Practical Considerations for Lateral Analysis of Modern Light-Frame Wood Buildings

Taylor Landry & Ashley Cagle

WoodWorks

Rivers Edge Apartments
Kitchen & Associates, KPFF,
McAlvain Construction
Photo Idaho Airships

"The Wood Products Council" is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES), Provider #G516.

Credit(s) earned on completion of this course will be reported to AIA CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This course is registered with AIA CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

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

AIA Approved Continuing Education

Course Description

Light-frame wood buildings primarily rely on wood-sheathed shear walls and diaphragms to resist wind and seismic forces. Modern architectural layouts often introduce offsets, irregular geometries, and varied framing conditions that complicate load paths. In these structures, establishing clear and continuous load paths is essential for long-term structural performance and occupant safety. This course examines how shear walls and diaphragms function together as part of the lateral force-resisting system in light-frame wood construction. Participants will learn methods for breaking down complex layouts, evaluating in-plane and out-of-plane loads, and assessing available design approaches, along with common connection and detailing strategies informed by building codes and construction practice.

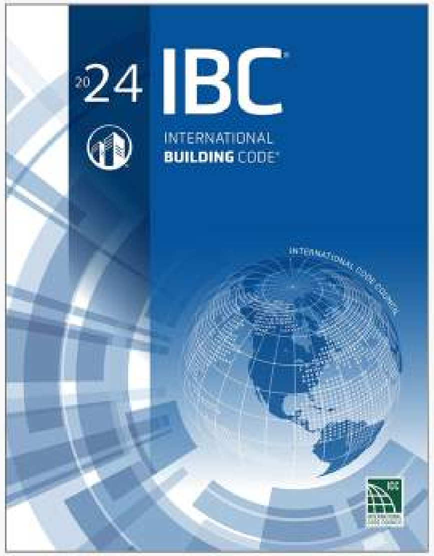
Learning Objectives

1. Identify and evaluate offset diaphragm and shear wall conditions commonly found in modern light-frame wood buildings and explain how they affect load paths and lateral force distribution.
2. Perform a preliminary breakdown of complex lateral systems to assess in-plane and out-of-plane force transfer and ensure continuity of the lateral force-resisting system and overall structural stability.
3. Understand how structural design interacts with fire-resistance requirements and energy-performance considerations, supporting long term building performance and occupant well-being.
4. Apply code-recognized detailing strategies for wood-sheathed shear walls to address common design challenges, improve constructability, and ensure building safety under wind and seismic events.

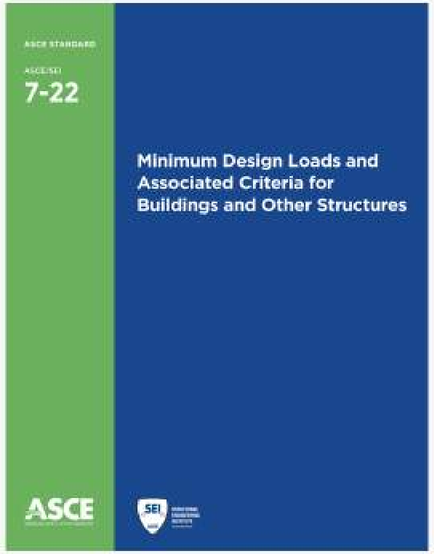
Today's Topics:

- General approaches to a gravity + lateral layout
  - Common challenges with real buildings
- Approaches to collector design
- Exterior shear wall analyses:
  - Segmented SW
  - Perforated SW
  - Force Transfer Around Openings (FTAO)
- Practical detailing considerations
  - Differences in framing systems
  - Unique material / product considerations

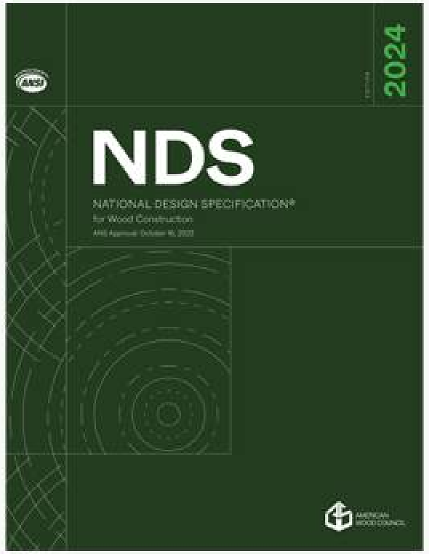
2024 IBC



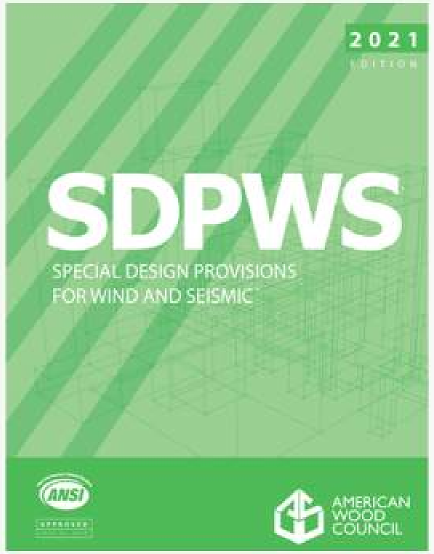
ASCE 7-22
(2022)



2024 NDS



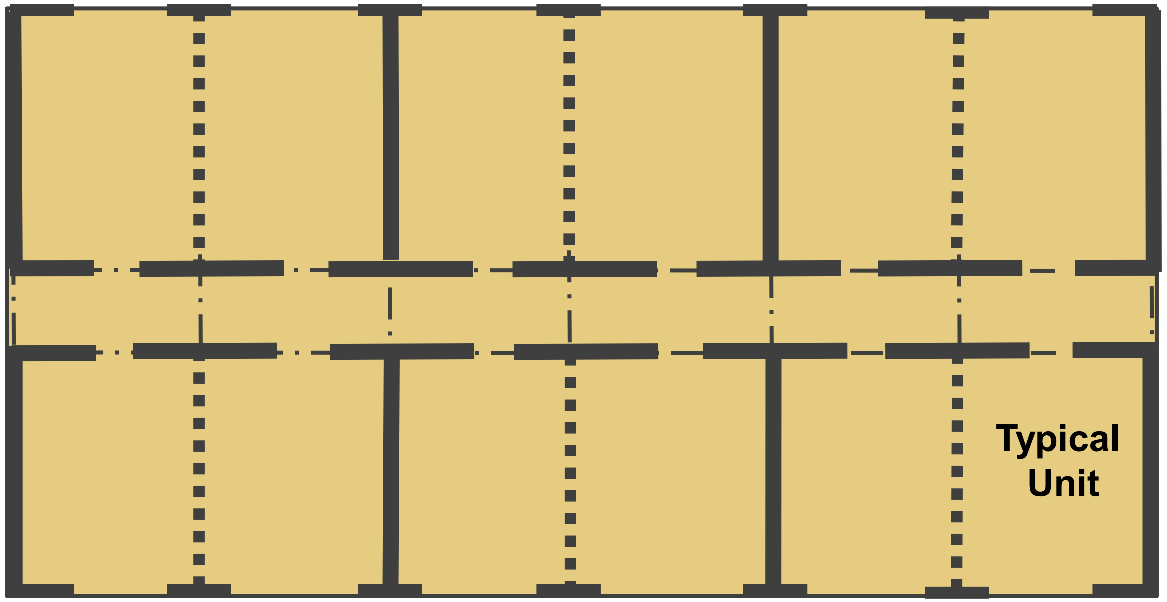
2021 SDPWS



Simplified, Textbook Example

» Rectangular floor plan, shear walls aligned

» Straight-forward load path

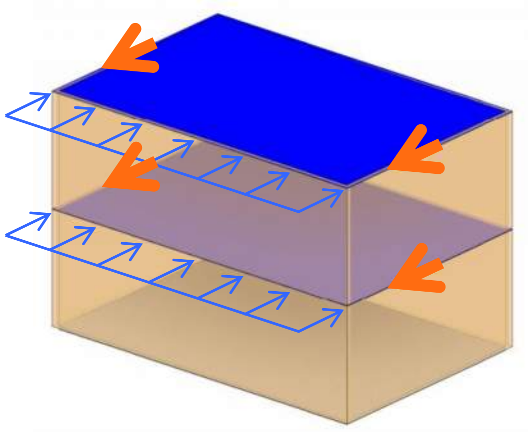


Possible Shear Wall Layouts

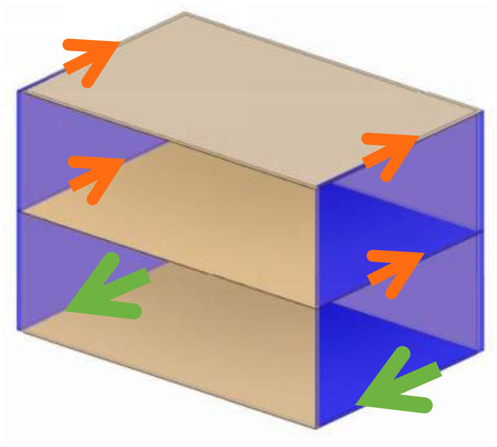
Basics of Lateral Layouts

» Often we have a very idealized structure to illustrate concepts

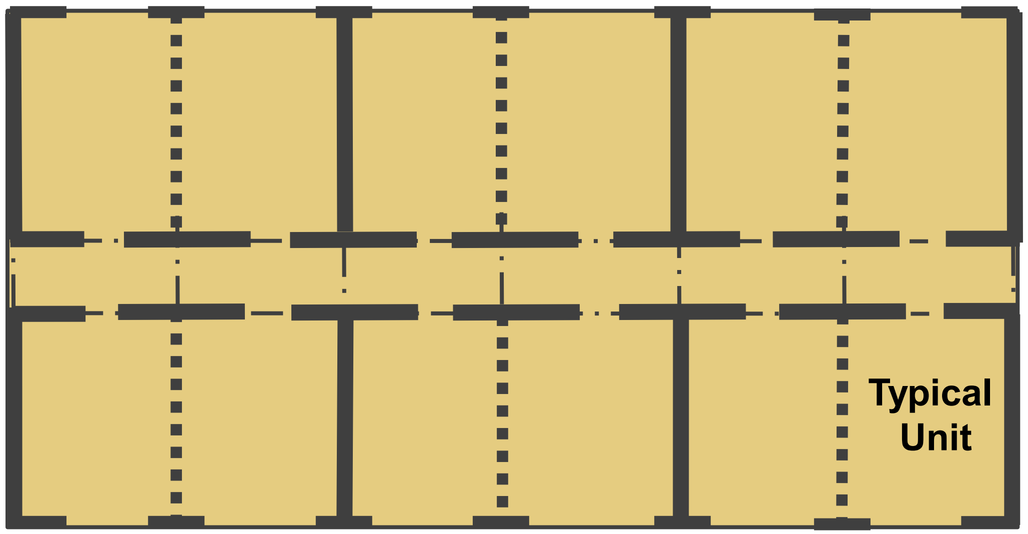
» Clean and neat, allows for a strong understanding of the engineering principals



Diaphragms

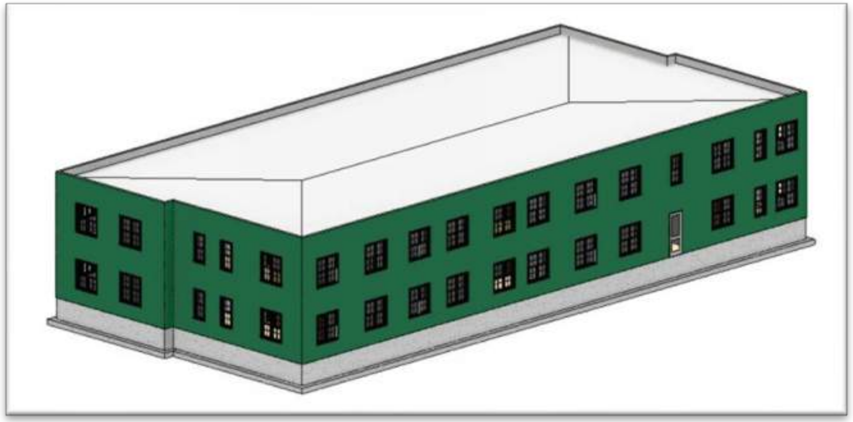


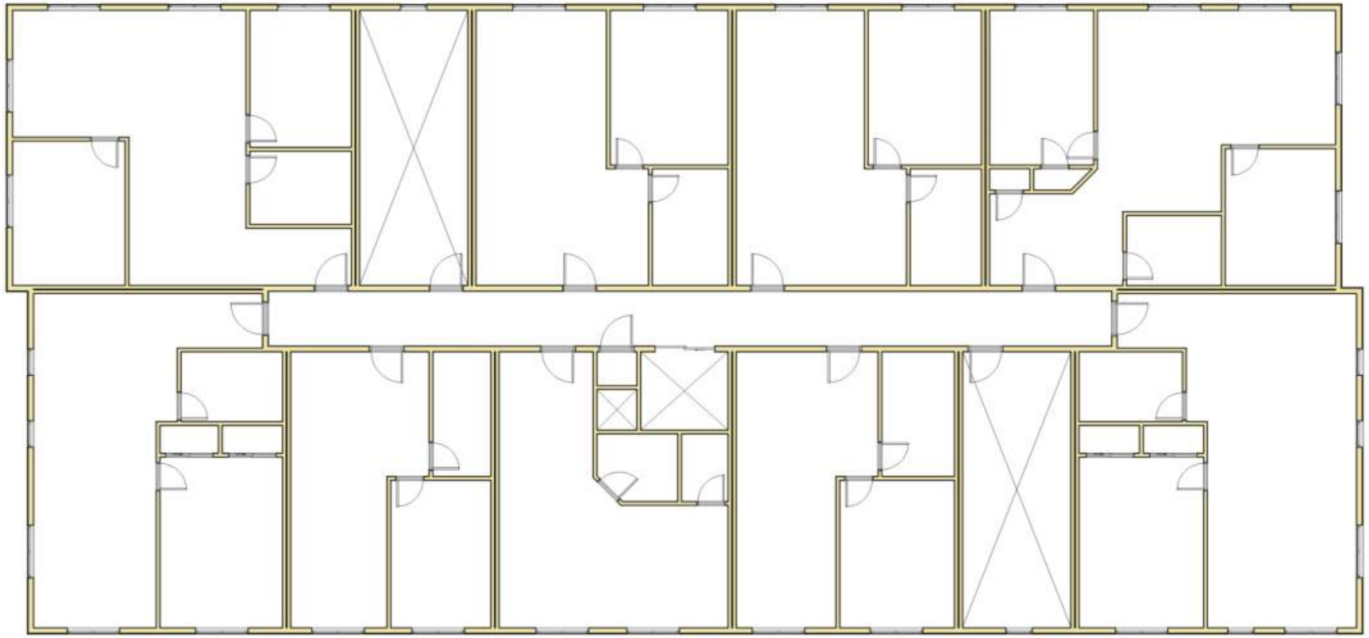
Shear Walls



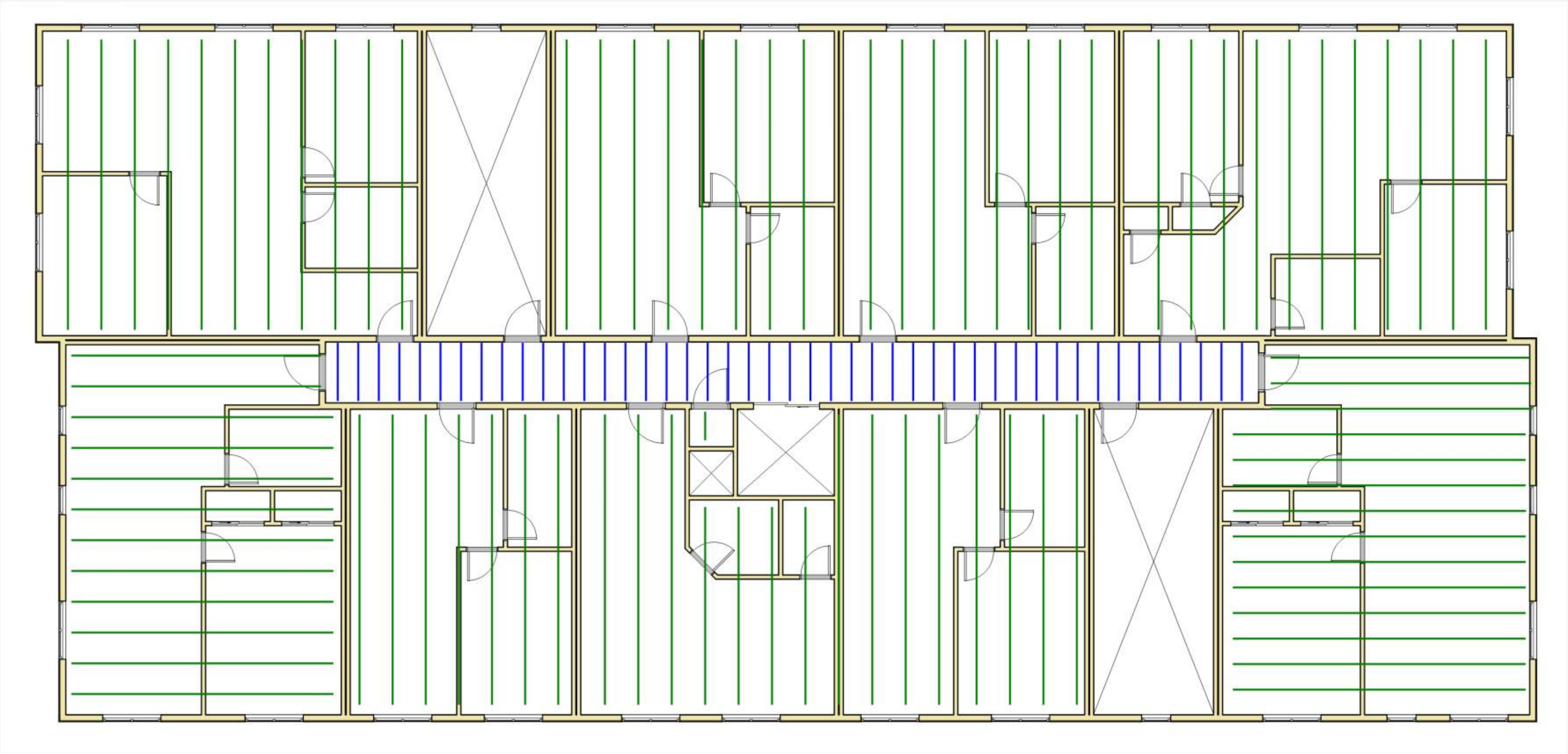
Our "Intermediate" Structure

- 2-Story Apartment Building
- 10'-6" Floor-to-Floor Heights
- Flat Roof with Parapet
- 125' x 60' Overall Footprint



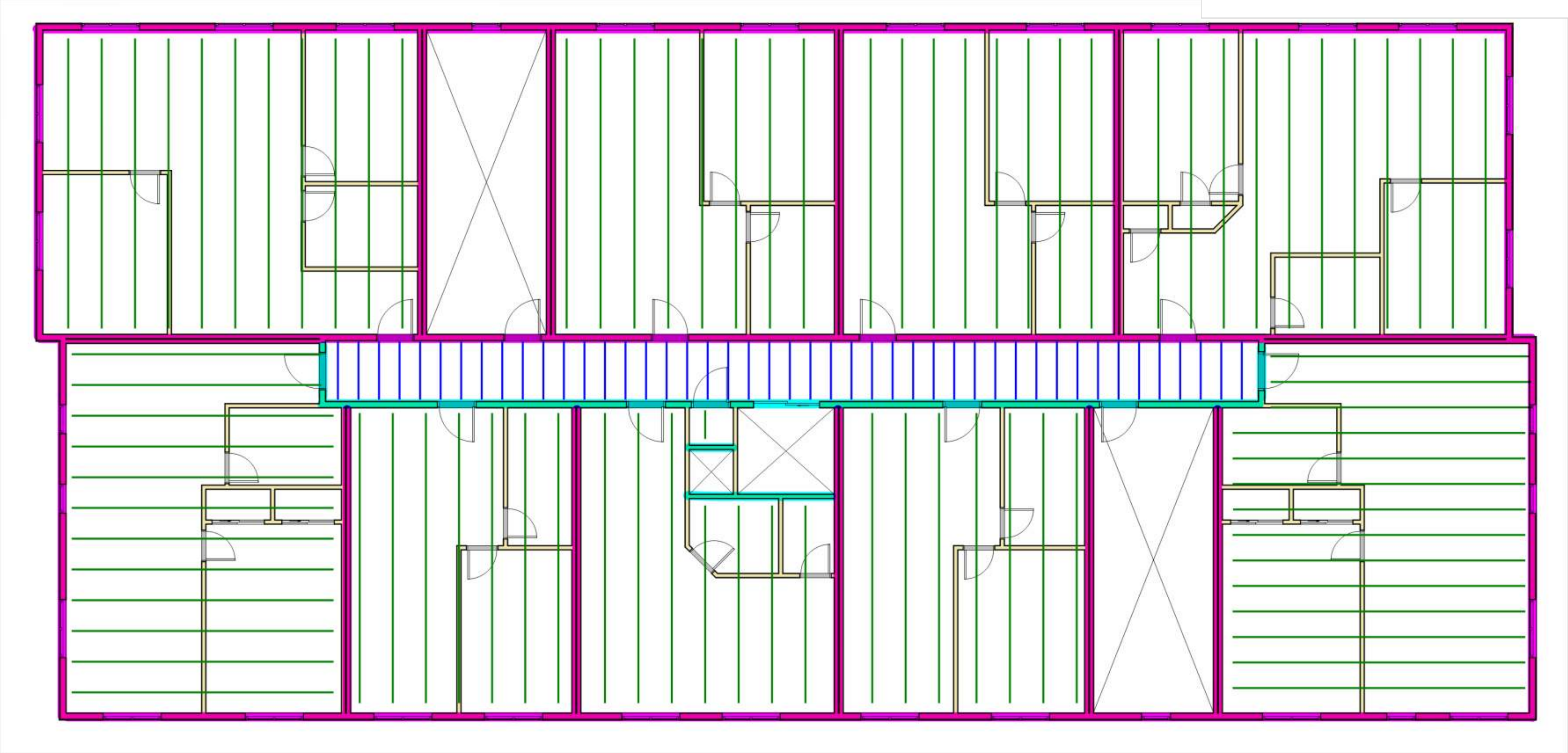


Layout Option 1: Trusses, Wind Design

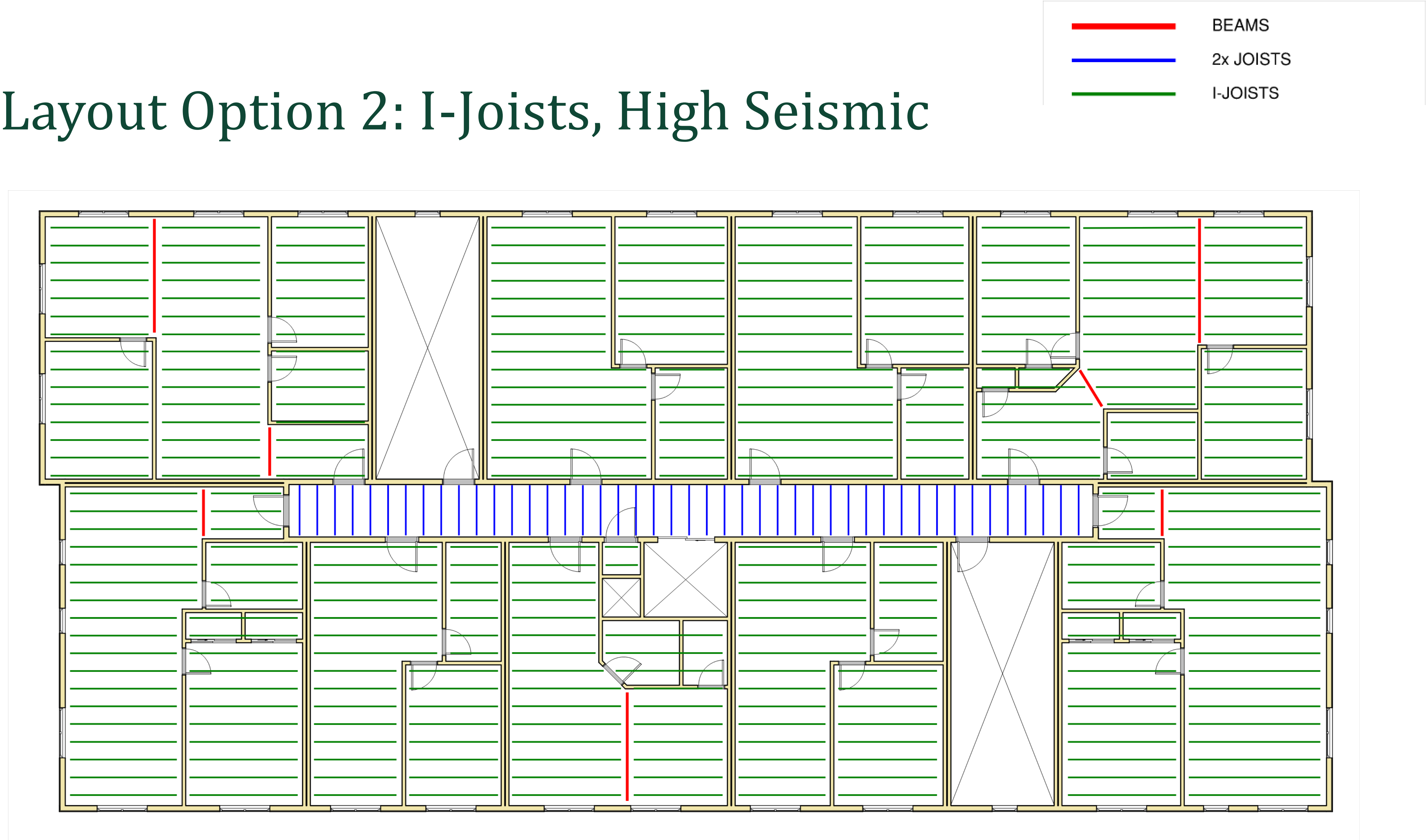


Layout Option 1: Trusses, Wind Design

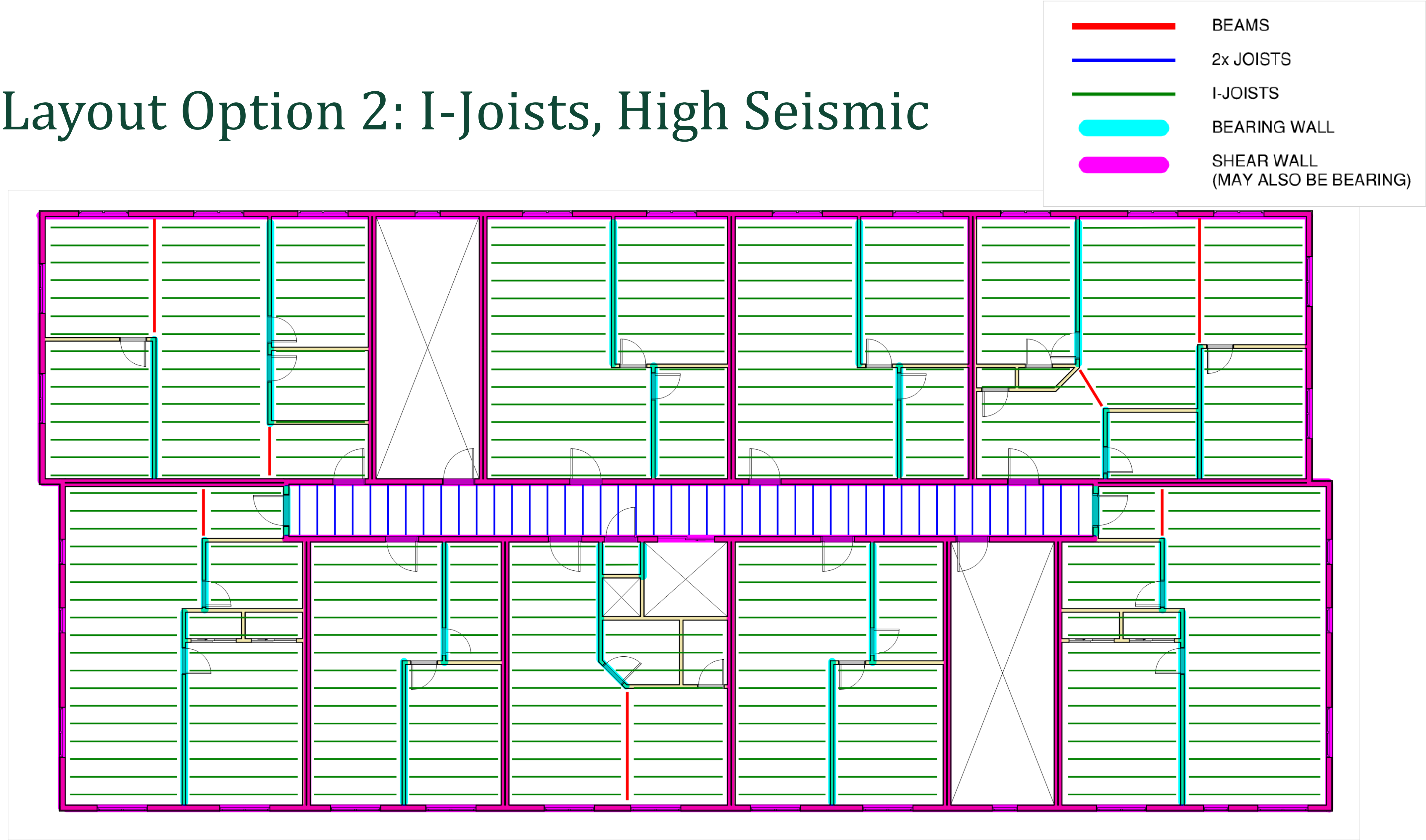
BEAMS
OTHER
TRUSSES
BEARING WALL
SHEAR WALL
(MAY ALSO BE BEARING)



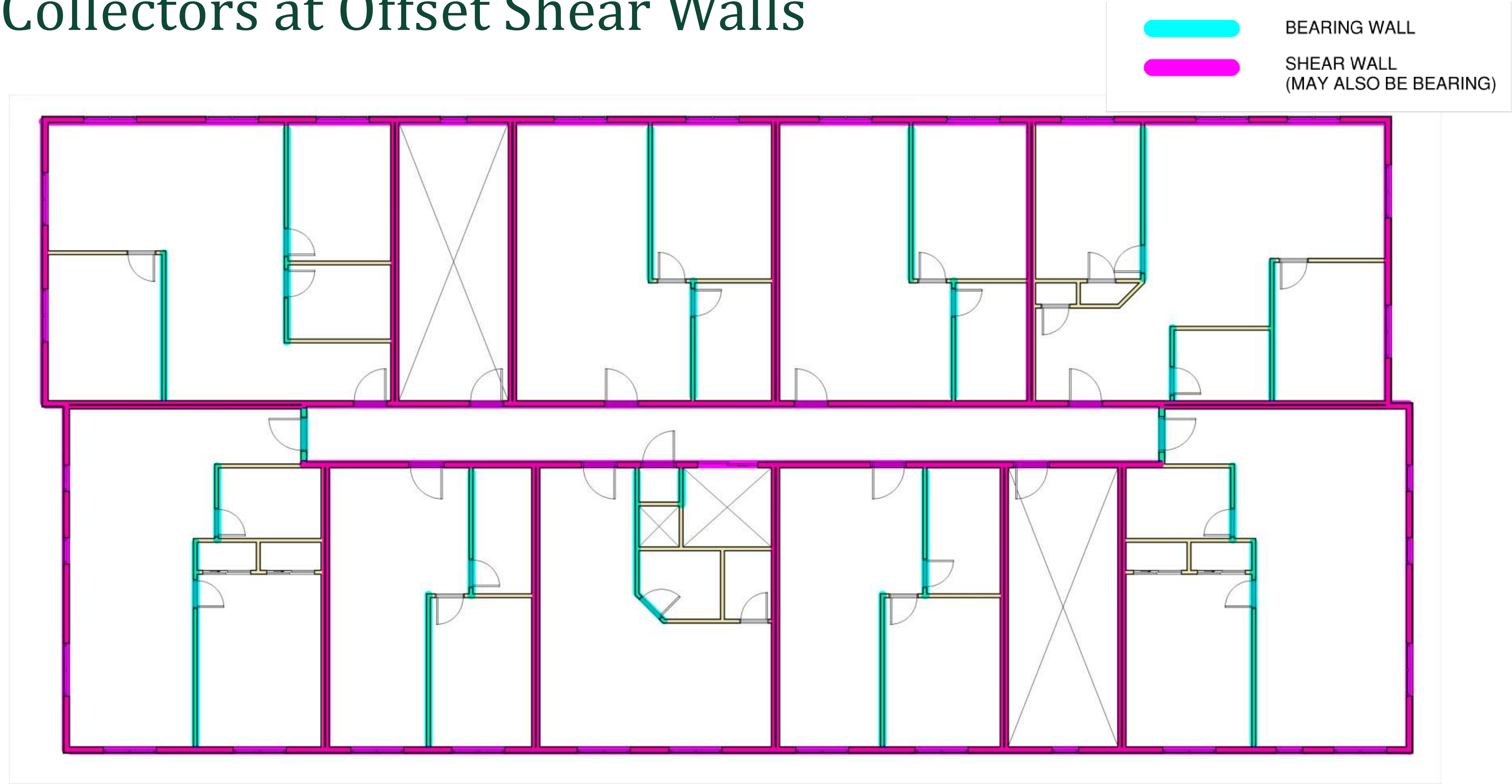
Layout Option 2: I-Joists, High Seismic



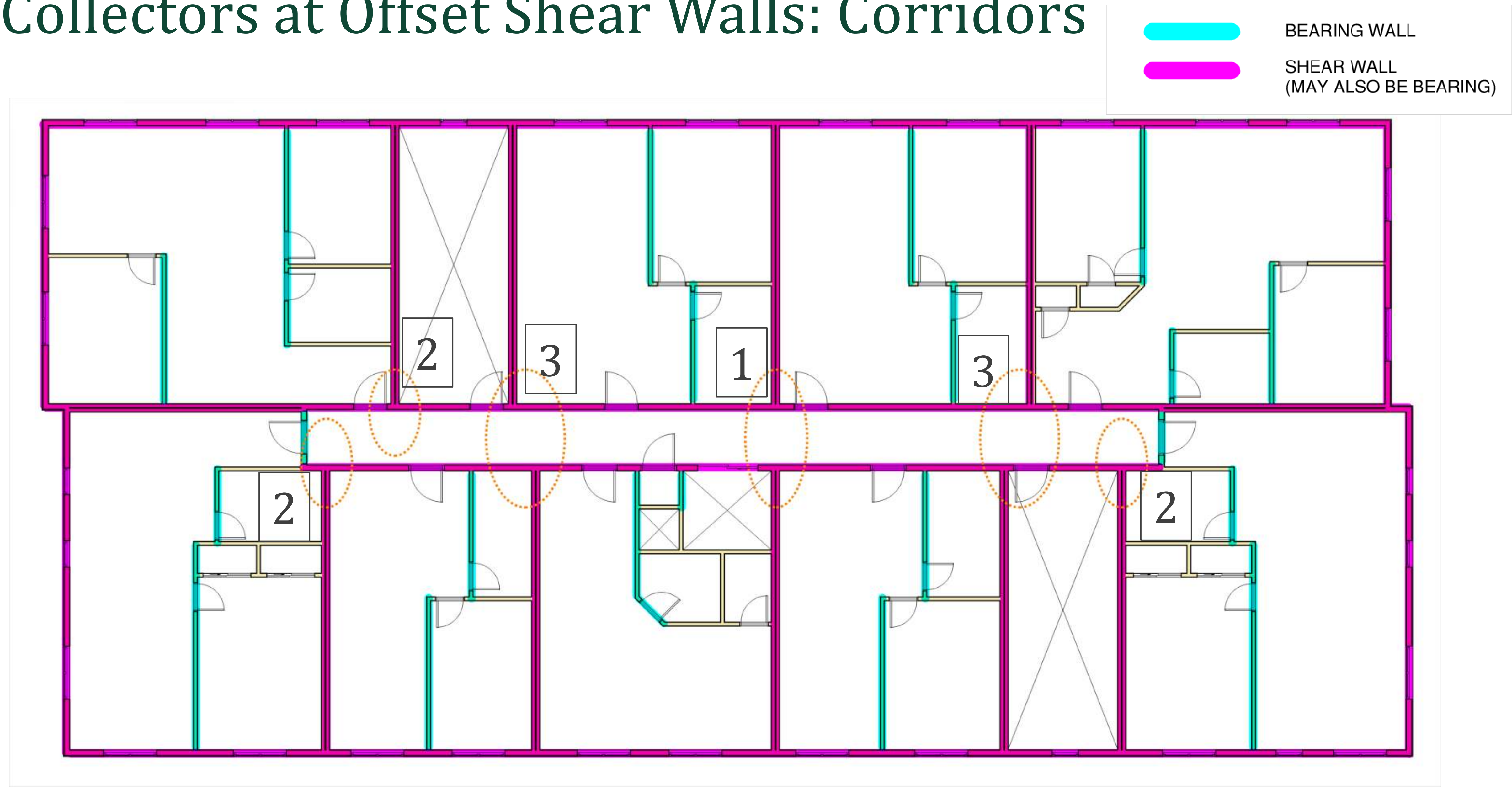
Layout Option 2: I-Joists, High Seismic



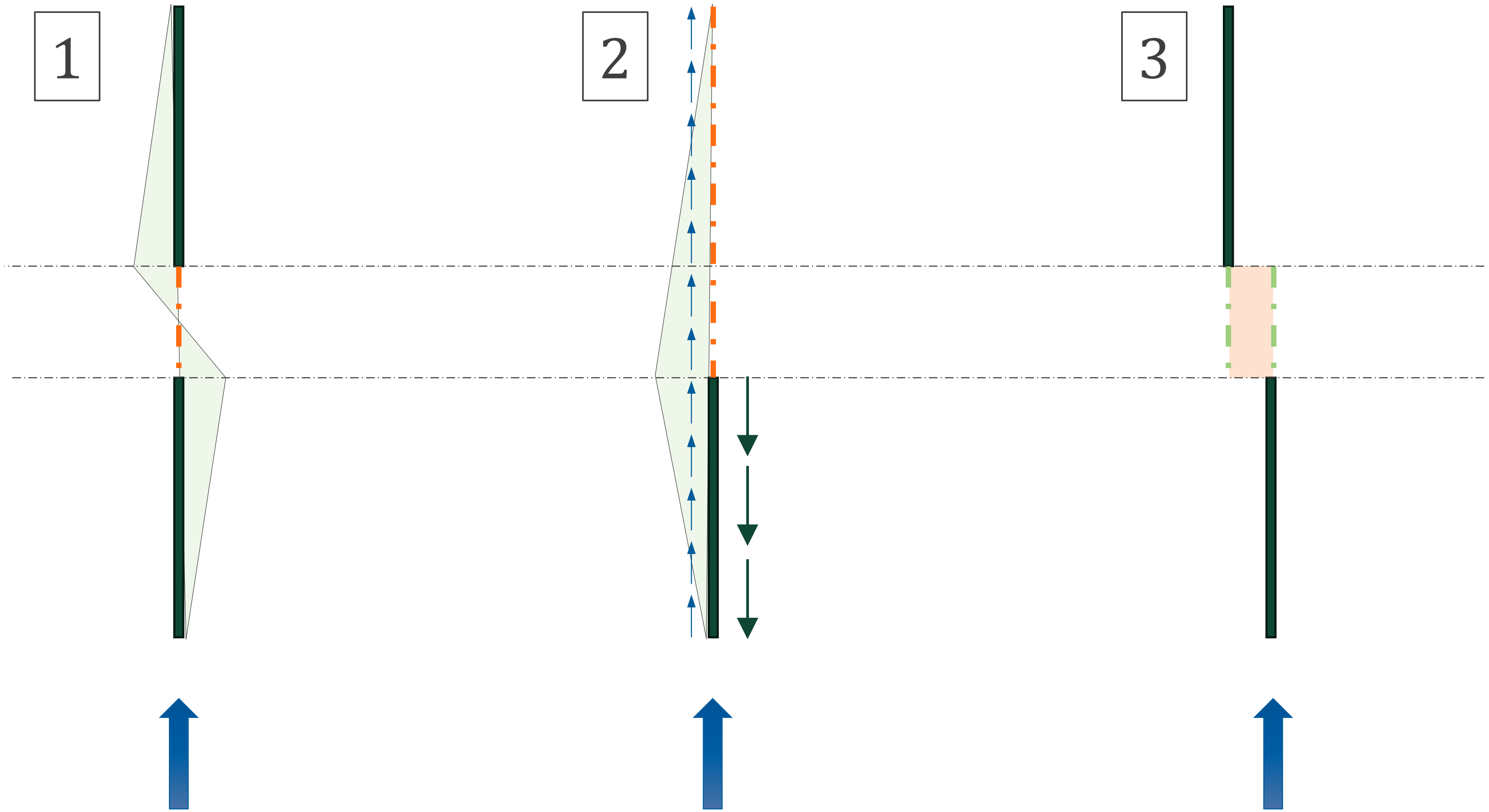
Collectors at Offset Shear Walls



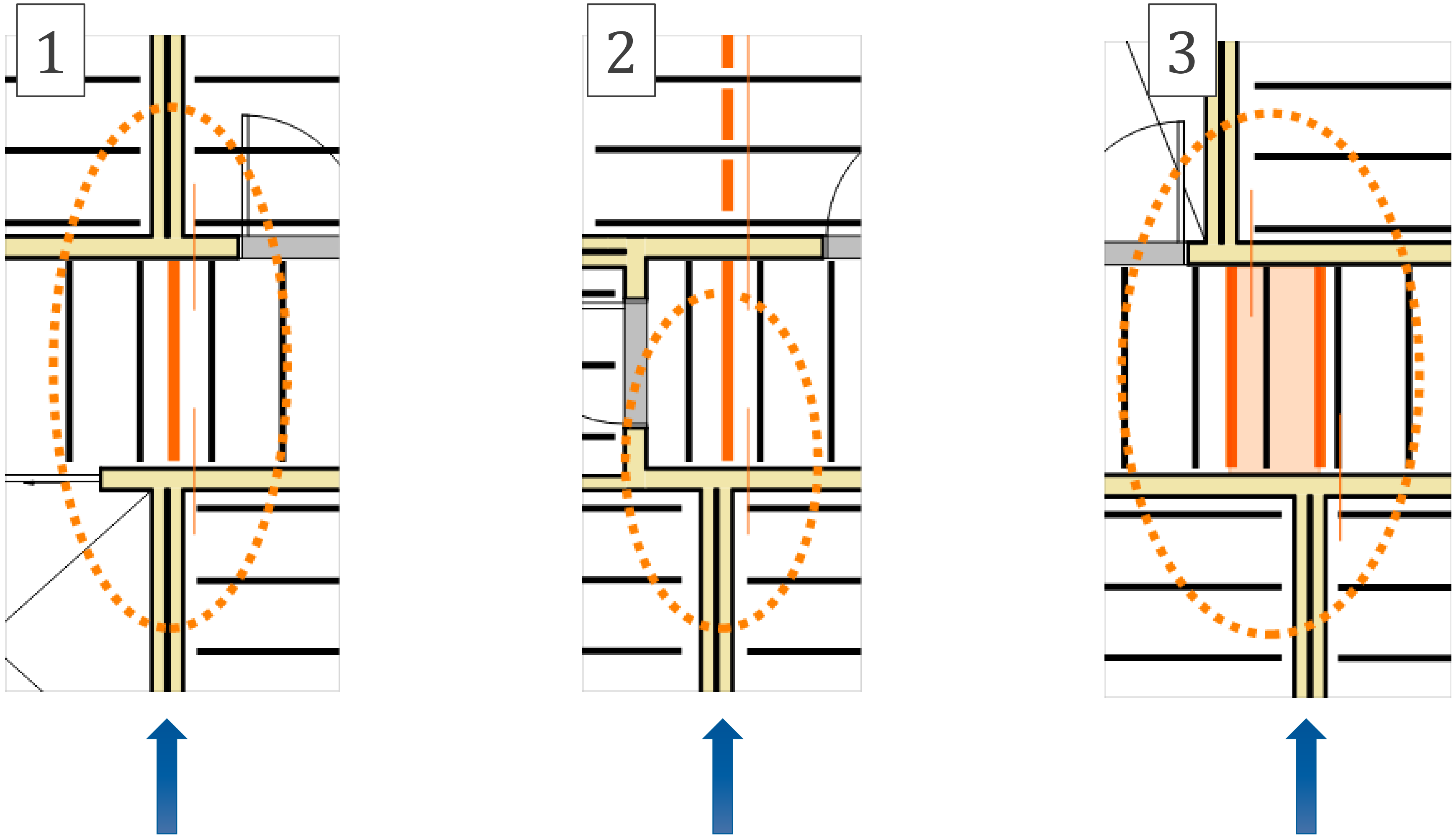
Collectors at Offset Shear Walls: Corridors



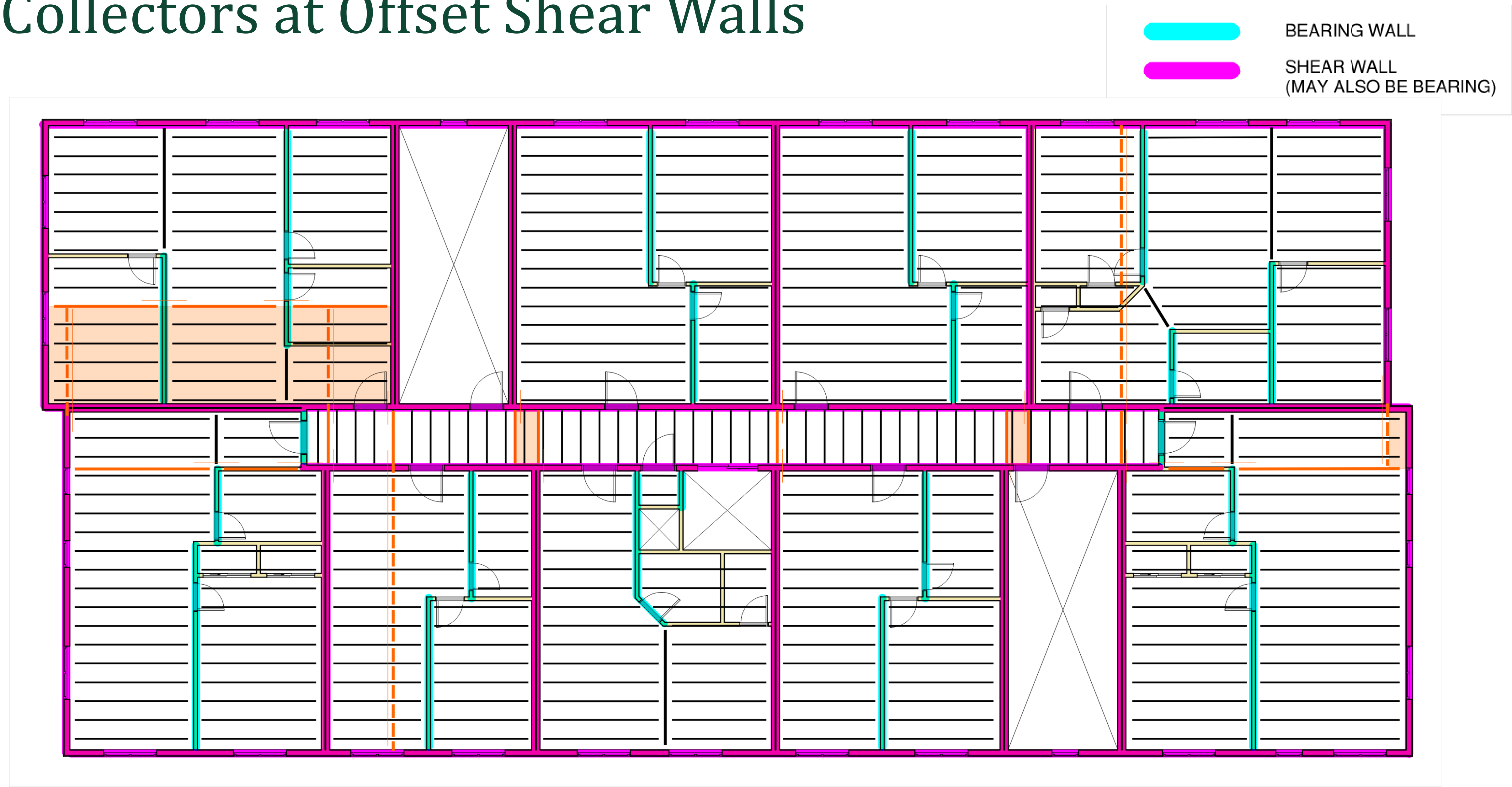
Collectors Across the Corridor



Collectors Across the Corridor

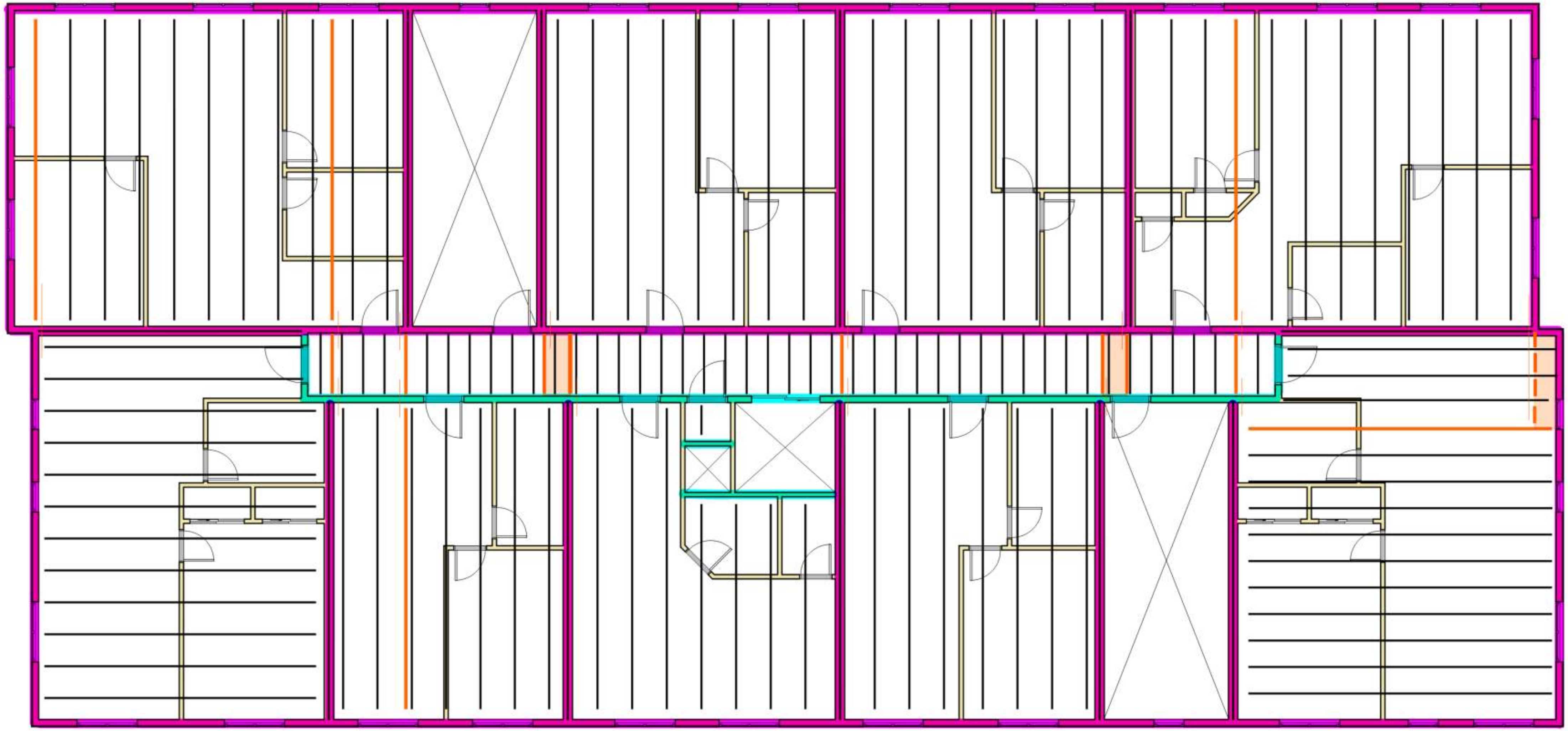


Collectors at Offset Shear Walls



Layout Option 1: Trusses, Wind Design

BEAMS
OTHER
TRUSSES
BEARING WALL
SHEAR WALL
(MAY ALSO BE BEARING)



Sheathing as the Collector?

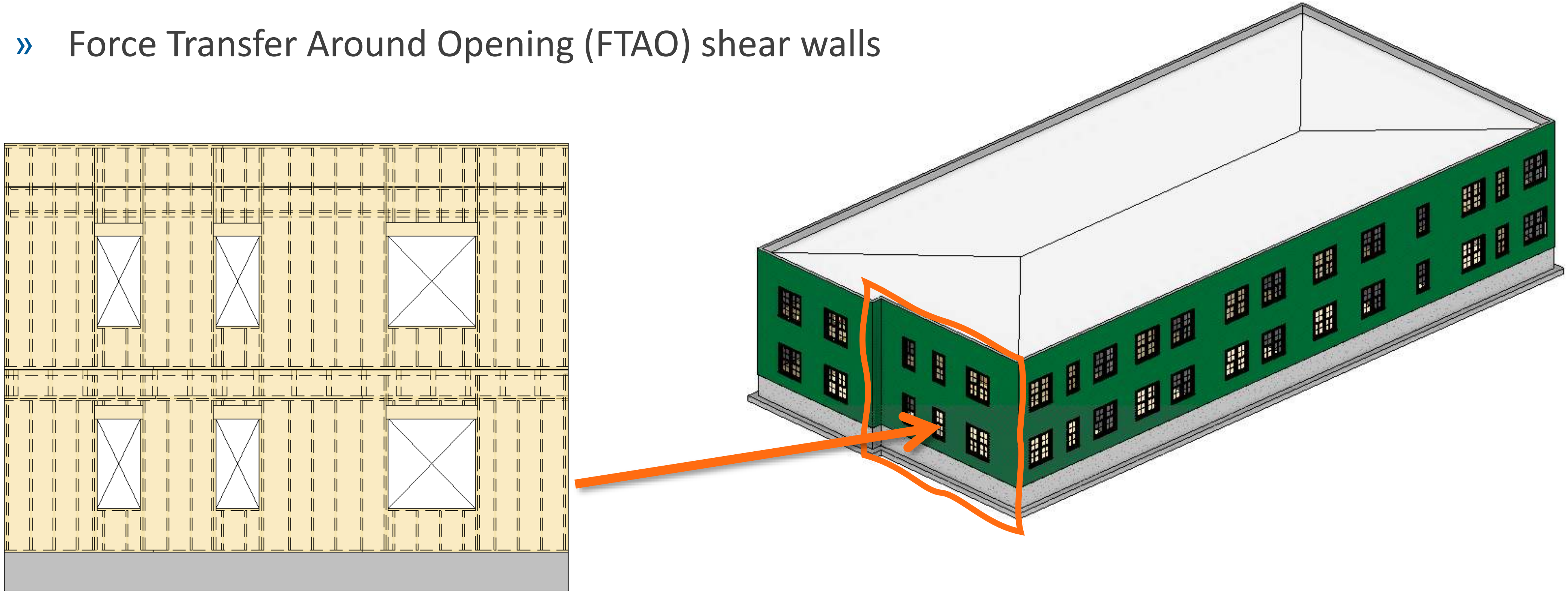
- No! Cannot use sheathing to transfer tension/compression forces
  - Tension: unknown splice locations
  - Compression: buckling (OOP)

SDPWS 4.1.9 Boundary Elements

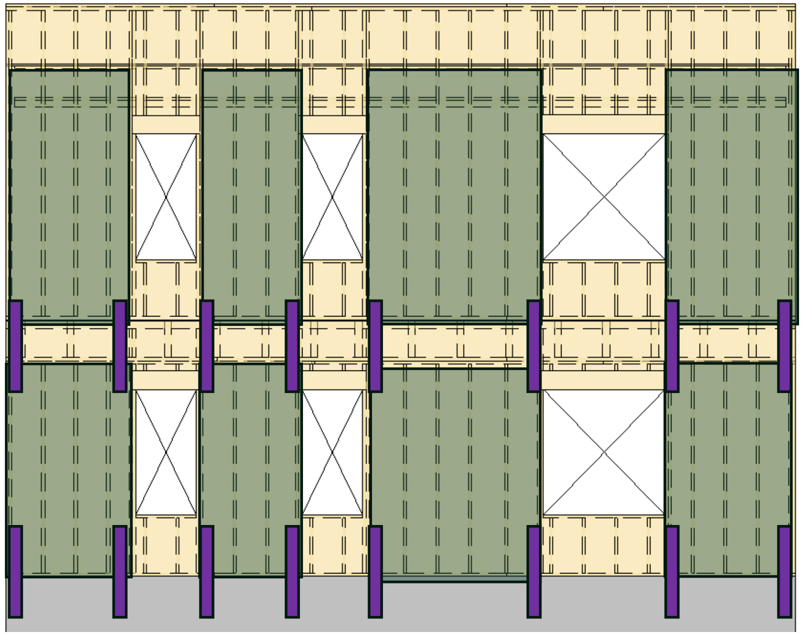
Shear wall and diaphragm boundary elements shall be provided to transfer the design tension and compression forces. Diaphragm and shear wall sheathing **shall not** be used to splice boundary elements. Diaphragm chords and collectors shall be placed in, or in contact with, the plane of the diaphragm framing unless it can be demonstrated that the moments, shears, and deflections, considering eccentricities resulting from other configurations, can be tolerated without exceeding the framing capacity and drift limits.

Exterior Shear Wall Design

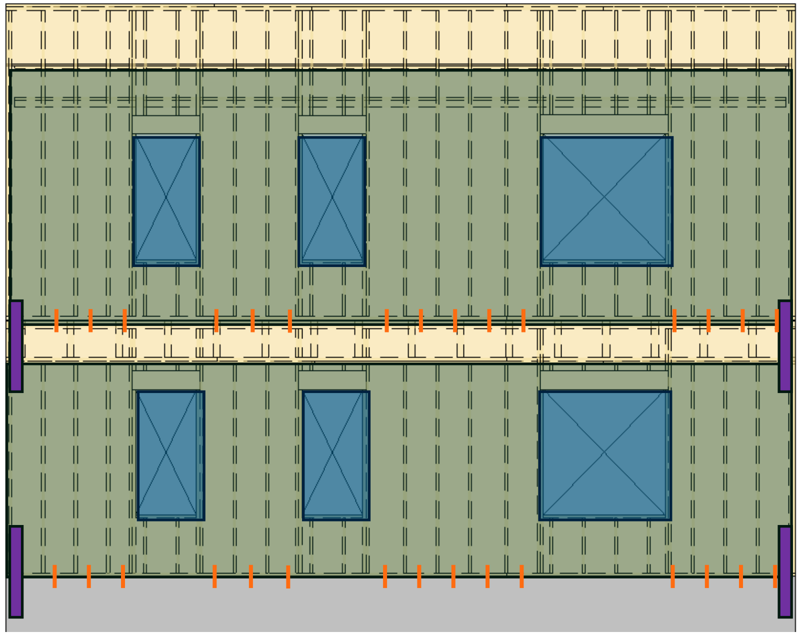
- 3 tools for exterior shear walls
  - Segmented shear walls
  - Perforated shear walls
  - Force Transfer Around Opening (FTAO) shear walls



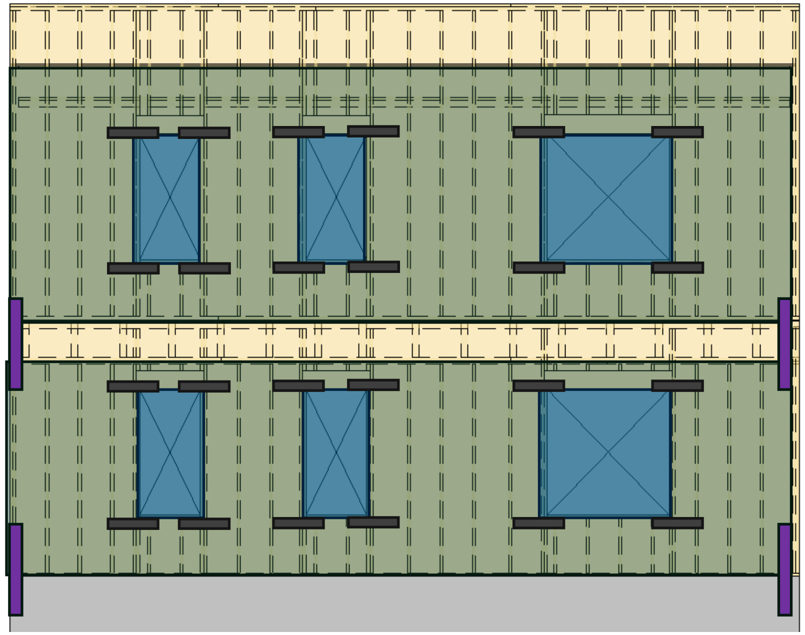
Exterior Shear Wall Design



Segmented
(SDPWS 4.3.2.1)

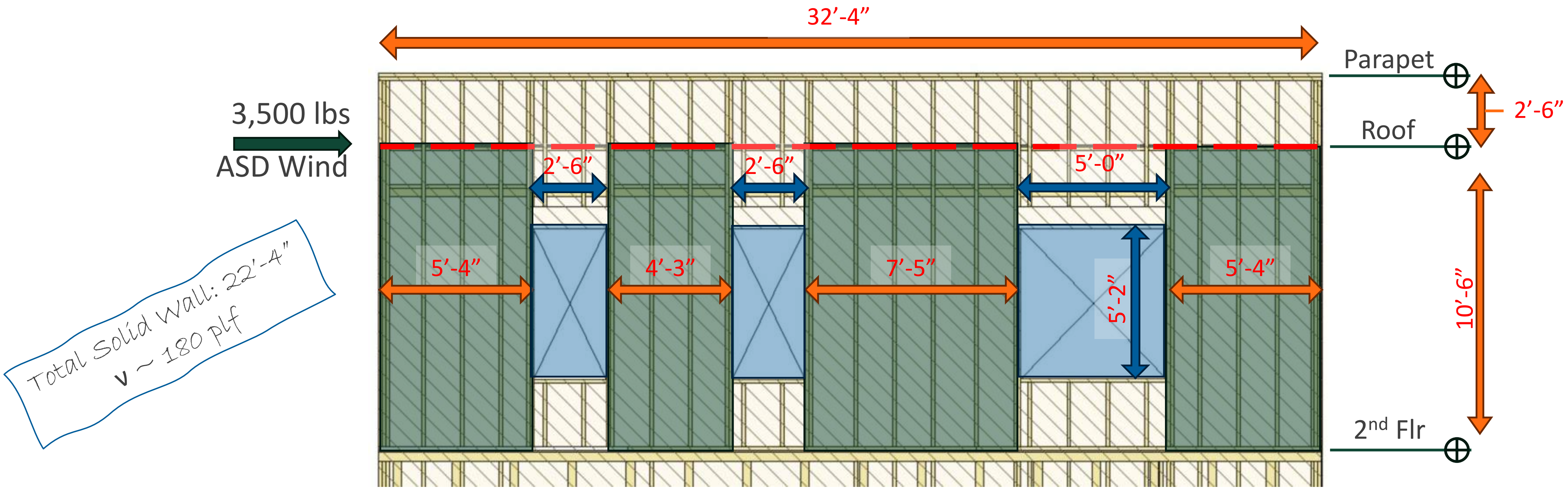


Perforated
(SDPWS 4.3.2.3)



FTAO
(SDPWS 4.3.2.2)

Exterior Shear Wall Design

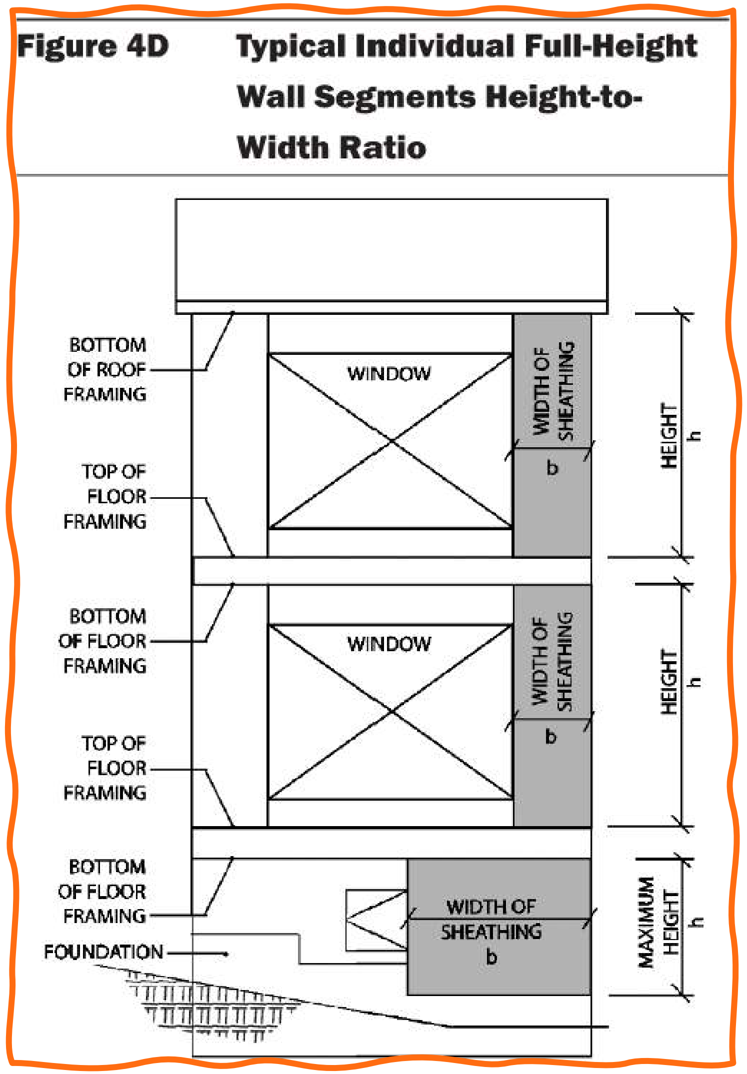


- DF-L No. 2
  - E = 1,600,000 PSI
  - S.G. = 0.50
  - (2)-2x6 boundary members
    A=16.5 in^2
- 7/16 OSB Rated Sheathing
  - 8d Nails @ 6" OC
  - 730 plf Nominal Capacity
    365 plf ASD wind capacity
  - GA = 15 kips/in

Exterior Shear Wall Design

Segmented Shear Wall

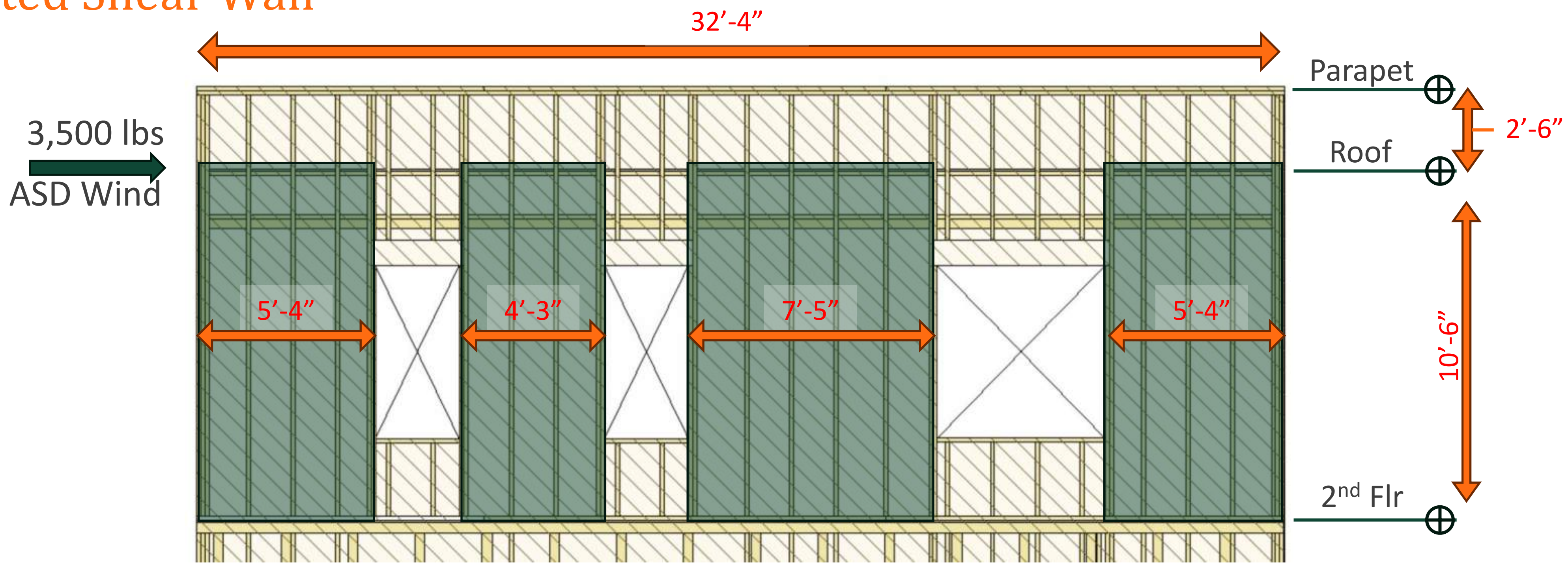
- Only utilize qualifying solid wall segments
- Key SDPWS Sections
  - 4.3.2.1 – Basic description of segmented shear wall analysis
  - 4.3.3.2 – Aspect ratio adjustment factors, 1.25-0.125h/b for WSP
  - Table 4.3.3 – Maximum shear wall aspect ratios
  - Figure 4D – graphical depiction of shear wall segments to set A.R.
  - 4.3.5.5 – Force distribution of shear walls in a line
- Expert Tip: Calculating the Capacity of Multiple Shear Walls in a Line



2021 SDPWS Figure 4D

Exterior Shear Wall Design

Segmented Shear Wall



Aspect Ratio:	1.97	**2.47**	1.42	1.97
SDPWS 4.3.3.2 Adj. Factor: 1.25-0.125(h/b)	N/A	**0.94**	N/A	N/A
ASD_{wind} Shear Capacity: (SDPWS Table 4.2A)	365 plf	**344 plf**	365 plf	365 plf

NOTE: Height for A.R. taken at diaphragm (roof) not top of parapet

Exterior Shear Wall Design
Segmented Shear Wall

- Using the equal deflection method discussed in **SDPWS 4.3.5.5.1**
  - Determine segment stiffness and proportion of loading applied

$$\delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{1000G_a} + \frac{h\Delta_a}{b}$$

SDPWS EQ. 4.3-1

Segment #	Length, b	Stiffness, K[1]	% Load Dist.	Applied Force	Applied Shear	Overturning Force[2]	Deflection
1	5.33	3,428 lb/in	23%	802 lbs	150.4 plf	1,743 lbs	0.234”
2	4.25	2,329 lb/in	16%	545 lbs	128.3 plf	1,527 lbs	0.234”
3	7.42	5,769 lb/in	39%	1350 lbs	182.0 plf	2,050 lbs	0.234”
4	5.33	3,428 lb/in	23%	802 lbs	150.4 plf	1,743 lbs	0.234”

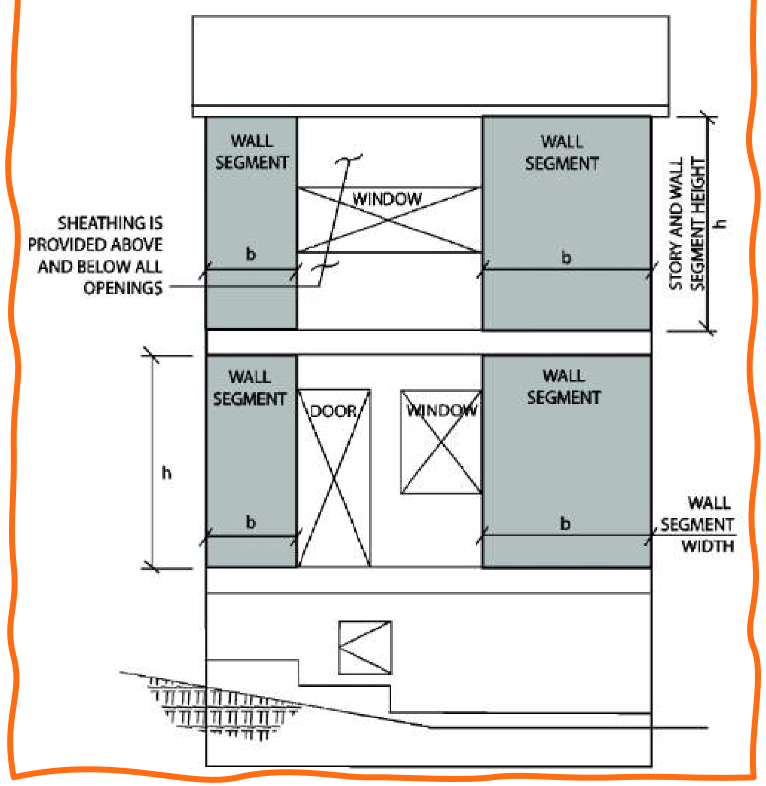
1. GA = 15 k/in,
2. B_{eff} taken as segment overall length minus 6”

Exterior Shear Wall Design

Perforated Shear Wall

- Utilizing the full wall length
- Adjustment factor applied based on total area of openings and qualifying solid segment lengths
- Key SDPWS Sections
  - 4.3.2.3 – Basic description of perforated shear wall analysis
  - 4.3.3.4 – Aspect ratio adjustment factors, $2b_i/h$
  - Table 4.3.3 – Maximum shear wall aspect ratios
  - Figure 4F – graphical depiction of shear wall segments to set A.R.
  - 4.3.4.2 – Deflection of perforated shear walls
  - 4.3.5.6 & Table 4.3.5.6 – Shear capacity adjustment factor, C_o
- AWC Perforated Shear Wall Design Example: https://awc.org/resources/perforated-shear-wall-design/

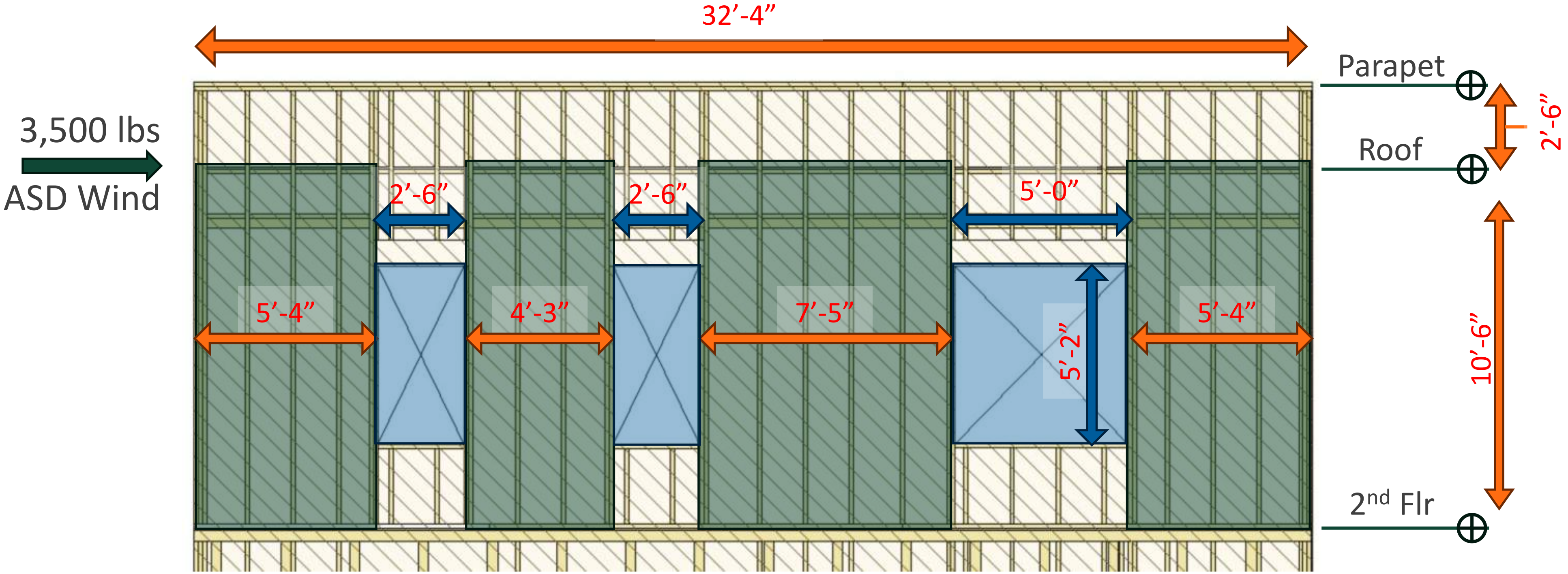
Figure 4F Typical Shear Wall Height-to-Width Ratio for Perforated Shear Walls



2021 SDPWS Figure 4F

Exterior Shear Wall Design

Perforated Shear Wall



Aspect Ratio:	1.97	**2.47**	1.42	1.97	
SDPWS 4.3.3.4 Adj. Factor: $(2b/h)$	N/A	**0.81**	N/A	N/A	
Effective Perf. Segments	5.33'	**3.44'**	7.42'	5.33'	$\sum b_i =$ **21.52'**

Exterior Shear Wall Design

Perforated Shear Wall

Total Wall Area, A_{wall}	Total Area of Openings, A_o	Total Area of Full Height Wall Segments, A_{fhs}	Sum of effective Perforated segment lengths, Σb_i
339.5 SF	51.67 SF	234.5 SF	21.52 FT

$$C_o = \frac{A_{wall}}{3A_o + A_{fhs}} \leq 1.0 \quad \Rightarrow \quad C_o = \frac{339.5}{3 * 51.67 + 234.5} = \mathbf{0.872}$$ SDPWS EQ. 4.3-6

$$V_n = v_n C_o \Sigma b_i \quad \Rightarrow \quad V_n = 730plf * 0.872 * 21.52 = \mathbf{13,699\ lbs}$$ SDPWS EQ. 4.3-5

$$V_{ASD,w} = \frac{13{,}699\ lbs}{2.0} = \mathbf{6,849.5\ lbs}$$

$$v_{max} = \frac{V}{C_o \Sigma b_i} \quad \Rightarrow \quad v_{max} = \frac{3{,}500\ lbs}{0.872 * 21.52\ ft} = \mathbf{186.6\ plf}$$ Sheathing Fastening — SDPWS EQ. 4.3-9

$$R = \frac{Vh}{C_o \Sigma b_i} \quad \Rightarrow \quad R = \frac{3{,}500\ lbs * 10.5\ ft}{0.872 * 21.52\ ft} = \mathbf{1,959\ lbs = T = C}$$ Hold-downs — SDPWS EQ. 4.3-8

Intermediate anchorage per SDPWS 4.3.6.4.2.1 $\Rightarrow$ $v_{max} = t = \mathbf{186.6\ plf}$ Sole plate anchorage — SDPWS EQ. 4.3-9

Exterior Shear Wall Design

Perforated Shear Wall

4.3.4.2 Deflection of Perforated Shear Walls: The deflection of a perforated shear wall shall be calculated in accordance with 4.3.4, where *v* in equation 4.3-1 is equal to v_{max} obtained in equation 4.3-9 and *b* is taken as Σb_i.

$$\delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{1000G_a} + \frac{h\Delta_a}{b}$$

$v \rightarrow v_{max}$, $b \rightarrow \Sigma b_i$

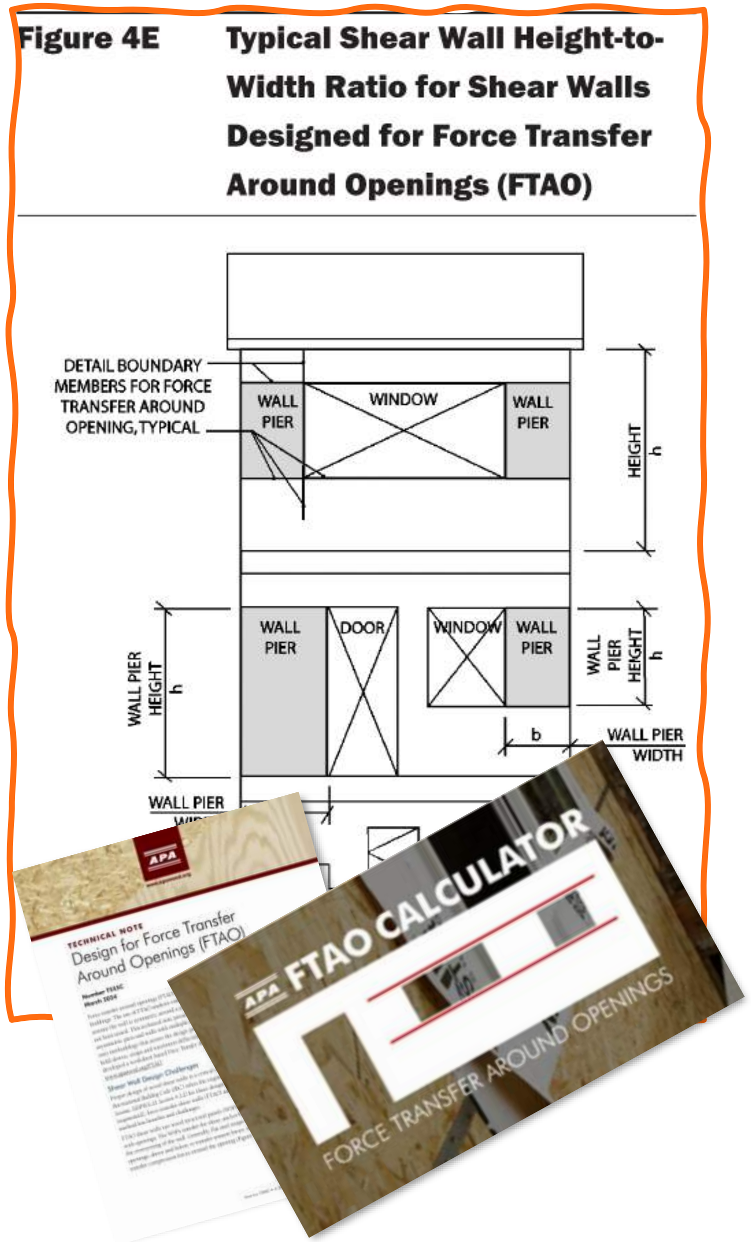
SDPWS EQ. 4.3-1

$$\delta_{sw} = \frac{8 * 186.5plf * 10.5ft^3}{1{,}600{,}000psi * 16.5in^2 * 21.52ft} + \frac{186.5plf * 10.5ft}{1000 * 15k/in} + \frac{10.5ft * 0.06in}{21.52ft} = 0.16"$$

Exterior Shear Wall Design

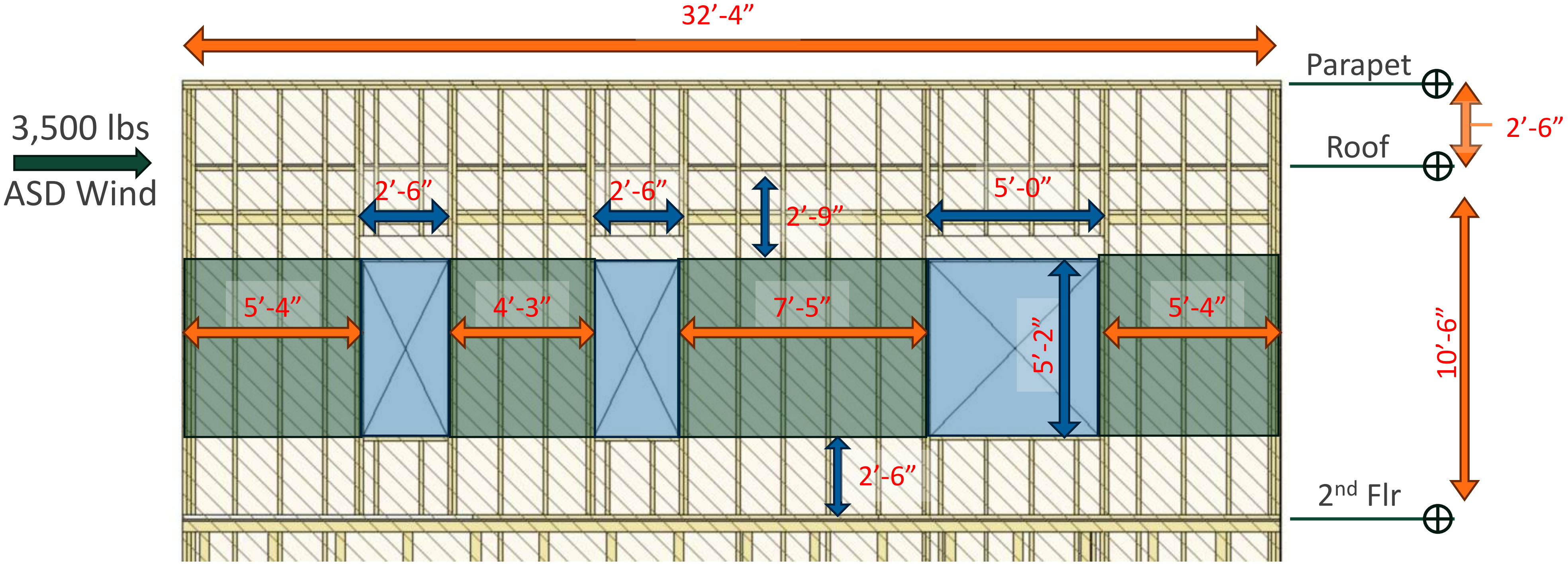
Force Transfer Around Opening (FTAO) Shear Wall

- » Utilizing the full wall length
- » Detailing for force transfer at opening corners
- » Key SDPWS Sections
  - » 4.3.2.2 – Basic description of FTAO shear wall analysis
  - » 4.3.3.3 – Aspect ratio limitations
  - » Table 4.3.3 – Maximum shear wall aspect ratios
  - » Figure 4E – graphical depiction of shear wall segments to set A.R.
- » APA FTAO Resources: Force Transfer Around Openings - APA



Exterior Shear Wall Design

FTAO Shear Wall



Aspect Ratio:	0.97	1.22	0.70	0.97
SDPWS 4.3.3.4 Adj. Factor: 1.25-0.125(h/b) **or** $(2b/h)$	N/A	N/A	N/A	N/A

All piers > 2'-0" wide
>12" above & below openings

Exterior Shear Wall Design

FTAO Shear Wall

No SDPWS Equations
Just statics

Step 1: Calculate hold-down forces

$$R = \frac{Vh}{L} \quad \Rightarrow \quad R = \frac{3{,}500\ lbs * 10.5\ ft}{32.33ft} = \mathbf{1,137\ lbs}$$

Step 2: Calculate unit shear above & below the openings

$$v_a = v_b = R/(h_a + h_b) \quad \Rightarrow \quad v_a = v_b = \frac{1{,}137lbs}{2.83ft + 2.5ft} = \mathbf{213.3\ plf}$$

Step 3: Boundary force above and below the openings

Opening 1 $\quad O_1 = v_a * L_{O1} \quad \Rightarrow \quad O_1 = 213.3\ plf * 2.5ft = \mathbf{533.3\ lbs}$

Opening 2 $\quad O_2 = v_a * L_{O2} \quad \Rightarrow \quad O_2 = 213.3\ plf * 2.5ft = \mathbf{533.3\ lbs}$

Opening 3 $\quad O_3 = v_a * L_{O3} \quad \Rightarrow \quad O_3 = 213.3\ plf * 5ft = \mathbf{1,066.6lbs}$

Exterior Shear Wall Design

FTAO Shear Wall

No SDPWS Equations
Just statics

Step 4: Calculate the Corner Forces

Corner 1 $$F_1 = \frac{O_1(L_1)}{L_1 + L_2} = \frac{533.3lbs(5.33ft)}{5.33ft + 4.25ft} = \mathbf{296.7\ lbs}$$

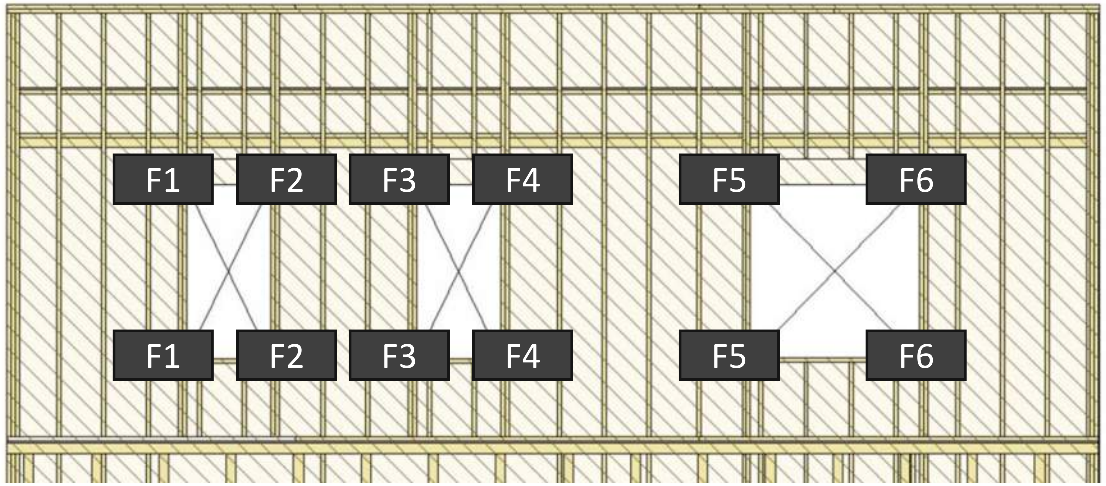
Corner 2 $$F_2 = \frac{O_1(L_2)}{L_1 + L_2} = \frac{533.3lbs(4.25ft)}{5.33ft + 4.25ft} = \mathbf{236.5\ lbs}$$

Corner 3 $$F_3 = \frac{O_2(L_2)}{L_2 + L_3} = \frac{533.3lbs(4.25ft)}{4.25ft + 7.42ft} = \mathbf{194.3\ lbs}$$

Corner 4 $$F_4 = \frac{O_2(L_3)}{L_2 + L_3} = \frac{533.3lbs(7.42ft)}{4.25ft + 7.42ft} = \mathbf{339.0\ lbs}$$

Corner 5 $$F_5 = \frac{O_3(L_3)}{L_3 + L_4} = \frac{1066.6lbs(7.42ft)}{7.42ft + 5.33ft} = \mathbf{620.5\ lbs}$$

Corner 6 $$F_6 = \frac{O_3(L_4)}{L_3 + L_4} = \frac{1066.6lbs(5.33ft)}{7.42ft + 5.33ft} = \mathbf{446.8\ lbs}$$



Exterior Shear Wall Design

FTAO Shear Wall

No SDPWS Equations
Just statics

Step 5: Calculate tributary length of openings

Opening 1L $$T_1 = \frac{L_1(L_{o1})}{L_1 + L_2} = \frac{5.33ft(2.5ft)}{5.33ft + 4.25ft} = \mathbf{1.39\ ft}$$

Opening 1R $$T_2 = \frac{L_2(L_{o1})}{L_1 + L_2} = \frac{4.25ft(2.5ft)}{5.33ft + 4.25ft} = \mathbf{1.11\ ft}$$

Opening 2L $$T_3 = \frac{L_2(L_{o2})}{L_2 + L_3} = \frac{4.25ft(2.5ft)}{4.25ft + 7.42ft} = \mathbf{0.91\ ft}$$

Opening 2R $$T_4 = \frac{L_3(L_{o2})}{L_2 + L_3} = \frac{7.42(2.5ft)}{4.25ft + 7.42ft} = \mathbf{1.59\ ft}$$

Opening 3L $$T_5 = \frac{L_3(L_{o3})}{L_3 + L_4} = \frac{7.42(5ft)}{7.42ft + 5.33ft} = \mathbf{2.91\ ft}$$

Opening 3R $$T_6 = \frac{L_4(L_{o3})}{L_3 + L_4} = \frac{5.33ft(5ft)}{7.42ft + 5.33ft} = \mathbf{2.09\ ft}$$

Step 6: Calculate unit shear beside the openings

$$v_1 = \frac{\frac{V}{L} * (L_1 + T_1)}{L_1} = \frac{\frac{3500lbs}{32.33ft} * (5.33ft + 1.39ft)}{5.33ft} = \mathbf{137\ plf}$$

$$v_2 = \frac{\frac{V}{L} * (T_2 + L_2 + T_3)}{L_2} = \frac{\frac{3500lbs}{32.33ft} * (1.11ft + 4.25ft + 0.91ft)}{4.25ft} = \mathbf{160\ plf}$$

$$v_3 = \frac{\frac{V}{L} * (T_4 + L_3 + T_5)}{L_3} = \frac{\frac{3500lbs}{32.33ft} * (1.59ft + 7.42ft + 2.91ft)}{7.42ft} = \mathbf{174\ plf}$$

$$v_4 = \frac{\frac{V}{L} * (T_6 + L_4)}{L_4} = \frac{\frac{3500lbs}{32.33ft} * (2.09ft + 5.33ft)}{5.33ft} = \mathbf{151\ plf}$$

Spot check: $v_1*L_1+v_2*L_2+v_3*L_3+v_4*L_4$ should equal the total shear applied to the wall

Exterior Shear Wall Design

FTAO Shear Wall

No SDPWS Equations
Just statics

Step 7: Calculate the resistance to corner forces

$$R_1 = v_1 * L_1 = 137plf * 5.33ft = \mathbf{728\ lbs}$$

$$R_2 = v_2 * L_2 = 160plf * 4.25ft = \mathbf{679\ lbs}$$

$$R_3 = v_3 * L_3 = 174plf * 7.42ft = \mathbf{1,290\ lbs}$$

$$R_4 = v_4 * L_4 = 151plf * 5.33ft = \mathbf{803\ lbs}$$

$$\boldsymbol{\Sigma} = \mathbf{3,500\ lbs}$$

Step 8: Calculate the difference in corner forces & resistance

$$R_1 - F_1 = 728lbs - 297lbs = \mathbf{431\ lbs}$$

$$R_2 - F_2 - F_3 = 679lbs - 237lbs - 194lbs = \mathbf{248\ lbs}$$

$$R_3 - F_4 - F_5 = 1290lbs - 339lbs - 620lbs = \mathbf{331\ lbs}$$

$$R_4 - F_6 = 803lbs - 446lbs = \mathbf{357\ lbs}$$

Step 9: Calculate unit shear in corner zones

$$v_{c1} = (R_1 - F_1)/L_1 = 431\ lbs/5.33ft = \mathbf{81\ plf}$$

$$v_{c2} = (R_2 - F_2 - F_3)/L_2 = 248\ lbs/4.25ft = \mathbf{58\ plf}$$

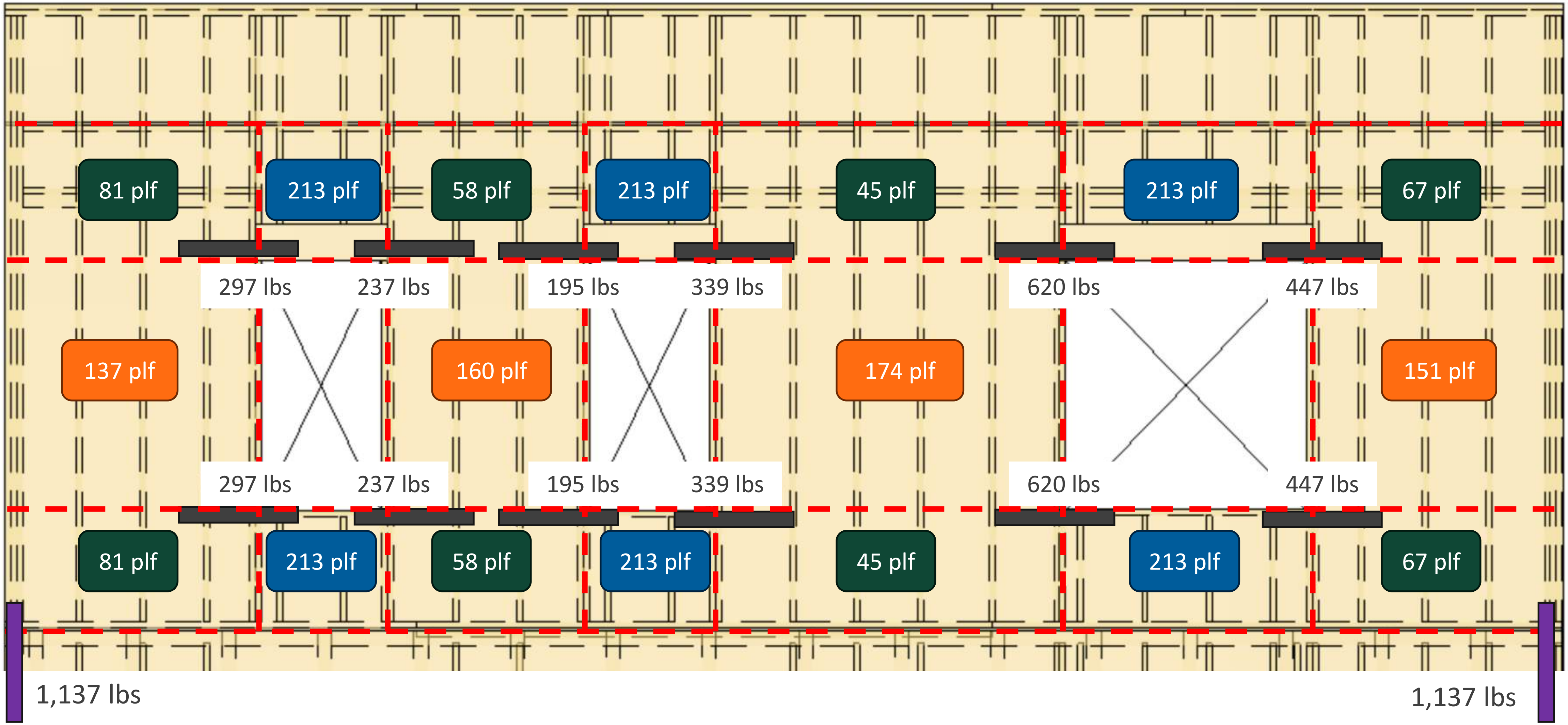
$$v_{c3} = (R_3 - F_4 - F_5)/L_3 = 331\ lbs/7.42ft = \mathbf{45\ plf}$$

$$v_{c4} = (R_4 - F_6)/L_4 = 357\ lbs/5.33ft = \mathbf{67\ plf}$$

Exterior Shear Wall Design

FTAO Shear Wall

Deflection, δ= 0.15”

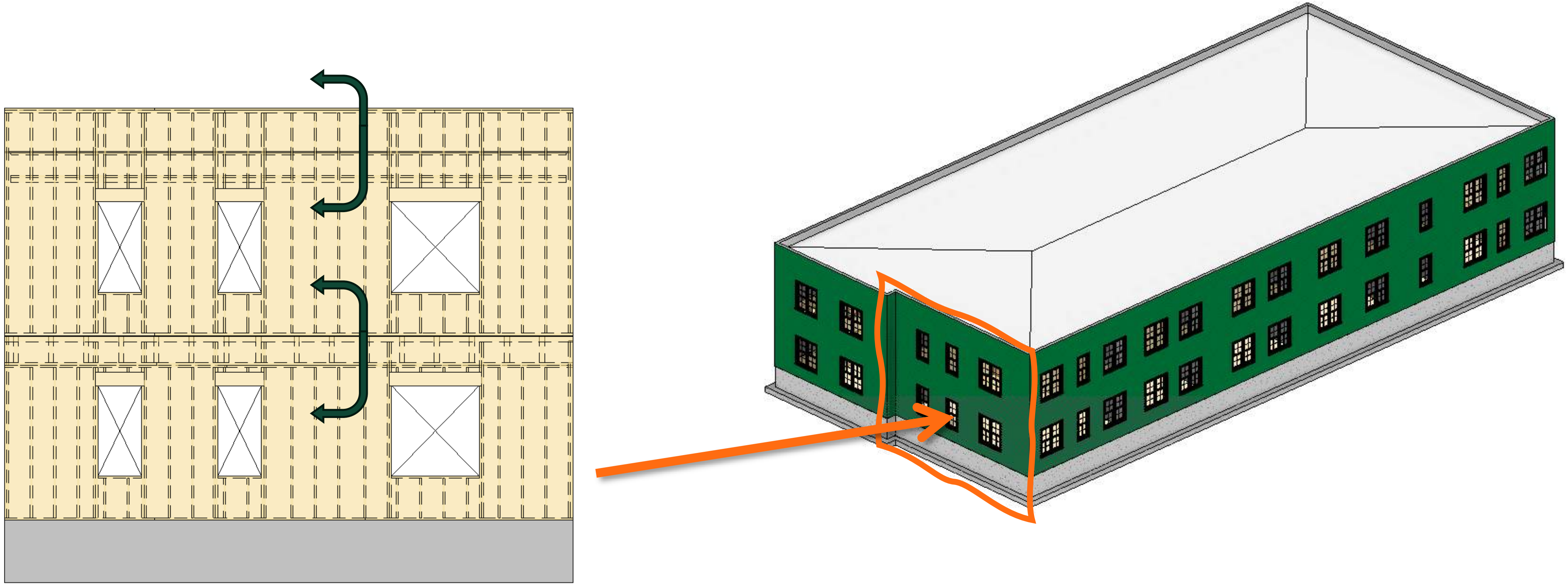


Exterior Shear Wall Design Comparison

- Key take aways
  - All yield fairly similar results
  - FTAO shear walls are computationally heavy, but can reduce hold-down forces and provide more flexibility when it comes to minimum pier dimensions
  - Segmented method tends to be more flexible
  - Pay attention to intermediate tension force for perforated method

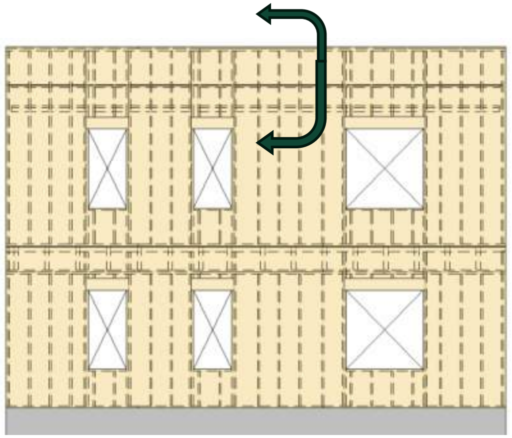
	Segmented Shear Wall	Perforated Shear Wall	FTAO Shear Wall
Maximum applied shear	181 plf	187 plf	213 plf
Max HD force	2,050 lbs	1,959 lb/in	1,137 lbs
Deflection	0.23”	0.16”	0.15”
Special Considerations	Overturning hardware required at each segment	Intermediate tension capacity	Straps at window corners

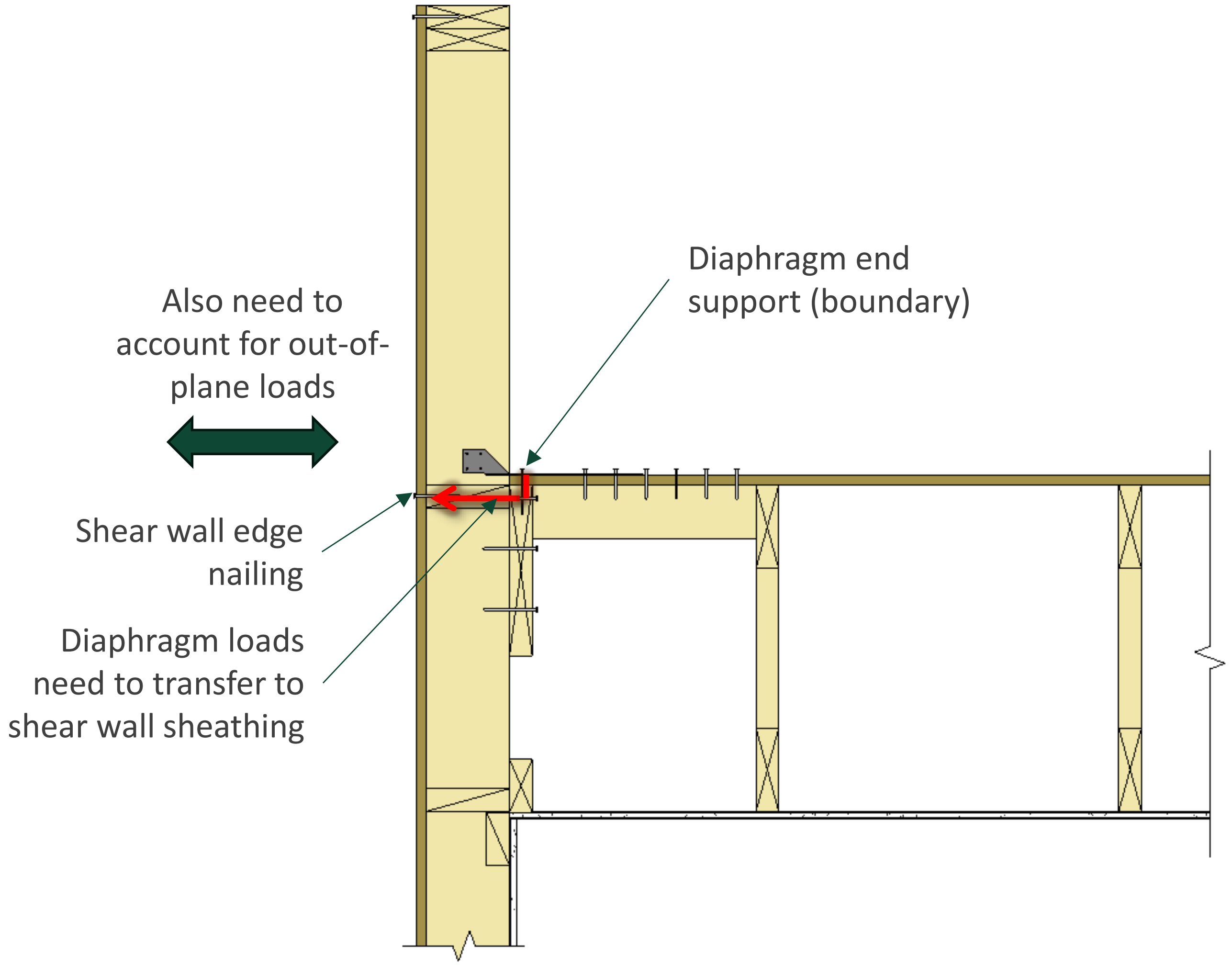
Exterior Shear Wall Design



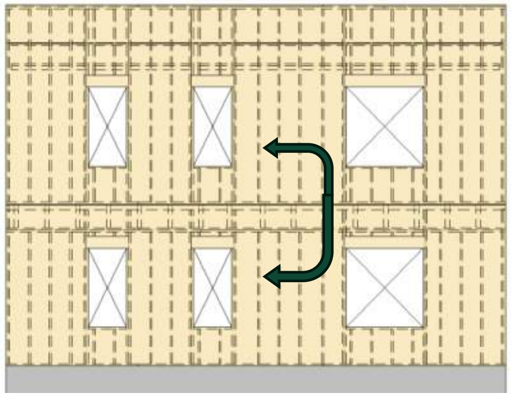
Exterior Shear Wall Design

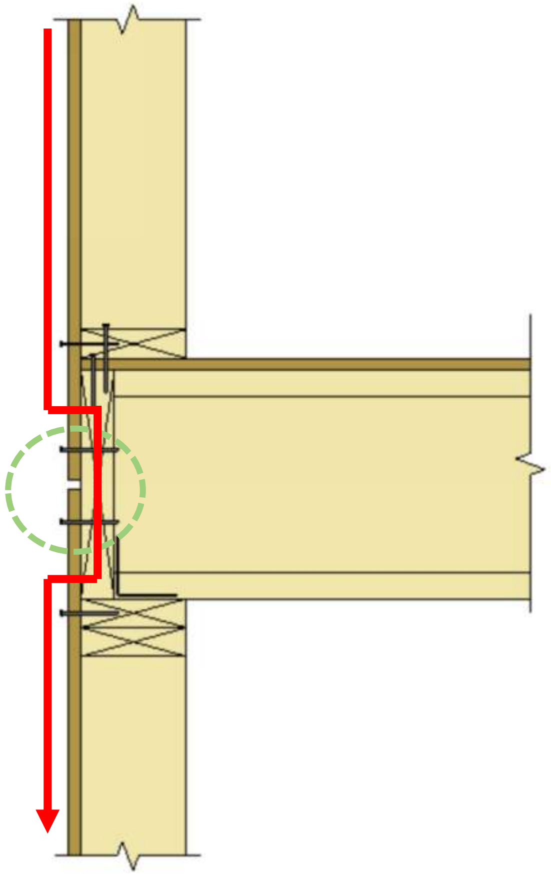
Load Transfer at Roof Level



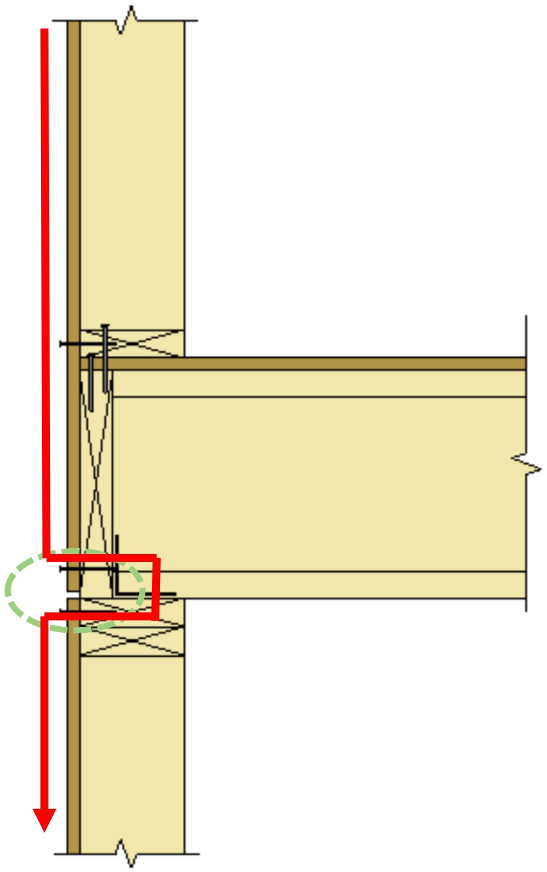


Detail: Rim Joist to Top Plates

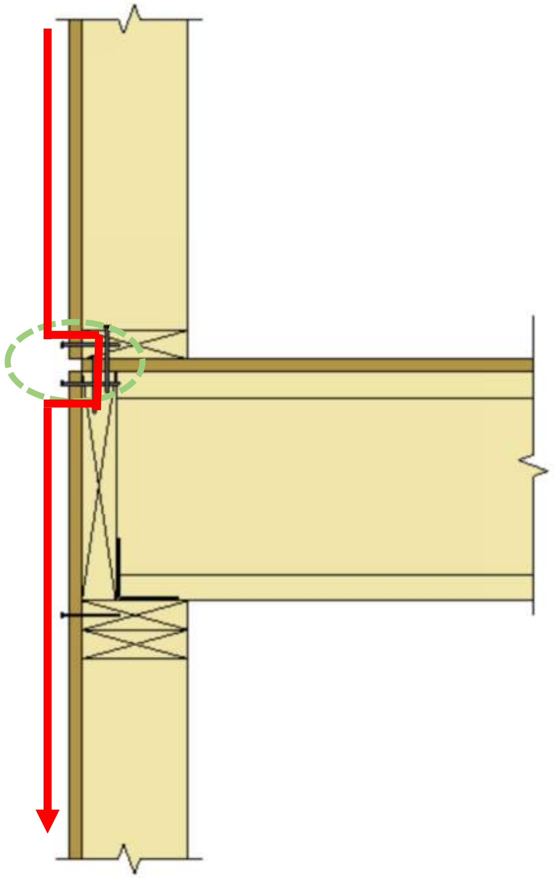




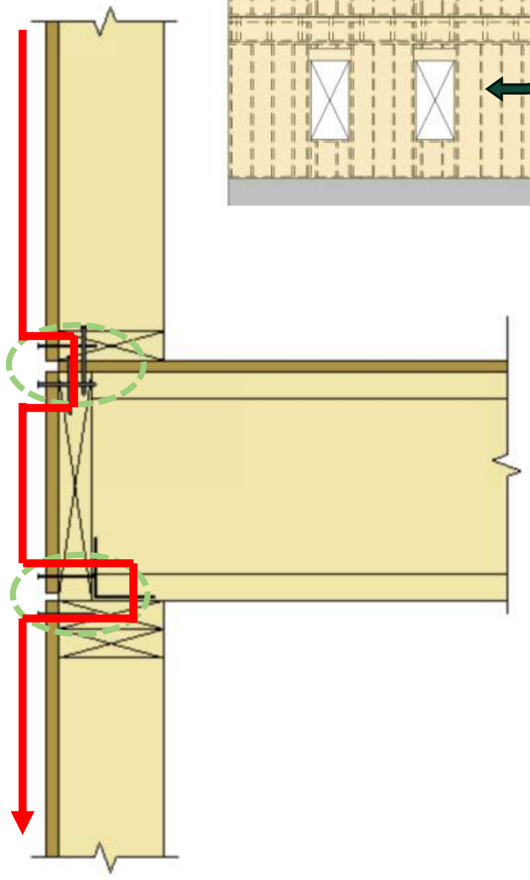
Option 1



Option 2



Option 3



Option 4

Exterior Shear Wall Design

Materials

- Variety of materials can be used at exterior walls
  - Oriented Strand Board (OSB), Plywood
  - Fire-retardant Treated wood (FRT)
  - Exterior Gypsum board
  - Sheathing with integrated continuous insulation

Image: IMEG

Exterior Shear Wall Design

Materials

Table 4.3A Nominal Unit Shear Capacities for Sheathed Wood-Frame Shear Walls [1,3,6]

Wood-based Panels [4]

Sheathing Material	Minimum Nominal Panel Thickness (in.)	Minimum Nail Bearing Length in Framing Member or Blocking, ℓ_m (in.)	Nail Type & Size [9] Length (in.) x Shank diameter (in.) x Head diameter (in.)	Panel Edge Nail Spacing (in.)											
				6			4			3			2		
				v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)	
					OSB	PLY		OSB	PLY		OSB	PLY		OSB	PLY
Wood Structural Panels - Structural I [4,5]	5/16	1-1/4	6d common nail (2 x 0.113 x 0.266) [8]	560	13	10	840	18	13	1090	23	16	1430	35	22
	3/8 [2]	1-3/8	8d common nail (2-1/2 x 0.131 x 0.281) [8]	645	19	14	1010	24	17	1290	30	20	1710	43	24
	7/16 [2]			715	16	13	1105	21	16	1415	27	19	1875	40	24
	15/32			785	14	11	1205	18	14	1540	24	17	2045	37	23
	15/32	1-1/2	10d common nail (3 x 0.148 x 0.312) [8,10]	950	22	16	1430	29	20	1860	36	22	2435	51	28

With FRT lumber and sheathing, reductions per manufacturer's literature must be applied

Exterior Shear Wall Design

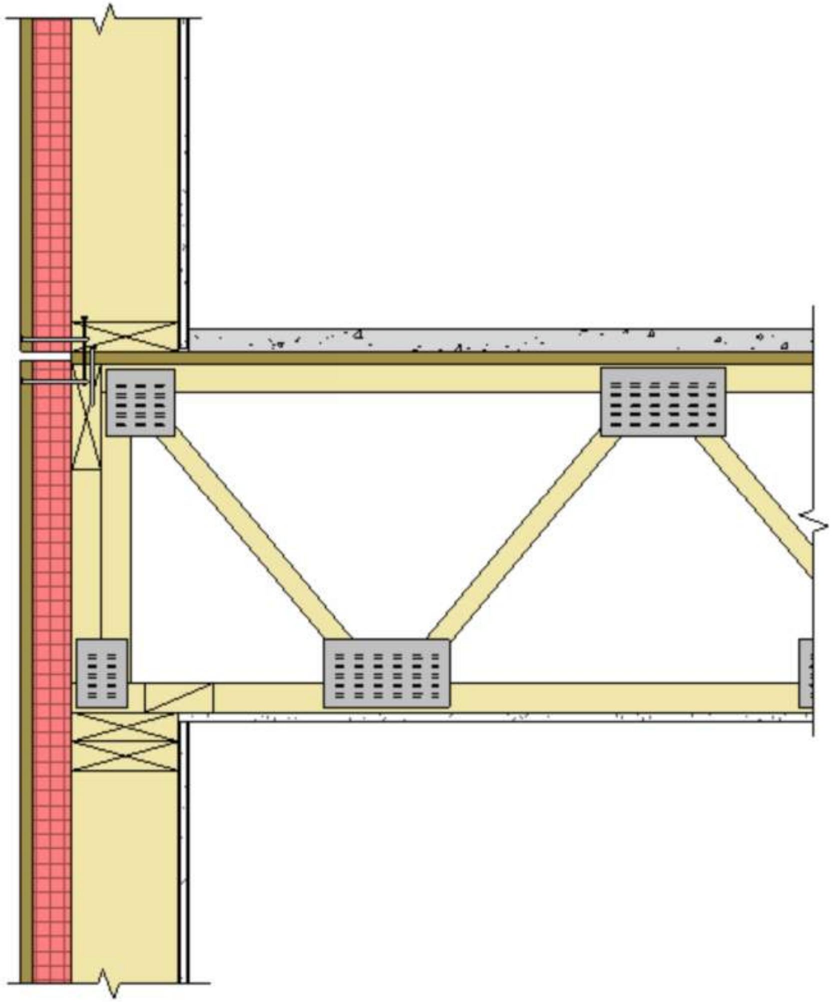
Materials

GA Fire Resistance Design Manual

Item 23, Section 1 of the General Explanatory Notes:

"When not specified as a component of a fire- resistance rated wall or partition system, wood structural panels shall be permitted to be added to one or both sides."

Exterior Gypsum Products



Sheathing with Continuous Insulation

Additional Resources

- Laying out shear walls for a building; calculating shear wall demand
  - Common Challenges in Wood Lateral Systems Layouts
  - Five-Story Light-Frame Wood Over Podium
  - Lateral 101 for Architects

- Shear wall design and detailing
  - Practical Considerations for Shear Wall Connections and Details
  - The Fine Print of Wood Design: Commonly Overlooked Code Provisions
  - Offset Shear Wall Design
  - FTAO Analysis for Complex Shear Wall Openings

Additional Resources

- Diaphragm design, including collectors
  - **A Master Class on Wood Lateral-Resisting Systems: In-Depth Diaphragm Layout and Analysis**
  - **The Analysis of Irregular Shaped Diaphragms**
  - **Offset Diaphragm Design**

- Cantilevered and rigid diaphragm analysis
  - **A Design Example of a Wood Cantilever Diaphragm:** Part 1, Part 2, Part 3, Part 4
  - **Design Example of a Cantilever Wood Diaphragm**

QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

Ashley Cagle, PE, SE

WoodWorks

ashley.cagle@woodworks.org

Taylor Landry, PE, MLSE

WoodWorks

taylor.landry@woodworks.org

Copyright Materials

Funding provided in part by the Softwood Lumber Board