Addendum to Cross-Laminated Timber Layup Tests Using Western Wood Products Association (WWPA) White fir Species Group Report

Summary

The goal of this project was to help validate the viability of white-fir use in cross laminated timber panels. White-fir falls within the Hem-fir species category within the National Design Specifications (NDS), which allows it to be used as a V5 or E5 grade panel. The grades are identified as V for use of visually graded lumber and E for use of machine stress rated (MSR) lumber within a panel, while the number 5 is the species category for Hem-fir. The two main wood species/groups used in America for CLT are Douglas-fir and spruce-pine-fir (SPF). As white fir is a common species in California, this study is intended to inform industry looking to California for siting a CLT facility on the usability of white-fir as an alternative to other species.

This addendum highlights the comparisons of white-fir CLT to that of the design values used within the CLT standard (PRG-320). Within the addendum, the process of creating the test values to compare to the design values are written out, along with side-by-side comparisons of the values. The data from the study shows that white-fir can meet the PRG-320 standard and is a viable option to be used for CLT. Next steps will include a manufacturer going through the certification process to make white fir panels before white-fir can be used within a structure.

Design Values

To better illustrate a comparison to the PRG 320's tabular values, the test values were converted per PRG 320 8.5 using the long and short-span testing data to compare against the design values. The testing values converted were the flatwise bending moment $(F_bS)_{eff,f,0}$, flatwise stiffness $(EI)_{eff,f,0}$, and flatwise shear capacity in the minor strength direction $V_{s,90}$. The first step of converting the testing values, was to calculate the three mechanical properties using the equations derived from ASTM D198 and ANSI PRG 320 Appendix X3. The equations used to calculate the properties are summarized below:

Effective Flatwise Bending Moment: $(F_bS)_{eff,f,0} = \frac{P}{2} \times \frac{L}{3}$

Where *P* is max load in lbf. and *L* is the total testing span in ft.

Effective Flatwise Stiffness: $(EI)_{eff,f,0} = E_i \times \frac{b \times h^3}{12}$

Where E_i is the modulus of elasticity, *b* is the sample width, and *h* is the sample thickness.

Flatwise Shear Capacity: $V_{s,90} = F_{s,major} \frac{2A_{gross,0}}{3}$

Where $F_{s,\,minor}$ is the shear stress in the minor direction and $A_{gross,\,0}$ is the gross cross-sectional area of the sample.

Once these properties were calculated, the 5th percentile tolerance limit was found, excluding the effective bending stiffness, where only the average was used. To finalize the converted values the 5th percentiles for the effective bending moment and shear capacity were divided by a safety factor (2.1), following the standard method described in PRG 320 section 8 (ANSI/APA 2019). The equation used for calculating the 5th percentile is stated below:

$$X_{\text{5th percentile}} = \mu - 1.64\,\sigma$$

Where μ is the mean and σ is the standard deviation of the properties, while 1.64 is the z-score for the 5th percentile.

After calculating the 5^{th} percentile and dividing the safety factor, the data was tabulated to compare it to other CLT grades from PRG 320 (Table 8). Within the table, values for grades V5 were listed alongside the converted values for the 2 grades of white-fir panels, #2 & better and #3 & better. The two grades for the white-fir (#2 & better and #3 and better) showed to be similar as expected, due to the properties not having any statistical differences. The CLT grade V5 are design values for different species within the panel and PRG 320 defines it as follows:

- No. 2 Hem-fir lumber in all longitudinal layers and No. 3 Hem-fir lumber in all transverse layers

When compared to the V5 CLT grade, the effective stiffness of the white-fir (95 and 97 x 10^6 lbf-in2 / ft of width) showed to be higher than the V5 grade (88 x 10^6 lbf-in2 / ft of width), while the effective flatwise bending moment (4551 and 4427 lbf-ft/ft of width) also showed to be higher than the V5 (1980 lbf-ft/ft of width). Lastly, the shear capacity of the white-fir (3707 and 3838 lbf/ft of width) had a higher design value than the V5 grade (550 lbf/ft of width).

Table 8: Summary of Converted Test Values from White-fir Data Compared to PRG 320 V5 Grade

Panel Type Type/Grade	**Effective Flatwise Bending Moment** $(F_bS)_{eff,f,0}$ (lbf-ft/ft of width)	**Effective Flatwise Stiffness** $(EI)_{eff,f,0}$ (10^6 lbf-in2 / ft of width)	**Flatwise Shear Capacity (Minor)** $V_{s,90}$ (lbf/ft of width)
3 & better Panels	4551	95	3707
2 & better Panels	4427	97	3838
V5 CLT Grade	1980	88	550

Appendix:

White-fir Long Span Bending values for #3 and Better Panels

Specimen	**Panel**	**Grade**	**Maximum Load** (lbf)	**Modulus of Rupture** (MOR) (psi)	**Bending Moment** $(F_bS)_{eff,f,0}$ (lbf-ft/ft of width)	**Modulus of Elasticity** (MOE) (psi)	**Flatwise Stiffness** $(EI)_{eff,f,0}$ (10^6 lbf-in^2)
6_A	6	3	9,461	5,282	14,980	1,425,766	100
6_B	6	3	7,297	4,074	11,554	1,228,487	86
6_D	6	3	6,500	3,629	10,292	1,206,859	85
6_F	6	3	9,563	5,339	15,141	1,238,041	87
6_G	6	3	7,244	4,044	11,470	1,090,954	77
7_A	7	3	7,089	3,958	11,224	1,287,038	90
7_B	7	3	10,770	6,013	17,053	1,461,845	103

7_D	7	3	5,919	3,305	9,372	1,219,393	86
7_F	7	3	11,844	6,613	18,753	1,509,095	106
7_G	7	3	8,339	4,656	13,203	1,437,194	101
8_A	8	3	11,430	6,381	18,098	1,506,627	106
8_B	8	3	8,041	4,489	12,732	1,481,021	104
8_D	8	3	9,713	5,423	15,379	1,377,698	97
8_F	8	3	10,048	5,610	15,909	1,408,895	99
8_G	8	3	7,218	4,030	11,429	1,461,687	103
9_A	9	3	11,151	6,226	17,656	1,528,773	107
9_B	9	3	11,139	6,219	17,637	1,497,074	105
9_D	9	3	8,612	4,808	13,636	1,427,377	100
9_F	9	3	8,097	4,521	12,820	1,298,713	91
9_G	9	3	8,914	4,977	14,114	1,380,301	97
10_A	10	3	7,981	4,456	12,637	1,333,158	94
10_B	10	3	12,383	6,914	19,606	1,517,730	107
10_D	10	3	7,802	4,356	12,353	1,324,271	93
10_F	10	3	8,051	4,495	12,747	1,252,260	88
10_G	10	3	11,970	6,683	18,953	1,333,599	94
12_A	12	3	9,751	5,444	15,439	1,379,924	97
12_B	12	3	10,229	5,711	16,196	1,299,201	91
12_D	12	3	7,285	4,067	11,535	1,145,485	80
12_F	12	3	6,633	3,703	10,502	1,322,799	93
12_G	12	3	9,328	5,208	14,769	1,420,838	100
			Count	30	30	30	30
			Average	**5,021**	**14,240**	**1,360,070**	**95**
			Minimum	3,305	9,372	1,090,954	77
			COV	20.0%	20.0%	8.6%	8.6%

K (5th%, 75% conf)	1.645	1.645
5th (ave-ave*k*COV)	3,370	9,557
5th/2.1	**1,003**	**4,551**

White-fir Long Span Bending Values for #2 and Better Panels

Specimen	**Panel**	**Grade**	**Maximum Load** (lbf)	**Modulus of Rupture** (MOR) (psi)	**Bending Moment** $(F_bS)_{eff,f,0}$ (lbf-ft/ft of width)	**Modulus of Elasticity** (MOE) (psi)	**Flatwise Stiffness** $(EI)_{eff,f,0}$ (10^6 lbf-in^2)
1_A	1	2	6,022	3,362	9,535	1,294,648	91

1_B	1	2	5,178	2,891	8,199	2,647,261	186
1_D	1	2	7,191	4,015	11,386	1,172,119	82
1_F	1	2	7,917	4,420	12,535	1,391,475	98
1_G	1	2	8,404	4,692	13,306	1,731,027	121
2_A	2	2	9,451	5,277	14,964	1,466,078	103
2_B	2	2	9,636	5,380	15,257	1,466,800	103
2_D	2	2	8,706	4,861	13,785	1,274,327	89
2_F	2	2	7,534	4,206	11,929	1,251,483	88
2_G	2	2	8,206	4,581	12,993	1,287,770	90
4_A	4	2	6,793	3,793	10,756	1,295,390	91
4_B	4	2	5,729	3,199	9,071	1,328,370	93
4_D	4	2	8,435	4,709	13,355	1,469,006	103
4_F	4	2	7,598	4,242	12,030	1,373,095	96
4_G	4	2	10,371	5,790	16,421	1,255,669	88
5_A	5	2	11,732	6,550	18,576	1,572,422	110
5_B	5	2	8,247	4,604	13,058	1,281,215	90
5_D	5	2	8,872	4,953	14,047	1,353,063	95
5_F	5	2	8,174	4,564	12,942	1,282,541	90
5_G	5	2	8,698	4,856	13,772	1,270,360	89
11_A	11	2	9,667	5,397	15,306	1,544,640	108
11_B	11	2	11,454	6,395	18,136	1,499,154	105
11_D	11	2	9,690	5,410	15,343	1,408,530	99
11_F	11	2	8,183	4,569	12,956	1,300,780	91
11_G	11	2	9,118	5,091	14,437	1,277,509	90
13_A	13	2	8,872	4,953	14,047	1,196,926	84
13_B	13	2	5,926	3,309	9,383	1,037,348	73
13_D	13	2	8,734	4,876	13,829	1,251,904	88
13_F	13	2	7,771	4,339	12,304	1,142,557	80
13_G	13	2	9,128	5,096	14,453	1,255,591	88
			Count	30	30	30	30
			Average	**4,679**	**13,270**	**1,379,302**	**97**
			Minimum	2,891	8,199	1,037,348	73
			COV	18.2%	18.2%	20.1%	20.1%

K (5th%, 75% conf)	1.645	1.645
5th (ave-ave*k*COV)	3,278	9,296
5th/2.1	**976**	**4,427**

White-fir Short Span Bending Values for #3 and Better Panels

Specimen	Panel	Grade	Maximum Load (lbf)	Shear Stress $f_{s,minor}$ (psi)	$V_{s,90}$ (lbf/ft of width)
3_2	3	3	17,465	265	8,733
3_4	3	3	14,828	225	7,414
3_6	3	3	18,127	275	9,064
3_8	3	3	16,384	248	8,192
6_2	6	3	20,228	306	10,114
6_4	6	3	21,213	321	10,607
6_6	6	3	19,559	296	9,780
6_8	6	3	21,166	321	10,583
7_2	7	3	18,644	282	9,322
7_4	7	3	19,833	301	9,917
7_6	7	3	19,078	289	9,539
7_8	7	3	19,037	288	9,519
10_2	10	3	21,383	324	10,692
10_4	10	3	23,993	364	11,997
10_8	10	3	23,182	351	11,591
12_2	12	3	20,084	304	10,042
12_4	12	3	22,424	340	11,212
12_6	12	3	15,769	239	7,885
12_8	12	3	19,033	288	9,517
			Count	19	19
			Average	**296**	**9,774**
			Minimum	225	7,414
			COV	12.4%	12.4%

K (5th%, 75% conf)	1.942	1.645
5th (ave-ave*k*COV)	225	7,785
5th/2.1	**67**	**3,707**

White-fir Short Span Bending Values for #2 and Better Panels

Specimen	Panel	Grade	Maximum Load (lbf)	Shear Stress $f_{s,minor}$ (psi)	$V_{s,90}$ (lbf/ft of width)
1_2	1	2	20,273	307	10,137
1_4	1	2	20,883	316	10,442

1_8	1	2	18,702	283	9,351
2_2	2	2	19,331	293	9,666
2_4	2	2	23,036	349	11,518
2_6	2	2	22,271	337	11,136
2_8	2	2	17,794	270	8,897
4_2	4	2	25,497	386	12,749
4_4	4	2	10,983	166	5,492
4_6	4	2	22,360	339	11,180
4_8	4	2	22,565	342	11,283
5_2	5	2	24,292	368	12,146
5_6	5	2	21,851	331	10,926
5_8	5	2	17,643	267	8,822
11_2	11	2	21,515	326	10,758
11_4	11	2	24,197	367	12,099
11_6	11	2	21,766	330	10,883
11_8	11	2	22,697	344	11,349
13_2	13	2	22,323	338	11,162
13_4	13	2	20,507	311	10,254
13_6	13	2	21,456	325	10,728
13_8	13	2	21,112	320	10,556
			Count	22	22
			Average	**319**	**10,524**
			Minimum	166	5,492
			COV	14.2%	14.2%

K (5th%, 75% conf)	1.645	1.645
5th (ave-ave*k*COV)	244	8,060
5th/2.1	**73**	**3,838**