Code Compliant Construction of Conventionally Framed Roofs and Roof Trusses

Overview

SBCA

Introduction

- This presentation covers the requirements for conventionally framed roofs and roof truss construction per International Residential Code (IRC) Section 802.

Background

- The code allows portions of a structure to be engineered in accordance with the International Building Code (IBC), without the entire structure requiring engineering. (R301.1.3)
- This means that some portions of the building may be engineered (e.g. trusses and other components), but the structure may still be able to utilize IRC prescriptive requirements.

Applications

- Structures within the scope of prescriptive code compliance include:
  - Detached one- and two-family dwellings and townhouses with separate means of egress [R101.2]
  - Light-frame construction (platform or balloon frame) [R301.1.2]

Prescriptive Code Compliance

- The following three tables list additional criteria the structure must meet with respect to loads and geometry:

Prescriptive Code Compliance - Loads

Load	Maximum Allowed	Code Section
Roof Live	20 psf	R301.6/Table R301.6
Ceiling/Floor Live	10, 20, 30 or 40 psf	R301.5/Table R301.5
Snow	70 psf	R301.2.3
Wind Speed (2012)	110 mph	R301.2.1.1/Figure R301.2(4)A
Wind Speed (2006/9)	110 mph 100 mph hurricane-prone regions	R301.2.1.1
Seismic – Townhouses	SDC: C, D_0, D_1, & D_2	R301.2.2 (SDC: A & B exempt)
Seismic – 1- & 2-family	SDC: D_0, D_1, & D_2	R301.2.2 (SDC: A, B & C exempt)

Prescriptive Code Compliance - Structure Geometry

Description	Maximum Allowed	Code Section
Story Height	10' (laterally unsupported) plus floor framing not to exceed 16" or 12' as allowed by exception	R302.3/Table R602.3(5)
Number of Stories	3 above grade plane	R101.2
Building Width (perpendicular to ridge)	36'	footnote to Tables R502.5(1) & R802.5(2)]
Building Length (parallel to ridge)	Not specified for wood	[CFS & ICF limited to 60']
Mean Roof Height	Up to 60' with application of adjustment factors	Table R602.3(1), Table R602.10.3(1) & Section R802.11.

Prescriptive Code Compliance - Roof Geometry

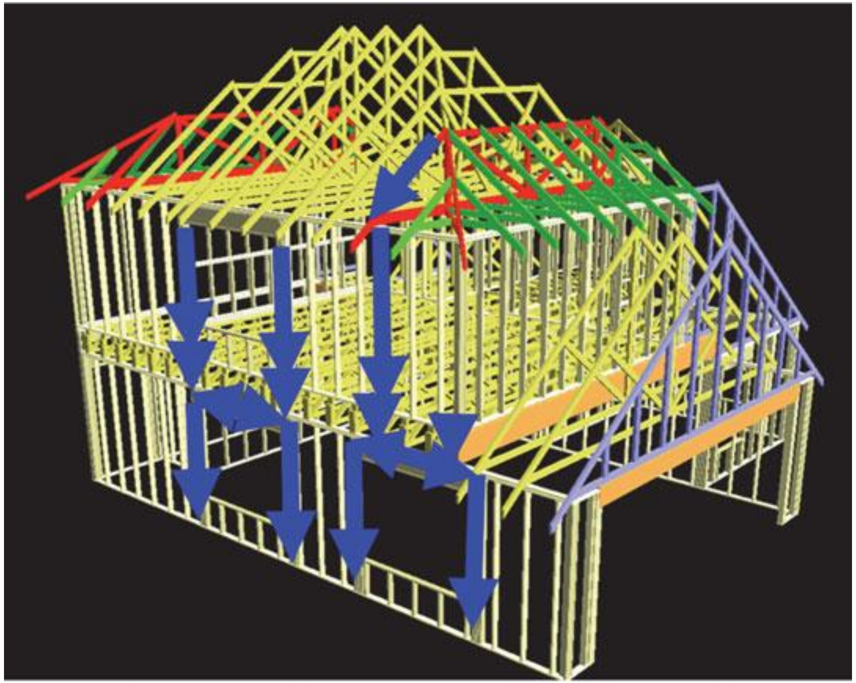
Description	Maximum Allowed	Code Section
Building Width (perpendicular to ridge)	40' (36' building plus max 24" overhang each side)	footnote to Tables R502.5(1) & R802.5(2) & R802.7.1.1
Rafter Span	Maximum tabulated or 26'	Footnote b Table R802.5(1)-(8)
Ceiling Joist Span	Maximum tabulated or 26'	Footnote b Table R802.4(1) & (2)
Rafter/Ceiling Joist Spacing	24" o.c.	Table R802.5(1)-(8) & Table R802.4(1) & (2)
Roof Pitch	3/12 to 12/12 or greater	Table R301.6 & R802.3

Prescriptive Code Compliance

- Finally, and perhaps most importantly, to meet prescriptive code compliance:
  - Construction documents shall be of sufficient clarity to indicate the location, nature and extent of work and show **in detail** that such work **conforms to the provisions of the code** [R106.1.1].
  - A complete **load path** from peak of roof to the foundation is required [R301.1].

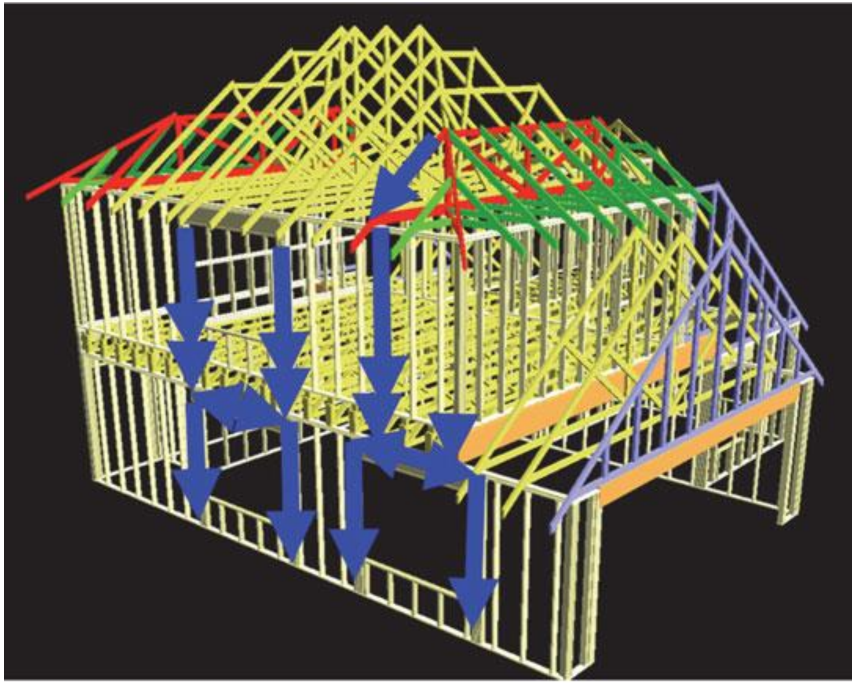
What is a Load Path?

- "A complete load path…meets all requirements for transfer of all loads from their point of origin through the load-resisting elements to the foundation." (R301.1)



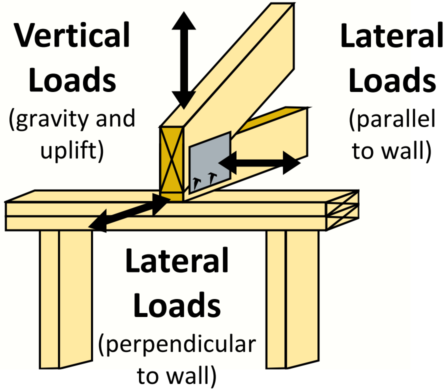
What is a Load Path?

- While framers build from the bottom up, load paths must be traced from the top down.
- Loads are typically applied on the roof surface and travel down to the foundation.
- In between roof and foundation, loads must be transferred along elements that are adequate to carry these loads.

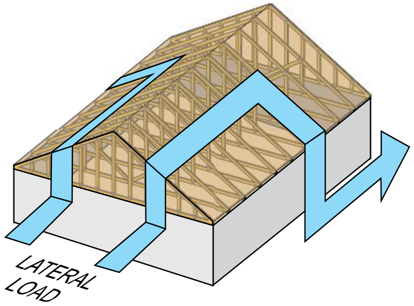


What is a Load Path?

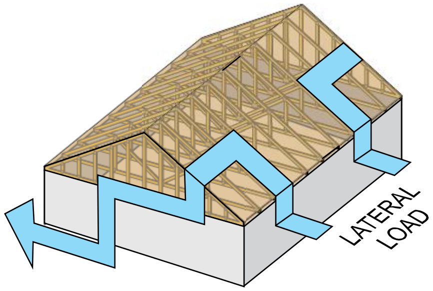
- Loads and load directions
  - Vertical loads
    - Gravity – easiest to trace from roof to foundation
    - Uplift – less well understood
  - Lateral loads
    - Parallel and perpendicular to structural element
    - e.g. Wind, Seismic – most difficult to address adequately



Lateral Load applied to end wall

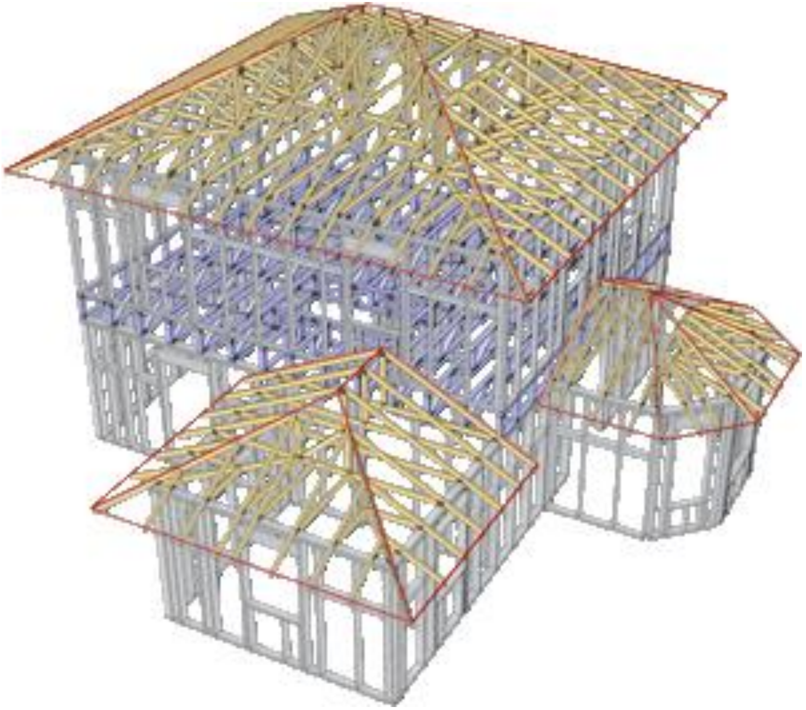


Lateral Load applied to side wall



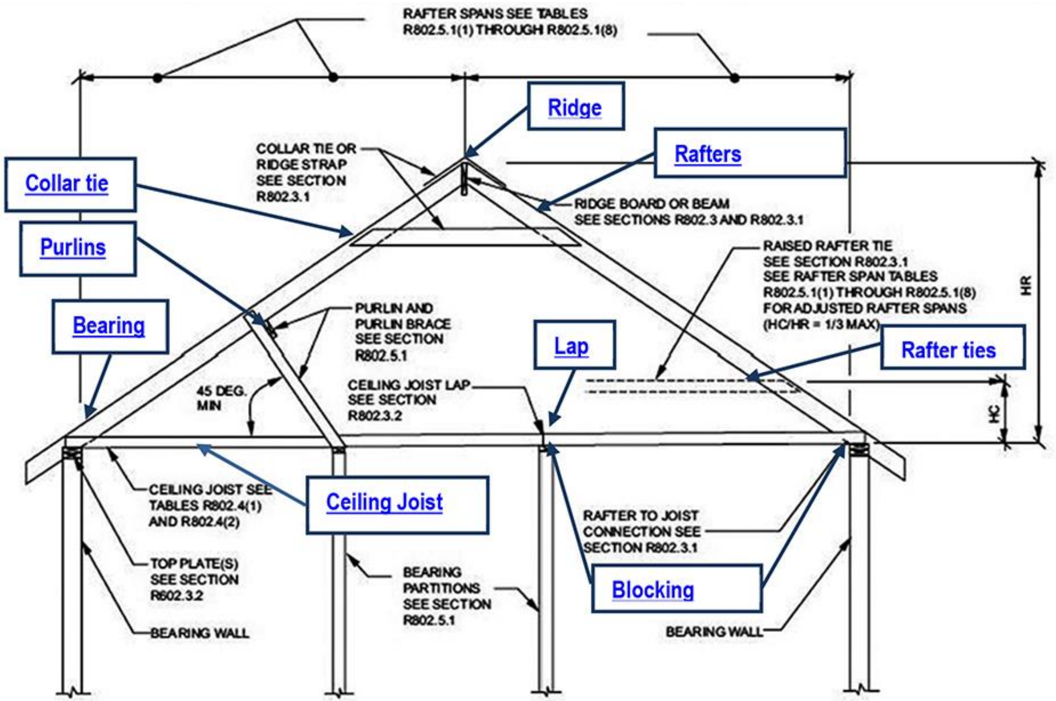
Conventional Framing Problem Areas

- Conventional roof framing and compliance with code requirements, including those involving the load path, is a complex topic.



Conventional Framing Requirements

- The IRC covers many roof framing elements in the prescriptive requirements:
  - Gable/Shed
  - Hip/Valley
  - Roof Openings
  - Notches and Holes



Conventional Framing Requirements

- However, the IRC gives no guidance on other aspects of the roof framing, such as:
  - Bracing design for high end of hip/valley rafters
  - Bracing design for rafter purlins
  - Non-symmetrical hip roofs
  - Roof diaphragms with plate height changes
  - Large roof openings (greater than 6' wide)

Conventional Framing Problem Areas

- A clear understanding of all framing code requirements is essential to avoid many pitfalls, as shown in the following examples.

Source: Aries Engineering

Example: Load Path (Roof Dormer)

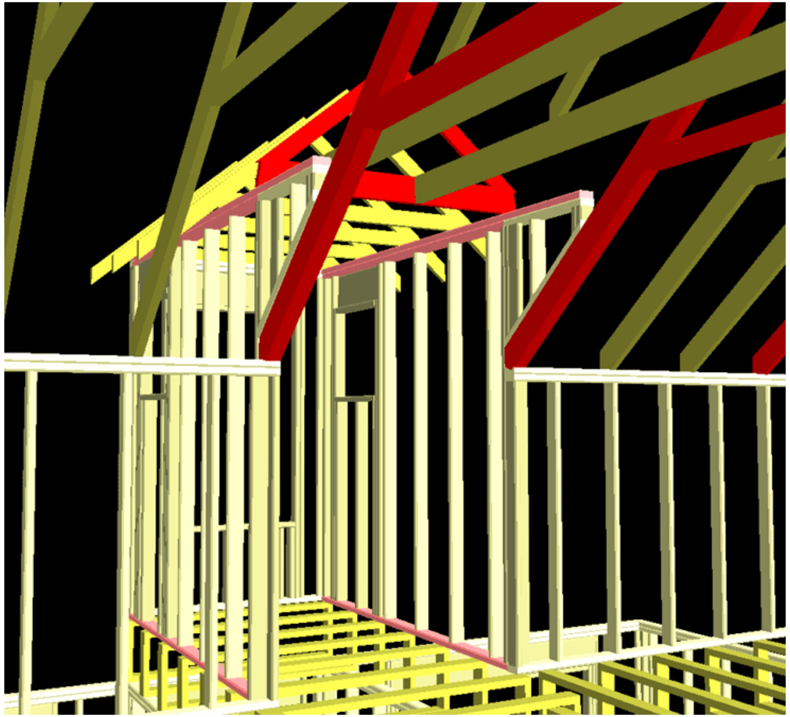
- The main ceiling joists are supported by a girder that is supported on next to nothing.
  - The joists should run further into the dormer, and the girder supporting them should be supported by posts in the dormer side walls.

Example: Load Path (Roof Dormer)

- The load path from the dormer flows down the side wall. However, the side wall does not extend to the floor in this area.
  - The load path needs to flow into the rafter next to the dormer side wall.
- However, only a single rafter is placed here.
  - If this rafter is supporting the dormer roof, it should designed to carry the dormer.

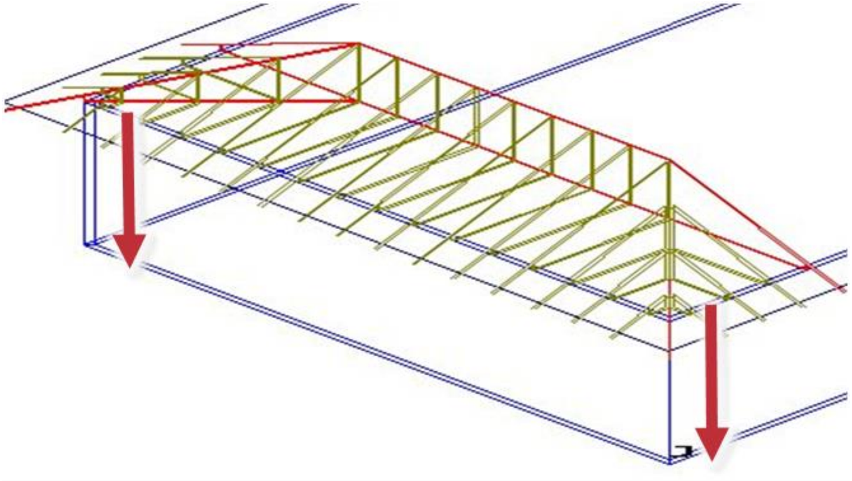
Example: Load Path (Roof Dormer)

- If this had been designed with trusses, a tail bearing girder truss designed to carry this load would have been used here.



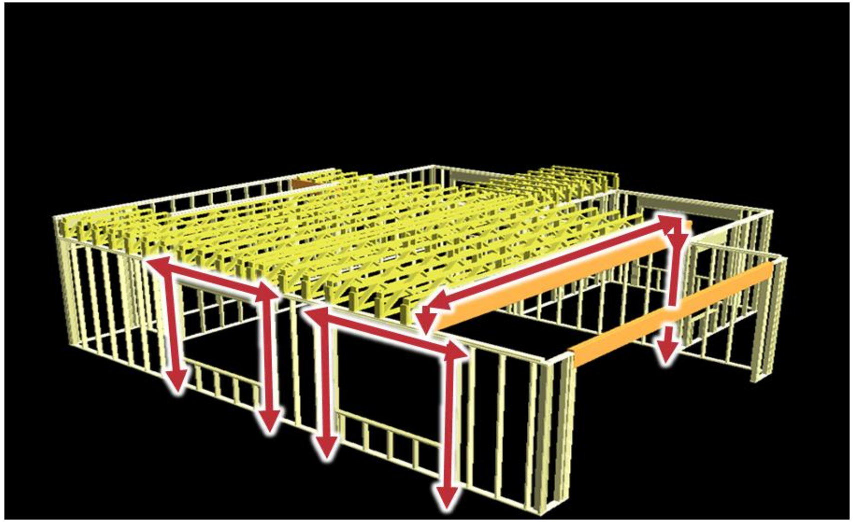
Example: Load Path (Wall)

- Whether using conventional framing or trusses, it is essential to pay attention to load paths, especially with today's larger, more complex houses.



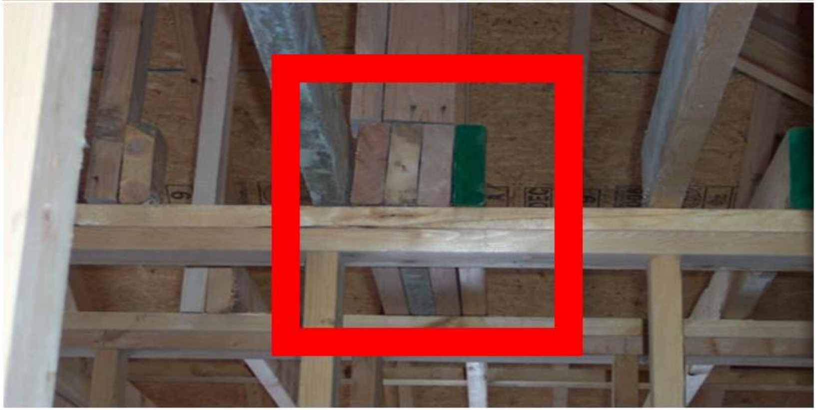
Example: Load Path (Wall)

- Where girder trusses are needed, large concentrated loads on exterior walls can occur.



Example: Load Path (Wall)

- Doubled I-joists in a roof-ceiling assembly carry a significant load, but they bear on two top plates between studs.
  - Note the joint in the lower of the two top plates. Joints in plates need not occur over studs; however, this is a particularly bad place for one.
- Similarly, a 4-ply beam bearing on the wall at right has no studs under it to transfer the load to the floor below.

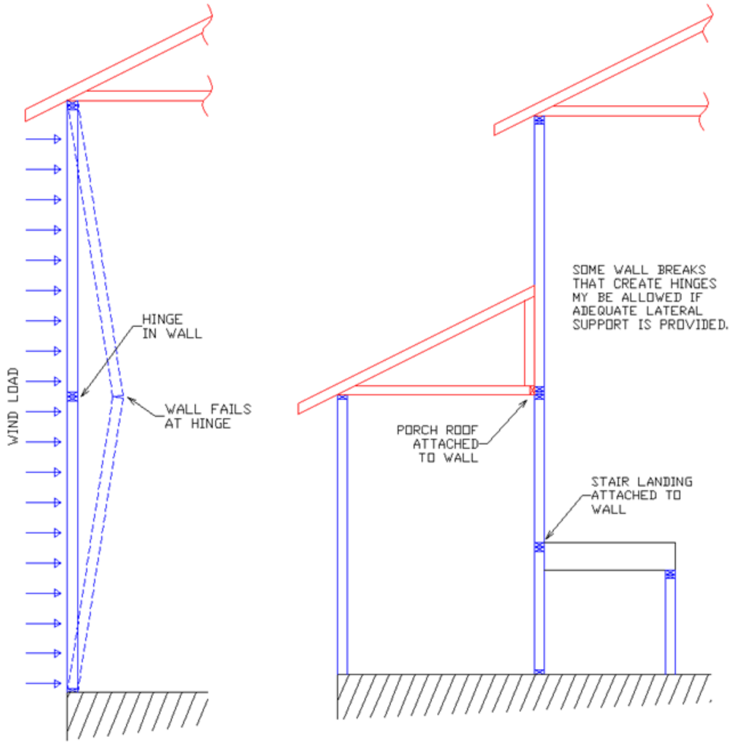


Example: Load Path (Wall)

- For tall walls (over 10’ in height) both gravity and lateral load paths need to be considered and are more complicated and critical.
- Any break in the continuity of these studs creates a “hinge” in the wall, which can easily deform or fail under wind load conditions.

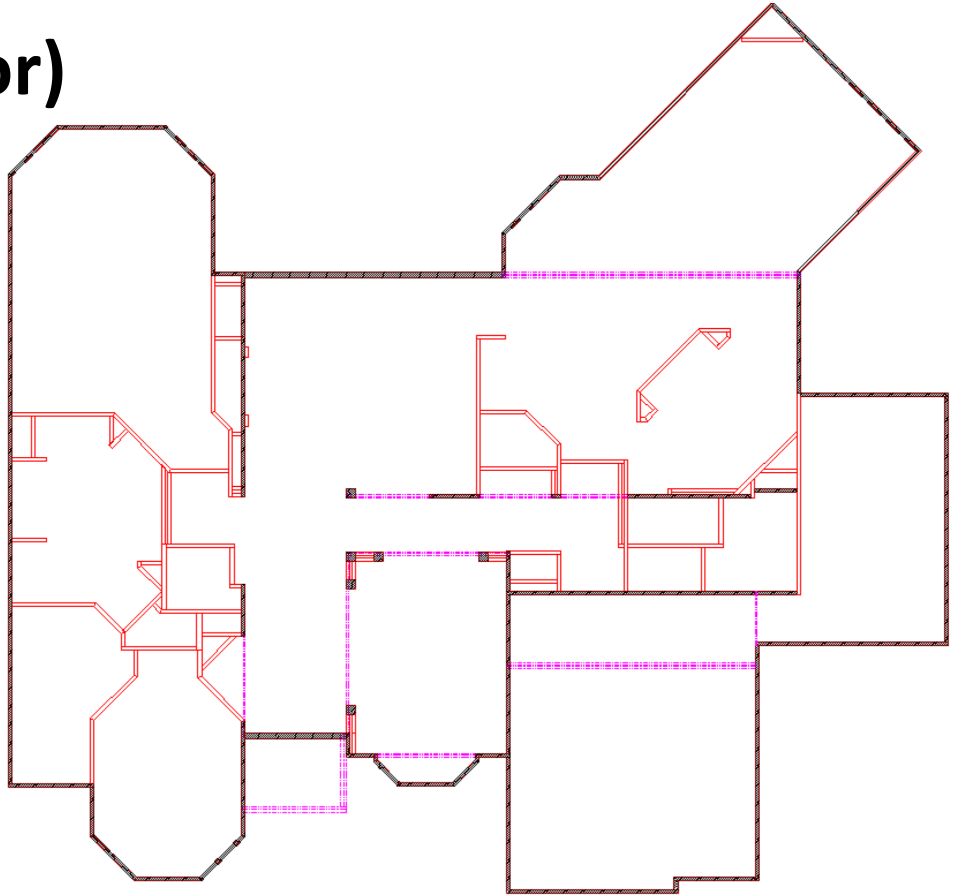
Example: Load Path (Wall)

- Not only is there a hinge created in this case but the outward thrust of the rafters also needs to be resisted.
- It is not clear in the previous picture how this is being accomplished.



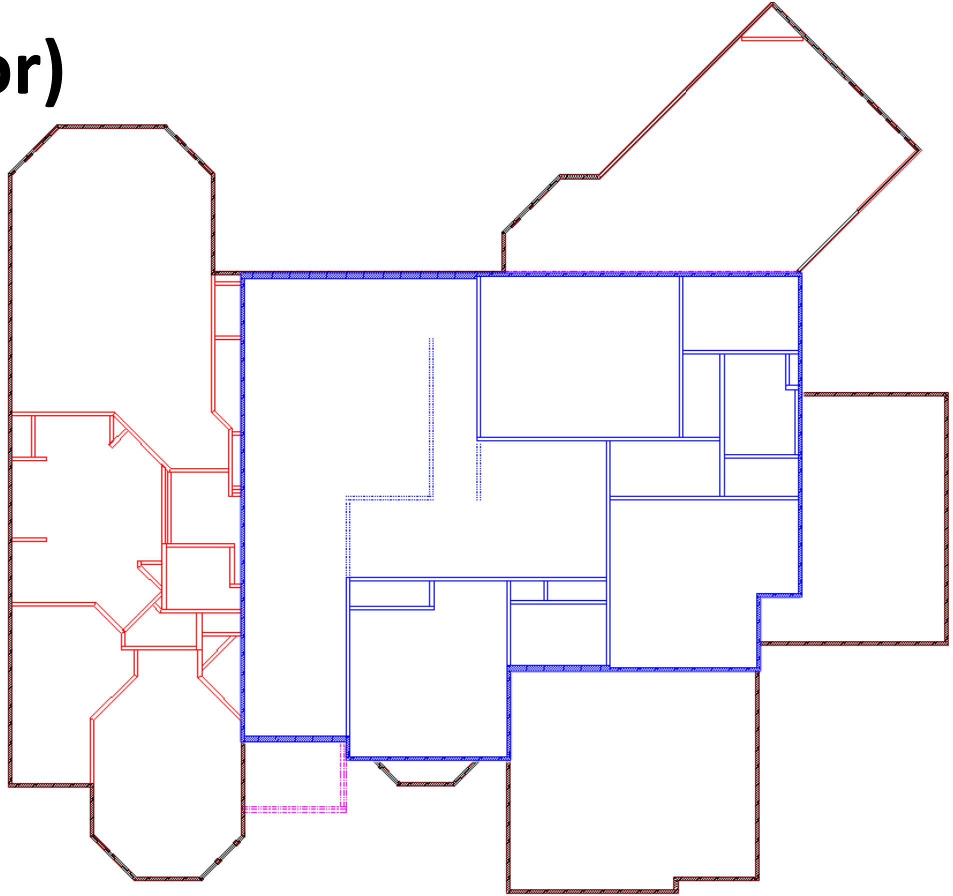
Example: Load Path (Floor)

- In truss construction, loads are typically carried by the outside walls and transferred down to the foundation walls.
- With conventional frame construction, loads must be transferred through the interior of the structure.



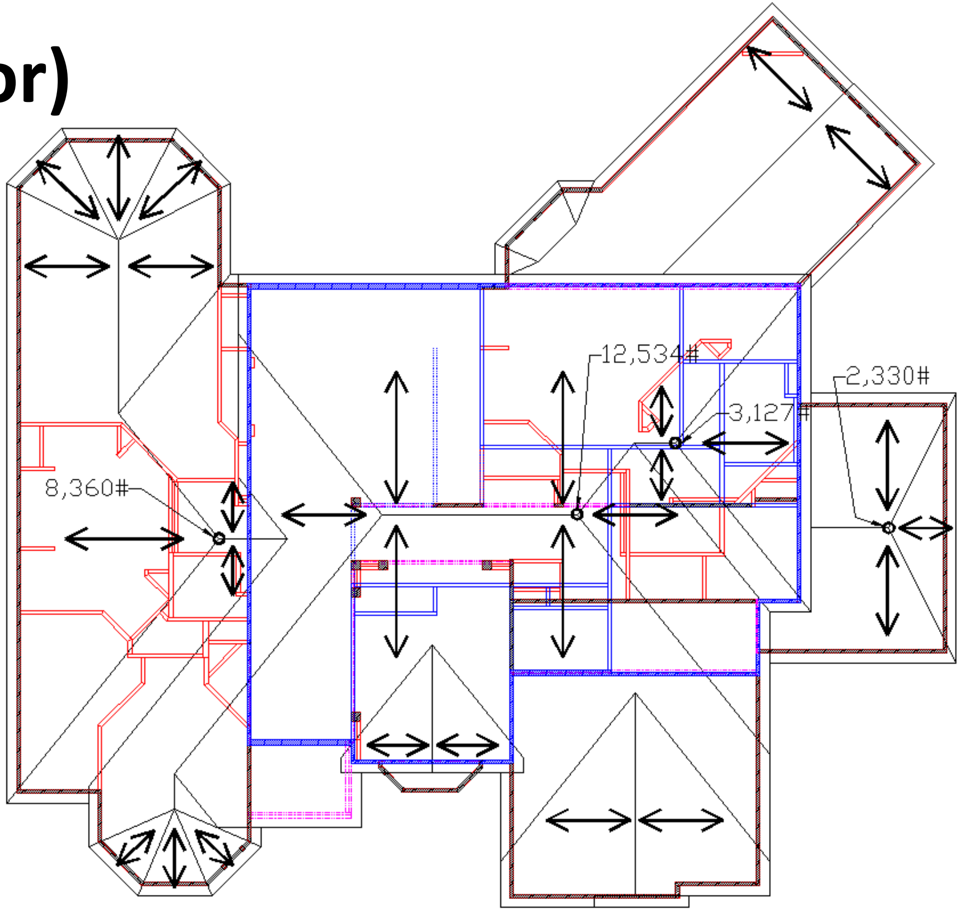
Example: Load Path (Floor)

- This can lead to large concentrated loads transferred through interior walls.
- Loads cannot be terminated on or, even worse, between floor framing elements without specific engineering considerations.



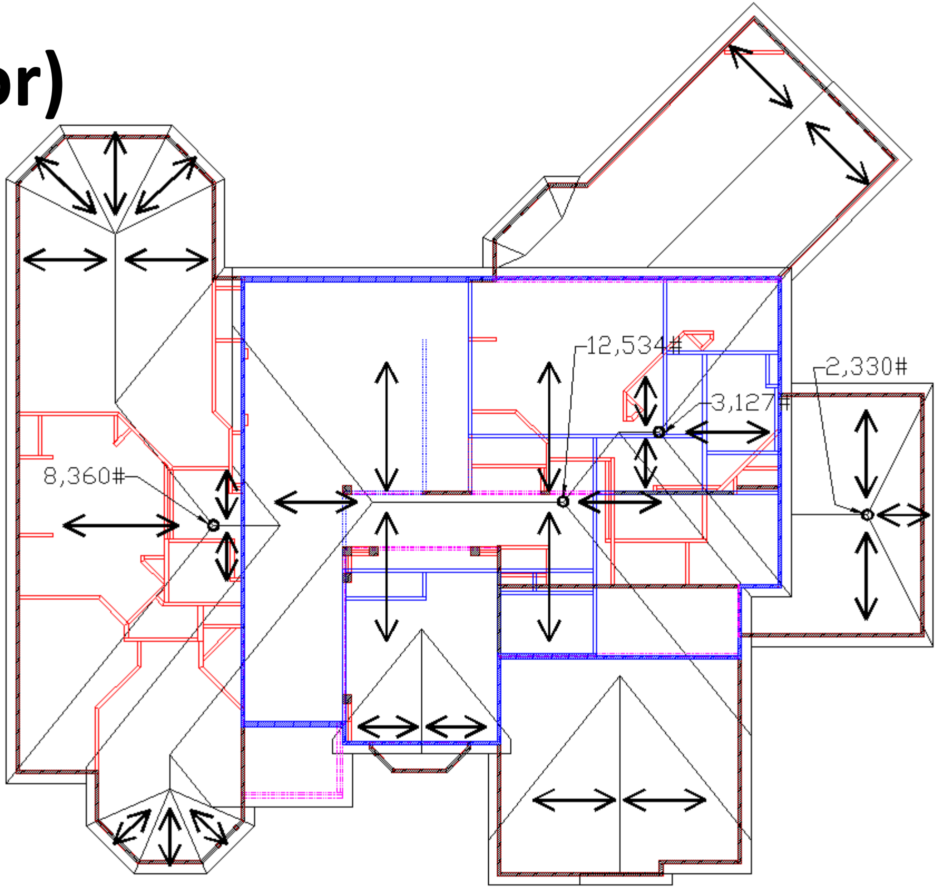
Example: Load Path (Floor)

- In this house plan, very few framing elements stack from level to level.
- The loads shown are approximate and reflect a 20 psf live or snow load and a 10 psf dead load.
- Loads will vary depending on snow load and details of the framing.



Example: Load Path (Floor)

- With few walls stacking or crossing, very few points exist to take roof loads down to the foundation.
- The stack points that do exist are not in useful locations.



Conventional Framing Problem Areas

- Additional areas to watch closely:
  - Connections
  - Supports
  - Structural member sizing

Example: Connection (Floor Sag)

- In this example, you can see a post at a corner of an interior wall. It is carrying a significant load from the beam above.

Example: Connection (Floor Sag)

- In the photo on the right, you can see this post rests on two different bottom plates and the floor appears to be sagging.
- This is a case where the roof loads applied to the floors were not considered – thus the sag.

Example: Connection (Floor Sag)

- In this photo, we can see a fairly clear sag in the floor at this post in a wall.
- This demonstrates that, if the path for these loads is not considered all the way down to a foundation element, there can easily be deflection problems, or low points in floors and possibly failure.
- Again, in this case the roof loads applied to the floors were not considered – thus the sag.

Example: Connection (Power Blocking)

- The IRC includes fastener requirements for conventional construction within the scope of the code.
- Problems may arise where there is end-grain nailing or where multiple members are joined.
- For example, nailing details like the one at right may or may not be sufficient, depending on conditions.

Example: Connection (Power Blocking)

- "Power Blocking" is not addressed or approved by the building code.
- In some cases, engineered design may be required.
- With trusses, much shorter end jacks are made to have a mechanical connection.
- Even where the code does cover a specific situation, it is often difficult to inspect whether the fasteners used meet code.

Example: Connection (Roofs)

- A basic problem of inspecting nailed connections is knowing whether the nails meet the code's fastener schedules.
- IRC Table R602.3(1) addresses a number of roof framing items

Nail Sizes in the IRC

Penny Weight	Length x Dia.
16d box	3½" × 0.135"
10d common	3" × 0.148"
10d box	3" × 0.128"
8d common	2½" × 0.131"
8d box	2½" × 0.113"
6d common	2" × 0.113"

TABLE R602.3(1)
FASTENER SCHEDULE FOR STRUCTURAL MEMBERS

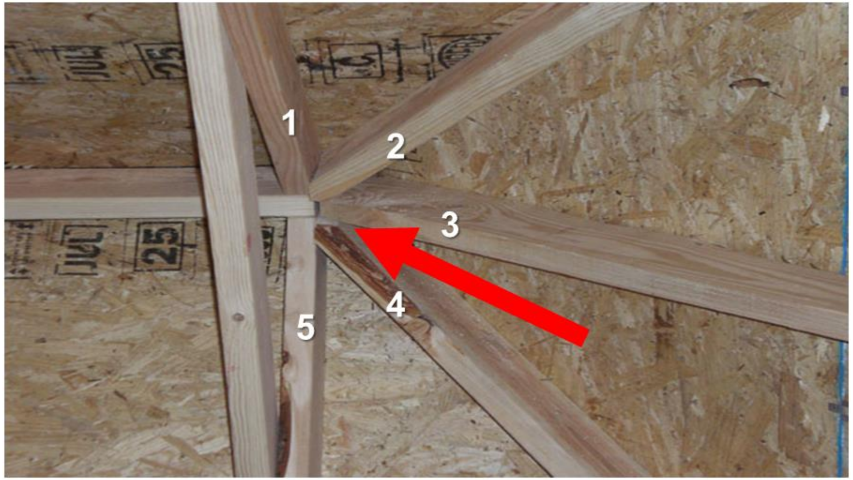
DESCRIPTION OF BUILDING ELEMENTS	NUMBER AND TYPE OF FASTENER[a,b,c]	SPACING OF FASTENERS
Blocking between joists or rafters to top plate, toe nail	3-8d ($2^1/_2'' \times 0.113''$)	—
Rafter to plate, toe nail	2-16d ($3^1/_2'' \times 0.135''$)	—
Roof rafters to ridge, valley or hip rafters: toe nail face nail	 4-16d ($3^1/_2'' \times 0.135''$) 3-16d ($3^1/_2'' \times 0.135''$)	 — —
Rafter ties to rafters, face nail	3-8d ($2^1/_2'' \times 0.113''$)	—
Collar tie to rafter, face nail, or $1^1/_4'' \times 20$ gage ridge strap	3-10d ($3'' \times 0.128''$)	—

Example: Connection (Roof Diaphragm)

- The heel connection at right was made in the plant, avoiding the difficulty of correctly connecting rafters to joists as in conventional construction.
- With trusses, the overall flow of loads is well defined, so specific mechanical fasteners can be utilized to meet resistance needs.

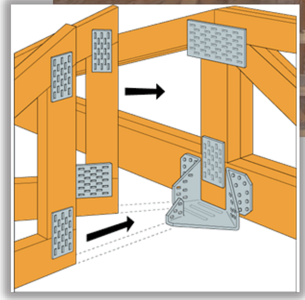
Example: Connection (Hip Rafters)

- This connection is probably not adequate.
- Trying to attach 5 members to the end of the ridge would require so many nails it would cause splitting in the ridge.
- End and edge distance limits on proper nailing would be violated.
- This joint as built is also weakened by the gap between these two members.



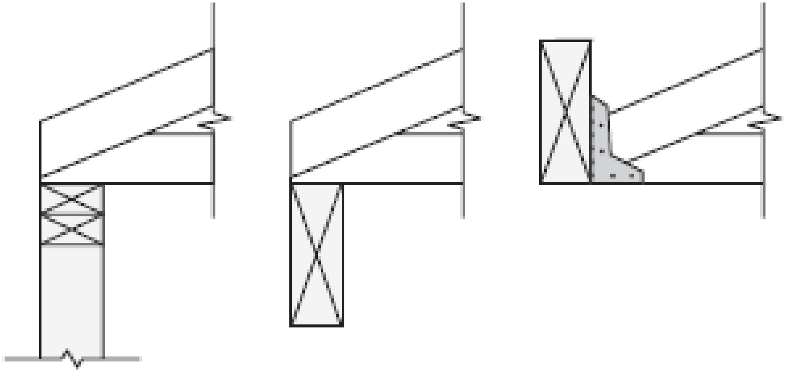
Example: Connection (Hip Rafters)

- With structural building components, connections where multiple members are joined are typically made with engineered mechanical fasteners.



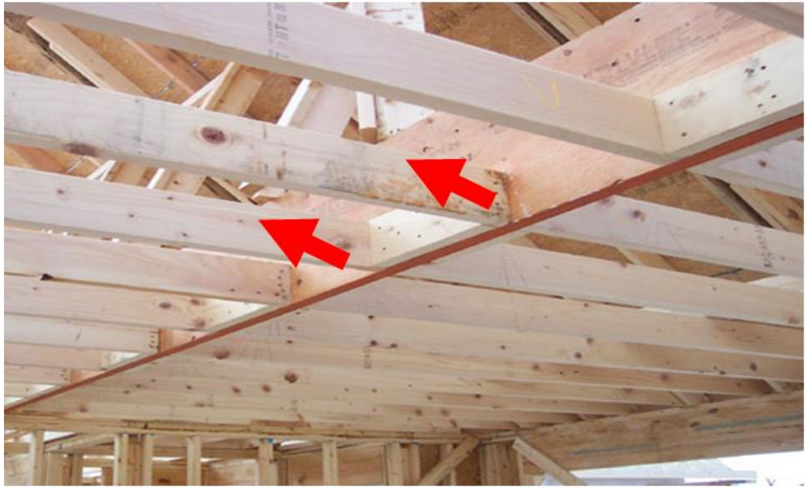
Example: Support (Bearing)

- Inadequate bearing supports are another problem in conventional construction.
- A structural bearing element must carry a structural member's gravity or uplift loads to the foundation.
- The bearing element must also be able to carry any concentrated or lateral loads parallel or perpendicular to the bearing member.



Example: Support (Bearing)

- Braces often connect to the top edge of LVL or conventional lumber beams.
- Beam span tables are typically not accurate when braces are used because the tables assume:
  - Uniform loads only, while the braces apply concentrated loads to the beam
  - Full top edge support is present (to prevent torsional buckling)
- The top edge of the LVL at right is not braced.
- In fact, the braces supporting the purlin run into the LVL at an angle, increasing buckling forces on it.



Example: Support (Rafter)

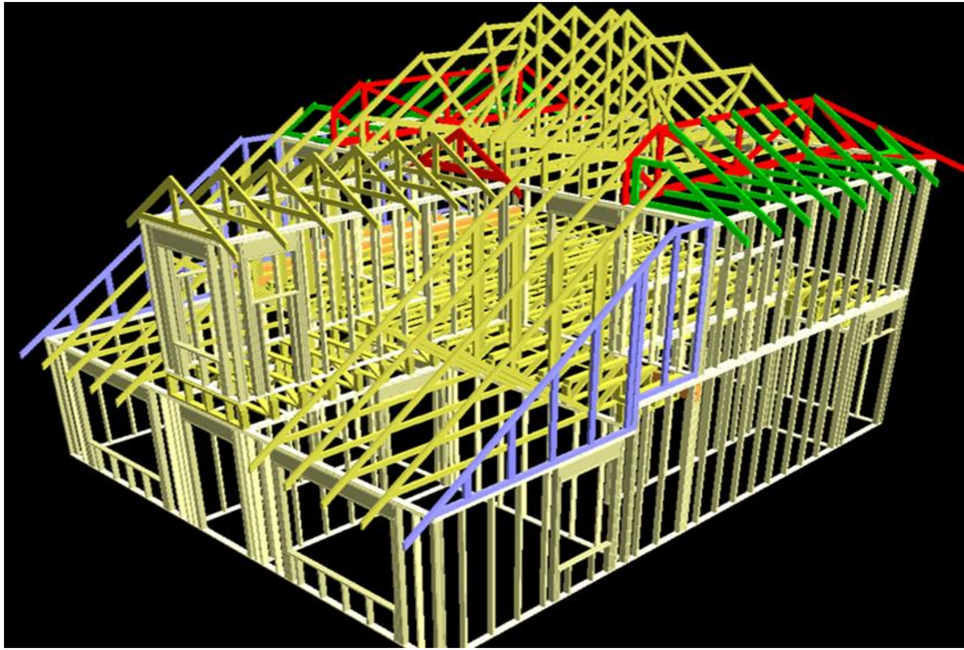
- This is an example of inadequate support of a valley rafter bearing on an unsupported beam.

Example: Support (Rafter)

- The photo on the right shows the end of a ridge beam for a dormer bearing on a 2x4.
- These problems of structural support in conventionally framed roofs tend to appear more often in complex and large roofs.

Example: Support (Rafter)

- The design of roofs of almost any complexity or size, however, can be accommodated fairly simply with trusses.
- The Truss Placement Diagram shows how these are laid out, and there is no guesswork on the jobsite about how the roof is to be adequately structurally supported.



Example: Support (Header)

- This is a field example of a very common “Unbraced Garage Door Header”.
- The beam spans a 18’-3” rough opening with a 2’-6” cripple wall on top and 24’-0” roof trusses at a 6/12 roof pitch on top of the cripple wall.

Example: Support (Header)

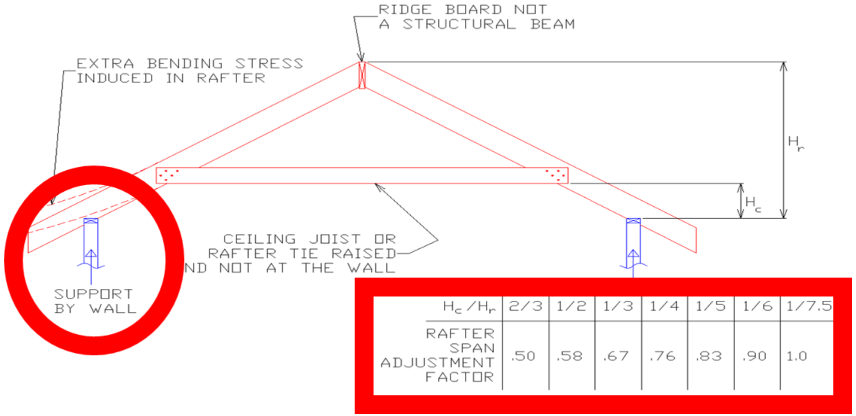
- The beam has no lateral support at its top to prevent it from buckling laterally.
- In situations like this, the beam should be located above the cripple wall to receive lateral support from the roof framing above.

Structural Member Sizing Example

- Another problem is the proper sizing of structural members.
- The roof at right has 2x8 #2 SYP rafters spanning 15’ at 24” o.c.
- Per the IRC, the maximum span for rafters of this material in this situation is typically 15’-10”.
- However, there are no ceiling joists at the bottom of the attic space or other method of resisting the outward push of the rafters.

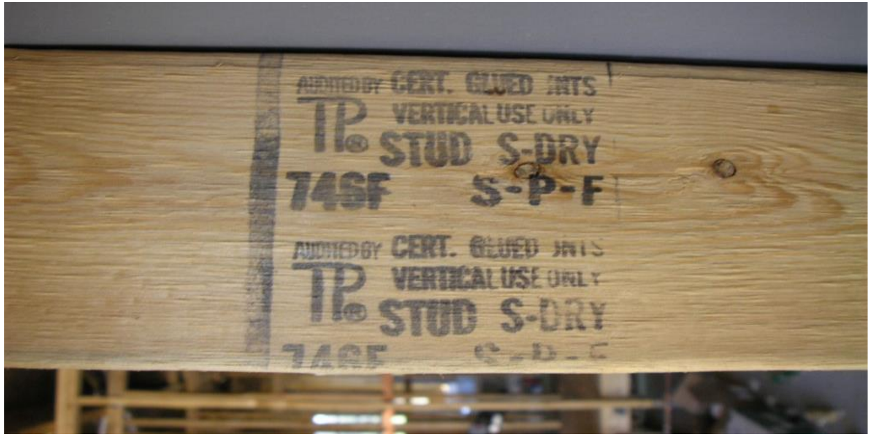
Structural Member Sizing Example

- The tabulated rafter spans assume that ceiling joists are present at the bottom of the attic space.
- Because of the extra bending force induced in the rafter, the maximum rafter spans must be reduced.
- When ceiling joists or rafter ties are located higher in the attic space, the maximum rafter spans shall be multiplied by adjustment factors.



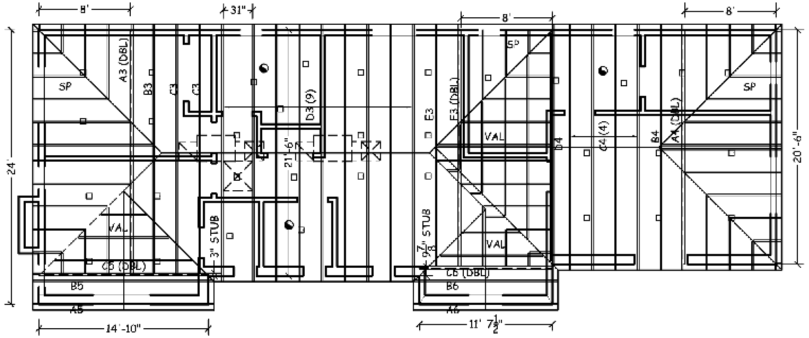
Roofs – Structural Member Sizing

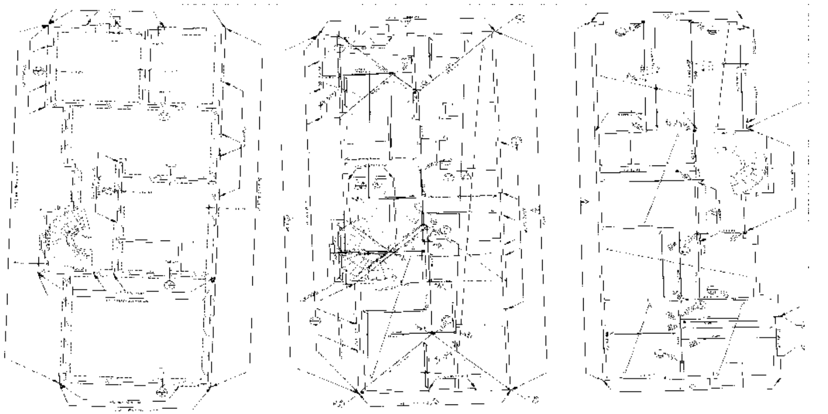
- Some finger-jointed lumber may be used in rafters and trusses.
- If stamped “vertical use only”, the finger-jointed lumber should not be used in horizontal structural applications such as rafters or trusses.



Framing Plan

- A framing plan provides information needed by the inspector, and helps avoid many of the ad-hoc framing solutions we see in the field.
- With truss construction, the Truss Placement Diagram serves this purpose.
- Often, with stick-framed houses, a framing plan is not provided.





Findings

- Inspection of conventional roof framing and all load paths in a structure can be a challenge.
  - Local education can help everyone understand the code and provide for safer structural performance.

Source: Aries Engineering

Findings

- Engineered roof truss framing simplifies the creation of a continuous load path that is fully compliant with Section R301.

Findings

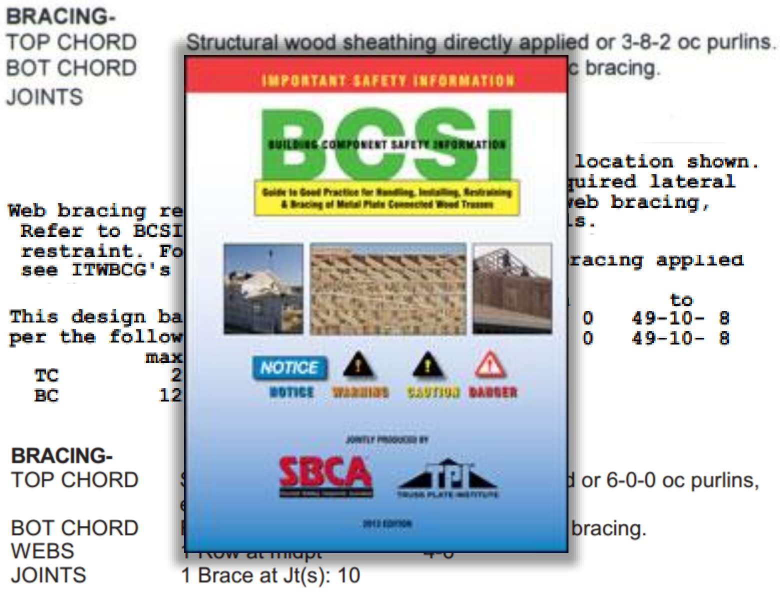
- Truss Design Drawings (TDD) comply with Sections R802.10.3 and R802.11 where applied loads and load path resistance is explicitly defined on the TDD.

NOTES-
1) Wind: ASCE 7-05; 90mph; TCDL=6.0psf; BCDL=3.0psf; h=25ft; Cat. II; Exp C; enclosed; MWFRS (low-rise); cantilever left and right exposed ; end vertical left and right exposed; Lumber DOL=1.33 plate grip DOL=1.33
2) TCLL: ASCE 7-05; Pf=95.0 psf (flat roof snow); Category II; Exp C; Partially Exp.; Ct= 1
3) Unbalanced snow loads have been considered for this design.
4) This truss has been designed for greater of min roof live load of 16.0 psf or 2.00 times flat roof load of 95.0 psf on overhangs non-concurrent with other live loads.
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.
7) Ceiling dead load (5.0 psf) on member(s). 6-7, 9-10, 7-17, 9-17
8) Bottom chord live load (40.0 psf) and additional bottom chord dead load (10.0 psf) applied only to room. 14-16
9) Provide mechanical connection (by others) of truss to bearing plate capable of withstanding 100 lb uplift at joint(s) 2, 13.
10) This truss is designed in accordance with the 2006 International Residential Code sections R502.11.1 and R802.10.2 and referenced standard ANSI/TPI 1.
11) ATTIC SPACE SHOWN IS DESIGNED AS UNINHABITABLE.

LOAD CASE(S) Standard

Findings

- Bracing and related connections can be found on the TDD and in BCSI.
- This supports a code compliant continuous load path
  - Uplift and gravity loads flow from the roof, through the permanent restraint/bracing of the structure, to the foundation system



Solutions

- Options to ensure code compliant framing:
  - Hire engineer of record
  - Eliminate ad-hoc framing solutions
  - **<u>Use Structural Building Components!</u>**

Solutions

- Builder:
  - Faster to install
  - Easier to schedule
  - Safer jobsite
  - Speed and simplicity
- Inspector:
  - Less to inspect
  - Engineer usually involved
- Homeowner
  - Fewer potential problems

Conclusion

- Using trusses & building components can make IRC code compliance much easier and result in a more structurally accurate and higher quality building.

References

- SRR 1410-02 Code Compliant Construction of Conventionally Framed Roofs and Roof Trusses
- *Building Component Safety Information* (*BCSI*): *Guide to Good Practice for Handling, Installing & Bracing of Metal Plate Connected Wood Trusses*, Structural Building Components Association and Truss Plate Institute, 2013.
- *International Residential Code* (*IRC*), International Code Council, 2012.
- *TPI 1 – National Design Standard for Metal Plate Connected Wood Truss Construction*, Truss Plate Institute, 2007.
- *WCD 1 – Details for Conventional Wood Frame Construction*, American Wood Council, 2001.
- *Wood Frame Construction Manual* (*WFCM*), American Wood Council, 2012.