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This webinar will be recorded and available on www.STRUCTUREmag.org
Advancements in Force Transfer Around Openings for Wood Framed Shear Walls
Learning Objectives

- Investigate past and current methods for determining force transfer around openings for wood shear walls
- Compare the effects of different sizes of openings and full-height piers, and their relationships to the three industry standards for calculation of force transfer around openings
- Assess new design methodologies for accurately estimating the forces around multiple openings with asymmetric piers
- Estimate the deflections for shear walls designed using the force transfer around openings design method
- Apply the FTAO design methodology to an example
- Introduce APA’s new force transfer around opening design resources
Shear Wall Design Challenges (SDPWS-15 4.3.5)

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

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

**Force Transfer**
1. Code does not provide guidance for this method
2. Different approaches using rational analysis could be used
Segmented Wood Shear Walls (SDPWS-15 Section 4.3.5.1)

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

Aspect ratio $h:b_s$ as shown in figure
Segmented Wood Shear Walls

Aspect Ratios SDPWS-15

- **Standard shear walls**

  Figure 4D

  - Wall width is defined as width of the full height sheathing adjacent to the opening but sheathing IS NOT required above and below openings
  - $h:w$ must not exceed 2:1 or 3.5:1 ratio depending on sheathing material
Perforated Shear Walls (SDPWS-15 4.3.5.3)

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

Aspect ratio applies to full height segment (dotted)
Perforated Shear Walls

Aspect Ratios SDPWS-15

- Perforated shear walls

Figure 4C

- Wall width is defined as width of the full height sheathing adjacent to the opening but full sheathing is provided above and below openings

- $h:w$ must not exceed 2:1 or 3.5:1 ratio depending on sheathing material

Note: $b_s$ is the minimum shear wall segment length, $b_s$ in the perforated shear wall.
FTAO Shear Walls
(SDPWS-15 Section 4.3.5.2)

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

Aspect ratio h:b as shown in figure
FTAO Shear Walls

Aspect Ratio SDPWS-15

- **Force Transfer Shear Walls Figure 4E**
  - Width of wall is defined as width of the full height sheathing adjacent to the opening and the height is the same as the opening height
  - h:w must not exceed 2:1 or 3.5:1 ratio
Aspect ratio (SDPWS-15 4.3.4.2)

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

Excerpt Fig 4D
h:w ratio Segmented

Excerpt Fig. 4E
h:w ratio FTAO
Shear distribution to shear walls in line (SDPWS-15 4.3.3.4.1)

- Individual shear walls in line shall provide the same calculated deflection. Exception:
  - Nominal shear capacities of shear walls having \(2:1<\text{aspect ratio}\leq3.5:1\) are multiplied by \(2bs/h\) for design. Aspect ratio factor (4.3.4.2) need not be applied.

Excerpt Fig 4D
h:w ratio Segmented

Excerpt Fig. 4E
h:w ratio FTAO
Shear Wall Design Challenges
Shear Wall Design Challenges

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

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

- \( v^p = \frac{2,000}{10.3} = 194 \text{ plf} \)
- \( v = \frac{2,000}{2.3 + 4} = 317 \text{ plf} \)
• $F_1 = (317-194) \cdot L_1$
• $F_2 = (317-194) \cdot L_2$
• $F_1 = (317-194) \cdot 2.3 = 284 \text{ lbf}$
• $F_2 = (317-194) \cdot 4 = 493 \text{ lbf}$
Ex. 2 – Cantilever Beam Analogy

- $v = \frac{2,000}{2.3 + 4} = 317$ plf
- $v = \frac{2,000}{2.3 + 4} = 317$ plf
- $V_1 = 317 \times 2.3 = 730$ lbf
- $V_2 = 317 \times 4 = 1,270$ lbf
Ex. 2 – Cantilever Beam Analogy

- $\sum M_1 = 0$
- $F_1 \times h_u = v_1 \times (h_u + h_o/2)$
- $F_1 \times 2 = 730 \times (2 + 4/2)$
- $F_1 = (730 \times 4)/2 = 1,460$ lbf
\[ \sum M_2 = 0 \]
\[ F_2 \cdot h_L = v_2 \cdot (h_L + h_o/2) \]
\[ F_2 \cdot 2 = 1,270 \cdot (2 + 4/2) \]
\[ F_2 = (1,270 \cdot 4)/2 = 2,540 \text{ lbf} \]

Ex. 2 – Cantilever Beam Analogy
Ex. 3 – Diekmann Technique

- \( H = \frac{2,000 \times 8}{10.3} = 1,553 \text{ lbf} \)
Ex. 3 – Diekmann Technique

- \( v_h = \frac{2,000}{2.3 + 4} = 317 \text{ plf} \)
- \( v_v = \frac{1,553}{2 + 2} = 388 \text{ plf} \)
\[ v_h = \frac{2,000}{2.3 + 4} = 317 \text{ plf} = (V_B = V_G) \]
\[ v_v = \frac{1,553}{2 + 2} = 388 \text{ plf} = (V_D = V_E) \]
**Ex. 3 – Diekmann Technique**

\[
F = 388 \times 4 = 1,552 \text{ lbf}
\]

\[
F_1 = 1,552 \times \frac{2.3}{2.3 + 4} = 567 \text{ lbf}
\]

\[
F_2 = 1,552 \times \frac{4}{2.3 + 4} = 986 \text{ lbf}
\]
Ex. 3 – Diekmann Technique

\[ V_A = V_C = V_F = V_H = \]
\[ \frac{567}{2.3} = 246 \text{ plf} \]
\[ \frac{986}{4} = 246 \text{ plf} \]
\[ 317 \text{ plf} - 246 \text{ plf} = 71 \text{ plf} \]
Ex. 3 – Diekmann Technique
**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

Cantilever Beam Analogy
- Martin, Z.A. (see above)

Diekmann Method

Thompson Method
CUREE Basic Loading Protocol
Test Plan

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

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

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

**Wall 3**
Objective: No FTAO, compare to Wall 1 and 2. Examine effect of compression blocking.

**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.
Wall 5
Objective: FTAO, compare to Wall 4. Examine effect of straps with larger opening
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity

Wall 6
Objective: Compare to Wall 4. Examine effect of sheathing around opening
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity

Wall 7
Objective: Est. baseline case for 2:1 segmented wall

Wall 8
Objective: Compare FTAO to Wall 7
Wall is symmetric, sheathing and force transfer load measurement on right pier not shown for clarity
**Test Plan**

**Wall 9**
Objective: Compare FTAO to Wall 7 and 8. Collect FTAO data for wall with larger opening.

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

**Wall 10**
Objective: FTAO for 3.5:1 Aspect ratio pier wall. No sheathing below opening. Two hold downs on pier (fixed case).

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

**Wall 11**
Objective: FTAO for 3.5:1 Aspect ratio pier wall. No sheathing below opening. One hold downs on pier (pinned case).

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

**Wall 12**
Objective: FTAO for asymmetric multiple pier wall.
Testing Observation

Wall 13

![Graph showing applied load vs. top of wall displacement for Wall 13 and Wall 4d.]

![Image of Wall 13 in a testing facility.]
Test Plan

Information obtained

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

<table>
<thead>
<tr>
<th>Wall ID</th>
<th>Measured Strap Forces (lbf) (1)</th>
<th>Drag Strut Technique</th>
<th>Cantilever Beam Technique</th>
<th>Diekmann Technique</th>
<th>Thompson Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top/Bottom</td>
<td>Top</td>
<td>Top</td>
<td>Bottom</td>
<td>Top</td>
</tr>
<tr>
<td>Wall 4a</td>
<td>687 / 1,485</td>
<td>178%</td>
<td>82%</td>
<td>652%</td>
<td>183%</td>
</tr>
<tr>
<td>Wall 4b</td>
<td>560 / 1,477</td>
<td>219%</td>
<td>83%</td>
<td>800%</td>
<td>184%</td>
</tr>
<tr>
<td>Wall 4c (3)</td>
<td>668 / 1,316</td>
<td>183%</td>
<td>93%</td>
<td>670%</td>
<td>207%</td>
</tr>
<tr>
<td>Wall 4d</td>
<td>1,006 / 1,665</td>
<td>122%</td>
<td>73%</td>
<td>445%</td>
<td>164%</td>
</tr>
<tr>
<td>Wall 5b</td>
<td>1,883 / 1,809</td>
<td>65%</td>
<td>68%</td>
<td>327%</td>
<td>256%</td>
</tr>
<tr>
<td>Wall 5c (3)</td>
<td>1,611 / 1,744</td>
<td>76%</td>
<td>70%</td>
<td>382%</td>
<td>265%</td>
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<tr>
<td>Wall 5d</td>
<td>1,633 / 2,307</td>
<td>75%</td>
<td>53%</td>
<td>377%</td>
<td>201%</td>
</tr>
<tr>
<td>Wall 6a</td>
<td>421 / 477</td>
<td>291%</td>
<td>256%</td>
<td>1063%</td>
<td>571%</td>
</tr>
<tr>
<td>Wall 6b</td>
<td>609 / 614</td>
<td>201%</td>
<td>199%</td>
<td>735%</td>
<td>444%</td>
</tr>
<tr>
<td>Wall 8a</td>
<td>985 / 1,347</td>
<td>118%</td>
<td>86%</td>
<td>808%</td>
<td>359%</td>
</tr>
<tr>
<td>Wall 8b (4)</td>
<td>1,493 / 1,079</td>
<td>78%</td>
<td>108%</td>
<td>533%</td>
<td>449%</td>
</tr>
<tr>
<td>Wall 9a</td>
<td>1,675 / 1,653</td>
<td>69%</td>
<td>70%</td>
<td>475%</td>
<td>383%</td>
</tr>
<tr>
<td>Wall 9b</td>
<td>1,671 / 1,594</td>
<td>69%</td>
<td>73%</td>
<td>476%</td>
<td>397%</td>
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<tr>
<td>Wall 10a</td>
<td>1,580 / n.a. (5)</td>
<td>73%</td>
<td>n.a. (5)</td>
<td>496%</td>
<td>n.a. (5)</td>
</tr>
<tr>
<td>Wall 10b</td>
<td>2,002 / n.a. (5)</td>
<td>58%</td>
<td>n.a. (5)</td>
<td>391%</td>
<td>n.a. (5)</td>
</tr>
<tr>
<td>Wall 11a</td>
<td>2,466 / n.a. (5)</td>
<td>47%</td>
<td>n.a. (5)</td>
<td>318%</td>
<td>n.a. (5)</td>
</tr>
<tr>
<td>Wall 11b</td>
<td>3,062 / n.a. (5)</td>
<td>38%</td>
<td>n.a. (5)</td>
<td>256%</td>
<td>n.a. (5)</td>
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<tr>
<td>Wall 12a</td>
<td>807 / 1,163</td>
<td>81%</td>
<td>94%</td>
<td>593%</td>
<td>348%</td>
</tr>
<tr>
<td>Wall 12b</td>
<td>1,083 / 1,002</td>
<td>60%</td>
<td>109%</td>
<td>442%</td>
<td>403%</td>
</tr>
</tbody>
</table>

(1) Measured Strap Forces (lbf)
(2) Error (%) for Predicted Strap Forces at ASD Capacity

---

**Wall 5b** and **Wall 9b** are marked with a superscript (3) or (4) to indicate additional notes or conditions.
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)
Wall 4

- Narrow piers
- Deep sill
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
Other Testing Observations

Failure modes expected (Wall 5)

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

Failure modes

- Contributions of wall segments
  - Variable stiffness
  - Banging effect
C-shaped Panels

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

2x flatwise blocking
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
Conclusions

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

- Comparison of analytical methods with tested values for walls detailed as FTAO
  - The drag strut technique was consistently un-conservative
  - The cantilever beam technique was consistently ultra-conservative
  - Thompson provides similar results as Diekmann
  - Thompson & Diekmann techniques provided reasonable agreement with measured strap forces

- Better guidance to engineers will be developed by APA for FTAO
  - Summary of findings for validation of techniques
  - New tools for IBC wall bracing
Report Available

www.apawood.org/publications

Enter “Force Transfer” or “M410”

149 pages, 28.5 MB
Multiple Openings

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

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

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2015 SEAOC CONVENTION PROCEEDINGS

Advancements in Force Transfer Around Openings for Wood Framed Shear Walls

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

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

The method assumes the following:

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

The method assumes the following:

- The shear of each pier is the total shear divided by the L of the wall, multiplied by the sum of the length of the pier and its tributary length, divided by the length of the pier:
  \[(V/L)(L_1+T_1)/L_1\]

- 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:
  \[V_{a1} = (v_1L_1 - F_1)/L_1\]
Diekmann Technique: Conceptual Keys

The method assumes the following:

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

\[ \Delta = \text{average}(\delta_1^+, \delta_2^+, \delta_3^+, \delta_1^-, \delta_2^-, \delta_3^-) \]
Deflection Calculations

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

![Deflection Calculations Diagram](image-url)
Shear Wall Design Examples

- ✓ Segmented Shear Wall Approach
- ❌ Force Transfer Around Opening Approach
Shear Wall Design Examples

Standard Example Wall with 3 openings.

\[ V = 3,750 \text{ lb} \]
Does not consider contribution of sheathing above and below openings
Segmented Approach

V = 3,750 lbs

Code Limitation
Height/width Ratio = 8:3.5
2w/h = (2)(3.5)/8 = 0.875
1. **Unit Shear**
   \[ V = \frac{V}{\sum L} = \frac{3,750}{15} = 250 \text{ lbs/ft} \]

2. **Allowable Shear 3’-6” walls**
   \[ v_{\text{allowable}} = 380 \times 0.875 = 332 \text{ lbs/ft} > 250 \text{ lbs/ft} \]
   
   **15/32” Rated Sheathing 8d @ 4”o.c. at 3.5’ walls**

3. **Allowable Shear 4’ walls (2:1 h:w)**
   \[ v_{\text{allowable}} = 260\text{lb/ft} > 250 \text{ lbs/ft} \]
   
   **15/32” Rated Sheathing 8d @ 6”o.c. @ 4’ walls**

4. **Hold-down forces**
   \[ H = vh = 250 \times 8 = 2,000 \text{ lbs} \]
   
   **8 – hold down @ 2000+ lb capacity**

---

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

15/32” Rated Sheathing 8d @ 4” o.c.

V = 3,750 lbs
v = 250 lbs/ft
H = 2,000 lbs

8 – hold downs @ 2000+ lb capacity

15/32” Rated Sheathing 8d @ 6” o.c.
Shear Wall Design Examples

- Segmented Shear Wall Approach

- Force Transfer Around Opening Approach
FTAO Approach

V = 3,750 lbs

Height/width Ratio = 2’-8” / 3’-6”
1. **Calculate the hold-down forces:**
   \[
   H = \frac{Vh}{L} = \frac{(3750 \times 8')}{19.5'} = 1538 \text{lbs}
   \]

2. **Solve for the unit shear above and below the openings:**
   \[
   va = vb = \frac{H}{(ha+hb)} = \frac{1538}{(1.33'+4')} = 289 \text{ plf}
   \]

*CK: The unit shear above and below the openings is equivalent.*
3. Find the total boundary force above and below the openings

First opening: \( O1 = va \times (Lo1) = 289 \text{ plf} \times 6' = 1734 \text{lbs} \)

Second opening: \( O2 = va \times (Lo2) = 289 \text{ plf} \times 2' = 578 \text{lbs} \)

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

\[ F_1 = \frac{O_1(L_1)}{L_1+L_2} = 866# \]
\[ F_2 = \frac{O_1(L_2)}{L_1+L_2} = 866# \]
\[ F_3 = \frac{O_2(L_2)}{L_2+L_3} = 308# \]
\[ F_4 = \frac{O_2(L_3)}{L_2+L_3} = 269# \]

\textit{CK: Strap forces}
5. Tributary length of openings (ft)

\[ T_1 = \frac{L_1(Lo_1)}{L_1+L_2} = 3' \quad T_2 = \frac{L_2(Lo_1)}{L_1+L_2} = 3' \]
\[ T_3 = \frac{L_2(Lo_2)}{L_2+L_3} = 1.1' \quad T_4 = \frac{L_3(Lo_2)}{L_2+L_3} = 0.9' \]

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

\[ V_1 = \frac{(V/L)(L_1 + T_1)}{L_1} = 337 \text{ plf} \]
\[ V_2 = \frac{(V/L)(T_2 + L_2 + T_3)}{L_2} = 388 \text{ plf} \]
\[ V_3 = \frac{(V/L)(T_4 + L_3)}{L_3} = 244 \text{ plf} \]

Check \( V_1 \cdot L_1 + V_2 \cdot L_2 + V_3 \cdot L_3 = V? \) YES

CK: The shear of each pier = the total shear / the \( L \) of the wall x (length of the pier + its tributary length)/ by the length of the pier
7. Resistance to corner forces
   - R1 = V1 * L1 = 1346lbs
   - R2 = V2 * L2 = 1551lbs
   - R3 = V3 * L3 = 853lbs

8. Resistance – corner force
   - R1 - F1 = 480lbs
   - R2 - F2 - F3 = 377lbs
   - R3 - F4 = 583lbs
9. Unit shear in the corner zones

- \( v_{a1} = \frac{(R1-F1)}{L1} = 120 \text{ plf} \)
- \( v_{a2} = \frac{(R2-F2-F3)}{L2} = 94 \text{ plf} \)
- \( v_{a3} = \frac{(R3-F4)}{L3} = 167 \text{ plf} \)

\textit{CK: The unit shear of the corner zones = panel resistance (R) - the corner forces . R = the shear of the pier x the pier length.}
10. Check your solution – YES to all
   - Line 1: va1(ha+hb)+v1(ho)=H?
   - Line 2: va(ha+hb)-va1(ha+hb)-V1(ho)=0?
   - Line 3: va2(ha+hb)+V2(ho)-va(ha+hb)=0?
   - Line 4 = Line 3
   - Line 5: va(ha+hb)-va3(ha+hb)-V3(ho)=0?
   - Line 6: va3(ha+hb)+V3(ho)=H?

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

Summary

26’-0”

6’-6”

3’-6” 3’-0” 4’-0” 6’-0” 4’-0” 3’-6”

2’-8”

V = 3,750 lb

v = 388 lbs/ft

H = 1,538 lbs

2-Horizontal straps rated at 866lbs

15/32” Rated Sheathing 8d @ 4”o.c.
Shear Wall Design Examples

Segmented Approach
- 15/32” Rated sheathing
- 8d @ 4” o.c. (3’-6” walls)
- 8d @ 6” o.c. (4’ walls)
- 8 – hold downs @ 2000+ lb capacity

Force Transfer
- 15/32” Rated Sheathing
- 8d @ 4” o.c.
- 2 – hold downs @ 1,538 lb capacity
- 2 Straps – 866 lb
Segmented & Perforated use full height segments
- 3.5:1 for 10’-0” = 34”

FTAO uses heights adjacent to openings
- 3.5:1 for 7’-0” = 24”  2:1 for 4’-0” = 24”

Shear Wall Design Examples
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.

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.
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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
- 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)
Force Transfer Around Openings (FTAO) 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.

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 sheer 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 $L_1$, $L_2$, $L_3$, and $L_4$ measured in feet (ft).
- $L_{o(i)}$: Length for individual clear openings as indicated by $L_{o1}$, $L_{o2}$, and $L_{o3}$ measured in feet (ft).
- $h_{o1}$: Maximum clear opening height of any opening in the wall system. Will be reported as $h_{o1}$, $h_{o2}$, and $h_{o3}$ measured in feet (ft).
- $h_a$: Height of continuous sheathing above the opening in correlation with $h_{o1}$ above. Will be reported as $h_{a1}$, $h_{a2}$, and $h_{a3}$ measured in feet (ft).
- $h_b$: Height of continuous sheathing below the opening in correlation with $h_{o1}$ above. Will be reported as $h_{b1}$, $h_{b2}$, and $h_{b3}$ 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 $h_{o1}$, $h_a$, and $h_b$.
- $L_{wall}$: Total calculated length of shear wall measured in feet (ft). Calculated as the summation of $L(i)$ and $L_{o(i)}$.

Variables for Shear Wall Deflection Calculations
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

**Shear Wall Calculation Variables**

<table>
<thead>
<tr>
<th>V</th>
<th>3750 lbf</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>4.00 ft</td>
</tr>
<tr>
<td>L2</td>
<td>4.00 ft</td>
</tr>
<tr>
<td>L3</td>
<td>3.50 ft</td>
</tr>
<tr>
<td>h_{wall}</td>
<td>8.00 ft</td>
</tr>
<tr>
<td>L_{wall}</td>
<td>19.50 ft</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opening 1</th>
<th>Opening 2</th>
<th>Wall Pier Aspect Ratio</th>
<th>Adj. Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>ha1</td>
<td>ha2</td>
<td>P1=ho1/L1=</td>
<td>0.67</td>
</tr>
<tr>
<td>ho1</td>
<td>ho2</td>
<td>P2=ho2/L2=</td>
<td>0.67</td>
</tr>
<tr>
<td>hb1</td>
<td>hb2</td>
<td>P3=ho2/L3=</td>
<td>0.76</td>
</tr>
</tbody>
</table>
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: \( O1 = va1 \times (Lo1) = \) 1731 lbf
   - Second opening: \( O2 = va2 \times (Lo2) = \) 577 lbf

4. Corner forces
   - \( F1 = O1/(L1)/(L1+L2) = \) 865 lbf
   - \( F2 = O1/(L2)/(L1+L2) = \) 865 lbf
   - \( F3 = O2/(L2)/(L2+L3) = \) 308 lbf
   - \( F4 = O2/(L3)/(L2+L3) = \) 269 lbf

5. Tributary length of openings
   - \( T1 = (L1\times Lo1)/(L1+L2) = \) 3.00 ft
   - \( T2 = (L2\times Lo1)/(L1+L2) = \) 3.00 ft
   - \( T3 = (L2\times Lo2)/(L2+L3) = \) 1.07 ft
   - \( T4 = (L3\times Lo2)/(L2+L3) = \) 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 \( V1 \times L1 + V2 \times L2 + V3 \times L3 = V \) = 3750 lbf OK

7. Resistance to corner forces
   - \( R1 = V1 \times L1 = \) 1346 lbf
   - \( R2 = V2 \times L2 = \) 1551 lbf
   - \( R3 = V3 \times L3 = \) 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

Design Summary

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

See Page 2
See Page 3
Design output:
- Required sheathing capacity
- Required strap force above and below openings
- Required hold-down force
- Maximum deflection

**Design Summary**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Sheathing Capacity</td>
<td>388 plf</td>
</tr>
<tr>
<td>Required Strap Force</td>
<td>855 lbf</td>
</tr>
<tr>
<td>Required HD Force (H)</td>
<td>1538 lbf</td>
</tr>
<tr>
<td>4-Term Deflection</td>
<td>0.316 in.</td>
</tr>
<tr>
<td>4-Term Story Drift%</td>
<td>0.013 %</td>
</tr>
<tr>
<td>3-Term Deflection</td>
<td>0.335 in.</td>
</tr>
<tr>
<td>3-Term Story Drift%</td>
<td>0.014 %</td>
</tr>
</tbody>
</table>

See Page 2 and Page 3
### FTAO Calculator

#### Shear Wall Deflection Calculation Variables

<table>
<thead>
<tr>
<th>Sheathing:</th>
<th>OSB 7/16 APA Rated Sheathing</th>
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<tbody>
<tr>
<td>Sheathing Material Performance Category Grade</td>
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<tr>
<td>Wood End Post Values:</td>
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<tr>
<td>Species:</td>
<td>Hem-Fir No.2</td>
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<tr>
<td>E:</td>
<td>1.60E+06 (psi)</td>
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<tr>
<td>Qty</td>
<td></td>
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<tr>
<td>Stud Size</td>
<td></td>
</tr>
<tr>
<td>Dimensions:</td>
<td>2x6</td>
</tr>
<tr>
<td>A:</td>
<td>16.5 (in.²)</td>
</tr>
<tr>
<td>A Override:</td>
<td></td>
</tr>
</tbody>
</table>

#### Four-Term Equation Deflection Check

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

<table>
<thead>
<tr>
<th>Sheathing:</th>
<th>Pier 1-L</th>
<th>Pier 1-R</th>
<th>Pier 2-L</th>
<th>Pier 2-R</th>
<th>Pier 3-L</th>
<th>Pier 3-R</th>
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<tbody>
<tr>
<td>Nail: 8d common</td>
<td>7/16</td>
<td>7/16</td>
<td>7/16</td>
<td>7/16</td>
<td>7/16</td>
<td>7/16</td>
</tr>
<tr>
<td>V_{sis}:</td>
<td>337</td>
<td>337</td>
<td>388</td>
<td>388</td>
<td>244</td>
<td>244</td>
</tr>
<tr>
<td>V_{strength}:</td>
<td>481</td>
<td>481</td>
<td>554</td>
<td>554</td>
<td>348</td>
<td>348</td>
</tr>
<tr>
<td>E:</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
</tr>
<tr>
<td>h:</td>
<td>8.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>8.00</td>
</tr>
<tr>
<td>A:</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
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<tr>
<td>Gt:</td>
<td>83,500</td>
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<td>83,500</td>
<td>83,500</td>
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<td>4</td>
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<td>4</td>
<td>4</td>
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<tr>
<td>Vn:</td>
<td>160</td>
<td>160</td>
<td>185</td>
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<td>e:</td>
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<td>0.0264</td>
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<td>0.0065</td>
</tr>
<tr>
<td>b:</td>
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<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
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<td>3.50</td>
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<td>2145</td>
<td>2145</td>
<td>2145</td>
<td>2145</td>
<td>2145</td>
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<tr>
<td>HD Defl:</td>
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<td>0.128</td>
<td>0.128</td>
<td>0.128</td>
<td>0.128</td>
<td>0.128</td>
</tr>
</tbody>
</table>
### FTAO Calculator

**Three-Term Equation Deflection Check**

\[
\delta_{sw} = \frac{8vh^2}{EAb} + \frac{vh}{1000G_a} + \frac{h\Delta_a}{b} \quad (4.3-1)
\]

<table>
<thead>
<tr>
<th>Sheathing:</th>
<th>Pier 1-L</th>
<th>Pier 1-R</th>
<th>Pier 2-L</th>
<th>Pier 2-R</th>
<th>Pier 3-L</th>
<th>Pier 3-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nail:</td>
<td>8d common</td>
<td>8d common</td>
<td>8d common</td>
<td>8d common</td>
<td>8d common</td>
<td>8d common</td>
</tr>
<tr>
<td>(v_{ssd})</td>
<td>337</td>
<td>337</td>
<td>388</td>
<td>388</td>
<td>244</td>
<td>244</td>
</tr>
<tr>
<td>(v_{strength})</td>
<td>481</td>
<td>481</td>
<td>554</td>
<td>554</td>
<td>348</td>
<td>348</td>
</tr>
<tr>
<td>(E)</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
<td>1.60E+06</td>
</tr>
<tr>
<td>(h)</td>
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<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>8.00</td>
</tr>
<tr>
<td>(A)</td>
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<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
</tr>
<tr>
<td>(G_a)</td>
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<td>22.0</td>
<td>22.0</td>
<td>22.0</td>
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<td>(b)</td>
<td>4.00</td>
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<td>4.00</td>
<td>4.00</td>
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<td>3.50</td>
</tr>
<tr>
<td>HD Capacity</td>
<td>2145</td>
<td>2145</td>
<td>2145</td>
<td>2145</td>
<td>2145</td>
<td>2145</td>
</tr>
<tr>
<td>HD Defl.</td>
<td>0.128</td>
<td>0.128</td>
<td>0.128</td>
<td>0.128</td>
<td>0.128</td>
<td>0.128</td>
</tr>
</tbody>
</table>

**Check Total Deflection of Wall System**

<table>
<thead>
<tr>
<th>Pier 1 (left)</th>
<th>Pier 1 (right)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Term 1</strong></td>
<td><strong>Term 2</strong></td>
</tr>
<tr>
<td>Bending</td>
<td>Shear</td>
</tr>
<tr>
<td>0.019</td>
<td>0.175</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>Sum</strong></td>
</tr>
<tr>
<td>0.653</td>
<td>0.205</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pier 2 (left)</th>
<th>Pier 2 (right)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Term 1</strong></td>
<td><strong>Term 2</strong></td>
</tr>
<tr>
<td>Bending</td>
<td>Shear</td>
</tr>
<tr>
<td>0.003</td>
<td>0.101</td>
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<tr>
<td><strong>Sum</strong></td>
<td><strong>Sum</strong></td>
</tr>
<tr>
<td>0.236</td>
<td>0.236</td>
</tr>
</tbody>
</table>

**Total Defl.**

\[ 0.335 \text{ in.} \]

**%drift**

\[ 0.0140 \text{ in.} \]
Final Design Output

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

For the Structural Engineer...
- Straightforward rational analysis
- Easy to program: Excel, web based application, or other
- Design check = confidence in calculations

<table>
<thead>
<tr>
<th>CHECK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1: va₁(ha + hb) + V₁(h₀) = H?</td>
</tr>
<tr>
<td>Line 2: va₁(ha + hb) - va₁(ha + hb) - V₁(h₀) = 0?</td>
</tr>
<tr>
<td>Line 3: va₂(ha + hb) + V₂(h₀) - va₁(ha + hb) = 0?</td>
</tr>
<tr>
<td>Line 4 = Line 3</td>
</tr>
<tr>
<td>Line 5: va₁(ha + hb) - va₃(ha + hb) - V₃(h₀) = 0?</td>
</tr>
<tr>
<td>Line 6: va₃(ha + hb) + V₃(h₀) = H?</td>
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<tr>
<td>641</td>
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<tr>
<td>1538</td>
</tr>
<tr>
<td>504</td>
</tr>
<tr>
<td>1538</td>
</tr>
<tr>
<td>889</td>
</tr>
</tbody>
</table>
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

Structural Systems that Enhance Energy Efficiency

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

Diagram:
- Min R10.7 header
- R19 batts (=R18)
- Min 7/16 CAT WSP
- WRB
- R4 (1” EPS)
- 1-coat stucco
Benefits of FTAO with Continuous WSPs

Air Infiltration = Energy Loss

- Air barrier should be continuous
- Joints need to be sealed (i.e. blocked panel edges)
- Need water resistive barrier
Benefits of FTAO with Continuous WSPs

Value proposition

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

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Questions?

APA Help Desk:
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Advancements in Force Transfer Around Openings for Wood Framed Shear Walls