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# EVALUATION OF GLULAM SHEAR STRENGTH USING A FULL-SIZE FOUR-POINT TEST METHOD

by

Borjen Yeh
T G Williamson
APA - The Engineered Wood Association

U.S.A.

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# Evaluation of Glulam Shear Strength Using A Full-Size Four-Point Test Method

Borjen Yeh, Ph.D., P.E.
Thomas G. Williamson, P.E.
*APA - The Engineered Wood Association, U.S.A.*

## Abstract

The shear strengths of structural glued laminated timber (glulam) have been traditionally evaluated in the United States based on the procedures set forth in ASTM Standards D3737 and D2555 using small block shear values of clear wood specimens. For most glulam products, the design shear stresses so derived are conservative. In recent years, the demand to optimize the design shear stress has been increased due to a higher design shear stress offered by competing structural wood composites, such as laminated veneer lumber (LVL) and parallel strand lumber (PSL).

Since 1997, APA has conducted a series of full-size shear tests on glulam manufactured with Douglas fir, Southern pine, and Spruce-Pine-Fir. A four-point load method with a clear distance between the edge of the reaction bearing plate to the edge of the nearest curved load bearing block of at least 2 times the specimen depth was used to test all specimens. Based on this experience, the full-size shear test method has been adopted in ASTM D3737 as a standard test method for determining the horizontal shear strength of glulam. This paper provides detailed descriptions of the test methods, experimental results, and data analyses.

The test results obtained from this study indicate that the characteristic shear strength values based on full-size shear tests are approximately 70% of the values determined from small block shear tests. However, the allowable horizontal shear stress could be increased by a factor of at least 1.25, including a 10% reduction to allow for occasional seasoning checks. This increase can be attributed in part to the difference in the procedures used to derive the design value between the full-size and small block shear tests.

## 1. Introduction

Glued laminated timber (glulam) has been extensively used in North America 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 bending stress or stiffness, there are 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 United States, the design (allowable) shear stresses for glulam have been traditionally determined based on the procedures set forth in ASTM D3737 [1] and D2555 [2] using small block shear values of 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 shear tests [3,4,5]. Based on the available data, it has been determined that the stress concentration factor of 4/9 is only applicable to small block shear specimens and should be removed from the reduction factor for use with the results of full-size shear 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 shear tests to establish design shear values.

Since 1997, APA has conducted a series of full-size shear tests on glulam manufactured with Douglas fir, Southern pine, and Spruce-Pine-Fir. This report provides detailed descriptions of the test methods, experimental results, and data analyses.

## 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 four-point 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 [6]. 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, but 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* [7]. 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.

A series of glulam beams, as shown in Table 1, were tested at the APA Research Center in Tacoma, Washington, in the as-received indoor conditions without any moisture preconditioning. The layups for these beams are shown in Table 2, which were designed to achieve a targeted 70% failure rate in shear using the test method selected.

Table 1. Specimen cross sections

| Species | DF | | SP | | SPF |
|---|---|---|---|---|---|
| Replicates | 39 | 40 | 42 | 40 | 40 |
| Net width | 171 mm (6-3/4 in.) | 79 mm (3-1/8 in.) | 171 mm (6-3/4 in.) | 79 mm (3-1/8 in.) | 105 mm (4-1/8 in.) |
| Net depth | 457 mm (18 in.) | 457 mm (18 in.) | 454 mm (17-7/8 in.) | 454 mm (17-7/8 in.) | 429 mm (16-7/8 in.) |

Table 2. Specimen layups

| 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 |

This shear failure rate was estimated by equating the predicted 25$^{th}$ percentile of the bending strength to the anticipated 95$^{th}$ percentile of the shear strength of the glulam. The bending strength of the glulam was predicted by using the GAP computer program that was developed by APA and is recognized by the major building code evaluation services as an alternative method for determining design stresses of a given layup combination of glulam [8]. The shear strength of the glulam was estimated based on the authors' experience and the information obtained from the literature [3,9,10,11].

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 were not microscopically determined.

# 4. Test Methods

A four-point load method, as shown in Figure 1, was applied to test all specimens. In this case, the four-point load method is considered superior to the center-point load method as the compressive stress perpendicular to grain under the load point is reduced to 1/2 of the compressive stress perpendicular to grain under the center-point load. This test setup significantly alleviates the wood crushing under the load point, which could interfere with the shear stress distribution in the specimen [9].

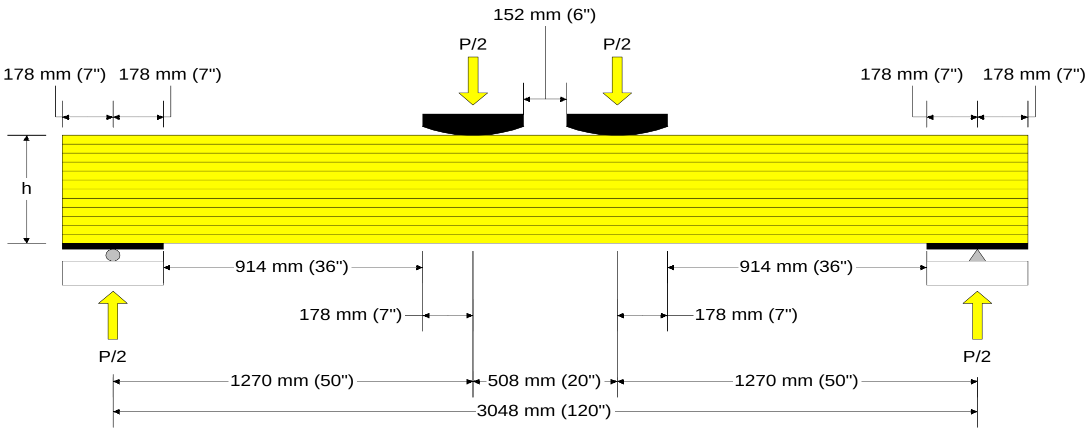


Figure 1. Test setup (see Table 1 for the depth, h, of each tested species)

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 [12]. 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 [9]. 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. The 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:

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

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

where:

$f_b$ = flexural stress, MPa (psi),
$f_v$ = shear stress, MPa (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* [13]. 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 [14], 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 [15] and D2395 [16], respectively.

# 6. Results and Discussions

## 6.1 Modes of failure

The summary of the failure modes for each tested 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 section, which is consistent with the observations reported by Freas and Selbo [10]. 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.

Table 3. Summary of failure modes

| Modes of failure | Percentage of specimens failed in each mode | | | | | |
|---|---|---|---|---|---|---|
| | DF | | SP | | SPF | Total |
| | 171 mm (6-3/4 in.) | 79 mm (3-1/8 in.) | 171 mm (6-3/4 in.) | 79 mm (3-1/8 in.) | 105 mm (4-1/8 in.) | |
| Shear | 82% | 73% | 62% | 92% | 43% | 70% |
| Flexure | 18% | 22% | 38% | 8% | 57% | 29% |
| Bearing | 0% | 5% | 0% | 0% | 0% | 1% |

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 maximum likelihood estimators (MLEs) described in Lawless [17]. 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 censored mean, the uncensored standard deviation might be also higher than the censored standard deviation. As a result, the characteristic value (5th percentile with 75% confidence) based on the uncensored data may or may not be actually higher than the value determined from the censored statistics.

## 6.2 Shear and flexural strengths

Table 4 shows the summary statistics for the moisture content and specific gravity of the core materials obtained from all specimens. The summary statistics for the calculated shear and flexural strengths after being adjusted to the standard moisture content of 12% are given in Table 5. The flexural strengths 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 strengths represented the stress states at failure and might not represent the ultimate shear and flexural strengths unless the specimen happened to fail in the specific mode.

Table 4. Summary statistics for moisture content and specific gravity[(a)]

| | DF | | SP | | SPF |
|---|---|---|---|---|---|
| | 171 mm (6-3/4 in.) | 79 mm (3-1/8 in.) | 171 mm (6-3/4 in.) | 79 mm (3-1/8 in.) | 105 mm (4-1/8 in.) |
| N | 39 | 40 | 42 | 40 | 40 |
| Mean MC | 11.4% | 11.5% | 11.0% | 10.3% | 14.5% |
| Mean SG | 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 5. Summary statistics for shear and flexural strengths[(a)]

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

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

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 [18]. This specimen ultimately failed at the lowest shear value of 3.35 MPa (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 [19], 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 MPa (418 psi) was included in the data analysis even though it can also be statistically justified as an outlying observation.

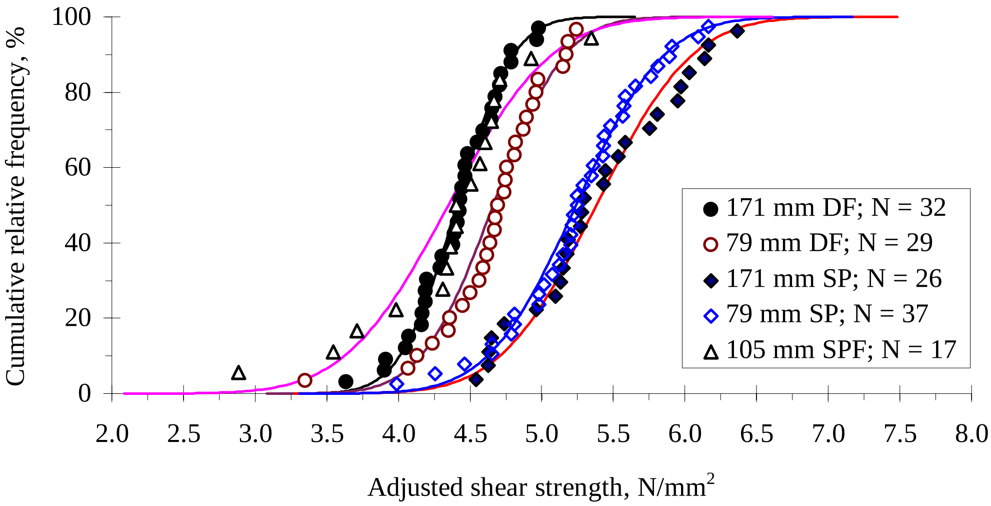


Figure 2. Shear strengths with an empirical normal distribution function overlaid

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.

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

| | DF | | SP | | SPF |
|---|---|---|---|---|---|
| | 171 mm (6-3/4 in.) | 79 mm (3-1/8 in.) | 171 mm (6-3/4 in.) | 79 mm (3-1/8 in.) | 105 mm (4-1/8 in.) |
| Normal Distribution | | | | | |
| Mean | 4.43 MPa (642 psi) | 4.73 MPa (686 psi) | 5.66 MPa (821 psi) | 5.26 MPa (763 psi) | 4.66 MPa (676 psi) |
| COV | 0.070 | 0.082 | 0.110 | 0.090 | 0.122 |
| Lognormal Distribution | | | | | |
| Mean | 4.43 MPa (642 psi) | 4.74 MPa (687 psi) | 5.67 MPa (822 psi) | 5.26 MPa (763 psi) | 4.72 MPa (684 psi) |
| COV | 0.073 | 0.090 | 0.115 | 0.094 | 0.144 |

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 [14]. The characteristic value for each tested species will be discussed below.

# 7. Characteristic Shear Strength

## 7.1 Douglas fir glulam

Table 7 shows the estimated characteristic values for DF glulam based on 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.

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

| | 171 mm (6-3/4 in.) | | | 79 mm (3-1/8 in.) | | |
|---|---|---|---|---|---|---|
| | N | Characteristic value | | N | Characteristic value | |
| | | Normal | Lognormal | | Normal | Lognormal |
| Shear failure only | 32 | **3.83 MPa (555 psi)** | 3.85 MPa (558 psi) | 29 | 3.92 MPa (569 psi) | **3.91 MPa (568 psi)** |
| All failure modes combined | 39 | 3.62 MPa (525 psi) | 3.63 MPa (527 psi) | 40 | 3.88 MPa (562 psi) | 3.88 MPa (562 psi) |
| MLE estimates | 39 | 3.86 MPa (560 psi) | 3.84 MPa (557 psi) | 40 | 4.02 MPa (583 psi) | 3.96 MPa (574 psi) |

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 MPa (555 psi) based on the normal distribution and 3.91 MPa (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. These values are significantly lower (approximately 30%) than the characteristic value of 5.50 MPa (798 psi) derived from the small block shear values given in ASTM D2555 [2] and adjusted to the standard moisture content of 12%.

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 MPa (265 psi) for 171-mm (6-3/4-in.) wide and 3.91/2.1 or 1.87 MPa (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 allowable value of 1.83 MPa (265 psi) was established for DF glulam of all widths. This value is significantly higher (approximately 35%) than the allowable shear value of 1.35 MPa (195 psi) based on the characteristic shear strength of the small block shear (5.50 MPa or 798 psi) multiplied by the reduction factor of 1/4.1 (see Section 1). This increase can be attributed in part to the difference in the adjustment factors used to derive the allowable shear stress based on full-size and small block shear test results.

## 7.2 Southern pine glulam

Table 8 shows the estimated characteristic values for SP glulam based on normal and lognormal distribution functions. As noted from Table 8, 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 characteristic shear strength even though the use of a higher value based on the MLE method may be justifiable.

Table 8. Parametric estimates of the characteristic shear strengths for SP glulam

| | 171 mm (6-3/4 in.) | | | 79 mm (3-1/8 in.) | | |
|---|---|---|---|---|---|---|
| | N | Characteristic value | | N | Characteristic value | |
| | | Normal | Lognormal | | Normal | Lognormal |
| Shear failure only | 26 | 4.39 MPa (636 psi) | 4.46 MPa (646 psi) | 37 | 4.35 MPa (631 psi) | 4.38 MPa (635 psi) |
| All failure modes combined | 42 | **4.43 MPa (642 psi)** | 4.48 MPa (650 psi) | 40 | **4.34 MPa (629 psi)** | 4.37 MPa (634 psi) |
| MLE estimates | 42 | 4.52 MPa (655 psi) | 4.48 MPa (650 psi) | 40 | 4.39 MPa (636 psi) | 4.36 MPa (632 psi) |

As a result, the characteristic shear value can be estimated as 4.43 MPa (642 psi) for 171-mm (6-3/4-in.) wide and 4.34 MPa (629 psi) for 79-mm (3-1/8-in.) wide SP glulam based on the normal distribution. These values are approximately 25% lower than the characteristic value of 5.66 MPa (820 psi) derived from the small block shear values given in ASTM D2555 [2] and adjusted to the standard moisture content of 12%.

Again, the allowable shear stress can be calculated as 2.10 MPa (305 psi) for 171-mm (6-3/4-in.) wide and 2.07 MPa (300 psi) for 79-mm (3-1/8-in.) wide SP glulam using the reduction factor of 1/2.1. Due to the small difference in the allowable shear stress between the tested widths, a single value of 2.07 MPa (300 psi) was assigned to SP glulam of all widths. This value is approximately 50% higher than the allowable shear value of 1.38 MPa (200 psi) based on the characteristic shear strength of the small block shear (5.66 MPa or 820 psi) multiplied by the reduction factor of 1/4.1 (see Section 1).

## 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 in another study [11].

The estimated characteristic values for SPF glulam based on normal and lognormal distribution functions are given in Table 9. As noted from Table 9, 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 characteristic shear strength even though the use of a higher value from the MLE method is justifiable.

Table 9. Parametric estimates of the characteristic shear strengths for SPF

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

Therefore, the characteristic shear value for the SPF glulam can be estimated as 3.38 MPa (490 psi) based on the normal distribution. This value is approximately 20% lower than the characteristic value of 4.10 MPa (595 psi) derived from the small block shear values given in ASTM D2555 [2] and adjusted to the standard moisture content of 12%.

Again, the allowable shear stress can be calculated as 1.62 MPa (235 psi) for SPF glulam using the reduction factor of 1/2.1. This value is approximately 60% higher than the allowable shear value of 1.00 MPa (145 psi) based on the characteristic shear strength of the small block shear (4.10 MPa or 595 psi) multiplied by the reduction factor of 1/4.1.

## 7.4 Allowance for checking

An important consideration when establishing the design shear stress for large dimension timber 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. The APA Glulam Technical Advisory Committee adopted a 10% reduction in 1997 to allow for checking based on full-size shear test results and the past industry practice.

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 Procedural calibration factors

The characteristic shear strength and allowable shear stress for glulam have been traditionally developed in the U.S. based on the provisions given in ASTM D3737 [1] using the small block shear data published in ASTM D2555 [2]. For SPF glulam, the calculated values for all sub-species in the SPF species group are in the range of 1.00 to 1.07 MPa (145 to 155 psi). As the actual sub-species for the SPF glulam 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 characteristic and allowable shear values 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. 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 10 compares the characteristic and allowable shear values derived from this study with those previously published based on the traditional small 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 and 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.

Table 10. Procedural calibration factor

| | DF | | SP | | SPF | |
|---|---|---|---|---|---|---|
| | $f_{v,g,k}$ | Allowable | $f_{v,g,k}$ | Allowable | $f_{v,g,k}$ | Allowable |
| Full-size shear[a] | 3.83 MPa (555 psi) | 1.66 MPa (240 psi)[b] | 4.34 MPa (629 psi) | 1.86 MPa (270 psi)[b] | 3.16 MPa (458 psi)[c] | 1.35 MPa (195 psi)[b,c] |
| Small block shear[d] | 5.50 MPa (798 psi) | 1.35 MPa (195 psi) | 5.66 MPa (820 psi) | 1.38 MPa (200 psi) | 4.10 MPa (595 psi) | 1.00 MPa (145 psi) |
| Ratio | 0.70 | 1.23 | 0.77 | 1.35 | 0.77 | 1.35 |

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

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 shear tests on all species used in the manufacture of glulam in the U.S., it was decided that the lowest ratio given in Table 10 could be used to determine the shear stress for those species not tested. As a result, the characteristic shear strength and allowable shear stress for the species other than DF, SP, and SPF can be established by multiplying the small block shear value by the procedural calibration factor of 0.70 and 1.25, respectively. The allowable shear stress derived using this procedural calibration factor includes a 10% allowance for checking.

## 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. ASTM D3737 adopted this test method in October 2000 as an alternative standard test method for determining the horizontal shear strength of glulam. Since then, this test method has been used by other researchers in the United States for evaluating glulam shear strength of ponderosa pine with equally satisfactory results [20].

- 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 characteristic shear strength and allowable shear stress for the species other than DF, SP, and SPF can be established by multiplying the small block shear value by the procedural calibration factor of 0.70 and 1.25, respectively. The allowable shear stress derived using this procedural calibration factor includes a 10% allowance for checking.

- 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.

# 9. References


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