APA

Advancements in Force Transfer Around Openings for Wood Framed Shear Walls

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

Course Description

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.

Test results from (8' x 12') full-scale wall configurations, in conjunction with the analytical results from a computer model developed by UBC, were used to develop and refine rational design methodologies in accordance with the International Building Code (IBC).

This presentation provides an update of that research with a focus on asymmetric piers and multiple openings. Rational design methodologies in accordance with the IBC (and California Building Code) will be shared.

Learning Objectives

1. Investigate past and current methods for determining force transfer around openings for wood shear walls.
2. 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.
3. Assess new design methodologies for accurately estimating the forces around multiple openings with asymmetric piers.
4. Estimate the deflections for shear walls designed using the force transfer around openings design method.

Agenda

Shear Wall Design Challenges

History of FTAO Research at APA

Advancements in FTAO

- **Asymmetric Pier Widths**
- **Multiple Openings**
- **C-shaped Panels**
- **Deflection Calculations**
- **Conceptual Keys**
- **Benefits**

Shear Wall Design Challenges

Shear Wall Design Challenges (SDPWS 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

Force Transfer

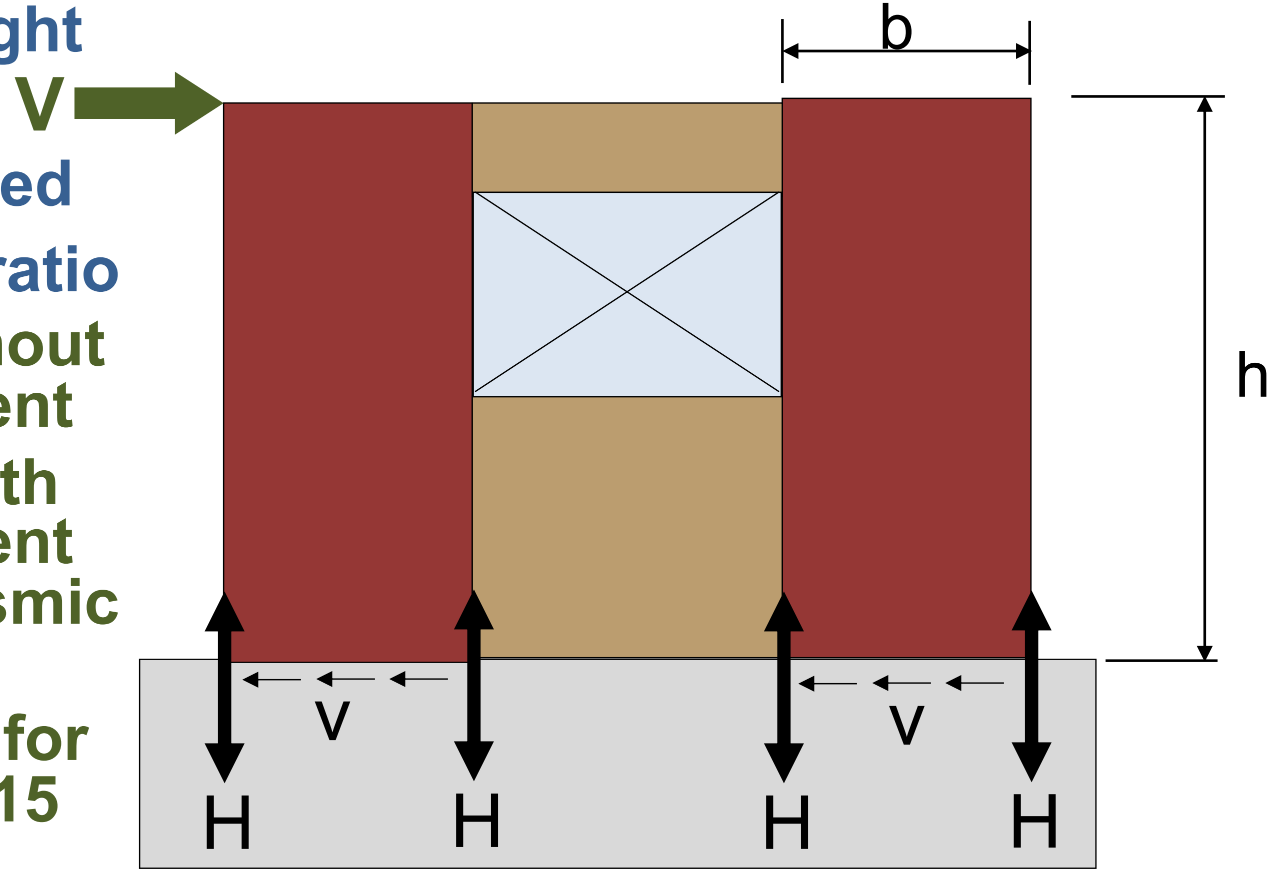
1. Code does not provide guidance for this method
2. Different approaches using rational analysis could be used

Perforated

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

Segmented Wood Shear Walls (SDPWS-08/15 Section 4.3.5.1)

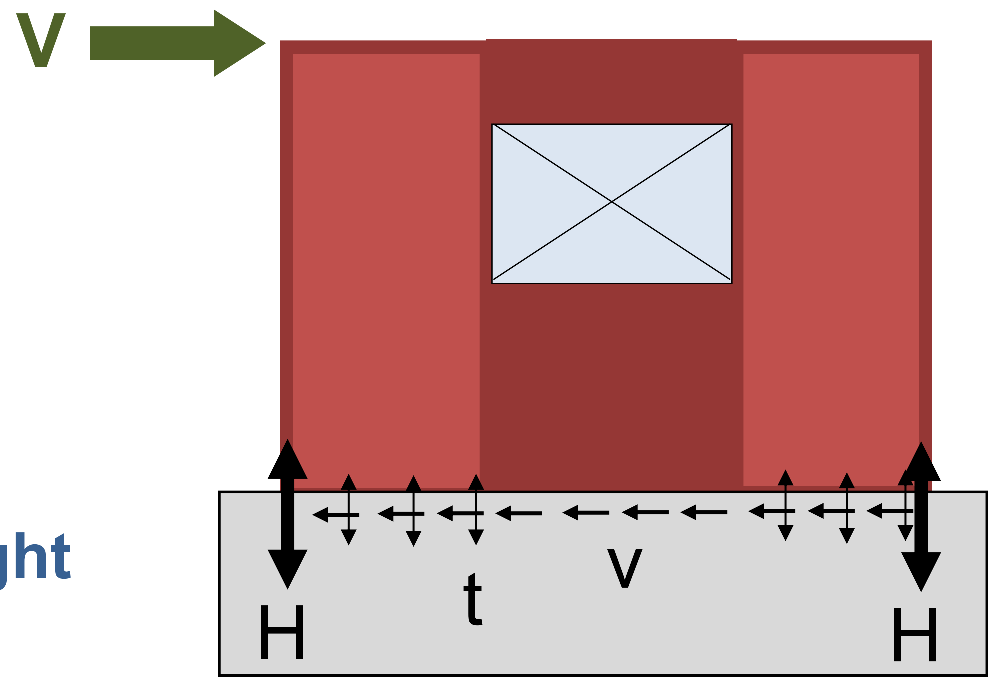
- Only full height segments are considered
- Max aspect ratio
  - * 2:1 – without adjustment
  - * 3.5:1 – with adjustment high seismic only
  - * Changes for SDPWS-15



Aspect ratio $h:b_s$ as shown in figure

Perforated Shear Wall (SDPWS-08/15 Section 4.3.5.3)

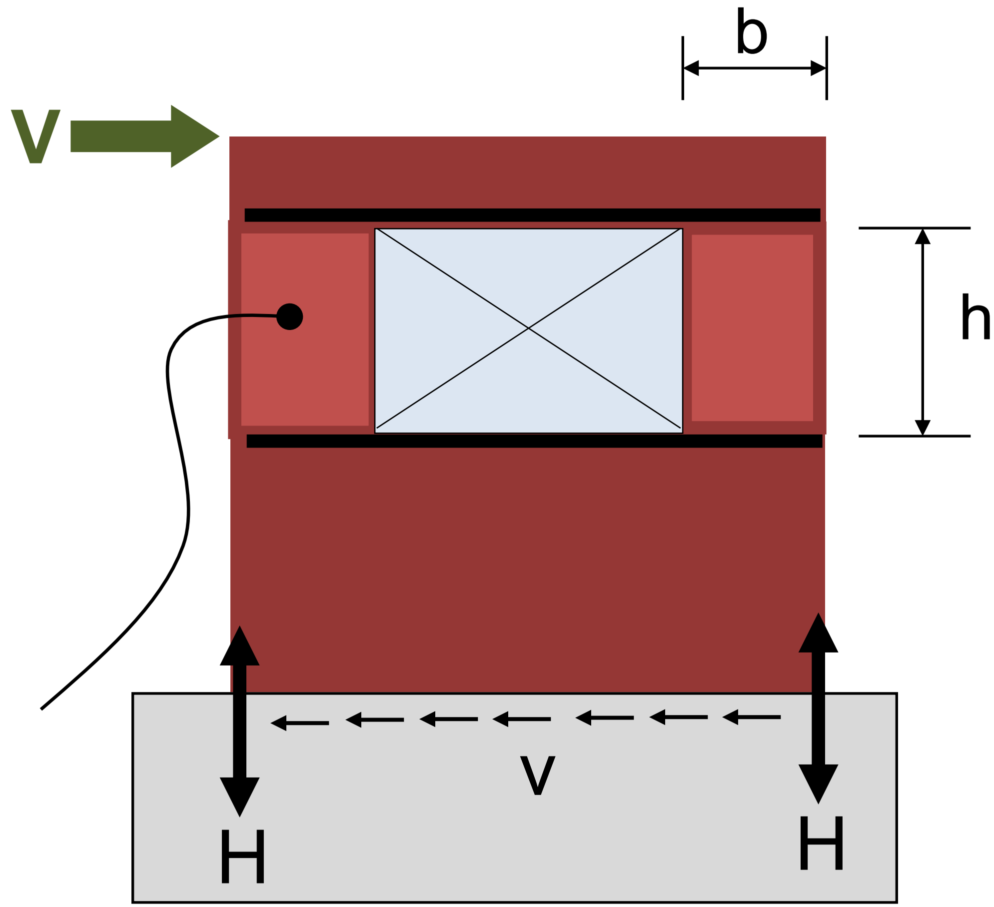
- Openings accounted for by empirical adjustment factor
- Hold-downs only at ends
- Uplift between hold downs, t, at full height segments is also required



Aspect ratio applies to full height segment (dotted)

FTAO
(SDPWS-08/15 Section 4.3.5.2)

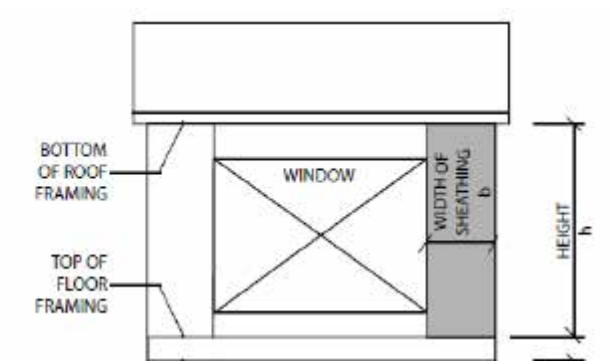
- Openings accounted for by strapping or framing
  - "based on a rational analysis"
- Hold-downs only at ends
- H/w ratio defined by wall pier



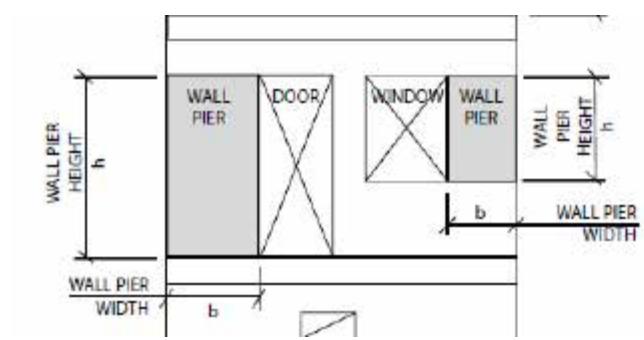
Aspect ratio h:b as shown in figure

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
- Aspect Ratio Factor (WSP) = 1.25-0.125h/bs
  - Formerly applied only to high seismic



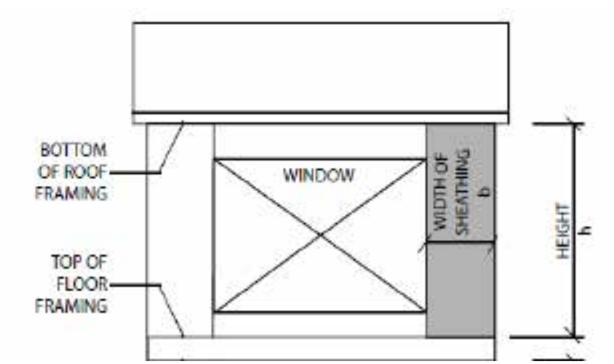
Excerpt Fig 4D
h:w ratio Segmented



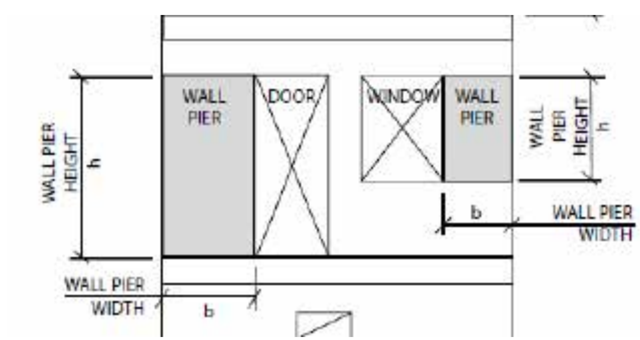
Excerpt Fig. 4E
h:w ratio FTAO

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

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:

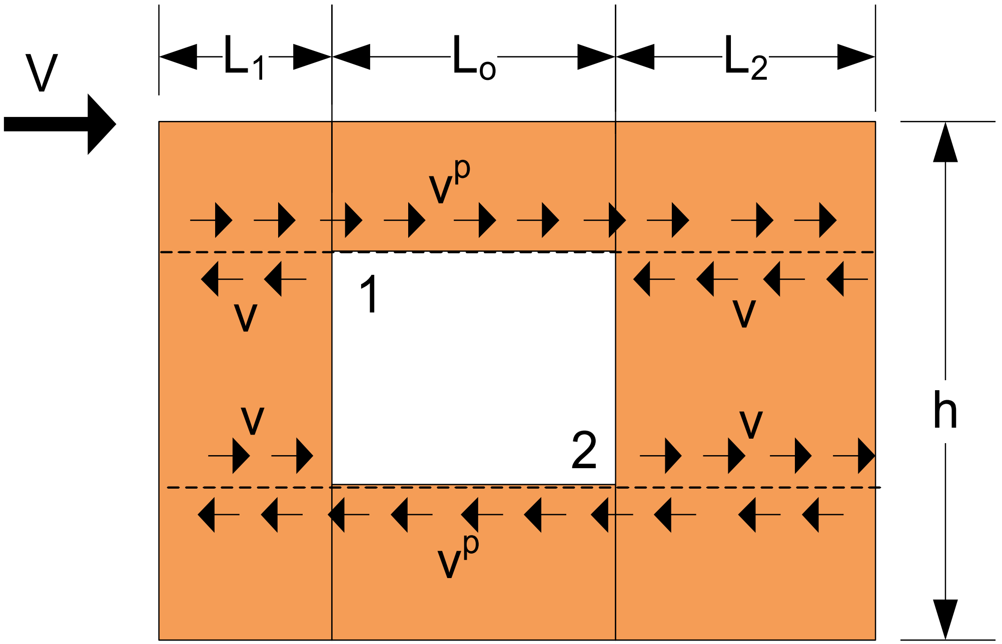
- Support design methodologies in estimating the forces around the openings
- Develop rational design methodologies for adoption in the building codes and supporting standards
- Create new tools/methodology for designers to facilitate use of FTAO

Different Techniques for FTAO

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

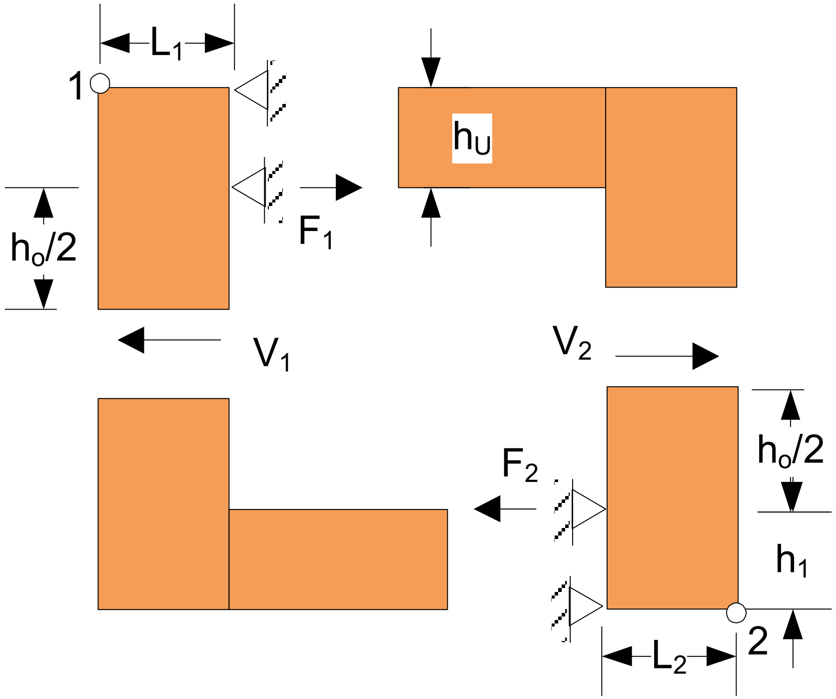
Different Techniques for FTAO

- 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



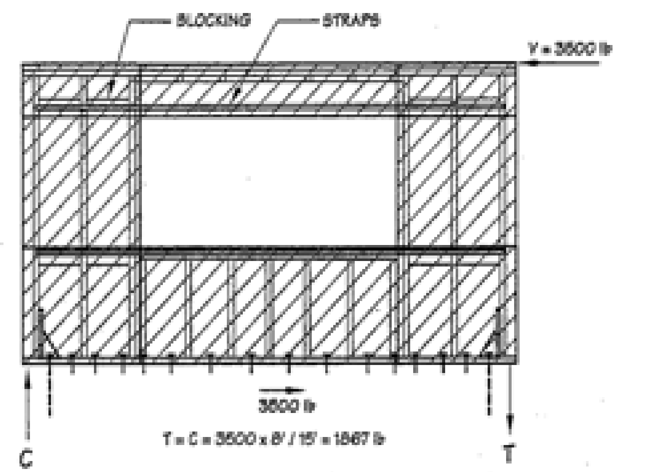
Different Techniques for FTAO

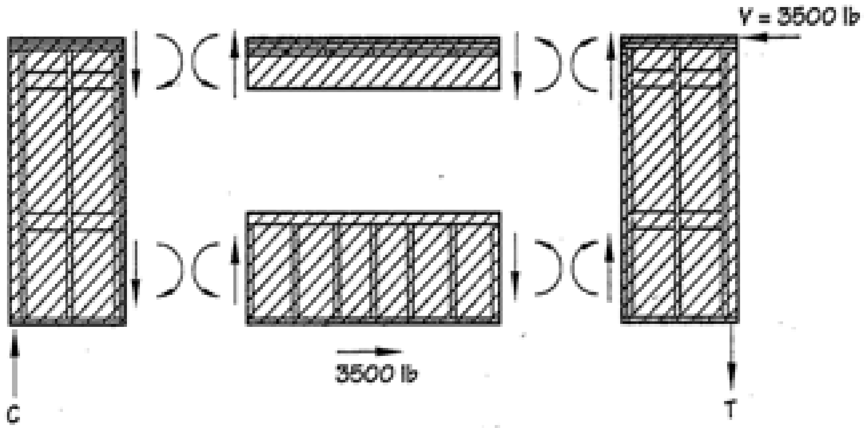
- Cantilever Beam Analogy
  - Forces are treated as moment couples
  - Segmented panels are piers at sides of openings
  - Strap forces are a function of height above and below opening and pier widths

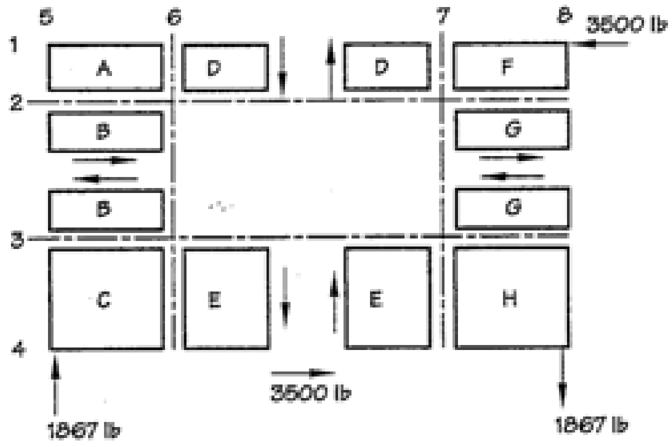


Different Techniques for FTAO

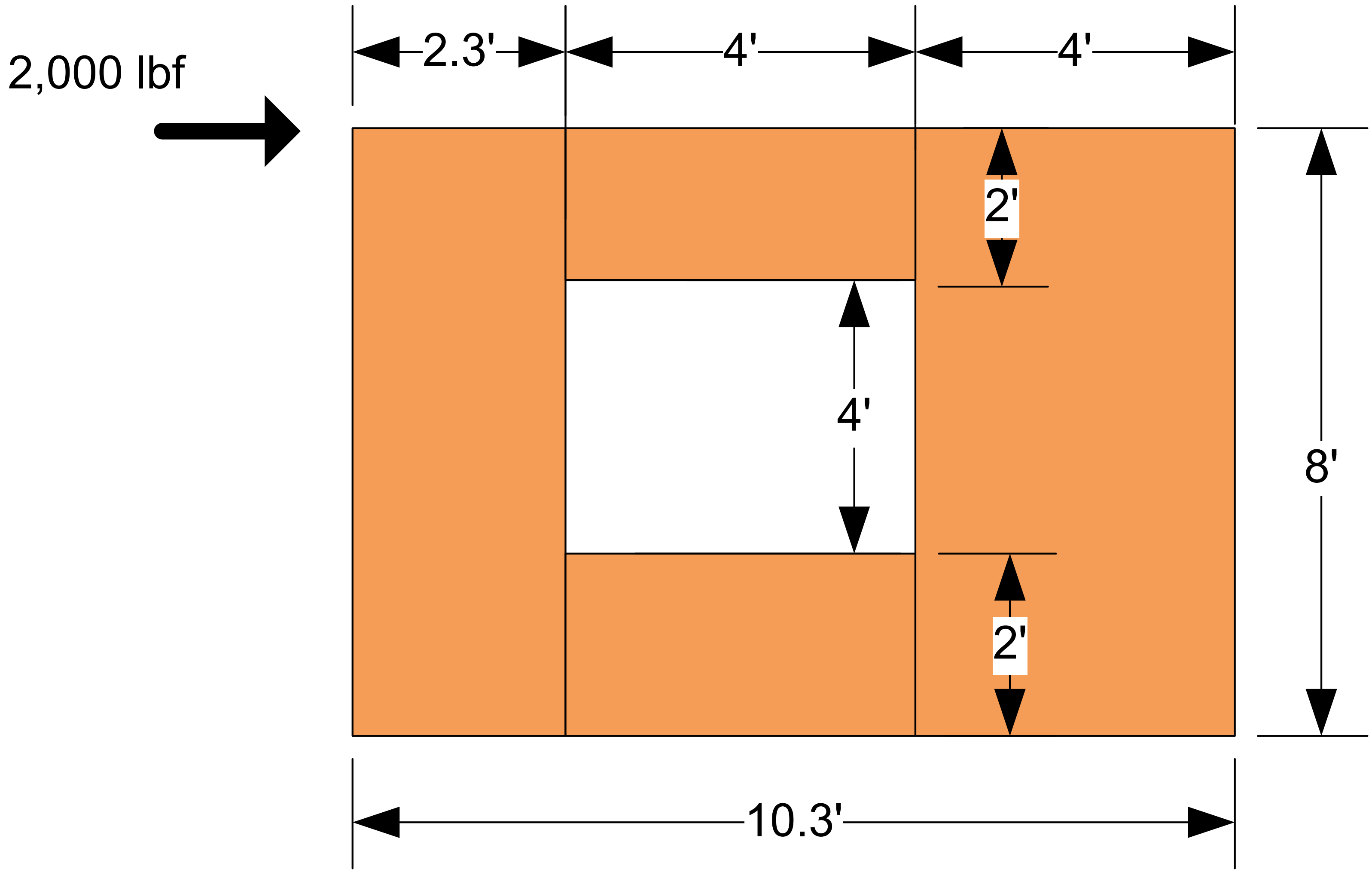
- Diekmann
  - Assumes wall behaves as monolith
  - Internal forces resolved via principles of mechanics







Design Examples



Design Example Summary

Drag Strut Analogy

- F_1 = 284 lbf
- F_2 = 493 lbf

Cantilever Beam Analogy

- F_1 = 1,460 lbf
- F_2 = 2,540 lbf

Diekmann Method

- F_1 = 567 lbf
- F_2 = 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.

SEAOC/Thompson Method

- 2015 IBC SEAOC Structural/Seismic Design Manual, Volume 2: Building Design Examples for Light-frame, Tilt-up Masonry www.iccsafe.org. Structural Engineers Association of California, Sacramento, CA

Test Data

Test Plan

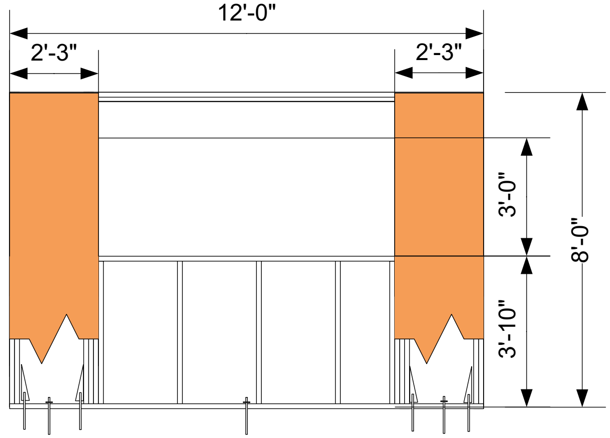
- 12 wall configurations tested (with and without FTAO applied)
- Wall nailing; 10d commons (0.148” x 3”) at 2” o.c.
- Sheathing; 15/32 Perf Cat oriented strand board (OSB) APA Structural I
- All walls were 12 feet long and 8 feet tall
- Cyclic loading protocol following ASTM E2126, Method C, CUREE Basic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

Test Plan

Wall1

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

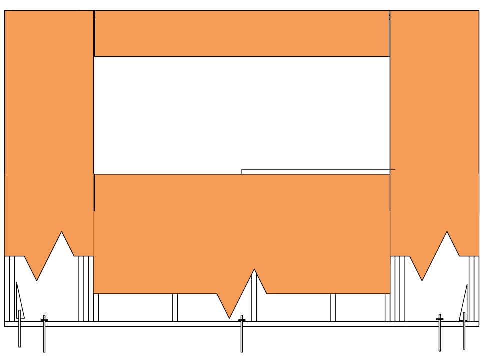
Segmented



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.

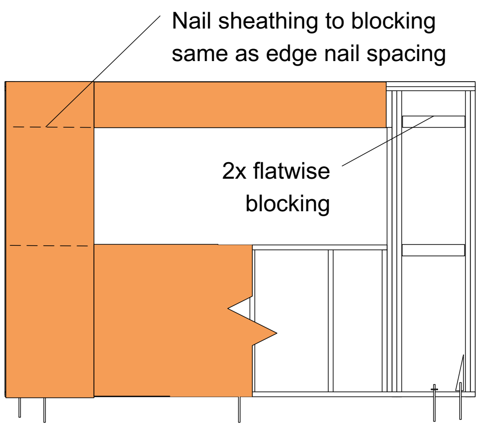
Perforated



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

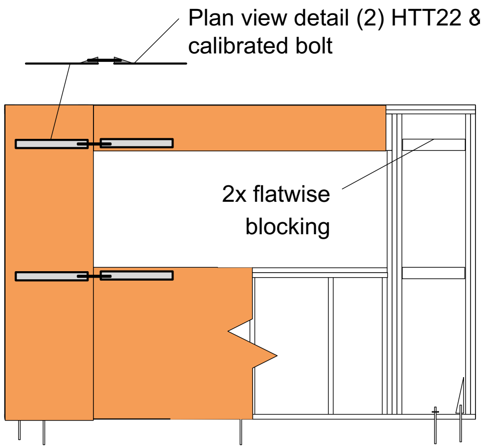


Wall 4

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

FTAO

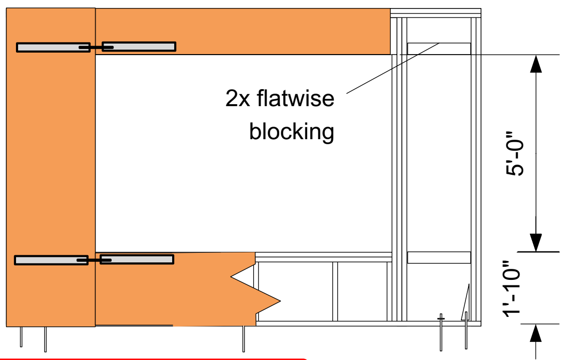


Test Plan

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

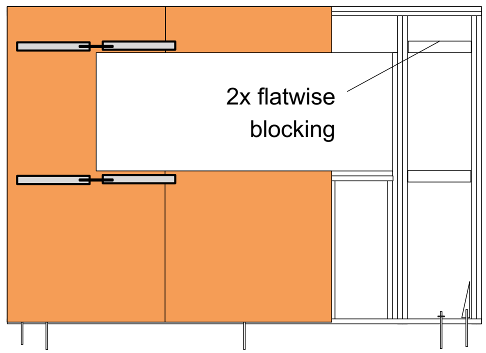


FTAO with bigger opening

Wall 6

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

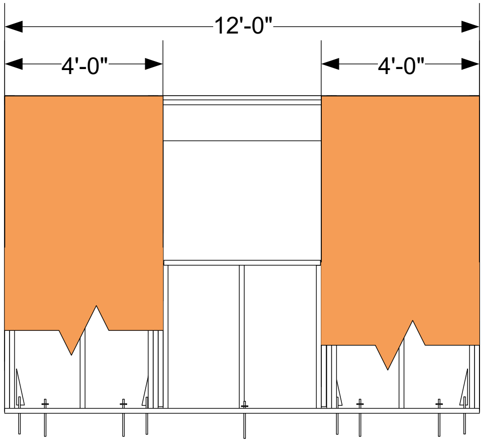
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



FTAO with C-shaped panel

Wall 7

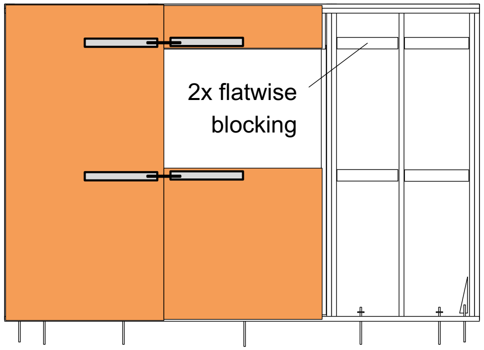
Objective:
Est. baseline case for 2:1 segmented wall



Wall 8

Objective:
Compare FTAO to Wall 7

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

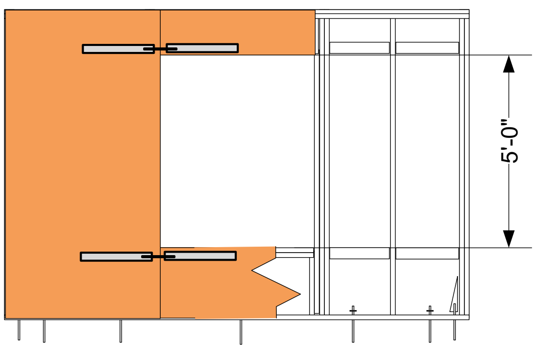


Test Plan

Wall 9

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

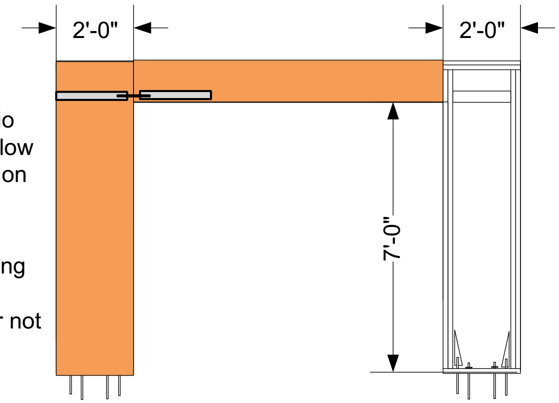
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 10

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

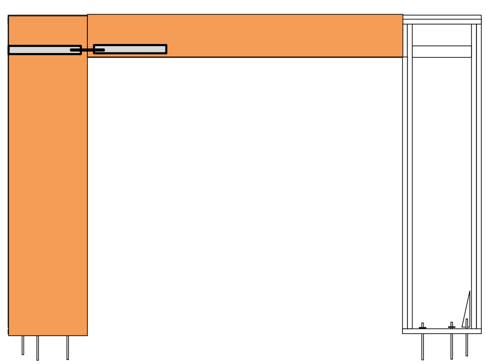
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 11

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

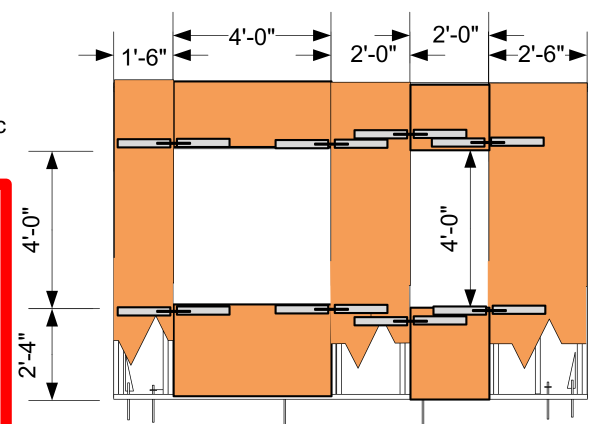
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



Wall 12

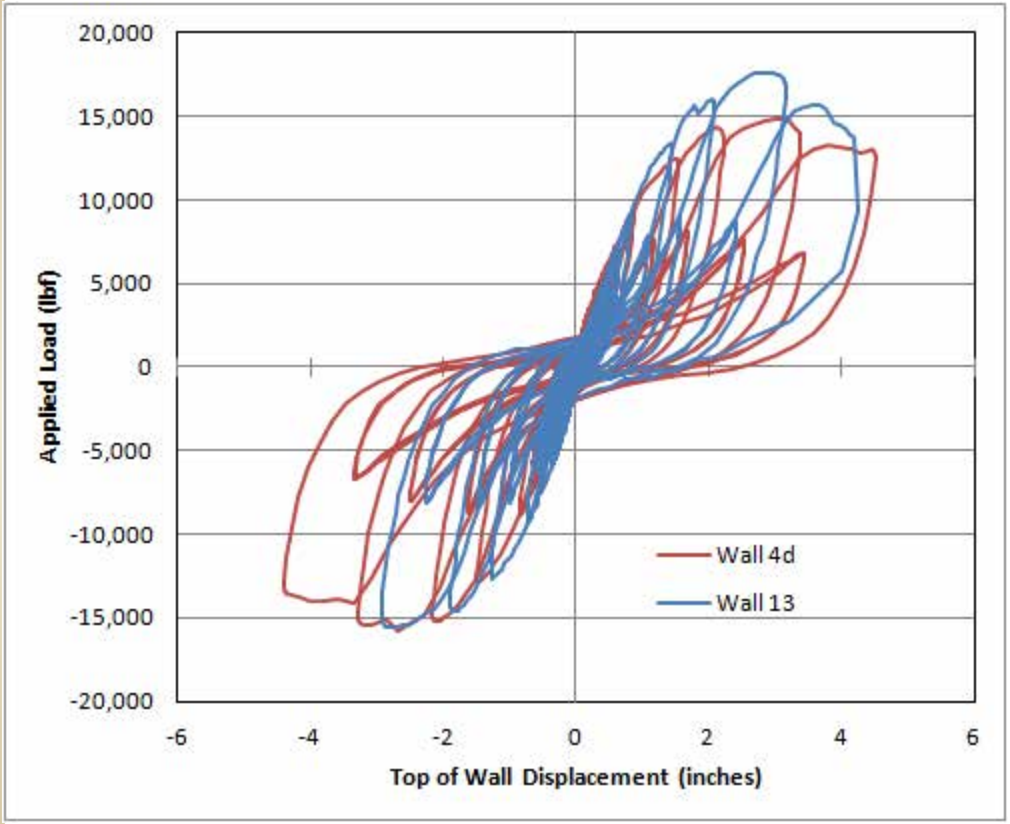
Objective:
FTAO for asymmetric multiple pier wall.

FTAO with multiple openings and asymmetric piers



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

Test Data

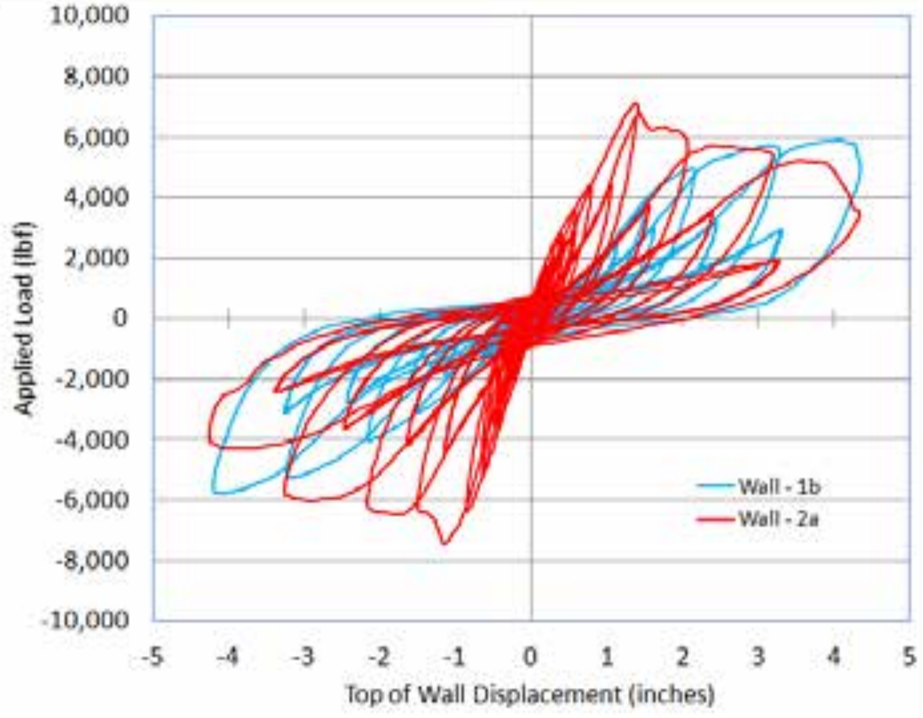
Measured vs Predicted Strap Forces

Forces underestimated Forces overestimated by 300%

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

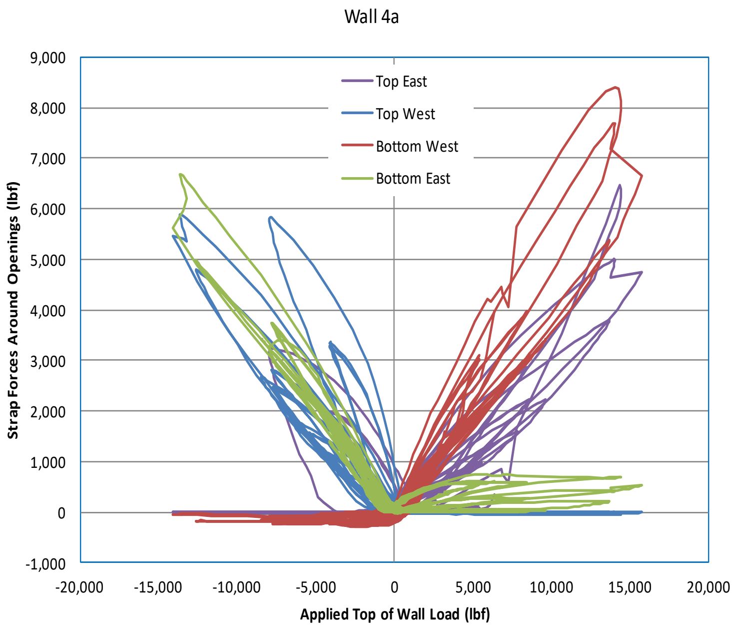
- The response curves are representative for wall 1 & 2
- Compares segmented piers vs. sheathed with no straps
- Observe the increased stiffness of perforated shear (Wall 2) vs. the segmented shear (Wall 1)

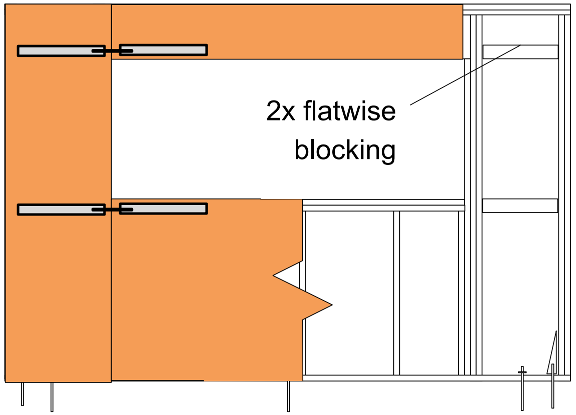


Testing Observation

Wall 4

- Narrow piers
- Deep sill

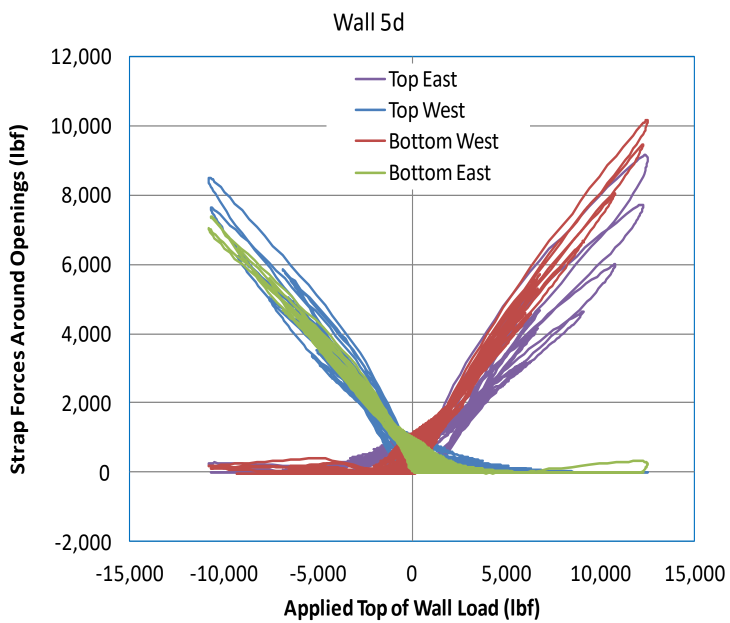


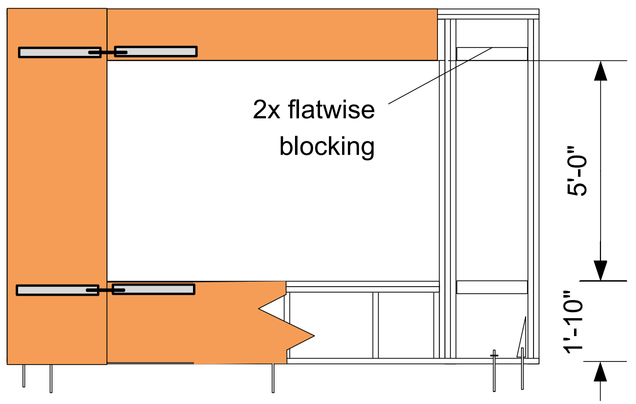


Testing Observation

Wall 5

- Increased opening from Wall 4
- Shallow sill

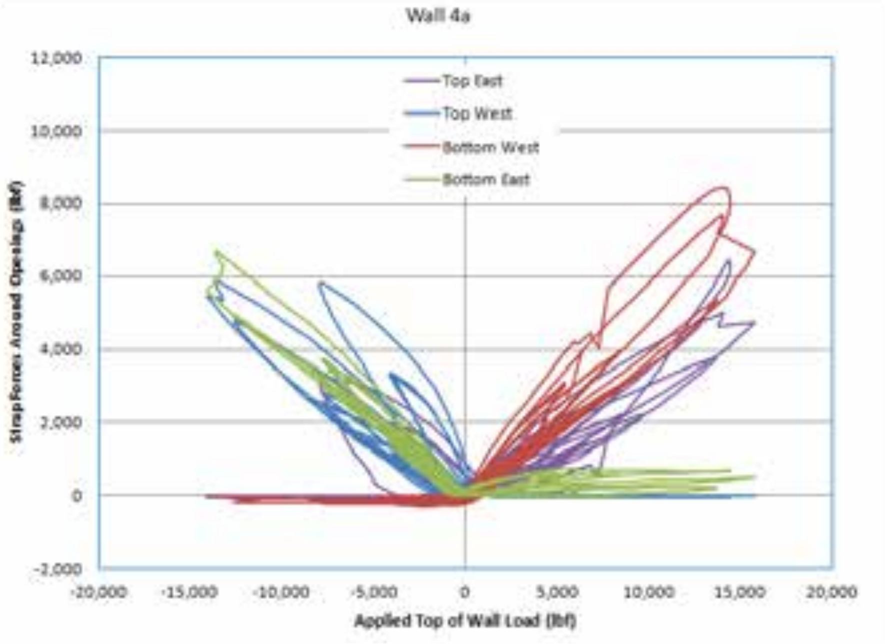


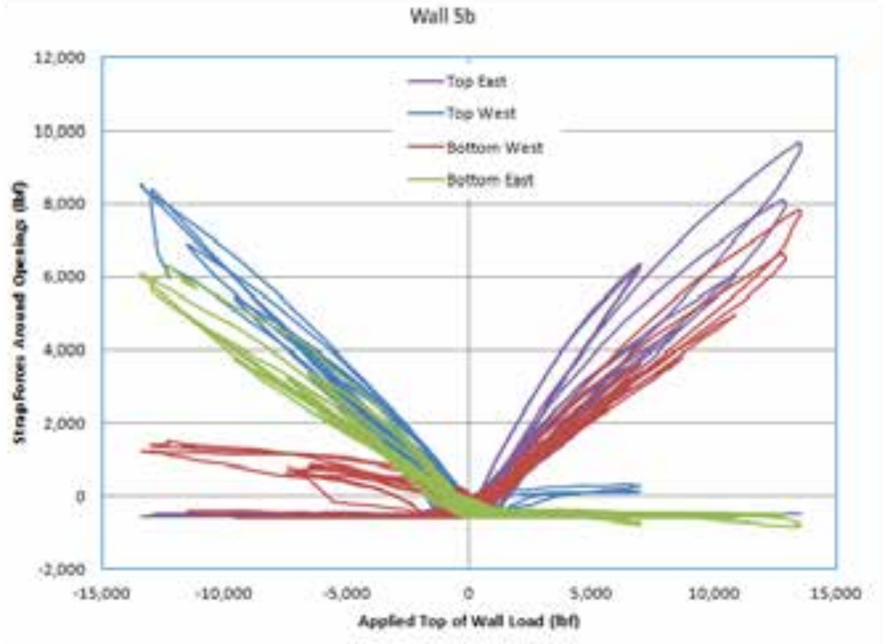


Local Response

Comparison of opening size vs. strap forces

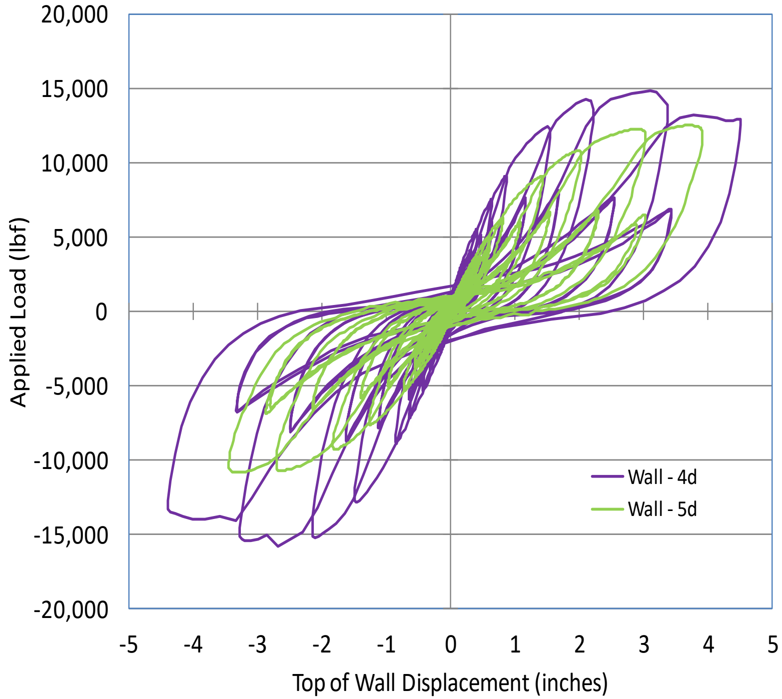
- Compared Wall 4 to 5





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



Conclusions

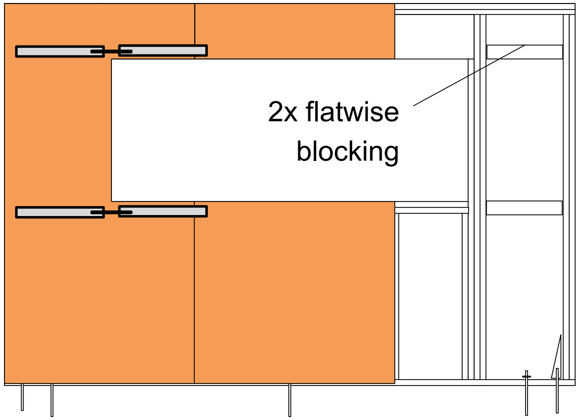
- 12 assemblies tested, examining the three approaches to designing and detailing walls with openings
  - Segmented
  - Perforated Shear Wall
  - Force Transfer Around Openings
- Walls detailed for FTAO resulted in better global response

Conclusions

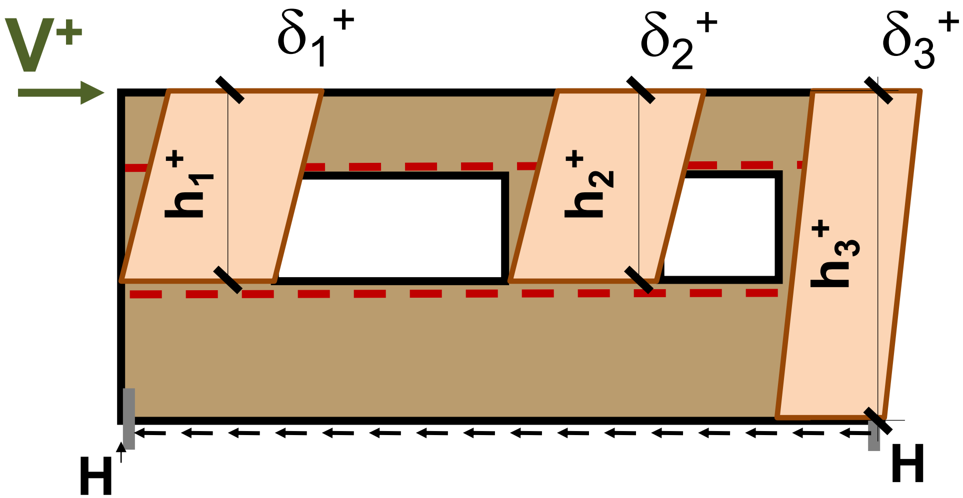
- Comparison of analytical methods with tested values for walls detailed as FTAO
  - The drag strut technique was consistently un-conservative
  - The cantilever beam technique was consistently ultra-conservative
  - SEAOC/Thompson provides similar results as Diekmann
  - SEAOC/Thompson & Diekmann techniques 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 IRC wall bracing

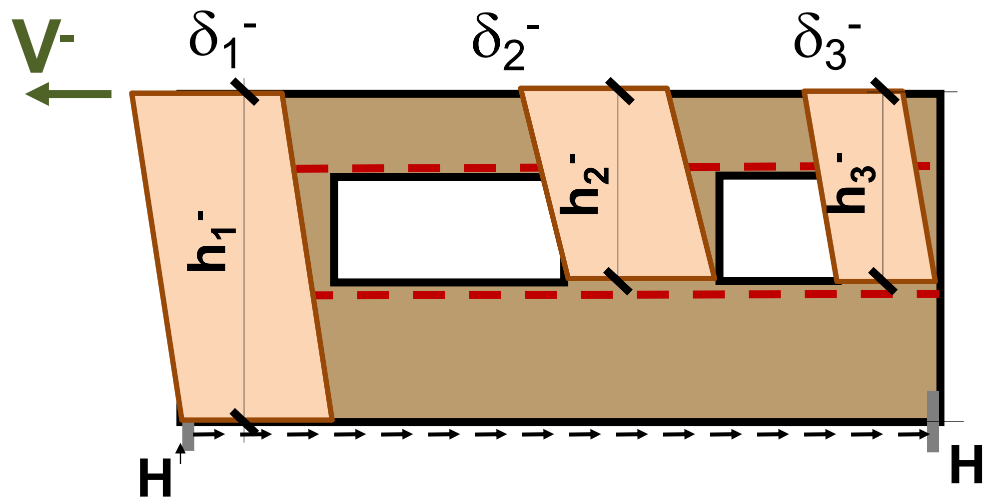
C-shaped Panels

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



Deflection Calculations - Concept

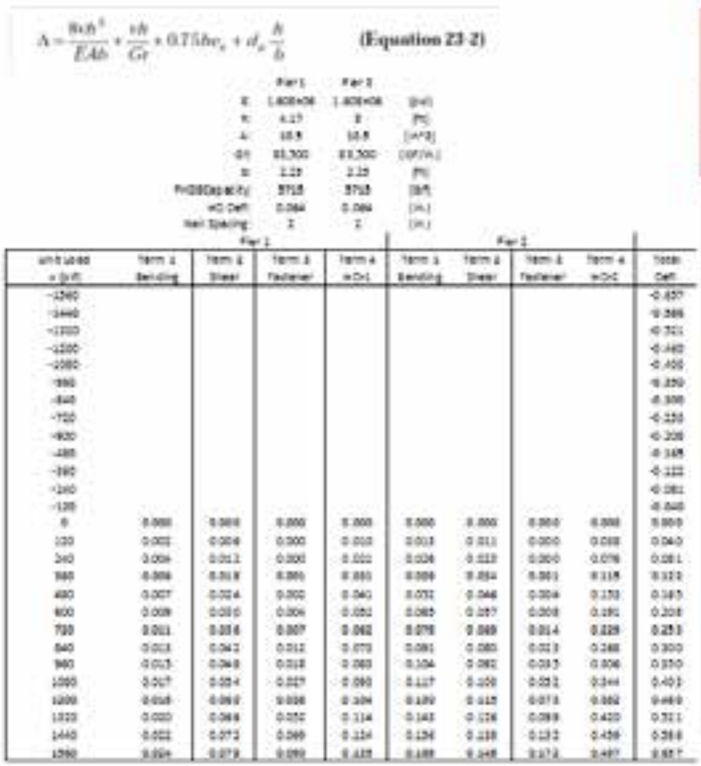


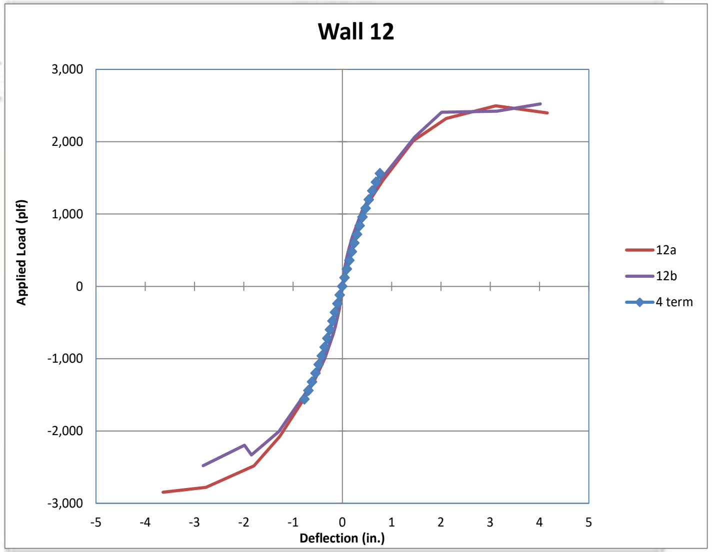


$$\Delta = \text{average}(\delta_1^+, \delta_2^+, \delta_3^+, \delta_1^-, \delta_2^-, \delta_3^-)$$

Deflection Calculations

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





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

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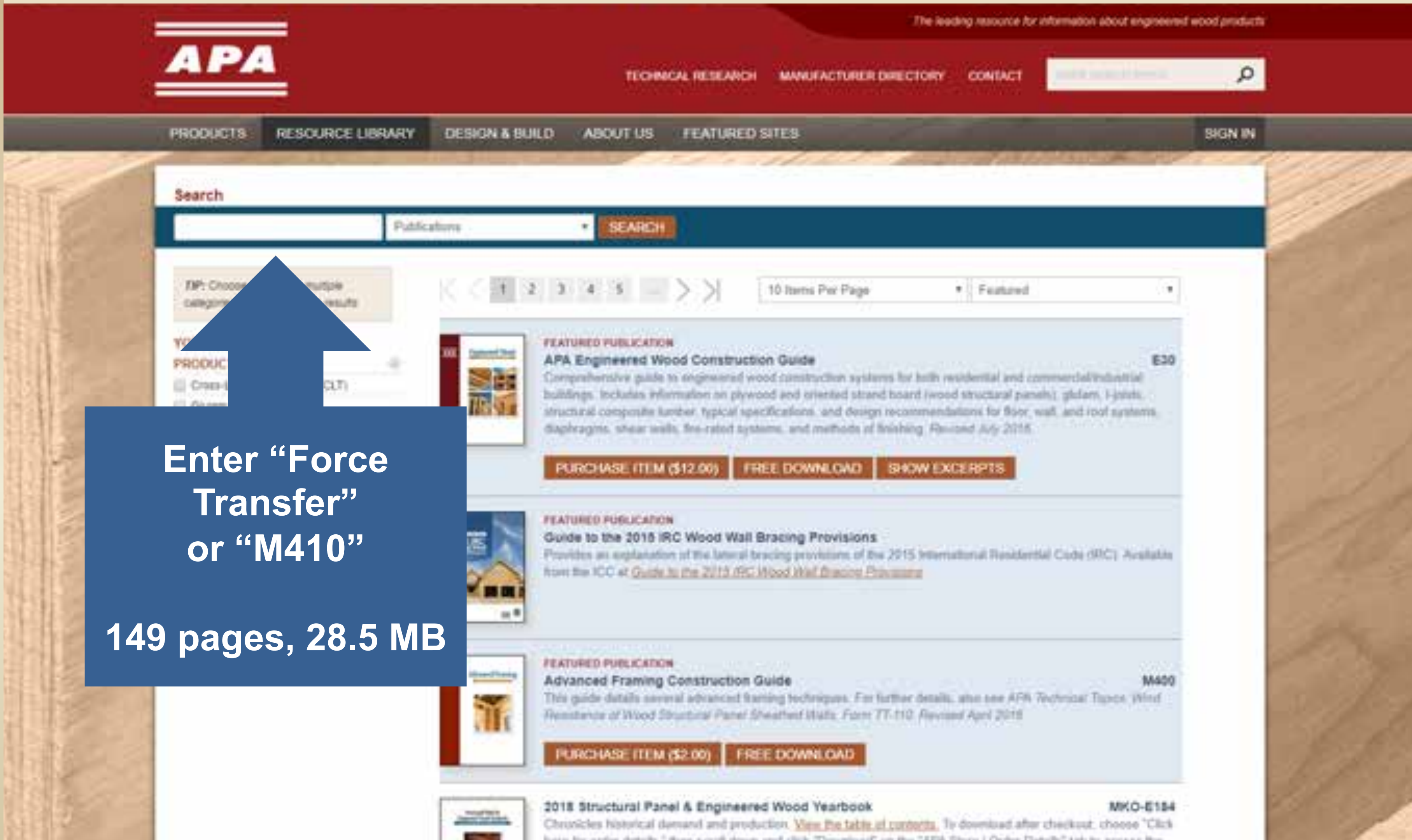
Report Available

www.apawood.org/publications



Enter "Force Transfer" or "M410"

149 pages, 28.5 MB

Asymmetric Pier widths

- **Martin, Diekmann (Wood Design Focus, 2005)**

Discussion and Closure —

"Design of St… A Compar… Wood…

Editor's Note: The *Inter*… ing states, "design for fo… tional method of analy… above.

Figures 1 and 2 from… ture. A figure develope… ures in Martin's origina…

Design of Wood Structural Panel Shear Walls with Openings: A Comparison of Methods

Zeno Martin, P.E.

Introduction

Existing methodologies for designing shear walls to resist lateral loads are in place, however, several different approaches are possible for designing shear walls with openings. This paper provides a comparison of methods for designing shear walls with openings, starting with the traditional segmented approach, then the perforated shear wall methodology, and finally the force transfer around openings procedure. All three approaches are incorporated in the 2003 *International Building Code* and specific references are shown herein.

Design of Shear Walls with Openings

The methods shown are for example purposes only and do not constitute the only solutions possible to the problem. Furthermore, these examples will show, in places, that in

L_o =	4	ft	h_1 =	2	ft
L_2 =	4	ft	h =	8	ft

Example 1.—Design as a Traditional (Segmented) Shear Wall

Calculate unit shear the wall shall resist, v:

$$v = \frac{V}{L_1 + L_2} \qquad v = 317 \quad \text{plf}$$

Assumes full height segments get an equal unit shear, another approach could distribute load based on wall length or stiffness, but in this case an aspect ratio adjustment factor will be used which is intended to provide near equal stiffness among narrow (greater than 2:1 aspect ratio) and wide (less than 2:1 aspect ratio) wall segments.

Advancements in FTAO

- **SEAOC Convention 2015 Proceedings**
- **Basis of APA Technical Note T555 Published January 2018**

2015 SEAOC CONVENTION PROCEEDINGS

Advancements in Force Transfer Around Openings for Wood Framed Shear Walls

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San Diego, CA

Tom Skaggs, P.E., Ph.D.
APA
Tacoma, WA

Abstract

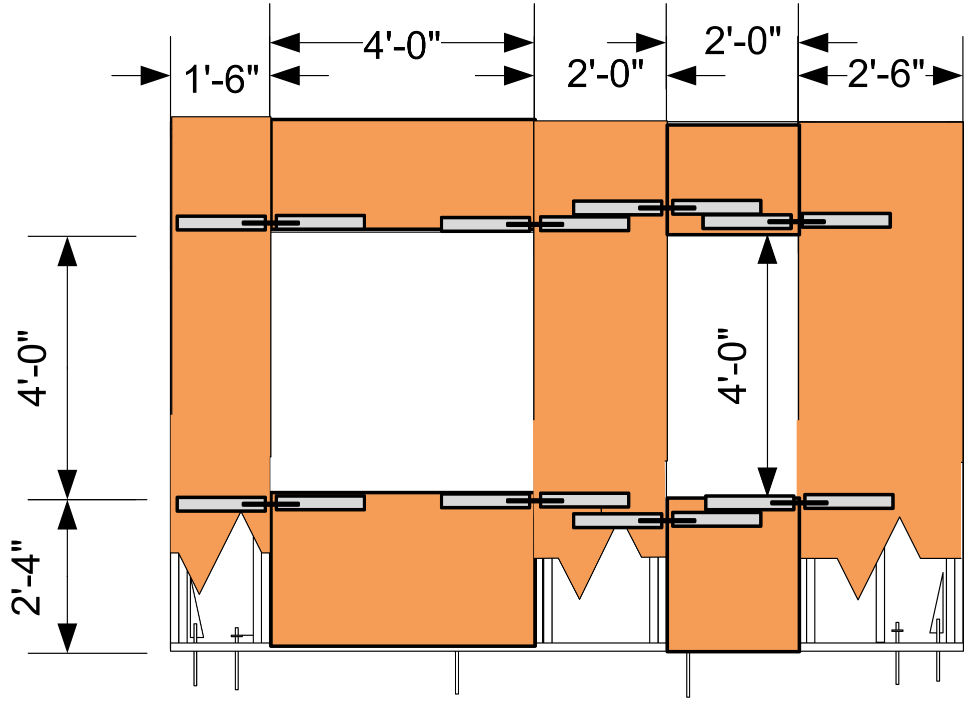
A joint research project of *APA – The Engineered Wood Association*, University of British Columbia (UBC), and USDA Forest Products Laboratory was initiated in 2009 to examine the variations of walls with code-allowable openings. This study examines the internal forces generated during these tests and 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.

Multiple Openings

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



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)

Deikmann Techniquie: 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.

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)

SHEAR WALL DESIGN CHALLENGES

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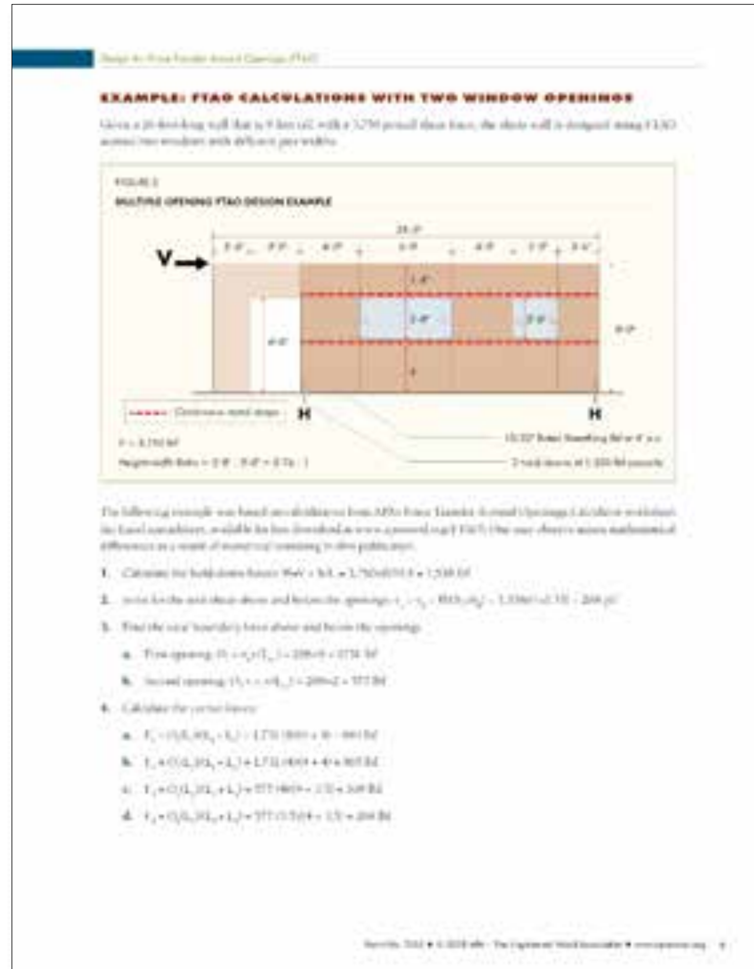
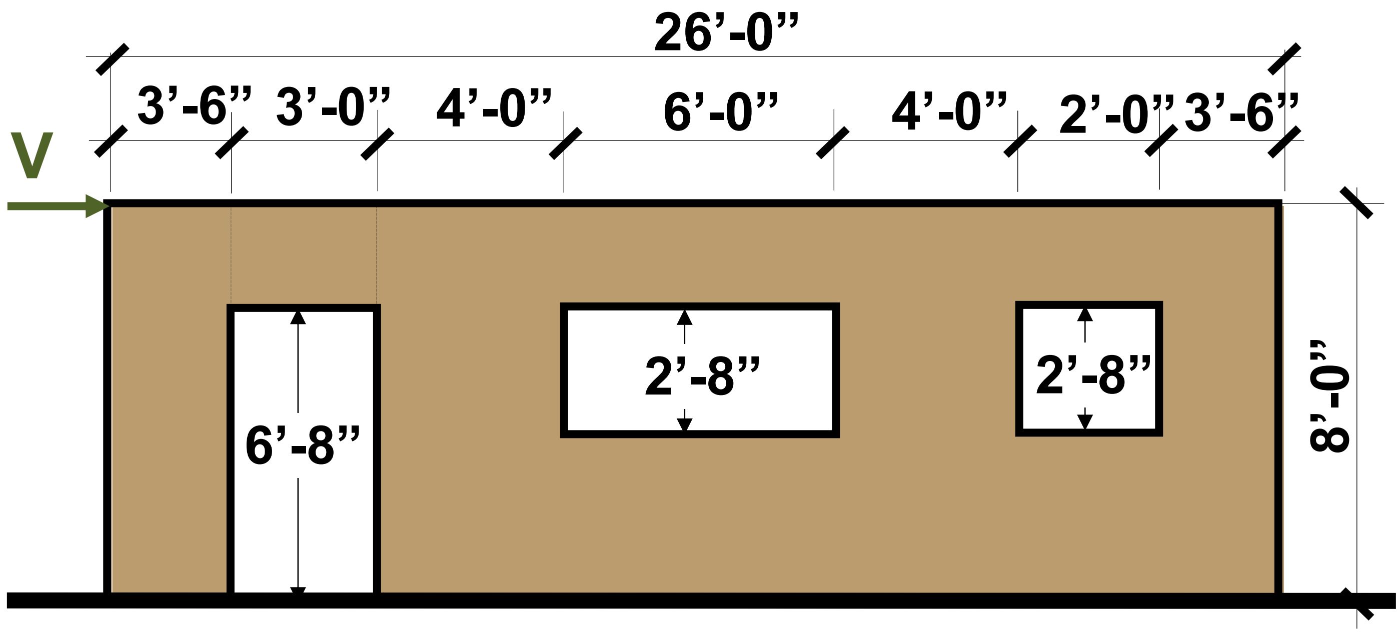
FTAO Technical Note: Form T555

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


EXAMPLE: FTAO CALCULATIONS WITH TWO WINDOW OPENINGS

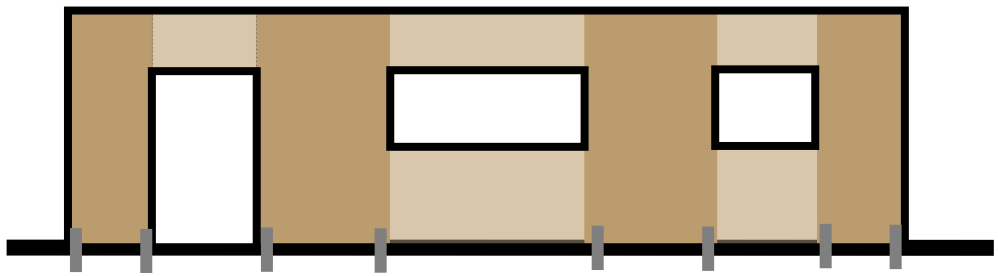
MULTIPLE OPENING FTAO DESIGN EXAMPLE

Design Example



V = 3,750 lbs

Segmented Approach



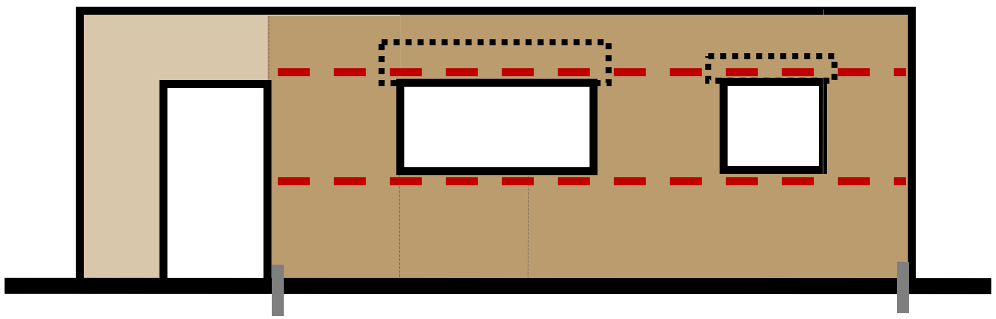
15/32” Rated sheathing

8d @ 4”o.c. (3’-6” walls)

8d @ 6” o.c. (4’ walls)

8 – hold downs @ 2000+ lb capacity

Force Transfer



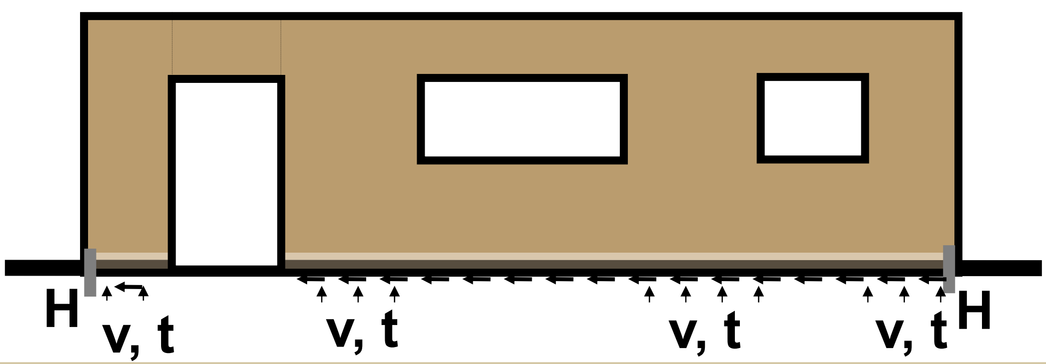
15/32” Rated Sheathing

8d @ 4”o.c.

2 – hold downs @ 1,550 lb capacity

2 Straps – 865 lb

Perforated



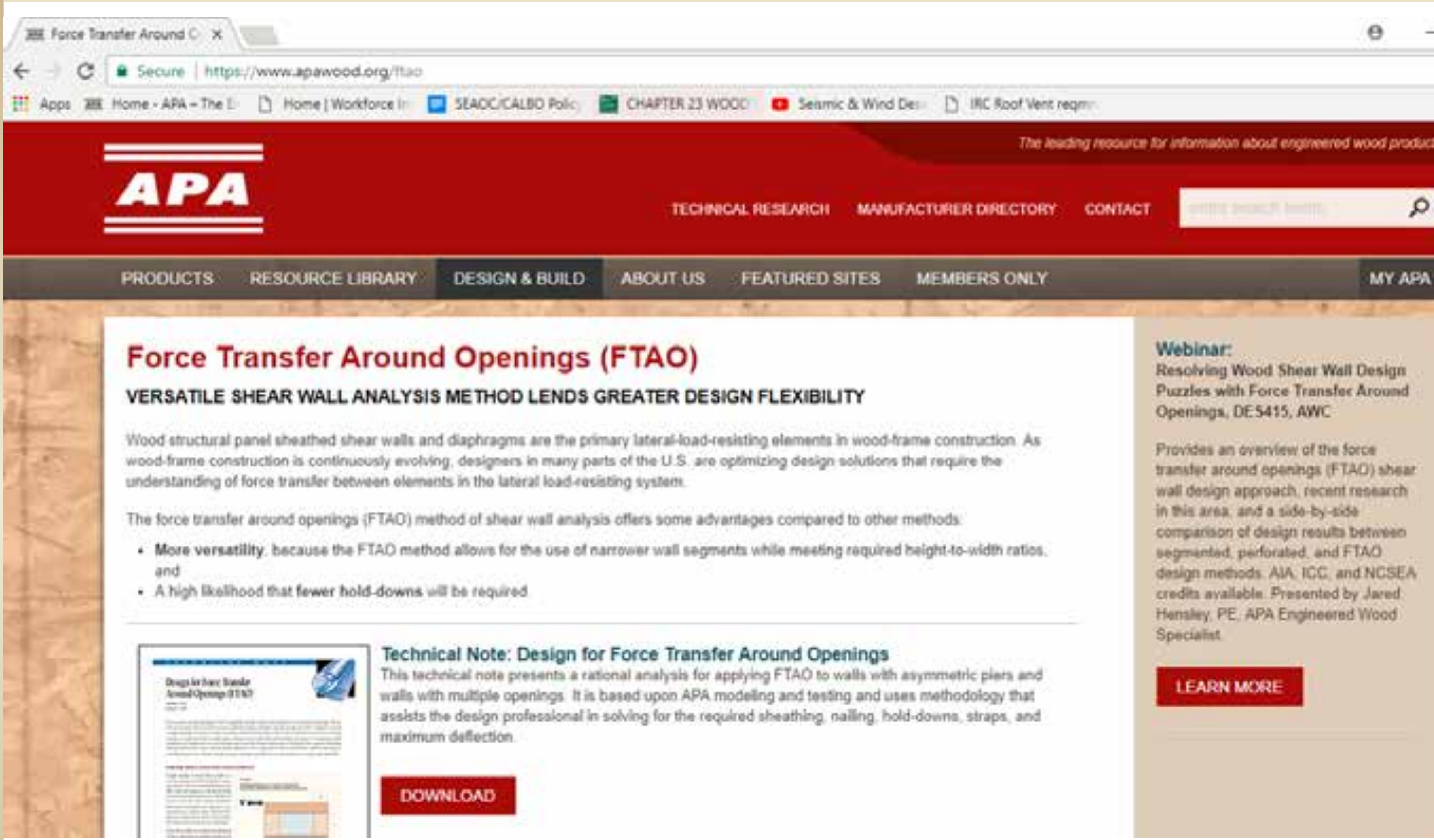
15/32” Rated Sheathing

8d @ 3”o.c.

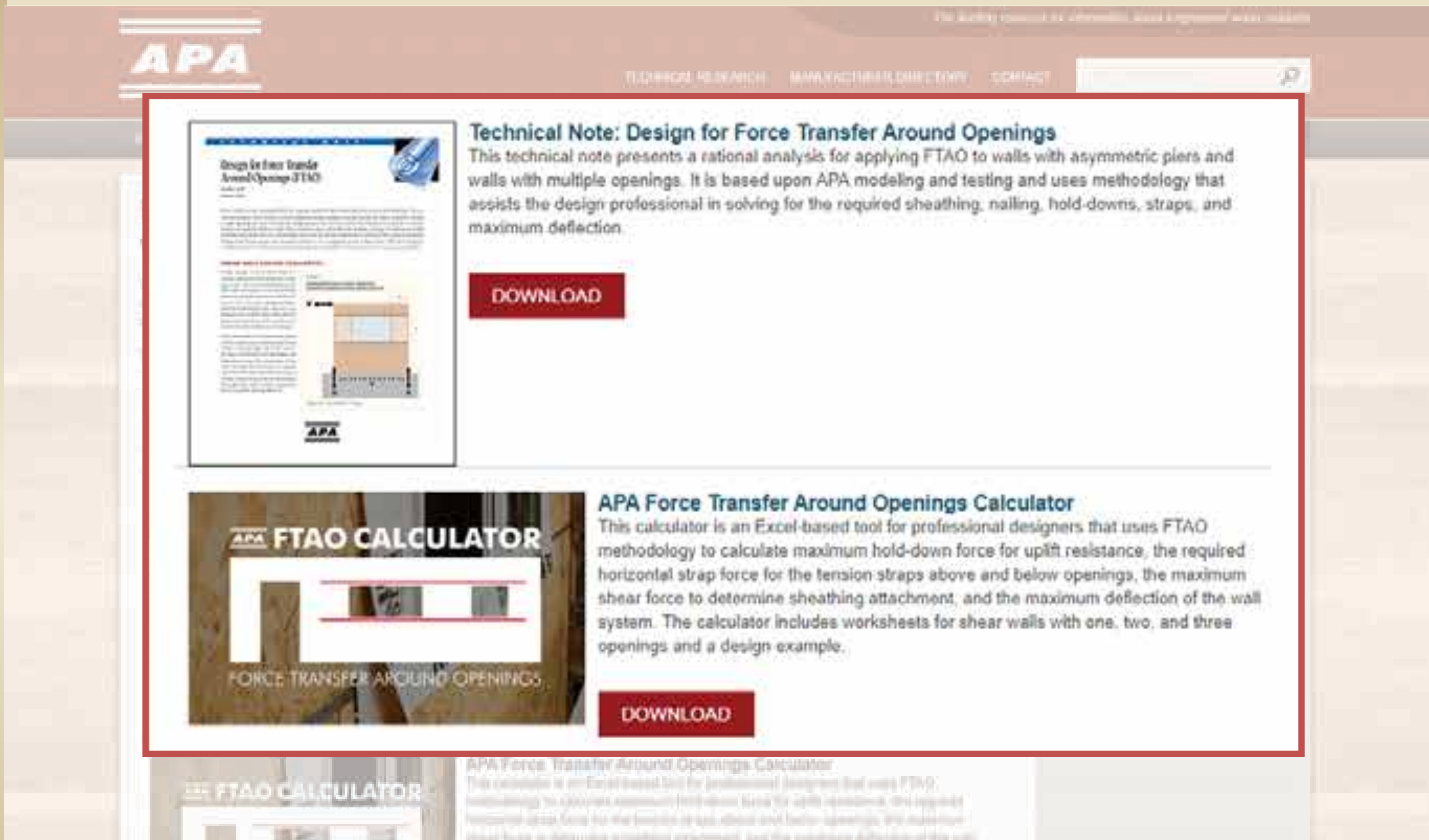
2 – hold downs @ 3280 lb capacity

extensive plate anchorage

www.apawood.org/FTAO

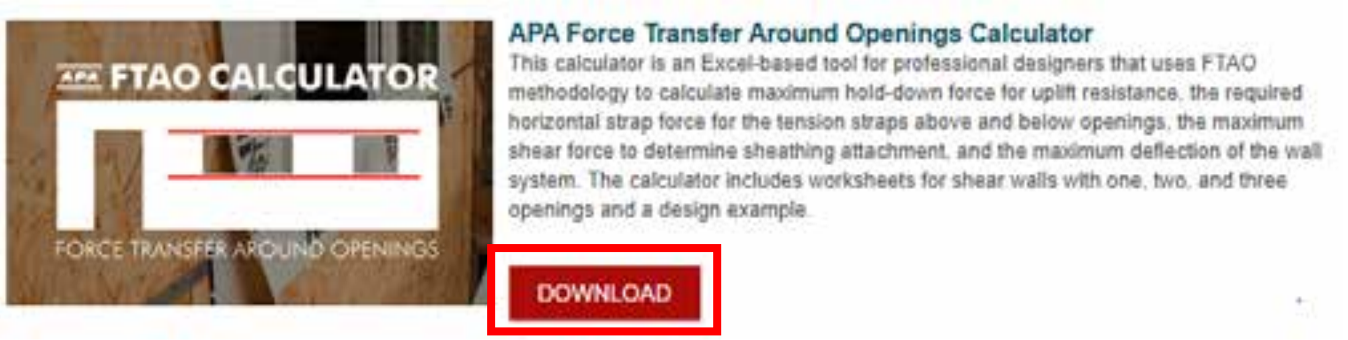


www.apawood.org/FTAO



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)



FTAO Calculator: Limitations

- Limited to shear walls with up to three openings
- Only provides design for wall systems utilizing wood structural panel wall sheathing
- Assumes that all window opening heights are equal
  - Users should utilize the wall dimensions at the largest openings when inputting the heights of openings
- The 'Stud Size' input is limited to the stud sizes shown in IBC Table 2308.5.1
  - For instances of uncommon wood stud or column dimensions, an 'A Overide' cell is provided
- The nail type input allows for the input of 8d common or 10d common nails
- Uses the most conservative published values for rigidity of wall sheathing and shear wall stiffness

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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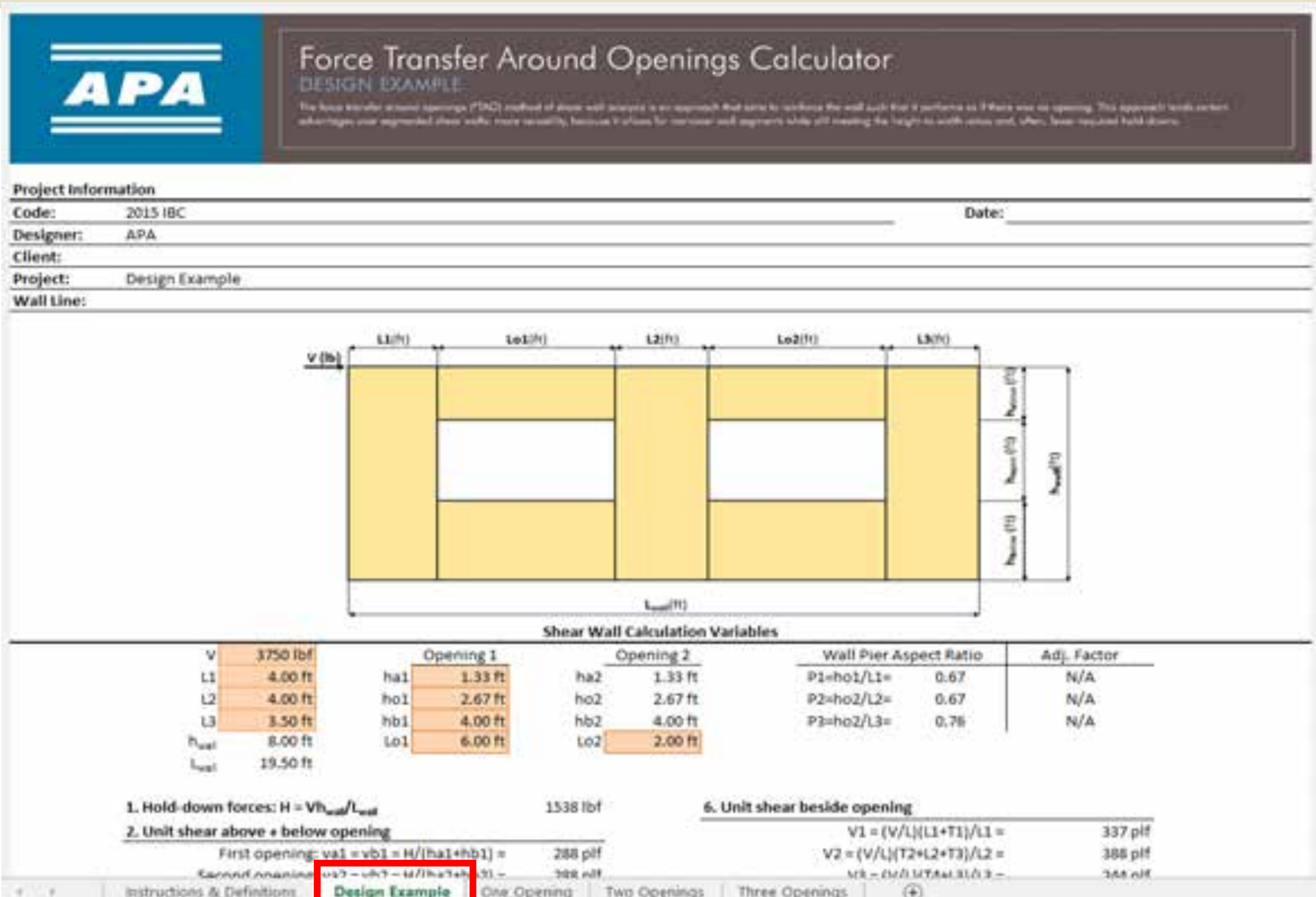
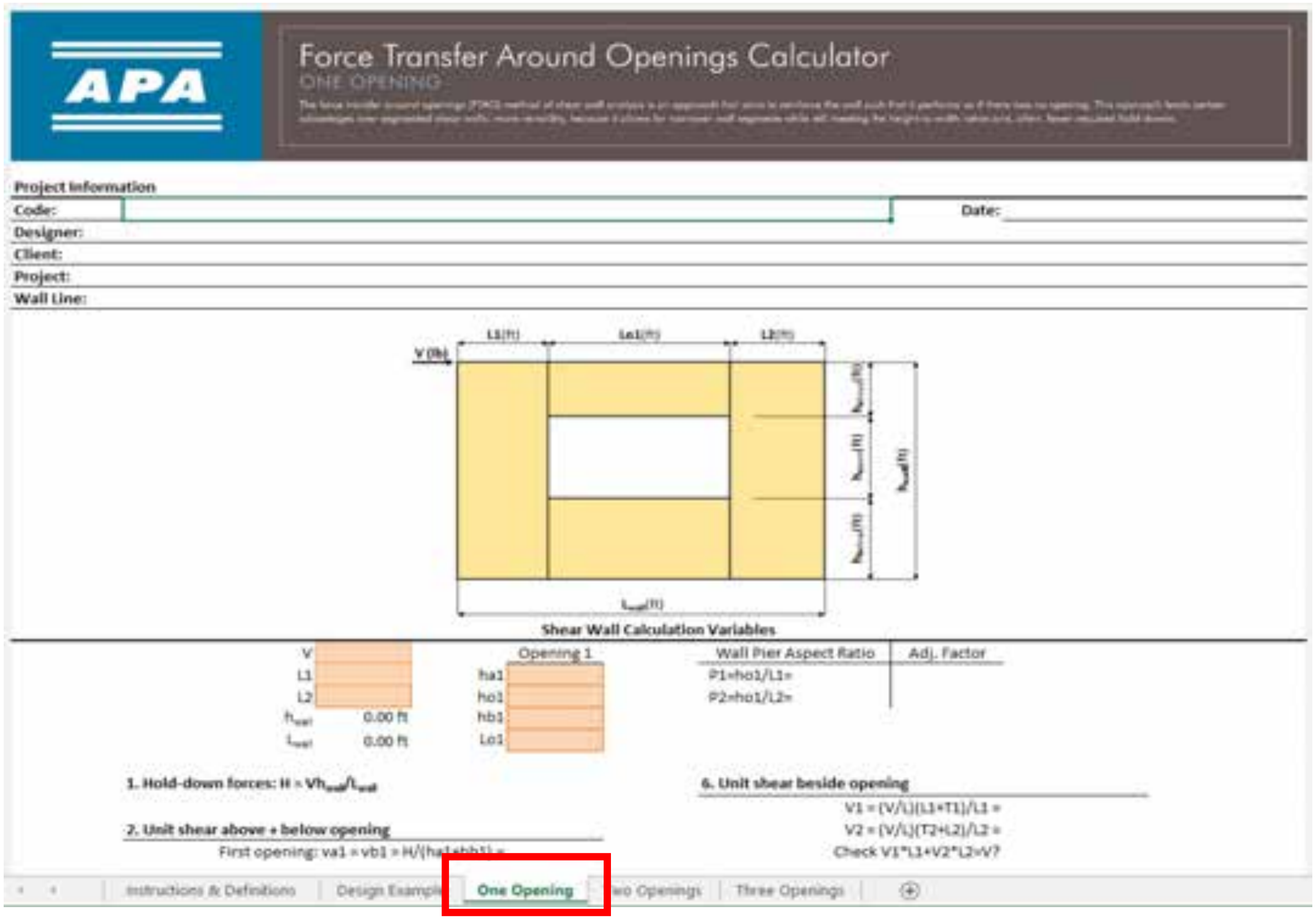
FTAO Calculator: Design Example

www.apawood.org/FTAO



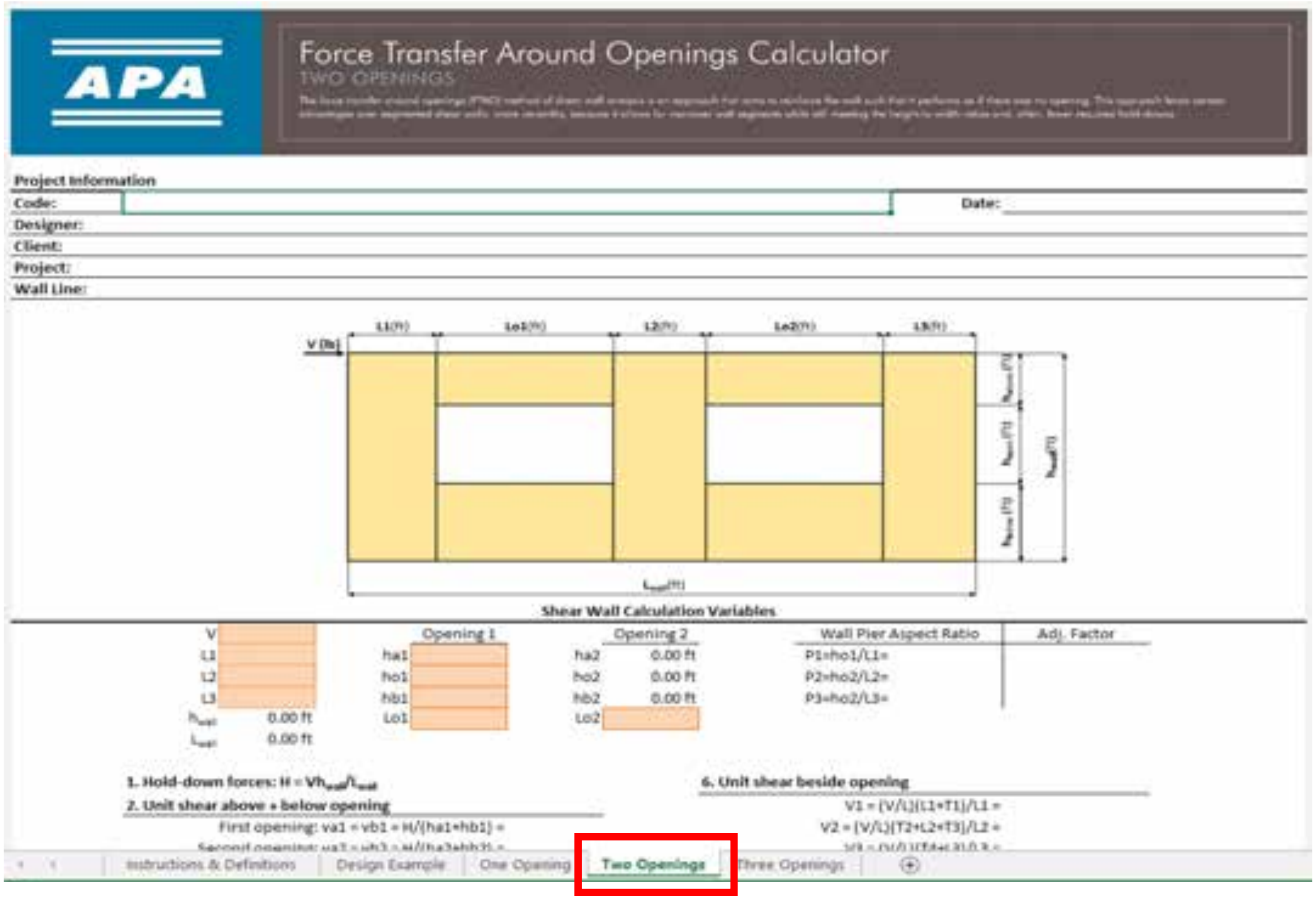
FTAO Calculator: One Opening

www.apawood.org/FTAO



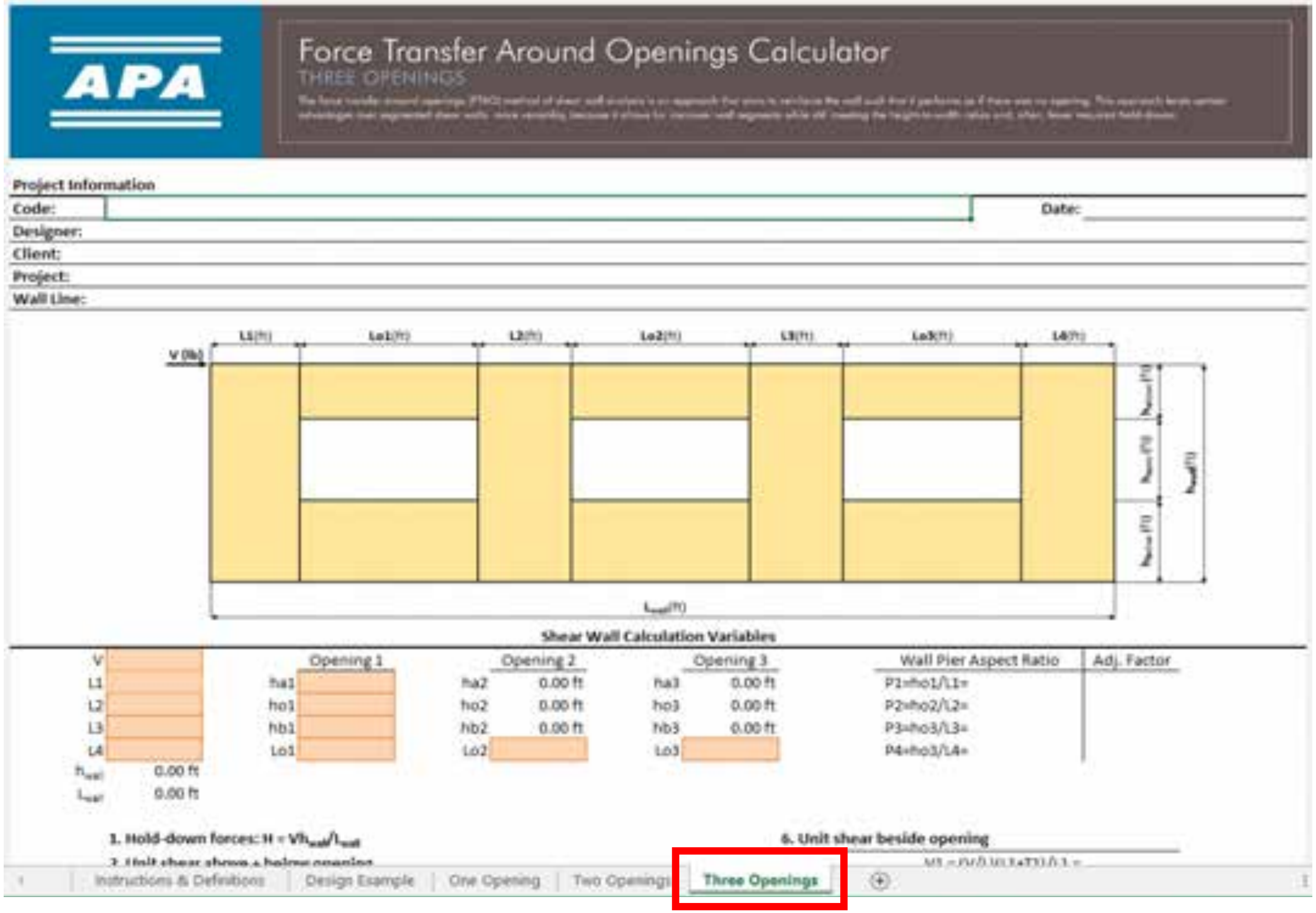
FTAO Calculator: Two Openings

www.apawood.org/FTAO



FTAO Calculator: Three Openings

www.apawood.org/FTAO



FTAO Calculator: Inputs

- V – Applied shear force at the top of the wall (lb)
- L(i) – Length of each wall pier segment
- Lo(i) – Length of each clear opening
- ho1 – Maximum clear opening height of any opening in the wall system
- ha1, hb1 – Height of continuous sheathing above and below the opening
  - Correlates with the opening height
- h_{wall} – Total calculated height of the shear wall from bottom of sill plate to top of top plate (ft)
- L_{wall} – Total calculated length of shear wall (ft)

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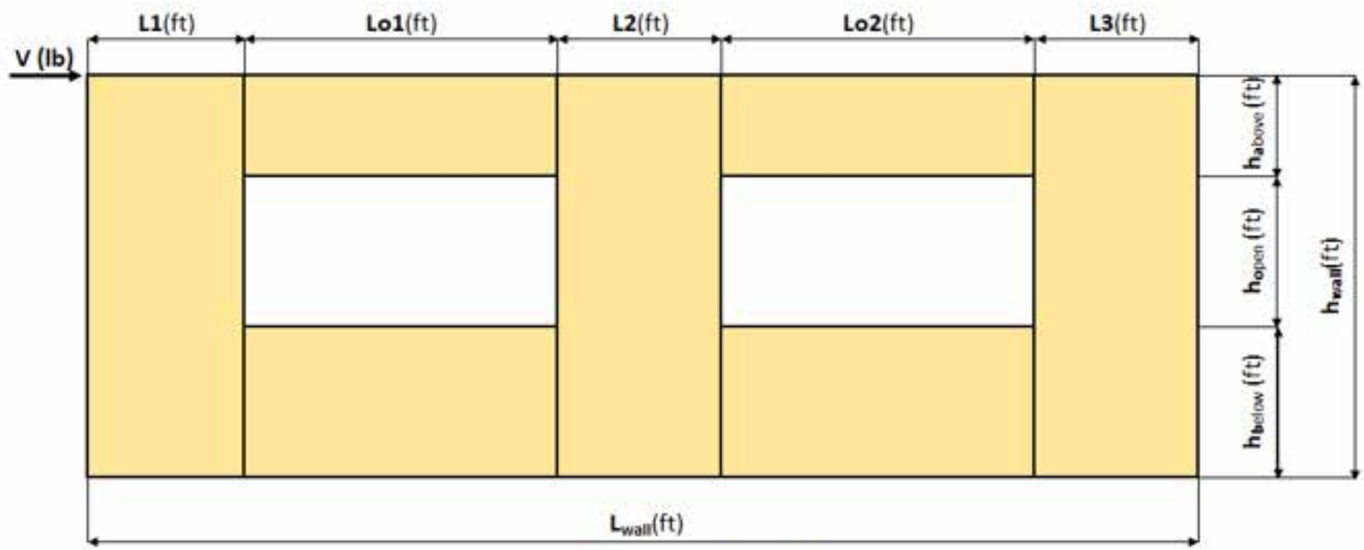
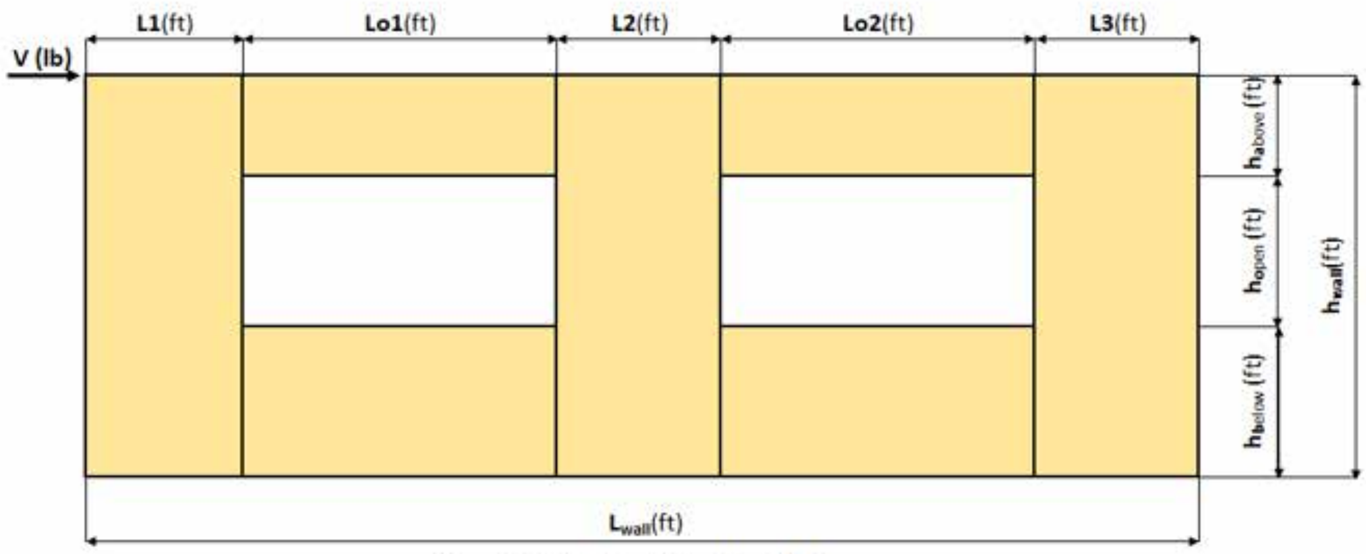
FTAO Calculator: Inputs



Shear Wall Calculation Variables

V	3750 lbf	Opening 1		Opening 2		Wall Pier Aspect Ratio		Adj. Factor
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

V	3750 lbf		Opening 1		Opening 2	Wall Pier Aspect Ratio	Adj. Factor
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

Strap 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

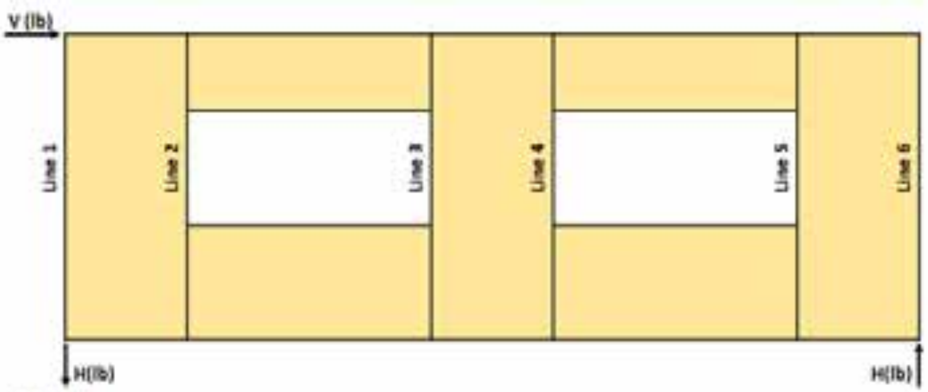
8. Difference corner force + resistance

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

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

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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.)

The calculator does not check the sheathing selection for the required capacity calculated above.

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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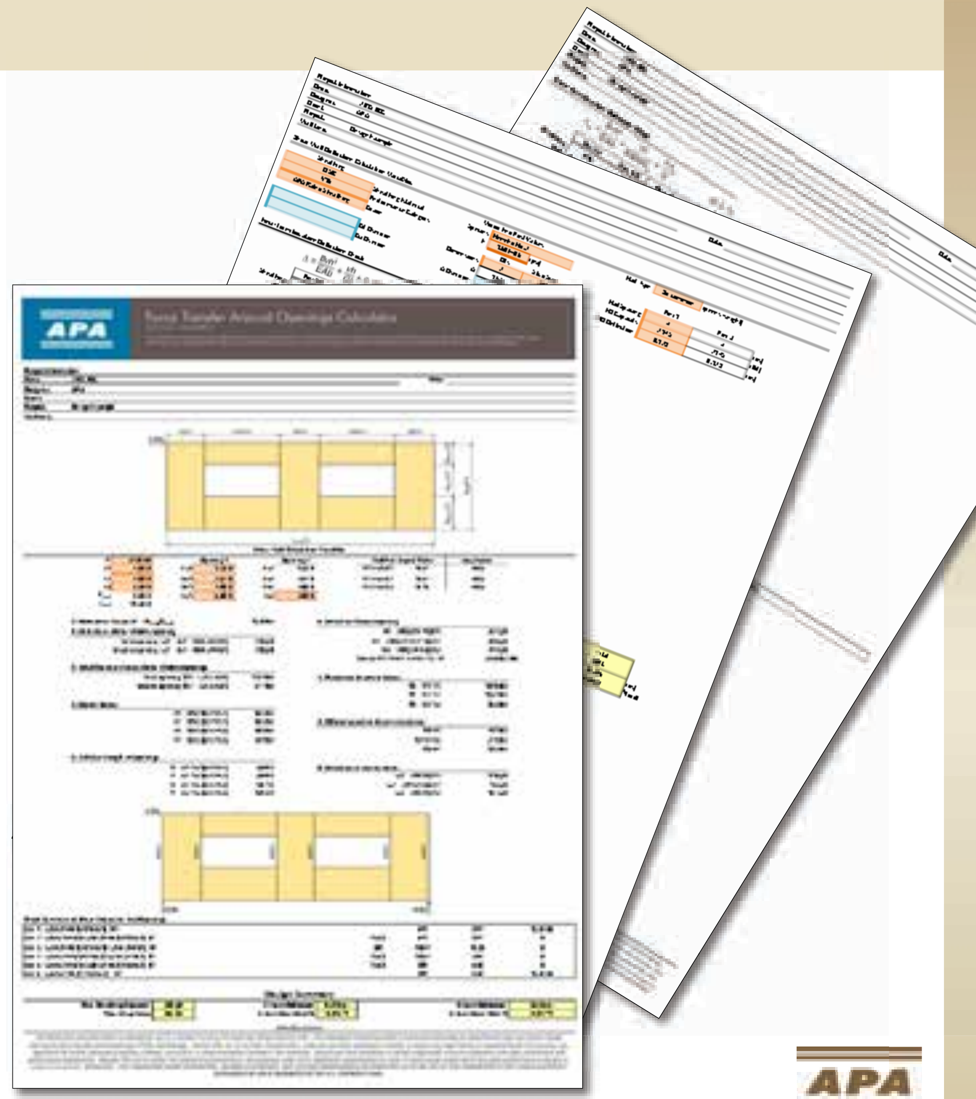
FTAO Calculator: Final Output

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 WSPs

For the Structural Engineer…

- **Straightforward rational analysis**
- **Easy to program: Excel, APA Worksheet**
- **Design check = confidence in calculations**

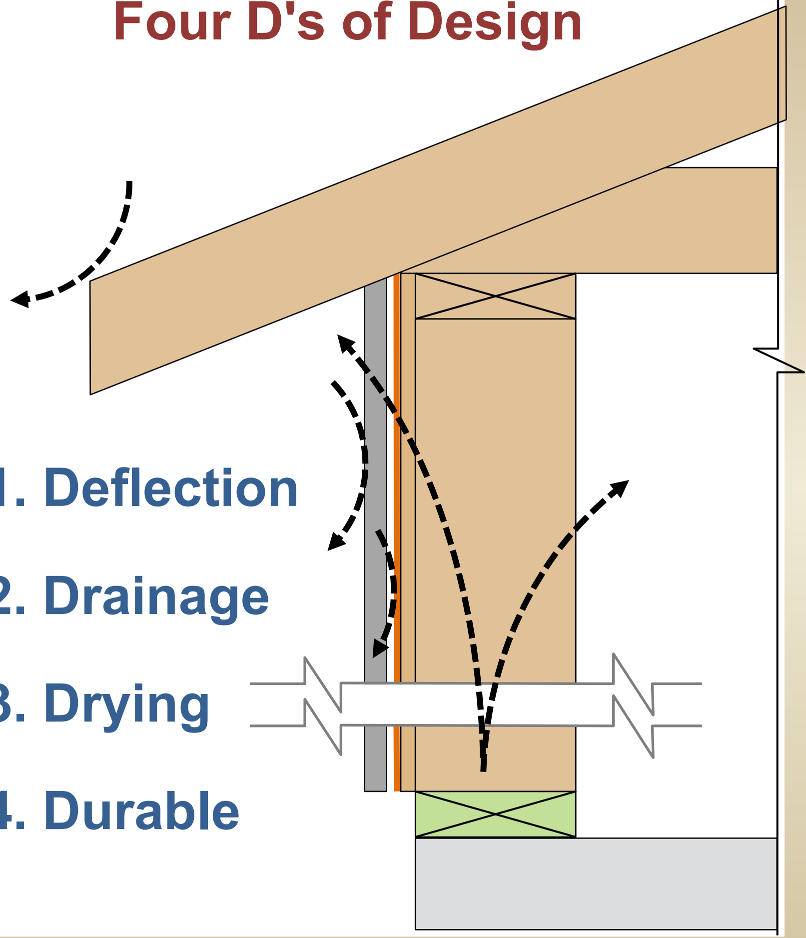
CHECK				
Line 1: va1(ha+hb)+V1(ho)=H?	641	897	1538	
Line 2: va(ha+hb)-va1 (ha+hb)-V1(ho)=0?	1538	641	897	0
Line 3: va2(ha+hb)+V2(ho)-va(ha+hb)=0?	504	1034	1538	0
Line 4 = Line 3				
Line 5: va(ha+hb)-va3 (ha+hb)-V3(ho)=0?	1538	889	650	0
Line 6: va3(ha+hb)+V3(ho)=H?	889	650	1538	

Benefits of FTAO with Continuous WSPs

Architectural flexibility

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

Four D's of Design



1. Deflection
2. Drainage
3. Drying
4. Durable

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

Learning Objectives

1. Investigate past and current methods for determining force transfer around openings for wood shear walls.
2. 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.
3. Assess new design methodologies for accurately estimating the forces around multiple openings with asymmetric piers.
4. Estimate the deflections for shear walls designed using the force transfer around openings design method.

Questions/ Comments?

- This concludes The American Institute of Architects Continuing Education Systems Course

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