6.3 Diaphragm Test Assemblies

6.3.1 Construction. With the exception of overall length and width, a diaphragm test assembly is required to be identical to the diaphragm in the building being designed. Specifically, frame members must be of identical size, spacing, species and grade; metal cladding must be identical in composition, profile and thickness; and fastener type and location must be the same. ASAE EP558 has established minimum sizes for diaphragm test assemblies to ensure that there is not *too* great a difference between the size of a diaphragm test assembly and the actual building diaphragm.

6.3.2 Test Configurations. ASAE EP558 allows for two different testing configurations: a cantilever test and a simple beam test (figures 6.2a and 6.2b, respectively). In both figures 6.2a and 6.2b, variable "a" represents the spacing between rafters/trusses (a.k.a. the frame spacing). This spacing should be equal to, or a multiple of, the frame spacing in the building being designed.

6.3.3 Shear Strength. The allowable design shear strength, of a diaphragm test assembly is equal to 40% of the ultimate strength of the assembly. In equation form:

Cantilever test:

$$v_a = 0.40\, P_u / b \qquad (6\text{-}1)$$

Simple beam test:

$$v_a = 0.40\, P_u / (2b) \qquad (6\text{-}2)$$

where:

v_a = allowable design shear strength, lbf/ft (N/m)
P_u = ultimate strength, lbf (N)
= total applied load at failure
b = assembly length, ft (m) (see figure 6.2)

If one or more of the test assembly failures were initiated by lumber breakage or by failure of the fastenings in the wood, then the allowable design shear stress must be adjusted to account for test duration. To adjust from a total elapsed testing time of 10 minutes to a normal load duration of ten years, divide v_a by a factor of 1.6. When this reduction is not applied (as would be the case when test assembly failure is not initiated by wood failure), the NDS load duration factor, C_D, can not be used to increase the allowable design shear strength during building design. Completely separate of the load duration factor adjustment is the 30% increase in allowable strengths allowed by most codes for wind loadings (see Section 3.9.4).

6.3.4 Shear Stiffness. The procedure for determining the effective shear modulus of a test assembly begins with calculation of the adjusted load-point deflection, D_T. This value takes into account rigid body rotation/translation during assembly test and is calculated as follows:

Cantilever test:

$$D_T = D_3 - D_1 - (a/b)\,(D_2 + D_4) \qquad (6\text{-}3)$$

Simple beam test:

$$D_T = (D_2 + D_3 - D_1 - D_4)\,/\,2 \qquad (6\text{-}4)$$

where:

D_T = adjusted load point deflection, in. (mm)
D_1, D_2, D_3, and D_4 = deflection measurements, in. (mm) (see figure 6.2)
a = assembly width, ft (m)
b = assembly length, ft (m)

The effective in-plane shear stiffness, c, for a diaphragm test assembly is defined as the ratio of applied load to adjusted load point deflection at 40% of ultimate load. In equation form:

Cantilever test:

$$c = 0.4\, P_u / D_{T,d} \qquad (6\text{-}5)$$

Simple beam test:

$$c = 0.2\, P_u / D_{T,d} \qquad (6\text{-}6)$$

where:

c = effective in-plane shear stiffness, lbf/in. (N/mm)
$D_{T,d}$ = adjusted load-point deflection, D_T, at $0.4\, P_u$, in. (mm)

The in-plane shear stiffness for the diaphragm test assembly, c, is converted to an effective shear modulus for the test assembly, G, as:

$$G = c\ (a/b) \qquad (6\text{-}7)$$

where:

G = effective shear modulus of the test assembly, lbf/in (N/mm)

6.4 Building Diaphragm Properties

6.4.1 General. As described in Chapter 5, each building diaphragm is sectioned for analysis. Each of these sections must be assigned a horizontal stiffness value, c_h, and an allowable load, v_a.

6.4.2 Shear Strength

The allowable design shear strength of a building diaphragm is equal to that calculated for the diaphragm test assembly. Consequently, to calculate the *total* in-plane shear load that a building diaphragm can sustain, simply multiply the allowable design shear strength, v_a, by the slope length of the building diaphragm.

6.4.3 In-Plane Shear Stiffness. The in-plane shear stiffness, c_p, of a building diaphragm section is calculated from the effective shear modulus, G, of the diaphragm test assembly using the following equation:

$$c_p = \frac{G\, b_s}{s} \qquad (6\text{-}8)$$

or

$$c_p = \frac{G\, b_h}{s \cos(\theta)} \qquad (6\text{-}9)$$

where:

G = effective shear stiffness of test assembly, lbf/in (N/mm)

b_S = slope length of building diaphragm section being modeled, ft (m)

s = width of the building diaphragm section being modeled, ft (m)

b_h = horizontal span length of building diaphragm section, ft (m)

θ = slope of the building diaphragm section, degrees

Implicit in equation 6-8 is the assumption that the total shear stiffness of a building diaphragm is a linear function of length.

6.4.4 Horizontal Shear Stiffness. The horizontal shear stiffness, c_h, of a building diaphragm section is related to its in-plane shear stiffness as follows:

$$c_h = c_p \cos^2(\theta) \qquad (6\text{-}10)$$

or

$$c_h = G\, b_h \cos(\theta) / s \qquad (6\text{-}11)$$

6.5 Building Shearwall Properties

6.5.1 General. The same procedure used to determine the strength and stiffness of building diaphragms is used to determine the strength and stiffness of building shearwalls. That is, representative test assemblies are loaded to failure, to determine their shear strength and stiffness. These properties are then linearly extrapolated to obtain strength and stiffness values for the building shearwall(s).

6.5.2 Shearwall Test Assemblies. ASAE EP558 also contains guidelines for construction and testing of shearwall test assemblies. With the exception of overall length and width, a shearwall test assembly is required to be identical to the shearwall in the building being designed. Specifically, frame members must be of identical size, spacing, species and grade; cladding must be identical; and fastener type and location must be the same.

6.6 Tabulated Data

6.6.1 Sources. Testing replicate samples of diaphragm test assemblies can get expensive. For this reason, a designer may choose not to conduct his/her own diaphragm tests, relying instead on designs that have been previously tested by others. Information on many tested designs is available in the public domain. Cladding manufacturers may have additional test information on assemblies that feature their own products.

6.6.2 Example Tabulated Data. Table 6.1 contains design details and engineering properties for roof diaphragm tests assemblies. The information in this table represents a small percentage of available data.

Table 6.1. Steel-Clad Roof Diaphragm Assembly Test Data

Test Assembly Number	1	2	3	4
Test Configuration	Cantilever	Cantilever	Cantilever	Cantilever
Cladding				
Manufacturer/Trade Name	Wick Agri Panel	Wick Agri Panel	Wick Agri Panel	Midwest Manu-facturing.
Base Metal Thickness Gauge	28	28	29	29
Major Rib Spacing, inches	12	12	12	12
Major Rib Height, inches	0.75	0.75	0.75	1.0
Major Rib Base Width, inches	1.25	1.25	1.25	2.5
Major Rib Top Width, inches	0.375	0.375	0.375	0.5
Yield Strength, ksi	50	50	80	80
Overall Design				
Width, feet	9	9	9	6
Length, b , feet	12	12	12	12
Purlin Spacing, feet	2	2	2	2
Rafter Spacing, feet	9	9	9	6
Purlin Location	Top running	Top running	Top running	Top running
Purlin Orientation	On edge	On edge	On edge	On edge
Number of Internal Seams	2	2	2	2
Wood Properties				
Purlin Size	2- by 4-inch	2- by 4-inch	2- by 4-inch	2- by 4-inch
Purlin Species and Grade	No.1 & 2 SPF	No.1 & 2 SPF	No.1 & 2 SPF	No.2 SYP
Rafter Species and Grade	No. 1 SYP	No. 1 SYP	No. 1 SYP	No. 1 SYP
Stitch Fastener				
Type	None	Screw	Screw	EZ Seal Nail
Length, inches		1.0	1.0	2.5
Diameter		#10	#10	8d
On Center Spacing, inches		24	24	24
Sheet-to-Purlin Fasteners				
Type	Screw	Screw	Screw	EZ Seal Nail
Length, inches	1.0	1.0	1.0	2.5
Diameter	#10	#10	#10	8d
Location in Field	In Flat	In Flat	In Flat	Major Rib
Location on End	In Flat	In Flat	In Flat	In Flat
Avg. On-Center Spacing in Field, in.	12	12	12	12
Avg. On-Center Spacing on End, in.	6	6	6	12
Purlin-to-Rafter Fastener	60d Threaded Hardened Nail	60d Threaded Hardened Nail	60d Threaded Hardened Nail	60d Threaded Hardened Nail
Engineering Properties				
Ultimate Strength, P_u, lbf.	2140	3390	3220	1930
Allowable Shear Strength, v_a, lbf/ft	71	113	107	64
Effective In-Plane Stiffness, c ,lbf/in	1625	2720	2720	1590
Effective Shear Modulus, G, lbf/in	1220	2040	2040	795
Reference	Anderson, 1989	Anderson, 1989	Anderson, 1989	Wee & Ander-son, 1990

Table 6.1. cont., Steel-Clad Roof Diaphragm Assembly Test Data

Test Assembly Number	5	6	7	8
Test Configuration	Cantilever	Cantilever	Cantilever	Cantilever
Cladding				
Manufacturer/Trade Name	Midwest Manu-facturing	Grandrib 3	Grandrib 3	Walters STR-28
Base Metal Thickness Gauge	29	29	29	28
Major Rib Spacing, inches	12	12	12	12
Major Rib Height, inches	1.0	0.75	0.75	0.94
Major Rib Base Width, inches	2.5	1.75	1.75	
Major Rib Top Width, inches	0.5	0.5	0.5	
Yield Strength, ksi	80	80	80	80
Overall Design				
Width, feet	6	9	9	9
Length, *b* , feet	12	12	12	16
Purlin Spacing, feet	2	2	2	2
Rafter Spacing, feet	6	9	9	9
Purlin Location	Top running	Top running	Top running	Top running
Purlin Orientation	On edge	On edge	On edge	On edge
Number of Internal Seams	2	2	2	2
Wood Properties				
Purlin Size	2- by 4-inch	2- by 4-inch	2- by 4-inch	2- by 4-inch
Purlin Species and Grade	No.2 SYP	No.2 DFL	No.2 SPF	No.2 SYP
Rafter Species and Grade	No. 1 SYP	No. 2 DFL	No. 2 SPF	1950f1.7E SYP
Stitch Fastener				
Type	EZ Seal Nail	None	None	Screw
Length, inches	2.5			1.5
Diameter	8d			#10
On Center Spacing, inches	24			24
Sheet-to-Purlin Fasteners				
Type	Screw	Screw	Screw	Screw
Length, inches	0.75	1.0	1.0	1.5
Diameter	#12	#10	#10	#10
Location in Field	In Flat	In Flat	In Flat	In Flat
Location on End	In Flat	In Flat	In Flat	In Flat
Avg. On-Center Spacing in Field, in.	6	12	12	12 and 18
Avg. On-Center Spacing on End, in.	6	6	6	12
Purlin-to-Rafter Fastener	60d Threaded Hardened Nail	1-60d Spike + 2-10d Toenails	1-60d Spike + 2-10d Toenails	60d Threaded Hardened Nail
Engineering Properties				
Ultimate Strength, P_u, lbf.	3995	3300	2775	4884
Allowable Shear Strength, v_a, lbf/ft	133	110	93	122
Effective In-Plane Stiffness, *c* ,lbf/in	2980	2920	2950	3890
Effective Shear Modulus, *G*, lbf/in	1490	2190	2210	2190
Reference	Wee & Ander-son, 1990	Lukens & Bundy, 1987	Lukens & Bundy, 1987	Bohnhoff and others, 1991

Table 6.1. cont., Steel-Clad Roof Diaphragm Assembly Test Data

Test Assembly Number	9	10	11	12
Test Configuration	Simple Beam			
Cladding				
Type	Regular Leg	Extended Leg	Regular Leg	Extended Leg
Base Metal Thickness Gauge	29			
Major Rib Spacing, inches	9			
Major Rib Height, inches	0.62			
Major Rib Base Width, inches	1.75			
Major Rib Top Width, inches	0.75			
Yield Strength, ksi	80			
Overall Design				
Width, feet	36			
Length, *b* , feet	12			
Purlin Spacing, feet	2			
Rafter Spacing	Pair of rafters every 12 feet (each pair spaced 6 in. apart)			
Purlin Location	Top running and lapped		Inset	
Purlin length, ft	13.2 and 12.0		11.25	
Purlin Attachment	To special blocking nailed between each pair of rafters		To joist hanger attached to rafters	
Purlin Orientation	On edge			
Number of Internal Seams	11			
Wood Properties				
Purlin Size	2- by 6-inch			
Purlin Species and Grade	No.2 DFL and 1650f DFL			
Rafter Species and Grade	No. 2 DFL			
Stitch Fastener*				
Type	None	Screw*	None	Screw*
Length, inches		1.5		1.5
Diameter		#10		#10
On Center Spacing, inches		24		24
Sheet-to-Purlin Fasteners				
Type	Screw			
Length, inches	1.5			
Diameter	#10			
Location in Field	In Flat			
Location on End	In Flat			
Avg. On-Center Spacing in Field, in.	9			
Avg. On–Center Spacing on End, in.	9			
Engineering Properties				
Ultimate Strength, P_u, lbf.	6950	7850	6400	6950
Allowable Shear Strength, v_a, lbf/ft	116	131	107	116
Effective In-Plane Stiffness, c ,lbf/in	4700	7500	3700	4400
Effective Shear Modulus, G, lbf/in	4700	7500	3700	4400
Reference	NFBA, 1996			

* Because of the extended leg, screws installed in the flat at overlapping seams function as stitch fasteners.

Table 6.1. cont., Steel-Clad Roof Diaphragm Assembly Test Data

Test Assembly Number	13	14	15
Test Configuration	Simple Beam	Simple Beam	Simple Beam
Cladding			
Manufacturer/Trade Name	Metal Sales Pro Panel II	Metal Sales Pro Panel II	McElroy Metal Max Rib
Base Metal Thickness Gauge	30	30	29
Major Rib Spacing, inches	9.0	9.0	9.0
Major Rib Height, inches			0.75
Major Rib Base Width, inches			1.75
Major Rib Top Width, inches			
Yield Strength, ksi	104	104	80
Overall Design			
Width, feet	24	24	24
Length, *b* , feet	12	12	12
Purlin Spacing, feet	2.33	2.33	2
Rafter Spacing, feet	Pair of rafters every 12 feet (each pair spaced 6 in. apart)	Pair of rafters every 12 feet (each pair spaced 6 in. apart)	8
Purlin Location	Top running	Top running	Top running
Purlin Orientation	On edge	On edge	NA
Number of Internal Seams	8	8	7
Wood Properties			
Purlin Size	2- by 6-inch	2- by 6-inch	Mac-Girt steel hat section: 1.5 in. tall, 3.2 in. wide, 18 ga.
Purlin Species and Grade	1650f 1.5E SPF	1650f 1.5E SPF	
Rafter Species and Grade	1650f 1.5E SPF	1650f 1.5E SPF	2250f 1.9E SP
Stitch Fastener			
Type	Screw	None	None
Length, inches	0.625		
Diameter	#12		
On Center Spacing, inches	9		
Sheet-to-Purlin Fasteners			
Type	Screw	Screw	Screw
Length, inches	1.5	1.5	1.0
Diameter	#10	#10 in field #14 in ends	#14
Location in Field	In Flat	In Flat	In Flat
Location on End	In Flat	In Flat	In Flat
Avg. On-Center Spacing in Field, in.	9	9	18 (3 screws/sheet)
Avg. On-Center Spacing on End, in.	4.5	4.5	9 (4 screws/sheet)
Purlin-to-Rafter Fastener			Two - #12 x 1.6 in. screws/joint
Engineering Properties			
Ultimate Strength, P_u, lbf.	9600	6600	8645
Allowable Shear Strength, v_a, lbf/ft	160	110	144
Effective In-Plane Stiffness, *c* ,lbf/in	7680	7100	10700
Effective Shear Modulus, *G*, lbf/in	7680	7100	7130
Reference	Townsend, 1992	Townsend, 1992	Myers, 1994