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

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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 procedures that are required for the generation of reference resistance for LRFD.

1. Scope

1.1 This specification covers procedures for computing the reference resistance of wood-based materials and structural connections for use in load and resistance factor design (LRFD). The reference resistance derived from this specification applies to the design of structures addressed by the load combinations in ASCE 7-02.

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

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
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 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 Structural Panels in Tension
D3501 Test Methods for Wood-Based Structural Panels in Compression
D3737 Practice for Establishing Allowable Properties for Structural Glued Laminated Timber (Glulam)
D4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material
D5055 Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists
D5456 Specification for Evaluation of Structural Composite Lumber Products
E105 Practice for Probability Sampling of Materials
2.2 *ASCE Standard:*[3]
ASCE 7-02 Minimum Design Loads 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.

3.1.2 *coefficient of variation, CV_w*—a relative measure of variability. For this specification, the calculation of CV_w is based on the shape parameter of the 2-parameter Weibull

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[1] This specification is under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D07.02 on Lumber and Engineered Wood 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.

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

distribution. It is not the traditional sample standard deviation of the data divided by the sample mean.

3.1.3 *data confidence factor, Ω*—a factor that is used to adjust member reference resistance for sample variability and sample size.

3.1.4 *distribution percentile, R_p*—the value of the distribution associated with proportion, *p*, of the cumulative distribution function.

3.1.5 *format conversion factor, K_F*—a factor applied to convert resistance from the allowable stress design (ASD) format to the LRFD format.

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

3.1.7 *reference resistance, R_n*—the value used in LRFD equations to represent member resistance (that is, strength or capacity).

3.1.8 *reliability normalization factor, K_R*—a factor used to establish the reference resistance to achieve a target reliability index for a reference set of conditions.

3.1.9 *resistance factor*—a factor applied to the resistance side of the LRFD equation.

4. Sampling

4.1 Samples selected for analysis and implementation with this specification shall be representative of the population about which inferences are to be made. Both manufacturing and material source variability shall be considered. The principles of Practice E105 shall be maintained. Practice D2915 provides methods for establishing a sampling plan. Special attention is directed to sampling procedures in which the variability is low and results can be influenced significantly by manufacturing variables. It is essential that the sampling plan address the relative magnitude of the sources of variability.

4.1.1 Data generated from a quality control program shall be acceptable if the criteria of 4.1 are maintained.

4.1.2 When data from multiple data sets are compiled or grouped, the criteria used to group such data shall be in keeping with the provisions of 4.1. When such procedures are available in applicable product standards, they shall be used.

4.2 *Sample Size*:

4.2.1 For data sets in which all specimens are tested to failure, the minimum sample size shall be 30.

NOTE 1—The confidence with which population properties can be estimated decreases with decreasing sample size. For sample sizes less than 60, extreme care must be taken during sampling to ensure a representative sample.

4.2.2 For lower tail data sets, a minimum of 60 failed observations is required for sample sizes of *n* = 600 or less. (This represents at least the lower 10 % of the distribution.) For sample sizes greater than 600, a minimum of the lowest 10 % of the distribution is required (for example, sample size, *n* = 720, 0.10 (720) = 72 failed test specimens in the lower tail). Only parameter estimation procedures designed specifically for lower tail data sets shall be used (see Appendix X2).

5. Testing

5.1 Testing shall be conducted in accordance with appropriate standard testing procedures. The intent of the testing shall be to develop data that represent the capacity of the product in service.

5.2 *Periodic Property Assessment*—Periodic testing is recommended to verify that the properties of production material remain representative of published properties.

6. Reference Resistance for LRFD

6.1 The derivation of LRFD reference resistance is addressed in this section. Parameters required for the derivation of reference resistance are also presented. These parameters include the distribution percentile, coefficient of variation, data confidence factor, and reliability normalization factor. An example derivation of reference resistance is provided in X1.7.

6.2 *Reference Resistance, R_n*—The following equation establishes reference resistance for LRFD:

$$R_n = R_p \times \Omega \times K_R \tag{1}$$

where:

R_p = distribution percentile estimate,
Ω = data confidence factor, and
K_R = reliability normalization factor.

6.3 *Distribution Percentile Estimate, R_p*:

6.3.1 Eq 2 is intended to be used to calculate any percentile of a two-parameter Weibull distribution. The percentile of interest depends on the property being estimated.

$$R_p = \eta[-ln(1 - p)]^{1/\alpha} \tag{2}$$

where:

η = Weibull scale parameter,
p = percentile of interest expressed as a decimal (for example, 0.05), and
α = Weibull shape parameter.

6.3.2 The shape (α) and scale (η) parameters of the two-parameter Weibull distribution shall be established to define the distribution of the material resistance.[4] Algorithms for common estimation procedures are provided in Appendix X2.

6.4 *Coefficient of Variation, CV_w*—The coefficient of variation of the material is necessary when determining the data confidence factor, Ω, and the reliability normalization factor, K_R. The CV_w can be estimated from the shape parameter of the Weibull distribution as follows:

$$CV_w \cong \alpha^{-0.92} \tag{3}$$

NOTE 2—The above approximation is within 1 % of the exact solution for CV_w values between 0.09 and 0.50. An exact relationship of CV_w and α is shown in Appendix X3.

6.5 *Data Confidence Factor, Ω*—The data confidence factor, Ω, accounts for uncertainty associated with data sets.[5] This factor, which is a function of coefficient of variation, sample size, and reference percentile, is applied as a multiplier on the

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[4] Weibull, W., "A Statistical Theory of the Strength of Materials," *Proceedings of the Royal Swedish Institute of Engineering Research*, Stockholm, Sweden, Report No. 151, 1939, pp. 1–45.
[5] *Load and Resistance Factor Design for Engineered Wood Construction—A Pre-Standard Report*, American Society of Civil Engineers, 1988.

distribution estimate. Table 1 provides data confidence factors appropriate for lower fifth-percentile estimates.

NOTE 3—When a distribution tolerance limit is developed on a basis consistent with Ω, the data confidence factor is taken as unity.

6.6 *Reliability Normalization Factor, K_R*—The reliability normalization factor, K_R, is used to adjust the distribution estimate (for example, $R_{0.05}$) to achieve a target reliability index. The reliability normalization factor is the ratio of the computed resistance factor, ϕ_c(X1.7), to the specified resistance factor, ϕ_s(Table 2), adjusted by a scaling factor. This adjustment factor is a function of CV_w and is generated for specific target reliability indices. The K_R values presented in Table 3 represent resistance factors (ϕ_c) computed at a live-to-dead load ratio of 3. Computations for determining reliability normalization factors for target reliability indices greater than β = 2.4 are contained in Zahn.[6]

6.7 *Format Conversion*:

6.7.1 As an alternative to the use of K_R, in which one chooses to adjust the design values to achieve a stated reliability index under the reference load conditions, it is permissible to generate LRFD reference resistance values 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.

NOTE 4—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.

6.7.2 For standardization purposes, format conversion reference resistance values shall be based on the arithmetic conversion at a specified reference condition that results from the calibration (defined as providing an identical required section modulus, cross-sectional area, allowable load capacity, and so forth) of basic ASD and LRFD equations. The specified reference condition shall be chosen such that changes in design capacity over the range of expected load cases and load ratios is minimized.

6.7.3 Values of the format conversion factor, K_F, are given in Table 4.

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[6] Zahn, J., *FORTRAN Programs for Reliability Analysis*, USDA Forest Service, FPL GTR-72, Forest Products Laboratory, Madison, WI, 1992.

TABLE 1 Data Confidence Factor, Ω on R$_{0.05}$, for Two-Parameter Weibull Distribution with 75 % Confidence[A]

CV_w	Sample Size, n									
	30	40	50	60	100	200	500	1000	2000	5000
0.10	0.95	0.95	0.96	0.96	0.97	0.98	0.99	0.99	0.99	1.0
0.15	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	0.99	0.99
0.20	0.89	0.91	0.92	0.93	0.94	0.96	0.98	0.98	0.99	0.99
0.25	0.87	0.88	0.90	0.91	0.93	0.95	0.97	0.98	0.98	0.99
0.30	0.84	0.86	0.88	0.89	0.92	0.94	0.96	0.97	0.98	0.99
0.35	0.81	0.84	0.86	0.87	0.90	0.93	0.96	0.97	0.98	0.99
0.40	0.79	0.81	0.84	0.85	0.89	0.92	0.95	0.96	0.97	0.98
0.45	0.76	0.79	0.82	0.85	0.87	0.91	0.94	0.96	0.97	0.98
0.50	0.73	0.77	0.80	0.81	0.86	0.90	0.94	0.95	0.97	0.98

[A] Interpolation is permitted. For CV_w values below 0.10, the values for 0.10 shall be used.

TABLE 2 Specified LRFD Resistance Factors, ϕ_s

Application	Property[A]	ϕ_s
Member	compression[A]	0.90
	bending, lateral buckling (stability)	0.85
	tension parallel	0.80
	shear, radial tension	0.75
Connection	all	0.65
Shear Wall, diaphragm	shear	0.80

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

TABLE 3 Fifth-Percentile Based Reliability Normalization Factors, K_R

CV_w%	K_R					
	Compression and Bearing	Bending	Tension Parallel	Shear (2.1 basis)	Shear (SCL, 3.15 basis)	Shear (I-Joist, 2.37 basis)
10	1.303	1.248	1.326	1.414	0.943	1.253
11	1.307	1.252	1.330	1.419	0.946	1.257
12	1.308	1.253	1.331	1.420	0.947	1.258
13	1.306	1.251	1.329	1.418	0.945	1.256
14	1.299	1.244	1.322	1.410	0.940	1.249
15	1.289	1.235	1.312	1.400	0.933	1.240
16	1.279	1.225	1.302	1.388	0.926	1.230
17	1.265	1.212	1.288	1.374	0.916	1.217
18	1.252	1.199	1.274	1.359	0.906	1.204
19	1.237	1.185	1.259	1.343	0.895	1.190
20	1.219	1.168	1.241	1.324	0.882	1.173
21	1.204	1.153	1.225	1.307	0.871	1.158
22	1.186	1.136	1.207	1.287	0.858	1.141
23	1.169	1.120	1.190	1.269	0.846	1.125
24	1.152	1.104	1.173	1.251	0.834	1.109
25	1.135	1.087	1.155	1.232	0.821	1.092
26	1.118	1.071	1.138	1.214	0.809	1.076
27	1.105	1.059	1.125	1.200	0.800	1.063
28	1.084	1.038	1.103	1.176	0.784	1.042
29	1.066	1.021	1.085	1.157	0.771	1.025
30	1.049	1.005	1.068	1.139	0.759	1.009

TABLE 4 Format Conversion Factor, K$_F$

Property	K$_F$
Compression Parallel to Grain	2.40
Bending	2.54
Tension Parallel	2.70
Shear, Radial Tension	2.88
Connections	3.32
Lateral Buckling (Stability)	1.76
Compression Perpendicular to Grain	1.67
Shear Wall and Diaphragm Shear	2.00[A]

[A] 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.

6.7.4 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-minute load duration.

6.7.5 For lateral buckling (stability) and compression perpendicular to grain, the value of K_F is based on the assumption that neither the ASD nor LRFD resistance values are subject to duration of load or time effect adjustments.

6.7.6 *Format Conversion Example*—An ASD bolt design value for a single shear connection is 800 lbf (based on normal

10-year load duration). From Table 4, the format conversion factor is 3.32. The corresponding LRFD bolt reference resistance value is as follows:

$$R_n = 3.32 \times 800 \qquad (4)$$

$$R_n = 2658 \text{ lbf}$$

6.7.7 *Format Conversion Example for Shear Walls or Diaphragms*—An ASD shear wall design value is 395 lb/ft (based on a 10-minute load duration). From Table 4, the format conversion factor is 2.00. The corresponding LRFD shear wall reference resistance value is as follows:

$$R_n = 2.00 \times 395 \qquad (5)$$

$$R_n = 790 \text{ lb/ft}$$

7. Presentation of Results

7.1 Report the sampling plan and testing in accordance with applicable standards. When lower tail data sets are used, report the sample size and data used in the calculations. Report the estimated shape and scale parameters along with the calculated coefficient of variation. When appropriate, also report the mean and standard deviation (derived from the calculated coefficient of variation). Include a plot showing the data points and fitted Weibull distribution. In addition to these basic parameters, also report the data confidence factor, calculated percentile estimate, reliability normalization factor, and reference resistance.

8. Keywords

8.1 load and resistance factor design (LRFD); reference resistance; wood-based

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 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 a given set of conditions for a given reference period. 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 current (allowable stress) design. LRFD provides incremental improvements in the design process in this way. The improvements provided by LRFD include the following:

X1.1.1.1 Consideration of the variability of various types of loads when assessing safety factors.

X1.1.1.2 Consideration of the consequences of various potential failure modes in a structure.

X1.1.1.3 Material resistance values that relate more closely to test data (member capacities).

X1.1.1.4 Consideration of resistance variability.

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 in use today, 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.

X1.1.3 Simulations have shown that the assumed distribution type can have a strong effect on computed LRFD resistance factors. However, much of this difference is due to the inability of standard distribution forms to fit the tail data precisely. By standardizing the distribution type, this procedure provides a consistent means for deriving these factors. In addition, by permitting tail fitting of the data, it provides a way of fitting data in this important region that is superior to full-distribution types.

X1.1.4 While the two-parameter Weibull distribution is the underlying basis for these calculations, the user of this specification is not burdened with applying statistical decisions. For LRFD purposes, the user must calculate the shape and scale parameters for the fitted Weibull distribution using the equations in the specification. All remaining steps in the calculations of a reference resistance are spelled out in the equations of the specification.

X1.2 *Commentary to Section 1, Scope*—The calculation procedures identified in this specification are common statistical procedures. This specification gives the user a document for