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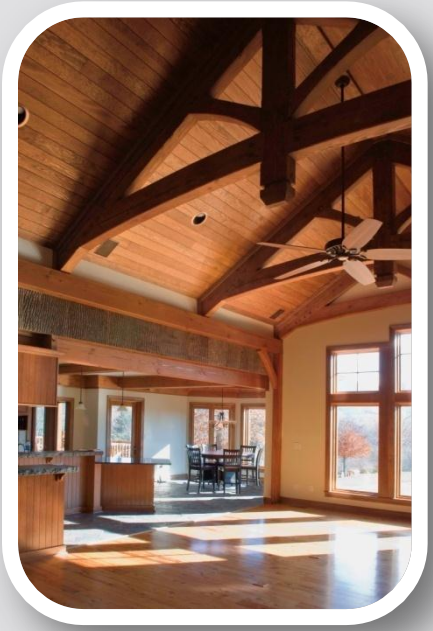
IMPROVING TIMBER CONNECTIONS THROUGH DESIGN



COURSE NUMBER: tlx06a

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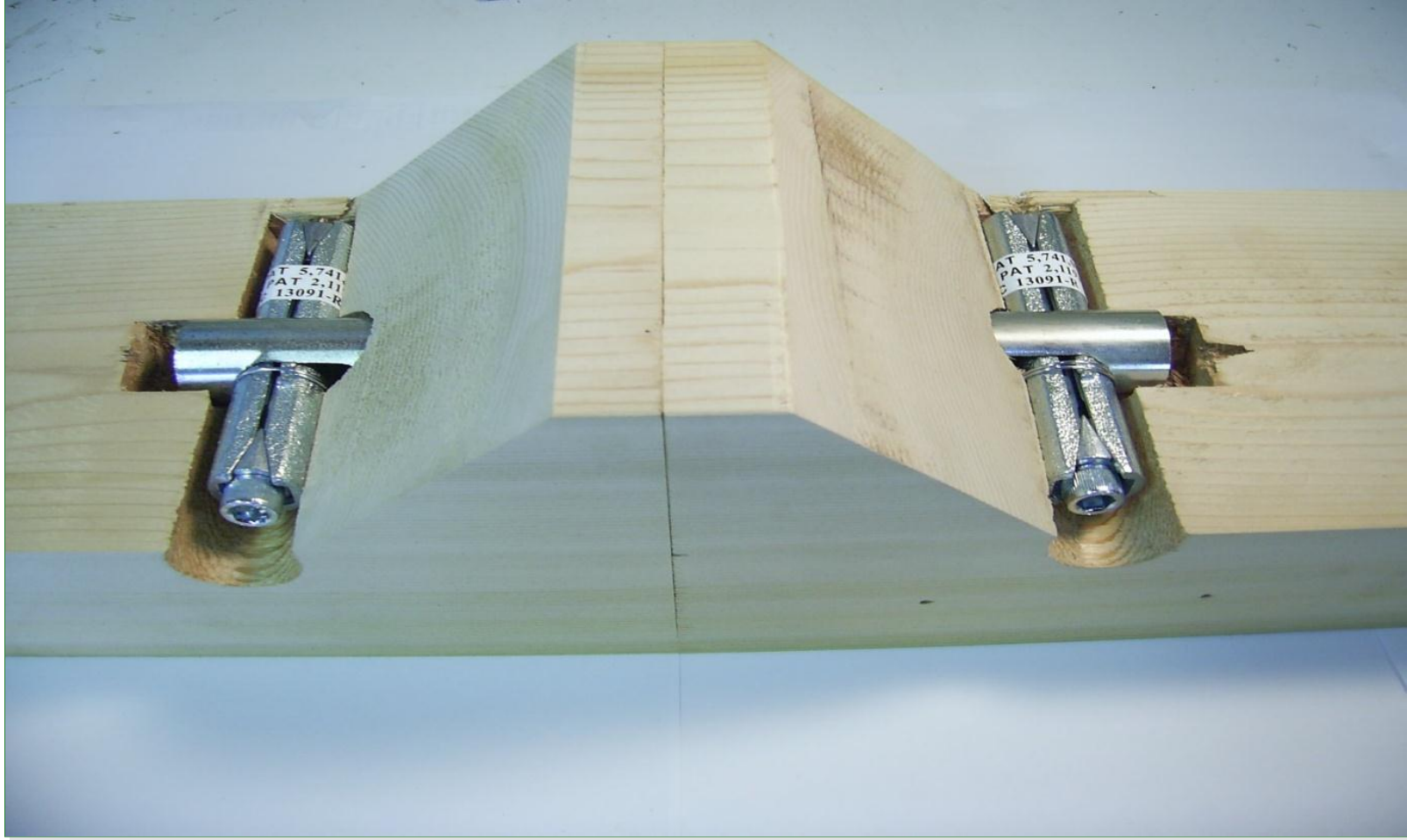


IMPROVING TIMBER CONNECTIONS WITH STEEL EMBEDDED CONNECTORS

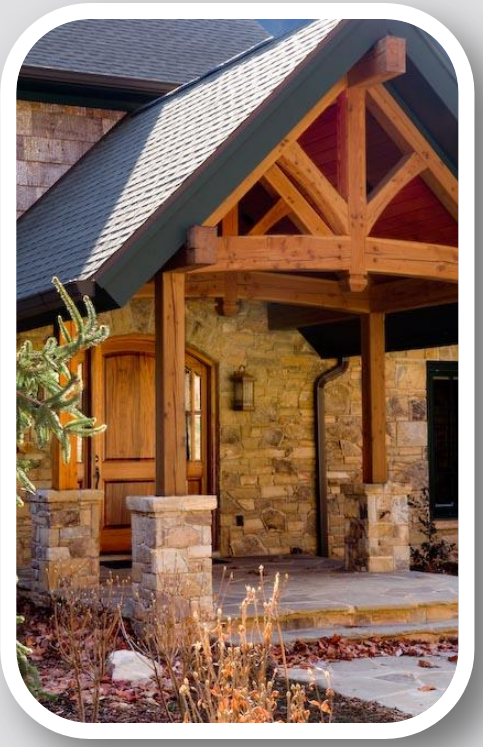
Description

Objectives

DESCRIPTION

Traditionally, connections in heavy timber structures (including glulam and log) were concealed. Approaches to achieving concealed connections include all-wood joinery, typical of timber frame construction. When necessary, because of engineering constraints, knife plates secured with bolts or drift pins are used. These usually have the nuts and bolts exposed.

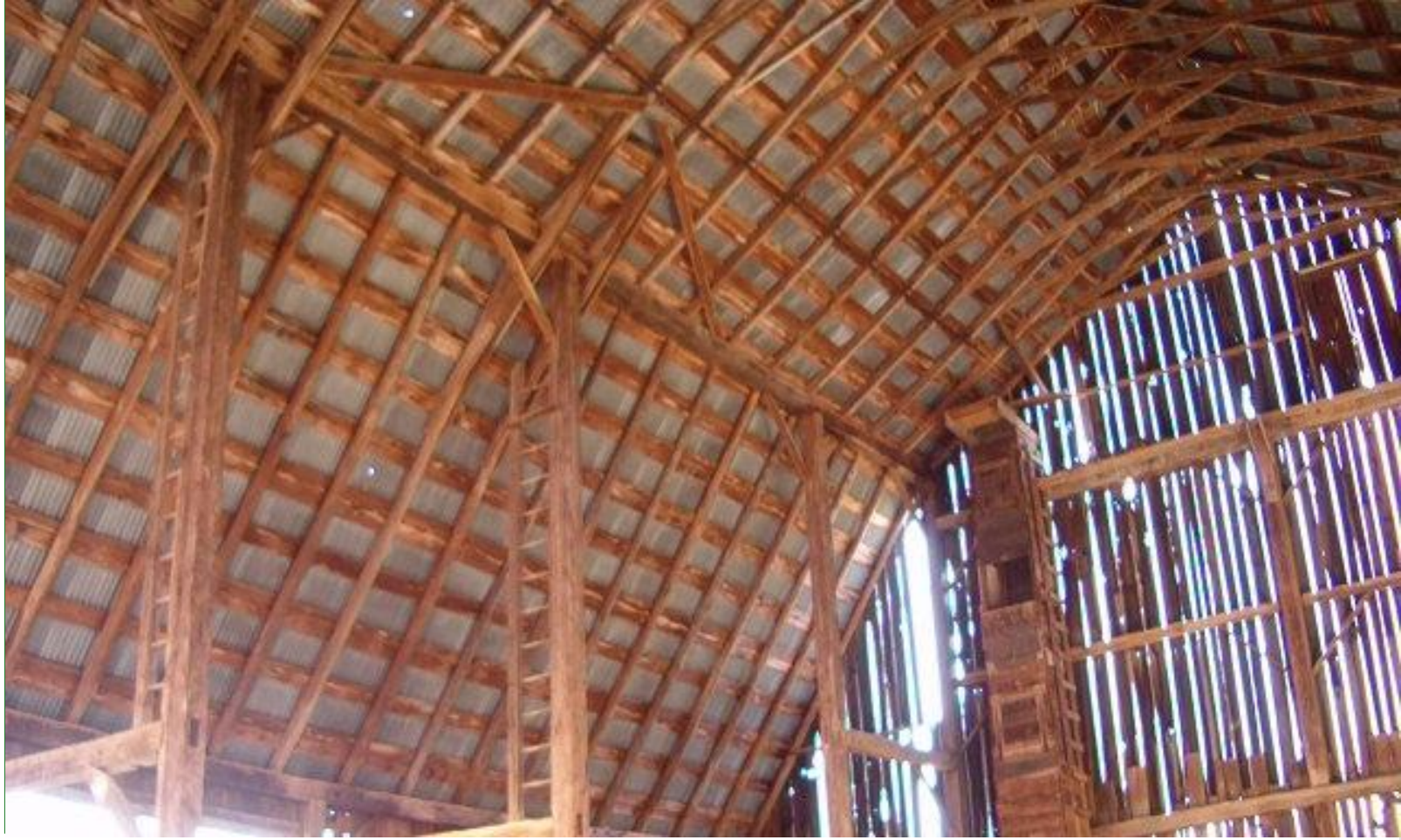
Steel embedded timber connectors provide an alternative, low-cost connection system that preserves the appearance of traditional joinery.



OBJECTIVES

By the end of this presentation, you will be able to:

- Compare traditional mortise and tenon (MT) joinery with embedded timber connectors
- Identify parts of a common timber frame
- Design for tension, compression, and shear utilizing steel embedded connectors
- Explain the installation of an embedded timber connector
- Specify different styles of embedded connectors for wood to wood, wood to concrete, and wood to steel connections



HISTORY

Timber Joinery Methods

HISTORY-Timber Joinery Methods

Historically, when building with timber, the joinery method was Mortise (a pocket cut into a piece of wood) and Tenon (a blade on the end of a member). These joints were secured using pegs, dowels and leather or cord lashings. Traditionally, a mortise and tenon joint was cut by hand. This method was passed down from generation to generation through the guild system.

With the advent of the Industrial Revolution, commercial saw mills developed the capacity to mass produce small pieces of lumber that could be nailed together. Then Balloon and Platform framing became the common method of building, and houses could be built quickly with an inexperienced work force. This virtually eliminated timber framing in North America.

A timber frame revival began in the early 1970's. There was little technical data on mortise and tenon joinery resulting in many trial and error methods. *cont'd*

HISTORY-Timber Joinery Methods

When engineering constraints dictated, external steel plates and dowel type connectors such as nails, spikes, bolts and screws were used. Various attempts were made to hide these fasteners.

The need for a mechanical connector was born.

Embedded timber connectors provide a traditional appearance and give designers and engineers a predictable failure mode that can be quantified.

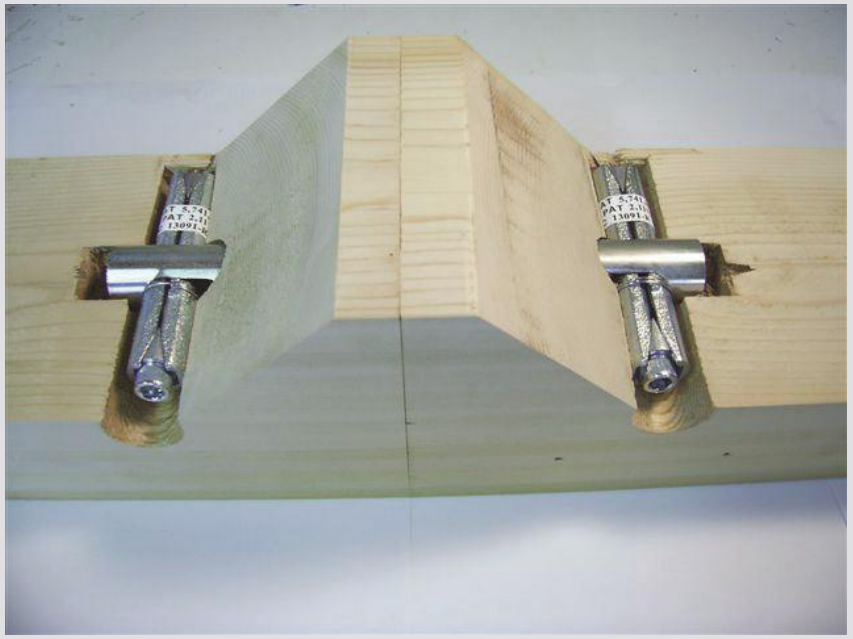
With the addition of embedded connectors, the scope of design has reached unlimited horizons.

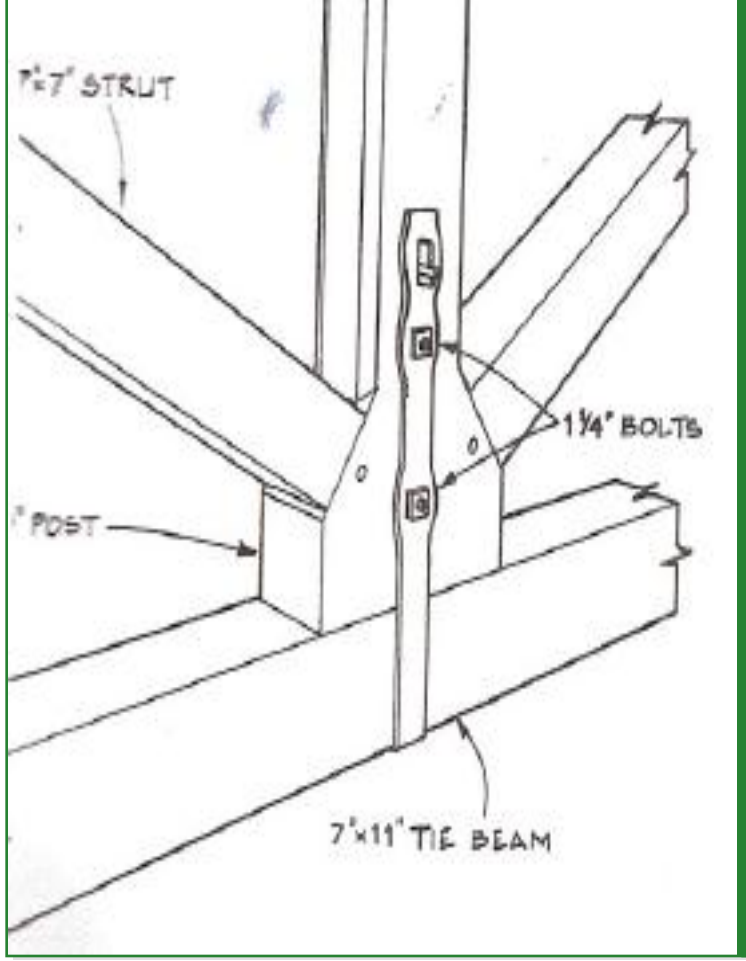
In 2007, there were approximately 15,000 timber frame and log home buildings in North America plus an unknown number of hybrid timber frames.

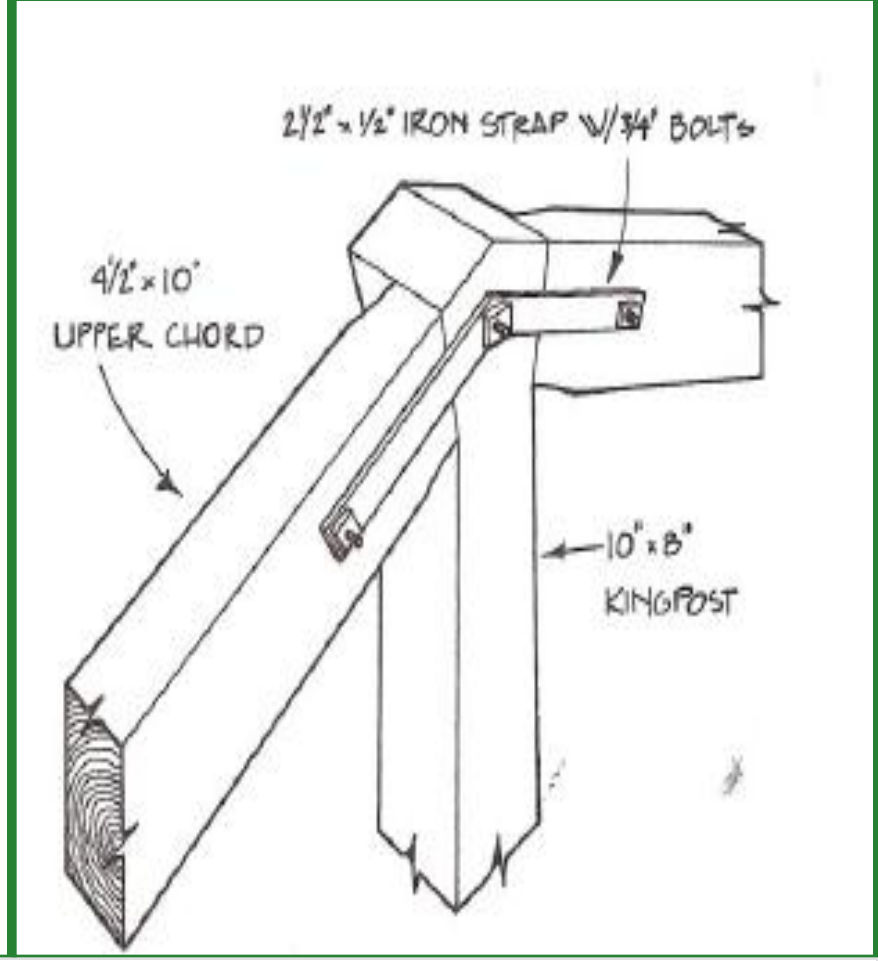
The demand for these magnificent long-lasting structures has returned with a vengeance.

HISTORY-Timber Connectors

- Originally designed to simply join two timbers together (right)
- The availability of mechanical connectors has expanded to include many different types which give the flexibility to replace any mortise and tenon joint, as well as achieve additional joints that were not possible before







TIMBER CONNECTORS

Describe the evolution of embedded timber connectors

Compare with traditional mortise and tenon (MT) joinery

THE NEED FOR STEEL EMBEDDED JOINERY

As interest in timber framing revived, traditional methods of joinery were studied. Large structures such as barns and cathedrals had been built using this system. The original buildings were very big, so hiding hardware behind or on top of the joint was common. But then there arose a need for building on a smaller scale – homes, cottages, etc.

The joints in a timber frame are the weakest parts of the building. Each piece of wood has different characteristics. Therefore, defining the design value of a mortise and tenon joint is more difficult than defining the value of an embedded steel connector which remains constant.

Originally, when extra strength was required, the builders who had studied the old methods used what they had seen in the past – external metal plates, straps, nuts and bolts.

THE NEED FOR STEEL EMBEDDED JOINERY

Embedded connectors came from the need to create a better joinery system that had well defined design values. Steel, in one form or another, has been used to enhance and help join wooden structures since the beginning of timber joinery, initially in the form of steel straps and nails usually hidden on top of the joinery out of sight. Steel embedded joinery was designed to be set into the wood and transfer loads between members by a combination of connectors in tension, and timber members in compression. Steel has tremendous tensile strength, especially compared to the traditional wood dowel connectors. The original idea of steel embedded joinery was born out of the need to provide defined engineered values, simplicity of installation and a traditional appearance.

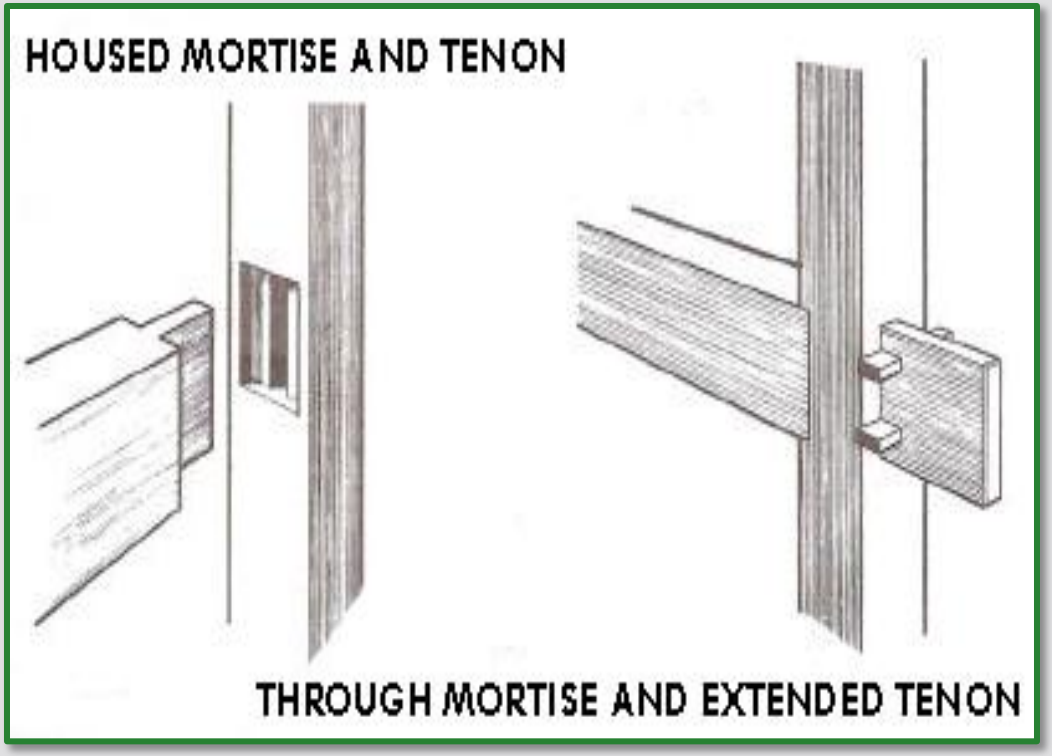
THE NEED FOR STEEL EMBEDDED JOINERY

Embedded connectors provide defined engineering values:

- “As engineers, we value connection systems that produce predictable failure modes, and that fail in the steel components where homogeneity and lower material variability lead to more accurate strength calculations. When steel failure governs, ductility can be included in the connection design - a preferable quality for structures in seismic regions” (Moses and Malczyk)

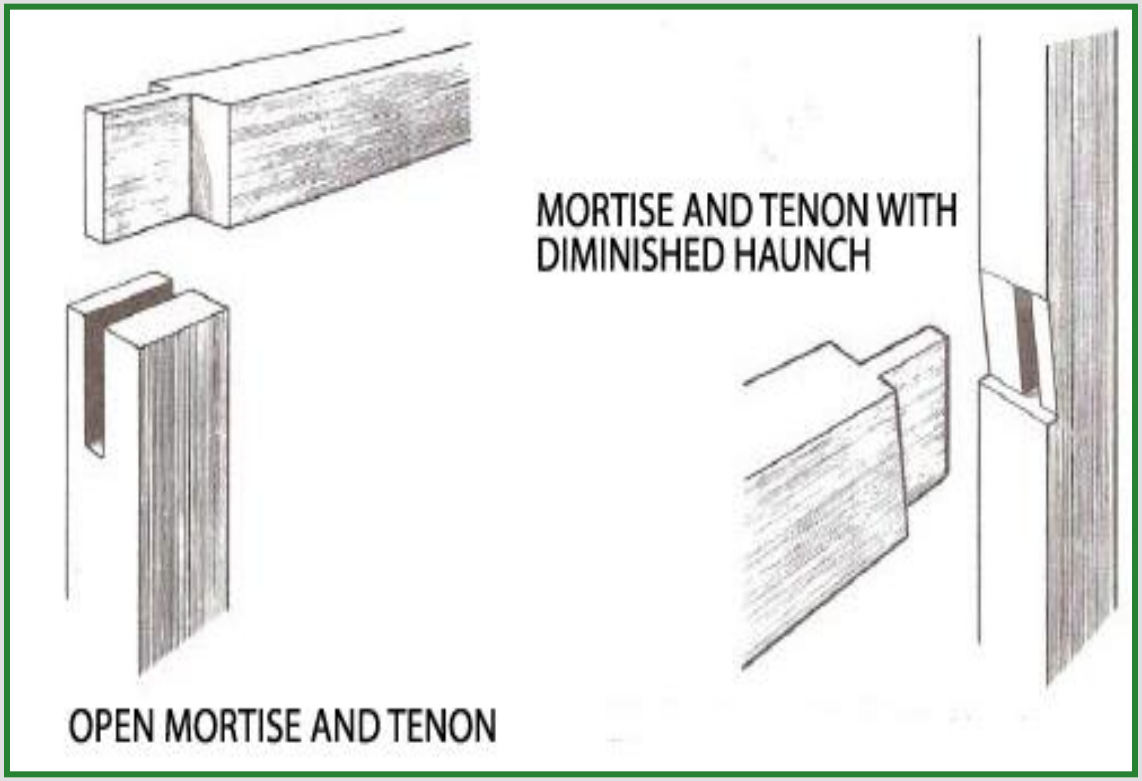
MORTISE AND TENON JOINTS

- Housed mortise and tenon
- A traditional through, wedged, mortise and tenon joint



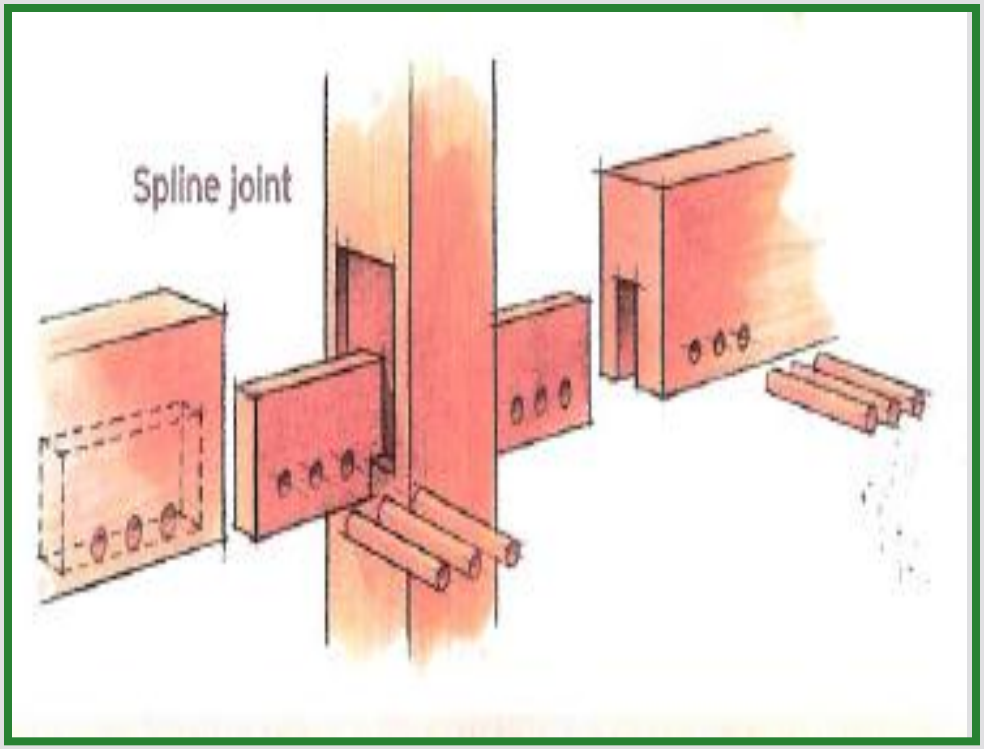
MORTISE AND TENON JOINTS

- Open mortise and tenon (a.k.a. Fork and Tongue Joint)
- Mortise and tenon with diminished haunch

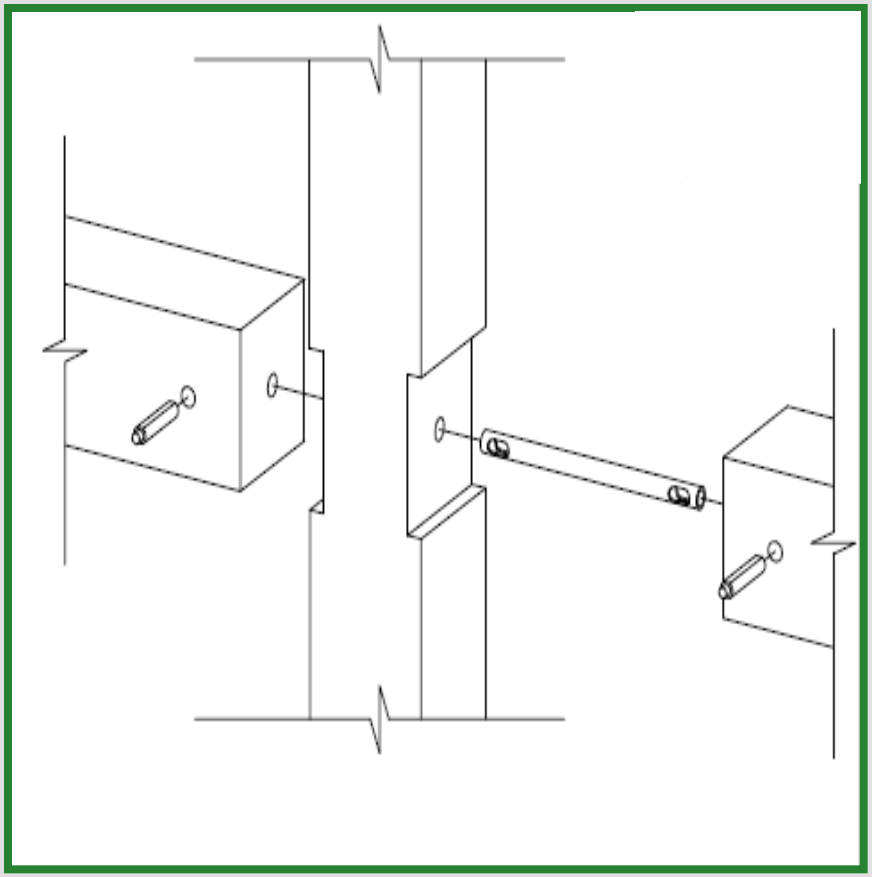


MORTISE AND TENON JOINTS

- Traditional spline joint



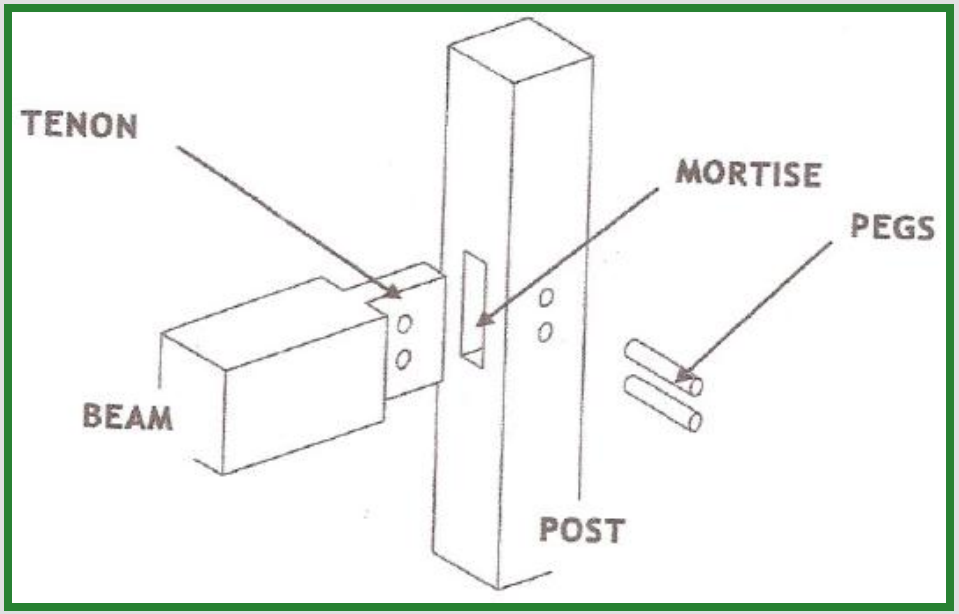
- Embedded connector spline joint



Embedded Spline Joint And Traditional Spline Joint Intersecting In The Same Location

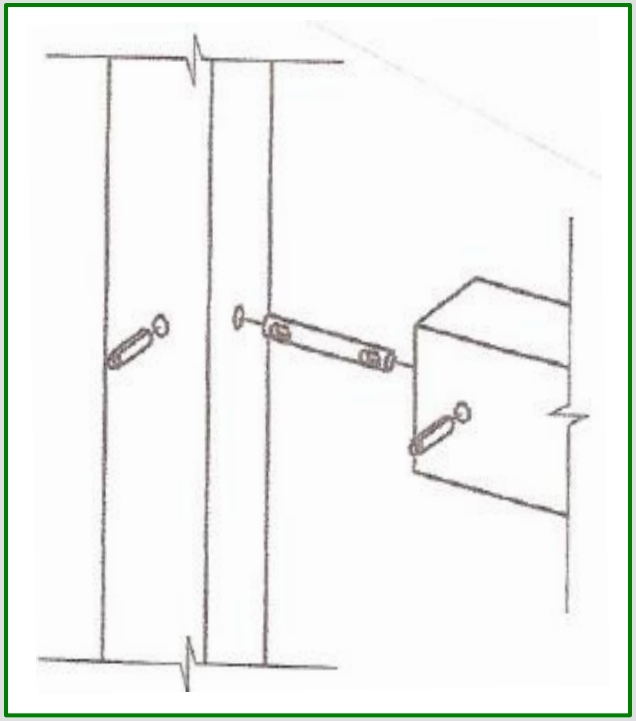
COMPARISON-Mortise and Tenon

- Wood governs failure
- Experienced timber framer required to construct
- Time consuming unless you have expensive equipment
- Longer assembly time
- Extreme accuracy required when drilling peg holes for draw boring



COMPARISON-Embedded Timber Connector

- Predictable failure modes
- Less wood removed to produce joint
- 4-way joinery connection possible now
- Can use smaller members in some cases
- Maintains traditional appearance
- Can be tightened during and after assembly
- Expansion pins put joint in compression
- Reduces shrinking effect
- Pipe itself has shear value
- Fast, reliable and easy to install
- Versatile

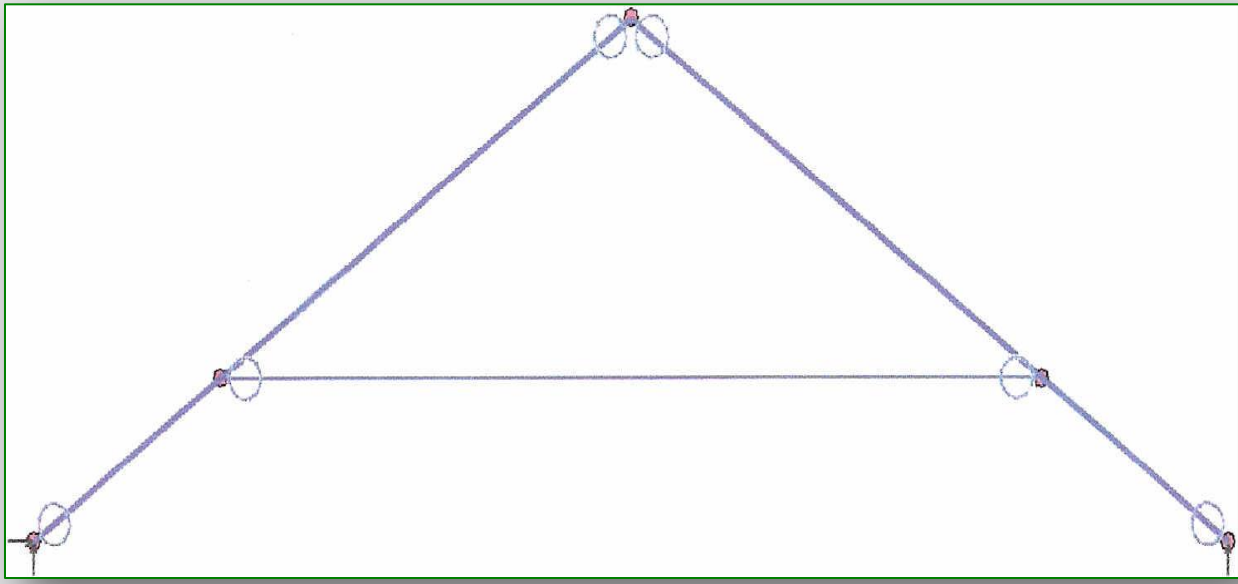


Timber Connectors vs. Mortise and Tenon Comparison

General Information:

- 8 in 12 roof pitch
- 24' wide, collar tie raised 2‘6“
- Timbers are 8" wide #1 Douglas Fir
- Full sawn, at 12% M.C.
- Loads are: 10psf DL, 40psf SL (projected)
- Trusses are spaced at 12' o.c.
- DL + SL loading controls
- Timber design per NDS (National Design Standard)

Example: A simple raised collar roof system



Analysis:

- Minimum Timber sizes:
  - Rafter = 8 x 14 (beam and stringer)
  - Collar Tie = 8 x 8 (post and timber)

- max tension in collar tie $T_{collar} := 8630\ lbf$
- max moment in rafter (at collar tie) $M_{rafter} := 302350\ lbf \cdot in$

Timber Connectors vs. Mortise and Tenon Comparison Con't

Timber Connectors Required:

2 pairs of 6.75" double slotted embedded steel connector + Threaded Rod per joint
Rafter size: 8" x 14"
Collar Tie size: 8" x 8"

To accomplish the same results using mortise and tenon, you must increase the sizes of the rafters and the collar tie. (Detailed calculations available upon request)

Rafter size: 8" x 16"
Collar Tie size: 8" x 16"

Wood required with steel connectors: 2x 8"x14"x16' + 1x 8"x 8"x18' = 394.662 BFT

Wood required for mortise and tenon: 2x 8"x16"x16' + 1x 8"x16"x18' = 533.333 BFT

Cost of #1 Douglas Fir full sawn, at 12% M.C. $2.25 BFT

Cost savings on wood per truss $312.00

ALL TRUSSES ARE ONLY AS STRONG AS THEIR JOINTS

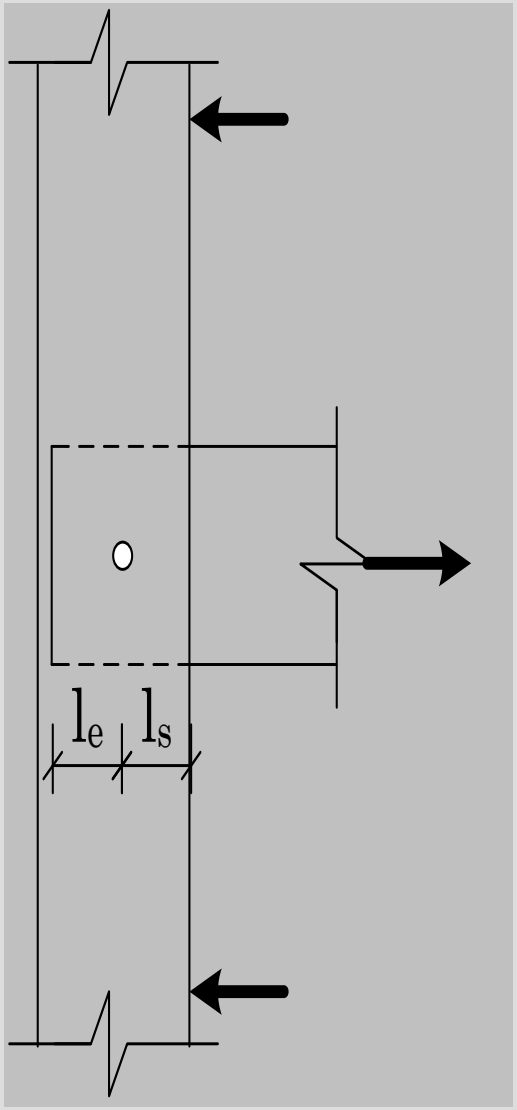
Allowable Stress Tension Design Value Comparison of Embedded Steel / Mortise & Tenon Connections

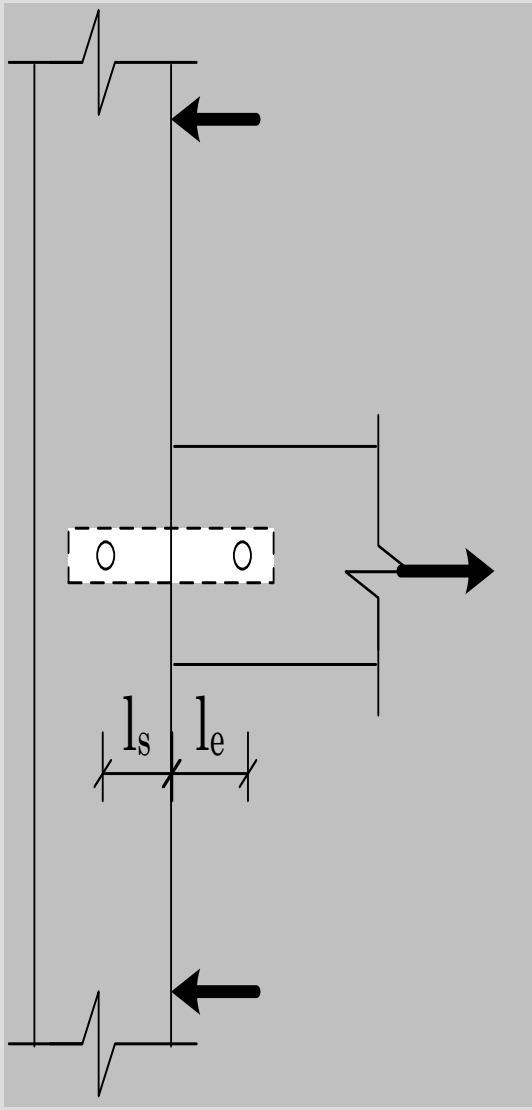
Timber (1)	Specific Gravity	Embedded Steel Connection (2), (5)			Mortise and Tenon Connection (3), (4), (5)		
		Capacity (lb)	l_e (in)	l_s (in)	Capacity (lb)	l_e (in)	l_s (in)
Eastern White Pine	0.36	1,930	5.25	3.0	725	3.36	1.92
Port Orford Cedar	0.39	2,440	5.25	3.0	770	3.36	1.92
Douglas Fir	0.50	2,210	5.25	3.0	935	3.15	1.80
White Oak	0.73	5,320	3.75	3.0	1180	2.20	1.76

Con't

Tension Design Cont…

1) Timbers are 6-inch square cross section with T connection. Stem of T is loaded in tension. (see figures on previous slide)
2) Connection with one 9.5” steel embedded connector (image right)
3) Connection with 1.5-inch thick tenon and one 1-inch diameter white oak peg (image left)
4) Design value and detailing dimensions determined from TFEC 1-07, Standard for Design of Timber Frame Structures
5) Detailing based on NDS & CSA O86-01 provisions





Note: the tenon must be this size to achieve the stated values.

Con’t

Net Section Effects

Section 3.1.2 of the NDS states:
"The net section area shall be used in calculating the load carrying capacity of a member."

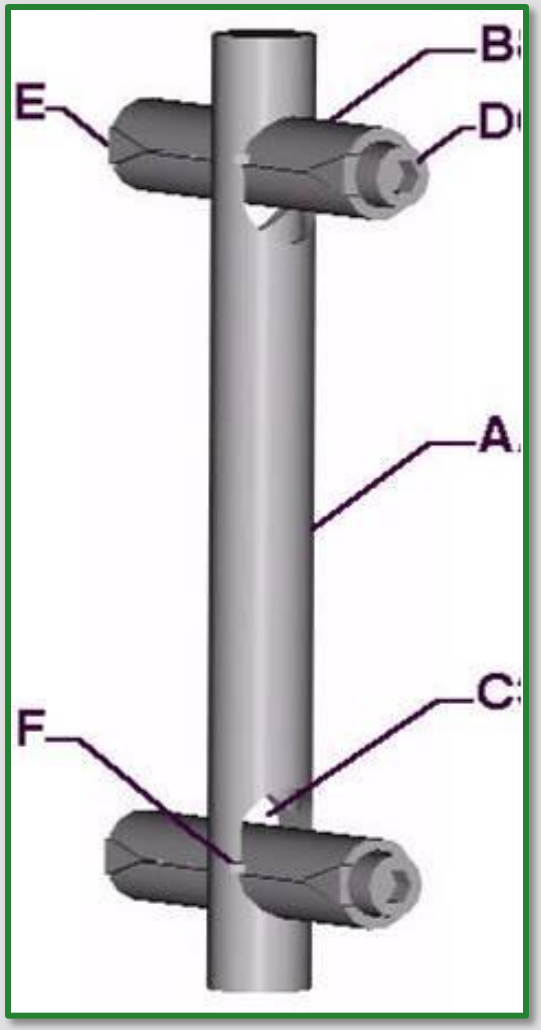
- On the previous slide we find that the mortise & tenon would require 45 in^3 of wood to be removed from the post to accommodate the tenon (approx 1/3rd of a 6"x6" post fully removed). A steel embedded connector would only require 11 ¼ in^3 to be removed, establishing a much stronger post.
- When a mortise and tenon connection is used in some building jurisdictions, California for example, they only allow the post value of its reduced size for loading calculations, reducing the once 6"x6" post to that of only a 4"x6".
- In this case, the post utilizing the mortise & tenon would most likely need to be increased in size from 6"x 6" to 8"x 8".
- In the same situation, the steel embedded connector would not only be at least three times as strong but would be paid for in the cost savings on wood alone.

STEEL TIMBER CONNECTORS

13.5” tube with expansion pins

This is a simple, concealed and adjustable fastening system. It consists of a hollow steel connection tube with elongated slots where expanding cross pins are inserted.

CONNECTOR DESCRIPTION



A: Connecting Tube

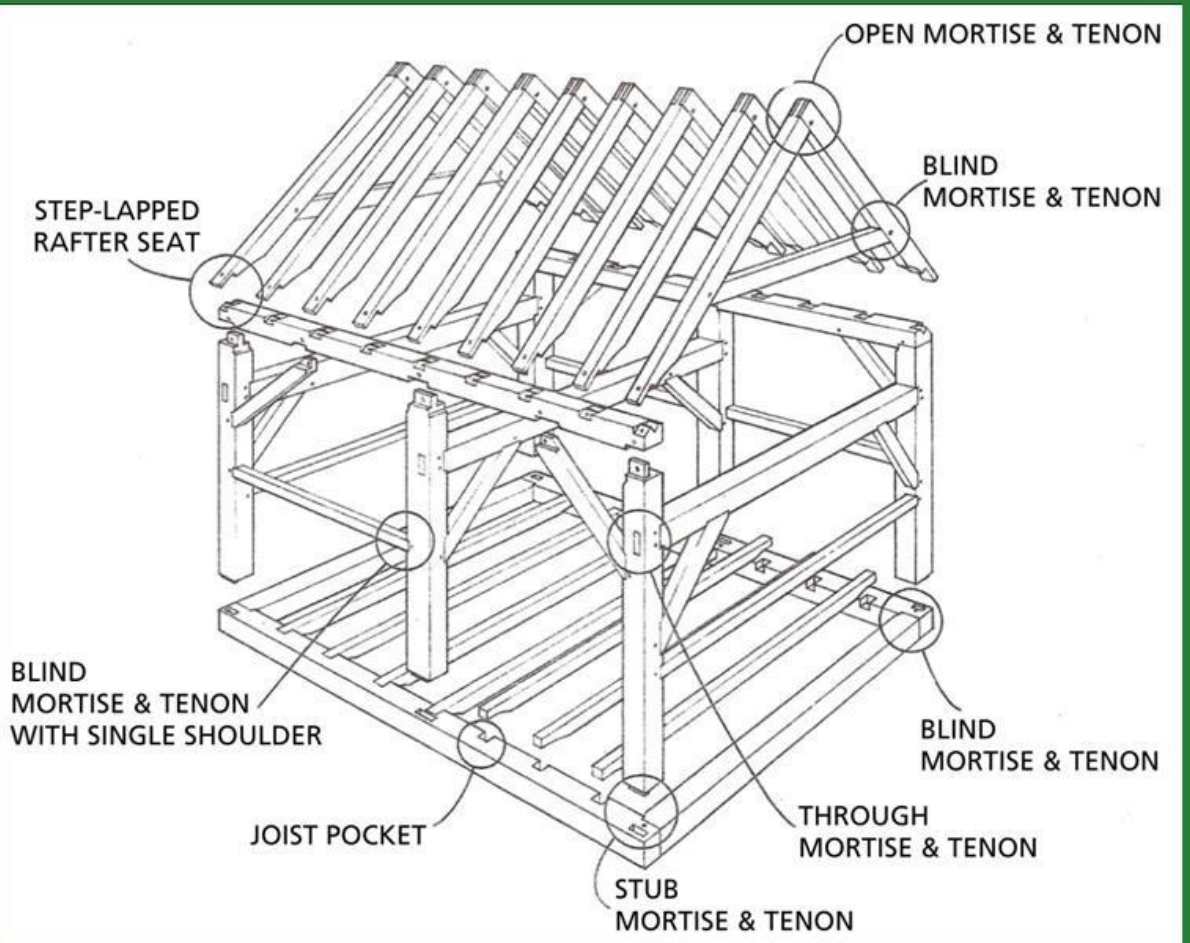
B: Expansion pin

C: Pin Slot

D: Tightening bolt

E: Expansion Wedges

F: Positioning Shoulder



DESIGNING WITH TIMBER FRAMES

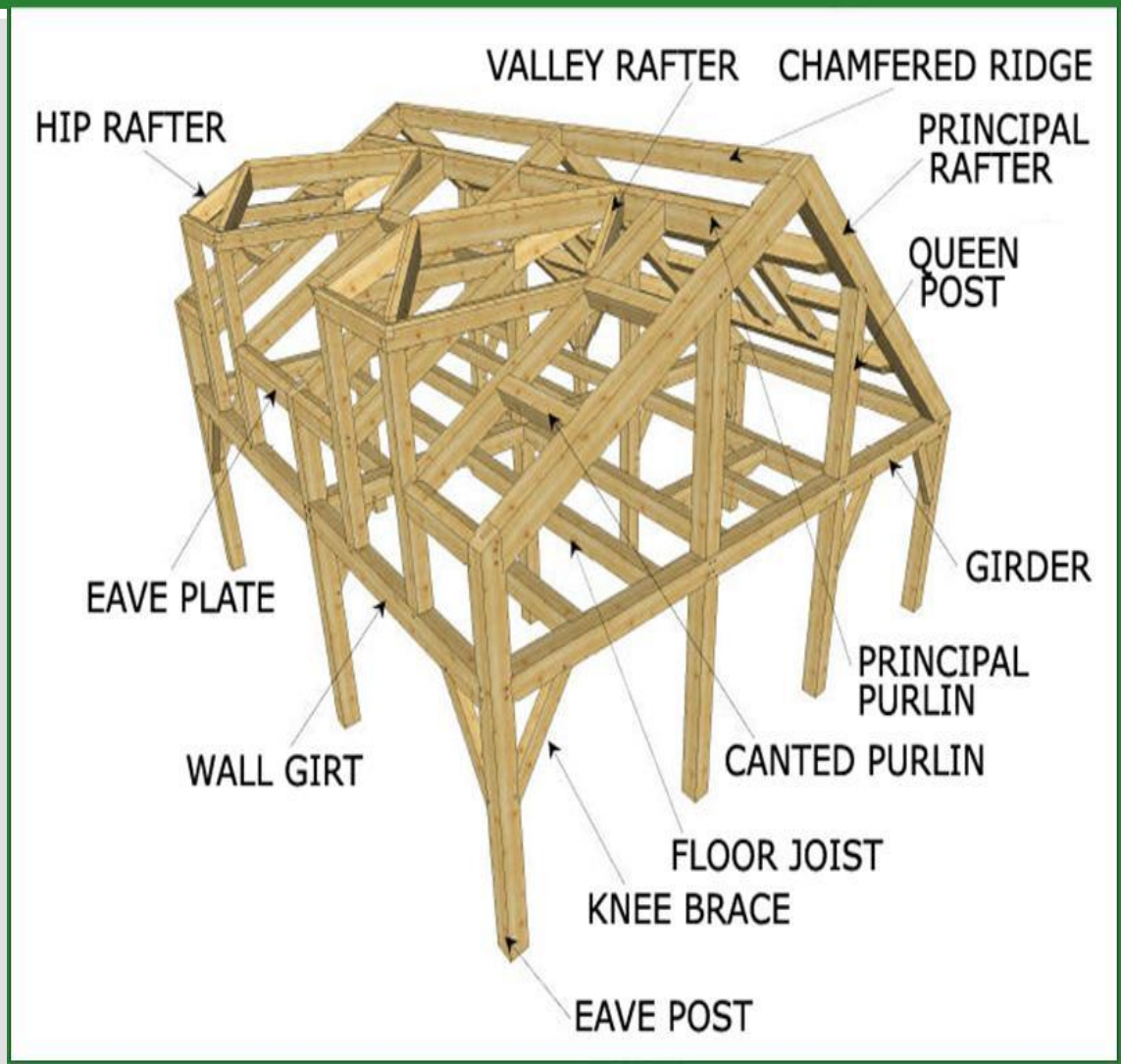
Identify parts of a common timber frame (use illustration)

Understand and learn how to design for tension, compression, and shear

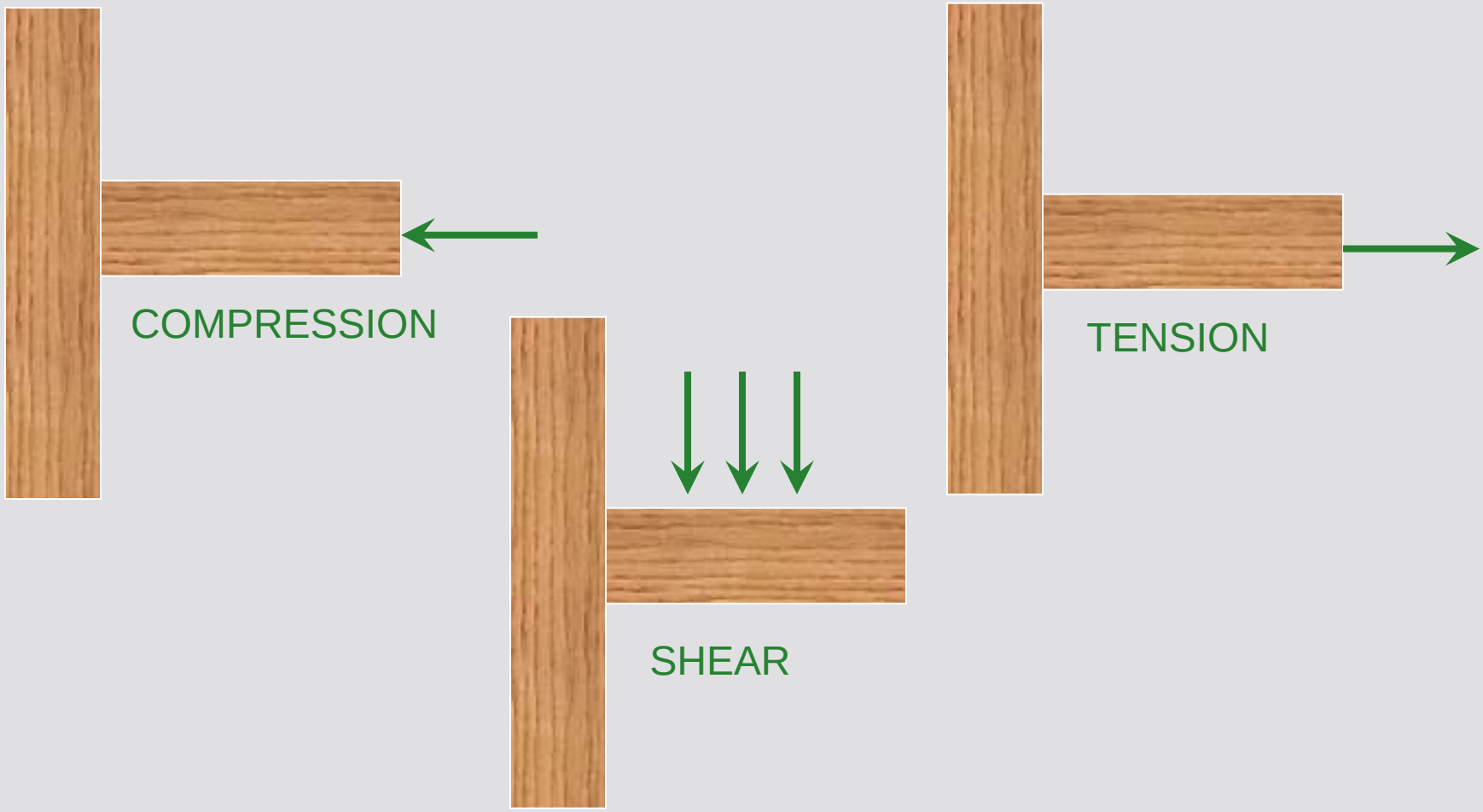
COMMON TIMBER FRAME

Parts of a common timber frame using mortise and tenon joinery.

Embedded steel connectors can be used in all of the joints illustrated, which would provide additional strength and stiffness to the building.

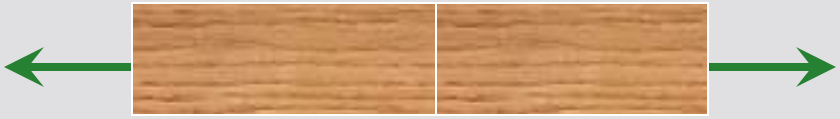


CONNECTIONS



TENSION DESIGN: Embedded Connector

Loading Parallel to grain

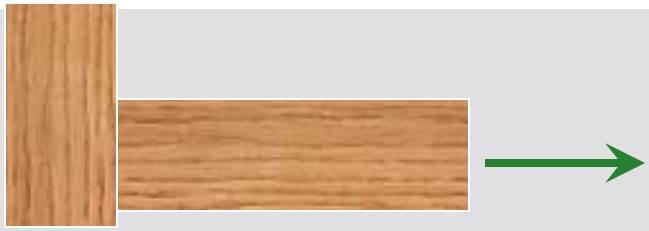


(in lbs)	Limit States Design	Working Stress Design
Eastern White pine	4,700	3,270
Port Orford cedar	5,080	3,530
White oak	7,640	5,320

Values for other species may be determined by interpolation, using published specific gravities.

TENSION DESIGN: Embedded Connector

Loading Perpendicular to grain

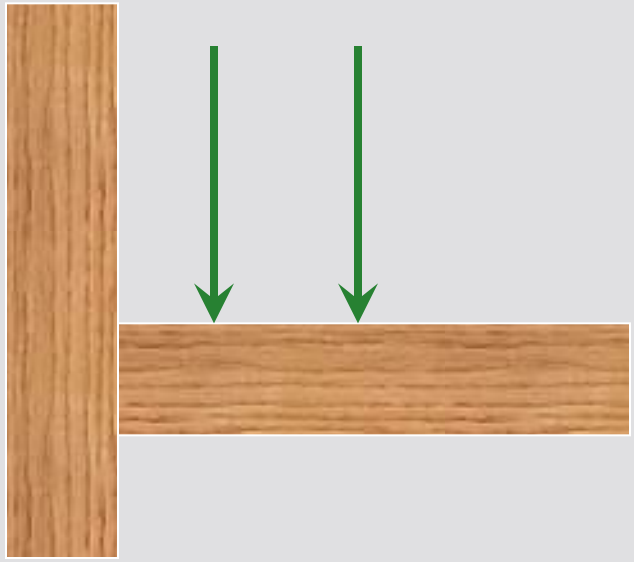


(in lbs)	Limit States Design	Working Stress Design
Eastern White pine	2,780	1,930
Port Orford cedar	3,500	2,440
White oak	7,640	5,320

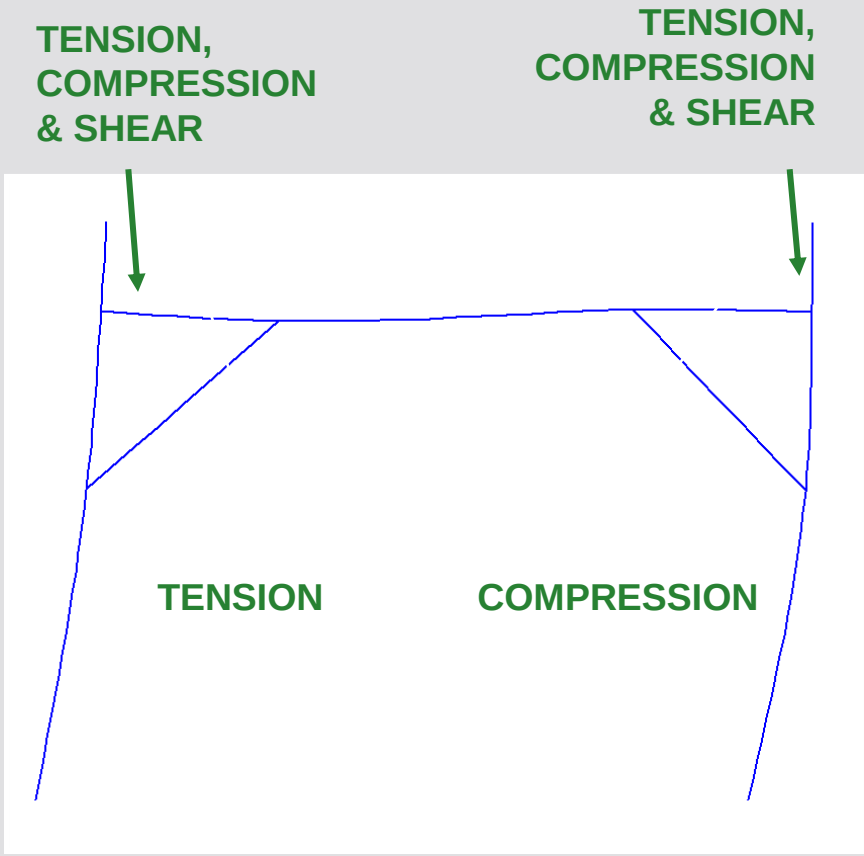
Values for other species may be determined by interpolation, using published specific gravities.

SHEAR DESIGN

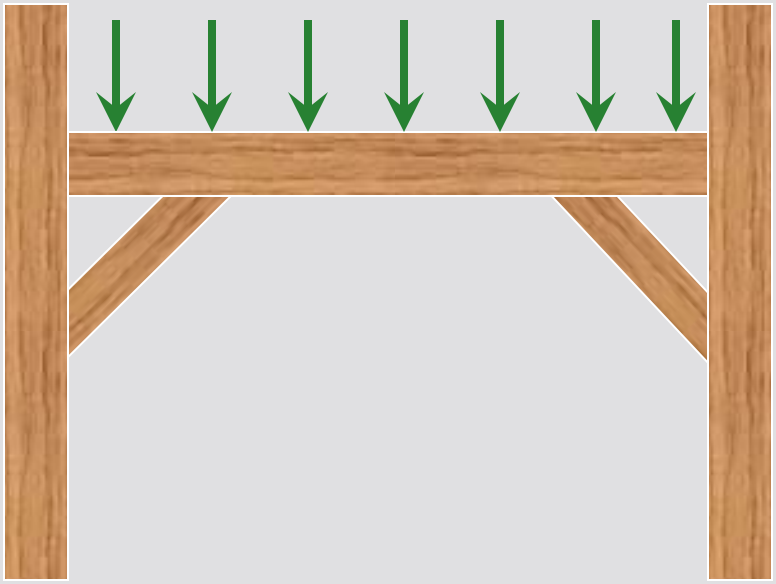
- 1 1/8” Tube carries all shear
  - Design using published yield model equations for dowel connectors
  - No interaction between shear capacity and tensile capacity
- Enhance with
  - Split rings
  - Shear plates
  - Housed connections

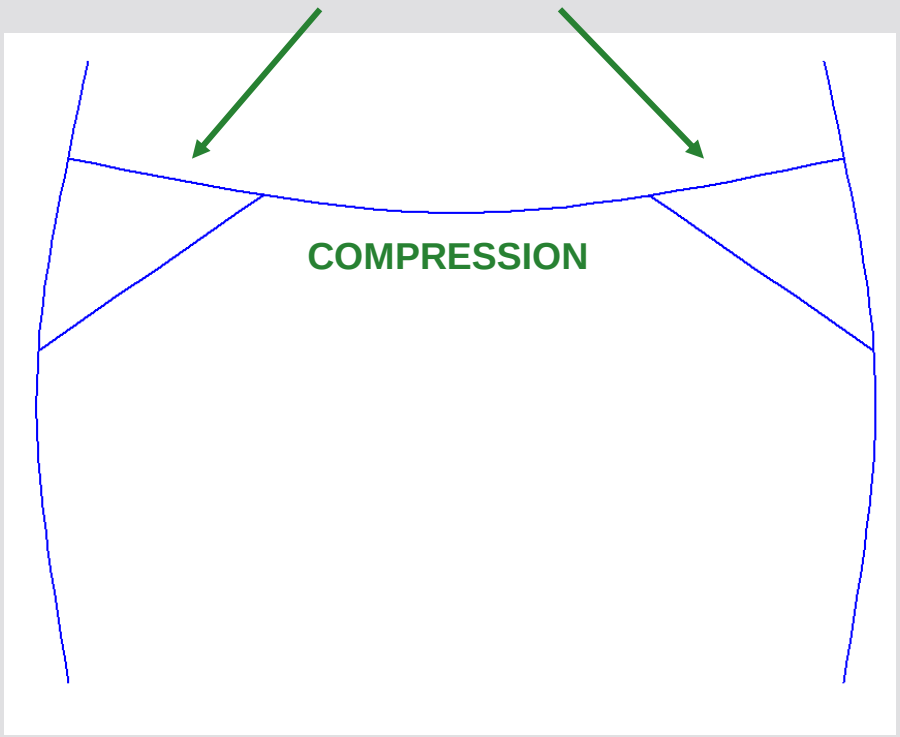


CONNECTION FORCES – Lateral Loads



CONNECTION FORCES – Gravity Loads





INSTALLATION

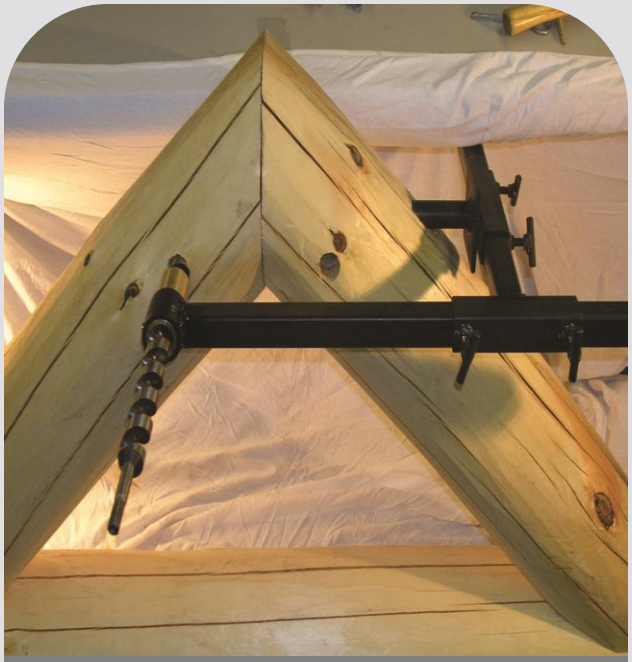
Installation methods

Drilling jig and other tools

INSTALLATION

Drilling Jigs:

- Set jig - drill pipe hole and pin hole in one operation
- Easily adjustable for various sizes
- Comes with brass bushings for 1 1/8" drill bits



One for Log Building

One for Timber Frames

INSTALLATION

Positioning Tool:

- Made from solid machine steel
- Helps to position slots exactly for insertion of pins
- Brings joints into position and holds them there
- Designed to fit in end of pipe for insertion

Positioning tools

INSTALLATION

Insertion tools:

- Made from solid machine steel
- Designed to fit over machine bolt head
- Applies force to end of castings so pins can be inserted without expanding

Insertion tools

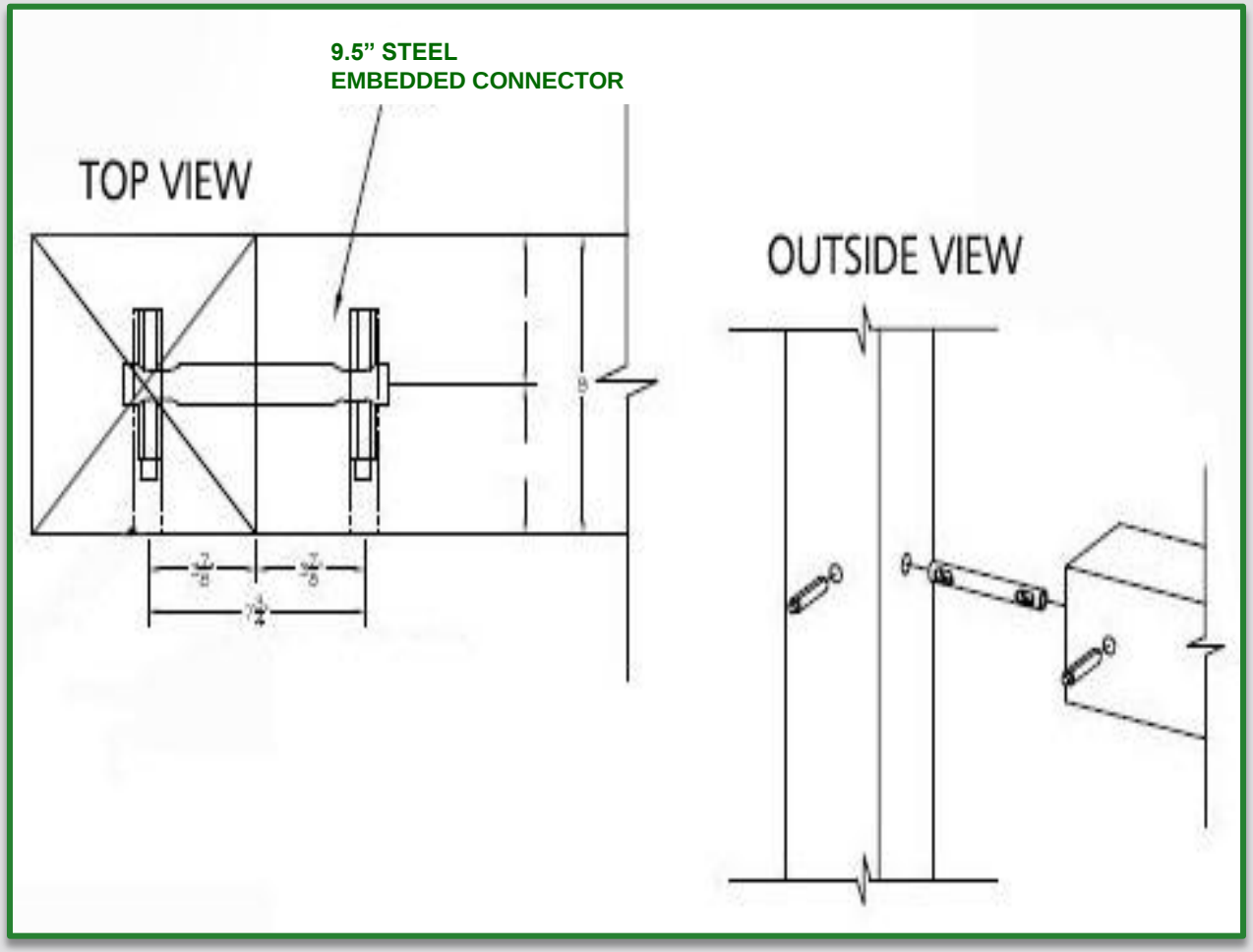
INSTALLATION: Advantages

- Enables four-way and three-way connections
- Can be used in any type of joint: wood to wood, wood to concrete, and wood to steel
- Strengthens every joint
- Can be easily tightened with an Allen key and completely concealed by a wood plug

INSTALLATION

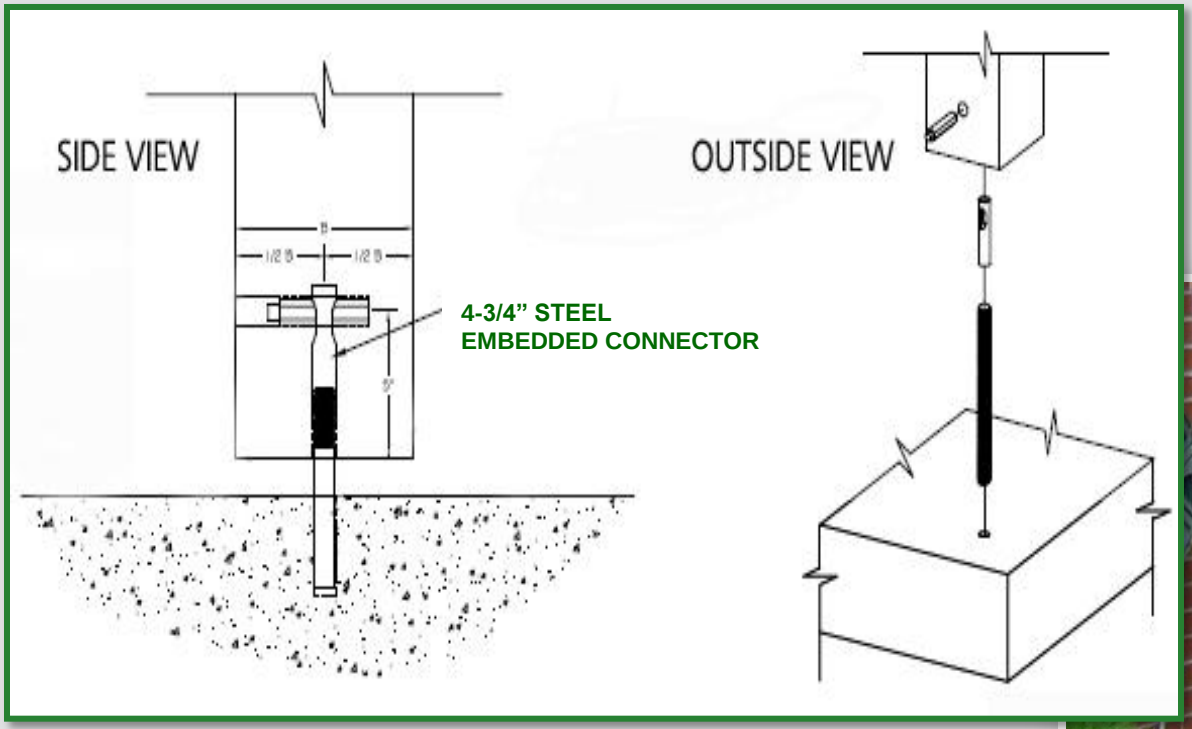
Beam to

Wooden Post:



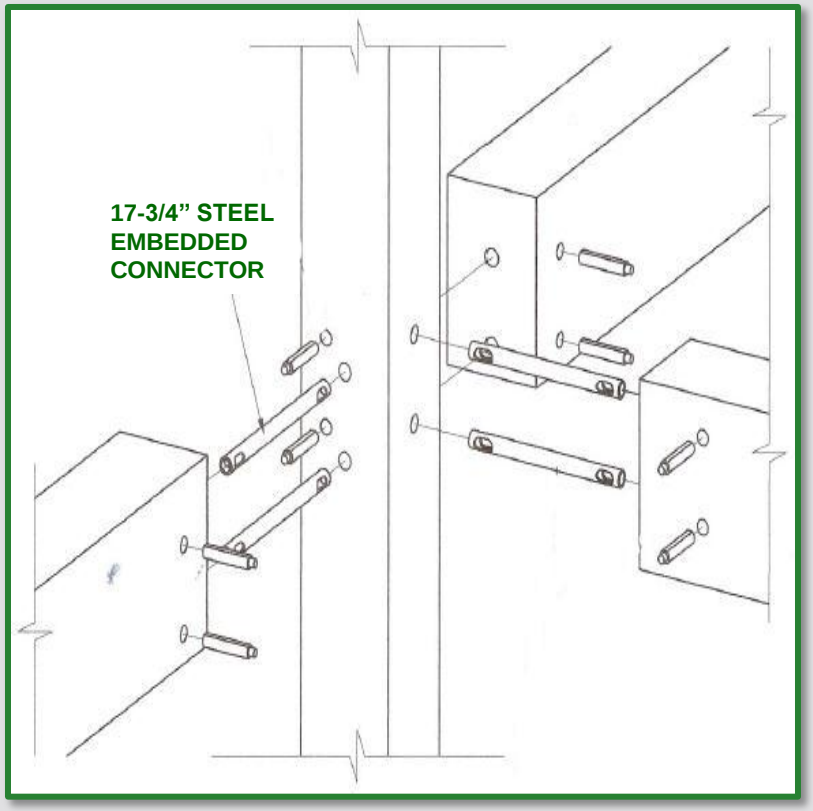
INSTALLATION

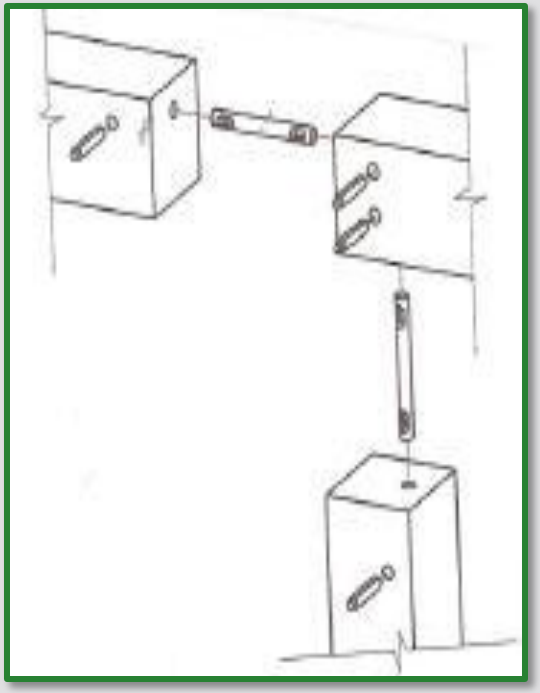
Post to Concrete:



INSTALLATION

Three-way connection:

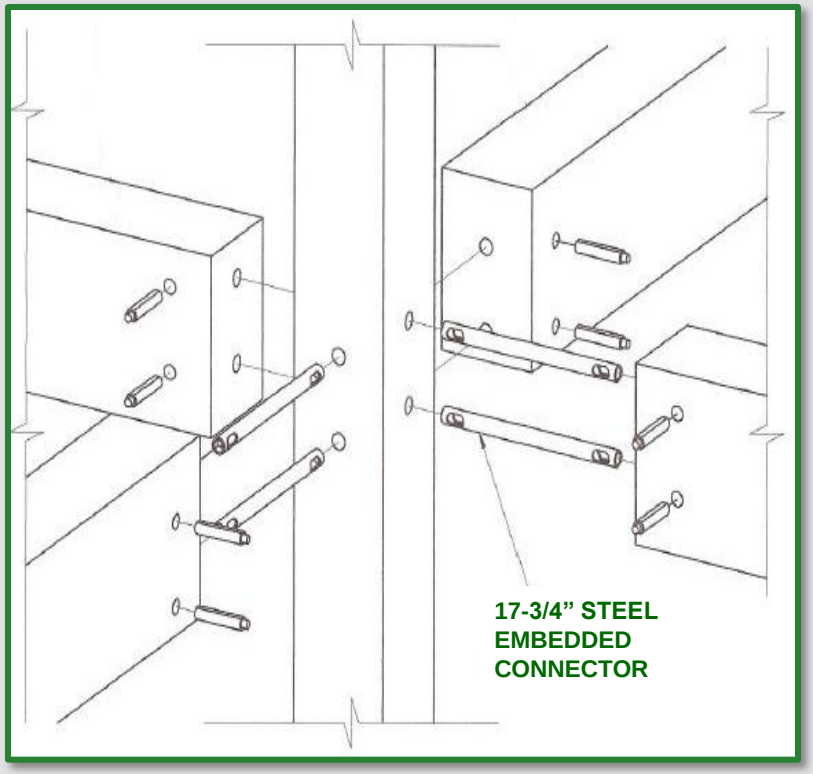


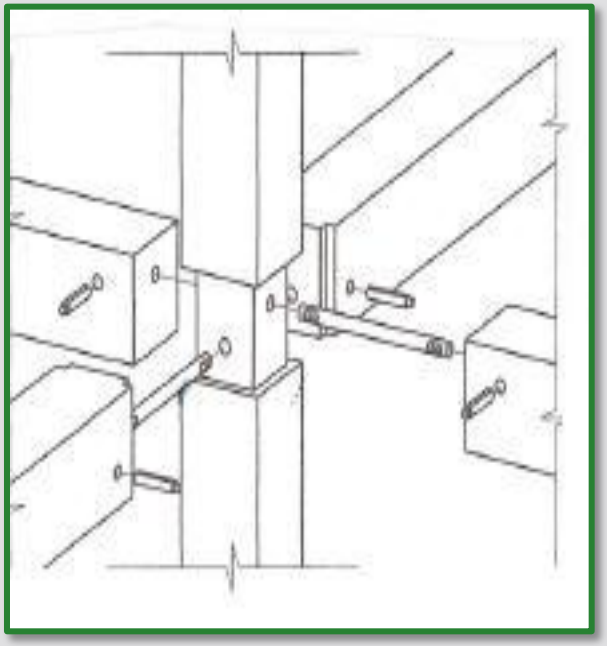


The number of connectors required is defined by the tension and shear loads.

INSTALLATION

Four-way connection:

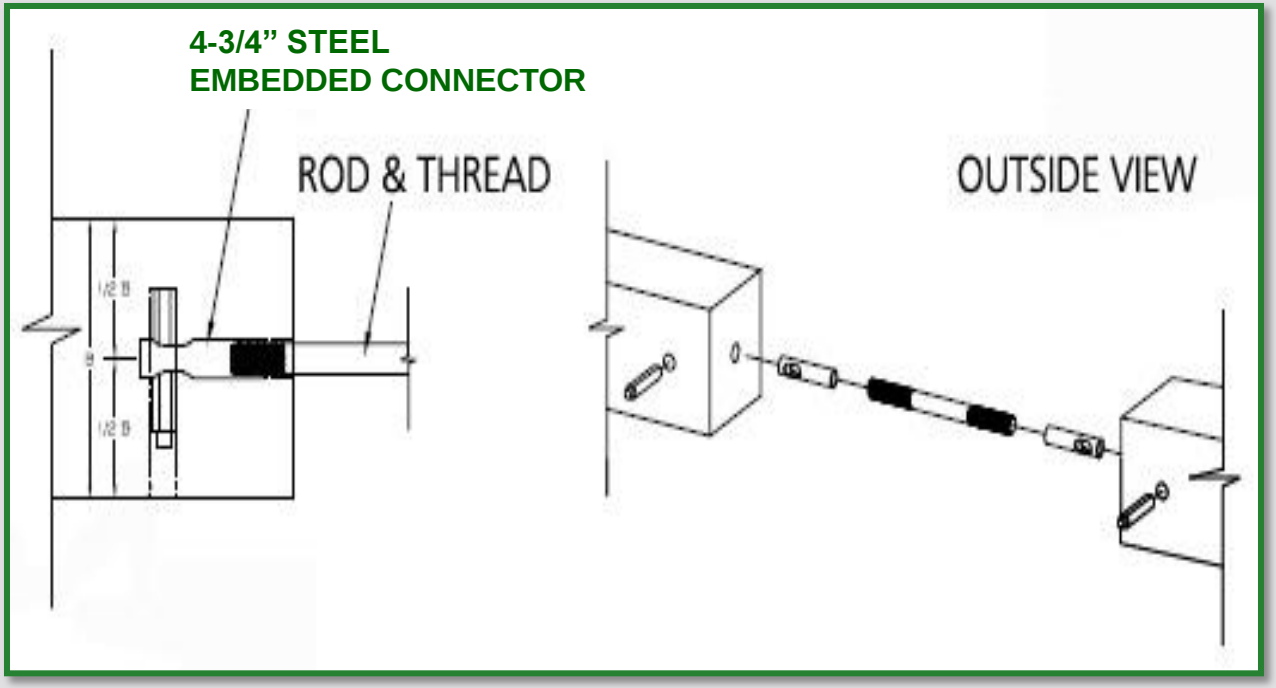




Two connectors for each joint for illustration only. The number of connectors required is defined by the tension and shear loads.

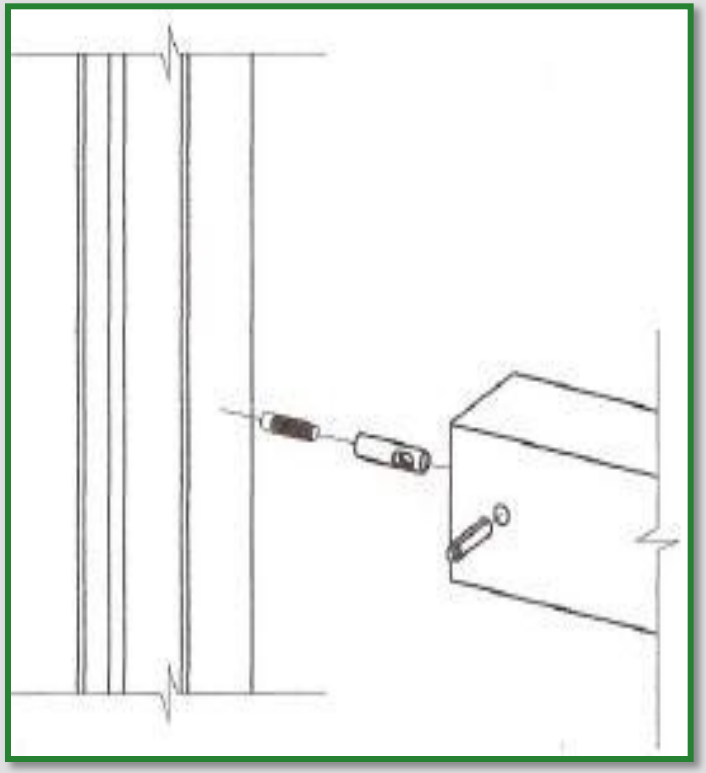
INSTALLATION

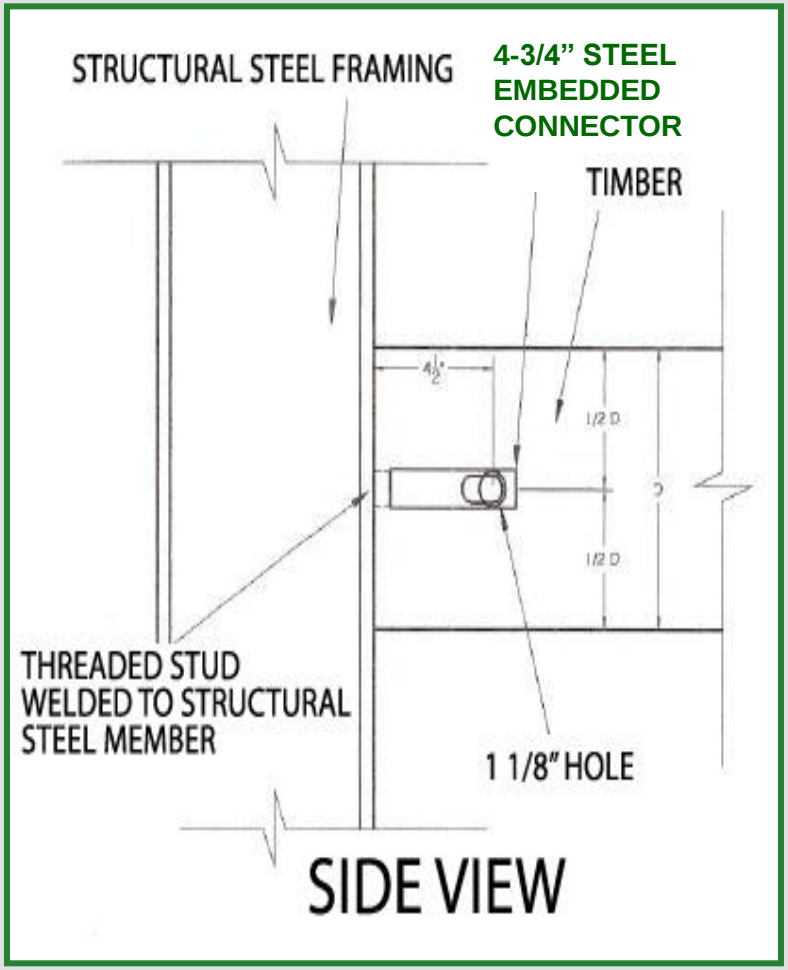
Tension Rod to Connector:



INSTALLATION

Beam to Steel:





STYLES

Different styles of embedded connectors

Applications

STYLES

There are currently 10 different types of timber connectors:

- 9.5” straight slot and 90° Slot
  - Overall length 9.5”
  - Pin holes center to center 7 3/4”
  - Both identical except orientation of slots to provide versatile pin access
- Applications:
  - General joining application
  - Used for all official testing

STYLES

- 13.5” pipe connector, straight slots
  - Straight slots
  - Pin holes center to center 11 3/4”
- Applications:
  - Designed to replace a 9.5” connector in larger timbers
  - Provides a 7 x pin diameter from edge of the joint (NDS)

STYLES

- 15.5” straight slot and 90° Slot
  - Overall length 15.5”
  - Pin holes center to center 13 ¾”
- Applications:
  - Designed to join 2 beams to a post
  - 6X6” timber butt joints at post
  - 8X8” timber 1” housed joints at post
  - Replaces spline joint (saves labor and adds strength)
  - Joins 4 beams to a post at 1 point

STYLES

- 17.5” straight slot and 90° Slot
  - Overall length 17.5”
  - Pin holes center to center 15 ¾”
- Applications:
  - Joins 2 beams to a post
  - 8X8” timber butt joints at post
  - 10X10” timber 1” housed joints at post
  - Replaces spline joint
  - Joins large sill beams end to end
  - Joins 4 beams to a post at 1 point

STYLES

- 4-3/4” steel embedded connector
  - Overall length 4 3/4”
  - One slot with 7/8” internal thread at other end
  - Pin hole centers 3 7/8” plus exposed threaded rod.
- Applications (new uses discovered everyday):
  - Two 4-3/4” connectors + threaded rod can customize any length of timber connector required
  - Joins wood to steel, wood to concrete and wood to wood

STYLES

- 6.75” Half Connector
  - Overall length 6 3/4”with two slots parallel
  - Pin hole centers 2 7/8” 5 7/8” + exposed threaded rod
  - Two slots at one end parallel, internal thread at other end
  - Twice as strong as 4-3/4” in tension

  Combine any two of the following half connectors with threaded rod to customize any connector imaginable. 4.75”, 6.75”, 6.75” 2 slots parallel, 6.75” 2 slots at right angles
  - Joins wood to steel, wood to concrete, wood to wood

STYLES

- 6.75”
  - Overall length 6 3/4” with 2 slots at 90°
  - Pin hole centers 3 7/8” 5 7/8” + exposed threaded rod
- Applications (new uses discovered everyday):
  - Used to customize any type of timber connector required at super strength
  - Joins wood to steel and wood to concrete wood to wood

APPLICATIONS

General Applications:

- **Beam to post**
- **Rafter to ridge**
- **Plate lap at post**
- **Knee brace to post**
- **Collar tie to rafter**
- **Thru tension rod**
- **Truss heel**
- **Truss tension chord**
- **Two-way beam to post**
- **Four-way beam to post**
- **Post hold down**
- **Rafter to plate**

APPLICATIONS

Targeted consumers:

- **Timber Framers**
- **Post and Beam**
- **Log Builders**
- **Small Producers**
- **Deck & Fence Companies**
- **Landscapers**
- **Custom Builders**
- **General Contractors**

TRUSS STYLES

The design of a truss is limited by the strength of the joints

SIMPLE TRUSS

KING POST WITH STRUTS

The complex joinery in a truss is
the ideal venue for mechanical fasteners

HAMMERBEAM

Embedded mechanical fasteners with their
added strength will widen the design horizon for trusses

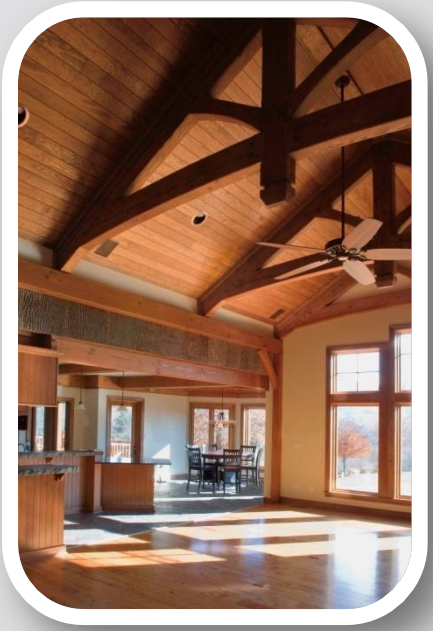
SUMMARY

Now you should be able to:

- Compare traditional mortise and tenon (MT) joinery with embedded timber connectors
- Talk to the timber fabricator
- Visualize the installation of an embedded timber connector
- Specify different styles of embedded connectors for wood to wood, wood to concrete, and wood to steel connections

AN AIA CONTINUING EDUCATION PROGRAM
CREDIT FOR THIS COURSE IS 1 AIA HSW CE Hour

IMPROVING TIMBER CONNECTIONS THROUGH DESIGN



COURSE NUMBER: tlx06a

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Please note: you will need to complete the conclusion quiz online at ronblank.com to receive credit

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