Wood Trusses:
Theory, Practice & Problems

March 2015

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Learning Objectives

- *Gain a general understanding of truss behavior*
- *Learn how to read a truss shop drawing*
- *Understand the importance of temporary and permanent restraint/bracing*
- *Recognize issues associated with gable end trusses*
- *Understand how truss repairs are implemented*

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Recognition

SBCA
Structural Building Components Association

TPI Truss Plate Institute

RELIABLE TRUSS

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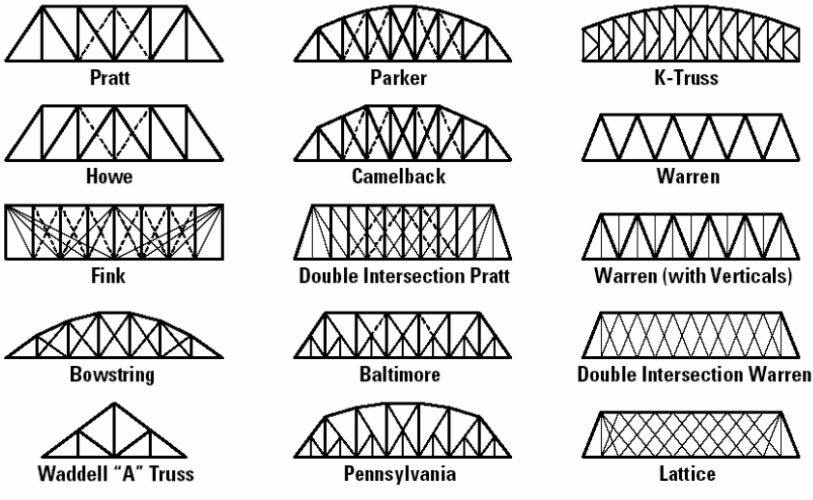
What is a truss?



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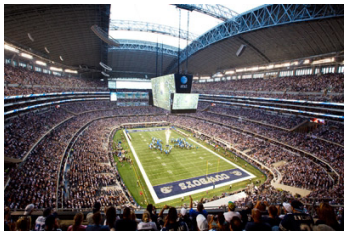
What is a truss?



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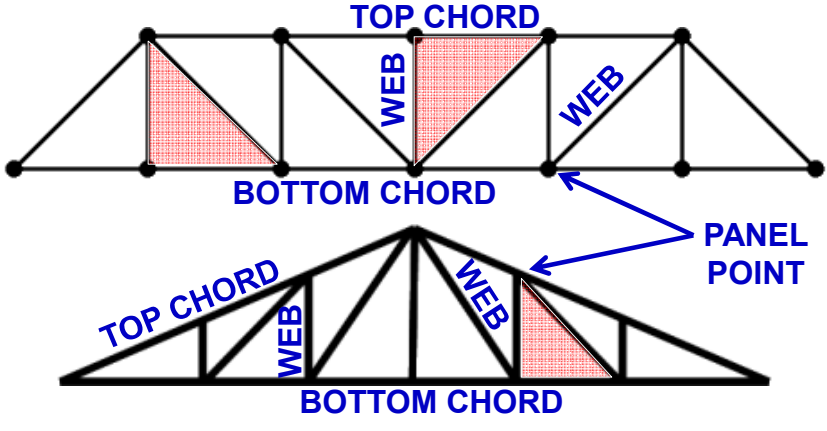

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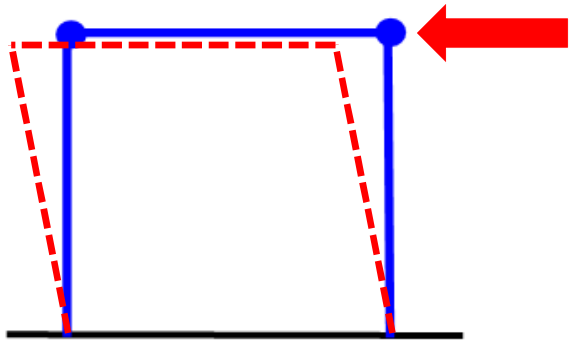

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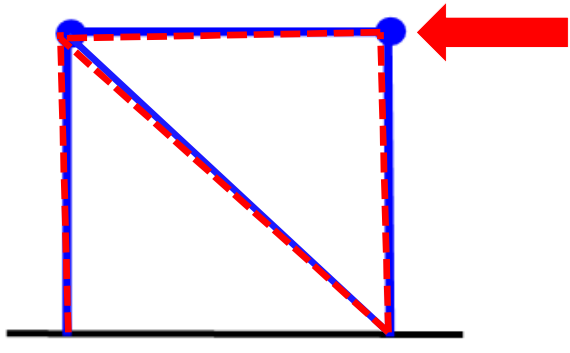
What is a truss?



Triangulation

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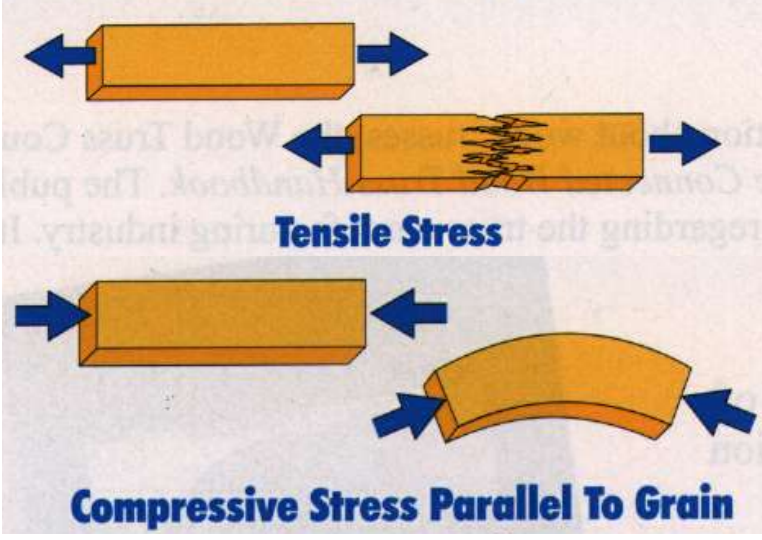
What is a truss?



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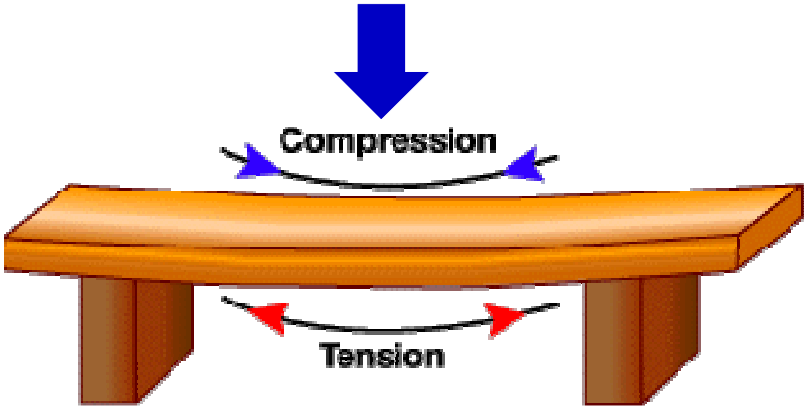
What is a truss?



Bending Stress

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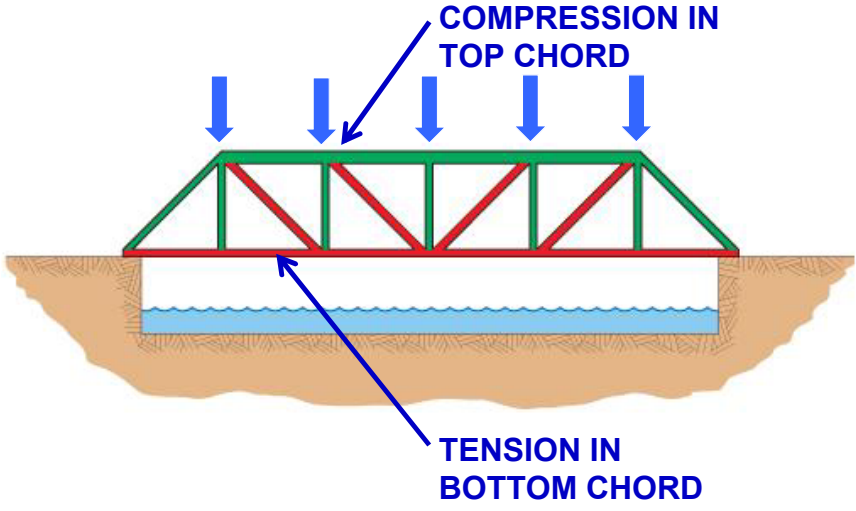
What is a truss?



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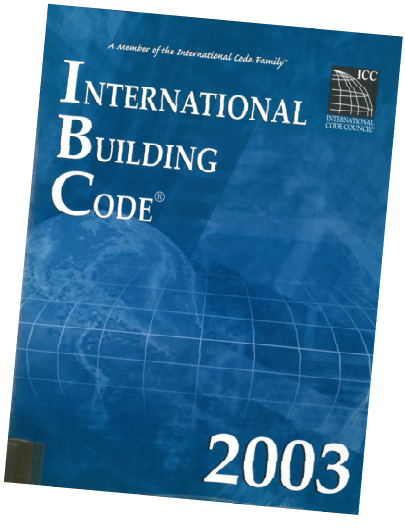
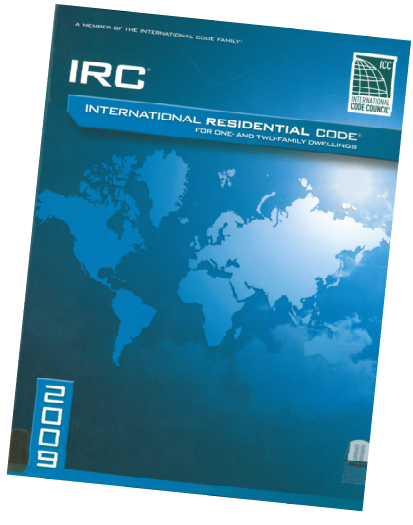
Truss Design





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Truss Design

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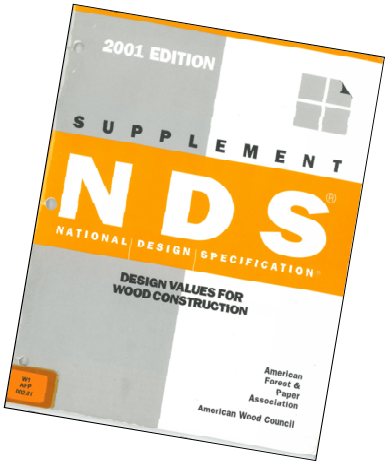
Wood Design Stresses



- *Many different species of wood*
- *Different qualities of wood*
- *Different Grading Rules Agencies*

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Wood Design Values

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)						Grading Rules Agency
		Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	
SPRUCE-PINE-FIR								
Select Structural	2" & wider	1250	700	135	425	1400	1,500,000	NLGA
No.1/No.2		875	450	135	425	1150	1,400,000	
No.3		500	250	135	425	650	1,200,000	
Stud	2" & wider	675	350	135	425	725	1,200,000	
Construction	2"-4" wide	1000	500	135	425	1400	1,300,000	
Standard		550	275	135	425	1150	1,200,000	
Utility		275	125	135	425	750	1,100,000	

Species/ Grade Size F_b F_t F_v $F_{c\perp}$ F_c E Agency

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Wood Design Values

Modification Factors:

- ***C_D – Load Duration Factor***
  - 1.0 Live Load; 1.15 Snow Load; 1.60 Wind Load
- ***C_M – Wet Service Factor***
- ***C_t – Temperature Factor***
- ***C_F – Size Factor***
- ***C_i – Incising Factor***

Allowable Wood Design Values

Tension:

- $F_t' = F_t \times C_D \times C_M \times C_T \times C_F \times C_i$

Compression Parallel to Grain:

- $F_c' = F_c \times C_D \times C_M \times C_T \times C_F \times C_i \times C_p$

C_p – Column Stability Factor

- Accounts for buckling
- Function of slenderness of compression element

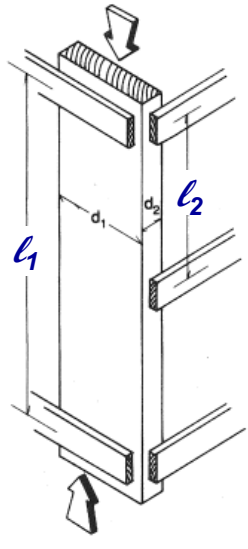
Allowable Wood Design Values

Slenderness Ratio

ℓ_e/d

Limitations

- General: $\ell_e/d \leq 50$
- Construction: $\ell_e/d \leq 75$
- Short Term Loads (Other than Gravity Loads): $\ell_e/d \leq 80$



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Allowable Wood Design Values

Column Stability Factor, C_p

$$C_P = \frac{1 + (F_{cE}/F_c^*)}{2c} - \sqrt{\left(\frac{1 + (F_{cE}/F_c^*)}{2c}\right)^2 - \frac{(F_{cE}/F_c^*)}{c}}$$

where

- $F_c^* = F_c \times C_D \times C_M \times C_T \times C_F \times C_i$
- $c = 0.8$ for sawn lumber

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Allowable Wood Design Values

$$F_{cE} = \frac{K_{cE}\, E'}{(l_e/d)^2}$$

where

- E' = modulus of elasticity (adjusted)
- K_{cE} = 0.3 for visually graded lumber
  = 0.384 for machine-evaluated lumber
  =0.418 for machine-stress-rated lumber

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Allowable Wood Design Values

How does the slenderness ratio affect the allowable compression stress?

- 2"x4" - No. 1/No. 2 Spruce-Pine-Fir
- Snow Load Condition – $C_D = 1.15$
- No Wet-Use, Temperature, Incising Issues

ℓ_e/d	F_c'	P_{allow}
10	1,385 psi	7,270#
26	557 psi	2,924#
50	164 psi	861#

For the same 2"x4" in tension, the allowable tension stress (F_t') is 518 psi, and the allowable tension load is 2,717# regardless of the length.

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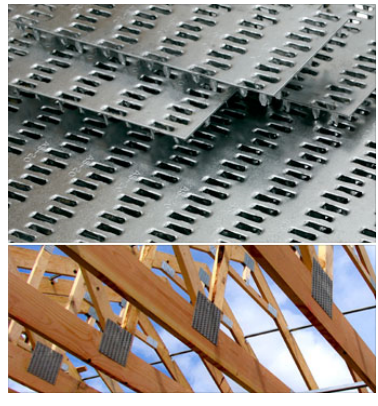
Truss Connections

- Chords and webs are interconnected through metal truss plates
- Light-gage metal with integral teeth that are pressed into the lumber
- Proprietary
- Design governed by TPI "National Design Standard for Metal Plate Connected Wood Truss Construction"



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Wood Truss Drawings

- Truss Placement Diagrams
- Truss Design Drawings

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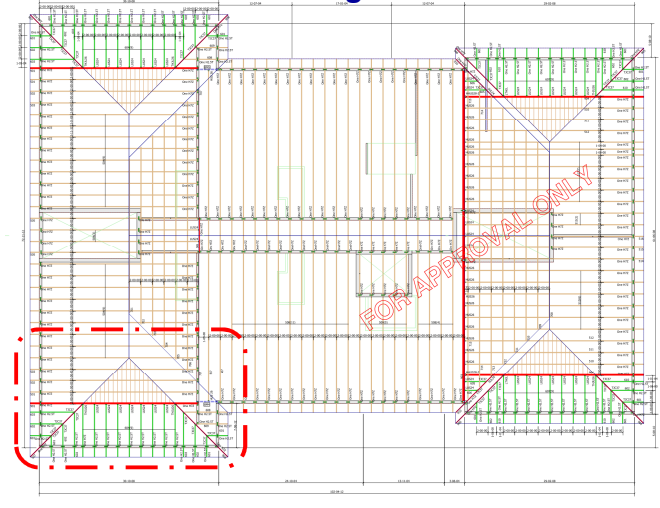
Wood Truss Drawings

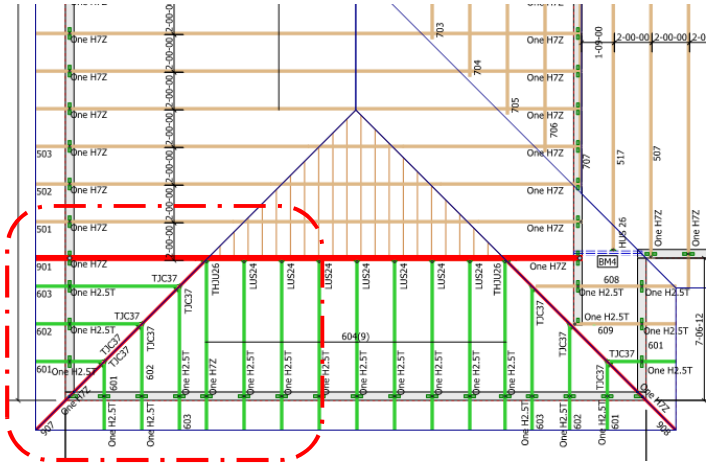
- Truss Placement Drawings



Wood Truss Drawings

- Truss Placement Drawings

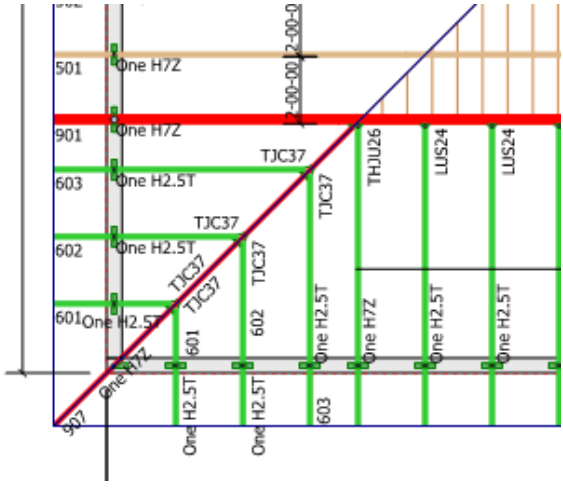
- Common Trusses
- Hip and Jack Trusses
- Girder Truss
- Overbuild (Valley Set)



Wood Truss Drawings

- Truss Placement Drawings

- Truss IDs
- Spacings/ Dimensions (FT-IN-16th)
- Hangers*
- Hurricane Anchors*



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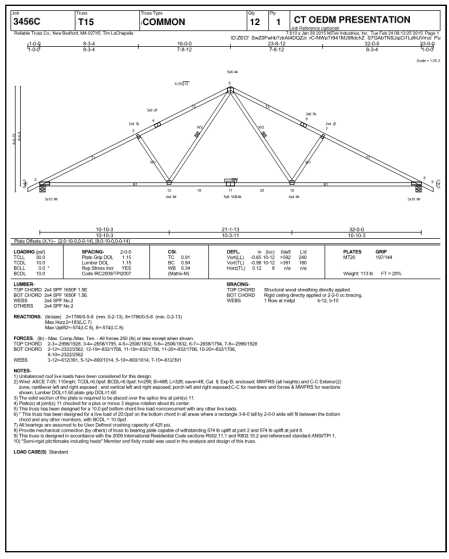
Wood Truss Drawings

Truss Design Drawings

- Truss IDs
- Geometry
- Truss Bearing
- Lumber
- Plates
- Permanent Restraint/Bracing
- Forces
- Deflections
- Design Loads
- Design Criteria
- Multi-Ply Girder Fastening



Wood Trusses: Theory, Practice & Problems

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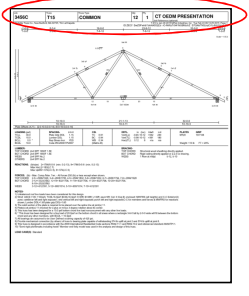
Wood Truss Drawings

Truss Design Drawings

- Truss IDs
  - Job Number
  - Truss Mark/No.
  - Type of Truss
  - No. of Trusses
  - No. of Plies
  - Other Reference Info.



Job	Truss	Truss Type	Qty	Ply	
3456C	T15	COMMON	12	1	CT OEDM PRESENTATION

Job Reference (optional)
Reliable Truss Co., New Bedford, MA 02745, Tim LaChapelle
7.610 s Jan 29 2015 MiTek Industries, Inc. Tue Feb 24 09:13:25 2015 Page 1

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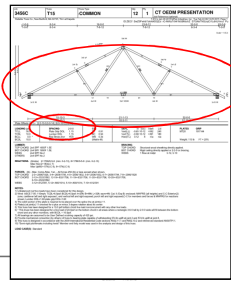
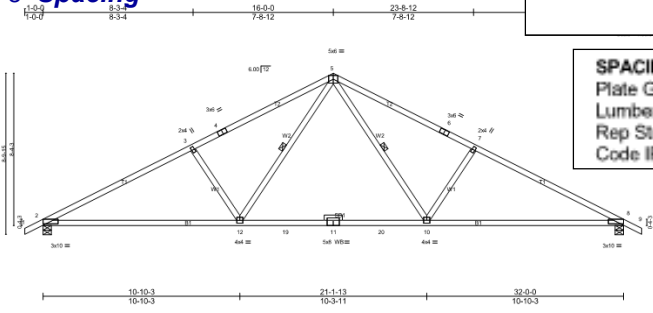
Wood Truss Drawings

Truss Design Drawings

- Truss Geometry
  - Dimensions/Height/Heel Height
  - Pitch
  - Joint Numbers
  - Member Designations
  - Spacing





SPACING-	2-0-0
Plate Grip DOL	1.15
Lumber DOL	1.15
Rep Stress Incr	YES
Code IRC2009/TPI2007	

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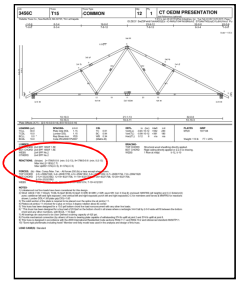
Wood Truss Drawings

Truss Design Drawings

- Truss Bearing
  - Reactions
    - Gravity
    - Uplift
    - Lateral
  - Bearing Width



REACTIONS. (lb/size) 2=1786/0-5-8 (min. 0-2-13), 8=1786/0-5-8 (min. 0-2-13)
Max Horz 2=183(LC 7)
Max Uplift2=-574(LC 8), 8=-574(LC 8)

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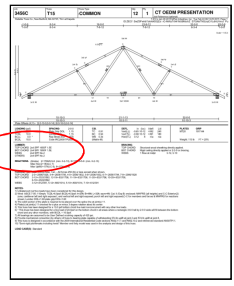
Wood Truss Drawings

Truss Design Drawings

- Lumber
  - Species
  - Grade



LUMBER-
TOP CHORD 2x4 SPF 1650F 1.5E
BOT CHORD 2x4 SPF 1650F 1.5E
WEBS 2x4 SPF No.2
OTHERS 2x4 SPF No.2

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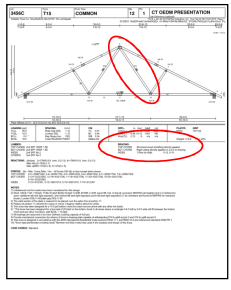
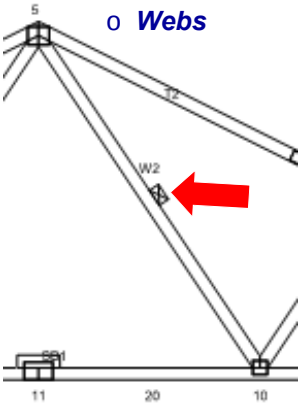
Wood Truss Drawings

Truss Design Drawings

- Permanent Restraint/Bracing
  - Top Chord
  - Bottom Chord
  - Webs



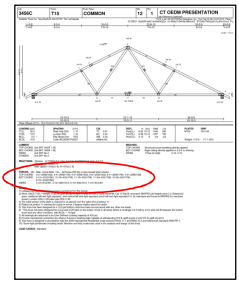


BRACING-
TOP CHORD Structural wood sheathing directly applied.
BOT CHORD Rigid ceiling directly applied or 2-2-0 oc bracing.
WEBS 1 Row at midpt 5-12, 5-10

Wood Truss Drawings

Truss Design Drawings

- Member Forces
  - Tension & Compression
  - Chords and Webs



FORCES. (lb) - Max. Comp./Max. Ten. - All forces 250 (lb) or less except when shown.
TOP CHORD 2-3=-2996/1928, 3-4=-2658/1795, 4-5=-2506/1832, 5-6=-2506/1832, 6-7=-2658/1794, 7-8=-2996/1928
BOT CHORD 2-12=-2322/2562, 12-19=-832/1706, 11-19=-832/1706, 11-20=-832/1706, 10-20=-832/1706, 8-10=-2322/2562
WEBS 3-12=-612/391, 5-12=-800/1014, 5-10=-800/1014, 7-10=-612/391

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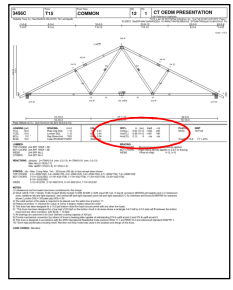
Wood Truss Drawings

Truss Design Drawings

- Deflections
  - Live Load (Snow Load)
  - Total Load
  - Actual and Relative Deflections



DEFL	in	(loc)	l/defl	L/d
Vert(LL)	-0.65	10-12	>592	240
Vert(TL)	-0.98	10-12	>391	180
Horz(TL)	0.12	8	n/a	n/a

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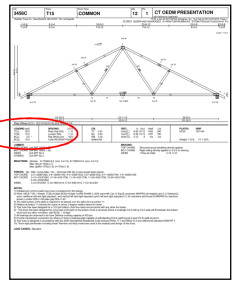
Wood Truss Drawings

Truss Design Drawings

- Design Loads
  - Live Loads and Dead Loads
  - Top Chord and Bottom Chord
  - Uniform Loads and Concentrated Loads
  - Also see NOTES for other loads and loading conditions



LOADING (psf)	
TCLL	30.0
TCDL	10.0
BCLL	0.0
BCDL	10.0

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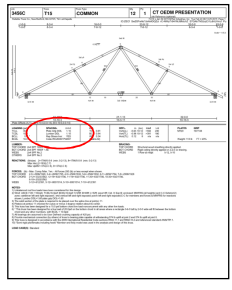
Wood Truss Drawings

Truss Design Drawings

- Design Criteria
  - Model Building Code
  - TPI Standard
  - Lumber Stress Adjustment Factors (DOL = Duration of Load)



SPACING-	2-0-0
Plate Grip DOL	1.15
Lumber DOL	1.15
Rep Stress Incr	YES
Code	IRC2009/TPI2007

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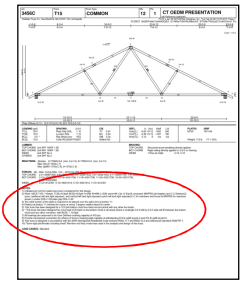
Wood Truss Drawings

Truss Design Drawings

- Additional Information (NOTES)
  - Fastening requirements for multi-ply (girder trusses)
  - Proprietary fasteners for truss-to-truss connections
  - Special design loads / conditions (e.g. wind, unbalanced snow, attic live load)



NOTES

1) 2-ply truss to be connected together with 10d (0.131"x3") nails as follows:
Top chords connected as follows: 2 X 8 - 2 rows at 0-9-0 oc, 2 X 6 - 2 rows at 0-9-0 oc.
Bottom chords connected as follows: 2 X 8 - 2 rows at 0-2-0 oc.
Webs connected as follows: 2 X 4 - 1 row at 0-9-0 oc, 2 X 6 - 2 rows at 0-9-0 oc.

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Wood Truss Drawings

Truss Design Drawings

- P.E. Certification
  - Individual Truss Design Drawings or cover sheet for Truss Design Drawing package should be signed and sealed by a Professional Engineer licensed in the State of Connecticut

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Wood Truss Drawings

Truss Design Drawings

- **Deferred Submittals**
  - **IBC 2012 (§107.3.4.1)**

"…deferred submittals are defined as those portions of the design that are not submitted at the time of the application and are to be submitted to the building official within a specified period."

"The registered design professional in responsible charge shall list the deferred submittals on the construction documents for review by the building official."

"Documents for deferred submittal items shall be submitted to the registered design professional …who shall review and forward them to the building official with a notation indicating that the deferred submittal documents have been reviewed and found to be in general conformance to the design of the building"

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Truss Restraint / Bracing

What are the consequences if trusses are not properly braced/restrained?

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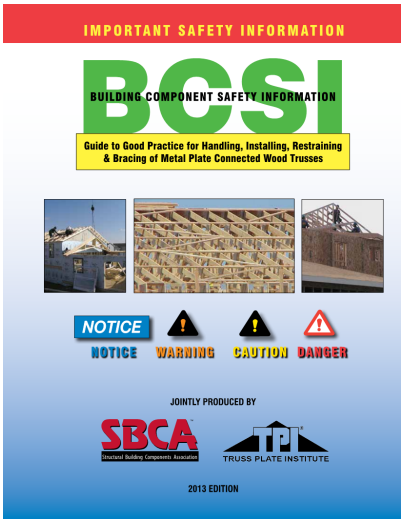
Truss Bracing



Building Component Safety Information "Guide to Good Practice for Handling, Installing, Restraining & Bracing of Metal Plate Connected Wood Trusses"

- *Structural Building Components Association / Wood Truss Council of America*
- *Truss Plate Institute*

www.sbcindustry.com

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Truss Restraint / Bracing

BCSI "Guide to Good Practice for Handling, Installing, Restraining & Bracing of Metal Plate Connected Wood Trusses"

- *B1 – Guide to Handling, Installing, Restraining & Bracing Trusses*
- *B2 – Truss Installation and Temporary Restraint/Bracing*
- *B3 – Permanent Restraint Bracing of Chords & Web Members*
- *B4 – Construction Loading*
- *B5 – Truss Damage, Jobsite Modifications & Installation Errors*
- *B7 – Temporary & Permanent Restraint/Bracing for Parallel Chord Trusses*
- *B8 – Using Toe-Nailed Connections to Attach Trusses at Bearing Locations*
- *B9 – Multi-Ply Girders*
- *B10 – Post Frame Truss Installation & Temporary Restraint/Bracing*
- *B11 – Fall Protection & Trusses*

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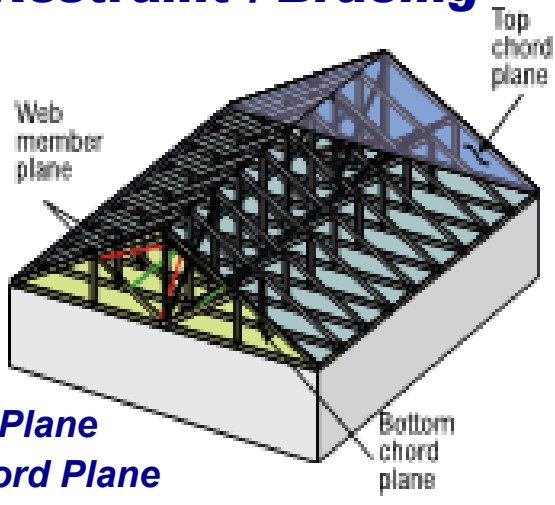
Truss Restraint / Bracing



- Top Chord Plane
- Bottom Chord Plane
- Web Member Plane

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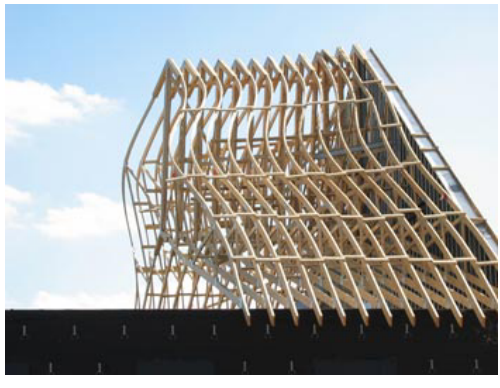
Truss Restraint / Bracing

Temporary Restraint/Bracing



During construction, unbraced or improperly braced or restrained trusses are particularly vulnerable to racking and buckling.

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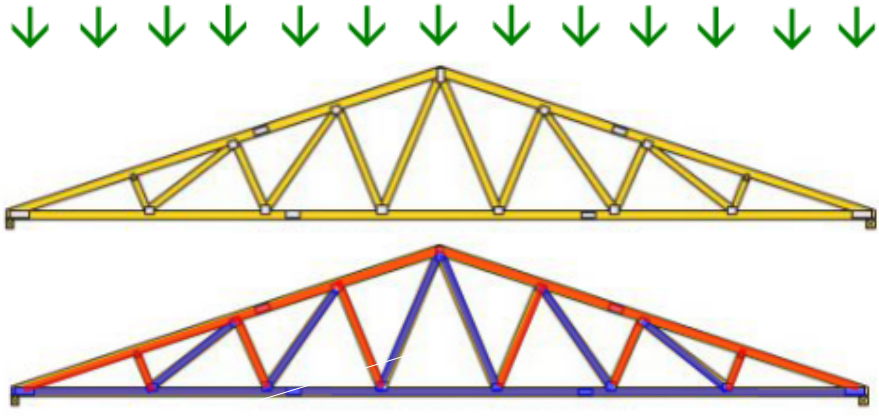
Temporary Truss Restraint / Bracing

Truss Stresses Primarily Due to Gravity Loads



Red = Compression **Blue** = Tension

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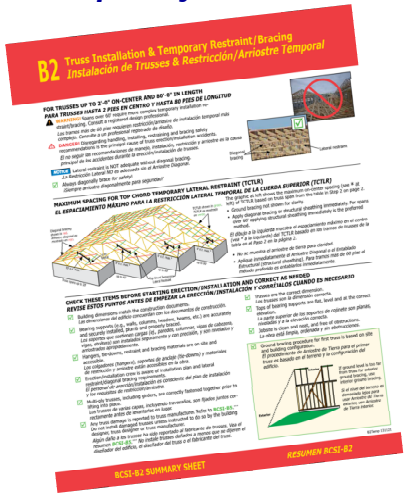
Permanent Truss Restraint / Bracing

- Guidelines for Temporary Restraint/Bracing per BCSI B2


B2 Truss Installation & Temporary Restraint/Bracing
Instalación de Trusses & Restricción/Arriostre Temporal

FOR TRUSSES UP TO 2'-0" ON-CENTER AND 80'-0" IN LENGTH
PARA TRUSSES HASTA 2 PIES EN CENTRO Y HASTA 80 PIES DE LONGITUD

MAXIMUM SPACING FOR TOP CHORD TEMPORARY LATERAL RESTRAINT (TCTLR)
ESPACIAMIENTO MÁXIMO PARA LA RESTRICCIÓN LATERAL TEMPORAL DE LA CUERDA SUPERIOR (TCTLR)

CHECK THESE ITEMS BEFORE STARTING ERECTION/INSTALLATION AND CORRECT AS NEEDED
REVISE ESTOS PUNTOS ANTES DE EMPEZAR LA ERECCIÓN/INSTALACIÓN Y CORRÍJALOS CUANDO SEA NECESARIO

BCSI-B2 SUMMARY SHEET RESUMEN BCSI-B2

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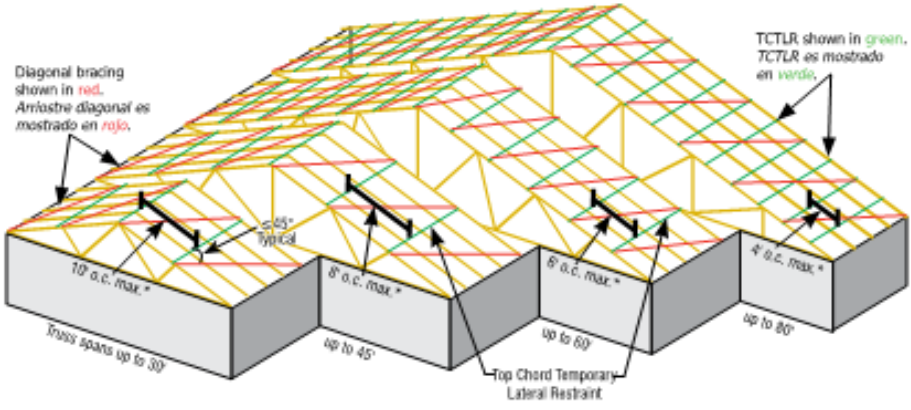
Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing



Need both lateral restraint (green)and diagonal bracing (red) to maintain spacing and to inhibit buckling

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Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing

- ***Frequency of lateral bracing is a function of the truss span.***

Maximum Top Chord Temporary Lateral Restraint Spacing**	
Truss Span	**TCTLR Spacing**
Up to 30'	10' on-center maximum
30' - 45'	8' on-center maximum
45' - 60'	6' on-center maximum
60' - 80'*	4' on-center maximum

Based on 2'-0" o.c. truss spacing

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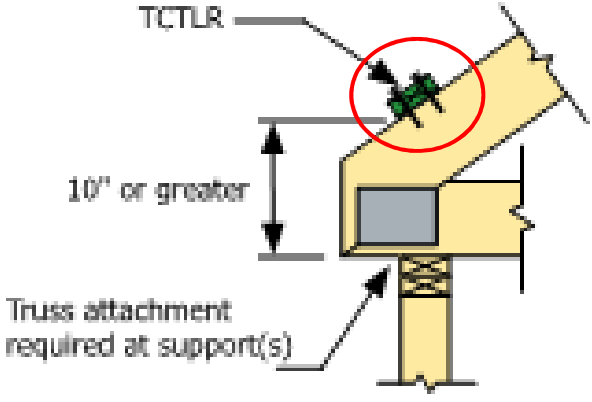
Truss Bracing

Top Chord Temporary Restraint/Bracing

- If truss has a heel height of 10" or more, horizontal bracing must be provided over the support



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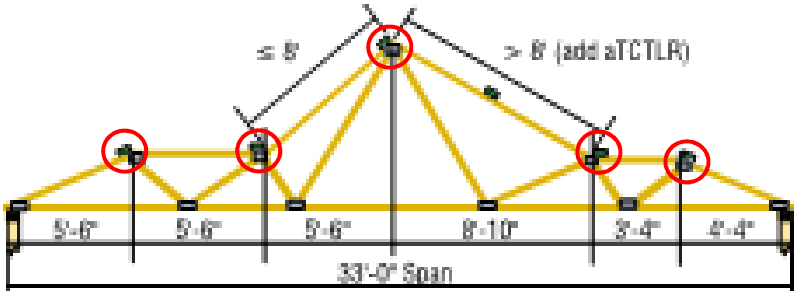
Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing

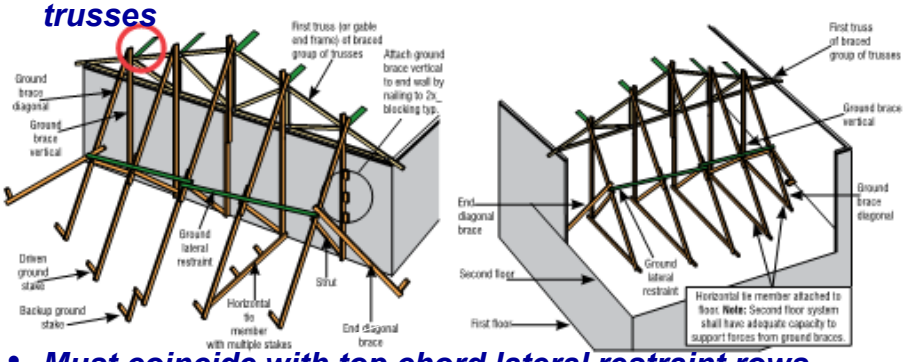
- If truss has a geometry with multiple breaks in roof pitch, a horizontal brace must be provided at each break.



Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing

- Before starting the truss installation sequence, ground bracing must be established to stabilize the initial trusses



- Must coincide with top chord lateral restraint rows
- May be exterior or interior

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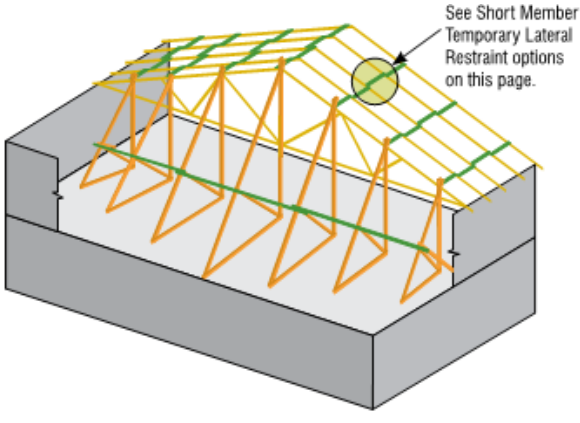
Wood Trusses: Theory, Practice & Problems

Truss Restraint / Bracing

Initial Top Chord Temporary Restraint/Bracing

- First five trusses are to be installed and restrained using "short member temporary lateral restraint".



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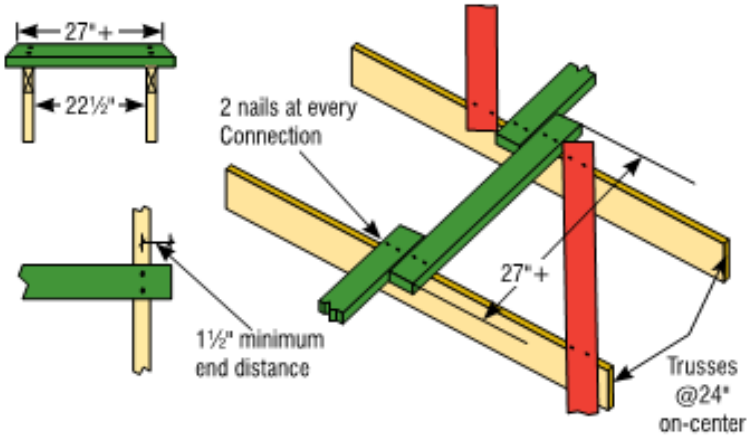
Truss Restraint / Bracing

Initial Top Chord Temporary Restraint/Bracing

- Short Member Temporary Lateral Restraint – Option 1



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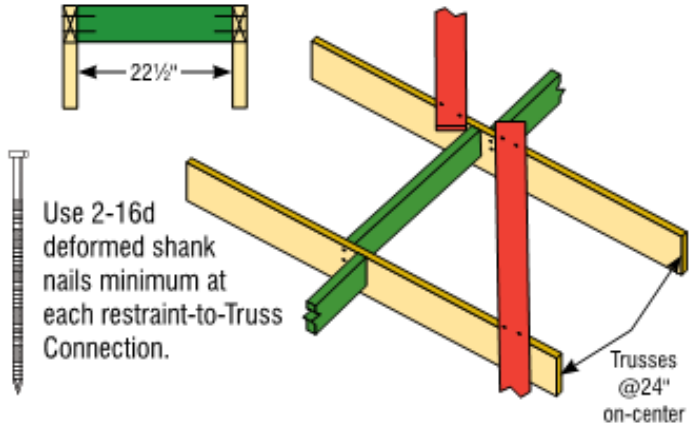
Truss Restraint / Bracing

Initial Top Chord Temporary Restraint/Bracing

- Short Member Temporary Lateral Restraint – Option 2



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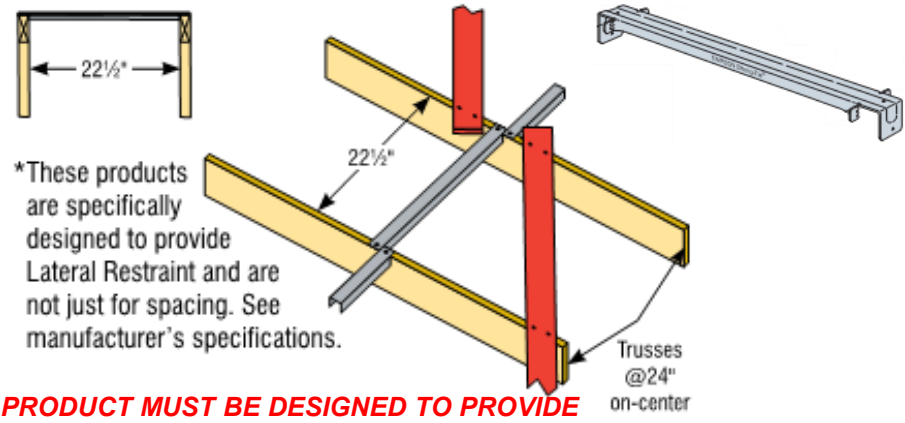
Truss Restraint / Bracing

Initial Top Chord Temporary Restraint/Bracing

- Short Member Temporary Lateral Restraint – Option 3



PRODUCT MUST BE DESIGNED TO PROVIDE LATERAL RESTRAINT, NOT JUST SPACING!!!!

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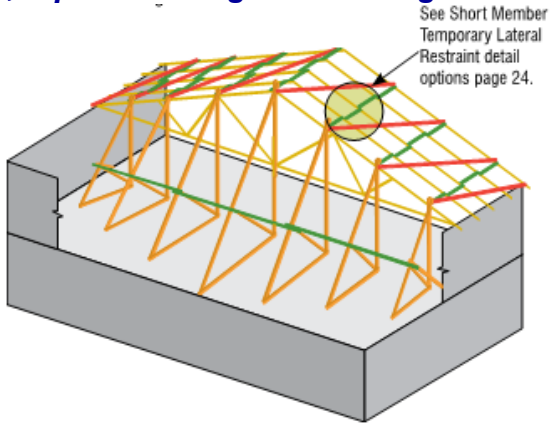
Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing

- After "short member temporary lateral restraint" is installed, top chord diagonal bracing is added



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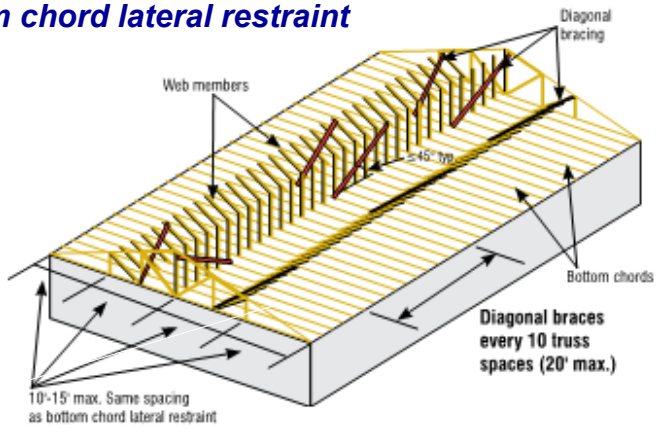
Truss Restraint / Bracing

Web Member Temporary Restraint

- Intermittent diagonal braces are added between the top and bottom chords to match the spacing of the bottom chord lateral restraint



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Wood Trusses: Theory, Practice & Problems

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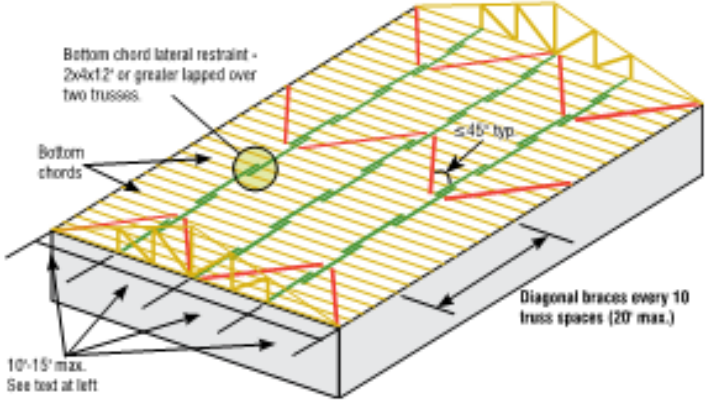
Truss Restraint / Bracing

Bottom Chord Temporary Restraint/Bracing

- Continuous rows of lateral restraint and intermittent diagonal bracing in bottom chord plane



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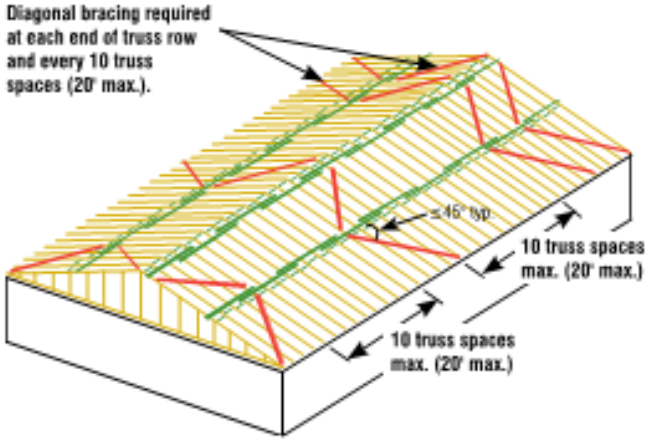
Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing

- Option 1 – Long Length Continuous Lateral Restraint



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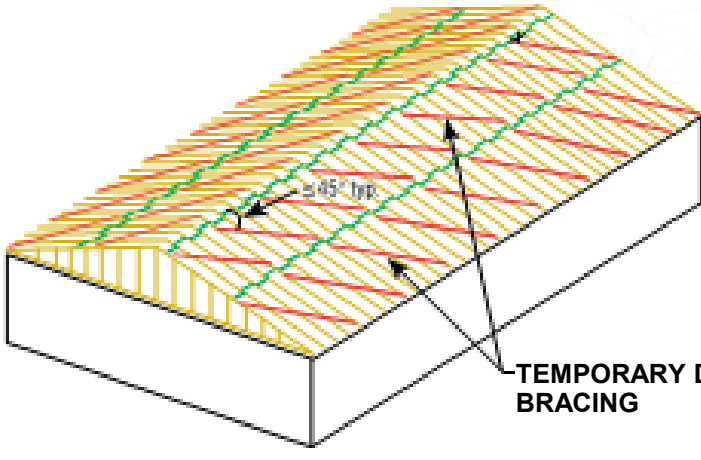
Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing

- Option 2 – Short Member Continuous Lateral Restraint



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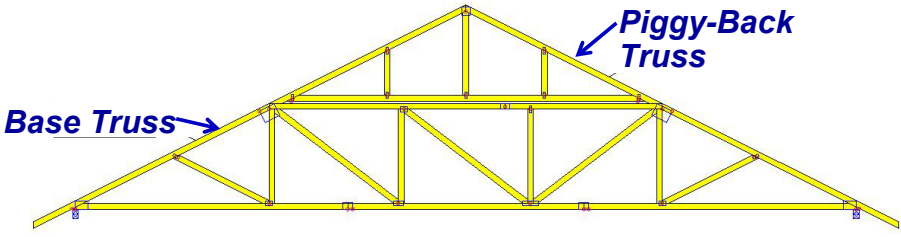
Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing

- Piggy-Back (Cap) Trusses



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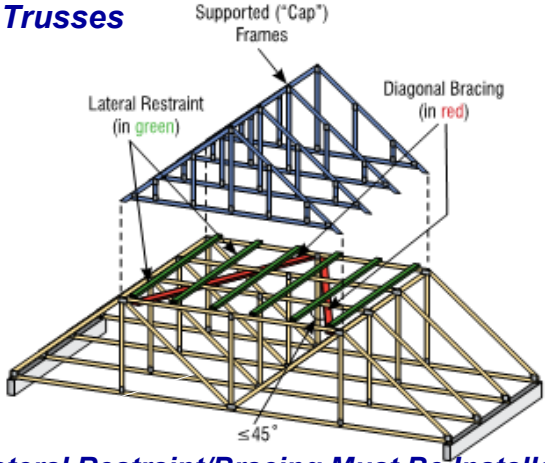
Truss Restraint / Bracing

Top Chord Temporary Restraint/Bracing

- Piggy-Back Trusses



** Permanent Lateral Restraint/Bracing Must Be Installed **

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Truss Restraint / Bracing

Temporary Restraint/Bracing

- Special Inspections
  - Current State Building Code – Based on 2003 IBC
    - No Special Inspections Requirements for Temporary Restraint/Bracing
  - Upcoming Building Code – Based on 2012 IBC
    - §1705.5.2 – "Where a truss clear span is 60 feet or greater, the special inspector shall verify that the temporary installation restraint/bracing…are installed in accordance with the approved truss submittal package"

Truss Restraint / Bracing

Temporary Restraint/Bracing

BREAK

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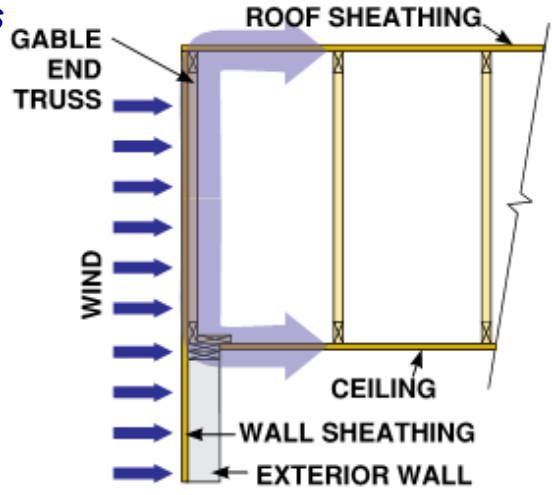
Permanent Truss Bracing

Gable End Trusses

- Need to establish load path by which to transfer lateral wind loads (pressure or suction) from the exterior wall surface into the structure so that they can ultimately be delivered down to the foundation.



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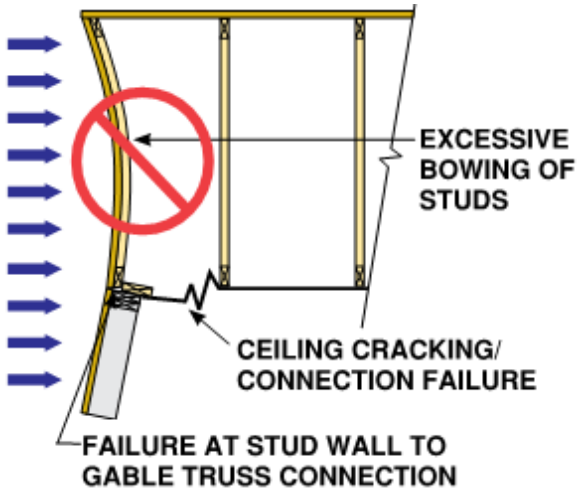
Permanent Truss Bracing

Gable End Trusses

- Potential Points of Failure



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Permanent Truss Bracing

Gable End Trusses

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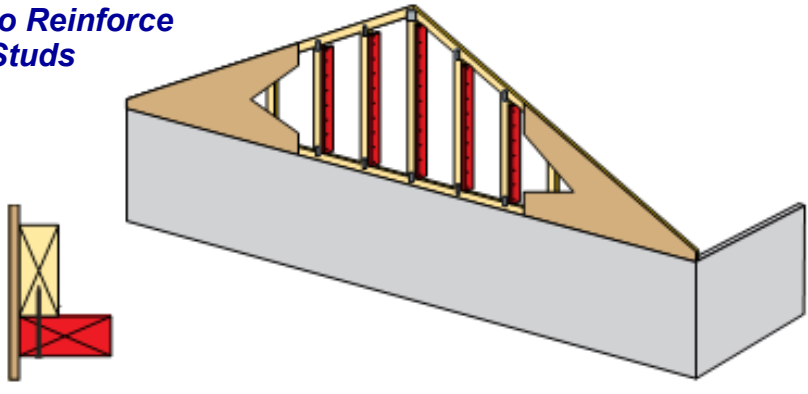
Permanent Truss Bracing

Gable End Trusses

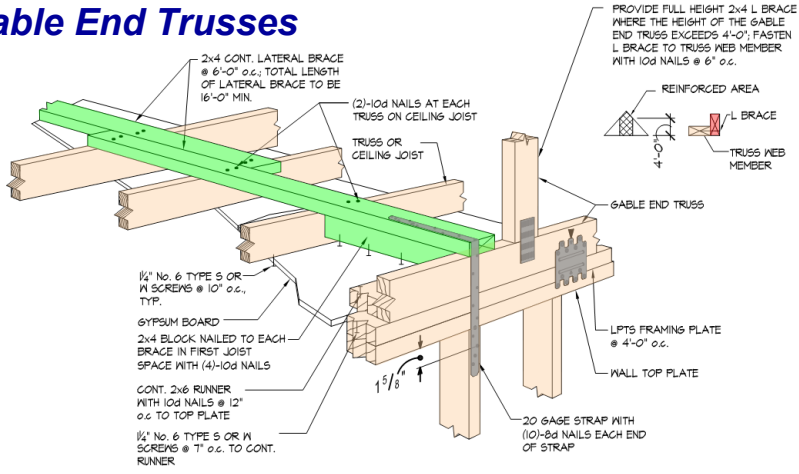
- Add L-Braces to Reinforce Studs



- Still need to transfer loads at ceiling elevation

Permanent Truss Bracing

Gable End Trusses



TYPICAL DETAIL OF CEILING BRACING AT GABLE END WALL TRUSS

NO SCALE

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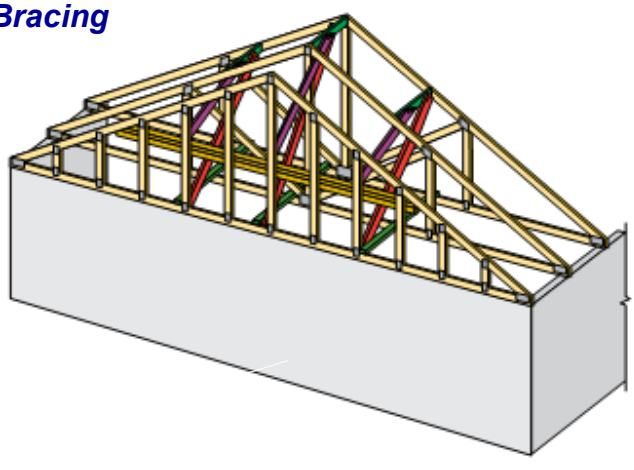
Wood Trusses: Theory, Practice & Problems

Permanent Truss Bracing

Gable End Trusses

- Add Bracing



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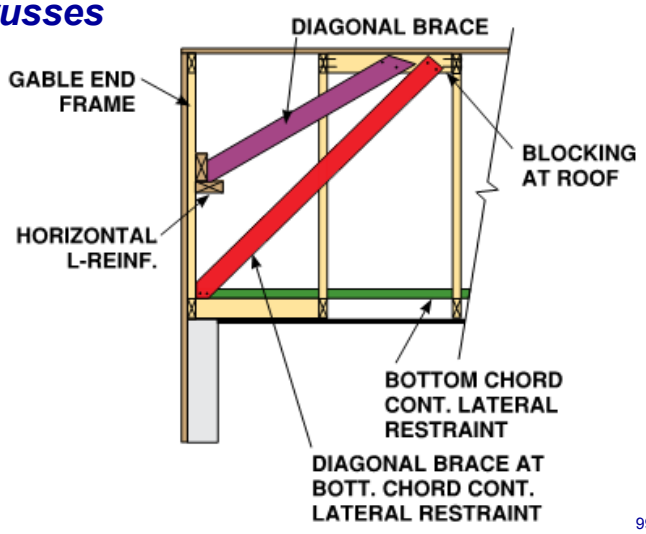
Permanent Truss Bracing

Gable End Trusses

- Add Bracing



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Truss Repairs

- Damage During Handling/Storage

100

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Truss Repairs

- Damage During Handling/Storage
- Damage During Erection

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Wood Trusses: Theory, Practice & Problems

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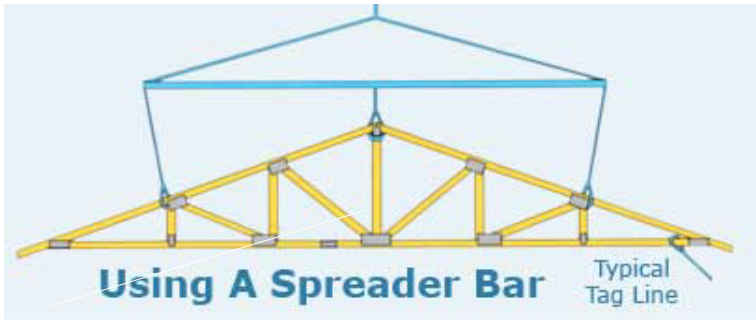
Truss Repairs

- Damage During Handling/Storage
- Damage During Erection



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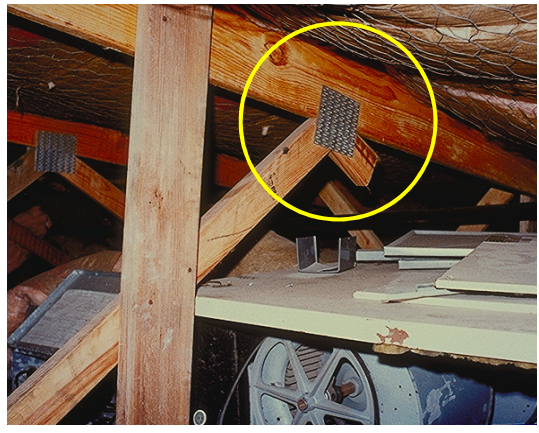
Truss Repairs

- Damage During Handling/Storage
- Damage During Erection
- Damage Due to Other Trades
- Issues Associated with Improper Erection
- Issues Associated with Improper Fabrication
- Issues Associated with Stupidity



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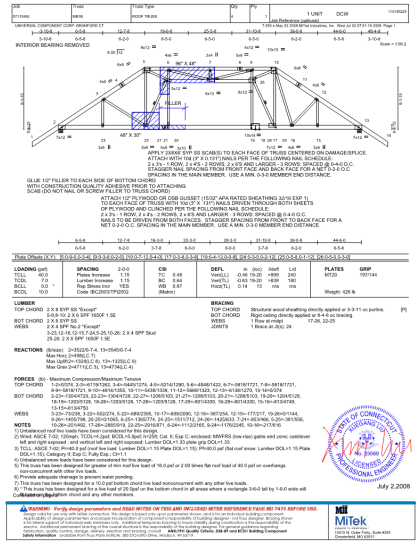
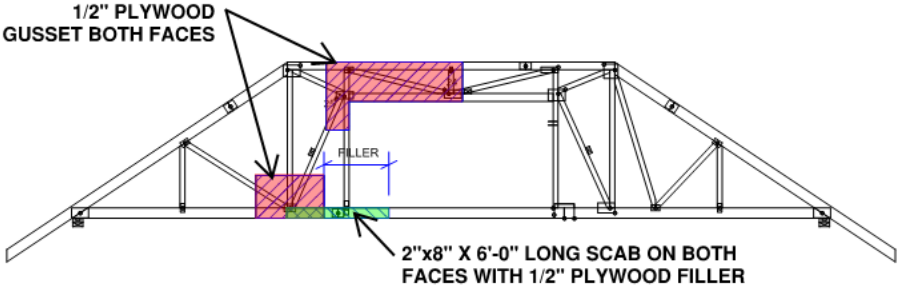
Truss Repairs

- Repairs must be designed by the Truss Designer
- Truss Design Drawing issued for repairs
- Repair drawings should be signed and sealed by a Professional Engineer



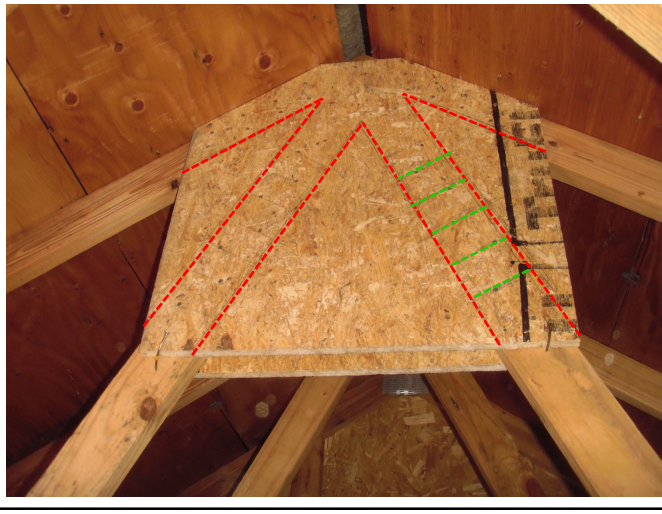
Truss Repairs

- Repairs often include the addition of wood structural sheathing (i.e. plywood or OSB) gussets, 2"x scabs or a combination thereof
- Strict adherence to fastening requirements are essential.



Truss Repairs

- Plywood Gusset Repair



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Acknowledgements

SBCA Structural Building Components Association

TPI Truss Plate Institute

RELIABLE TRUSS

Tim LaChapelle, P.E.

DiBlasi Associates, PC Structural Engineers

Appendix "A"

Sample Truss Design Drawing

Job	Truss	Truss Type	Qty	Ply	
3456C	T15	COMMON	12	1	CT OEDM PRESENTATION

Job Reference (optional)

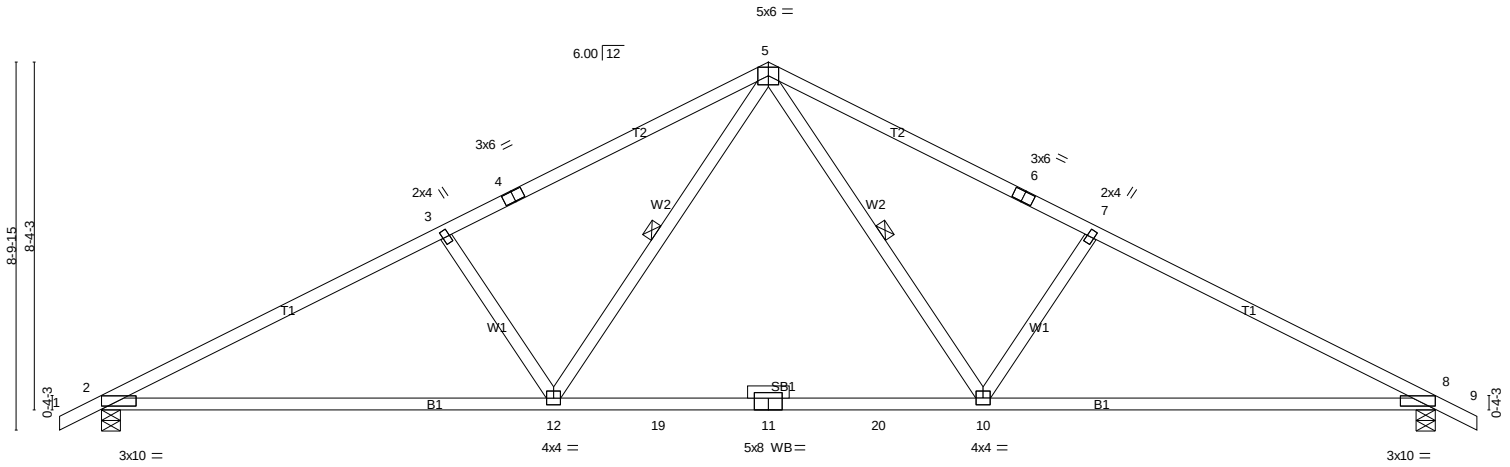
Reliable Truss Co., New Bedford, MA 02745, Tim LaChapelle

7.610 s Jan 29 2015 MiTek Industries, Inc. Tue Feb 24 09:13:25 2015 Page 1

ID:ZECf_SwZ0Fwhb?zkAt4DQZzi_rC-NWpTr941MJ9fIdchZ_S7GAbTNSJgjCi1LdhUVmzi_Pu

1-0-0	8-3-4	16-0-0	23-8-12	32-0-0	33-0-0
1-0-0	8-3-4	7-8-12	7-8-12	8-3-4	1-0-0

Scale = 1:55.3



10-10-3	21-1-13	32-0-0
10-10-3	10-3-11	10-10-3

Plate Offsets (X,Y)-- [2:0-10-0,0-0-14], [8:0-10-0,0-0-14]

LOADING (psf)		SPACING-	2-0-0	CSI.		DEFL.	in	(loc)	l/defl	L/d	PLATES	GRIP
TCLL	30.0	Plate Grip DOL	1.15	TC	0.91	Vert(LL)	-0.65	10-12	>592	240	MT20	197/144
TCDL	10.0	Lumber DOL	1.15	BC	0.94	Vert(TL)	-0.98	10-12	>391	180		
BCLL	0.0 *	Rep Stress Incr	YES	WB	0.34	Horz(TL)	0.12	8	n/a	n/a		
BCDL	10.0	Code IRC2009/TPI2007		(Matrix-M)							Weight: 113 lb	FT = 20%

LUMBER-

TOP CHORD	2x4 SPF 1650F 1.5E
BOT CHORD	2x4 SPF 1650F 1.5E
WEBS	2x4 SPF No.2
OTHERS	2x4 SPF No.2

BRACING-

TOP CHORD	Structural wood sheathing directly applied.
BOT CHORD	Rigid ceiling directly applied or 2-2-0 oc bracing.
WEBS	1 Row at midpt 5-12, 5-10

REACTIONS. (lb/size) 2=1786/0-5-8 (min. 0-2-13), 8=1786/0-5-8 (min. 0-2-13)
Max Horz 2=183(LC 7)
Max Uplift2=-574(LC 8), 8=-574(LC 8)

FORCES. (lb) - Max. Comp./Max. Ten. - All forces 250 (lb) or less except when shown.

TOP CHORD	2-3=-2996/1928, 3-4=-2658/1795, 4-5=-2506/1832, 5-6=-2506/1832, 6-7=-2658/1794, 7-8=-2996/1928
BOT CHORD	2-12=-2322/2562, 12-19=-832/1706, 11-19=-832/1706, 11-20=-832/1706, 10-20=-832/1706, 8-10=-2322/2562
WEBS	3-12=-612/391, 5-12=-800/1014, 5-10=-800/1014, 7-10=-612/391

NOTES-

1) Unbalanced roof live loads have been considered for this design.
2) Wind: ASCE 7-05; 110mph; TCDL=6.0psf; BCDL=6.0psf; h=25ft; B=48ft; L=32ft; eave=4ft; Cat. II; Exp B; enclosed; MWFRS (all heights) and C-C Exterior(2) zone; cantilever left and right exposed ; end vertical left and right exposed; porch left and right exposed;C-C for members and forces & MWFRS for reactions shown; Lumber DOL=1.60 plate grip DOL=1.60
3) The solid section of the plate is required to be placed over the splice line at joint(s) 11.
4) Plate(s) at joint(s) 11 checked for a plus or minus 3 degree rotation about its center.
5) This truss has been designed for a 10.0 psf bottom chord live load nonconcurrent with any other live loads.
6) * This truss has been designed for a live load of 20.0psf on the bottom chord in all areas where a rectangle 3-6-0 tall by 2-0-0 wide will fit between the bottom chord and any other members, with BCDL = 10.0psf.
7) All bearings are assumed to be User Defined crushing capacity of 425 psi.
8) Provide mechanical connection (by others) of truss to bearing plate capable of withstanding 574 lb uplift at joint 2 and 574 lb uplift at joint 8.
9) This truss is designed in accordance with the 2009 International Residential Code sections R502.11.1 and R802.10.2 and referenced standard ANSI/TPI 1.
10) "Semi-rigid pitchbreaks including heels" Member end fixity model was used in the analysis and design of this truss.

LOAD CASE(S) Standard