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Designation: ~~D7258 – 09~~ D7258 – 14

Standard Specification for Polymeric Piles[1]

This standard is issued under the fixed designation D7258; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. ~~Scope~~ 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

[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.
Current edition approved ~~Sept. 1, 2009~~Jan. 1, 2014. Published ~~September 2009~~January 2014. Originally approved in 2009. Last previous edition approved in 2009 as D7258 – 09. DOI: ~~10.1520/D7258-09.~~10.1520/D7258-14.

[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**

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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 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.

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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,

[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.

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:

$$b = 0.98a \quad (1)$$

where:

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

(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).

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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.

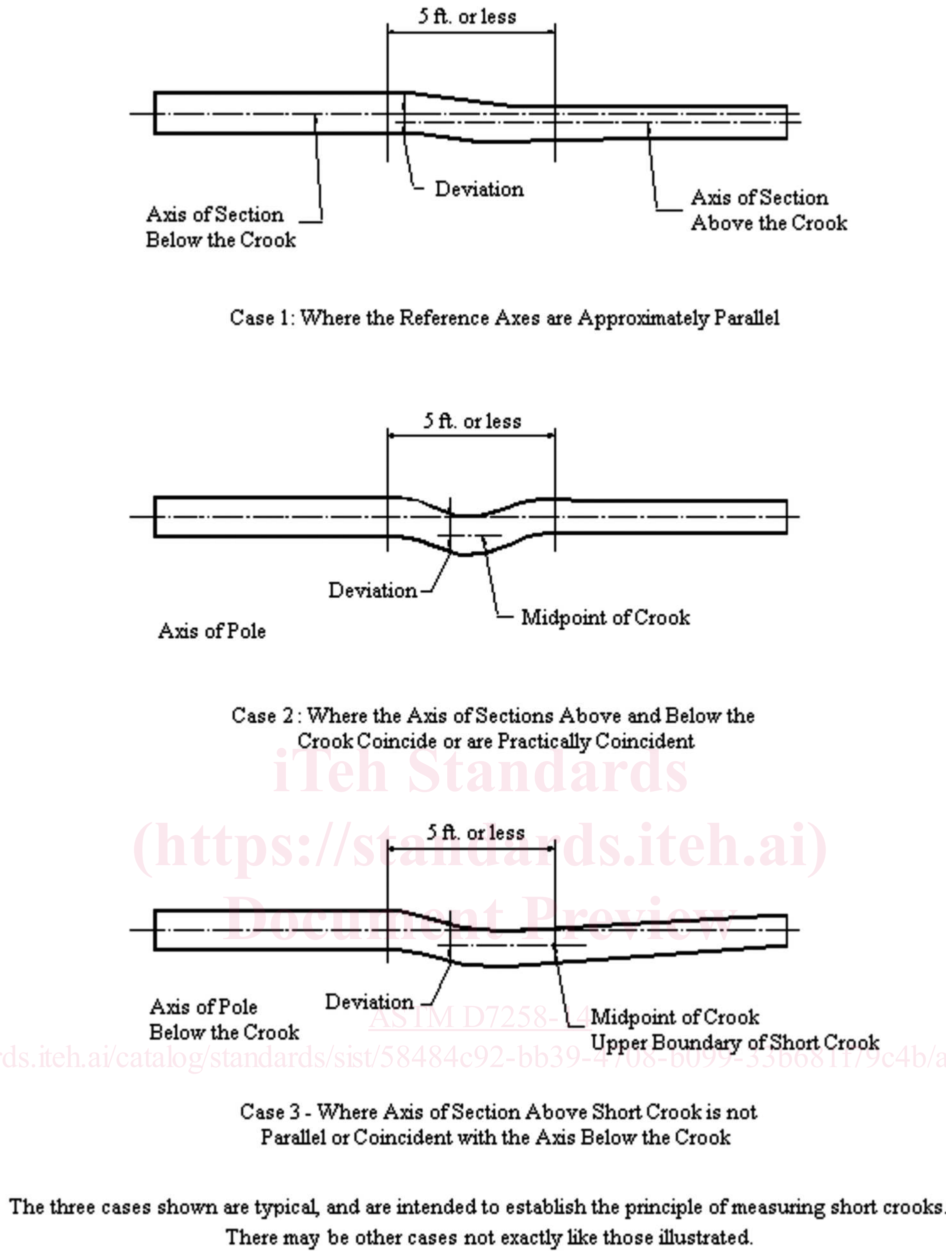

FIG. 1 Measurement of Short Crook N.T.S.

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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:

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

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.

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:

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

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:

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

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:

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

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 ($t \geq d$), round sections, or a beam with full lateral support. For all other beams:

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

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where:

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

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

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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.

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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:

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

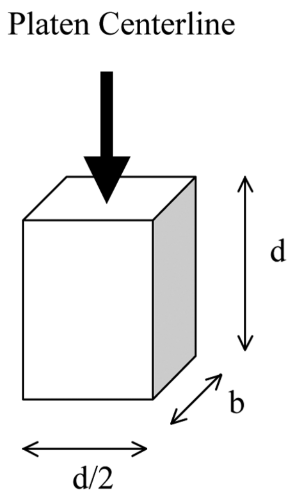

FIG. 2 Bearing Perpendicular to the Direction of Extrusion

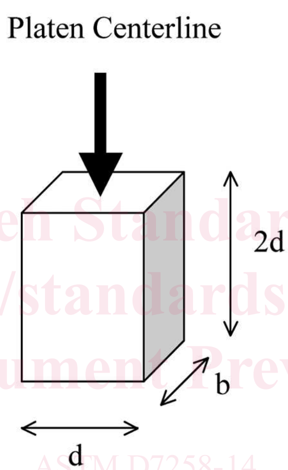

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FIG. 3 Bearing Parallel to the Direction of Extrusion

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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:

$$F_{C\perp} = F_{C\perp t} \cdot \beta \leq F_{cr} \quad (14)$$

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:

$$F_{C\|}' = \left(F_{C\|}/FS\right) \cdot C_T \quad (15)$$

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:

$$F_{C\|} = F_{C\|\,t} \cdot \beta \leq F_{cr} \quad (16)$$

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:

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

where:

V = design vessel velocity (in./s),

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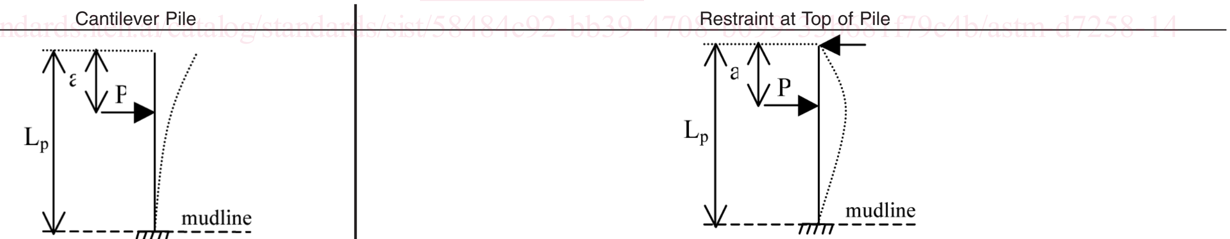

	All values of a	$a \leq 0.414L_P$	$a > 0.414L_P$
λ	$\frac{1.11}{(L_P - a)(2L_p + a)}$	$\frac{0.278 \cdot (a^2 - 3L_P^2)^2 \cdot (a + 2L_P)}{(a + L_P)^2 \cdot (L_P^2 - a^2) \cdot L_P^3}$	$\frac{0.556 \cdot (a + 2L_P)}{L_P^3 \cdot \sqrt{\frac{a}{a + 2L_P}}}$
ψ	$\frac{108 \cdot (L_P - a)^2 \cdot (2L_P +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

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:

$$P(\Delta_t) = A\Delta_t^3 + B\Delta_t^2 + C\Delta_t \quad (18)$$

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:

$$P(\Delta_p) = A\Delta_p^3 + B\Delta_p^2 + C\Delta_p \quad (19)$$

where:

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

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

where:

ψ = adjustment coefficient as defined in Fig. 4.

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

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

where:

Δ_f = deflection at defined failure strain calculated as:

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

where:

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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:

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$$\varepsilon_f \leq \varepsilon_r$$

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:

$$\text{Scale Factor} = C_{D,t_b} / C_{D,t_a} \quad (23)$$

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.