Structural Engineering of Texas Mid-Rise Buildings

Presented by Drew Dudley, PE, SE

DUDLEY | DUNHAM ENGINEERING

CONSTRUCTION SCIENCE
TEXAS A&M UNIVERSITY

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Course Description

This presentation is intended for structural engineers who are seeking to broaden their knowledge of design considerations associated with 4- to 6-story light wood-frame buildings in Texas. Topics will include structural design steps, considerations, and detailing best practices related to both gravity and lateral systems. Lateral design discussion will review engineering for high winds and design of open front structures due to the increasing desire for large window and door penetrations at exterior walls. Other topics will include specification of plated wood trusses, options for exterior balcony framing, masonry shelf angle design for taller veneers (exceeding 30 feet), wood shrinkage, and floor vibration.

Learning Objectives

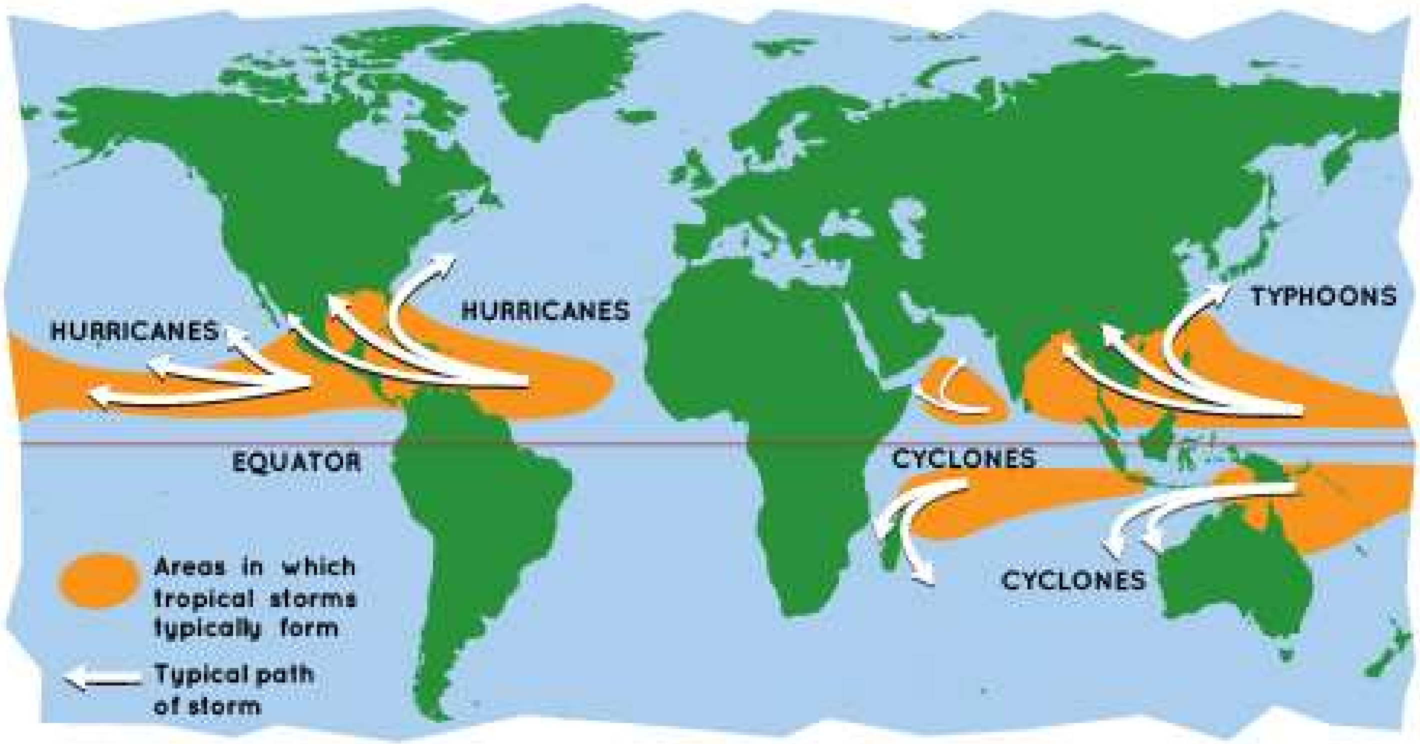
1. Discuss lateral design considerations such as high winds and cantilever diaphragm/shear wall design (open front structures), and the associated code provisions.

2. Review the basics of specifying metal plate-connected wood trusses.

3. Highlight code-compliant balcony framing options.

4. Discuss masonry shelf angle design for taller veneers, wood shrinkage, and floor vibration.

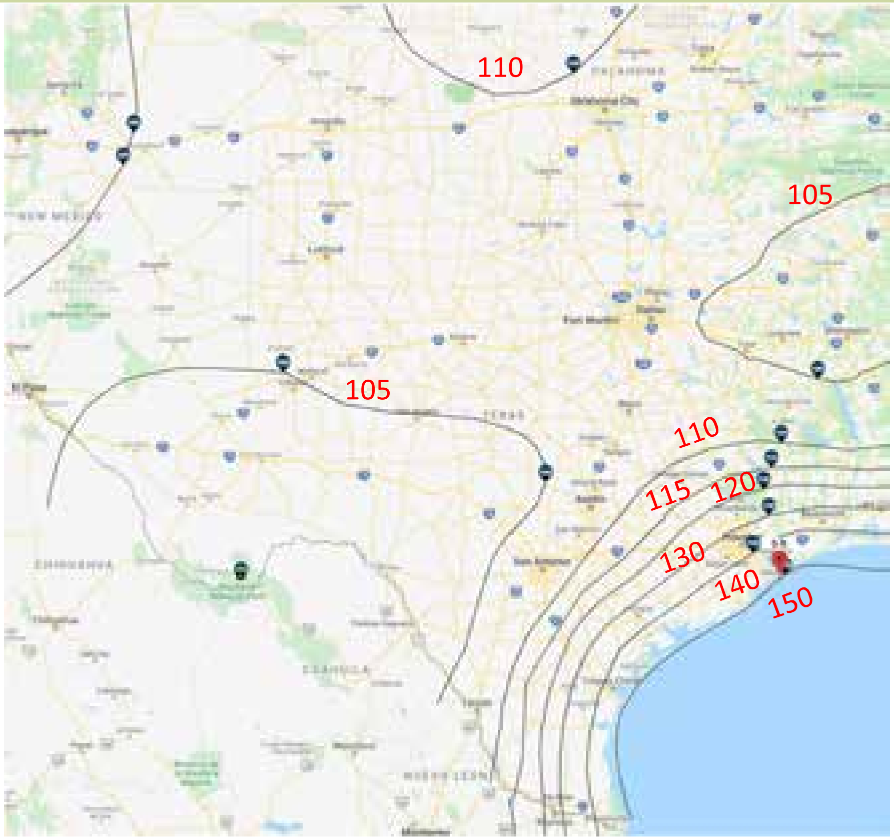
High Winds



TROPICAL CYCLONE REGIONS AROUND THE WORLD

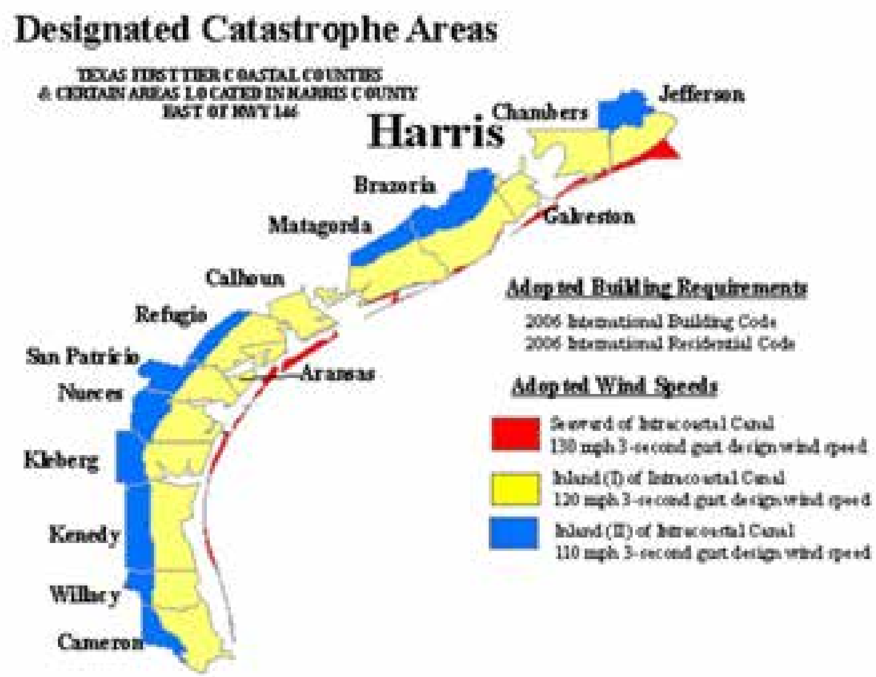
https://spaceplace.nasa.gov/hurricanes/en/

High Winds



ASCE 7-16 WIND MAP RISK CATEGORY II -

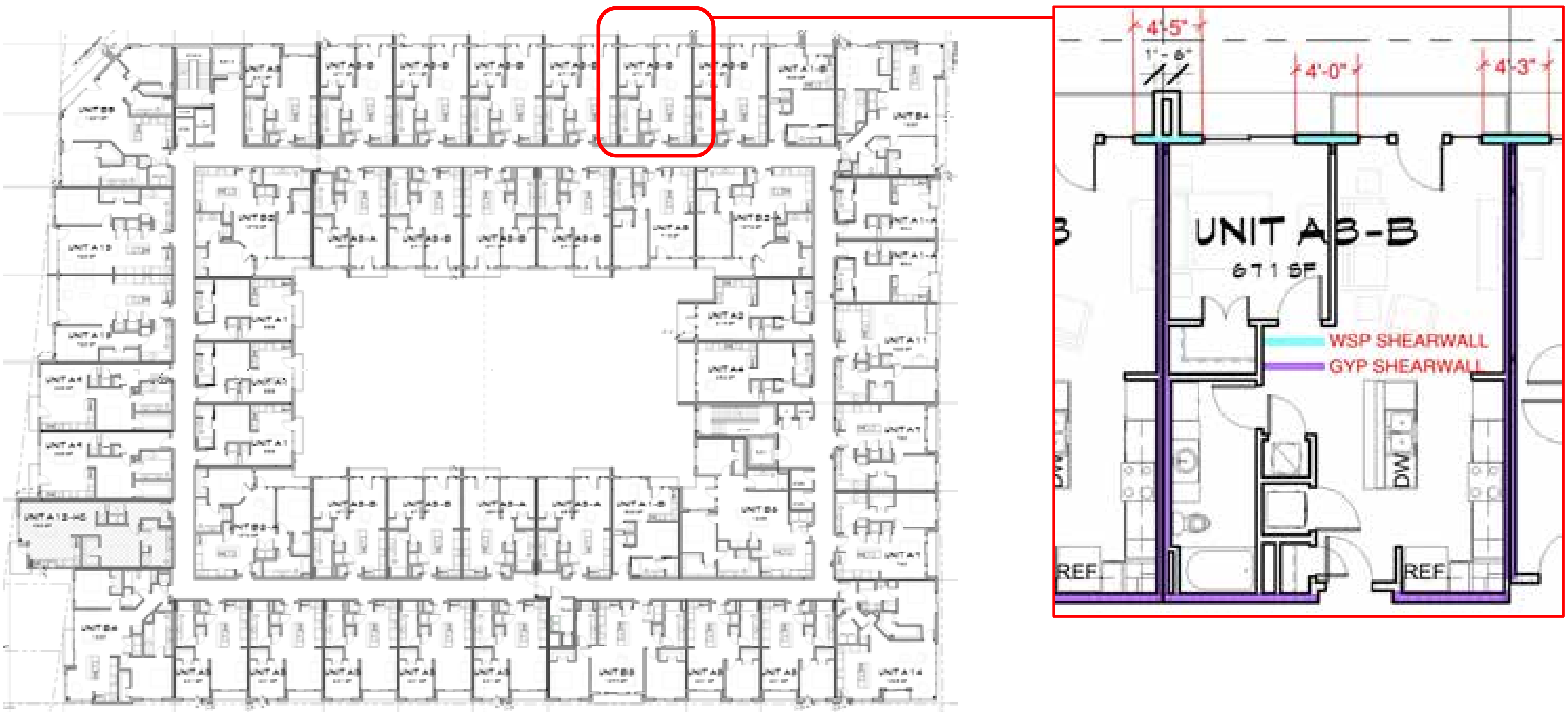
https://hazards.atcouncil.org/#/



TEXAS DEPARTMENT OF INSURANCE – DESIGNATED CATASTROPHE AREAS

https://www.tdi.texas.gov/wind/maps/index.html

Shear Walls


4'-5"
1'-6"
4'-0"
4'-3"
UNIT A3-B
671 SF
WSP SHEARWALL
GYP SHEARWALL
DW
DW
REF
REF

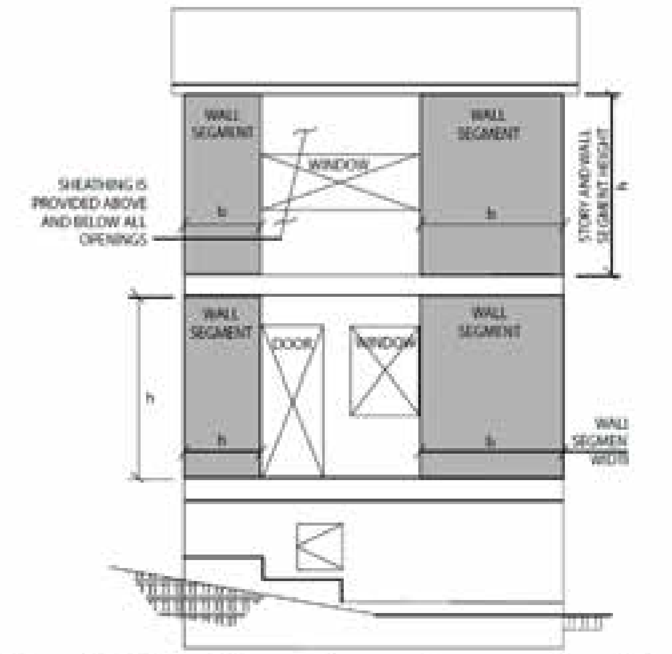
Shear Walls

Table 4.3.4 Maximum Shear Wall Aspect Ratios

Shear Wall Sheathing Type	Maximum h/b_s Ratio
Wood structural panels, unblocked	2:1
Wood structural panels, blocked	3.5:1
Particleboard, blocked	2:1
Diagonal sheathing, conventional	2:1
Gypsum wallboard	2:1[1]
Portland cement plaster	2:1[1]
Structural Fiberboard	3.5:1

1 Walls having aspect ratios exceeding 1.5:1 shall be blocked shear walls.

SDPWS-2015 TABLE 4.3.4



Note: b_s is the minimum shear wall segment length, b, in the perforated shear wall.

SDPWS-2015 FIGURE 4C

Shear Walls

SHEAR WALL SCHEDULE

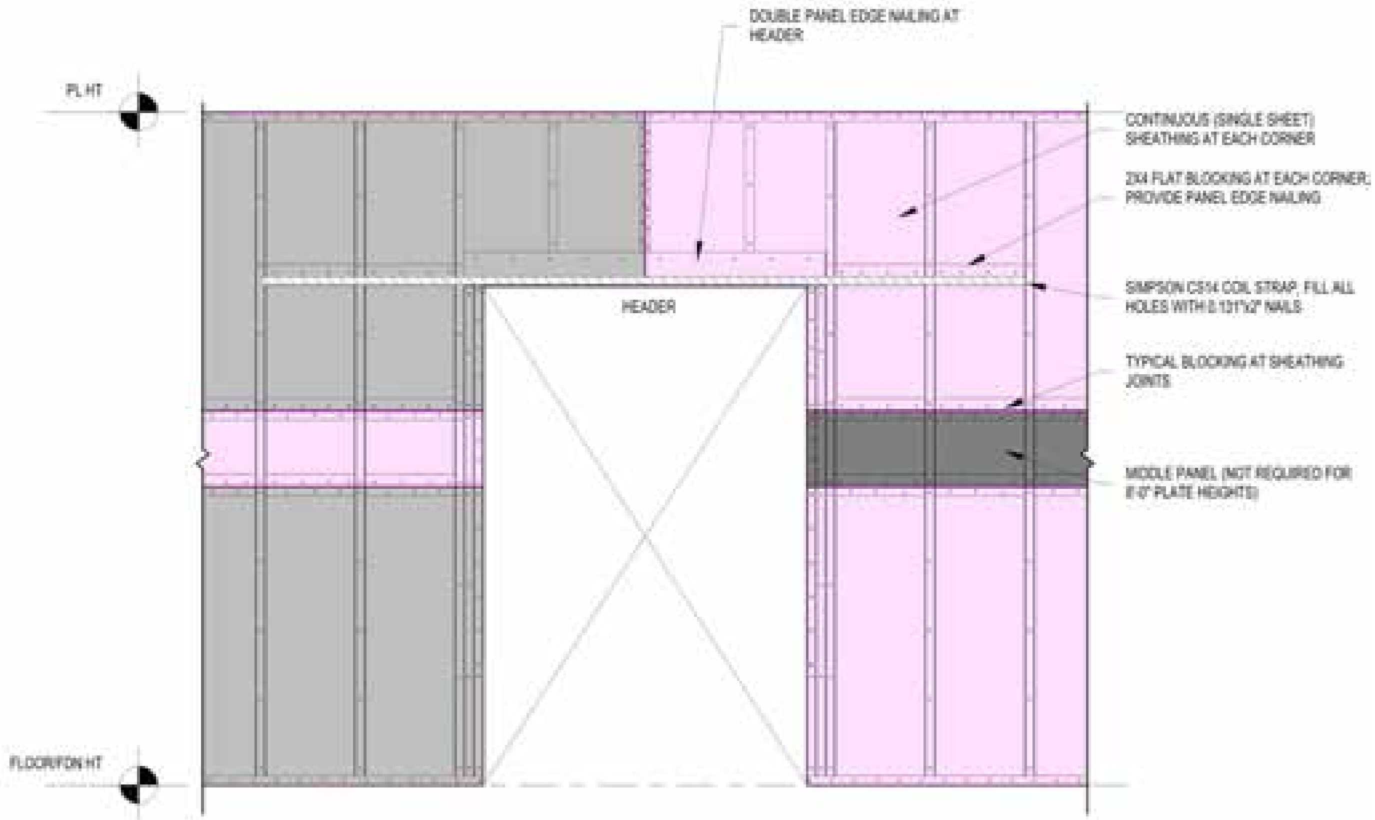
SHEAR WALL TYPE	SHEATHING TYPE	PANEL EDGE NAILING	FIELD NAILING	BOTTOM PLATE ANCHORAGE (CONCRETE)[3]	BOTTOM PLATE FASTENING (WOOD)	ALLOWABLE WIND SHEAR CAPACITY
SW1	7/16" WSP	6"	12"	5/8"Ø @ 40" OC	0.131"Ø X 3" LONG NAILS @ 3" OC	335 PLF
SW2	7/16" WSP	4"	12"	5/8"Ø @ 32" OC	0.131"Ø X 3" LONG NAILS @ 3" OC	490 PLF
SW3	7/16" WSP	3"	12"	5/8"Ø @ 24" OC	0.131"Ø X 3" LONG NAILS @ 2" OC	630 PLF
SW4	15/32" WSP	3"	12"	5/8"Ø @ 24" OC	0.131"Ø X 3" LONG NAILS @ 2" OC	840 PLF
SW5	15/32" WSP	2"	12"	5/8"Ø @ 24" OC	0.148"Ø X 3" LONG NAILS @ 2" OC	991 PLF
GW1	1/2" GYP WALLBOARD[2]	7"	12"	5/8"Ø @ 48" OC	0.131"Ø X 3" LONG NAILS @ 12" OC	75 PLF
GW2	1/2" GYP WALLBOARD[2]	4"	12"	5/8"Ø @ 48" OC	0.131"Ø X 3" LONG NAILS @ 12" OC	110 PLF

1. ALL FASTENERS FOR WOOD STRUCTURAL PANEL SHALL BE FLAT HEAD NAILS CONSISTING OF THE FOLLOWING UNO:
   A. 0.131"Ø X 2" LONG
   B. 0.148"Ø X 2½" LONG
2. FASTENERS FOR GYPSUM WALLBOARD SHALL BE 5d COOLER NAILS (0.086" X 1 5/8" LONG, 15/64" HEAD)
3. ANCHORS INTO CONCRETE SHALL EITHER BE CAST-IN-PLACE J-BOLTS OR ADHESIVE ANCHORS WITH A MINIMUM EMBEDMENT OF 8". THE CONTRACTOR SHALL SUBMIT PROPOSED ADHESIVE ANCHOR ASSEMBLY FOR APPROVAL.
4. ALL PANEL EDGES SHALL BE BLOCKED.
5. WSP = WOOD STRUCTURAL PANEL. REF GENERAL NOTES FOR SPECIFICATIONS.
6. IF WALL IS SHEATHED ON BOTH SIDES, THEN SILL PLATE ANCHORAGE AND CONNECTION OF BOTTOM PLATE TO TOP PLATE SHALL BE DOUBLED.
7. PANELS MUST BE INSTALLED DIRECTLY TO FRAMING.
8. VALUES CALCULATED ARE FOR SOUTHERN PINE OR DOUGLAS-FIR LARCH FRAMING. CONTACT EOR IF OTHER SPECIES ARE USED.

DUDLEY DUNHAM ENGINEERING TYPICAL SHEAR WALL SCHEDULE

Shear Walls

Force Transfer Around Opening



DUDLEY DUNHAM ENGINEERING TYPICAL FORCE TRANSFER AROUND OPENING

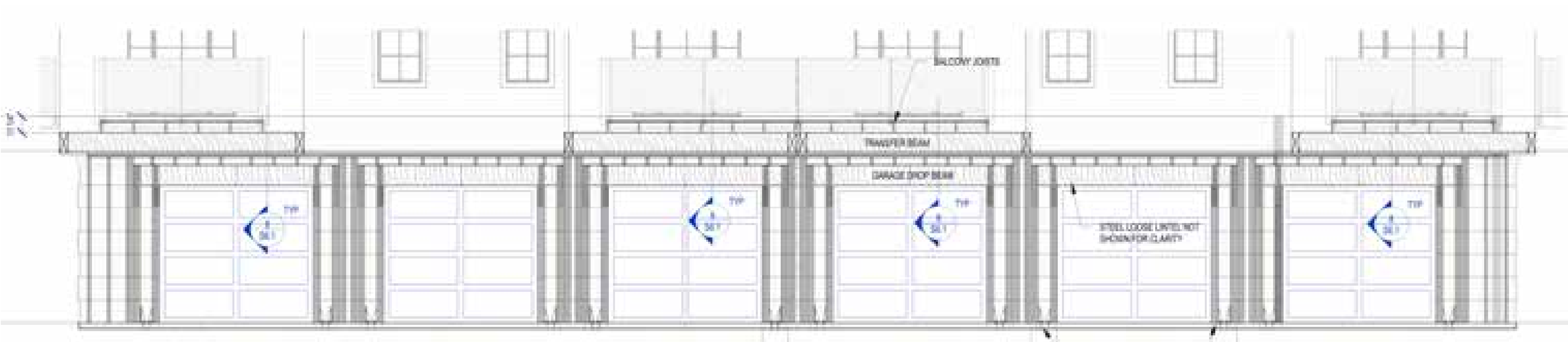
Shear Walls

Highly Perforated Walls – Open Front Structures

Arch. Images

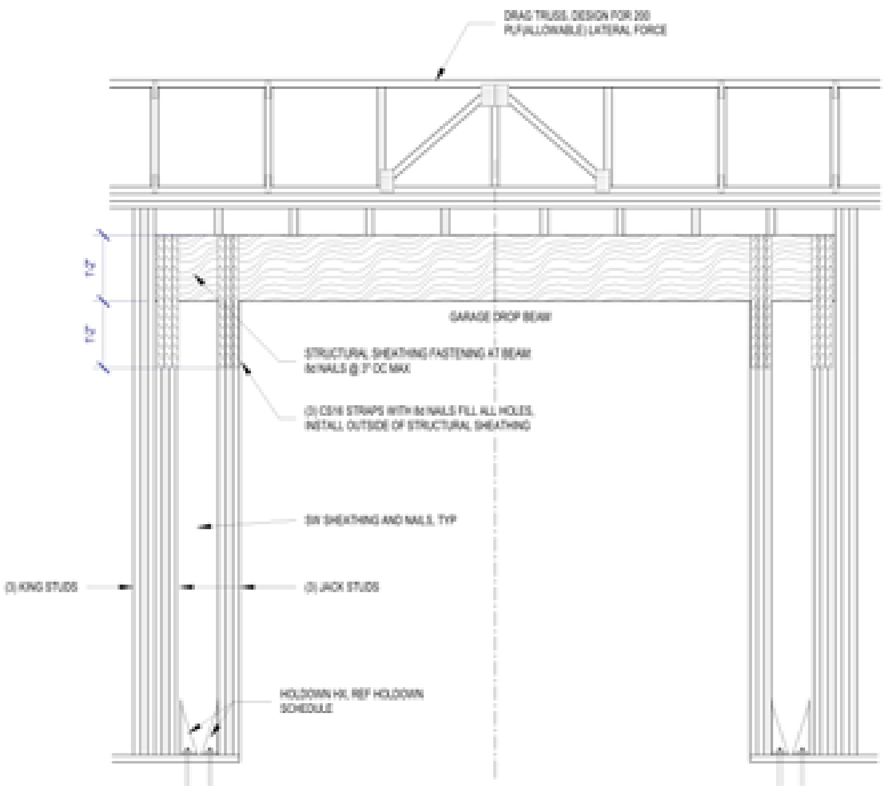
Courtesy of

PACT DESIGN STUDIO



Shear Walls

Portal Frames



DUDLEY DUNHAM ENGINEERING TYPICAL GARAGE PORTAL FRAME

Table 1. Recommended Allowable Design Values for APA Portal Frame Used on a Rigid-Base

Minimum Width (in.)	Maximum Height (ft)	Allowable Design (ASD) Values per Frame Segment: Shear[a,b] (lbf)	Deflection (in.)	Load Factor
16	8	850	0.33	3.09
	10	625	0.44	2.97
24	8	1,675	0.38	2.88
	10	1,125	0.51	3.42

APA TECHNICAL NOTE TT-100F– APRIL 2014

Shear Walls

Open Front Structures – Diaphragm – Does it Apply to Wind Load?

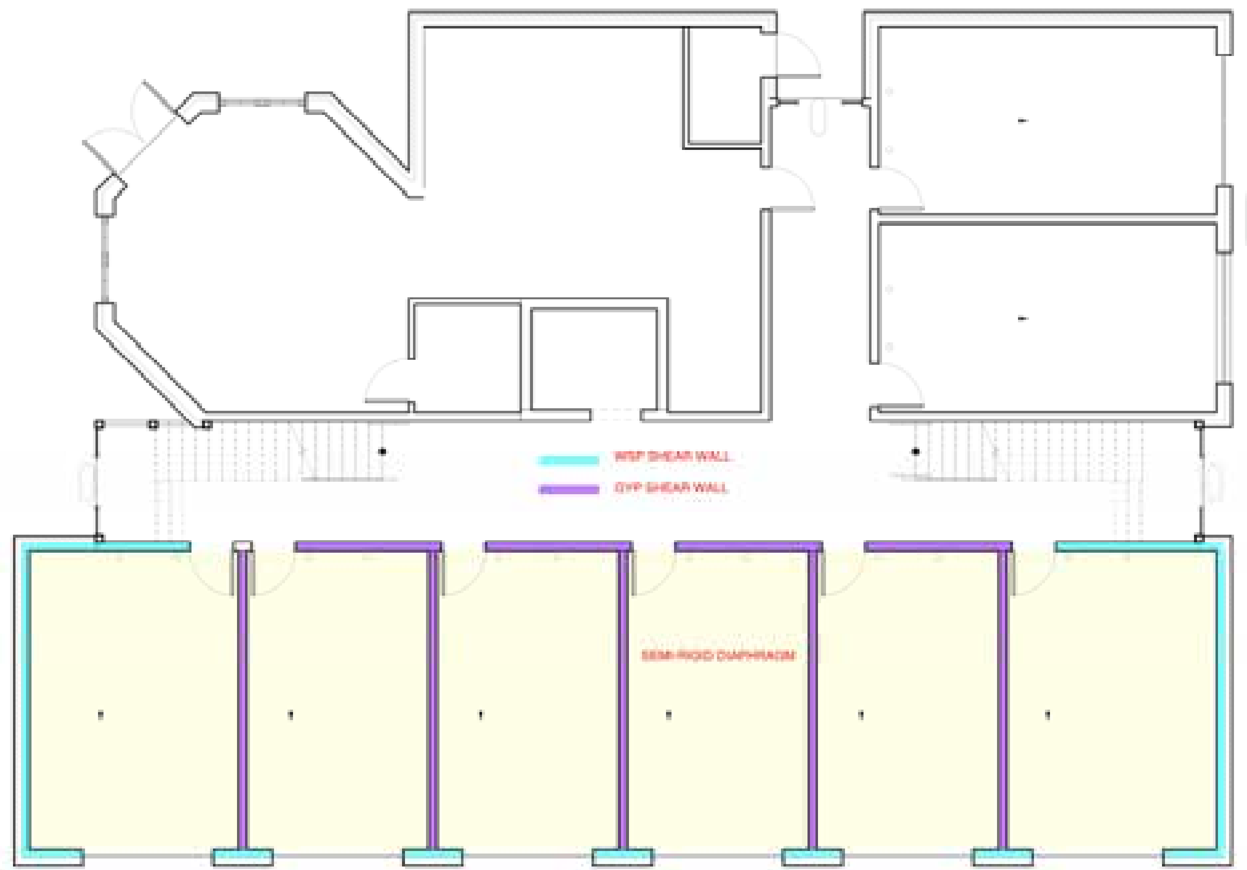
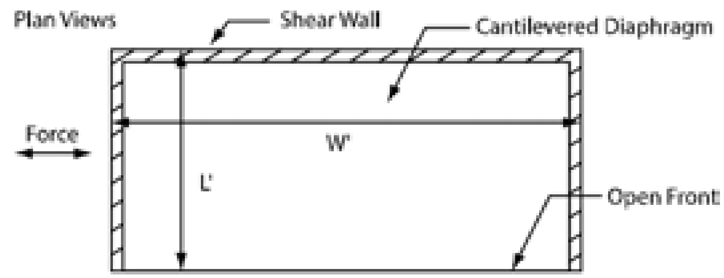


Figure 4A **Examples of Open Front Structures**

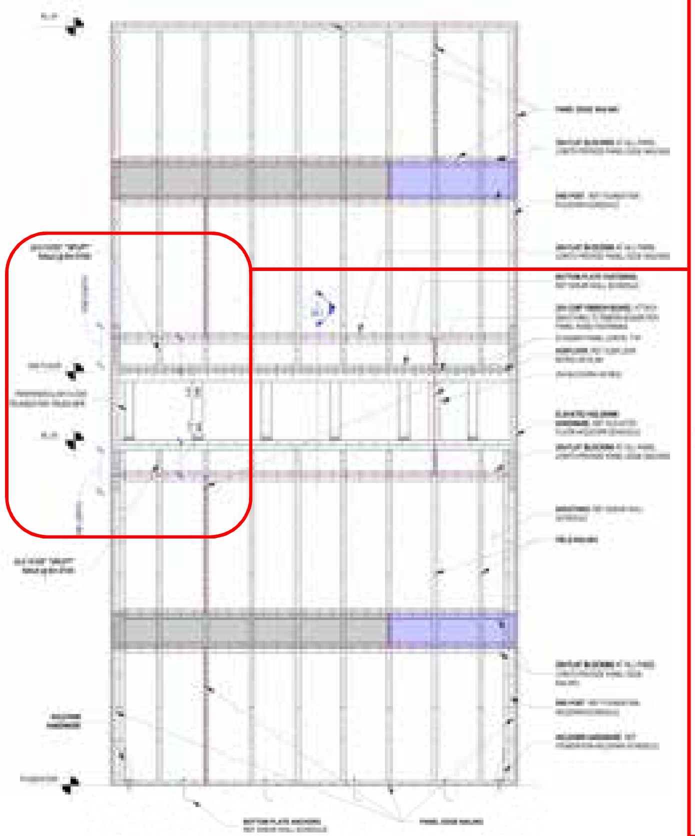


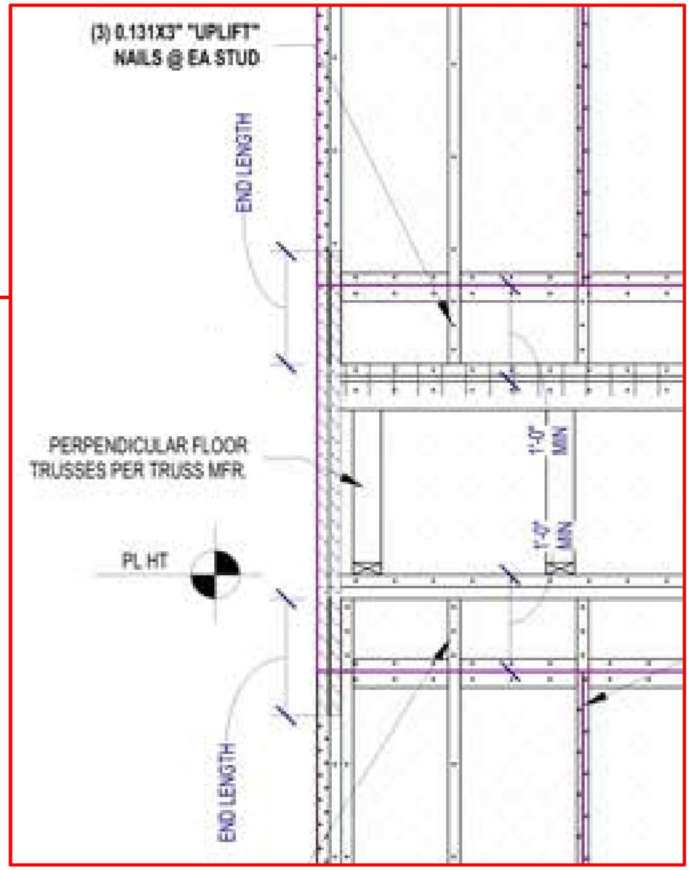
SDPWS -2015 FIGURE 4A

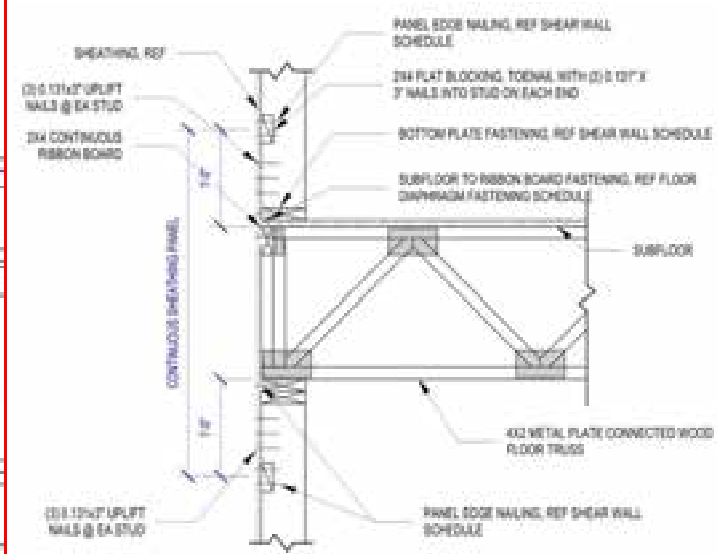
L’ ≤ 35’

L’/W’ ≤ 1.5 (WSP SUBFLOOR)

Combined Lateral and Uplift Load Path







APA TECHNICAL NOTE NO. E510A – FEB. 2008

DUDLEY DUNHAM ENGINEERING TYPICAL DETAIL AT ELEVATED FLOOR

Specifying Metal Plate Connected Wood Trusses

FLOOR TRUSS FABRICATION

ROOF TRUSSES INSTALLED

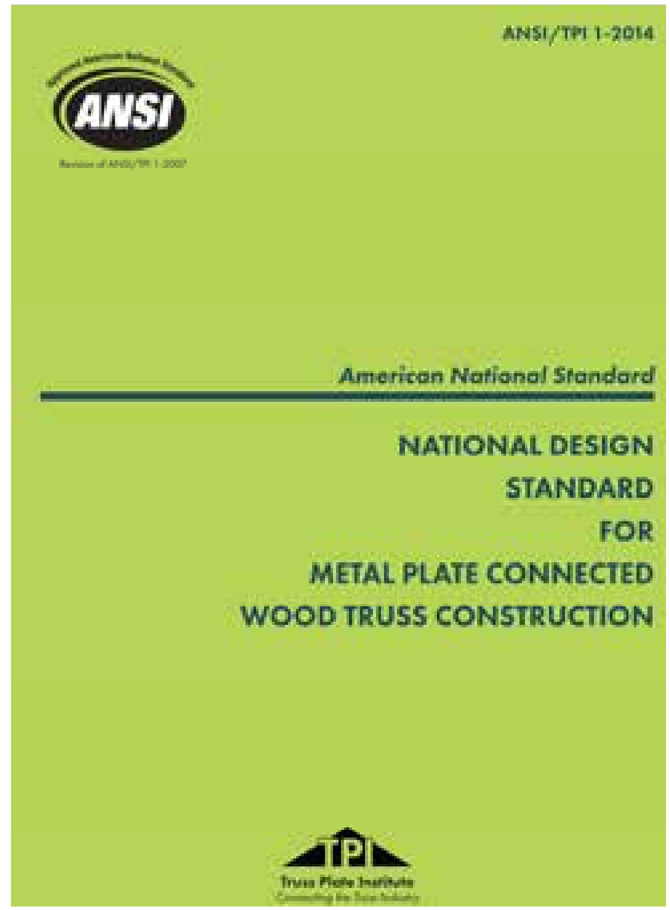
Specifying Metal Plate Connected Wood Trusses

2303.4.6 TPI 1 specifications. In addition to Sections 2303.4.1 through 2303.4.5, the design, manufacture and quality assurance of metal-plate-connected wood trusses shall be in accordance with TPI 1. Job-site inspections shall be in compliance with Section 110.4, as applicable.

IBC 2015

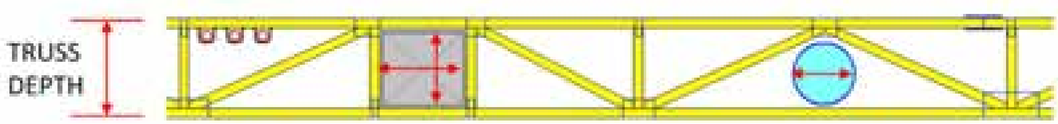
§2.3.2 OF TPI 1 – Requirements of the Building Designer

- Indicate location, nature and extent of work proposed and show in detail that such documents conform to the Building Code
- List trusses as a deferred submittal in the Construction Documents & review said deferred submittals.
- Required info on Construction Documents
  - Structural element orientation and locations
  - Info to determine all truss profiles
  - All support conditions and bearing locations
  - Location, direction and magnitude of all loads applicable to trusses
  - All anchorage design and connections to the structure
  - Serviceability criteria
  - Permanent lateral bracing (if not covered by BCSI-B3)



Specifying Metal Plate Connected Wood Trusses

Overall Truss Depth (Inches)	Width (W) (Inches) When Height (H) Equals:						Diameter (D) (Inches)
	3"	4"	5"	6"	7"	8"	
12	32	25	19	12	6	–	7
13	34	28	23	17	11	5	8
14	36	31	26	20	15	10	9
15	38	33	28	23	19	14	10
16	40	35	31	26	22	17	11
17	41	37	32	28	24	20	12
18	42	38	34	30	26	22	13
19	43	39	36	32	28	25	14
20	44	40	37	33	30	26	15
21	44	41	38	35	31	28	16
22	45	42	39	36	33	30	17
23	46	43	40	37	34	31	18
24	46	43	41	38	35	32	18-1/2



Open-Web Maximum Chase Clearances – Mitek Floor Truss Advantage

40/10/0/10 = 60 PSF @ 0%

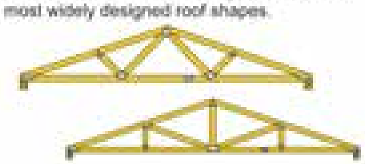
Depth (Inches)	24" o.c.	19.2" o.c.	16" o.c.	12" o.c.
12	16-04	18-08	20-06	20-06
13	17-02	19-06	21-08	22-02
14	17-11	20-04	22-07	23-11
15	18-07	21-02	23-06	25-07
16	19-03	21-11	24-04	27-03
17	19-11	22-08	25-02	29-00
18	20-06	23-05	25-11	30-05
20	21-09	24-09	27-06	32-03
22	22-11	26-01	28-11	33-11
24	24-00	27-04	30-04	35-06

Floor Truss Max Spans– Mitek Floor Truss Advantage

Specifying Metal Plate Connected Wood Trusses

Alpine truss designs are engineered to meet specific span, configuration and load conditions. The shapes and spans shown here represent only a fraction of the millions of designs processed by Alpine engineers.

Common – Truss configurations for the most widely designed roof shapes.



Mono – Used where the roof is required to slope only in one direction. Also in pairs with their high ends abutting on extremely long spans with a support underneath the high end.

Scissors – Provides a cathedral or vaulted ceiling. Most economical when the difference in slope between the top and bottom chords is at least 3/12 or the bottom chord pitch is no more than half the top chord pitch.

Total load(PSF) / Duration factor / Live load(PSF) / Roof type	55 / 1.15 / 40 snow shingle; 55 / 1.15 / 30 snow tile			47 / 1.15 / 30 snow shingle			40 / 1.15 / 20 snow shingle			40 / 1.25 / 20 ** shingle / **construction or rain, not snow load		
Top Chord	2x4	2x6	2x6	2x4	2x6	2x6	2x4	2x6	2x6	2x4	2x6	2x6
Bottom Chord	2x4	2x4	2x6	2x4	2x4	2x6	2x4	2x4	2x6	2x4	2x4	2x6
Pitch	**Spans in feet to out of bearing**											
Common												
2/12	24	24	33	27	27	37	31	31	43	33	33	46
2.5/12	29	29	39	33	33	45	37	38	52	39	40	55
3/12	34	34	46	37	39	53	40	44	60	43	46	64
3.5/12	39	39	53	41	44	61	44	50	65	47	52	70
4/12	41	43	59	43	49	64	46	56	69	49	57	74
5/12	44	52	67*	46	56	69*	49	66	74*	53	66	80*
6/12	46	60*	69*	47	67*	71*	51	74*	76*	55	74*	82*
7/12	47	67*	70*	48*	72*	72*	52*	77*	77*	56*	80*	83*
Mono												
2/12	24	24	33	25	27	38	27	31	41	29	32	44
2.5/12	28	29	40	29	32	43	31	37	46	33	37	49
3/12	30	33	45	31	37	47	34	42	50	36	42	54
3.5/12	33	37	49*	34	41	51*	36	46	54*	39	46	58*
4/12	35	41	52*	36	45*	54*	39	50*	58*	42*	49*	62*
5/12	38*	47*	57*	39*	51*	59*	42*	56*	63*	45*	54*	68*
Scissors												
6/12 - 2/12 ‡	40	43	59*	42	49	62*	45	56*	66	48	57*	71*
6/12 - 2.5/12 ‡	37	38	52	38	44	57*	41	50	61*	44	52	66*
6/12 - 3/12 ‡	33	33	45	35	38	52	38	43	56*	40	46	60*
6/12 - 3.5/12 ‡	28	28	38	32	32	44	34	37	50	36	39	54
6/12 - 4/12 ‡	22	22	31	26	26	36	30	30	41	32	32	44

‡ Other pitch combinations available with these spans.
For Example, a 5/12 - 2/12 combination has approx. the same allowable span as a 6/12 - 3/12

Roof Truss Span Tables– Apline Engineered Products

Specifying Metal Plate Connected Wood Trusses

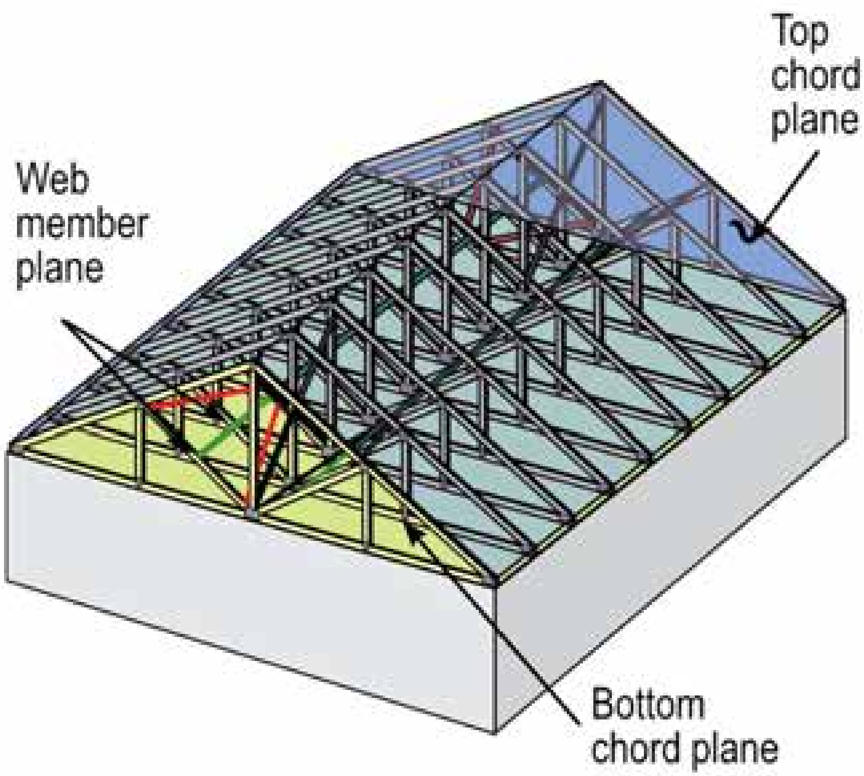
Gable-end Roof Damage

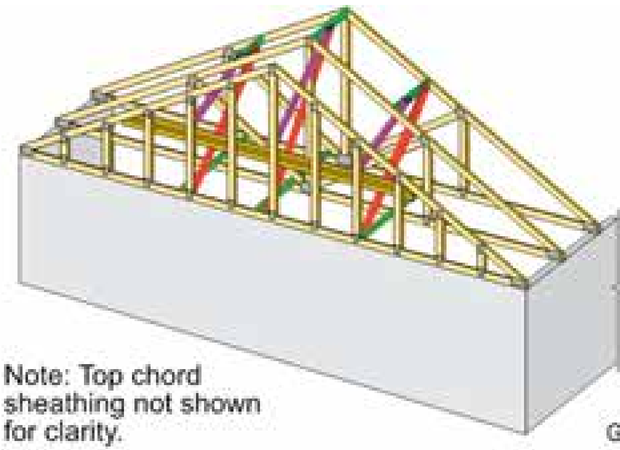
(Source: Bryan Tyson, PE – Dudley Dunham Engineering)

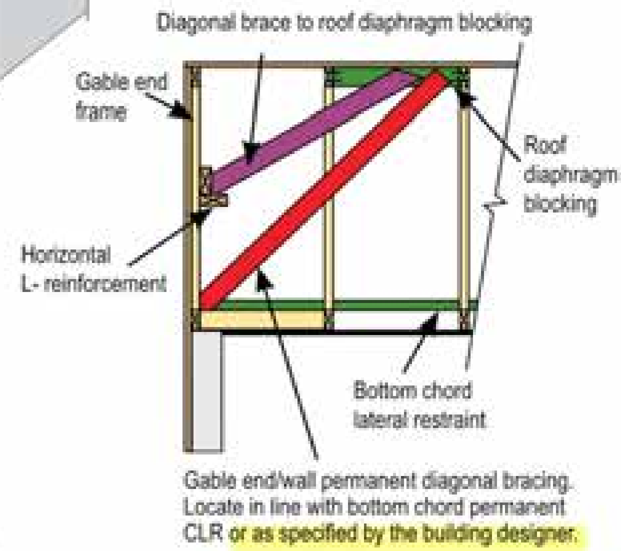
Gable-end Roof Damage

(Source: disastersafety.org)

Specifying Metal Plate Connected Wood Trusses

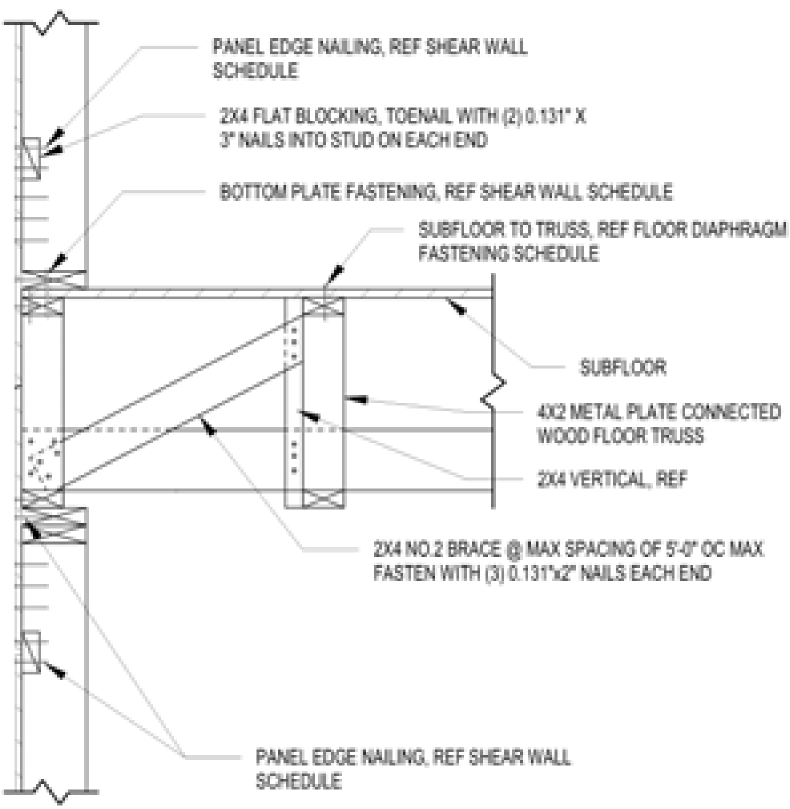




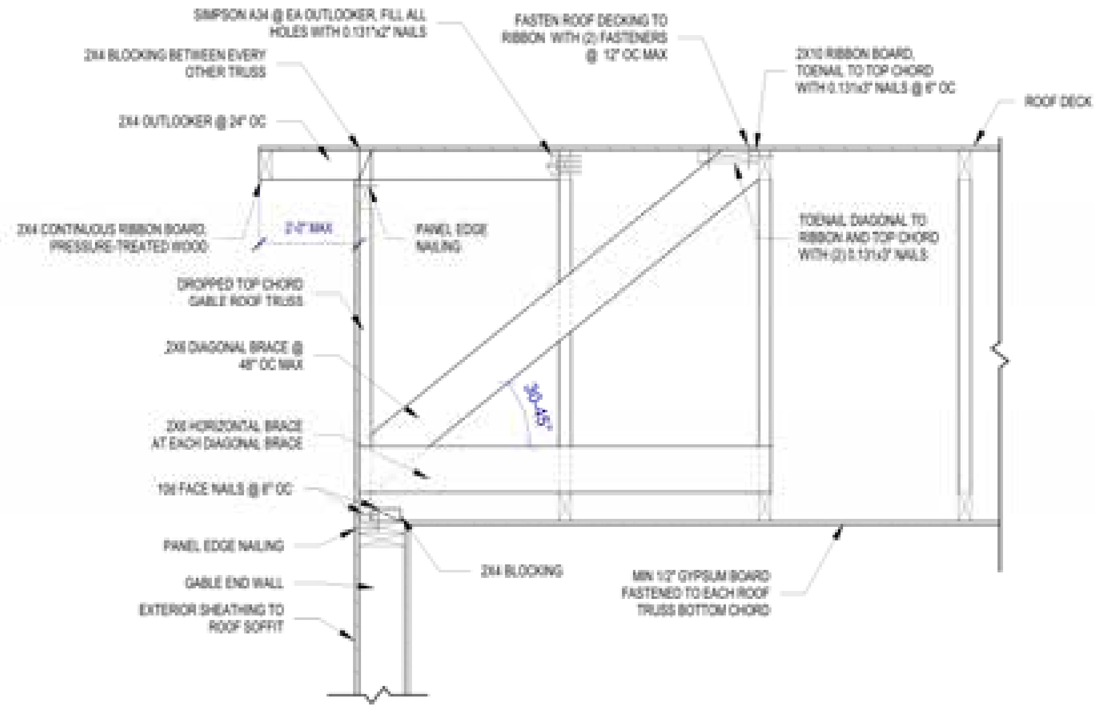


BCSI –B3 Summary Sheet – Permanent Restraint/Bracing of Chords and Web Members

Specifying Metal Plate Connected Wood Trusses

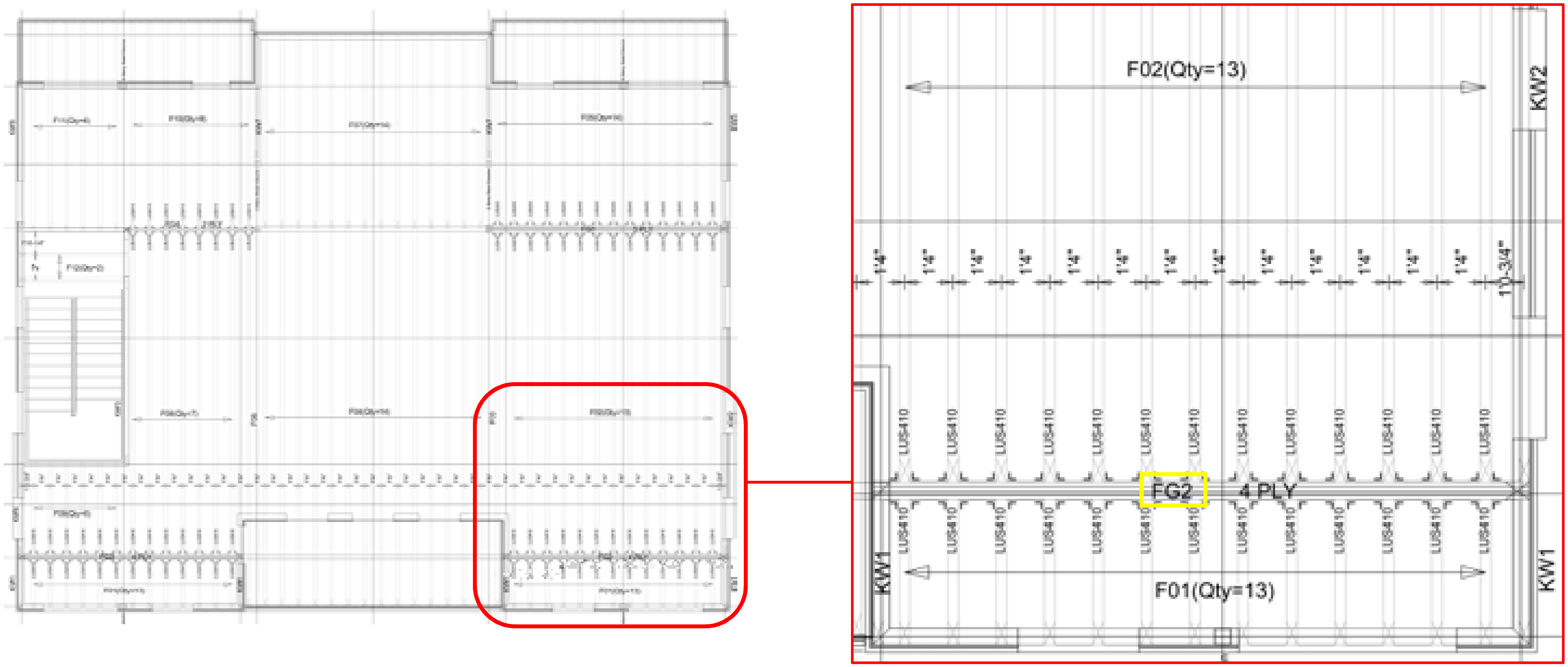


TYPICAL DETAIL – FLOOR TRUSS PARALLEL TO EXT. WALL



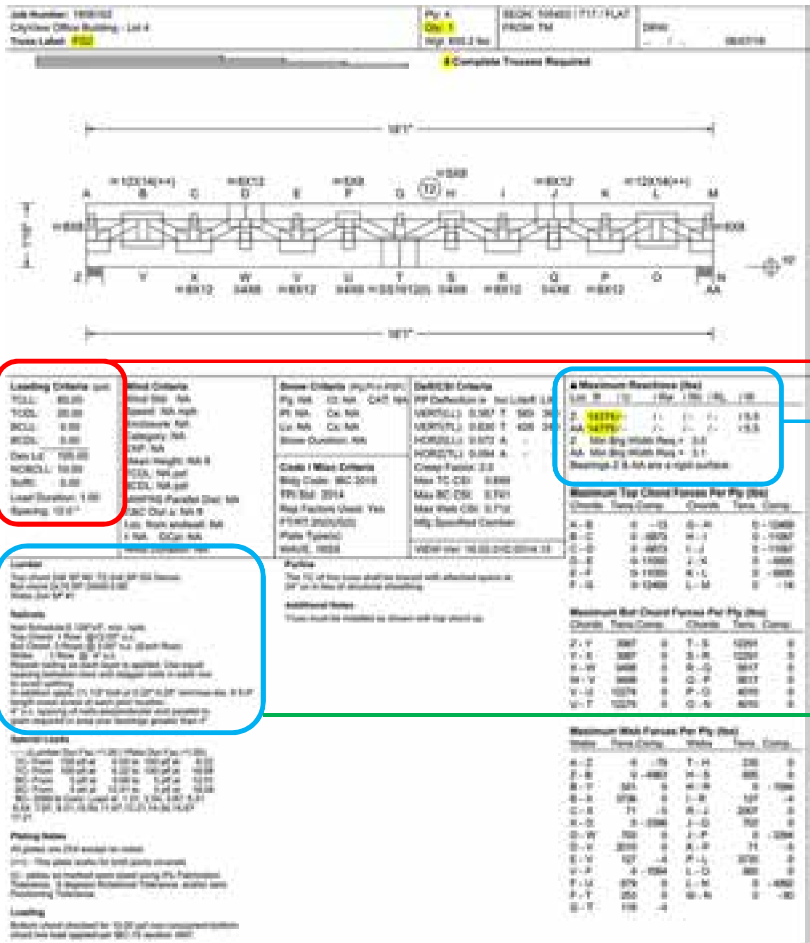
TYPICAL DETAIL – GABLE END ROOF TRUSS

Wood Trusses Submittals



Truss Placement Diagram

Wood Trusses Submittals



Loading Criteria (psf)

TCLL:	80.00
TCDL:	20.00
BCLL:	0.00
BCDL:	5.00
Des Ld:	105.00
NCBCLL:	10.00
Soffit:	5.00
Load Duration:	1.00
Spacing:	12.0 "

▲ Maximum Reactions (lbs)

Loc	R	/ U	/ Rw	/ Rh	/ RL	/ W
Z	14274 /	-	/ -	/ -	/ -	/ 5.5
AA	14775 /	-	/ -	/ -	/ -	/ 5.5

Z Min Brg Width Req = 3.0
AA Min Brg Width Req = 3.1
Bearings Z & AA are a rigid surface.

Lumber

Top chord 2x6 SP #2 :T2 2x6 SP SS Dense:
Bot chord 2x10 SP 2400f-2.0E
Webs 2x4 SP #1

Nailnote

Nail Schedule:0.128"x3", min. nails
Top Chord: 1 Row @12.00" o.c.
Bot Chord: 3 Rows @ 3.00" o.c. (Each Row)
Webs : 1 Row @ 4" o.c.
Repeat nailing as each layer is applied. Use equal spacing between rows and stagger nails in each row to avoid splitting.
In addition apply (1) 1/2" bolt or 0.22"-0.25" min/max dia. X 6.0" length wood screw at each joint location.
4" o.c. spacing of nails perpendicular and parallel to grain required in area over bearings greater than 4"

Truss Design Drawing (TDD)

Balcony Framing

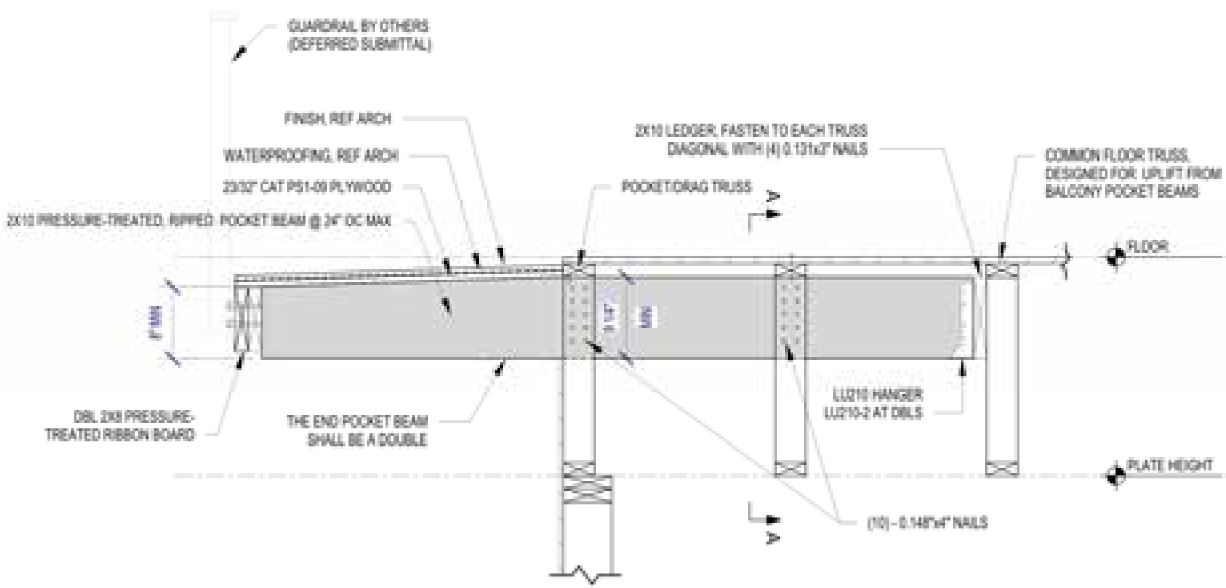
Balcony Collapse

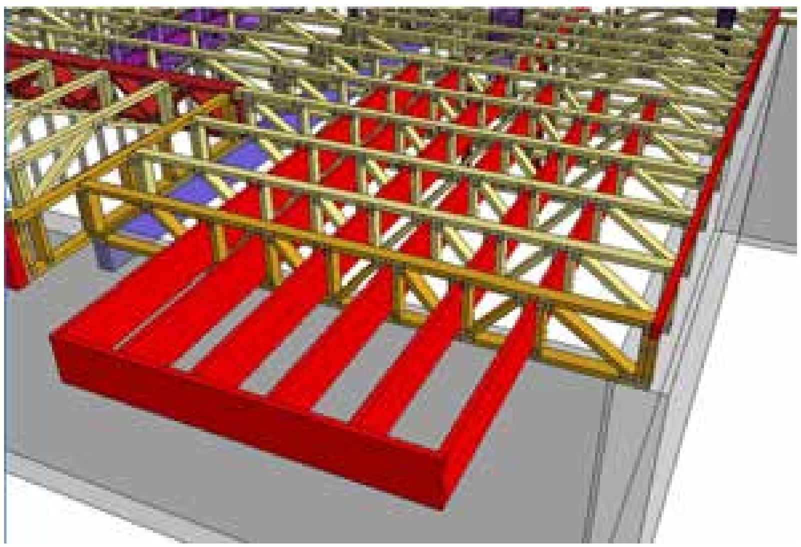
(Source: Drew Dudley, PE)

Balcony Collapse

(Source: Drew Dudley, PE)

Balcony Framing

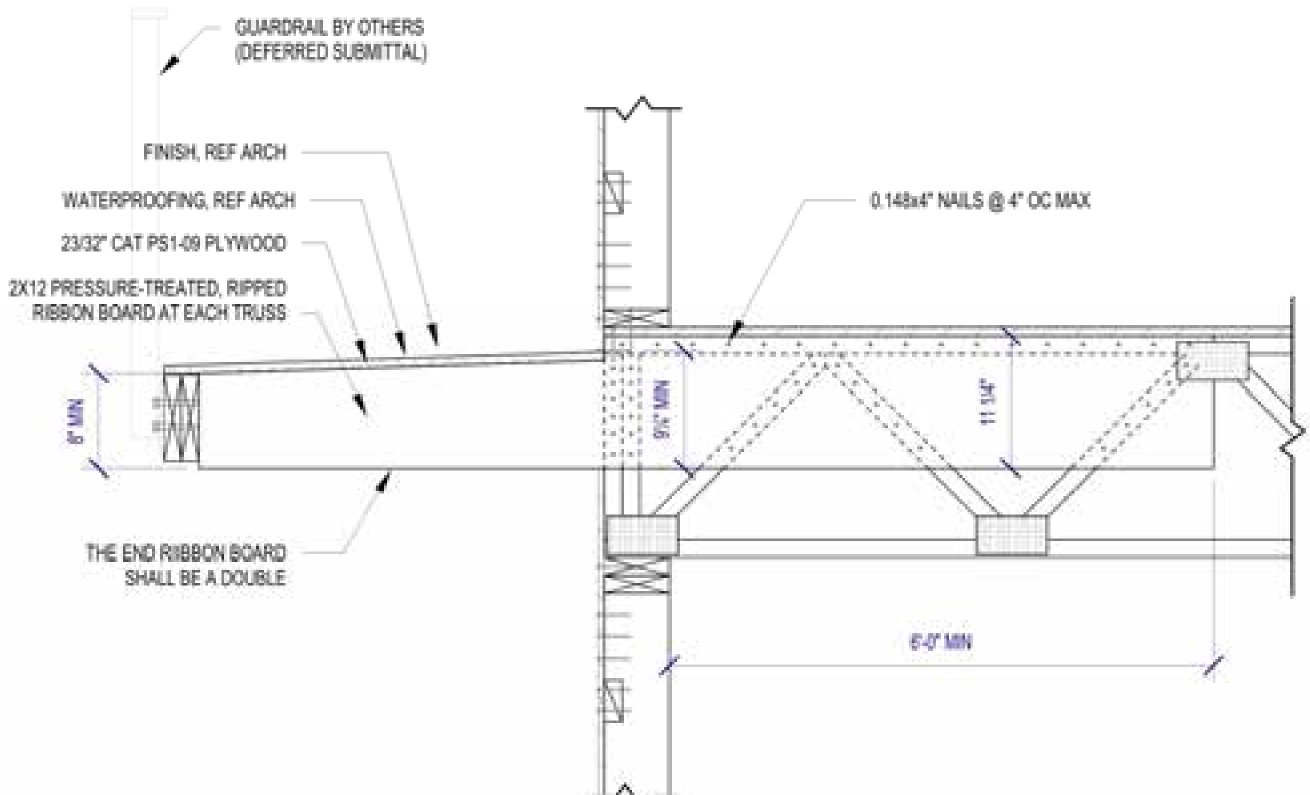




Mitek Floor Truss Advantage

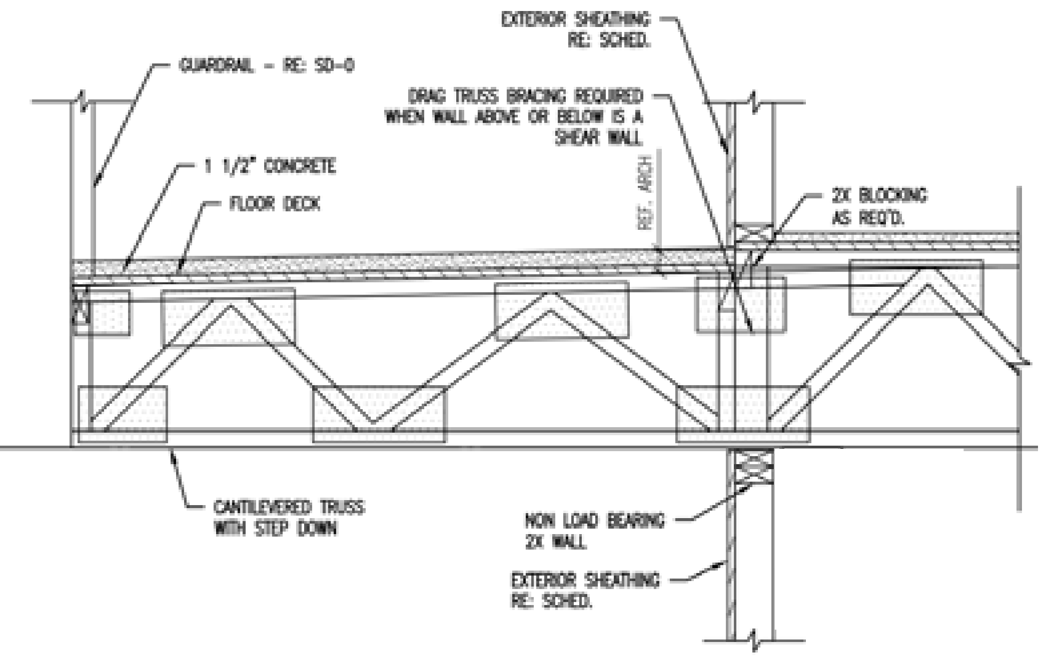
<u>Pocket Beam Balcony Framing</u>

Balcony Framing

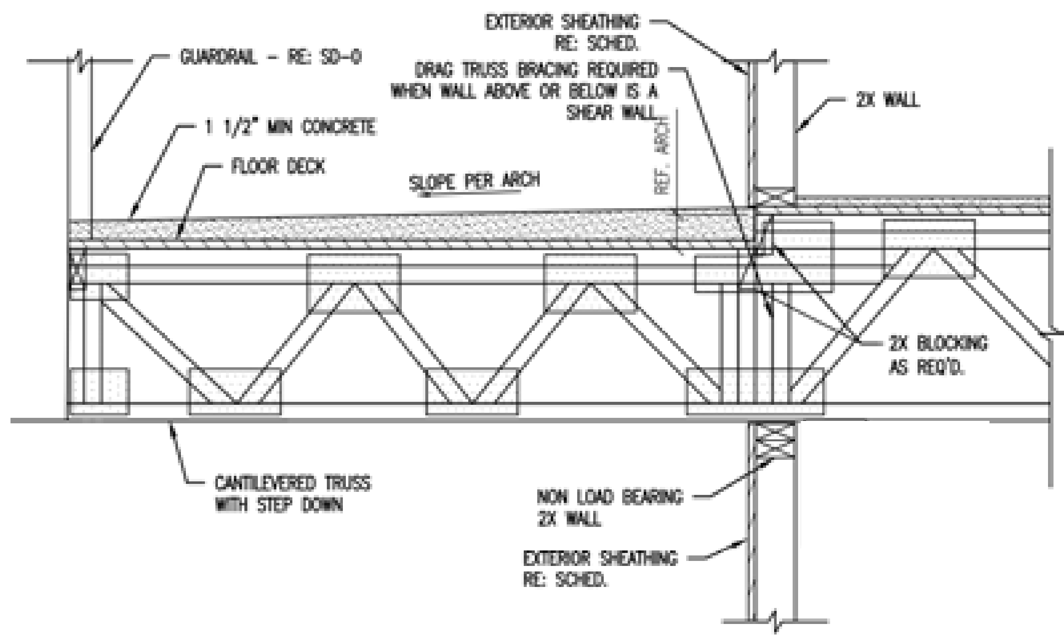


Sistered Board Balcony Framing

Balcony Framing

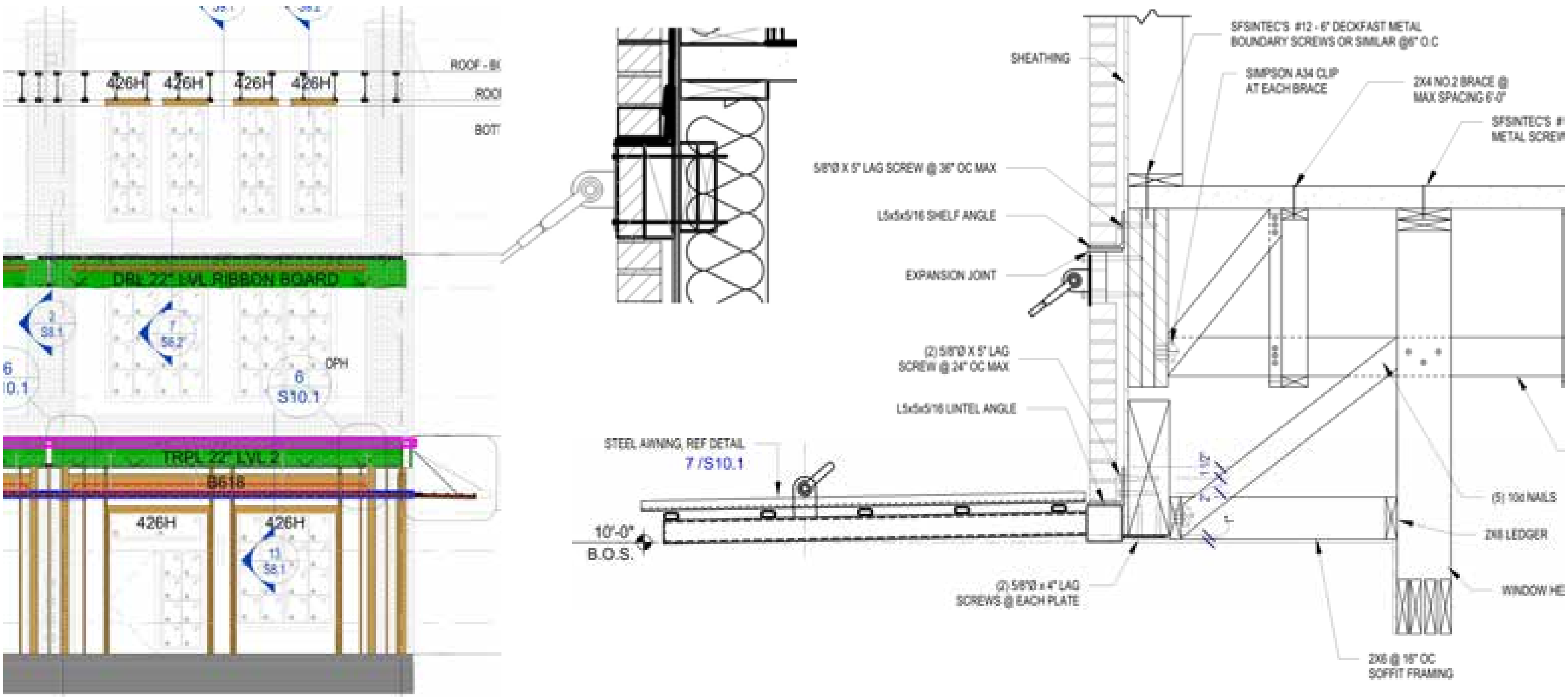


Cantilever Truss – Sloping Top Chord Balcony Framing

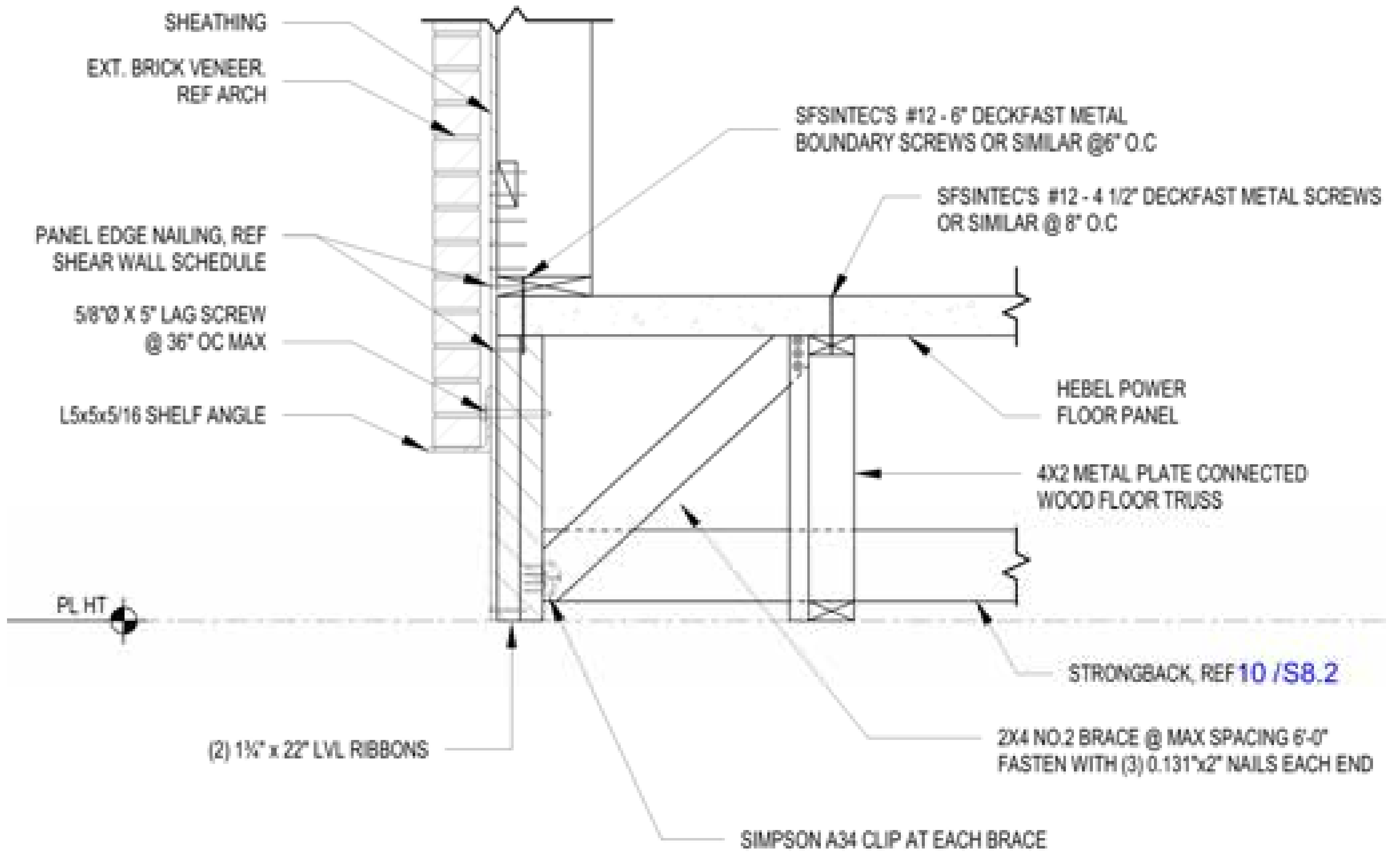


Cantilever Truss – Sloped Topping Slab Balcony Framing (Not Recommended)

Brick Veneer – Shelf Angles



Brick Veneer – Shelf Angles



Brick Veneer – High Wind Requirements

Comparison of *IRC* and *IBC* Requirements for Brick Veneer/Wood Stud Walls

Subject of Provision		*IRC* Requirement	*IBC* Requirement
Veneer Height	Above Noncombustible Foundation	30 ft (9.14 m) max. height. (38 ft [11.58 m] max height at gable)	30 ft max height (38 ft at gable) in SDC A; see *IBC* "Wood" chapter for additional requirements in other SDCs.
	Above Preservative-Treated Wood Stud Foundation	Building height limited to two floors.	18 ft (5.49 m) max. height
		In SDC D and above, foundation must be designed by an engineer.	
	Above Other Wood Construction	12 ft-8 in. (3.9 m) max. height if (1) using prescribed steel angle or roof construction methods, and (2) veneer supported on wood is isolated by expansion joints.	12 ft (3.7 m) max. height if (1) there is no direct contact between veneer and wood, (2) deflection due to dead plus live loads ≤ smaller of L/600 or 0.3 in. (8 mm) and (3) veneer supported on wood is isolated by expansion joints.
Stud Deflection (Out-Of-Plane)		—	L/240 max. for brittle finishes
High Wind Areas		Where the wind pressure exceeds 30 psf (1.44 kPa), reduce wall area supported by each anchor to a maximum of 2 sq ft (0.2 m²).	Where wind velocity pressure exceeds 40 psf (1.95 kPa) and the building's mean roof height does not exceed 60 ft (18.3 m): (1) reduce wall area supported by each anchor by 70 percent; (2) do not space anchors more than 18 in. (457 mm) vertically and horizontally; and (3) place anchors within 12 in. (305 mm) around the perimeter of openings larger than 16 in. (406 mm) at a maximum spacing of 24 in. (610 mm) o.c.
		Where basic wind speed is 110 mph (49 m/s) or higher, veneer attachment must resist component and cladding loads specified in *IRC* "Building Planning" chapter, adjusted for height and exposure.	Where wind velocity pressure exceeds 55 psf (2.63 kPa) or building's mean roof height exceeds 60 ft (18.3 m), rationally design the veneer.
Anchor Spacing (See additional requirements for seismic and high-wind areas)		Vertical: 24 in. (610 mm) max. Horizontal: 32 in. (813 mm) max. 2⅔ sq ft (0.25 m²) max. wall area per anchor.	Vertical: 25 in. (635 mm) max. Horizontal: 32 in. (813 mm) max.
Where Bond Pattern Is Not Running Bond		—	Include at minimum single wire joint reinforcement, size W1.7 (MW11) spaced no more than 18 in. (457 mm) o.c. vertically.

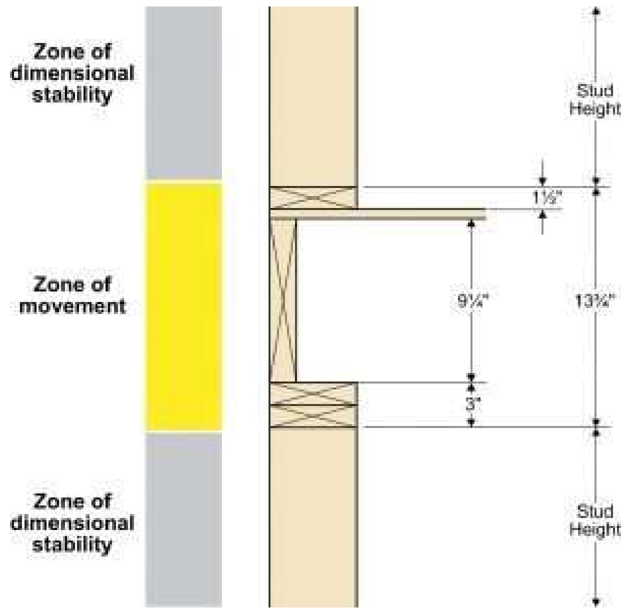
Table 3 from TN-28 "Brick Veneer/Wood Stud Walls" from the Brick Industry Association

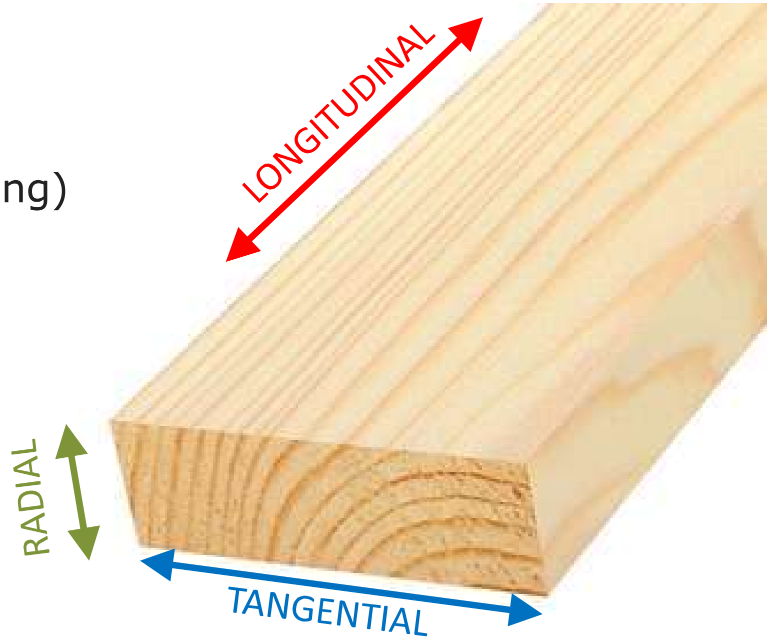
Fig. 3-2 Wood-Framed Wall with Anchored Masonry Veneer Example Project Application

National Masonry Systems Guide

Wood Shrinkage

Factors Affecting Wood Shrinkage:
1. Installed MC (spepcification)
2. In-service MC (largely out of designers control)
3. Cumulative thickness of cross-grain wood elements (detailing)





SHRINKAGE FOR 30% MC CHANGE

LONGITUDINAL	0.1-0.2%
RADIAL	4-5%
TANGENTIAL	7-8%

QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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