

## LRFD versus ASD for Wood Design

by

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**Summary:** Load and resistance factor design (LRFD) for wood was recently adopted in US building codes. Several case studies have recently been conducted to compare the new LRFD methodology to allowable stress design (ASD) methodology for wood. These case studies will be discussed and their relevance to wood buildings identified. Potential benefits to using LRFD will be shown.

**Keywords:** Load and resistance factor design, LRFD, wood design, post-frame building design, allowable stress design, ASD.

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## INTRODUCTION

In structural engineering, there is a growing trend to replace existing allowable stress design (ASD) methodologies with load and resistance factor design (LRFD) procedures, Pollock, *et al.* (1994). The wood industry responded to this emerging preference by publishing the *Load and Resistance Factor Design (LRFD) Manual for Engineered Wood Construction*, AF&PA (1996).

The wood industry chose to adopt two out of a possible three-stage process to transition from deterministic design (ASD) to a reliability (LRFD) basis. LRFD for wood adopts code accepted load factors (stage 1) that smooth reliability across load cases. It also adopts the concept of a target reliability index (stage 2) for a reference design case and adjusts designs to match that target. The final stage 3, that permits additional adjustment of designs based on individual data set analysis, is not currently being employed (even though it is permitted in the underlying standards). The wood industry does not believe that there is sufficient consensus regarding techniques for adopting this level of refinement in a uniform and equitable manner across construction materials.

## CASE STUDIES

Case studies comparing designs using LRFD methodology to those using ASD procedures as prescribed in the *National Design Specification® (NDS®) for Wood Construction*, AF&PA (1997), indicate similar results for beams and connections with live to dead load ratios of 3:1. Showalter, *et al.*, (1998) indicated that a 15% smaller cross-section was achieved for certain column designs using LRFD versus ASD, due primarily to load factoring for combinations of wind, snow, and crane loads on the column.

Additional calculations indicate as much as 30% smaller cross sections for structural members carrying multiple transient loads (roof live and occupancy) - again due to load factoring. These are further discussed in the results section of this paper.

Riegel and Manbeck (1997a,b) determined that for post-frame construction, post sizes will rarely be affected by use of LRFD instead of ASD. Review of their results, however, also indicates that load combinations play a significant role in differences between LRFD and ASD. One apparent anomaly revealed by their results is an approximate 50% increase in design stresses for certain load combinations. Specifically, they reported that,

“full snow and reduced wind loads controlled most post-frame designs greater than 40 ft. wide in LRFD, whereas half snow plus full wind controlled most post designs in ASD. Both CSI values and shear ratios were between 40% and 55% greater for LRFD than for ASD for the full snow and reduced wind load combination. However, only three out of 36 frames examined required larger posts under LRFD for this load case.”

## LOAD COMBINATIONS

Table 1 outlines ASD loads and load reductions from *ASCE 7-95* (1995). Applicable load duration factors are taken from AF&PA's *NDS for Wood Construction* Table 2.3.2. Note that several building codes, as well as *ASCE 7-95*, allow reductions to transient loads used in combination. For example, *ASCE 7-95* allows a 25% reduction in transient loads used in combination. *SBCCI's Standard Building Code* (1997) allows either the wind or snow load to be reduced 50% when used in combination. The 25% reduction as shown in column 7 of Table 1 was accounted for in this load combination comparison.

For LRFD loads and load factors, *AF&PA/ASCE 16-95 Standard* Table 1.4-2 outlines load combinations and time effect factors. For comparison purposes, identical load combinations are shown as those for ASD in Table 1.

Due to the varied treatment of seismic loads in combination with other loads in the various building codes, they have been omitted from this comparison. Impact loads also were not included.

Sixteen load combinations are shown in Table 1 combining dead, live, construction, snow, and wind loads. Load magnitudes commonly specified in building codes are used to calculate a total load, which is adjusted by applicable reduction factors for ASD or load factors for LRFD. Note that results provided in Table 1 would differ for other load magnitudes. The load duration factor,  $C_D$ , for ASD and time effect factor,  $\lambda$ , for LRFD are divided out of the total load to determine a comparable strength limit state. Column 16 shows the ratio of LRFD/ASD adjusted total loads. This ratio is then divided by 2.16 to allow relative comparison of these two methodologies (see *ASTM D5457* for details). A ratio less than one indicates that LRFD should provide a more efficient design should that load combination control. Conversely, a ratio greater than unity indicates a benefit using ASD loads.

Several load combinations in ASD are repeated (e.g., lines 6 & 7, 10 & 11, etc.). This is because two comparable load combinations are evaluated in LRFD, with the larger of the two controlling. Again, results would change with different load magnitudes.

Note that in Table 1, transient load combinations including wind (lines 9-16) only address instances where wind is cumulative with gravity loads for design of wood members. Wind uplift loading (e.g., nail withdrawal from roof sheathing; top chords of trusses resisting wind uplift; etc.) and wind lateral loading (e.g., sheathing nails in shearwalls; splice connections in diaphragm/shearwall chords) are not explicitly addressed in Table 1.

Additionally, column buckling and beam buckling are not explicitly addressed in Table 1, since in those cases it is not appropriate to divide

loads directly by  $C_D$  or  $\lambda$ . By extension, many cases of combined loading are not completely addressed by the simplified treatment in Table 1 (since most combined loading scenarios involve column buckling and/or beam buckling).

**Table 1. LRFD/ASD Load Combination Comparisons**

	Allowable Stress Design							Load and Resistance Factor Design							LRFD load/ ASD load	LRFD/(2.16*ASD)	
	Load Types					ASCE 7 load factor	$C_D$	load/ $C_D$	Load Types					load/ $\lambda$			
	D	L	C	S	W				D	L	$L_r$	S	W				$\lambda$
1	1					1	0.9	11.11	1.4					0.6	23.33	2.10	0.97
2	1	1				1	1	50.00	1.2	1.6				0.8	95.00	1.90	0.88
3	1		1			1	1.25	24.00	1.2		1.6			0.8	55.00	2.29	1.06
4	1			1		1	1.15	34.78	1.2			1.6		0.8	75.00	2.16	1.00
5	1				1	1	1.6	21.88	1.2				1.3	1	44.50	2.03	0.94
6	1	1		1		0.75	1.15	54.35	1.2	1.6		0.5		0.8	113.75	2.09	0.97
7	1	1		1		0.75	1.15	54.35	1.2	0.5		1.6		0.8	100.00	1.84	0.85
8	1	1	1			0.75	1.25	44.00	1.2	1.6	0.5			0.8	107.50	2.44	1.13
9	1	1	1		1	0.75	1.6	46.09	1.2	0.5	1.6			0.8	80.00	1.74	0.80
10	1	1		1	1	0.75	1.6	50.78	1.2			1.6	0.8	0.8	100.00	1.97	0.91
11	1	1		1	1	0.75	1.6	50.78	1.2	0.5		0.5	1.3	1	79.50	1.57	0.72
12	1	1			1	0.75	1.6	36.72	1.2	0.5			1.3	1	64.50	1.76	0.81
13	1		1		1	0.75	1.6	27.34	1.2		1.6		0.8	0.8	80.00	2.93	1.35
14	1		1		1	0.75	1.6	27.34	1.2		0.5		1.3	1	54.50	1.99	0.92
15	1			1	1	0.75	1.6	32.03	1.2			1.6	0.8	0.8	100.00	3.12	1.45
16	1			1	1	0.75	1.6	32.03	1.2			0.5	1.3	1	59.50	1.86	0.86

D = dead, L = floor live, C = construction (roof live),  $L_r$  = roof live, S = snow, W = wind

D=10 psf, L=40 psf, C or  $L_r$ =20 psf, S=30 psf, W=25 psf

For “extraordinary events” such as fire, ASCE 7-95 Commentary section 2.5 provides for the use of factored loads in strength design. For example, heavy timbers are often designed for one-hour fire endurance using code approved methodology shown in AF&PA’s *Design for Code Acceptance No. 2, Design of Fire-Resistive Exposed Wood Members*. Loads are typically determined using ASD load combinations as shown in Table 1. ASCE 7-95 provides the following factored loads for checking the capacity of a structure or structural element to withstand the effect of an extraordinary event, using the following load combinations:

$$1.2D + A_k + (0.5L + 0.2S)$$

$$(0.9 \text{ or } 1.2)D + A_k + 0.2W$$

where:

D = dead load

L = floor live load

S = snow load

W = wind load

$A_k$  = value of load or load effect resulting from an extraordinary event.

Again, factored loads reflect the small probability of a joint occurrence of the extraordinary load and the design live, snow or wind load. Thus, LRFD will also provide more efficient results in designing for fire resistance.

## RESULTS

As noted in the discussion of case studies above, as much as 30% smaller cross sections for structural members carrying multiple transient loads (roof live and occupancy) are possible using LRFD versus ASD. As shown in Table 1, load combinations 6 and 7 would show a 30% benefit using LRFD versus ASD. Examples of this would be headers and studs on the first floor of multi-story buildings. These members will typically carry snow and occupancy live loads. Specific results comparing several types of structural headers are shown in Table 2.

**Table 2. ASD/LRFD Comparison of Structural Headers for Multi-Story Structures**

Structural Headers	ASD	LRFD
Visually graded #2 Southern Pine	two-2x10	two-2x8
16F Glued-laminated timber	3"x8-1/4"	3-1/8"x6-7/8"
1.8E Laminated Veneer Lumber	two 1-3/4"x7-1/4"	two 1-3/4"x5-1/2"

Also noted in the discussion of case studies above is an apparent anomaly in results of comparisons of columns in post-frame structures under combined wind and snow loads. These results indicate that LRFD is approximately 50% more conservative than ASD for this scenario. The main reason for the difference appears to be that these particular load combinations use a 1.3 and 0.8 load factor on the wind load, rather than the 1.0 and 0.5 that is used for the comparable ASD load combinations. This alone results in a 30-60% increase in lateral load depending on which combination controls. This, coupled with the fact that a  $\lambda = 0.8$  is used for the LRFD load combination shown in lines 13 and 15 of Table 1, rather than the  $\lambda = 1.0$  for other lateral loads, substantiates the conservative results shown by Riegel and Manbeck (1997a,b). This should be addressed by the appropriate committee.

## SUMMARY

Load factors seem to contribute significantly to differences in design results using LRFD versus ASD. In many cases, more economical designs result using LRFD procedures. The underlying premise of load factoring is to move more of the safety factor, or reliability, to the loads side, since more information is available on loads today. It is reasonable to expect that more efficiency in the design process results from this knowledge.

Post-frame buildings, as well as other wood structures, can benefit from LRFD procedures; especially in cases where multiple transient loads are present.

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