EVALUATING BEARING PROPERTIES OF WOOD PEG CONNECTION USING FOUR DIFFERENT TEST METHODS

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Abstract. The objective of this study was to evaluate appropriate test methods for the bearing properties of wood peg connection using four different test methods: ASTM D 5764 (2013), the method of Church and Tew (1997), the method of Schmidt and Daniels (1999), and the method of Schmidt and Mackay (1997). Bearing properties of wood peg connection were compared using digital image correlation. Although ASTM D 5764 (2013), the method of Church and Tew (1997), or the method of Schmidt and Daniels (1999) could not differentiate bearing properties by peg orientation, the method of Schmidt and Mackay (1997) could differentiate such properties by peg orientation. ASTM D 5764 (2013), the method of Church and Tew (1997), and the method of Schmidt and Daniels (1999) created unrealistic strain distributions which affected yield load determined from the load–displacement curve. The method of Schmidt and Mackay (1997) showed the highest strain distribution at the bearing area between the wood peg and the main member, resulting in load–displacement curve by bearing mainly. These results suggest that the method of Schmidt and Mackay (1997) could determine the bearing properties of wood peg connection.

Keywords: Bearing properties, connection, digital image correlation, stress, strain, wood peg.

INTRODUCTION

Wood peg connections have been used in traditional timber frame buildings for connecting beam to column, column to column, and beam to beam. Depending on the bearing strength of wood materials used for the main member and the wood peg, the bearing strength of wood peg connection could be determined. To design wood peg connections, predicting the strength of wood peg connection associated with failure behavior and a guideline for determining the end distance of wood peg are required.

Burnett et al (2003) investigated the effect of end distance of wood peg on stiffness and strength of wood peg connections. Double shear test was conducted for different main members and side members made of Douglas-fir (*Pseudotsuga menziesii*), eastern white pine (*Pinus strobus*), and northern red oak (*Quercus rubra*) using northern red oak peg. The stiffness of wood peg joint from these three species did not decrease with a decrement in end distance. The strength was decreased with a decrement in end distance when Douglas-fir (*P. menziesii*) was used as the main member for wood peg joint. However, the strength was not decreased with a decrement of end distance up to 50% of National Design Specification requirement (AWC 2015) when

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eastern white pine or northern red oak was used as the main member.

Shanks and Walker (2009) predicted the strength and stiffness of wood peg connection using energy approach and a four-point bending analogy. The analytical model assumed that wood peg showed idealized elastoplastic behavior and the yield load was dependent on shear span and yield moment of wood peg. By assuming that most energy was absorbed by wood peg, the strength and stiffness of wood peg connection were predicted.

Sandberg et al (2000) have developed a prediction equation for the bearing strength of wood peg connection. Red oak (*Q. rubra*) wood peg and white pine (*P. strobus*) or sugar maple (*Acer saccharum*) main members were used in their study. The strength of the wood peg connection was determined from six different failure modes for double shear of wood peg connection. The first four failure modes were similar to the failure modes shown in NDS. Two additional failure modes were a bearing failure in the peg and a shear failure in the peg. A prediction equation for the stiffness of wood peg connection was suggested. It could be used to predict mortise and tenon joint based on the stiffness of the wood peg and the main member.

Miller et al (2010) suggested a design method for shear yield of wood peg. The predicted equation for yield stress of peg was developed based on the peg and base material–specific gravities. A reduction factor of 3.44 for the shear yield of wood peg was calculated using the ratio between predicted yield equation from least square regression and the predicted equation from the Monte Carlo simulation.

Although the bearing strength of wood peg connection could be predicted based on previous studies (Sandberg et al 2000; Miller et al 2010) and the end distance of wood peg connection was guided from Burnet et al (2003), the predicted bearing strength of differently oriented wood peg and main member should be determined based on a reliable experimental test. The standard for designing timber frame structures and commentary (TFEC 1 2007) has provided design guidelines for wood peg connections and suggested three different approaches to determine the bearing properties of wood peg connection in TFEC 1 (2007).

Different approaches can be used to determine the bearing properties of wood peg connections based on previous studies, including Church and Tew (1997), Schmidt and Mackay (1997), Schmidt and Daniels (1999), and ASTM (2013). Church and Tew (1997) applied a modified bearing strength of wood peg connection. Effects of peg orientation, peg diameter, orientation of main member, main member species, and hole clearance on the bearing strength of wood peg connection were determined. Their results showed that peg orientation, peg diameter, and hole clearance did not significantly influence the bearing strength of wood peg connection. However, orientations of main member significantly influenced the bearing strength of wood peg connection.

Schmidt and Mackay (1997) suggested a dowel-bearing test fixture to determine the bearing properties of differently oriented wood peg connections. Schmidt and Daniels (1999) suggested a prediction equation to determine the bearing strength of wood peg connection. This prediction equation was based on two separate experimental tests for the stiffness of the wood peg and the main member. From the sum of the load of the wood peg and the main member at the same displacement, a load–displacement curve of wood peg connection was plotted and the yield load was determined with a 5% offset.

In this study, different test methods including the method of Schmidt and Mackay (1997), the method of Church and Tew (1997), the method of Schmidt and Daniels (1999), and ASTM D 5764 (2013) were used to determine the bearing properties of differently oriented wood peg connections. Strain distribution around the bearing area was examined. In addition, statistical comparisons of different test methods were conducted to determine the effect of wood peg orientation on the bearing strength.

MATERIAL AND METHODS

Materials

Differently oriented main members and wood pegs made of ash (*Fraxinus rhynchophylla*) are shown in Fig 1. Main members were fabricated from 120 × 120 × 3600-mm 5-ply glulam made of Japanese cedar (*Cryptomeria japonica*) from Kyungmin Co., Ltd (South Korea). Specific gravity of the main member was 0.37. The size of the main member was 120 × 120 × 140 mm. A 20-mm half hole was bored using a drill. To find a reliable test method for wood peg connection, two different orientations of the main member (radial-longitudinal [RL] and tangential-longitudinal [TL]) and 20-mm-diameter wood peg were prepared. The first letter indicated the plane parallel to the length direction of wood peg whereas the second letter indicated the loading direction. Specific gravity of wood peg was 0.63. Two different wood peg grain directions (parallel to the load direction [PA] and perpendicular to the load direction [PE]) were tested with different orientations of the main member.

Methods

To determine the bearing properties of wood peg connection, the methods of ASTM D 5764 (2013), Church and Tew (1997), Schmidt and Daniels (1999), and Schmidt and Mackay (1997) were compared. For each test method, a minimum of 20 specimens were conducted. Universal testing machine equipped with a 150-kN load cell was used to apply compression load. The load was applied at a loading rate of 1 mm/min until the load was dropped 60% from the peak load.

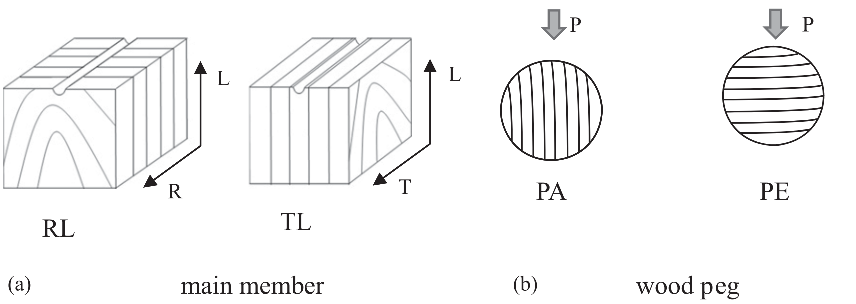
Figure 2 shows different test methods for evaluating the bearing properties of wood peg connections. Figure 2(a) shows ASTM D 5764. It applies the load directly to the wood peg. Figure 2(b) shows the method used by Church and Tew (1997). It applies the load to the main member to avoid crushing of the wood peg. Figure 2(c) shows the method of Schmidt and Daniels (1999). For this method, two separate bearing tests are conducted for the main member and the wood peg. Load–displacement curves from the main member and the wood peg are analytically combined to calculate the bearing properties of wood peg connection using Eq 1. The bearing strength of wood peg in PA and PE is then determined (Fig 2(c)).

$$\frac{1}{K_{\text{total}}}=\frac{1}{K_{\text{peg}}}+\frac{1}{K_{\text{base}}}, \tag{1}$$

where

K_{total}: stiffness of wood peg connection;
K_{peg}: stiffness of wood peg;
K_{base}: stiffness of main member.

Figure 2(d) shows the method of Schmidt and Mackay (1997). It uses a metal plate with a



L : Longitudinal, R : Radial, T : Tangential

Figure 1. Differently oriented main member (radial-longitudinal [RL] and tangential-longitudinal [TL], the first letter indicates the length direction of wood peg and the second letter indicates the loading direction) and wood peg (parallel to the load direction [PA]: the grain of wood is parallel to the loading direction; perpendicular to the load direction [PE]: the grain of wood is perpendicular to the loading direction).

semicylindrical slot to prevent crushing of wood peg. The load is applied to the main member. In the four different methods, the bearing strength (σ_b) was determined using Eq 2:

$$\text{Bearing strength (MPa)} = \frac{P_y}{(T \times D)}, \quad (2)$$

where

P_y: 5% offset yield load (N);
T: Thickness of the bearing specimen (mm);
D: Diameter of wood peg (mm).

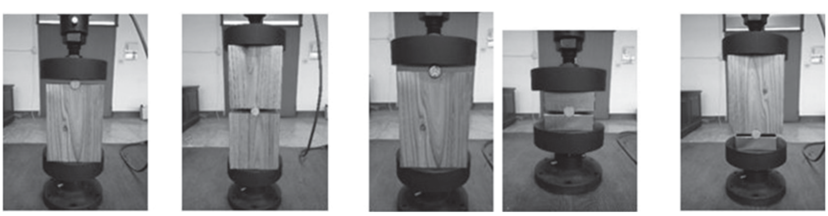
Figure 3 shows experimental test setup associated with digital image correlation (DIC) to determine the bearing strength and strain distributions of differently oriented wood peg connections. To analyze strain distribution of wood peg connection, a DIC technique was applied. Two charge-coupled device (CCD) cameras were mounted on a stereo plate with a distance of 35 cm between the two cameras. The angle of the camera was adjusted to see the same point of view of the specimen. The distance between the camera and object was 50 cm to provide enough field of view to analyze strain distribution of the specimen and obtain clear images. To obtain proper contrast, an LED lamp was used to light the specimen evenly.

Image of the specimen surface was taken at a rate of 10 frames per second until the specimen failed or after yield. The resolution of the image was 640 × 480 pixel. The pixel dimension was 7.4 μm × 7.4 μm. DIC was conducted using Aramis software (GOM). Figure 4 shows a path definition to analyze strain values along path directions. To analyze strain x, strain y, and shear strain xy along the path, 100 data points were defined along the path.

Two-way analysis of variance (ANOVA) comparison with an alpha value of 0.05 was used for statistical comparisons among bearing strength values of differently oriented bearing specimens using the four test methods. The null hypothesis was that all bearing strength means from differently oriented bearing specimen were equal to each other. Comparisons between RL-PA and RL-PE, TL-PA and TL-PE, RL-PA and TL-PA, RL-PA and TL-PE, RL-PE and TL-PA, and RL-PE and TL-PE were conducted.

RESULTS AND DISCUSSION

Figure 5 shows the bearing properties of differently oriented specimens determined by the four test methods. Two solid lines indicated the average bearing strength of wood pegs in PA and PE. Dotted lines indicated standard deviation of the bearing strength of wood pegs. The bearing strength values of wood peg in PA and PE determined from experimental tests were important because these values could show the maximum bearing strength of wood peg connection. The bearing strength of wood peg connection could be determined by either wood peg or the main member. For example, because the bearing strength of wood peg in PA was much higher than the bearing strength of wood peg in PE, the bearing strength of wood peg connection in



(a) ASTM D 5764 (2013) (b) Church and Tew (1997) (c) Schmidt and Daniels (1999) (d) Schmidt and Mackay (1997)

Figure 2. Different experimental methodologies used for determination of bearing strength of wood peg connection. (a) ASTM D 5764 (2013), (b) Method of Church and Tew (1997), (c) Method of Schmidt and Daniels (1999), and (d) Method of Schmidt and Mackay (1997).

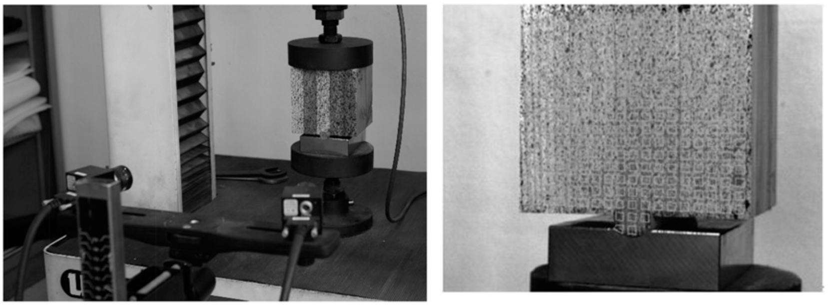
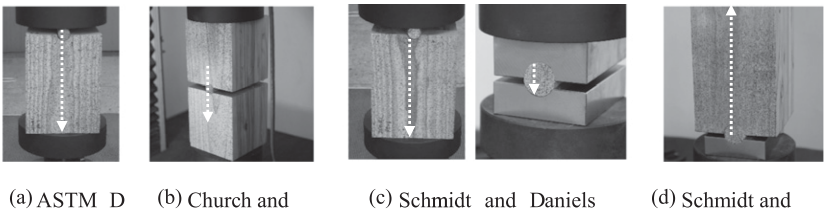


Figure 3. Digital image correlation test setup and virtual grids on specimen surface.

RL-PA and TL-PA should be much higher than the bearing strength of wood peg connection in RL-PE and TL-PE.

Using the method of Church and Tew (1997), the bearing properties of RL-PE were higher than those of TL-PA. This controversial result was induced by crushing of wood peg in PE which resulted in load increase even after the yield of wood peg. Using the method of Schmidt and Daniels (1999), bearing strength values of RL-PA, RL-PE, and TL-PA overlapped with each other. Although difference in bearing strength values by peg orientation was found using the method of ASTM D 5764, much lower value of bearing strength in RL-PA than the bearing strength of wood peg in PA was found. However, much high values of bearing strength in RL-PE and TL-PE compared with the bearing strength of wood peg in PE were found. However, the method of Schmidt and Mackay (1997) showed ability to differentiate the bearing strength of different wood peg orientations by peg orientation.

Figure 6 shows load–displacement curves of wood peg connection using different test methods. The load–displacement obtained from ASTM D 5764 (2013) did not show yield load because the load was applied directly to wood peg, including crushing and densifying wood peg simultaneously. This might have created load accumulation continually. The yield load of wood peg connection obtained from ASTM D 5764 (2013) resulted from a combination of the yield of the main member and the densified wood peg. The highest load–displacement curve of RL-PA and similar curves of TL-PA, RL-PE, and TL-PE were found with the method of Church and Tew (1997). The load–displacement curve from Schmidt and Daniels (1999) did not show distinctive difference by the main member or peg orientation. Such results could be due to the fact that the method of Schmidt and Daniels (1999) used a combined load–displacement curve from the main member and the wood peg based on the same displacement point. When load–displacement curves were combined, the load–displacement curve from the main member might mainly control the entire curve. Therefore, results of load–displacement curves from Schmidt and Daniels (1999) would be similar to those



(a) ASTM D 5764 (2013) (b) Church and Tew (1997) (c) Schmidt and Daniels (1999) (d) Schmidt and Mackay (1997)

Figure 4. Virtual path generated on specimen surface to analyze strain values.

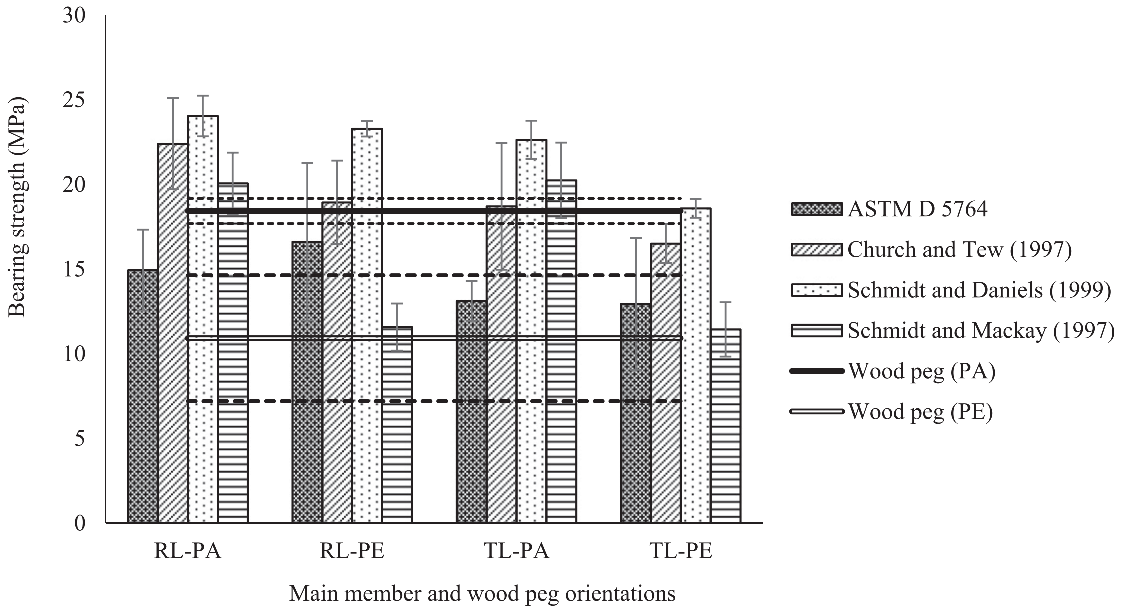


Figure 5. Bearing strength of differently oriented wood peg connections with various experimental methodologies.

shown in Fig 6. The load–displacement curve obtained with the method of Schmidt and Mackay (1997) showed the highest difference by wood peg orientation. The load–displacement curve from RL-PA and TL-PA and that from RL-PE and TL-PE showed similar trends.

The bearing properties of wood peg connections (RL-PA, TL-PA, RL-PE, and TL-PE) determined by the four different methods including proportional limit load (P_L), yield load (P_Y), and bearing strength (σ_b) are summarized in Table 1. Comparing the bearing strength of wood peg connection obtained with different test methods with the bearing strength of wood peg, the bearing strength values of RL-PE and TL-PE obtained with ASTM D 5764 were 15% and 19% higher, respectively, than the bearing strength of wood peg in PE. Those values of RL-PE and TL-PE evaluated with the method of Church and Tew (1997) were 55% and 69% higher, respectively. Using the method of Schmidt and Daniels (1999), those values of RL-PE and TL-PE were 113% and 70% higher, respectively. However, the bearing strength values of RL-PE and TL-PE obtained with the test method of Schmidt and Mackay (1997) were 6% and 4% higher, respectively, than the bearing strength of wood peg in PE. Because failures of RL-PE and TL-PE occurred mainly in wood peg, the difference between the bearing strength of wood peg connection for RL-PE and TL-PE and the bearing strength of wood peg should be small compared with the bearing strength of wood peg in PE.

Statistical comparison of differently oriented wood peg connections with the four different methods were determined with ANOVA and Duncan multiple comparison procedure (Table 2). Whereas the bearing strength of wood peg connection was not significantly different by the orientation of wood peg when ASTM D 5764 (2013), the method of Church and Tew (1997), or the method of Schmidt and Daniels (1999) was used, results obtained with the method of Schmidt and Mackay (1997) showed that bearing strength values of wood peg connections were significantly different by wood peg orientations.

Figure 7 shows strain distributions of different bearing tests and strain values of RL and TL along the path using different test methods with DIC. Figure 7(a) shows the result of ASTM D5764, indicating strain concentration on the

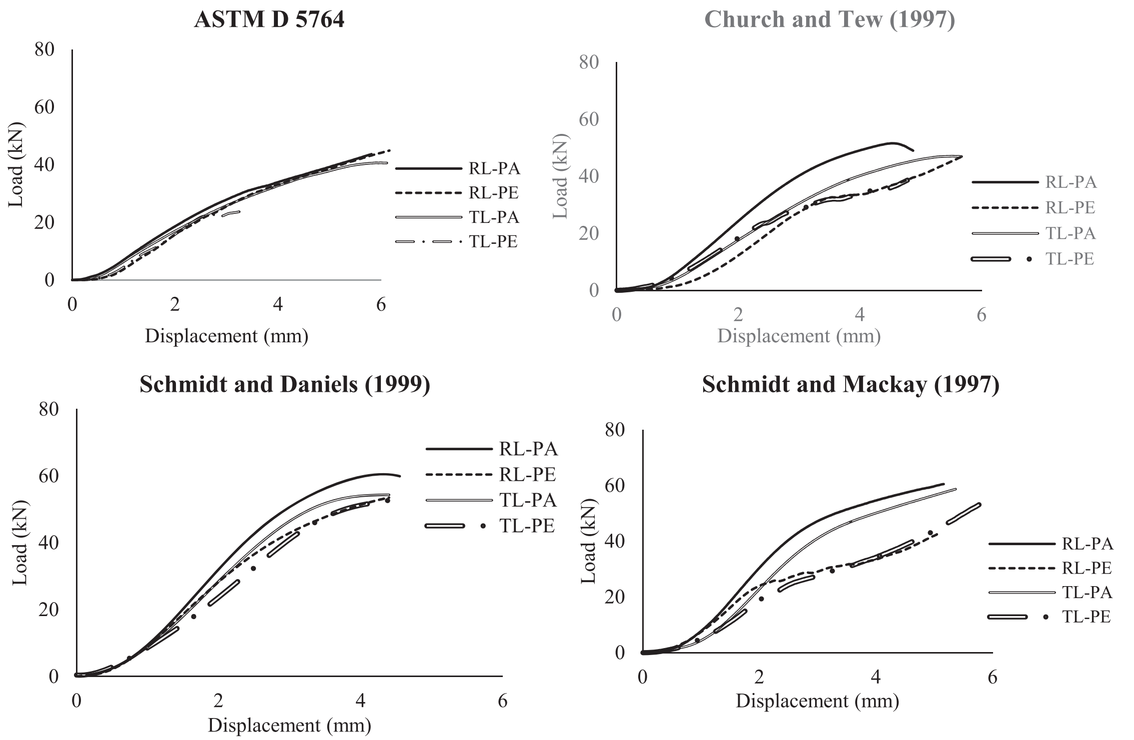


Figure 6. Load–displacement curves of differently oriented wood peg connections with various experimental methodologies.

upper part of the wood peg. When ASTM D5764 was used, two peaks were observed in the upper tip of the wood peg near the loading head and bearing area, respectively.

Figure 7(b) shows strain distributions when the method of Church and Tew (1997) was used. Although two high strain peaks were observed at the bearing area between the main member and the wood peg, higher strain peak was constantly observed at the upper bearing area close to the load applied. The uneven strain distribution between the upper bearing area and the lower bearing area created different stress distribution. Whereas crushing of the wood peg occurred at the upper part, bearing of the main member occurred at the lower part. Such uneven strain distribution created different stress partitioning at the two bearing areas, resulting in similar load–displacement curves regardless of peg orientation (Fig 6).

Figure 7(c) shows strain distribution when the method of Schmidt and Daniels (1999) was used. Different high strain distributions were observed in different locations for both the main member and the wood peg. High strain distribution around the bearing area occurred from the main member. For the wood peg in PE, the highest strain occurred in the middle of the peg. Using the method of Schmidt and Daniels (1999), the highest strain occurred at the bearing area. However, it was the lowest among values obtained from the four test methods. Because the main member and the wood peg were tested separately in Fig 7(c), strain distribution from two separate tests could not represent strain distribution of wood peg connection.

Figure 7(d) shows strain distributions when the method from Schmidt and Mackay (1997) was used. High strain distribution occurred around the bearing area between the wood peg and the main member which dominantly controlled the load–displacement curve in Fig 6. It can be speculated that the load–displacement curve occurred mainly by bearing between the wood peg and the main

Table 1. Comparison of bearing properties with ASTM D 5764 (2013), the method of Church and Tew (1997), the method of Schmidt and Daniels (1999), and the method of Schmidt and Mackay (1997).

Orientations		Bearing properties	ASTM D 5764(2013)	Church and Tew (1997)	Schmidt and Daniels (1999)	Schmidt and Mackay (1997)	Wood peg
RL	PA	P_L (kN)	18.62 (0.28)[a]	29.59 (0.17)	38.54 (0.09)	34.93 (0.06)	28.89 (0.05)
		P_Y (kN)	33.96 (0.16)	45.08 (0.21)	54.80 (0.05)	47.97 (0.10)	44.24 (0.04)
		σ_b (MPa)	14.94 (0.16)	22.40 (0.12)	24.04 (0.05)	20.07 (0.09)	18.43 (0.04)
	PE	P_L (kN)	15.70 (0.39)	23.07 (0.15)	38.86 (0.15)	23.66 (0.14)	20.21 (0.19)
		P_Y(kN)	29.85 (0.27)	37.21 (0.18)	51.76 (0.07)	27.28 (0.10)	26.21 (0.34)
		σ_b (MPa)	13.13 (0.28)	18.94 (0.13)	23.29 (0.02)	11.58 (0.12)	10.92 (0.34)
TL	PA	P_L (kN)	19.24 (0.04)	24.41 (0.20)	38.71 (0.11)	33.55 (0.08)	28.89 (0.05)
		P_Y (kN)	37.87 (0.09)	37.04 (0.29)	53.52 (0.06)	48.24 (0.11)	44.24 (0.04)
		σ_b (MPa)	16.62 (0.09)	18.71 (0.20)	22.63 (0.05)	20.24 (0.11)	18.43 (0.04)
	PE	P_L (kN)	19.76 (0.14)	22.55 (0.16)	35.14 (0.16)	24.25 (0.12)	20.21 (0.19)
		P_Y (kN)	29.64 (0.29)	33.19 (0.10)	49.70 (0.09)	27.22 (0.14)	26.21 (0.34)
		σ_b (MPa)	12.95 (0.30)	16.51 (0.07)	18.59 (0.03)	11.44 (0.14)	10.92 (0.34)

RL, radial-longitudinal; TL, tangential-longitudinal; PA, parallel to the load direction; PE, perpendicular to the load direction.
[a] Coefficient of variation.

member. The bearing should be influenced by the characteristics of the wood peg and the main member. In other words, results from the method of Schmidt and Mackay (1997) could determine the effect of peg and main member orientation on the bearing strength of wood peg connections.

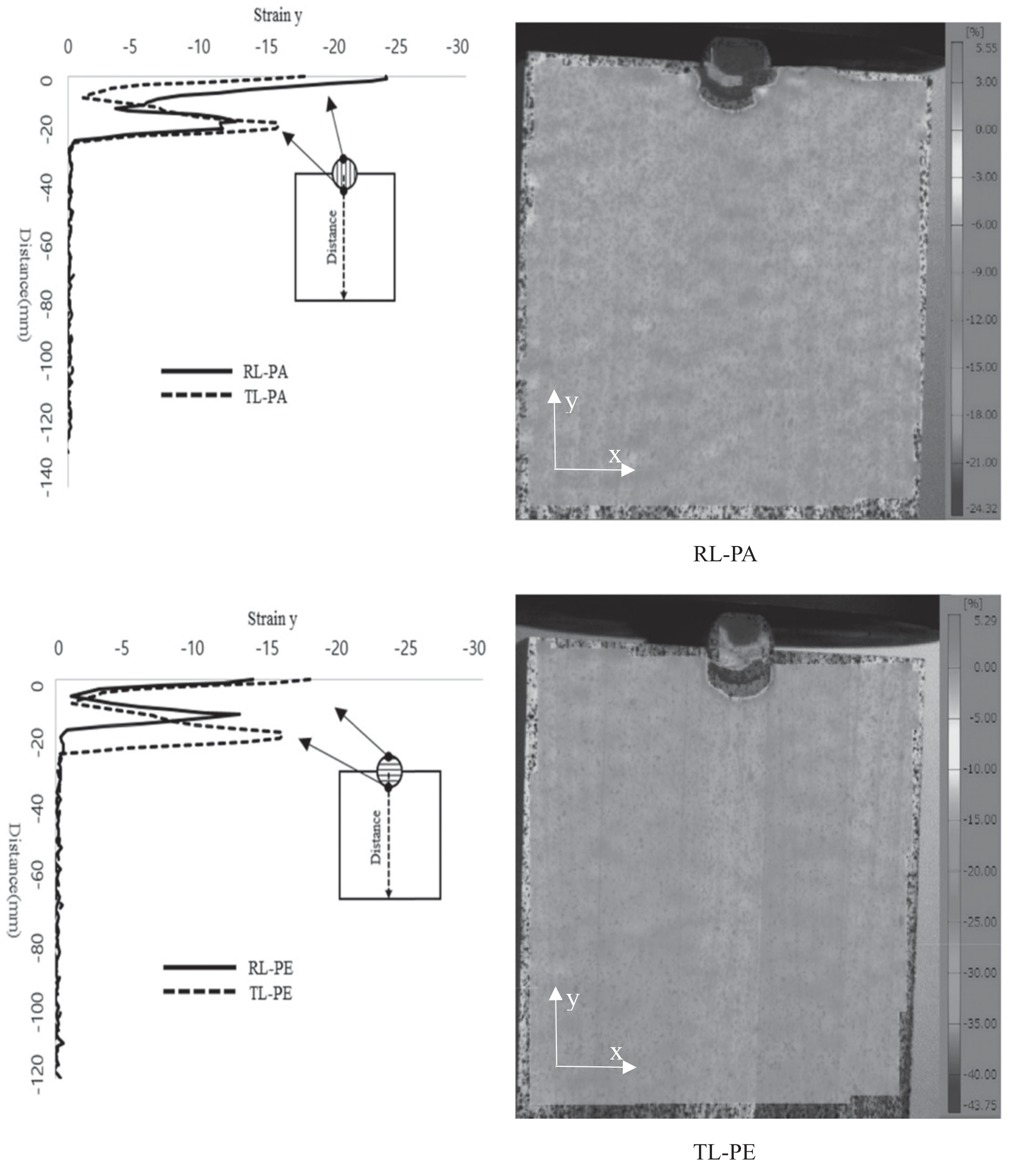
Based on the results obtained with different test methods, ASTM D 5764 (2013) created stress concentration and crushing at the top of the wood peg where the load was applied. This influenced the load–displacement curve. The bearing strength obtained with ASTM D 5764 (2013) did not differ by wood peg orientation. The bearing strength of wood peg connection obtained with the method of Church and Tew (1997) showed much higher bearing strength values than the bearing strength of wood peg alone. The bearing strength determined with the method of Church and Tew (1997) showed that the bearing strength of RL-PE was higher than the bearing strength of TL-PA. The method of Schmidt and Daniels (1999) showed much higher bearing strength of RL-PA, RL-PE, and TL-PA than the bearing strength of wood peg. The method of Schmidt and Daniels (1999) did not show difference by wood peg orientation either. However, the method of Schmidt and Mackay (1997) showed difference in the bearing strength of wood peg connection by wood peg orientation. Strain distribution from wood peg connection also indicated that the highest strain occurred at the bearing area between the wood peg and the main member, which resulted in a load–displacement curve by bearing. Therefore, the method of Schmidt and Mackay (1997) should provide reliable results for the determination of wood peg connection.

CONCLUSIONS

Four different test methods were evaluated to find an appropriate test method for the determination of the bearing properties of wood peg connections. The bearing properties of wood peg connections

Table 2. Comparison of differently oriented bearing properties (MPa) from various experimental tests by Duncan analysis of variance (means with the same letter [A or B] are not significantly different).

Methodology	Orientations				p-value
	RL-PA	RL-PE	TL-PA	TL-PE	
ASTM D 5764	14.93 A	13.12 A	16.62 A	12.92 A	0.443
Church and Tew (1997)	22.39 A	18.93 B	18.70 B	16.50 B	0.007
Schmidt and Daniels (1999)	22.04 A	23.28 A	22.62 A	18.59 B	<0.001
Schmidt and Mackay (1997)	20.06 A	11.57 B	20.23 A	11.43 B	<0.001

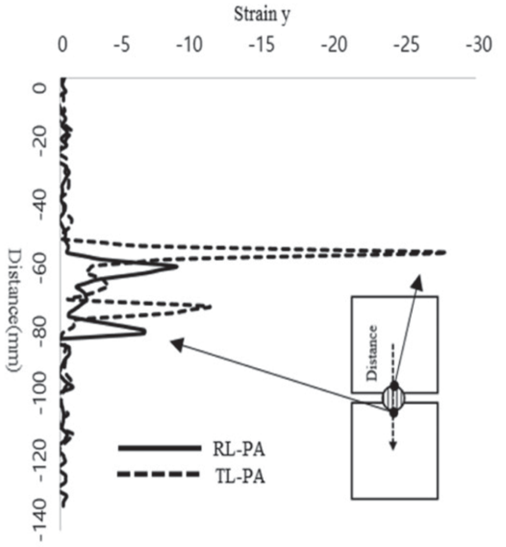


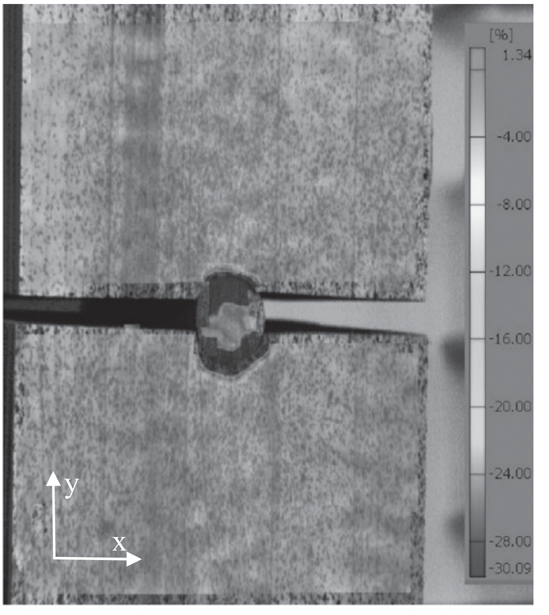
(a) Path strain distribution from ASTM D 5764 (2013)

Figure 7. Strain values along the path and strain distributions from differently oriented wood peg connections at yield load.

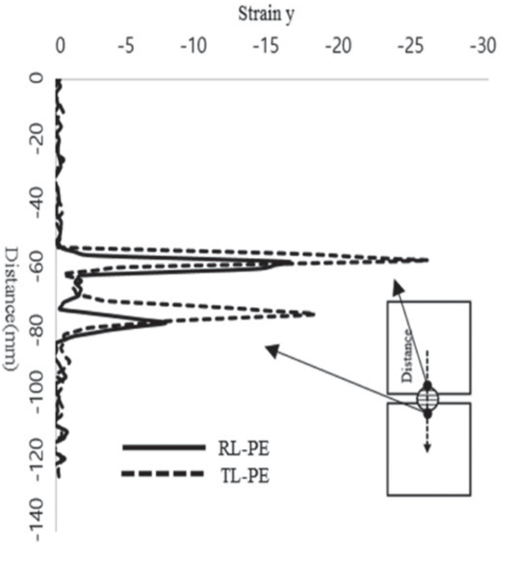
(RL-PA, TL-PA, RL-PE, and TL-PE) determined from ASTM D 5764 (2013), the method of Church and Tew (1997), the method of Schmidt and Daniels (1999), and the method of Schmidt and Mackay (1997). The bearing strength of wood peg was 18.43 MPa in PA and 10.92 MPa in PE.

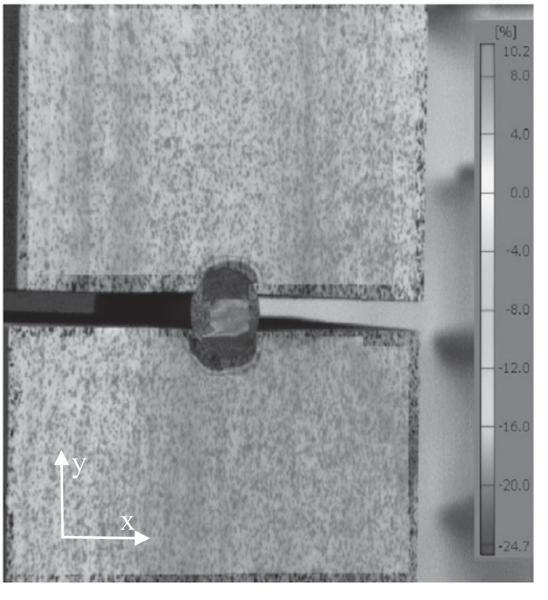
Because failures of RL-PE and TL-PE occurred mainly in wood peg, the difference between the bearing strength of wood peg connection for RL-PE and TL-PE and the bearing strength of wood peg should be small compared with the bearing strength of wood peg in PE.





TL-PA

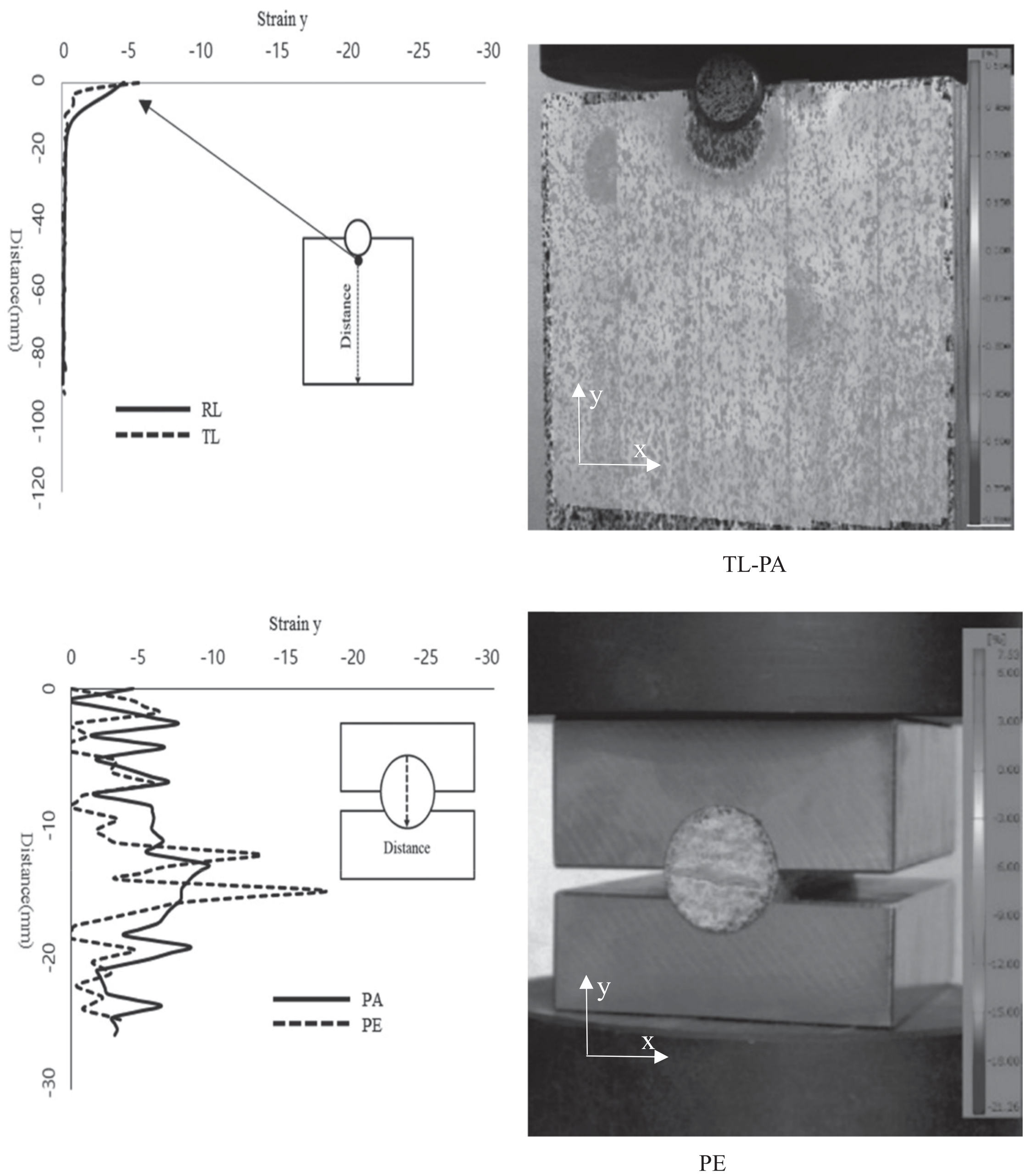




RL-PE

(b) Path strain distribution from Church and Tew (1997)

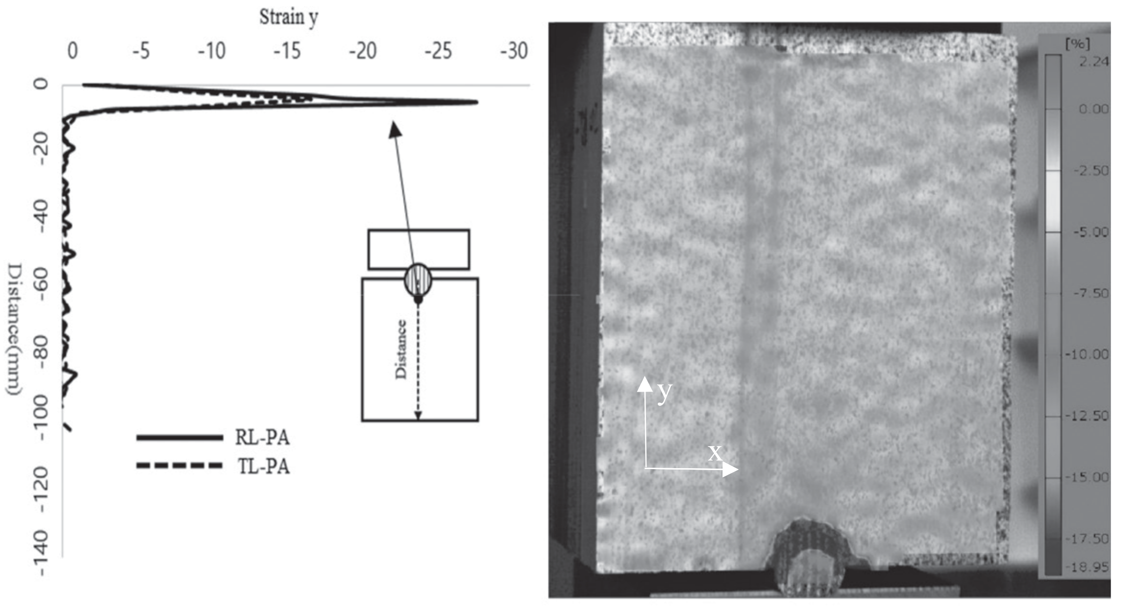
Figure 7. (Continued)



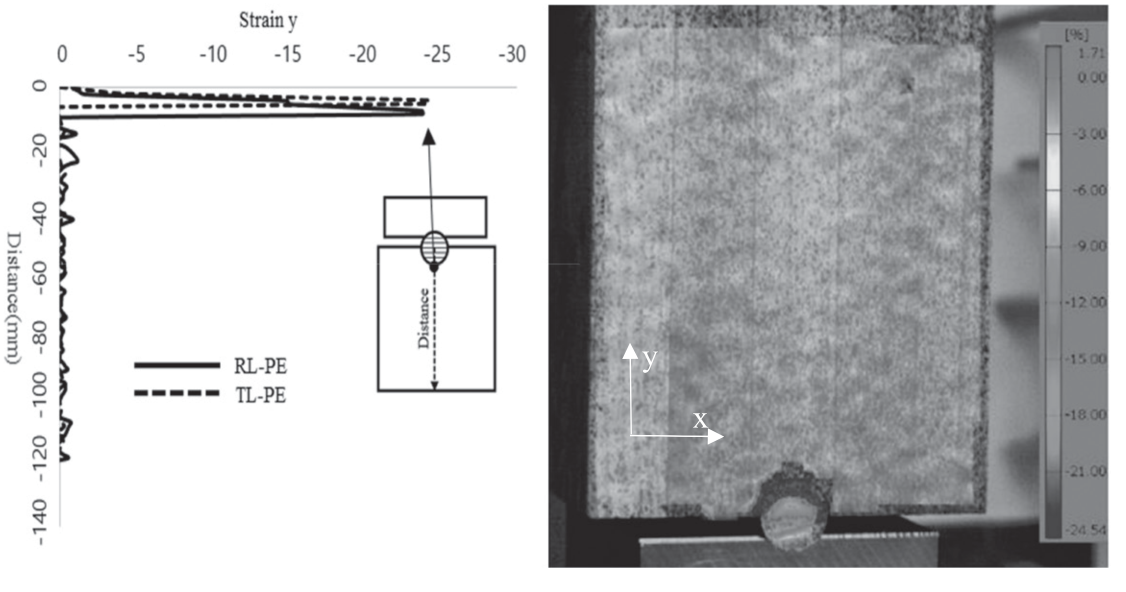
(c) Path strain distribution from Schmidt and Daniels (1999)

Figure 7. (Continued)

Whereas the bearing strength values of RL-PE and TL-PE obtained with the test method of Schmidt and Mackay (1997) were 6% and 4% higher, respectively, than the bearing strength of wood peg in PE, those values of RL-PE and TL-PE evaluated with ASTM D 5764 (2013), the method of Church and Tew (1997), and the method of Schmidt and Daniels (1999) ranged



RL-PA



TL-PE

(d) Path strain distribution from Schmidt and Mackay (1997)

Figure 7. (Continued)

from 15% to 113% higher than the bearing strength of wood peg in PE.

Although the bearing strength of wood peg connection should be characterized by either bearing strength of the wood peg or bearing strength of the main member, ASTM D 5764 (2013), the method of Church and Tew (1997), and the method of Schmidt and Daniels (1999) failed to show differences in bearing strength by wood peg orientations.

However, the bearing strength obtained with the test method of Schmidt and Mackay (1997) showed differences by wood peg orientations. The method of Schmidt and Mackay (1997) showed high strain distribution around the bearing area between the wood peg and the main member, which resulted in different load–displacement curves by wood peg orientations.

Stress concentration and crushing at the top of the wood peg from ASTM D 5764 (2013) and the uneven strain distribution between the upper bearing area and the lower bearing area from the method of Church and Tew (1997) and different high strain distributions were observed in different locations for both the main member and the wood peg from Schmidt and Daniels (1999) influenced the load–displacement curves, which resulted in bearing properties regardless of the main member orientation associated with the peg orientation.

These results suggest that the test method of Schmidt and Mackay (1997) could be used to determine the bearing properties of wood peg connection affected by the material properties of the main member and the wood peg.

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REFERENCES

AWC (2015) National design specification for wood construction. American Wood Council, Washington, DC.

ASTM (2013) Standard test method for evaluating dowel-bearing strength of wood and wood based products (D5764-97a). Annual book of standards, vol. 04.10. Philadelphia, PA, America Society of Civil Engineer. 1997. National Design and Specification for Timber Construction of U.S.ASCE.

Burnett DT, Clouston P, Damery DT, Fisette P (2003) Strucutural properties of pegged timber connections as affected by end distance. Forest Prod J 53(2):50-57.

Church JR, Tew BW (1997) Characterizaion of bearing factors in pegged timber connections. J Struct Eng 123(3): 326-332.

GOM mbH (2007) ARAMIS user manual—Software. aramis_v6_1st_en_revc, Braunschweig, Germany.

Miller JF, Schmidt RJ, Bulleit WM (2010) New yield model for wood dowel connections. J Struct Eng 126(10): 1255-1261.

Sandberg LB, Bulleit WM, Reid EH (2000) Strength and stiffness of oak pegs in traditional timber-frame joints. J Struct Eng 126(6): 171-723.

Schmidt RJ, Daniels CE (1999) Design considerations for mortise and tenon connections. Research report, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY.

Schmidt RJ, Mackay RB (1997) Timber frame tension joinery. Research report, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY.

Shanks JD, Walker P (2009) Strength and stiffness of all-timber pegged connections. J Mater Civ Eng 21(1):10-18.

Timber Frame Engineering Council (TFEC 1) (2007) Standard for design of timber frame structures and commentary. Beckett, MA.