Heavy Timber Trusses

Workshop:
Exposed Connections in Timber Trusses and Structures: Designing for Beauty and Function

Presented by RL. Ben Brungraber, PhD, PE
Fire Tower Engineered Timber

Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board
In timber designs where the structure is an integral part of the architecture, detailing for trusses and member intersections can be particularly challenging. Presented by renowned timber specialists, this workshop will provide insight relevant to both engineers and architects on heavy timber trusses, glulam post and beam and mass timber component connections. Timber truss topics include an overview of heavy timber truss configurations, guidance on their applications and important design considerations. An introduction to modern timber connections will review guiding principles of mass timber connections, custom and prefabricated hardware, codes, and design considerations using project examples. Among topics included are methods for achieving fire resistance, design simplicity and construction efficiency.
Workshop: Learning Objectives

At the end of this program, participants will be able to:

1. Review various heavy timber truss configurations, applications and important design considerations.
2. Discuss structural design, connection options and fabrication processes of timber trusses including insight on specifications and cost.
3. Explore modern glulam and mass timber connection solutions available including commodity, pre-engineered and custom designed connections.
4. Explore practical aspects of design such as fire-resistance, design simplicity and construction efficiency.
• Loading the trusses – Ridge beams can halve load, etc.
• Analysis – no pins and continuous members
• Eccentric Connections – nearly unavoidable and often preferable
• Deflections – connection slips and deformations are hard to include
• End Wall Trusses – maddeningly common; can be worse than useless
Heavy Timber Truss Types:
- Pitched Top Chord (including curved top chord)
- Scissor (including curved bottom chord)
- Parallel Chords
- Miscellaneous/”Mongrel” – Including Collared Rafters

Heavy Timber Truss Connections:
- Notches
- Plates (heavy/bolted and toothed/light)
- Rods and Fittings – historic examples
- Machine Shop vs Welding Shop
- Steel tension members? Diagonals
- All-wood members? Tension perpendicualrs

Heavy Timber Truss Miscellany
- Lateral Bracing
- The Dark Art of Camber
- Top chord buckling (Bottom chord in load reversals)
- Simple alignment for seasoning in-situ timbers
- End wall drumming
How DO we “Get Into Stuff?” Me, circa 1973
A Truss Whisperer is Made
Bigger Models; More Testing
A “Fair Fight?”
Bucknell Undergraduate Project – 50’ Pedestrian Bridge; c. 1981
Another Jump in Scale; 240’ Pedestrian Bridge
Old School and New School Construction Techniques/Technologies
Pitched Top Chord Trusses

• Span < 80’
• 12’ < Spacing < 20’
• 1:6 < Slope < 1:16
• 1:5 < Span/Depth < 1:7
• Specials: Curved Chord, Scissors, Rods
“Simple” Trusses

The Quintessential Industrial Revolutionary Truss
Diagonals onto King Post and at Roughly Roof Pitch
Traditional Truss Design/Analysis

写ben@ftet.com if you really NEED all of this
Corbel and/or Brace Support
Concealed, “Starter Blocks” Hardware at Chords Joint
Everyone Ought to get a Chance at a Cathedral
Or, at least, a Church
A True King Post - Perhaps the Most Complex Timber Joint I Have Designed
What Can Happen, When a Client Calls Your Bluff?
“All Wood Joinery”
Eccentricity in “Heel Plates”
Heavy Sawn Planks, Corbels, Pegs, & Light Screws
Diagonal Rods in 72’ Spans
Raising Choreography to Protect Tails
Grand Opening show in new Performing Arts Center
With 70 kips in Each Rod,
Those are not Shear Bolts
Curved Top Chord – “Bowstring” Trusses up to 250’ spans

1:6 < span/depth < 1:8
top chord radius roughly the span
Scissors Trusses
The Scissors Crux Connection

1 CONNECTION DETAIL @ 5-1/2" WIDE KINGPOST
Clasping King Posts
Scissors Trusses – and Dimensions Change During Process
Concealing the Connectors can be a DRAG
At Foot of Grandfather Mountain, Boone, NC
Curved Chords – How to Fabricate Curves?
Trees, Generally, Grow Straight – Pay Attention to This
Curved Chord Trusses
Steam-bent; or CompWood
“Curve Issues”: Bending, Radial Tension, and Straightening
And: “How to Grab Curve Without Undue Damage?”
King Post Gets a Crown and a Stirrup Turns Tension into Compression
Shear Keys Transfer Chord Forces at Eave Connections
Longer Intersection between Members
Truss Analysis

Visual Analysis (version 5.50) -
Wed Nov 01 10:38:34 2006
Annette Doy
Dead and Snow loads

Bending Stress, kips (y)
All Members:
Max = 0.91 kips (M15)
Min = -0.37 kips (M13)

Graph showing the forces and stresses in a truss structure, indicating bending stress values and maximum and minimum stress points.
*Heel joints* in pitched trusses are sometimes a problem to students. Such joints may be designed so the truss is supported by its top chord (Figure 82b), or its bottom chord (Figure 82a). The load to grain angles in the members depend upon which arrangement is followed. The distinction should be fairly self-evident, yet it is a common source of error.

![Diagram of heel joint arrangements](image)

**Figure 82** Heel joint arrangements for ring-connected trusses

So Basic; So Neglected – from Hoyle, *Design of Wood Structures*
Which Member is the Support?
The "King Rod/Post" is Crucial Component
Options:
- Notch
- Top Plate/Chock
- Pinned Plate
Options:
- Straps
- Rod
- Support the Plate
What we seem to Wish
But this is "More Realistic"
The "Actual" Bolt Forces are Quite Complex, Indeed

Cross-Grain Prying Components
Parallel Chord Trusses

• 1:8 < Span/Depth < 1:10
• Diagonal Direction Matters, a Lot
• Least Efficient Layout; ignores M & V
• Added Arches – Burr Trusses
• Town Lattice “Truss-Girders”
Parallel Chords
Best Barn/Shop – Ever. 40’ x 50’ Clear (Basement, too)
Cambering and Adjusting can be “Simple,” with Steel Rods
Tension in Bottom Chord can be Minimal
Span/Depth = 1:5
Feng Shui Bad News
Tension Diagonals of Timber – and Panel Length Varies
My Sole Split Ring Job
Compression Diagonals of Timber
Note “Diagonal-Free” center panel
Tension Diagonals of Steel
Note: Rod Angle Changes
Overly Sloped Rods – Add Apparent Length
The Golden Age of Heavy Timber Trusses

ben@ftet.com for ALL of this
Industrial Revolution Trusses

**Western Style Roof Framing**

*Shinjuku truss roof framing (Case 3).*

Right angle joint of the bottom chord and end of the top chord.

There are many varieties of right angle joint for the end of the top chord, but in almost all cases, faces A and B as shown on the top center illustration must be able to resist the compressive force, $N_c$, of the top chord. Also faces B and C must be able to resist the tensile force, $N_t$, of the bottom chord. The joint must be constructed to meet these conditions.
STRESSES

BILL OF MATERIAL FOR ONE TRUSS

COMPLETE DESIGN FOR A WOODEN ROOF TRUSS
Industrial Revolution Ripoffs – 2 Timbers & 3 Rods
1 Timber, 2 Rods
Avoid Turnbuckles to Increase Capacity and Reduce Depth
One Timber and Both 1 and 2 Rods
A “Barn Full of Fun”
Context for Truss
Plumb Posts can get SO Boring, after a while
This Might Just Be “My Best Shot, Ever”
Concealed Steel
Celebrated Steel
It’s ALL About the Hardware
Hardware
We see this, and worse, all the time
End joint detail of roof truss.

- 2 - 8½" PLS
- 4×8′ Flat 8′ Long
- 7/8″ bolts - 1¾" holes

End joint detail of roof truss.

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Notches
In the case of loose abutment of the first step all the shear stresses must be taken up by the second. To avoid the danger of shearing the second step in the length between them the depth of its notch \( h_{\text{notch}} \) must exceed that of the first step by not less than 2 cm.

When setting out the notching the top of the second step should be located approximately on the axis of the chord under compression.

The check on the resistance to shear for the depth \( h_{\text{notch}} \) within the range \( h_{\text{notch}} \) is carried out by considering the length \( h_{\text{notch}} = 10 h_{\text{notch}} \) for the entire force \( N_c \). In this case a reduction in the concentration of \( r \) is accounted for by applying to \( R_{\text{th}} \) a special factor of working conditions, equal to 1.45. The standards and specifications for double-step joints specify "particularly careful fitting" of the supporting surfaces of both steps.

In accordance with the general requirements set out above for the basic types of joint in structural members, the double-step joints can only be recommended when the governing factor is not the shearing, but the bearing stresses, i.e., with large values of the angle \( \gamma \) and especially when a load is applied to the upper chords of round or squared-timber trusses away from the joint. The steeper the direction of the force \( N_c \) (at an angle \( \gamma \)) or the resultant \( R \) (at an angle \( \angle = 60-55^\circ \) it is necessary to fit safety connectors, which should increase the angle of slope of the thrust to 60-55° to the plane of shear (i.e., up to 50-55° to the perpendicular) so that the thrust forces (the action of the bolts) do not exceed 60% of the total load.

The work of a safety bolt when the notch of a step joint is sheared away.

Fig. 50. Double-step joint

Basic standard requirements: 

\[ h_{\text{notch}} = 3 \text{ cm}, \quad h_{\text{notch}} = 2 \text{ cm}, \quad h_{\text{notch}} = \frac{h_{\text{notch}}}{2}, \quad q_{\text{chord}} = 30 \text{ cm} \]

Fig. 49. The work of a safety bolt when the notch of a step joint is sheared away.
To ensure that the joint is correctly designed the following conditions should be met:

(a) the bearing between the compression chord and the tension tie should be perpendicular to the line of the compression chord, with a gap between the

(b) the lines of the thrust, tension and reaction should coincide at one point O, so that the tension force is concentric with the next section AA below the step,

(c) the clear length of the tie must be provided beyond the step joint, to give adequate clear space to resist the force of thrust parallel to the

(d) a cover should be added to the tie member to provide a bearing for the tie bolt. The cover should be attached to the tie to transfer the

(e) a bearing pad should be fixed underneath the bearing so that the reaction occurs directly below point O.

When the required detail results in a failure of the line of the thrust, tension and reaction to coincide (Fig. 21.17), the next section AA must be designed for the moment

\[ M_e = V_{e} - T_{e} \]
slope is taken in bearing, while the component parallel to the slope is taken first in bearing by the bearing block and is then transferred in shear (either by connectors or a glue line) into the top chord (Fig. 21.15). Maximum bearing pressure is developed by ensuring that the bearing line between the internal strut and the bearing block bisects the angle $\phi$ between them, giving the same angle of load to grain for both the strut and the bearing block.

The heel joint of a rod-end-block truss requires careful detailing. It is a stepped (or bridled) joint and can be weakened by eccentricities if the loads do not intersect at one point. The detail is sketched in Fig. 21.16.

To ensure that the joint is correctly designed the following conditions should be met:

(a) the bearing between the compression chord and the ceiling tie should be perpendicular to the line of the compression chord, with a gap between the
Weitere Bezeichnungen siehe Abbildung 5.10

Ausdrucke:

\[ e = \frac{1}{2} \left( h_d - t_v \right) \]

Erforderliche Versatzerfolge:

\[ t_v = \frac{D}{b} \cos \left( \frac{\alpha}{2} \right) \]

Näherung:

\[ t_v = \frac{D}{0.70 \cdot b} \]

D in [kN], b in [cm]

Abbildung 5.10. Stimversatz in der Winkelhalbierenden

Tabelle 5.8 Zulässige Strebenkraft zur D in kN je cm Holzbreite und erforderliche Vorholzlänge erf l, in cm für den Stimversatz in der Winkelhalbierenden, Nadelholz Güteklasse II, Lastfall H²

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Collared Rafters

“Raised Chord Trusses”

• Collar Strut, Tie, or Beam?
• Failing Roofs for Centuries
“Fire, Ready, Aim”
Slate Roof AND $70,000 worth of windows “pre-installed”
In Tension, Compression, or “Minimal?”

It’s All About the Supports
Collar Strut, Tie, or BEAM
Humans have been repairing these for n-2 years;

Where: \( n = \) Number of Years ago the first ones were built
A Truss?  Tied Eaves – NO Compression Capacity
Curved/Collared?

ELEVATION:
SCALE: 1/8" = 1'-0"
Modeling the Connections; Blade to Rafters and Collar
“Other Trusses”

Vierendeel Truss and/or Girder
Point Load at Support – The Tough Spot
Non-Trusses
Lots of Elements AND My Stupidest “Truss” – (so far)
A “Minor Dip” in the Ridge is NOT Minor – in a 1000’ Ridge
Supporting a 1000’ Wooden Balloon –
Using 150’ Steel Needles
Previous Repair Splints – but Still Looking Troubled, Back There
Just How Troubled IS it? 4” & 6” Heavy Planks, 180’ Up
Would you drive a Suburban across this?
Maybe THIS Rig, and only very quickly