Advancements in Force Transfer Around Openings for Wood Framed Shear Walls

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Advancements in Force Transfer Around Openings for Wood Framed Shear Walls



Learning Objectives

- Investigate past and current methods for determining force transfer around openings for wood shear walls
- Compare the effects of different sizes of openings and full-height piers, and their relationships to the three industry standards for calculation of force transfer around openings
- Assess new design methodologies for accurately estimating the forces around multiple openings with asymmetric piers
- Estimate the deflections for shear walls designed using the force transfer around openings design method
- Apply the FTAO design methodology to an example
- Introduce APA's new force transfer around opening design resources

Shear Wall Design Challenges (SDPWS-15 4.3.5)

Segmented

1. Aspect Ratio up to 2:1 for wind and seismic
2. Aspect ratio up to 3.5:1, if allowable shear is reduced by 1.25-0.125h/bs

Perforated

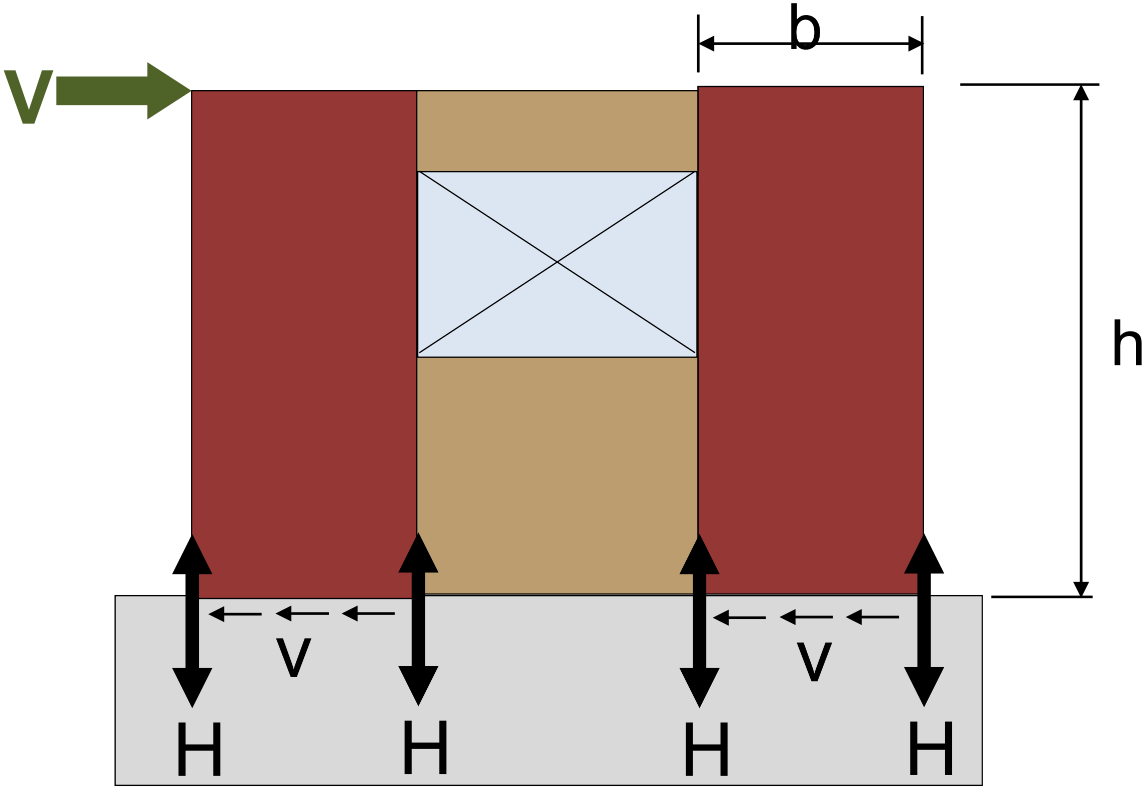
1. Code provides specific requirements
2. The capacity is determined based on empirical equations and tables

Force Transfer

1. Code does not provide guidance for this method
2. Different approaches using rational analysis could be used

Segmented Wood Shear Walls (SDPWS-15 Section 4.3.5.1)

- Only full height segments are considered
- Max aspect ratio
  - * 2:1 – without adjustment
  - * 3.5:1 – with adjustment
  - * Updated in SDPWS-15

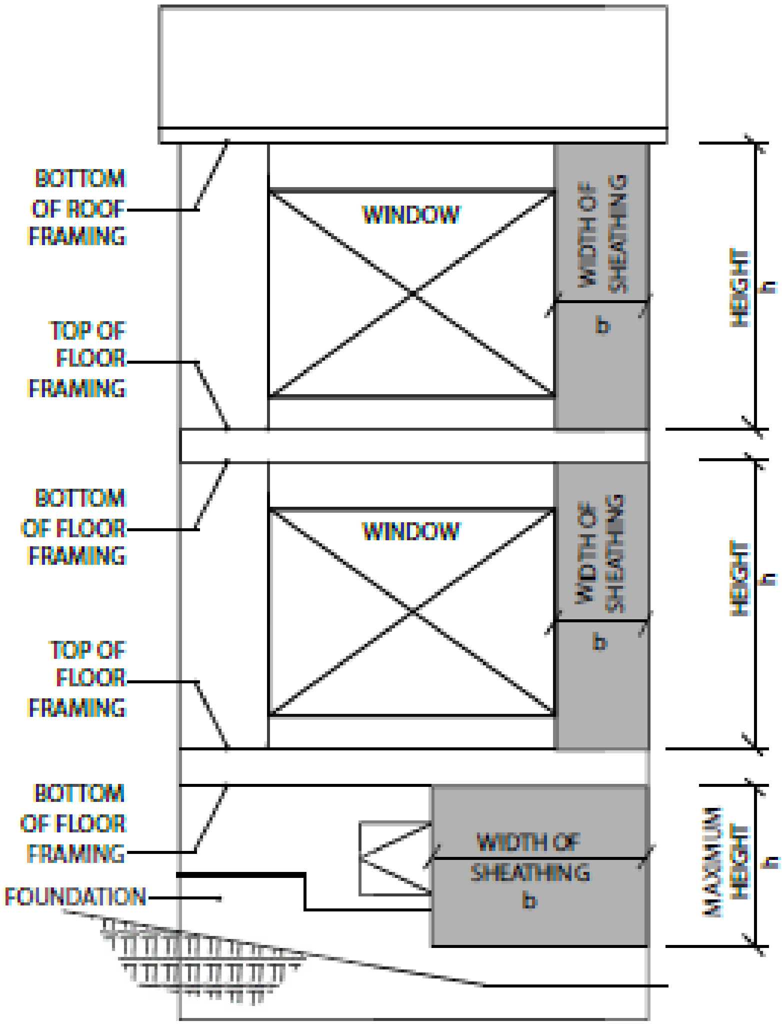


Aspect ratio $h:b_s$ as shown in figure

Segmented Wood Shear Walls

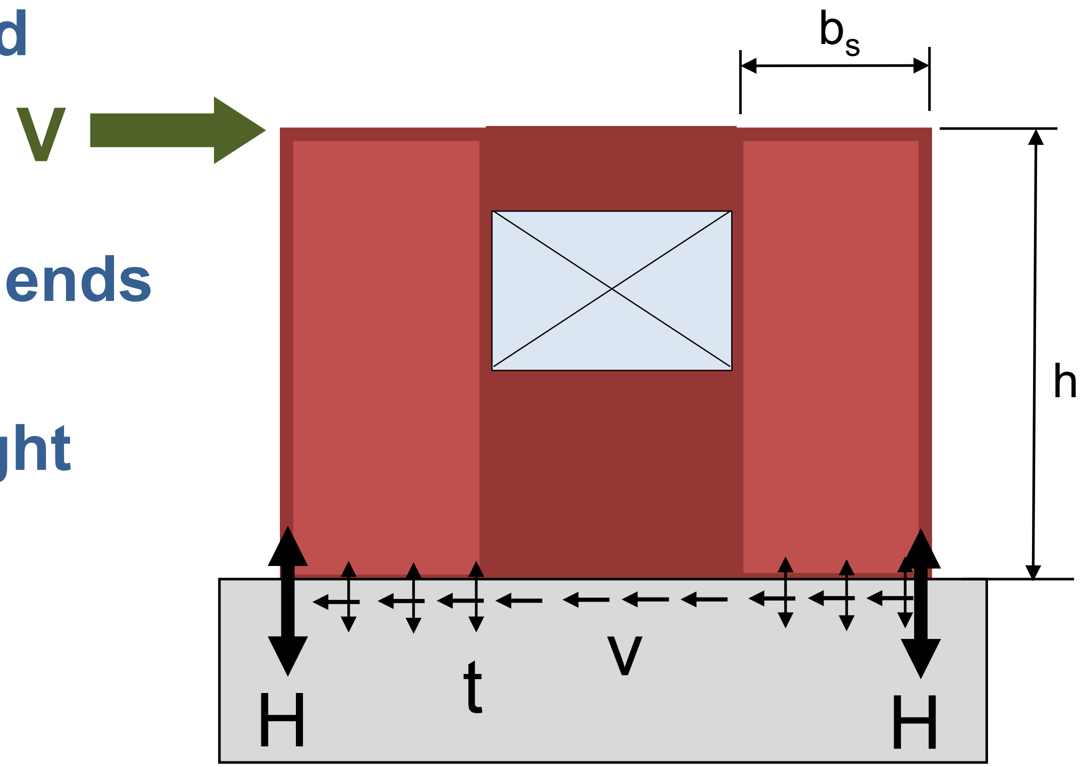
Aspect Ratios SDPWS-15

- **Standard shear walls Figure 4D**
  - **Wall width is defined as width of the full height sheathing adjacent to the opening but sheathing IS NOT required above and below openings**
  - **h:w must not exceed 2:1 or 3.5:1 ratio depending on sheathing material**



Perforated Shear Walls (SDPWS-15 4.3.5.3)

- Openings accounted for by empirical adjustment factor
- Hold-downs only at ends
- Uplift between hold downs, t, at full height segments is also required
- Limited to 870 plf (ASD, seismic)

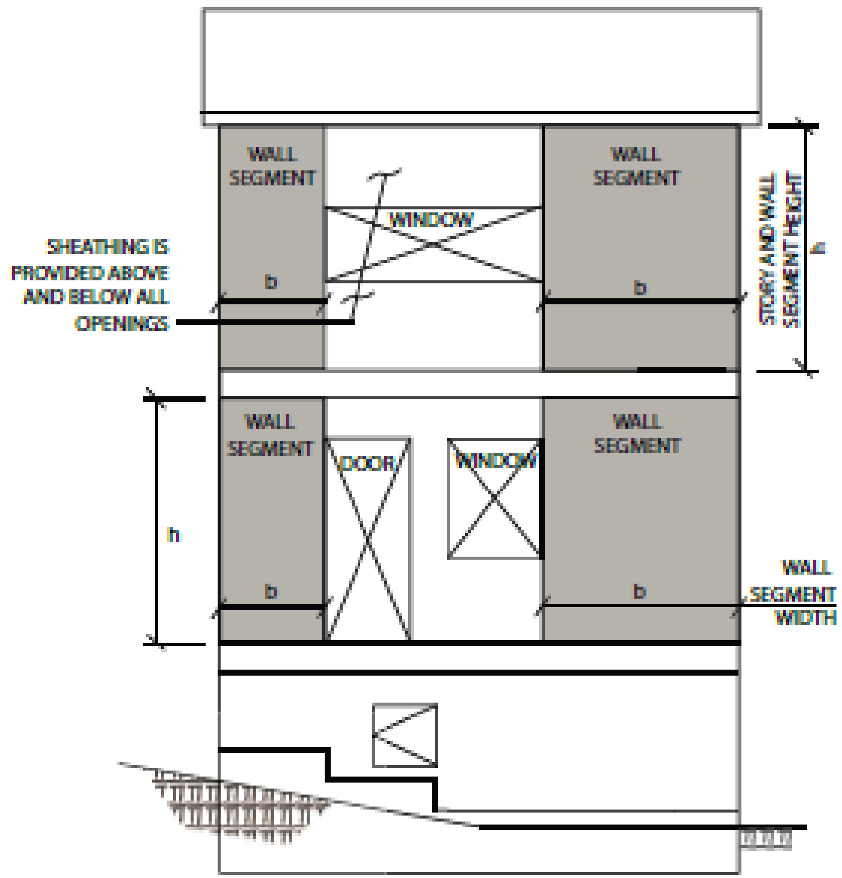


Aspect ratio applies to full height segment (dotted)

Perforated Shear Walls

Aspect Ratios SDPWS-15

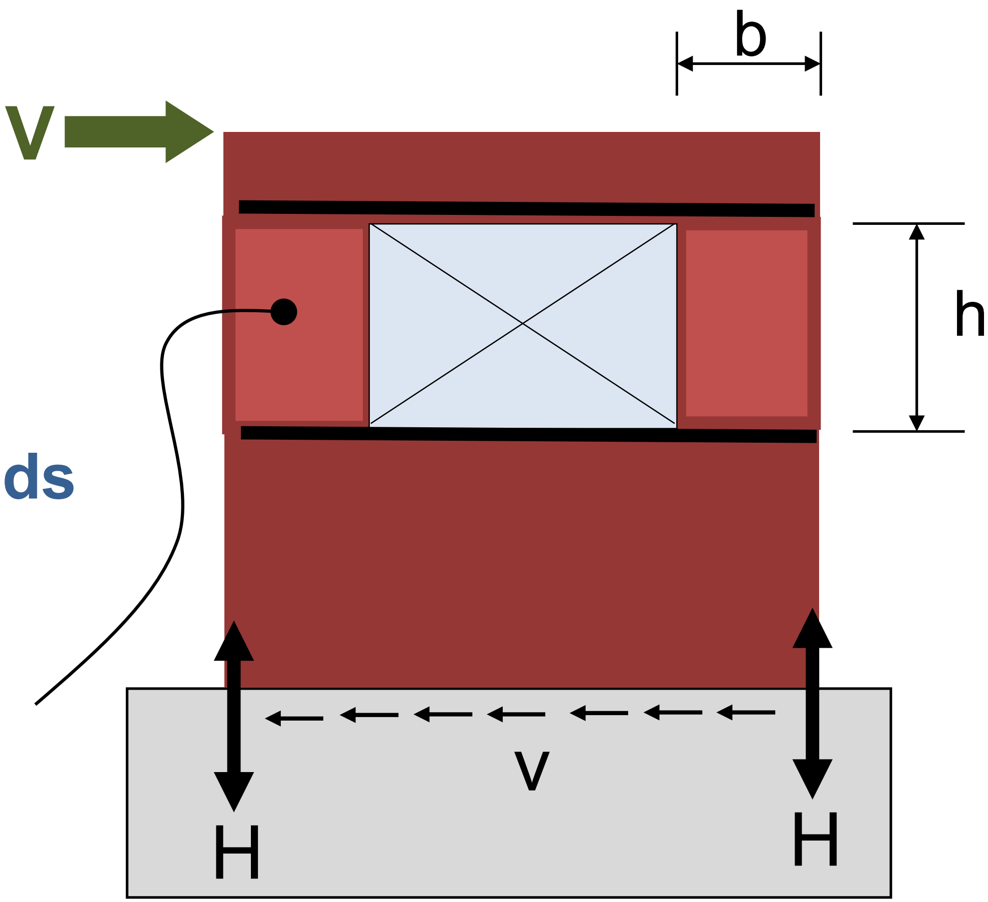
- **Perforated shear walls Figure 4C**
  - Wall width is defined as width of the full height sheathing adjacent to the opening but full sheathing is provided above and below openings
  - h:w must not exceed 2:1 or 3.5:1 ratio depending on sheathing material



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

FTAO Shear Walls (SDPWS-15 Section 4.3.5.2)

- Openings accounted for by strapping or framing
  - "based on a rational analysis"
- Hold-downs only at ends
- H/w ratio defined by wall pier

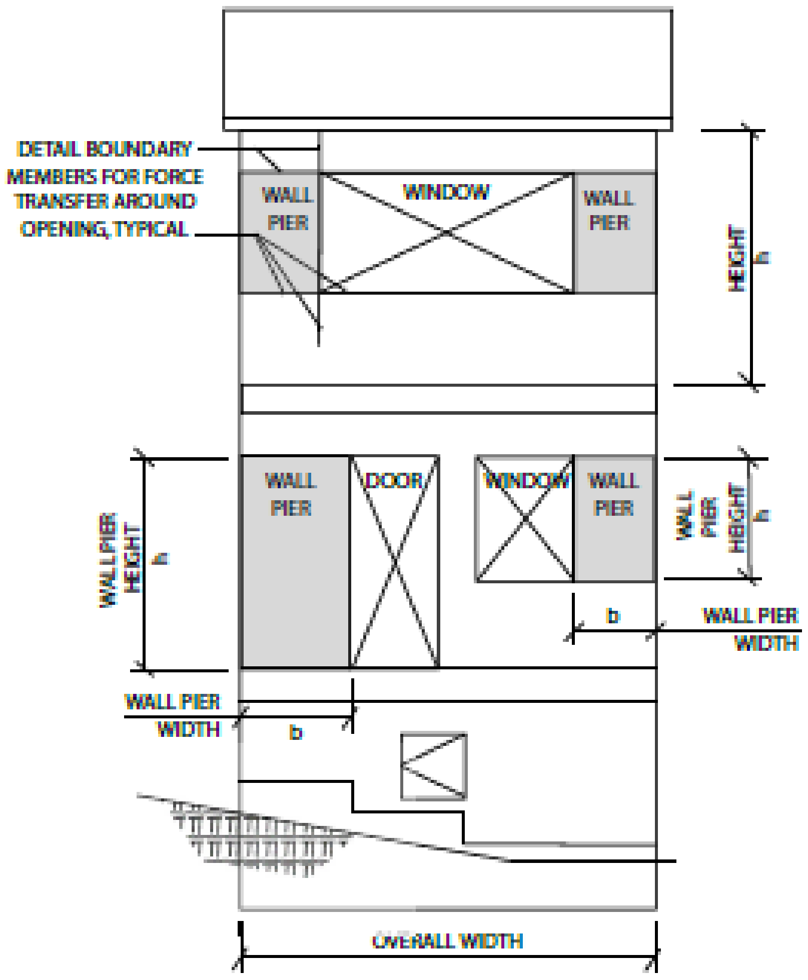


Aspect ratio h:b as shown in figure

FTAO Shear Walls

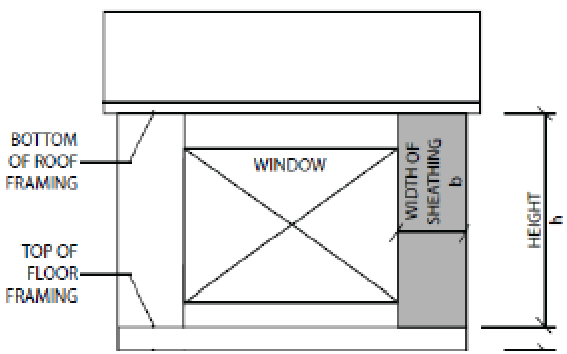
Aspect Ratio SDPWS-15

- **Force Transfer Shear Walls Figure 4E**
  - Width of wall is defined as width of the full height sheathing adjacent to the opening and the height is the same as the opening height
  - h:w must not exceed 2:1 or 3.5:1 ratio

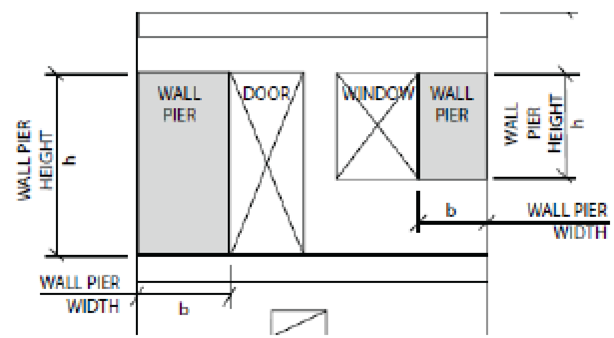


Aspect ratio (SDPWS-15 4.3.4.2)

- Definition of h and w is the same as previous code
- ALL shear walls with 2:1 < aspect ratios <= 3.5:1 shall apply reduction factor, aspect ratio factor
  - Formerly applied only to high seismic
- Aspect Ratio Factor (WSP) = 1.25-0.125h/bs



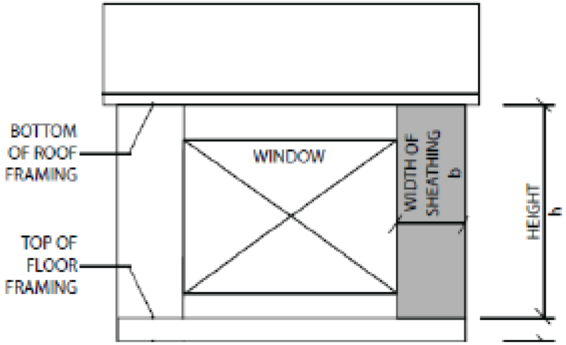
Excerpt Fig 4D
h:w ratio Segmented



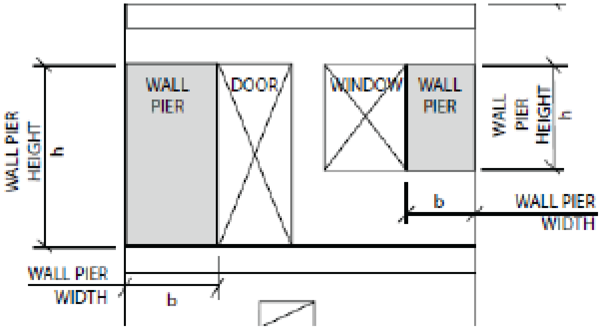
Excerpt Fig. 4E
h:w ratio FTAO

Shear distribution to shear walls in line (SDPWS-15 4.3.3.4.1)

- Individual shear walls in line shall provide the same calculated deflection. Exception:
  - Nominal shear capacities of shear walls having 2:1<aspect ratio<=3.5:1 are multiplied by 2bs/h for design. Aspect ratio factor (4.3.4.2) need not be applied.



Excerpt Fig 4D
h:w ratio Segmented



Excerpt Fig. 4E
h:w ratio FTAO

Shear Wall Design Challenges

Shear Wall Design Challenges

Typical FTAO Application

- Residential, Multifamily
  - Single Opening
  - Design assumes equal pier width
- Commercial
  - Strap continuous wall line above and below openings
  - Fully sheath wall

Field Survey

- 18+ sites fall 2010 (LA, Orange and San Diego Counties)
- Multi-Family
  - 40-90% of all shear applications utilized FTAO
- Single-Family
  - 80% Minimum 1-application on front or back elevation
  - 70% Multiple applications on front, back or both
  - 25% Side wall application in addition to front or back application

History of FTAO Research at APA

Joint research project

- APA - The Engineered Wood Association (Skaggs & Yeh)
- University of British Columbia (Lam & Li),
- USDA Forest Products Laboratory (Rammer & Wacker)

Study was initiated in 2009 to:

- Examine the variations of walls with code-allowable openings
- Examines the internal forces generated during full-scale testing
- Evaluate the effects of size of openings, size of full-height piers, and different construction techniques
- Create analytical modeling to mimic testing data

Research Overview

Study results will be used to:

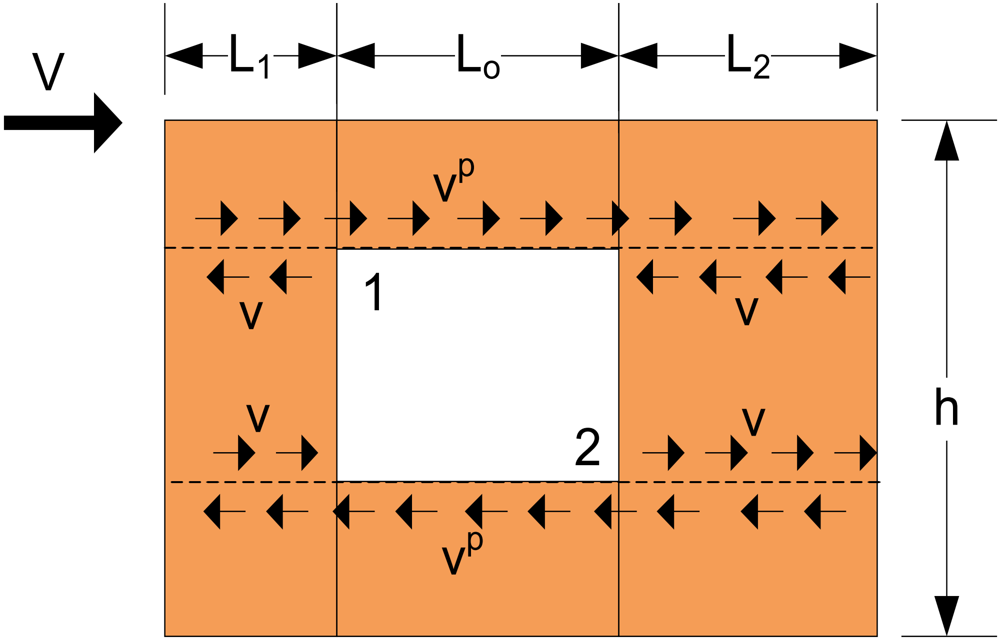
- Support design methodologies in estimating the forces around the openings
- Develop rational design methodologies for adoption in the building codes and supporting standards
- Create new tools/methodology for designers to facilitate use of FTAO

Different Techniques for FTAO

- **Drag Strut Analogy**
- **Cantilever Beam Analogy**
- **Diekmann Method**
  - **Thompson Method**

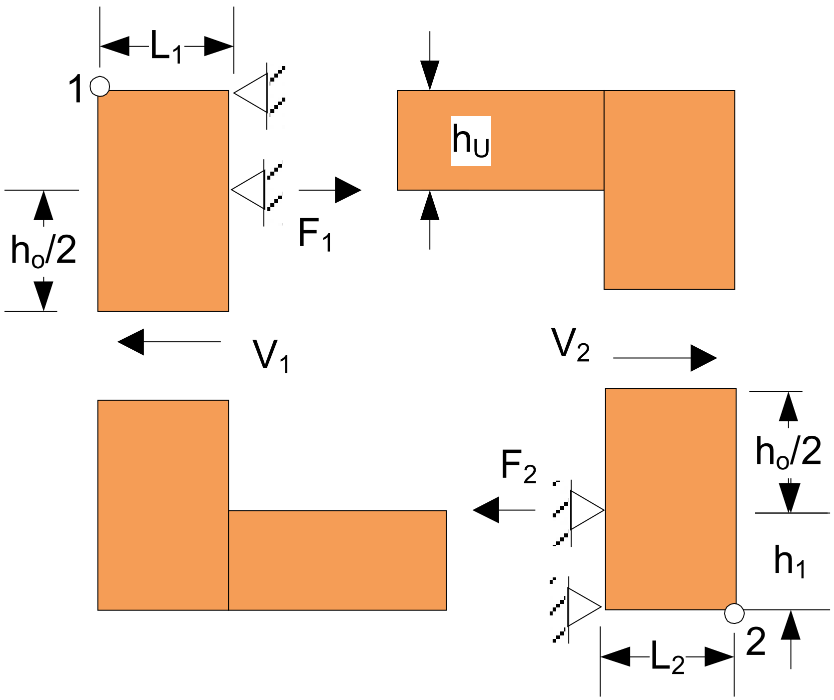
Different Techniques for FTAO

- **Drag Strut Analogy**
  - **Forces are collected and concentrated into the areas above and below openings**
  - **Strap forces are a function of opening and pier widths**



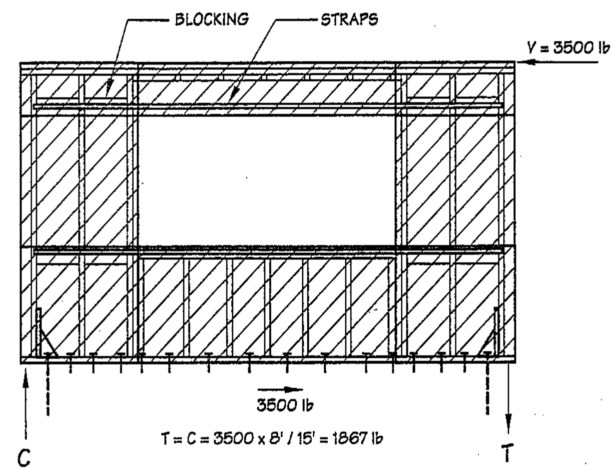
Different Techniques for FTAO

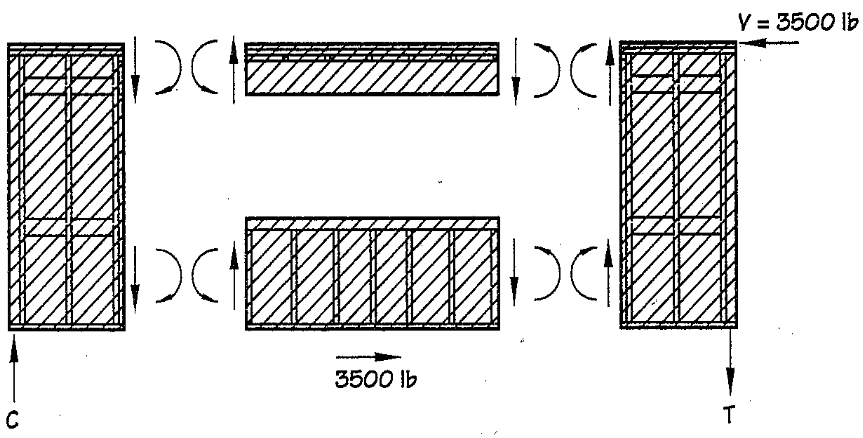
- **Cantilever Beam Analogy**
  - **Forces are treated as moment couples**
  - **Segmented panels are piers at sides of openings**
  - **Strap forces are a function of height above and below opening and pier widths**

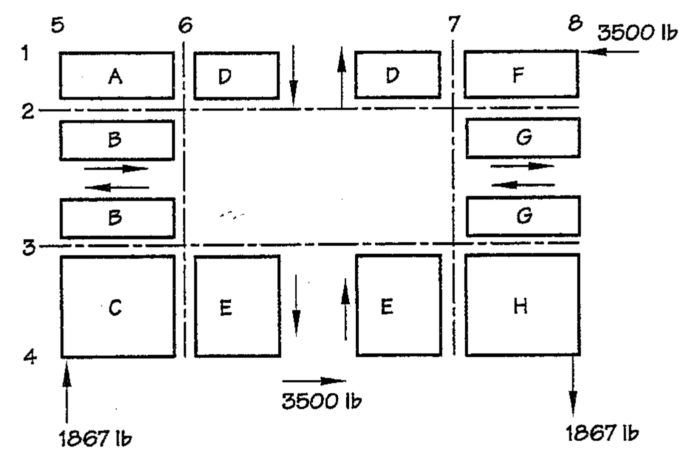


Different Techniques for FTAO

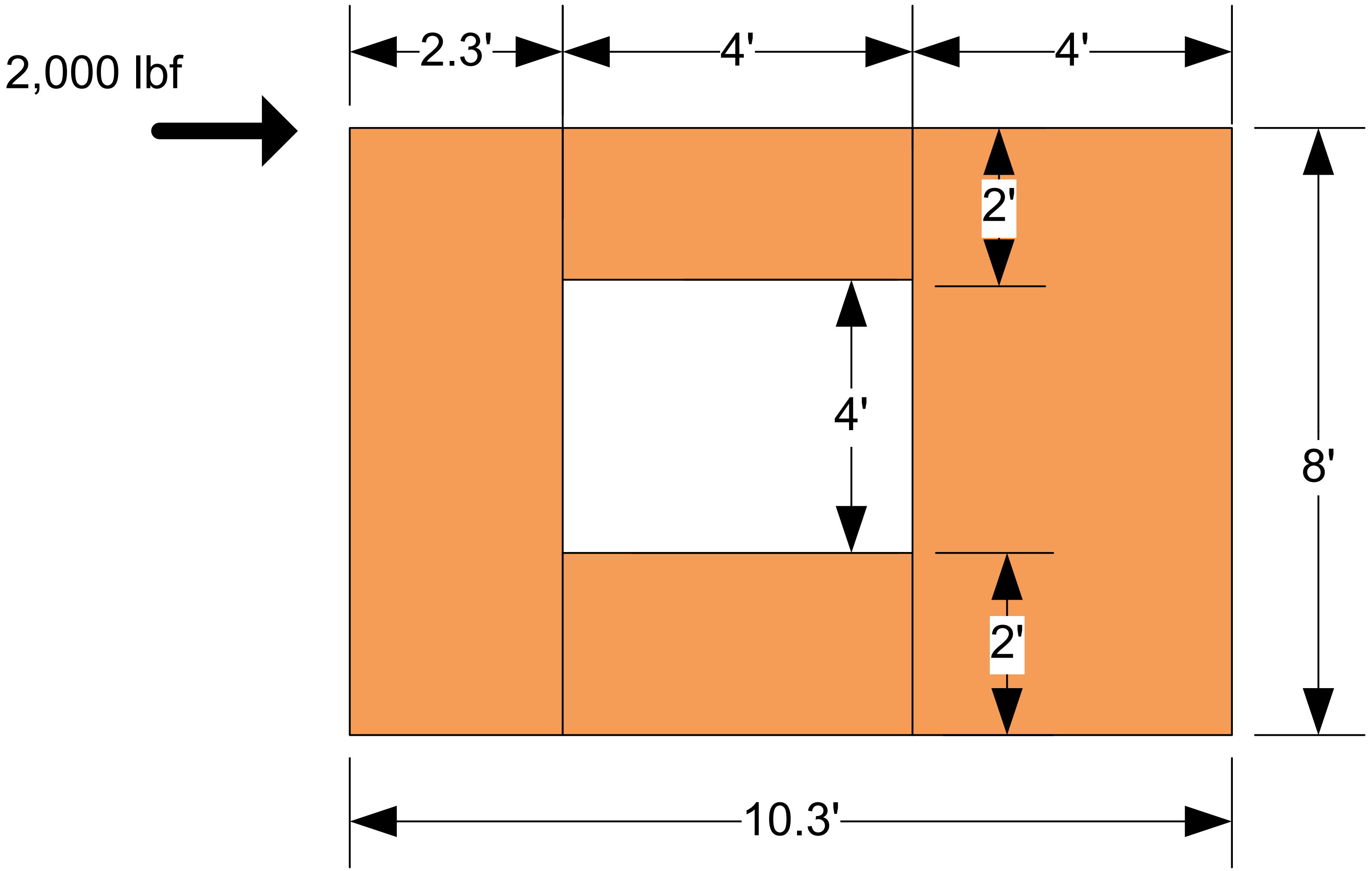
- **Diekmann**
  - **Assumes wall behaves as monolith**
  - **Internal forces resolved via principles of mechanics**





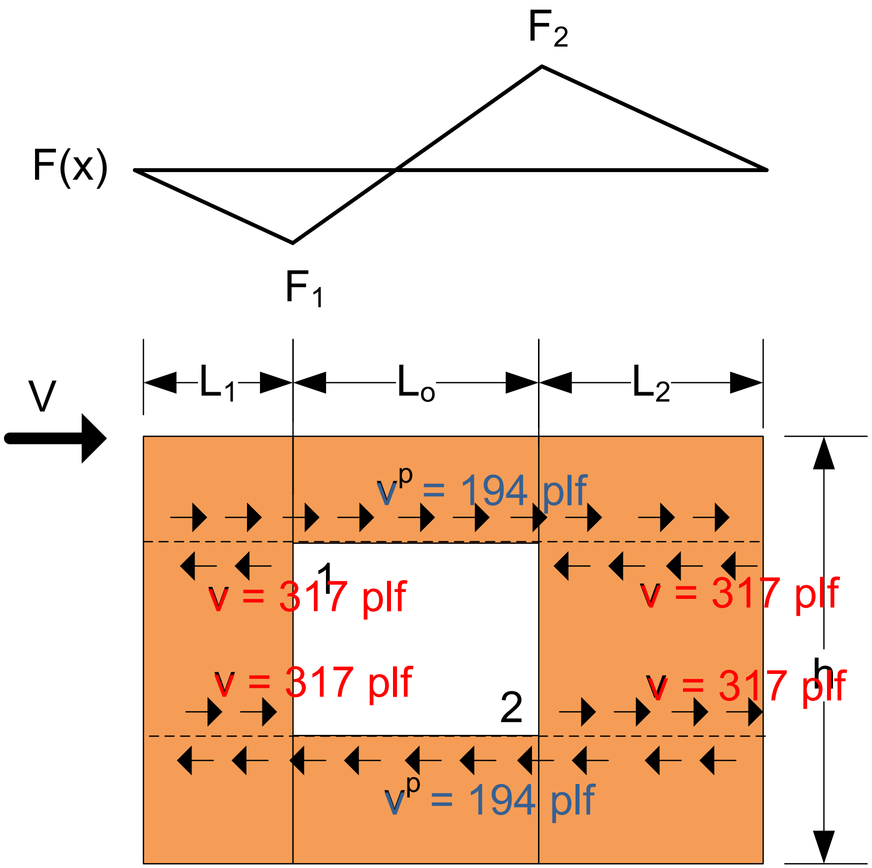


Design Examples



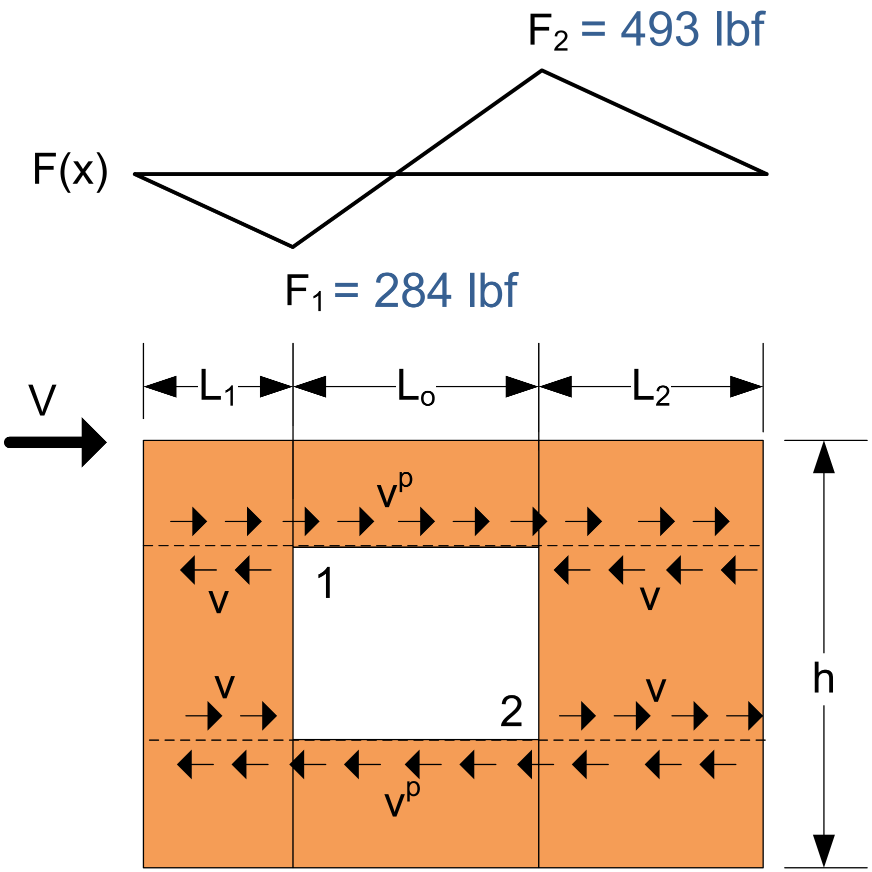
Ex. 1 – Drag Strut Analogy

- v^p = 2,000/(10.3) = 194 plf
- v = 2,000/(2.3 + 4) = 317 plf



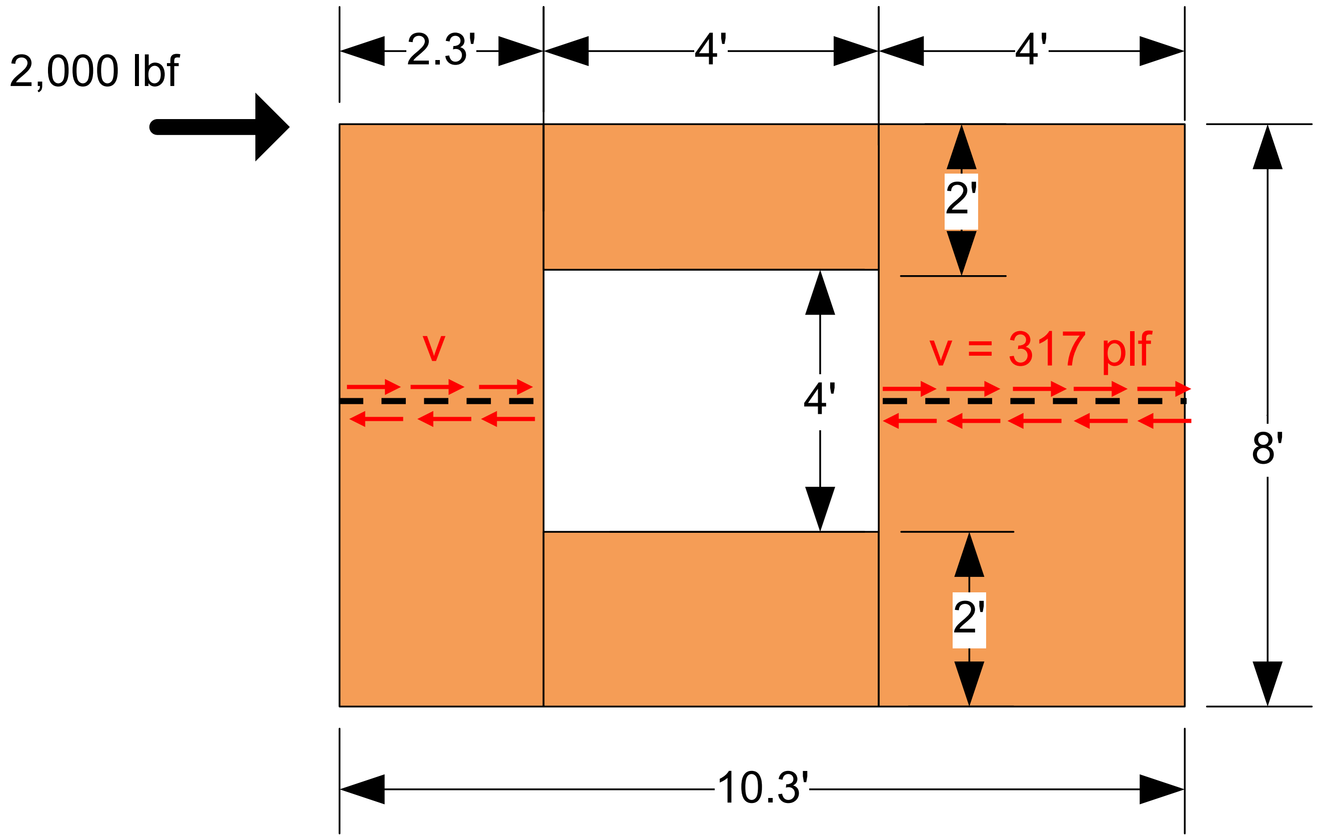
Ex. 1 – Drag Strut Analogy

- $F_1 = (317\text{-}194)*L_1$
- $F_2 = (317\text{-}194)*L_2$
- $F_1 = (317\text{-}194)*2.3 = 284$ lbf
- $F_2 = (317\text{-}194)*4 = 493$ lbf



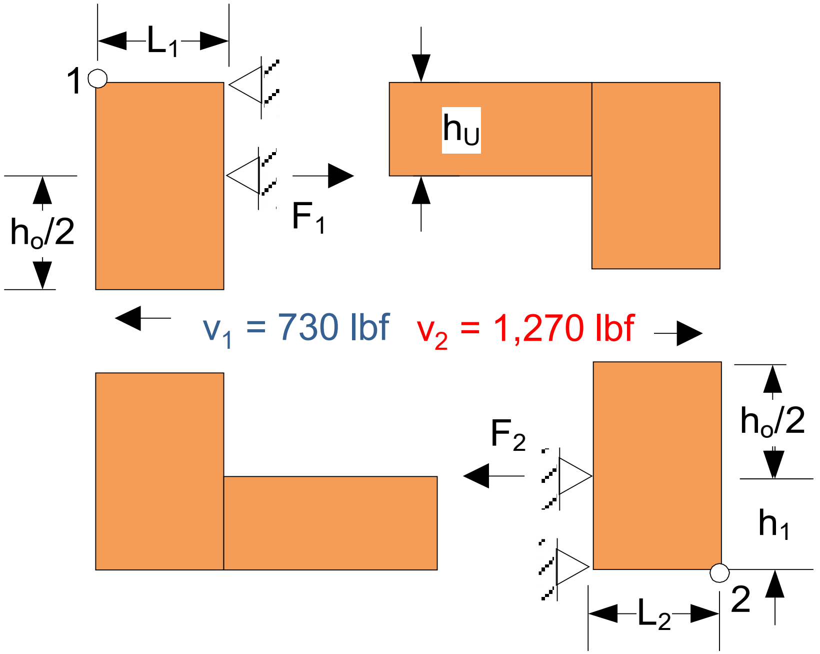
Ex. 2 – Cantilever Beam Analogy

- **v = 2,000/(2.3 + 4) = 317 plf**



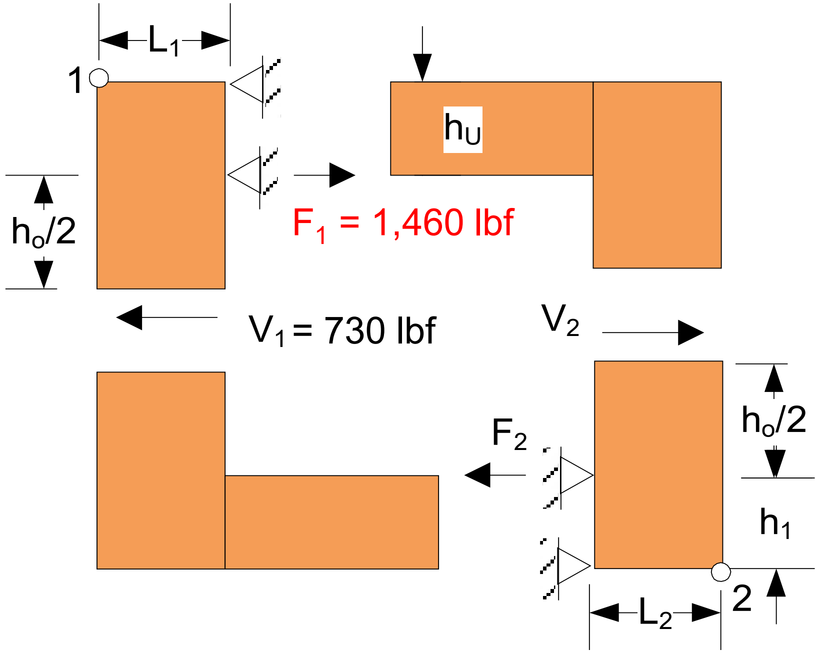
Ex. 2 – Cantilever Beam Analogy

- **$v = 2{,}000/(2.3 + 4) = 317$ plf**
- **$V_1 = 317 * 2.3 = 730$ lbf**
- **$V_2 = 317 * 4 = 1{,}270$ lbf**



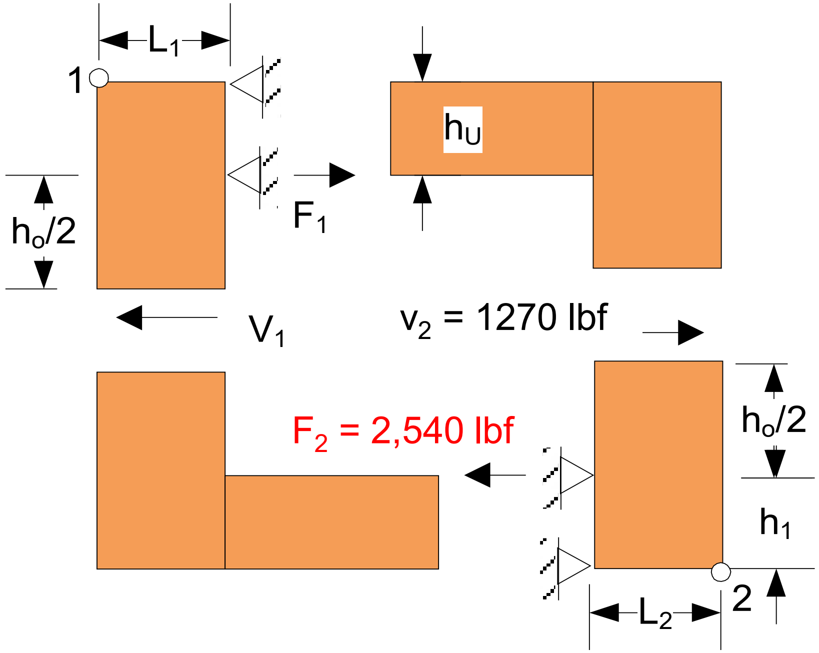
Ex. 2 – Cantilever Beam Analogy

- $\sum M_1 = 0$
- $F_1 * h_u = v_1 * (h_u + h_o/2)$
- $F_1 * 2 = 730 * (2 + 4/2)$
- $F_1 = (730 * 4)/2 = 1{,}460$ lbf



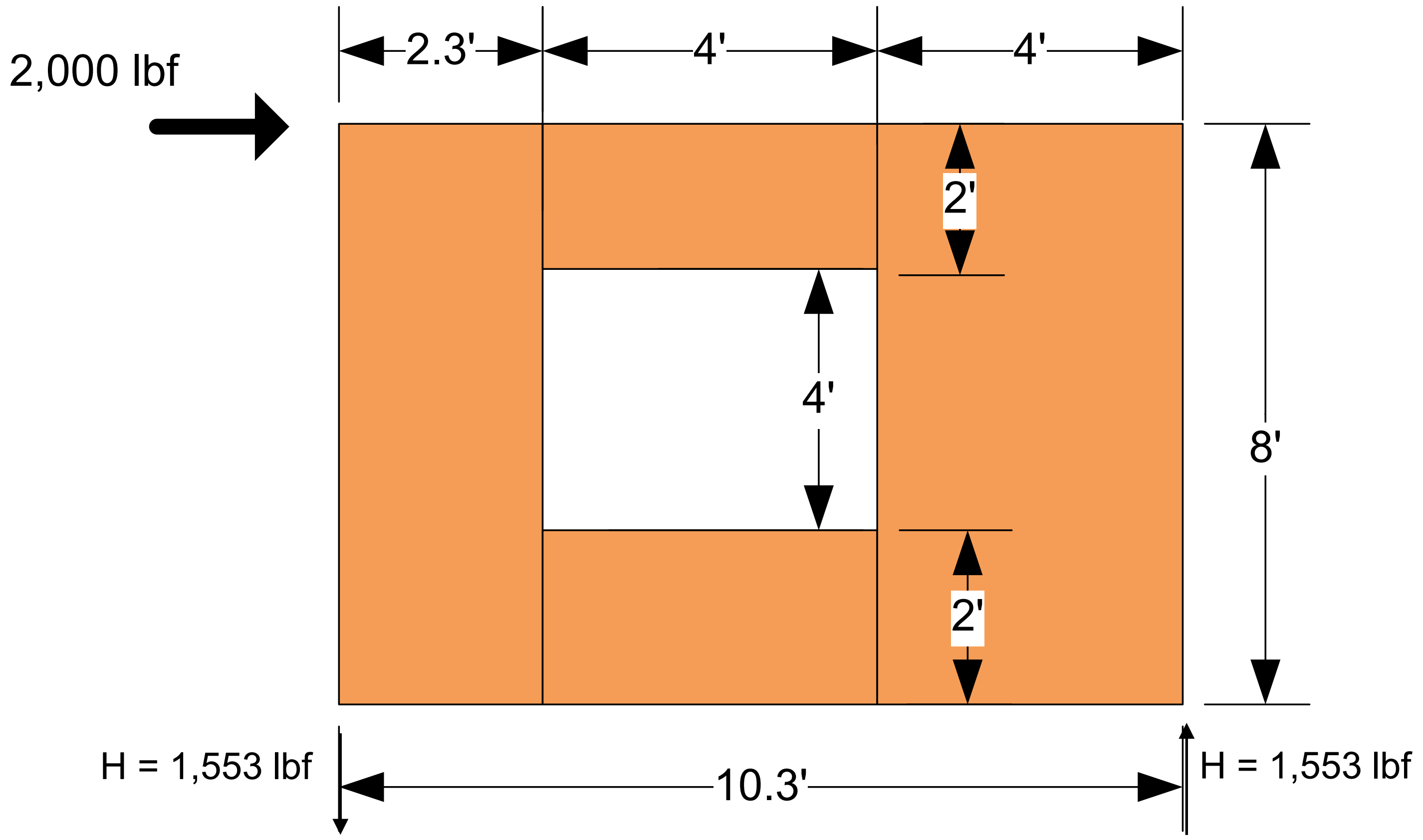
Ex. 2 – Cantilever Beam Analogy

- $\sum M_2 = 0$
- $F_2 * h_L = v_2 * (h_L + h_o/2)$
- $F_2 * 2 = 1{,}270 * (2 + 4/2)$
- $F_2 = (1{,}270 * 4)/2 =$ **2,540 lbf**



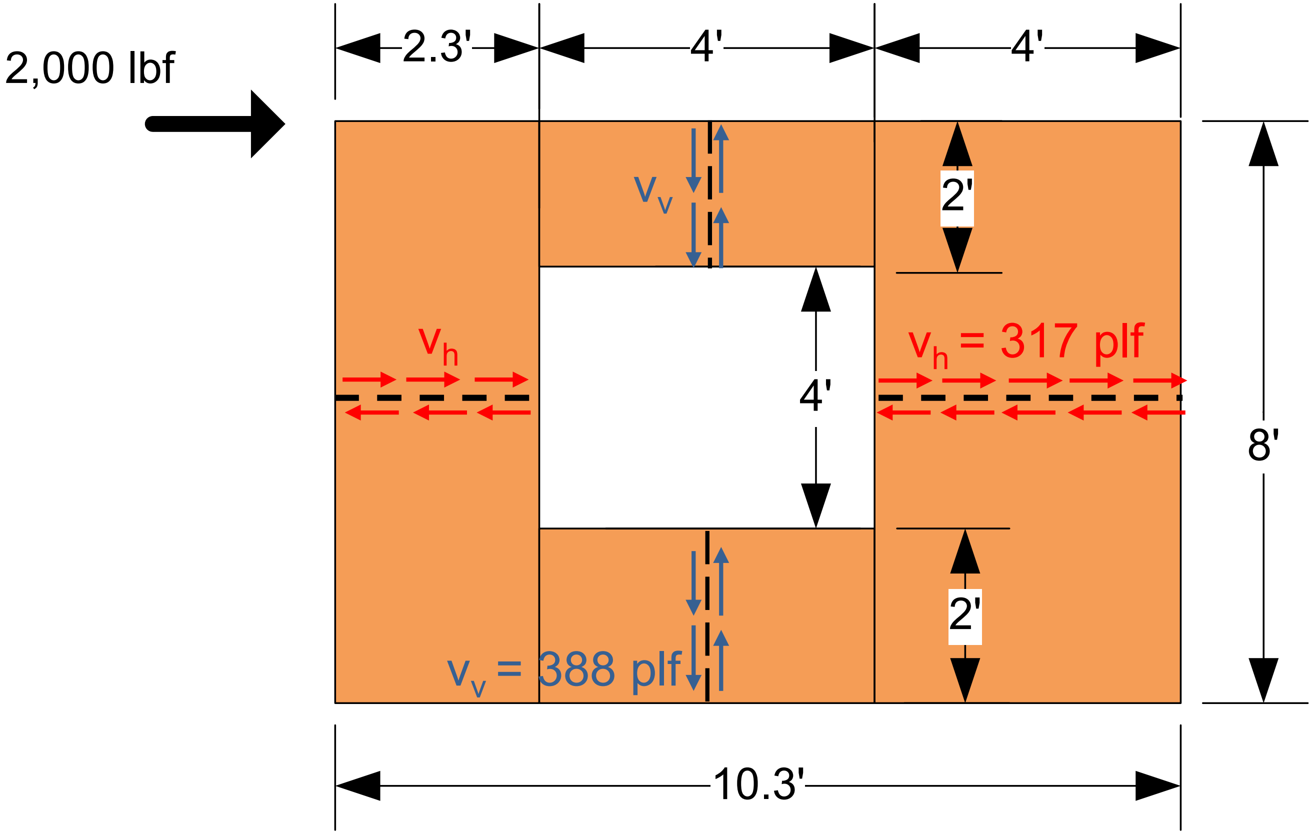
Ex. 3 – Diekmann Technique

- **H = (2,000 * 8) / 10.3 = 1,553 lbf**



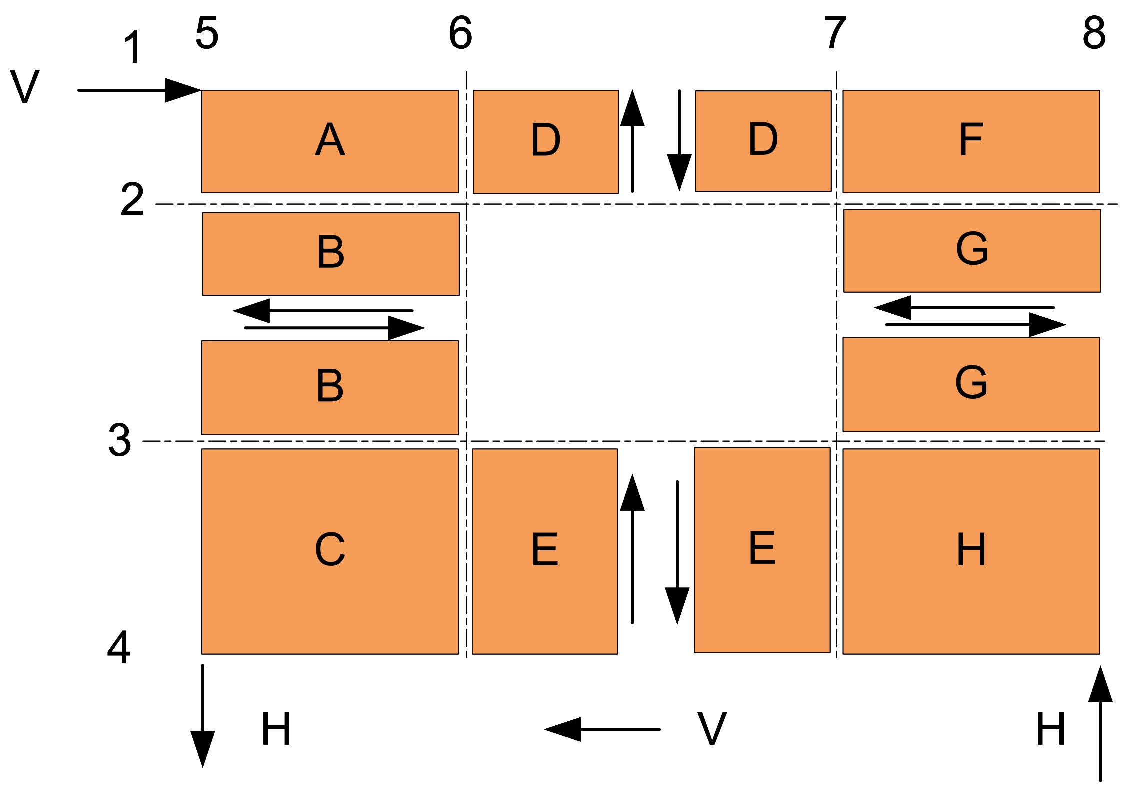
Ex. 3 – Diekmann Technique

- v_h = 2,000/(2.3 + 4) = 317 plf
- v_v = 1,553/(2 + 2) = 388 plf



Ex. 3 – Diekmann Technique

- v_h = 2,000/(2.3 + 4) = 317 plf = ($V_B = V_G$)
- v_v = 1,553/(2 + 2) = 388 plf = ($V_D = V_E$)

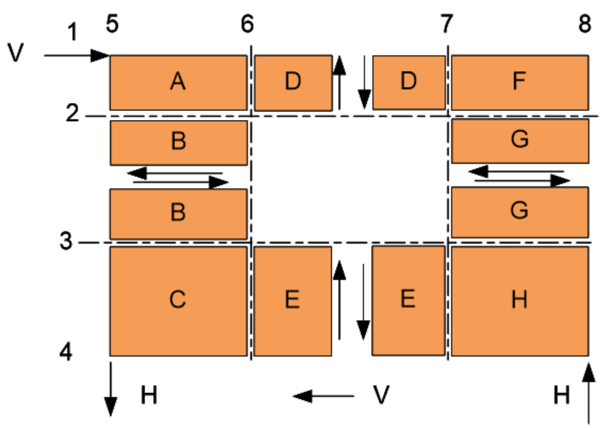


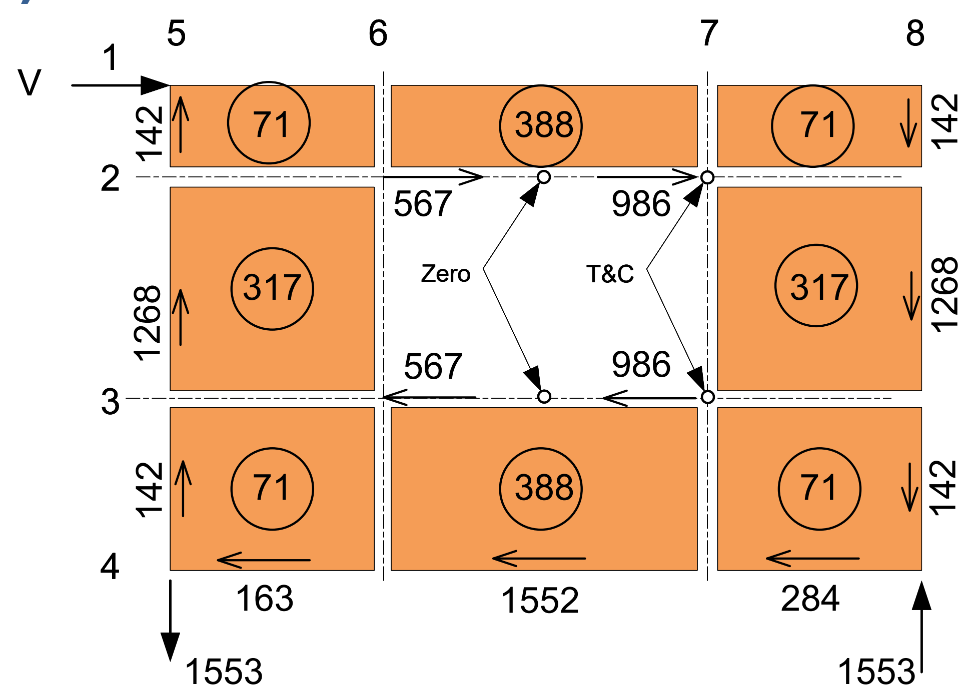
Ex. 3 – Diekmann Technique

F = 388 * 4 = 1,552 lbf

F_1 = 1,552 * 2.3/(2.3 + 4) = 567 lbf

F_2 = 1,552 * 4/(2.3 + 4) = 986 lbf





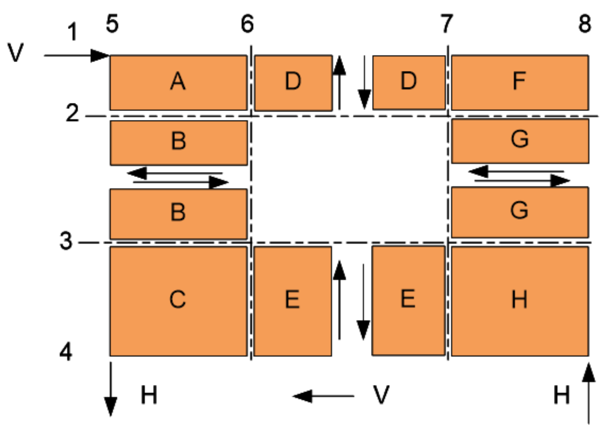
Ex. 3 – Diekmann Technique

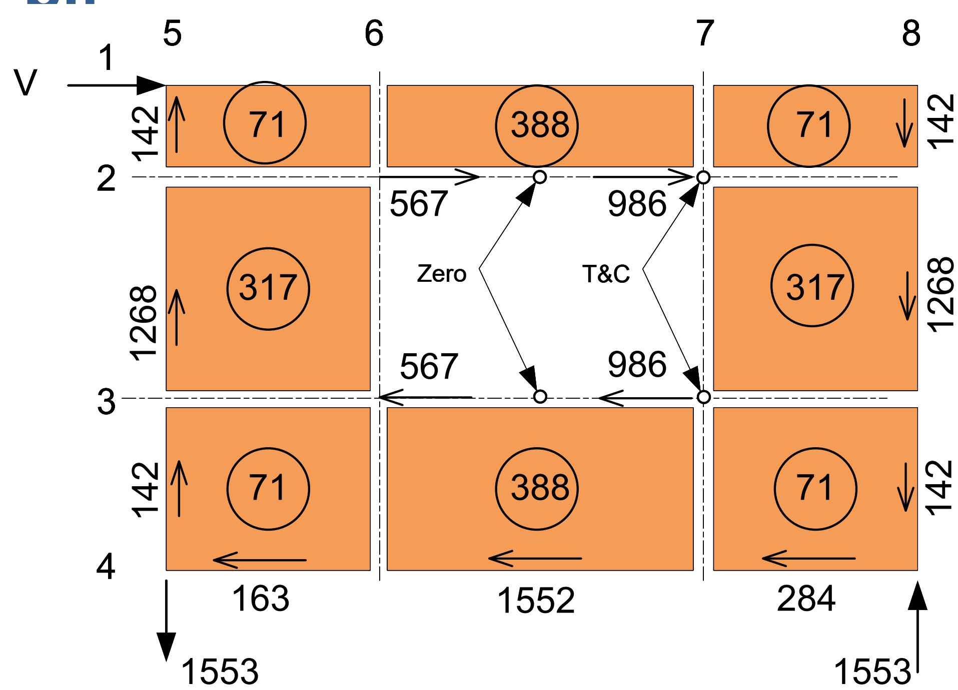
$V_A = V_C = V_F = V_H =$

$567/2.3 = 246$ plf

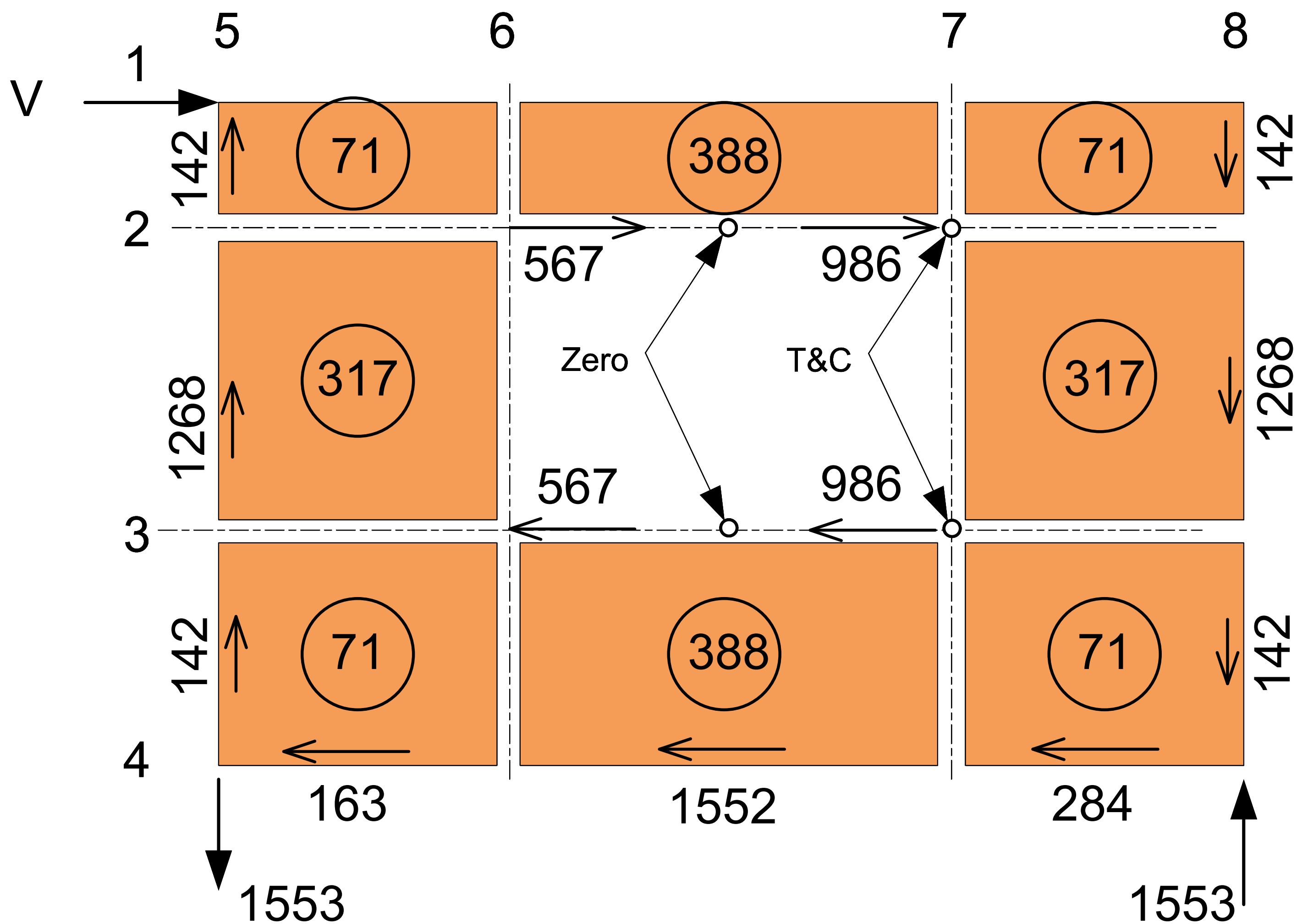
$986/4 = 246$ plf

317 plf – 246 plf = 71 plf



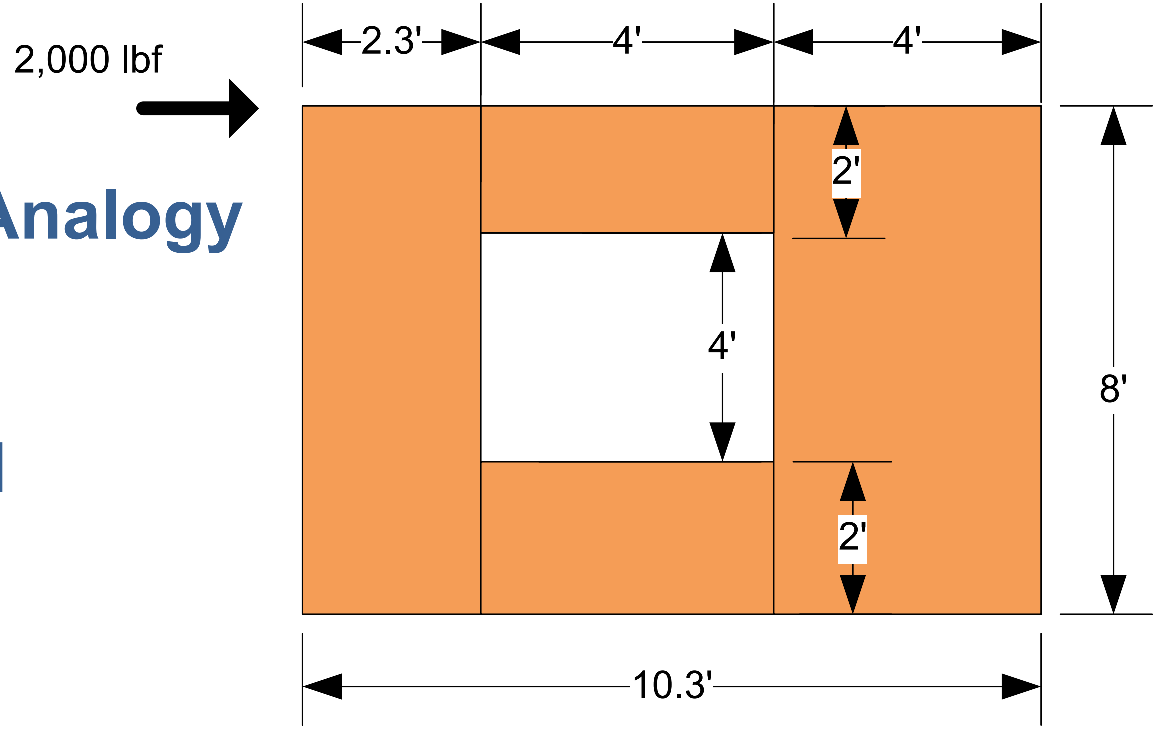


Ex. 3 – Diekmann Technique



Design Example Summary

- **Drag Strut Analogy**
  - **F1 = 284 lbf**
  - **F2 = 493 lbf**
- **Cantilever Beam Analogy**
  - **F1 = 1,460 lbf**
  - **F2 = 2,540 lbf**
- **Diekmann Method**
  - **F1 = 567 lbf**
  - **F2 = 986 lbf**



References

Drag Strut Analogy

- Martin, Z.A. 2005. Design of wood structural panel shear walls with openings: A comparison of methods. Wood Design Focus 15(1):18-20

Cantilever Beam Analogy

- Martin, Z.A. (see above)

Diekmann Method

- Diekmann, E. K. 2005. Discussion and Closure (Martin, above), Wood Design Focus 15(3): 14-15
- Breyer, D.E., K.J. Fridley, K.E. Cobeen and D. G. Pollock. 2007. Design of wood structures ASD/LRFD, 6th ed. McGraw Hill, New York.

Thompson Method

- SEAOC. 2007. 2006 IBC Structural/Seismic Design Manual, Volume 2: Building Design Examples for Light-frame, Tilt-up Masonry. Structural Engineers Association of California, Sacramento, CA

CUREE Basic Loading Protocol

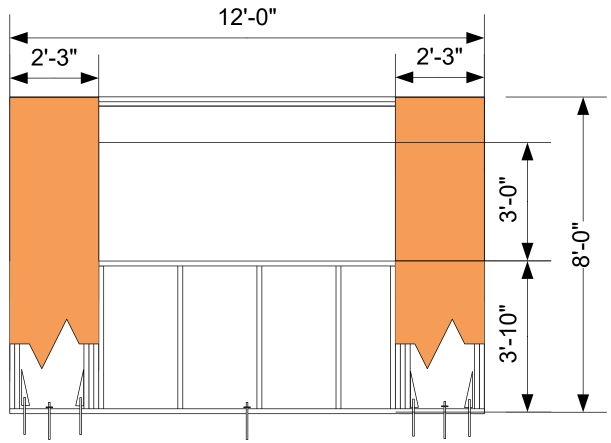
Test Plan

- **12 wall configurations tested (with and without FTAO applied)**
- **Wall nailing: 10d commons (0.148” x 3”) at 2” o.c.**
- **Sheathing: 15/32 Perf Cat oriented strand board (OSB) APA Structural I**
- **All walls were 12 feet long and 8 feet tall**
- **Cyclic loading protocol following ASTM E2126, Method C, CUREE Basic Loading Protocol**

Test Plan

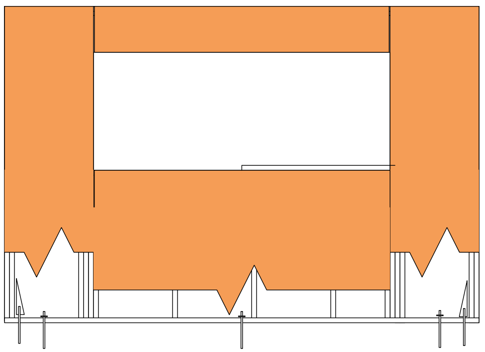
Wall1

Objective:
Est. baseline case for 3.5:1 segmented wall



Wall 2

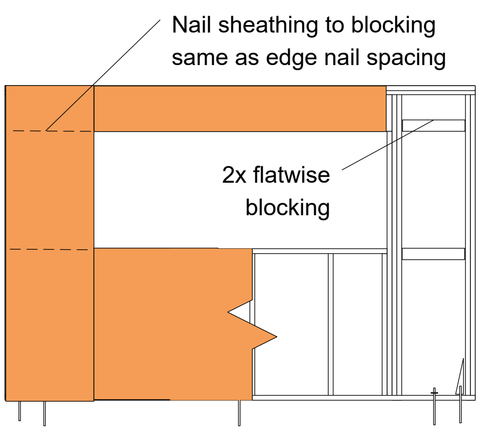
Objective:
No FTAO, compare to Wall 1. C_o = 0.93. Examine effect of sheathing above and below opening w/ no FTAO. Hold down removed.



Wall 3

Objective:
No FTAO, compare to Wall 1 and 2. Examine effect of compression blocking.

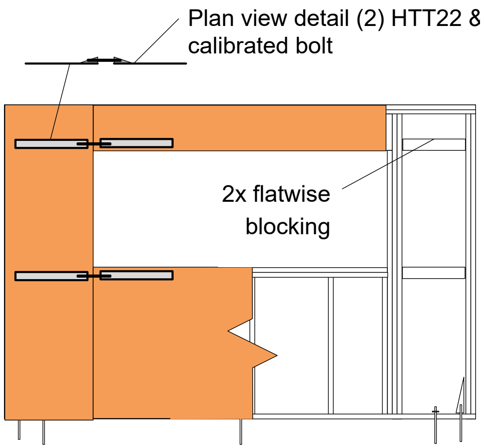
Wall is symmetric, sheathing on right pier not shown for clarity



Wall 4

Objective:
FTAO, compare to Wall 1. Examine effect of straps

Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity

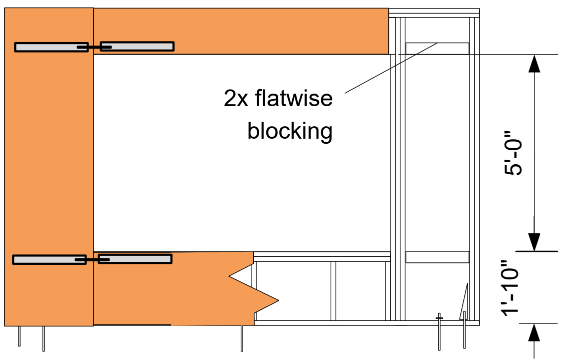


Test Plan

Wall 5

Objective:
FTAO, compare to Wall 4. Examine effect of straps with larger opening

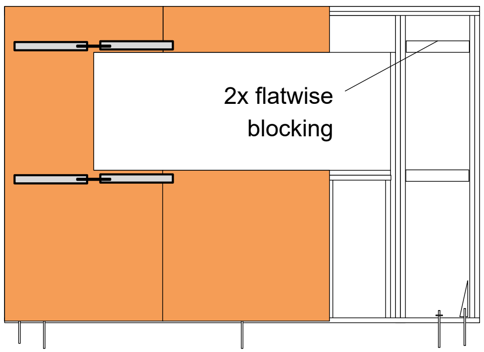
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 6

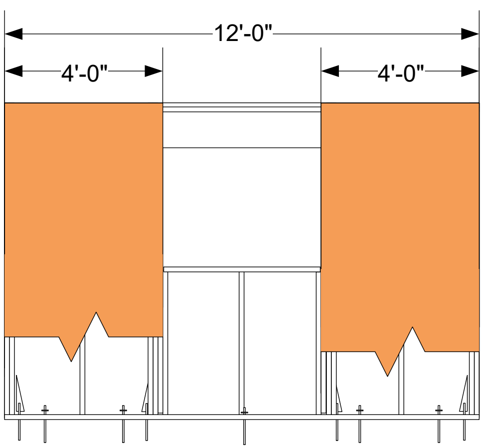
Objective:
Compare to Wall 4. Examine effect of sheathing around opening

Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 7

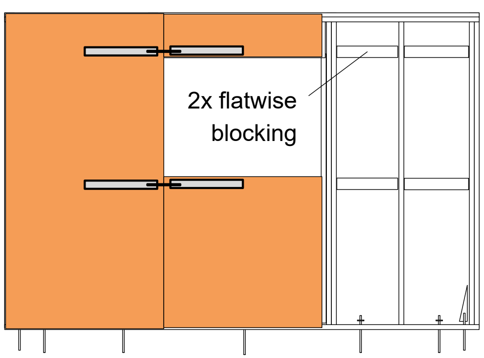
Objective:
Est. baseline case for 2:1 segmented wall



Wall 8

Objective:
Compare FTAO to Wall 7

Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity

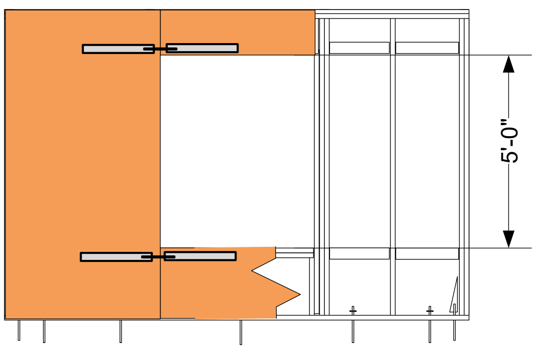


Test Plan

Wall 9

Objective:
Compare FTAO to Wall 7 and 8. Collect FTAO data for wall with larger opening

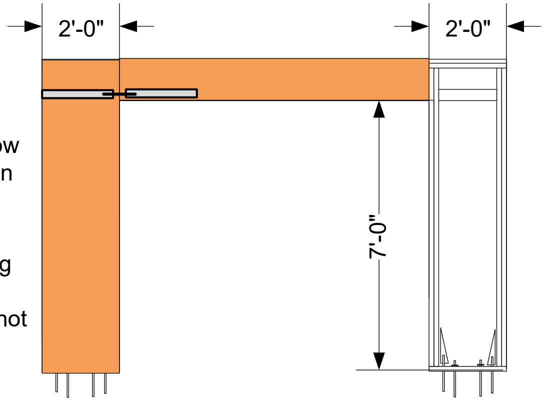
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 10

Objective:
FTAO for 3.5:1 Aspect ratio pier wall. No sheathing below opening. Two hold downs on pier (fixed case)

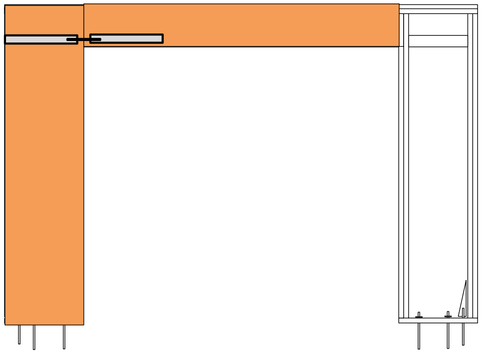
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 11

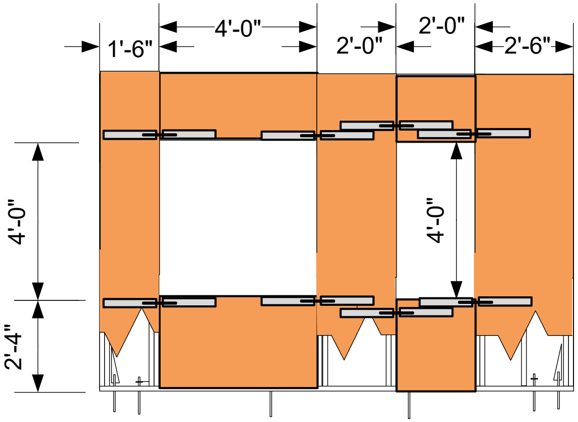
Objective:
FTAO for 3.5:1 Aspect ratio pier wall. No sheathing below opening. One hold downs on pier (pinned case)

Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



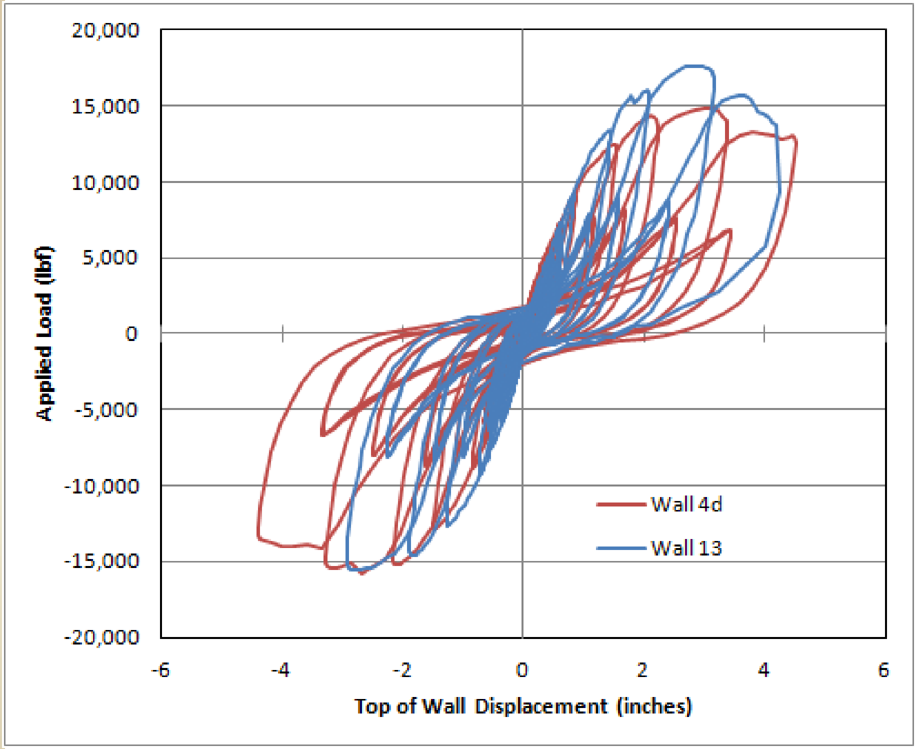
Wall 12

Objective:
FTAO for asymmetric multiple pier wall.



Testing Observation

Wall 13



Test Plan

Information obtained

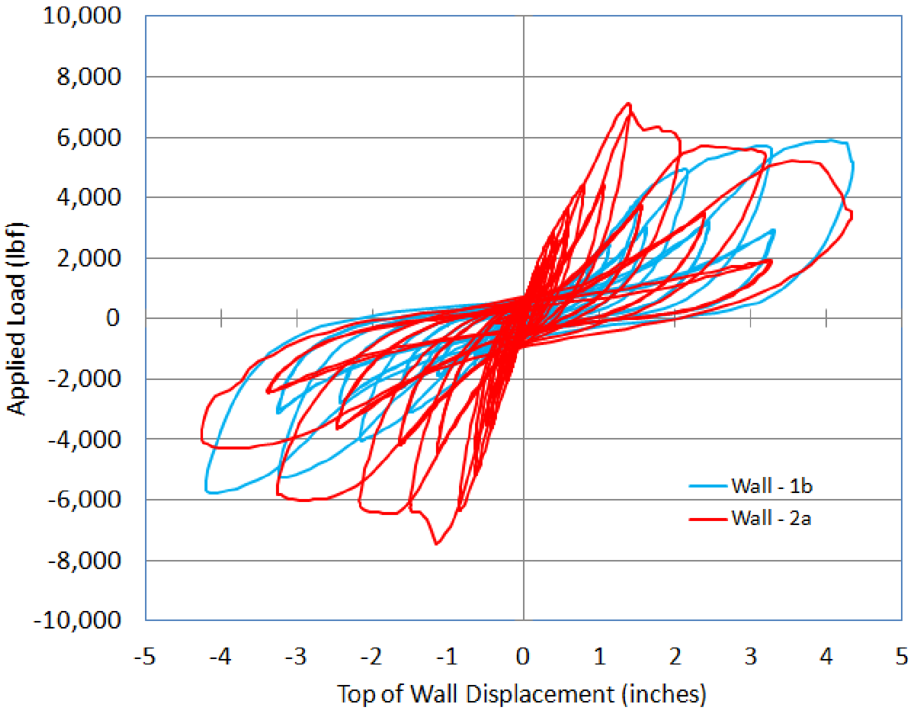
- Cyclic hysteretic plots and various cyclic parameters of the individual walls
- Hold down force plots
- Anchor bolt forces plots
- Hysteric plots of the applied load versus the displacement of the walls
- Hysteric plots of the applied load versus strap forces

Measured vs Predicted Strap Forces

Wall ID	Measured Strap Forces (lbf) [1]		Error [2] For Predicted Strap Forces at ASD Capacity (%)						
			Drag Strut Technique		Cantilever Beam Technique		Diekmann Technique	Thompson Technique	
	Top	Bottom	Top	Bottom	Top	Bottom	Top/Bottom	Top	Bottom
Wall 4a	687	1,485	178%	82%	652%	183%	132%	406%	115%
Wall 4b	560	1,477	219%	83%	800%	184%	133%	499%	115%
Wall 4c [3]	668	1,316	183%	93%	670%	207%	149%	418%	129%
Wall 4d	1,006	1,665	122%	73%	445%	164%	118%	278%	102%
Wall 5b	1,883	1,809	65%	68%	327%	256%	173%	204%	160%
Wall 5c [3]	1,611	1,744	76%	70%	382%	265%	187%	238%	166%
Wall 5d	1,633	2,307	75%	53%	377%	201%	141%	235%	125%
Wall 6a	421	477	291%	256%	1063%	571%	410%	663%	357%
Wall 6b	609	614	201%	199%	735%	444%	319%	458%	277%
Wall 8a	985	1,347	118%	86%	808%	359%	138%	269%	120%
Wall 8b [4]	1,493	1,079	78%	108%	533%	449%	124%	177%	150%
Wall 9a	1,675	1,653	69%	70%	475%	383%	185%	217%	166%
Wall 9b	1,671	1,594	69%	73%	476%	397%	185%	218%	172%
Wall 10a	1,580	n.a. [5]	73%	n.a. [5]	496%	n.a. [5]	n.a. [5]	n.a. [5]	n.a. [5]
Wall 10b	2,002	n.a. [5]	58%	n.a. [5]	391%	n.a. [5]	n.a. [5]	n.a. [5]	n.a. [5]
Wall 11a	2,466	n.a. [5]	47%	n.a. [5]	318%	n.a. [5]	n.a. [5]	n.a. [5]	n.a. [5]
Wall 11b	3,062	n.a. [5]	38%	n.a. [5]	256%	n.a. [5]	n.a. [5]	n.a. [5]	n.a. [5]
Wall 12a	807	1,163	81%	94%	593%	348%	128%	n.a. [5]	n.a. [5]
Wall 12b	1,083	1,002	60%	109%	442%	403%	138%	n.a. [5]	n.a. [5]

Local Response

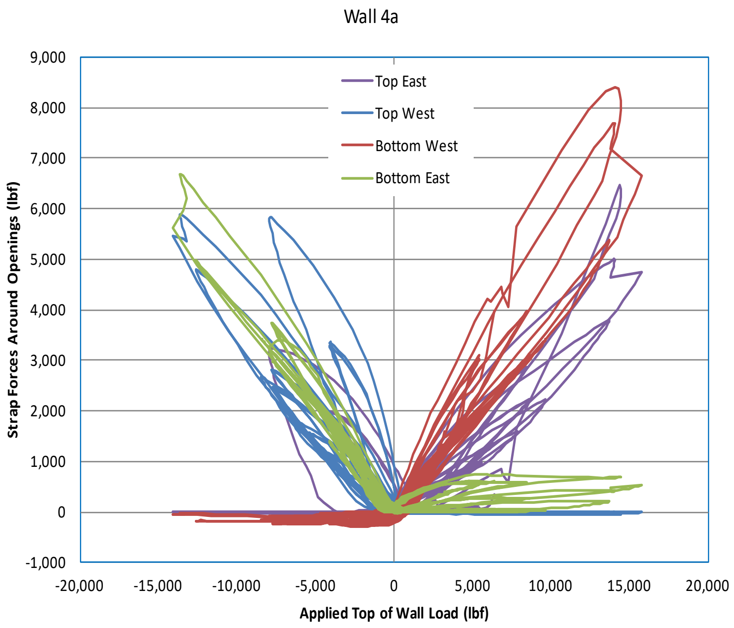
- The response curves are representative for wall 1 & 2
- Compares segmented piers vs. sheathed with no straps
- Observe the increased stiffness of perforated shear (Wall 2) vs. the segmented shear (Wall 1)

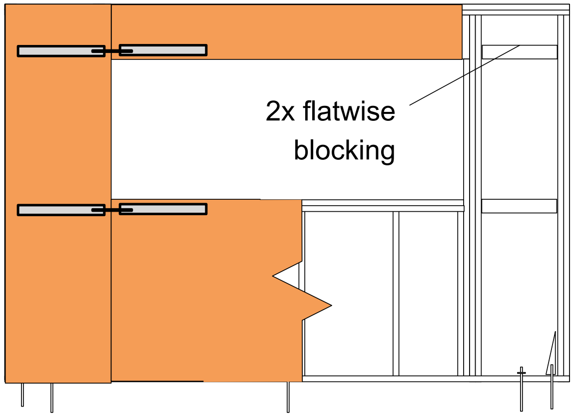


Testing Observation

Wall 4

- Narrow piers
- Deep sill

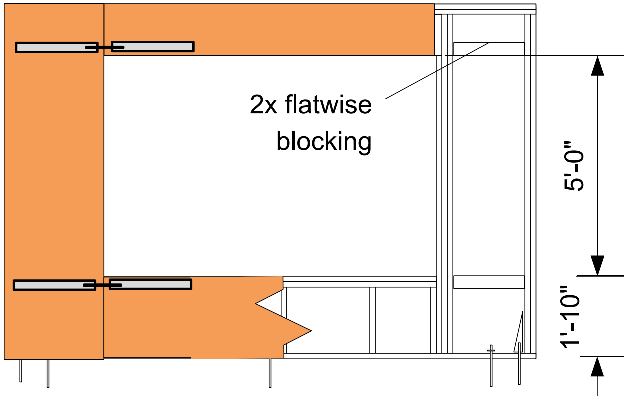


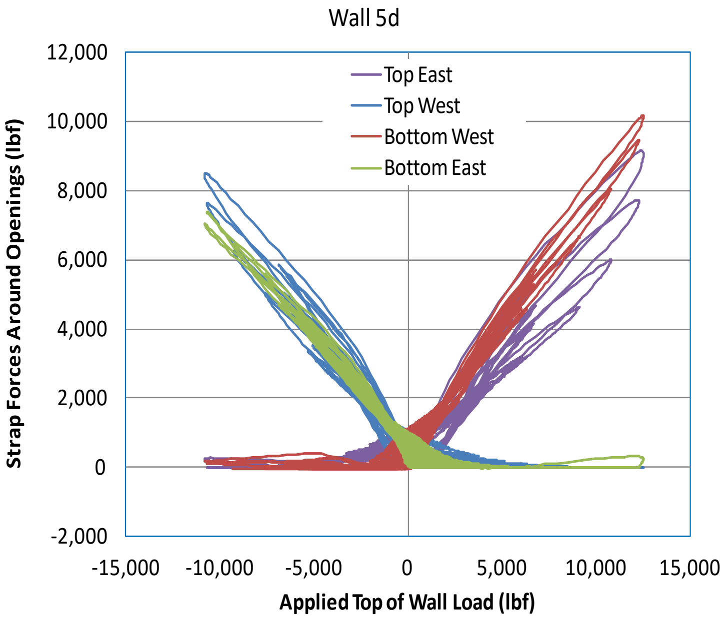


Testing Observation

Wall 5

- Increased opening from Wall 4
- Shallow sill

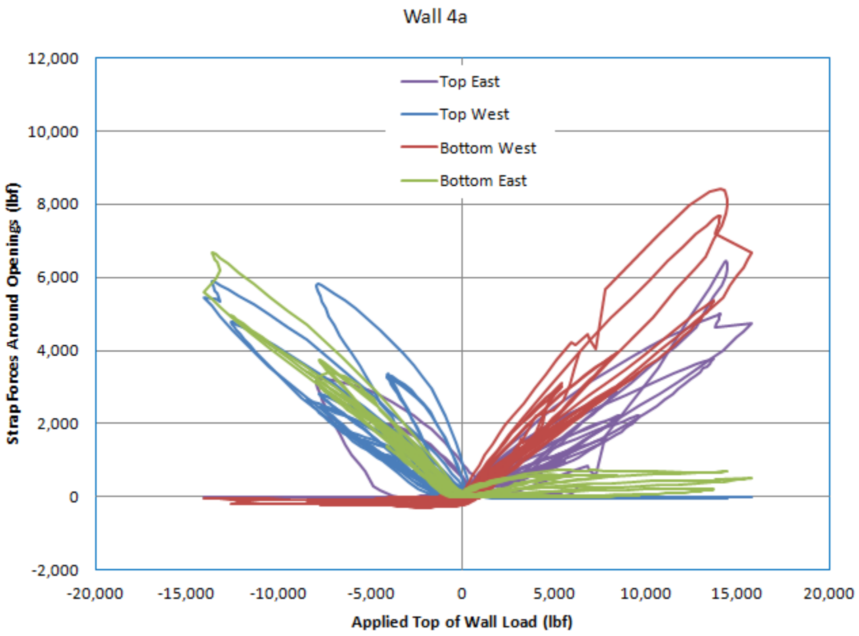


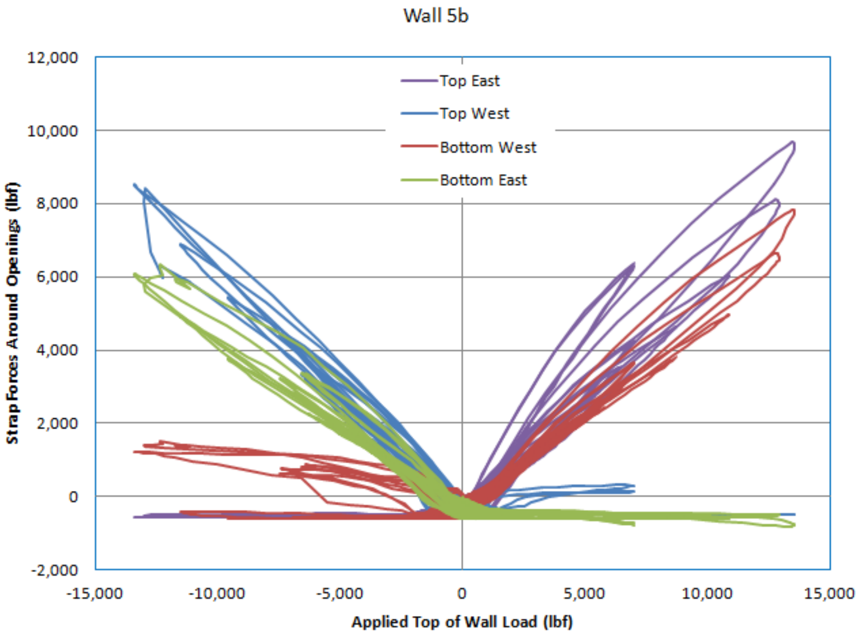


Local Response

Comparison of opening size vs. strap forces

- **Compared Wall 4 to 5**

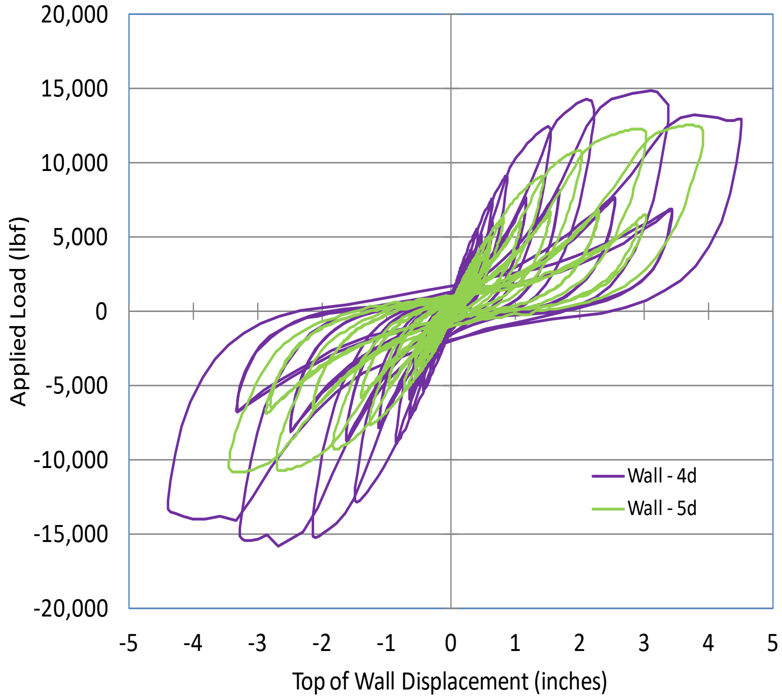




APA

Global Response

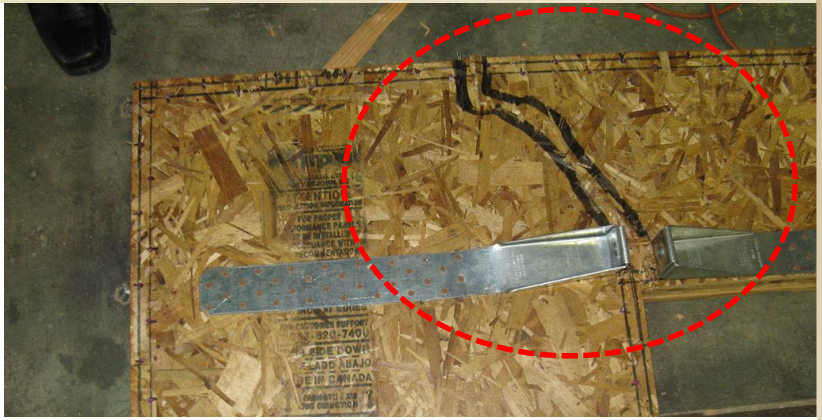
- Comparison of opening size vs. strap forces
- Wall 4 vs. 5 reduction in stiffness with larger opening
- Wall 4 & 5d demonstrated increased stiffness as well as strength over the segmented walls 1 & 2
- Larger openings resulting in both lower stiffness and lower strength.
- Relatively brittle nature of the perforated walls
- Shear walls resulted in sheathing tearing

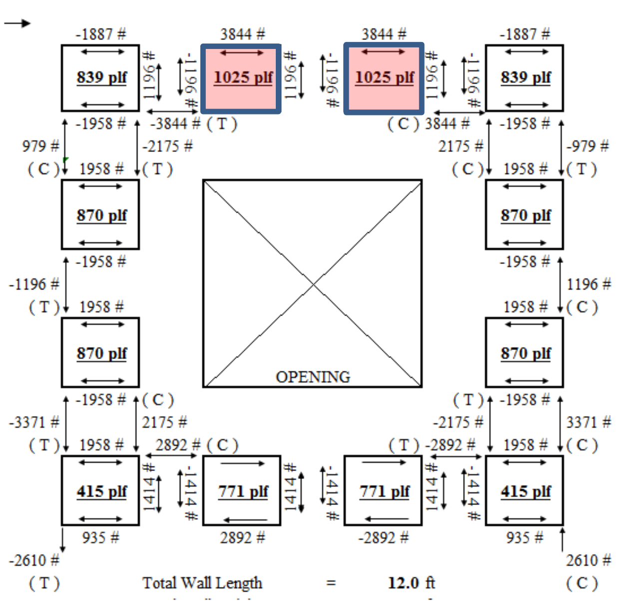


Other Testing Observations

Failure modes expected (Wall 5)

- Relatively brittle nature of the perforated walls
  - Shear walls resulted in sheathing tearing
- Concentration of forces from analysis (Thompson)
  - Drives shear type and nailing

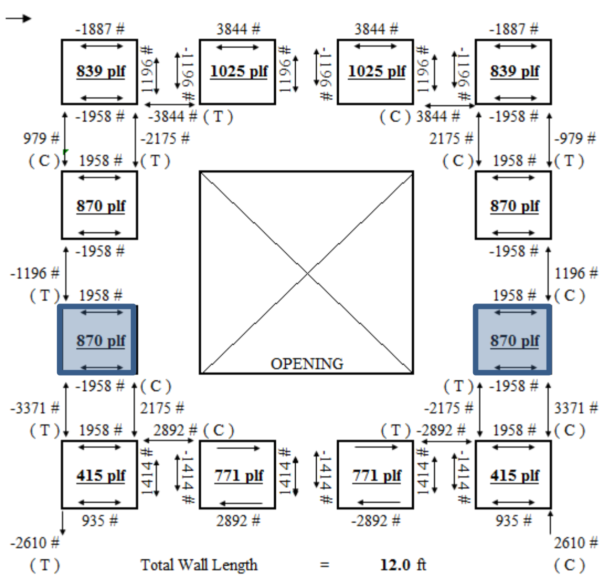




Other Testing Observations

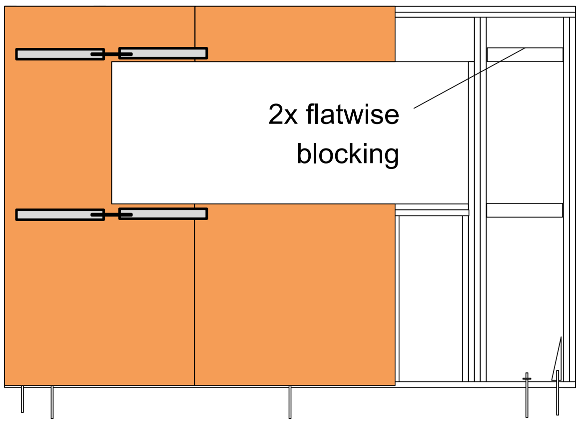
Failure modes

- Contributions of wall segments
  - Variable stiffness
  - Banging effect



C-shaped Panels

- APA FTAO Test Wall 6
- Framing status quo
- Reduce/eliminate strap force



Advancements in FTAO

Strapping Above and Below Openings

- SDWPS Section 4.3.5.2 specifies collectors
  - Full length horizontal elements. Top & Bottom Plates, drag struts, beams, etc..
  - Transfer forces from diaphragm into shear wall
- Strapping is not a collector
  - Can be discontinuous
  - Resists internal tension forces not shear
  - Similar to hold downs at end of wall

APA

Conclusions

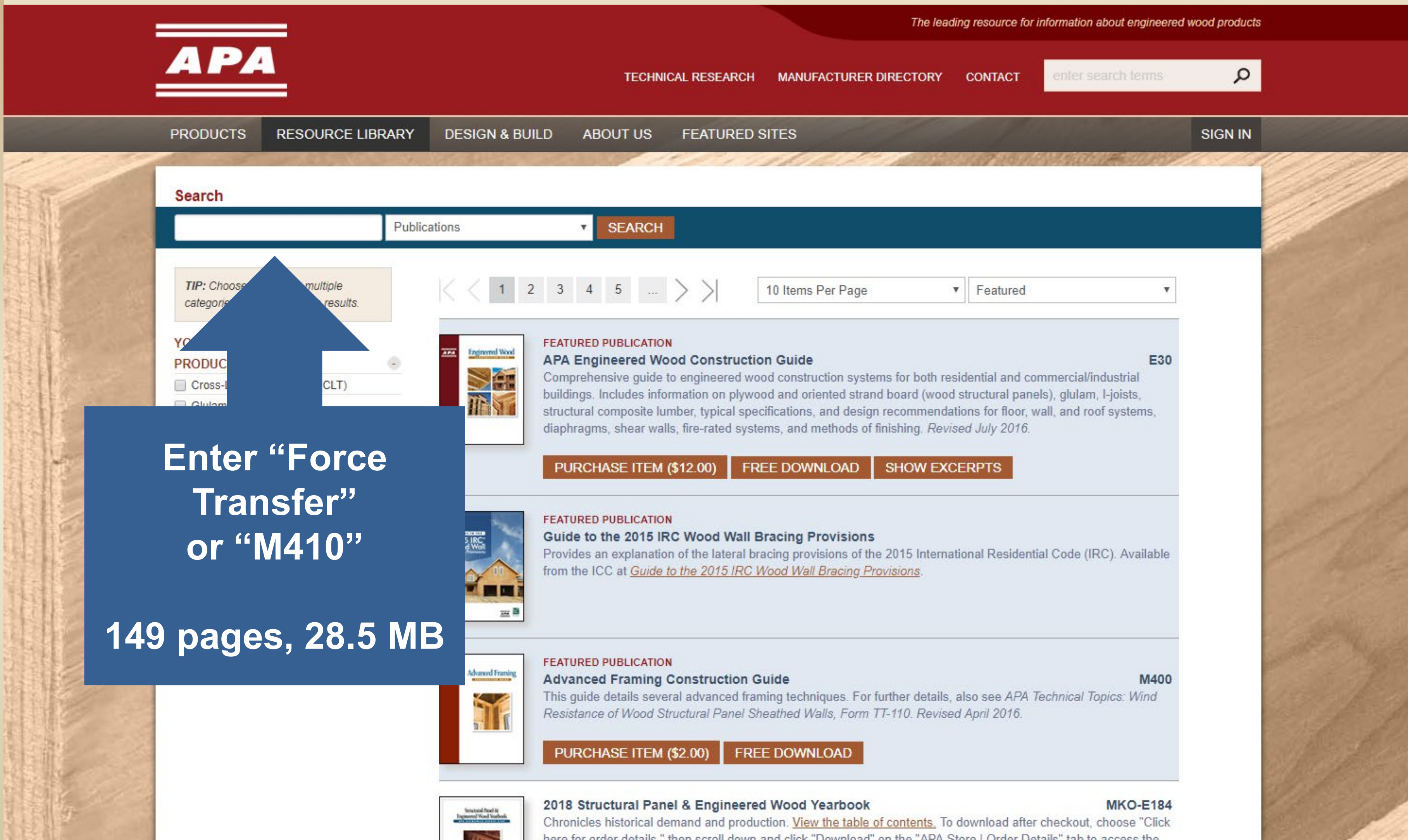
- 12 assemblies tested, examining the three approaches to designing and detailing walls with openings
  - Segmented
  - Perforated Shear Wall
  - Force Transfer Around Openings
- Walls detailed for FTAO resulted in better global response

Conclusions

- Comparison of analytical methods with tested values for walls detailed as FTAO
  - The drag strut technique was consistently un-conservative
  - The cantilever beam technique was consistently ultra-conservative
  - Thompson provides similar results as Diekmann
  - Thompson & Diekmann techniques provided reasonable agreement with measured strap forces
- Better guidance to engineers will be developed by APA for FTAO
  - Summary of findings for validation of techniques
  - New tools for IBC wall bracing

Report Available

www.apawood.org/publications

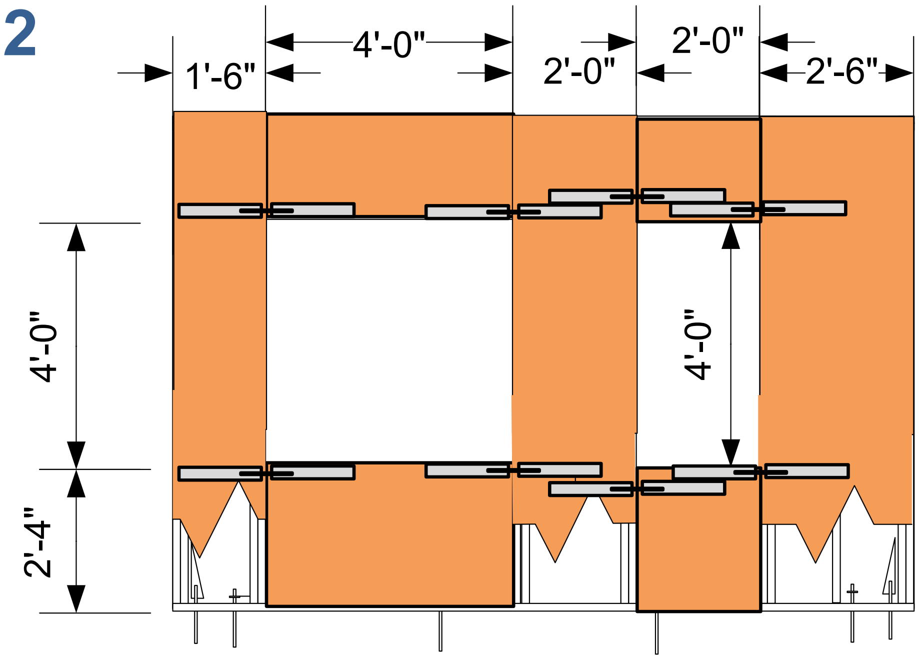


Enter "Force Transfer" or "M410"

149 pages, 28.5 MB

Multiple Openings

- APA FTAO Testing Wall 12
  - Multiple openings
  - Asymmetric pier widths
- Diekmann Rational Analysis



Advancements in FTAO

- **SEAOC Convention 2015 Proceedings**
- **Basis of APA Technical Note Form T555**

2015 SEAOC CONVENTION PROCEEDINGS

Advancements in Force Transfer Around Openings for Wood Framed Shear Walls

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Abstract

A joint research project of *APA – The Engineered Wood Association*, University of British Columbia (UBC), and USDA Forest Products Laboratory was initiated in 2009 to examine the variations of walls with code-allowable openings. This study examines the internal forces generated during these tests and evaluates the effects of size of openings, size of full-height piers, and different analysis techniques, including the segmented method, the perforated

Introduction

Force transfer around openings (FTAO) is a popular method of shear wall analysis for wood-framed shear walls. However, the analysis method varies from engineer to engineer, published design examples typically assume the wall is symmetric around a single opening, and until recently, this design method has not been tested.

Diekmann Technique: Conceptual Keys

The method assumes the following:

- The unit shear above and below the openings is equivalent.
- The corner forces are based on the shear above and below the openings and only the piers adjacent to that unique opening.
- The tributary length of the opening is the basis for calculating the shear to each pier. This tributary length is the ratio of the length of the pier multiplied by the length of the opening it is adjacent to, then divided by the sum of the length of the pier and the length of the pier on the other side of the opening.
  - For example, T1 = (L1*Lo1)/(L1+L2)

Diekmann Technique: Conceptual Keys

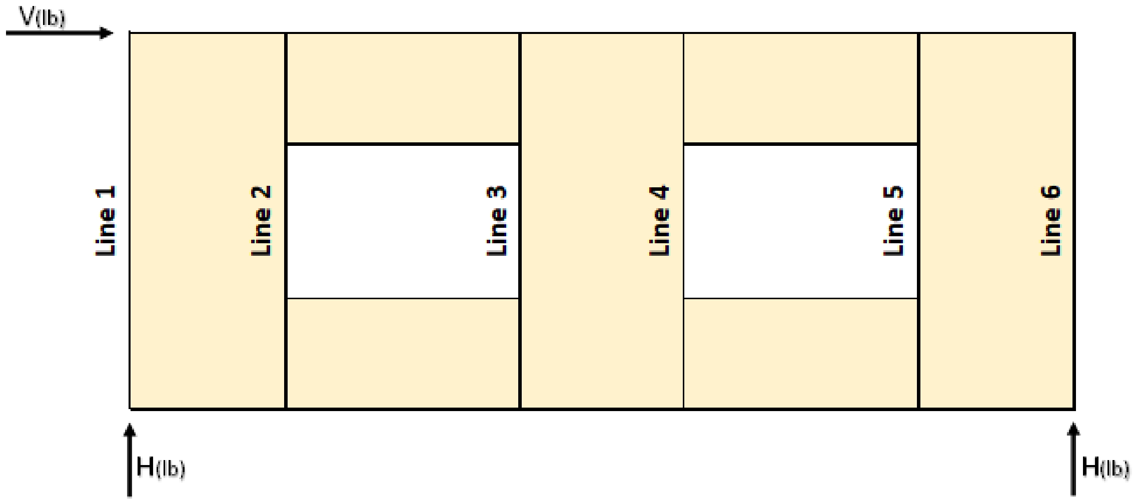
The method assumes the following:

- The shear of each pier is the total shear divided by the L of the wall, multiplied by the sum of the length of the pier and its tributary length, divided by the length of the pier:
  - (V/L)(L1+T1)/L1
- The unit shear of the corner zones is equal to subtracting the corner forces from the panel resistance, R. R is equal to the shear of the pier multiplied by the pier length:
  - Va1 = (v1L1 – F1)/L1

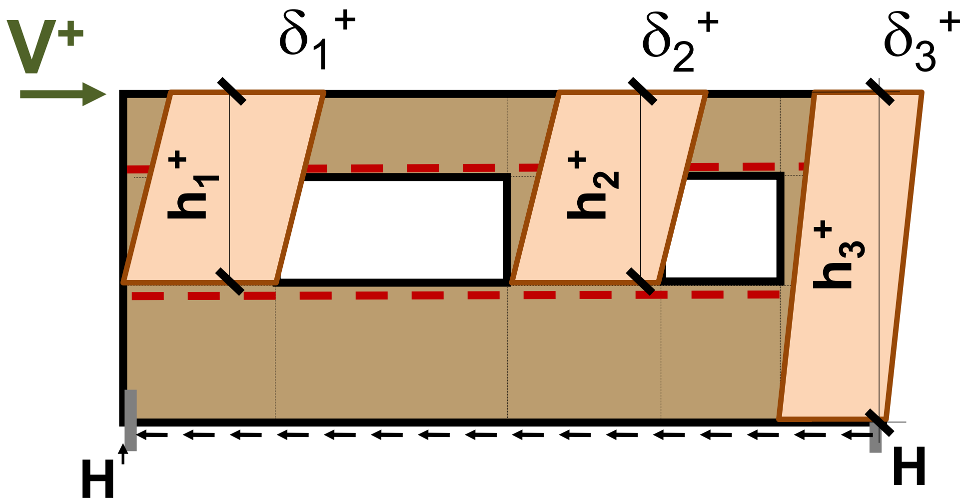
Diekmann Technique: Conceptual Keys

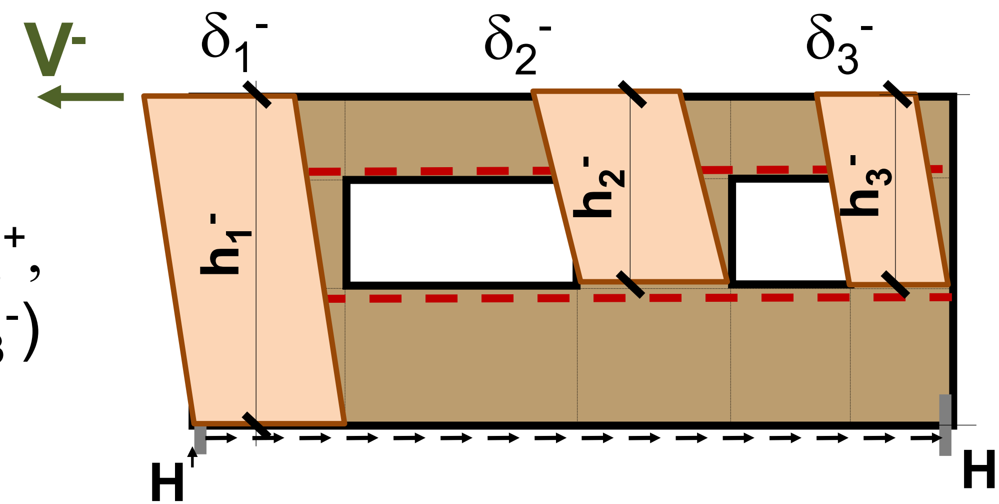
The method assumes the following:

- Once the entire segment shears have been calculated, then the design is checked by summing the shears vertically along each line. The first and last line equal the hold-down force, and the rest should sum to zero.



Deflection Calculations - Concept





$$\Delta = \text{average}(\delta_1^+, \delta_2^+, \delta_3^+, \delta_1^-, \delta_2^-, \delta_3^-)$$

Deflection Calculations

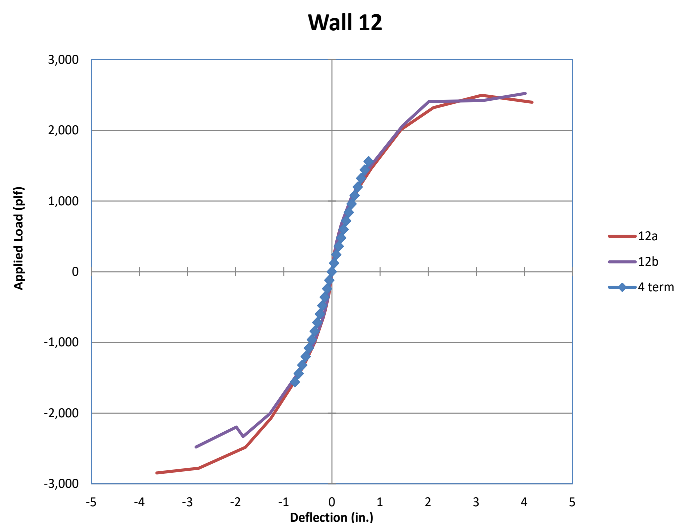
- **Wall drift estimation when using FTAO**
- **Historical 4-term deflection equation**
  - **Average deflection, varying h**

$$\Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75he_n + d_a\frac{h}{b} \qquad \text{(Equation 23-2)}$$

	Pier 1	Pier 2	
E:	1.60E+06	1.60E+06	(psi)
h:	4.17	8	(ft)
A:	10.5	10.5	(in^2)
Gt:	83,500	83,500	(lbf/in.)
b:	2.25	2.25	(ft)
PHD8Capacity:	5715	5715	(lbf)
HD Defl:	0.064	0.064	(in.)
Nail Spacing:	2	2	(in.)

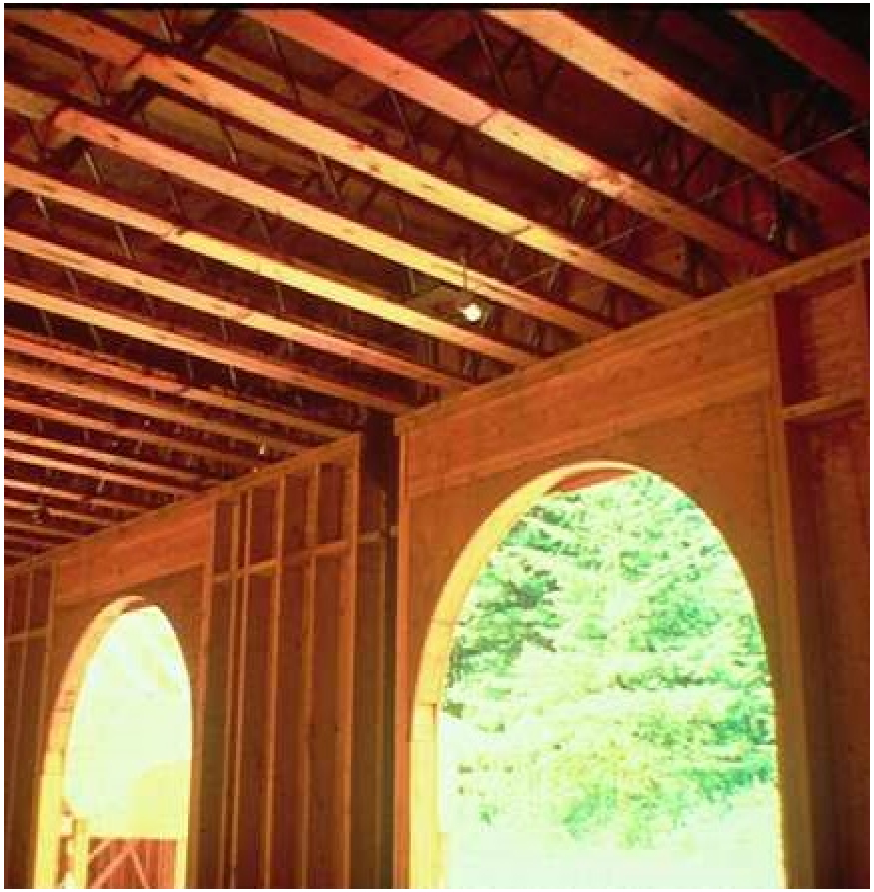
	Pier 1				Pier 2				
Unit Load v (plf)	Term 1 Bending	Term 2 Shear	Term 3 fastener	Term 4 HD-1	Term 1 Bending	Term 2 Shear	Term 3 fastener	Term 4 HD-2	Total Defl.
-1560									-0.657
-1440									-0.586
-1320									-0.521
-1200									-0.460
-1080									-0.403
-960									-0.350
-840									-0.300
-720									-0.253
-600									-0.208
-480									-0.165
-360									-0.122
-240									-0.081
-120									-0.040
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120	0.002	0.006	0.000	0.010	0.013	0.011	0.000	0.038	0.040
240	0.004	0.012	0.000	0.021	0.026	0.023	0.000	0.076	0.081
360	0.006	0.018	0.001	0.031	0.039	0.034	0.001	0.115	0.122
480	0.007	0.024	0.002	0.041	0.052	0.046	0.004	0.153	0.165
600	0.009	0.030	0.004	0.052	0.065	0.057	0.008	0.191	0.208
720	0.011	0.036	0.007	0.062	0.078	0.069	0.014	0.229	0.253
840	0.013	0.042	0.012	0.073	0.091	0.080	0.023	0.268	0.300
960	0.015	0.048	0.018	0.083	0.104	0.092	0.035	0.306	0.350
1080	0.017	0.054	0.027	0.093	0.117	0.103	0.052	0.344	0.403
1200	0.018	0.060	0.038	0.104	0.130	0.115	0.073	0.382	0.460
1320	0.020	0.066	0.052	0.114	0.143	0.126	0.099	0.420	0.521
1440	0.022	0.072	0.069	0.124	0.156	0.138	0.132	0.459	0.586
1560	0.024	0.078	0.090	0.135	0.169	0.149	0.172	0.497	0.657

Model No.	Ga	Dimensions (in.)					Fasteners		Minimum Wood Member Thickness[1] (in.)	Allowable Tension Loads (lbs.) (160)		
		W	H	B	℄	SO	Anchor Bolt Dia. (in.)	SDS Screws		DF/SP	SPF/HF	Deflection at Allowable Load[4] (in.)
HDQ8-SDS3	7	2⅝	14	2½	1¼	2⅜	⅞	20-SDS ¼"x3"	3	5715	4115	0.064
								20-SDS ¼"x3"	3½	7630	5495	0.094
								20-SDS ¼"x3"	4½	9230	6645	0.095
HHDQ11-SDS2.5	7	3	15¼	3½	1½	⅝	1	24-SDS ¼"x2½"	5½	11810	8505	0.131
HHDQ14-SDS2.5	7	3	18¾	3½	1½	⅝	1	30-SDS ¼"x2½"	7¼	13015[5]	9370[5]	0.107
									5½[8]	13710[8,9]	10745[9]	0.107



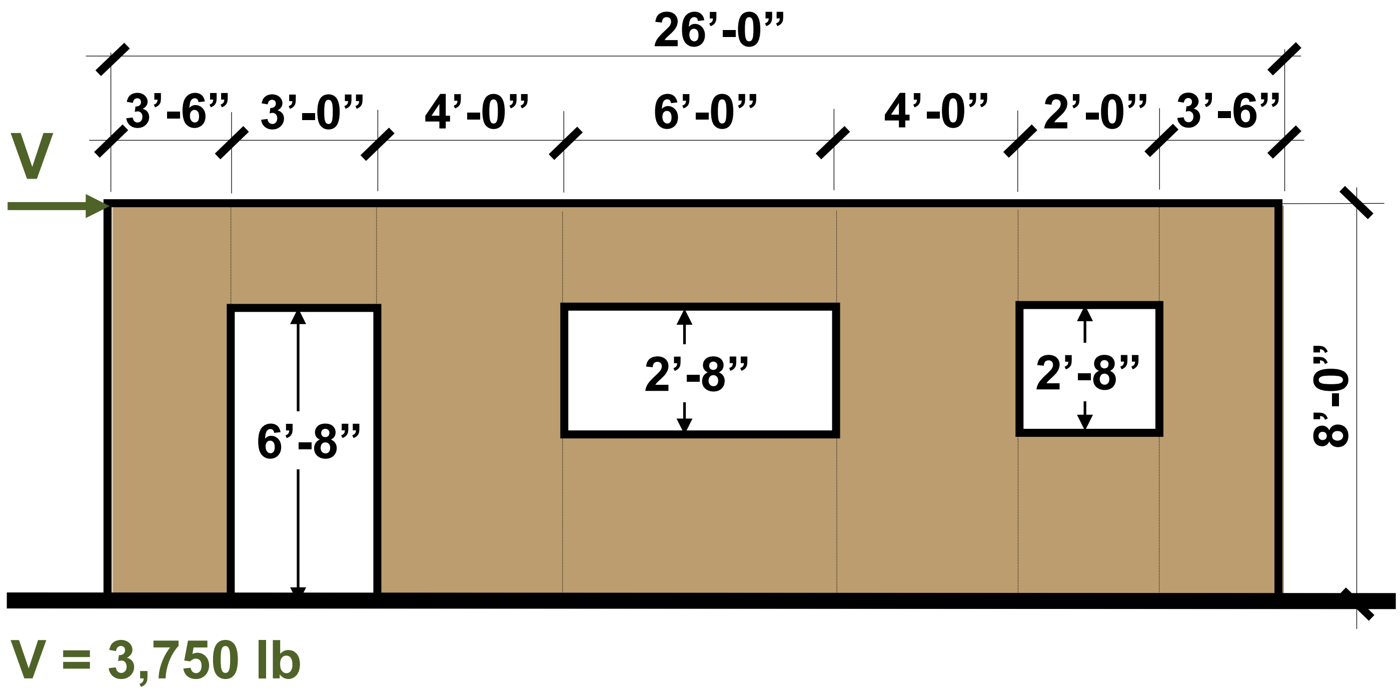
Shear Wall Design Examples

- ☑ **Segmented Shear Wall Approach**
- ☐ **Force Transfer Around Opening Approach**

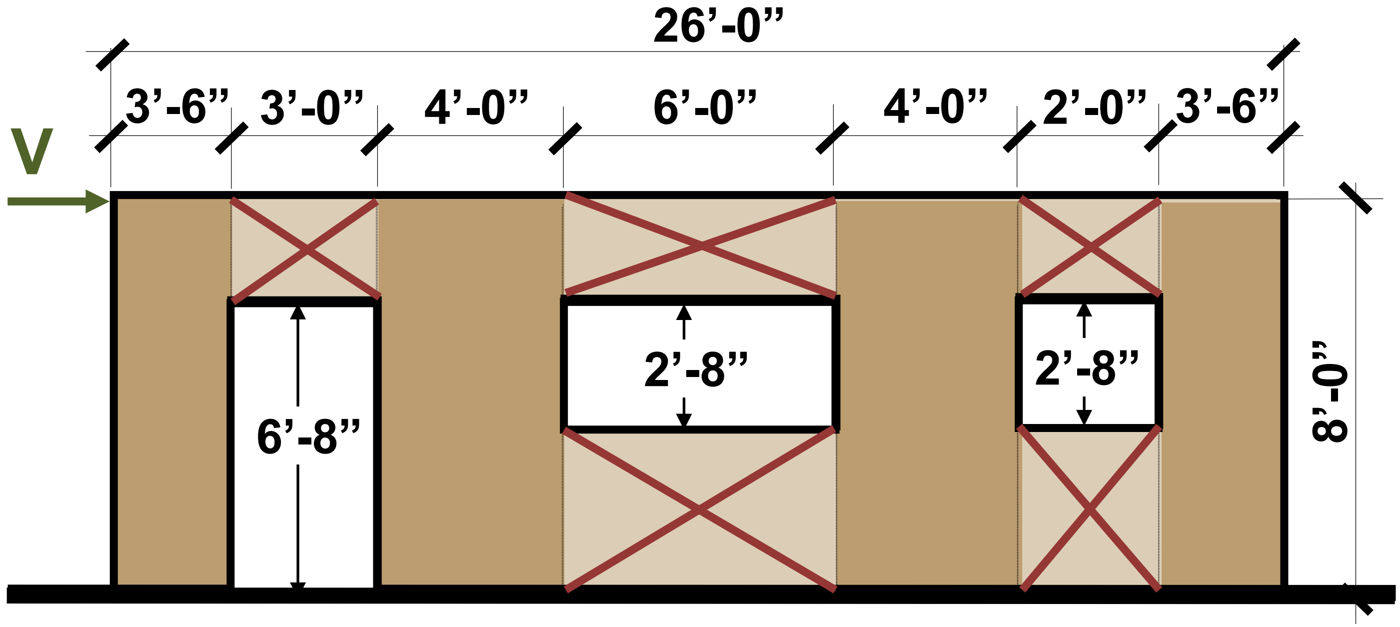


Shear Wall Design Examples

Standard Example Wall with 3 openings.

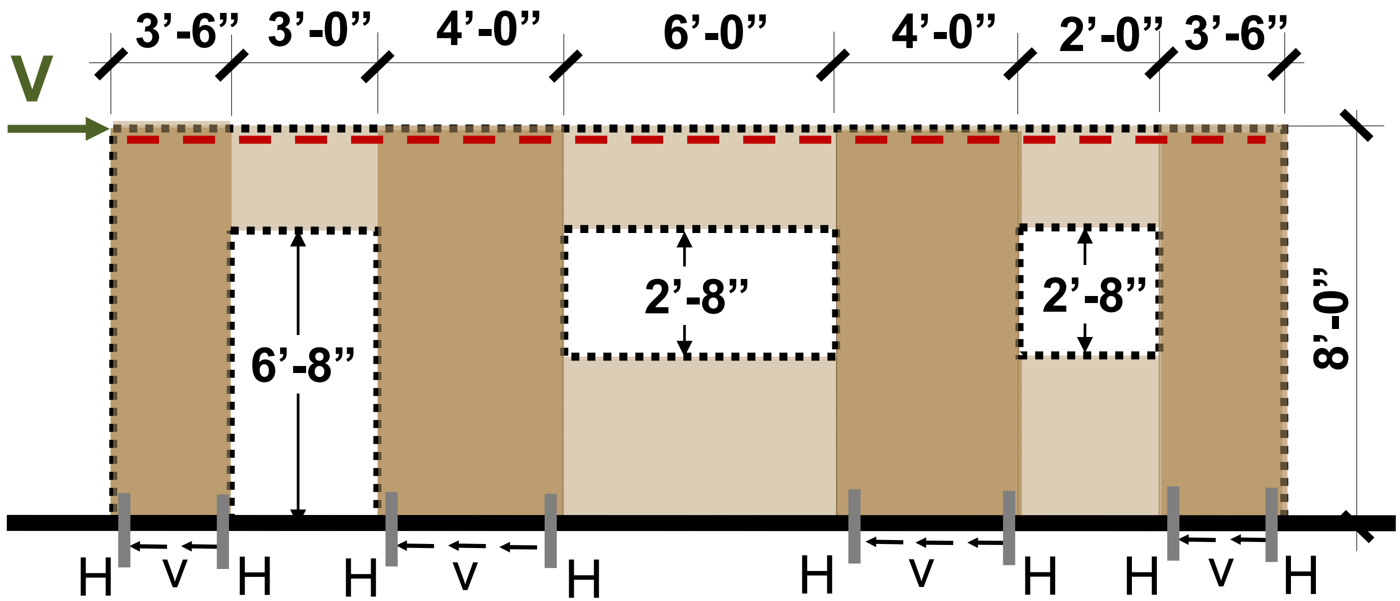


Segmented Approach



Does not consider contribution of sheathing above and below openings

Segmented Approach



V = 3,750 lbs

Code Limitation

Height/width Ratio = 8:3.5

2w/h = (2)(3.5)/8 = 0.875

15 SDPWS 4.3.3.4.1

Segmented Approach

1. **Unit Shear**

   V = V/∑L = 3,750/15 = 250 lbs/ft

2. **Allowable Shear 3'-6" walls**

   v allowable = 380 (0.875)=332 lbs/ft > 250 lbs/ft

   15/32" Rated Sheathing 8d @ 4"o.c. at 3.5' walls

3. **Allowable Shear 4' walls (2:1 h:w)**

   v allowable = 260lb/ft > 250 lbs/ft

   15/32" Rated Sheathing 8d @ 6"o.c. @ 4' walls

4. **Hold-down forces**

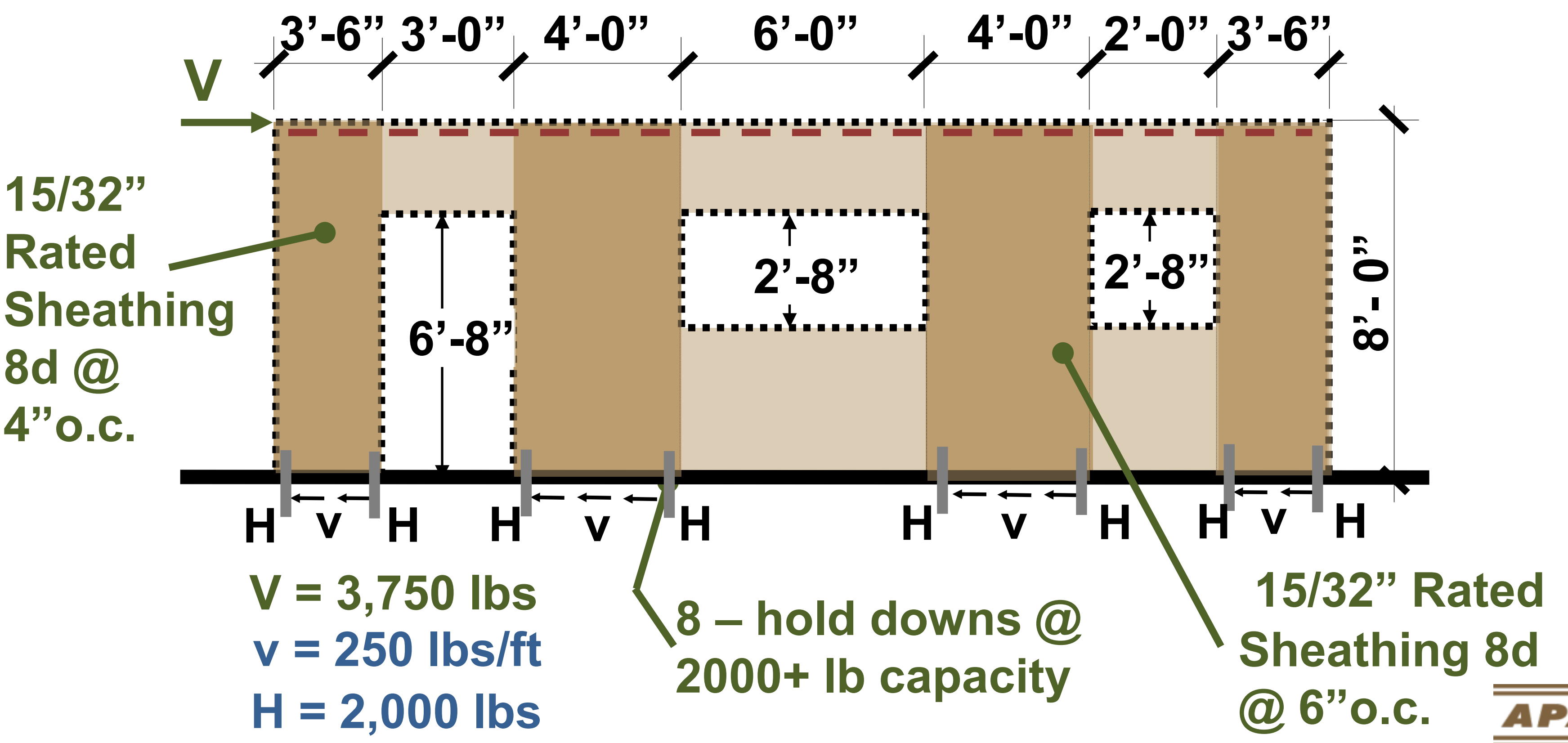
   H = vh = 250 x 8 = 2,000 lbs

   8 – hold downs @ 2000+ lb capacity

Note: For simplicity Dead Load contributions and various footnote adjustments have been omitted

Segmented Approach

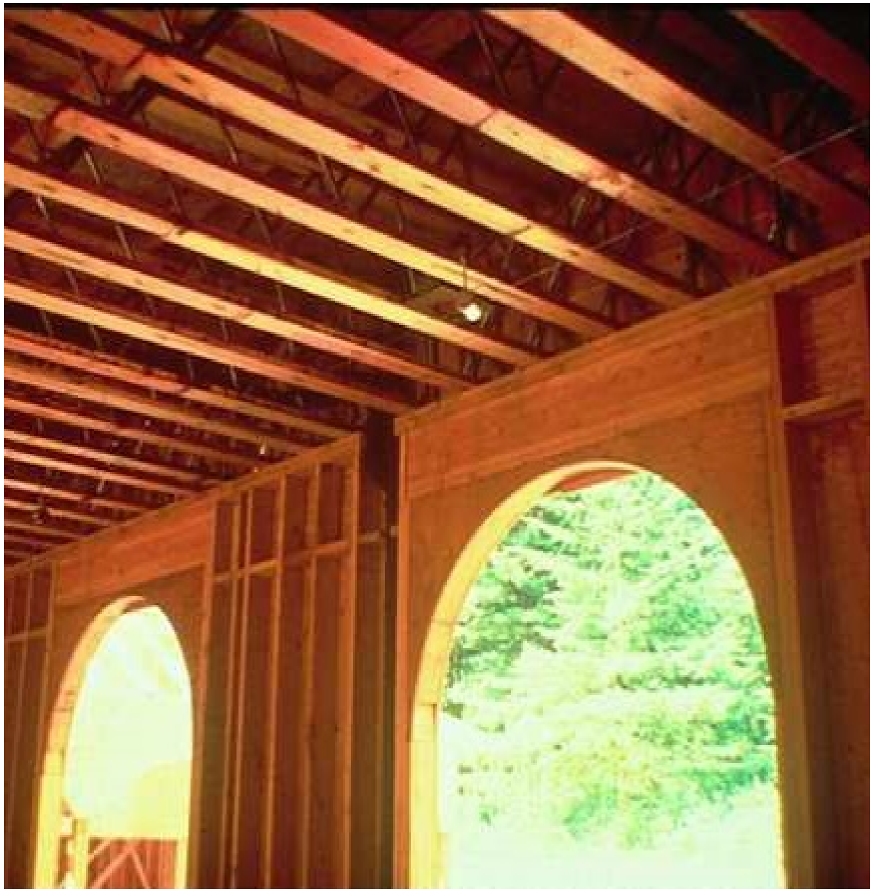
Summary



APA

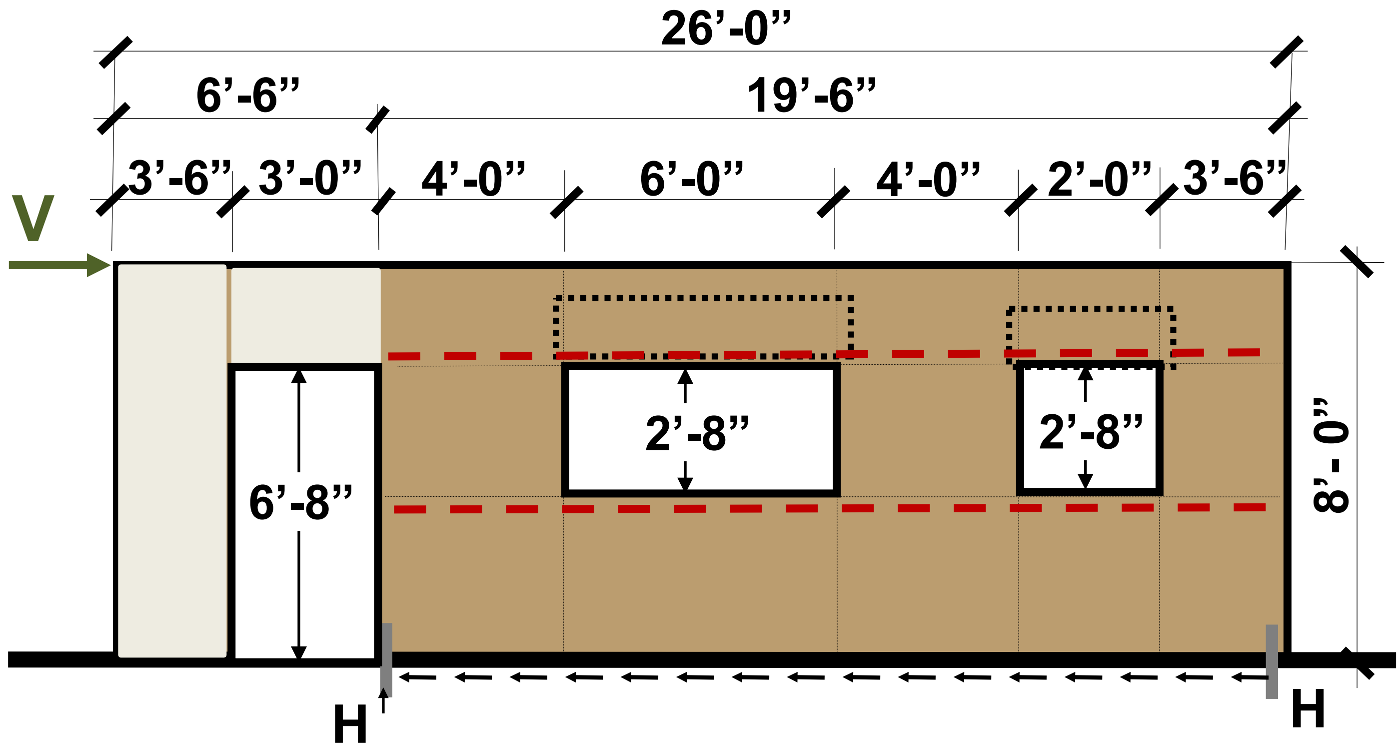
Shear Wall Design Examples

- ❑ Segmented Shear Wall Approach
- ☑ Force Transfer Around Opening Approach



APA

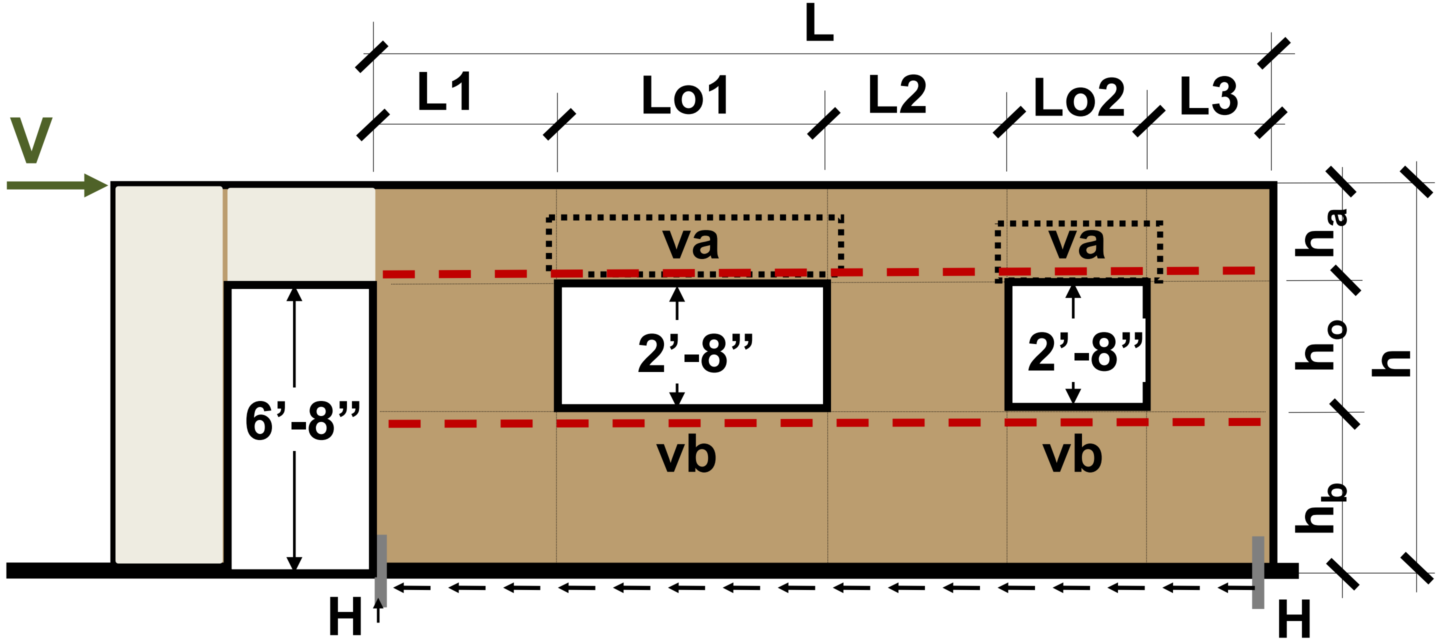
FTAO Approach



V = 3,750 lbs

Height/width Ratio = 2'-8" / 3'-6"

FTAO Approach



1. **Calculate the hold-down forces:**

   H = Vh/L = (3750 x 8')/19.5' = 1538lbs

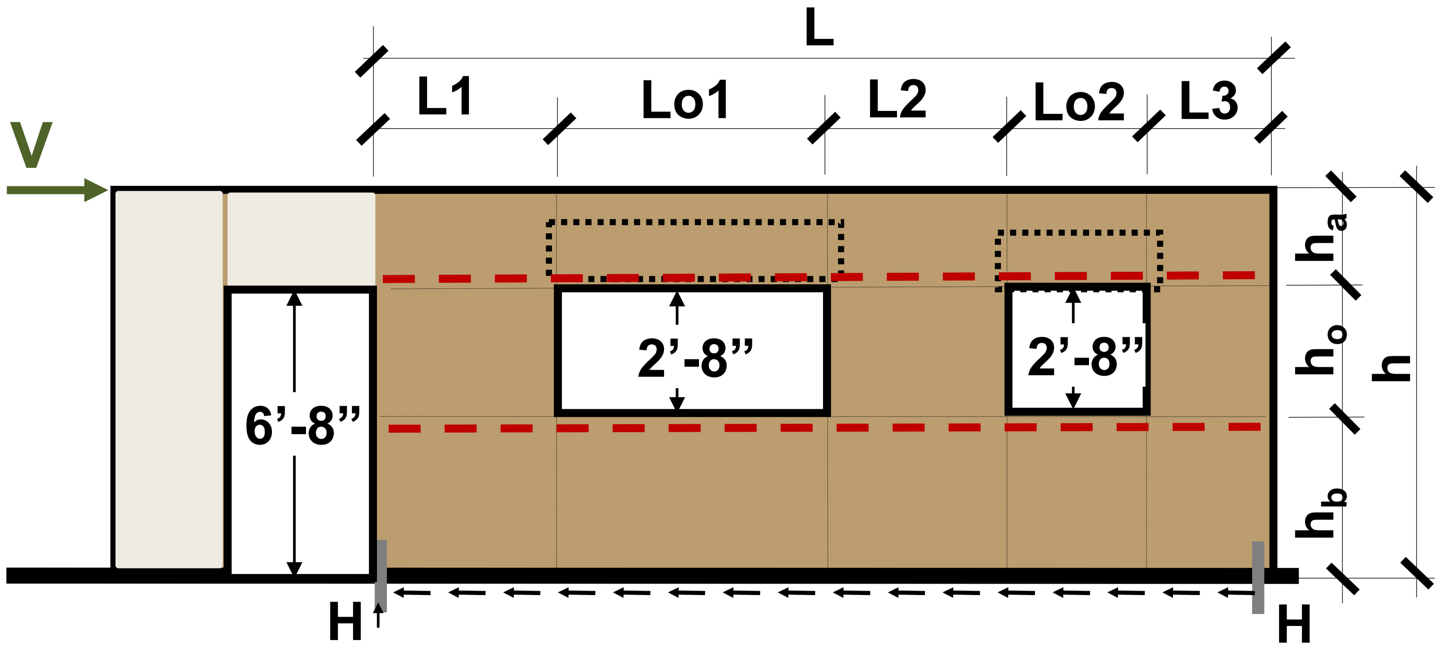
2. **Solve for the unit shear above and below the openings:**

   va = vb = H/(ha+hb) = 1538/(1.33'+4') = 289 plf

CK: The unit shear above and below the openings is equivalent.

APA

FTAO Approach



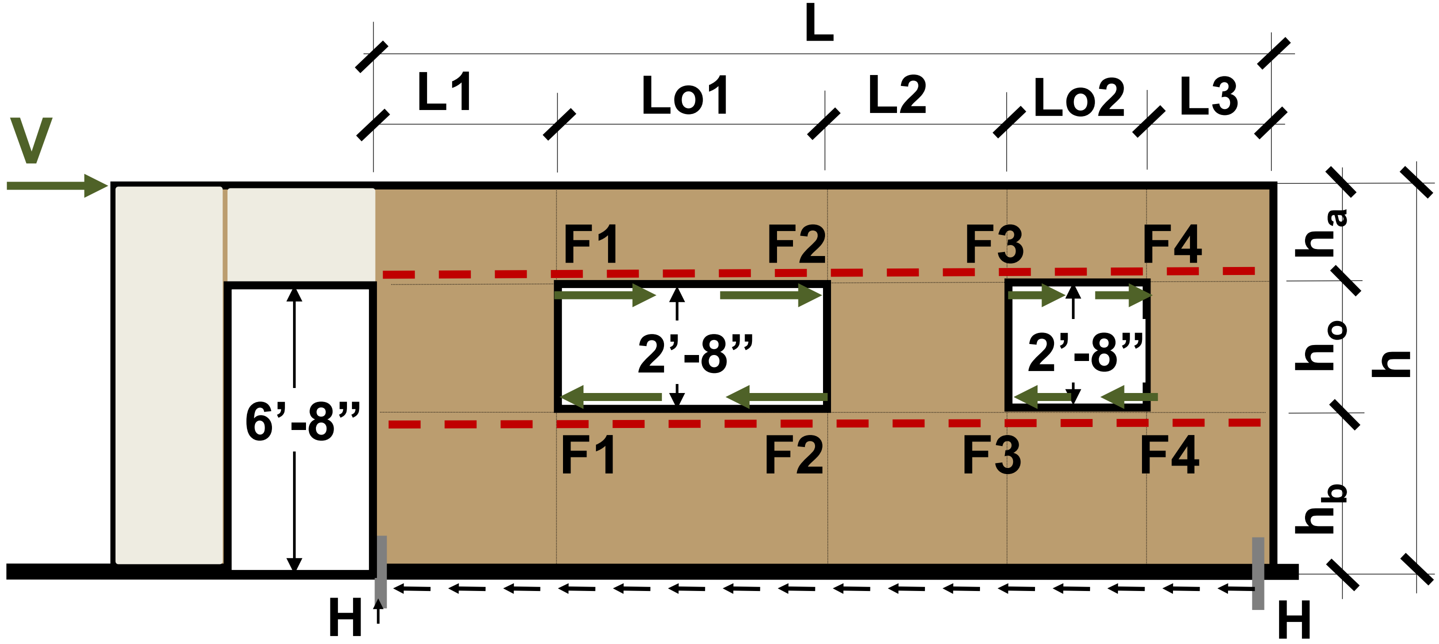
3. **Find the total boundary force above and below the openings**

   First opening: O1 = va x (Lo1) = 289 plf x 6' = 1734lbs

   Second opening: O2 = va x (Lo2) = 289 plf x 2' = 578lbs

CK: The corner forces are based on the shear above and below the openings and only the piers adjacent to that unique opening.

FTAO Approach



4. **Calculate the corner forces:**

F1 = O1(L1)/(L1+L2) = 866#

F2 = O1(L2)/(L1+L2) = 866#

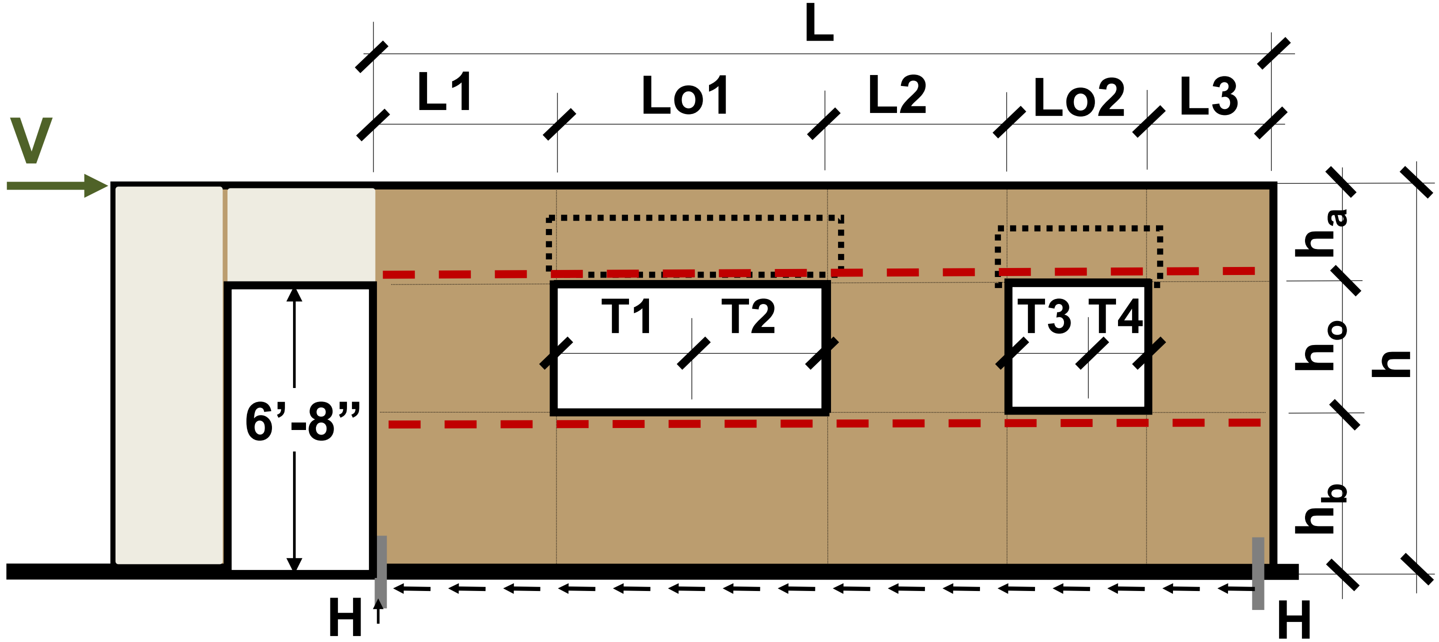
F3 = O2(L2)/(L2+L3) = 308#

F4 = O2(L3)/(L2+L3) = 269#

CK: Strap forces

APA

FTAO Approach



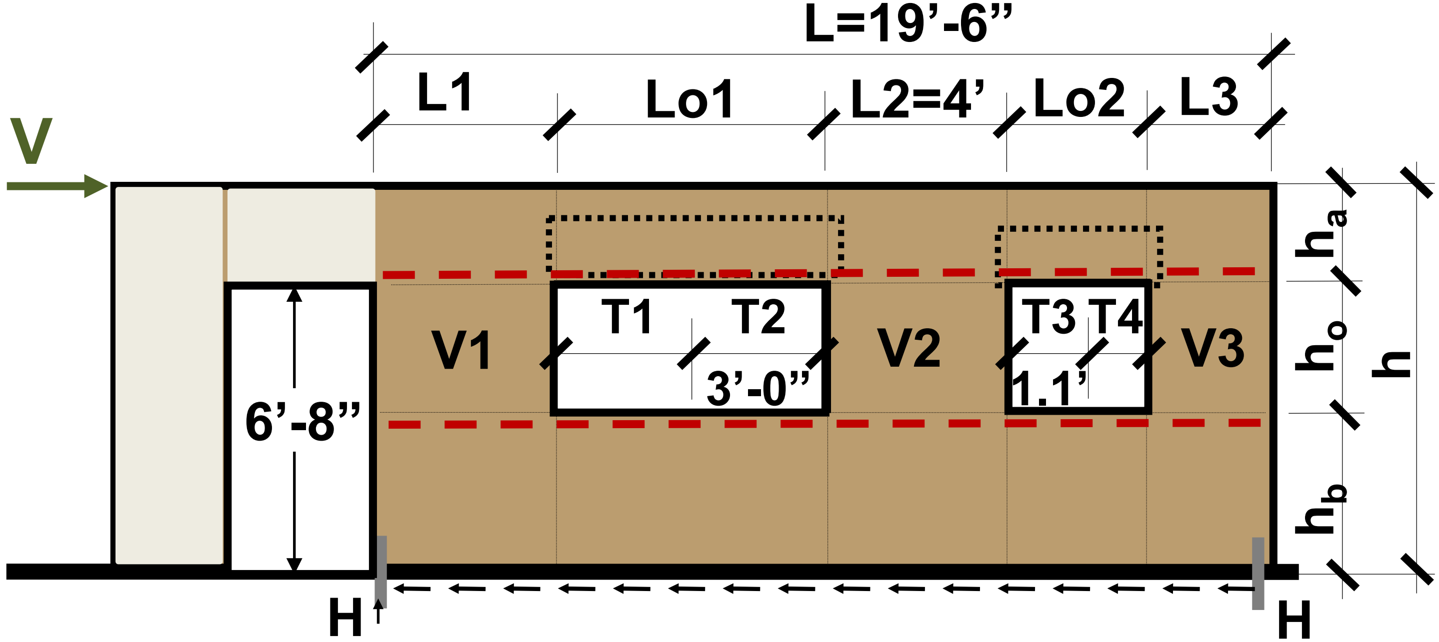
5. **Tributary length of openings (ft)**

T1 = L1(Lo1)/(L1+L2) = 3' **T2 = L2(Lo1)/(L1+L2) = 3'**

T3 = L2(Lo2)/(L2+L3) = 1.1' **T4 = L3(Lo2)/(L2+L3) = 0.9'**

CK: Ratio of the length of the pier x length of the opening it is adjacent to, then / (length of the pier + length of the pier on the other side of the opening).

FTAO Approach



6. **Unit shear beside the opening**

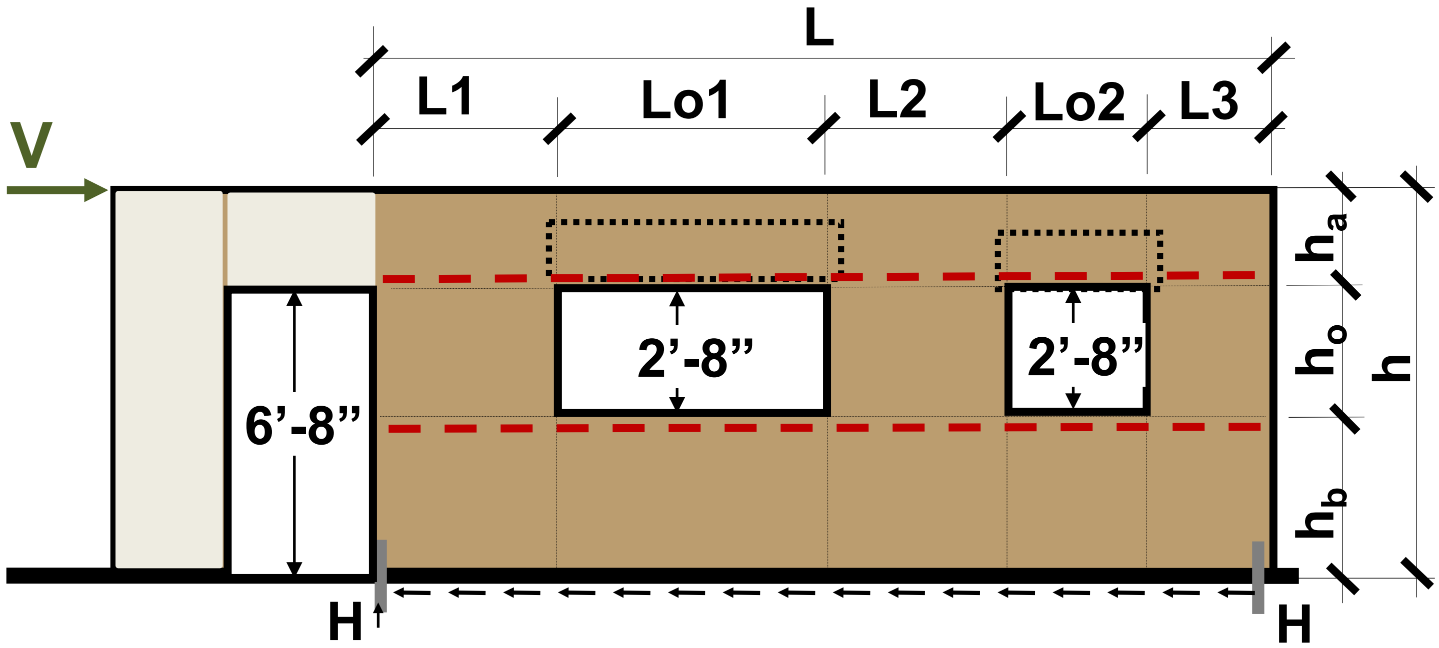
V1 = (V/L)(L1+T1)/L1 = 337 plf   V2 = (V/L)(T2+L2+T3)/L2 = 388 plf

V3 = (V/L)(T4+L3)/L3 = 244 plf   Check V1*L1 +V2*L2+V3*L3=V? YES

CK: The shear of each pier = the total shear / the L of the wall x (length of the pier + its tributary length)/ by the length of the pier

APA

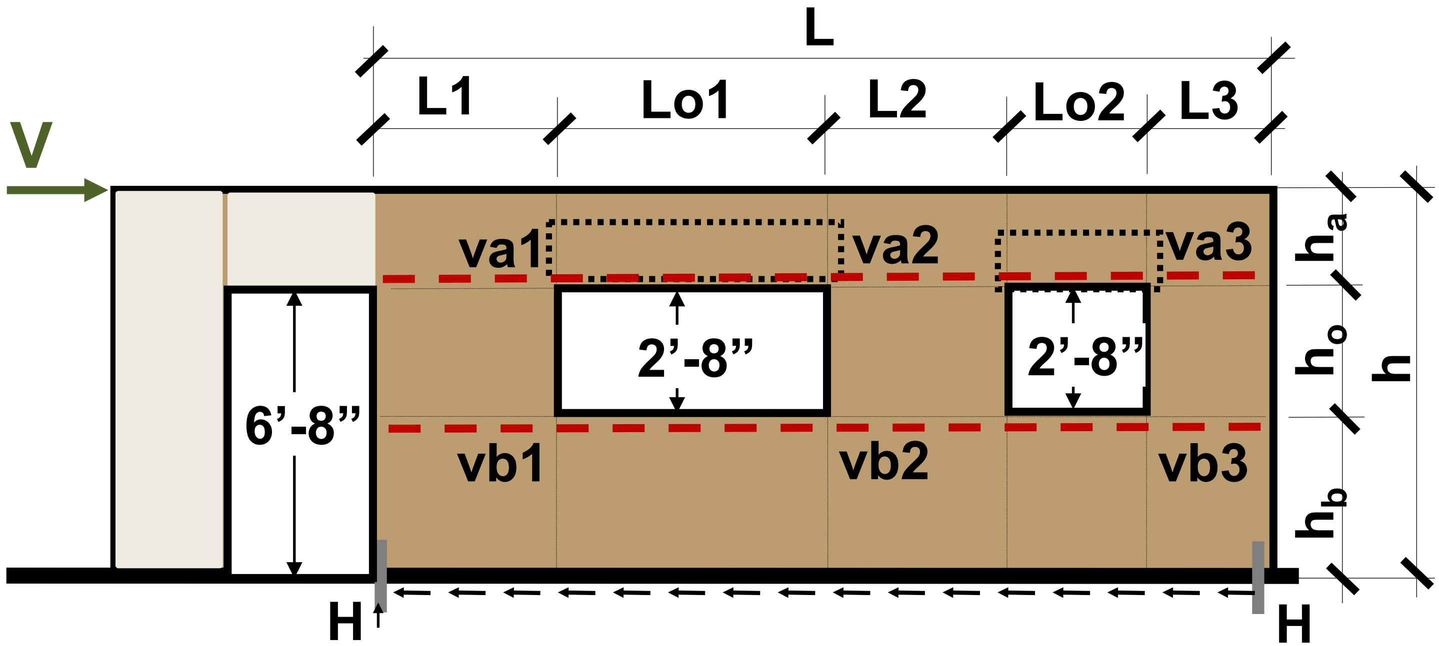
FTAO Approach



7. Resistance to corner forces
   - R1=V1*L1 = 1346lbs
   - R2 = V2*L2 = 1551lbs
   - R3 = V3*L3 = 853lbs

8. Resistance – corner force
   - R1-F1 = 480lbs
   - R2-F2-F3 = 377lbs
   - R3-F4 = 583lbs

FTAO Approach

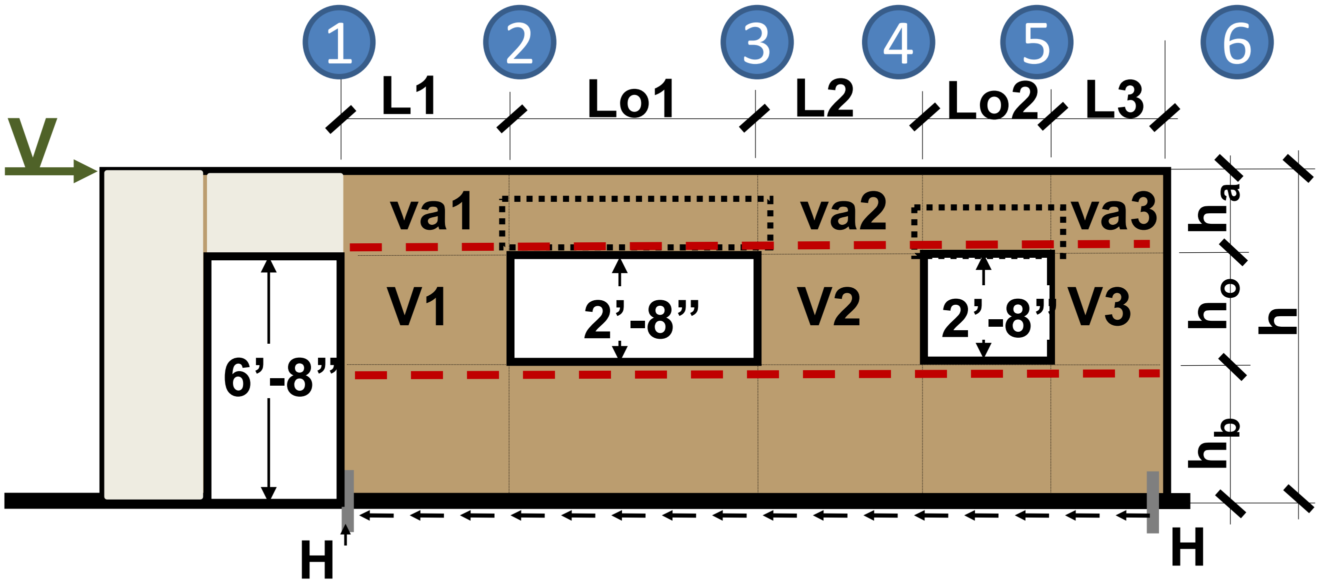


9. **Unit shear in the corner zones**

- **va1 = (R1-F1)/L1 = 120 plf**
- **va2 = (R2-F2-F3)/L2 = 94 plf**
- **va3 = (R3-F4)/L3 = 167 plf**

CK: The unit shear of the corner zones = panel resistance (R) - the corner forces . R = the shear of the pier x the pier length.

FTAO Approach



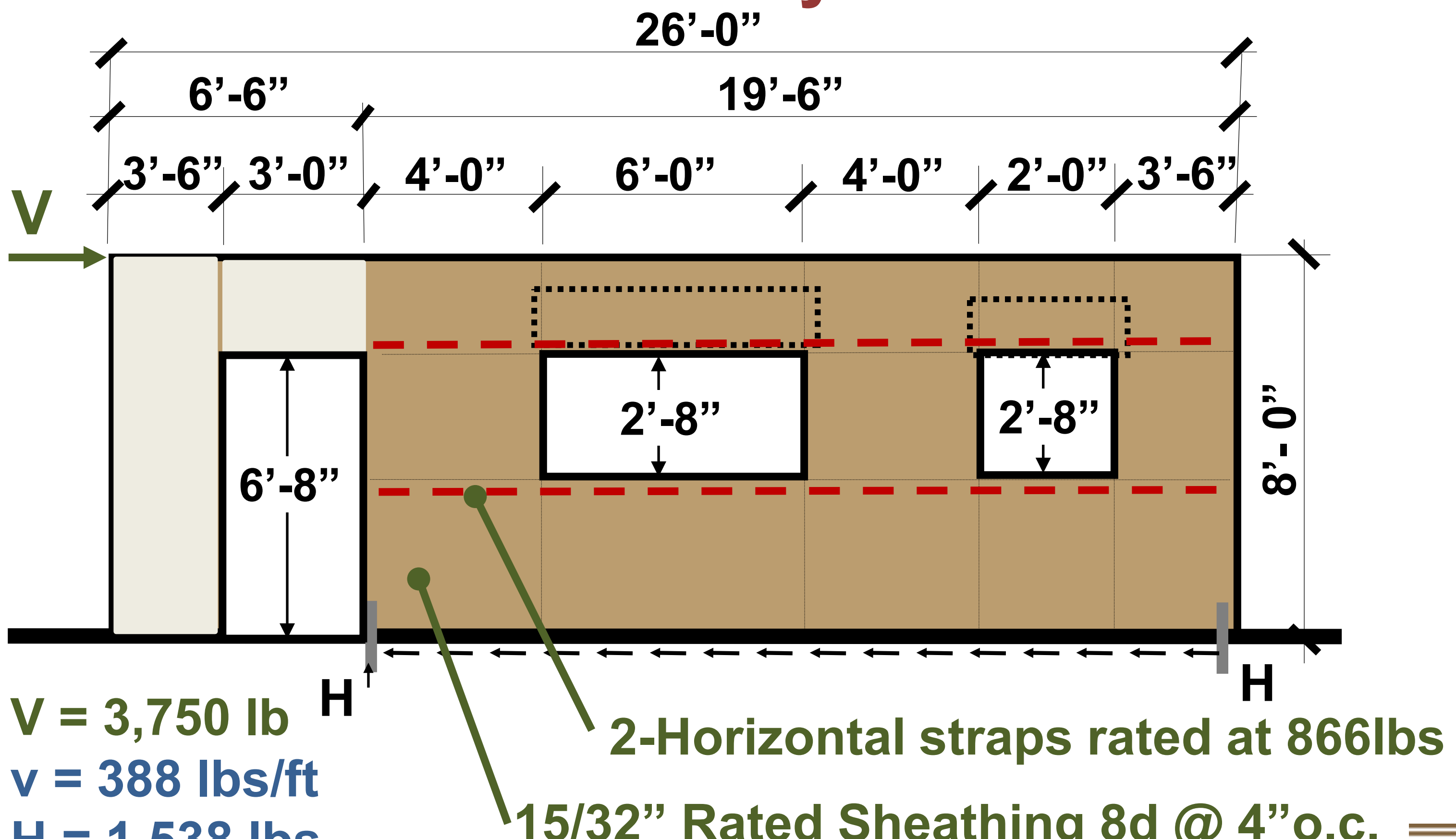
10. **Check your solution – YES to all**
    - Line 1: va1(ha+hb)+v1(ho)=H?
    - Line 2: va(ha+hb)-va1(ha+hb)-V1(ho)=0?
    - Line 3: va2(ha+hb)+V2(ho)-va(ha+hb)=0?
    - Line 4 = Line 3
    - Line 5: va(ha+hb)-va3(ha+hb)-V3(ho)=0?
    - Line 6: va3(ha+hb)+V3(ho)=H?

CK: Once all segment shears are calculated, check the design by summing the shears vertically along each line. The 1st and last = hold-down force, and the rest should = zero.

APA

FTAO Approach

Summary

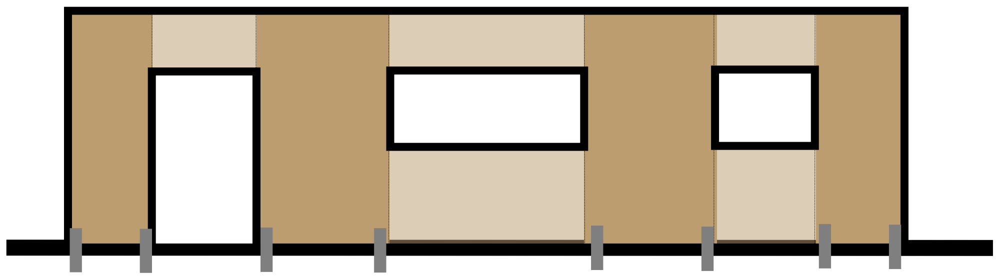


V = 3,750 lb
v = 388 lbs/ft
H = 1,538 lbs

APA

Shear Wall Design Examples

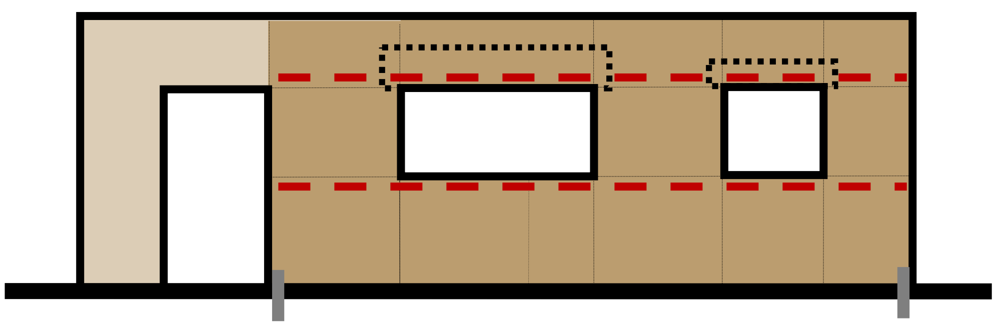
Segmented Approach



15/32" Rated sheathing

- 8d @ 4"o.c. (3'-6" walls)
- 8d @ 6" o.c. (4' walls)
- 8 – hold downs @ 2000+ lb capacity

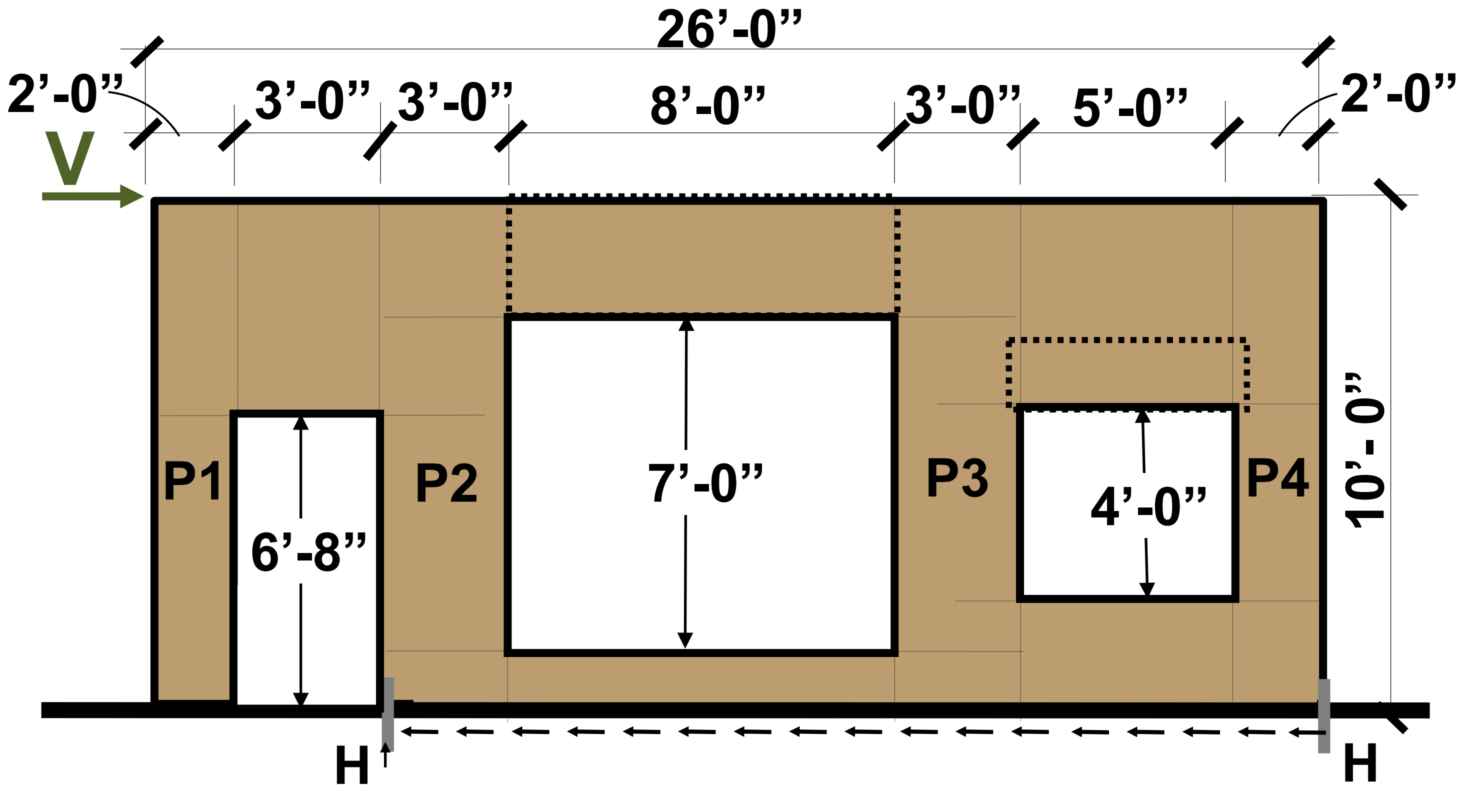
Force Transfer



15/32" Rated Sheathing

- 8d @ 4"o.c.
- 2 – hold downs @ 1,538 lb capacity
- 2 Straps – 866 lb

Shear Wall Design Examples



Segmented & Perforated use full height segments

- 3.5:1 for 10'-0" = 34"

FTAO uses heights adjacent to openings

- 3.5:1 for 7'-0" = 24"   2:1 for 4'-0" = 24"

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Force Transfer Around Openings (FTAO)

VERSATILE SHEAR WALL ANALYSIS METHOD LENDS GREATER DESIGN FLEXIBILITY

Wood structural panel sheathed shear walls and diaphragms are the primary lateral-load-resisting elements in wood-frame construction. As wood-frame construction is continuously evolving, designers in many parts of the U.S. are optimizing design solutions that require the understanding of force transfer between elements in the lateral load-resisting system.

The force transfer around openings (FTAO) method of shear wall analysis offers some advantages compared to other methods:

- **More versatility**, because the FTAO method allows for the use of narrower wall segments while meeting required height-to-width ratios, and
- A high likelihood that **fewer hold-downs** will be required.

Technical Note: Design for Force Transfer Around Openings

This technical note presents a rational analysis for applying FTAO to walls with asymmetric piers and walls with multiple openings. It is based upon APA modeling and testing and uses methodology that assists the design professional in solving for the required sheathing, nailing, hold-downs, straps, and maximum deflection.

DOWNLOAD

APA Force Transfer Around Openings Calculator

This calculator is an Excel-based tool for professional designers that uses FTAO methodology to calculate maximum hold-down force for uplift resistance, the required horizontal strap force for the tension straps above and below openings, the maximum shear force to determine sheathing attachment, and the maximum deflection of the wall

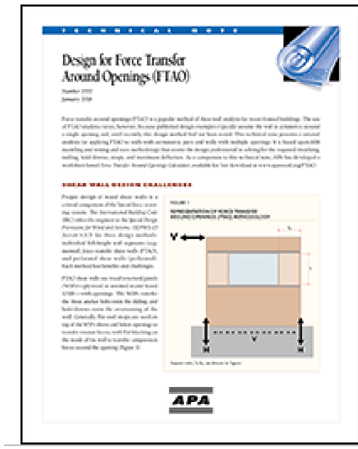
Webinar:

Resolving Wood Shear Wall Design Puzzles with Force Transfer Around Openings, DES415, AWC

Provides an overview of the force transfer around openings (FTAO) shear wall design approach, recent research in this area, and a side-by-side comparison of design results between segmented, perforated, and FTAO design methods. AIA, ICC, and NCSEA credits available. Presented by Jared Hensley, PE, APA Engineered Wood Specialist.

LEARN MORE

www.apawood.org/FTAO



Technical Note: Design for Force Transfer Around Openings

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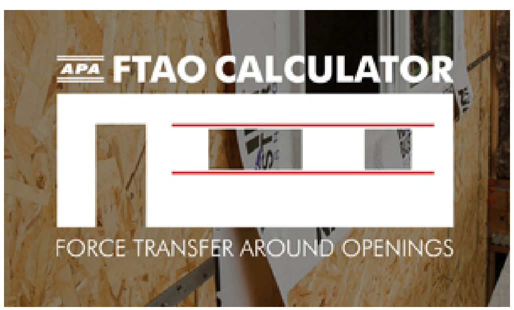
DOWNLOAD



APA Force Transfer Around Openings Calculator

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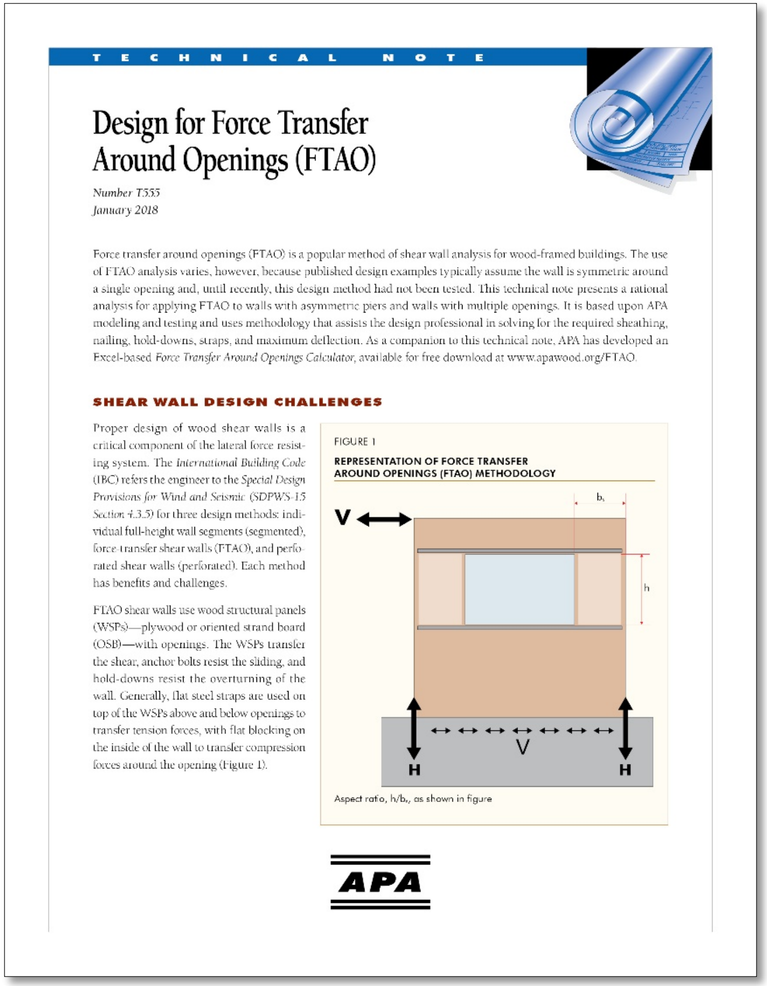
DOWNLOAD

APA Force Transfer Around Openings Calculator
This calculator is an Excel-based tool for professional designers that uses FTAO methodology to calculate maximum hold-down force for uplift resistance, the required horizontal strap force for the tension straps above and below openings, the maximum shear force to determine sheathing attachment, and the maximum deflection of the wall

FTAO Technical Note: Form T555

- Technical Note: Design for Force Transfer Around Openings (FTAO)
  - APA Form T555
- Presents a rational analysis for applying FTAO to walls with asymmetric piers and walls with multiple openings
- Based on Wall 12 testing configuration



TECHNICAL NOTE

Design for Force Transfer Around Openings (FTAO)

Number T555
January 2018

Force transfer around openings (FTAO) is a popular method of shear wall analysis for wood-framed buildings. The use of FTAO analysis varies, however, because published design examples typically assume the wall is symmetric around a single opening and, until recently, this design method had not been tested. This technical note presents a rational analysis for applying FTAO to walls with asymmetric piers and walls with multiple openings. It is based upon APA modeling and testing and uses methodology that assists the design professional in solving for the required sheathing, nailing, hold-downs, straps, and maximum deflection. As a companion to this technical note, APA has developed an Excel-based *Force Transfer Around Openings Calculator*, available for free download at www.apawood.org/FTAO.

SHEAR WALL DESIGN CHALLENGES

Proper design of wood shear walls is a critical component of the lateral force resisting system. The *International Building Code* (IBC) refers the engineer to the *Special Design Provisions for Wind and Seismic* (SDPWS-15 Section 4.3.5) for three design methods: individual full-height wall segments (segmented), force-transfer shear walls (FTAO), and perforated shear walls (perforated). Each method has benefits and challenges.

FTAO shear walls use wood structural panels (WSPs)—plywood or oriented strand board (OSB)—with openings. The WSPs transfer the shear, anchor bolts resist the sliding, and hold-downs resist the overturning of the wall. Generally, flat steel straps are used on top of the WSPs above and below openings to transfer tension forces, with flat blocking on the inside of the wall to transfer compression forces around the opening (Figure 1).

FIGURE 1

REPRESENTATION OF FORCE TRANSFER AROUND OPENINGS (FTAO) METHODOLOGY

Aspect ratio, h/b, as shown in figure

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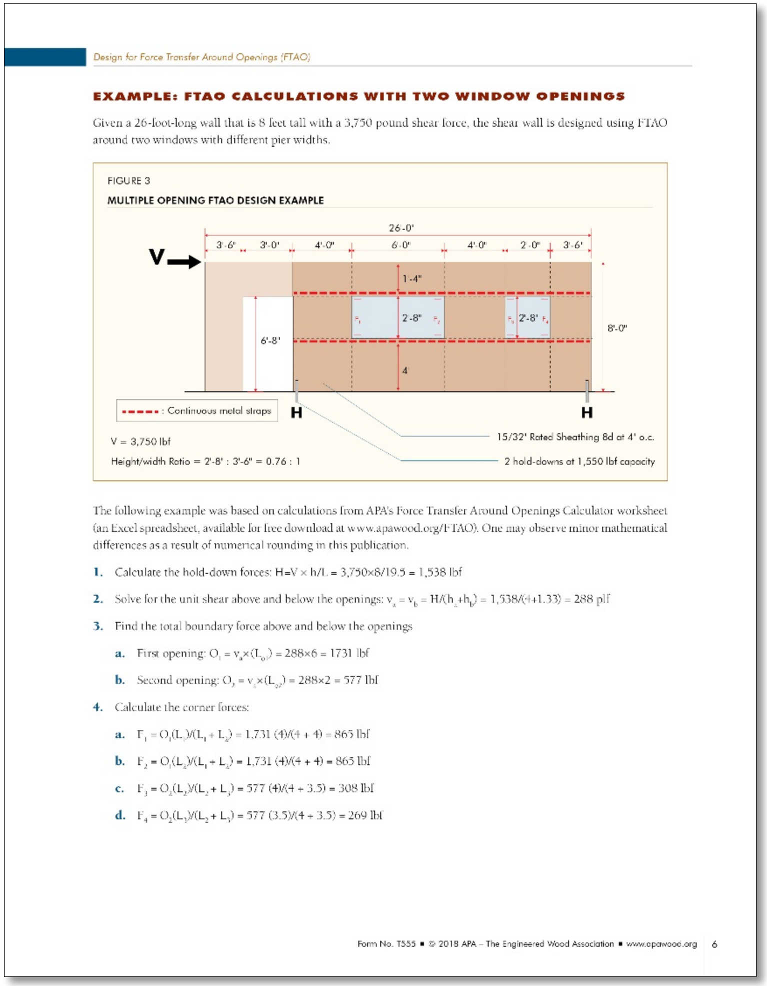
FTAO Technical Note: Form T555

- Provides a design example for FTAO wall with two window openings
- FTAO Calculator: Companion to Technical Note



EXAMPLE: FTAO CALCULATIONS WITH TWO WINDOW OPENINGS

Given a 26-foot-long wall that is 8 feet tall with a 3,750 pound shear force, the shear wall is designed using FTAO around two windows with different pier widths.

FIGURE 3

MULTIPLE OPENING FTAO DESIGN EXAMPLE

V = 3,750 lbf

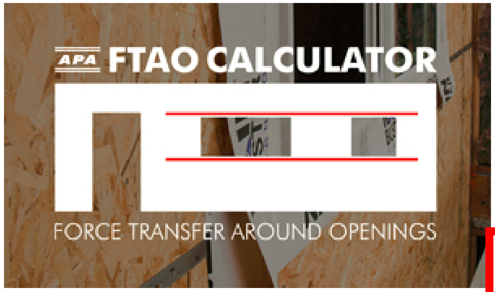
Height/width Ratio = 2'-8" : 3'-6" = 0.76 : 1

The following example was based on calculations from APA's Force Transfer Around Openings Calculator worksheet (an Excel spreadsheet, available for free download at www.apawood.org/FTAO). One may observe minor mathematical differences as a result of numerical rounding in this publication.

1. Calculate the hold-down forces: $H = V \times h/L = 3{,}750 \times 8/19.5 = 1{,}538$ lbf
2. Solve for the unit shear above and below the openings: $v_a = v_b = H/(h_a + h_b) = 1{,}538/(4+1.33) = 288$ plf
3. Find the total boundary force above and below the openings
   - a. First opening: $O_1 = v_a \times (L_{o1}) = 288 \times 6 = 1731$ lbf
   - b. Second opening: $O_2 = v_a \times (L_{o2}) = 288 \times 2 = 577$ lbf
4. Calculate the corner forces:
   - a. $F_1 = O_1(L_1)/(L_1 + L_2) = 1{,}731\ (4)/(4 + 4) = 865$ lbf
   - b. $F_2 = O_1(L_2)/(L_1 + L_2) = 1{,}731\ (4)/(4 + 4) = 865$ lbf
   - c. $F_3 = O_2(L_2)/(L_2 + L_3) = 577\ (4)/(4 + 3.5) = 308$ lbf
   - d. $F_4 = O_2(L_3)/(L_2 + L_3) = 577\ (3.5)/(4 + 3.5) = 269$ lbf

APA FTAO Calculator

- **Excel-based tool released January 2018**
- **Based on design methodology developed by Diekmann**
- **Calculates:**
  - **Max hold-down force for uplift resistance**
  - **Required horizontal strap force above and below openings**
  - **Max shear force for sheathing attachments**
  - **Max deflection**
- **Design example corresponds with FTAO Technical Note (Form T555)**



APA Force Transfer Around Openings Calculator

This calculator is an Excel-based tool for professional designers that uses FTAO methodology to calculate maximum hold-down force for uplift resistance, the required horizontal strap force for the tension straps above and below openings, the maximum shear force to determine sheathing attachment, and the maximum deflection of the wall system. The calculator includes worksheets for shear walls with one, two, and three openings and a design example.

DOWNLOAD

APA FTAO Calculator

www.apawood.org/FTAO

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Force Transfer Around Openings Calculator

The force transfer around openings (FTAO) method of shear wall analysis is an approach that aims to reinforce the wall such that it performs as if there was no opening. This approach lends certain advantages over segmented shear walls: more versatility, because it allows for narrower wall segments while still meeting the height-to-width ratios and, often, fewer required hold-downs.

Force Transfer Around Openings (FTAO) Calculator Instructions

The APA Force Transfer Around Openings (FTAO) Calculator is divided into three worksheets: shear wall with one opening, shear wall with two openings, and shear wall with three openings. Each calculation tab will produce the maximum hold-down force for uplift resistance, the required horizontal strap force for the tension straps above and below openings, the maximum shear force to determine sheathing attachment, and the maximum deflection of the wall system.

To use the calculator, input the required information into the ORANGE input cells; definitions for the required cell inputs can be found below. Move quickly between input cells by using the **TAB** key. Certain input cells, such as the Hold-Down Capacity input in the deflection calculation, have comment dialogue to clarify the input.

Variables for Shear Wall Calculations

V = Applied shear as lateral force at top of wall in pounds (lb).
L(i) = Length of individual wall pier segment as indicated by L1, L2, L3 and L4 measured in feet (ft).
Lo(i) = Length for individual clear openings as indicated by Lo1, Lo2 and Lo3 measured in feet (ft).
ho1 = Maximum clear opening height of any opening in the wall system. Will be reported as ho1, ho2 and ho3 measured in feet (ft).
ha1 = Height of continuous sheathing above the opening in correlation with **ho1** above. Will be reported as ha1, ha2 and ha3 measured in feet (ft).
hb1 = Height of continuous sheathing below the opening in correlation with **ho1** above. Will be reported as hb1, hb2 and hb3 measured in feet (ft).
h_{wall} = Total **calculated** height of shear wall from bottom of sill plate to top of top plate measured in feet (ft). Calculated as the summation of **ho1, ha1**, and **hb1**.
L_{wall} = Total **calculated** length of shear wall measured in feet (ft). Calculated as the summation of **L(i)** and **Lo(i)**.

Variables for Shear Wall Deflection Calculations

Instructions & Definitions | Design Example | One Opening | Two Openings | Three Openings ...

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FTAO Calculator: Design Example

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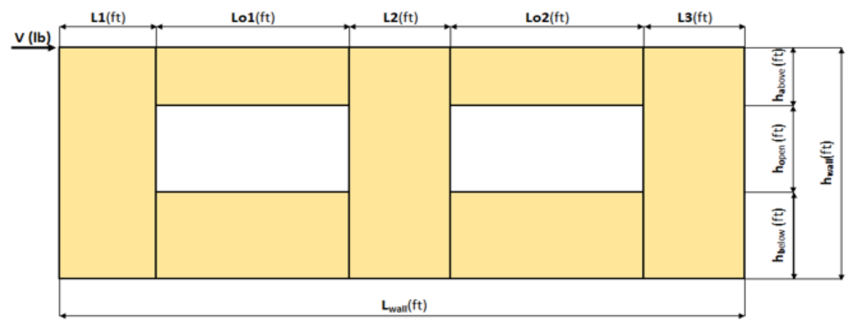
Force Transfer Around Openings Calculator

DESIGN EXAMPLE

The force transfer around openings (FTAO) method of shear wall analysis is an approach that aims to reinforce the wall such that it performs as if there was no opening. This approach lends certain advantages over segmented shear walls: more versatility, because it allows for narrower wall segments while still meeting the height-to-width ratios and, often, fewer required hold-downs.

Project Information

Code:	2015 IBC	**Date:**	
Designer:	APA		
Client:			
Project:	Design Example		
Wall Line:			



Shear Wall Calculation Variables

			Opening 1		Opening 2	Wall Pier Aspect Ratio		Adj. Factor
V	3750 lbf							
L1	4.00 ft	ha1	1.33 ft	ha2	1.33 ft	P1=ho1/L1=	0.67	N/A
L2	4.00 ft	ho1	2.67 ft	ho2	2.67 ft	P2=ho2/L2=	0.67	N/A
L3	3.50 ft	hb1	4.00 ft	hb2	4.00 ft	P3=ho2/L3=	0.76	N/A
h_{wall}	8.00 ft	Lo1	6.00 ft	Lo2	2.00 ft			
L_{wall}	19.50 ft							

1. Hold-down forces: $H = Vh_{wall}/L_{wall}$ 1538 lbf

2. Unit shear above + below opening

First opening: va1 = vb1 = H/(ha1+hb1) = 288 plf

Second opening: va2 = vb2 = H/(ha2+hb2) = 288 plf

6. Unit shear beside opening

V1 = (V/L)(L1+T1)/L1 = 337 plf

V2 = (V/L)(T2+L2+T3)/L2 = 388 plf

V3 = (V/L)(T4+L3)/L3 = 244 plf

Instructions & Definitions | **Design Example** | One Opening | Two Openings | Three Openings

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FTAO Calculator: One Opening

www.apawood.org/FTAO

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Force Transfer Around Openings Calculator

ONE OPENING

The force transfer around openings (FTAO) method of shear wall analysis is an approach that aims to reinforce the wall such that it performs as if there was no opening. This approach lends certain advantages over segmented shear walls: more versatility, because it allows for narrower wall segments while still meeting the height-to-width ratios and, often, fewer required hold-downs.

Project Information

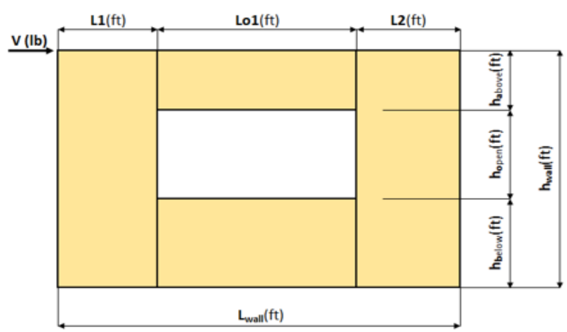
Code: **Date:**

Designer:

Client:

Project:

Wall Line:



Shear Wall Calculation Variables

			Opening 1		Wall Pier Aspect Ratio	Adj. Factor
V		ha1			P1=ho1/L1=	
L1		ho1			P2=ho1/L2=	
L2		hb1				
h_{wall}	0.00 ft	Lo1				
L_{wall}	0.00 ft					

1. Hold-down forces: H = Vh_{wall}/L_{wall}

2. Unit shear above + below opening

First opening: va1 = vb1 = H/(ha1+hb1) =

6. Unit shear beside opening

V1 = (V/L)(L1+T1)/L1 =

V2 = (V/L)(T2+L2)/L2 =

Check V1*L1+V2*L2=V?

Instructions & Definitions | Design Example | One Opening | Two Openings | Three Openings

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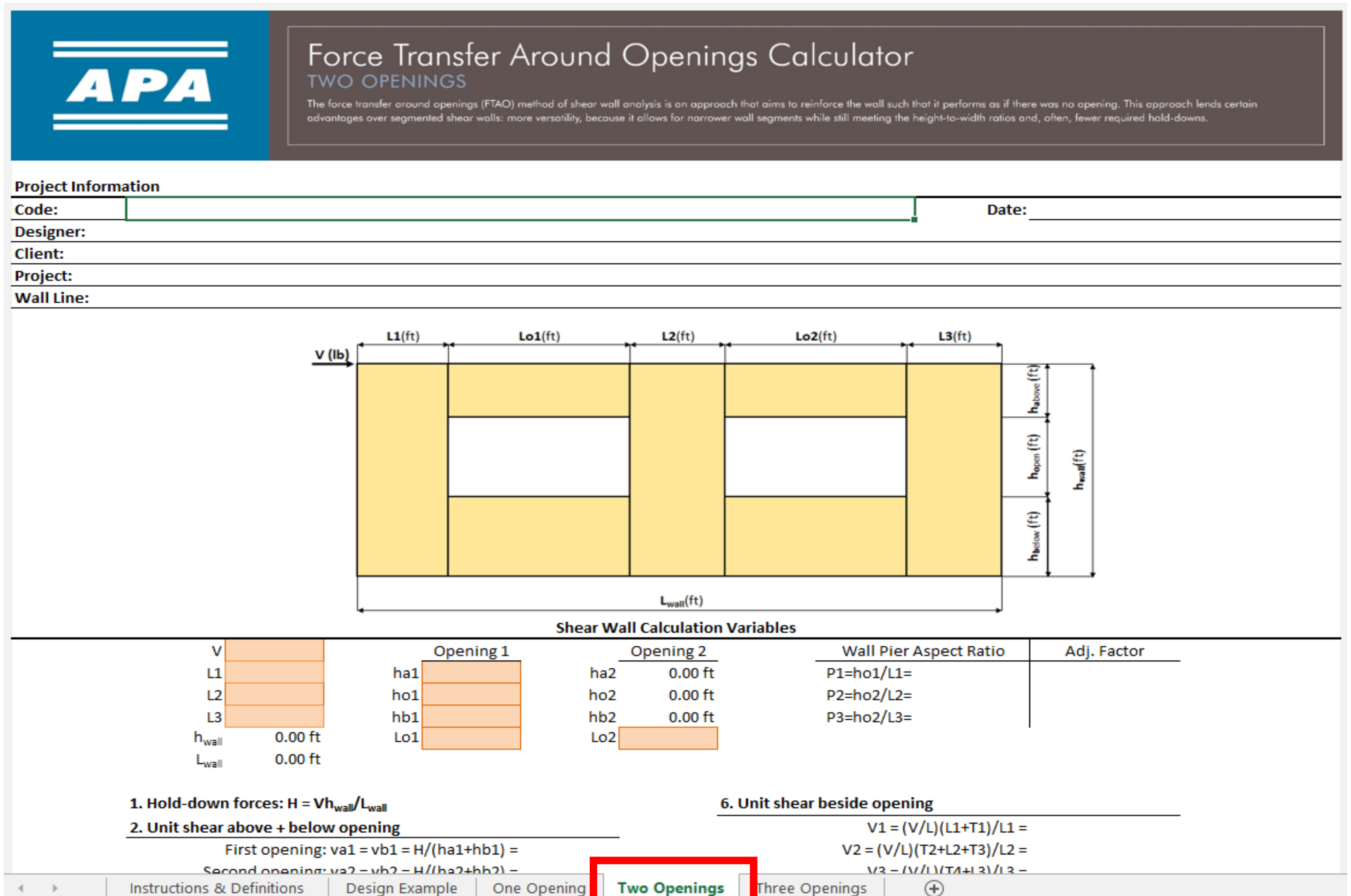
FTAO Calculator: Two Openings

www.apawood.org/FTAO



FTAO Calculator: Three Openings

www.apawood.org/FTAO

Force Transfer Around Openings Calculator

THREE OPENINGS

The force transfer around openings (FTAO) method of shear wall analysis is an approach that aims to reinforce the wall such that it performs as if there was no opening. This approach lends certain advantages over segmented shear walls: more versatility, because it allows for narrower wall segments while still meeting the height-to-width ratios and, often, fewer required hold-downs.

Project Information

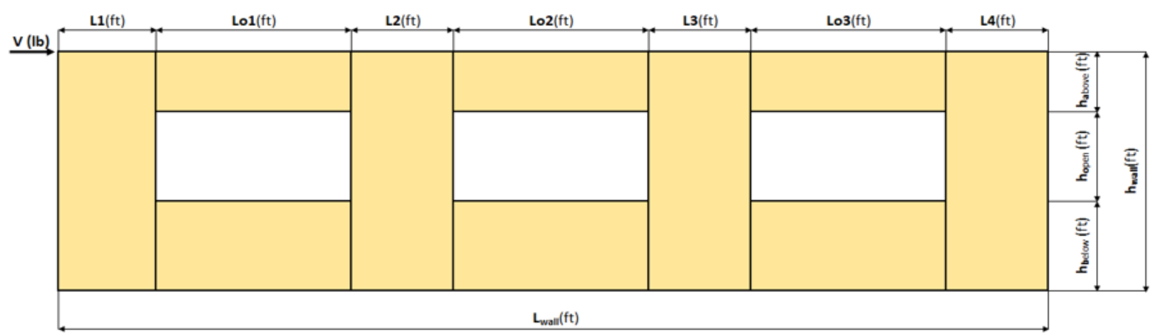
Code: **Date:**

Designer:

Client:

Project:

Wall Line:



Shear Wall Calculation Variables

			Opening 1		Opening 2		Opening 3	Wall Pier Aspect Ratio	Adj. Factor
V									
L1		ha1		ha2	0.00 ft	ha3	0.00 ft	P1=ho1/L1=	
L2		ho1		ho2	0.00 ft	ho3	0.00 ft	P2=ho2/L2=	
L3		hb1		hb2	0.00 ft	hb3	0.00 ft	P3=ho3/L3=	
L4		Lo1		Lo2		Lo3		P4=ho3/L4=	
h_{wall}	0.00 ft								
L_{wall}	0.00 ft								

1. Hold-down forces: $H = Vh_{wall}/L_{wall}$

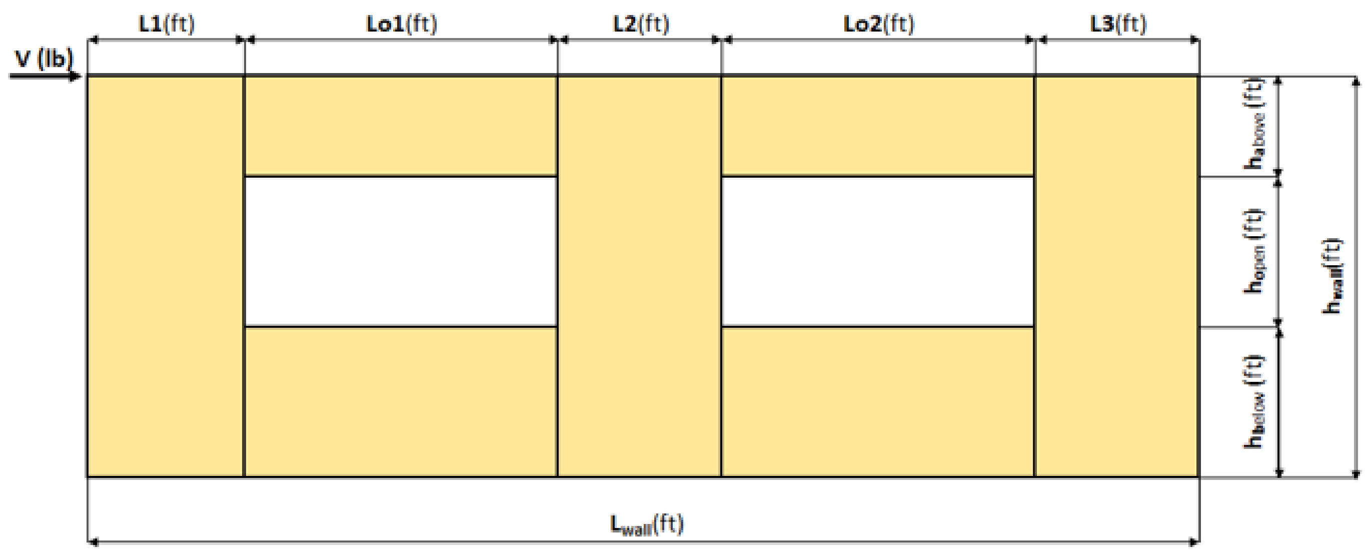
2. Unit shear above + below opening

6. Unit shear beside opening

V1 = (V/L)(L1+T1)/L1 =

Instructions & Definitions | Design Example | One Opening | Two Openings | **Three Openings**

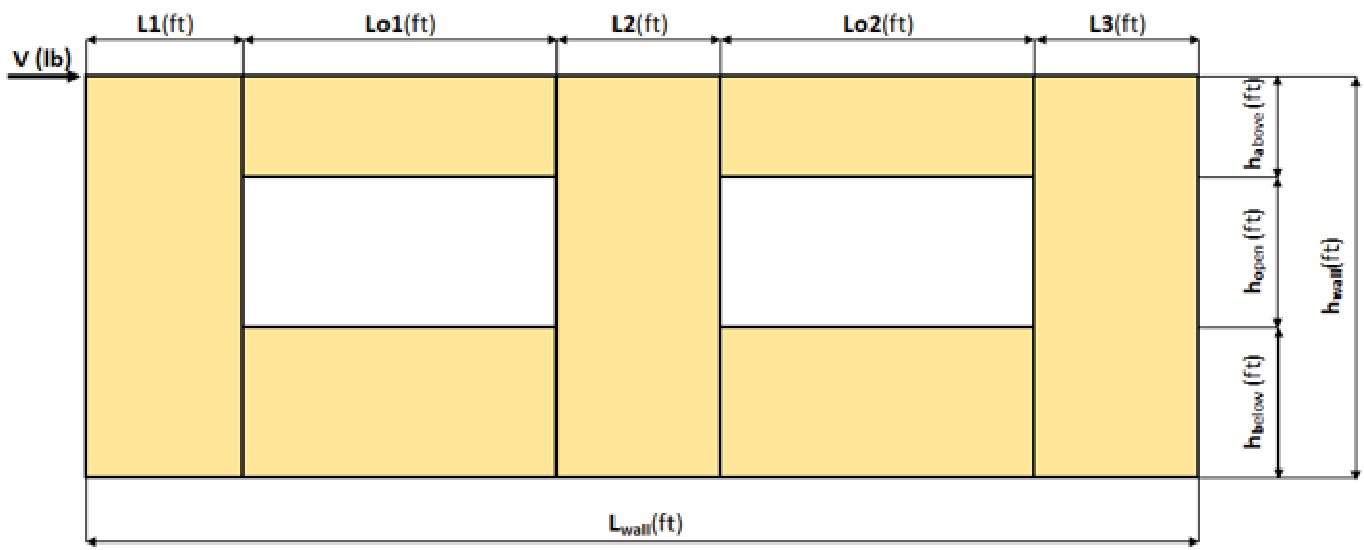
FTAO Calculator: Inputs



Shear Wall Calculation Variables

			Opening 1		Opening 2	Wall Pier Aspect Ratio		Adj. Factor
V	3750 lbf							
L1	4.00 ft	ha1	1.33 ft	ha2	1.33 ft	P1=ho1/L1=	0.67	N/A
L2	4.00 ft	ho1	2.67 ft	ho2	2.67 ft	P2=ho2/L2=	0.67	N/A
L3	3.50 ft	hb1	4.00 ft	hb2	4.00 ft	P3=ho2/L3=	0.76	N/A
h_{wall}	8.00 ft	Lo1	6.00 ft	Lo2	2.00 ft			
L_{wall}	19.50 ft							

FTAO Calculator: Inputs



Shear Wall Calculation Variables

			Opening 1		Opening 2	Wall Pier Aspect Ratio		Adj. Factor
V	3750 lbf							
L1	4.00 ft	ha1	1.33 ft	ha2	1.33 ft	P1=ho1/L1=	0.67	N/A
L2	4.00 ft	ho1	2.67 ft	ho2	2.67 ft	P2=ho2/L2=	0.67	N/A
L3	3.50 ft	hb1	4.00 ft	hb2	4.00 ft	P3=ho2/L3=	0.76	N/A
h_{wall}	8.00 ft	Lo1	6.00 ft	Lo2	2.00 ft			
L_{wall}	19.50 ft							

FTAO Calculator: Shear wall analysis

1. Hold-down forces: H = Vh$_{wall}$/L$_{wall}$ 1538 lbf

2. Unit shear above + below opening

First opening: va1 = vb1 = H/(ha1+hb1) =	288 plf
Second opening: va2 = vb2 = H/(ha2+hb2) =	288 plf

3. Total boundary force above + below openings

First opening: O1 = va1 x (Lo1) =	1731 lbf
Second opening: O2 = va2 x (Lo2) =	577 lbf

4. Corner forces

F1 = O1(L1)/(L1+L2) =	865 lbf
F2 = O1(L2)/(L1+L2) =	865 lbf
F3 = O2(L2)/(L2+L3) =	308 lbf
F4 = O2(L3)/(L2+L3) =	269 lbf

5. Tributary length of openings

T1 = (L1*Lo1)/(L1+L2) =	3.00 ft
T2 = (L2*Lo1)/(L1+L2) =	3.00 ft
T3 = (L2*Lo2)/(L2+L3) =	1.07 ft
T4 = (L3*Lo2)/(L2+L3) =	0.93 ft

6. Unit shear beside opening

V1 = (V/L)(L1+T1)/L1 =	337 plf	
V2 = (V/L)(T2+L2+T3)/L2 =	388 plf	
V3 = (V/L)(T4+L3)/L3 =	244 plf	
Check V1*L1+V2*L2+V3*L3=V?	3750 lbf	**OK**

7. Resistance to corner forces

R1 = V1*L1 =	1346 lbf
R2 = V2*L2 =	1551 lbf
R3 = V3*L3 =	853 lbf

8. Difference corner force + resistance

R1-F1 =	481 lbf
R2-F2-F3 =	378 lbf
R3-F4 =	583 lbf

9. Unit shear in corner zones

vc1 = (R1-F1)/L1 =	120 plf
vc2 = (R2-F2-F3)/L2 =	95 plf
vc3 = (R3-F4)/L3 =	167 plf

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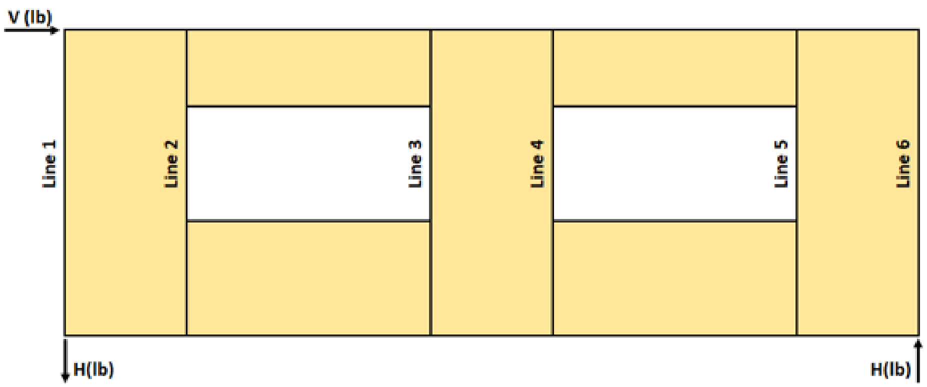
FTAO Calculator: Shear wall analysis



Check Summary of Shear Values for Two Openings

Line 1: vc1(ha1+hb1)+V1(ho1)=H?		641	897	1538 lbf
Line 2: va1(ha1+hb1)-vc1(ha1+hb1)-V1(ho1)=0?	1538	641	897	0
Line 3: vc2(ha1+hb1)+V2(ho1)-va1(ha1+hb1)=0?	504	1034	1538	0
Line 4: va2(ha2+hb2)-V2(ho2)-vc2(ha2+hb2)=0?	1538	1034	504	0
Line 5: va2(ha2+hb2)-vc3(ha2+hb2)-V3(ho2)=0?	1538	889	650	0
Line 6: vc3(ha2+hb2)+ V3(ho2) = H?		889	650	1538 lbf

Design Summary

Req. Sheathing Capacity	388 plf	**4-Term Deflection**	0.316 in.	**3-Term Deflection**	0.335 in.
Req. Strap Force	865 lbf	**4-Term Story Drift %**	0.013 %	**3-Term Story Drift %**	0.014 %
Req. HD Force (H)	1538 lbf		See Page 2		See Page 3

FTAO Calculator: Design Output

Design output:

- Required sheathing capacity
- Required strap force above and below openings
- Required hold-down force
- Maximum deflection

Design Summary

Req. Sheathing Capacity	388 plf	4-Term Deflection	0.316 in.	3-Term Deflection	0.335 in.
Req. Strap Force	865 lbf	4-Term Story Drift %	0.013 %	3-Term Story Drift %	0.014 %
Req. HD Force (H)	1538 lbf		See Page 2		See Page 3

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FTAO Calculator

Shear Wall Deflection Calculation Variables

Sheathing:		Wood End Post Values:				Nail Type:	8d common	(penny weight)	
OSB	Sheathing Material	Species:	Hem-Fir No.2						
7/16	Performance Category	E:	1.60E+06	(psi)			Pier 1	Pier 3	
APA Rated Sheathing	Grade		Qty	Stud Size		Nail Spacing:	4	4	(in.)
		Dimensions:	2	2x6		HD Capacity:	2145	2145	(lbf)
	Gt Override	A:	16.5	(in.^{2})		HD Deflection:	0.128	0.128	(in.)
	Ga Overide	A Override:		(in.^{2})					

Four-Term Equation Deflection Check

$$\Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75he_a + d_a\frac{h}{b} \qquad \text{(Equation 23-2)}$$

	Pier 1-L	Pier 1-R	Pier 2-L	Pier 2-R	Pier 3-L	Pier 3-R	
Sheathing:	7/16	7/16	7/16	7/16	7/16	7/16	
Nail:	8d common	8d common	8d common	8d common	8d common	8d common	
v_{asd}:	337	337	388	388	244	244	(plf)
$v_{strength}$:	481	481	554	554	348	348	(plf)
E:	1.60E+06	1.60E+06	1.60E+06	1.60E+06	1.60E+06	1.60E+06	(psi)
h:	8.00	4.00	4.00	4.00	4.00	8.00	(ft)
A:	16.5	16.5	16.5	16.5	16.5	16.5	(in.^{2})
Gt:	83,500	83,500	83,500	83,500	83,500	83,500	(lbf/in.)
Nail Spacing:	4	4	4	4	4	4	(in.)
Vn:	160	160	185	185	116	116	(plf)
e:	0.0172	0.0172	0.0264	0.0264	0.0065	0.0065	(in.)
b:	4.00	4.00	4.00	4.00	3.50	3.50	(ft)
HD Capacity:	2145	2145	2145	2145	2145	2145	(lbf)
HD Defl:	0.128	0.128	0.128	0.128	0.128	0.128	(in.)

FTAO Calculator

Three-Term Equation Deflection Check

$$\delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{1000G_a} + \frac{h\Delta_a}{b} \qquad (4.3\text{-}1)$$

	Pier 1-L	Pier 1-R	Pier 2-L	Pier 2-R	Pier 3-L	Pier 3-R	
Sheathing:	7/16	7/16	7/16	7/16	7/16	7/16	
Nail:	8d common	8d common	8d common	8d common	8d common	8d common	
v_{asd}:	337	337	388	388	244	244	(plf)
$v_{strength}$:	481	481	554	554	348	348	(plf)
E:	1.60E+06	1.60E+06	1.60E+06	1.60E+06	1.60E+06	1.60E+06	(psi)
h:	8.00	4.00	4.00	4.00	4.00	8.00	(ft)
A:	16.5	16.5	16.5	16.5	16.5	16.5	($in.^2$)
Ga:	22.0	22.0	22.0	22.0	22.0	22.0	(kips/in.)
b:	4.00	4.00	4.00	4.00	3.50	3.50	(ft)
HD Capacity:	2145	2145	2145	2145	2145	2145	(lbf)
HD Defl:	0.128	0.128	0.128	0.128	0.128	0.128	(in.)

Check Total Deflection of Wall System

Pier 1 (left)			Pier 1 (right)		
Term 1 Bending	Term 2 Shear	Term 3 Fastener	Term 1 Bending	Term 2 Shear	Term 3 Fastener
0.019	0.175	0.459	0.002	0.087	0.115
	Sum	0.653		Sum	0.205
Pier 2 (left)			**Pier 2 (right)**		
Term 1 Bending	Term 2 Shear	Term 3 Fastener	Term 1 Bending	Term 2 Shear	Term 3 Fastener
0.003	0.101	0.132	0.003	0.101	0.132
	Sum	0.236		Sum	0.236

Total Defl.	
0.335	(in.)
0.0140	%drift

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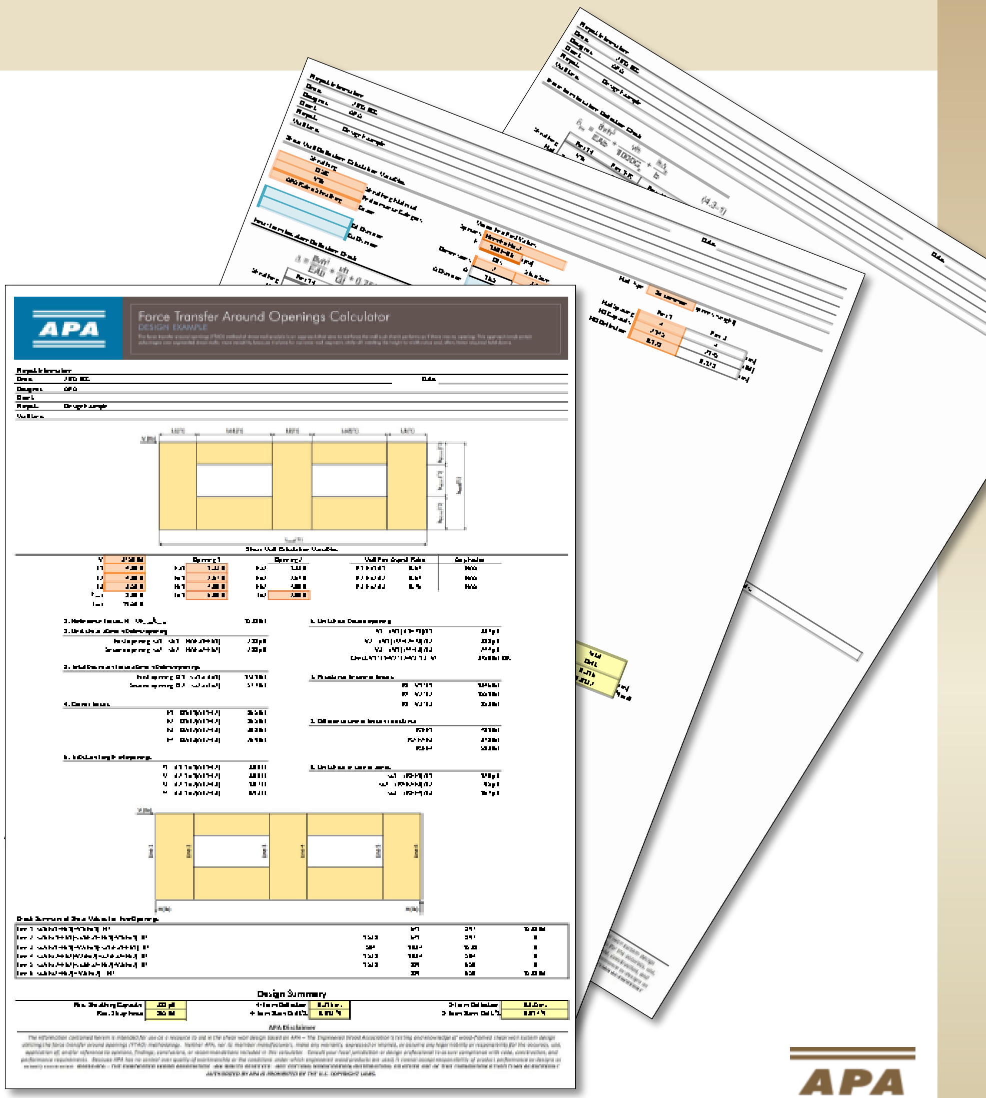
FTAO Calculator: Final Output

Final Design Output

- Summary of input parameters
- FTAO shear wall analysis
- Summary of final design requirements
- Total calculated deflection
- Three-page shear wall design to include in calculation package
    - Print directly from Excel
    - Save as PDF



Benefits of FTAO with Continuous Wood Structural Panels

For the Structural Engineer…

- **Straightforward rational analysis**
- **Easy to program: Excel, web based application, or other**
- **Design check = confidence in calculations**

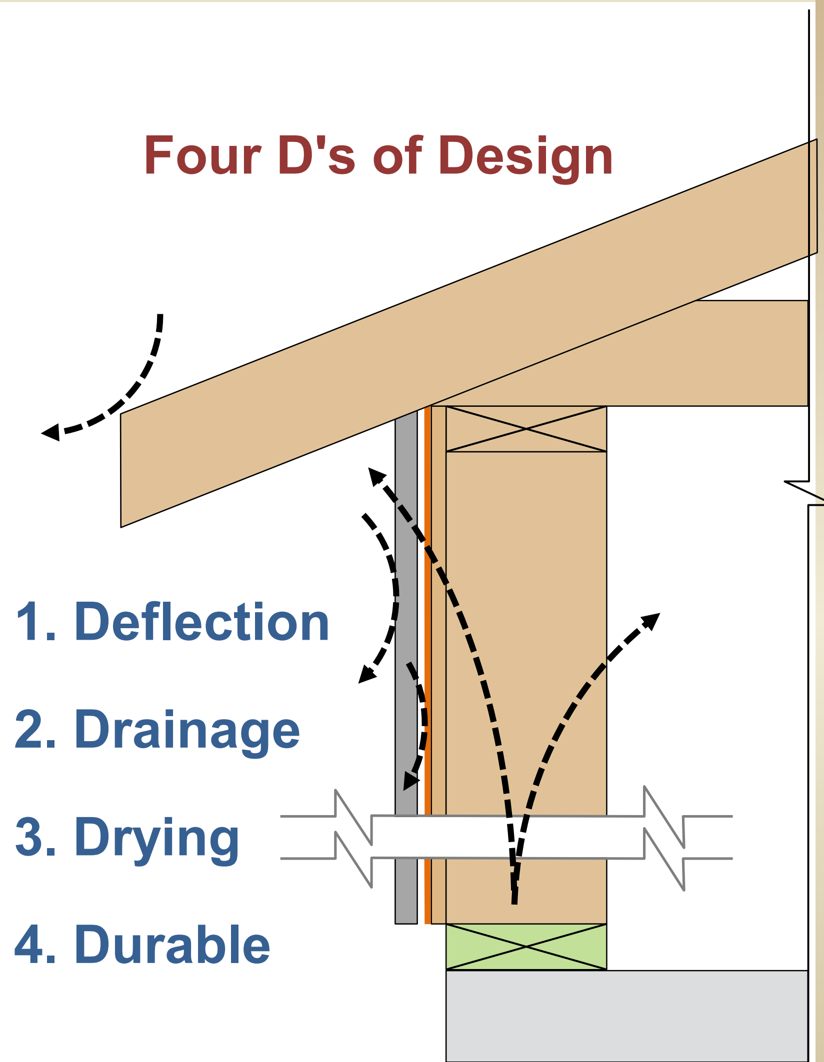
CHECK				
Line 1: va1(ha+hb)+V1(ho)=H?	641	897	1538	
Line 2: va(ha+hb)-va1 (ha+hb)-V1(ho)=0?	1538	641	897	0
Line 3: va2(ha+hb)+V2(ho)-va(ha+hb)=0?	504	1034	1538	0
Line 4 = Line 3				
Line 5: va(ha+hb)-va3 (ha+hb)-V3(ho)=0?	1538	889	650	0
Line 6: va3(ha+hb)+V3(ho)=H?	889	650	1538	

Benefits of FTAO with Continuous WSPs

Architectual flexibility

- Definition of aspect ratio
- Building envelope
  - Uninterrupted drainage plane
  - Minimize water intrusion

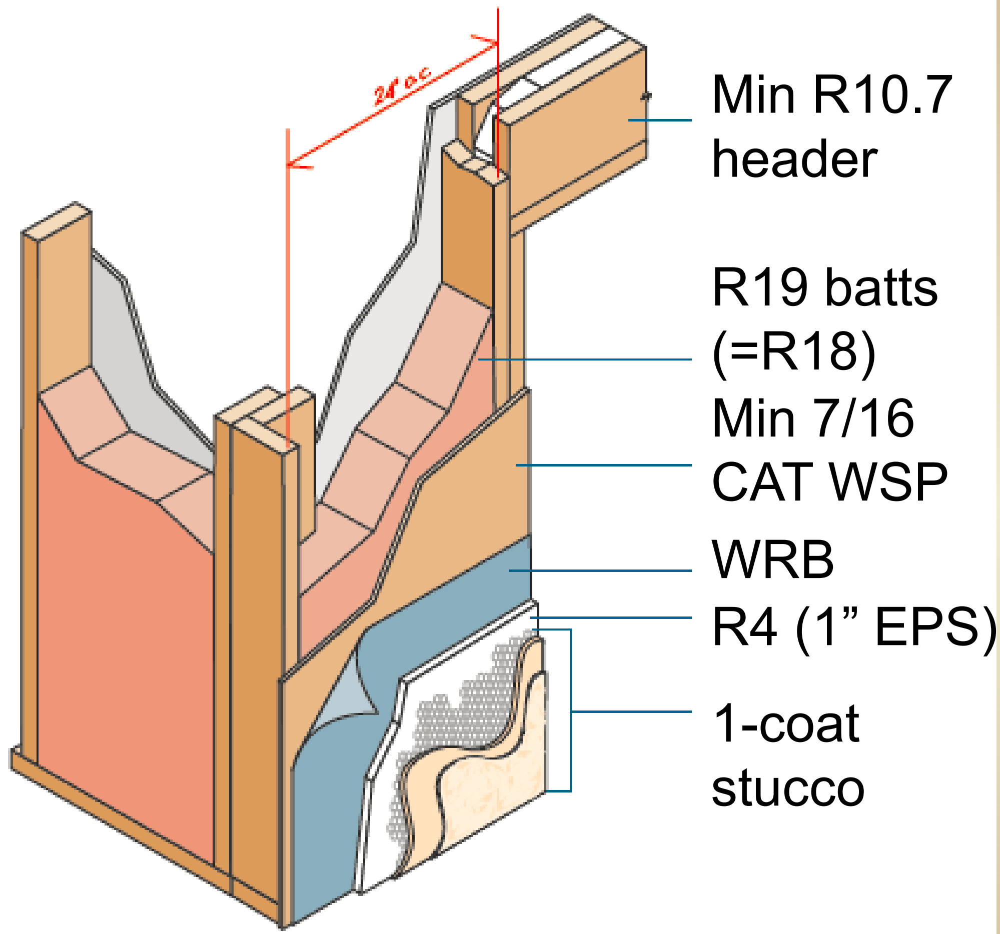
Four D's of Design



Benefits of FTAO with Continuous WSPs

Structural Systems that Enhance Energy Efficiency

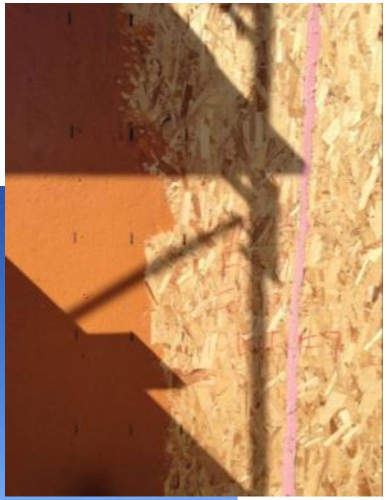
- **High Performance Wall Systems**
  - **2x6 Advanced Framing**
  - **Insulated headers and corners**



Benefits of FTAO with Continuous WSPs

Air Infiltration = Energy Loss

- Air barrier should be continuous
- Joints need to be sealed (i.e. blocked panel edges)
- Need water resistive barrier



Benefits of FTAO with Continuous WSPs

Value proposition

- Reduction of more costly components
- Continuous nail base + stiffer wall = fewer callbacks due to:
  - Stucco cracking, water intrusion, wall buckling

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Conclusions

www.apawood.org/FTAO

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Force Transfer Around Openings (FTAO)

VERSATILE SHEAR WALL ANALYSIS METHOD LENDS GREATER DESIGN FLEXIBILITY

Wood structural panel sheathed shear walls and diaphragms are the primary lateral-load-resisting elements in wood-frame construction. As wood-frame construction is continuously evolving, designers in many parts of the U.S. are optimizing design solutions that require the understanding of force transfer between elements in the lateral load-resisting system.

The force transfer around openings (FTAO) method of shear wall analysis offers some advantages compared to other methods:

- **More versatility**, because the FTAO method allows for the use of narrower wall segments while meeting required height-to-width ratios, and
- A high likelihood that **fewer hold-downs** will be required.

Technical Note: Design for Force Transfer Around Openings

This technical note presents a rational analysis for applying FTAO to walls with asymmetric piers and walls with multiple openings. It is based upon APA modeling and testing and uses methodology that assists the design professional in solving for the required sheathing, nailing, hold-downs, straps, and maximum deflection.

DOWNLOAD

APA Force Transfer Around Openings Calculator

This calculator is an Excel-based tool for professional designers that uses FTAO methodology to calculate maximum hold-down force for uplift resistance, the required horizontal strap force for the tension straps above and below openings, the maximum shear force to determine sheathing attachment, and the maximum deflection of the wall

Webinar:
Resolving Wood Shear Wall Design Puzzles with Force Transfer Around Openings, DES415, AWC

Provides an overview of the force transfer around openings (FTAO) shear wall design approach, recent research in this area, and a side-by-side comparison of design results between segmented, perforated, and FTAO design methods. AIA, ICC, and NCSEA credits available. Presented by Jared Hensley, PE, APA Engineered Wood Specialist.

LEARN MORE

Questions?


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Advancements in Force Transfer Around Openings for Wood Framed Shear Walls