Designation: D 2899 – 03

Standard Practice for Establishing Allowable Stresses for Round Timber Piles[1]

1. Scope

1.1 This practice contains procedures for establishing allowable stresses for round timber piles starting with clear wood strength properties.

1.2 Stresses established under this practice are applicable to piles conforming to the quality, straightness, spiral grain, knot, check, shake, and split provisions of Specification D 25.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 25 Specification for Round Timber Piles

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber

D 2555 Test Methods for Establishing Clear Wood Strength Values

3. Terminology

3.1 *Definitions:*

3.1.1 *allowable stress*—the numeric value of pile strength that is appropriate for use in structural analysis.

3.1.2 *end-bearing*—compression-parallel-to-the-grain stress resulting when pile load is not carried to the soil through skin friction.

3.1.3 *load sharing*—the distribution of load in proportion to pile stiffness. This results in piles that perform as a group reducing effects of between-pile variability and increasing system reliability over that of piles which perform independently.

3.1.4 *skin friction*—the interaction between the pile surface and the soil which serves to distribute load either away from or into a pile. A positive skin friction refers to pile loads distributed to the soil. Negative skin friction distributes load to the pile when soil strata subside or consolidate.

3.2 *Symbols*:

C_{cp} = adjustment for small clear compression perp for annual ring orientation (1/1.67)

C_{ct} = conditioning factor

C_{dol} = adjustment for duration of load and factor of safety

C_d = adjustment for density applied for Douglas fir and Southern pine only

C_{fs} = combined adjustment for form and size (= 0.97)

C_g = adjustment for grade characteristics applied to all species including bending (0.75), compression (0.93), and shear (0.50)

C_h = adjustment for height in the tree (= 0.96 if softwoods and = 1.0 for hardwoods)

C_{hv} = adjustment for height and for reduced variability (*MOR* = 0.91 for softwoods, 1.05 for hardwoods, *C*// = 0.91 for softwoods, 1.05 for hardwoods, Shear = 0.99 for softwoods, 1.03 for hardwoods)

C_{ls} = load sharing adjustment (structural engineers option)

C_s = size adjustment

C_v = adjustment for shear deflection in calculation for bending modulus of elasticity (= 1.06)

D = diameter of a round timber pile

E = clear wood unseasoned average modulus of elasticity from Test Methods D 2555

MOE = modulus of elasticity (average)

F_β = allowable stress for stress designated by the subscript β

F_c = allowable compression stress for pile tips

f_{c05} = small clear lower 5 % exclusion compression strength in accordance with Test Methods D 2555

f_{i05} = lower 5 % exclusion value for stress "*x*" determined using the green, small clear strength and standard deviation values reported in Test Methods D 2555

β = stress value subscripts, *c* = compression parallel, *cp* = compression perpendicular, *b* = bending, *v* = shear

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[1] This practice is under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D07.04 on Pole and Pile Products.

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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.

4. Significance and Use

4.1 This practice is intended for use by associations, technical societies and other groups that develop national design standards and use recommendations for round timber piles.

4.2 In using allowable stresses established under this practice, factors specific to each end use which may affect the performance of the pile system shall be considered. Such factors include the location of the critical section, the bearing capacity of the soil, the ability of the pile to withstand driving forces and conditions of service.

PRINCIPLES INVOLVED IN ESTABLISHING ALLOWABLE STRESSES

5. Species

5.1 This practice applies to any species of piles for which clear wood strength values are given in Test Methods D 2555.

5.2 Where pile allowable stress is to be established for a combination of species and or regions, clear wood values assigned to such combinations are based on the grouping criteria given in Section 5 of Test Methods D 2555.

6. Clear Wood Properties

6.1 Information on average properties and their variation given in Test Methods D 2555 apply to small, clear, straight-grained wood in the green condition under short-term loading.

6.2 Round timber piles having minimum tip diameters of 5 in. or larger are considered by this practice to be comparable to sawn timbers: General adjustment factors used to establish allowable stress for such timbers under Practice D 245 also are applied to piles.

6.3 For the properties of bending strength (modulus of rupture), compression strength parallel to the grain and horizontal shear strength, clear-wood 5 % -exclusion values calculated from Test Methods D 2555 are divided by the adjustment factors given in Table 10 of Practice D 245 to obtain basic values for these properties from which pile allowable stress is established. The adjustment factors for the three strength properties include a reduction for normal duration of load and a factor of safety.

6.4 For the properties of modulus of elasticity and compression perpendicular to grain at 0.04-in. deformation, clear wood average values from Test Methods D 2555 are divided by the adjustment factors for these properties given in Table 10 of Practice D 245 to obtain basic values from which pile allowable stress for these properties also are established. The modulus of elasticity factor is a shear deflection adjustment. The compression perpendicular to grain factor is an adjustment to account for limiting ring position.

7. Pile Variability

7.1 Standard deviations given in Test Methods D 2555 and used to calculate 5 % exclusion values include both variability in properties between trees and variability in properties occurring within the cross section and along the length of an individual tree.

7.2 For round timber piles, only the between tree component of variance is applicable. Clear wood 5 % exclusion values applied to piles are adjusted to account for this reduced variability.

8. Minimum Tip and Critical Section Properties

8.1 Average clear wood properties given in Test Methods D 2555 represent volume weighted average whole tree values where the average property is that associated with material occurring between heights of 8 and 16 ft. For softwood species, clear wood strength properties generally decrease as the height location in the tree increases.

8.2 For compression parallel to grain, the minimum strength of the pile occurs at the pile tip, or at a minimum diameter of 5 in. For bending and shear strengths, the critical section of the pile is assumed to occur at a point 10 ft above the pile tip. In terms of location in the tree, both of these sections occur at heights in the tree which are appreciably greater than the heights associated with the whole tree average property values. Therefore clear wood average properties obtained from Test Methods D 2555 must be reduced to account for this height effect when establishing compression parallel to grain, bending, shear and modulus of elasticity design stresses for piles made with softwood species.

9. Density

9.1 Specification D 25 requires the outer 50 % of the radius at the pile tip to have an average rate of growth of at least 6 rings per inch and an average summerwood content of not less than 33.3 %. Piles with less than 6 rings per inch are acceptable if the average summerwood content in the outer 50 % of the pile tip radius is 50 % or more.

9.2 Practice D 245 provides for the classification of Douglas fir and southern pine sawn lumber meeting growth rate and summerwood content requirements similar to those in Specification D 25 as dense material. The properties of such lumber, except shear, are increased to account for the increased strength and stiffness associated with limiting the occurrence of low density material.

9.3 Increases for density applicable to Douglas fir and southern pine lumber also are applicable to piles of the same species. The increase for density in compression parallel to grain applicable to lumber must be adjusted when applied to piles to account for the inner core of the pile tip that is not required to meet the density provisions.

10. Form and Size

10.1 The average bending strength of round wood sections based on standard beam formulas is greater than that of matched rectangular sections. However, the section modulus of a round beam is less (1/1.18) than that of a square beam of equivalent area by approximately the same ratio as the strength of the round member is greater than that of the rectangular member. Round members therefore are assigned a unit strength equal to 1.18 times that based on rectangular sections when the section modulus of the circular cross section is used.

10.2 Clear wood bending stresses in Test Methods D 2555 are based on tests of 2-in. deep rectangular sections. Under

Practice D 245, such values are adjusted for depth (d) by the factor $(2/d)^{1/9}$ when applied to sawn lumber members. Based on a circular section having an area equal to that of a square section, the equivalent depth adjustment for a round member is $(2.2568/D)^{1/9}$.

10.3 Under standard practice, bending allowable stress for beams and stringers and post and timbers are given for a 12-in. beam depth. Values for beams exceeding 12 in. are reduced using the 1/9 power equation. The same practice is employed with round timber piles. Pile bending stresses are indexed to the diameter of a circular section having an area equal to that of a 12-in. square, or 13.5 in. Clear wood bending values are adjusted to a 13.5-in. pile diameter by the factor 0.82.

11. Grade

11.1 Knots in round piles reduce compression parallel to grain and bending strength properties. Limits on allowable size and spacing of knots along the pile length are given in Specification D 25.

11.2 The effect of knots on pile tip strength is determined from tests of full size pile sections containing various knot sizes. Regression analyses of compression strength against knot size and specific gravity establish the effect of allowable knots on compression parallel to grain strength.

11.3 The effect of allowable knots on pile bending strength is derived assuming load-carrying capacity is reduced by the ratio of the section modulus of a wedge section occupied by the knot to the section modulus of the total circular section. The combined interaction of clear wood strength, knot size and knot location along the pile length is assessed through random products simulation assuming (*1*) a rectangular distribution of strength ratio, (*2*) a normal clear wood distribution, and (*3*) linear induced moment in 2-ft length segments over a 10-ft cantilever beam length from the top of the pile to the critical section.

11.4 The effect of splits, checks, and shakes on pile shear strength is considered to be the same as that on the shear strength of sawn timber.

12. Duration of Load

12.1 Wood strength properties are affected by the duration of the maximum applied load: the shorter the duration the greater the maximum load that can be carried. Allowable stress for round timber piles established under this practice are short-term test values reduced to a normal load duration basis. Normal load duration represents application of a load that fully stresses a member to its design stress for a cumulative duration of approximately 10 years.

TABLE 1 Strength and Stiffness Adjustments for Density (*d*), Grade (*g*), and Combined Duration of Load and Factor of Safety (*dol*)

Stress Factor	Bending	Shear	Compression Parallel to grain	Compression Perpendicular to grain	MOE
C_d[A]	1.17	1.00	1.13	1.17	1.05
C_g	0.75	0.50	0.93	1.00	1.00
$C_{dol\text{-}Sftwd}$	1/2.1	1/2.1	1/1.9	1.00	1.00
$C_{dol\text{-}Hrdwd}$	1/2.3	1/2.3	1/2.1	1.00	1.00

[A] Density adjustments apply only to Douglas fir and southern pine.

12.2 When the cumulative duration of the full maximum load is less than or more than ten years, pile allowable stress for bending, compression parallel to grain and horizontal shear shall be modified in accordance with the duration of load adjustments shown in Fig. 6 of Practice D 245. Load duration adjustments greater than 1.6 shall not apply to piles preservatively treated with water-borne salts.

12.3 Duration of load adjustments are not applied to pile allowable stress for modulus of elasticity and compression perpendicular to grain based on a deformation limit.

13. Moisture Content

13.1 Allowable stress established by this practice applies to piles that are continuously wet or are continuously exposed to the weather.

13.2 No increase in properties for material that is partially above ground and may be partially seasoned is recognized.

14. Preservative Treatment

14.1 Preservative treatment by approved processes and chemicals does not significantly affect allowable stress values for round timber piles established in this practice.

14.2 Conditioning of piles by kiln drying, steaming or boiling in liquids prior to pressure treatment to facilitate penetration of preservative chemicals does affect strength properties. Reduction of allowable stress (Table 2) to account for such effects are based on compression parallel to grain tests of end-matched conditioned and unconditioned full-size pile sections.

TABLE 2 Conditioning Effects on the Strength of Round Timber

Conditioning	Air Drying	Kiln Drying	Boulton Drying	Steaming (Normal)	Steaming (Marine)
C_{ct}	1.0	0.90	0.95	0.80	0.74

14.3 No adjustments are made for conditioning prior to treatment of allowable stress for modulus of elasticity (E) and compression perpendicular to grain at 0.04-in. deformation (F_{cp}).

DERIVATION OF ALLOWABLE STRESS FOR UNTREATED PILES

15. Compression Parallel to Grain

15.1 Calculate compression allowable stress for pile tips using the following equation:

$$F_c = (f_{c05}C_{dol})[C_{hv}][C_d][C_g] \quad (1)$$

15.2 Where the critical section in compression parallel to grain is located above the pile tip as a result of skin friction from the soil through which the pile is driven, or equivalent other effect; F½ c for softwood species may be increased by the following adjustment:

$$P = 0.4(L) \leq 9.0 \quad (2)$$

where:

P = percentage increase in pile compression strength, softwoods only, and

L = distance from pile tip to critical section, ft.

16. Extreme Fiber in Bending

16.1 Calculate extreme fiber in bending allowable stress using the following equation:

$$F_b = f_{b05} \times C_{dol} \times C_{hv} \times C_d \times C_{fs} \times C_g \quad (3)$$

16.2 When the diameter of the pile 10 ft above the pile tip (D) exceeds 13.5 in., the extreme fiber in bending allowable stress shall be adjusted by the following size factor, C_s:

$$C_s = (13.5/D)^{1/9} \quad (4)$$

17. Horizontal Shear

17.1 Calculate horizontal shear allowable stress using the following equation:

$$F_v = f_{v05} \times C_{dol} \times C_{hv} \times C_g \quad (5)$$

18. Modulus of Elasticity

18.1 Calculate modulus of elasticity allowable stress using the following equation:

$$MOE = E \times C_v \times C_h \times C_d \quad (6)$$

19. Compression Perpendicular to Grain

19.1 Calculate compression perpendicular to grain allowable stress at a 0.04-in. deformation limit using the following equation:

$$F_{cp} = f_{cp} \times C_{cp} \times C_d \quad (7)$$

ADDITIONAL ADJUSTMENT FACTORS

20. Load Sharing

20.1 Round timber piles are commonly connected by reinforced concrete caps or equivalent load distributive elements such that the pile cluster deforms as a single member under axial or bending load. The load-carrying capacity of these pile clusters is greater than the sum of the individual pile capacities as a result of load sharing.

20.2 The increase in the load-carrying capacity of piles acting as a group is established through random products simulation assuming clear wood strength is normally distributed and knot strength ratios are rectangularly distributed. The 5th percentile average strength of a pile cluster is compared to the 5th percentile strength of a single pile to quantify the effect of the interaction. As load sharing is a function of differences in relative stiffness, the actual increase in load-carrying capacity of a pile cluster is dependent on the variation in individual pile strength values that is accounted for by pile modulus of elasticity.

20.3 Coefficient of determination (r^2) values for strength versus modulus of elasticity regressions are obtained from tests of full-size piles. Conservative increases for load sharing are established by multiplying ratios of 5th percentile average strength of pile clusters to 5th percentile strength of a single pile by the factor $r^2/2$.

20.4 Compression parallel to grain (F_c) and bending (F_b) allowable stress for a pile cluster connected by a concrete cap or equivalent load distributive element such that the pile cluster deforms as a single member under load may be increased by the following factors (C_{ls}):

Allowable Stress	Number of Piles in Cluster	C_{ls}	
		Softwoods	Hardwoods
F_c	2	1.06	1.00
	3	1.09	1.00
	4 or more	1.11	1.00
F_b	2	1.05	1.05
	3	1.07	1.07
	4 or more	1.08	1.08

21. Rounding

21.1 Pile allowable stress shall be rounded after all adjustments have been made in accordance with the following increments:

F_c, F_b	nearest 50 psi for values ≥ 1000 psi
	nearest 25 psi for values < 1000 psi
F_v, F_{cp}	nearest 5 psi
E	nearest 100 000 psi

21.2 The rounding rules of Practice E 380 shall be followed.

DESIGN CONSIDERATIONS

22. Pile Circumference and Diameter

22.1 The minimum pile butt and tip circumferences (diameters) given in Specification D 25 shall be used with allowable stress established by this practice to determine load-carrying capacities and stiffnesses. The actual pile may be larger than the minimum circumferences at every point along the length of the pile.

23. Responsibility of Designer

23.1 It is the sole responsibility of the design engineer to relate allowable stress to design assumptions, and to determine the appropriateness of allowable stress adjustments for the specific conditions of end use.

24. Keywords

24.1 design; piles; stresses; timber

APPENDIX

(Nonmandatory Information)

X1. EXAMPLES OF DEVELOPMENT OF ALLOWABLE STRESSES

NOTE X1.1—F_i, *MOE* = Allowable values for untreated, single piles. F_i = Allowable stress adjusted for conditioning and load sharing.

X1.1 *Single Species*: Coast Douglas fir

Conditioning: Boulton
Cluster: three

X1.1.1 *Stress Values*:

	D 2555 Table 1, Section 5.2			
Property	Average	V.I.	S.D.	5 % E.V.
Compression parallel	3784	1.05	734	1577
Modulus of rupture	7665	1.05	1317	5499
Horizontal shear	904	1.03	131	689
Modulus of elasticity	1560			
Compression	700			

X1.1.2
$F_c = f_{c05}[C_{hv}][C_d]C_g]$
= 2577[1/1.9]
= 1297
$F'_c = F_c[C_{ls}]$
= 1297[0.95]
= 1343 ι 1350 psi

X1.1.3
$F_b = f_{b05}[C_{hv}][C_d][C_{fs}][C_g]$
= 5499[1/2.1]
= 2184
$F'_b = F_b[C_{1s}]$
= 2184[0.95]
= 2220 ι 2200 psi

X1.1.4
$F_v = f_{v05}[C_{hv}][C_g]$
= 689[1/2.1]
= 162
$F'_v = F_v[C_{1s}]$
= 162[0.95]
= 155 ι 155 psi

X1.1.5
$MOE = E\ [C_v][C_h][C_d]$
= 1560[1.06]
= 1673 ι 1 700 000 psi

X1.1.6
$F_{cp} = F'_{cp} = f_{cp}[C_d]$
= 700[1/1.67]
= 490 psi

X1.2 *Species Group*: southern pine (timber volumes available)

	% vol. (D 2555 Table 4)
Loblolly pine (LOBL)	0.507
Shortleaf pine (SHOR)	0.300
Longleaf pine (LONG)	0.101
Slash pine (SLAS)	0.092

Conditioning: steaming, normal
Cluster: three

X1.2.1 S_i *Values*:

		D 2555 Table 1, Section 5.2.2				
Property	Species	Average	V.I.	S.D.	5 % E.V.	CDF
Compression parallel	LOBL	3511	1.09	612	2504	0.95
	SHOR	3527	1.05	564	2599	1.28
	LONG	4321	1.07	707	3158	1.98
	SLAS	3823	1.07	547	2923	1.71
Combination, 5.2.2.2 note 8					A = 2637	
Adj. For CDF < 1.18: (3511/1.09) - 1.18 (612)					= 2499	
Modulus of rupture	LOBL	7300	1.08	1199	5328	0.94
	SHOR	7435	1.04	1167	5515	1.30
	LONG	8538	1.07	1305	6391	1.80
	SLAS	8692	1.09	1127	6838	2.08
Combination, 5.2.2.2 note 8					A = 5630	
Adj. For CDF < 1.18 (7300/1.08) - 1.18 (1199)					= 5344	
Horizontal shear	LOBL	863	1.05	112	679	1.02
	SHOR	905	1.05	125	699	1.23
	LONG	1041	1.05	120	844	2.36
	SLAS	964	1.05	128	753	1.64
Combination, 5.2.2.2 note 8					708	
Adj. For CDF < 1.18 (863/1.05) - 1.18 (112)					690	

		D 2555 Table 1, Section 5.2		
Property	Species	Average	V.I.	(Ratio, A/spec. av./V.I.)
Modulus of elasticity	LOBL	1402	1.08	1.10
	SHOR	1388	1.04	1.07
	LONG	1586	1.07	0.96
	SLAS	1532	1.08	1.01
Combination, 5.2.1 A =		1428		required <1.16
Compression perpendicular	LOBL	661	1.00	1.01
	SHOR	573	1.00	1.17
	LONG	804	1.00	0.83
	SLAS	883	1.00	0.76
Combination, 5.2.2 A =		670		required ≤1.10
Adj. For ratio >1.10		630 = 573(1.10)		

X1.2.2
$F_c = f_{c05}[C_{hv}][C_d]C_g]$
= 2499[1/1.9]
= 1258
$F'_c = F_c[C_{1s}]$
= 1258 [0.85]
= 1165 ι 1160 psi

X1.2.3
$F_b = f_{b05}[C_{hv}][C_d][C_{fs}][C_g]$
= 5344[1/2.1]
= 2123

$F'_b = F_b[C_{1s}]$
$= 2123[0.80]$
$= 1817$ ι 1800 psi

X1.2.4

$F_v = f_{v05}[C_{hv}][C_g]$
$= 690[1/2.1]$
$= 163$

$F'_v = F_v[C_{1s}]$
$= 163[0.80]$
$= 130$ psi

X1.2.5

$MOE = E\ [C_v][C_h][C_d]$
$= 1428[1.06]$
$= 1531$ ι $1\ 500\ 000$ psi

X1.2.6

$F_{cp} = F'_{cp} = f_{cp}[C_d]$
$= 630[1/1.67]$
$= 441$ ι 440 psi

X1.3 *Species Group*: red oak (no timber volumes available)

northern red oak (NRO)
southern red oak (SRO)
Conditioning: Boulton
Cluster: three

X1.3.1 S_i *Values*:

D 2555 Table 2, Section 513

Property	Species	Average	S.D.	5 % E.V.
Compression parallel	NRO	3440	619	2422
	SRO	3030	545	2133
Modulus of rupture	NRO	8300	1328	6115
	SRO	6920	1107	5099
Horizontal shear	NRO	1214	170	934
	SRO	934	131	719
Modulus of elasticity	NRO	1353		
	SRO	1141		
Compression perpendicular	NRO	987		
	SRO	912		

X1.3.2

$F_c = f_{c05}[C_{hv}][C_d]C_g]$
$= 2133[1/2.1]$
$= 992$

$F'_c = F_c[C_{1s}]$
$= 992\ [0.95]$
$= 942$ ι 950 psi

X1.3.3

$F_b = f_{b05}[C_{hv}][C_d][C_{fs}][C_g]$
$= 6099[1/2.3]$
$= 1693$

$F'_b = F_b[C_{1s}]$
$= 1693[0.95]$
$= 1721$ ι 1700 psi

X1.3.4

$F_v = f_{v05}[C_{hv}][C_g]$
$= 719[1/2.3]$
$= 161$

$F'_v = F_v[C_{1s}]$
$= 161[0.95]$
$= 153$ ι 155 psi

X1.3.5

$MOE = E\ [C_v][C_h][C_d]$
$= 1141[1.06]$
$= 1214$ ι 1200 ksi

X1.3.6

$F_{cp} = F'_{cp} = f_{cp}[C_d]$
$= 912[1/1.67]$
$= 546$ ι 545 psi