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Standard Specification for Computing Reference Resistance of Wood-Based Materials and Structural Connections for Load and Resistance Factor Design[1]

This standard is issued under the fixed designation D5457; 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.

INTRODUCTION

Load and resistance factor design (LRFD) is a structural design method that uses concepts from reliability theory and incorporates them into a procedure usable by the design community. The basic design equation requires establishing a reference resistance based on several material property parameters. A standard method for calculating the required material property input data is critical so that all wood-based structural materials can be treated equitably. This specification provides the format conversion procedure that is required for the generation of reference resistance for LRFD. A non-mandatory appendix of this specification provides broad guidance for users who wish to pursue the test-based approach for the generation of reference resistance for LRFD.

1. Scope

1.1 This specification covers the format conversion procedure for computing the reference resistance of wood-based materials and structural connections for use in load and resistance factor design (LRFD). The format conversion procedure is outlined in Section 4. The reference resistance derived from this specification applies to the design of structures addressed by the load combinations in ASCE 7-16.

1.2 A commentary to this specification is provided in Appendix X1.

1.3 Guidance for users considering test-based derivation of reference resistance is provided in Appendix X2.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D9 Terminology Relating to Wood and Wood-Based Products
D143 Test Methods for Small Clear Specimens of Timber
D198 Test Methods of Static Tests of Lumber in Structural Sizes
D1037 Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials
D1761 Test Methods for Mechanical Fasteners in Wood and Wood-Based Materials
D1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens
D2718 Test Methods for Structural Panels in Planar Shear (Rolling Shear)
D2719 Test Methods for Wood Structural Panels in Shear Through-the-Thickness
D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products
D3043 Test Methods for Structural Panels in Flexure
D3500 Test Methods for Wood Structural Panels in Tension
D3501 Test Methods for Wood-Based Structural Panels in Compression
D3737 Practice for Establishing Allowable Properties for

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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.

Structural Glued Laminated Timber (Glulam)
D4761 Test Methods for Mechanical Properties of Lumber and Wood-Based Structural Materials
D5055 Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists
D5456 Specification for Evaluation of Structural Composite Lumber Products
E105 Guide for Probability Sampling of Materials
2.2 *ASCE Standard:*[3]
ASCE 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures

3. Terminology

3.1 *Definitions:*

3.1.1 For general definitions of terms related to wood, refer to Terminology D9.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *ASD reference design value, F_x*—the design value at reference conditions used in allowable stress design (ASD) prior to application of the load duration factor (C_D).

3.2.2 *coefficient of variation, CV_w*—the standard deviation divided by the mean of a 2-parameter Weibull distribution.

3.2.2.1 *Discussion*—Coefficient of variation, CV_w, can be calculated three ways: the traditional method of moments; method of maximum likelihood; and method of least squares. The method of moments calculates the mean and standard deviation directly from the data of a complete data set. The methods of maximum likelihood and least squares calculate the Weibull parameters from complete or incomplete data sets. An incomplete data set includes suspended data (for example, data from proof loading.) Mean and standard deviation (and CV_w) are then calculated from the Weibull parameters.

3.2.3 *factored resistance*—the product of the resistance factor (ϕ) and the reference or nominal resistance (R_n).

3.2.4 *format conversion factor, K_F*—a factor applied to convert resistance from the allowable stress design (ASD) format to the LRFD format, equal to the ratio R_n/F_x.

3.2.5 *lower tail*—a portion of an ordered data set consisting of all test specimens with the lowest property values (for example, lowest strengths).

3.2.6 *nominal resistance*—a term equivalent to the reference resistance used in reliability analysis and LRFD standards.

3.2.7 *reference conditions*—the design basis for which all applicable adjustment factors are equal to unity, except for the load duration factor in ASD or the time effect factor in LRFD.

3.2.8 *reference resistance, R_n*—the design value at reference conditions used in LRFD to represent member resistance prior to application of the resistance factor (ϕ) and the time effect factor (λ).

3.2.8.1 *Discussion*—The reference value represents member resistance at 10-minute load duration.

3.2.9 *reliability normalization factor, K_R*—a factor used to establish the reference resistance (R_n) to achieve a target reliability index for a specific set of conditions.

3.2.10 *resistance factor, ϕ*—a factor applied to the resistance side of the LRFD equation.

4. Reference Resistance for LRFD

4.1 Reference resistance for LRFD shall be determined using the format conversion procedure per 4.2.

NOTE 1—Appendix X2 discusses considerations that should be addressed by users considering test-based approaches for the generation of reference resistance for LRFD. Appendix X5 provides discussion of alternative methods to determine reference resistance for LRFD.

4.2 *Format Conversion Procedure:*

4.2.1 Resistance values for LRFD shall be based on format conversion from code-recognized allowable stress design (ASD). It shall not be claimed that reference resistance values generated in this manner achieve a stated reliability index. Resistance factors for determining LRFD factored resistance, ϕR_n, are given in Table 1.

NOTE 2—Examples of standards that are used to generate code-recognized ASD values include Test Methods D143, D198, D1037, D1761, D2718, D2719, D3043, D3500, D3501, and D4761; Practices D1990 and D3737; and Specifications D5055 and D5456.

4.2.2 For standardization purposes, format conversion reference resistance values shall be based on the arithmetic conversion for a specific design case that results from the calibration of basic ASD and LRFD equations. Here, the calibration means providing an identical required section modulus, cross-sectional area, allowable load capacity, and so forth. The specific design case was chosen such that changes in design capacity over the range of expected load cases and load ratios were minimized.

4.2.3 Values of the format conversion factor, K_F, are given in Table 2.

4.2.4 The format conversion reference resistance is computed by multiplying the ASD resistance by K_F. For members and connections, the ASD resistance is based on a normal (10-year) load duration. For shear walls and diaphragms, the ASD resistance is based on a 10-min load duration.

4.2.5 For lateral buckling (stability), compression perpendicular to grain, and rolling shear that is not subject to load duration or time effect adjustments, the value of K_F is based on the assumption that neither the ASD nor LRFD resistance values are modified by duration of load or time effect adjustments.

4.2.6 *Format Conversion Example*—An ASD bolt design value for a single shear connection, F_x, is 800 lbf (3.56 kN) (based on normal 10-year load duration). From Table 2, the

TABLE 1 Specified LRFD Resistance Factors, ϕ_s

Application	Property	ϕ_s
Members	compression[A]	0.90
	bending, lateral buckling (stability)	0.85
	tension parallel	0.80
	shear, radial tension	0.75
Connections	all	0.65
Shear Walls, diaphragms	shear (wind)	0.80
	shear (seismic)	0.50

[A] Compression parallel-to-grain, compression perpendicular-to-grain, and bearing.

[3] Available from The American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191.

TABLE 2 Format Conversion Factor, K_F

Property	K_F
Compression Parallel to Grain	2.40
Bending	2.54
Tension Parallel to Grain	2.70
Shear	2.88[A]
Radial Tension	2.88
Connections	3.32
Lateral Buckling (Stability)	1.76
Compression Perpendicular to Grain	1.67
Shear Wall and Diaphragm Shear (wind)	2.00[B]
Shear Wall and Diaphragm Shear (seismic)	2.80[B]

[A] The value of the format conversion factor is 2.00 where shear is not subject to load duration or time effect adjustments (for example, rolling shear in cross-laminated timber).

[B] The format conversion factor for shear wall and diaphragm shear is only intended to be applied to the design capacity of shear wall or diaphragm assemblies, not to the design of individual members or subcomponents of these assemblies.

format conversion factor, K_F, is 3.32. The corresponding LRFD bolt reference resistance value is as follows:

$$R_n = (K_F)(F_x) = (3.32)(800) = 2658 \text{ lbf } (11.82 \text{ kN}) \quad (1)$$

4.2.7 *Format Conversion Example for Shear Walls and Diaphragms*—An ASD shear wall design value, F_x, is 350 lb/ft (5.11 kN/m) for seismic design, and 490 lb/ft (7.15 kN/m) for wind design. From Table 2, the format conversion factor, K_F, is 2.8 for seismic design and 2.0 for wind design. The corresponding LRFD shear wall reference resistance values for seismic and wind are as follows:

For seismic:

$$R_n = (K_F)(F_x) = (2.8)(350) = 980 \text{ lb/ft } (14.30 \text{ kN/m}) \quad (2)$$

For wind:

$$R_n = (K_F)(F_x) = (2.0)(490) = 980 \text{ lb/ft } (14.30 \text{ kN/m}) \quad (3)$$

5. Keywords

5.1 format conversion; load and resistance factor design (LRFD); reference resistance; structural connections; test-based derivation; wood-based materials

APPENDIXES

(Nonmandatory Information)

X1. COMMENTARY TO THE TEXT

X1.1 *Commentary to the Introduction*:

X1.1.1 Load and resistance factor design (LRFD) is a design format. LRFD is a subset of a broader design methodology known as reliability-based design (RBD). The distinction between the two design procedures is significant. RBD implies, and often calculates, quantities related to the reliability of a member under a given set of conditions. A higher reliability corresponds to a lower probability of failure. One practical concern that arises when one attempts to apply RBD to real structural applications is that the calculations must idealize both the loads and the structural system response to reduce it to a mathematically tractable problem. This idealization process reduces the final calculation to a theoretically interesting, but often inapplicable, number. LRFD was developed by selecting a few of the basic concepts of RBD and using them to develop a format that is similar in many ways to allowable stress design.

X1.1.2 Previous standards for developing allowable properties for many types of wood-based products directed the user to various ways of computing a population lower fifth-percentile estimate. This single number was the basis for an allowable strength property assignment. At the other extreme, a realistic RBD would require an accurate definition of a large portion of the lower tail of the material distribution and a large portion of the upper tail of the load distribution. LRFD requires somewhat more information than current procedures (for example, reference values and variability) but substantially less than RBD. In the most advanced LRFD procedures, one needs only a distribution type and the parameters that describe that distribution. Refinements of these procedures suggest that estimates of the distribution and its parameters give the most accurate reliability estimates when they represent a tail portion of the distribution rather than the full distribution. This reflects the fact that, for common building applications, only the lower tail of the resistance and upper tail of the load distribution contribute to failure probabilities.

X1.2 *Commentary to Section 1, Scope*—Format conversion per 4.2 is the standard method for determination of reference resistance for LRFD. The test-based approach per Appendix X2 provides broad guidance for users who wish to pursue the test-based approach for the generation of reference resistance for LRFD. Due to the sensitivity of reliability to changes in some of the parameters, these procedures offer a limited set of options to ensure that LRFD reference resistances are generated in a consistent manner. Other methods for computing reference resistance that are beyond the scope of this standard are discussed in Appendix X5.

X1.3 *Commentary to Section 3, Terminology*:

X1.3.1 The term "factored resistance" is specifically defined as the product of the resistance factor (ϕ) and the nominal resistance (R_n) to differentiate it from the nominal (reference) resistance. Users are cautioned to include all applicable adjustment factors when determining the LRFD adjusted design value.

X1.3.2 The term "nominal resistance" is the most widely used term in reliability analysis and material specifications. As described in Ref (**1**),[4] users are cautioned that the term "nominal" has been defined in various ways over the years. This standard focuses on the term "reference resistance," used in the NDS.

X1.3.3 The term "reference conditions" is added to clarify that the design checking equations presented in this specification do not include notations for the myriad of potential end-use adjustment factors that might be applicable to specific designs. The rationale is that all end-use adjustment factors, with the notable exceptions of the load duration factor in ASD and the time effect factors in LRFD, are identical in both design formats and will mathematically cancel in the calculation of the ratio R_n / F_x. Users are cautioned to include all applicable adjustment factors when determining the LRFD adjusted design value.

X1.3.4 The term "reference resistance" is retained as the primary terminology in this version of the standard for continued compatibility with the NDS (**2**) and other design documents, but its definition is clarified to indicate that it does not include the resistance factor (ϕ), the time-effect factor (λ) and other adjustments for end-use conditions that will be subsequently applied in the design checking equation.

X1.3.5 As discussed in Ref (**3**), an underlying assumption in virtually all reliability analyses is that every adjustment factor applied in the design checking equation applies equally across the entire resistance population. From an analysis standpoint, this results in identical reliability indices for the reference and adjusted design cases.

X1.3.6 Ref (**3**) also describes the difficulty of applying the same judgment to the time effect factor (λ). The time effect factor is different from other design adjustment factors in two respects. First, it represents an interaction between the load side and the resistance side of the design equation. This fact leads to a dilemma regarding the format of the design checking equation: should the time effect factor be expressed separately (that is, $\lambda\phi_s R_n$) or embedded into the adjusted resistance like other adjustment factors? Second, test specimens at the lower tail of the strength distribution exhibit shorter times to failure under constant load than those higher in the distribution, while most of those at the upper end don't fail at all, because they are effectively loaded at a lower stress ratio.

X1.4 *Commentary to 4.2, Format Conversion*—Format conversion is the method used to develop format conversion factors to adjust reference ASD design values (based on normal 10-year load duration) to LRFD reference resistances (based on 10-min load duration). Format conversion factors in Table 2 are developed to provide similar member and connection sizes when considering specific ASD and LRFD load cases and specified values of the resistance factor, ϕ, for LRFD as provided in Table 1.

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

X1.5 *Commentary to Table 2, Format Conversion Factor, K_F, for Compression Parallel to Grain, Bending, Tension Parallel to Grain, Shear, Radial Tension and Connections*:

X1.5.1 The format conversion factors for compression parallel to grain, bending, tension parallel to grain, shear, radial tension and connections that are subject to load duration or time effect adjustments, can be obtained from Eq X1.2.

X1.5.2 The factor of 2.16 is the algebraic solution at the calibration point, the ratio of R_n / F_x for *S/D* = 3, λ = 0.80, and C_D = 1.15.

$$LRFD\text{: } \lambda\phi R_n \geq 1.2D + 1.6(L \text{ or } S) \quad (X1.1)$$

$$ASD\text{: } C_D F_x \geq D + (L \text{ or } S) \quad (X1.2)$$

where:

λ	=	time effect factor (LRFD),
ϕ	=	specified resistance factor (LRFD),
R_n	=	reference resistance value (LRFD),
D, L, S	=	dead, live, and snow load effects, respectively,
C_D	=	load duration factor (ASD), and
F_x	=	ASD design value (ASD).

Substituting and solving for K_F (= R_n/F_x):

$$K_F = 2.16/\phi_s \quad (X1.3)$$

X1.5.3 Use of a single constant for the format conversion factor, K_F, is appropriate, based on the judgment of the committee, over a broad range of design cases. As shown in Fig. X1.1, this judgment produces exact calibration between ASD and LRFD for one specific design case (S/D = 3, C_d = 1.15, λ = 0.8). Differences between ASD and LRFD designs will result for other design cases. The algebraic format conversion solution for the precise constant in the numerator of Eq X1.3 is not to be confused as the RBD basis supporting Eq X1.3 (see Appendix X2). The RBD basis of the format conversion factor involved first order, second moment reliability methods to graph R_n/F_x across a range of load ratios for three distinct live-load cases (occupancy floor, snow roof, and non-snow roof), where R_n and F_x come directly from the LRFD and ASD design equations. The factor in the numerator of Eq X1.3 is in the range from 2.1 to 2.2 and resulted from the application of engineering judgment as a balance of increases for floors at low L/D ratios versus decreases for non-snow roofs at higher L/D ratios.

X1.6 *Commentary to Table 2, Format Conversion Factor, K_F, for Lateral Buckling (Stability), Compression Perpendicular to Grain, and Rolling Shear not subject to load duration or time effect adjustments*:

X1.6.1 The format conversion factors for lateral buckling (stability), compression perpendicular to grain, and rolling shear values that are not subject to load duration or time effect adjustments, can be obtained from Eq X1.4:

$$K_F = 1.5/\phi_s \quad (X1.4)$$

X1.6.2 The K_F of 1.5/ϕ is the algebraic solution at the point of calibration - the ratio of R_n/F_x for *L/D* = 3. Terms λ and C_D

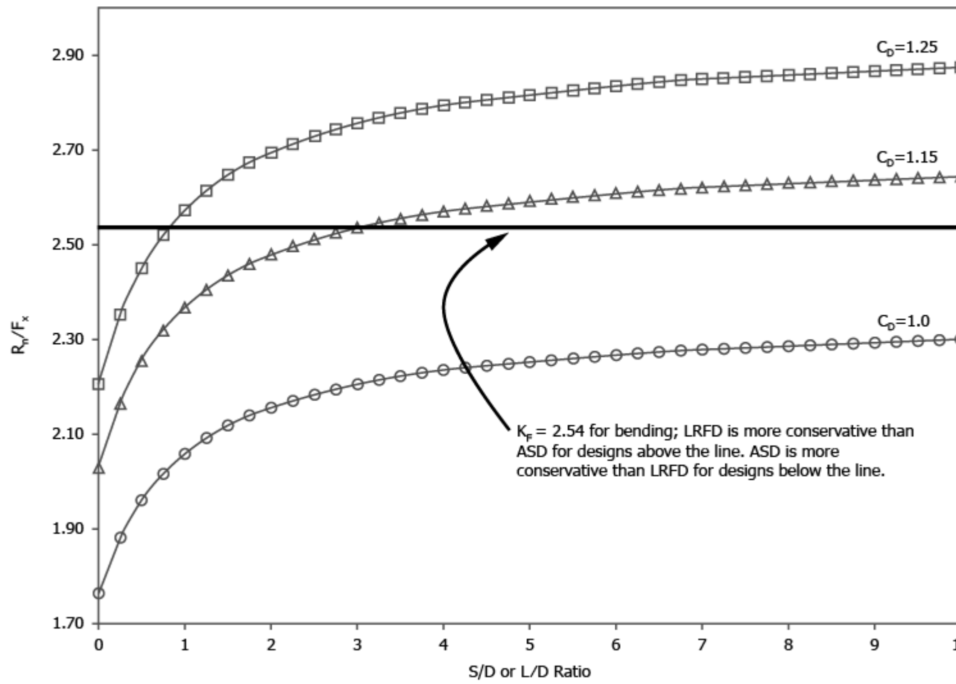

FIG. X1.1 R_n/F_x Producing Exact Calibration Between ASD and LRFD for Bending (ϕ_s = 0.85; $K_F = 2.16/\phi_s = 2.54$)

do not appear in the design checking equations because they are not applicable for modulus of elasticity for beam and column stability (E_{min}), compression perpendicular to grain, and rolling shear in accordance with the NDS.

$$\text{LRFD:} \quad \phi_s R_n \geq 1.2D + 1.6(L \text{ or } S) \quad (X1.5)$$

$$\text{ASD:} \quad F_x \geq D + (L \text{ or } S) \quad (X1.6)$$

Substituting and solving for $K_F(= R_n / F_x)$:

$$K_F = 1.5/\phi_s$$

X1.6.3 *Format Conversion for Lateral Buckling (Stability)*—The format conversion factor of 1.76 for stability is applied to E_{min} which is the modulus of elasticity used in ASD for beam stability and column stability calculations (not to the average modulus of elasticity, E, used for deflection calculations). Using the format conversion factor of 1.76, E_{min} for LRFD can be calculated from E_{05} as follows:

$$\text{For ASD:} \quad E_{min} = E_{05}/1.66 \quad (X1.7)$$

where:

E_{05} = fifth percentile shear-free E value, and
1.66 = safety factor for beam and column stability calculations.

$$\text{For LRFD:} \quad \textit{Multiply by } K_F = 1.5/\phi_s \quad (X1.8)$$

$$E_{min} = (E_{05}/1.66)(1.76)$$

$$= (1.06)(E_{05})$$

X1.6.4 Equations for K_{bE} and K_{cE} contained in the 2001 NDS beam and column stability provisions adjust tabulated average modulus of elasticity, E, values to fifth percentile shear-free E values divided by a 1.66 safety factor. In the 2005 NDS, K_{bE} and K_{cE} equations were replaced with a reference to tabulated E_{min} values (fifth percentile shear-free E values divided by a 1.66 safety factor) to simplify design equations for beam and column stability and to enable use of the same equations for both ASD and LRFD.

X1.6.4.1 E_{min} values tabulated in the NDS Design Value Supplement for sawn lumber are estimated in accordance with Eq X1.9 where for sawn lumber $E_{05} = 1.03E(1\text{-}1.645(COV_E))$:

$$E_{min} = \frac{1.03E(1 - 1.645(COV_E))}{1.66} \quad (X1.9)$$

X1.6.5 *Format Conversion for ASD Deformation-Based Compression Perpendicular to Grain Values*—Wood compression perpendicular to grain stresses are based on serviceability criteria from testing of small specimens (Test Methods D143, square cross-section block, 2 in. loading block). However, in many cases, these allowable stresses are being applied more broadly. In some compression perpendicular to grain applications, especially where laterally unsupported tall/narrow sections are used, failure modes, such as instability or splitting, can occur. These failure modes have been demonstrated in short-term tests to occur at compression perpendicular to grain stress levels as low as 1.5 times the ASD value for compression perpendicular to grain. Designers must be certain to check the failure modes of buckling or splitting that may now control the design. Alternatively, the designer may choose to brace the tall/narrow member at the bearing to prevent this mode from occurring.

X1.6.6 One method to compute buckling capacity in the perpendicular to grain direction for ASD may be done by using an elastic-buckling (Euler) type formula similar to that now used for visually graded lumber. This calculation could supplement the standard ASD compression perpendicular to grain calculation. In the calculation, the relevant modulus of elasticity is the transverse modulus (often assumed to be $E/20$) and the relevant dimensions (relative to buckling direction) would also be substituted.

X1.7 *Commentary to* Table 2, *Format Conversion Factor, K_F, for Shear Walls and Diaphragms*:

X1.7.1 The format conversion factor, $K_F = 2.0$ for wind and $K_F = 2.8$ for seismic, for shear walls and diaphragms has been derived as the algebraic solution (with rounding) at specific points of calibration. The ratio of R_n/F_x for $\phi_s = 0.80$ for wind design, and the ratio of R_n/F_x for $\phi_s = 0.50$ for seismic design, and where F_x is determined in accordance with SDPWS in Ref (**4**). Terms λ and C_D do not appear in the design checking equations because design values for wind and seismic load cases in accordance with SDPWS Ref (**4**) are tabulated based on a 10-min load duration and require no further designer adjustment for short duration wind or seismic loading.

X1.7.2 Design equations for wind load effects based on wind load factors from ASCE 7–16 are as follows:

$$\text{LRFD:} \quad \phi_s R_n \geq 1.0\, W \tag{X1.10}$$

$$\text{ASD:} \quad F_x \geq 0.6\, W \tag{X1.11}$$

Substituting and solving for $K_F(=R_n/F_x)$:
$K_F = 1.0/(0.6\phi_s) = 2.08$

where:

W = wind load effects.

X1.7.3 Design equations for seismic (earthquake) load effects are as follows:

$$\text{LRFD:} \quad \phi_s R_n \geq 1.0\, E \tag{X1.12}$$

$$\text{ASD:} \quad F_x \geq 0.7\, E \tag{X1.13}$$

Substituting and solving for $K_F(=R_n/F_x)$:
$K_F = 1.43/\phi_s = 2.86$

where:

E = earthquake load effects.

X1.7.4 The rounded values of the format conversion factor, K_F, in Table 2 are slightly conservative to values derived from exact calibration (that is, approximately 4 % for wind and 2 % for seismic). Table 1 factors for shear walls and diaphragms are consistent with those within SDPWS. The following section is provided to assist users to trace the history of these factors within Specification D5457.

X1.7.4.1 To simplify the initial transition to LRFD in the 1990s, Specification D5457 adopted a single resistance factor, ϕ, for shear walls and diaphragms. Subsequently, *Special Design Provisions for Wind and Seismic* (SDPWS) accommodated the use of a single ϕ and differences in historical design levels between seismic design and wind design by tabulating different nominal unit shear capacities for seismic and wind. More recently, simplification of the shear wall and diaphragm tables to utilize a single nominal unit shear capacity value associated with a nominal strength estimate is coupled with different values of ϕ for seismic design and wind design. For LRFD, $\phi = 0.5$ for seismic design and $\phi = 0.8$ for wind design. For ASD, the ASD reduction factor is 2.8 for seismic design and 2.0 for wind design. Calibration arithmetic in accordance with 2021 SDPWS follows.
Allowable nominal unit shear capacity for seismic design and wind design in accordance with 2021 SDPWS:

$$v_{ASD-SEISMIC} = v/2.8 \tag{X1.14}$$

$$v_{ASD-WIND} = v/2.0 \tag{X1.15}$$

where:

v = nominal unit shear capacity.

Design checking equations for seismic:

$$\text{ASD:}\, v/2.8 \geq 0.7\, E \tag{X1.16}$$

$$\text{LRFD:}\, (\phi_{seismic})(v) \geq 1.0\, E \tag{X1.17}$$

Substituting and solving for $\phi_{seismic}$:

$$0.7E(2.8) = 1.0E/\phi_{seismic} \tag{X1.18}$$

$$\phi_{seismic} = 0.510$$

A rounded value of $\phi = 0.5$ for seismic design is specified in 2021 SDPWS.
Design checking equations for wind:

$$\text{ASD:}\, v/2.0 \geq 0.6\, W \tag{X1.19}$$

$$\text{LRFD:}\, (\phi_{wind})(v) \geq 1.0\, W \tag{X1.20}$$

Substituting and solving for ϕ wind:

$$0.6W(2.0) = 1.0W/\phi_{wind} \tag{X1.21}$$

$$\phi_{wind} = 0.833 \tag{X1.22}$$

A rounded value of $\phi = 0.8$ for wind design is specified in 2021 SDPWS.

X2. USING TEST-DATA TO COMPUTE REFERENCE RESISTANCE VALUES FOR LRFD

X2.1 *Overview of this Appendix*—The primary purpose of this specification is to provide users with the ability to generate reference resistance values for LRFD by applying format conversion factors to generally accepted allowable stress design (ASD) values. Prior versions of this specification also included an annex that permitted users to derive LRFD reference resistance values directly from test-data. More recently, the Committee felt that the prior annex had outlived its usefulness for several reasons. First, because the field of reliability analysis has evolved dramatically since this specification was originally approved in 1993, the methods embodied in the annex were outdated. Second, the Committee realized that the limited sampling and testing guidance in the annex was not as robust as the guidance in comparable ASD standards for structural wood products and their connections. Third, the test-based method in the annex was seldom used. And, if the test-based method was used, it would produce different reference resistance values than associated with the format conversion method. These differences can be of varying magnitudes and are due in part to requirements for development of ASD values that are not addressed in the test-based approach. Rather than attempt to update the annex, the Committee recommended that the annex be converted to a non-mandatory appendix that could provide broad guidance for users who wish to pursue the test-based approach.

X2.2 *Generally accepted Reliability Analysis Methods*—When this specification was adopted in 1993, the Committee relied on the ASCE Committee on Wood Pre-Standard Report (**5**) to provide the template for reliability analysis methods. That report in turn relied on the National Bureau of Standards NBS SP577 Report (**6**), which documented the most advanced reliability analysis techniques of its time. These reports proposed using standardized "first-order, second-moment" (FOSM) methods of analysis, also known as Rackwitz-Fiessler methods (**7**), to compute reliability indices for problems containing multiple variables with non-normal underlying statistical distributions. The examples provided later in this appendix are based on FOSM methods.

X2.2.1 *Limitations of Early Reliability Analysis Methods*—Early references that applied FOSM methods to broadly-applicable material specifications faced several challenges. These methods produced reliability indices with the inference of being more theoretically advanced, and therefore more preferable, than the historical ASD methods. However, the "precision" of the computed reliability indices was only as good as the underlying data. When one tested 50 combinations of a product's variables (such as grade/size/species in lumber), one computed 50 different reliability indices for a single reference design condition (one load combination at one load ratio). And, at this point in its adoption, FOSM methods had no standardization in their implementation recommendations. Should these 50 reliability indices simply be averaged? Alternatively, should the minimum value be advertised as representative of that given product line? Which reference design condition should be used to define the target – since computed reliability indices are different for various load combinations?

X2.2.2 *Other Data Collection Decisions*—Similarly, when a production facility wisely chose to include a broad range of potential variability in a candidate data set (such as production over multiple time periods or multiple manufacturing lines), this decision would penalize that facility with lower computed reliability indices (because increasing variability leads to decreasing computed reliability).

X2.2.3 *Decisions vary by Structural Material*—The first version of an LRFD Manual for Steel Construction in the U.S. was adopted in 1978. The commentary to this manual illustrated elementary reliability analysis concepts that pre-dated NBS SP577 (**6**) methods. Later references to the reliability methods used for hot-rolled steel indicate that more modern calculations are used. However other references that apply to cold-formed steel and other materials indicate that a range of reliability analysis methods – some taken directly from 1970s publications – still form the basis of many reliability estimates.

X2.2.4 *Evolution in the ASCE 7 Standard*—Each version of ASCE 7 since 2010 has provided new options for users to apply reliability analyses. Some options have evolved toward simplicity (such as the ability to use a single equation to compute a product's resistance factor as a function of target reliability index, β, and the product's Mean/Nominal ratio and coefficient of variation). Conversely, other options permit complex analyses (such as the "performance-based" approach in which users can conduct a reliability analysis in any technically acceptable manner, provided that the results are peer-reviewed by a qualified reviewer).

X2.2.5 *Recommendations*—Appendix X2 recommends that users choose a reliability analysis method that is technically sound and acceptable to the authority having jurisdiction over the range of product application. Users are cautioned that many of the decisions used in the analysis will not have firm guidelines in the absence of available standardized methods. These analysis decisions are beyond the scope of this specification.

X2.3 *Guidance related to Sampling and Testing*—Decisions related to sampling and testing for structural wood products and their connections should rely on a single overriding principle – users should familiarize themselves with all the applicable requirements embedded within the existing ASD standards for the product of interest and follow each requirement closely and completely. For example, for a structural composite lumber product, one should follow all of the qualification requirements in Specification D5456, and, in addition, establish an ongoing quality monitoring system that provides assurance of continuing compliance with the assumptions underlying design value and adjustment factor derivations.