SHEAR STRENGTH OF STRUCTURAL GLUED LAMINATED TIMBER BASED ON FULL-SIZE FLEXURE TESTS

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SUMMARY

In the Unites States, the allowable horizontal shear stresses of structural glued laminated timber (glulam) have been traditionally determined based on the procedures set forth in ASTM Standards D3737 and D2555 using block shear values of small-clear wood specimens as the basis. In recent years, however, information has been generated, suggesting that the allowable shear stresses so derived may be overly conservative when compared to the results of full-size flexure tests. Unfortunately, all available U.S. data on full-size glulam tests, as related to shear strength, were either proprietary or conducted using a non standard test method. Moreover, the different test setups used by these studies made the data comparison difficult. A systematic evaluation on major wood species used in the production of glulam in the U.S. based on a consistent full-size flexure test method was considered critical by the U.S. glulam industry to determine the appropriate allowable horizontal shear stresses for glulam.

During 1996-97, *APA - The Engineered Wood Association* conducted a total of 201 full-size tests on glulam manufactured with Douglas fir, Southern pine, and Spruce-Pine-Fir. A two-point load method with a clear distance between the edge of the reaction bearing plate to the edge of the nearest curved loading block of at least 2 times the specimen depth was used to test all specimens. Overall, 70% of the specimens failed in the targeted shear mode, indicating that the test method used in this study can be considered as a practical standard test method for determining the horizontal shear strength of glulam.

Results of this study indicated that the allowable horizontal shear stress for those species tested can be increased from the previously published values by a factor of at least 1.25, including a 10% reduction to allow for occasional seasoning checks. This paper provides detailed descriptions of the test methods, experimental results, and data analyses.

1. INTRODUCTION

Glued laminated timber (glulam) is used extensively throughout the United States in both residential and nonresidential applications. Nonresidential uses include commercial and industrial buildings, marinas, transmission structures, and pedestrian, highway and railroad bridges. While most applications are controlled by allowable bending stresses or stiffness, there are many situations in which horizontal shear is the controlling design stress. Examples include heavily loaded floor beams, bridge stringers, and cantilever or continuous beams.

In the Unites States, the allowable shear stresses for glulam have been traditionally determined based on the procedures set forth in ASTM D3737 [1] and D2555 [2] using block shear values of small-clear wood specimens. The shear reduction factor customarily applied to test results of small scale block shear specimens is 1/4.1, which is composed of the effects of load duration (10/16) and stress concentration (4/9), and a factor of safety (8/9).

In recent years, however, information has been generated, indicating that the allowable shear stresses so derived are overly conservative for glulam when compared to the results of full-size flexure tests [3,4,5]. This has been the subject of recent discussions at the ASTM D07 Committee on Wood and the ASTM D 07.02.02 Glulam Section Committee, and at glulam industry technical advisory committee meetings.

Based on the available data, it has been determined that the stress concentration factor of 4/9 is only applicable to small scale specimens and should be removed from the reduction factor for use with the results of full-size beam tests. It has been further determined that the factor of safety should be revised to be the same as the allowable flexural stress (10/13). Combining this with the duration of load factor of 10/16 results in a net reduction factor of 1/2.1 that can then be applied to the 5th percentile shear results obtained from full-size glulam beam tests to establish design shear values.

Unfortunately, all available data on full-size glulam tests, as related to shear strength, were either proprietary or conducted using a non-standard test method. Moreover, the different test setups used by the studies noted makes the comparison of test data difficult. A systematic evaluation on selected wood species used in the manufacture of glulam in the U.S. based on a consistent full-size flexure test method was therefore considered critical by the glulam industry to determine the appropriate design shear values for glulam.

In 1996, APA staff developed a study plan to determine the horizontal shear stress of glulam based on a full-size flexure test method. It was intended that the test results obtained from the study would be used to revise the design shear values published in the APA National Evaluation Service Report NER-486 [6] and other national design standards. This report provides detailed descriptions of the test methods, experimental results, and data analyses in accordance with this study plan.

2. OBJECTIVE

The main purpose of this study was to systematically evaluate the shear strengths of glulam for various wood species used in the manufacture of glulam in North America based on a full-size flexure test method.

3. MATERIALS

Three major wood species used in the manufacture of glulam in North America, these being Douglas fir (DF), Southern pine (SP), and Spruce-Pine-Fir (SPF), were identified for testing in this study. As the primary goal was to evaluate the shear strengths, it was essential to fail as many glulam specimens in shear as possible. In addition, it was considered critical that the specimen dimension should be sufficiently large so as to prevent the shear stress distribution from being affected by the interaction of the compressive stress perpendicular to grain.

Consequently, a specimen depth of approximately 457 mm (18 in.) with a simply supported test span (from the center of support to the center of support) of 3048 mm (10 ft) was selected, resulting in a span-to-depth ratio of approximately 6.7. This specimen dimension was also selected to represent the boundary size in which the allowable shear stress governs the design of typical residential floor beam construction [7]. It can be expected that either bending or deflection will control the design as the span-to-depth ratio increases.

All specimens were manufactured using full-length laminations without any end joints to induce failures in shear and not at an end joint in the critical tension zone of the test beams. The manufacturing processes followed the provisions of American National Standards Institute (ANSI) A190.1, *American National Standard for Wood Products -- Structural Glued Laminated Timber* [8]. Wet-use adhesives were used for face bonding of the laminations. APA staff was present during the lumber selection and manufacturing for all test specimens.

In this study, a total of 201 glulam beams, as shown in Table 1, was tested at the APA Research Center in Tacoma, Washington in the as-received indoor conditions without any moisture pre-conditioning. The layups for these beams are shown in Table 2. Based on previous industry experience in testing glulam beams, it was estimated that approximately 70% of the specimens would fail in shear using the test method selected.

The layups shown in Table 2 were based on commercially available combinations except that the tension laminations were generally up-graded to increase the probability of shear failure. The shear-critical core laminations were all carefully selected as being “on-grade.” The laminations used for manufacturing the specimens were Douglas fir grown west of the Cascade mountains, Southern pine grown in Southern Alabama and Southern Arkansas-Northern Louisiana, and Spruce-Pine-Fir grown in Southeast British Columbia, Canada. The actual sub-species of the species group was not microscopically determined.

	Douglas fir		Southern pine		Spruce-Pine-Fir
No. of beams	39	40	42	40	40
Net width (mm)	171 (6-3/4 in.)	79 (3-1/8 in.)	171 (6-3/4 in.)	79 (3-1/8 in.)	105 (4-1/8 in.)
Net depth (mm)	457 (18 in.)	457 (18 in.)	454 (17-7/8 in.)	454 (17-7/8 in.)	429 (16-7/8 in.)

Table 1. Specimens tested in this study.

Species	Tension zones			Core	Compression zones		
DF	1 - 302-26	1 - L1	1 - L2	6 - L3	1 - L2	1 - L1	1 - 302-26
SP	1 - 302-26	1 - N1D14	2 - N1D8	5 - N2M8	2 - N1D8	1 - N1D14	1 - 302-26
SPF	1 - 302-24	1 - 1.8E3	--	8 - 1.4E2	--	1 - 1.8E3	1 - 302-24

Table 2. Specimen layups.

4. TEST METHODS

A two-point load method, as shown in Figure 1, was applied to test all specimens. The test apparatus, including rocker-type reaction supports, reaction bearing plates and rollers, load bearing blocks, and load bearing rollers were set up following ASTM D198 [9].

The curved load bearing blocks had a chord length of 356 mm (14 in.) and a radius of curvature of 711 mm (28 in.). The clear distance between the edge of the bearing plate to the edge of the nearest load bearing block was 914 mm (36 in.) for all specimens, which was at least 2 times the specimen depth. This clear distance was regarded as critical to prevent the shear stress distribution from being influenced by the compressive stress perpendicular to grain [10]. All specimens were cut to the exact length of 3404 mm (134 in.) and no overhangs were allowed. Load was applied by a hydraulic cylinder at a constant rate so as to reach the ultimate load in about 10 minutes. Load readings were continuously recorded by a computerized data acquisition system up to the ultimate load. However, deflection readings were not recorded.

5. ANALYSIS METHODS

Based on the theory of elasticity, the flexural (f_b) and shear (f_v) stresses at the time of specimen failure were calculated using the following equations:

$$f_b = \frac{3\,P_{ult}\,a}{b\,h^2} \qquad \text{[Eq. 1]}$$

$$f_v = \frac{3\,P_{ult}}{4\,b\,h} \qquad \text{[Eq. 2]}$$

where:
f_b = flexural stress, N/mm^2 (psi),
f_v = shear stress, N/mm^2 (psi),
P_{ult} = ultimate total load, N (lbf),
a = distance between the reaction point to the nearest loading point, mm (in.),
b = measured beam width, mm (in.), and
h = measured beam depth, mm (in.)

The flexural stress of each specimen, as calculated from Eq. 1, was adjusted by a volume factor, C_v, in accordance with the *National Design Specification for Wood Construction* [11]. In addition, as the members were not pre-conditioned prior to testing, the moisture content adjustment factor, C_M, as shown in Eq. 3 based on ASTM D2915 [12], was used to adjust the test results to the standard 12% moisture content.

$$C_M = \frac{C_1 - C_2 \times 12}{C_1 - C_2 \times M} \qquad \text{[Eq. 3]}$$

where:
C_M = moisture content adjustment factor,
M = actual moisture content of the specimen, %,
C_1 = 1.75 for f_b and 1.33 for f_v, and
C_2 = 0.0333 for f_b and 0.0167 for f_v.

After testing, a 51-mm (2-in.) section was cut from each tested specimen at approximately 305 mm (12 in.) in from each beam end. The laminations other than the core laminations (L3 for DF, N2M8 for SP, and 1.4E2 for SPF) were then removed from these end sections. The resulting sections, which represented the core laminations, were then used to determine the moisture content and specific gravity of each beam in accordance with the oven-drying method of ASTM D4442 [13] and D2395 [14], respectively.

6. RESULTS AND DISCUSSIONS

6.1 Modes of failure

The summary of the failure modes for each species is shown in Table 3. Typically, the shear failure was initiated at one end of the specimen near the neutral axis or in the bottom half of the cross

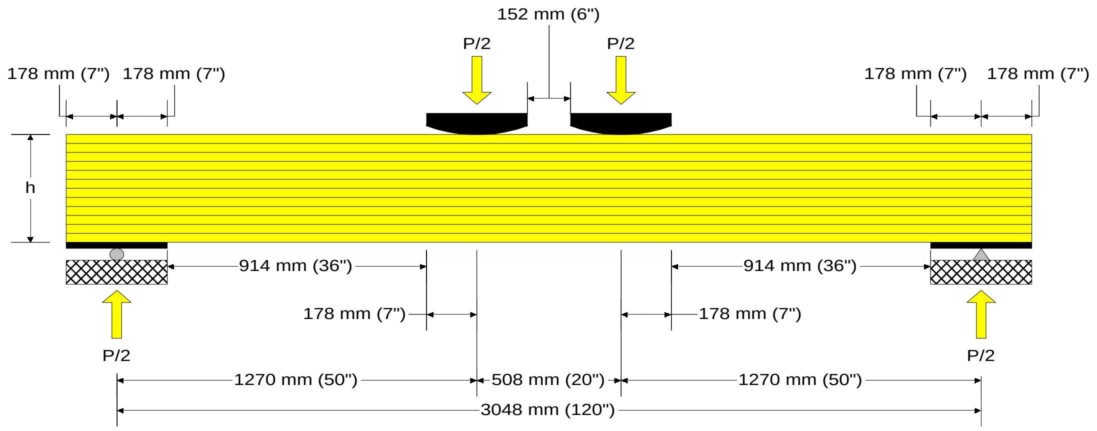

Figure 1. Test setup (see Table 1 for the depth, h, of each tested species).

	Number of specimens failed in each mode					
	DF		SP		SPF	Total
Width (mm)	171 (6-3/4”)	79 (3-1/8”)	171 (6-3/4”)	79 (3-1/8”)	105 (4-1/8”)	
Shear	32 (82.1%)	29 (72.5%)	26 (61.9%)	37 (92.5%)	17 (42.5%)	141 (70.1%)
Flexure	7 (17.9%)	9 (22.5%)	16 (38.1%)	3 (7.5%)	23 (57.5%)	58 (28.9%)
Bearing	0 (0%)	2 (5.0%)	0 (0%)	0 (0%)	0 (0%)	2 (1.0%)
Total	39 (100%)	40 (100%)	42 (100%)	40 (100%)	40 (100%)	201 (100%)

[(a)] Number in the parentheses is the percentage of specimens that failed in the specified mode.

Table 3 Summary of failure modes.[(a)]

section, which is consistent with the observations reported by Freas and Selbo [15]. The patterns of failure surface were similar for all tested species. In general, the failure surface followed a growth ring along the late wood and early wood interface of a flat-grained lamination and in some cases then jumped over to the adjacent growth rings or laminations.

From Table 3, the overall percentage of shear failure is 70%, which coincides with the anticipated shear failure rate previously mentioned. However, due to the relatively low percentage of shear failure for SPF, the test results were highly censored when the analysis is performed using all data combined. Therefore, it is necessary to conduct a censored data analysis for each species and tested width.

For the censored data analysis, the uncensored mean and standard deviation can be estimated by using the methodology for the maximum likelihood estimators (MLEs), as described in Lawless [16]. The estimates of the uncensored statistics from the highly censored data are critical due to the fact that although the uncensored mean is expected to be higher than the mean based on the censored data, the standard deviation might also be higher. As a result, the characteristic value (5th percentile with 75% confidence) based on the uncensored data may or may not actually be higher than the value determined from the censored statistics.

6.2 Shear and flexural stresses

Table 4 shows the summary statistics for the moisture content and specific gravity of the core materials obtained from all 201 specimens. The summary statistics for the calculated shear and flexural stresses after being adjusted to the standard moisture content of 12% are given in Table 5. The flexural stresses have been further adjusted by a volume factor. It should be noted that the dead weight of the specimen was not included in the calculations. In addition, the calculated shear and flexural stresses represented the stress states at failure and might not represent the ultimate shear

	DF		SP		SPF
Width (mm)	171 (6-3/4 in.)	79 (3-1/8 in.)	171 (6-3/4 in.)	79 (3-1/8 in.)	105 (4-1/8 in.)
N	39	40	42	40	40
MC - Mean (%)	11.4	11.5	11.0	10.3	14.5
SG[(a)] - Mean	0.43	0.43	0.51	0.47	0.40

[(a)] Based on the oven-dry weight and as-received volume of the core laminations only.

Table 4. Summary statistics for moisture content and specific gravity.

	DF		SP		SPF
Width (mm)	171 (6-3/4 in.)	79 (3-1/8 in.)	171 (6-3/4 in.)	79 (3-1/8 in.)	105 (4-1/8 in.)
Shear failure only					
N	32	29	26	37	17
f_v, Mean (N/mm^2)	4.40 (639 psi)	4.66 (676 psi)	5.38 (780 psi)	5.24 (760 psi)	4.34 (630 psi)
f_v, COV	0.070	0.085	0.098	0.092	0.130
f_b, Mean (N/mm^2)	48.9 (7095 psi)	48.0 (6957 psi)	59.8 (8669 psi)	55.7 (8075 psi)	51.8 (7507 psi)
f_b, COV	0.071	0.086	0.098	0.091	0.130
All failure modes combined					
N	39	40	42	40	40
f_v, Mean (N/mm^2)	4.33 (628 psi)	4.60 (667 psi)	5.41 (785 psi)	5.22 (757 psi)	4.18 (616 psi)
f_v, COV	0.089	0.086	0.100	0.092	0.112
f_b, Mean (N/mm^2)	48.1 (6970 psi)	47.4 (6868 psi)	60.1 (8718 psi)	55.5 (8045 psi)	50.6 (7341 psi)
f_b, COV	0.089	0.086	0.100	0.090	0.111

[(a)] Calculated stresses adjusted for moisture content and volume effect (f_b only) at time of specimen failure.

Table 5. Summary statistics for shear and flexural stresses.[(a)]

and flexural strengths unless the specimen happened to fail in the specific mode.

The data distribution for those specimens that failed in shear is shown in Figure 2 with an empirical normal distribution function overlaid. It should be noted that there was one 79-mm (3-1/8-in.) wide DF specimen that was noted to contain an off-grade ring shake that extended from the wide face into the thickness at an angle less than 45 degrees from the wide face, which is not permitted by industry standards [17]. This specimen ultimately failed at the lowest shear value of 3.35 N/mm^2 (486 psi) among all 40 specimens of the same size, including those that failed in a flexural or bearing mode. Although this test result can be statistically quantified as an outlying observation at the 5% significance level in accordance with ASTM E178 [18], it was still included in the data analysis to be conservative. Similarly, the SPF specimen that failed at the lowest adjusted shear strength of 2.88 N/mm^2 (418 psi) was included in the data analysis even though it can also be statistically justified as an outlying observation.

Using the MLE method, the uncensored mean and standard deviation for the shear strength of each tested width were calculated based on all data combined (censored data), as shown in Table 6. When compared to the results obtained from the specimens that failed in shear (see Table 5), the MLE method in general gives a comparable mean and COV.

According to the statistics given in Tables 5 and 6, the parametric estimates of the shear strength at the 5th percentile with 75% confidence (characteristic values) can be determined following the procedures given in ASTM D2915 [12]. Tables 7 and 8 show the estimates based on the normal and lognormal distribution functions. The assumed normality for both distribution functions cannot be rejected at the 20% statistical significance level for all tested species and widths in accordance with the Kolmogorov-Smirnov test statistics (the higher the significance level, the easier to reject the null hypothesis assuming the same distribution). In fact, the characteristic values determined from both types of distribution functions are generally similar.

7. ALLOWABLE SHEAR STRESSES

7.1 Douglas fir glulam

As noted from Table 7, the characteristic values for DF, as derived from the shear-failure-only data and the MLE method, are all higher than the values determined from the all-failure-modes-combined data. From a statistical viewpoint, the values obtained from the MLE method can be inferred as being better than the conservative estimates calculated from the censored data (all failure modes combined).

Therefore, it is justifiable to establish the characteristic shear value for each tested width based on the lower value between the MLE estimates and the characteristic value determined from the shear-failure-only data. As a result, the characteristic shear value of 3.83 N/mm^2 (555 psi) based on the normal distribution and 3.92 N/mm^2 (568 psi) based on the lognormal distribution was determined, respectively, for the 171-mm (6-3/4-in.) and 79-mm (3-1/8-in.) wide specimens for deriving the allowable shear stress.

Using the reduction factor of 1/2.1 (see Section 1), the allowable shear stress can be calculated as 3.83/2.1 or 1.83 N/mm^2 (265 psi) for 171-mm (6-3/4-in.) wide and 3.92/2.1 or 1.87 N/mm^2 (270 psi) for 79-mm (3-1/8-in.) wide DF glulam. Due to the small difference in the allowable shear stress between the tested widths, a single value of 1.83 N/mm^2 (265 psi) was established for DF glulam of all widths.

7.2 Southern pine glulam

As noted from Table 7, the characteristic values for SP, as derived from the shear-failure-only data and the MLE method, are not always higher than the values determined from the all-failure-modes-combined data. For example, for the 171-mm (6-3/4-in.) wide specimens, the characteristic value determined from the all-failure-modes-combined data is higher than the value obtained from the shear-failure-only data due in part to the large difference in the sample size. As the characteristic value based on the all-failure-modes-combined data can be regarded as a conservative estimate of the actual shear strength, it is prudent in this case to use such a value for deriving the allowable shear stress even though the use of a higher value based on the MLE method may be justifiable.

As a result, the characteristic shear value can be estimated as 4.43 N/mm^2 (642 psi) for 171-mm (6-3/4-in.) wide and 4.35 N/mm^2 (631 psi) for 79-mm (3-1/8-in.) wide SP glulam based on the normal distribution. Using the reduction factor of 1/2.1, the allowable shear stress is calculated as 2.10 N/mm^2 (305 psi) for 171-mm (6-3/4-in.) wide and 2.07 N/mm^2 (300 psi) for 79-mm (3-1/8-in.) wide SP glulam. Due to the small difference in the allowable shear stress between the tested widths, a single value of 2.07 N/mm^2 (300 psi) was assigned to SP glulam of all widths.

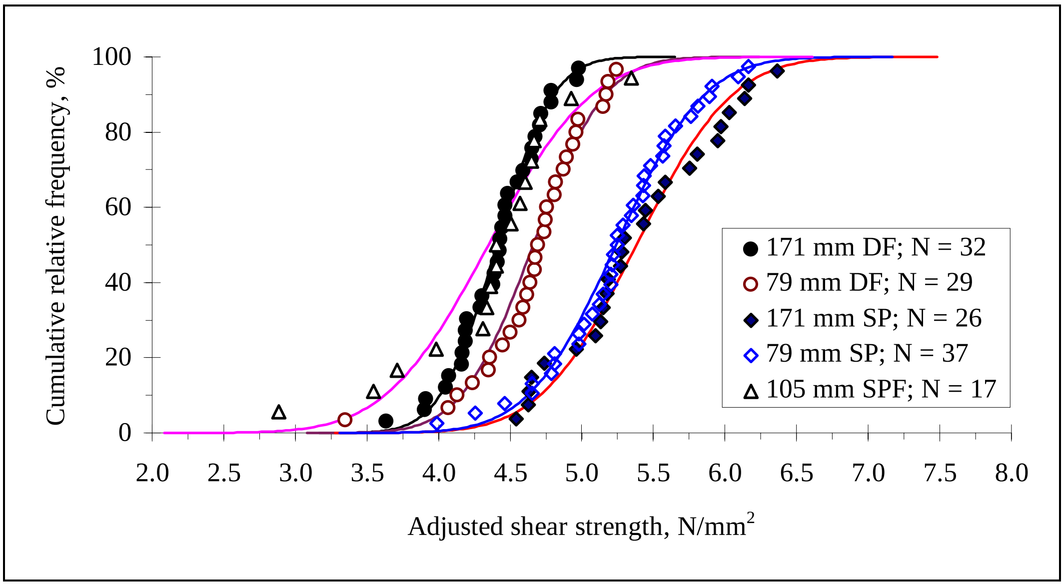

Figure 2. Shear strengths with an empirical normal distribution function overlaid.

	DF				SP				SPF	
Width (mm)	171 (6-3/4 in.)		79 (3-1/8 in.)		171 (6-3/4 in.)		79 (3-1/8 in.)		105 (4-1/8 in.)	
Distrib. type	Nml	LN	Nml	LN	Nml	LN	Nml	LN	Nml	LN
Mean (N/mm^2)	4.43	4.43	4.73	4.74	5.66	5.67	5.26	5.26	4.66	4.72
Stdev (N/mm^2)	0.31	0.32	0.39	0.43	0.62	0.65	0.48	0.49	0.57	0.67
COV	0.070	0.073	0.082	0.090	0.110	0.115	0.090	0.094	0.122	0.144

Table 6. Estimated statistics from the censored data analyses using the MLE technique.

	171 mm (6-3/4 in.)			79 mm (3-1/8 in.)		
	N	Characteristic value (N/mm^2)		N	Characteristic value (N/mm^2)	
		Normal	Lognormal		Normal	Lognormal
DF						
Shear failure only	32	3.83 (555 psi)	3.85 (558 psi)	29	3.92 (569 psi)	3.91 (568 psi)
All failure modes combined	39	3.62 (525 psi)	3.63 (527 psi)	40	3.88 (562 psi)	3.88 (562 psi)
MLE estimates	39	3.86 (560 psi)	3.84 (557 psi)	40	4.02 (583 psi)	3.96 (574 psi)
SP						
Shear failure only	26	4.39 (636 psi)	4.46 (646 psi)	37	4.35 (631 psi)	4.38 (635 psi)
All failure modes combined	42	4.43 (642 psi)	4.48 (650 psi)	40	4.34 (629 psi)	4.37 (634 psi)
MLE estimates	42	4.52 (655 psi)	4.48 (650 psi)	40	4.39 (636 psi)	4.36 (632 psi)

Table 7. Parametric estimates of the characteristic shear strengths for DF and SP.

	105 mm (4-1/8 in.)		
	N	Characteristic value (N/mm^2)	
		Normal	Lognormal
Shear failure only	17	3.23 (469 psi)	3.26 (473 psi)
All failure modes combined	40	3.38 (490 psi)	3.40 (493 psi)
MLE estimates$^{(b)}$	40	3.61 (524 psi)	3.48 (504 psi)

Table 8. Parametric estimates of the characteristic shear strengths for SPF.

7.3 Spruce-Pine-Fir glulam

As the difference in the allowable shear stress between the tested widths for both DF and SP was negligible, only one net width, 105 mm (4-1/8 in.), was tested for SPF. This width was selected based on the available resource at the glulam plant fabricating the SPF specimens. Note that the width effect on the shear strength of SPF glulam was previously reported as insignificant by another study [19].

As noted from Table 8, the characteristic values for SPF, as derived from the MLE method, are all higher than the values determined from the censored data (all failure modes combined). In addition, the characteristic value determined from the all-failure-modes-combined data is higher than the value based on the shear-failure-only data. As the characteristic value based on the all-failure-modes-combined data can be regarded as a conservative estimate of the actual shear strength, it is appropriate to use such a value for deriving the allowable shear stress even though the use of a higher value from the MLE method is justifiable.

Therefore, the characteristic shear value for the SPF glulam can be estimated as 3.38 N/mm^2 (490 psi) based on the normal distribution. Using the reduction factor of 1/2.1, the allowable shear stress can be calculated as 1.62 N/mm^2 (235 psi) for SPF glulam independent of width.

7.4 Allowance for checking

An important consideration when establishing the allowable horizontal shear stress for wood is the allowance for checking or splits which may occur in service. Although the degree of in-service checking normally observed for glulam, as compared to sawn timber, is considerably less severe, it has been a common practice for the glulam industry in the U.S. to publish reduced allowable shear stresses to account for possible in-service checking. In November 1997, the APA Glulam Technical Advisory Committee adopted a 10% reduction to allow for checking based on these new test results and the past industry practice.

Applying this 10% reduction to the test results gives an allowable shear stress of 1.65 N/mm^2 (240 psi) for Douglas fir, 1.86 N/mm^2 (270 psi) for Southern pine, and 1.45 N/mm^2 (210 psi) for Spruce-Pine-Fir glulam. It should be noted that the higher shear stress values as previously mentioned could be applied to un-checked glulam.

Note that seasoning checks in glulam most commonly occur along the first glueline adjacent to an outer lamination due to the exposure of the larger surface area of the outer lamination to the environment. However, at a given cross section along the beam length, the shear stress at the first glueline is significantly lower than the shear stress at the neutral axis and varies with beam depth. Therefore, the 10% checking allowance should permit typical in-service checks (occurring at the first glueline) that are considerably deeper than 10% of the glulam width without impairing the structural integrity of the member.

In addition, checks frequently occur in the radial direction of a lamination and do not coincide with the shear surface, which typically occurs along growth rings. This is distinctly different from sawn lumber joists whose checks often occur near the neutral axis in the radial direction of the growth rings and are mostly likely to coincide with the maximum shear plane. As such, the 10% checking allowance is likely to still be conservative even when a 10% deep check does occur at the neutral axis of a glulam beam that is controlled by shear.

7.5 Calibration factors

The allowable shear stresses for glulam have been traditionally developed in the U.S. based on the provisions given in ASTM D3737 [1] using the clear wood shear stress data (unseasoned condition) published in ASTM D2555 [2]. For SPF glulam, the calculated values for all sub-species in this species group is in the range of 1.00 to 1.07 N/mm^2 (145 to 155 psi). As the actual sub-species for the SPF tested in this study was not determined, the ratio between the minimum and maximum calculated shear stresses for this species group, 1.00/1.07, was used to adjust the allowable shear value derived above to account for the possibility that the actual tested sub-species might have been the higher strength sub-species, such as Black spruce, Jack pine, and/or Lodgepole pine. Therefore, the allowable shear stress for SPF glulam after the 10% reduction for checking becomes 1.45 × 1.0/1.07 or 1.35 N/mm^2 (195 psi). It should be noted that the species calibration factor is equal to 1.0 for both DF and SP glulam.

According to the discussions given above, Table 9 compares the new allowable shear stresses derived from this study with those previously published based on the traditional small-clear block shear values. The variation in the new and previously published values can be regarded as the difference in the procedures used to derive the design value between the full-size tests and the small block shear tests. Then, when generalized, this information can be used as a calibration factor for adjusting the design values derived from small-clear block shear data.

	F_v (N/mm^2)		
	DF	SP	SPF
New[(a)]	1.65	1.86	1.35[(b)]
Previous[(c)]	1.31	1.38	1.00
Ratio	1.26	1.35	1.35

(a) Based on the results obtained from this study and reduced by 10% to allow for checking.
(b) Adjusted for the sub-species effect.
(c) Based on ASTM D3737 and D2555.

Table 9. Procedural calibration factor.

It is noted that the three species tested in this study represent about 85% of total glulam production in North America today. Since it is not feasible to conduct full-size tests on all species used in the manufacture of glulam in the U.S., it was decided that the lowest ratio given in Table 9 could be used to determine the shear stress for those species not tested. As a result, the allowable shear stress for the species other than DF, SP, and SPF can be established by multiplying the previously published value by the procedural calibration factor of 1.25.

7.6 Limitations on use of results

It is very important to realize that these new allowable shear values obtained from this study are intended to be limited to prismatic glulam members subjected to typical dead, live, snow, wind, and earthquake loads only. The allowable shear stresses for impact or cyclic loading, such as may occur in bridges or crane rail applications, have not been evaluated. Neither have the effects of these higher shear stresses been accounted for in the design of non-prismatic members which are typically subjected to an interaction of shear stresses with other stresses. For these applications, the previously published shear values, which have been proven adequate through years of experience, should be retained for design use.

8. CONCLUSIONS

The following conclusions are based on the results obtained from this study:

- The setup used in this study can be used to evaluate the shear strength of full-size glulam.
- The width effect on the characteristic shear strength was determined to be negligible for DF and SP glulam members and assumed to be negligible for all other species.
- The allowable shear stress can be assigned as 1.65 N/mm^2 (240 psi) for DF, 1.85 N/mm^2 (270 psi) for SP, and 1.35 N/mm^2 (195 psi) for SPF glulam members, which includes a 10% allowance for checking.
- The allowable shear stresses derived from the small-clear block shear data using the existing procedures given in ASTM D3737 can be increased by a factor of 1.25, including a 10% allowance for checking, to determine the shear stress values for those species not tested.

As a final note, results obtained from this study have been accepted by the major building code agencies in the U.S. and the new allowable shear values are being used by the wood engineering community.

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