon retest, failure occurs, the quantity of product represented by the test(s) shall be rejected.

18. Packaging and Packing

18.1 The polymeric piling products shall be packaged in accordance with normal commercial practice and packed to assure acceptance by common carrier and to provide protection against damage during normal shipping, handling, and storage.

19. Keywords

19.1 axial load-bearing pile; composite; fender pile; lateral load-bearing pile; piles; polymeric

ANNEXES

(Mandatory Information)

A1. DERIVATION OF ALPHA AND BETA FACTORS

A1.1 The following method shall be used to calculate α and β based on short-term experimental data. This procedure is based on a Rutgers University thesis titled "Time Dependence of the Mechanical Properties of an Immiscible Polymer Blend" by Jennifer Lynch dated October 2002.

A1.1.1 Perform five constant strain rate tests at ε' = 3 %/min in accordance with Test Method D6109. Continue the test until 5 % strain or until rupture. Record all data at the same time interval for all tests. Determine the average values of load, deflection, stress, strain, and strain energy density ($SED = \sigma e$) for each time interval recorded. If the coefficient of variation at any time interval is greater than 8 % increase the number of specimens in accordance with subsection 3.4.2 of Practice D2915 until the coefficient of variation is less than 8 %. Fit fifth order polynomial regression curves for stress versus time and *SED* versus strain.

$$\sigma_{3\,\%}(t) = A_5\,t^5 + A_4\,t^4 + A_3\,t^3 + A_2\,t^2 + A_1\,t \qquad (A1.1)$$

$$SED_{3\,\%}(\varepsilon) = B_5\,\varepsilon^5 + B_4\,\varepsilon^4 + B_3\,\varepsilon^3 + B_2\,\varepsilon^2 + B_1\,\varepsilon \qquad (A1.2)$$

where:

A_x and B_x = regression constants for each curve.

A1.1.2 Repeat the procedure outlined in A1.1.1 for a strain rate of ε' = 0.03 %/min. Provide all test data and regression curves required by A1.1.1.

Discussion—It is permitted to use strain rates other than those recommended in A1.1.1 and A1.1.2 provided that the strain rate of A1.1.1 is approximately 100 times the strain rate of A1.1.2. For the remainder of this procedure $\varepsilon'_{3\,\%}$ and $\varepsilon'_{0.03\,\%}$ are left as variables to allow the use of alternate strain rates.

A1.1.3 Procedure for determining the rate relation exponent function m ($\sigma\,\varepsilon_{0.03\,\%}$):

A1.1.3.1 Select 30 *SED* values such that the interval between values is equal and the largest value is equal to the largest *SED* from the 0.03%/min strain rate test. Each *SED* value shall be calculated using the following equation:

$$SED_i = \left(SED_{\max,0.03\,\%}\right)\cdot i/30 \qquad (A1.3)$$

where:

i = 1 through 30.

A1.1.3.2 For both the 0.03 %/min test and the 3 %/min test determine the strain for each *SED* value calculated in A1.1.3.1 using Eq A1.2. Calculate stress ($\sigma = SED\ /\ \varepsilon$) and time ($t = \varepsilon\ /\ \varepsilon'$) for each *SED* value.

A1.1.3.3 For each *SED* value, determine a value of *m*, as given by the following equation:

$$m = \frac{\log\left(\dfrac{\varepsilon_{0.03\,\%}}{\varepsilon_{3\,\%}}\right)}{\log\left(\dfrac{\varepsilon'_{3\,\%}}{\varepsilon'_{0.03\,\%}}\right)} \qquad (A1.4)$$

A1.1.3.4 From the 30 calculated *m* values, fit a fifth order polynomial regression curve:

$$m\left(\sigma\,\varepsilon_{0.03\,\%}\right) = C_5\varepsilon_{0.03\,\%}{}^5 + C_4\varepsilon_{0.03\,\%}{}^4 + C_3\varepsilon_{0.03\,\%}{}^3 + C_2\varepsilon_{0.03\,\%}{}^2 + C_1\varepsilon_{0.03\,\%} \qquad (A1.5)$$

A1.1.4 Procedure for determining ten-year failure stress:

Discussion—Steps A1.1.4 and A1.1.5 are an iterative process. It is recommended that these steps are performed using mathematical computer software capable of performing numerical iterations.

A1.1.4.1 For each of the 30 *SED* values calculated in A1.1.3.1, calculate the predicted stress at ten years with the equation:

$$\sigma_{10} = \sigma_{0.03\%/\min} \cdot (\varepsilon'_{10}/\varepsilon'_{0.03\%})^{m(\sigma\ \varepsilon)} \quad (A1.6)$$

where:

$\sigma_{0.03\%/\min}$ = stress from 0.03 %/min test for a particular *SED* value,
ε'_{10} = ε_f / (5,256,000 min),
$m(\sigma\ \varepsilon)$ = m as a function of *SED* calculated in A1.1.3.4, and
ε_f = the lesser of 0.03 or the strain corresponding to the creep rupture strain, F_{cr} calculated in 11.5.

A1.1.4.2 For the 30 predicted stress values, fit a fifth order polynomial regression curve for stress versus strain:

$$\sigma_{(10)}(\varepsilon) = D_5\,\varepsilon^5 + D_4\,\varepsilon^4 + D_3\,\varepsilon^3 + D_2\,\varepsilon^2 + D_1\,\varepsilon \quad (A1.7)$$

where:

D_x = regression constants, and
ε = *SED* / σ_{10}.

A1.1.4.3 Calculate the failure stress at ten years by substituting ε_f into Eq A1.7:

$$\sigma_{f,10} = \sigma_{10}(\varepsilon_f) \quad (A1.8)$$

where:

ε_f = initial failure strain estimate, ε_{fi}, defined below for the first iteration and $\varepsilon_{f,c}$ as defined in A1.1.5.4 for all subsequent iterations.

$$\varepsilon_{fi} = (\varepsilon_f/2)\cdot(1+n_c) \quad (A1.9)$$

where:

ε_f = lesser of 0.03 or the strain corresponding to the creep rupture strain, F_{cr}, calculated in 11.5, and
n_c = initial estimate of the creep exponent = 0.05.

A1.1.5 Procedure for predicting creep:

A1.1.5.1 Equate the average stress of the 3%/min test with $\sigma_{f,10}$ calculated in A1.1.4.3 and solve for t_{r1} as follows:

$$\sigma_{3\%}(t_{r1})_{ave} = \frac{\int_0^{t_{r1}} \sigma_{3\%}(t)dt}{\int_0^{t_{r1}} dt} = \sigma_{f,10} \quad (A1.10)$$

where:

$\sigma_{3\%}(t)$ = as calculated in A1.1.1.

A1.1.5.2 Equate the average stress of the 0.03 %/min test with $\sigma_{f,10}$ calculated in A1.1.4.3 and solve for t_{r2} as follows:

$$\sigma_{0.03\%}(t_{r2})_{ave} = \frac{\int_0^{t_{r2}} \sigma_{0.03\%}(t)dt}{\int_0^{t_{r2}} dt} = \sigma_{f,10} \quad (A1.11)$$

where:

$\sigma_{0.03\%}(t)$ = as calculated in A1.1.2.

A1.1.5.3 Solve for the creep exponent n_c as follows:

$$n_c = \frac{\log\left(\frac{\varepsilon_{0.03\%}}{\varepsilon_{3\%}}\right)}{\log\left(\frac{t_{r1}}{t_{r2}}\right)} \quad (A1.12)$$

where:

$\varepsilon_{3\%}$ = $\varepsilon'_{3\%} \cdot t_{r1}$
$\varepsilon_{0.03\%}$ = $\varepsilon'_{0.03\%} \cdot t_{r2}$

A1.1.5.4 Recalculate ε_f to incorporate creep:

$$\varepsilon_{f,c} = (\varepsilon_f/2)\cdot(1+n_c) \quad (A1.13)$$

A1.1.5.5 Repeat A1.1.4 and A1.1.5 using $\varepsilon_{f,c}$ for ε_f until there is less than 1 % variation in $\sigma_{f,10}$ between iterations.

A1.1.6 Perform five creep tests in accordance with Test Methods D6112, at a constant stress equal to the final iterated value of $\sigma_{f,10}$ calculated above. Record all data at the same time interval for all creep tests. If the coefficient of variation at any time interval is greater than 8 %, increase the number of specimens in accordance with subsection 3.4.2 of Practice D2915 until the coefficient of variation is less than 8 %. Plot average strain versus time and perform a power regression to determine n_c:

$$\varepsilon(t) = Kt^{nc} \quad (A1.14)$$

A1.1.6.1 $n_{c,test}$ shall be within 5 % of $n_{c,predicted}$ calculated in A1.1.5.3. If the difference is greater than 5 %, recalculate $\varepsilon_{f,c}$ in A1.1.5.4 using $n_{c,test}$ and $\sigma_{f,10}$ in A1.1.4 with the recalculated $\varepsilon_{f,c}$. Repeat the creep test at a constant stress equal to the recalculated $\sigma_{f,10}$. This shall be repeated until $n_{c,test}$ is within 5 % of $n_{c,predicted}$.

A1.1.7 Calculate β:

$$\beta = \sigma_{f,10}/F_{bt} \quad (A1.15)$$

where:

F_{bt} = experimental flexural stress as described in 11.7.3, (psi), and
$\sigma_{f,10}$ = failure stress determined after sufficient iterations performed in accordance with A1.1.6.

A1.1.8 Calculate α:

$$\alpha = E/E_{10} \quad (A1.16)$$

where:

E = modulus of elasticity as described in 11.7.4 (psi), and
E_{10} = failure modulus calculated as follows:

$$E_{10} = \sigma_{f,10}/\varepsilon_{fc} \quad (A1.17)$$

where:

$\sigma_{f,10}$ = failure stress determined after sufficient iterations performed in accordance with A1.1.6, and
ε_{fc} = final iterated ten-year failure strain as determined in A1.1.6.

A2. DETERMINATION OF LOAD DURATION FACTOR C_D

A2.1 The following procedure shall be used to determine the load duration factor C_D. This procedure is only valid for load durations greater than or equal to three times the duration (from start to failure or 3 % strain) of the slow test described in A1.1. This procedure does not apply when creep does not have a significant impact on the failure of the member, which is the case in rapid loading. For durations less than three times the duration of the slow test, the value of C_D corresponding to the load duration of three times the slow test duration shall be used.

NOTE A2.1—The following procedure is an extension of the procedure presented in Annex A1. Completion of the Annex A1 procedure is required to determine C_D using the procedure presented below.

A2.1.1 Determine the duration of loading, recommended durations for typical load types are presented in Table X3.1.

A2.1.2 Determine the strain rate for the duration of loading:

$$\varepsilon'_t = \varepsilon_{f,c}/t \tag{A2.1}$$

where:

$\varepsilon_{f,c}$ = final iterated ten-year failure strain determined in A1.1.5.4, and
t = duration of loading.

A2.1.3 Procedure for determining *t*-year failure stress:

A2.1.3.1 For each of the 30 *SED* values calculated in A1.1.3.1, calculate the predicted stress at *t* years with the equation:

$$\sigma_t = \sigma_{0.03/\mathrm{min}} \cdot (\varepsilon'_t/\varepsilon'_{0.03\%})^{m(\sigma\ \varepsilon)} \tag{A2.2}$$

where:

$\sigma_{0.03/\mathrm{min}}$ = stress from 0.03 %/min test for a particular *SED* value,
ε'_t = $\varepsilon_{f,c}$ / (t min),
$m(\sigma\ \varepsilon)$ = m as a function of *SED* calculated in A1.1.3.4, and
ε_f = final iterated ten-year failure strain determined in A1.1.5.4.

A2.1.3.2 For the 30 predicted stress values, fit a fifth order polynomial regression curve for stress versus strain:

$$\sigma_t(\varepsilon) = D_5\,\varepsilon^5 + D_4\,\varepsilon^4 + D_3\,\varepsilon^3 + D_2\,\varepsilon^2 + D_1\,\varepsilon \tag{A2.3}$$

where:

D_x = regression constants, and
ε = *SED* / σ_t

A2.1.3.3 Calculate the failure stress at *t* years by substituting $\varepsilon_{f,c}$ into Eq A2.3:

$$\sigma_{f,t} = \sigma_t\,(\varepsilon_{f,c}) \tag{A2.4}$$

where:

$\varepsilon_{f,c}$ = as defined in A2.1.3.1.

A2.1.4 Determine C_D for the load duration *t*:

$$C_D = \sigma_{f,t}/\sigma_{f,10} \tag{A2.5}$$

where:

$\sigma_{f,10}$ = final iterated value determined in A1.1.8.

A3. DETERMINATION OF TEMPERATURE FACTOR C_T

A3.1 The following procedure shall be performed to determine the Temperature Factor for compression or flexure. This procedure shall be performed for all intended uses of the product, but need not be performed for both uses, that is, it is permitted to only perform the flexural tests if only the flexural temperature factor is required for the intended use. All specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability. Interpolation of temperature dependent properties is permissible provided that the interpolation is performed in accordance with 11.4.

A3.2 Conduct tests on a control group comprised of a minimum of 28 specimens at 23 ± 2°C (73.4 ± 4°F). The stress at 3 % strain or failure of the control group shall be averaged in order to establish the standard performance of the product.

A3.3 Conduct tests on experimental groups comprised of a minimum of five specimens at –10 ± 2°C (14 ± 4°F), and 50 ± 2°C (122 ± 4°F) in accordance with A3.2.

A3.4 If the coefficient of variation for any of the tests on experimental groups is greater than 8 %, then additional tests shall be performed to increase the sample size to that of a nonparametric approach for a 5 % lower tolerance limit with 75 % confidence in accordance with Practice D2915.

A3.5 Determine an experimental temperature factor, C_{Ti}, for each tested specimen such that:

$$C_{Ti} = F_i/F_{CTL} \tag{A3.1}$$

where:

F_i = stress at 3 % strain or failure, and
F_{CTL} = standard performance of the control group.

A3.6 Average the experimental temperature factors calculated in A3.5 for each temperature. Plot average temperature factor, C_T, versus temperature.

A3.7 Determine the best-fit polynomial equation for C_T versus temperature. The order of the polynomial shall be sufficiently high to characterize the C_T versus temperature curve.

A3.8 To determine C_T for a specific project substitute the maximum expected in service temperature into the equation determined in A3.7.

NOTE A3.1—The maximum in service temperature shall be determined from regional climate maps such as those published by the National Weather Service, by local experience of the design engineer, or by other temperature resources deemed acceptable by the design engineer.

APPENDIXES

(Nonmandatory Information)

X1. SAMPLE CALCULATION OF CREEP RELATED FACTORS

X1.1 Determine the creep factor, α, the stress time factor, β, and the load duration factor, C_D, for a two-month load duration based on the following data:

X1.1.1 Five tests performed at the constant strain rate of 0.8 %/min yield the average curves:

$$\sigma(t) = -2921.37\ t^5 + 13{,}073.0\ t^4 - 21{,}836.1\ t^3 + 14{,}693.3\ t^2 + 316.746\ t \quad (X1.1)$$

$$SED(\varepsilon) = 0\ \varepsilon^5 + 0\ \varepsilon^4 + 0\ \varepsilon^3 + 32{,}6805\ \varepsilon^2 - 319.319\ \varepsilon$$

where:

SED = strain energy density and equals σε.

X1.1.1.1 The minimum failure strain at this rate was 1.04 %.

X1.1.2 Five tests performed at the constant strain rate of 0.008%/min yield the average curves:

$$\sigma(t) = -2.14493E - 8\ t^5 + 1.3225E - 5\ t^4 - 0.002584\ t^3 + 0.062839\ t^2 + 34.4802\ t \quad (X1.2)$$

$$SED(\varepsilon) = 0\ \varepsilon^5 + 0\ \varepsilon^4 - 18{,}463{,}500\ \varepsilon^3 + 494{,}488\ \varepsilon^2 - 323.140\ \varepsilon$$

X1.1.2.1 The minimum failure strain at this rate was 1.42 % and the failure stress was 3080.36 psi.

X1.1.3 Five creep tests performed at a constant stress of 2200 lb yield the average curve:

$$\varepsilon = 0.0031\ t^{0.078618} \quad (X1.3)$$

NOTE X1.1—The numbers presented in this and following examples are shown with 6 significant figures. The analysis on which this data is based was conducted using computer software that calculated values and curve formulas with more than six significant figures. Therefore, users of this guide should not be dismayed if some variation exists, due to round off, between values they calculate while trying to follow the example and values presented here.

X1.2 Determine the rate relation exponent function: $m\ (\sigma\varepsilon)$:

X1.2.1 Thirty *SED* values, equally spaced between zero and the maximum measured *SED* value of 43.8662, are determined. Calculate the strain, stress, and time for each *SED* value for both strain rates as shown in Table X1.1.

X1.2.1.1 For example, the first set of slow strain rate data is calculated as follows:

$SED\ (\varepsilon) = 0\ \varepsilon^5 + 0\ \varepsilon^4 - 18463500\ \varepsilon^3 + 494488\ \varepsilon^2 - 323.140\ \varepsilon$
$1.46221 = 0\ \varepsilon^5 + 0\ \varepsilon^4 - 18463500\ \varepsilon^3 + 494488\ \varepsilon^2 - 323.140\ \varepsilon$
$\varepsilon = 0.002073$ in./in.
$\sigma = SED\ /\ \varepsilon$
$\sigma = 1.46221\ /\ 0.002073$
$\sigma = 705.421$ psi
$t = \varepsilon'\ /\ \varepsilon$
$t = 0.002073\ /\ 0.00008$
$t = 25.9102$ min

X1.2.2 For each *SED* value determined in Table X1.1, calculate the rate relaxation exponent, *m*, in accordance with Eq A1.4. For example:

$$m = \frac{\log\left(\frac{\varepsilon_{0.08\%}}{\varepsilon_{0.8\%}}\right)}{\log\left(\frac{\varepsilon'_{0.8\%}}{\varepsilon'_{0.08\%}}\right)} = \frac{\log\left(\frac{0.002073}{0.001557}\right)}{\log\left(\frac{0.008}{0.00008}\right)} = 0.062076 \quad (X1.4)$$

X1.2.3 Perform regression analysis on the *m* and corresponding slow test strain values determined in X1.2.2 and X1.2.1 respectively. The resulting fifth order polynomial for the *m* versus strain curve is:

$$m\ (\sigma\ \varepsilon_{0.008\%}) = 10{,}735{,}400{,}000\ \varepsilon_{0.008\%}{}^5 - 397{,}781{,}000\ \varepsilon_{0.008\%}{}^4 + 5{,}396{,}680\ \varepsilon_{0.008\%}{}^3 - 31{,}525\ \varepsilon_{0.008\%}{}^2 + 69.1211\ \varepsilon_{0.008\%} \quad (X1.5)$$

X1.3 Procedure for determining ten-year failure stress:

X1.3.1 Using each of the 30 *SED* values shown in X1.2.1, determine the predicted corresponding stress at ten years in accordance with Eq A1.6. For example:

$$\sigma_{10} = \sigma_{0.008\%}\cdot(\varepsilon'_{10}/\varepsilon'_{0.008\%})^m = 705.421\cdot(5.70776E - 9/0.00008)^{0.062076} = 389.980\ \text{psi} \quad (X1.6)$$

X1.3.2 Determine the predicted strains corresponding to the stresses calculated in the last section by dividing each *SED* by the corresponding predicted stress. For example:

$$\varepsilon = SED/\sigma_{10} = 1.46221/389.980 = 0.003749\ \text{in./in.} \quad (X1.7)$$

X1.3.2.1 Plot the calculated stress-strain points and perform a regression analysis. The resulting fifth order polynomial to the curve is:

$$\sigma_{10}(\varepsilon) = -2.22351E + 13\ \varepsilon^5 + 1.26983E + 12\varepsilon^4 - 25{,}804{,}100{,}000\ \varepsilon^3 + 206{,}094{,}000\ \varepsilon^2 - 292{,}349\ \varepsilon \quad (X1.8)$$

X1.3.3 The initial estimate of the failure stress at ten years can be determined from the above equation by substituting the

TABLE X1.1 Example *SED*, Strain, Stress, and Time Values

SED	Slow Strain Rate			Fast Strain Rate		
	Strain (in./in.)	Stress (psi)	Time (min)	Strain (in./in.)	Stress (psi)	Time (min)
1.46221	0.002073	705.421	25.9102	0.001557	938.858	0.194679
2.92441	0.002807	1041.84	35.0872	0.002363	1237.40	0.295420
4.38662	0.003391	1293.56	42.3889	0.002987	1468.34	0.373435
5.84882	0.003898	1500.41	48.7270	0.003515	1663.84	0.439406
7.31103	0.004356	1678.20	54.4557	0.003981	1836.42	0.497642
8.77324	0.004781	1834.94	59.7653	0.004403	1992.62	0.550358
10.2354	0.005181	1975.60	64.7617	0.004791	2136.39	0.598876
11.6976	0.005562	2103.32	69.5188	0.005153	2270.28	0.644064
13.1599	0.005927	2220.30	74.0881	0.005492	2396.17	0.686505
14.6221	0.006281	2328.17	78.5063	0.005814	2515.18	0.726691
16.0843	0.006624	2428.00	82.8060	0.006119	2628.42	0.764921
17.5465	0.006961	2520.82	87.0079	0.006412	2736.66	0.801456
19.0087	0.007291	2607.31	91.1316	0.006692	2840.49	0.836504
20.4709	0.007615	2688.06	95.1934	0.006962	2940.43	0.870233
21.9331	0.007937	2763.53	99.2078	0.007222	3036.87	0.902782
23.3953	0.008255	2834.05	103.18828	0.007474	3130.16	0.934268
24.8575	0.008572	2900.01	107.14387	0.007718	3220.59	0.964787
26.3197	0.008887	2961.58	111.08813	0.007955	3308.48	0.994402
27.7819	0.009202	3018.95	115.03119	0.008186	3393.87	1.02324
29.2441	0.009519	3072.29	118.98352	0.008411	3477.05	1.05133
30.7063	0.009837	3121.63	122.95802	0.008630	3558.19	1.07872
32.1685	0.010157	3167.13	126.96264	0.008844	3637.44	1.10547
33.6307	0.010481	3208.83	131.00868	0.009053	3714.91	1.13161
35.0929	0.010809	3246.60	135.11430	0.009258	3790.72	1.15720
36.5551	0.011143	3280.45	139.29187	0.009458	3864.97	1.18226
38.0174	0.011485	3310.07	143.56714	0.009655	3937.72	1.20683
39.4796	0.011836	3335.47	147.95333	0.009847	4009.15	1.23092
40.9418	0.012199	3356.29	152.48130	0.010037	4079.27	1.25457
42.4040	0.012575	3372.10	157.18659	0.010222	4148.11	1.27781
43.8662	0.012969	3382.30	162.11690	0.010405	4215.83	1.30064

appropriate strain. The initial estimate of the failure strain is calculated in accordance with Eq A1.9 as follows:

$\varepsilon_{f,i} = (\varepsilon_f/2)\cdot(1+n_c)$
$\varepsilon_{f,i} = (0.03/2)\cdot(1+0.05)$
$\varepsilon_{f,i} = 0.01575$ in./in.

X1.3.3.1 Substitute this value into the stress-strain equation calculated in X1.3.2 in accordance with Eq A1.8 as follows:

$\sigma_{f,10} = \sigma_{10}(\varepsilon_{f,i})$
$\sigma_{10}(0.01575) = -2.22351\,E{+}13\,(0.01575)^5 + 1.26983E{+}12\,(0.01575)^4 - 25{,}804{,}100{,}000\,(0.01575)^3 + 206{,}094{,}000\,(0.01575)^2 - 292349\,(0.01575)$
$\sigma_{f,10} = 2234.37$ psi

X1.4 Procedure for Predicting Creep:

X1.4.1 Equate the average stress of the fast test with the initial estimation of the ten-year failure stress, $\sigma_{f,10}$, calculated above as follows:

$$2234.37 = \frac{\int_0^{t_{r1}} -2921.37t^5+13{,}073.0t^4-21{,}836.1t^3+14{,}693.3t^2+316.746t}{\int_0^{t_{r1}} dt} \qquad \text{(X1.9)}$$

$$\sigma_{f,10} = \frac{\int_0^{t_{r1}} \sigma_{0.8\%}(t)\,dt}{\int_0^{t_{r1}} dt}$$

$$t_{r1} = 1.37095\text{min}$$

X1.4.1.1 Repeat this process for the slow test. The resulting time, t_{r2}, is 207.163 min.

X1.4.2 The strains corresponding to the times just calculated can be determined by multiplying the time by the strain rate. For example:

$$\varepsilon_{0.008\%} = \varepsilon'\cdot t_{r2} = 0.00008\cdot 207.163 = 0.016573\text{ in./in.} \qquad \text{(X1.10)}$$

X1.4.2.1 Substitute the time and strain values calculated above into Eq A1.12 to solve for the creep exponent as follows:

$$n_c = \frac{\log\left(\frac{\varepsilon_{0.008\%}}{\varepsilon_{0.8\%}}\right)}{\log\left(\frac{t_{r1}}{t_{r2}}\right)} = \frac{\log\left(\frac{0.016573}{0.010968}\right)}{\log\left(\frac{207.163}{1.37095}\right)} = 0.082270 \qquad \text{(X1.11)}$$

X1.4.3 Recalculate the expected failure strain in accordance with Eq A1.13:

$$\varepsilon_{fc} = \left(\frac{\varepsilon_f}{2}\right)\cdot(1+n_c) = \left(\frac{0.03}{2}\right)\cdot(1+0.082270) = 0.016234\text{ in./in.} \qquad \text{(X1.12)}$$

X1.5 Repeat the procedure outlined in A1.1.4 and A1.1.5 substituting ε_{fc} for ε_f. When the value of $\sigma_{f,10}$ has converged to a difference of less than 1 % between iterations, the value of the failure strain is 0.016235, the expected stress to cause failure in ten years is 2234.83 psi, and the value of n_c is 0.082322.

X1.6 Compare the calculated n_c to the value determined from testing performed in accordance with A1.1.6 as follows:

$$\frac{|0.082322 - 0.078618|}{0.082322} = 4.5\,\% \le 5.0\,\% \qquad \text{(X1.13)}$$

X1.6.1 Therefore, no new test is required.

X1.7 The stress time factor, β, to convert a short term test at a constant strain rate of 0.008%/min to a long term value is calculated in accordance with Eq A1.15 as follows:

$$\beta = \sigma_{f,10}/F_{bt} = 2234.83/3080.36 = 0.725509 \qquad (X1.14)$$

X1.8 Procedure to calculate the creep factor, α:

X1.8.1 Determine the modulus of elasticity in accordance with 11.7.4 as follows:

X1.8.1.1 The stress at failure for the slow test was 3080.36 psi. Therefore:

(a) 0.1 F_{bt} = 308.036 psi
(b) 0.4 F_{bt} = 1232.144 psi

X1.8.1.2 The corresponding strains, interpolated from measured data, are 0.1375 % and 0.386 % respectively.

X1.8.1.3 By principles of mechanics:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{1232.144 - 308.036}{0.00386 - 0.001375} = 371{,}874 \text{ psi} \qquad (X1.15)$$

X1.8.2 Calculate E_{10} in accordance with A1.1.8:

$$E_{10} = \frac{\sigma_{f10}}{\varepsilon_{fc}} = \frac{2234.83}{0.016235} = 137{,}655 \text{ psi} \qquad (X1.16)$$

X1.8.3 Determine α in accordance with Eq A1.16:

$$\alpha = \frac{E}{E_{10}} = \frac{371{,}874}{137{,}655} = 2.70149 \qquad (X1.17)$$

X1.9 Procedure to determine the load duration factor, C_D:

X1.9.1 Compute the strain rate in accordance with Eq A2.1:

$$\varepsilon'_t = \varepsilon_f/t = 0.016235/86{,}400\text{min} = 1.87905E - 7 \text{ in./in./min} \qquad (X1.18)$$

X1.9.2 For each of the 30 SED values determined in X1.2.1, calculate the predicted stress at the end of the duration of the load in accordance with Eq A2.2. For example:

$\sigma_t = \sigma_{0.03\%/\text{min}} \cdot (\varepsilon'_t / \varepsilon'_{0.03\%})^{m(\sigma\ \varepsilon)}$
$\sigma_t = 705.421 \cdot (1.87905E\text{-}7 / 0.00008)^{0.0062076}$
$\sigma_t = 484.4$ psi

X1.9.3 Determine the corresponding strains to the stresses calculated in the last section in the same manner as in X1.3.2. Plot the predicted stresses and strains at the end of the duration of the load. The fifth order polynomial regression curve for the plot is:

$$\sigma_{10}(\varepsilon) = -3.33664E+13\ \varepsilon^5 + 1.66225E+12\ \varepsilon^4 - 29{,}795{,}700{,}000\ \varepsilon^3 + 210{,}686{,}000\ \varepsilon^2 - 200861\ \varepsilon \qquad (X1.19)$$

X1.9.4 Determine the failure stress at the end of the load duration by substituting the ten-year failure strain into the equation calculated in X1.9.3:

$\sigma_{f,10} = \sigma_{10}(0.016235)$
$\sigma_{10} = -3.33664\ E+13\ (0.016235)^5 + 1.66225E+12\ (0.016235)^4 - 29{,}795{,}700{,}000\ (0.016235)^3 + 210{,}686{,}000\ (0.016235)^2 - 200861\ (0.016235)$
$\sigma_{f,10} = 2618.82$ psi

X1.9.5 Determine C_D for the duration in accordance with Eq A2.5:

$$C_D = \sigma_{f,t}/\sigma_{f,10} = 2618.82/2234.83 = 1.17 \qquad (X1.20)$$

X2. SAMPLE CALCULATION OF THE TEMPERATURE FACTOR

X2.1 Determine the Temperature Factor, C_T, for a flexural member to be used in New York City, given the following information:

X2.1.1 The maximum expected in service temperature for New York City is 38°C.

X2.1.2 The average stress at failure of 28 specimens tested at 23°C is 4811 psi.

X2.1.3 The stresses at failure of five specimens tested at –10°C and 50°C are:

Temperature (°C)	Stress at Failure (psi)				
–10	7949	7896	7678	7898	7919
50	2982	2982	3218	3102	3196

X2.2 Calculate Example Temperature Factors, C_{Ti}, in accordance with Eq A3.1. For example:

$$C_{Ti} = \frac{F_i}{F_{CTL}} = \frac{7948}{4811} = 1.652 \qquad (X2.1)$$

X2.2.1 The C_{Ti} values for both experimental groups are:

Temperature (°C)	C_{Ti}				
–10	1.652	1.641	1.596	1.642	1.646
50	0.620	0.620	0.669	0.645	0.664

X2.3 Average C_{Ti}'s by temperature and plot Temperature Factor versus Temperature. See Fig. X2.1.

X2.4 Calculate the best-fit polynomial to the curve of C_T versus temperature:

$$C_T = 0.0001 \cdot T^2 - 0.0206 \cdot T + 1.4196 \qquad (X2.2)$$

where:

T = maximum expected in service temperature (C).

X2.5 Substitute the maximum expected in service temperature for that location into the equation determined in X2.4:

$C_T = 0.0001 \cdot 38^2 - 0.0206 \cdot 38 + 1.4196$
$C_T = 0.7812$

X2.6 Example C_T's for other temperatures for the same material are shown in Table X2.1.

Temperature	Average C_T
−10	1.6353
50	0.6435

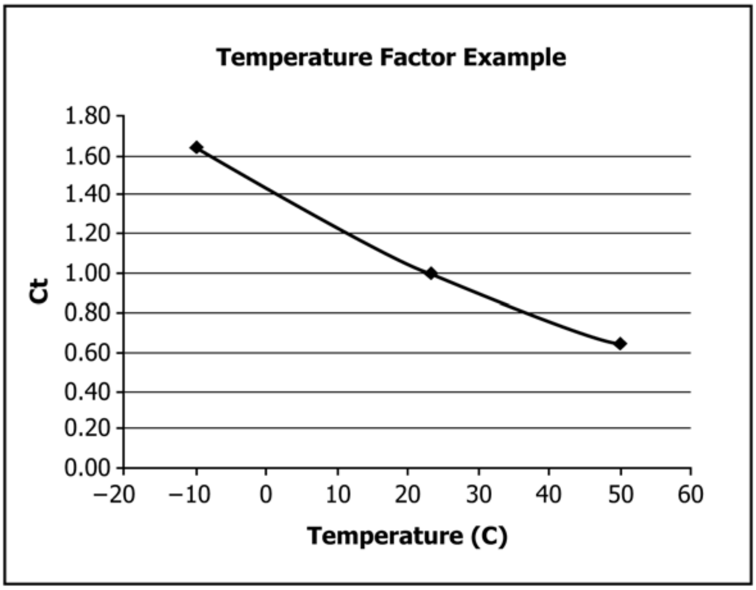


FIG. X2.1 Temperature Factor Example

TABLE X2.4 Temperature Factors for an Example Product

Temperature, °C (°F)	C_T
–10 (14)	1.64
0 (32)	1.42
15 (59)	1.13
23 (73.4)	1.00
50 (122)	0.64
60 (140)	0.54

X3. LOAD DURATION DATA FOR AN EXAMPLE PRODUCT

See Table X3.1 and Fig. X3.1.

TABLE X3.1 Load Duration Factors for Various Load Durations for an Example Product

Duration of Load	Load Duration Factor
Wind/ Seismic Load—10 min	2.12
1 h	1.28
Construction Load—7 days	1.20
Snow Load—2 months	1.17
1 year	1.10
Live Load—10 years	1.00
Permanent/ Dead Load—30 years	0.97

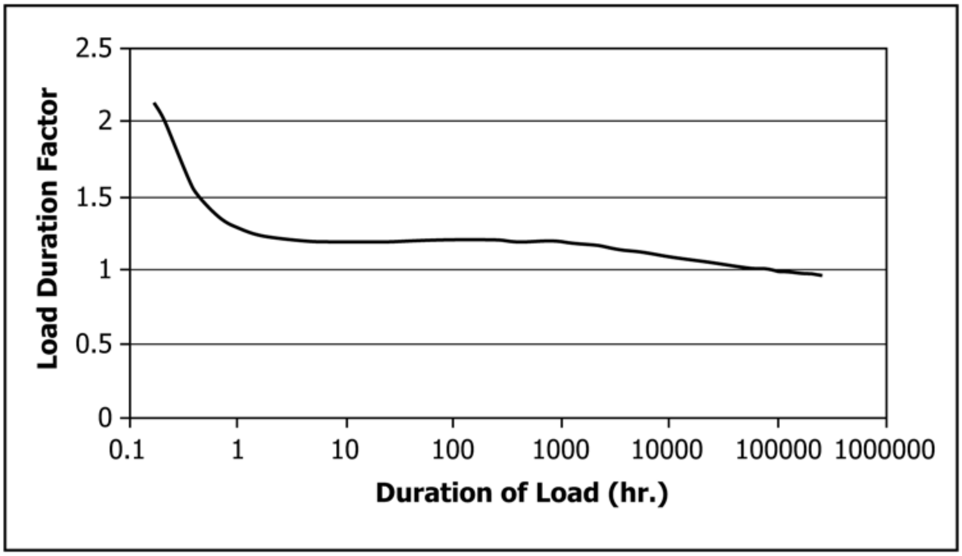


FIG. X3.1 Graph of Load Duration Factors for an Example Product

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D7258 – 14) that may impact the use of this standard. (March 1, 2017)

(1) Revised 11.16.3.

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