Structural Design for Residential Construction

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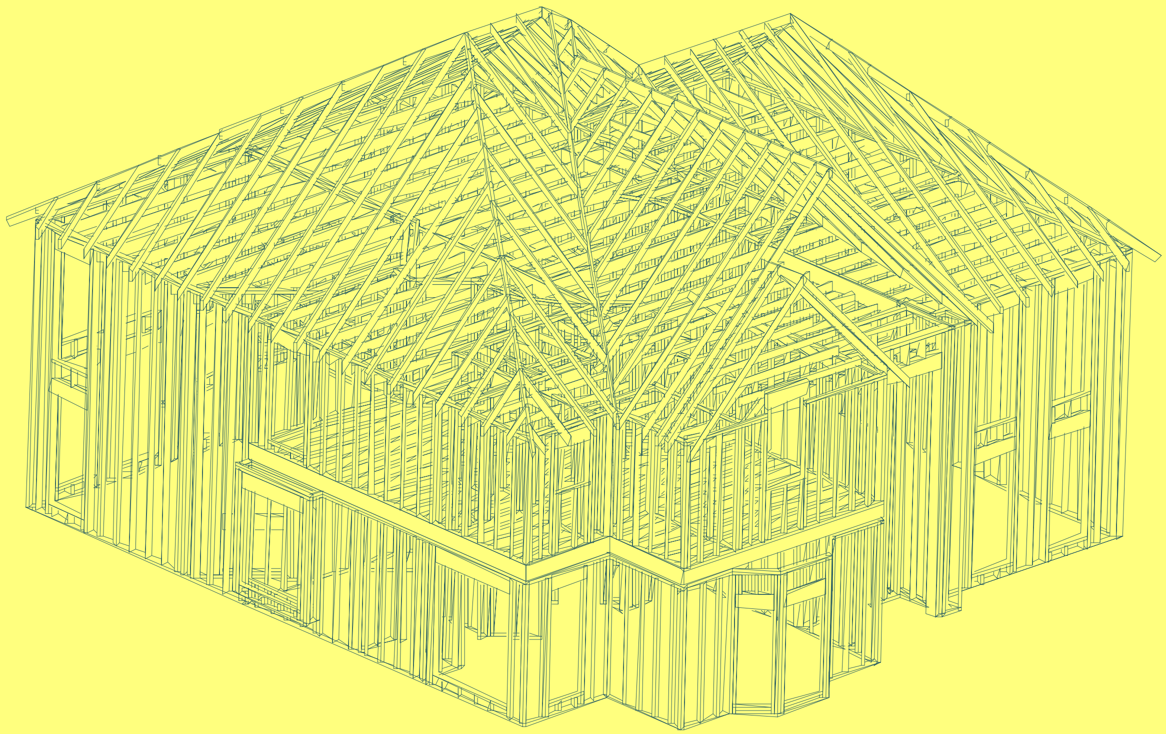
What is residential construction?

- One and two family dwellings
- Typically wood framed construction in this part of the world

What does a structural engineer typically do?



- Analyze load paths to ensure they go down to a foundation
- Connections – connections – connections
- Roof, floor, and wall assemblies
- Beams, columns, headers
- Lateral load resisting system (diaphragms, shear walls, collectors, struts, anchorage, overturning analysis)
- Footings/foundations

Drawing by Americad

What does a structural engineer typically not do?

- Land surveying
- Geotechnical engineering
- Layout of rooms
- Room sizes, ceiling heights
- Egress, ventilation & lighting
- Stairway geometry
- Mechanical, electrical, & plumbing
- Fire protection
- Energy efficiency
- Permitting

Gray areas

- Chimneys
- Moisture protection
- Termite mitigation
- Drainage

All you need to know about structure

- Equal and opposite forces
- What is up must come down
- The wind will always blow it over

Code Requirements

- Building Codes:
  - CT: BOCA National Building Code 1996/IRC 2003
  - MA: State Building Code, 6th Edition (Ch. 36, 1&2 family dwellings)
  - NH: IBC 2000/1&2 family dwellings per town
  - RI: IBC 2003/IRC 2003
  - VT: BOCA National Building Code
- Minimum standard
- Residential code – prescriptive vs. engineered

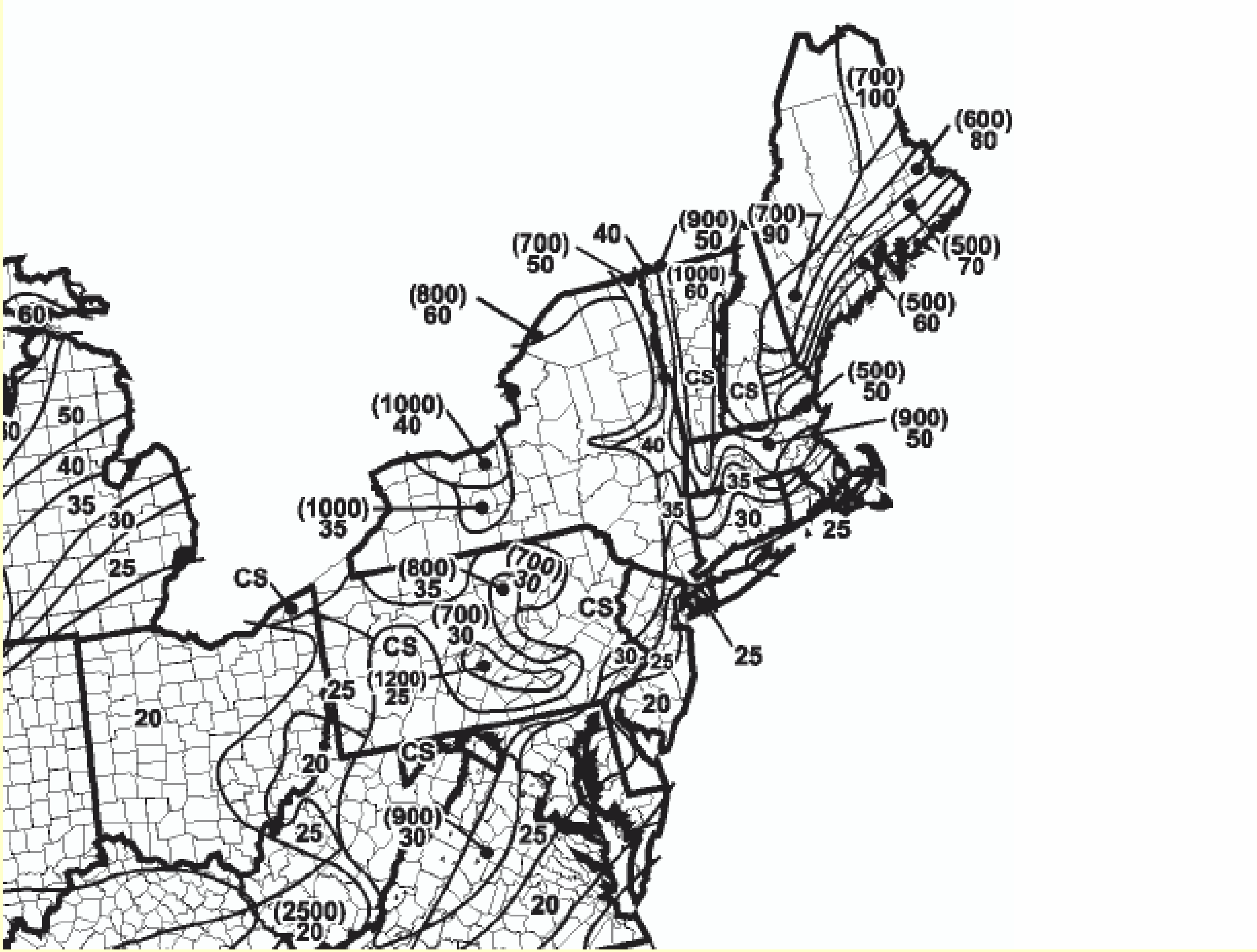
Parts of structure

- Connections, connections, connections
- Beams, columns, headers
- Diaphragms, shear walls, collectors, struts, anchorage (lateral force resisting system)
- Foundations to hold it all up
- Soil is part of the structure too

What we don't use as part of the structure

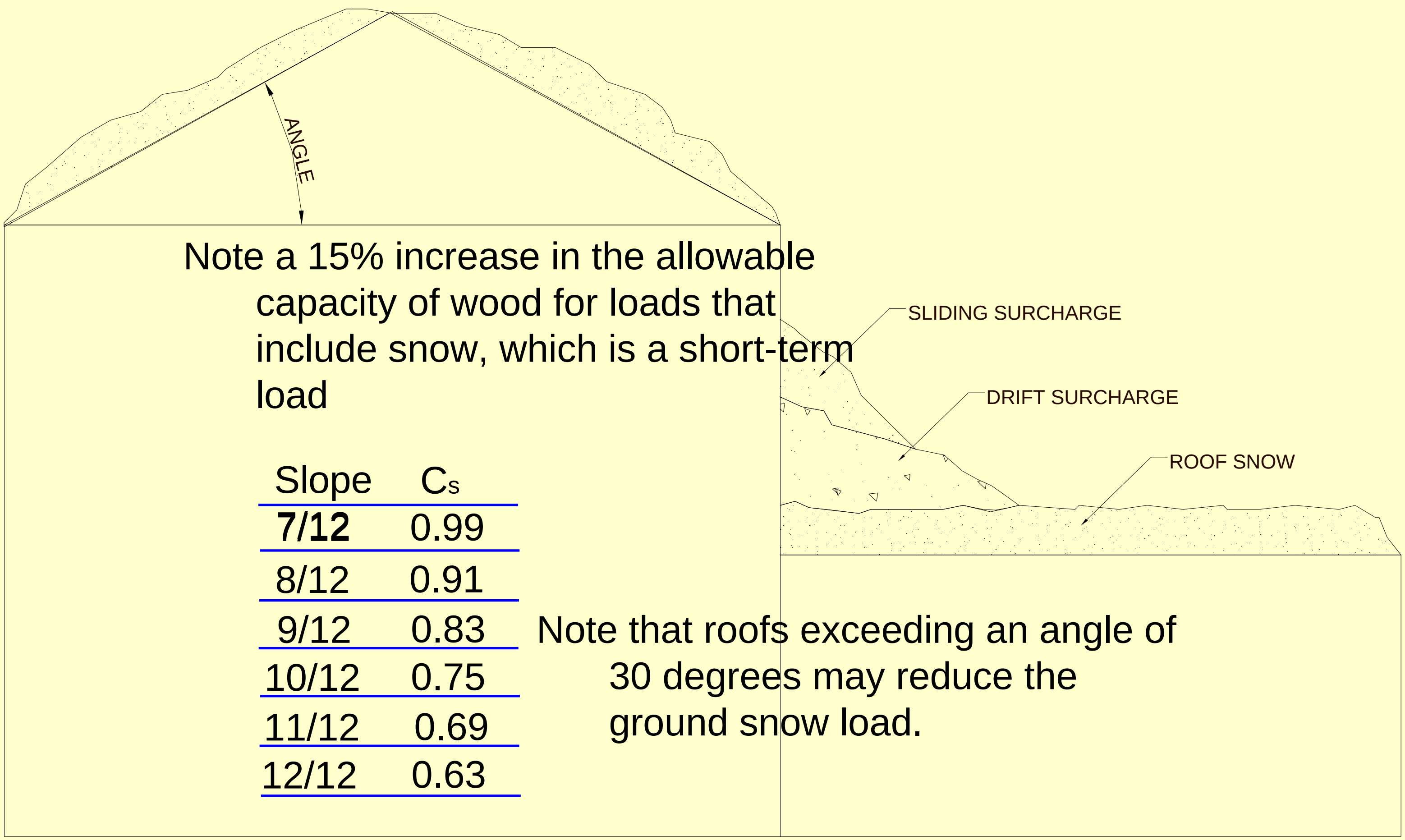
- We do not use the plywood as a T beam to increase the capacity of the joists – instead the plywood is the diaphragm to transfer lateral loads to shearwalls
- Interior partitions (excluding center bearing wall) are dead loads only
- The gypsum board inside is dead load
- Interior walls not used to resist horizontal forces from wind.

Ground Snow Loads



IBC 2003

Snow Loads

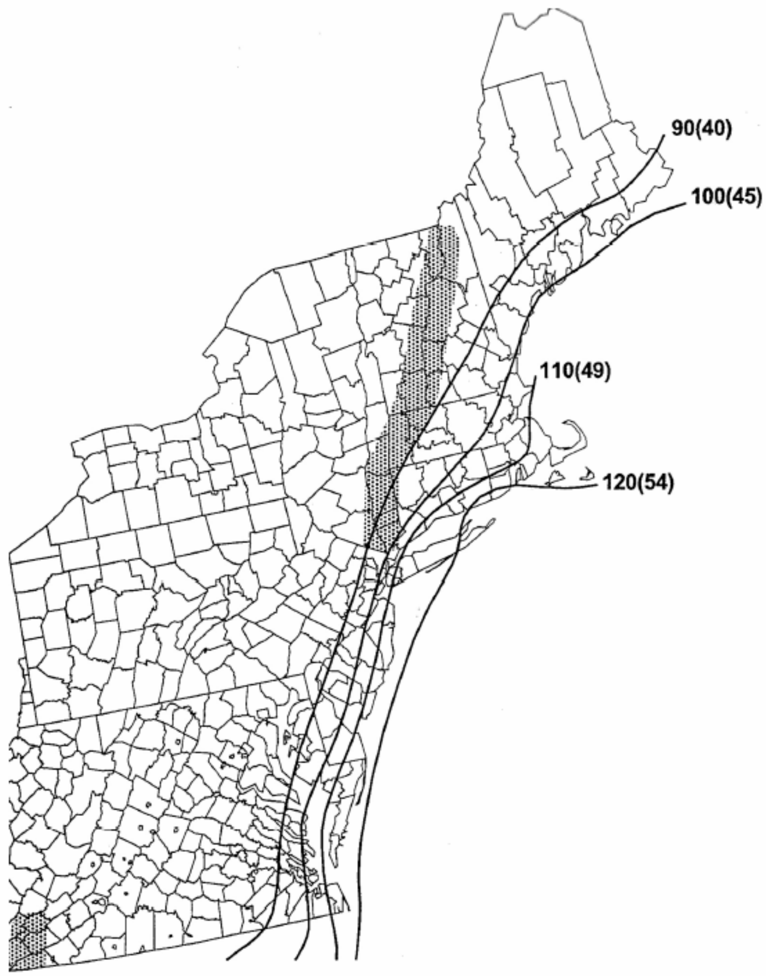


Note a 15% increase in the allowable capacity of wood for loads that include snow, which is a short-term load

Slope	C_s
7/12	0.99
8/12	0.91
9/12	0.83
10/12	0.75
11/12	0.69
12/12	0.63

Note that roofs exceeding an angle of 30 degrees may reduce the ground snow load.

Wind Loads



Zone	V_{30} (mph)
1 (Western Mass.)	70
2 (Central Mass.)	80
3 (Eastern Mass.)	90

Table 1611.3, Wind velocity "fastest mile" 30 feet above the ground, exposure C Mass. State Code, 6th Ed.

Reference wind pressures

Zone	Pressure (psf)
1 (Western Mass.)	12
2 (Central Mass.)	17
3 (Eastern Mass.)	21

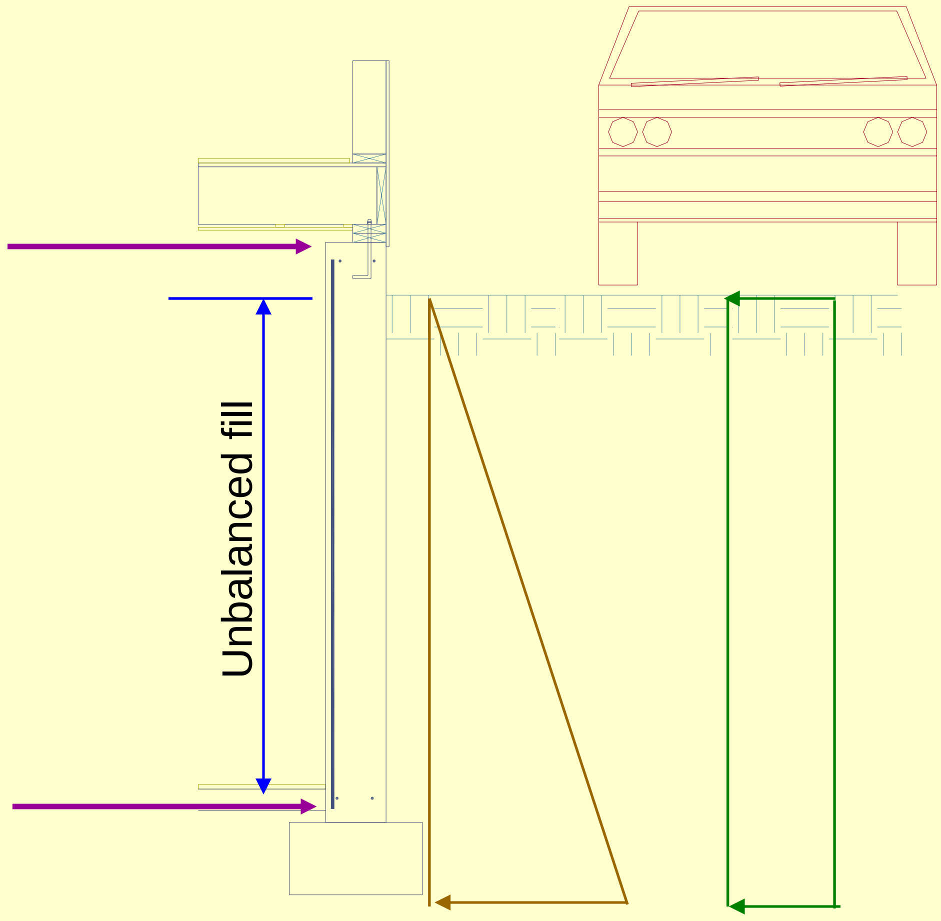
TABLE 1609.3.1
EQUIVALENT BASIC WIND SPEEDS[a,b,c]

V_{3S}	85	90	100	105	110	120	125	130	140	145	150	160	170
V_{fm}	70	75	80	85	90	100	105	110	120	125	130	140	150

3-second gust
Fastest mile

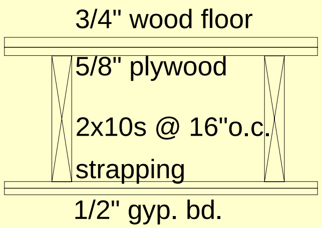
Above, Figure 1609, Basic Wind Speed (3-second gust), 33 feet above ground, exposure C
IBC 2003

Soil and Surchare



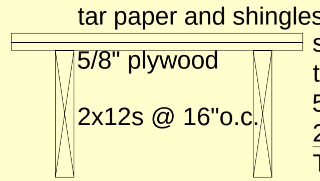
Seismic??

Dead Loads



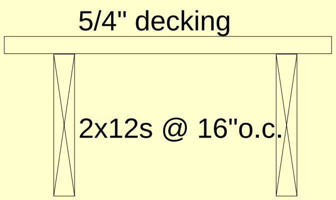
3/4" wood floor/fin	3.0 psf
5/8" plywood	1.9 psf
2x10s @ 16" o.c.	3.0 psf
gyp + plaster/paint	3.0 psf
Total	10.9 psf

FLOOR



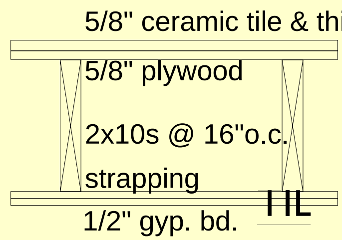
shingles	2.0 psf (1 layer - code allows up to 3)
tar paper	0.7 psf
5/8" plywood	1.9 psf
2x12s @ 16" o.c.	3.5 psf
Total	8.1 psf (12.1 with 3 layers of shingles

ROOF
(unfinished below)



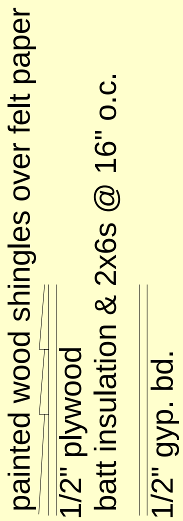
5/4" decking	4.2 psf
2x12s @ 16" o.c.	3.5 psf
Total	7.7 psf

DECKING



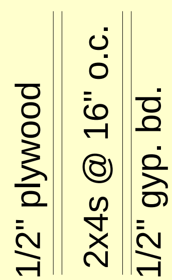
5/8" tile and thinset	7.8 psf
5/8" plywood	1.9 psf
2x10s @ 16" o.c.	3.0 psf
gyp + plaster/paint	3.0 psf
Total	15.7 psf

TILE FLOOR



wood shingles	2.0 psf
felt paper	1.0 psf
1/2" plywood	1.7 psf
2x6s @ 16" o.c.	1.7 psf
batt insul.	0.5 psf
gyp + plaster/paint	3.0 psf
Total	10.9 psf

EXTERIOR WALL

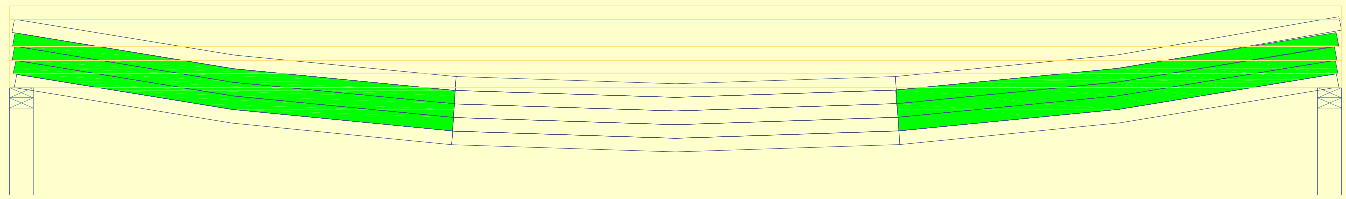


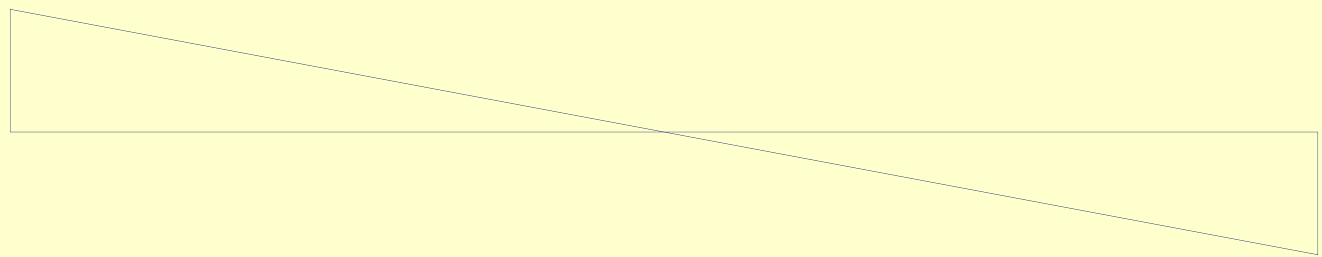
gyp + plaster/paint	3.0 psf
2x4s @ 16" o.c.	1.1 psf
gyp + plaster/paint	3.0 psf
Total	7.1 psf

INTERIOR WALL

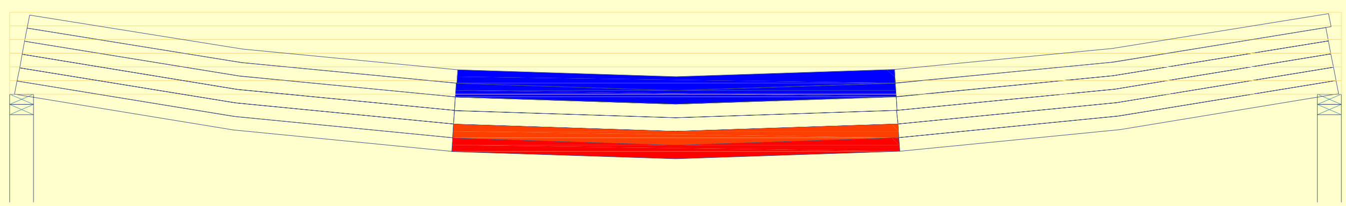
BEAMS

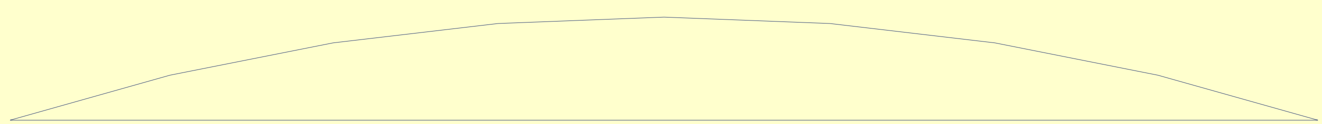
Shear



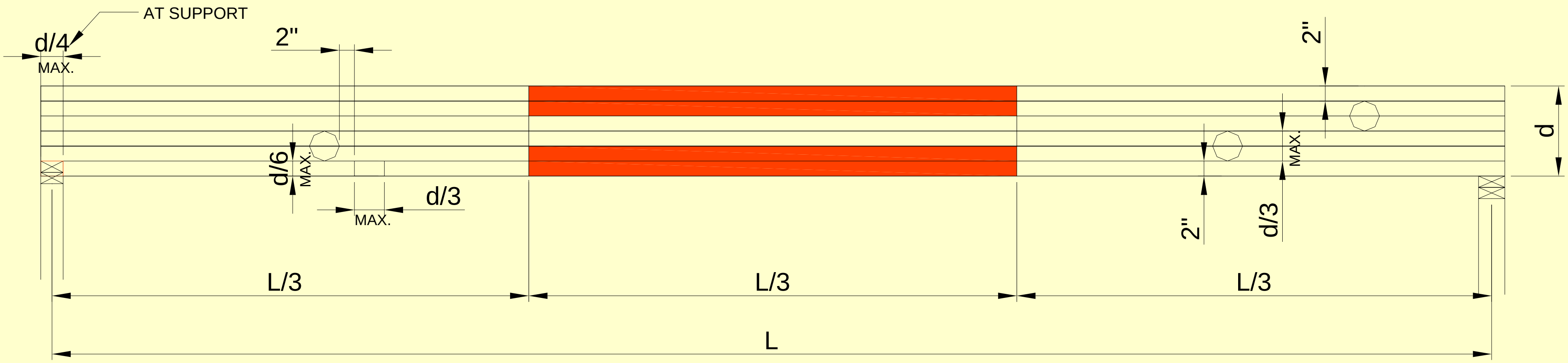


Bending

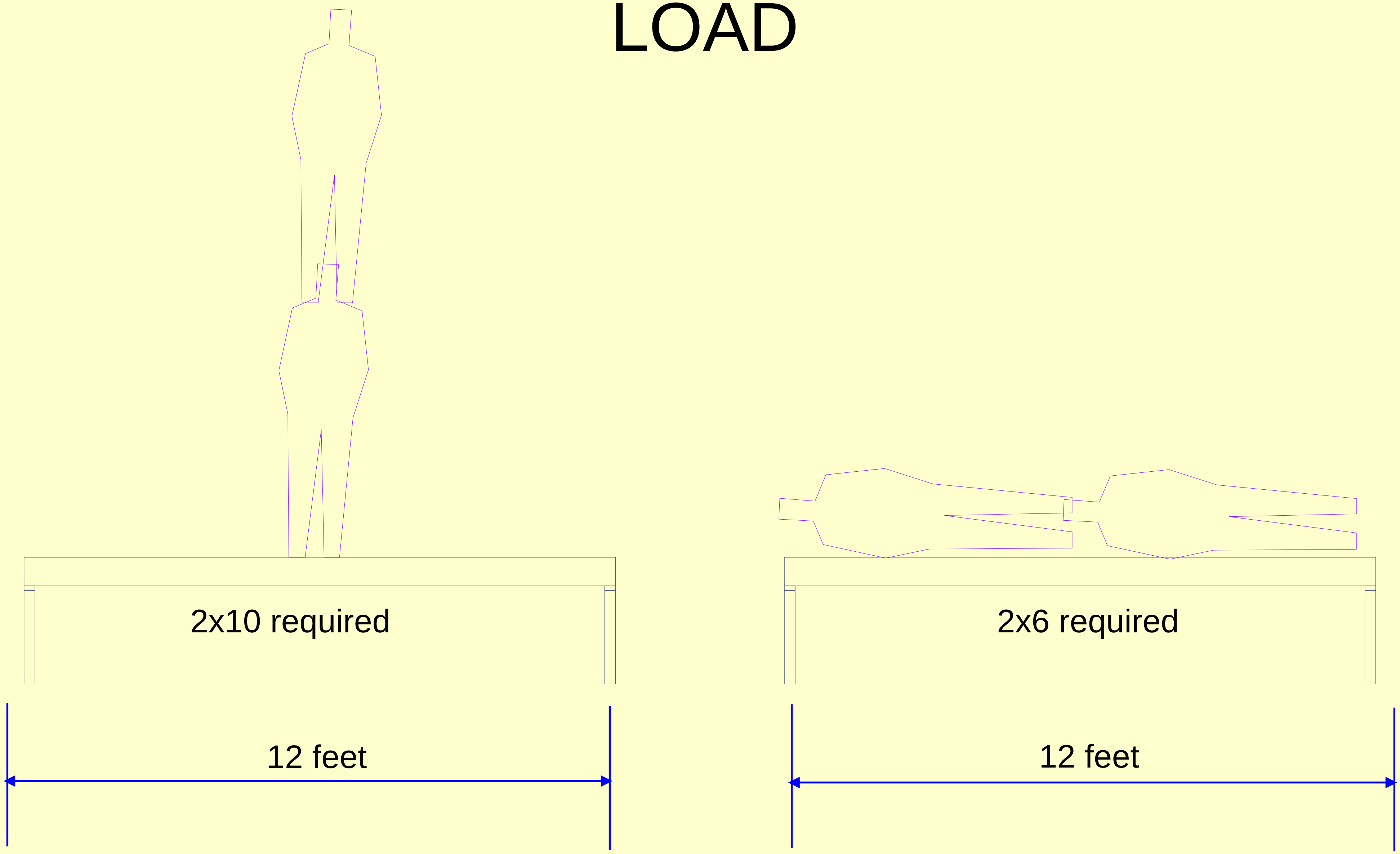




Notching and Boring



CONCENTRATED vs UNIFORM LOAD



LESSON LEARNED

Uniform loads …

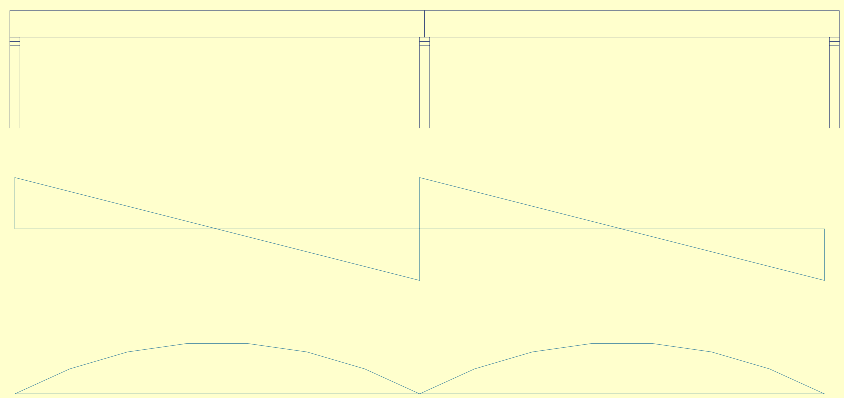
good

Concentrated loads …

more of a challenge

SIMPLY SUPPORTED vs CONTINUOUS OVER SUPPORTS

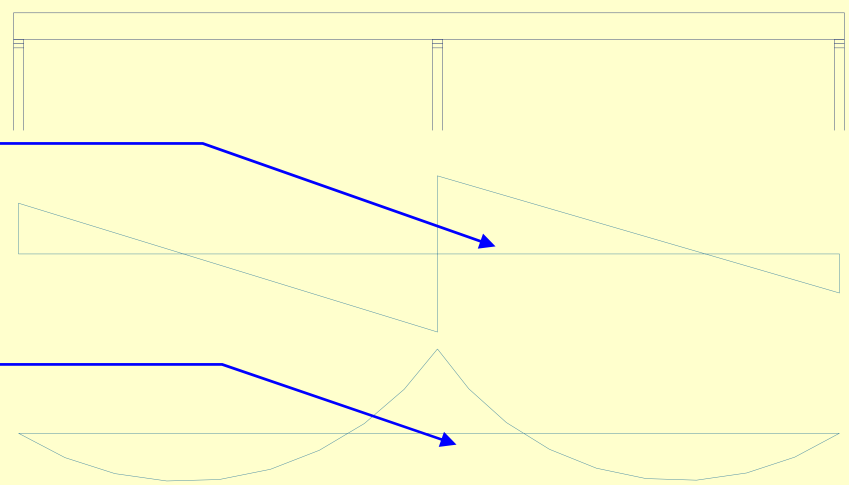
2 simply supported beams



Shear diagram

Moment diagram

1 long beam spanning over center column



Higher shear stress and
reaction to column
compared to simple span

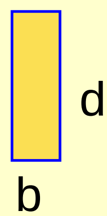
Shear diagram

Stress reversal;
compression at the top,
tension at the bottom

Moment diagram

Restraint against twisting & lateral stability

Aspect ratio, d/b

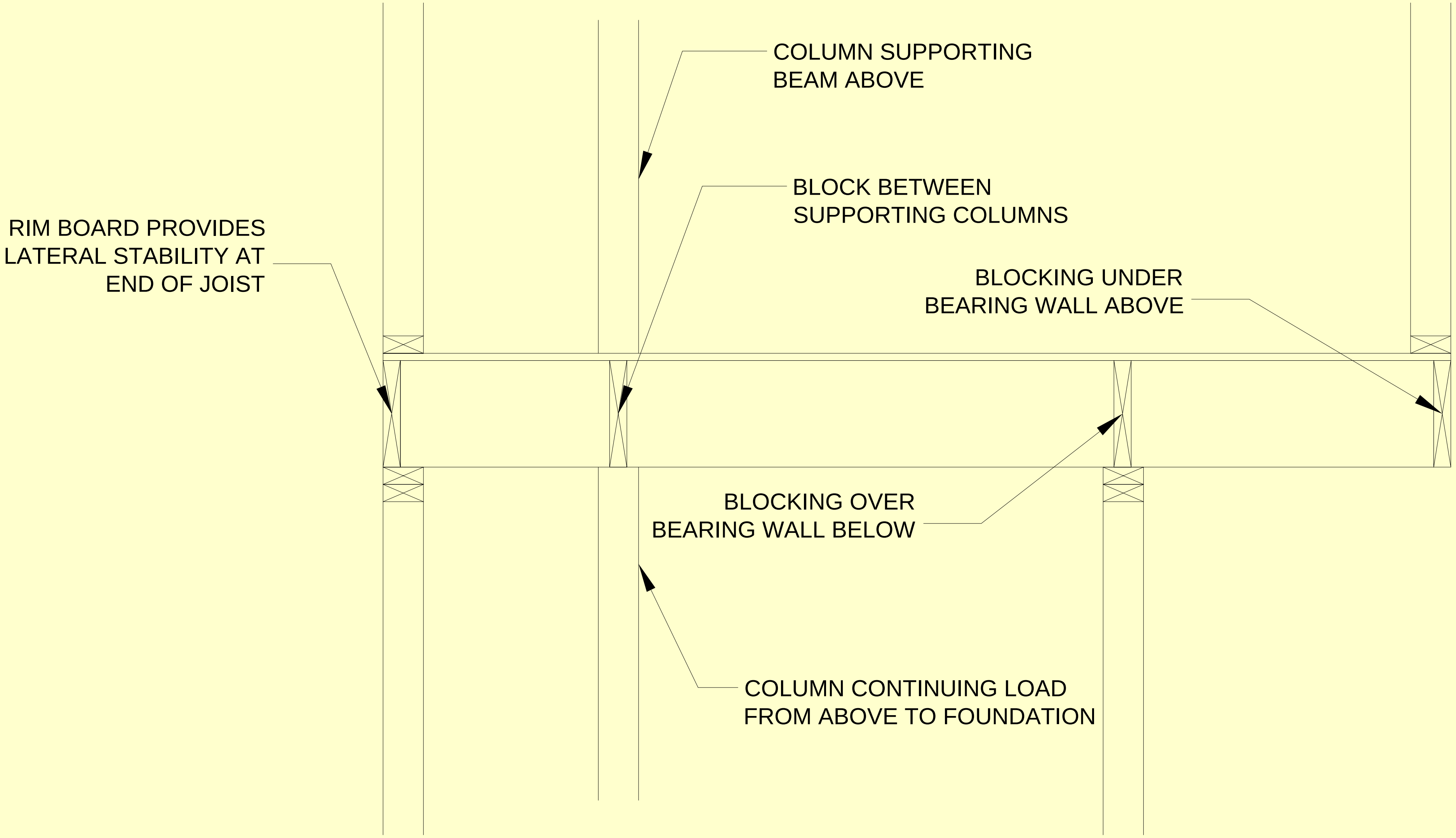


Aspect ratios of common beam sizes:

	Single	Double	Triple
2x6	3.7	1.8	1.2
2x8	4.8	2.4	1.6
2x10	6.2	3.1	2.1
2x12	7.3	3.8	2.5
2x14	8.8	4.4	2.9

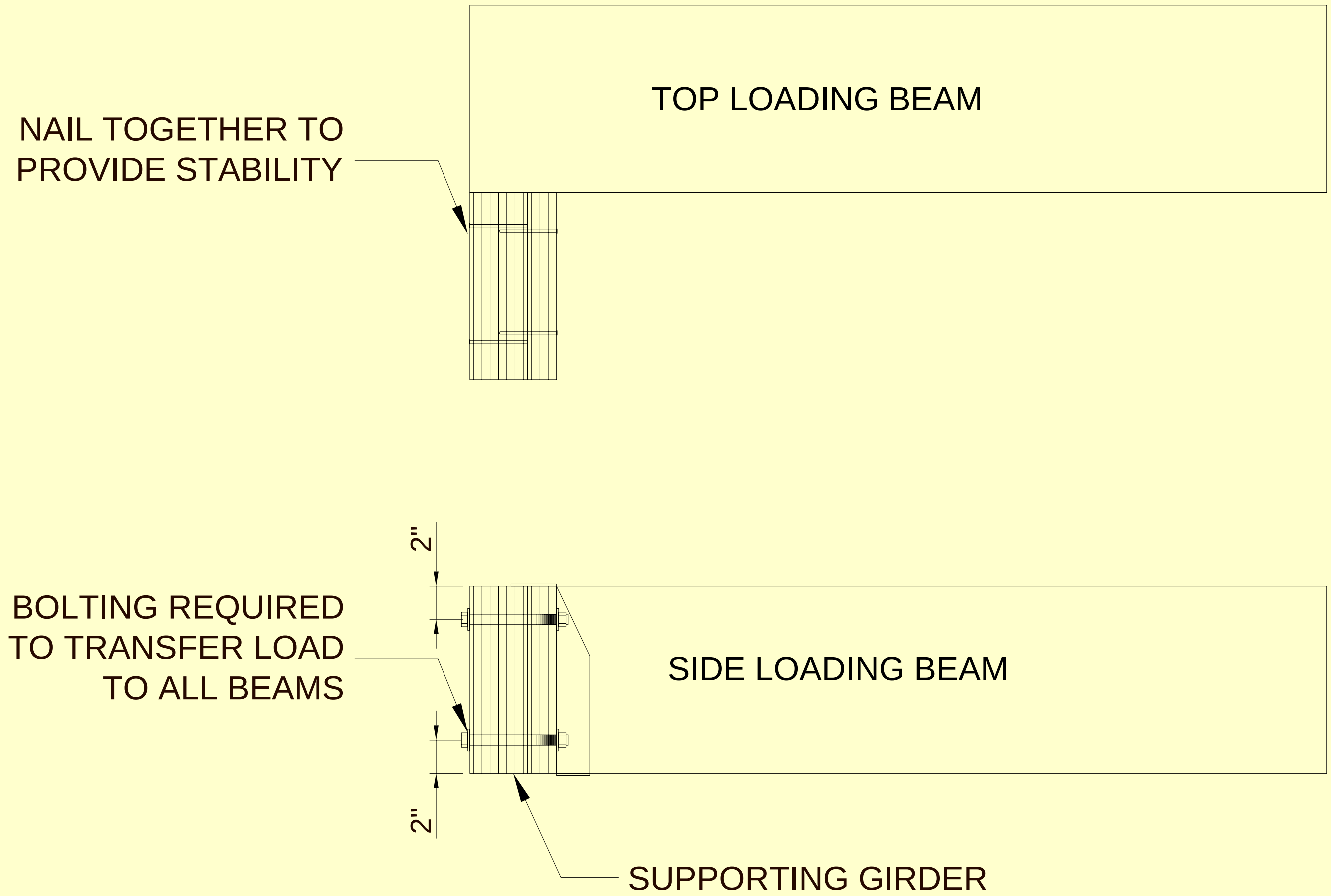
- $d/b \leq 2$ — no lateral support required
- $2 < d/b \leq 4$ — ends held in position
- $5 < d/b \leq 6$ — laterally restrain ends and at intervals along length of less than 8ft. and compression edge held in position with sheathing
- $6 < d/b \leq 7$ — laterally restrain ends both compression and tension sides shall be supported for the entire length.

Blocking

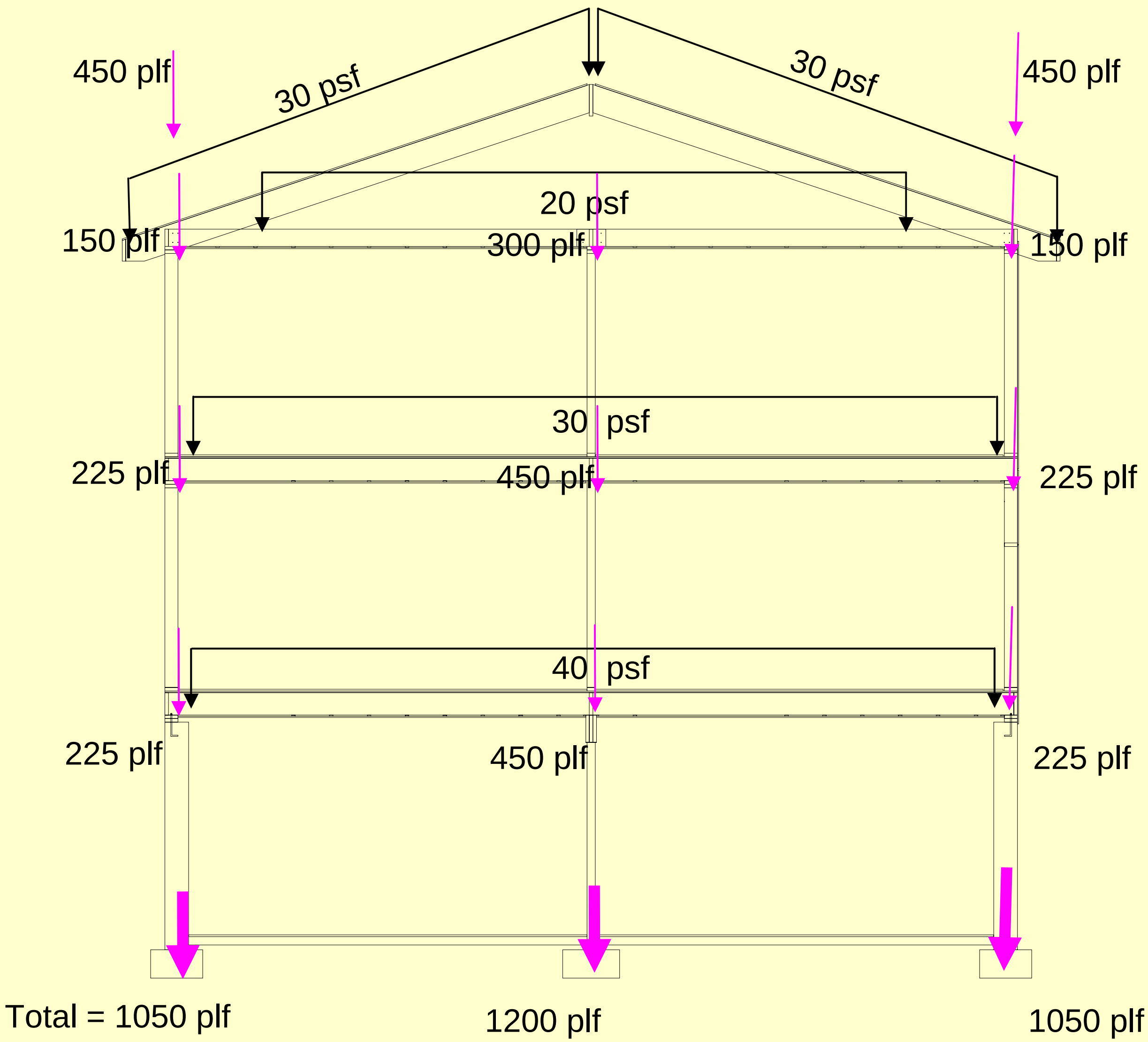


COLUMN SUPPORTING
BEAM ABOVE
BLOCK BETWEEN
SUPPORTING COLUMNS
RIM BOARD PROVIDES
LATERAL STABILITY AT
END OF JOIST
BLOCKING UNDER
BEARING WALL ABOVE
BLOCKING OVER
BEARING WALL BELOW
COLUMN CONTINUING LOAD
FROM ABOVE TO FOUNDATION

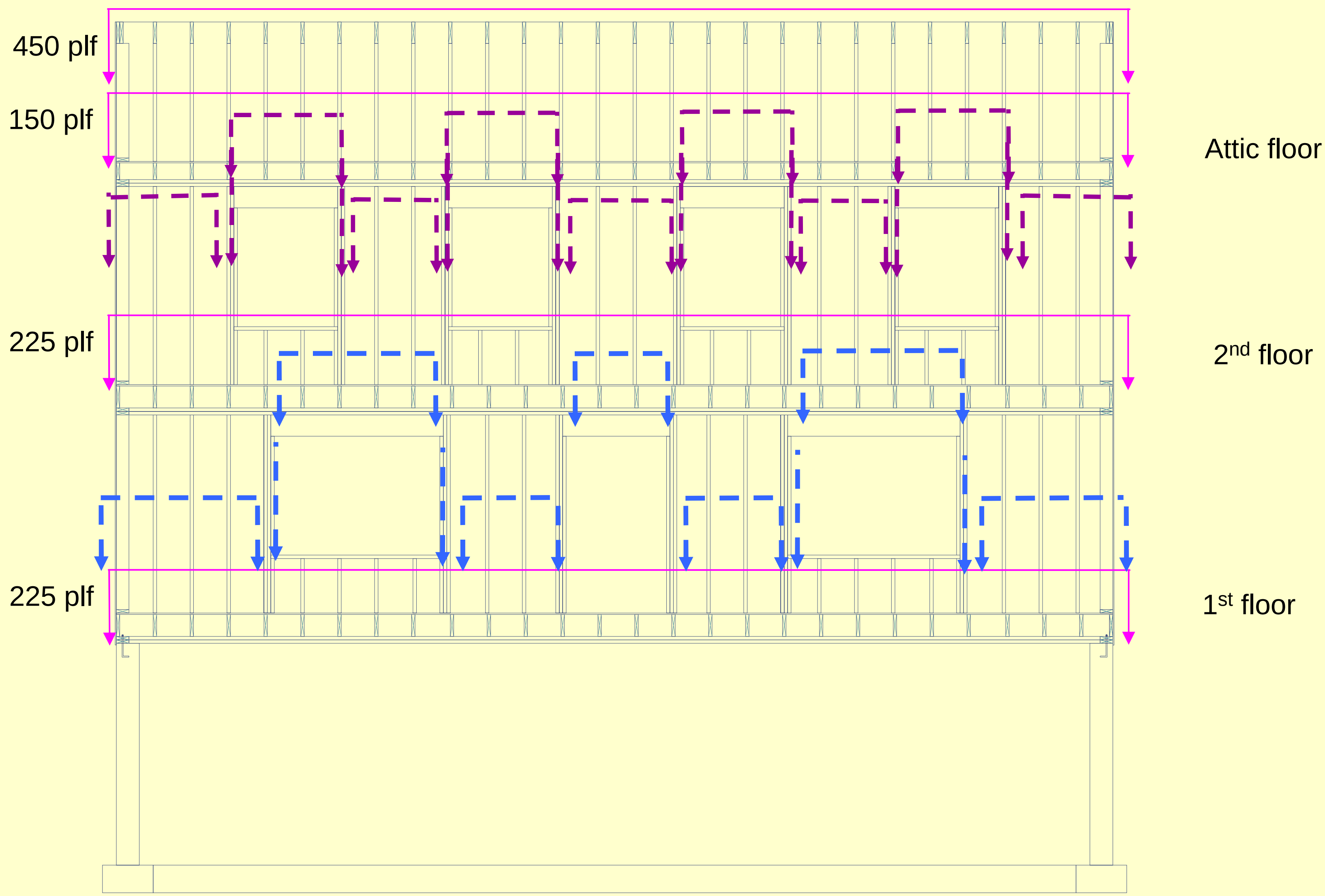
Connections of multiple LVLs



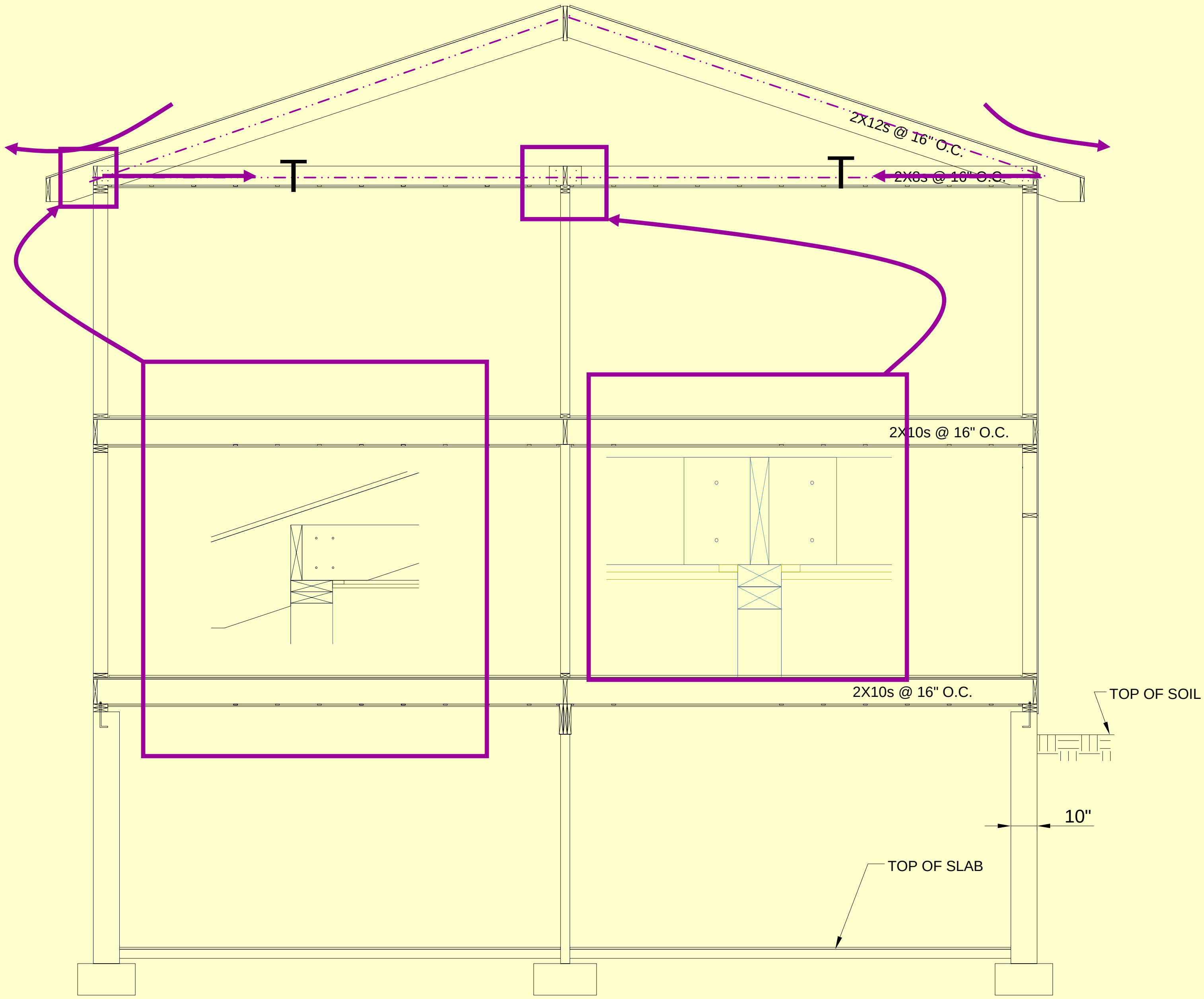
Follow the load path due to gravity



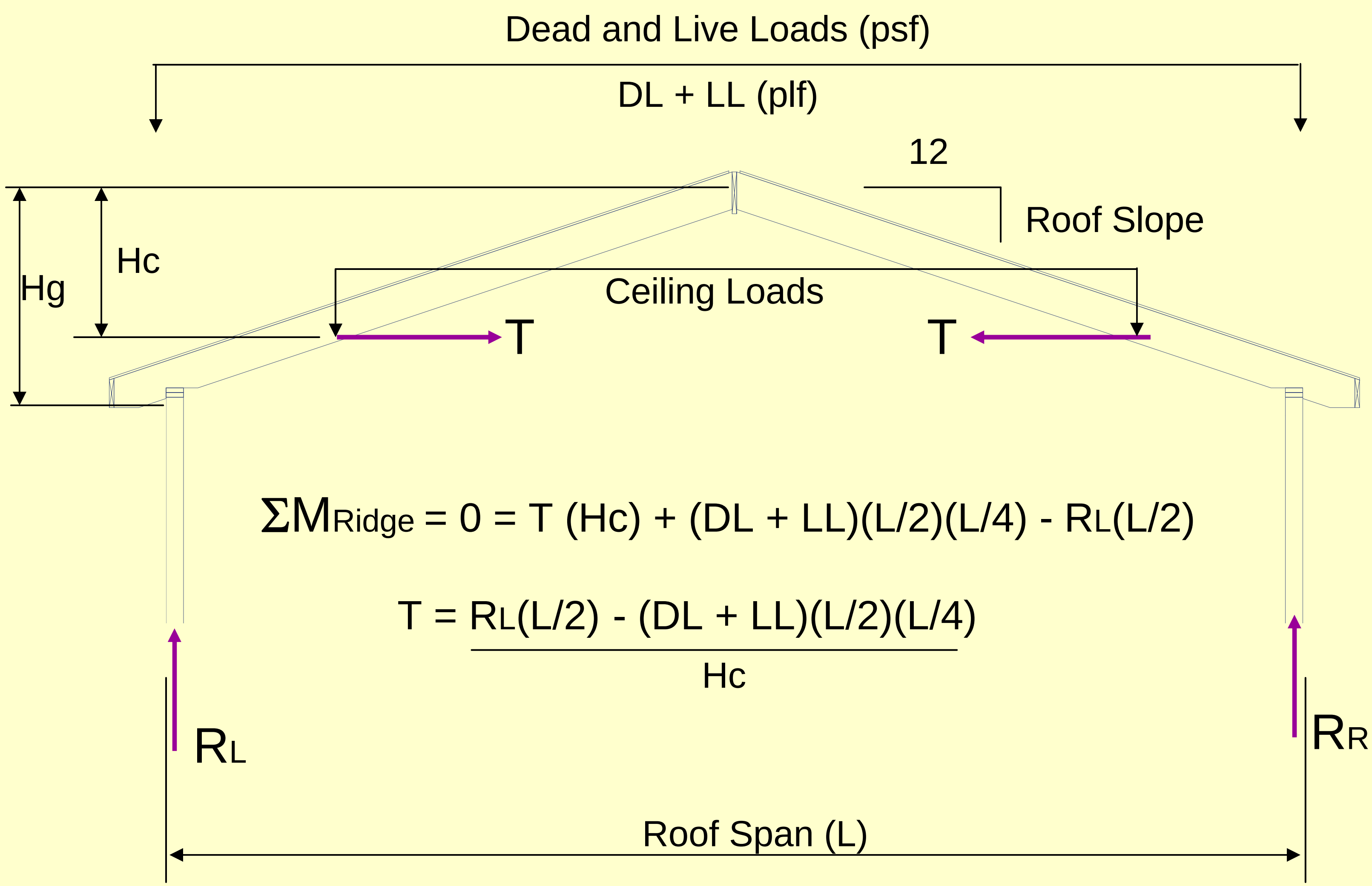
Follow the load path due to gravity



The simple house framing



Rafter/Ceiling Joist Heel Joint Connection



$$\Sigma M_{Ridge} = 0 = T\,(H_c) + (DL + LL)(L/2)(L/4) - R_L(L/2)$$

$$T = \frac{R_L(L/2) - (DL + LL)(L/2)(L/4)}{H_c}$$

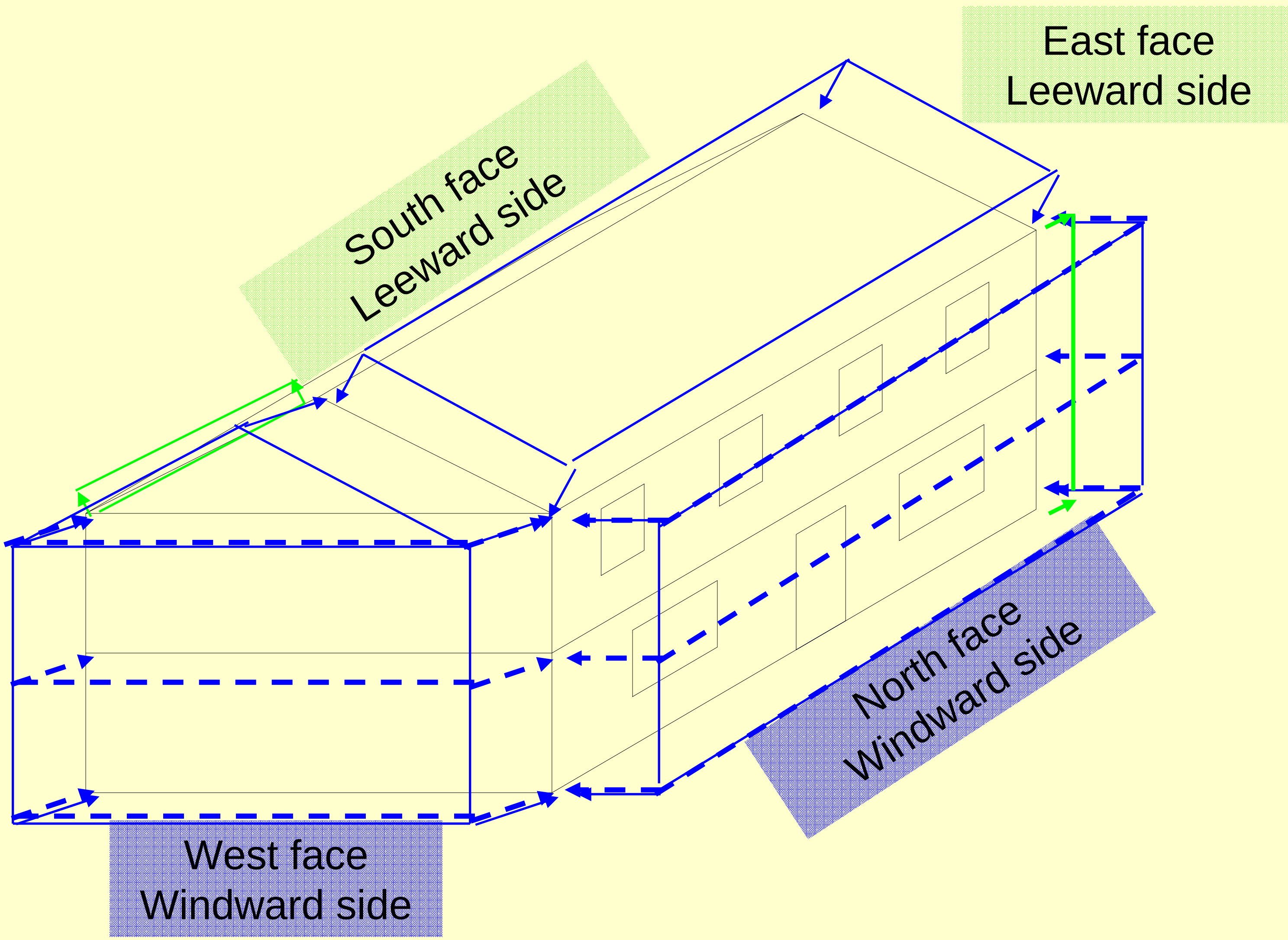
Redundancy

- Unlike bridges, houses have many structural members.
- Credit is provided for repetitive members of joists

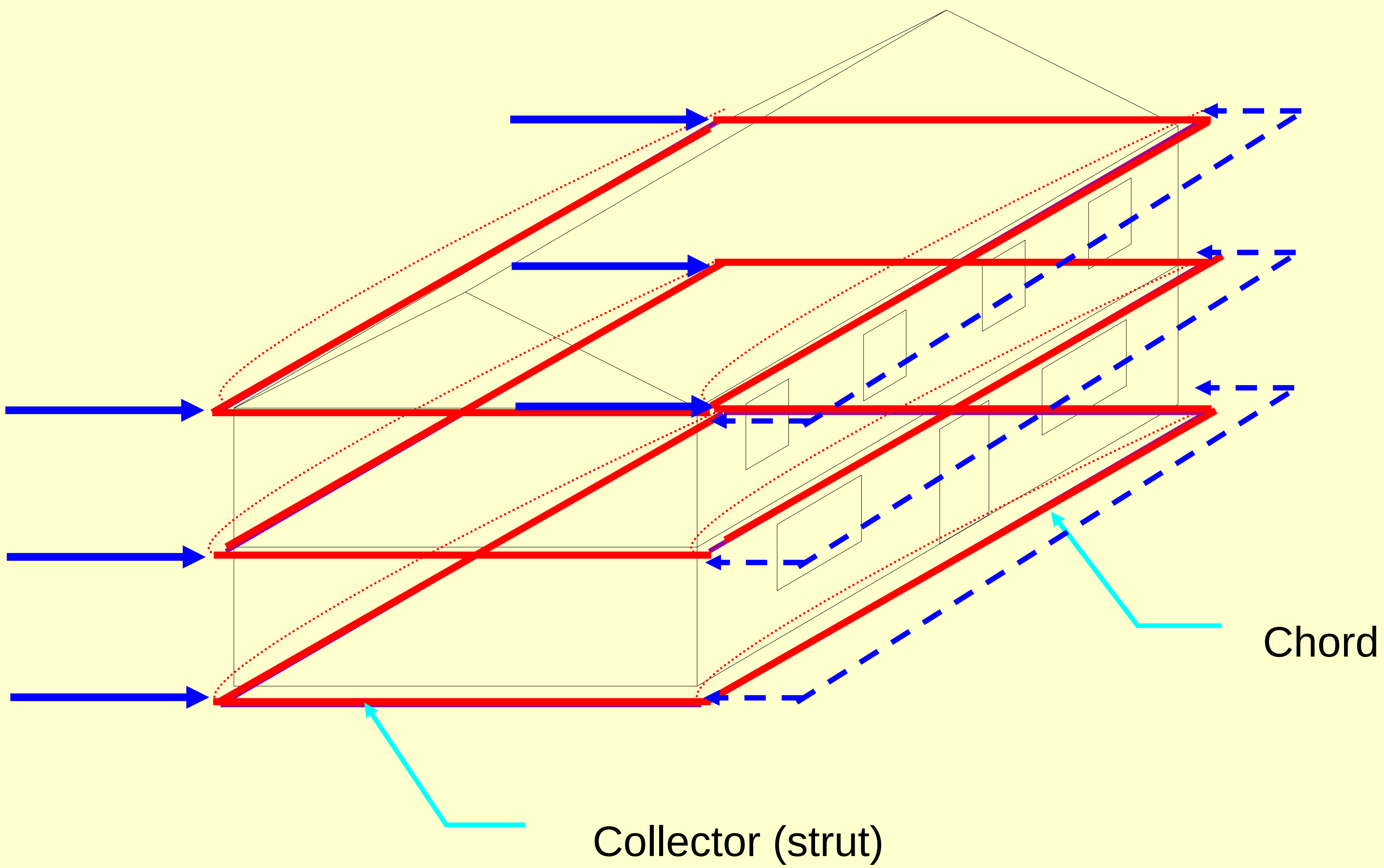
Laterial force resisting system

- Horizontal Diaphragm (plywood subfloor)
  - Collectors
  - Cords
- Vertical Diaphragm (exterior wall)
  - Strut
  - Cords
- The building code provides some information on LFRS – see WFCM.

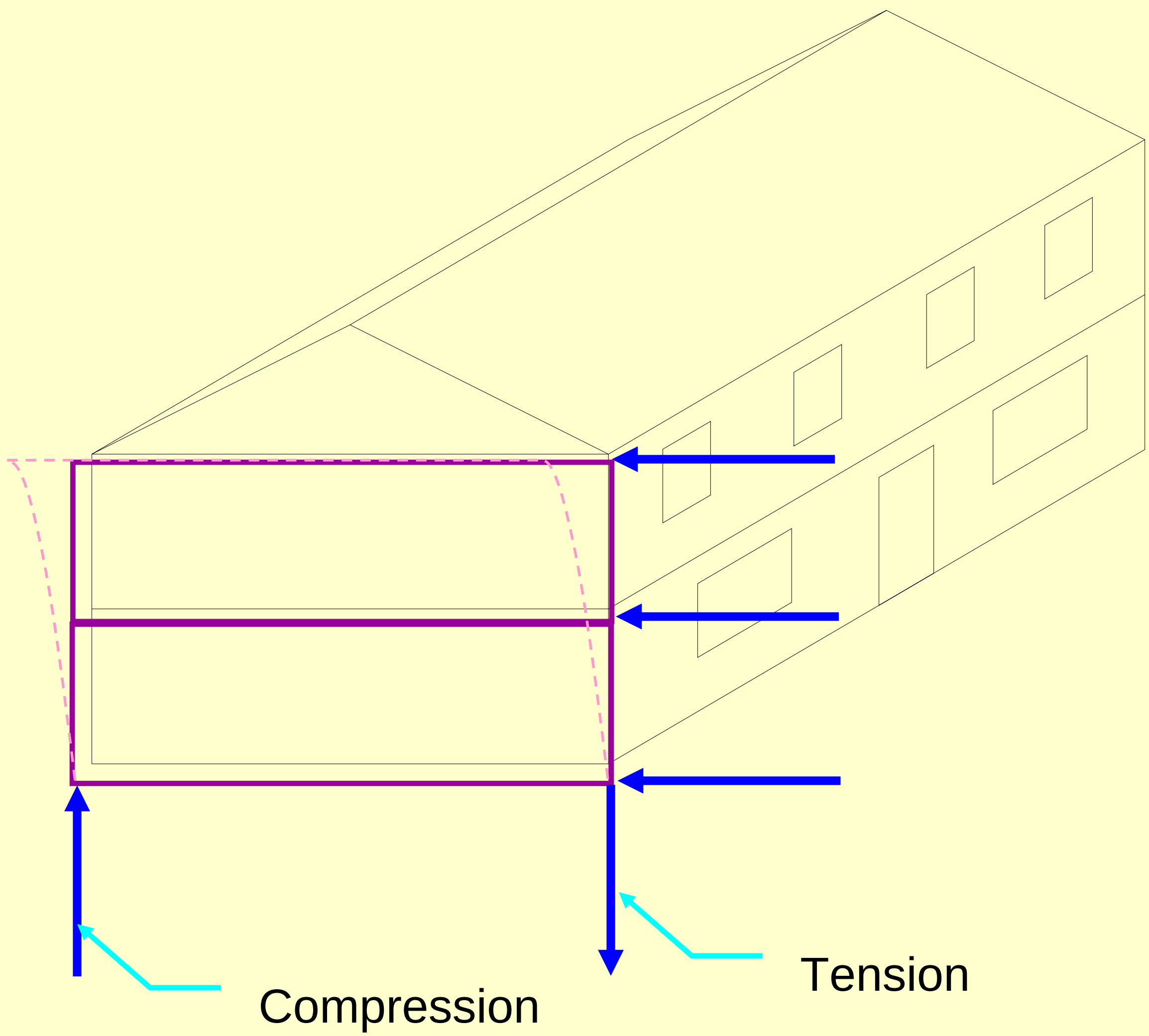
Follow the load path due to wind



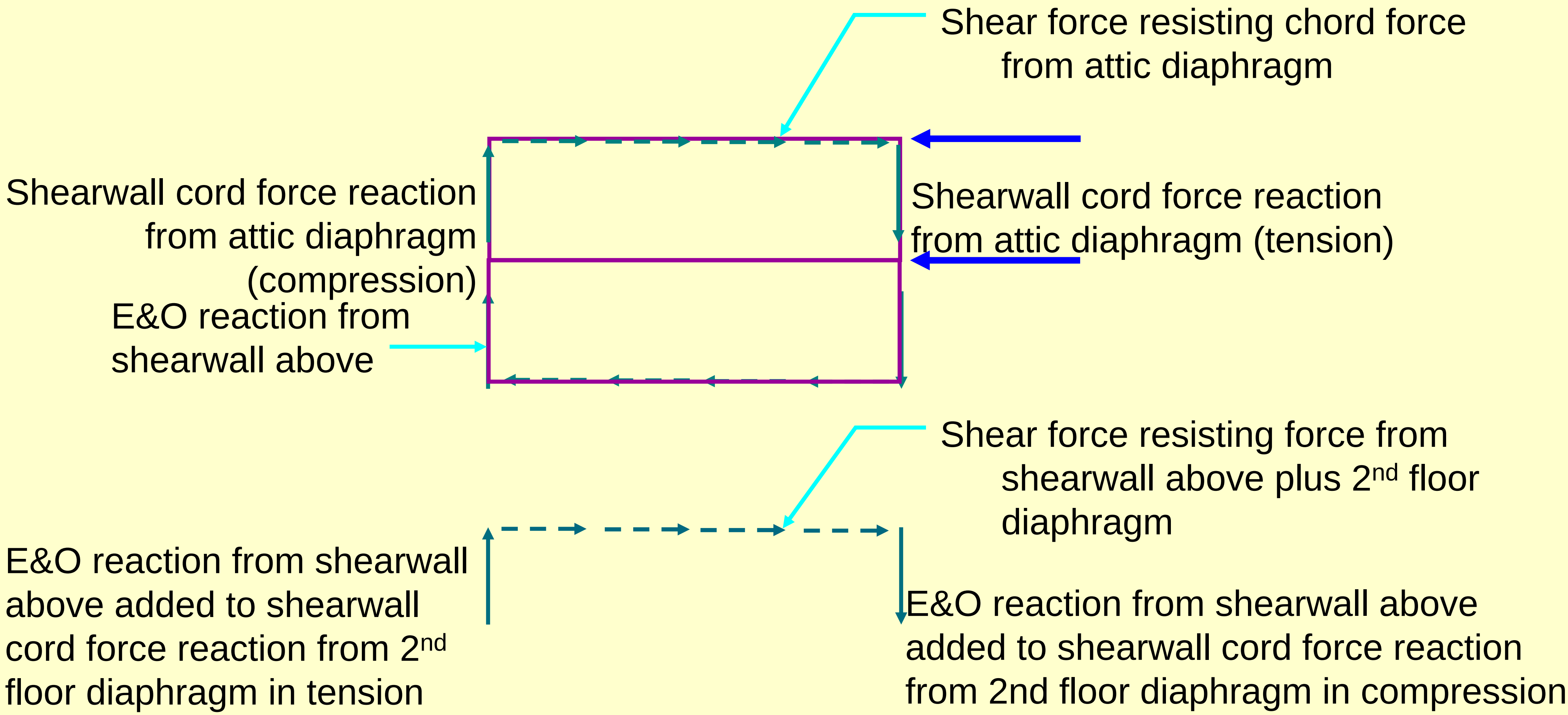
North Wind affect to Horizontal Diaphragm



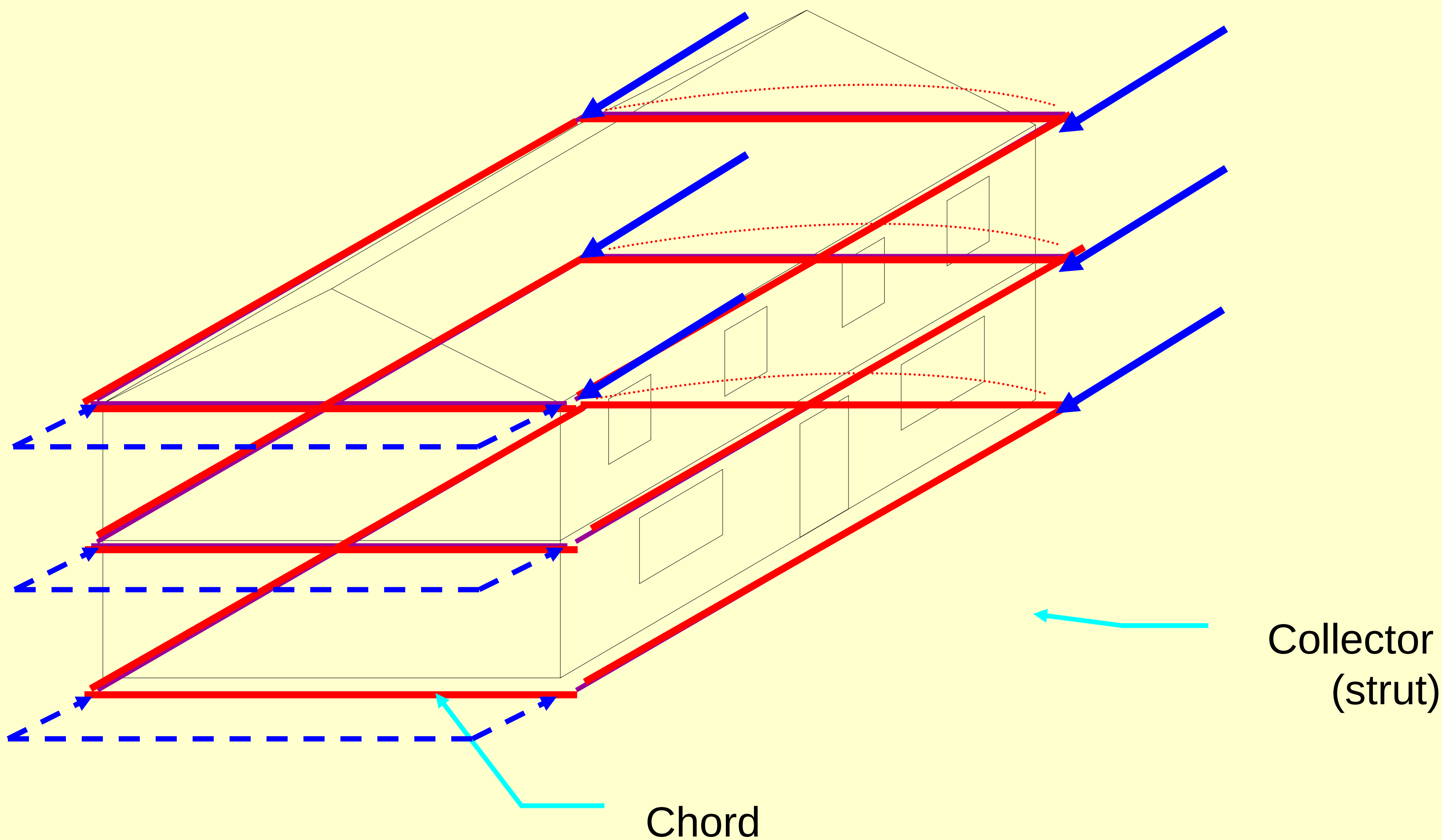
North Wind Horizontal Diaphragm affects to West/East Shearwalls



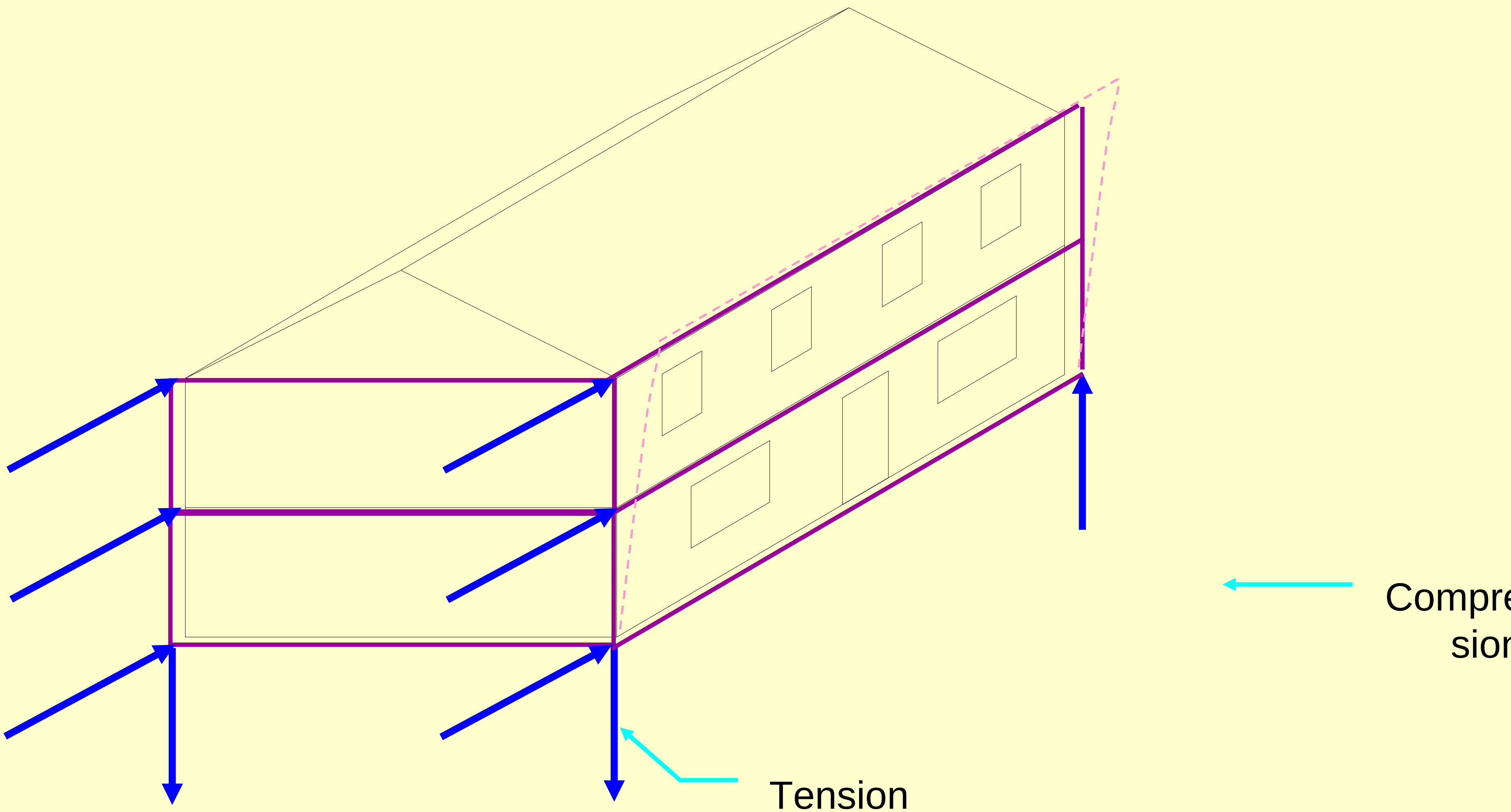
A closer look at the West Shearwall



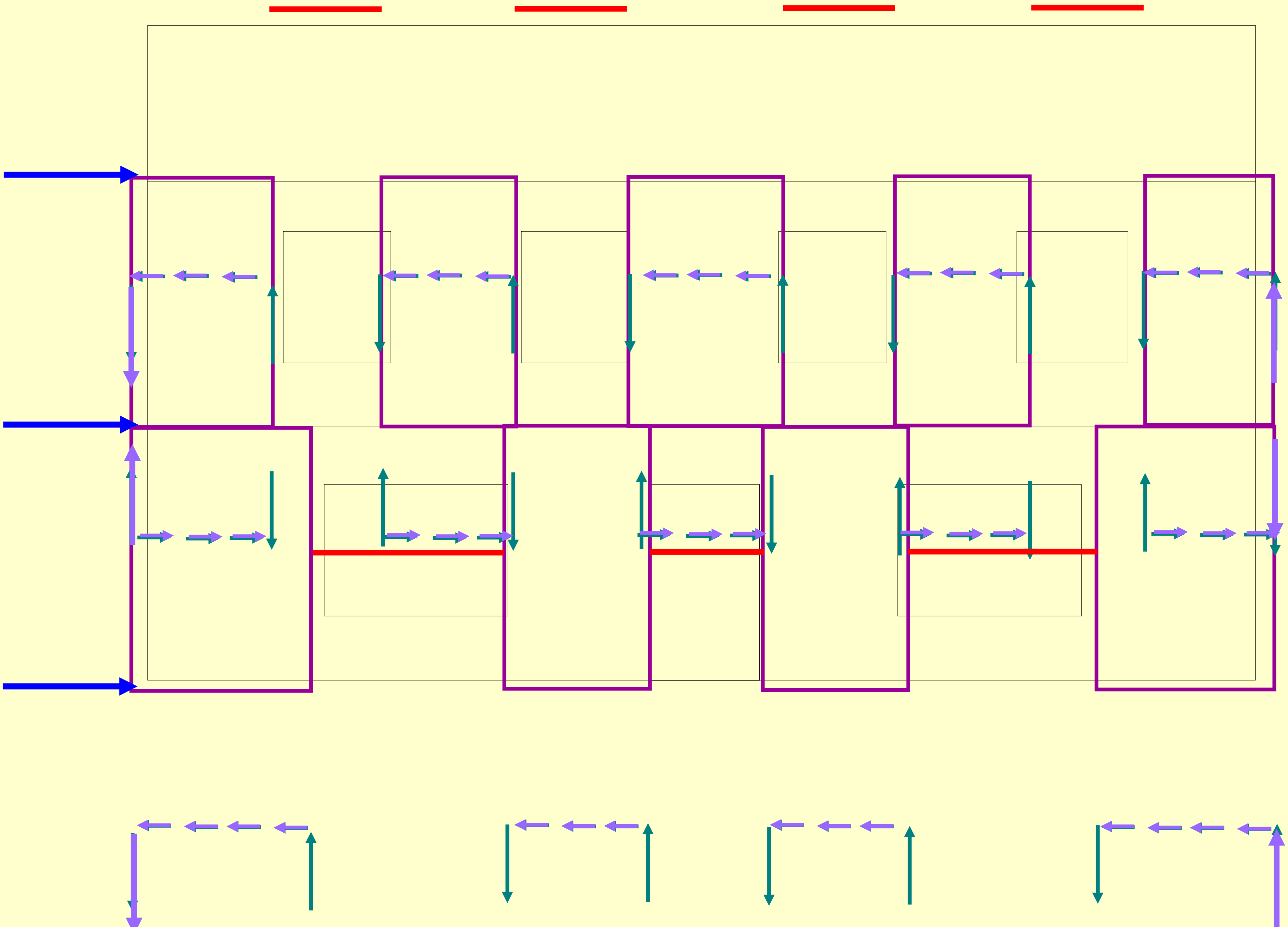
West Wind affect to Horizontal Diaphragm



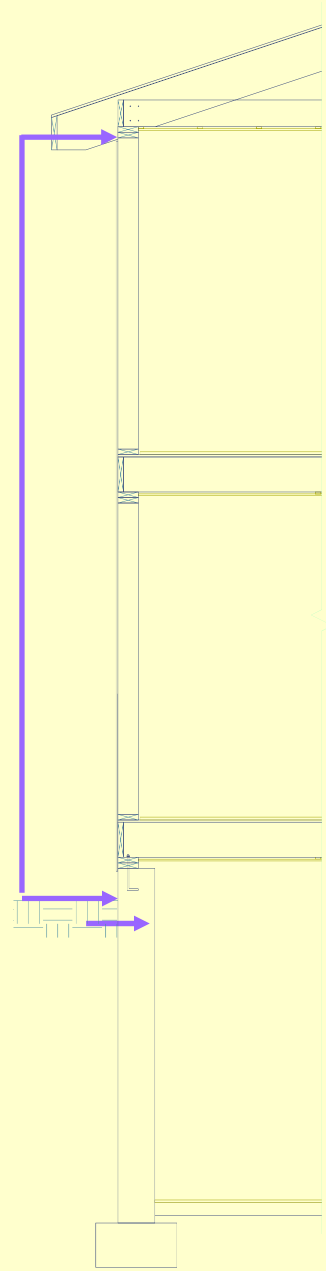
West Wind Horizontal Diaphragm affects to North/South Shearwalls



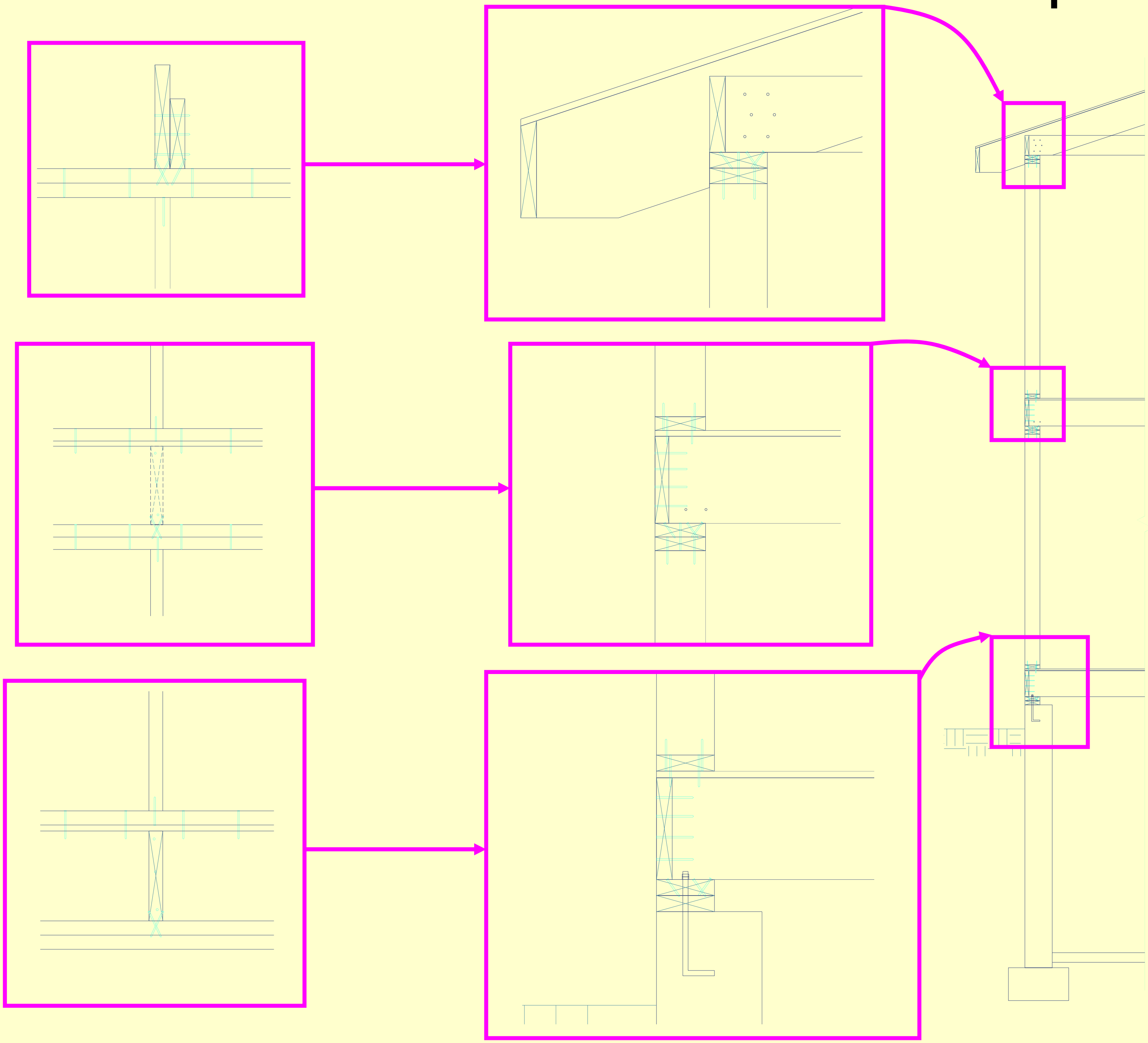
A closer look at the North Shearwall



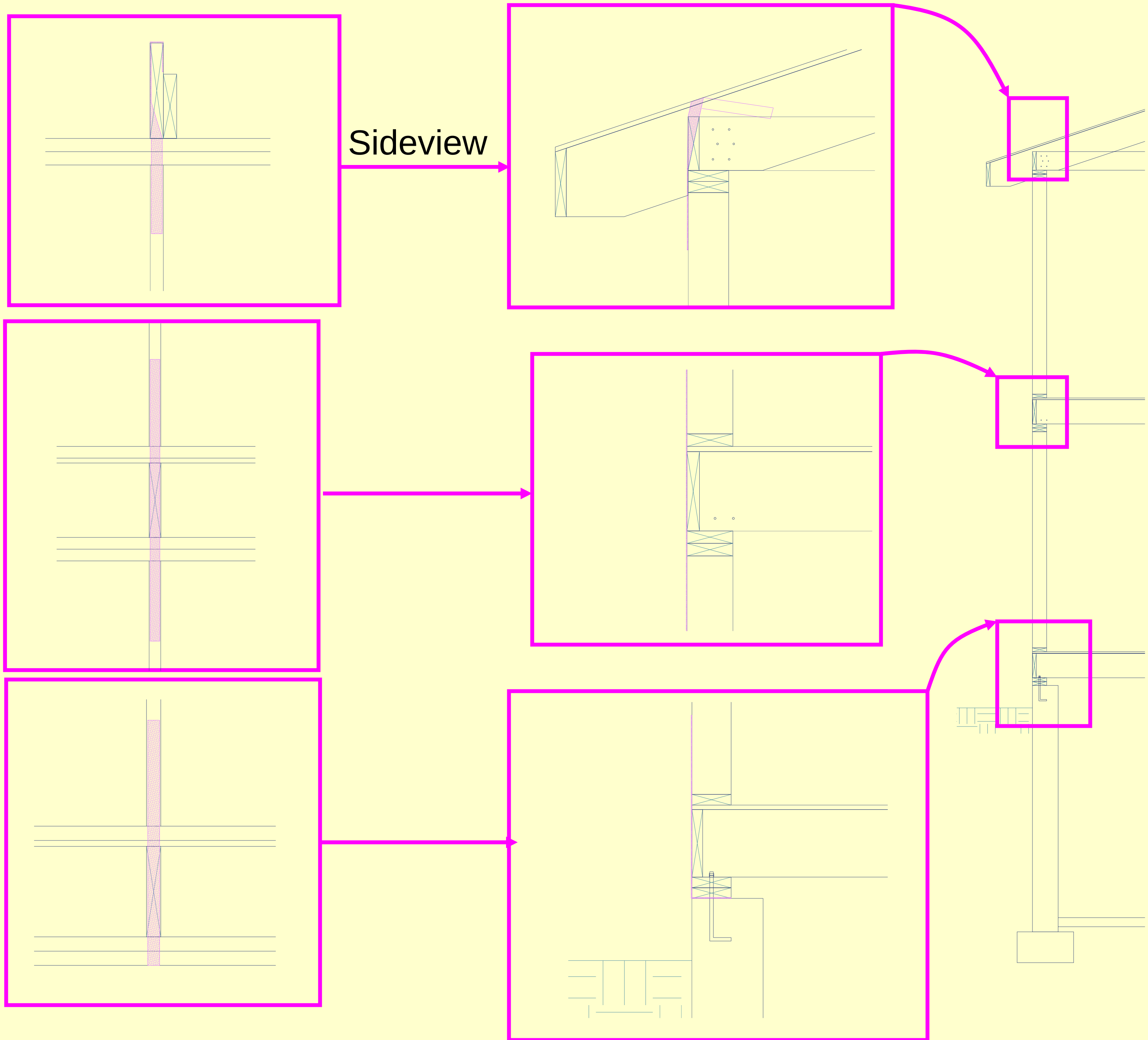
Wind forces normal to the wall



Designed from top to bottom
Constructed from bottom to top

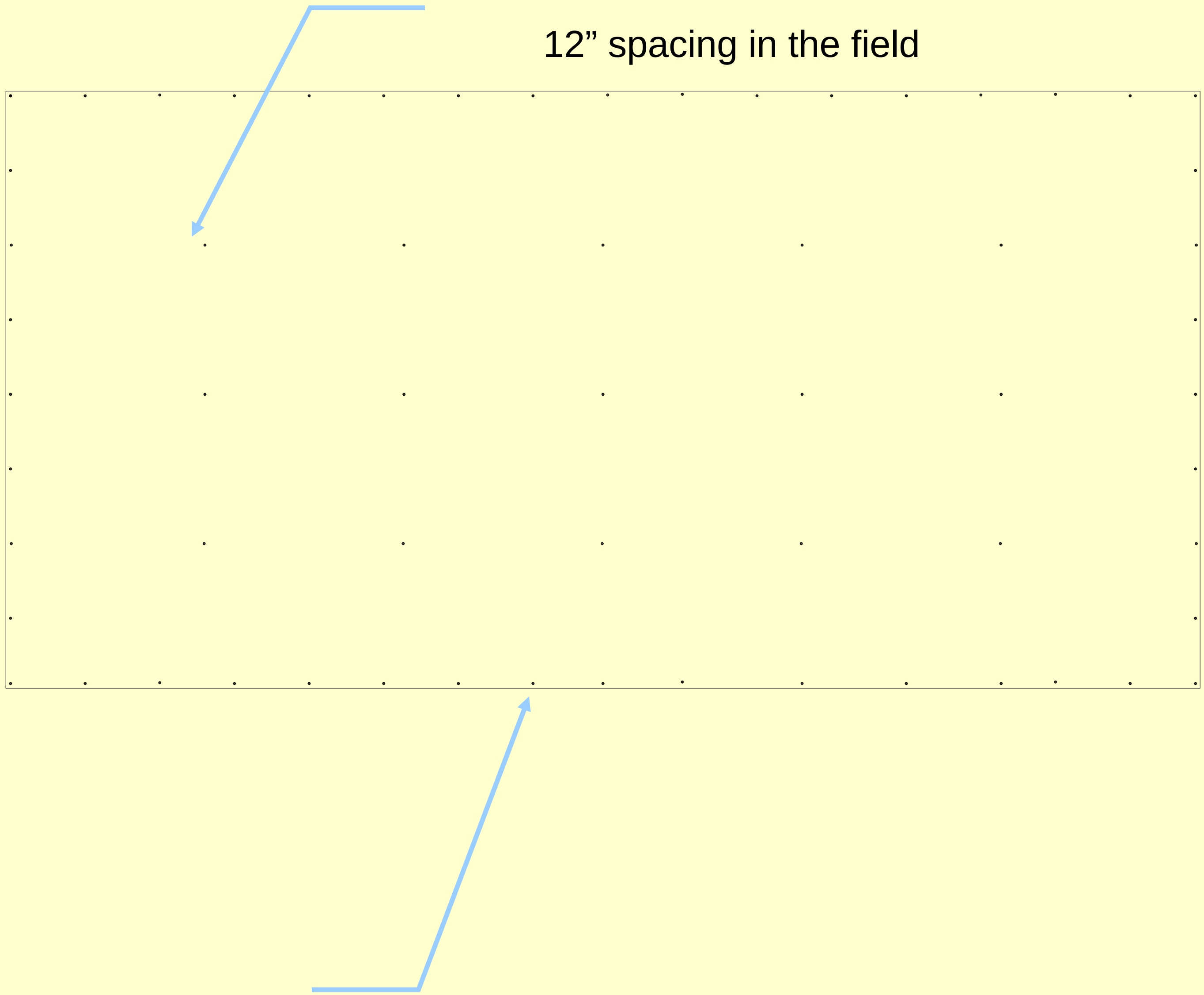


Shearwall anchorage



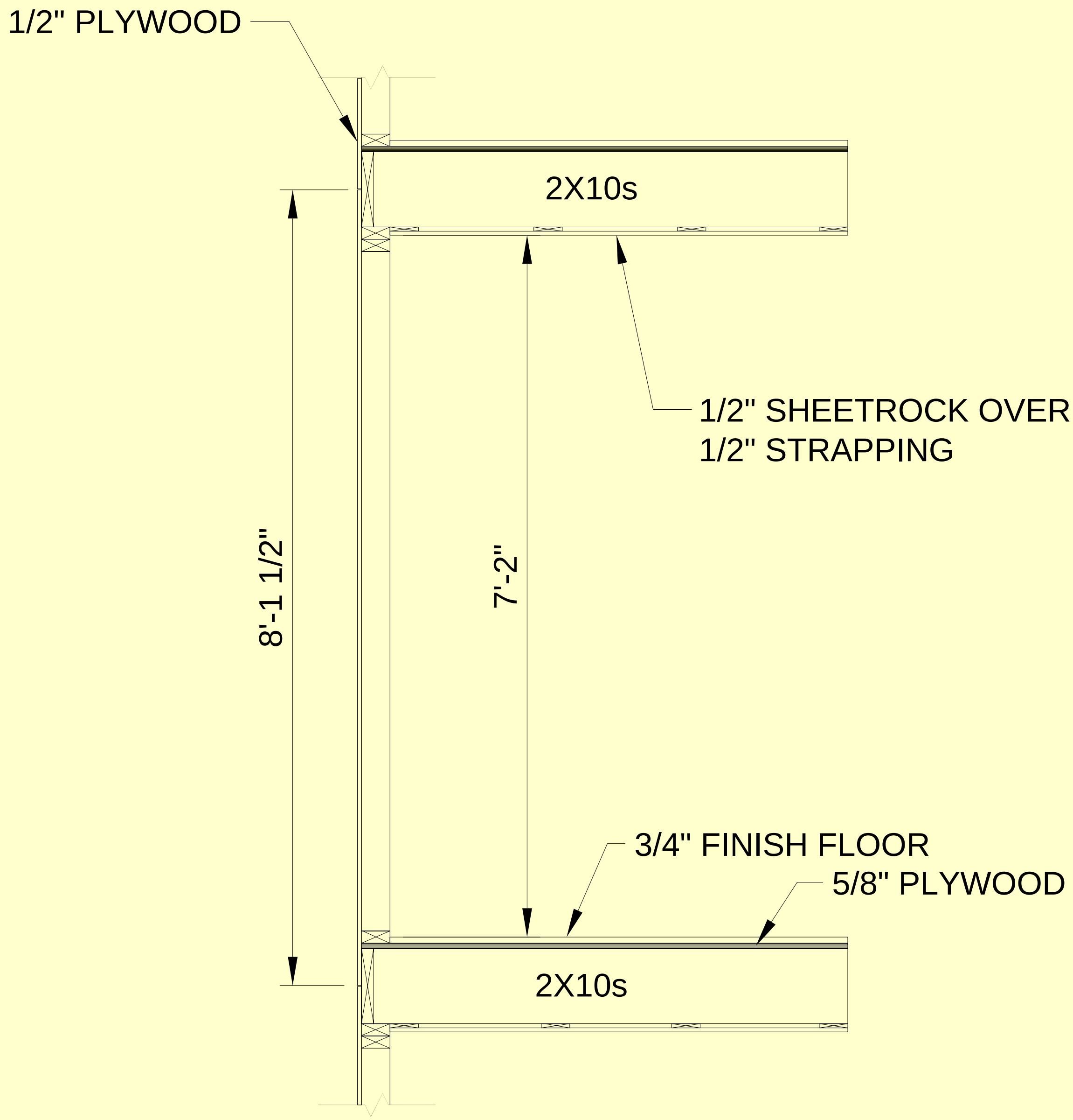
Plywood diaphragm details

12” spacing in the field

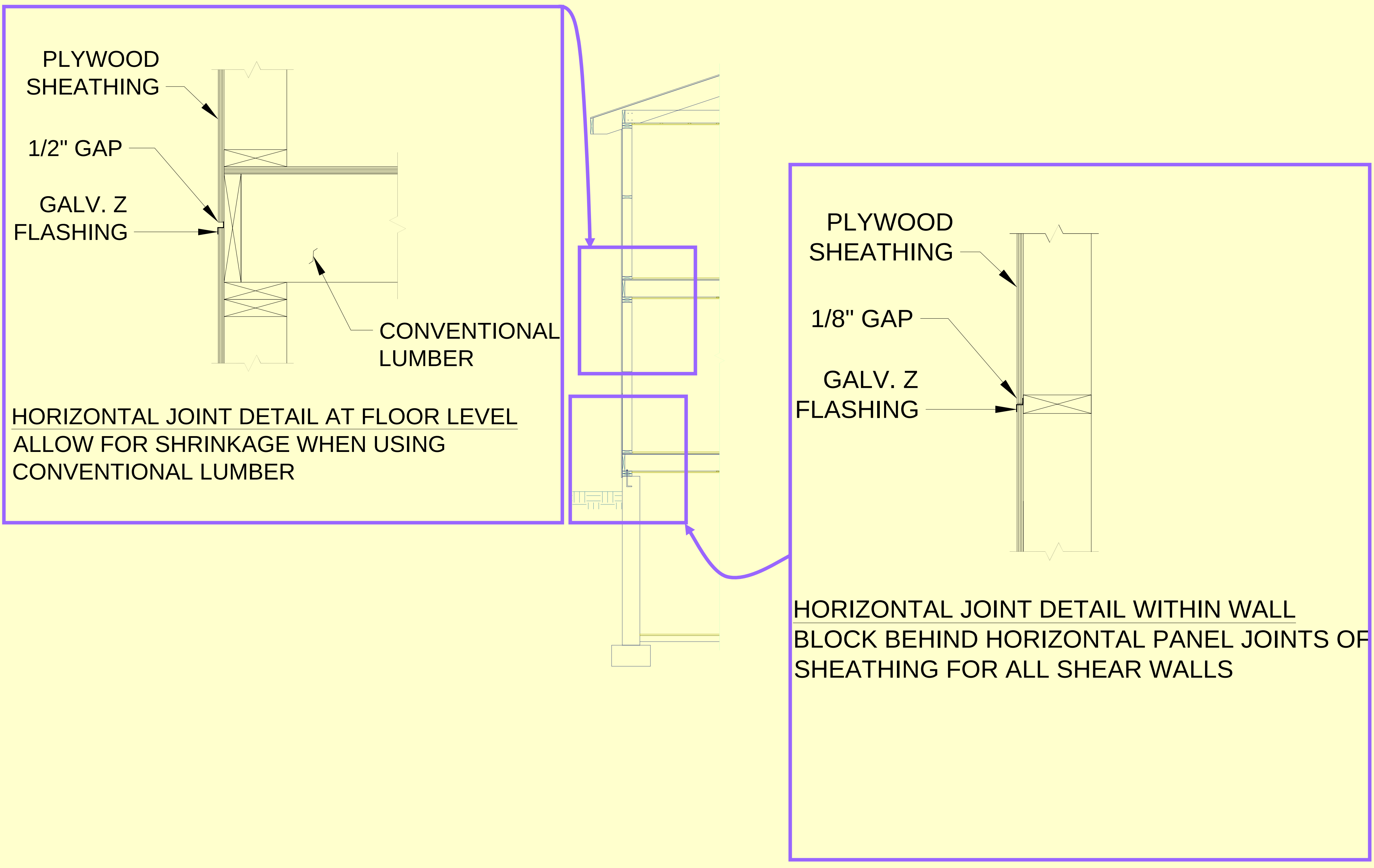


6” spacing at supported edges

Plywood on exterior walls



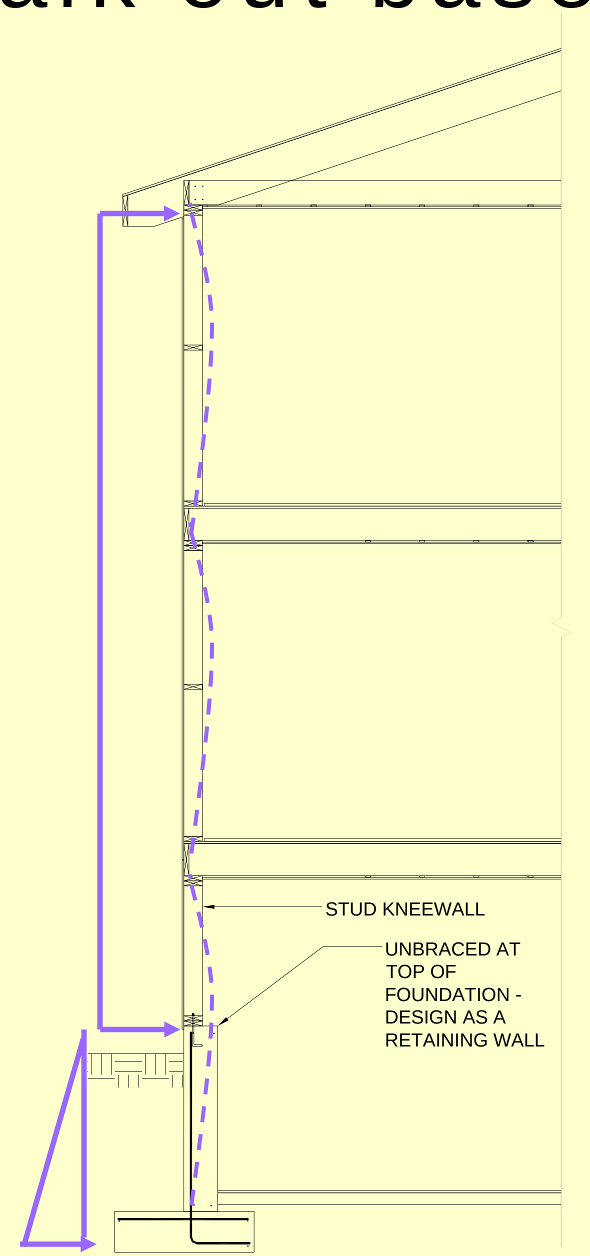
Plywood installation to exterior walls



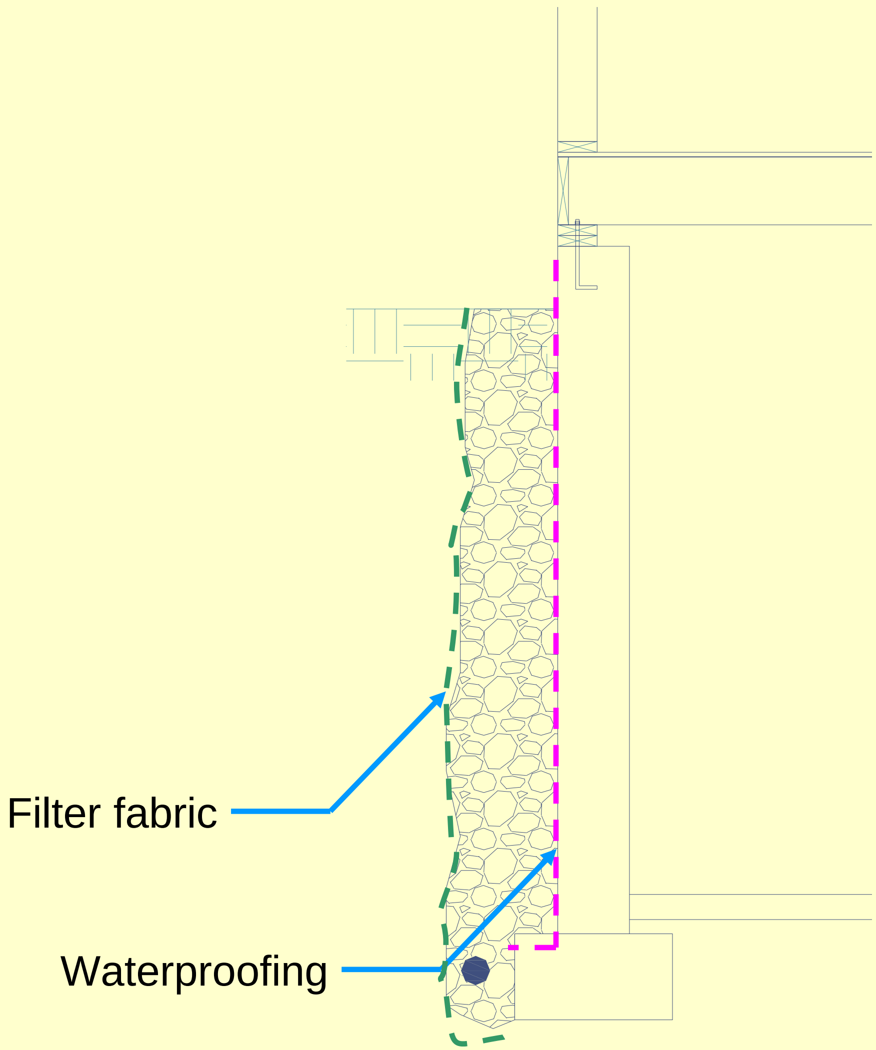
HORIZONTAL JOINT DETAIL AT FLOOR LEVEL
ALLOW FOR SHRINKAGE WHEN USING CONVENTIONAL LUMBER

HORIZONTAL JOINT DETAIL WITHIN WALL
BLOCK BEHIND HORIZONTAL PANEL JOINTS OF SHEATHING FOR ALL SHEAR WALLS

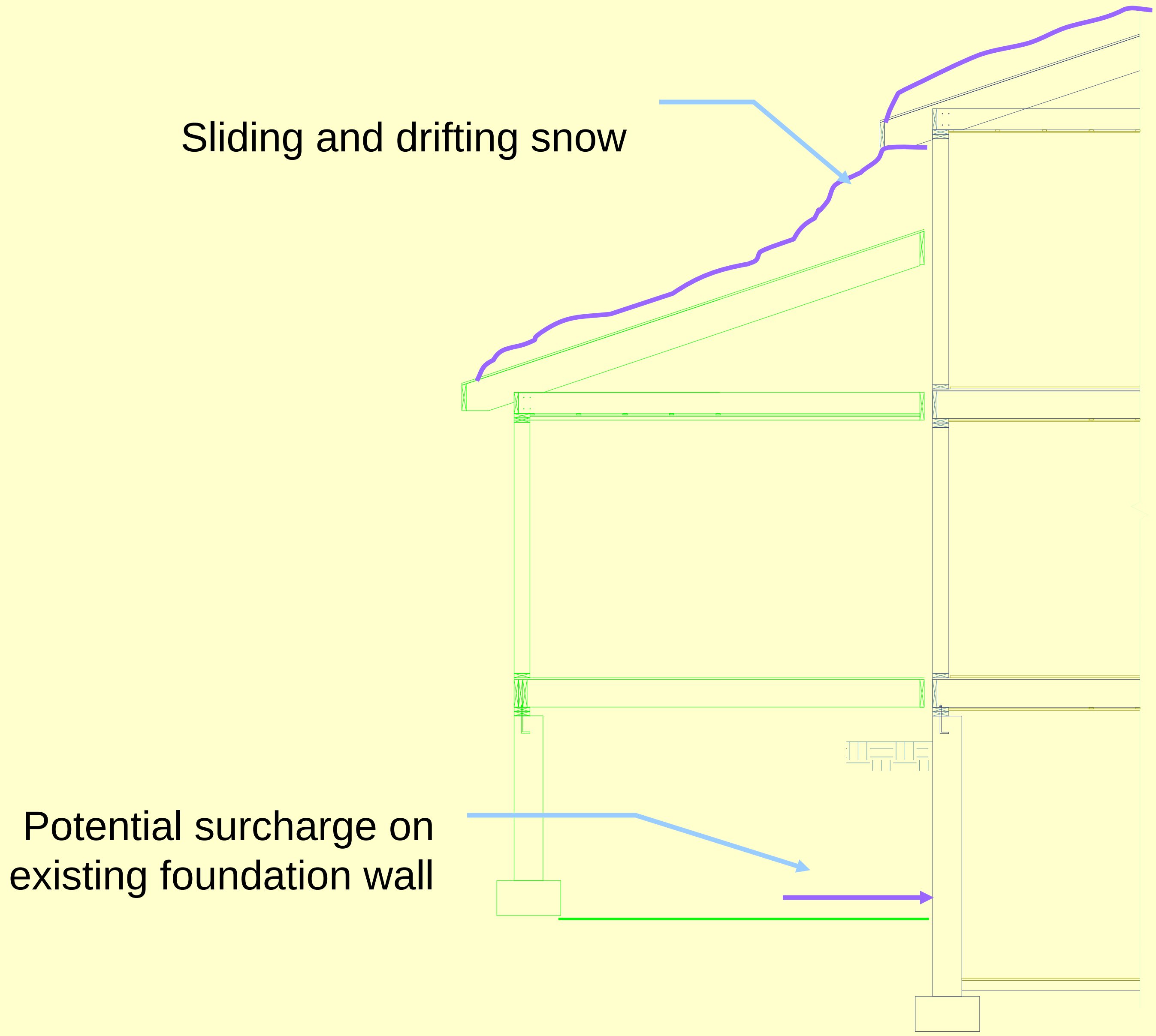
Foundation bracing (walk-out basement)



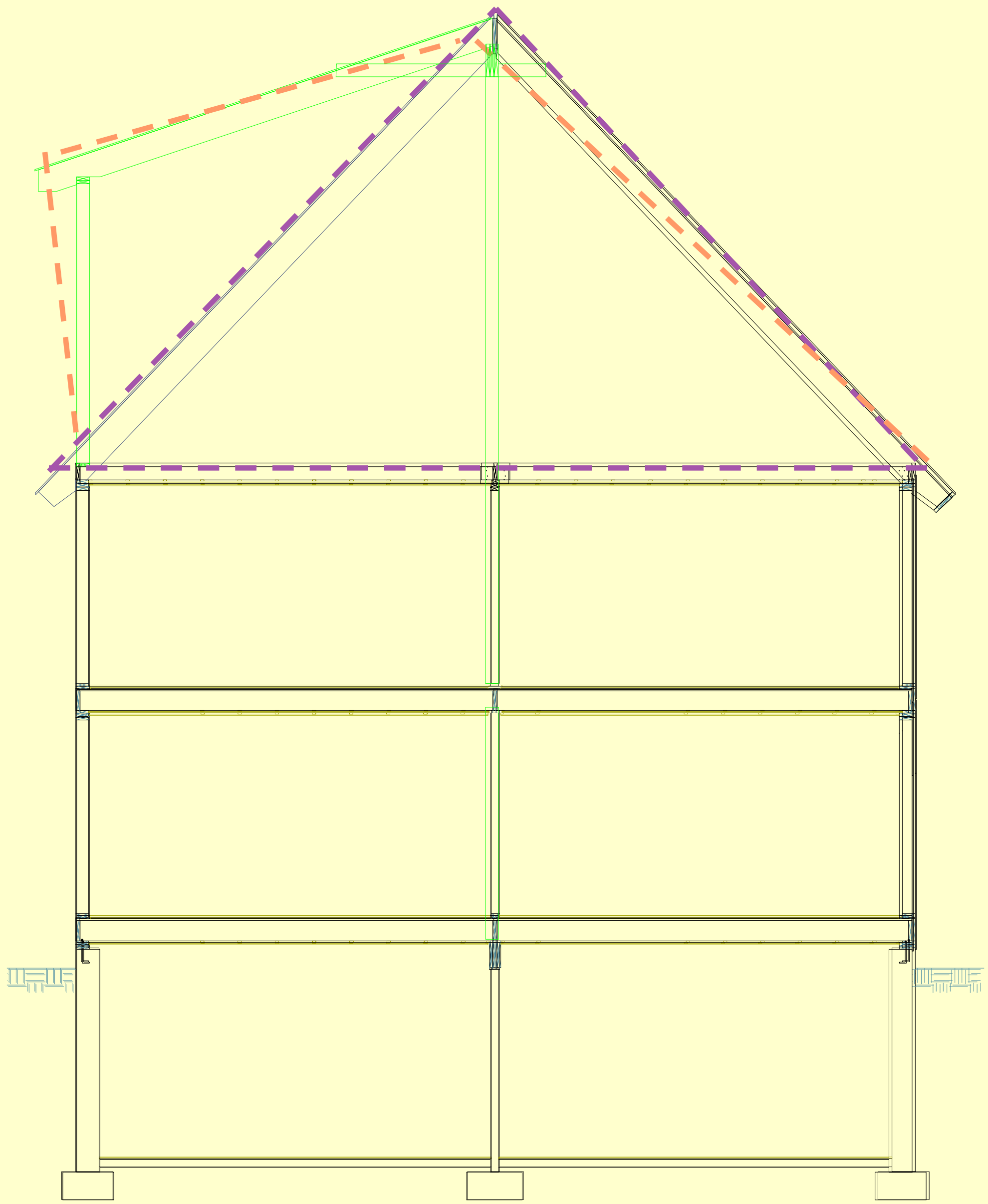
Foundation drainage



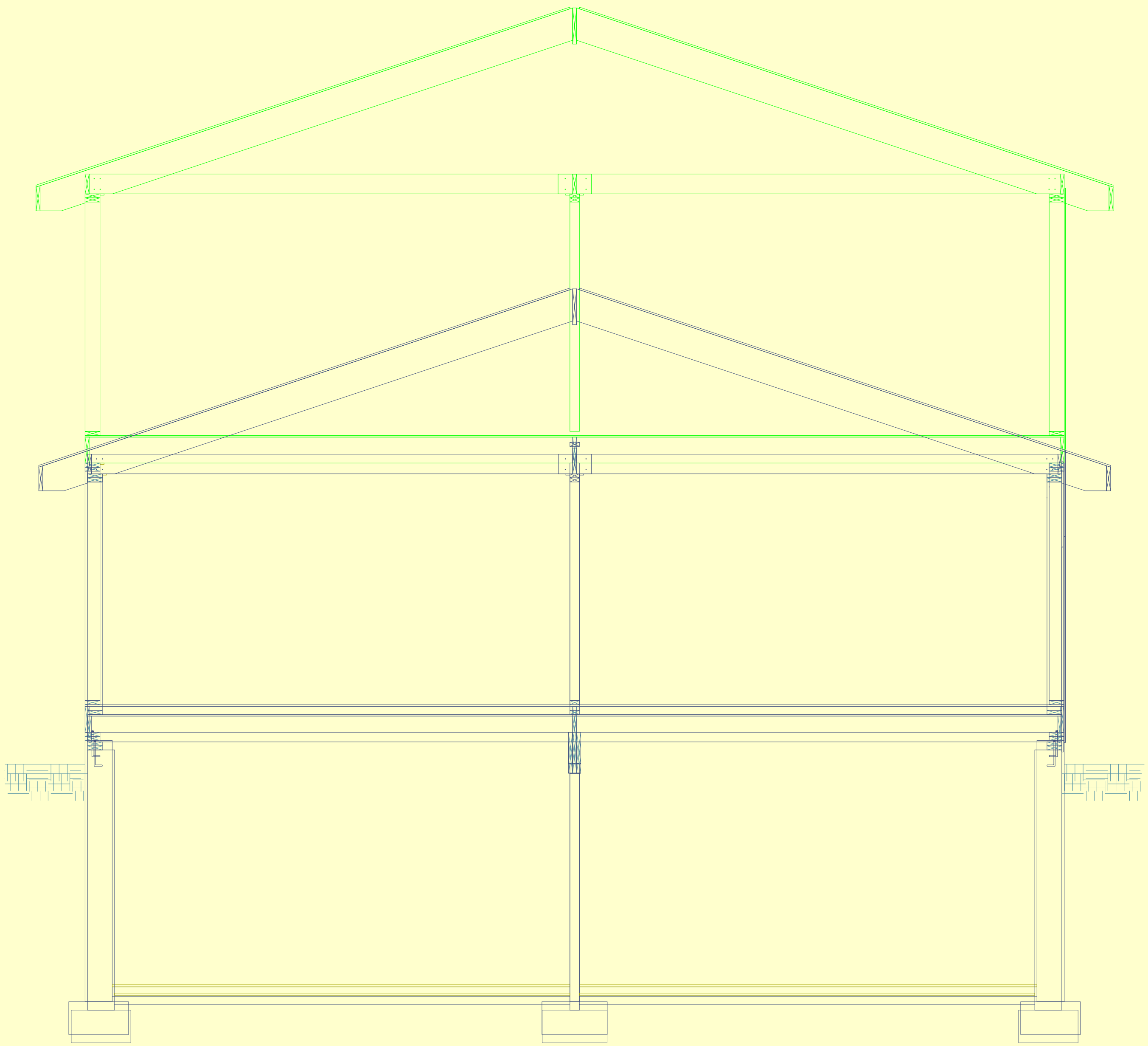
Addition on back of house



Adding a shed dormer



Adding a second floor



Closing in a 3-season porch

- Consideration of added sail area.
- May need to reduce size of windows or provide a connection that will not translate at the roof.
- Don’t forget the roof diaphragm.

Decks

- Research at Virginia Tech. University, Department of Wood Science and Forest Products (see resources, “Load-Tested Deck Ledger Connection”)
- Loads on decks – consideration of size – new codes will require 100 psf for decks over 100 SF.
- Snow – drift & sliding?
- Firewood?
- Planters?
- Long-term loading such as planters more critical than snow

Pressure Treated Wood

- The Z-Max is recommended by Simpson Strong-tie
- Stainless steel may be an option
  - No posted connection capacities
  - Limited available types
  - ~ 4 X $

Built-up Column

2-2x4 studs fastened together for a column

$\neq$

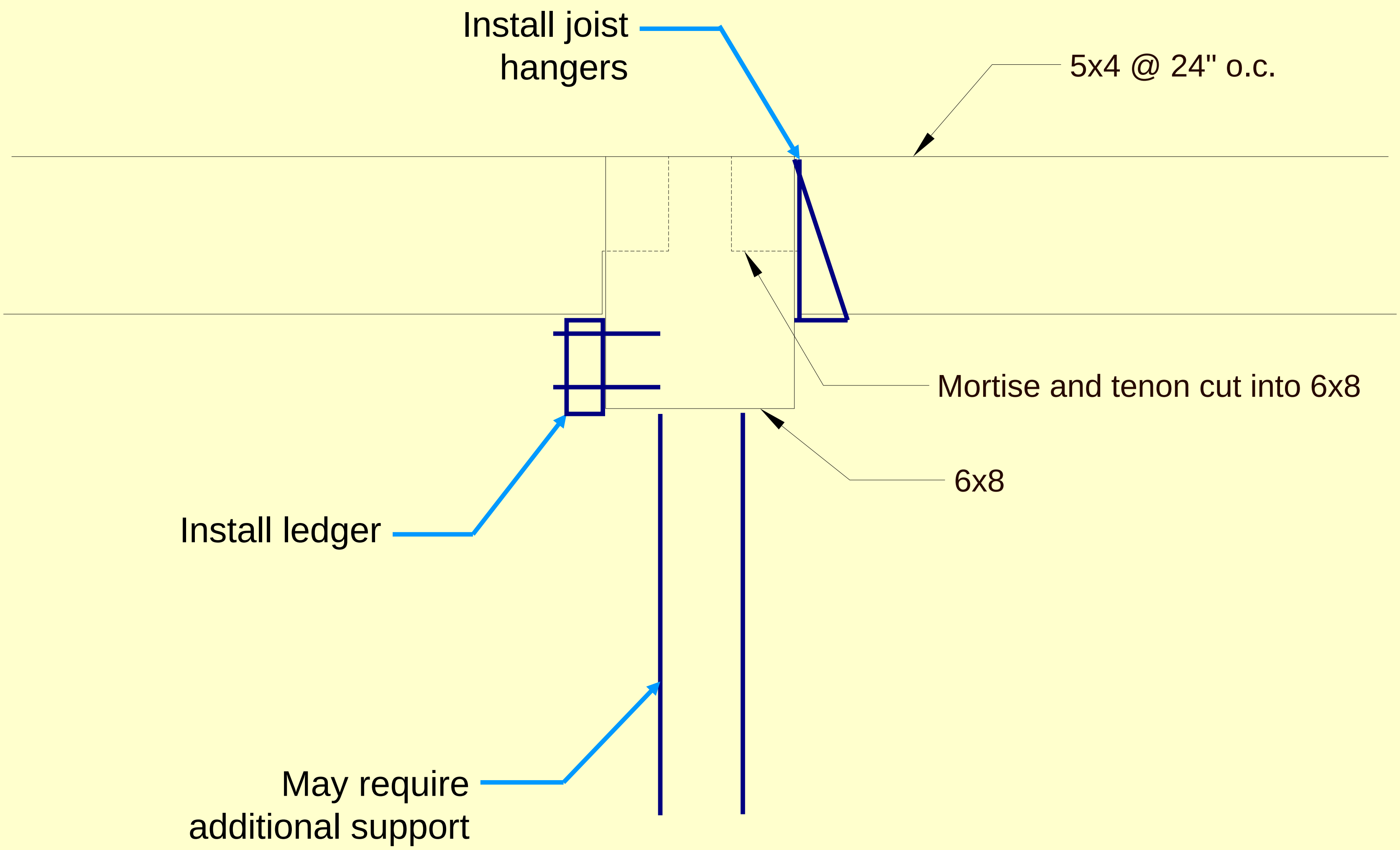
1-4x4 column

~ 60% less capacity

They don’t build ‘em like that anymore…

because It’s against the law.

Old house framing



Resources

- www.ChabotEngineering.com (slide presentation location)
- Massachusetts State Building Code, 6th Edition, 780 CMR http://www.mass.gov/bbrs/NEWCODE.HTM web version; http://www.sec.state.ma.us/spr/sprcat/agencies/780.htm order a copy
- "Wood Frame Construction Manual for One- and two-family dwellings", American Forest & Paper Association & American Wood Council http://www.awc.org/Standards/wfcm.html
- "Design of Wood Structures", D. Breyer, K. Fridley, & K. Cobeen
- "Design/Construction Guide – Diaphragms and Shear Walls", APA – The Engineered Wood Association http://www.apawood.org/level_b.cfm?content=pub_main
- *The Journal of Light Construction* http://www.jlconline.com/
- "Load-Tested Deck Ledger Connection", *The Journal of Light Construction, March 2004*
- *Fine Homebuilding* http://www.taunton.com/finehomebuilding/index.asp
- International Building Code, 2003 http://www.iccsafe.org/
- International Residential Code, 2003 http://www.iccsafe.org/

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