

# Commentary to TFEC 1-2010

## Standard for Design of Timber Frame Structures

### **1.0 General Requirements for Structural Design and Construction**

#### **1.1 Applicability and Scope**

The Standard defines the standard of practice for the structural design of timber frame construction, which is typified by use of carpenter-style joinery to connect members. Carpenter-style joinery includes, but is not limited to, use of mortise and tenon joints, dovetails, fork and tongue joints, and scarf joints. These joints are normally secured with wood pegs or wedges.

The Standard is intended as a supplement to provisions of the NDS<sup>®</sup>, not as an alternative or replacement. For instance, design of connections for heavy timber members using steel side plates and bolts is adequately defined in the NDS<sup>®</sup>; thus the Standard does not address this aspect of timber design.

The provisions of the Standard are not intended to limit or prohibit use of alternative materials and methods for structural design and construction. Practices and procedures that have been shown to be safe and effective are not restricted. Alternative design approaches based on reliability-based concepts or other recognized approaches are also not restricted.

#### **1.2 Liability**

-- no comment --

## **1.3 General Requirements**

### **1.3.1 Strength**

The loads applied during assembly and raising of a timber frame can differ substantially in character and magnitude from those that act on a completed frame. Supplemental strengthening and bracing may be needed to protect the integrity of the frame during construction. Structural analysis and design of these supplemental systems may be necessary.

### **1.3.2 Serviceability**

As with all structures, the appropriate serviceability limits are dependent on the conditions and use of the building. Limits on deflections or drift are not defined in the Standard. Local building codes normally include appropriate deflection and drift limits.

### **1.3.3 General Structural Integrity**

The requirement for general structural integrity is intended to assure that a building can sustain local damage under unanticipated loads without progressive, catastrophic collapse of the remainder of the structure. Statically determinate systems without multiple load paths are particularly vulnerable.

## **1.4 Design Loads**

-- no comment --

## **1.5 Construction Documents**

### **1.5.1 Types of Documents**

-- no comment --

### **1.5.2 Material Selection**

Design values vary with the species of timber as well as the geographic source of the material. For instance, design values for Douglas fir produced in the United States differ from those for Douglas fir produced in Canada. To assure accurate account of both strength and stiffness of members, the specific material, source, stress grade and grading rules must be identified.

### **1.5.3 Member Sizes**

There is no definitive relationship between nominal size and actual size of timbers used in timber framing. Mill conventions as well as joinery practices influence the size of timber actually produced. To assure accurate account of both strength and stiffness of members, the actual member sizes must be identified.

### **1.5.4 Connection Details**

Design values for connections are dependent upon use of accurate joinery details, including tenon thickness, width and length; mortise width, height and depth; and peg hole size and placement.

## **1.6 Materials**

### **1.6.1 Timber**

Normally, timber used in structural applications is visually graded based on rules approved by the American Lumber Standards Committee. However, these rules do not apply to all material that might be used in a timber frame. For instance, grading rules do not generally apply to recycled or remanufactured material. Also, timber produced from a particular subspecies may exhibit properties significantly different from those for the corresponding species group. In these

cases, the building official may permit use of such material in a structural application based on visual examination, nondestructive testing, or other rationale provided by the engineer of record.

### **1.6.2 Structural Glued Laminated Timber**

--no comment --

### **1.6.3 Wood Pegs**

Experience suggests that wood pegs used in structural applications must contain sound, straight-grain, defect-free material. Presence of defects or slope-of-grain can lead to failure of the peg during installation. Research results on the strength of pegged connections are based on the use of hardwood pegs with specific gravity of the peg stock equal to or exceeding that of the timber stock. A minimum peg specific gravity of 0.57 has been recommended in Reference 1. A maximum peg specific gravity of 0.73, corresponding to the assigned value for white oak in Table 11.3.2A of the NDS, is selected as an upper limit for use in the provisions of the Standard. Pegs with higher specific gravity may be used in frame construction, but their design capacities may not exceed that of material with  $G = 0.73$ . The NDS<sup>®</sup> supplement Design Values for Wood Construction should not be used to assign design values to pegs.

### **1.6.4 Wood Wedges**

Experience suggests that wood wedges used in structural applications must contain sound, straight-grain, defect-free material. Presence of defects or slope-of-grain can lead to failure of the wedge during installation. No research on the behavior of wedged joints in timber frames is available. However, use of hardwood wedge stock with specific gravity equal to or exceeding that of the timber stock is required to reduce the likelihood of wedge failure by compression perpendicular to the grain.

## 1.7 Notation

-- no comment --

## **2.0 Structural Members**

### **2.1 General**

The Standard stands as a supplement to the ANSI/AF&PA NDS<sup>®</sup>. Hence, the Standard contains provisions for timber frame design not included in the NDS<sup>®</sup>. The NDS<sup>®</sup> remains the primary governing design document for structural design of wood buildings.

### **2.2 Seasoning Effects**

Timber frame structures are often cut and assembled using unseasoned timbers. Seasoning in place can lead to shrinkage, checking, cross section distortion, and other effects that may influence the integrity of joinery-style connections. In particular, member shrinkage can lead to loss of bearing at the ends of beams and changes in contact surfaces for members joined at non-orthogonal orientations. Cross section distortion due to shrinkage can cause tenons to be pushed out of their mortise, resulting in distress to the pegs that secure the joint. These effects can be avoided or minimized through proper detailing and cutting of joinery.

### **2.3 Notching**

The effects of notching on member stiffness will vary, as there are no standard limits on notch geometry and placement. Hence, each situation must be evaluated on a case-by-case basis by the engineer of record. Some research is available on the effects of notching on member stiffness. See, for instance, Reference 2.

The provisions of the NDS<sup>®</sup> are applicable to design of bending members that are notched across the full width of their tension or compression faces. Such notches often occur when beam ends are coped at their bearing surfaces. According to NDS<sup>®</sup> Section 3.4.3.2(d), the stress

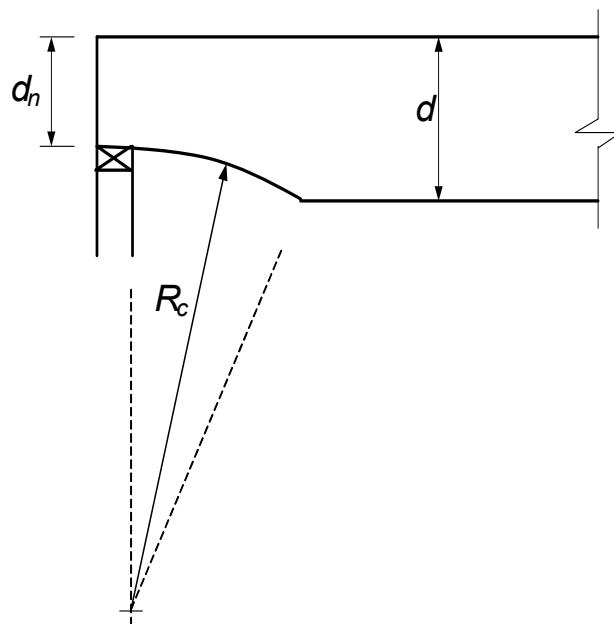
concentration for shear can be eliminated with a suitable “gradual change in cross section.” Any number of approaches may be used to achieve this condition. One such approach is a notch geometry in the form of a circular arc that is tangent to the bearing surface at the end of the member and intersects the tension face of the member at a distance of  $4(d - d_n)$  from the bearing surface. When such a notch is provided, the shear capacity of the bending member may be taken as that of an unnotched member with a depth of  $d_n$ . When such gradual change is achieved by coping to a circular arc of radius  $R_c$  given by

$$R_c = 8.5(d - d_n) \quad (2.3-1)$$

where the arc is tangent to the bearing surface at the end of the member (see Figure C-2A), then the allowable design shear  $V_r'$  may be calculated as

$$V_r' = \frac{2}{3} F_v' b d_n \quad (2.3-2)$$

Figure C-2A Coped bending member notch



Partial-width notches are common in timber frame structures and typically consist of mortises, housings, and beam pockets. Partial-width notches occur when a mortise is cut to receive a tenon. Partial-width notches also occur in, among others, ridge beams, purlins, and wall plates that support rafters. The provisions for bending strength and shear strength of members with partial-width notches are based on judgement and limited experimental results of similar notches cut in dimension lumber bending members.

Partial-width notches on the lateral faces of bending members that extend below mid-depth of the member from the compression face are common in timber framing, for example where joists frame into the sides of beams. In such instances, bearing of the joist on the bottom surface of the notch may induce tension stress perpendicular to grain. While rules of thumb exist for the minimum distance from the loaded surface of the notch to the tension face of the member, no testing has been performed or analytical models developed to define the relationships between notch dimensions, clear distance to the tension face, mechanical properties of the wood (in particular tensile strength perpendicular to the grain), and safe load-carrying capacity of the notch. It is recommended that, whenever possible, load-bearing notches not extend below mid-depth of the member.

Where partial width notches in the lateral faces of a bending member occur on opposite lateral faces at the same cross section of the member, the limit on width  $w_3$  applies individually to each notch. The flexural and shear capacities of the member can be determined in accordance with Section 2.3.4.3 of the Standard.

Housings may consist of relatively shallow partial-width or full-width notches in a member to receive the end of a joining member. The provisions in this standard for partial-width notches are not intended to apply to or restrict the use of shallow, partial-width housings. Rather

determination of the effects of housings on the strength and stiffness of a timber member is left to the judgement of the engineer of record. Full-width housing are covered by provisions of the NDS<sup>®</sup>, Sec. 4.4.3 and Sec. 5.4.4.

## **3.0 Connections**

### **3.1 General**

The provisions of the NDS<sup>®</sup> apply to a broad range of connections using metallic fasteners. However, explicit provisions to guide the design of connections using non-standard fasteners are not included. Rather, Section 11.1.7 of the NDS<sup>®</sup> permits other dowel-type fasteners, including wood pegs, to be used to transfer lateral load in connections, provided that the variation in connection type is accounted for and detailing dimensions are sufficient to prevent splitting. The Standard addresses use of wood pegs and wedges as fasteners in connections.

#### **3.1.1 Terminology**

-- no comment --

#### **3.1.2 Installation of Pegs**

Normally, holes for round pegs are drilled to the same diameter as the pegs. Hole size for pegs of noncircular cross section should be determined by trial.

Draw boring has the potential to cause damage to the peg and to the tenon if the offset in the peg hole is too great. Successful draw boring can effectively increase initial stiffness of a mortise and tenon connection under tension and can reduce long-term deflections of the joint due to seasoning and sustained load effects (see Reference 3). In such cases, the tensile strength of the joint is not compromised. For connections using 3/4" diameter pegs, typical values of peg hole offset between the tenon and the mortised member are 1/16-inch for hardwood timbers and 1/8-inch for softwood timbers.

### **3.1.3 Installation of Wedges**

Wedges must be sized and installed to apply only tension load parallel to the grain of the member that receives the wedge. If a wedge is too wide (in the dimension between the two parallel faces), it will cause tension perpendicular to the grain of the receiving member. This tension can subsequently increase due to shrinkage of the member and lead to splitting.

### **3.1.4 Connection Design**

Sufficient research on the performance of mortise and tenon connections has been performed to support development of specification provisions. Similar research for other joinery-type connections, including dovetails, scarfs, and laps, is not available. Hence, design of these connections must be based on the principles of engineering mechanics and the judgement of the engineer of record.

## **3.2 Withdrawal**

### **3.2.1 Prohibition of Withdrawal Loading**

It might be argued that a wood peg has some nominal withdrawal capacity, similar to that for drift pins (see Reference 4). However, since both the timber member and wood peg are subject to size variation due to moisture cycling, the variability in withdrawal capacity of a wood peg would be significantly larger than that of a drift pin. Also, accepted timber framing practice is to avoid withdrawal loading of pegs. Hence, no withdrawal design value is assigned.

### **3.3 Mortise and Tenon Connections Loaded in Shear**

#### **3.3.1 Load Transfer by Direct Bearing**

Pegs used to secure a tenon within a mortise may not be relied upon for transfer of shear loads. Such a load path produces tension perpendicular to the grain of the tenon, which can lead to brittle failure at relatively low loads (see Reference 5). In addition, transverse shear loading of the tenon can result in rolling shear failure of the tenoned member. Hence, transfer of shear load through a mortise and tenon connection must be by direct bearing of the tenon on the mortise housing.

#### **3.3.2 Shear Capacity**

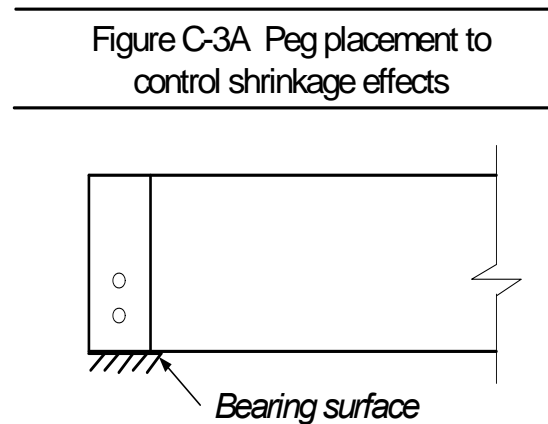
Shear load in a beam may be transferred to the mortised member through direct bearing across the width of the tenon for a beam that is not housed, or across the full width of the beam for a fully housed beam.

#### **3.3.3 Strength Contribution of Pegs**

Direct bearing between a tenon and a mortise housing provides a load path with substantial stiffness, relative to that of a pegged connection. Hence, virtually all of the shear load in the joint will be transferred through the bearing surface. Pegs may be needed to carry some short-term load during assembly and erection of the frame, before the bearing surfaces come into full contact.

### 3.3.4 Connection Detailing

The effects of shrinkage after joint assembly must be considered such that direct bearing between members is maintained. Placement of pegs close to the bearing surface is one effective means to control shrinkage effects (see Figure C-3A).



## 3.4 Mortise and Tenon Connections Loaded in Tension

### 3.4.1 Yield Limit Equations

The yield model approach can be used to predict the tensile strength of pegged mortise and tenon connections. With this approach, the tenon is regarded as the main member and the mortise side walls are regarded as side members in a double-shear connection. Yield modes that have been observed in pegged mortise and tenon connections include:

Mode  $I_m$  – crushing in the main member and peg material due to bearing action

Mode  $I_s$  – crushing in the side member and peg material due to bearing action

Mode  $III_s$  – combined flexure of the peg and crushing of the timber due to bearing

Mode V – double shear failure of the peg

Modes II and III<sub>m</sub> in the NDS<sup>®</sup> are not applicable due to geometric constraints of a double shear connection. Mode IV has not been observed in pegged mortise and tenon connections due to the restraint (confinement) placed on the pegs in the connection. For connections with relatively large diameter pegs, Mode III<sub>s</sub> failure occurs with a single flexural hinge in the peg. For connections with relatively small diameter pegs, Mode V failure is observed. In some cases, pegs exhibit evidence of both flexural (Mode III<sub>s</sub>) and shear (Mode V) failure.

The shear strength  $F_{vp}$  of a peg for Mode V failure is related to the values of specific gravity  $G_t$  and  $G_p$  for the timber and peg, respectively. The relationship for  $F_{vp}$  in Table 3A of the Standard was derived from regression analysis of test results, supplemented with finite element analyses (see Reference 5).

The majority of research available on the behavior of pegged mortise and tenon joints utilizes 1-inch diameter pegs. Some test results are available for joints with 0.75-inch and 1.25-inch pegs. Hence, the provisions of the Standard are limited to pegs in this range of sizes.

### **3.4.2 Dowel Bearing Strength**

In a pegged mortise and tenon connection under tension load, the peg and the mortise side walls are loaded in bearing perpendicular to grain, whereas the tenon is loaded in bearing parallel to grain. Hence, dowel bearing strength for a pegged connection depends upon the deformation of both the peg and the timber. Equations (3.4-9) and (3.4-10) for  $F_{e||}$  and  $F_{e\perp}$  respectively account for the deformation of both the wood peg and the timber base material under dowel bearing load. These equations were developed from a regression analysis of physical test results and a numerical study to generate dowel bearing strength data for 48 combinations of peg species, timber base material species, and load direction. Good correlations between dowel bearing

strength and material specific gravity were found. The coefficients of determination were  $R^2 = 0.65$  and  $R^2 = 0.77$  for Equations (3.4-9) and (3.4-10) respectively.

In situations for which use of Equations (3.4-9) and (3.4-10) is not appropriate, alternative approaches may be used to determine dowel bearing strengths for a pegged mortise and tenon connection.

In the first approach, strength data is taken directly from physical tests following ASTM D5764 (see Reference 6) but with the steel dowel required by the test standard replaced with a wood peg of the same species, quality and diameter as that used in the prototype connection. In these tests, the wood peg must be supported such that it is not crushed or bent during the test. Procedures for two different versions of this modified test are found in References 7 and 8.

In the second approach, dowel bearing strength can be determined by combining load-displacement records from separate bearing tests of the timber and the peg. In this approach, dowel bearing tests of the timber are performed according to ASTM D5764. A bearing test is performed on the peg in which, in effect, the wood block specified in ASTM D5764 is replaced by a metallic load block with a semicylindrical slot across one face matching the peg diameter. In this test, the metallic load block is pressed into the side of a peg while the peg is supported along its full length to prevent crushing and bending under load. Load-displacement records from these two tests are then combined assuming that combined behavior corresponds to a “springs in series” model. Dowel bearing strength is determined from the combined load-displacement record using the conventional 5% diameter ( $0.05D$ ) offset method described in ASTM D5764. The approach for combining load-displacement records from the separate timber and peg tests is presented in References 3 and 9.

The third approach to finding dowel bearing strength is simply to choose the minimum value of  $F_e$  for the materials used in a connection.  $F_e$  for the timber material may be taken from tabulated data or empirical equations based on physical tests according to ASTM D5764.  $F_e$  for the peg is similarly determined by tests on pegs following ASTM D5764 but with the wood block replaced by a metallic load block with a semicylindrical slot matching the peg diameter across one face. Such data is available in Table 11.3.2 of the NDS<sup>®</sup>.

### **3.4.3 Dowel Bearing Strength at an Angle to Grain**

-- no comment --

### **3.4.4 Dowel Bearing Length**

-- no comment --

### **3.4.5 Bending Yield Strength of Pegs**

Values of modulus of rupture (MOR) in the Wood Handbook (see Reference 4) were developed from small, clear, straight-grain specimens and represent average values for a given species. Based on bending tests of pegs commonly used in timber frame construction (see Reference 7), average values of  $F_{yb}$  using the 5% diameter ( $0.05D$ ) offset method for pegs are consistently higher than the values of MOR in the Wood Handbook. The higher flexural strength of the wood peg can be attributed to the form factor associated with round pegs, the smaller size of the peg compared to the ASTM D143 (Reference 10) standard test specimen, inadequate population sampling for the peg tests, and possibly lower moisture content in the pegs. Nevertheless, the values of MOR at 12% MC in the Wood Handbook appear to be conservative estimates of  $F_{yb}$  for wood pegs used in timber frame construction. When the specific subspecies of wood used in the peg is not known, the smallest value of MOR for the species group should be selected. The

Wood Handbook provides equations relating the mechanical properties of clear straight-grained wood to its specific gravity. The modulus of rupture (in psi) for hardwoods at 12 percent moisture content is given as  $24,850 G^{0.13}$

### **3.4.6 Peg Diameter**

-- no comment --

### **3.4.7 Seasoning and Creep Effects**

A pegged mortise and tenon joint assembled from unseasoned timber and loaded in tension will experience significant long-term deflection due to creep and shrinkage. Joint deflection increases beyond the initial elastic deflection due to shrinkage of the pegs and timbers, flexural and shear creep in the peg, and localized compression creep in the timbers around the peg hole. Joint deflection tends to stabilize after the timbers reach equilibrium moisture content (EMC). The stabilized deflection at EMC can be 3 to 8 times larger than the initial elastic deflection, depending on initial moisture content, load history, and joinery details. This creep behavior does not appear to negatively influence joint load capacity (see Reference 3). One approach to controlling creep behavior is to avoid subjecting pegged mortise and tenon joints to long-term tension loads.

### **3.4.8 Edge Distance, End Distance and Spacing**

NDS<sup>®</sup> provisions for edge distance, end distance and spacing in wood connections with dowel-type fasteners are based upon the use of steel fasteners. Since a wood peg has substantially lower lateral load capacity than a steel dowel of the same diameter, the required minimum detailing dimensions (edge distance, end distance, and spacing) to prevent splitting in a pegged joint are less than those for a joint with steel fasteners. One approach to selecting appropriate

end and edge distances is to proportion the joint based on the assumption that steel bolts will be used instead of wood pegs. The bolt size is selected such that one steel bolt has the same capacity as one wood peg used in the actual connection. Then end and edge distances are selected based on the steel bolt diameter. Spacing between pegs should conform to the provisions of the NDS<sup>®</sup> with no adjustment in fastener diameter. The detailing dimensions in Table C3A have been shown by physical tests to develop the full strength of a pegged mortise and tenon connection without splitting of the timber (see References 3 and 5). Use of the provisions of Section 3.4.8 of the Standard may result in end and edge distances smaller than those in Table C3A and may be used accordingly.

**Table C3A –Detailing Dimensions Based on Physical Tests**

Timber Species	End Distance	Edge Distance	Spacing
Douglas Fir	$2D$	$2.5D$	$2.5D$
Eastern White Pine	$4D$	$4D$	$3D$
Red & White Oak	$3D$	$2D$	$2.5$
Southern Yellow Pine	$2D$	$2D$	$3D$
Yellow Poplar	$2.5D$	$2.5D$	$3D$

### 3.4.9 Adjustment Factors for Peg Connections

The applicability of the various adjustment factors to peg connections has not been satisfactorily determined. Some research on the duration of load effects has been conducted (see Reference 3) and it appears that duration of load has no discernable effect on connection capacity.

Nevertheless, use of the load duration factor  $C_D$  is permitted until its applicability is resolved.

The flexibility of wood pegs might be sufficient to permit transverse shrinkage strains to develop

without causing splitting of timbers. Hence, this flexibility could render the wet service factor inapplicable for joints assembled from unseasoned timber that seasons naturally in service.

#### **3.4.10 Tenon size and quality**

-- no comment --

#### **3.4.11 Mortise Placement**

-- no comment --

### **3.5 Seasoning Effects**

Timber frame structures are often cut and assembled while the timbers are unseasoned.

Seasoning in place can lead to shrinkage, checking, cross section distortion, and other effects that may influence the integrity of joinery-style connections. In particular, member shrinkage can lead to loss of bearing at the ends of beams and changes in contact surfaces for members joined at non-orthogonal orientations. Cross section distortion due to shrinkage can cause tenons to be pushed out of their mortise, resulting in distress to the pegs that secure the joint. These effects can be avoided or minimized through proper detailing and cutting of joinery.

## **4.0 Design for Lateral Loads**

### **4.1 Stand-Alone Timber Frames**

Stiffness of pegged mortise and tenon joints is sufficiently low that substantial drift (lateral displacement) has been observed in frames that rely only on knee braces for lateral stability. Conventional structural analysis programs can accurately predict the behavior of stand-alone frames when the stiffness of pegged joints is included in the analysis models. Appropriate modeling techniques are presented in References 11, 12 and 13. Based on tests of individual joints, the axial stiffness  $k$  (lb/in) of a mortise and tenon joint secured with two 1-inch diameter oak pegs may be approximated by  $k = 110,000G_t$ , where  $G_t$  is the specific gravity of the timber (see Reference 14).

### **4.2 Timber Frames and Diaphragm - Shear Wall Systems**

When lateral load resistance in a timber frame is shared with or entirely reliant on a diaphragm - shear wall system, the members of the timber frame may be used as components, such as chord and strut elements, of the diaphragm - shear wall system. The stiffness of a timber frame sheathed with structural insulated panels (SIPs) can be an order of magnitude higher than that of the stand-alone frame (see References 11 and 15). Hence, in coupled timber frame and diaphragm -shear wall systems, the timber frame is not likely to carry significant lateral load. A diaphragm-frame interaction structural analysis such as that described in Reference 15 is recommended. In lean-on systems, all lateral load must be transferred to and resisted by the shear wall system. Continuity of load path through the timber frame to the shear wall system is essential.

## ***Appendix A – Glossary***

Refer to *TIMBER FRAMING Journal of the Timber Framers Guild* No. 68 June 2003 for a more complete glossary of terms related to timber framing.

## References

1. Kessel, M. H. and Augustin, R. (1996) "Load Behavior of Connections with Pegs II," *Timber Framing, Journal of the Timber Framers Guild*, No. 39, pp. 8-10, March.
2. Foliente, G. C. and McLain, T. E. (1998) "End-notching effect on flexural stiffness of lumber: preliminary evaluation," *Forest Products Journal*, v 48, n 7-8, Jul-Aug, 1998, p 54-56.
3. Schmidt, R. J. and Scholl, G. F. (2000), Load Duration and Seasoning Effects on Mortise and Tenon Joints, Research Report, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY
4. Wood Handbook: Wood as an Engineering Material, General Technical Report 113, Forest Products Laboratory, U. S. Department of Agriculture, 1999.
5. Schmidt, R. J. and Miller, J. F. (2004) Capacity of Pegged Mortise and Tenon Joinery, Research Report, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY
6. ASTM Standard D5764-1997, Test Method for Evaluating Dowel Bearing Strength of Wood and Wood Base Products, ASTM, West Conshohocken, PA, 1997.
7. Schmidt, R. J. and MacKay, R. B., (1997) Timber Frame Tension Joinery, Research Report, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY
8. Church, J. R. and Tew, B. W. (1997). "Characterization of Bearing Strength Factors in Pegged Timber Connections," *Journal of Structural Engineering*, March 1997, 326-332.

9. Schmidt, R. J. and Daniels, C. E., (1999) Design Considerations for Mortise and Tenon Connections, Research Report, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY
10. ASTM Standard D143-94, Standard Methods of Testing Small Clear Specimens of Timber, ASTM, West Conshohocken, PA, 1997.
11. Erikson, R. G. and Schmidt, R. J. (2003) Behavior of Traditional Timber Frame Structures Subjected to Lateral Load, Research Report, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY
12. Bulleit, W. M., Sandberg, L. B., O'Bryant, T. L., Weaver, D. A., and Pattison, W. E., (1996). "Analysis of Frames with Traditional Timber Connections," Proceedings, International Wood Engineering Conference, New Orleans, LA. 4, 232-239
13. Bulleit, W. M., Sandberg, L. B., Drewek, M. W., and O'Bryant, T. L., (1999). "Behavior and Modeling of Wood-Pegged Timber Frames," *Journal of Structural Engineering*, 125(1), 3-9.
14. Erikson, R. E. and Schmidt, R. J. (2004) "Lateral Load Response of Full-Scale Traditional Timber Frame Structures," *Wood Design Focus*, American Forest and Paper Association, Third Quarter.
15. Carradine, D. M, Woeste, F. E., Dolan, J. D., and Loferski, J. R. (2004) Utilizing diaphragm action for wind load design of timber frame and structural insulated panel buildings," *Forest Products Journal*, 54(5): 73-80, May.