APPENDIX A

STRUCTURAL ENGINEERS ASSOCIATION OF SOUTHERN CALIFORNIA TEST PROTOCOL

The *Standard Method of Cyclic (Reversed) Test for Shear Resistance of Framed Walls for Buildings* (SEAOSC, 1996) is designed to evaluate the shear stiffness and shear strength of a typical section of a framed wall system including its shear connections and hold-down connectors under reversed (cyclic) load conditions. AC130 specifies this design protocol for ICBO approval of alternate wood-framed shear walls.

The test is as follows. The wall assembly is tested so that all components and sheathing surfaces are observed during testing. The bottom of the wall is attached to a rigid base with shear connections as required to resist the anticipated maximum load. The wall is assembled with materials used in actual building construction. The species and grade of all wood materials is recorded. The material specifications and thicknesses of all metal connectors are recorded. The panel assembly connections are designed so that the contribution of the displacements of these connections at the SLS is 0.15% of the wall height. The wall assembly has an aspect ratio that is consistent with the intended use in building construction. The wall assembly is braced to prevent out-of-plane distortion, but is allowed to move freely for in-plane wall distortion.

A minimum of two tests are required on identical assemblies to determine the shear stiffness and shear strength of the panels. If the force displacement relationship from the tests is not within 10% of one another, then a third test is conducted and the mean value is computed from the three values determined. If only two tests are used (and they are within 10% of each other) then the mean value of the two tests are used. The racking load is applied horizontally to the top of the panel assembly along the length of the panel. A programmable double-acting hydraulic actuator with an integral load cell is suggested by SEAOSC for conducting the tests.

The increments selected for the sequential-phased-displacement procedure are based on the first major event (FME). The FME can be determined from preliminary cyclic load tests on an identical wall assembly. The FME is defined as the first significant event that marks the separation between two behavioral states (elastic to inelastic) at which some structural behavior of the element or system is altered significantly. The load-testing procedure consists of applying three cycles of fully reversing displacement, at each displacement increment representing 25%, 50%, and 75% of FME. Wall displacement is then increased for one cycle to 100% of FME. Next, the "decay" cycles of displacement for one cycle each at 75%, 50%, and 25% of maximum displacement (e.g., 100% of FME) are applied, followed by three cycles of displacement at maximum displacement (100% FME) to stabilize the force displacement response of the wall. The next increment of increased displacement (125% of FME) is then applied, followed by similar decay and stabilization cycles. The incremental force displacement and decay cycles continued to 150%, 175%, 200%, 300%, 350%, and 400% of FME or until the applied force diminishes to 25% of the strength limit state. See Table A.1 for cycle numbers and percent of FME displacements.

Panel displacement is input into a controller to control the actuator displacement. The cyclic frequency is a maximum of 1.0 Hz (note this is lower than the 2.0 Hz used in ATC R-1) to avoid the inertial effects of the mass of the wall and test fixture hardware during cyclic loading, which could affect system response to cyclic loading. During the later stages of the cyclic loading sequence, the cyclic frequency may be slowed to 0.2 Hz to properly control the hydraulic system with the instrument displacement input that is due to the larger displacements anticipated at these load levels. The large displacement

Table A.1. Sequential Phased Displacement Load Procedure for Shear Walls

Cycle No.	% of FME	Cycle No.	% of FME	Cycle No.	% of FME	Cycle No.	% of FME
0	0	33	125	75	200	117	350
1	25	34	-125	76	-200	118	-350
2	-25	35	94	77	150	119	263
3	25	36	-94	78	-150	120	-263
4	-25	37	63	79	100	121	175
5	25	38	-63	80	-100	122	-175
6	-25	39	31	81	50	123	88
7	50	40	-31	82	-50	124	-88
8	-50	41	125	83	200	125	350
9	50	42	-125	84	-200	126	-350
10	-50	43	125	85	200	127	350
11	50	44	-125	86	-200	128	-350
12	-50	45	125	87	200	129	350
13	75	46	-125	88	-200	130	-350
14	-75	47	150	89	250	131	400
15	75	48	-150	90	-250	132	-400
16	-75	49	113	91	188	133	300
17	75	50	-113	92	-188	134	-300
18	-75	51	75	93	125	135	200
19	100	52	-75	94	-125	136	-200
20	-100	53	38	95	63	137	100
21	75	54	-38	96	-63	138	-100
22	-75	55	150	97	250	139	400
23	50	56	-150	98	-250	140	-400
24	-50	57	150	99	250	141	400
25	25	58	-150	100	-250	142	-400
26	-25	59	150	101	250	143	400
27	100	60	-150	102	-250	144	-400
28	-100	61	175	103	300		
29	100	62	-175	104	-300		
30	-100	63	131	105	225		
31	100	64	-131	106	-225		
32	-100	65	88	107	150		
		66	-88	108	-150		
		67	44	109	75		
		68	-44	110	-75		
		69	175	111	300		
		70	-175	112	-300		
		71	175	113	300		
		72	-175	114	-300		
		73	175	115	300		
		74	-175	116	-300		

problems for the actuator may be overcome by using linkage with a pivot that would limit the displacement of the actuator, but would require more force on the linkage. This is how several of the tests in the early 1990s were performed since large force actuators were available from testing of other materials.

Displacement is measured with LVDTs with a resolution of .005″, or other suitable devices, for continuously measuring displacement under cyclic loading conditions at a minimum sampling rate of 100 readings per cycle. The following instrumentation is provided for measuring displacements and hold-down connector forces when required:

1. Horizontal displacement of the wall at the top plate.
2. Vertical displacement of both end stud's uplift and compression are relative to the rigid base. The reference point for this measurement is on or immediately adjacent to the face of the post to which the hold-down connector is installed and is located in the plane of the hold-down connector base.
3. Horizontal displacement of the bottom plate relative to the rigid base (lateral in-plane sliding).
4. Vertical displacement of the hold-down connectors relative to the end posts (deformation or fastener slip).
5. When specified, loads on the bolts fastening the hold-down connectors to the rigid base.

Calculation of specimen strengths and rigidities: from the tests performed, the following calculations are made:

1. Maximum shear strength $s_{max} = p_{max}/L$ where s_{max} = maximum shear strength in plf.
2. Shear stiffness (determine the shear stiffness on the basis of applied load at specified reference displacement levels for use in displacement calculations).
3. From the hysteresis loops for both positive and negative cycles of displacement recorded during the cyclic tests, compute the shear modules, G', at the YLS and SLS.

   $G' = P/\Delta \times H/L$:

   3.1 G' = shear modules calculated

   3.2 P =lateral shear force measured at the top edge of the wall, lbf

   3.3 Δ = displacement of the top edge of the wall during the test including the effects of sheathing and hold-down connection system

   3.4 H = height of the shear wall, feet

   3.5 L = length of the shear wall, feet
4. Calculate the mean values for displacement shear forces and shear modules at the YLS and SLS as previously determined.
5. Establish a bilinear force displacement response that passes through the origin and the mean displacement or shear forces at yield limit state and strength limit state.

APPENDIX B

PANEL SPECIFICATION DRAWINGS

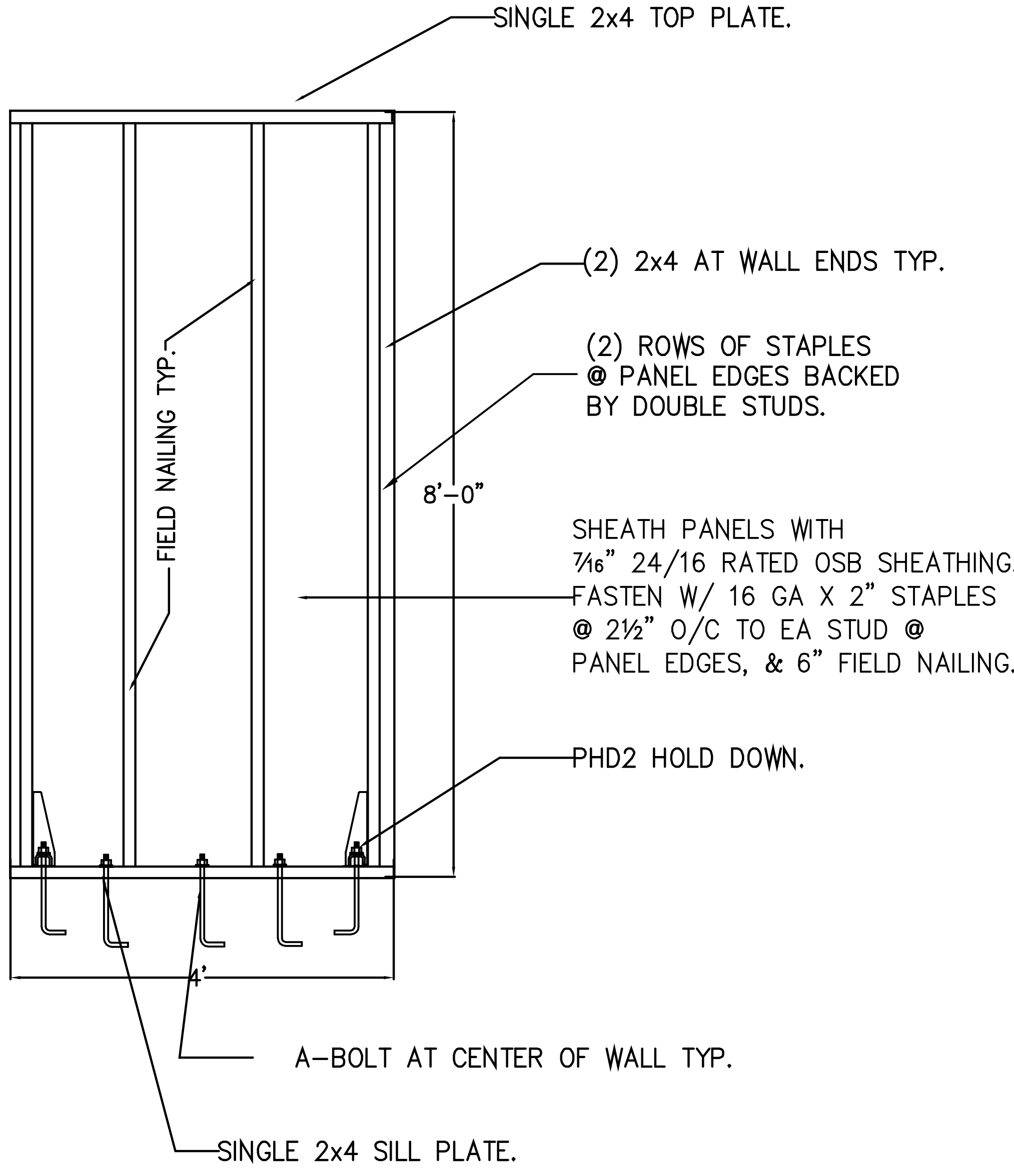

Figure B.1 Panels 1, 2, 3,and 5.

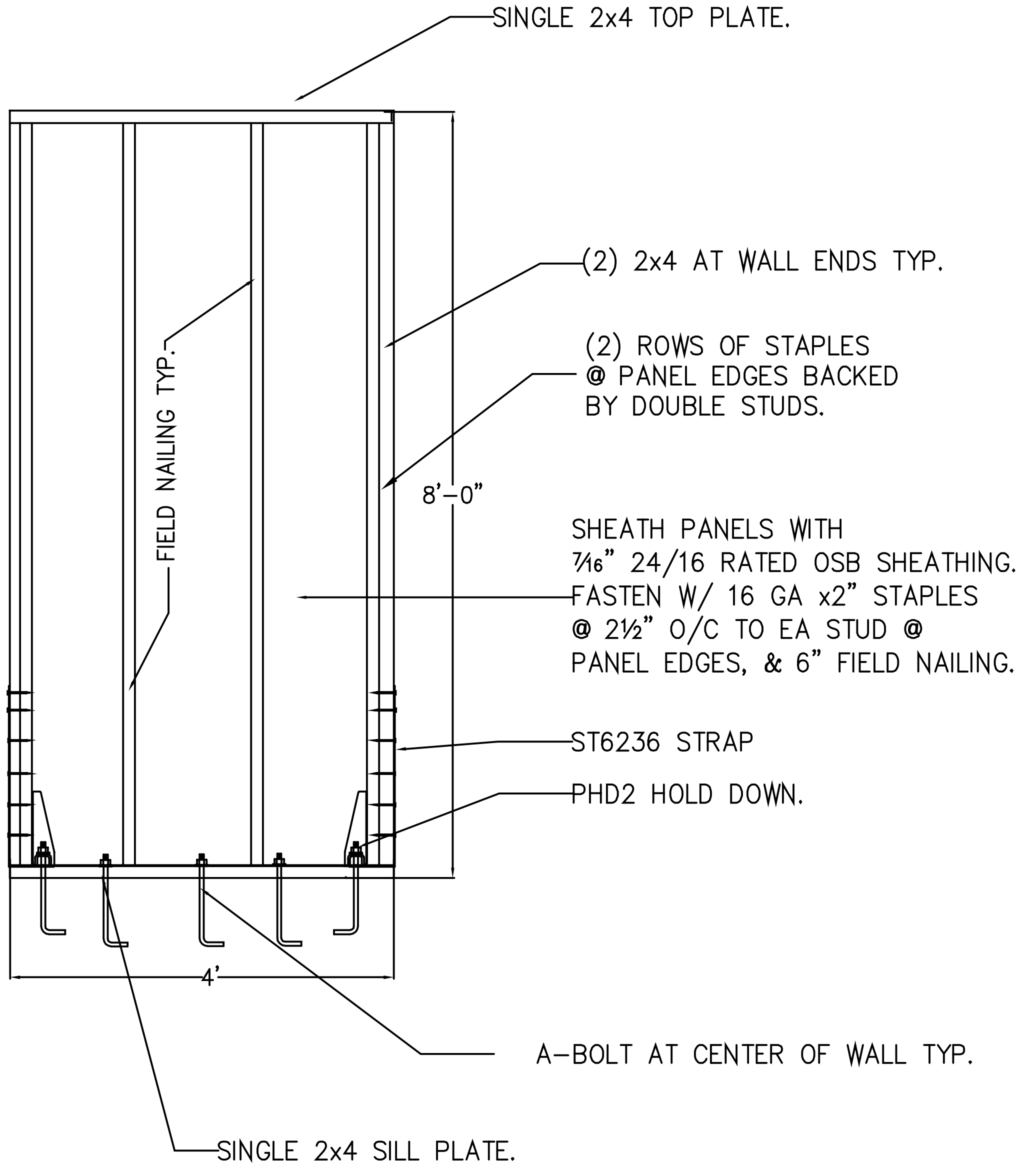

Figure B.2 Panel 4.

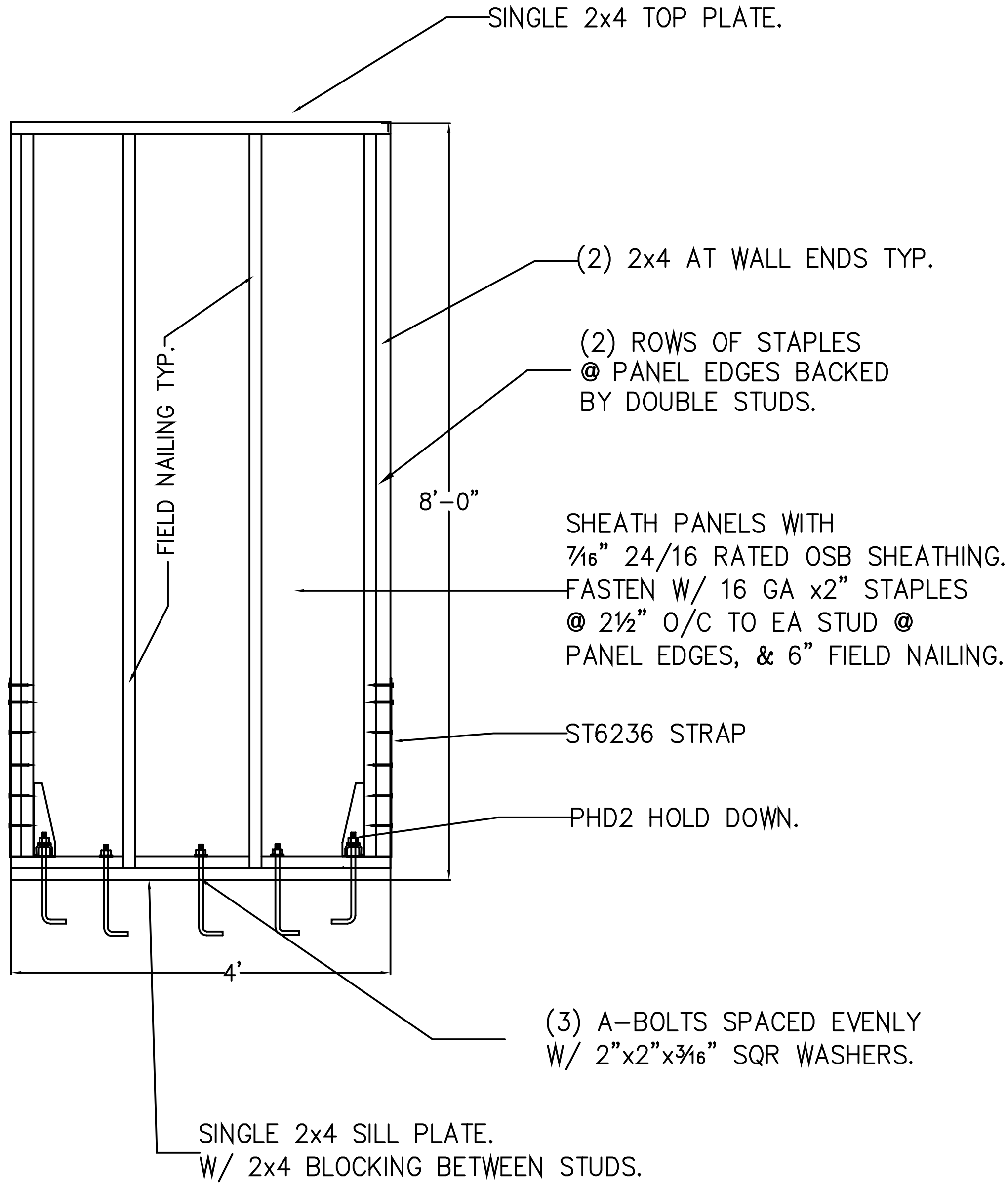

Figure B.3 Panel 6.

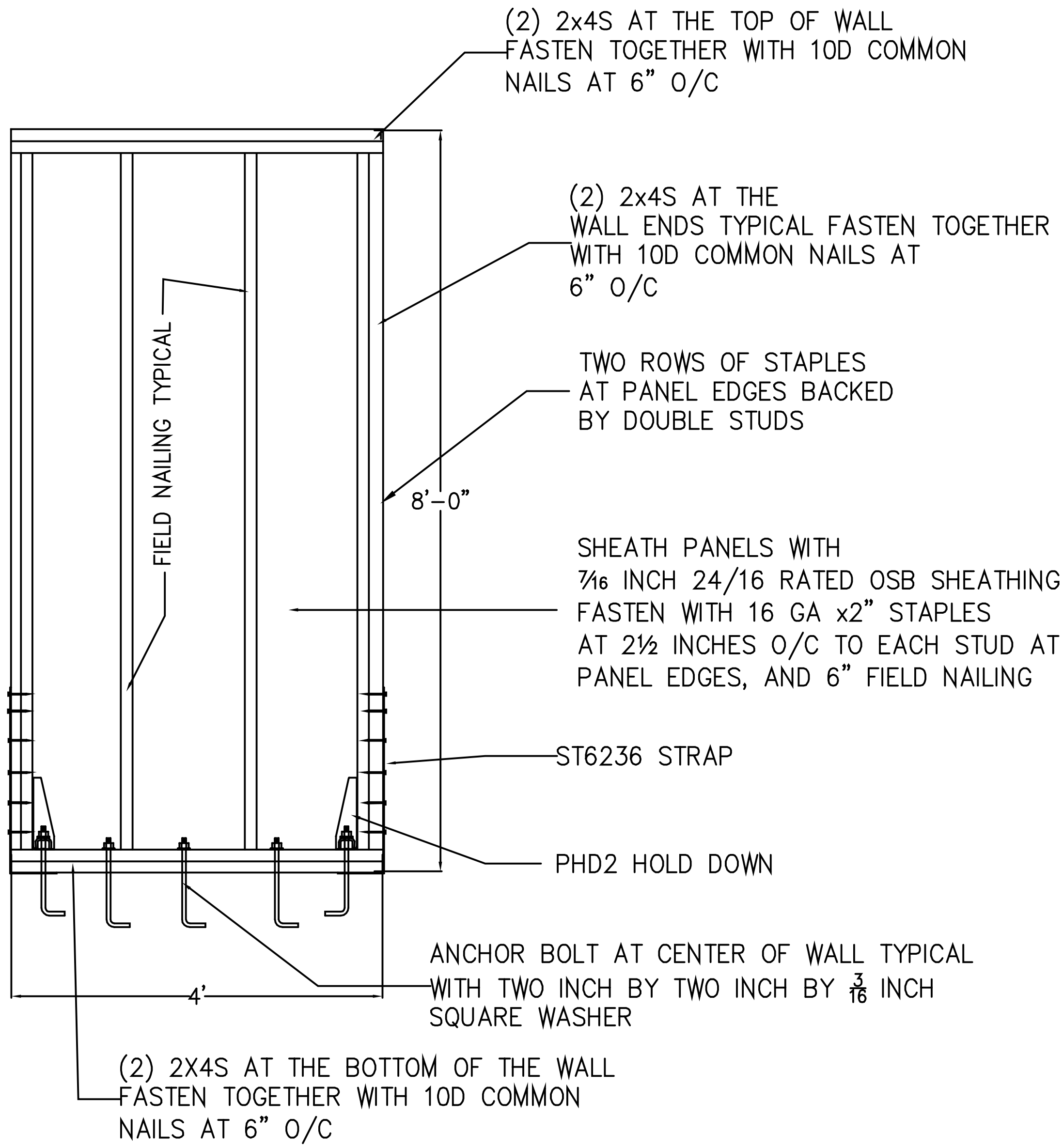

Figure B.4 Panels 7, 8, and 9.

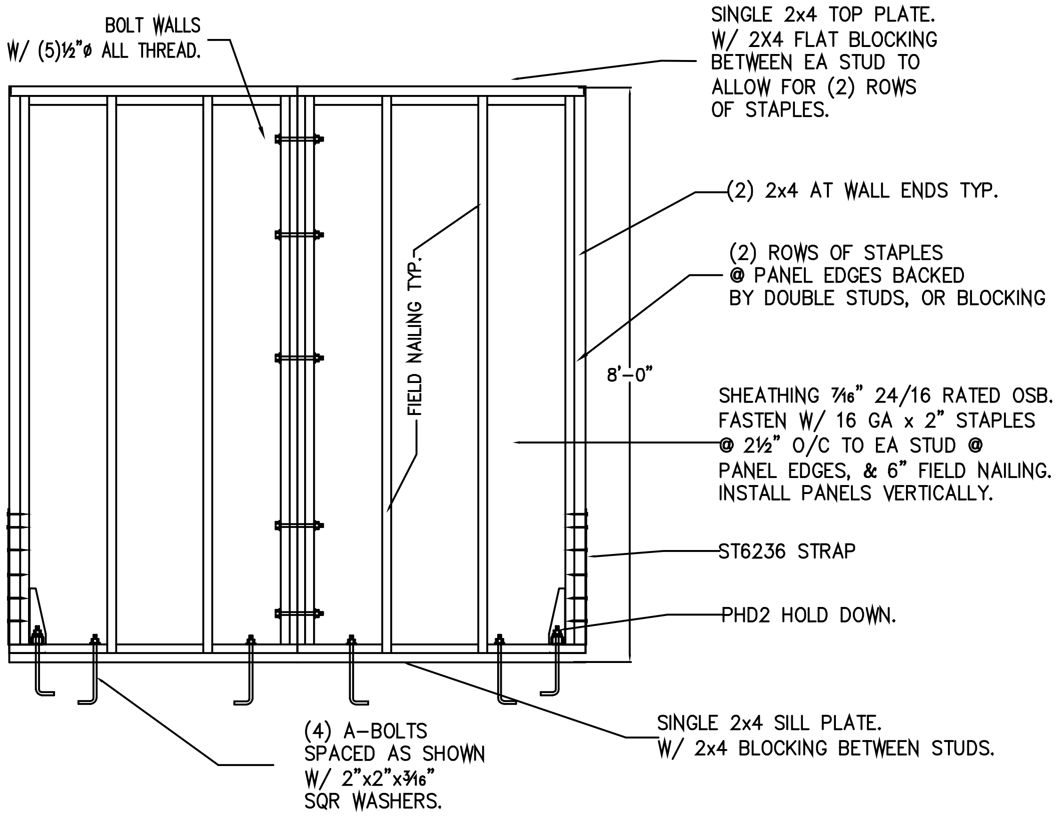

Figure B.5 Panels 10 and 11.

APPENDIX C

TEST SETUP PHOTOS

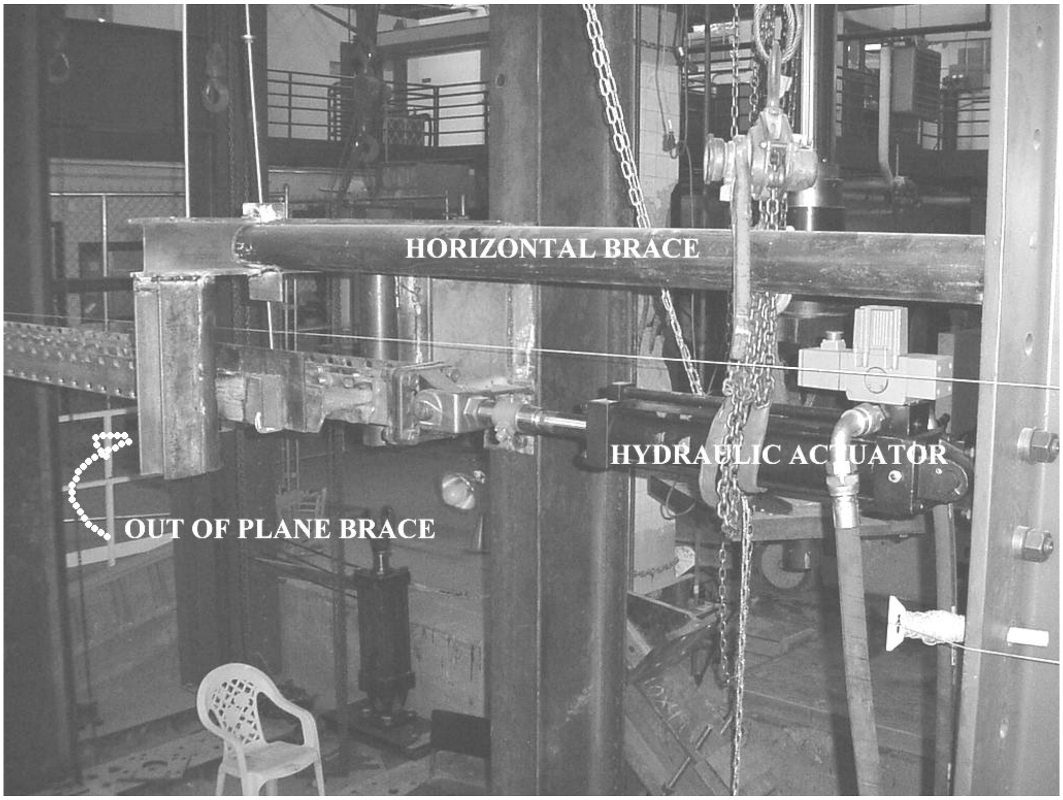

Figure C.1. Hydraulic actuator and steel bracing photos.

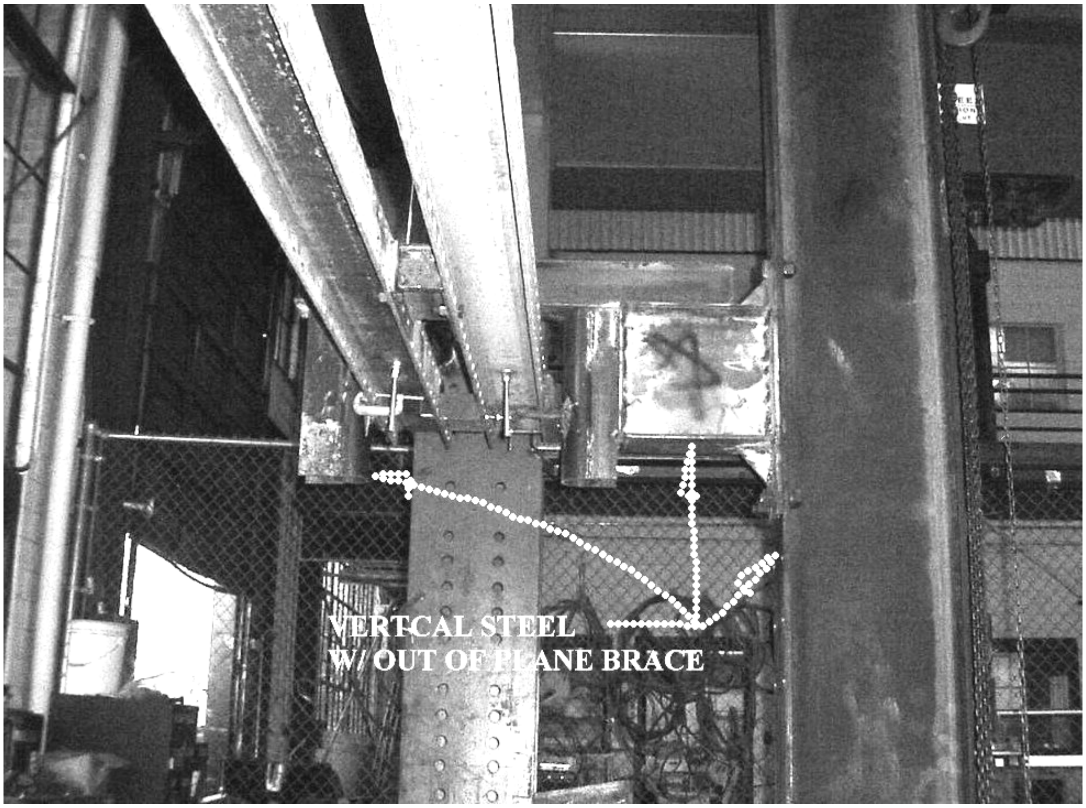

Figure C.2. Out-of-plane lateral bracing.

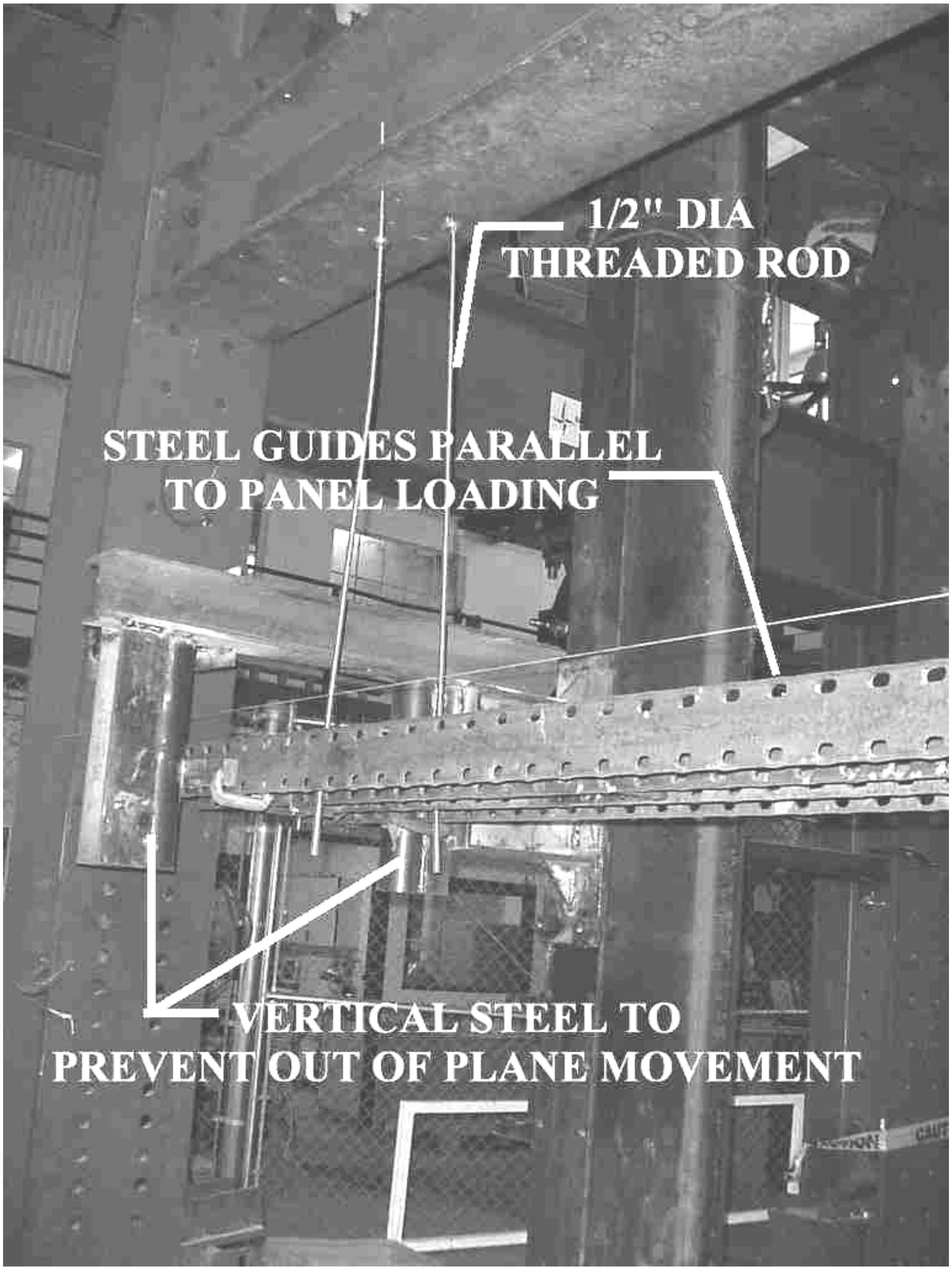

Figure C.3. Guide rails and out-of-plane lateral bracing.

APPENDIX D

TEST DATA AND HYSTERESIS LOOPS

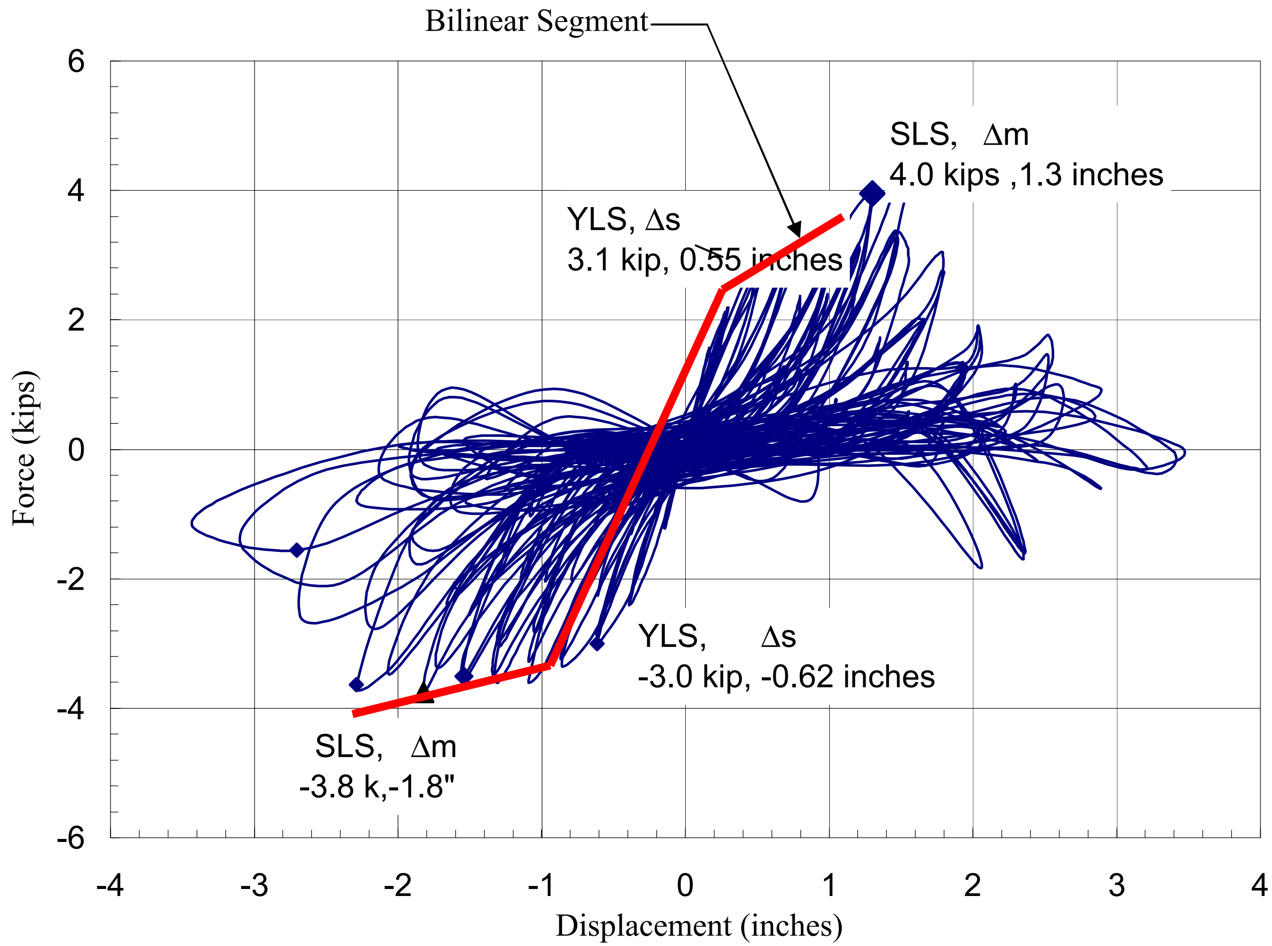

Figure D.1 Hysteresis load-displacement curves panel 2.

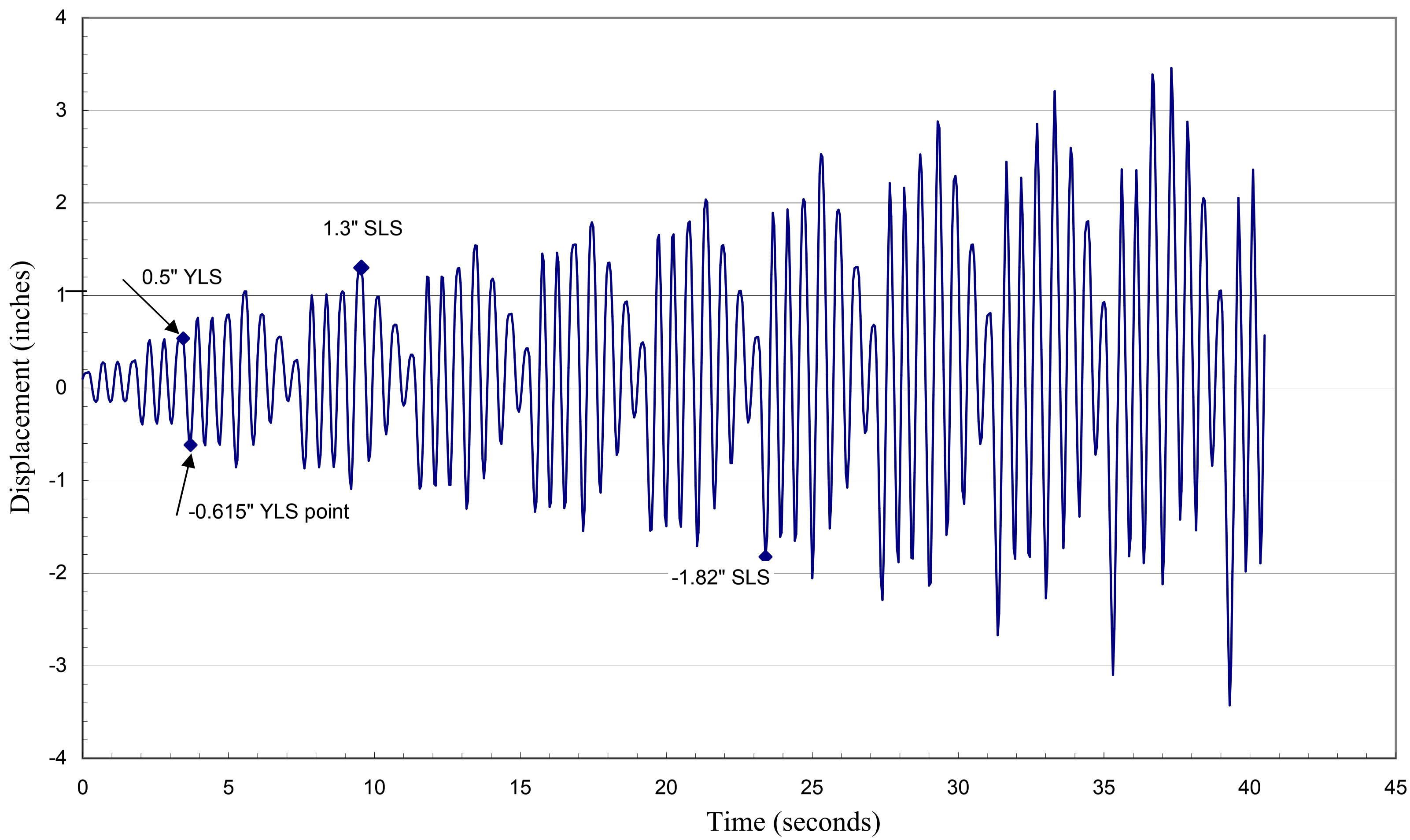

Figure D.2 Displacement versus time panel 2.

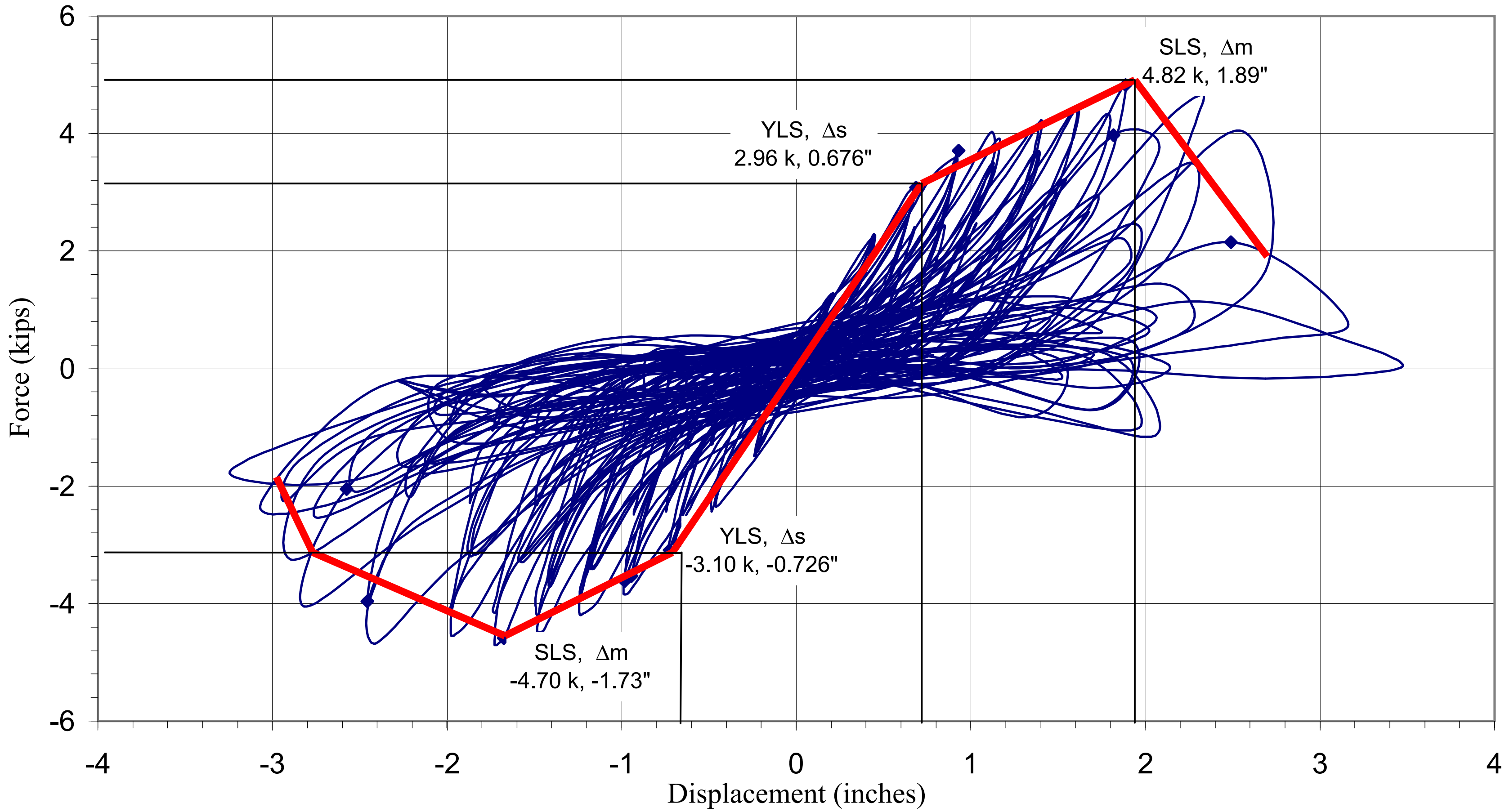

Figure D.3 Hysteresis load-displacement curves panel 3.

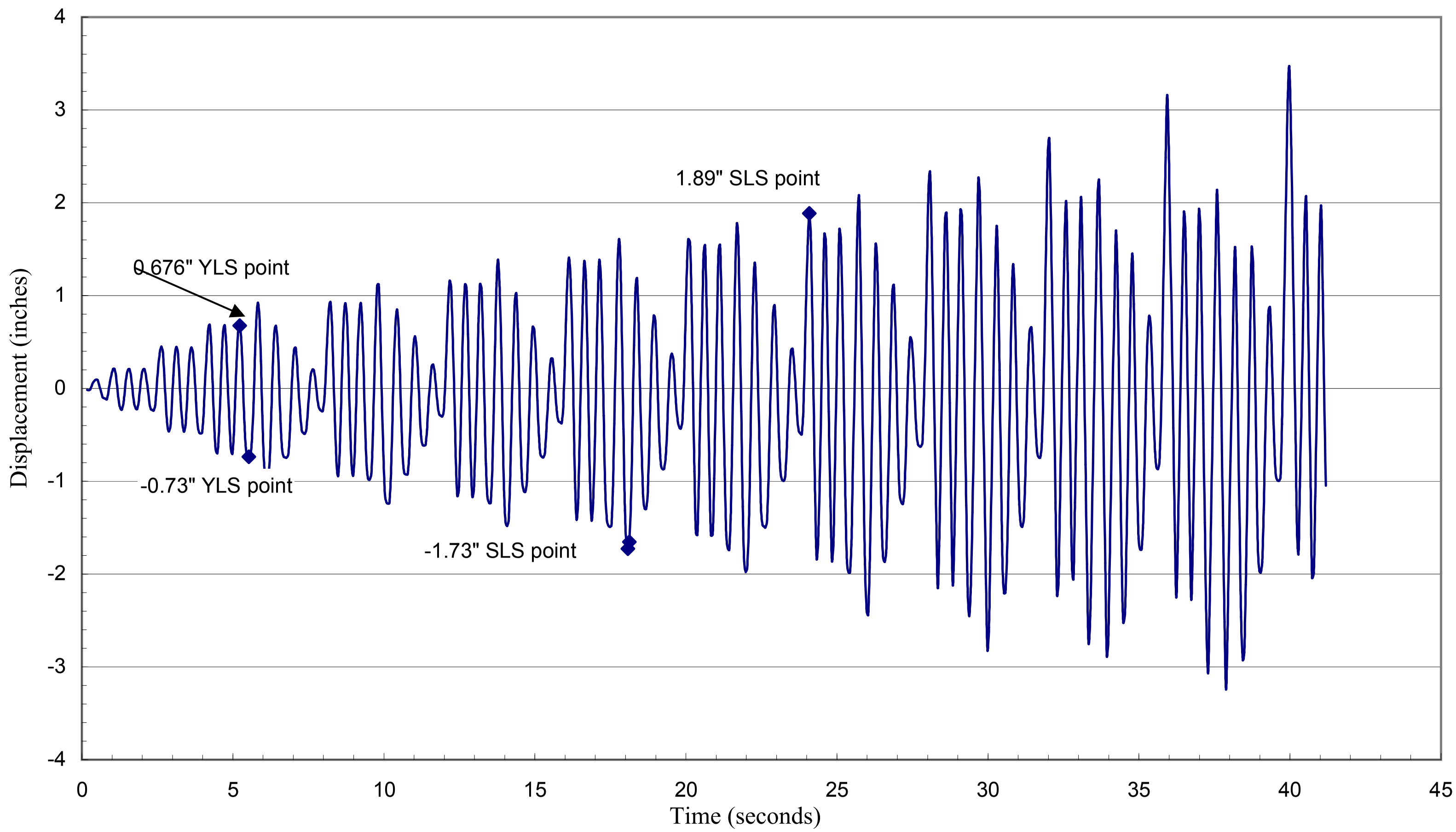

Figure D.4 Displacement versus time panel 3.

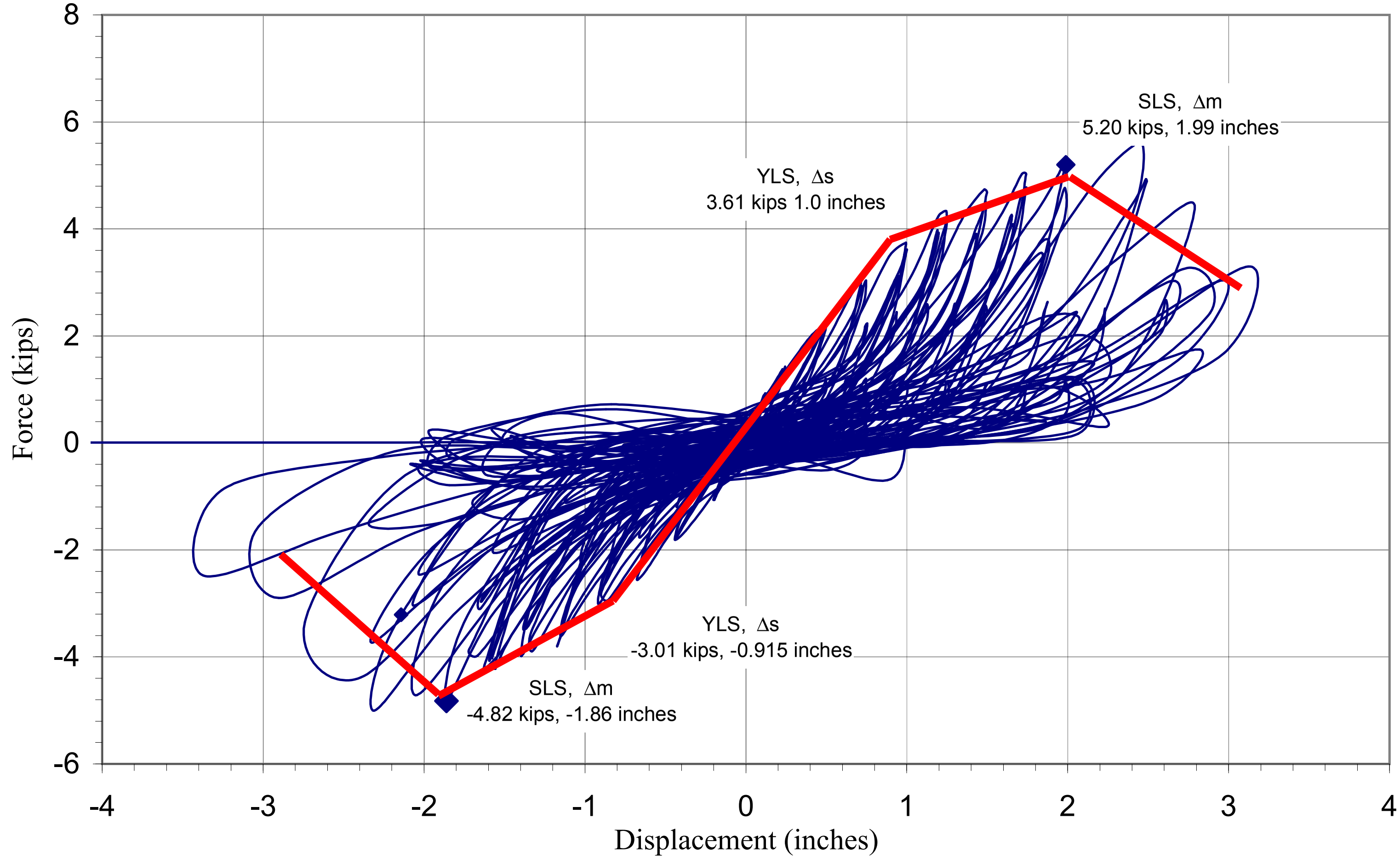

Figure D.5 Hysteresis load-displacement curves panel 4.

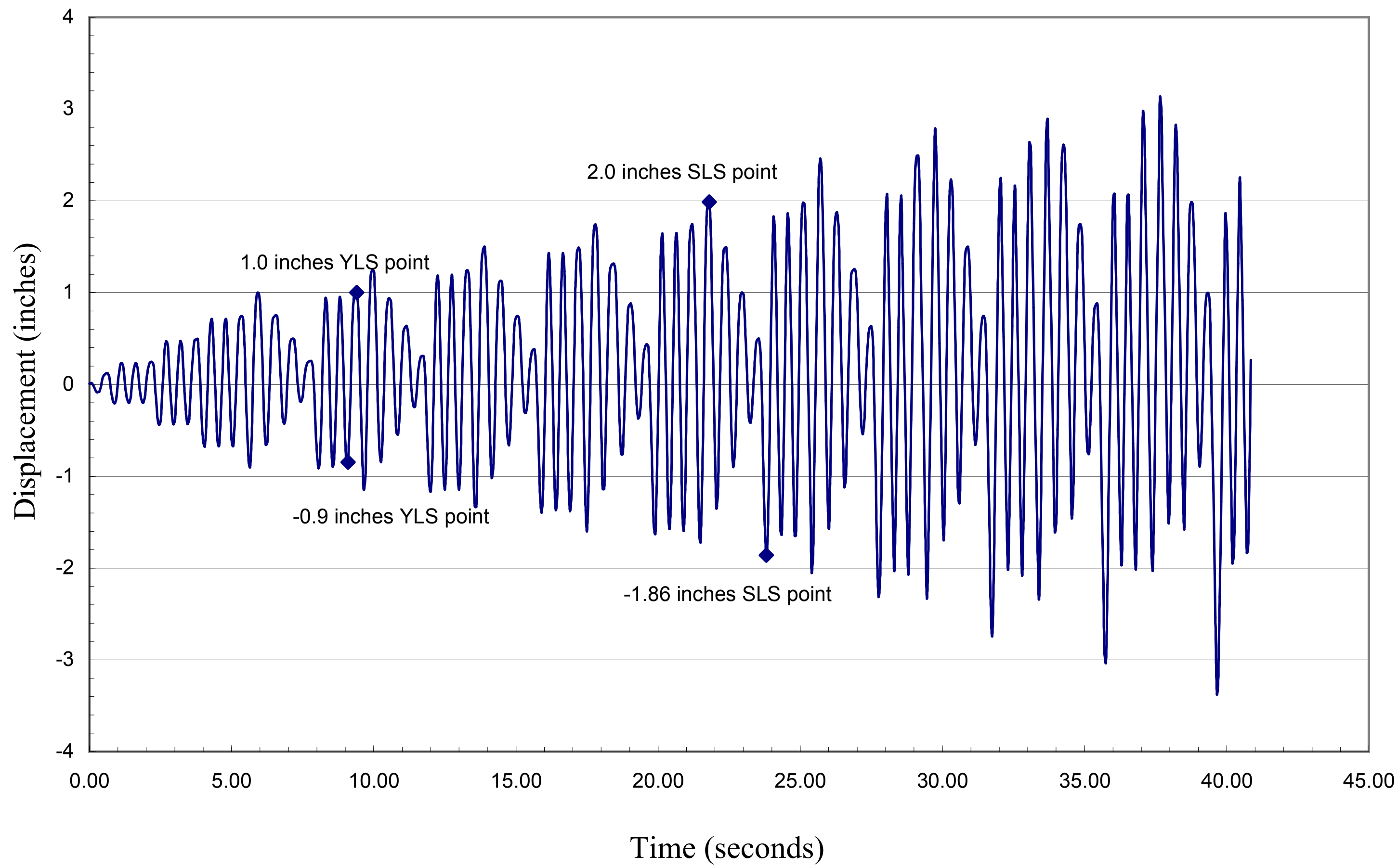

Figure D.6   Displacement versus time panel 4.

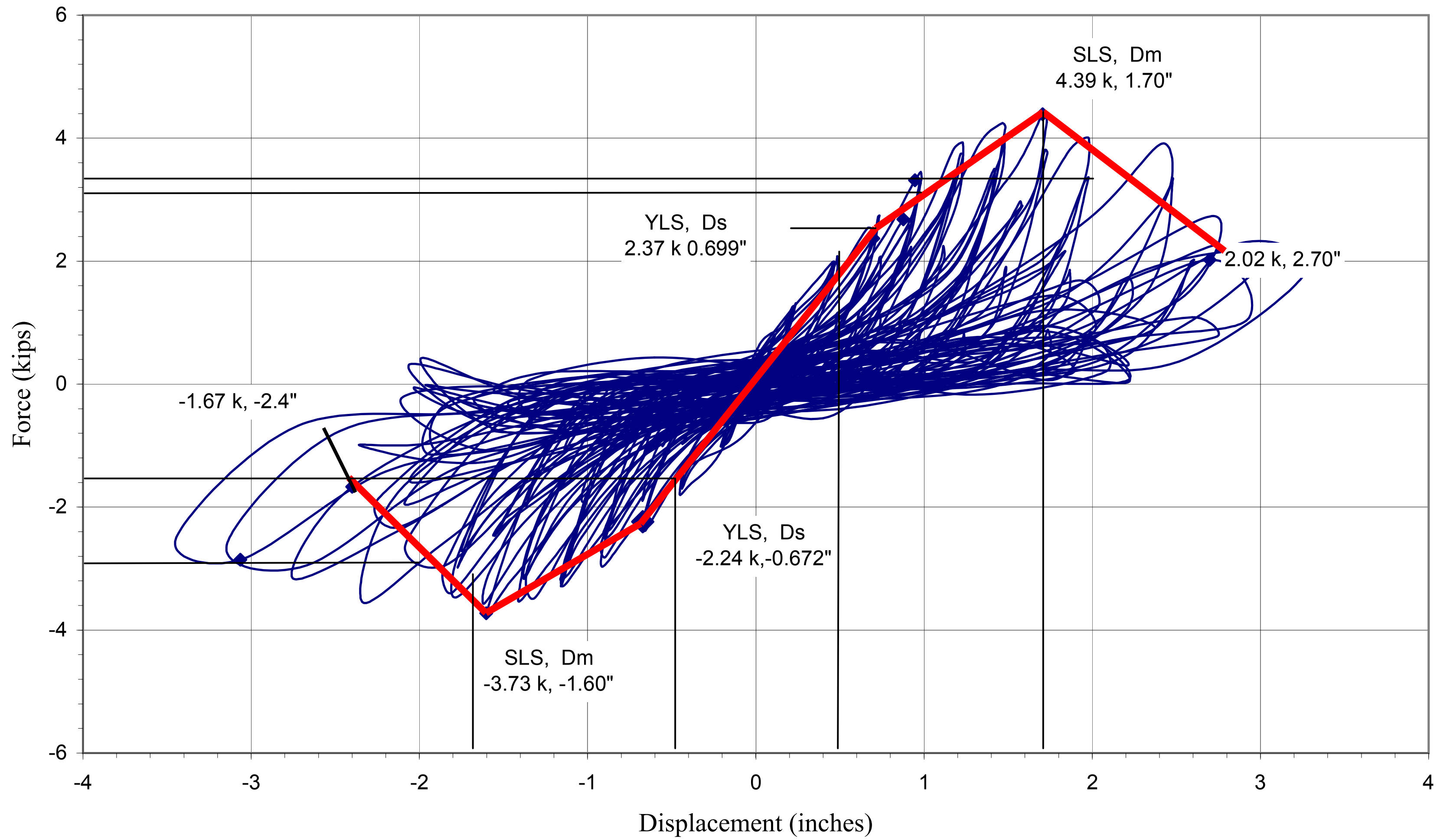

Figure D.7 Hysteresis load-displacement curves panel 5.

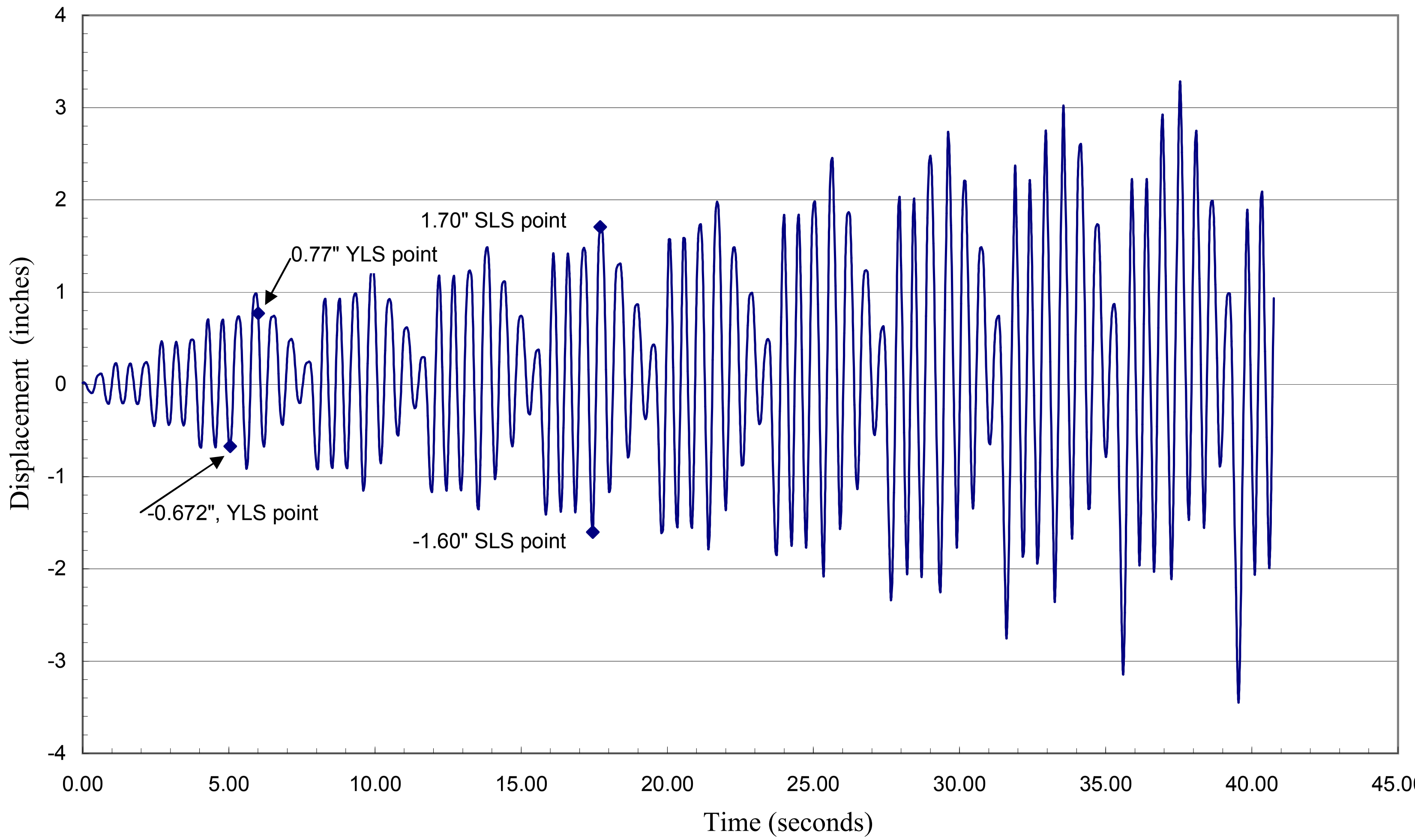

Figure D.8 Displacement versus time panel 5.

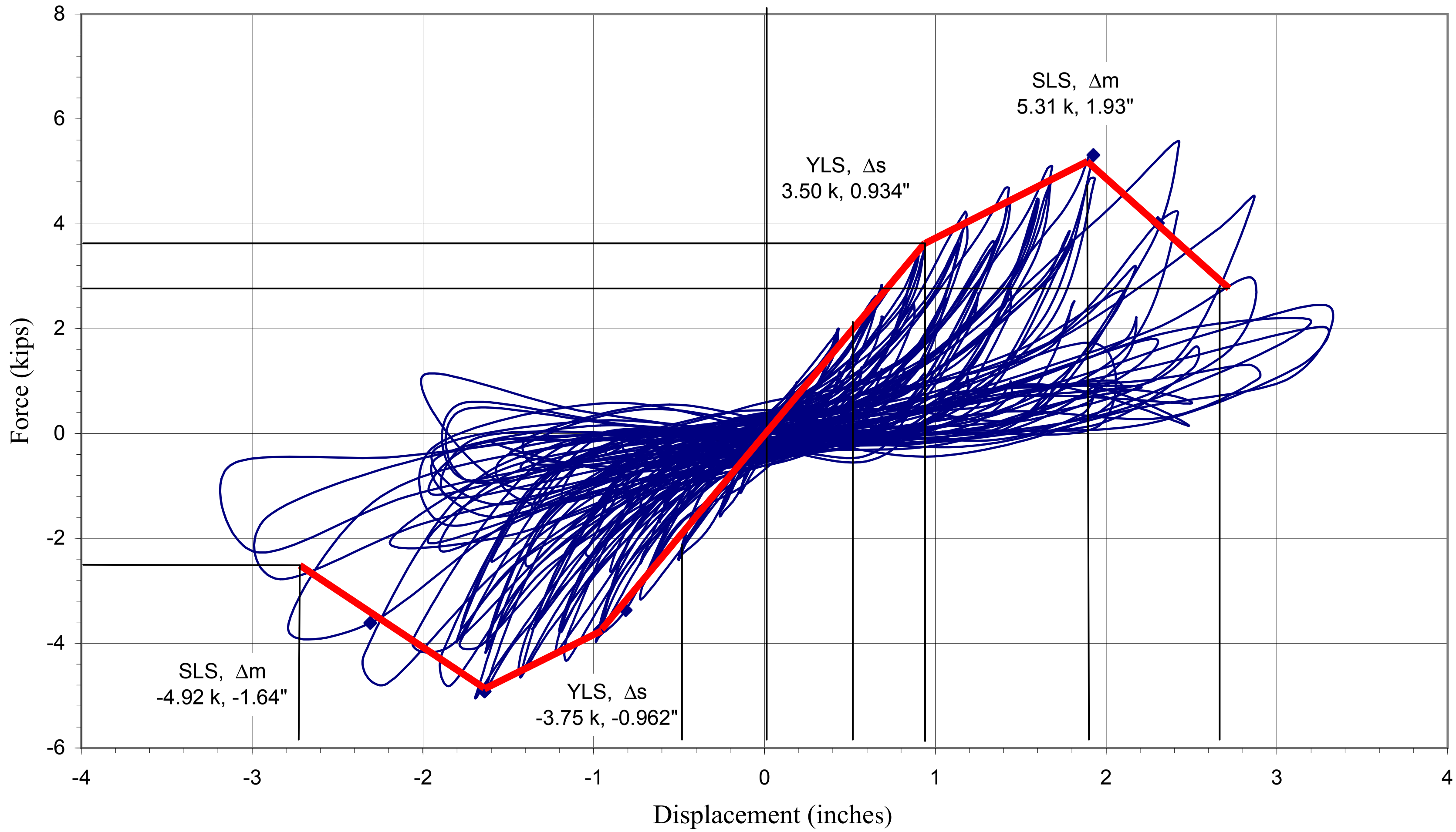

Figure D.9 Hysteresis load-displacement curves panel 6.

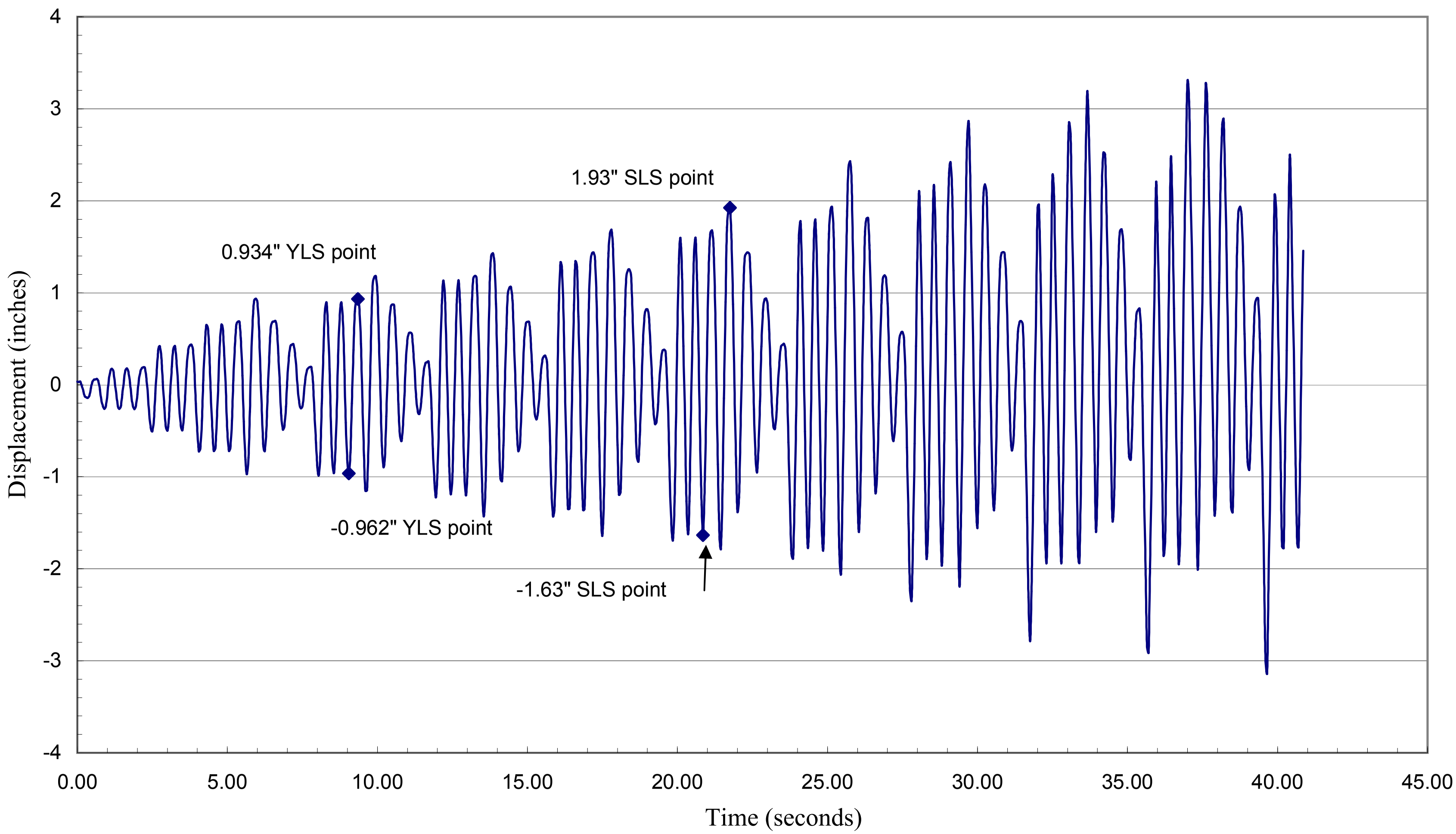

Figure D.10   Displacement versus time panel 6.

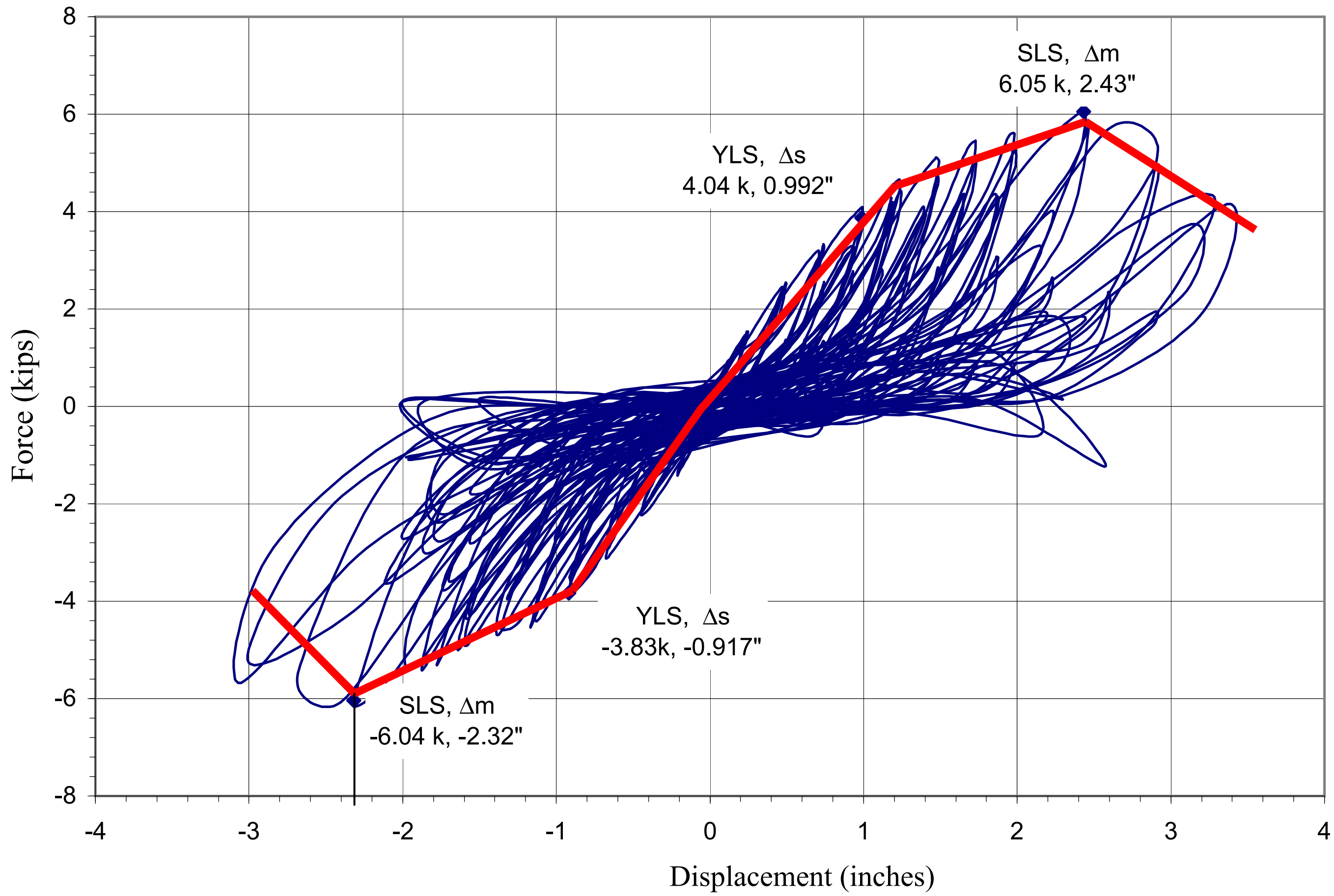

Figure D. 11 Hysteresis load-displacement curves, panel 7.

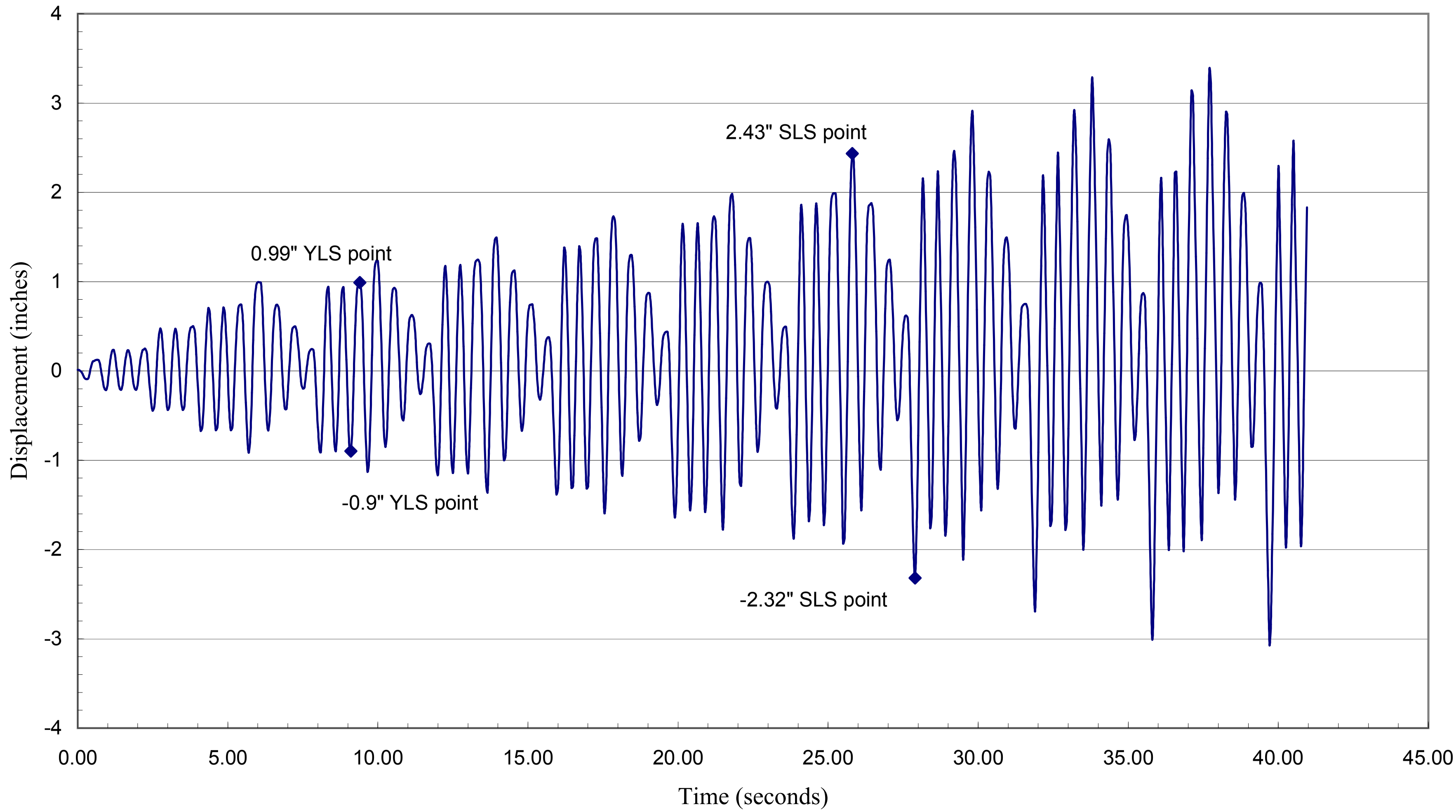

Figure D.12 Displacement versus time panel 7.

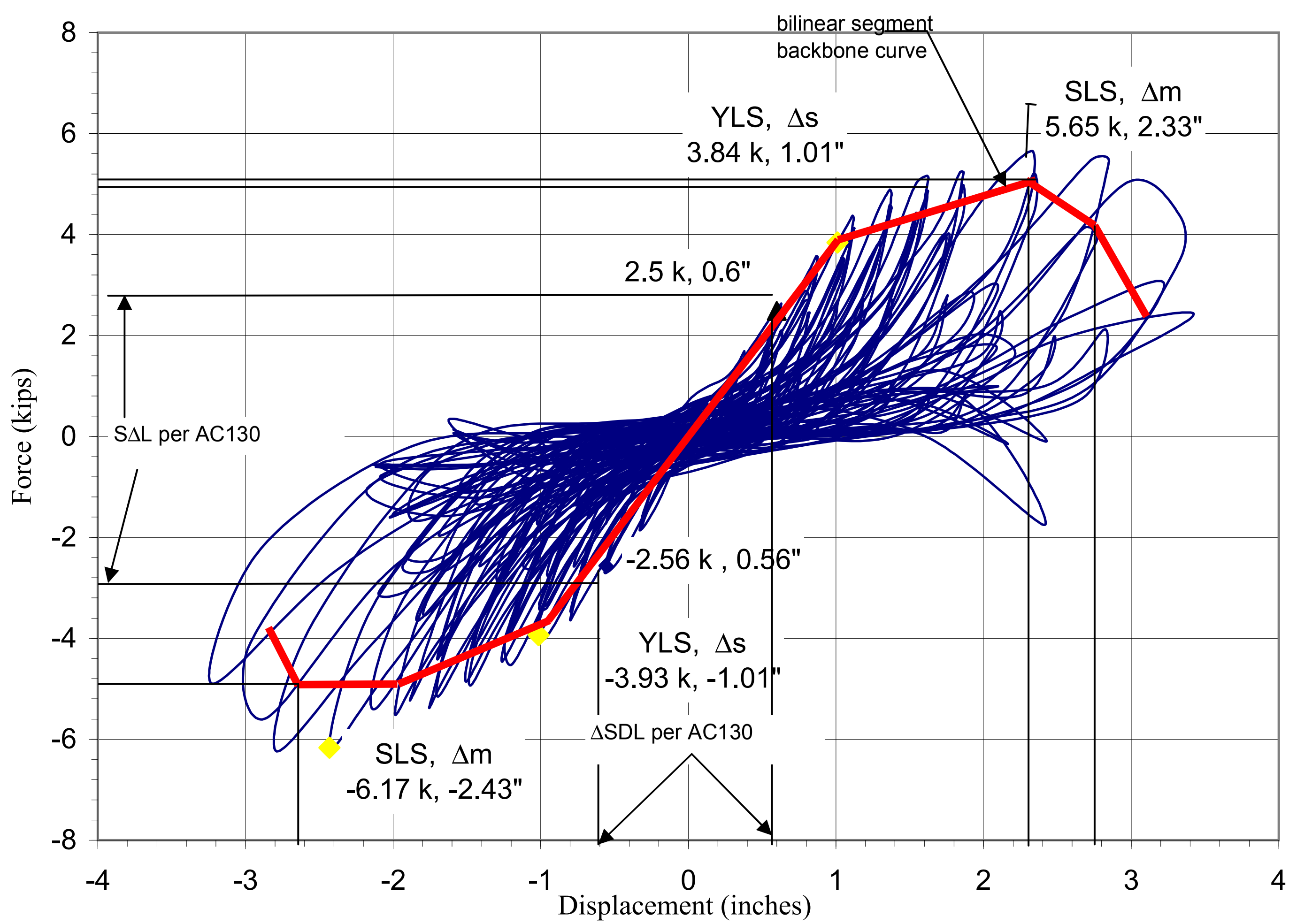

Figure D.13 Hysteresis load-displacement curves panel 9.

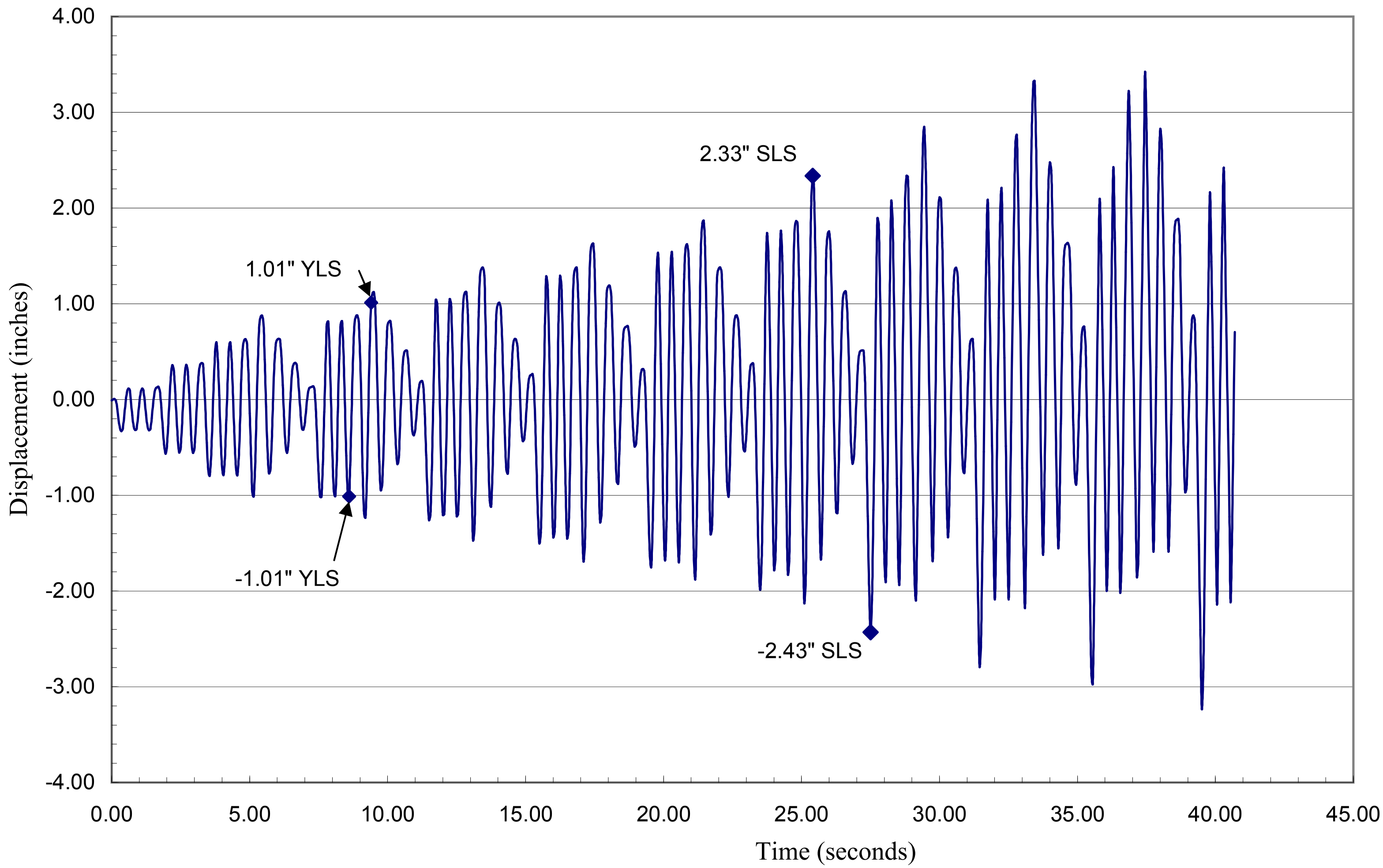

Figure D.14 Displacement versus time panel 9.

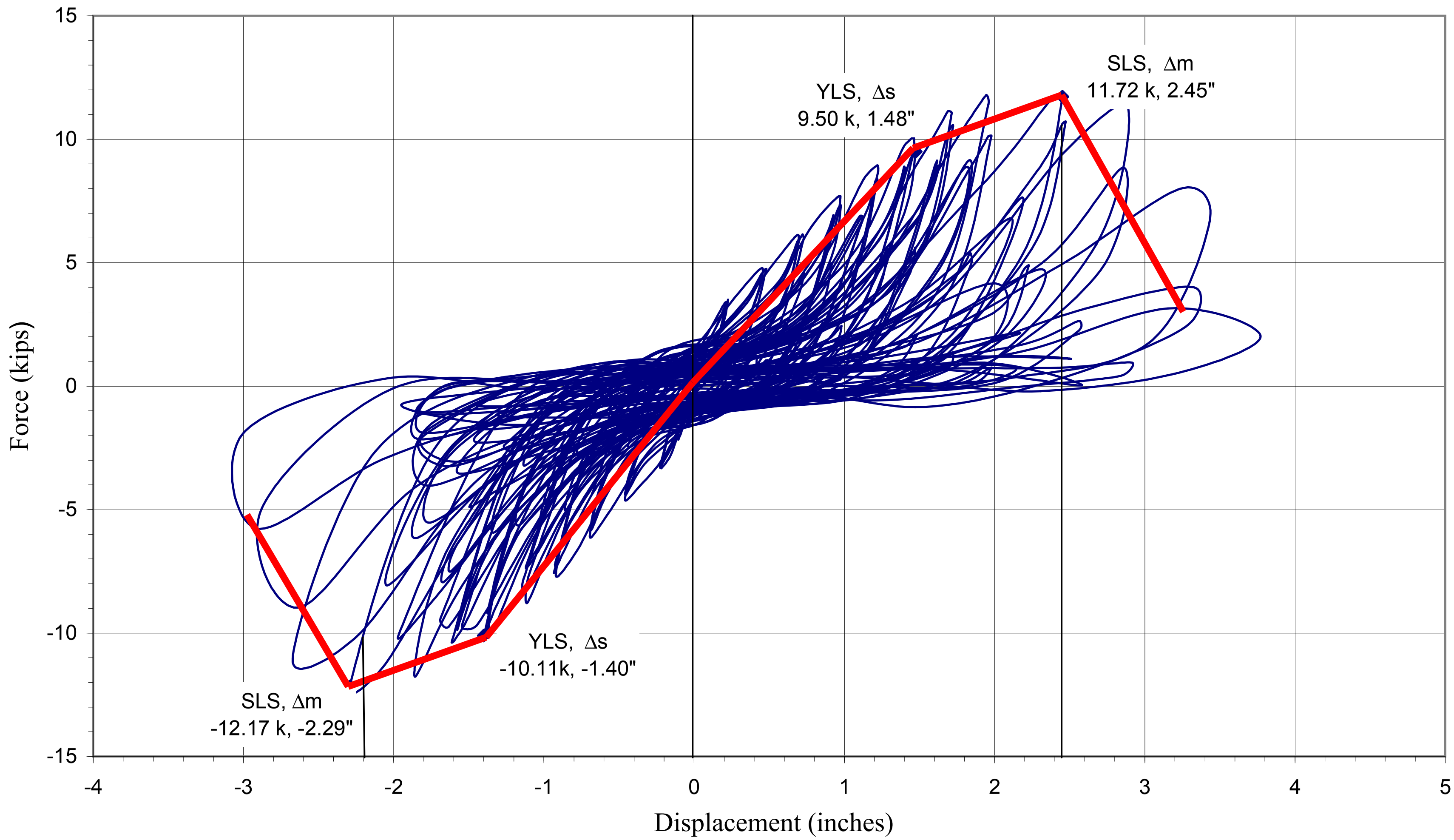

Figure D.15 Hysteresis load-displacement curves panel 10.

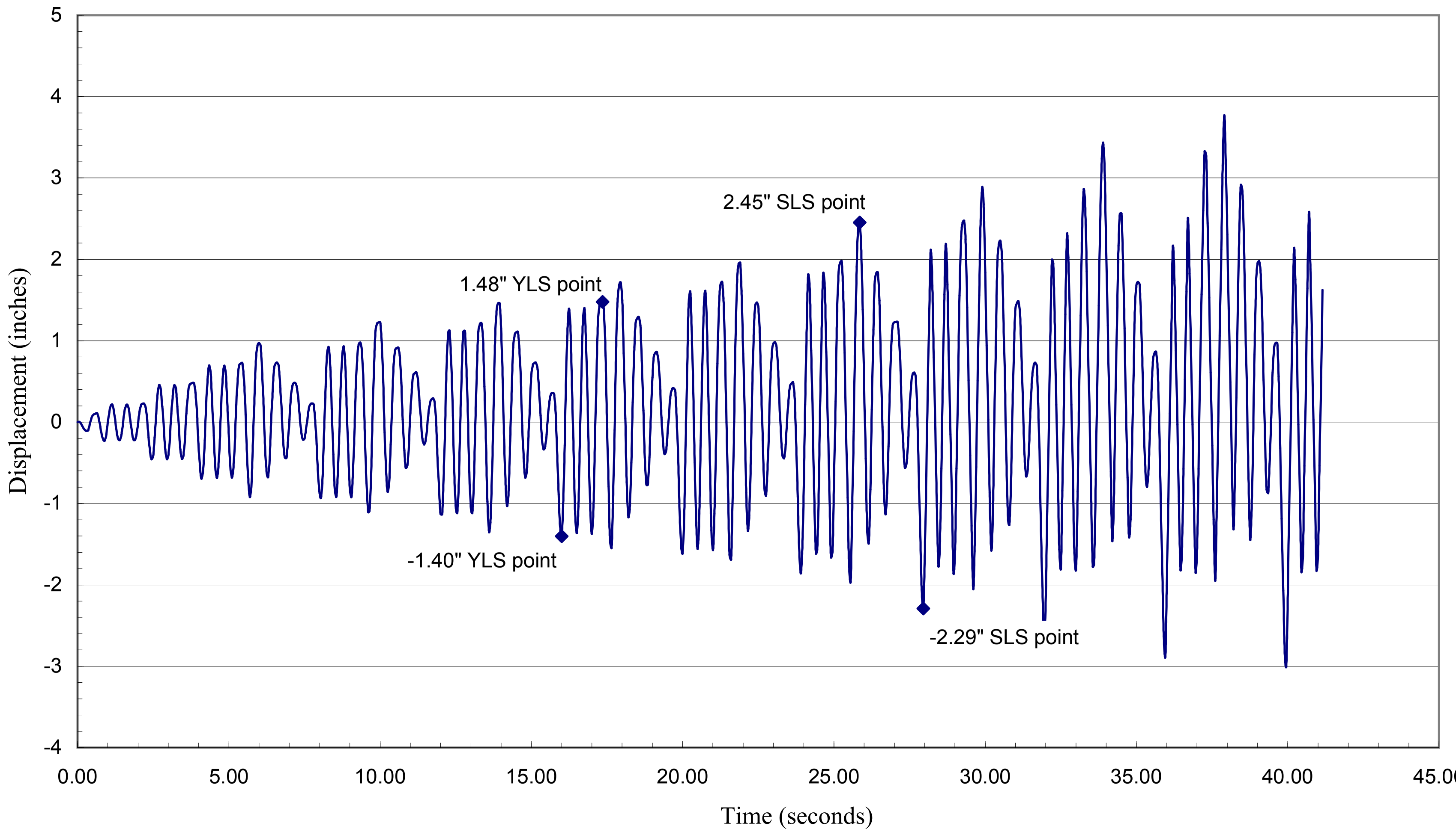

Figure D.16 Displacement versus time panel 10.

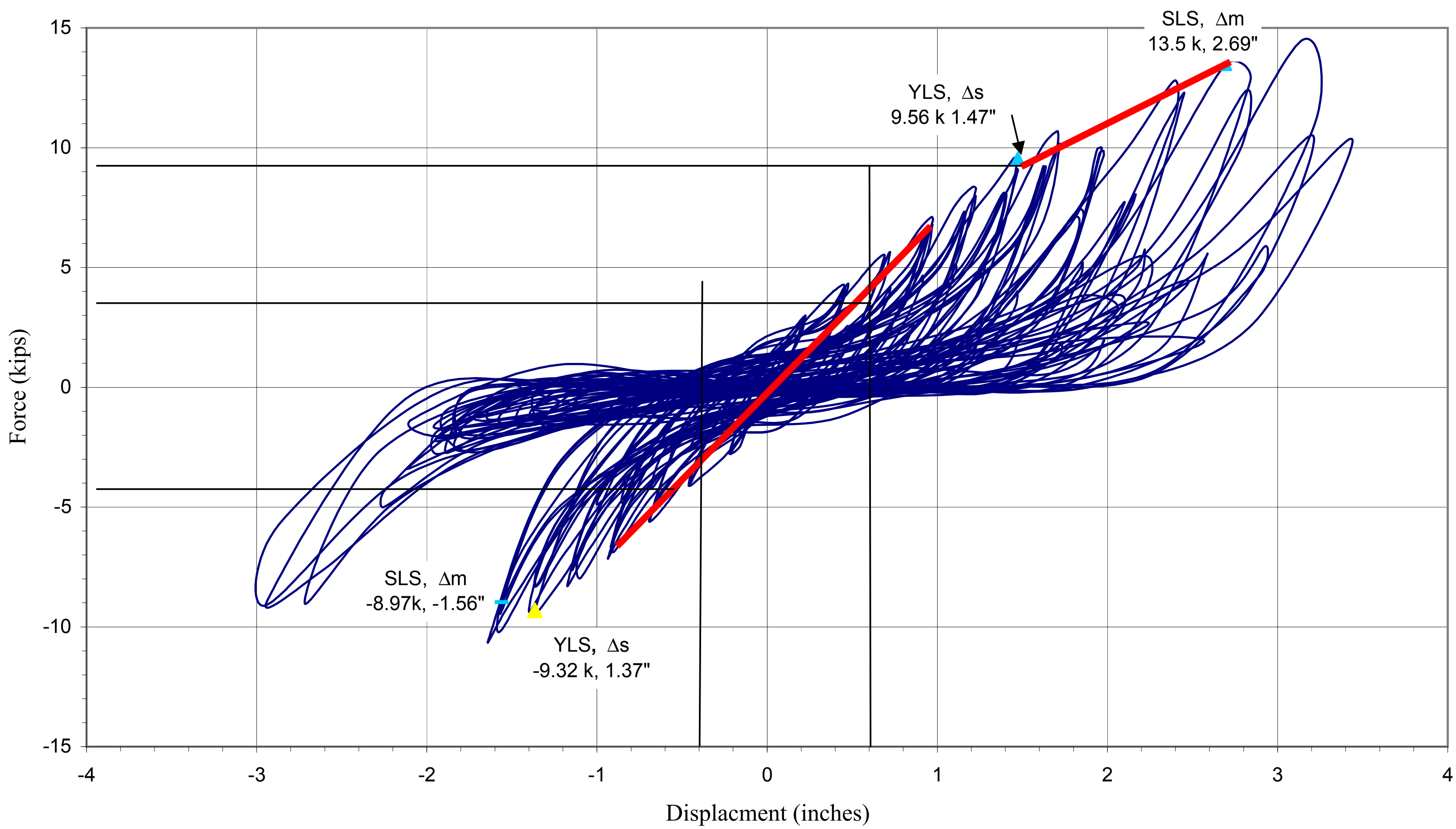

Figure D.17 Hysteresis load-displacement curves panel 11.

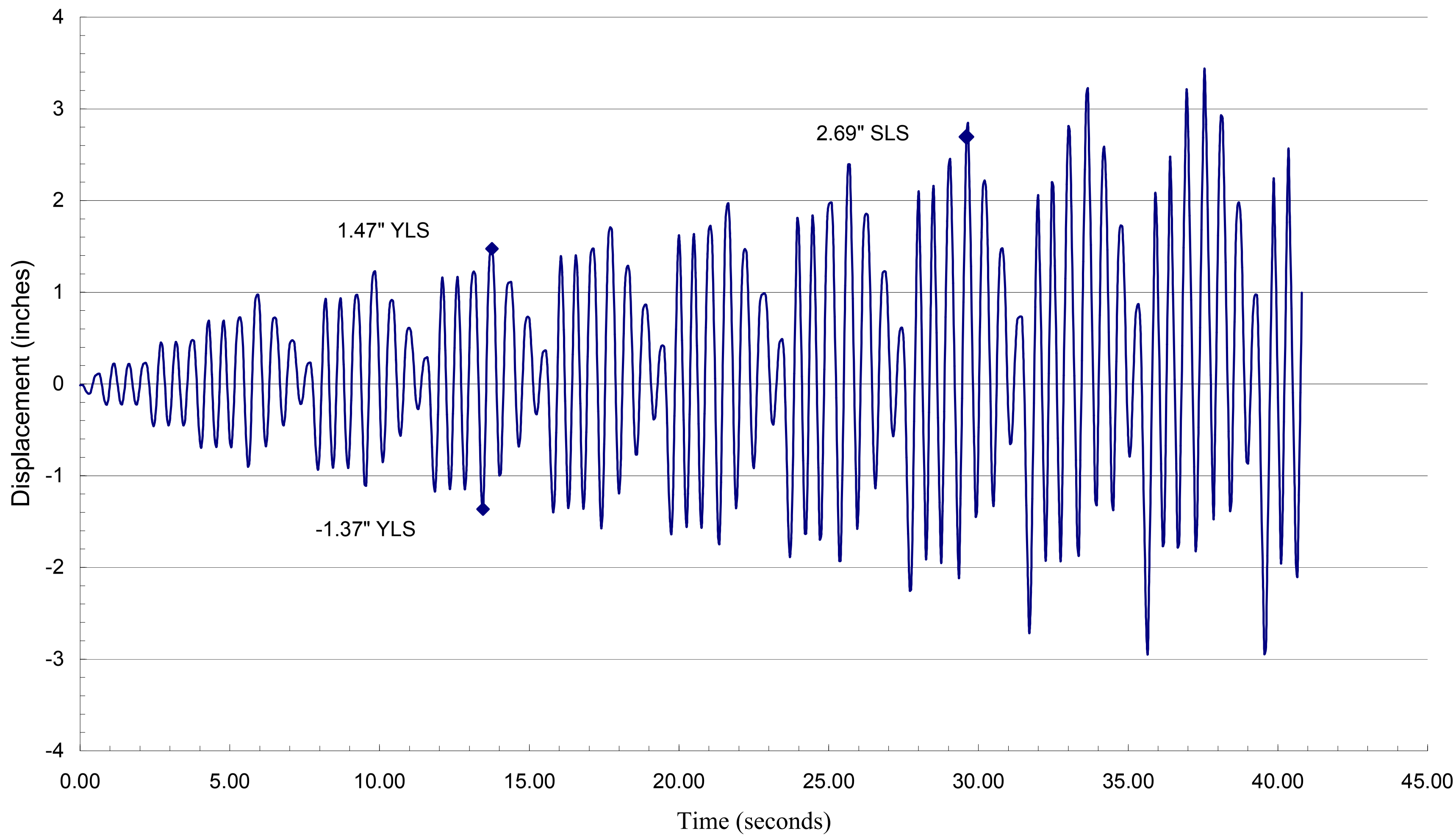

Figure D.18 Displacement versus time panel 11.

APPENDIX E

CALCULATIONS PER ACCEPTANCE CRITERIA 130

AC130 sample calculations for panels 7 and 9.

Section 5.2.3 of AC130 specifies how design loads are to be calculated. The criterion differentiates between Allowable Stress Design loads and Load and Resistance Factor Design loads.

Allowable Stress Design method is based on the lesser of the drift limit loads or the ultimate load limits. The drift limit is determined by first computing the load which occurs at the inelastic drift limit as defined in UBC 1630.10.2 or the mean displacement at the SLS of the tested assembly. For Panels 7 and 9 the mean displacement at the SLS controlled, i.e. was less then the calculated inelastic drift limit. The resulting displacement is then divided by 0.7, and R (the response modification factor per 1997 UBC table 16.)

The reduced displacement corresponds to the strength design limit (SDL) loads. The loads were determined from plotting the displacement on hysteresis loops in Appendix D. The SDL, YLS and SLS are marked clearly on each graph. The SDL load was recorded for each panel. This load was then averaged for the two panels. This average load was then compared to the SLS load average for each panel divided by 2 and the lesser value is used. In this case, and for the other panels, the loads corresponding to the SDL displacement controlled the calculations. The final load value was then divided by 1.4 to reduce it to allowable stress design load levels.

For Panel 7

SLS =	6.05	kips
D m =	2.38	inches
Determination of Ds = (Dm /0.7/R) =		
Ds =	0.617	inches
R =	5.5	from UBC 1997 table
Strength Design Level (SDL) load =	2.8	kips from plotting Ds on the hysteresis loops

For Panel 9

SLS =	5.91	kips
Δ m =	2.38	inches
Determination of Δs = (Δm /0.7/R) =		
Δs =	0.618	inches
R =	5.5	
Strength Design Level (SDL) =	2.8	kips from plotting Ds on the hysteresis loops

AC130 allowable stress design load

Strength Design Level (SDL) load based on Ultimate load

SLS / 2 =	2.99	kips

Strength Design Level load based on displacement (controls)

Divide the controlling load (the lesser of the displacement SDL vs the Ultimate SDL) / 1.4 to determine the ASD loads

AC130 load =	2.00	kips
load in plf =	500	plf

Comparison of YLS loads and SDL loads

YLS =	3.9	kips
SDL =	2.8	kips
% difference =	39.64%	
SLS =	5.98	kips
ASD load =	2.00	kips
Factor SLS /ASD =	2.99	
Factor YLS /ASD =	1.96	

The last two lines calculated above the load factors of SLS/ASD design loads and YLS/ASD design loads factors were calculated to compare with the values which are stated in FEMA 274. The values in FEMA 274 are SLS/ASD = 3.5 and YLS/ASD = 2.76 using a load duration factor of 1.6. Adjusting these for a load duration factor of 1.33 gives SLS/ASD = 2.88, and YLS/ASD = 2.29. these number correspond to the values I have generated which provide "support" for the published numbers.

APPENDIX F

FEMA 273/356 *m* VALUE CALCULATIONS

Data points from the hysteresis loops in Appendix D were used to calculate the *m* values in accordance with FEMA 273 Sections 2.9.4 and 2.13.3. The data were processed in two different manners: (1) first as a type-1 force deformation curve; and (2) as a type-2 force deformation curve. The type-1 curves produced *m* values that were from 40% to 50% lower than the published *m* values for similar wood shear walls. The type-2 curves use lower yield points represented by Q_y' and g'. These values are 2/3 of the yield points derived from the panel's hysteresis loops. The resulting calculated *m* values are within 10% of the published values for walls fastened with equivalent common nail fasteners and spacing.

Rows 2 and 14 on the attached spreadsheet lists the critical points required from each panel to be obtained from the hysteresis loops. The definitions follow:

(1) *Qy* is the capacity at yield point defined as the load past which permanent deformation occurs;

(2) *g* is the deformation corresponding to the yield point;

(3) *e* is the deformation at the SLS point;

(4) *d* is the point at which beyond all load carrying capacities are destroyed;

(5) *a* is the difference between points *g* and *e*;

(6) the stiffness *k* is the elastic stiffness or *Qy/g* in column *G*;

(7) *IO* is the deformation point corresponding to the immediate occupancy performance category;

(8) *IO* is defined by FEMA 273 as the lesser of 120% of g or 2/3 of the LS (life safety deformation point);

(9) *LS* deformation point is 75% of the SLS deformation point;

(10) column J calculates the CP (collapse prevention deformation point);

(11) *CP* is defined as 75% of point *e* or point *d*, whichever is less; (12) *m* at *IO*, *LS*, and *CP* is defined as 75% of the ratio of the respective points *IO*, *LS*, and *CP* divided by point *g*. The wall capacities are listed in columns *B*, *C*, and *D*; row 31 lists the averages in kips.

These capacities determined in accordance with FEMA 273 and are defined as *m* x Q_{CE}. The published *m* values are compared with the values calculated from the test I performed, and the wall assemblies' design strengths are compared with published values. Group 2, (Panels 7 and 9), using the type-2 curve, had the closest matches to the published FEMA values.

	A	B	C	D	E	F	G	H
1				FEMA 273 Acceptance Criteria:				
2	Panel #	Qy kips	g (in)	e (in)	d (in)	a	stiffness k	
3	Panel 2	3.1	0.5845	1.88	2.3	1.2905	5.24	
4	Panel 3	3.7	0.95	1.95	2.7	1	3.84	
5	Panel 5	3.1	0.925	2	2.55	1.075	3.30	
6	averages:	3.26	0.82	1.94	2.52	Ave stiffness:	4.13	
7	Panel 4							
8	Panel 6							
9								
10	Panel 7	3.75	0.95	2.30	3.10	1.35	3.95	
11	Panel 9	3.95	1	2.45	2.7	1.45	3.95	
12	averages:	3.85	0.98	2.38	2.90	Ave stiffness:	3.95	
13								
14	Panel #	IO	LS	CP	m @ IO	m @ LS	m @ CP	
15	Panel 2	0.701	1.41	1.74	0.90	1.80	2.23	
16	Panel 3	0.980	1.46	1.95	0.77	1.15	1.54	
17	Panel 5	1.005	1.50	1.91	0.81	1.22	1.55	
18	averages:	0.976	1.46	1.89	0.89	1.33	1.73	
19	Panel 4							
20	Panel 6							
21								
22	Panel 7	1.140	1.73	2.30	0.90	1.36	1.82	
23	Panel 9	1.200	1.84	2.03	0.90	1.38	1.52	
24	averages:	1.170	1.78	2.18	0.90	1.37	1.67	
25								
26		IO	LS	CP				
27	Panel #	m * QCE	m * QCE	m * QCE				
28	Panel 2	2.76	5.53	6.83	kips			
29	Panel 3	2.82	4.21	5.62	kips			
30	Panel 5	2.49	3.71	4.73	kips			
31	averages:	2.91	4.34	5.63	kips			
32	Panel 4							
33	Panel 6							
34								
35	Panel 7	3.38	5.11	6.81	kips			
36	Panel 9	3.56	5.44	6.00	kips			
37	averages:	3.47	5.28	6.44	kips			
38								
39		FEMA published values for shear walls:			1.4	2.6	3	
40				w/ 2:1 h/w ratio				
41								
42								

	A	B	C	D	E	F	G	H
43				FEMA Acceptance Criteria using a type 2 curve.				
44	Panel #	Q'y kips	g' (in)	e' (in)		a	stiffness k'	
45	Panel 2	2.0	0.39	2.3		1.93	5.24	
46	Panel 3	2.4	0.63	2.7		2.07	3.84	
47	Panel 5	2.0	0.62	2.55		1.93	3.30	
48	averages:	2.17	0.55	2.52		Ave stiffness:	4.13	
49								
50	Panel 7	2.5	0.63	3.10		1.35	3.95	
51	Panel 9	2.6	0.67	2.7		1.45	3.95	
52	averages:	2.57	0.65	2.90		Ave stiffness:	3.95	
53								
54	Panel #	IO	LS	CP	m @ IO	m @ LS	m @ CP	
55	Panel 2	0.701	1.74	2.32	1.35	3.34	4.46	
56	Panel 3	1.140	2.03	2.70	1.35	2.40	3.20	
57	Panel 5	1.110	1.91	2.55	1.35	2.33	3.10	
58	averages:	0.984	1.89	2.52	1.35	2.69	3.58	
59								
60	Panel 7	1.140	2.33	3.10	1.35	2.75	3.67	
61	Panel 9	1.200	2.03	2.70	1.35	2.28	3.04	
62	averages:	1.170	2.18	2.90	1.35	2.52	3.35	
63								
64		% difference between Panels 2,3,&5						
65			vs 7 & 9.					
66		IO	LS	CP				
67		m * QCE	m * QCE	m * QCE				
68		19%	22%	14%				
69	Panel #	m * QCE	m * QCE	m * QCE				
70	Panel 2	2.76	6.83	9.10	kips			
71	Panel 3	3.29	5.84	7.78	kips			
72	Panel 5	2.75	4.73	6.31	kips			
73	averages:	2.93	5.83	7.78	kips			
74								
75	Panel 7	3.38	6.88	9.18	kips			
76	Panel 9	3.56	6.00	8.00	kips			
77	averages:	3.47	6.46	8.61	kips			
78								
79	FEMA published values for shear walls:			1.4	2.6	3		
80			w/ 2:1 h/w ratio					
81	averages:							
82			Per FEMA273 Table 8-3					
83	Ultimate load	3.6	kips		Capacity for a 4' wall *m* x Qce (kips)			
84	Yield load =	2.9	kips		IO	LS	CP	
85					4.0	7.5	8.6	
86	IO CP and LS % difference between				IO	LS	CP	
87	FEMA 273 loads and test data			Group 1 type 1	-27.9%	-42.1%	-34.8%	
88				Group 2 type 1	-14.1%	-29.6%	-25.4%	
89				Group 1 type 2	-27.3%	-22.1%	-10.0%	
90				Group 2 type 2	-14.1%	-13.8%	-0.4%	
91	Panel 2		Panel 3		Panel 5			
92	Normalized Load (kips)	Normalized Displ.	Normalized Load (kips)	Normalized Displ.	Normalized Load (kips)	Normalized Displ.		
93	2.43	2.97	2.42	3.59	1.91	3.44		
94	3.09	7.94	3.79	9.27	3.24	8.45		
95	1.10	11.86	1.99	13.83	1.47	13.06		
96								

	A	B	C	D	E	F	G	H
97	Panel 4		Panel 6		Panel 7		Panel 9	
98	Normalized Load (kips)	Normalized Displ.	Normalized Load (kips)	Normalized Displ.	Normalized Load (kips)	Normalized Displ.	Normalized Load (kips)	Normalized Displ.
99	2.64	4.90	2.74	4.88	3.14	4.89	3.10	5.17
100	3.99	9.99	4.08	9.12	4.82	12.16	4.71	12.19
101	2.19	14.08	1.99	14.08	3.19	15.88	3.51	13.83
102								
103	% difference between Panels 2,3,&5 vs							
104		7 & 9.						
105	IO	LS	CP					
106	m * QCE	m * QCE	m * QCE					
107	18%	11%	11%					

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