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# Standard Specification for
# Computing the 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 7-88.

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

## 2. Referenced Documents

2.1 *ASTM Standards:*
D 9 Terminology Relating to Wood[2]
D 143 Method of Testing Small Clear Specimens of Timber[2]
D 198 Methods of Static Tests of Timbers in Structural Sizes[2]
D 1037 Test Methods of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials[2]
D 1761 Method of Testing Mechanical Fasteners in Wood[2]
D 1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber From In-Grade Tests of Full-Size Specimens[2]
D 2718 Test Method for Structural Panels in Planar Shear (Rolling Shear)[2]

D 2719 Test Methods for Structural Panels in Shear Through-the-Thickness[2]
D 2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber[2]
D 3043 Methods of Testing Structural Panels in Flexure[2]
D 3500 Test Method for Structural Panels in Tension[2]
D 3501 Methods of Testing Plywood in Compression[2]
D 4761 Test Method for Mechanical Properties of Lumber and Wood-Base Structural Material[2]
D 5055 Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists[2]
E 105 Practice for Probability Sampling of Materials[3]
2.2 *ASCE Standard:*
ASCE 7-88 Minimum Design Loads for Buildings and Other Structures[4]

## 3. Terminology

3.1 *Definitions*—For general definitions of terms related to wood, refer to Terminology D 9.

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

3.1.2 *data confidence factor, $\Omega$*—a factor that is used to adjust member reference resistance for sample variability and sample size.

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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] *Annual Book of ASTM Standards*, Vol 04.10.

[3] *Annual Book of ASTM Standards*, Vol 14.02.
[4] Available from American Society of Civil Engineers, 345 East 47th Street, New York, NY 10017-2398.

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

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

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

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

3.1.7 *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.

3.1.8 *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 E 105 shall be maintained. Method D 2915 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,
$\Omega$ = 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:
$\eta$ = Weibull scale parameter,
*p* = percentile of interest expressed as a decimal (for example, 0.05), and
$\alpha$ = Weibull shape parameter.

6.3.2 The shape ($\alpha$) and scale ($\eta$) parameters of the two-parameter Weibull distribution shall be established to define the distribution of the material resistance.[5] 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, $\Omega$, 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 $\alpha$ is shown in Appendix X3.

6.5 *Data Confidence Factor, $\Omega$*—The data confidence factor, $\Omega$, accounts for uncertainty associated with data sets.[6] This factor, which is a function of coefficient of variation, sample size, and reference percentile, is applied as a multiplier on the 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 $\Omega$, 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

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[5] 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.

[6] *Load and Resistance Factor Design for Engineered Wood Construction—A Pre-Standard Report*, American Society of Civil Engineers, 1988.

**TABLE 1 Data Confidence Factor, Ω on R₀.₀₅, 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 3 Fifth-Percentile Based Reliability Normalization Factors, $K_R$**

| $CV_w$,% | $K_R$ | | | | | |
|---|---|---|---|---|---|---|
| | Compression and Bearing | Bending | Tension Parallel | Shear (Lumber) | Shear (SCL) | Shear (I-Joist) |
| 10 | 1.303 | 1.248 | 1.326 | 0.724 | 0.943 | 1.253 |
| 11 | 1.307 | 1.252 | 1.330 | 0.727 | 0.946 | 1.257 |
| 12 | 1.308 | 1.253 | 1.331 | 0.727 | 0.947 | 1.258 |
| 13 | 1.306 | 1.251 | 1.329 | 0.726 | 0.945 | 1.256 |
| 14 | 1.299 | 1.244 | 1.322 | 0.722 | 0.940 | 1.249 |
| 15 | 1.289 | 1.235 | 1.312 | 0.717 | 0.933 | 1.240 |
| 16 | 1.279 | 1.225 | 1.302 | 0.711 | 0.926 | 1.230 |
| 17 | 1.265 | 1.212 | 1.288 | 0.704 | 0.916 | 1.217 |
| 18 | 1.252 | 1.199 | 1.274 | 0.696 | 0.906 | 1.204 |
| 19 | 1.237 | 1.185 | 1.259 | 0.688 | 0.895 | 1.190 |
| 20 | 1.219 | 1.168 | 1.241 | 0.678 | 0.882 | 1.173 |
| 21 | 1.204 | 1.153 | 1.225 | 0.669 | 0.871 | 1.158 |
| 22 | 1.186 | 1.136 | 1.207 | 0.659 | 0.858 | 1.141 |
| 23 | 1.169 | 1.120 | 1.190 | 0.650 | 0.846 | 1.125 |
| 24 | 1.152 | 1.104 | 1.173 | 0.641 | 0.834 | 1.109 |
| 25 | 1.135 | 1.087 | 1.155 | 0.631 | 0.821 | 1.092 |
| 26 | 1.118 | 1.071 | 1.138 | 0.622 | 0.809 | 1.076 |
| 27 | 1.105 | 1.059 | 1.125 | 0.615 | 0.800 | 1.063 |
| 28 | 1.084 | 1.038 | 1.103 | 0.603 | 0.784 | 1.042 |
| 29 | 1.066 | 1.021 | 1.085 | 0.593 | 0.771 | 1.025 |
| 30 | 1.049 | 1.005 | 1.068 | 0.583 | 0.759 | 1.009 |

computed resistance factor, $\phi_c$(Appendix X1), to the specified resistance factor, $\phi_s$(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 ($\phi_c$) 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.[7]

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 D 143, D 198, D 1037, D 1761, D 2718, D 2719, D 3043, D 3500, D 3501, and D 4761; Practice D 1990; and Specification D 5055.

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, etc.) 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.

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

**TABLE 2 Specified LRFD Resistance Factors, $\phi_s$**

| Application | Property | $\phi_s$ |
|---|---|---|
| Member | compression[A] | 0.90 |
| | bending | 0.85 |
| | tension parallel | 0.80 |
| | shear, radial tension | 0.75 |
| Connection | all | 0.65 |

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

6.7.3 Based on the same load factors and load ratio as those given in 6.6, with an ASD load duration adjustment factor of 1.15 and a LRFD time effect factor of 0.80, the format conversion factor, $K_F$, is as follows:

$$K_F = \frac{2.16}{\phi_s} \qquad (4)$$

6.7.4 Since ASD deformation-based compression perpendicular to grain values are not subject to the duration of load adjustment, the constant in the numerator of Eq (4) is 1.875 for this property.

6.7.5 The format conversion reference resistance is computed by multiplying the ASD resistance (based on normal 10-year duration) by $K_F$.

6.7.6 *Format Conversion Example*—An ASD bolt design value for a single shear connection is 800 lbf. From Table 2, the specified LRFD resistance factor is 0.65. Using Eq (4), the corresponding LRFD bolt design value is as follows:

$$R_n = \left(\frac{2.16}{0.65}\right) \times 800 \qquad (5)$$

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

## 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