CIB-W18/39-12-3

INTERNATIONAL COUNCIL FOR RESEARCH AND INNOVATION IN BUILDING AND CONSTRUCTION

WORKING COMMISSION W18 - TIMBER STRUCTURES

EFFECT OF CHECKING AND NON-GLUED EDGE JOINTS ON THE SHEAR STRENGTH OF STRUCTURAL GLUED LAMINATED TIMBER BEAMS

B Yeh

T G. Williamson

Z A Martin

APA - The Engineered Wood Association

U.S.A.

MEETING THIRTY-NINE

FLORENCE

ITALY

AUGUST 2006

Effect of Checking and Non-Glued Edge Joints on the Shear Strength of Structural Glued Laminated Timber Beams

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

Abstract

Shear strength of structural glued laminated timber (glulam) beams may be affected by the in-service conditions or manufacturing processes. While glulam is typically manufactured with kiln-dry lumber and therefore less susceptible to checking and splitting, glulam beams still check or split, usually at the first or second glueline and at the beam ends, as they gain or lose moisture in response to direct exposure to water, changing relative humidity and temperature in the surrounding environment.

Literature is available for determining the effect of checks or splits on the horizontal shear strength of glulam beams based on conservative assumptions. It is not uncommon for the architect, builder or homeowner to be alarmed when a significant check or split is found on a glulam beam. In many instances, however, the check or split may have limited influence on the horizontal shear strength of a glulam beam and the structural integrity of the glulam beam is not compromised. In order to define the boundaries of checks or splits, upon which the influence of such checks or splits can be safely ignored, APA - The Engineered Wood Association (APA) conducted a series of full-scale glulam beam tests based on the most common configurations and locations of checks or splits.

The glulam manufacturing processes may also affect the horizontal shear strength of a glulam beam. For example, the U.S. design code reduces the horizontal shear strength of a glulam beam when manufactured with non-glued edge joints using multiple pieces of side-by-side lumber and loaded in the direction parallel to the wide face of the laminations (y-y axis). The shear strength reduction is not required when such a glulam beam is loaded in the direction perpendicular to the wide face of the laminations (x-x axis). However, there is only limited data available to substantiate these cases. In support of a revision to the Japanese Agricultural Standard (JAS) for Structural Glued Laminated Timber, APA conducted a series of full-scale glulam beam tests to evaluate the effect of non-glued edge joints in multiple-piece layups on the horizontal shear strength of glulam beams. This paper describes the test results and findings from the checking and non-glued edge joint studies.

1. Introduction

Shear strength of structural glued laminated timber (glulam) beams may be affected by the in-service conditions or manufacturing processes. While glulam is typically manufactured with kiln-dry lumber and therefore less susceptible to checking and splitting, glulam beams still check or split, usually at the first or second glueline and at the beam ends, as it gains or loses moisture in response to direct exposure to water, changing relative humidity and temperature in the surrounding environment.

It is not uncommon for the architect, builder or homeowner to be alarmed when a significant check or split is found on a glulam beam. In fact, the effect of checking on the structural integrity of glulam beams is one of the most frequently asked questions received by the APA Helpdesk, which provides technical and educational support to timber engineers, specifiers, builders, distributors, building officials, and general public. In many instances, the check or split may be of limited influence on the horizontal shear strength of a glulam beam and the structural integrity of the glulam beam is not compromised.

While there are mathematical models, such as the fracture mechanics and finite element method, that are available for analyzing the effect of checks on glulam strength, most designers in the U.S. typically prefer to use a less sophisticated method, such as the prescriptive methods published by the glulam industry in North America [1]. In general, the glulam industry has recommended a simple methodology by proportioning the shear strength with the remaining unchecked cross section for side checks at the shear critical zone, defined as the areas at both ends of a simply supported beam within a distance from each end equal to 3 times the beam depth and within the middle 1/2 depth of the beam. For example, for a side check of 1/4 of the beam width, the shear strength of the glulam is assumed to be 3/4 of the published design value. Note that the length of the side check is not regarded as a factor. For end checks or splits, the effect is governed by the length of the end check, which is assumed to be 1/3 of a side check. For example, an end check of 30 mm (1.18 in.) in length is considered to be equivalent to a side check of 10 mm (0.39 in.) into the beam width.

While these simplistic guidelines have been successfully used in North America for years, there is very limited data available to support them. Furthermore, the existing methodology requires an engineering analysis to determine the extent of the strength reduction as long as there are any checks present. Throughout the years, many designers have expressed their desire to have an even simpler methodology by quantifying the limitation of checks upon which the effect of checks can be safely ignored. Accordingly, APA conducted a series of full-scale bending tests on glulam beams made with artificial checks, as described in the following sections.

On a related subject, the effect of non-glued edge joints in multiple-piece width layups on the glulam shear strength was recently questioned by glulam experts in Japan. In the U.S. design code, the horizontal shear strength of a glulam beam is reduced when the glulam beam is manufactured with non-glued edge joints in the laminations and loaded in the direction parallel to the wide face of the laminations (y-y axis). However, the shear strength reduction is not required when the glulam beam is loaded in the direction perpendicular to the wide face of the laminations (x-x axis). These code provisions have very limited data available to substantiate them. In support of a revision to the JAS glulam standard [2], APA conducted a series of full-scale glulam beam tests in November 2005 to evaluate the effect of non-glued edge joints on the horizontal shear strength of glulam beams.

2. Materials and Test Methods

2.1 Checking Study

Glulam beams with no glue on a portion of the wide face of certain laminations were manufactured to simulate the effect of seasoning checks. Two sets of artificially checked beams were manufactured and tested. One set of beams had “checks” (unglued faces) in the ends (Group E), while the other set had a check in the middle (Group M) of the beam span at the first glueline. Note that the end checks were actually full-width splits that represent the worse case conditions for a check or split.

Douglas-fir glulam beams with a dimension of 130 mm x 457 mm x 4724 mm (5-1/8 in. x 18 in. x 186 in.) were manufactured in accordance with the *American National Standard for Wood Products - Structural Glued Laminated Timber*, ANSI A190.1 [3], using the 24F-V4/DF layup combination that is the most popular in the U.S. The beam size was selected in accordance with the full-scale test setup for evaluating the shear strength of glulam beams, as specified in Annex A7 of ASTM D3737 [4], with the exception that the span-to-depth ratio was set at 10:1 and the loading was applied at the third points of the span. The span-to-depth ratio of 10:1 was determined based on a structural analysis as the critical ratio for the shear strength to govern the ultimate beam performance for a simply supported beam subjected to uniform loads. When the span-to-depth ratio is greater than 10:1, the bending strength or deflection is expected to govern the beam design. The locations of the unglued faces used to simulate the seasoning checks are shown in Figures 1 and 2. The bearing plates were 152 mm (6 in.) in length.

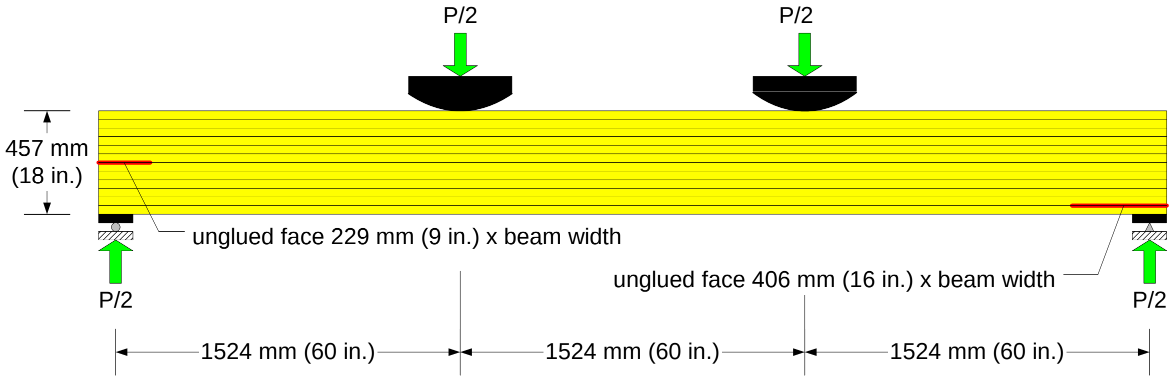

Figure 1. Group E beam test setup, and size and location of unglued faces

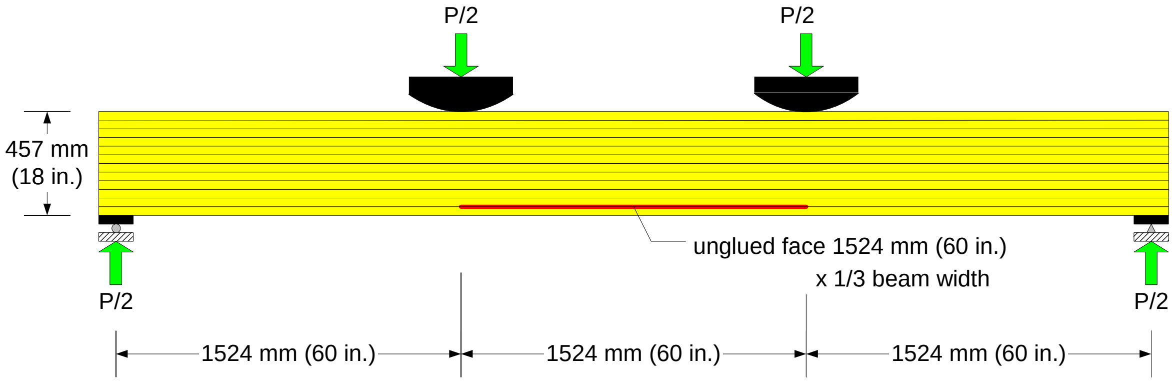

Figure 2. Group M beam test setup, and size and location of unglued faces

The locations of the unglued faces for Group E beams (Figure 1) were selected to evaluate the end checks in a "green zone", as shown in Figure 3. Based on a survey of major glulam distributors in North America, the end check within the green zone represents the vast majority of end checks observed in the field. It was anticipated that within the "green zone," the end checks, as simulated by the unglued faces, would not affect the beam performance. The location of the unglued faces for Group M beams (Figure 2) was intended for the evaluation of the side checks in the moment critical zone due to the frequently occurred checks at the first glueline. The actual depth of the side check manufactured into Group M beams was 51 mm (2 in.), which is 1/3 of the nominal beam width of 152 mm (6 in.).

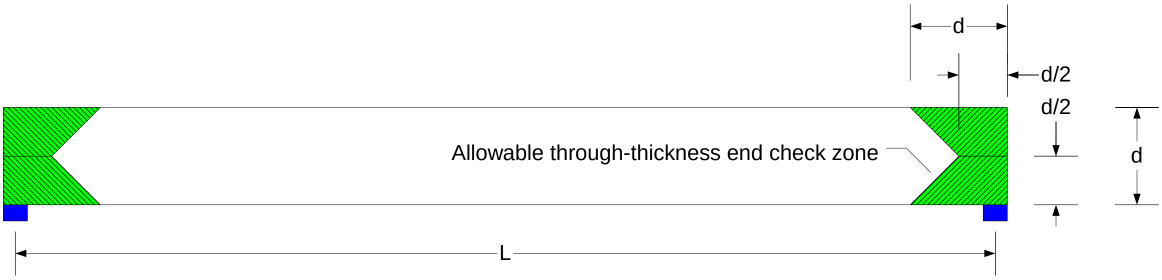

Figure 3. “Green zone” for end checks or splits

In order to create the unglued faces, wax paper and tape were used to cover a portion of a lamination as it went through a glue spreader, as shown in Figures 4 through 6. The tape and wax paper were then removed, leaving a clean non-glued face on the lamina, before the beam layup and clamping.

Figure 4. Taped wax paper was applied to a lamina as glue was spread (Group E)

Figure 5. Taped wax paper was then removed from the lamina prior to clamping (Group E)

2.2 Non-Glued Edge Joint Study

The glulam beams used for the non-glued edge joint study were manufactured with Douglas-fir laminations using the JAS E120-F330 layup combination. Since the objective of this study was to evaluate the effect of non-glued edge joints on the glulam shear strength, the tested beams were manufactured without end joints to minimize bending failures. The beam sizes and non-glued edge joints are shown in Figures 7 and 8.

Figure 6. Tape used to create unglued surface (Group M)

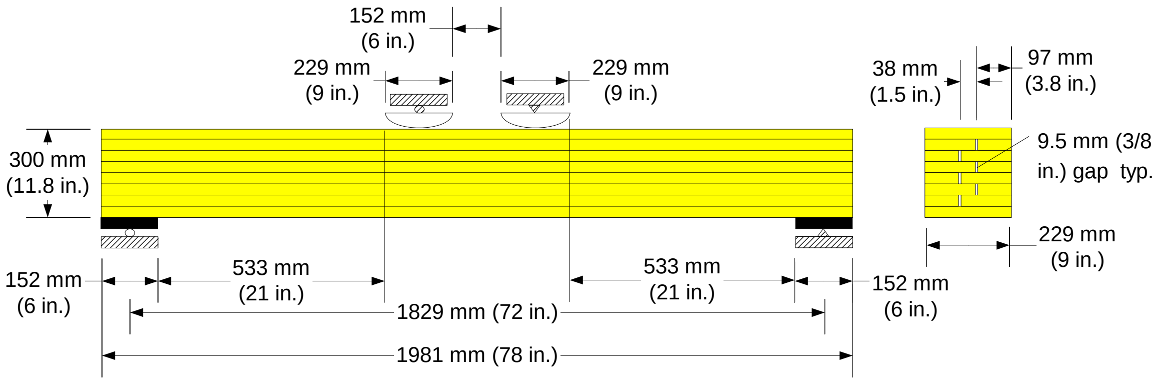

Figure 7. Group X beams

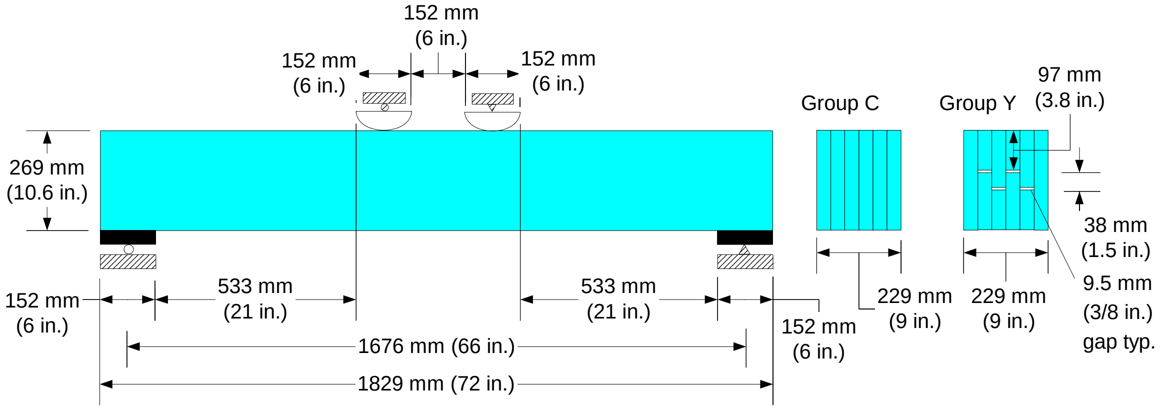

Figure 8. Groups C and Y beams

The face laminations for all beams tested in this study were full width. Middle and inner laminations for Group X in the x-x orientation and Group Y in the y-y orientation were not edge-glued. The gap of the non-glued edge joints between side-by-side lumber laminations was manufactured to 9.5 mm (3/8-in.), which is the maximum gap permitted in ANSI A190.1 [3]. The "control" beams (Group C in the y-y orientation) were manufactured from full-width laminations in accordance with the JAS E120-F330 layup combination.

3. Test Methods

Full-scale beam tests were conducted in accordance with ASTM D198 [5] and D3737 [4]. All beams were tested in the as-received conditions. The mean moisture content and specific gravity (based on oven-dry weight and as-received volume) of the glulam beams used in the checking study was approximately 14% and 0.46, respectively.

4. Results and Discussions

4.1 Checking Study

A summary of test results is given in Tables 1 and 2. All beams failed in bending for both beam groups with the exception of Beam E6, which failed in shear (at the end check location), and Beam M9, which failed as a result of bearing failure at one of the end reactions. Note that the mean MOR values from both beam groups are very similar and the minimum MOR values are still at the expected level, 2.1 x 16.5 or 34.7 MPa, (2.1 x 2,400 or 5,040 psi) for 24F glulam beams despite the simulated checks at the shear and moment critical zones. Beam E6 that failed in shear at the end check location still had a shear strength, 2.96 MPa (430 psi), which meets the allowable shear stress of 2.92 MPa (265 x 1.6 or 424 psi) for Douglas-fir glulam beams after taking into account the short load duration at test. These results suggest that the glulam beam performance is not compromised by the end checks and side checks tested in this study.

Table 1. Summary of test results for Group E beams

Beam #	Width (mm)	Depth (mm)	Max Load (kN)	Bending Stress[(a)] (MPa)	Shear Stress[(a)] (MPa)	Failure Mode
E1	130.3	457.2	232.7	39.1	2.93	Bending
E2	129.9	457.2	207.9	35.0	2.62	Bending
E3	130.0	457.2	217.9	36.7	2.75	Bending
E4	130.0	457.2	216.0	36.3	2.73	Bending
E5	129.9	457.2	210.7	35.5	2.66	Bending
E6	130.1	457.2	235.0	39.5	2.96	Shear
E7	130.0	455.6	247.0	41.8	3.13	Bending
E8	129.7	456.4	270.3	45.7	3.42	Bending
E9	129.5	456.4	219.1	37.1	2.78	Bending
E10	130.2	454.8	243.7	41.4	3.09	Bending
E11	129.7	455.6	246.0	41.8	3.12	Bending
E12	129.8	454.8	238.0	40.5	3.02	Bending
N	12	12	12	12	12	
Minimum	129.5	454.8	207.9	35.0	2.62	
Maximum	130.3	457.2	270.3	45.7	3.42	
Mean	129.9	456.4	232.0	39.2	2.93	
COV	--	--	0.079	0.082	0.081	

[(a)] Stress at the time of beam failure

Table 2. Summary of test results for Group M beams

Beam #	Width (mm)	Depth (mm)	Max Load (kN)	Bending Stress[(a)] (MPa)	Shear Stress[(a)] (MPa)	Failure Mode
M1	129.6	457.2	268.8	45.4	3.40	Bending
M2	129.7	457.2	280.0	47.2	3.54	Bending
M3	129.9	457.2	215.9	36.3	2.73	Bending
M4	129.9	457.2	231.7	39.0	2.93	Bending
M5	129.8	457.2	226.6	38.2	2.86	Bending
M6	130.1	457.2	224.4	37.7	2.83	Bending
M7	130.1	457.2	251.3	42.2	3.17	Bending
M8	129.7	456.4	211.2	35.8	2.68	Bending
M9	130.0	456.4	239.2	40.4	3.02	End bearing
N	9	9	9	9	9	
Minimum	129.6	456.4	211.2	35.8	2.68	
Maximum	130.1	457.2	280.0	47.2	3.54	
Mean	129.9	457.0	238.8	40.2	3.02	
COV	--	--	0.099	0.099	0.099	

[(a)] Stress at the time of beam failure

4.2 Non-Glued Edge Joint Study

The Group X beam results (shear in the x-x orientation with non-glued edge joints) are given in Table 3. All 3 beams failed in shear.

Table 3. Summary of test results for Group X beams

Beam #	Width (mm)	Depth (mm)	Max Load (kN)	Bending Stress[a] (MPa)	Shear Stress[a] (MPa)	Failure Mode
X1	231.7	302.4	394.7	40.4	4.22	Shear
X2	231.8	302.2	392.7	40.3	4.20	Shear
X3	231.8	303.0	425.4	43.4	4.54	Shear
Mean	231.8	302.5	404.2	41.4	4.32	
COV	--	--	0.045	0.043	0.044	

[a] Stress at the time of beam failure

The mean shear strength of these beams, 4.32 MPa (627 psi), is comparable to the mean shear strength of 4.41 MPa (639 psi), as reported in CIB W18/34-12-2 [6] for 171-mm (6-3/4-inch) wide Douglas-fir glulam beams without any edge joints (full-width laminations). Therefore, the non-glued edge joints in this study did not have an effect on the shear strength of glulam beams in the x-x orientation.

The Group C (control without edge joints) and Group Y beam test results (shear in the y-y orientation with non-glued edge joints) are given in Tables 4 and 5. Noted that 4 out of 10 Group C beams failed in bending. This percentage of shear failure is parallel to the results given in CIB-W18/34-12-2 [6]. On the other hand, all Group Y beams failed in shear. With this difference in failure modes, the data can be compared as follows:

Table 4. Summary of test results for Group C (control) beams

Beam #	Width (mm)	Depth (mm)	Max Load (kN)	Bending Stress[a] (MPa)	Shear Stress[a] (MPa)	Failure Mode
C1	228.0	271.1	428.7	52.7	5.20	Bending
C2	228.8	271.1	450.8	55.1	5.45	Shear
C3	227.4	270.6	438.1	54.1	5.34	Bending
C4	227.9	271.2	407.7	50.0	4.95	Shear
C5	228.9	270.6	440.5	54.1	5.33	Bending
C6	229.8	270.8	420.8	51.4	5.07	Shear
C7	229.3	270.8	444.1	54.3	5.36	Shear
C8	229.0	270.7	308.5	37.8	3.73	Shear
C9	229.0	270.7	442.5	54.2	5.35	Bending
C10	229.0	270.9	398.0	48.7	4.81	Shear
N	10	10	10	10	10	
Minimum	227.4	270.6	308.5	37.8	3.73	
Maximum	229.8	271.2	450.8	55.1	5.45	
Mean	228.7	270.9	418.0	51.3	5.06	
COV	--	--	0.101	0.101	0.101	

[a] Stress at the time of beam failure

1) If the difference in the failure mode is ignored, the mean shear strength of 4.32 MPa (626 psi) for Group Y beams is about 85% of the mean shear strength of 5.06 MPa (734 psi) for Group C beams. Similarly, the minimum shear strength of 3.64 MPa (528

psi) for Group C is about 98% of the minimum shear strength of 3.73 MPa (541 psi) for Group C beams. Note that the minimum shear strength for Group C beams was caused by a shear failure.

Table 5. Summary of test results for Group Y beams

Beam #	Width (mm)	Depth (mm)	Max Load (kN)	Bending Stress[(a)] (MPa)	Shear Stress[(a)] (MPa)	Failure Mode
Y1	229.1	270.2	370.7	45.6	4.49	Shear
Y2	228.7	270.1	299.8	37.0	3.64	Shear
Y3	228.9	270.5	328.1	40.3	3.97	Shear
Y4	229.5	271.2	383.4	46.7	4.62	Shear
Y5	228.7	270.8	382.9	47.0	4.64	Shear
Y6	229.0	270.7	385.3	47.3	4.66	Shear
Y7	229.4	271.1	334.2	40.8	4.03	Shear
Y8	228.8	270.5	341.8	42.0	4.14	Shear
Y9	229.0	271.2	395.6	48.3	4.78	Shear
Y10	229.1	270.8	348.6	42.7	4.22	Shear
N	10	10	10	10	10	
Minimum	228.7	270.1	299.8	37.0	3.64	
Maximum	229.5	271.2	395.6	48.3	4.78	
Mean	229.0	270.7	357.1	43.8	4.32	
COV	--	--	0.087	0.086	0.086	

[(a)] Stress at the time of beam failure

2) If the data due to bending failure in Group C is ignored, the mean shear strength for Group C beams that failed in shear is 4.90 MPa (710 psi). Therefore, the mean shear strength of 4.32 MPa (626 psi) for Group Y is about 88% of the mean shear strength of 4.90 MPa (710 psi) for Group C beams. The comparison on the minimum shear strength, as given in 1) above, remains unchanged.

Based on the methodology currently adopted by the glulam industry in the U.S., the Group Y beams with non-glued edge joints would be designed with 2/3 of the shear strength of the Group C (control) beams because the non-glued edge joints result in a 1/3 less area at the critical shear plane. However, according to the analysis given above, the glulam beams with non-glued edge joints in the y-y orientation have 85 - 88% of the shear strength obtained from the control beams. Therefore, results from this study confirm that the methodology currently adopted by the glulam industry in the U.S. is quite conservative.

5. Conclusion

Based on the test results, the presence of unbonded areas between laminations, as could be caused by seasoning checks, does not affect the performance of glulam beams. A new publication on this subject, *Owner's Guide to Understanding Checks in Glued Laminated Timber* [7] was developed and released by APA in March 2006. Figure 9 shows a flow chart included in the Guide, which provides simple guidance for evaluating glulam checks. Note that an engineering analysis is still required when a check exceeds the limitations specified in the Guide. For simplistic reasons, the Guide does not prescribe the "green zone" shown in Figure 3, which is justifiable based on the test data given in this paper.

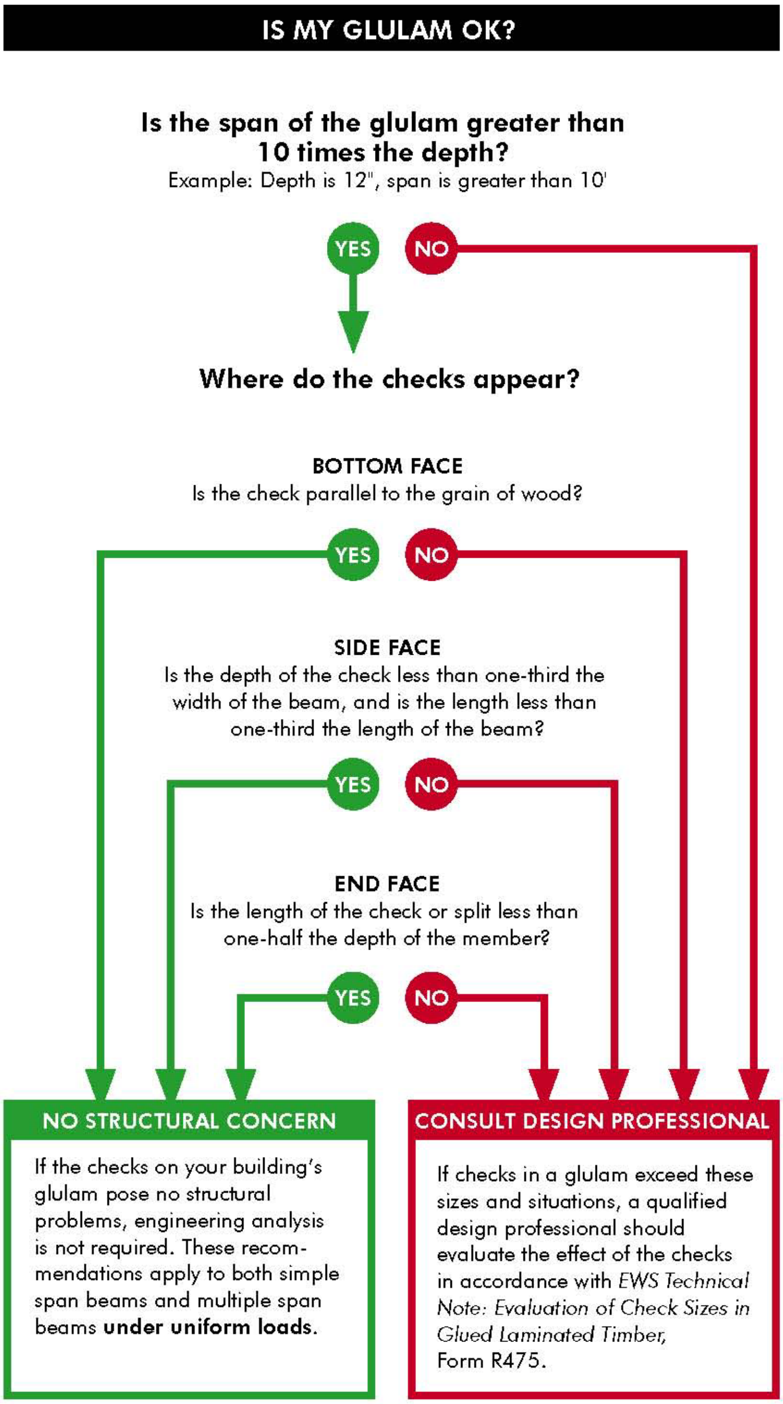

Figure 9. Guidelines for evaluating glulam checks

For the non-glued edge joints, the glulam shear strength is not affected by the non-glued edge joints in the x-x orientation based on the test results reported above. The effect of non-glued edge joints on the glulam shear strength in the y-y orientation can be conservatively estimated in accordance with the methodology currently adopted by the glulam industry in the U.S. These results have been used to support the revision of the JAS glulam standard to permit the use of non-edge glued joints in the core and inner laminations of JAS glulam beams. Further research on a more realistic strength reduction factor due to non-glued edge joints is recommended.

6. References

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