Ionic Structures & Design LLC

04-27-2014

STRUCTURAL ISSUES IN RESIDENTIAL CONSTRUCTION PART II

Presented by:
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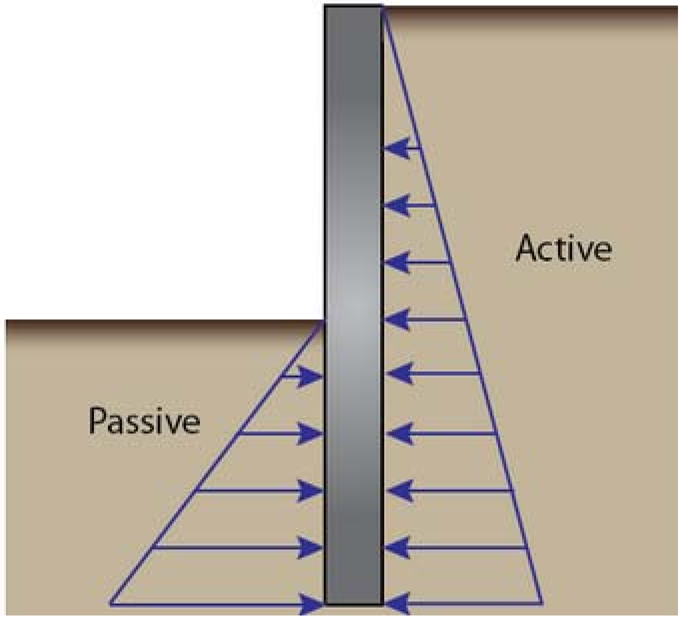
Presentation Outline

- Basements:
  - Basis of wall bracing
  - Load Paths from Roof to Foundation
  - Roof Framing
  - Floor Framing
  - Wall Framing
- Lateral Loads
  - Basement walls
  - Wind Loads and Shear walls – Future presentation

Retaining and Basement Wall Basics

Understanding Soil Loads:

- Active Pressure: The horizontal load exerted on a retaining wall when some small degree of wall movement is anticipated.   This pressure is used on retaining walls
- Passive Pressure: The horizontal force soil exerts when being pressed against by active soil pressure
- At-Rest Pressure: The horizontal load exerted on a wall when no wall movement is anticipated.   This pressure is used on basement walls.



Full Height Basement Wall Loads

Loads

- Total horizontal load W=q*h^2/2
- q varies based on soil type
- Top reaction = W/3
- Bottom reaction = 2/3W

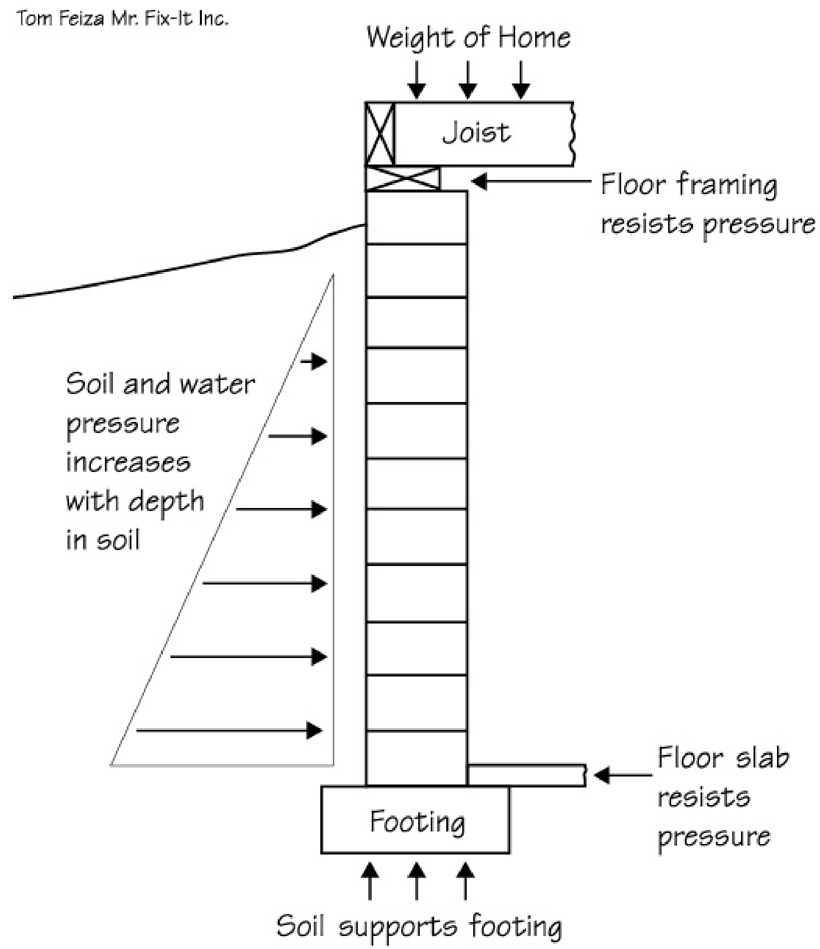


Image from Home Systems Data, Denver, USA
http://www.hsdi.us/library/

Lateral Soil Load Chart
Wisconsin Residential Code

Table 321.18–A
SOIL LATERAL LOAD

Description of Backfill Material[e]	Unified Soil Classification	Design Lateral Soil Load[a] PSF per Foot of Depth
Well graded, clean gravels; gravel–sand mixes	GW	30[c]
Poorly graded clean gravels; gravel–sand mixes	GP	30[c]
Silty gravels, poorly graded gravel–sand mixes	GM	40[c]
Clayey gravels, poorly graded gravel–and–clay mixes	GC	45[c]
Well–graded, clean sands; gravelly sand mixes	SW	30[c]
Poorly graded clean sands; sand–gravel mixes	SP	30[c]
Silty sands, poorly graded sand–silt mixes	SM	45[c]
Sand–silt clay mix with plastic fines	SM–SC	45[d]
Clayey sands, poorly graded sand–clay mixes	SC	60[d]
Inorganic silts and clayey silts	ML	45[d]
Mixture of inorganic silt and clay	ML–CL	60[d]
Inorganic clays of low to medium plasticity	CL	60[d]
Organic silts and silt clays, low plasticity	OL	[b]
Inorganic clayey silts, elastic silts	MH	60[d]
Inorganic clays of high plasticity	CH	[b]
Organic clays and silty clays	OH	[b]

[a]Design lateral soil loads are given for moist conditions for the specified soils at their optimum densities. Actual field conditions shall govern. Submerged or saturated soil pressures shall include the weight of the buoyant soil plus the hydrostatic loads.

[b]Unsuitable as backfill material.

[c]For relatively rigid walls, as when braced by floors, the design lateral soil load shall be increased for sand and gravel type soils to 60 psf per foot of depth. Basement walls extending not more than 8 feet below grade and supporting flexible floor systems are not considered relatively rigid walls.

[d]For relatively rigid walls, as when braced by floors, the design lateral load shall be increased for silt and clay type soils to 100 psf per foot of depth. Basement walls extending not more than 8 feet below grade and supporting flexible floor systems are not considered relatively rigid walls.

[e]Soil classes are in accordance with the Unified Soil Classification System, ASTM D2487, and design lateral loads are for moist soil conditions without hydrostatic pressure.

Items C and D in the footnotes are unclear. In my experience, ALL masonry and concrete basement walls should be considered rigid and designed for the 60 or 100 psf loads.

These values are somewhat conservative and a geotechnical investigation would yield pressures of 50 to 80 psf loads

Lateral Soil Load Chart - IRC

TABLE 1610.1
LATERAL SOIL LOAD

DESCRIPTION OF BACKFILL MATERIAL[c]	UNIFIED SOIL CLASSIFICATION	DESIGN LATERAL SOIL LOAD[a] (pound per square foot per foot of depth)	
		Active pressure	At-rest pressure
Well-graded, clean gravels; gravel-sand mixes	GW	30	60
Poorly graded clean gravels; gravel-sand mixes	GP	30	60
Silty gravels, poorly graded gravel-sand mixes	GM	40	60
Clayey gravels, poorly graded gravel-and-clay mixes	GC	45	60
Well-graded, clean sands; gravelly sand mixes	SW	30	60
Poorly graded clean sands; sand-gravel mixes	SP	30	60
Silty sands, poorly graded sand-silt mixes	SM	45	60
Sand-silt clay mix with plastic fines	SM-SC	45	100
Clayey sands, poorly graded sand-clay mixes	SC	60	100
Inorganic silts and clayey silts	ML	45	100
Mixture of inorganic silt and clay	ML-CL	60	100
Inorganic clays of low to medium plasticity	CL	60	100
Organic silts and silt clays, low plasticity	OL	Note b	Note b
Inorganic clayey silts, elastic silts	MH	Note b	Note b
Inorganic clays of high plasticity	CH	Note b	Note b
Organic clays and silty clays	OH	Note b	Note b

Sample Loads

Design example: Wall = 8' tall with 8' of unbalanced fill

Clay Soil:

- Total horizontal load W=100*8'x8'/2= 3200 plf
- Top reaction = 1066 plf
- Bottom reaction = 2133 plf

Granular Soil:

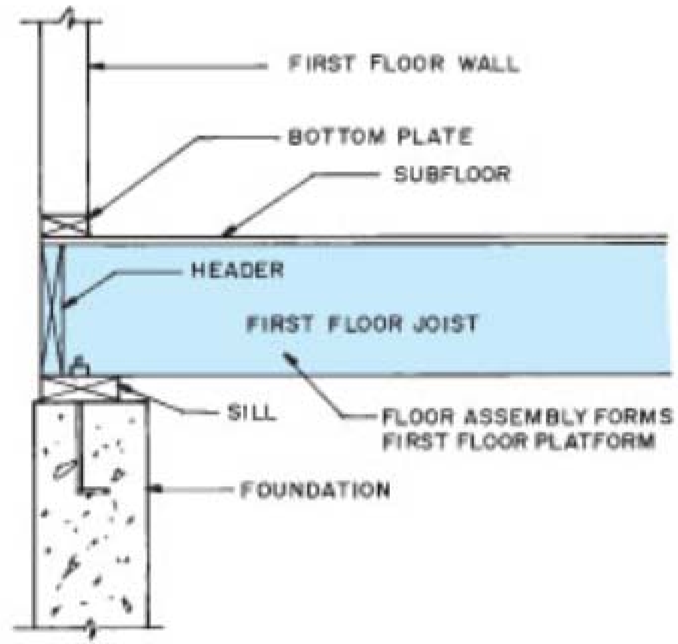
- Total horizontal load W=60*8'x8'/2= 1920 plf
- Top reaction = 640 plf
- Bottom reaction = 1280 plf

Resolution of the soil loads

- Base reaction:
  - Resisted by slab on grade.
- Top reaction:
  - Resisted by floor system
    - Anchor bolts
    - Joist anchorage to sill plate
    - Floor diaphragm – plywood subfloor
- These are large forces, so it is paramount that the slab is poured and the floor system with connections are completed prior to backfilling.

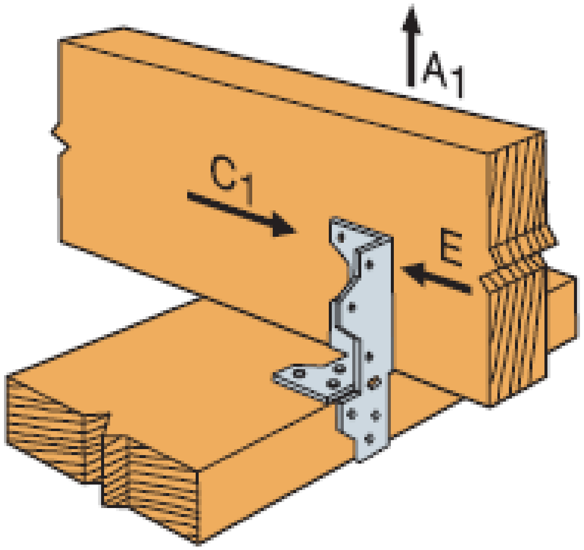
Anchor Bolt Connection

- WI-UDC & IRC
  - Requires ½" dia bolt at 6'-0" o.c. (min)
- Capacity of bolt against failure in wood treated sill plate:
  - =410 lbs per bolt (NDS – Table 11E and by calculation)
  - By calculation, these bolts are needed every **5" to 8" o.c.**
  - Code modifications are needed for both building codes or alternate methods of attachment should be developed.



Joist to sill anchorage

- Typical connection: Toenail: (3) 8d
  - Capacity = 184 lbs
  - Required capacity at 16" o.c. = 853 lbs to 1421 lbs
  - Additional Code changes are needed here. Suggest requiring the usage of manufactured products such as USP or Simpson connectors



The Floor Diaphragm – how it works

- The reaction at the top of the wall acts on the floor diaphragm and is transferred into the walls parallel to the load which act as shear walls
- If the basement does not have any exposure, the system will act in equilibrium as the forces on either side of the diaphragm will be equal and opposite.
- If the basement is exposed on one side, the load will be unbalanced. Improper connections can lead to the outside exposed wall bowing outward. This is even more problematic where walls are partial height.

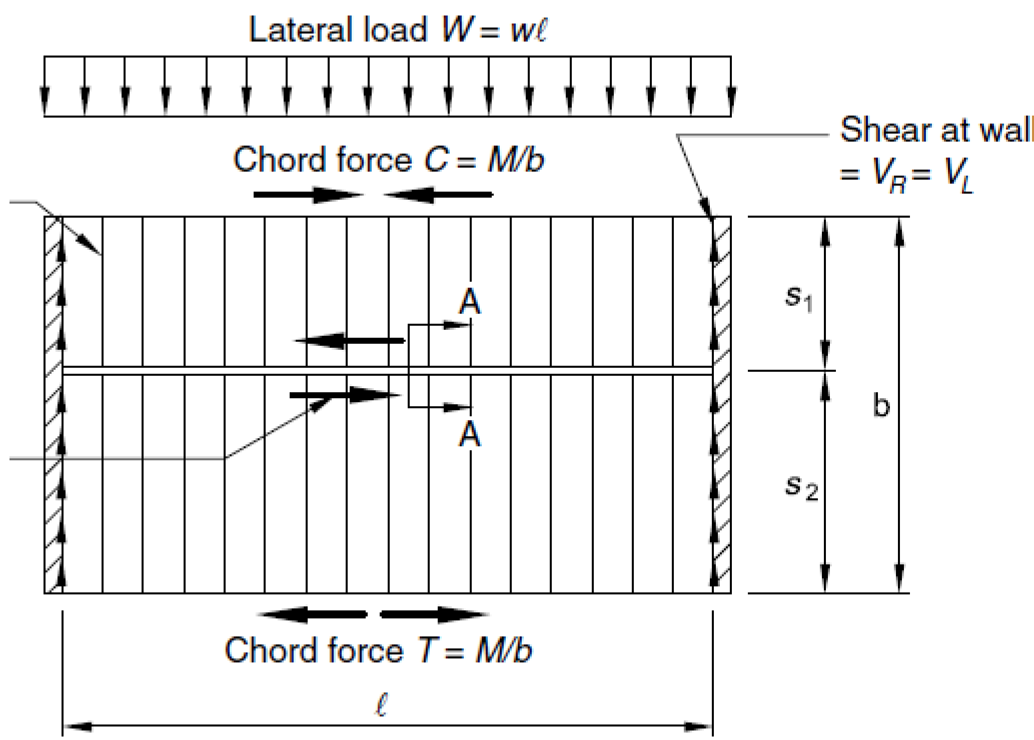


Image from: Precast/Prestressed Concrete Institute. 2010 PCI Design Handbook, 7th Edition. pp 4-56

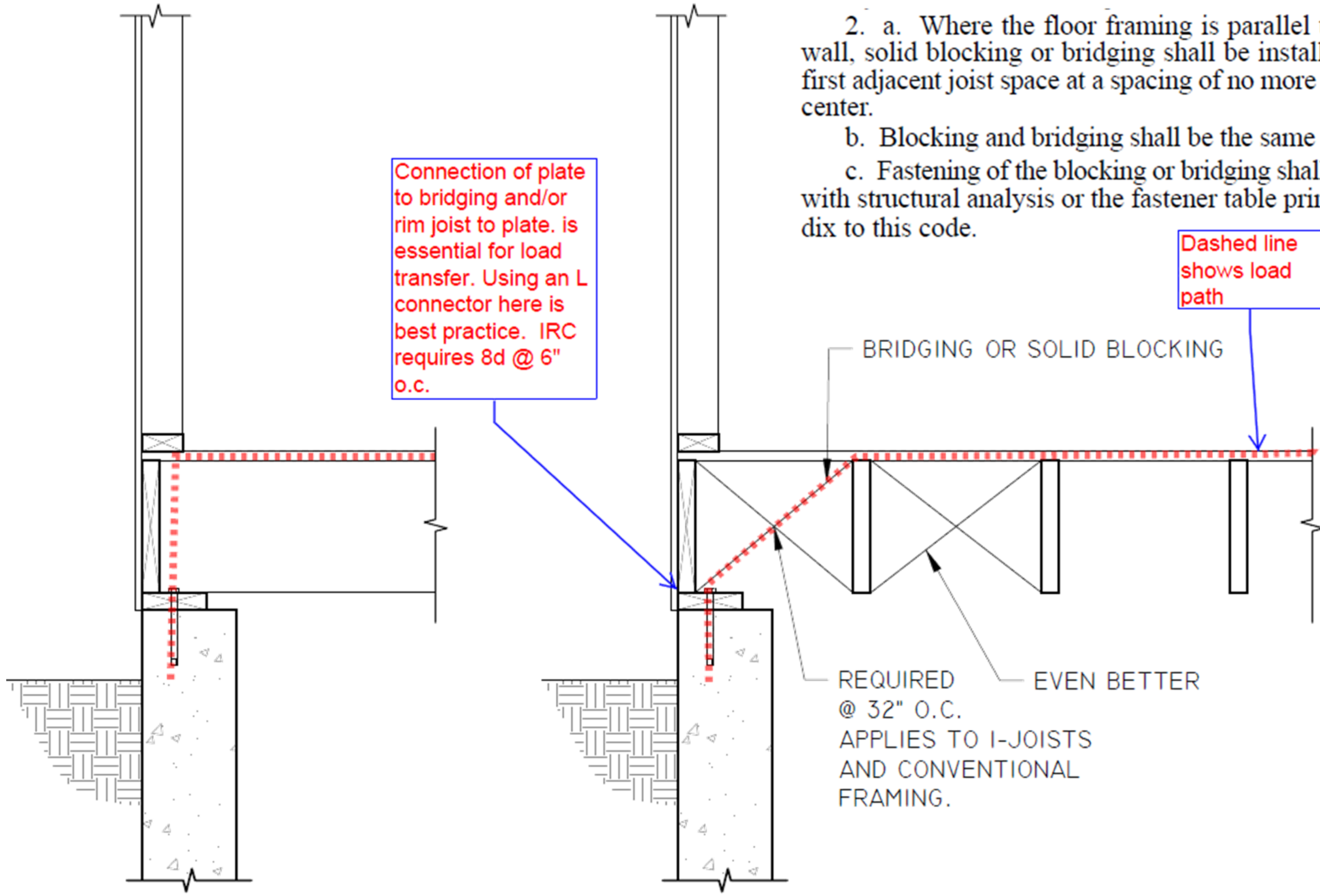
Transferring the Load into the Floor Diaphragm

WI-UDC

2. a. Where the floor framing is parallel to the foundation wall, solid blocking or bridging shall be installed in at least the first adjacent joist space at a spacing of no more than 32 inches on center.

b. Blocking and bridging shall be the same depth as the joist.

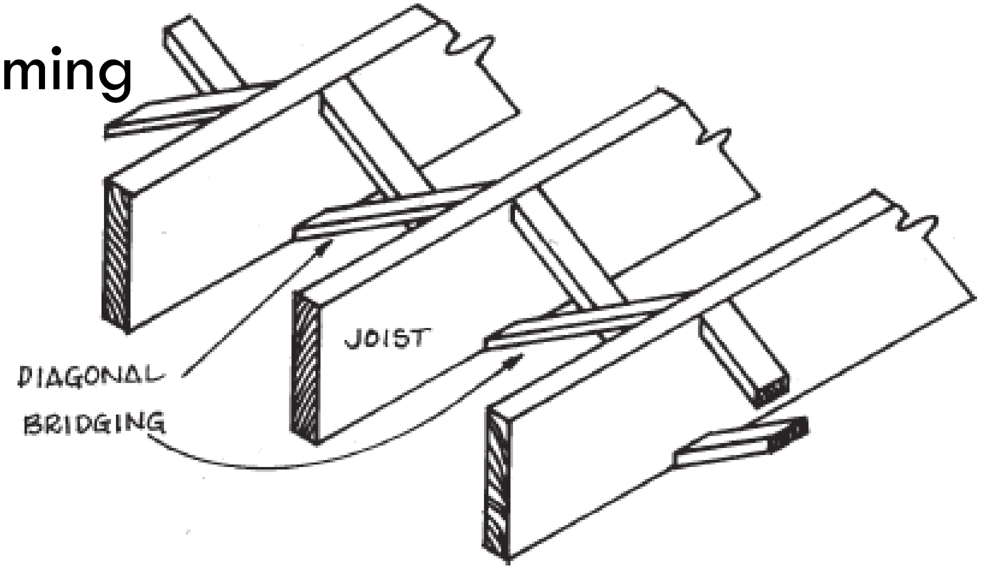
c. Fastening of the blocking or bridging shall be in accordance with structural analysis or the fastener table printed in the appendix to this code.

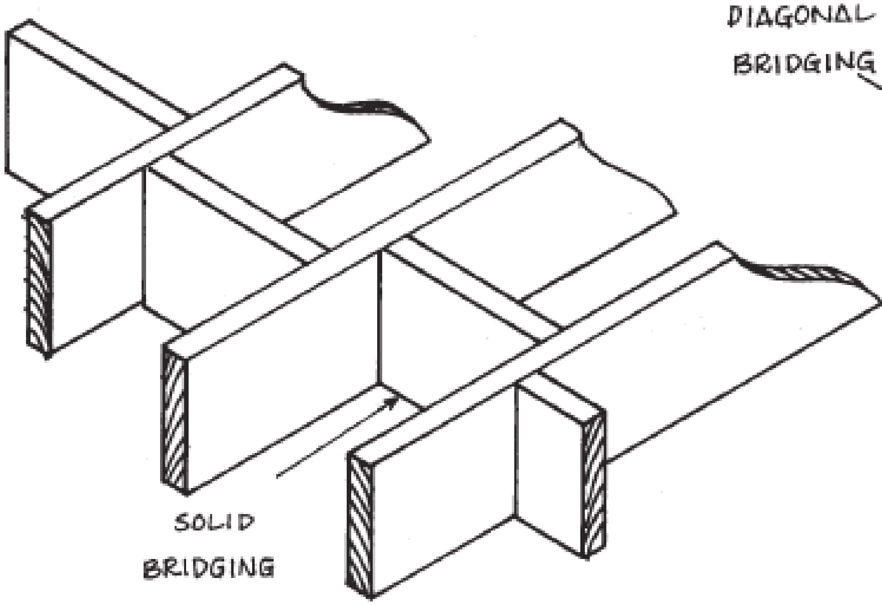


Bridging

Bridging/Blocking –
Conventional wood framing

- Diagonal
- Solid





Partial Height Foundation Walls

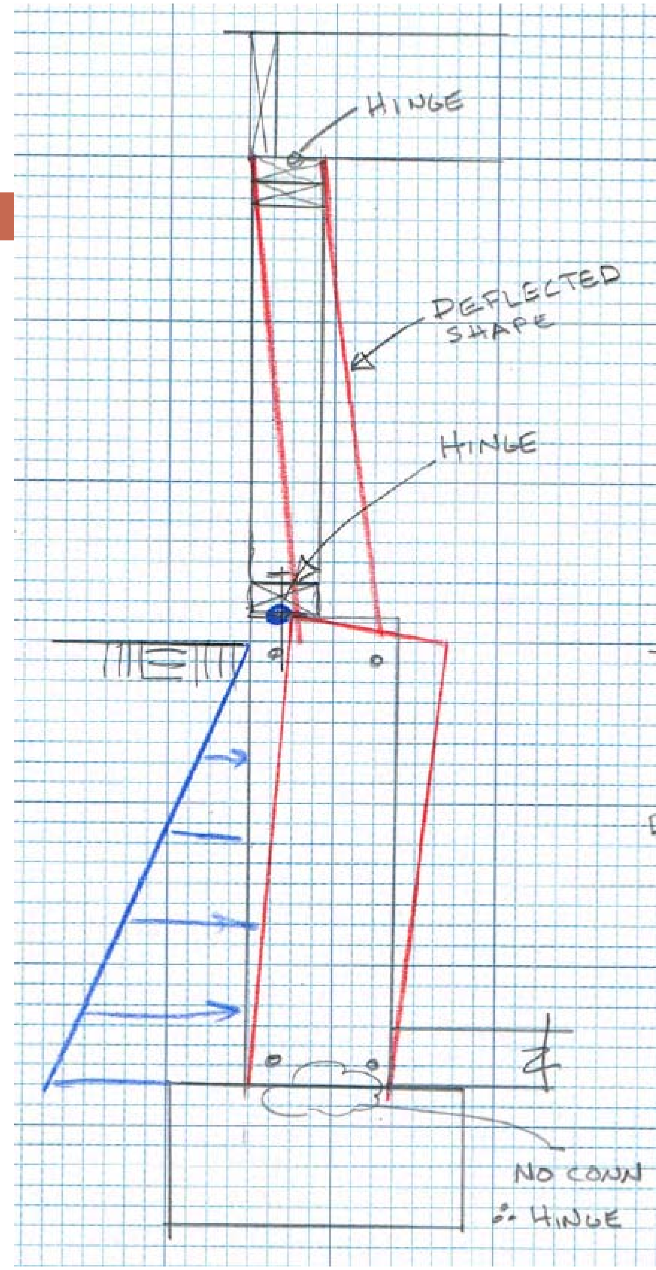
Observed Condition

Potential failure:

- Rotation of the frost wall inward
- Excessive rotation could cause a first floor framing collapse

Repair Methods – for existing conditions

- Install wood or metal studs full height inside the wall capable of supporting full lateral load. Anchor studs to slab on grade and wood floor framing above.



Partial Height Foundation Walls Code Requirements

WI-UDC

- **SPS 321.18 Foundations. (1)** GENERAL. (a) *Design*. Foundation walls shall be designed and constructed to support the vertical loads of the dwelling, lateral soil pressure, and other loads without exceeding the allowable stresses of the materials of which the foundations are constructed.
- (b) *Lateral support at base*. Lateral support such as floor slab or framing shall be provided at the base of foundation walls.
- (c) *Lateral support at top*. Lateral support shall be provided at the top of the foundation walls by one of the following:
  - 2. Structural analysis. A system designed through structural analysis
  - 3. Anchor bolts. a. Structural steel anchor bolts, at least ½inch in diameter, embedded at least 7 inches into the [concrete or] grouted masonry with a maximum spacing of 72 inches and located within 18 inches of wall corners.

Partial Height Foundation Walls Code Requirements

IRC

R404.1.2.2.2 Concrete foundation stem walls supporting light-frame above-grade walls. Concrete foundation stem walls that support light-frame above-grade walls shall be designed and constructed in accordance with this section. 1. Stem walls not laterally supported at top. Concrete stem walls that are not monolithic with slabs-on-ground or are not otherwise laterally supported by slabs-on-ground and retain 48 inches (1219 mm) or less of unbalanced fill, measured from the top of the wall, shall be constructed in accordance with Section R404.1.2. Foundation stem walls that retain more than 48 inches (1219 mm) of unbalanced fill, measured from the top of the wall, shall be designed in accordance with Sections R404.1.3 and R404.4.

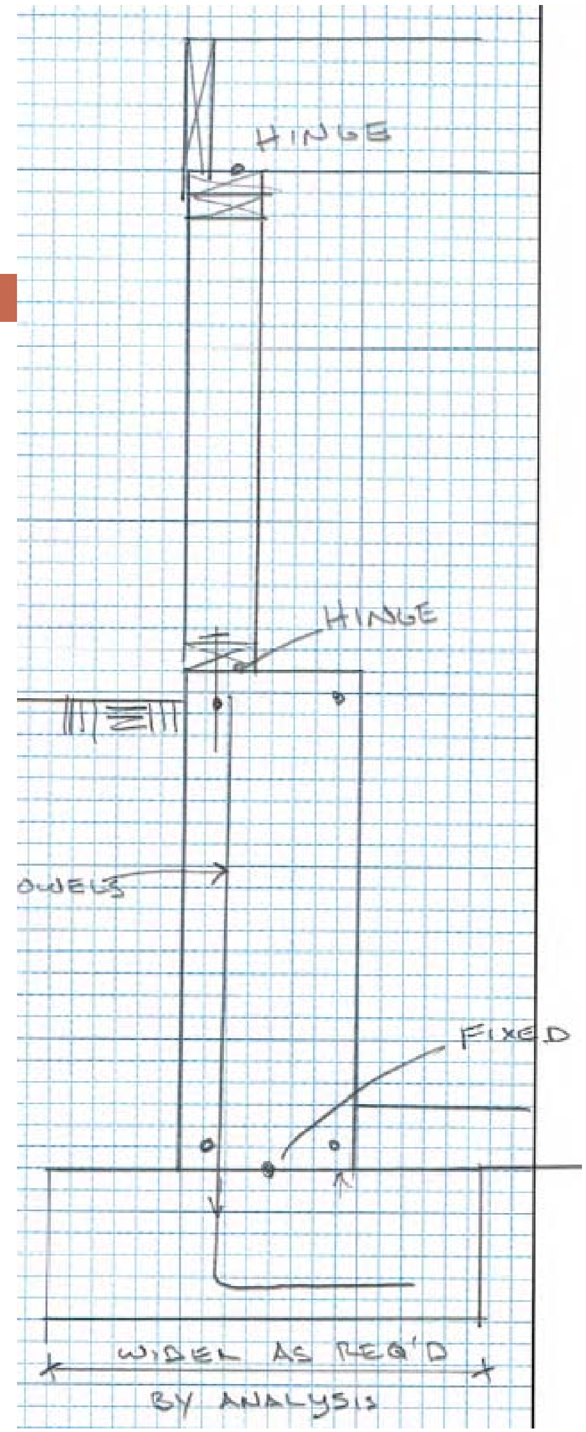
R404.1.3 Design required. Concrete or masonry foundation walls shall be designed in accordance with accepted engineering practice when either of the following conditions exists: 1. Walls are subject to hydrostatic pressure from groundwater. 2. Walls supporting more than 48 inches (1219 mm) of unbalanced backfill that do not have permanent lateral support at the top or bottom.

R404.4 Retaining walls. Retaining walls that are not laterally supported at the top and that retain in excess of 24 inches (610 mm) of unbalanced fill shall be designed to ensure stability against overturning, sliding, excessive foundation pressure and water uplift. Retaining walls shall be designed for a safety factor of 1.5 against lateral sliding and overturning.

Partial Height Foundation Walls

Correct Design Condition

- Design lower portion of wall as a retaining wall.
- Wall needs to be connected to footing with dowels at uniform spacing.
- Connection between wall and footing is considered "fixed" rather than hinged.



Topics from your Suggestions

Foundations:

FROST WALLS AT GARAGE DOORS

- Condition
  - Some contractors discontinue the frost walls at garage doors.
- Concerns
  - Post loads at either side of the garage door. At load bearing walls, foundations may not be sufficient.
  - Frost heave.
  - Edge of slab support at entry will not be present and over time slab will likely settle and door will not close properly.

Foundations:

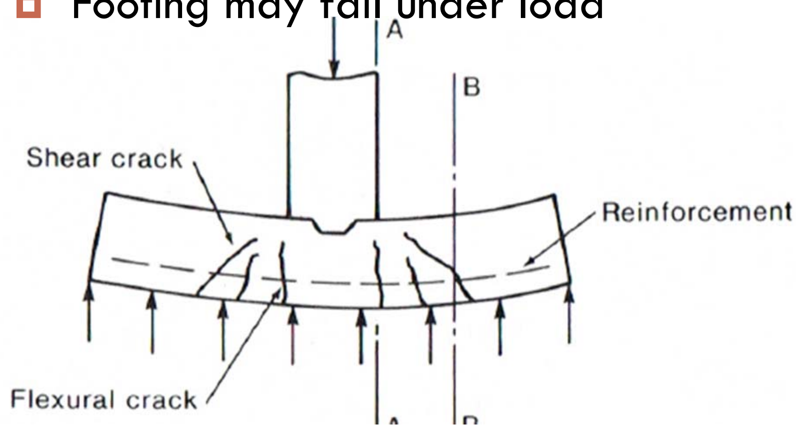
SILL PLATE INSTALLATION AND ANCHORAGE

- Condition
  - Cantilevered bottom plate overhanging edge of foundation wall by up to 2”
- Concerns
  - Anchor bolts may not have enough distance to edge of concrete
  - If the bolt is installed at the edge of the wood plate, it may tear out easily since they are already insufficient to resist lateral load.

Footings and Slabs – Rebar Placement

Footings

- Purpose of Rebar
  - Provide flexural reinforcement at bottom of footing
- Placement
  - Near bottom of footing with 3" of cover
- Consequences of improperly placed rebar?
  - Footing may fail under load

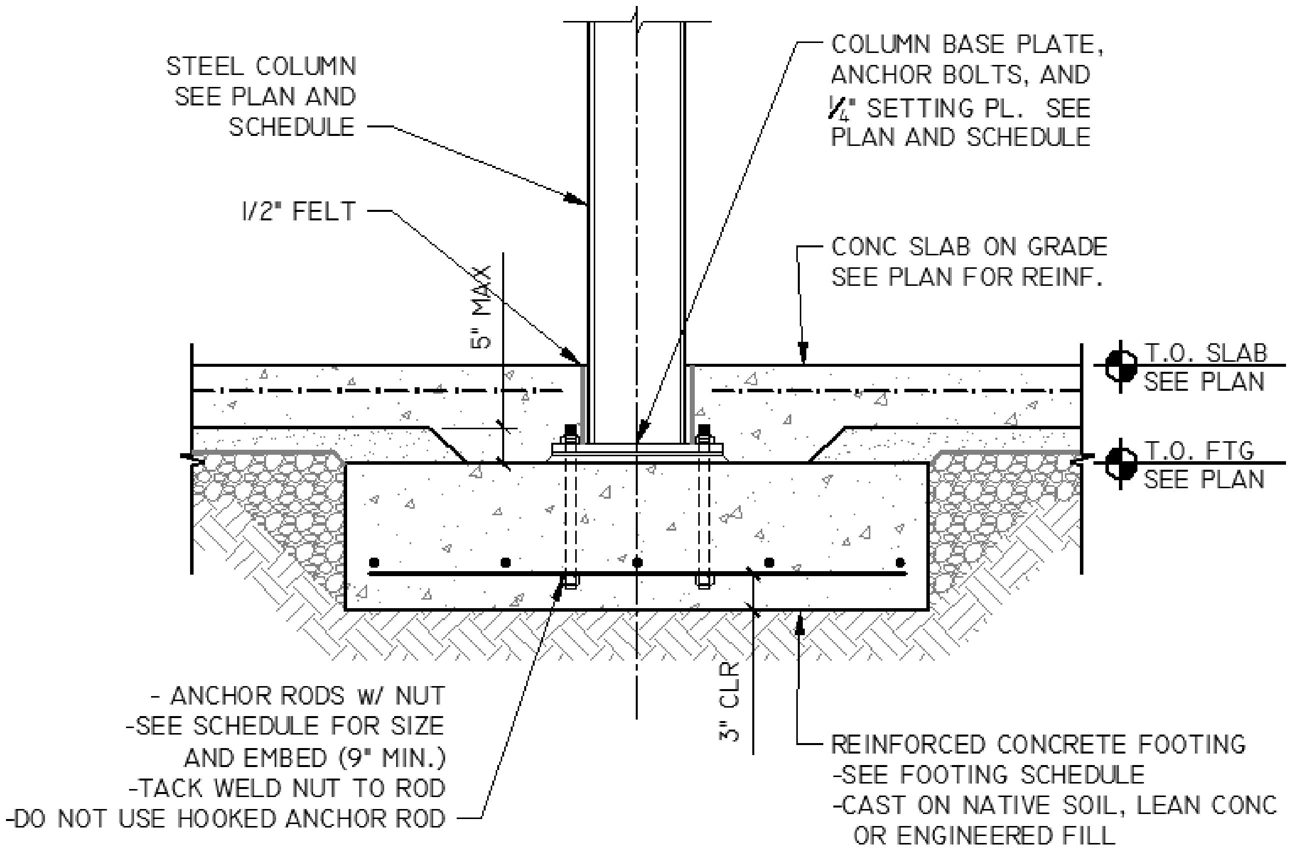


Slabs

- Purpose of Rebar
  - Provide temperature and shrinkage reinforcement (i.e. hold concrete together once it cracks)
- Placement
  - At t/3 from top of slab, but not less than 1 ½"
- Consequences of improperly placed rebar?
  - Waste of money and will not hold the slab together if cracks develop.
- Fiber reinforcement is a good alternative

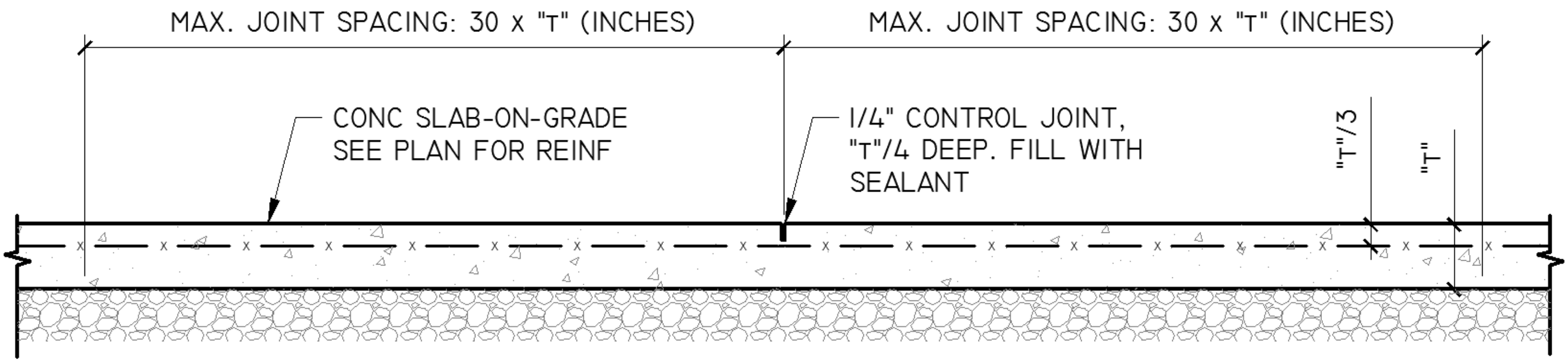
Footings – Rebar Placement

Footings



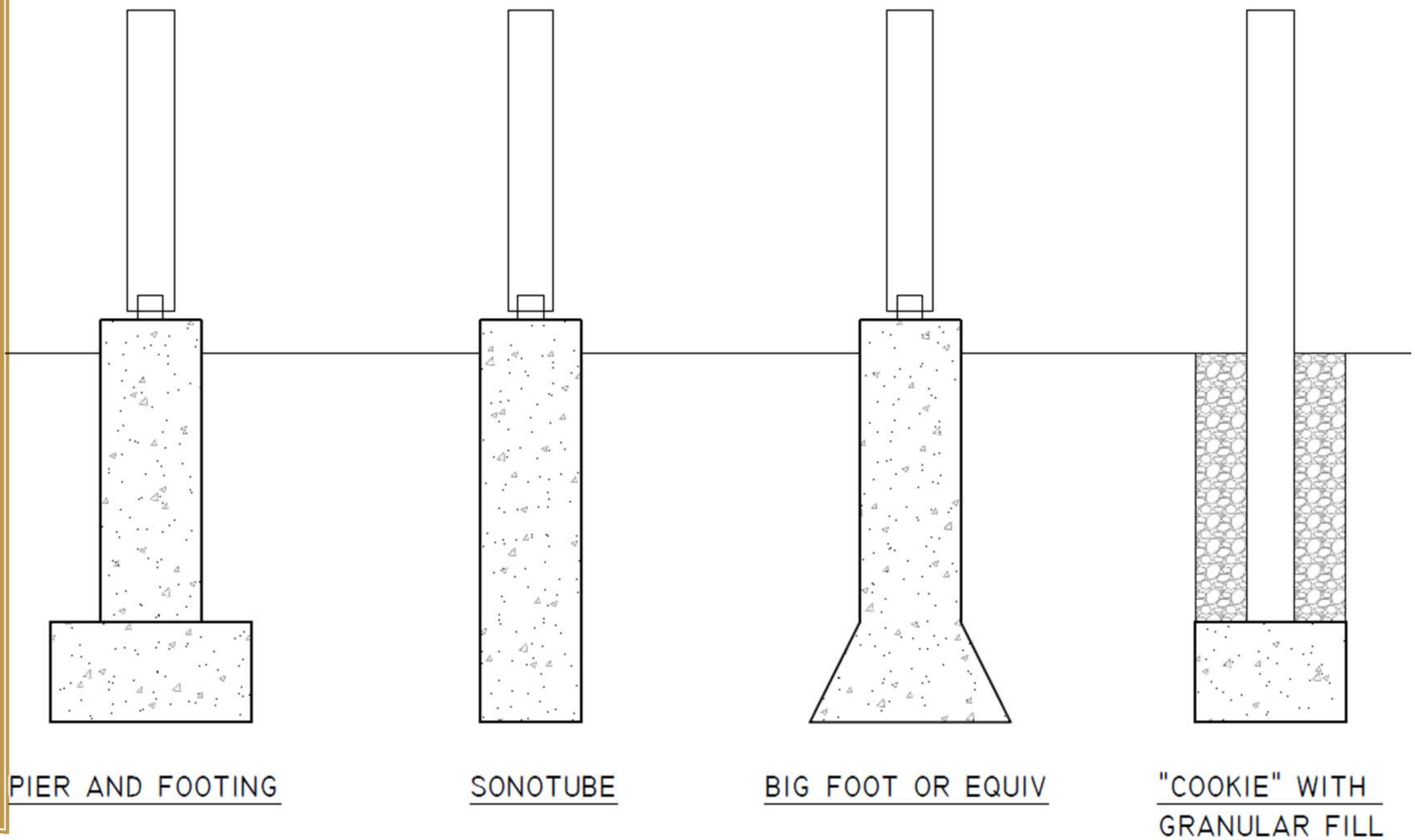
Slabs – Rebar Placement

Slabs



Deck Foundations

Frost protected deck foundations



Advantages and Disadvantages

Pier and Footing

- Advantages
  - Greatest design flexibility
  - Highest possible capacity
  - Good corrosion protection for the wood posts
- Disadvantages
  - Highest cost
  - Longest construction time
  - Post connection is pinned, requires deck bracing
  - Greatest amount of excavation

Sonotube

- Advantages
  - Good corrosion protection for the wood posts
  - Lower cost
  - Readily available material
  - Short construction time
- Disadvantages
  - Low capacity
  - Post connection is pinned, requires deck bracing

Advantages and Disadvantages

Big Foot or other proprietary pier

- Advantages
  - Good capacity
  - Good corrosion protection for the wood posts
  - Fast construction time
- Disadvantages
  - Higher cost
  - Material availability
  - Post connection is pinned, requires deck bracing.

"Cookie" with Granular Backfill

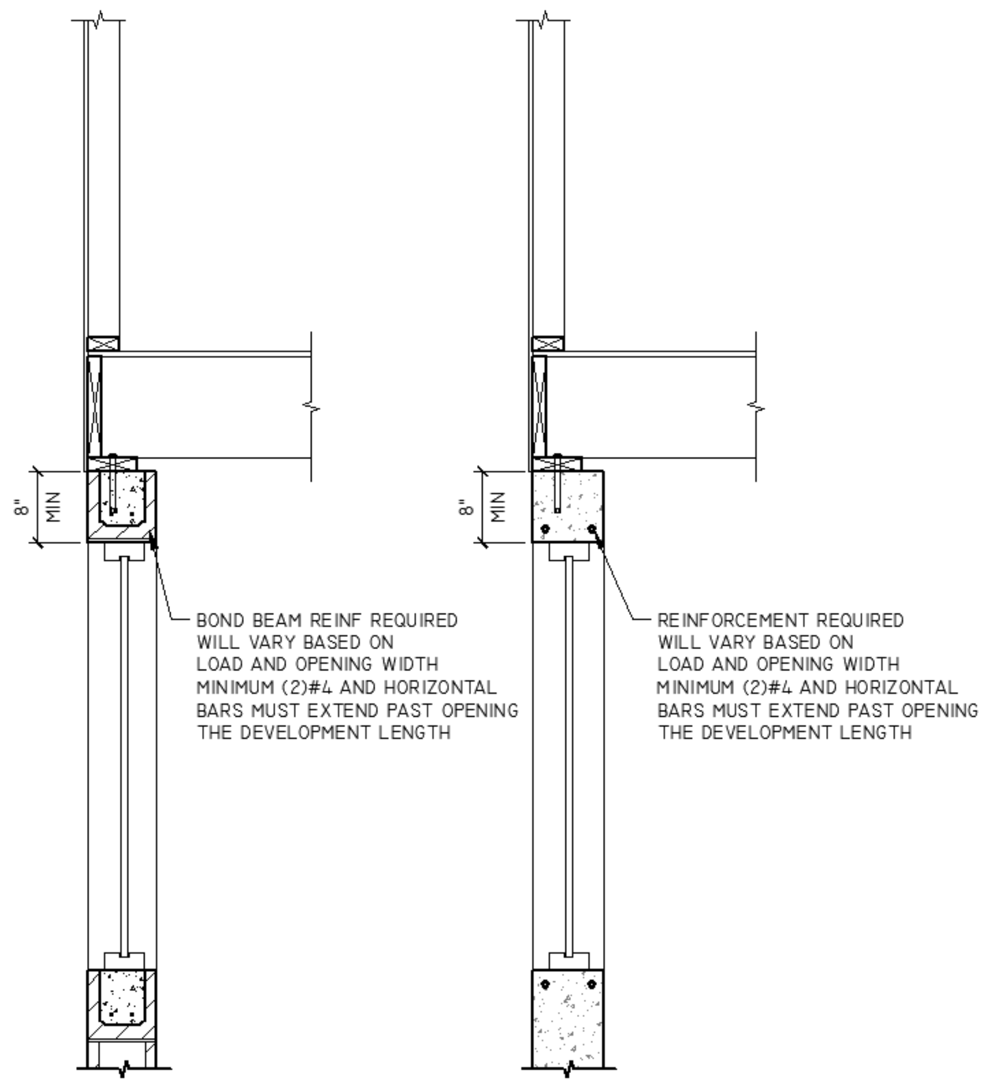
- Advantages
  - Lower cost
  - Readily available material
  - Short construction time
  - Low material cost
  - Post is somewhat fixed and more rigid than pinned connection.
- Disadvantages
  - Low capacity
  - Wood post subject to deterioration and cannot be readily inspected

Basement Egress Window Framing

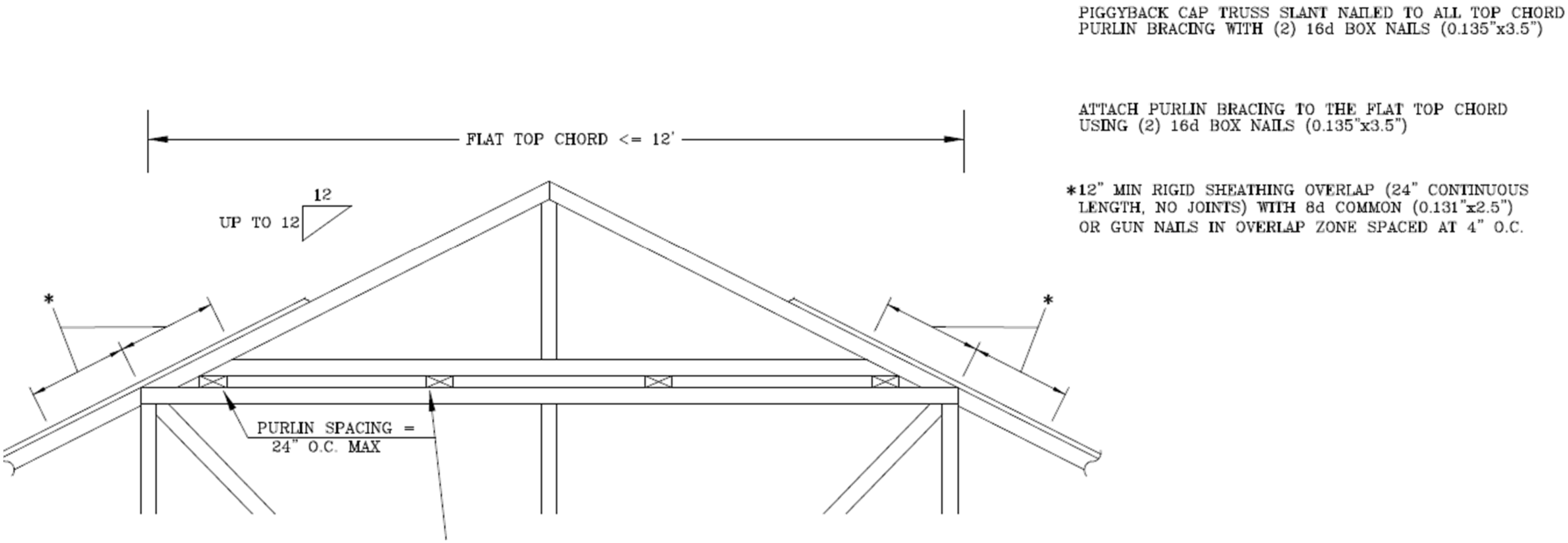
- Question: When installing egress windows, is there a required or recommended thickness above the window and is reinforcement required?
- There are two structural implications
  - Capacity of “header” above window
  - Capacity of wall adjacent to window

Basement Egress Window Framing

- Options shown:
  - Bond Beam Lintel
  - CIP wall with integral beam above
- Other options
  - Steel Lintel
  - Treated wood beam



Piggy-Back Trusses

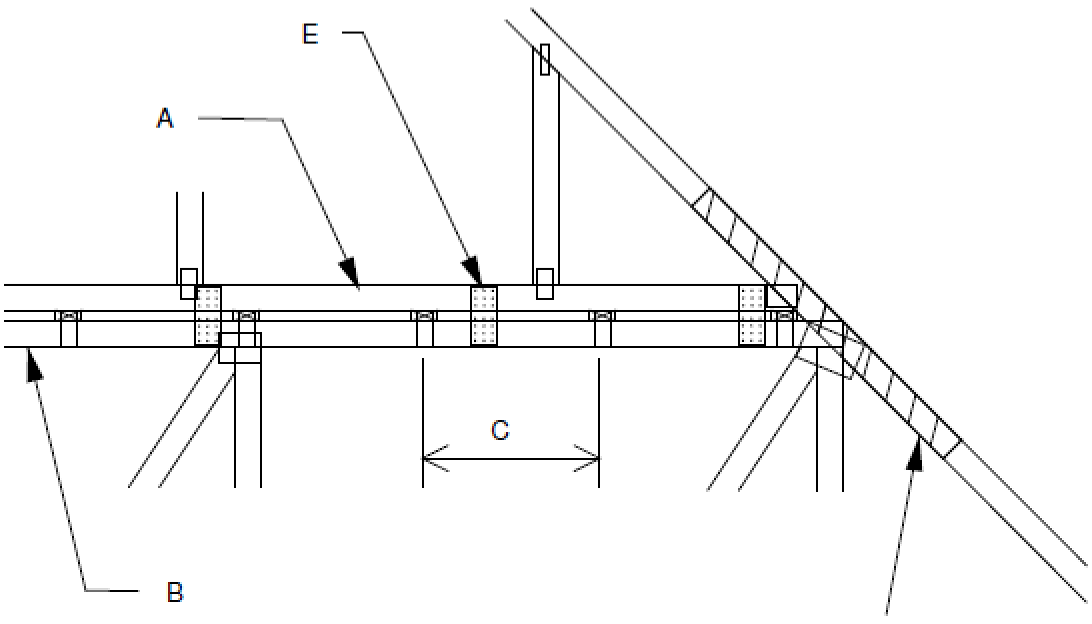


- Condition:
  - Piggyback connection is often not a direct connection and load transfer relies on sheathing overlap.
- Concern
  - Trusses are frequently installed with the incorrect amount of sheathing overlap.
- Solution:
  - Use light gage connectors between structural truss and piggyback truss.

Piggy-Back Trusses

MiTek USA, Inc.

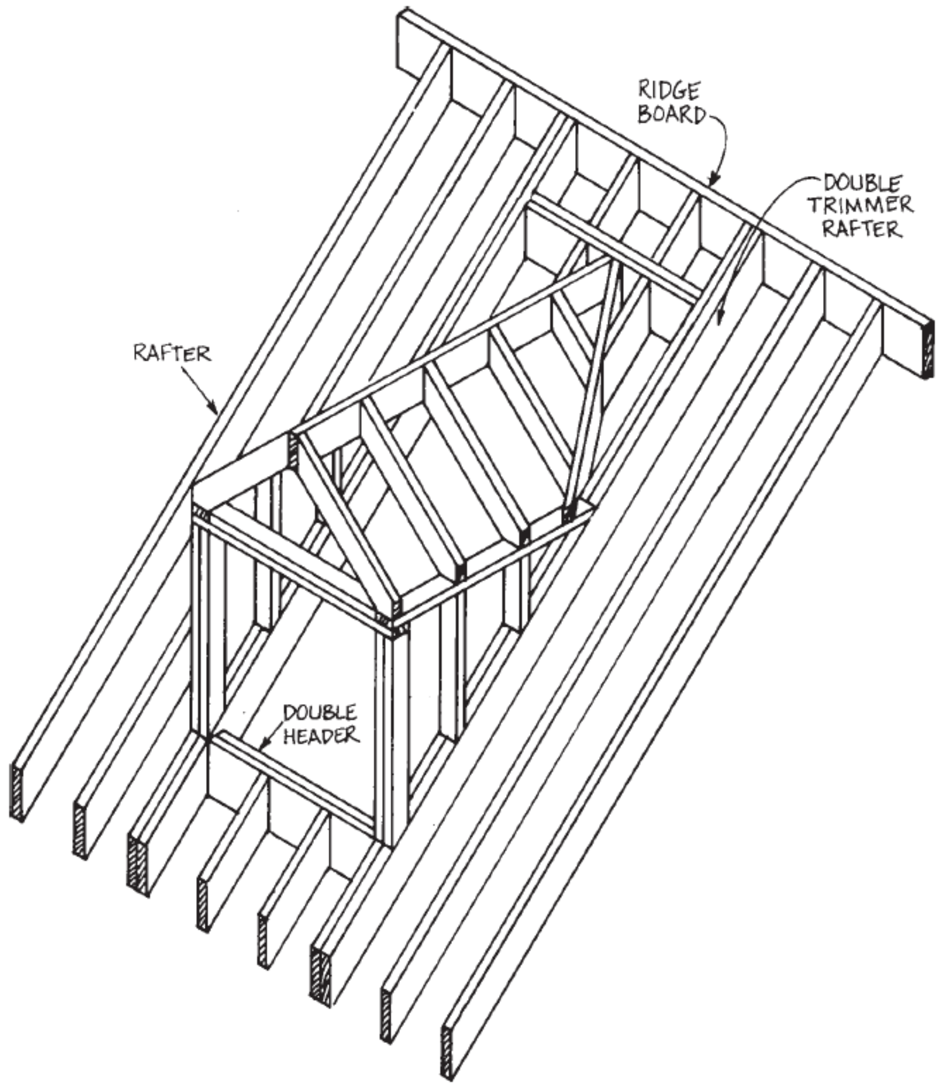
MAXIMUM WIND SPEED = REFER TO NOTES D AND OR E MAX MEAN ROOF HEIGHT = 30 FEET MAX TRUSS SPACING = 24 " O.C. CATEGORY II BUILDING EXPOSURE B or C ASCE 7-10 DURATION OF LOAD INCREASE : 1.60
DETAIL IS NOT APPLICABLE FOR TRUSSES TRANSFERING DRAG LOADS (SHEAR TRUSSES). ADDITIONAL CONSIDERATIONS BY BUILDING ENGINEER/DESIGNER ARE REQUIRED.



Dormer Framing

- Following the load path…
  - The dormer is simply another "window" opening
  - A header is required above and below. Hangers should be used.
  - Additional rafters (king studs) are required on either side of the opening
  - General rule.. However many rafters have been cut to make the opening, add half that amount either side for support of opening. Must be nailed together in accordance with NDS

    Example: 4 rafters have been cut to make a dormer (5'-4" wide). Use (2) additional rafters on either side of opening to carry this load.
  - Wider openings should be designed by an engineer and may require LVL members



Load Bearing Wood Studs

- Capacity of studs is based on:
  - Max spacing.
  - Assumed loads.
  - Stud grade species
  - Fully braced studs in weak direction.
    - Application of sheathing or drywall on one side or
    - Blocking at 4'-0" o.c. (minimum)

Gravity Design – Wood walls

WI - UDC

- Maximum allowable unbraced height for a load bearing wall is 10'-0" without additional engineering

Table 321.25–A

SIZE, HEIGHT AND SPACING OF WOOD STUDS[a]

Stud Size (inches)	Bearing Walls					Nonbearing Walls	
	Laterally unsupported stud height[a] (feet)	Maximum spacing when supporting roof and ceiling only (inches)	Maximum spacing when supporting one floor, roof and ceiling (inches)	Maximum spacing when supporting two floors, roof and ceiling (inches)	Maximum spacing when supporting one floor only (inches)	Laterally unsupported stud height[a] (feet)	Maximum spacing (inches)
2 x 3[b]	–	–	–	–	–	10	16
2 x 4	10	24	16	–	24	14	24
3 x 4	10	24	24	16	24	14	24
2 x 5	10	24	24	–	24	16	24
2 x 6	10	24	24	16	24	20	24

[a] Listed heights are distances between points of lateral support placed perpendicular to the plane of the wall. Increases in unsupported height are permitted where justified by analysis. Studs shall be stud grade or better, except that utility grade may be used when spaced not more than 16 inches on center, supports no more than a roof and ceiling and does not exceed 8 feet in height for exterior walls or 10 feet in height for interior nonload–bearing walls.

[b] May not be used in exterior walls.

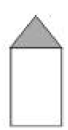
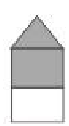
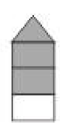
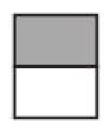
Note: A 3–story frame house with walls constructed of 2 x 4 standard grade studs would require a 12–inch stud spacing on the lowest level, a 24–inch stud spacing on the intermediate level, and a 24–inch stud spacing on the upper level.

Gravity Design – Wood walls

IRC

- Maximum allowable unbraced height for a load bearing wall is 10'-0" without additional engineering

TABLE R602.3(5) SIZE, HEIGHT AND SPACING OF WOOD STUDS[a]

STUD SIZE(inches)	BEARING WALLS					NONBEARING WALLS	
	Laterally unsupported stud height[a](feet)	Maximum spacing when supporting a roof-ceiling assembly or a habitable attic assembly, only (inches)	Maximum spacing when supporting one floor, plus a roof-ceiling assembly or a habitable attic assembly(inches)	Maximum spacing when supporting two floors, plus a roof-ceiling assembly or a habitable attic assembly(inches)	Maximum spacing when supporting one floor height[a] (feet)	Laterally unsupported stud height[a](feet)	Maximum spacing(inches)
							
2 × 3[b]	-	-	-	-	-	10	16
2 × 4	10	24[c]	16[c]	-	24	14	24
3 × 4	10	24	24	16	24	14	24
2 × 5	10	24	24	-	24	16	24
2 × 6	10	24	24	16	24	20	24

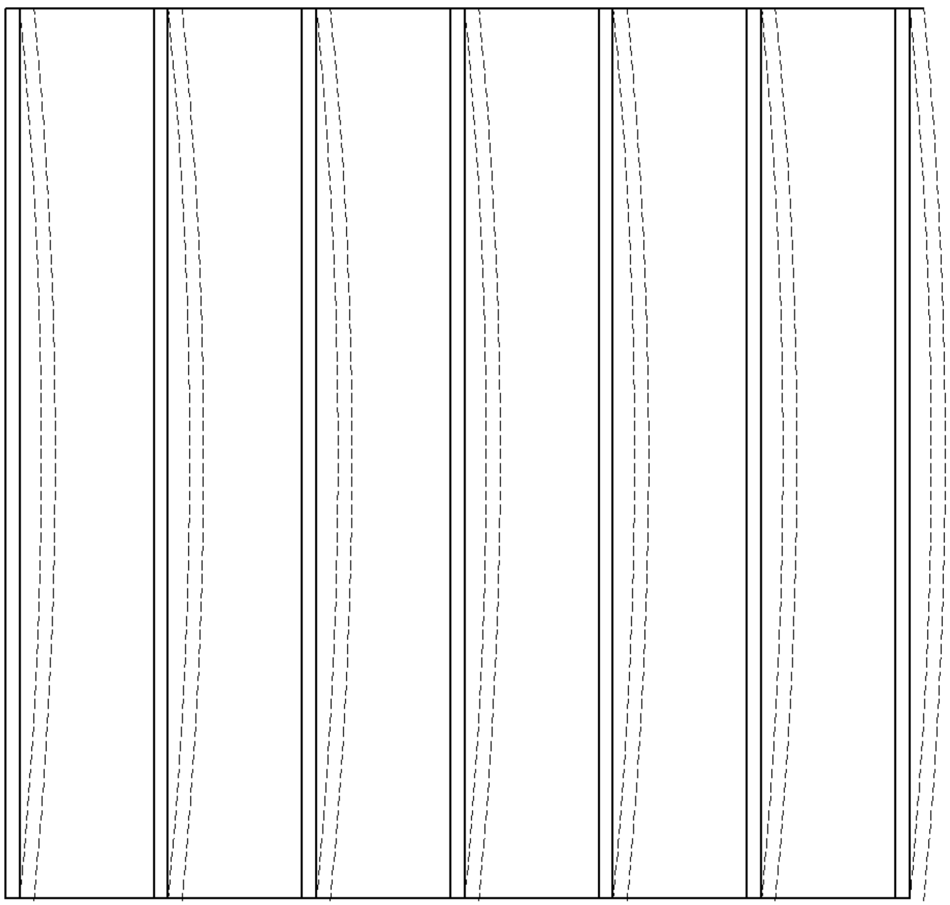
a. Listed heights are distances between points of lateral support placed perpendicular to the plane of the wall. Increases in unsupported height are permitted where justified by analysis.

b. Shall not be used in exterior walls.

c. A habitable attic assembly supported by 2 × 4 studs is limited to a roof span of 32 feet. Where the roof span exceeds 32 feet, the wall studs shall be increased to 2 × 6 or the studs shall be designed in accordance with accepted engineering practice.

What Happens if the Walls are NOT braced?

- The wall will be more than 200% overstressed due to the weak axis bending!



Code Changes

IRC

- a. Listed heights are distances between points of lateral support placed perpendicular to the plane of the wall. Bearing walls shall be sheathed on at least one side or bridging shall be installed not greater than 4 feet apart measured vertically from either end of the stud. Increases in unsupported height are permitted where in compliance with exception 2 of Section R602.3.1 or designed in accordance with accepted engineering practice.

WI - UDC

- None which specifically address weak axis bracing for interior load bearing walls… yet.

Roof Truss – Gable End Framing

Gable End Framing

- Top of wall bracing typically accomplished by attachment of drywall sheathing to truss bottom chord which is then transferred into the perpendicular walls

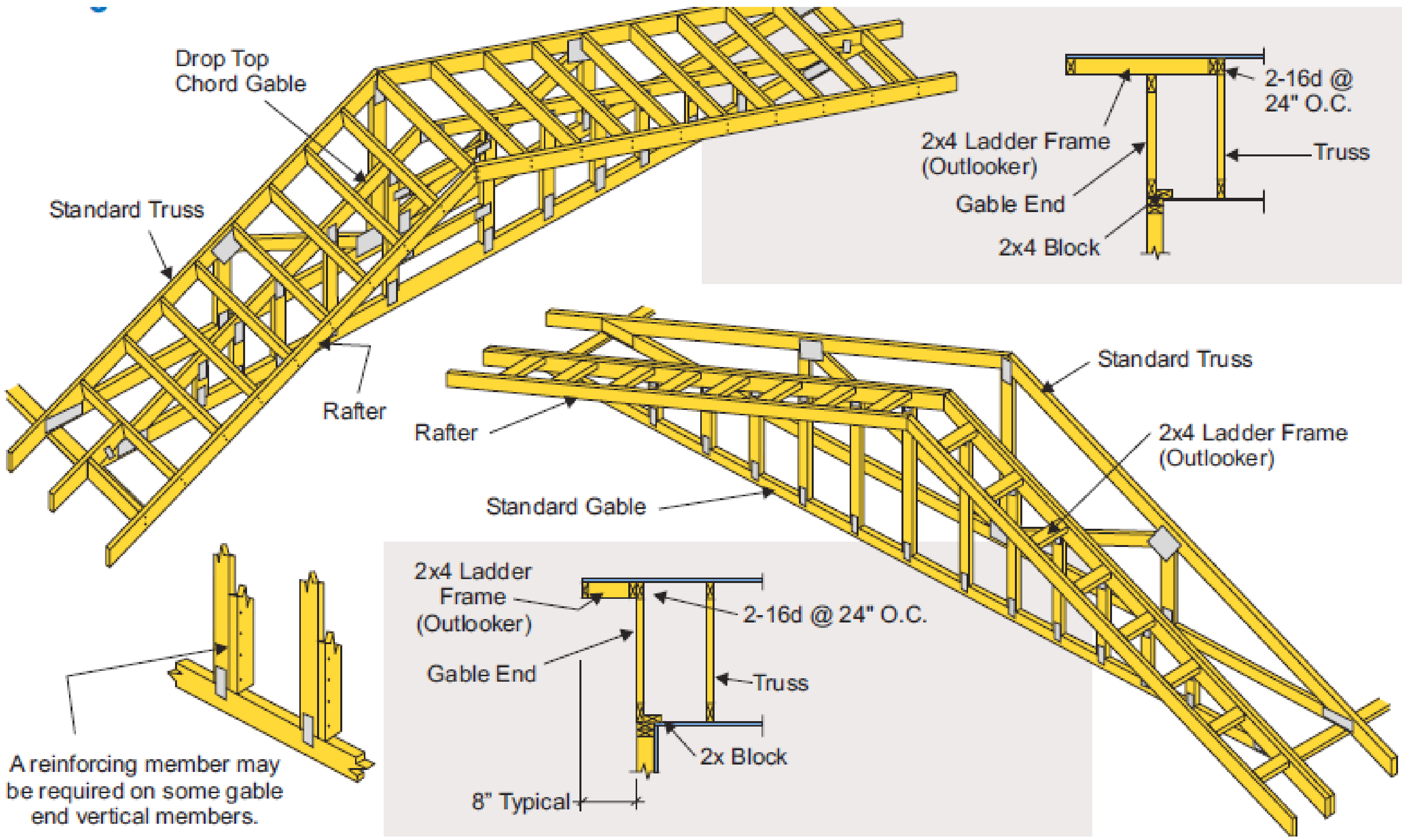
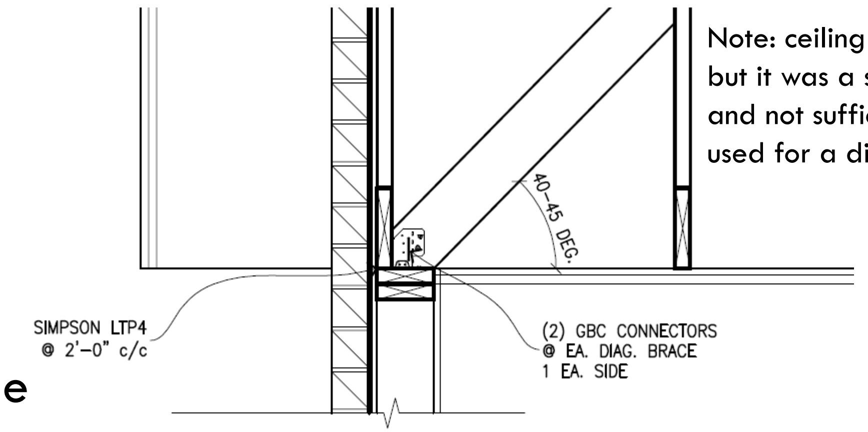


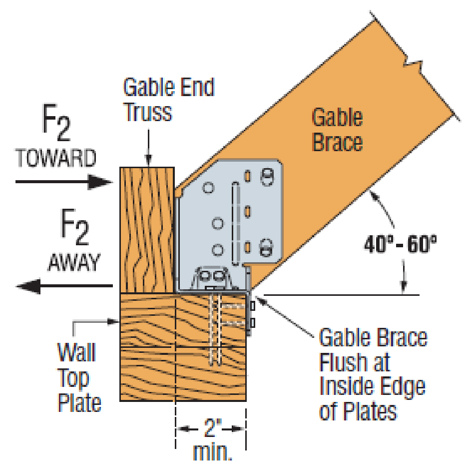
Illustration from the Alpine Encyclopedia of Trusses

Roof Truss –
Attachment of Gable End Framing

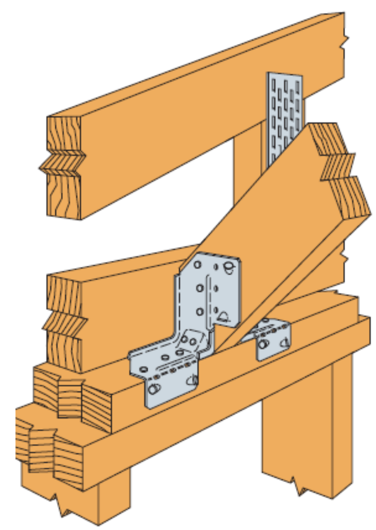
- 2 – Attachments
  - Bottom chord to top of wall.
    - Truss manufacturers require this to be designed by EOR
    - LTP4 used in this example for shear transfer.
    - Can also use angle type brackets – especially where there is a ceiling.
  - Top of wall and bottom chord to diagonal brace.
    - Gable end brace connector (typically not required if there is a ceiling).



Note: ceiling is present, but it was a small area and not sufficient to be used for a diaphragm



Typical Sloped Installation



Typical GBC Installation

Roof Truss – Gable End Framing

Gable End Framing

- Diagonal bracing used to transfer the wind reaction to the wood roof diaphragm

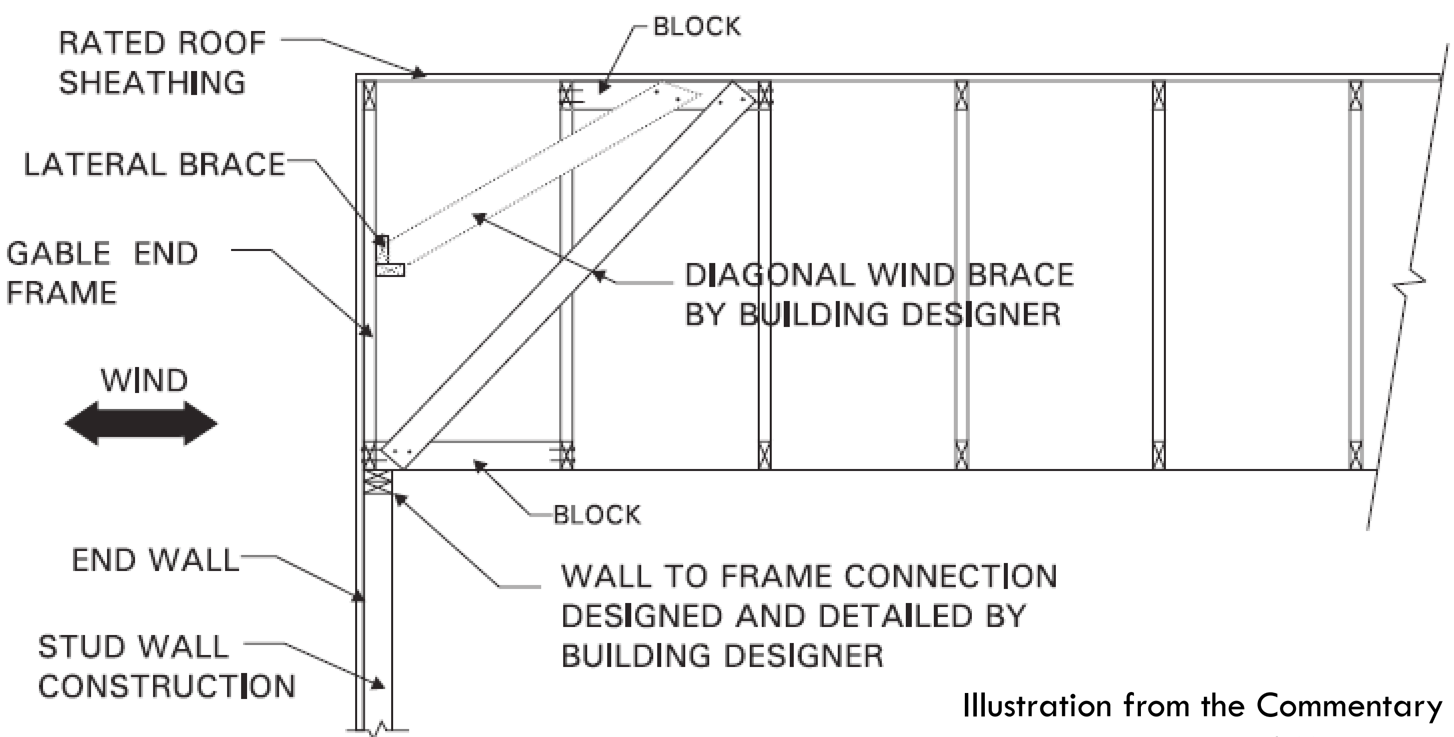


Illustration from the Commentary for Permanent Bracing of Metal Plate Connected Wood Trusses, John E. Meeks

Stairway Framing

- Load path for this example:
  - Stringers bear on top plate of load bearing wall
  - Opening in wall below stairs is supported by a header.

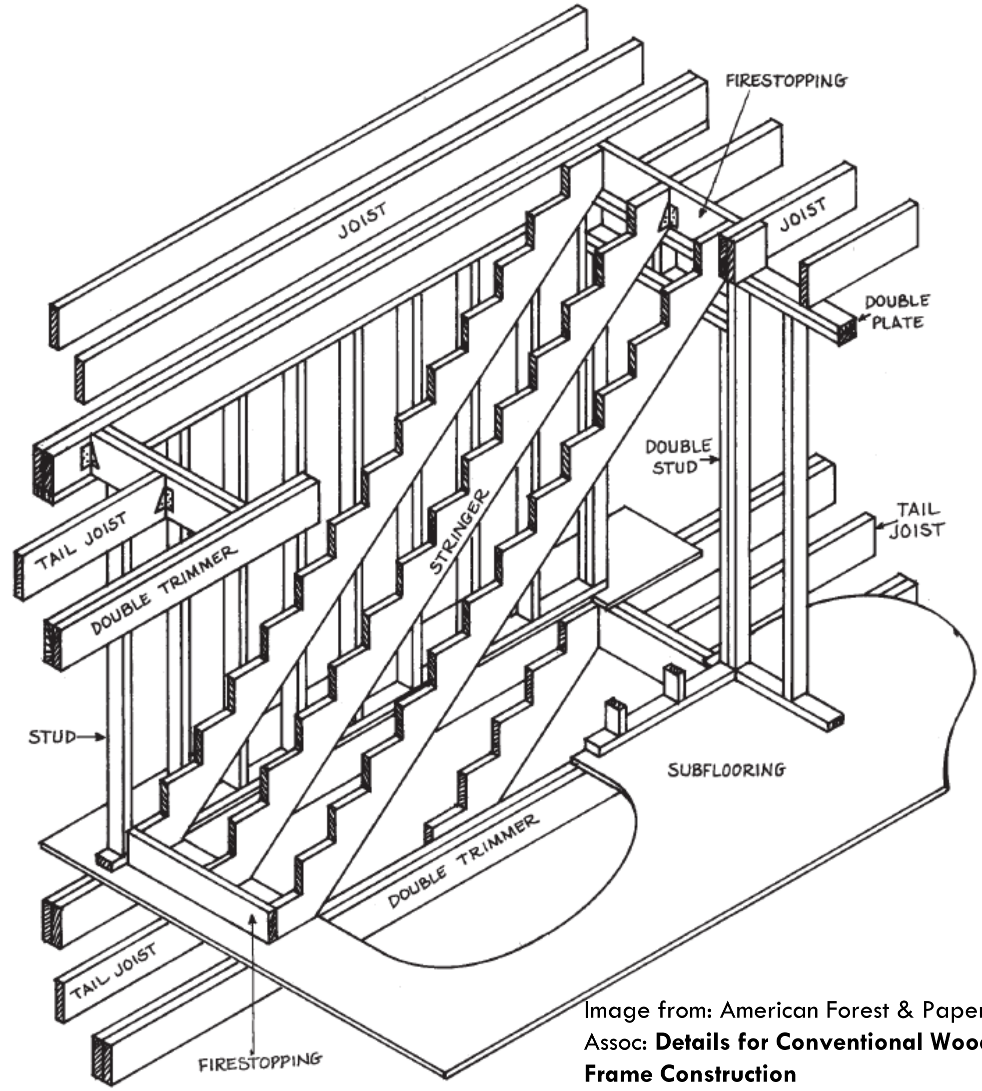
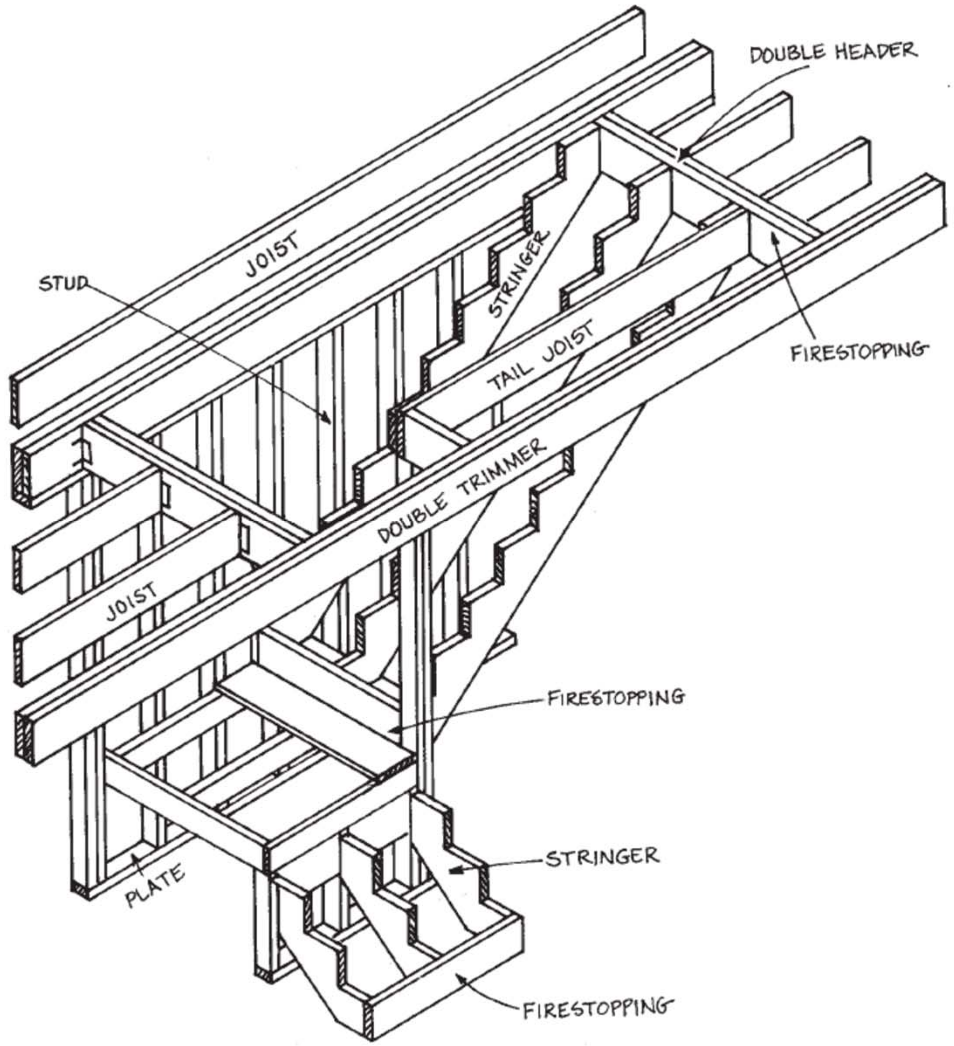


Image from: American Forest & Paper Assoc: **Details for Conventional Wood Frame Construction**

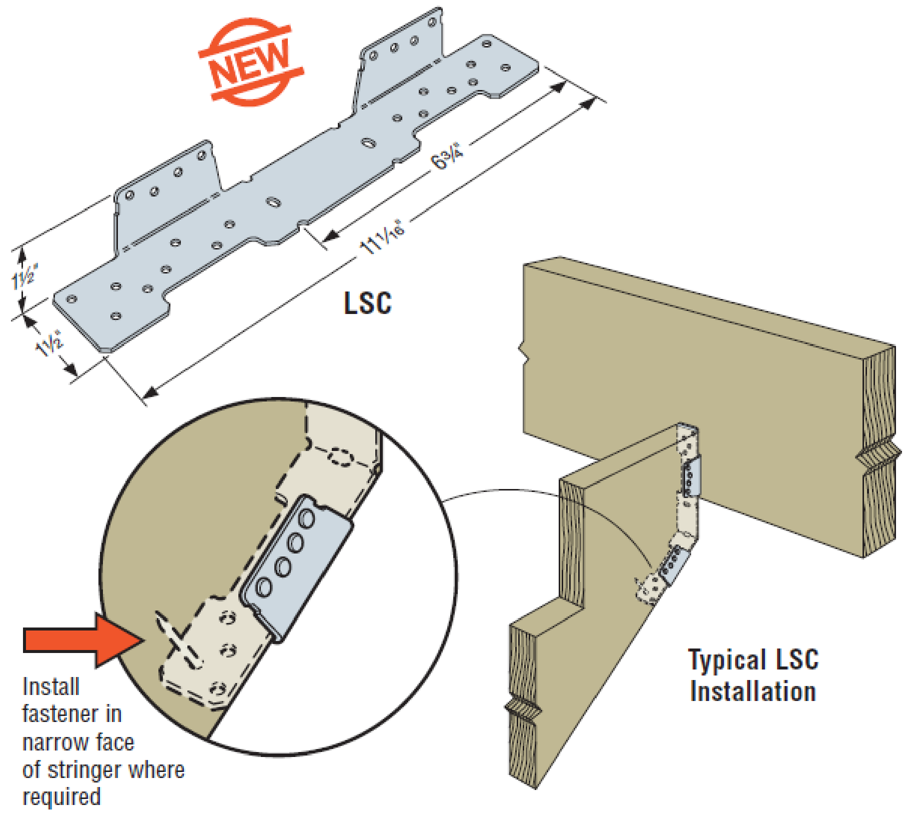
Stairway Framing

- Load path for this example:
  - Stringers bear on header
  - Header is supported by double trimmers



Stairway Framing

- Wood stringer support methods:
  - Stringer specific attachment
  - Use of angles each side of stringer
  - Use of traditional joist hangers with blocking to make up bottom slope of stringer.



Questions?

- Also, please feel free to ask questions via phone or email at:
  - Slasecki@ionic-sd.com
  - 414-540-8755