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Behavior of Steel Sheet Sheathed Cold-Formed Steel Walls Subjected to Combined Lateral and Vertical Loads

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Abstract

This paper presents an experimental investigation of the behavior of cold-formed steel (CFS) framed walls sheathed by steel sheets subjected to both lateral and gravity loads. The research focuses were on the collapse limit of the CFS shear wall using steel sheet sheathing and the shear resistance of CFS bearing walls. The test results showed that the gravity load has limited impact to the CFS shear wall's behavior and performance. The CFS bearing wall could provide considerable shear resistance and it shall be considered in numerical modeling CFS buildings.

Keywords: Cold-formed steel, shear walls, bearing walls, vertical load

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1. Introduction

Given the properties of light weight, high strength, ease mass production and prefabrication, uniform quality, non-combustibility, etc., cold-formed steel (CFS) is becoming widely used in low- and mid-rise buildings.

According to International Building Code (IBC, 2012) and the North American Standard for Cold-Formed Steel Framing - Lateral Design (AISI S213-12), three types of sheathing materials including structural plywood, oriented strand board (OSB), and steel sheet are provided for sheathing materials of CFS shear walls. CFS shear walls and bearing walls with steel sheets are of great importance due to its all-steel nature and non-combustibility. In this paper, the seismic performances of CFS shear walls and bearing walls with steel sheet sheathing are studied and reported herein.

Yu (2007) tested a series of CFS shear walls sheathed by steel sheet. The tested shear walls were different in aspect ratio, screws spacing, thickness of steel sheet, and thickness of stud and track members. In the previous studies, shear walls were considered as the only lateral resistance component in CFS buildings, the bearing wall lateral resistance ability was ignored. Bearing walls were also tested to study its lateral resistance ability. In the actual buildings, CFS walls usually bear not only lateral loads but also vertical loads from upper floor. It is the intent of this research to study the effect of vertical load on the seismic performances of CFS shear walls and bearing walls.

This paper presents a recent research project conducted at the University of North Texas to study the seismic performance of various configurations of CFS shear walls and bearing walls sheathed by steel sheet. A total of 6 monotonic and 2 cyclic full-scaled tests are included. All test specimens were of 4-ft. (1.22 m) in width and 8-ft. (2.44 m) in height, and subjected to both vertical and lateral loading. Base on the test results, a simplified model in OpenSees was created for the shear and bearing walls, it was shown that the model can simulate the CFS shear walls appropriately and therefore recommended for future seismic performance analyses on buildings.

2. Test Program

2.1 Test Setup

All the tests were conducted on a 16-ft. (4.88 m) span, 12-ft. (3.66 m) high adaptable steel testing frame located in the structural testing laboratory of the University of North Texas. As shown in Figure 1, the testing frame was equipped with a 35 kip (156 kN) hydraulic actuator with ±5 in. (13 mm) stroke. A 20 kip (89 kN) compression/tension load cell was used to measure the applied force, and the load cell was pin connected to a T-shape beam. By No. 12 hex washer head (HWH) self-drilling screws, T-shape beam was installed on the top of the test specimens, and the lateral supports on the frame was used to restrict out of plane displacement of the test specimens. The force was applied to the top of test specimens horizontally. Consequently, a uniform linear racking force could be transmitted to the top track of the test specimens. At last, test specimens were fix on the base beam of testing frame by shear bolts.

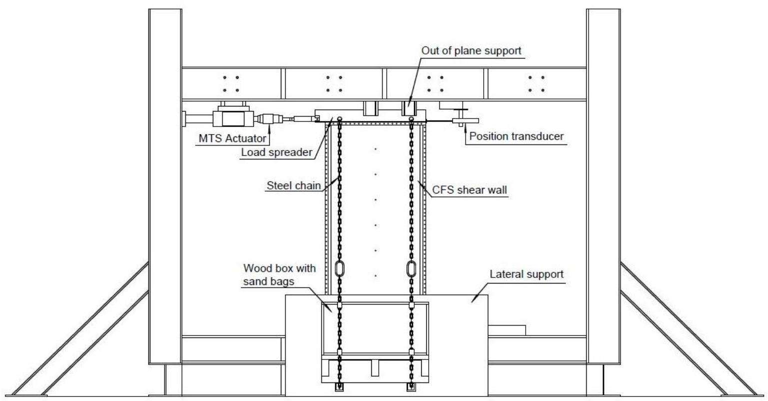

Fig. 1. Front view of the test setup

In order to obtain seismic performance of CFS shear walls and bearing walls under combined lateral and vertical loading, steel chains connected with 2 box that contained sand bags were used to apply vertical loading on the top of test specimens as illustrated in Figures 2 and 3. The weight of each box was 412 lbs (186.88 kg), and weight of each sand bags was 60 lbs (27.2 kg). The total weight applied on the top of the test specimens was 5380 lbs (2440 kg), while the line load on top of the wall was 1345 lbs / ft. (19.49kN / m). Lateral support was placed to keep the boxes from contacting the test specimens. Five position transducers were employed to measure the horizontal displacement at the top of the wall, as well as the vertical and horizontal displacements at the bottoms of the two boundary studs.

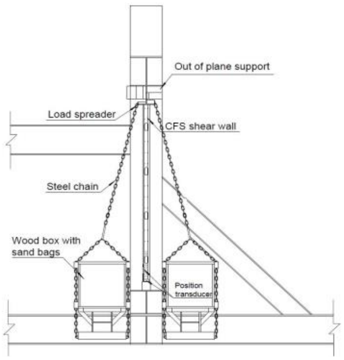

Fig. 2. Side view of test setup

Fig. 3. Photograph of test setup

2.2 Test Procedure

Both monotonic and cyclic tests were conducted in a displacement control mode. For cyclic tests, the test specimens were loaded based on CUREE protocol in accordance with ASTM E2126 (2004). For the sake of comparing different tests results, Δ was chose as 2.25 in. (57.2 mm). A constant cycling frequency of 0.2-Hz (5 seconds per cycle) for the CUREE loading history was adopted to all the cyclic tests as listed in Table 1. The standard CUREE loading history includes 40 cycles with specific displacement amplitudes. But in order to fully investigate the post peak behavior of the test specimens, 43 cycles were adopted in the test programs as shown in Figure 4.

Table 1 CUREE loading history

Cycle No.	% Δ	Cycle No.	% Δ	Cycle No.	% Δ	Cycle No.	% Δ
1	5	12	5.6	23	15	34	53
2	5	13	5.6	24	15	35	100
3	5	14	10	25	30	36	75
4	5	15	7.5	26	23	37	75
5	5	16	7.5	27	23	38	150
6	5	17	7.5	28	23	39	113
7	7.5	18	7.5	29	40	40	113
8	5.6	19	7.5	30	30	41	200
9	5.6	20	7.5	31	30	42	150
10	5.6	21	20	32	70	43	150
11	5.6	22	15	33	53		

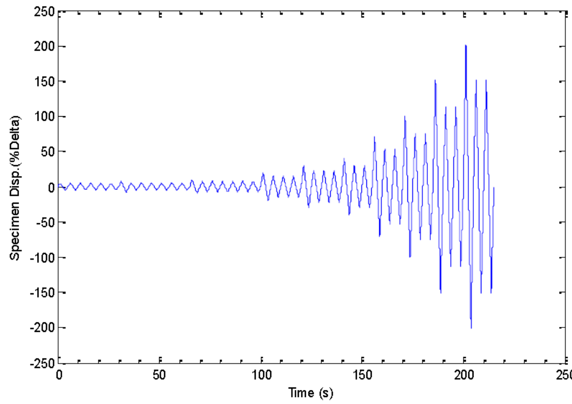

Fig. 4. CUREE basic loading history

2.3 Monotonic and cyclic tests

2.3.1 Test specimen assembly

All the test specimens had the same overall dimensions of 4-ft. (1.22 m) in width and 8-ft. (2.44 m) in height (2:1 aspect ratio). Steel Studs Manufacturers Association (SSMA, 2004) structural stud and track members were used for the framing members of all test specimens.

For shear walls test specimens assembly, shown in Figure 5, 2 studs fastened together back-to-back with No.8 × 1/2-in. modified truss head self-drilling tapping screws pairs at every 6 in. (152.4 mm) on center as the boundary studs for the shear walls test specimens, and a single stud was employed as the middle stud. Then both top and bottom ends of all studs were connected to the tracks by No.8×1/2-in. modified truss head self-drilling tapping screws. At the bottom of shear walls, 2 Simpson Strong Tie HD/S 15S hold down were fixed on the inner side of boundary studs as illustrated in Figure 5 and 6. Steel sheet was installed on one side of the test specimens by No. 8 × 1/2-in. modified truss head self-drilling tapping screws. The screw spacing was 2 in. (50.8 mm) or 4 in. (101.6 mm) in the panel edges and 12 in. (304.8 mm) in the field. Hold down was fixed on the base beam by 3/4 in. (19 mm) diameter ASTM A307 shear bolts, and the bottom tracks were fixed on the base beam by two 5/8 in. (16 mm) diameter ASTM A490 shear bolt. For the bearing walls, shown in Figure 7, both boundary studs were single stud, and no hold-down were employed in these specimens. The bearing walls connected to the base beam using 4 ASTM A490 anchor bolts as illustrated in Figure 8.

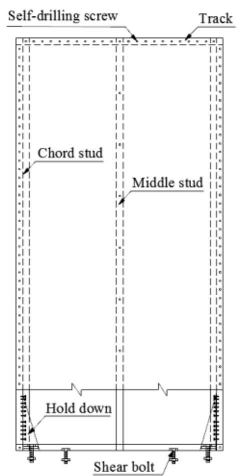

Fig. 5. Sketch of shear wall

Fig. 6 Hold-down and shear bolts at bottom of shear wall

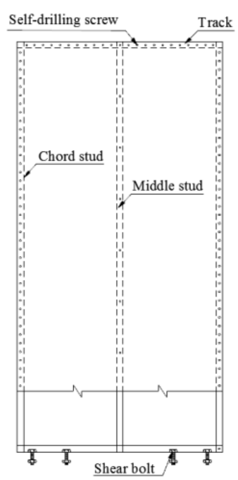

Fig. 7. Sketch of bearing wall

Fig. 8. Shear bolts at bottom of bearing wall

2.3.2 Test matrix

A total of 6 shear walls test specimens and 2 bearing walls test specimens in different configurations were studied in this paper. Cyclic full-scale tests were conducted on 2 shear walls test specimens, and monotonic full-scale test were conducted on 4 shear walls test specimens and 2 bearing walls test specimens. The thickness of all steel sheets are 0.838mm, Table 2 summarizes the test matrix of all tests. For the meaning of test label in the table, for example, S-54-M means the test specimen is shear wall, thickness of framing member is 54 mil (1.372 mm) and test procedure is monotonic test. B-68-C means the test specimen is bearing wall, thickness of framing members are 68 mil (1.727 mm) and test procedure is cyclic test.

Table 2 Test matrix

Test label	Vertical loading	Perimeter fastener spacing (in.)	Stud	Track
S-43-M1	-	4	350 S 162-43[1]	350 T 150-43[4]
S-43-M2	√	4	350 S 162-43	350 T 150-43
S-54-M	√	2	350 S 162-54[2]	350 T 125-54[5]
S-54-C	√	2	350 S 162-54	350 T 125-54
B-54-M	√	2	350 S 162-54	350 T 125-54
S-68-M	√	2	350 S 200-68[3]	350 T 150-68[6]
S-68-C	√	2	350 S 200-68	350 T 150-68
B-68-M	√	2	350 S 200-68	350 T 150-68

Note:
1. 350S162-43 SSMA 3.5 in. x 1.625 in. structural stud made of 43 mil Grade 33 steel
2. 350S162-54 SSMA 3.5 in. x 1.625 in. structural stud made of1.54 mil Grade 33 steel
3. 350S200-68 SSMA 3.5 in. x 2.00 in. structural stud made of 68 mil Grade 50 steel
4. 350T150-43 SSMA 3.5 in. x 1.50 in. structural track made of 43 mil Grade 33 steel
5. 350T125-54 SSMA 3.5 in. x 1.25 in. structural track made of 54 mil Grade 50 steel
6. 350T150-68 SSMA 3.5 in. x 1.50 in. structural track made of 68 mil Grade 50 steel

2.3.3 Material Properties

Coupon tests were conducted to obtain the actual properties of the materials used in test specimens. The testing procedure conformed to the ASTM A370 (2006), “Standard Test Methods and Definitions for Mechanical Testing of Steel Products”. A total of three coupons were tested for each member, and the average results, including actual uncoated thicknesses of the materials, are provided in Table 3.

Table 3 Material properties

Component	Uncoated Thickness (in.)	Yield Stress F_y (ksi)	Tensile Strength F_u (ksi)	F_u/F_y
33 mil steel sheet	0.0358	41.62	53.88	1.3
350 T 150-43	0.042	43.1	55.6	1.29
350 S 162-43	0.043	47.6	55.1	1.15
350 T 125-54	0.0555	52.96	68.47	1.293
350 S 162-54	0.0553	38.9	54.84	1.41
350 T 150-68	0.0721	53.15	70.07	1.32
350 S 200-68	0.0709	55.01	71.075	1.29

2.4 Test Results

The average peak load, initial stiffness, drift ratio at the peak load and the ductility factor are provided in Table 4. The ductility of test specimens was evaluated by using the concept of equivalent energy elastic plastic model (EEEP) which was first proposed by Park (1989) and later revised by Kawai (1997) et al.

Table 4 Summary of test results

Test label	Peak load (plf)	Drift ratio at peak load (%)	Initial stiffness （lbs/in.）	Ductility factor
S-43-M1	1174	1.80	5435	3.10
S-43-M2	1169	1.46	6852	3.79
S-54-M	1953	1.75	13241	4.54
S-54-C	2218	1.58	10540	3.15
B-54-M	1013	1.82	5020	2.80
S-68-M	2262	2.94	11241	7.61
S-68-C	2308	2.19	12198	4.80
B-68-M	1332	2.51	6344	3.69

Load-deformation curve and hysteresis curve obtained from tests as shown in Figure 9 to 13.

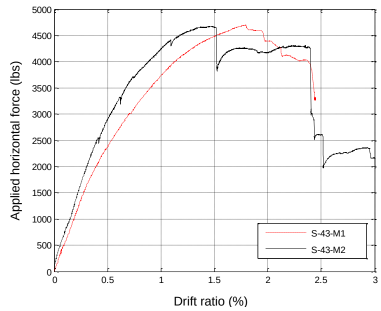

Fig. 9. Load-deformation curve for S-43-M1 and S-43-M2

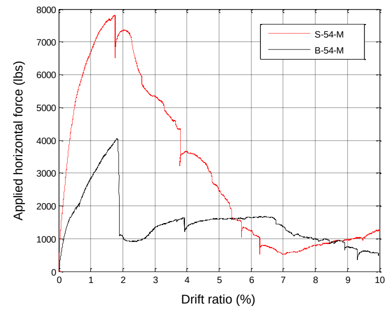

Fig. 10. Load-deformation curve for S-54-M and B-54-M

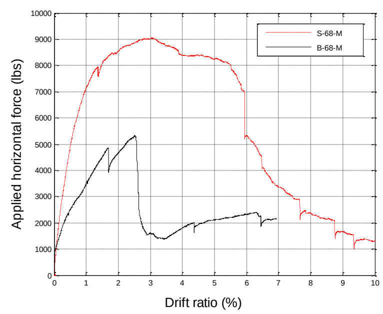

Fig. 11. Load-deformation curve for S-68-M and B-68-M

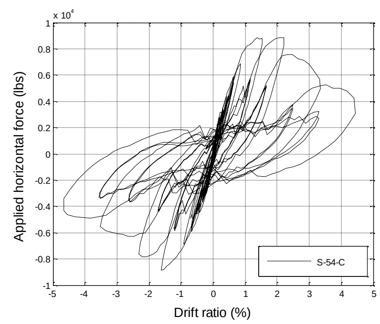

Fig. 12. Test hysteresis for S-54-C

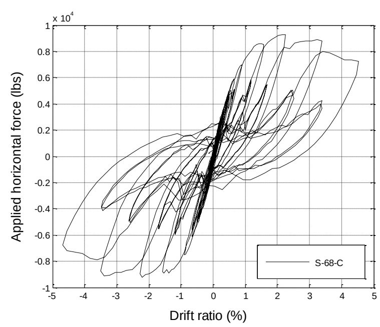

Fig. 13. Test hysteresis for S-68-C

Comparing test reslut of S-43-M1 and S-43-M2, shown that the peak load of shear wall with vertical loading and without vertical loading are almost same, but in terms of the drift ratio at peak load, shear wall without vertical loading is 27.6% greater than the shear wall with vertical loading. For the initial stiffness, shear wall with vertical loading is 22% greater than the shear wall without vertical loading. Comparing test reslut of S-54-M and B-54-M, the peak load of shear wall is 92.7% greater than bearing wall, the deflections at peak load of bearing wall is 4% greater than shear wall, and the initial stiffness of shear wall is 163.75% greater than bearing wall. Comparing test reslut of S-68-M and B-68-M ,the peak load of shear wall is 69.83% greater than bearing wall, the deflections at peak load of shear wall is 4% greater than bearing wall and the initial stiffness of shear wall is 77.2% greater than bearing wall. Failure mode of all test specimens is listed in Table 5. Details of failure modes are shown in Figure 14.

Table 5 Failure modes

Test label	Failure mode		
	Screw pull out	Boundary Stud buckling	Middle stud buckling
S-43-M1	√	-	-
S-43-M2	-	√	√
S-54-M	-	√	√
S-54-C	-	√	√
G-54-M	√	√	√
S-68-M	-	√	√
S-68-C	-	√	√
G-68-M	√	√	-

Fig. 14. Failure mode of test specimens: (a) screw pull out, and (b) middle stud buckling, and (c) boundary stud buckling

4. Conclusion

A series tests on the seismic performance of various configurations of CFS shear walls and bearing walls sheathed by steel sheet were conducted. The test results showed that the gravity load has limited impact to the CFS shear wall's behavior and performance and vertical loading won't weaken the lateral force resistance ability of shear walls. Secondly, The CFS bearing walls could provide considerable shear resistance which would generate conservativeness to the current lateral design method specified in AISI standards. The shear strength of bearing walls shall be considered into the numerical modeling of CFS buildings.

5. Acknowledgement

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