Design for Force Transfer Around Openings (FTAO)

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

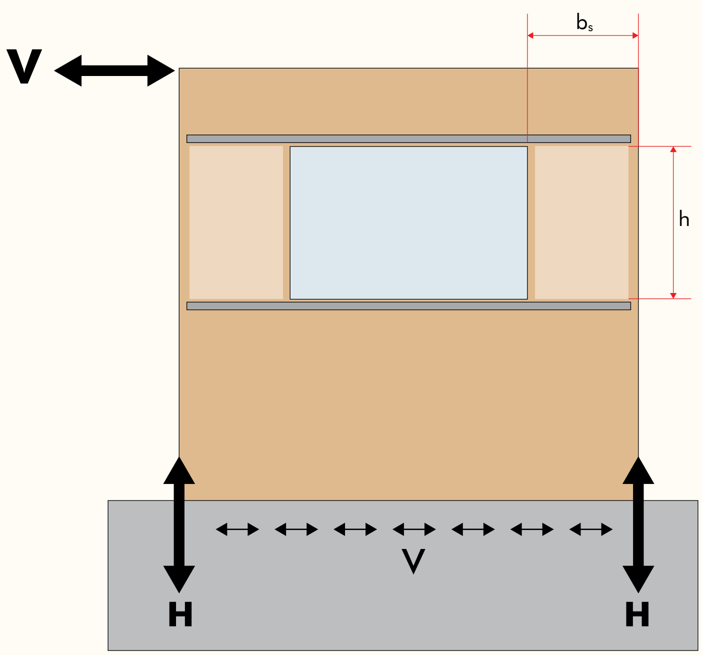
SHEAR WALL DESIGN CHALLENGES

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

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

FIGURE 1

REPRESENTATION OF FORCE TRANSFER AROUND OPENINGS (FTAO) METHODOLOGY



Aspect ratio, h/b_s, as shown in figure

While the FTAO design method requires comprehensive analysis and detailing, it has significant benefits when considering aspect ratio, anchorage requirements, and the nonstructural benefits of a consistent wall plane created through the use of continuous sheathing. FTAO can be used for a wider range of wall sizes and multiple openings than possible with the segmented or perforated methods, too.

Maximum shear wall aspect ratios are defined in *SDPWS-15 Section 4.3.4*. Differentiating the code-allowable design methods with regard to aspect ratios, the segmented and perforated methods define (h) as the height of the wall segment from the bottom plate to the top plate. In the FTAO method, (h) represents the height of the opening that the segment is adjacent to, as shown in Figure 1. This important distinction is why many structural engineers use FTAO when they cannot meet the aspect ratio limitations for segmented or perforated design.

Historically, walls designed to resist seismic forces were limited to a maximum aspect ratio of 2:1 or 3.5:1 with a reduction in capacity. Now, *SDPWS-15* applies this limitation to all shear walls (wind and seismic). This may make FTAO more useful to designers in low seismic zones where a design reduction may be required.

Another structural advantage is the elimination of hold-downs. Using FTAO, the engineer designs the hold-downs for the boundaries, eliminating two or more hold-downs that would otherwise be sized for the segmented approach. Continous sheathing with plywood or OSB also creates an uninterrupted drainage plane; enables the sheathing to act as an air barrier; provides a continuous nail base for cladding materials; and creates a stiffer wall, mitigating stucco cracking.

HISTORY OF FTAO RESEARCH AT APA

The FTAO method is a codified rational analysis for design. Significant engineering consideration has been given to the topic of rational analysis, and excellent examples targeted to practitioners have been developed by a number of sources. The lack of available test data and the variability in rational analyses motivated APA's research of the force transfer around openings method.

Joint Research Report: Evaluation of Force Transfer Around Openings—Experimental and Analytical Studies, Form M410, available at www.apawood.org/resource-library, provides a comprehensive discussion of various rational analyses, as well as supporting test data that leads to the conclusion that the Diekmann technique most accurately estimates the force distribution of FTAO walls. The test data also verified the deflection design shown herein.

The Diekmann technique provided reasonable predicted results for all walls that transferred the forces around openings through the use of metal straps. The only exception was an atypical wall where the sheathing wrapped around the opening. In that case, the forces were transferred through the sheathing, as opposed to the straps. This finding shows wood structural panels are transferring a significant portion of the force around the openings.

A separate rational analysis (outside the scope of this technical note) may be considered, particularly for low tension forces, to eliminate tension strapping and should take into consideration that the ultimate failure of the wall sheathing in this atypical wall was due to tearing. Although APA has not further developed this concept, obvious items to consider are panel shear, panel tension, in-plane bending and geometry of the remaining portion of the panel. Regardless, many framers hang full four-foot-wide panels and later cut the opening out of the panel section, yielding added structural redundancy.

The Thompson method and the Diekmann technique provided similar results, with good agreement between predicted and measured strap forces. (For more information on the Thompson method, see *2015 IBC SEAOC Structural/Seismic Design Manual Volume 2: Examples for Light-Frame, Tilt-Up and Masonry Buildings*, available on www.iccsafe.org.)

Ultimately, the Diekmann methodology is the basis for this publication; reference *Joint Research Report: Evaluation of Force Transfer Around Openings—Experimental and Analytical Studies*, Form M410, Table 2, where calculated forces for wall 12 (which has 2 openings with asymmetric piers) using the Diekmann technique reasonably matched the measured forces.

FTAO DETAILING

1. Check the aspect ratio, height divided by the width (h/b_s), of the FTAO wall by examining the full height piers. The height of the wall pier (h) is defined as the height of the maximum opening on either side of each full height pier. The width (b_s) is the length of the full height wall pier with sheathing and without an opening. (*SDPWS-15 Section 4.3.4.4 and Figure 4E*):

- **a.** The aspect ratio, h/b_s, is limited to 2:1 without adjustment.
- **b.** When (h/b_s) is greater than 2:1 and less than 3.5:1, the nominal shear capacity shall be multiplied by the aspect ratio adjustment factor = $1.25 – 0.125\ (h/b_s)$.
- **c.** Wall piers with aspect ratios exceeding 3.5:1 shall not be considered as portions of the force-transfer walls.

2. Sheathing shall be installed with 10d common (3.0 inches x 0.148 inch) or smaller nails. Section 4.3.5.2(1) of SDPWS requires the length of each wall pier be not less than 2 feet. Based on *Joint Research Report: Evaluation of Force Transfer Around Openings—Experimental and Analytical Studies*, Form M410, this technical note permits the minimum sheathed width of a pier to be 18 inches or greater, provided that aspect ratio of the pier is 3.5:1 or less, and all wood structural panel edges are blocked.

3. The maximum fastener spacing shall be 6 inches on the perimeter of the panel and 12 inches in the field of the panel. Nail spacing is permitted to be reduced to 2 inches on center for nail spacing at the perimeter of the panel, and 3 inches on center for the field of the panel. Closer field nail spacing shall be permitted when following the strap manufacturer's installation recommendations, or as required by analysis. Wall opening corner forces shall be designed in accordance with this publication. The methodology for resisting the corner forces (straps or increased nailing to wall sheathing) is the responsibility of the design professional.

4. Design properties for lumber framing, including blocking, studs, and top and bottom plates, as well as anchor bolts, shall be designed in accordance with the *ANSI/AWC National Design Specification for Wood Construction (NDS)* and *NDS Supplement*. The unit shear wall values shall be designed in accordance with *SDPWS*. The forces around openings shall be determined in accordance with this publication. Wood structural panel capacities shall be designed in accordance with APA's *Panel Design Specification*, Form D510, available at www.apawood.org/resource-library. Metal strap reinforcement and overturning anchorage design shall be the responsibility of the design professional.

5. Metal straps, when required, are commonly attached on the outside of the building, placed over the wood structural panel sheathing. However, for deflection-sensitive exterior cladding, it shall be permitted to place straps on the inside of the wall framing.

DESIGN ASSUMPTIONS AND PROCEDURES

Methodology

1. The unit shear above and below the openings is equivalent.
2. The corner forces are based on the unit shear forces above and below the openings and the length of the piers adjacent to that individual opening.
3. The tributary opening length is the basis for calculating the shear load in each pier. This tributary opening length is based on opening length and the percent weighted average length of the adjacent piers.
4. The shear to each pier is based on total wall shear and the summation of length of pier and tributary opening lengths to pier.
5. The unit shear in the corner zones is based on the difference between panel resistance and the corner forces.
6. Once all of the segment shears have been calculated, 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 shall sum to zero.

Shear Wall Deflection

The approach begins with the historical four-term deflection equation (IBC Equation, 23-2) and the assumption that the FTAO wall is controlled by the deflection of the full-height piers. For calculation purposes, the height of the pier that is deflecting away from the sheathed area under the window opening is the full height of the wall. For the pier that is being loaded toward the sheathed area under the window, the wall height is calculated as the distance from the top of sheathed area below the window opening to the top of the wall. The deflection of the wall is then calculated as the average of the calculated deflection for each full height pier pushed in both directions. The remainder of the terms in the four-term deflection equation are identical to the traditional use of the equation. The three-term deflection equation, as published in *SDPWS*, provides a more conservative estimation of the wall drift. Figure 2 provides a visualization of this methodology for multiple openings.

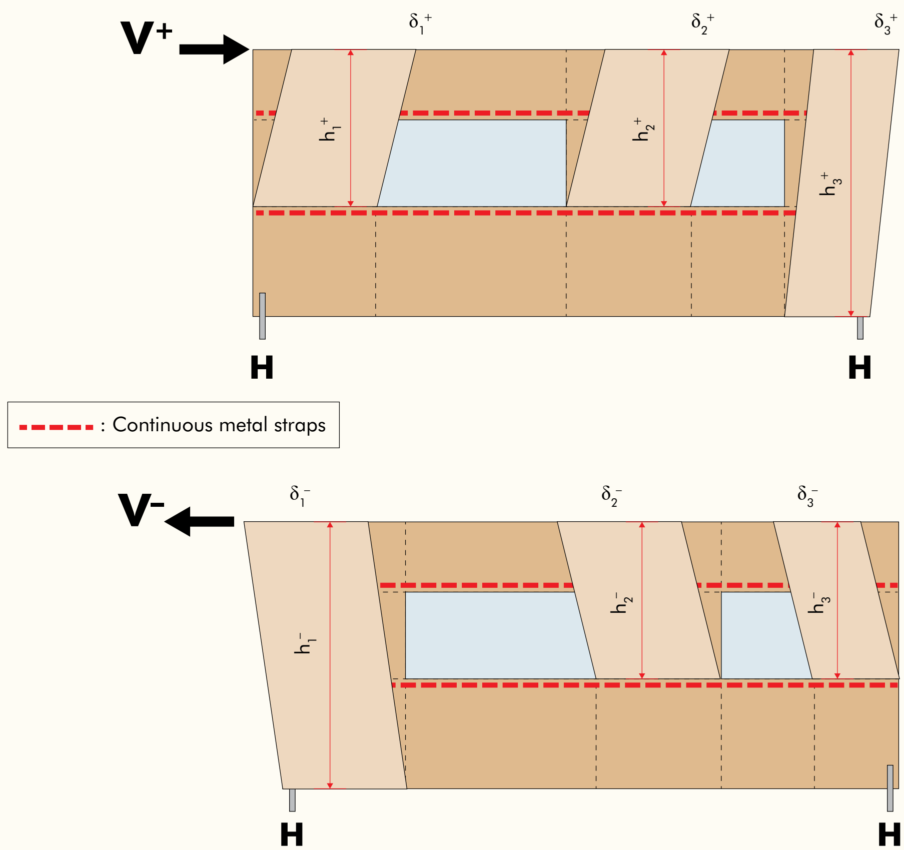
EQUATION 1

FOUR-TERM DEFLECTION

$$\Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75he_a + d_a\frac{h}{b} \qquad \text{(Equation 23-2 of the 2018 IBC)}$$

FIGURE 2

CONCEPTUAL METHODOLOGY FOR ESTIMATING DEFLECTION OF WALLS WITH OPENINGS



Δ = average $(\delta_1^+, \delta_2^+, \delta_3^+, \delta_1^-, \delta_2^-, \delta_3^-)$

Limitations

1. Wood structural panel sheathing for use in this application shall meet requirements of *Voluntary Product Standard PS 1-09 Structural Plywood* or *PS 2-10 Performance Standard for Wood-Based Structural-Use Panels* with the design properties as specified in APA *Panel Design Specification*, Form D510.

2. Transverse wind loads are beyond the scope of this document.

3. This methodology is not applicable to full-height openings.

4. The methodology presented in this document does not preclude any other rational analysis and engineering judgement.

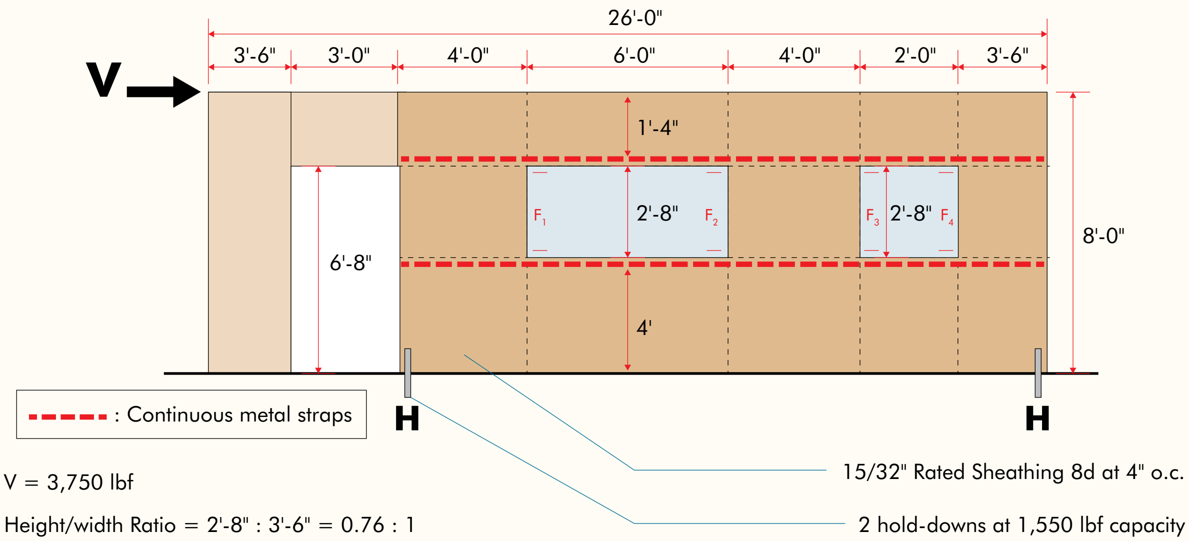
5. This technical note is subject to periodic review. The latest copy is available for free download at www.apawood.org/resource-library.

EXAMPLE: FTAO CALCULATIONS WITH TWO WINDOW OPENINGS

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

FIGURE 3

MULTIPLE OPENING FTAO DESIGN EXAMPLE



V = 3,750 lbf

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

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

1. Calculate the hold-down forces: $H = V \times h/L = 3{,}750 \times 8/19.5 = 1{,}538$ lbf

2. Solve for the unit shear above and below the openings: $v_a = v_b = H/(h_a + h_b) = 1{,}538/(4+1.33) = 288$ plf

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

   a. First opening: $O_1 = v_a \times (L_{o1}) = 288 \times 6 = 1731$ lbf

   b. Second opening: $O_2 = v_a \times (L_{o2}) = 288 \times 2 = 577$ lbf

4. Calculate the corner forces:

   a. $F_1 = O_1(L_1)/(L_1 + L_2) = 1{,}731\ (4)/(4 + 4) = 865$ lbf

   b. $F_2 = O_1(L_2)/(L_1 + L_2) = 1{,}731\ (4)/(4 + 4) = 865$ lbf

   c. $F_3 = O_2(L_2)/(L_2 + L_3) = 577\ (4)/(4 + 3.5) = 308$ lbf

   d. $F_4 = O_2(L_3)/(L_2 + L_3) = 577\ (3.5)/(4 + 3.5) = 269$ lbf

5. Tributary length of openings:

   a. $T_1 = L_1(L_{o1})/(L_1 + L_2) = 4\ (6)/(4 + 4) = 3'$

   b. $T_2 = L_2(L_{o1})/(L_1 + L_2) = 4\ (6)/(4 + 4) = 3'$

   c. $T_3 = L_2(L_{o2})/(L_2 + L_3) = 4\ (2)/(4 + 3.5) = 1.1'$

   d. $T_4 = L_3(L_{o2})/(L_2 + L_3) = 3.5\ (2)/(4 + 3.5) = 0.9'$

6. Unit shear beside the opening:

   a. $V_1 = (V/L)(L_1 + T_1)/L_1 = (3{,}750/19.5)(4 + 3)/4 = 337$ plf

   b. $V_2 = (V/L)(T_2 + L_2 + T_3)/L_2 = (3{,}750/19.5)(3 + 4 + 1.1)/4 = 388$ plf

   c. $V_3 = (V/L)(T_4 + L_3)/L_3 = (3{,}750/19.5)(0.9 + 3.5)/3.5 = 244$ plf

   d. Check $V_1 \times L_1 + V_2 \times L_2 + V_3 \times L_3 = V$? $337 \times 4 + 388 \times 4 + 244 \times 3.5 = 3{,}750$ (**YES**)

7. Resistance to corner forces:

   a. $R_1 = V_1 \times L_1 = 337 \times 4 = 1{,}346$ lbf

   b. $R_2 = V_2 \times L_2 = 388 \times 4 = 1{,}551$ lbf

   c. $R_3 = V_3 \times L_3 = 244 \times 3.5 = 853$ lbf

8. Difference of the corner force and resistance:

   a. $R_1 - F_1 = 1{,}346 - 865 = 481$ lbf

   b. $R_2 - F_2 - F_3 = 1{,}551 - 865 - 308 = 378$ lbf

   c. $R_3 - F_4 = 853 - 269 = 583$ lbf

9. Unit shear in the corner zones:

   a. $v_{c1} = (R_1 - F_1)/L_1 = 481/4 = 120$ plf

   b. $v_{c2} = (R_2 - F_2 - F_3)/L_2 = 378/4 = 95$ plf

   c. $v_{c3} = (R_3 - F_4)/L_3 = 583/3.5 = 167$ plf

10. Check your solution—YES to all:

a. Line 1: $v_{c1}(h_a + h_b) + V_1(h_o) = H?$
120 (1.33 + 4) + 337 (2.67) = 1,538 lbf (**YES**)

b. Line 2: $v_a(h_a + h_b) - v_{c1}(h_a + h_b) - V_1(h_o) = 0?$
288 (1.33 + 4) – 120 (1.33 + 4) – 337 (2.67) = 0 (**YES**)

c. Line 3: $v_{c2}(h_a + h_b) + V_2(h_o) - v_a(h_a + h_b) = 0?$
95 (1.33 + 4) + 388 (2.67) – 288 (1.33 + 4) = 0 (**YES**)

d. Line 4 = Line 3

e. Line 5: $v_a(h_a + h_b) - v_{c3}(h_a + h_b) - V_3(h_o) = 0?$
288 (1.33 + 4) – 167(1.33 + 4) – 244 (2.67) = 0 (**YES**)

f. Line 6: $v_{c3}(h_a + h_b) + V_3(h_o) = H?$
167 (1.33 + 4) + 244 (2.67) = 1,538 lbf (**YES**)

As shown by step 10, the solution checks. Figure 4 summarizes the shear stresses in the wall, as well as the forces required. Refer to step 6 for the shear force in the piers ranging from 244 to 388 plf. 15/32 Category Rated Sheathing with 8d nails at 4 inches on center at the panel edges and 12 inches on center in the field is good for 380 plf (*APA Engineered Wood Construction Guide*, Form E30, Table 23). The shear force on pier 2 (V2) is overstressed by 2%, but within an acceptable range. The strap force varies from 269 to 865 pounds, well within the common 16-gauge coil straps with capacities of approximately 1,700 lbf (Consult strap manufacturer's literature for exact design values).

FIGURE 4

SUMMARY OF STRAP FORCES (lbf) AND SHEAR FORCES (plf)

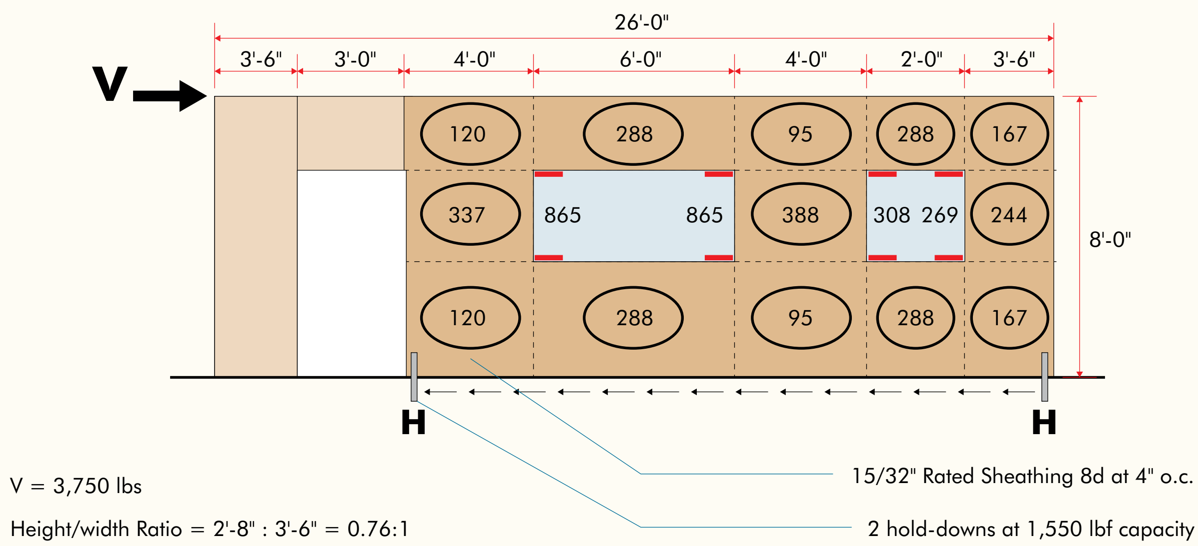


Figure 5 demonstrates the calculations using the four-term deflection equation, and Figure 6 demonstrates the deflection calculations utilizing the three-term deflection equation from *SDPWS*.

Using the four-term deflection equation, the calculated deflection is 0.317 inch. If one uses the three-term deflection equation, the calculated deflection is 0.335 inch which is 6% more than the 4-term deflection equation. The three-term deflection equation is calibrated to be equal to the four-term deflection equation at 1.4 times the allowable stress design capacity. Since the shear stresses in the piers are less than 1.4 times the capacity of the 15/32 category sheathing, the three-term equation yields a larger wall deflection.

FIGURE 5

WORKSHEET CALCULATIONS USING THE FOUR-TERM DEFLECTION EQUATION

$$\Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75he_a + d_a\frac{h}{b}$$ (Equation 23-2 of the 2018 IBC)

	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	(ft)
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 Deflection:	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 4 HD-1	Term 1 Bending	Term 2 Shear	Term 3 Fastener	Term 4 HD-2
0.019	0.046	0.103	0.459	0.002	0.023	0.052	0.115
		Sum	**0.627**			**Sum**	**0.192**
Pier 2 (Left)				**Pier 2 (Right)**			
Term 1 Bending	Term 2 Shear	Term 3 Fastener	Term 4 HD-1	Term 1 Bending	Term 2 Shear	Term 3 Fastener	Term 4 HD-2
0.003	0.027	0.079	0.132	0.003	0.027	0.079	0.132
		Sum	**0.241**			**Sum**	**0.241**
Pier 3 (Left)				**Pier 3 (Right)**			
Term 1 Bending	Term 2 Shear	Term 3 Fastener	Term 4 HD-1	Term 1 Bending	Term 2 Shear	Term 3 Fastener	Term 4 HD-2
0.002	0.017	0.019	0.095	0.015	0.033	0.039	0.380
		Sum	**0.133**			**Sum**	**0.467**

Total Deflection:	**0.317 (in.)**	**0.0132 (%drift)**

FIGURE 6

WORKSHEET CALCULATIONS USING THE THREE-TERM DEFLECTION EQUATION

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

	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 Deflection:	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**
Pier 3 (Left)			**Pier 3 (Right)**		
Term 1 Bending	Term 2 Shear	Term 3 Fastener	Term 1 Bending	Term 2 Shear	Term 3 Fastener
0.002	0.063	0.095	0.015	0.127	0.380
	Sum	**0.160**		**Sum**	**0.522**
			Total Deflection:	**0.335(in.)**	**0.0140 (%drift)**

CONCLUSION

Structural engineers can design shear walls with multiple, asymmetric openings based on the recent force transfer around openings (FTAO) testing. FTAO continues to be a popular solution where walls have narrow piers, and it provides structural and nonstructural benefits, including reduced anchorage and added redundancy. FTAO's incorporation of continuous wall sheathing also aids with cladding attachment and improves drainage and energy efficiency of the building. APA's *Force Transfer Around Openings Calculator* worksheet is available for free download at www.apawood.org/FTAO.

REFERENCES

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9. *Force Transfer Around Openings (FTAO) Calculator* Excel worksheet available at www.apawood.org/FTAO.

Design for Force Transfer Around Openings (FTAO)

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