



Advancements in Force Transfer Around Openings for Wood Framed Shear Walls



Karyn Beebe, PE, LEED AP

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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 the (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 $1.25 - 0.125h/b_s$



Force Transfer

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

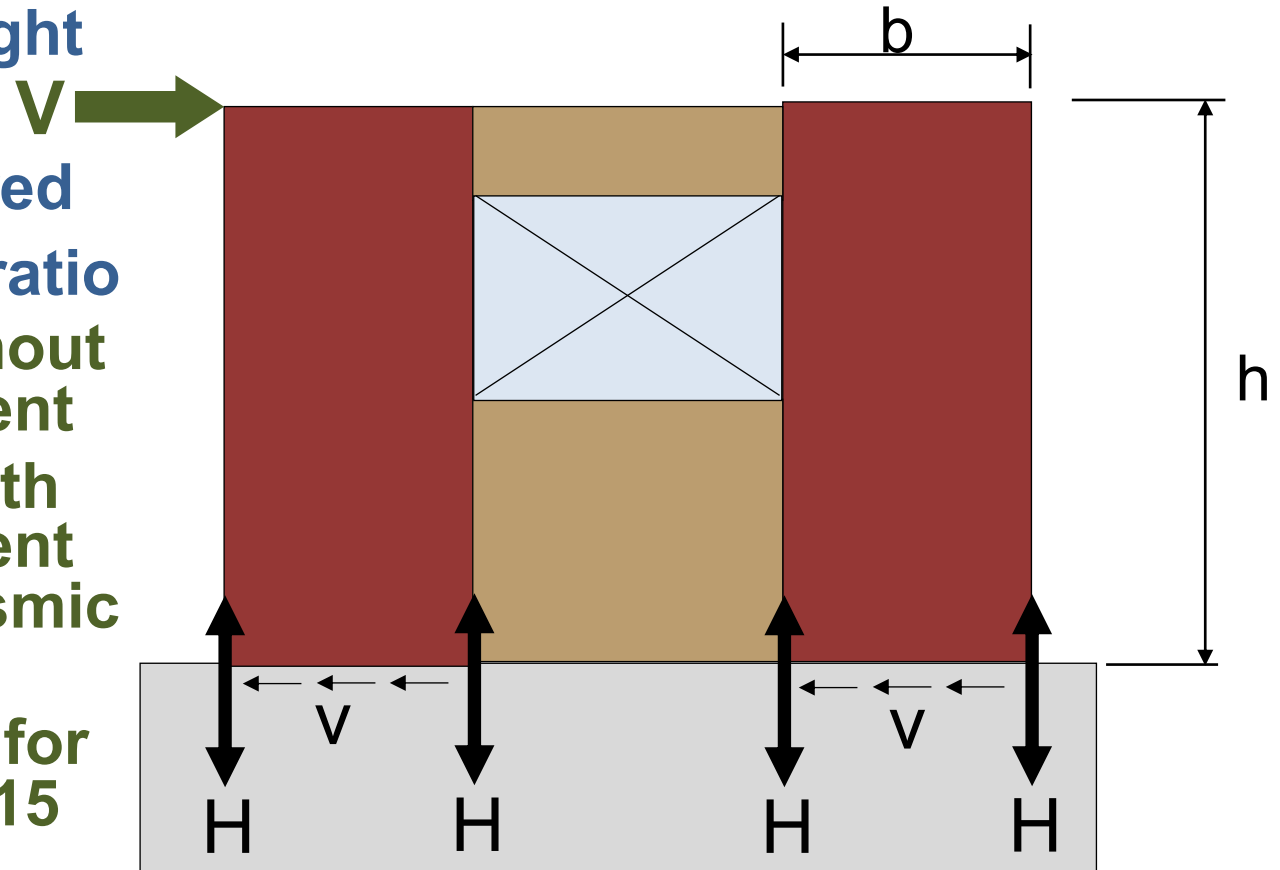


Perforated

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

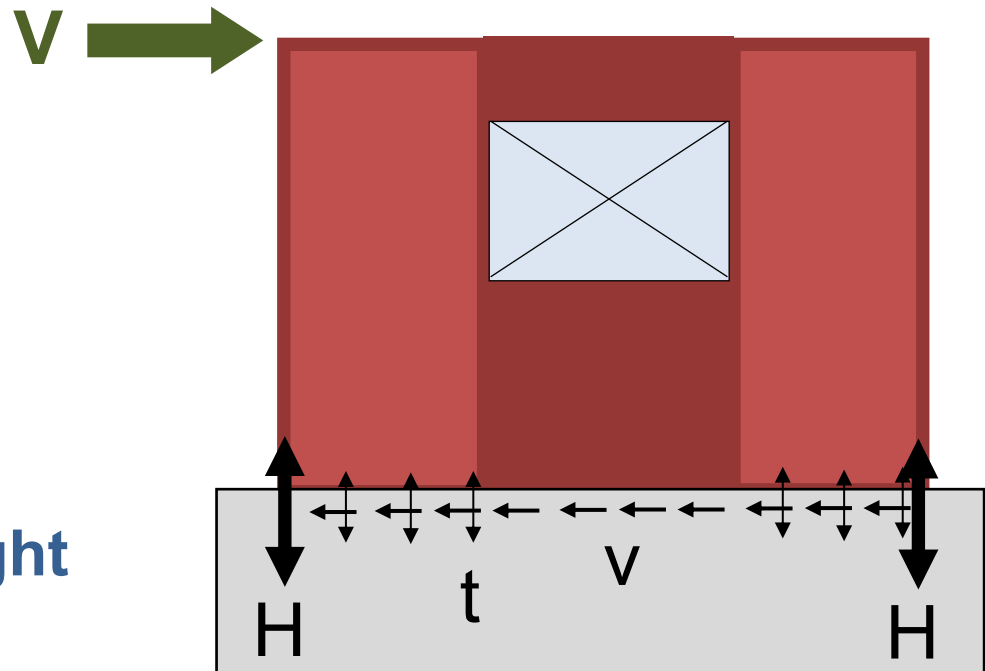


Aspect ratio $h:b_s$ as shown in figure

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 segment is also required

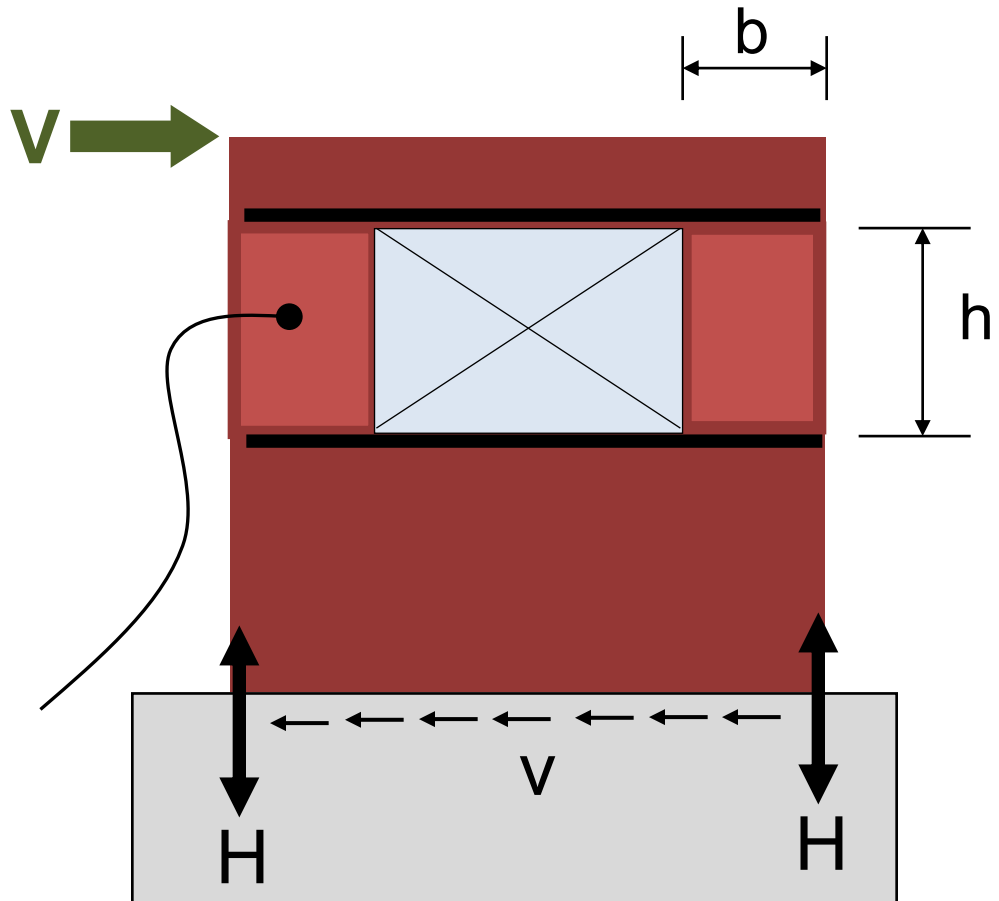


Aspect ratio applies to full height segment (dotted)

FTAO

(SDPWS-08/15 Section 4.3.5.2)

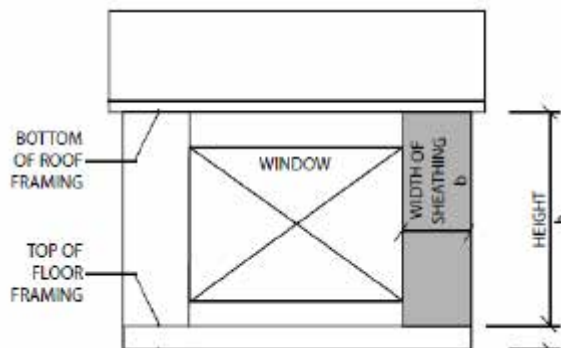
- Openings accounted for by strapping or framing
 - “based on a rational analysis”
- Hold-downs only at ends
- H/w ratio defined by wall pier



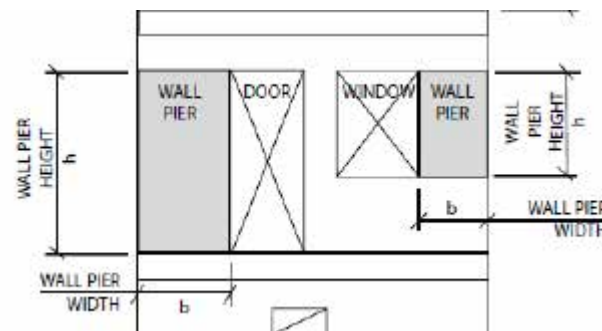
Aspect ratio $h:b$ as shown in figure

Aspect ratio (SDPWS-15 4.3.4.2)

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



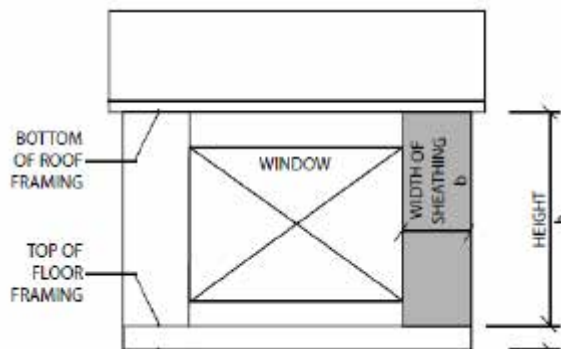
Excerpt Fig 4D
 $h:w$ ratio Segmented



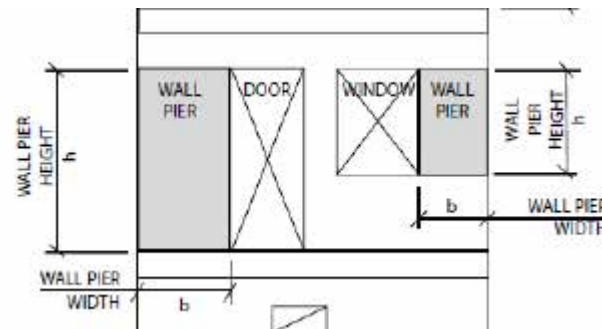
Excerpt Fig. 4E
 $h:w$ ratio FTAO

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 $2:1 < \text{aspect ratio} \leq 3.5:1$ are multiplied by $2b_s/h$ 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)**

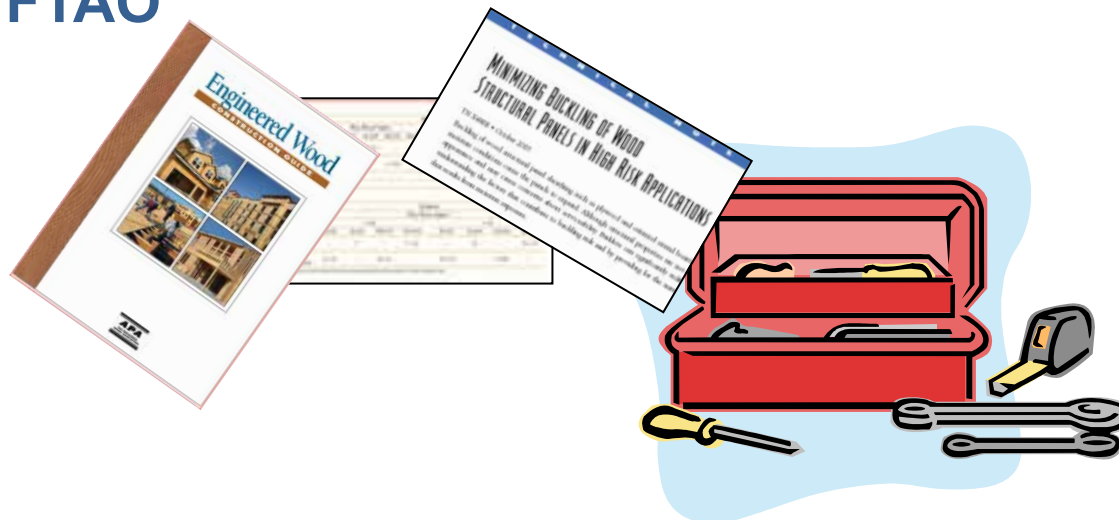
Study was initiated in 2009 to:

- **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



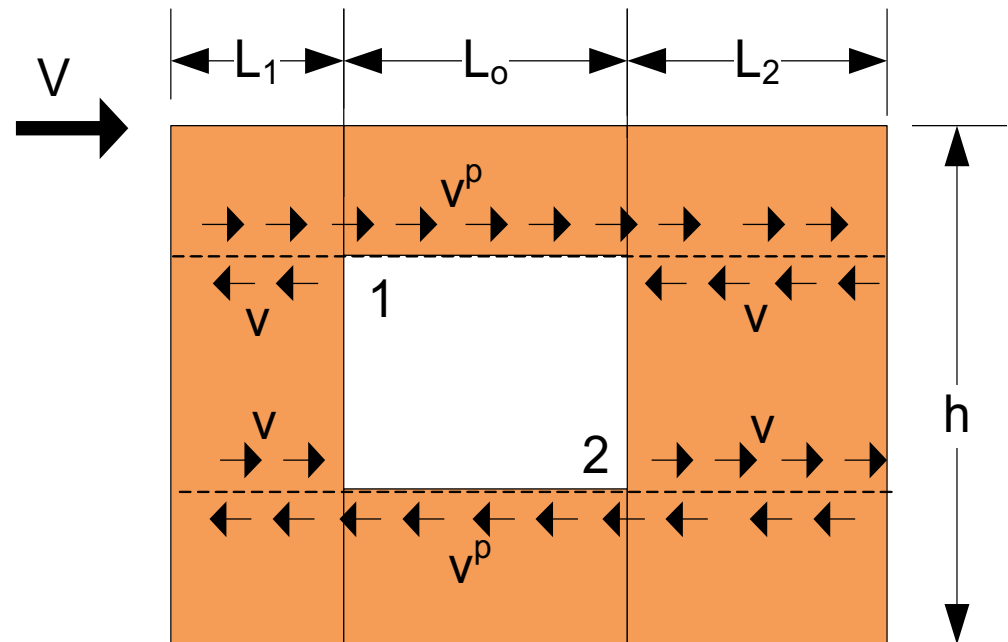
Different Techniques for FTAO

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



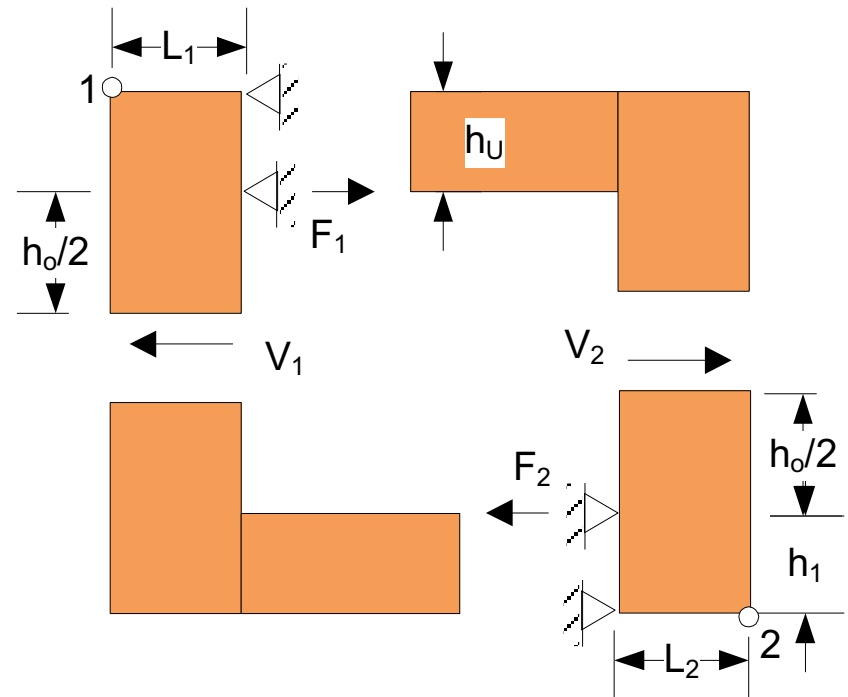
Different Techniques for FTAO

- **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

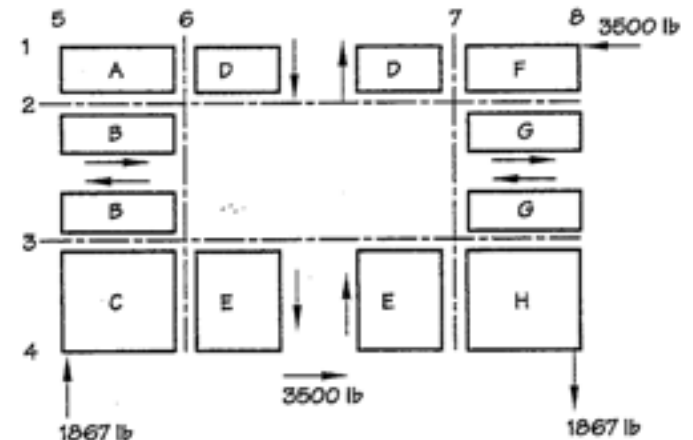
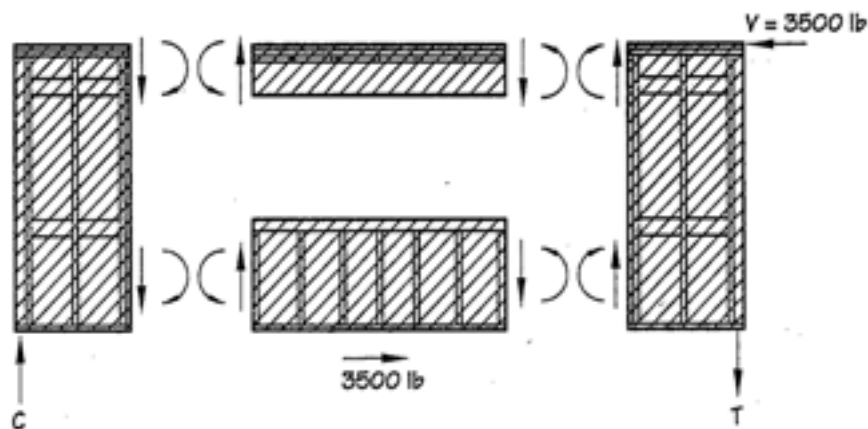
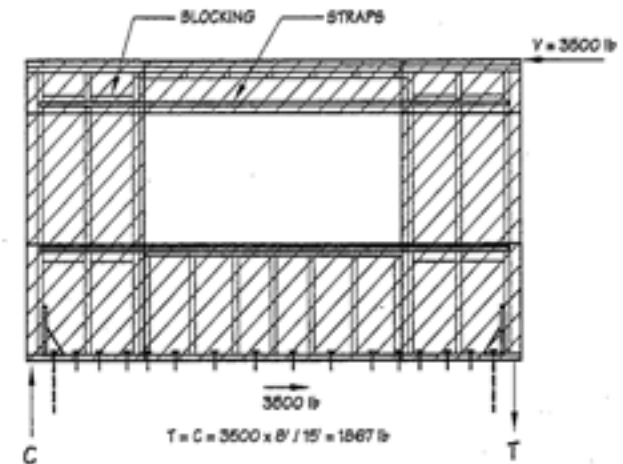
- **Cantilever Beam Analogy**
 - Forces are treated as moment couples
 - Segmented panels are piers at sides of openings
 - Strap forces are a function of height above and below opening and pier widths



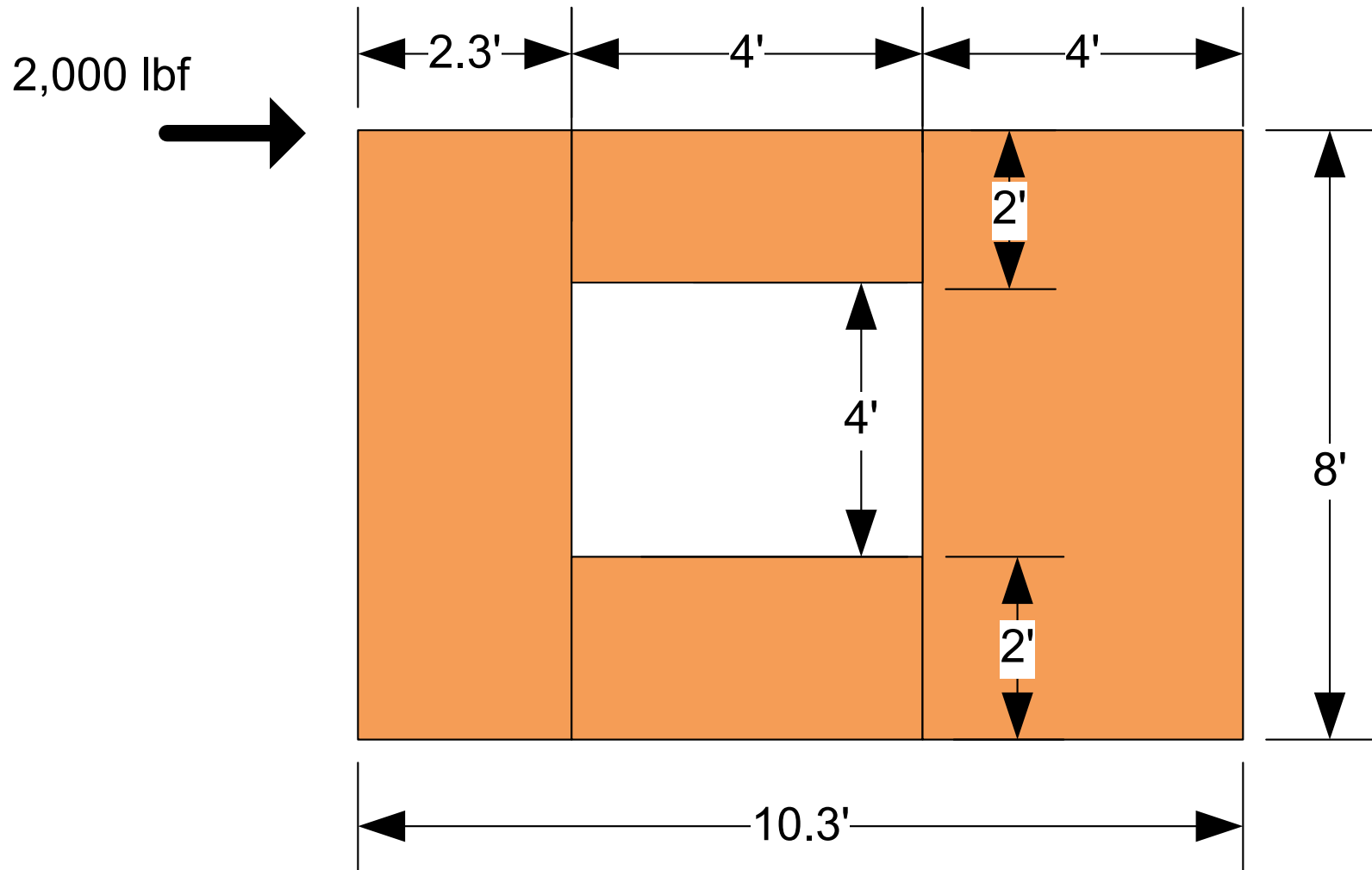
Different Techniques for FTAO

■ Diekmann

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



Design Examples



Design Example Summary

Drag Strut Analogy

- $F_1 = 284 \text{ lbf}$
- $F_2 = 493 \text{ lbf}$

Cantilever Beam Analogy

- $F_1 = 1,460 \text{ lbf}$
- $F_2 = 2,540 \text{ lbf}$

Diekmann Method

- $F_1 = 567 \text{ lbf}$
- $F_2 = 986 \text{ lbf}$

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. Cobein 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

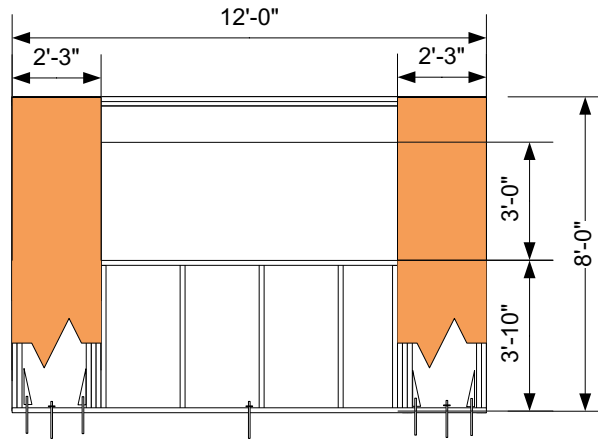
- 12 wall configurations tested (with and without FTAO applied)
- Wall nailing; 10d commons (0.148" x 3") at 2" o.c.
- Sheathing; 15/32 Perf Cat oriented strand board (OSB) APA STR I
- All walls were 12 feet long and 8 feet tall
- Cyclic loading protocol following ASTM E2126, Method C, CUREE Basic Loading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

Test Plan

Wall 1

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

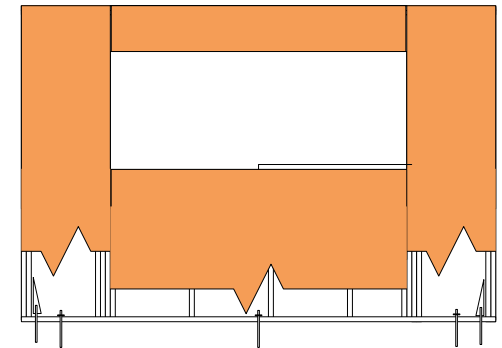
Segmented



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.

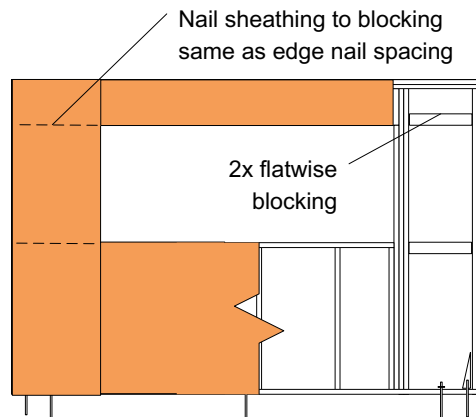
Perforated



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

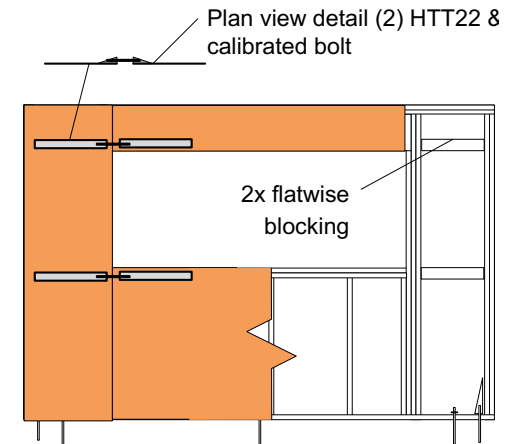


Wall 4

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

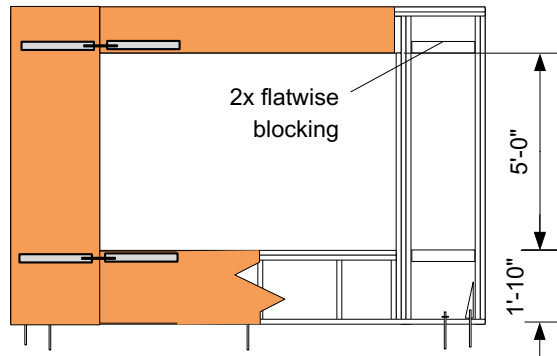


Test Plan

Wall 5

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

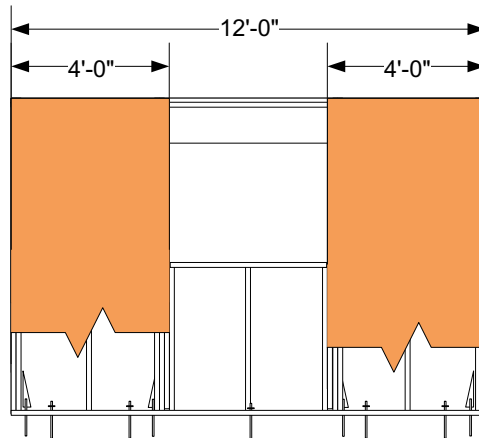
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity



FTAO with bigger opening

Wall 7

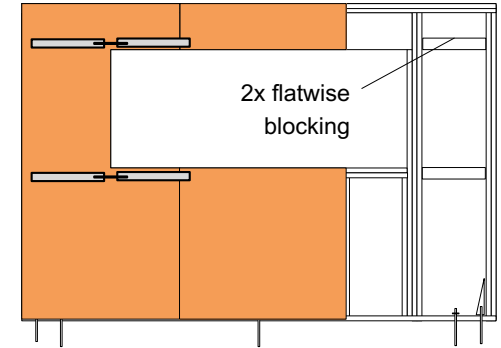
Objective:
Est. baseline case for 2:1 segmented wall



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

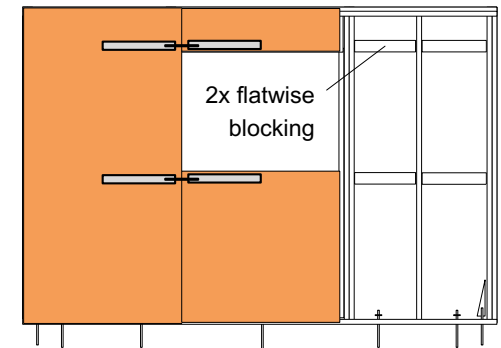


FTAO with C-shaped panel

Wall 8

Objective:
Compare FTAO to Wall 7

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

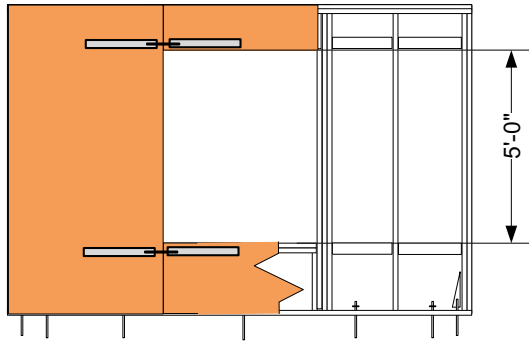


Test Plan

Wall 9

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

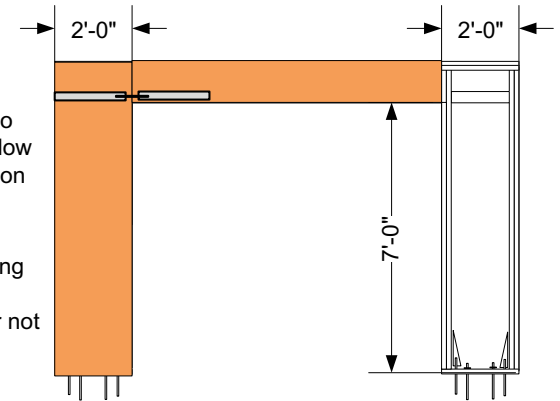
Wall is symmetric,
sheathing and force
transfer load
measurement on right pier
not shown for clarity



Wall 10

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

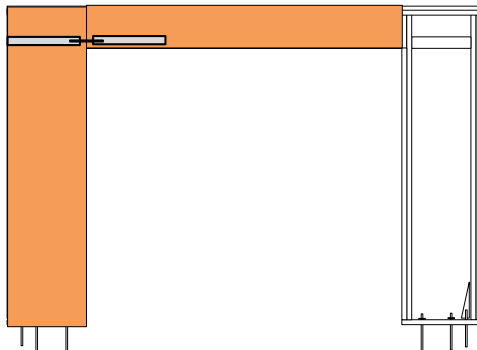
Wall is symmetric, sheathing
and force transfer load
measurement on right pier not
shown for clarity



Wall 11

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

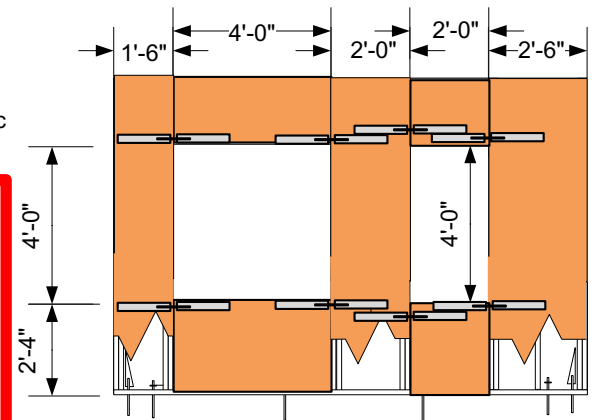
Wall is symmetric,
sheathing and force
transfer load
measurement on right pier
not shown for clarity



Wall 12

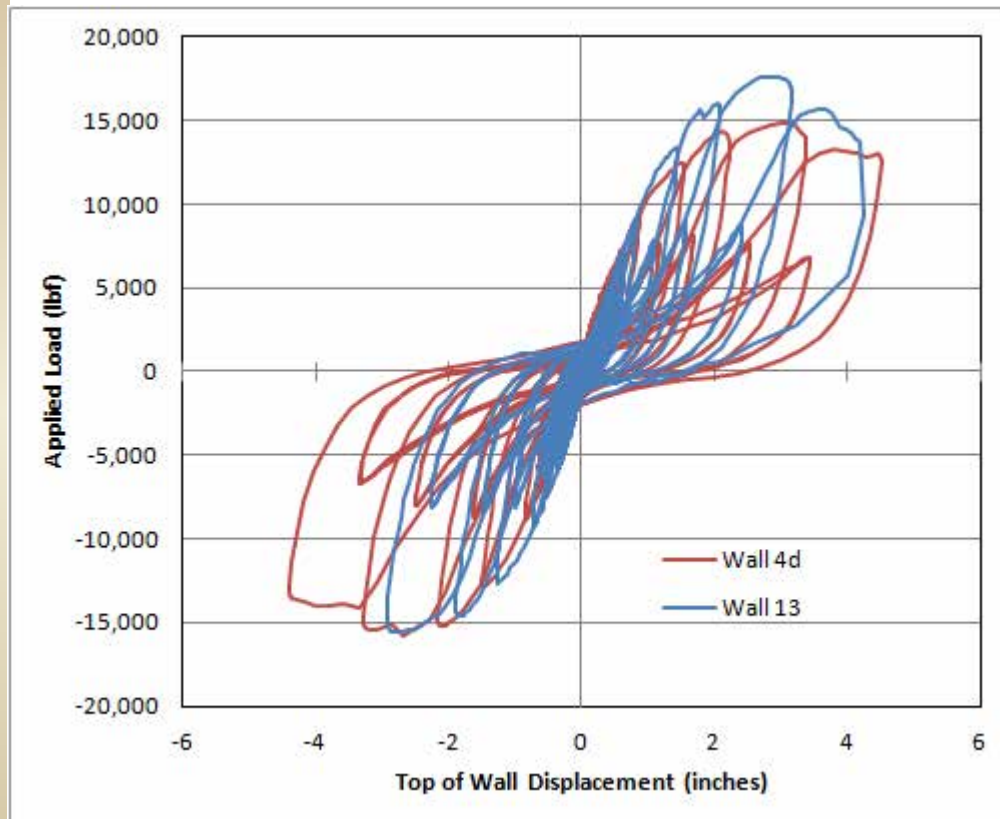
Objective:
FTAO for asymmetric
multiple pier wall.

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

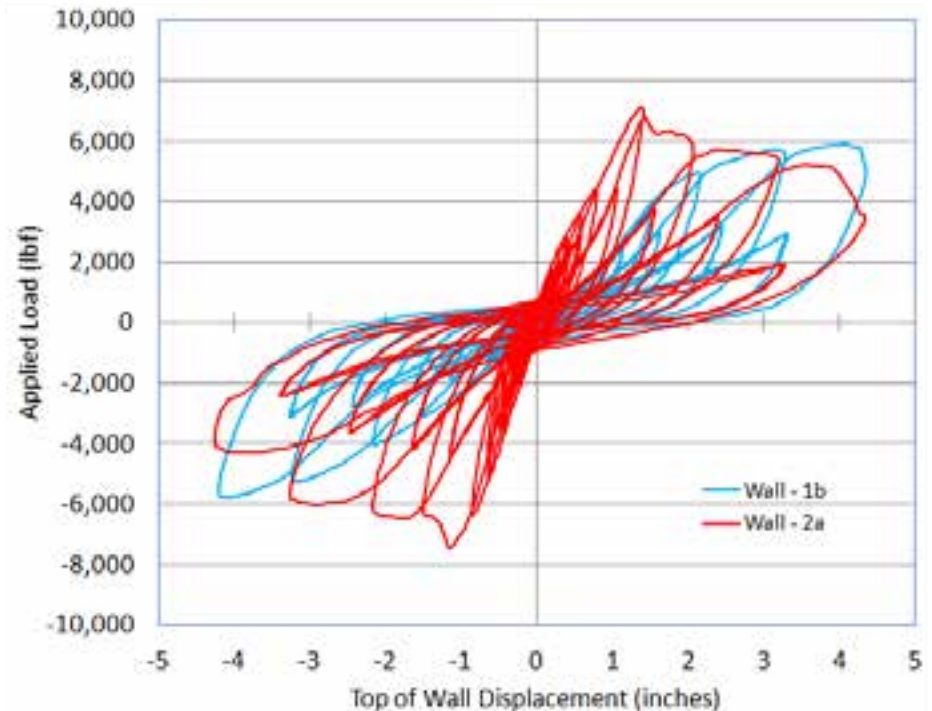


Measured vs Predicted Strap Forces

Wall ID	Measured Strap Forces (lbf) ⁽¹⁾		Error ⁽²⁾ For Predicted Strap Forces at ASD Capacity (%)						
			Drag Strut Technique		Cantilever Beam Technique		Diekmann Technique	SEAOC/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

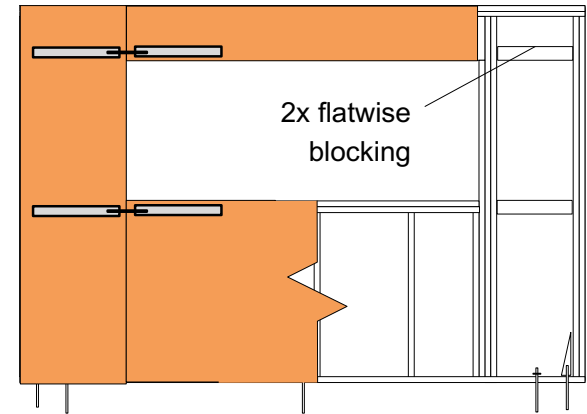
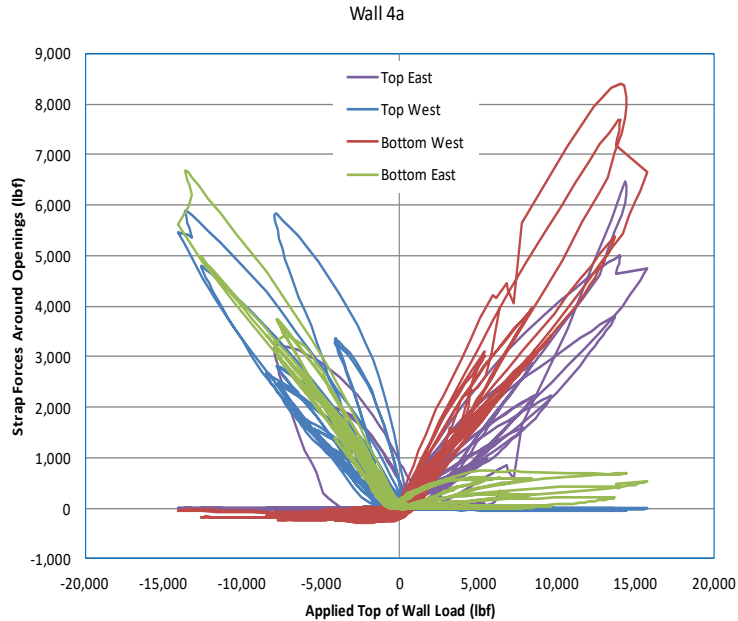
- The response curves are representative for wall 1 & 2
- Compares segmented piers vs. sheathed with no straps
- Observe the increased stiffness of perforated shear (Wall 2) vs. the segmented shear (Wall 1)



Testing Observation

Wall 4

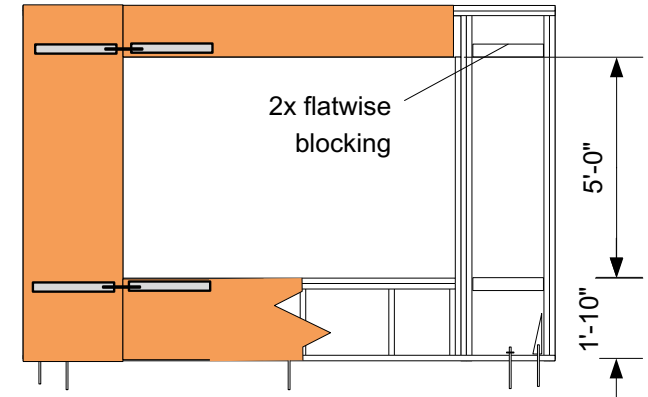
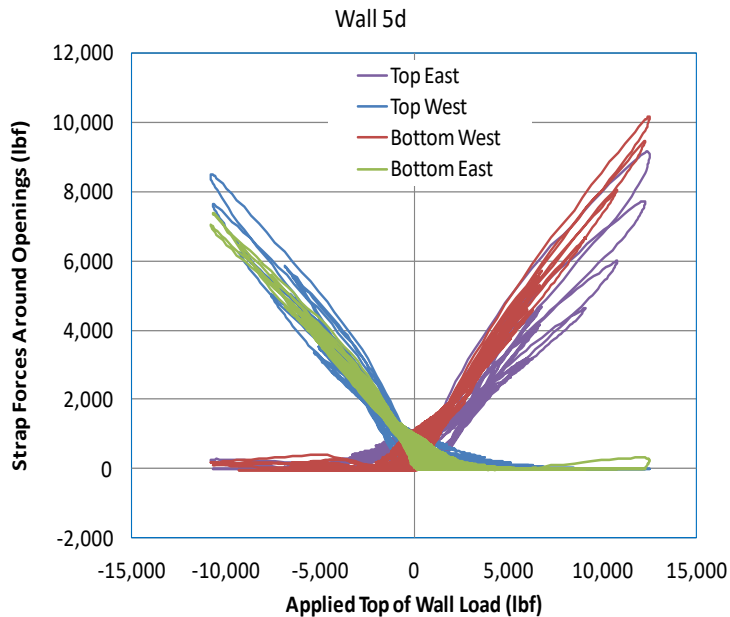
- Narrow piers
- Deep sill



Testing Observation

Wall 5

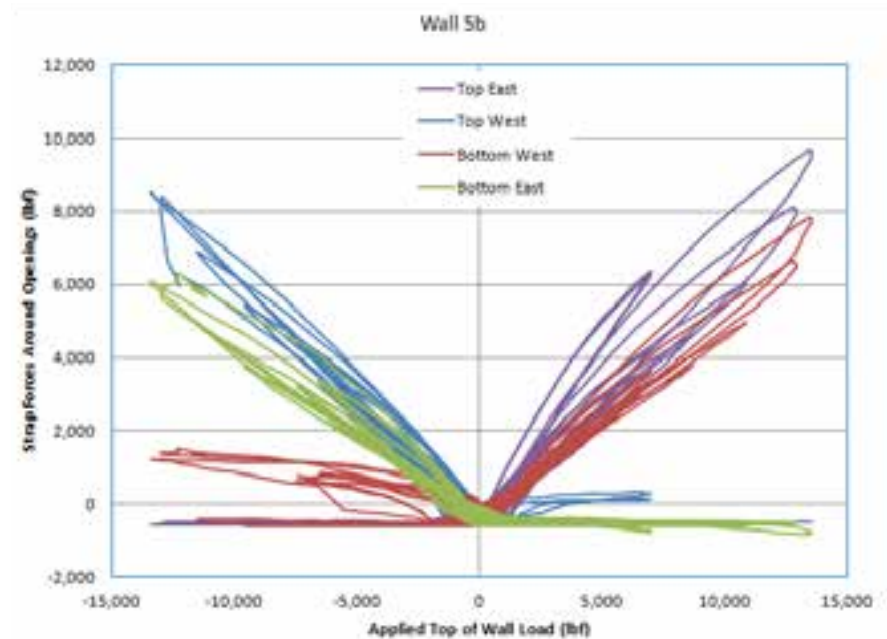
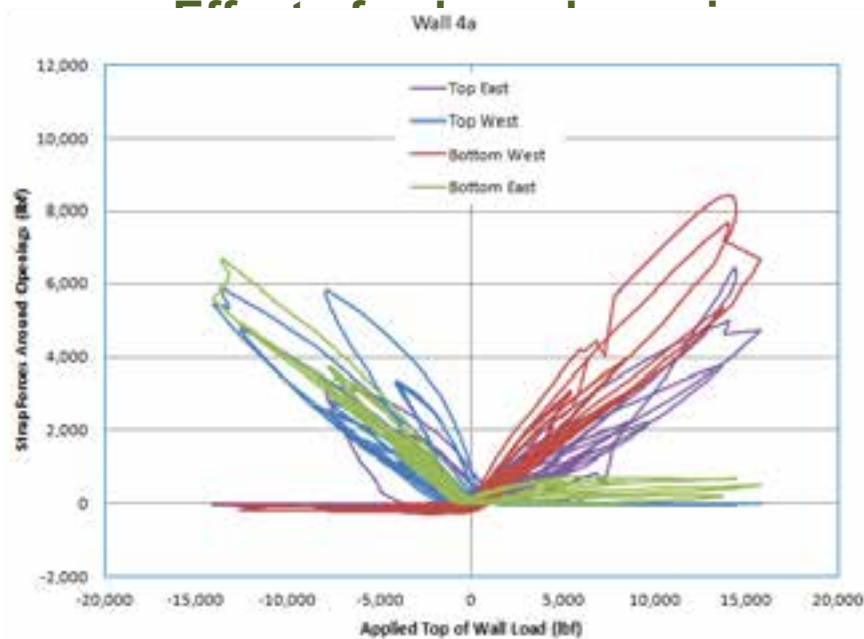
- Increased opening from Wall 4
- Shallow sill



Local Response

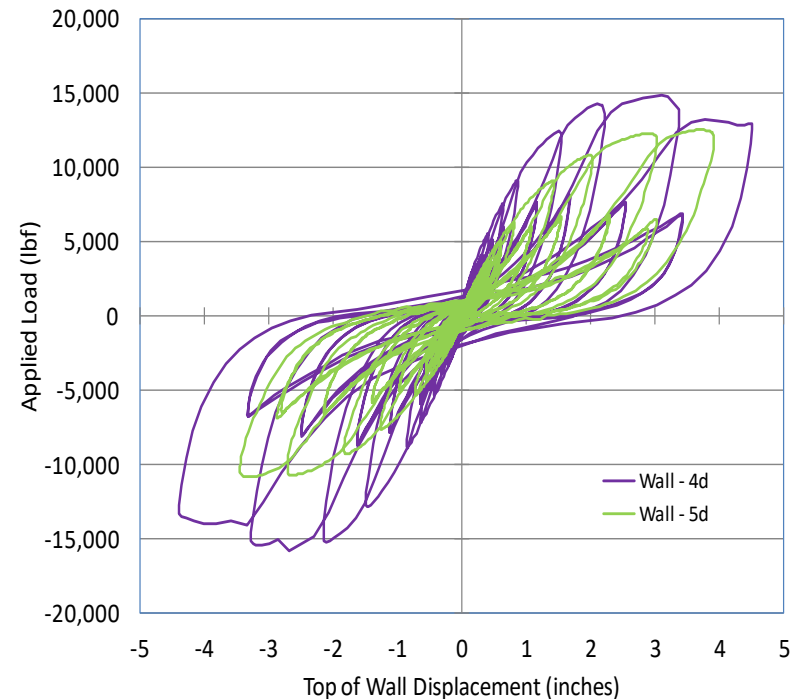
Comparison of opening size vs. strap forces

- 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

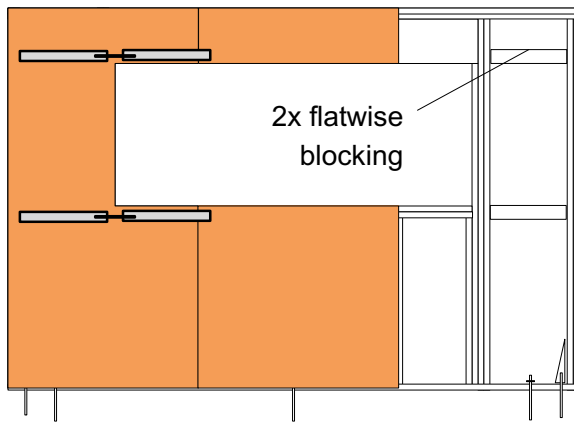
- **12 assemblies tested, examining the three approaches to designing and detailing walls with openings**
 - **Segmented**
 - **Perforated Shear Wall**
 - **Force Transfer Around Openings**
- **Walls detailed for FTAO resulted in better global response**

Conclusions

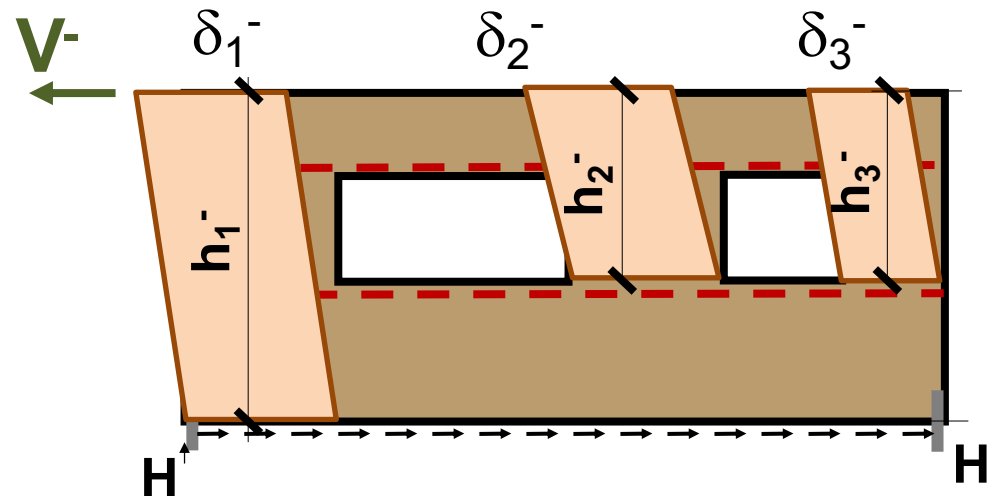
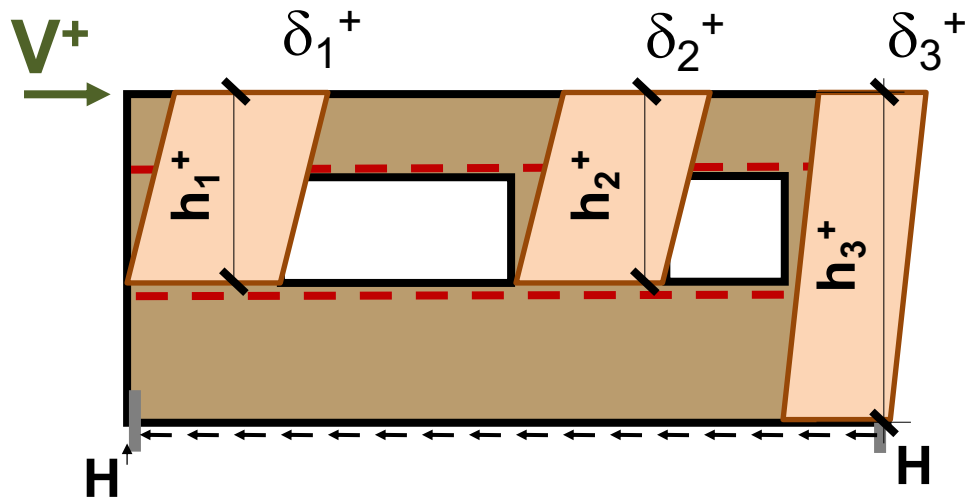
- **Comparison of analytical methods with tested values for walls detailed as FTAO**
 - The drag strut technique was consistently **un-conservative**
 - The cantilever beam technique was consistently ultra-conservative
 - SEAOC/Thompson provides similar results as Diekmann
 - SEAOC/Thompson & Diekmann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



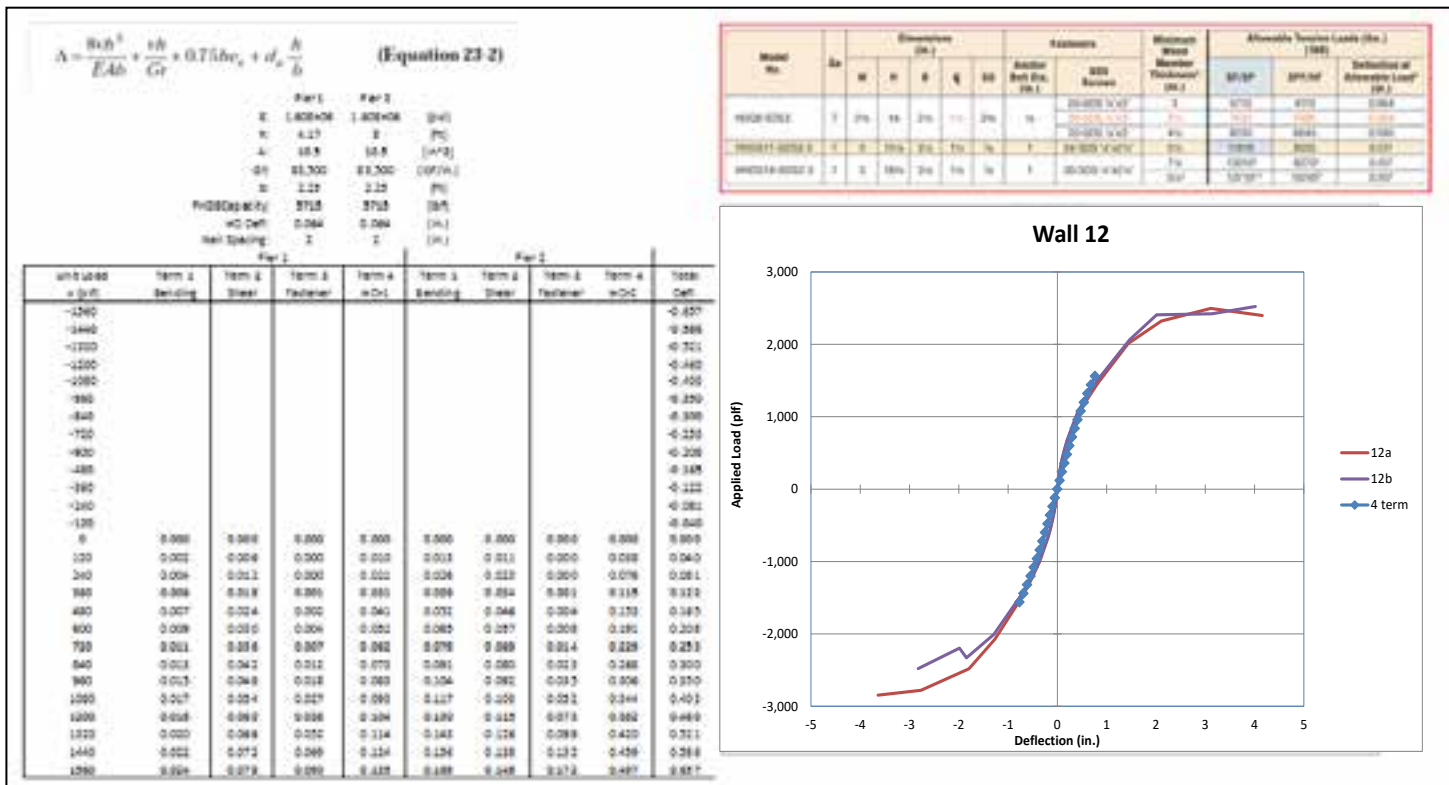
Deflection Calculations - Concept



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

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



Report Available

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Featured

Enter "Force Transfer" or "M410"

149 pages, 28.5 MB



FEATURED PUBLICATION

APA Engineered Wood Construction Guide

E30

Comprehensive guide to engineered wood construction systems for both residential and commercial/industrial buildings. Includes information on plywood and oriented strand board (wood structural panels), glulam, I-joists, structural composite lumber, typical specifications, and design recommendations for floor, wall, and roof systems, diaphragms, shear walls, fire-rated systems, and methods of finishing. Revised July 2015.

PURCHASE ITEM (\$12.00)

FREE DOWNLOAD

SHOW EXCERPTS



FEATURED PUBLICATION

Guide to the 2015 IRC Wood Wall Bracing Provisions

Provides an explanation of the lateral bracing provisions of the 2015 International Residential Code (IRC). Available from the ICC at [Guide to the 2015 IRC Wood Wall Bracing Provisions](#)



FEATURED PUBLICATION

Advanced Framing Construction Guide

M400

This guide details several advanced framing techniques. For further details, also see APA Technical Topic: Wood Resistance of Wood Structural Panel Sheathed Walls, Form TT-110. Revised April 2015.

PURCHASE ITEM (\$2.00)

FREE DOWNLOAD



2018 Structural Panel & Engineered Wood Yearbook

MPK-E184

Chronicles historical demand and production. [View the table of contents](#). To download after checkout, choose "Click here for order details," then scroll down and click "Download" on the "APA Store | Order Details" tab to access the

Asymmetric Pier widths

- Martin, Diekmann (Wood Design Focus, 2005)

Discussion and Closure —

“Design of Structural Panel Shear Walls with Openings:

A Comparison of Methods Wood

Editor's Note: The *International Building Code* states, “design for functional method of analysis above.”

Figures 1 and 2 from the paper. A figure develops the design procedure in Martin's original paper.

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

$$\begin{array}{lll} L_0 = 4 & \text{ft} & h_1 = 2 \text{ ft} \\ L_2 = 4 & \text{ft} & h = 8 \text{ ft} \end{array}$$

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

Calculate unit shear the wall shall resist, v :

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

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

Karyn Beebe, P.E., LEED AP BD+C
APA
San Diego, CA

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

Abstract

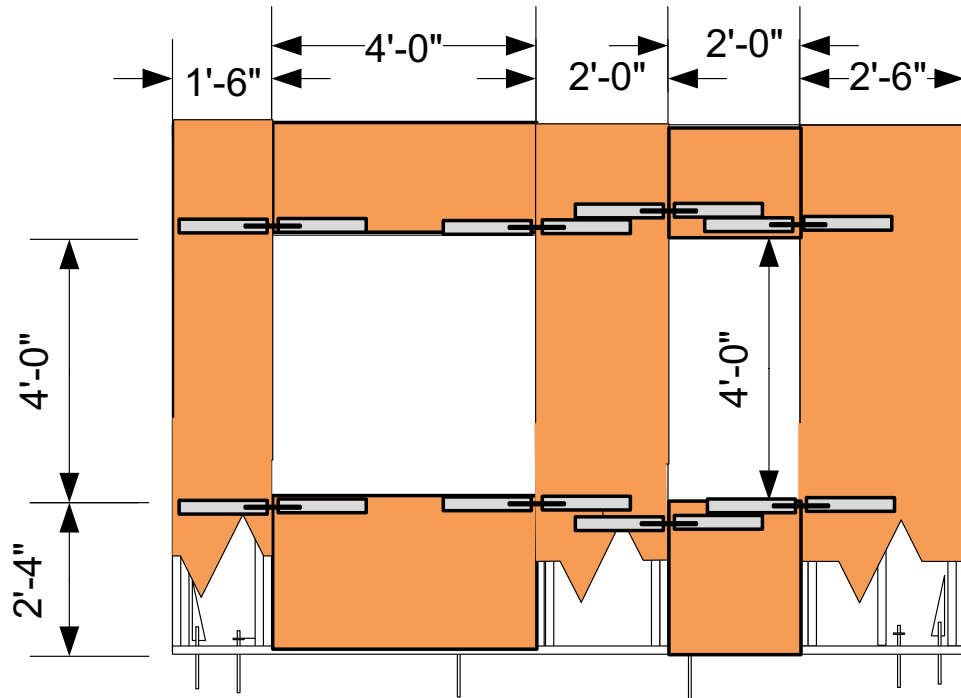
A joint research project of *APA – The Engineered Wood Association*, University of British Columbia (UBC), and USDA Forest Products Laboratory was initiated in 2009 to examine the variations of walls with code-allowable openings. This study examines the internal forces generated during these tests and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



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, $T1 = (L1 * Lo1) / (L1 + L2)$

Conceptual Keys

The method assumes the following:

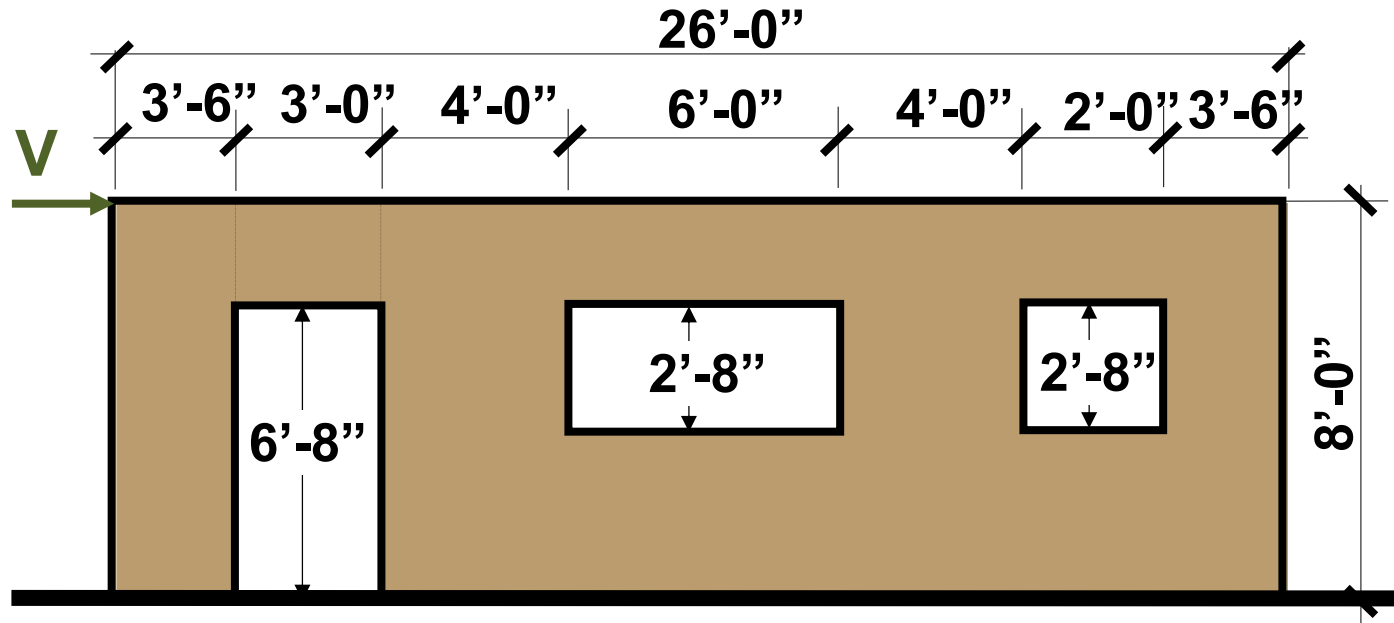
- The shear of each pier is the total shear divided by the L of the wall, multiplied by the sum of the length of the pier and its tributary length, divided by the length of the pier:
 - $(V/L)(L_1+T_1)/L_1$
- The unit shear of the corner zones is equal to subtracting the corner forces from the panel resistance, R. R is equal to the shear of the pier multiplied by the pier length:
 - $V_{a1} = (v_1L_1 - F_1)/L_1$

Conceptual Keys

The method assumes the following:

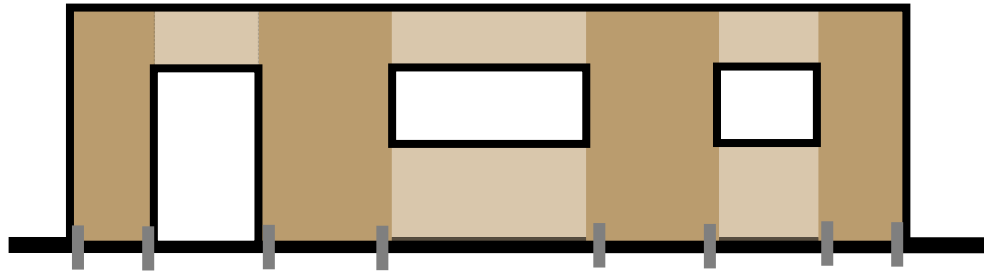
- **Once the entire segment shears have been calculated, then the design is checked by summing the shears vertically along each line. The first and last line equal the hold-down force, and the rest should sum to zero.**

Design Example



$$V = 3,750 \text{ lbs}$$

Segmented Approach



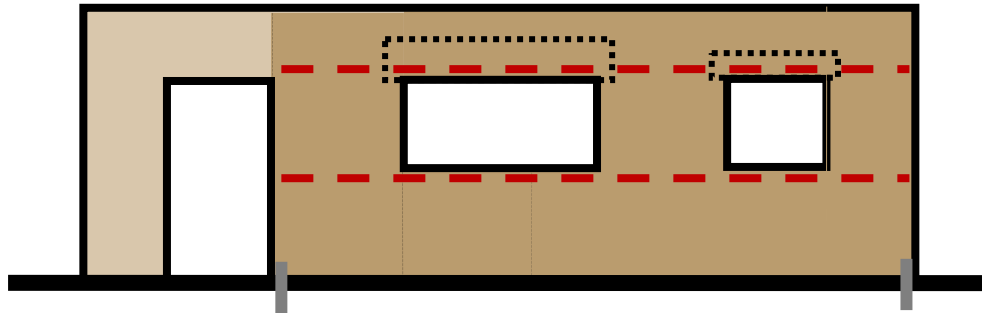
15/32" Rated sheathing

8d @ 4" o.c. (3'-6" walls)

8d @ 6" o.c. (4' walls)

8 – hold downs @ 2000+
lb capacity

Force Transfer



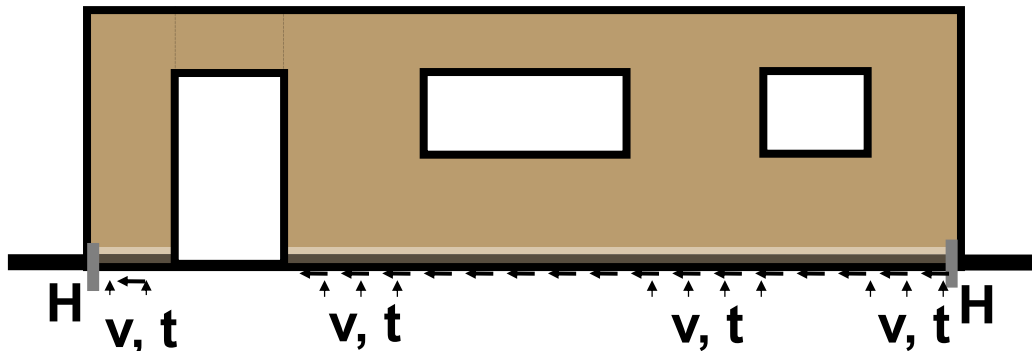
15/32" Rated Sheathing

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

The screenshot shows a web browser window with the URL <https://www.apawood.org/ftao>. The browser's address bar and tabs are visible at the top. The website's header is red with the APA logo on the left and navigation links (TECHNICAL RESEARCH, MANUFACTURER DIRECTORY, CONTACT) on the right. Below the header is a dark grey navigation bar with links for PRODUCTS, RESOURCE LIBRARY, DESIGN & BUILD, ABOUT US, FEATURED SITES, MEMBERS ONLY, and MY APA. The main content area has a white background with a red title "Force Transfer Around Openings (FTAO)" and a subtitle "VERSATILE SHEAR WALL ANALYSIS METHOD LENDS GREATER DESIGN FLEXIBILITY". The text explains that wood structural panel sheathed shear walls and diaphragms are the primary lateral-load-resisting elements in wood-frame construction. It then lists advantages of the FTAO method: more versatility and fewer hold-downs. A technical note titled "Design for Force Transfer Around Openings (FTAO)" is featured, with a thumbnail image and a "DOWNLOAD" button. On the right side, a sidebar promotes a webinar titled "Resolving Wood Shear Wall Design Puzzles with Force Transfer Around Openings, DE5415, AWC", providing an overview of the FTAO design approach and design methods (AIA, IGC, and NCSEA). A "LEARN MORE" button is located at the bottom of the sidebar.

Force Transfer Around

Secure | <https://www.apawood.org/ftao>

Apps Home > APA - The E... Home | Workforce In SEAO/CALBO Pol... CHAPTER 23 WOOD Seismic & Wind Des... IRC Roof Vent requir...

APA

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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

Webinar:
Resolving Wood Shear Wall Design Puzzles with Force Transfer Around Openings, DE5415, 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, IGC, and NCSEA credits available. Presented by Jared Hensley, PE, APA Engineered Wood Specialist.

LEARN MORE

www.apawood.org/FTAO

APA

TECHNICAL RESEARCH

MANUFACTURER DIRECTORY

CONTACT



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 system. The calculator includes worksheets for shear walls with one, two, and three openings and a design example.

DOWNLOAD

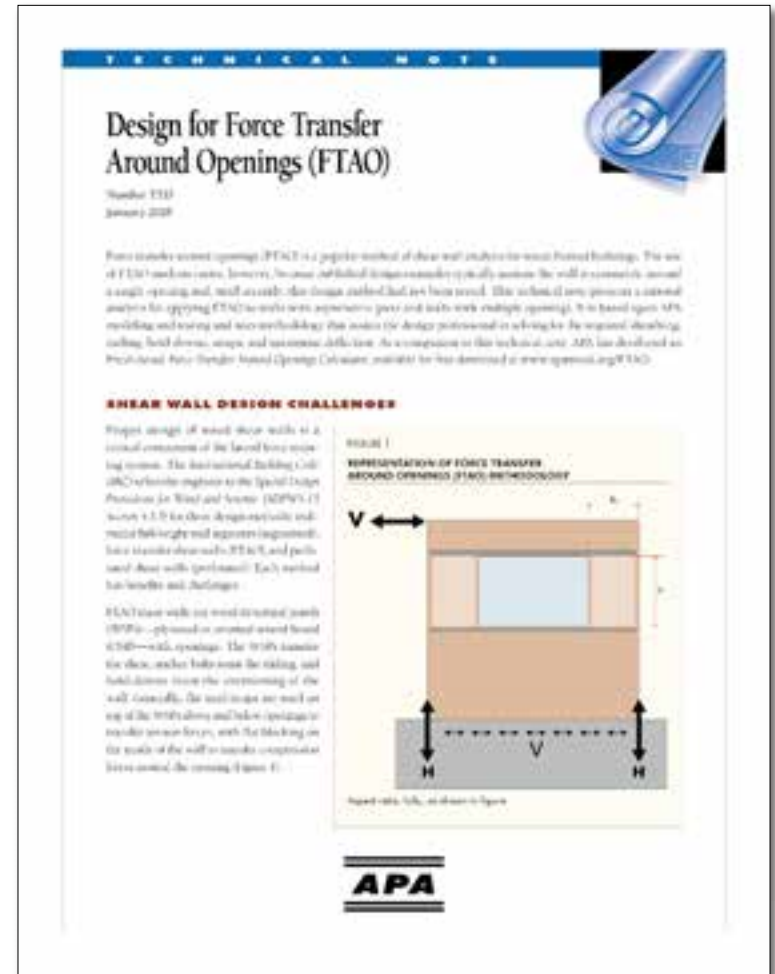
APA FTAO CALCULATOR

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.

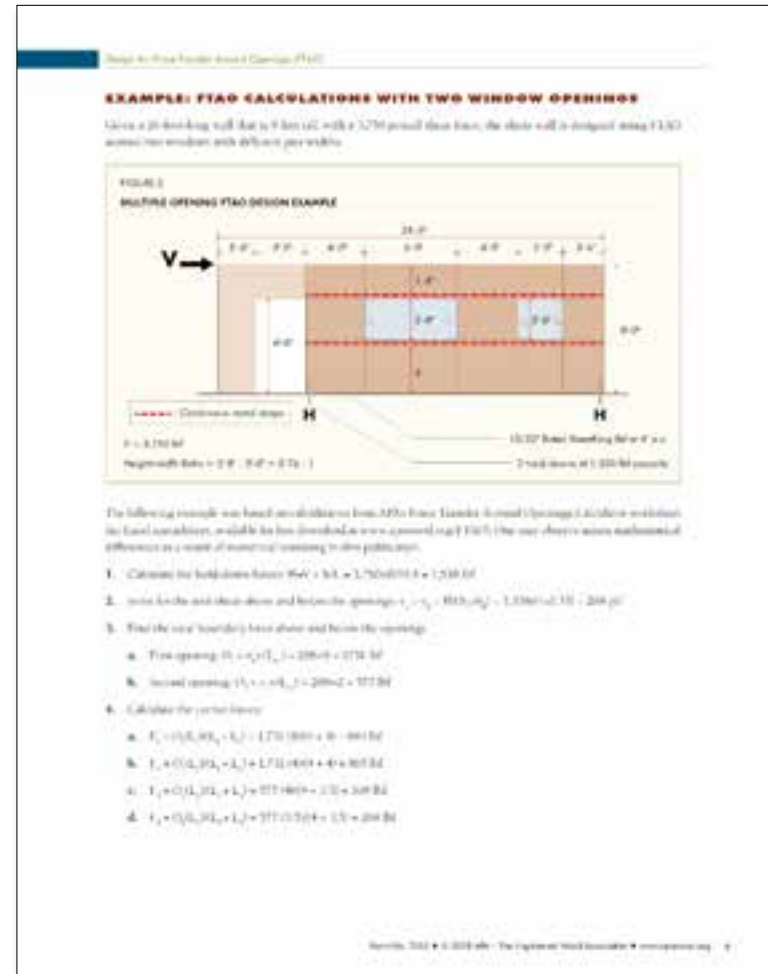
FTAO Technical Note: Form T555

- **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**



FTAO Technical Note: Form T555

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



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



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 **CHANGE** 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 ...



FTAO Calculator: Design Example

www.apawood.org/FTAO



Force Transfer Around Openings Calculator

DESIGN EXAMPLE

The Force Transfer Around Openings (FTAO) method of shear wall analysis is an approach that aims to maintain the wall section if performed as if there was no opening. This approach treats certain shortcomings with segmented shear walls, where verticality, because it allows for maximum wall segment width and pier spacing, the length-to-width ratios and other factors beyond field design.

Project Information

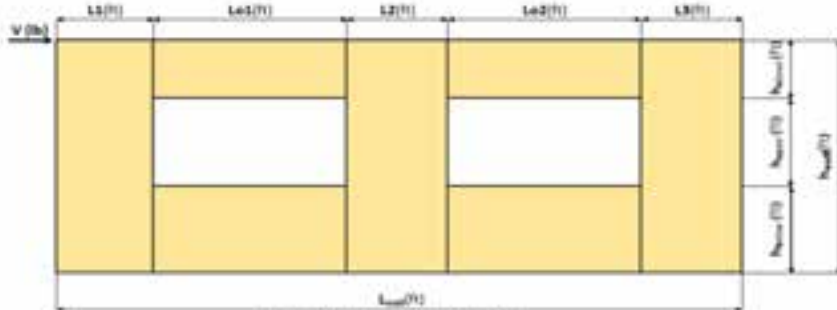
Code: 2015 IBC Date: _____

Designer: APA

Client: _____

Project: Design Example

Wall type: _____



Shear Wall Calculation Variables

	Opening 1	Opening 2	Wall Pier Aspect Ratio	Adj. Factor
V	3750 lbf			
L1	4.00 ft	ha1	P1=ho1/L1=	N/A
L2	4.00 ft	ho1	P2=ho2/L2=	N/A
L3	3.50 ft	hb1	P3=ho2/L3=	N/A
Hwall	8.00 ft	Lo1		
Lwall	15.50 ft	Lo2		

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

2. Unit shear above + below opening

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

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

6. Unit shear beside opening

$V1 = (V/L) \times (L1 + T1) / L1 =$ 337 pif

$V2 = (V/L) \times (T2 + L2 + T3) / L2 =$ 388 pif

$V3 = (V/L) \times (T3 + L3) / L3 =$ 344 pif

Instructions & Definitions
Design Example
One Opening
Two Openings
Three Openings

FTAO Calculator: One Opening

www.apawood.org/FTAO



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 integrated shear walls: more flexibility, because it allows for narrower wall segments while still meeting the height-to-width ratios and other, lesser-restricted hold-downs.

Project Information

Code: _____ Date: _____

Designer: _____

Client: _____

Project: _____

Wall Line: _____

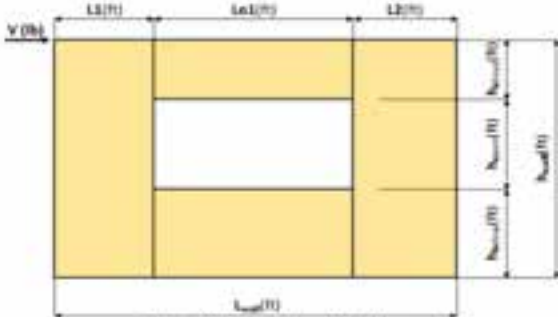


Diagram illustrating the Force Transfer Around Openings (FTAO) method for a shear wall with one opening. The wall is divided into three vertical sections with lengths $L1$, l_{o1} , and $L2$. The height of the wall is divided into three horizontal sections with heights h_{w1} , h_{o1} , and h_{w2} . The total height is H_w and the total length is L_w . A shear force V is applied to the wall.

Shear Wall Calculation Variables

	Opening 1	Wall Pier Aspect Ratio	Adj. Factor
V	h_{a1}	$P1 = h_{o1}/L1 =$	
$L1$	h_{o1}	$P2 = h_{o1}/L2 =$	
$L2$	h_{b1}		
h_{w1} 0.00 ft	l_{o1}		
l_{w1} 0.00 ft			

1. Hold-down forces: $H = Vh_{w1}/l_{w1}$

2. Unit shear above + below opening
First opening: $v_{a1} = v_{b1} = H/(h_{a1}h_{b1}) =$

5. Unit shear beside opening
 $V1 = [V/L](L1+L2)/L1 =$
 $V2 = [V/L](L2+L1)/L2 =$
Check $V1*L1 + V2*L2 = V?$

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



FTAO Calculator: Two Openings

www.apawood.org/FTAO



Force Transfer Around Openings Calculator

TWO OPENINGS

The force transfer around openings (FTAO) method of shear wall design is an approach that aims to replicate the wall such that it performs as if there were no opening. This approach forces certain arrangements and dimensions of shear walls, more accurately, because it allows for maximum wall segments while still meeting the height-to-width ratio and other basic required hold-downs.

Project Information

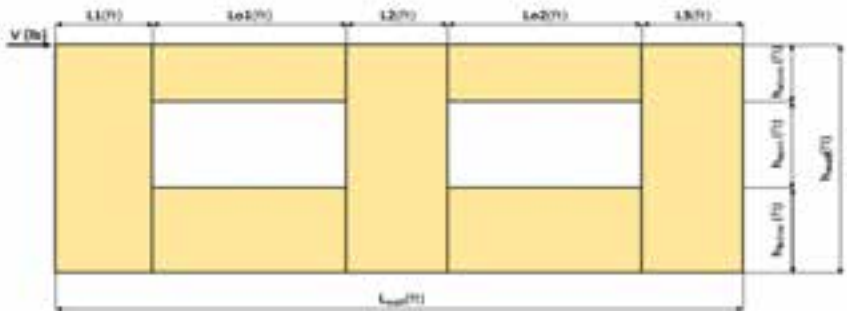
Code: _____ Date: _____

Designer: _____

Client: _____

Project: _____

Wall Line: _____



Shear Wall Calculation Variables

V	Opening 1	Opening 2	Wall Pier Aspect Ratio	Adj. Factor
L1	ha1	ha2	P1=ho1/L1=	
L2	ho1	ho2	P2=ho2/L2=	
L3	hb1	hb2	P3=ho2/L3=	
h _{total}	Lo1	Lo2		
l _{total}				

1. Hold-down forces: $H = Vh_{total}/l_{total}$

2. Unit shear above & below opening

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

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

6. Unit shear beside opening

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

$V2 = [V/L1](T2+L2+T3)/L2 =$

$V3 = (V/L3)(T4+L3+T5) =$

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



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 replicate the wall and pier behavior as if there was no opening. This approach treats corner openings that represent shear walls more accurately because it allows for increased wall segments while still meeting the height-to-width ratio and other force transfer field design.

Project Information

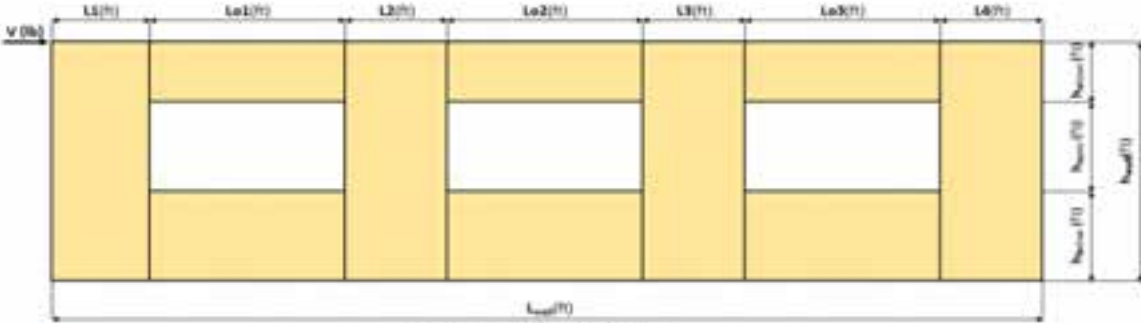
Code: _____ Date: _____

Designer: _____

Client: _____

Project: _____

Wall Line: _____



Shear Wall Calculation Variables

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

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

2. First shear above a hold-down location

3. Unit shear beside opening

4. Unit shear beside opening

5. Unit shear beside opening

6. Unit shear beside opening

7. Unit shear beside opening

8. Unit shear beside opening

9. Unit shear beside opening

10. Unit shear beside opening

11. Unit shear beside opening

12. Unit shear beside opening

13. Unit shear beside opening

14. Unit shear beside opening

15. Unit shear beside opening

16. Unit shear beside opening

17. Unit shear beside opening

18. Unit shear beside opening

19. Unit shear beside opening

20. Unit shear beside opening

21. Unit shear beside opening

22. Unit shear beside opening

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95. Unit shear beside opening

96. Unit shear beside opening

97. Unit shear beside opening

98. Unit shear beside opening

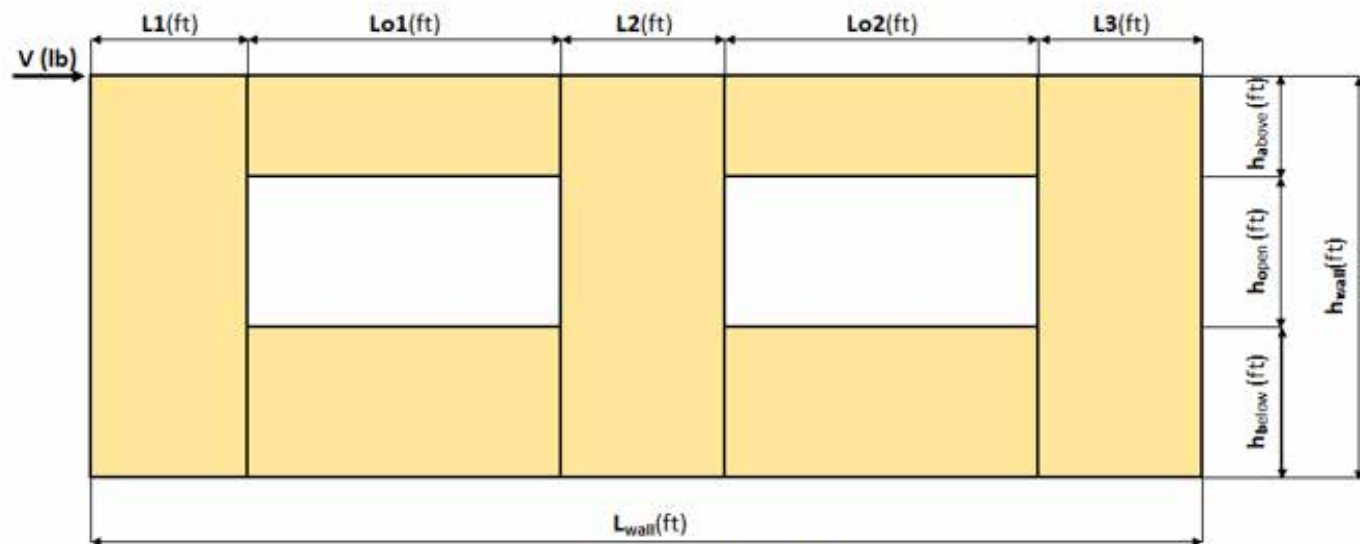
99. Unit shear beside opening

100. Unit shear beside opening

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



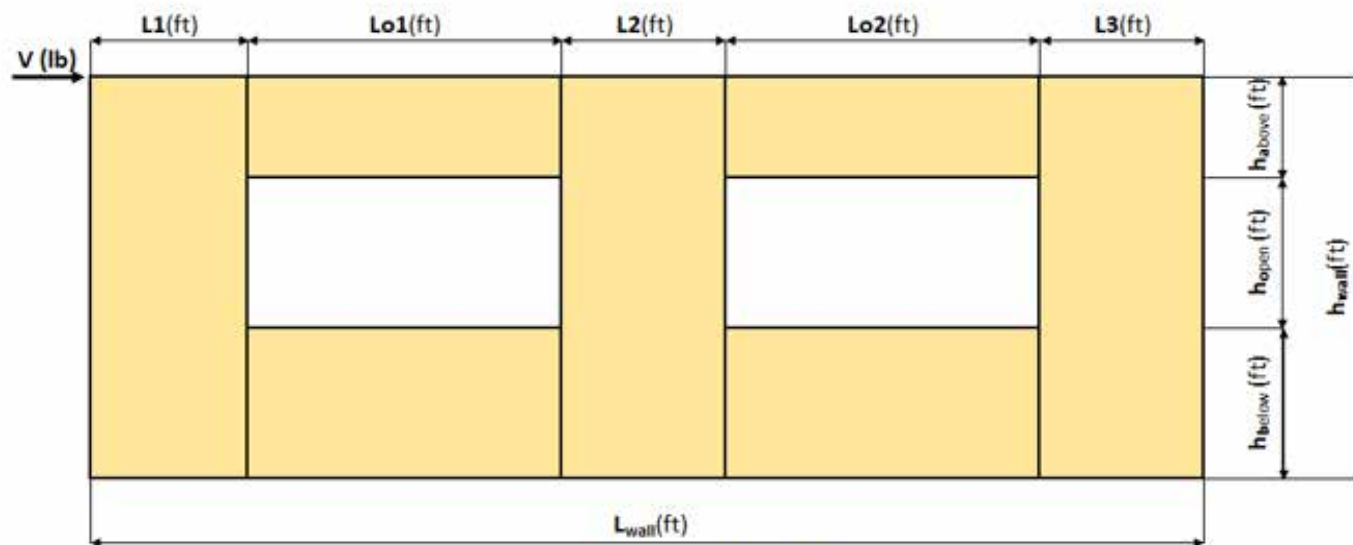
FTAO Calculator: Inputs



Shear Wall Calculation Variables

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

FTAO Calculator: Inputs



Shear Wall Calculation Variables

V	3750 lbf
L1	4.00 ft
L2	4.00 ft
L3	3.50 ft
h_{wall}	8.00 ft
L_{wall}	19.50 ft

Opening 1	
ha1	1.33 ft
ho1	2.67 ft
hb1	4.00 ft
Lo1	6.00 ft

Opening 2	
ha2	1.33 ft
ho2	2.67 ft
hb2	4.00 ft
Lo2	2.00 ft

Wall Pier Aspect Ratio		Adj. Factor
P1=ho1/L1=	0.67	N/A
P2=ho2/L2=	0.67	N/A
P3=ho2/L3=	0.76	N/A

FTAO Calculator: Shear wall analysis

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

2. Unit shear above + below opening

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

3. Total boundary force above + below openings

First opening: $O1 = va1 \times (Lo1) = 1731 \text{ lbf}$
 Second opening: $O2 = va2 \times (Lo2) = 577 \text{ lbf}$

4. Corner forces

$F1 = O1(L1)/(L1+L2) = 865 \text{ lbf}$
 $F2 = O1(L2)/(L1+L2) = 865 \text{ lbf}$
 $F3 = O2(L2)/(L2+L3) = 308 \text{ lbf}$
 $F4 = O2(L3)/(L2+L3) = 269 \text{ lbf}$

Strap
Forces

5. Tributary length of openings

$T1 = (L1*Lo1)/(L1+L2) = 3.00 \text{ ft}$
 $T2 = (L2*Lo1)/(L1+L2) = 3.00 \text{ ft}$
 $T3 = (L2*Lo2)/(L2+L3) = 1.07 \text{ ft}$
 $T4 = (L3*Lo2)/(L2+L3) = 0.93 \text{ ft}$

6. Unit shear beside opening

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

7. Resistance to corner forces

$R1 = V1*L1 = 1346 \text{ lbf}$
 $R2 = V2*L2 = 1551 \text{ lbf}$
 $R3 = V3*L3 = 853 \text{ lbf}$

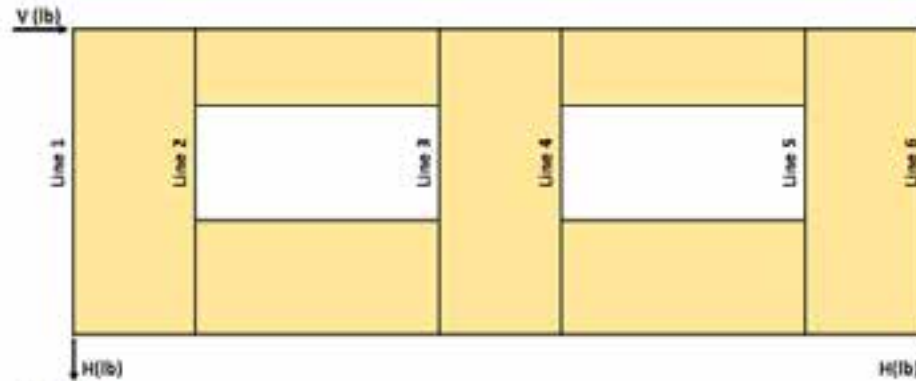
8. Difference corner force + resistance

$R1-F1 = 481 \text{ lbf}$
 $R2-F2-F3 = 378 \text{ lbf}$
 $R3-F4 = 583 \text{ lbf}$

9. Unit shear in corner zones

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

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
Req. Strap Force	865 lbf
Req. HD Force [H]	1538 lbf

4-Term Deflection	0.316 in.
4-Term Story Drift %	0.013 %

See Page 2

3-Term Deflection	0.335 in.
3-Term Story Drift %	0.014 %

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	

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)			
APA Rated Sheathing	Grade	Qty	Stud Size		
		2	2x6		
	Gt Override	A: 16.5 (in. ²)			
	Ga Override	A Override:	(in. ²)		
				Pier 1	Pier 3
				Nail Spacing: 4	4 (in.)
				HD Capacity: 2145	2145 (lbf)
				HD Deflection: 0.128	0.128 (in.)

Four-Term Equation Deflection Check

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

	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 _{stronger} :	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.)
V _n :	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

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

	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)
G_a :	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

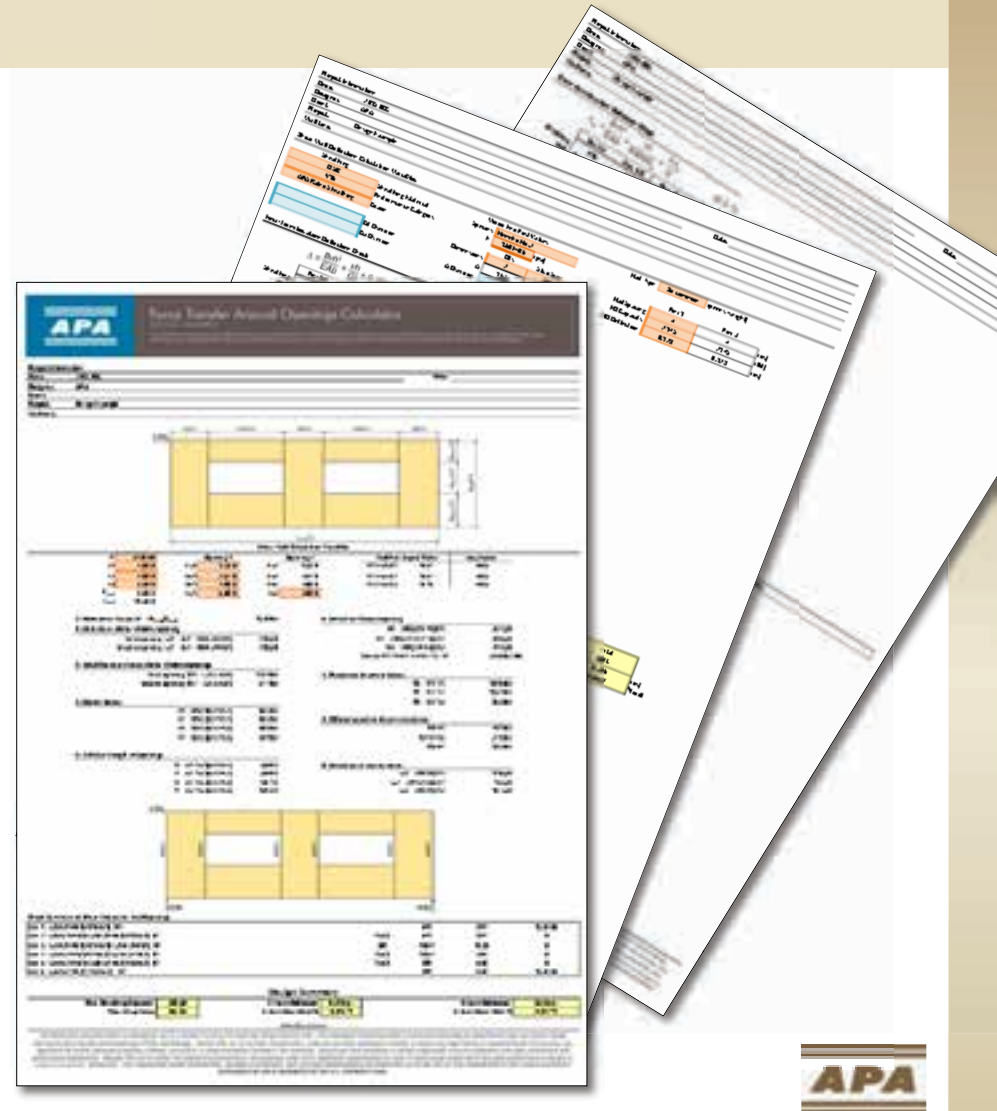
Total Defl.	
0.335	(in.)
0.0140	%drift



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



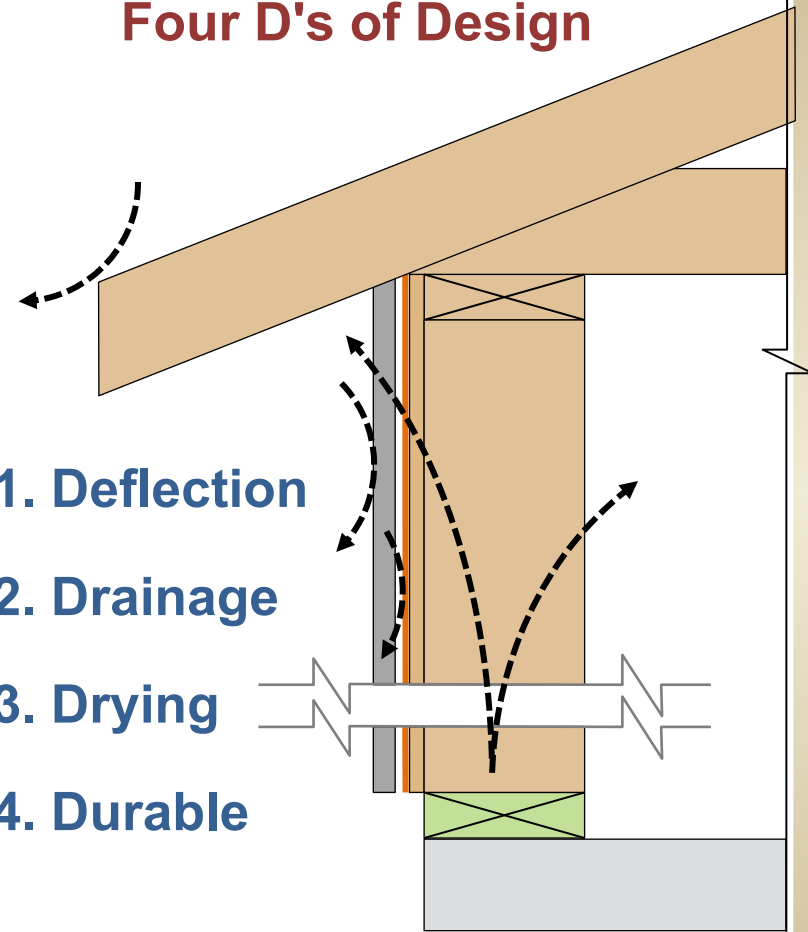
Four D's of Design

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



Karyn Beebe, PE, LEED AP

Karyn.beebe@apawood.org (858)668-7161 www.apawood.org