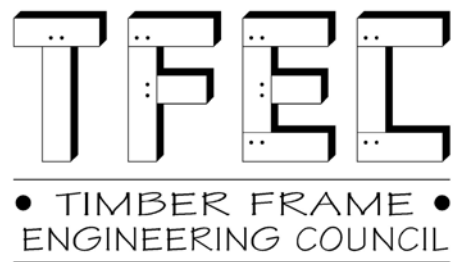


TFEC 1-07

Standard for Design of Timber Frame Structures and Commentary



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Standard for Design of Timber Frame Structures

1.0 General Requirements for Structural Design and Construction

1.1 Applicability and Scope

This Standard defines the engineering and design requirements for timber frame construction. A timber frame shall be regarded as a structural building frame system or a portion thereof that is composed of heavy timber members in which connections between interlocking members are created by carpenter-style joinery using wood pegs and wood wedges.

This Standard is not intended to preclude use of other materials, assemblies, structures or designs not meeting the criteria herein, provided it is demonstrated by analysis based on recognized theory, full scale or prototype loading tests, studies of model analogues or extensive experience in use that the material, assembly, structure or design will perform satisfactorily in its intended end use.

This Standard is intended as a supplement to provisions of the National Design Specification for Wood Construction (ANSI/AF&PA NDS[®], Reference 1). In the event of conflicts or contradictory requirements between this Standard and the NDS[®], the provisions of the latter specification shall apply.

1.2 Liability

It is intended that this document be used in conjunction with competent engineering design, accurate fabrication, and adequate supervision of construction. The Timber Frame Business Council and the Timber Framers Guild do not assume any responsibility for errors or omissions

in this document, nor for engineering designs, plans, or construction prepared from it. Those using this Standard assume all liability arising from its use. The design of engineered structures is within the scope of expertise of licensed engineers, architects, or other licensed professionals for applications to a particular structure.

1.3 General Requirements

1.3.1 Strength

Buildings and other structures shall be designed and constructed to safely support the anticipated loads that are likely to occur during the lifetime of the structure. In addition, assemblies and subassemblies shall be designed and constructed to safely support those loads that are likely to occur during construction, including but not limited to frame assembly and raising.

1.3.2 Serviceability

Structural systems and members thereof shall be designed to have adequate stiffness to limit deflections, lateral drift, vibration, or any other deformations that adversely affect the intended use and performance of the system.

1.3.3 General Structural Integrity

Buildings and other structures shall be designed to sustain local damage with the structural system as a whole remaining stable and not damaged to an extent disproportional to the original damage location. This shall be accomplished by providing sufficient continuity, redundancy, or energy-dissipating capacity (ductility), or a combination thereof, in the members of the structure.

1.3.4 Conformance with Standards

The quality of wood products and fasteners and the design of load-supporting members and connections shall conform to the standards specified herein or shall otherwise be permitted at the discretion of the local building official.

1.4 Design Loads

1.4.1 Governed by Codes

Minimum design loads shall be in accordance with the local building code under which the structure is designed. In the absence of a local building code, the minimum design loads specified in Minimum Design Loads for Buildings and Other Structures (SEI/ASCE 7; see Reference 4) shall be used.

1.4.2 Loads Included

Where applicable, design loads shall include any or all of the following loads or forces: dead, live, snow, wind, earthquake, erection and other static and dynamic forces.

1.5 Construction Documents

1.5.1 Types of Documents

Construction documents shall be understood to include contracts, plans, specifications, shop drawings and other documents as agreed by the contracting parties intended to convey the construction requirements for the structure.

1.5.2 Material Selection

The construction documents shall indicate the species or species group of the timber as well as the stress grade and grading rules for each member used in construction. The design values used in design shall be permitted to be indicated on the construction documents. The construction documents shall also indicate the species and assumed density of wood used for pegs and wedges in the structure.

1.5.3 Member Sizes

The construction documents shall indicate whether timber member sizes are stated in terms of standard nominal dimensions, standard net dimensions, or other designations.

1.5.4 Connection Details

The construction documents shall indicate the dimensions necessary for connection fabrication. Locations and sizes of tenons, mortises, housings, and other connection components shall be specified such that fabrication quality can be evaluated.

1.6 Materials

1.6.1 Timber

Design values for solid-sawn timbers used as structural load-carrying members shall be based on the species groups and commercial grades defined in the National Design Specification for Wood Construction Supplement, Design Values for Wood Construction (DVWC). Lumber shall be identified by the grade mark of, or certificate of inspection issued by, a lumber grading or inspection bureau or agency recognized as being competent (PS 20, Reference 5). A distinct grade mark of a recognized lumber grading or inspection bureau or agency, indicating that glue

joint integrity is subject to qualification and quality control, shall be applied to glued lumber products.

1.6.2 Wood Pegs

Wood pegs used as fasteners in connections shall be fabricated from clear, straight-grain, defect-free, hardwood stock with a slope of grain not greater than 1:15. The specific gravity of the peg stock shall not be less than that of the timber used in the connection, but in no case shall the oven-dry specific gravity of the peg stock be less than 0.57.

1.6.3 Wood Wedges

Wood wedges used to secure through-tenons or scarf joints, or used for other structural applications shall be fabricated from clear, straight-grain, defect-free, hardwood stock. Wedges shall be fabricated to minimize slope of grain, but in no case shall slope of grain be greater than 1:6 relative to each face of the wedge. The specific gravity of the wedge stock shall not be less than that of the timber used in the connection, but in no case shall the oven-dry specific gravity of the wedge stock be less than 0.57.

1.7 Notation

Except where otherwise noted, the symbols used in this Standard have the following meanings.

C_d = load duration factor, see 3.4.9

C_m = wet service factor, see 3.4.9

C_g = group action factor for connections, see 3.4.9

C_t = temperature factor, see 3.4.9

C_{Δ} = geometry factor for connections, see 3.4.9

D = diameter of peg, in., see 3.4.1

F_{em} = dowel bearing strength of main member, psi, see 3.4.1

F_{es} = dowel bearing strength of side member, psi, see 3.4.1

F_{vp} = shear strength of peg, psi, see 3.4.1

$F_{e\theta}$ = dowel bearing strength at an angle to the grain, psi, see 3.4.1

F_{yb} = dowel bearing yield stress of the peg, or bending yield strength of peg, psi, see 3.4.1
and 3.4.5

G_t, G_p = specific gravity of tenoned member and of peg, dimensionless, see 3.4.1

R_e = ratio of specific gravities of main member and side member, see 3.4.1

Z, Z' = reference and adjusted lateral design value for a single fastener connection, lbs,
see 3.4

b = breadth of rectangular bending member, in.

d = depth of bending member or least dimension of rectangular compression member, in.

d_n = depth of member remaining at a notch, in., see 2.3.3

l_e = end distance, in., see 3.1.1.2

l_m = dowel bearing length in the main member, or tenon breadth, in., see 3.4.1

l_s = dowel bearing length in the side member, or minimum mortise side wall thickness on
one side of tenon, in., see 3.4.1

l_{s1}, l_{s2} = spacing between centers of adjacent fasteners measured perpendicular to grain
and parallel to grain respectively, in., see 3.1.1.3

l_v = edge distance, in., see 3.1.1.1

w_1, w_2, w_3 = width of partial-width notch, in., see 2.3.4

w_m = width of mortise, see 3.4.11

w_s = width of side wall on either side of mortise, see 3.4.11

θ = maximum angle of load to grain for any member in a connection, deg, see 3.4.1

2.0 Structural Members

2.1 General

The provisions of the ANSI/AF&PA NDS[®] shall apply for design of wood bending members, compression members, tension members, members subjected to combined bending and axial loading, and members subjected to bearing.

2.2 Seasoning Effects

For structural members fabricated from unseasoned timber, consideration shall be given to the potential effects of shrinkage and distortion due to warping prior to and after assembly of the structure.

2.3 Notching

2.3.1 Effects on Member Stiffness

The effects of notching on member stiffness with respect to serviceability shall be considered.

2.3.2 Tension or Compression Face Notches

The provisions of the ANSI/AF&PA NDS[®] shall apply for the design of bending members that are notched across the full width of their tension or compression face. The provisions of Sections 2.3.3 and 2.3.4 of this Standard shall also apply.

2.3.3 Coped Tension Face Notches

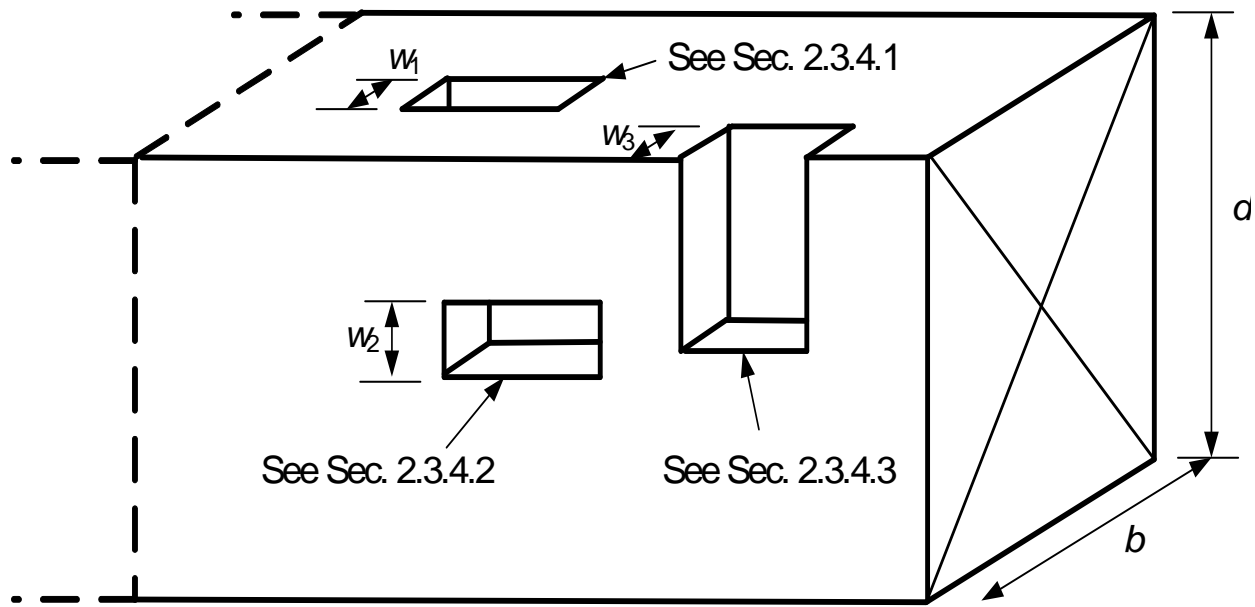
A gradual change in cross section compared with a square notch decreases the actual shear stress parallel to the grain nearly to that computed for an unnotched bending member with the same net

depth d_n . Such a gradual change shall be achieved by providing smooth transitions between surfaces with no overcuts at reentrant corners.

2.3.4 Partial-width Notches

A notch on the face of a bending member that does not extend across the full width of the face is a partial-width notch (see Figure 2A).

Figure 2A Partial-width notches



2.3.4.1 If the width w_1 of a partial-width notch on the tension or compression face of a bending member does not exceed one-third the breadth b of the member, the flexural and shear capacities of the member shall be determined by the principles of engineering mechanics using the net cross section of the member at the notch.

2.3.4.2 If a partial-width notch on the lateral face of a bending member has width w_2 no greater than $d/4$, the flexural and shear capacities of the member shall be determined by the principles of engineering mechanics using the net cross section of the member at the notch.

2.3.4.3 If a partial-width notch extending from the compression face down the lateral face of a bending member has a width w_3 not exceeding $b/4$, the flexural and shear capacities of the member shall be determined by the principles of engineering mechanics using an effective rectangular cross section consisting of the depth of the member and the net breadth of the member at the notch.

3.0 Connections

3.1 General

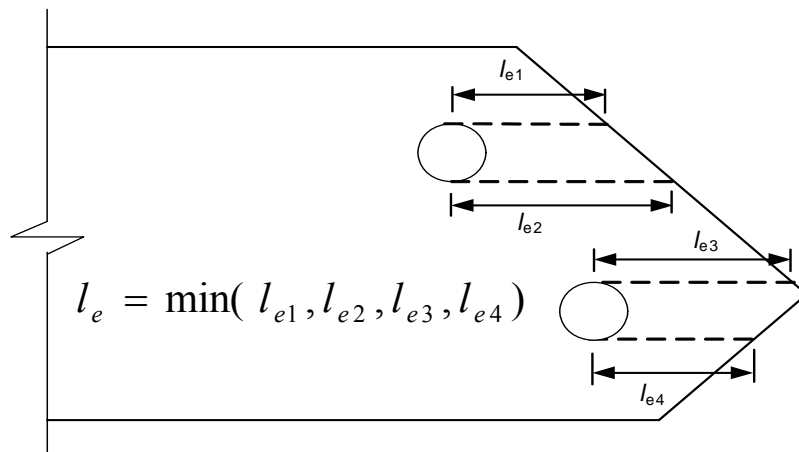
Chapter 3 applies to the engineering design of connections using wood-on-wood bearing and wood fasteners, including pegs and wedges, for load transfer. The provisions of the ANSI/AF&PA NDS[®] shall apply for the design of connections using metallic fasteners and metal connector plates.

3.1.1 Terminology

3.1.1.1 “Edge distance” is the distance l_v from the edge of a member or the inside face of a housing to the center of the nearest fastener, measured perpendicular to grain. When a member is loaded perpendicular to grain, the loaded edge shall be defined as the edge in the direction toward which the fastener is acting. The unloaded edge shall be defined as the edge opposite to the loaded edge.

3.1.1.2 “End distance” is the distance l_e measured parallel to grain from the square-cut end of a member to the center of the nearest fastener. For a member with a tapered-cut end, “end distance” is the minimum distance measured parallel to grain from the face of the cut end of a member to a diametrical line oriented perpendicular to grain through the center of the nearest fastener (see Figure 3A).

Figure 3A End distance for tapered member ends



3.1.1.3 “Spacing” is the distance l_{s1} between centers of adjacent fasteners measured perpendicular to grain or the distance l_{s2} between centers of adjacent fasteners measured parallel to grain.

3.1.2 Installation of Pegs

3.1.2.1 Holes for pegs shall be sized such that pegs are held securely by friction after installation, but pegs shall not be damaged by crushing, mushrooming, flexure, or splitting as they are driven into the hole.

3.1.2.2 Draw boring shall be permitted where it can be demonstrated by full-scale or prototype tests or extensive experience in use that wood splitting in the tenon and damage to the peg do not occur and that the strength of the connection is not compromised.

3.1.3 Installation of Wedges

3.1.3.1 The opening in the receiving member for a wedge shall be sized such that the wedge is held in place by direct bearing of the wedge against endgrain inside the opening of the

receiving member. Tension perpendicular to grain in the receiving member through direct bearing of the wedge shall not be permitted.

3.1.3.2 Joint detailing and assembly shall be as required to prevent splitting of the tenon, spline, or other joint material that receives the wedge as a result of wedge installation.

3.1.4 Connection Design

3.1.4.1 Design of mortise and tenon connections for shear or tension shall conform to the provisions of Sections 3.3 through 3.6 of this Standard.

3.1.4.2 Design of other connections (dovetails, scarfs, laps, etc.) shall be according to the principles of engineering mechanics with appropriate consideration for stress concentrations from notching.

3.2 Withdrawal

3.2.1 Prohibition of Withdrawal Loading

Joint detailing and assembly that may result in withdrawal loading of a peg or wedge is prohibited.

3.3 Mortise and Tenon Connections Loaded in Shear

3.3.1 Load Transfer by Direct Bearing

Transfer of shear load in a tenoned member to a mortised member shall be achieved by direct bearing of the tenon within the mortise or by direct bearing of the tenoned member on a mortise housing.

3.3.2 Shear Capacity

The shear capacity of the tenoned member shall be determined based on the breadth of the bearing surface of the tenoned member supported by the mortised member.

3.3.3 Strength Contribution of Pegs

Pegs shall not be considered to contribute to the shear strength of the tenoned member.

3.3.4 Connection Detailing

Pegs in connections in which the tenoned member is loaded in shear shall be located as close as practicable to the bearing surface.

3.4 Mortise and Tenon Connections Loaded in Tension

3.4.1 Yield Limit Equations

Transfer of tension load in a tenoned member to a mortised member shall be permitted to be achieved by lateral load transfer through one or more pegs provided that:

- (a) faces of the tenon and mortise are in close contact
- (b) the load acts perpendicular to the axis of the peg
- (c) the peg is loaded in double shear
- (d) edge distance, end distance, and spacing are in accordance with provisions of Sec. 3.4.8
- (e) the penetration length of the peg in the mortise side wall on each side of the tenon equals at least the thickness of the tenon
- (f) the size and species of the pegs in a multiple-peg joint are identical

(g) the peg diameter is no less than 0.75 inches and no greater than 1.25 inches.

The nominal design value Z for one peg shall be the minimum computed yield value using equations in Table 3A. The capacity of the connection shall be the capacity of one peg times the number of pegs in the connection.

Table 3A Yield Limit Equations, Double Shear

<u>Yield Mode</u>	<u>Capacity</u>	<u>Yield Mode</u>	<u>Capacity</u>
I_m	$Z = \frac{D l_m F_{em}}{4K_\theta}$ (3.4-1)	III_s	$Z = \frac{k_3 D l_s F_{em}}{1.6(2 + R_e)K_\theta}$ (3.4-3)
I_s	$Z = \frac{D l_m F_{es}}{2K_\theta}$ (3.4-2)	V	$Z = \frac{\pi D^2}{2} F_{vp}$ (3.4-4)

Notes: $K_\theta = 1 + 0.25(\theta / 90)$ (3.4-5)

$$k_3 = -1 + \sqrt{\frac{2(1 + R_e)}{R_e} + \frac{2F_{yb}(2 + R_e)D^2}{3F_{em}l_s^2}}$$
 (3.4-6)

$$F_{vp} = 1365 G_p^{0.926} G_t^{0.778}$$
 (3.4-7)

D = peg diameter (in)

F_{yb} = dowel bearing yield strength of the peg (psi)

$R_e = F_{em}/F_{es}$

l_m = tenon breadth (in)

l_s = minimum mortise side wall thickness on one side of tenon (in)

F_{em} = tenon dowel bearing strength parallel to grain (psi)

F_{es} = mortise side wall dowel bearing strength perpendicular to grain (psi)

θ = maximum angle ($0^\circ \leq \theta \leq 90^\circ$) of load to grain for any member in a connection (deg)

F_{vp} = shear strength of the peg (psi)

G_p = specific gravity of the peg material

G_t = specific gravity of the timber material

3.4.2 Dowel Bearing Strength

Dowel bearing strength F_{es} and F_{em} used in the yield limit equations shall be determined using methods provided in ASTM D5764 (Reference 2) and shall account for the combined response of the timber and the wood peg fasteners used in the connection.

3.4.3 Dowel Bearing Strength at an Angle to Grain

When a mortised member is loaded at an angle to the grain, the dowel bearing strength $F_{e\theta}$ for the member shall be determined as follows:

$$F_{e\theta} = \frac{F_{e\parallel} F_{e\perp}}{F_{e\parallel} \sin^2 \theta + F_{e\perp} \cos^2 \theta} \quad (3.4-8)$$

where θ is the angle between the direction of load and the direction of grain (the longitudinal axis of the member).

3.4.4 Dowel Bearing Length

3.4.4.1 Dowel bearing length in the main member and side member(s) represent the length of dowel bearing perpendicular to the applied load. The length of dowel bearing shall not include the tapered tip of a peg.

3.4.4.2 Dowel bearing length l_m in the main member shall be taken as the thickness of the tenon.

3.4.4.3 Dowel bearing length l_s in the side member shall be taken as the minimum of the two penetration lengths in the side walls of the mortise.

3.4.5 Bending Yield Strength of Pegs

3.4.5.1 Bending yield strength F_{yb} for wood pegs shall be based on yield strength derived using methods provided in ASTM F 1575 (Reference 3).

3.4.6 Peg Diameter

3.4.6.1 For nominally round pegs, peg diameter D shall be taken as the mean diameter of the peg.

3.4.6.2 For octagonal or other faceted cross-section pegs, peg diameter D shall be the minimum dimension measured across the peg between two parallel faceted faces.

3.4.7 Seasoning and Creep Effects

The effects of seasoning and creep on the serviceability of mortise and tenon connections loaded in tension shall be considered. The possible redistribution of forces due to long-term deflection of connections shall be examined.

3.4.8 Edge Distance, End Distance and Spacing

Mortise and tenon joints loaded in tension shall be proportioned such that splitting of the wood members does not occur. In the absence of connection details shown to produce satisfactory performance in their intended end use, edge distance, end distance and spacing of pegs shall meet the provisions of the ANSI/AF&PA NDS[®], Section 10.1.2 and Section 11.5 in which the fastener diameter shall be taken as the diameter of a steel dowel of lateral design capacity equivalent to that of one wood peg used in the same connection.

3.4.9 Adjustment Factors for Peg Connections

The nominal design capacity Z for a connection shall be multiplied by all applicable adjustment factors to determine the allowable design value Z' . Equation (3.4-9) specifies the adjustment factors that apply to the nominal design value Z .

$$Z' = Z \times [C_D C_M C_t C_g C_\Delta] \quad (3.4-9)$$

The actual load applied to a connection shall not exceed the allowable design value Z' for the connection.

3.4.9.1 Load Duration Factor, C_D : The nominal design value Z shall be multiplied by the load duration factor C_D specified in Section 2.3.2 of the ANSI/AF&PA NDS[®]. The impact load duration factor shall not apply to connections.

3.4.9.2 Wet Service Factor, C_M : Nominal design values are for connections in wood seasoned to a moisture content of 19% or less and used under continuously dry conditions, as in most covered structures. For connections in wood that is unseasoned or partially seasoned, or when connections are exposed to wet service conditions in use, the nominal design value shall be multiplied by the wet service factor C_M specified in Table 3B.

Table 3B Wet Service Factor

Moisture Content		C_m
At Time of Connection Assembly	In Service	
$\leq 19\%$	$\leq 19\%$	1.0
$> 19\%$	$\leq 19\%$	see Note
any	$> 19\%$	0.7

Note: Consideration shall be given to any potential strength reduction caused by restraint of shrinkage in pegged connections when the moisture content at the time of assembly exceeds 19% and the moisture content during service will be less than or equal to 19%.

3.4.9.3 Temperature Factor, C_t : Nominal design values shall be multiplied by the temperature factors C_t in Table 10.3.4, ANSI/AF&PA NDS[®], for connections that will experience sustained exposure to elevated temperatures up to 150°F.

3.4.9.4 Group Action Factor, C_g : Nominal design values shall be multiplied by the group action factor C_g defined in Section 10.3.6, ANSI/AF&PA NDS[®], for connections with multiple pegs in a row parallel to the line of applied force.

3.4.9.5 Geometry Factor, C_{Δ} : When the end distance, edge distance or spacing provided for peg connections is less than the minimum required for full design value, but greater than the minimum required for reduced design value, nominal design values shall be multiplied by the smallest applicable geometry factor determined from the end distance, edge distance

and spacing requirements. The smallest geometry factor, specified in Section 11.5.1 of the ANSI/AF&PA NDS[®], for any peg in a group shall apply to all pegs in the group.

3.4.10 Tenon size and quality

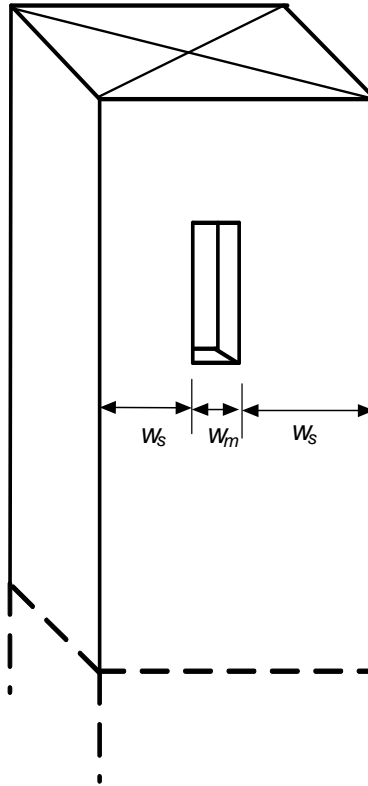
3.4.10.1 Tenon Size: The thickness of a tenon shall not exceed one-third the breadth of the face of the mortised member that receives the tenon.

3.4.10.2 Tenon Quality: Tenons shall be fabricated in a manner and location such that the strength of the tenon is not disproportionately reduced from that of the member due to the presence, size, and location of knots, shakes, slope of grain, pith, and other defects.

3.4.11 Mortise Placement

Mortises shall be placed such that the minimum side-wall width w_s on each side of the mortise is not less than the width w_m of the mortise (see Figure 3B).

Figure 3B Mortise Placement



3.5 Seasoning Effects

For connections fabricated from unseasoned lumber, consideration shall be given to the potential effects of distortion due to shrinkage or warping prior to and after assembly of the structure. In addition, the potential effects of seasoning on the assembled connection shall be considered. In particular the possible loss of bearing contact between two members and the change in orientation of bearing surfaces shall be considered.

4.0 Design for Lateral Loads

4.1 Stand-Alone Timber Frames

Stand-alone timber frames have been shown to have limited stiffness under lateral loads due to the relatively low stiffness of wood-pegged joints. Hence, the effects of joint stiffness shall be considered in the structural analysis of stand-alone timber frames to assure that the strength and serviceability of the structural system are adequate for the intended end use.

4.2 Timber Frames and Diaphragm - Shear Wall Systems

The strength and stiffness of timber frames constructed with diaphragms and shear walls to resist lateral load shall be determined by one of the following methods.

4.2.1 Coupled Timber Frame and Diaphragm - Shear Wall System

For timber frames that are intended to share lateral load with diaphragms and shear walls, structural analysis of the coupled system shall consider the effects of joint stiffness in the frame and the connections among the frame, diaphragms, and shear walls.

4.2.2 Lean-on Timber Frame System

For timber frames that are intended to lean on a diaphragm - shear wall system for lateral support, the diaphragm - shear wall system shall be designed to resist all lateral loads on the building system. In addition, connections between the timber frame and the diaphragm - shear wall system shall be adequate to transfer forces from the timber frame to the diaphragm -shear wall system.

Appendix A – Glossary

COPE – a notch cut on the tension face of a bending member at the member's bearing surface.

DRAW BORING – traditional framing technique in which the peg hole in the tenon is deliberately offset from the peg hole in the mortise to draw a joint tight when assembled and fastened with a tapered pin or peg, and to hold the joint tight after shrinkage of the mortised member occurs.

EDGE DISTANCE –The distance from the center of a peg hole to the edge of the member, or to the edge of the housing, in a mortised member measured perpendicular to the grain direction.

END DISTANCE –The distance from the center of a peg hole to the end of the member, measured parallel to the grain direction.

HOUSING – a recess in a supporting member to permit the full width of an adjoining member to bear on the supporting member.

LATERAL FACE – a face of a structural member that is parallel to the plane of the loads on the bending member. The lateral face is perpendicular to the tension and compression faces.

LEAN-ON SYSTEM – a structural system that provides no resistance to lateral load. A lean-on system distributes lateral load to another structural system and relies on that system for structural stability.

MOISTURE CONTENT – the weight of water in the cell walls and cavities of wood, expressed as a percentage of oven-dry weight.

MORTISE – a rectangular notch, slot, or hole cut into a structural component that will accept a corresponding tenon or spline.

MORTISE AND TENON (M&T) – a joint in which a projection (tenon) on one end of a piece is inserted into a notch, slot or hole (mortise) in another piece.

MORTISE SIDE WALL – the portion of the mortised member between the inside face of the mortise and the outside face of the member.

NOTCH – an area in a timber where a portion of the cross-section has been cut away, typically as part of joinery between two intersecting members.

NOTCH, FULL-WIDTH – a notch on the tension or compression face of a bending member that extends across the full width of the face.

NOTCH, PARTIAL-WIDTH – a notch on the tension or compression face of a bending member that does not extend across the full width of the face.

PEG – a cylindrical or slightly tapered wooden dowel or pin with round, octagonal, or other faceted cross section.

SCARF JOINT – a joint made by notching and lapping two timbers such that the longitudinal axes of the timbers are collinear.

SPECIFIC GRAVITY (G) –The ratio of a material's density to the density of water.

SPLINE (aka: FREE TENON) – a lumber or engineered wood element placed in slot cuts, grooves, dados, etc. to secure joints between two components.

STAND-ALONE TIMBER FRAME – a timber frame structure designed to resist lateral loads without the use of shear walls or other supplementary structural systems.

TENON – a projecting square or rectangular end on a timber that fits into a mortise to complete the connection of two pieces.

TIMBER FRAME – a structural building frame system or portion thereof that is composed of heavy timber members in which connections between interlocking members are typically created by carpenter-style joinery using wood pegs and wood wedges but may be supplemented with some metallic fastener components.

WEDGE – a tapered wood element with rectangular cross section used to secure through-tenons, through-splines and scarf joints.

Appendix B – References

1. ANSI/AF&PA, NDS[®]-2005, National Design Specification for Wood Construction, AF&PA, Washington, D. C.
2. ASTM Standard D5764-1997, Test Method for Evaluating Dowel Bearing Strength of Wood and Wood Base Products, ASTM, West Conshohocken, PA, 1997.
3. ASTM Standard F1575-2003, Standard Test Method for Determining Bending Yield Moment of Nails, ASTM, Conshohocken, PA, 1995.
4. SEI/ASCE Standard 7-2005, Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers, Reston, VA
5. National Institute of Standards and Technology Voluntary Product Standard PS 20-05, American Softwood Lumber Standard, Washington, DC, 2005.

Commentary to TFEC 1-07

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[®], 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[®]; 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 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. The NDS[®] supplement Design Values for Wood Construction should not be used to assign design values to pegs.

1.6.3 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[®]. Hence, the Standard contains provisions for timber frame design not included in the NDS[®]. The NDS[®] 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[®] 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[®] Section 3.4.3.2(d), the stress

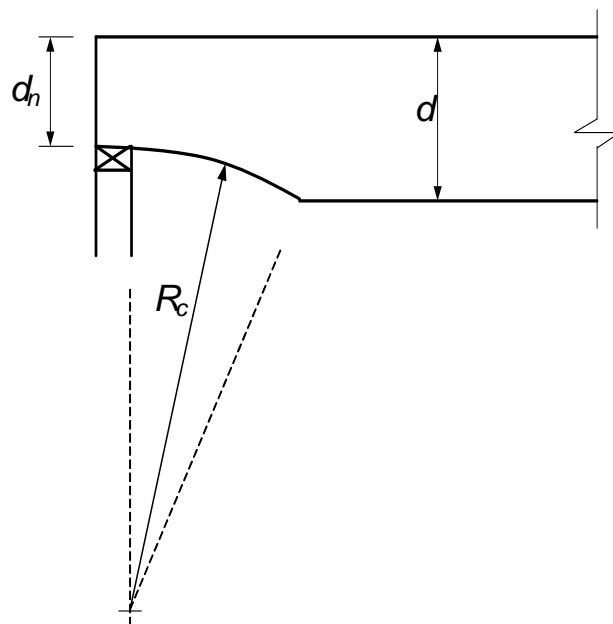
concentration for shear can be eliminated with a suitable “gradual change in cross section.” Any number of approaches may be used to achieve this condition. One such approach is a notch geometry in the form of a circular arc that is tangent to the bearing surface at the end of the member and intersects 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 most often when a mortise is cut to receive a tenon or a beam is fully housed into a post. Partial-width notches also occur in 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. No quantitative guidelines or limits can be provided at this time.

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 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.

3.0 Connections

3.1 General

The provisions of the NDS[®] 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[®] 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 tension stiffness of a mortise and tenon connection 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

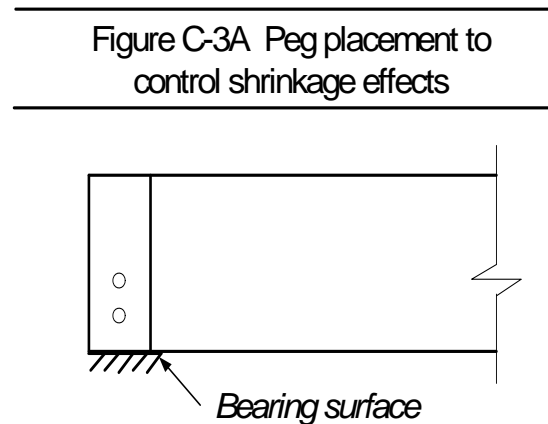
Shear load in a beam may be transferred to the mortised member through direct bearing across the width of the tenon for a beam that is not housed, or across the full width of the beam for a fully housed beam.

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_m in the NDS[®] 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_s 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_s) 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. Dowel bearing strength for a pegged connection depends upon the deformation of both the peg and the timber. Three approaches are available for determining dowel bearing strengths F_{es} and F_{em} for a peg bearing in the mortise side wall and a peg bearing in the tenon.

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 matching the peg diameter across one face. 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[®].

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.

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[®] 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[®] with no adjustment in fastener diameter. The recommended detailing dimensions shown in Table C3A have been shown to develop the full strength of a pegged mortise and tenon connection without splitting of the timber (see References 3 and 5).

Table C3A – Recommended Minimum Detailing Dimensions

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. 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.

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