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Mahsa Mahdavian

Wenying Zhang

Cheng Yu

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Sheathing Overlapping and Attachment Methods for Cold-Formed Steel Shear Walls with Corrugated Steel Sheathing

Mahsa Mahdavian[1], Wenying Zhang[2], Cheng Yu[3]

Abstract

Cold-formed steel (CFS) shear walls sheathed with corrugated steel sheathing are a feasible solution to non-combustible high structural performance CFS shear walls in mid-rise buildings. Corrugated steel sheathings have high in-plane strength and stiffness due to the cross sectional shape of the sheet. This paper presents an experimental study on two specific issues: (1) the sheathing overlapping configurations and their impact to the shear wall performance, (2) the attachment method for sheathing to framing. For the overlapping issue, one overlap and two overlaps in the corrugated sheets were experimentally investigated, it was found that the overlap differences did not cause significant different behaviors and strength of CFS shear walls. For the sheathing-to-framing attachment method, self-drilling screws and dual spot welding were studied. A portable spot welder with dual heads was used in this research. Connection tests and full scale shear wall tests were conducted to study the two different connection methods. It was found that the dual spot welding yielded a weaker connection than the conventional self-drilling screw connections. This paper

[1] Research Assistant, University of North Texas, Denton, Texas, mahsa_mahdavian@yahoo.com
[2] Ph.D. Student, Tongjing University, Shanghai, China, wenyingchangan@163.com
[3] Associated Professor, University of North Texas, Denton, Texas, cheng.yu@unt.edu

presents the details of the test programs, research findings and recommendations for CFS shear wall applications.

Introduction

The usage of Cold-Formed Steel (CFS) members as primary structural elements has increased in recent years. Most of these structures are mid-rise residential and commercial buildings which fall under Type I and Type II construction of the International Building Code (IBC 2012). Due to Section 602.2 of IBC, building elements of these construction categories must be of noncombustible material. Therefore, lateral force resisting systems are limited to two types of: 1. Shear wall with flat steel sheathing, and 2. Steel strap cross bracing shear wall. Shear wall with flat steel sheathing has low shear strength and is not suitable for mid-rise buildings in high seismic and wind hazardous areas. Steel strap bracing shear wall requires special instillation details which result in higher material and labor costs. A noncombustible CFS shear wall with high structural performance is needed in the mid-rise construction field.

CFS shear walls sheathed with corrugated steel sheathing are a feasible solution to a high performance all steel shear resisting system. Fulop and Dubina (2004) performed a series of full-scale shear wall tests with different sheathing materials including gypsum board, OSB and corrugated steel sheets. The framing members of all specimens were kept identical in order to be able to study the sheathing effect on shear wall performance. Fulop and Dubina concluded that CFS shear walls with corrugated steel sheathings were rigid and capable of resisting lateral loading. The failure mechanism of these specimens were reported in the seam fasteners. Stojadinavic and Tipping (2007) conducted a series of 44 cyclic tests on CFS shear walls with corrugated steel sheathing. Different design parameters including: corrugated steel sheet gauge, framing gauge, fastener type and size, seams fastener spacing, as well as different sheathing materials. In all tests, the failure mode reported was the eventual pulling out of screws due to the corrugated sheet warping. CFS shear walls with corrugated steel sheathings are continuously under research at University of North Texas. Yu et al. (2009) studied the new shear resisting system under monotonic and cyclic lateral loading. The parameters under investigation included the framing member thickness, fastener size and spacing, and the boundary stud configurations. Results indicated that corrugated sheathed shear walls yielded higher strength and greater initial stiffness in comparison to CFS shear walls with flat steel sheets having the same thickness.

CFS shear walls with corrugated steel sheathings have demonstrated high structural performance. Design details of shear walls such as sheathing connections, seams connections and corrugated sheathing profile have high influences to the structural performance of a shear wall. Sheathing overlapping configuration and sheathing to frame connection methods are the focus of this paper. Design details, test details, and analysis results of the shear walls under cyclic lateral loading are reported herein.

Shear Wall Test Setup

Shear wall tests were conducted on a 16 ft. by 13.3 ft. high self-equilibrating steel testing frame located in the Structural Laboratory at the University of North Texas. The testing frame is equipped with a MTS 35 kip hydraulic actuator with a 10 in. stroke. A MTS 407 controller and a 20-GPM MTS hydraulic power unit were used to drive the loading system. A 20 kip TRANSDUCER TECHNIQUES SWO universal compression/tension load cell was used to pin-connected the actuator shaft to the T-shape loading beam. A total of five NOVOTECHNIC position transducers were used to measure the horizontal displacement at the top of the shear wall, and to measure the vertical and horizontal displacements at the bottom of the two boundary frame members. The data acquisition system consisted of a National Instruments unit and an HP Compaq desktop. The applied force and the five displacements were recorded instantaneously during each test. Details of the testing frame and the location of the position transducers are shown in Figure 1.

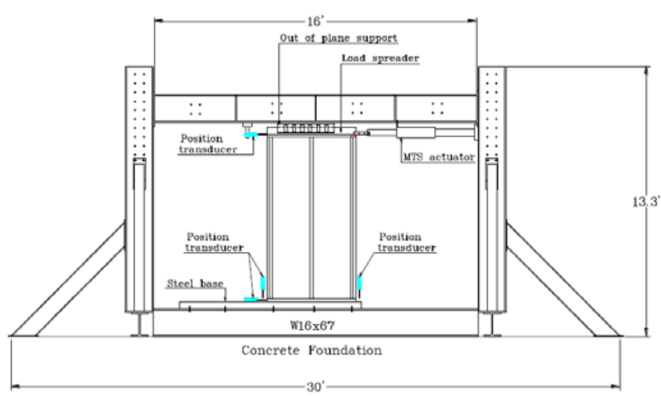

Figure 1 - Testing frame and position transducer locations

The specimens were bolted to the base of the testing frame and loaded horizontally at the top. The base beam is a 5 in. × 5 in. × ½ in. structural steel tube and is bolted to a W16×67 structural steel beam which is anchored to the floor. One web of the base beam has cut outs in several locations to provide access of the anchor bolts connection hold-downs to the base beam. Figure 2 demonstrate the testing frame with an 8 ft. × 4 ft. shear wall installed.

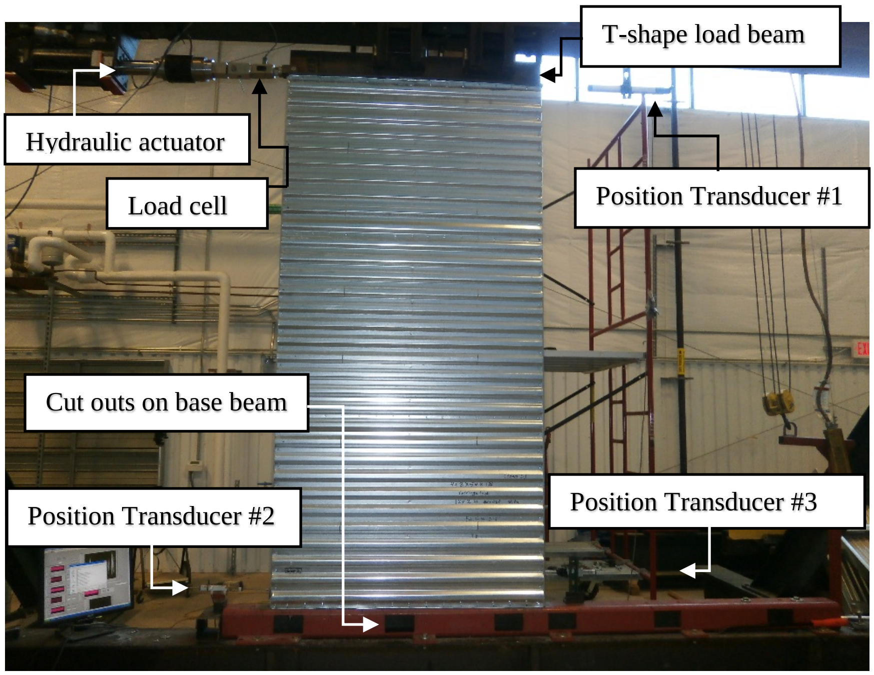

Figure 2 - Testing frame, front view

The lateral loading was applied directly to the T-shaped load beam by the actuator. The load beam was attached to the web of the top track using a pair of No. 12-14 × 1 ¼ in. hex head self-drilling screws every 3 in. on center so that a uniform linear racking force could be transmitted to the top track of the shear wall. The stem of the T-shape beam was placed in the gap between the rollers located at the top of the testing frame to prevent out-of-plane movement of the walls. The rotation of the rollers were able to reduce the friction generated by the movement of the T-shape during the test procedure and were also able to guide the loading T-shape beam. To anchor the specimen to the base beam of the testing frame, two Simpson Strong-Tie S/HD15S hold-downs with 33 pre-drilled holes corresponding to No. 14-14 × 1 in. hex washer head self-drilling screws were used. In cases which studs had a punch-out at the hold-down location, additional welding around the edge of the punch-out was used to reinforce the hold-down to stud attachment. In addition, two Grade 8 3/4 in. bolts and two Grade 8 5/8 in. bolts were used in the anchorage system.

Cyclic tests were conducted in a displacement control mode following CUREE protocol in accordance with the ICC-ES AC130 (2004). The CUREE basic loading history includes 43 cycles with specific displacement amplitudes. The specified displacement amplitudes are based on Guowang Yu's research (2013). A constant cycling frequency of 0.2-Hz (5 seconds) for the CUREE loading history was adopted for all tests.

Shear Wall Test Specimens

The specimens tested in this research were of 8 ft. height by 4 ft. width (2:1 aspect ratio). Boundary studs (350S162-68, 50 ksi) are connected back-to-back using a pair of No. 12-14 × 1 ¼ in. hex washer head self-drilling screws every 6 in. on center starting from above the hold-downs. One track steel member (350T150-68, 50 ksi) was used as top and bottom track. Studs were inserted into tracks and flanges were connected using No. 12-14 × 1 ¼ in. hex washer head self-drilling screws on both sides of each wall. The sheathing is Verco Decking SV36 27 mil thick corrugated steel sheet with 9/16 in. rib height. For each wall specimen, the sheathing was made of three corrugated steel sheets which over-lapped and were connected by a single line of screws at the over-lapped locations. The sheathing is installed on one side of the wall and on the outside of the frame using No. 12-14 × 1 ¼ in. hex washer head self-drilling screws. Due to the sheathing profile, the spacing of the screws were limited to 3 in. on the boundary studs and tracks as well as the seams locations, and 6 in. fastener spacing along the field stud. Specimen 1, the corrugated sheets over lapped by two ribs. For specimen 2, the top and bottom sheathing of the shear walls were cut so that the sheathings only over lapped by one rib. Both specimens have a total of 24 vertical slits, each have 2 in. length, in order to improve the ductility of the shear walls following Guowang Yu (2013) research. Figure 3 shows details of the two specimens.

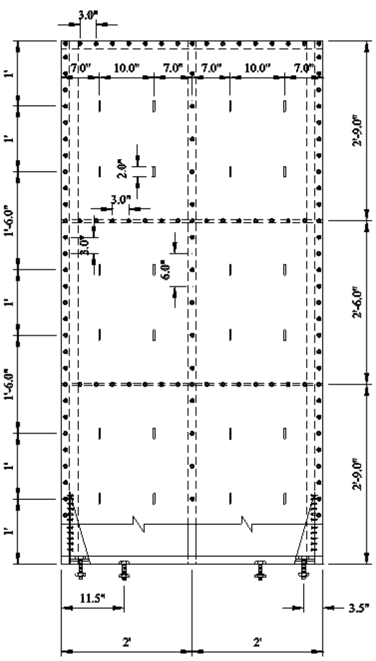

Figure 3 - Specimen 1 and specimen 2 design details

For specimens 3 and 4, a different sheathing connection method was investigated. Instead of using self-drilling screws, a spot-welding machine, shown in Figure 4, was employed for all sheathing connections. The spot-welder "EQUA-PRESS Dual Tip Holders "model 4010 was purchased from LORS Machinery. Also, two "A" pointed double bent shanks with ½ in. diameter points were purchased. Due to the double bent shank, the spacing between the two welders could be adjusted (between 2 in. to 4 in.) to meet our design requirements. The sheathing connection spacing for these two specimens were 3 in. along the boundary studs, field stud, and at seams locations. Due to the dual tip of the spot-welding machine, the sheets were connected at seams in two parallel rows (Figure 5). A designated spot-welding power supply was purchased from TECNA to be able to control the power and the rest time between each cycle to obtain stronger welds.

Figure 4 - Spot-welding machine and "A" pointed double bent shanks

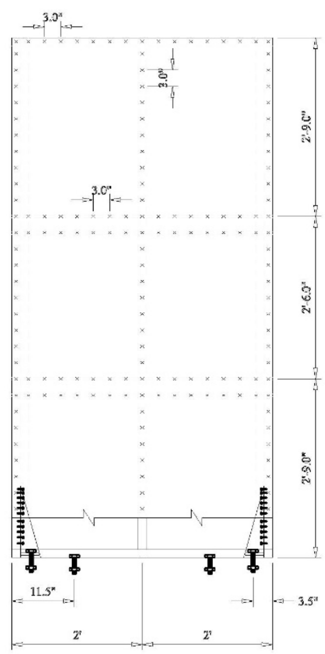

Figure 5 - Spot-welded specimen details

Test Results & Discussions

Sheet Over-lapping

Shear wall specimen 1 with double overlapping ribs and shear wall specimen 2 with a single overlapping rib both failed due to sheathing connection failure along boundary studs. Table 1 is a summary of numerical test results. The average peak load and average displacement of the two specimen were only 3% and 6% different, respectively. Figure 6 compares the hysteresis curve of the two shear walls. It is appropriate to conclude that different over-lapping configurations have minimum impact on the shear wall performance. As a result, double overlapping is recommended as to reduce the construction duration and labor required.

Table 1 - Over-lapping test results

Specimen #	Average peak load (lbs)	Average disp (in.)
1	10865	2.601
2	11179	2.453

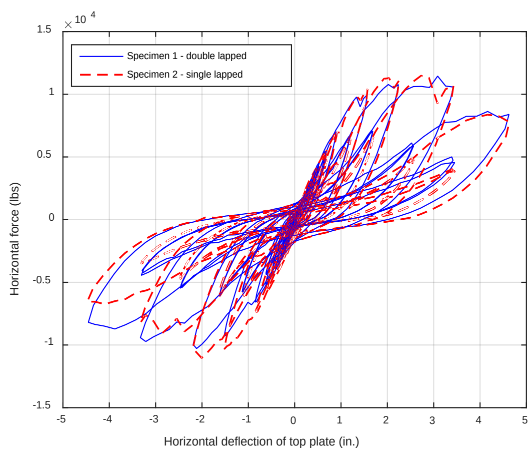

Figure 6 - Hysteresis curve comparison - over-lapping

Sheathing Connections

Connection Tests

A series of connection tests were performed on the self-drilling and spot-welding (resistance welding) connections. The connection tests were conducted following AISI S905-13 “Test Standard for Cold-Formed Steel Connections” on No. 12 Hex Washer Head (HWH) self-drilling screws as well as different voltage and cycle time settings of the spot-welding machine. The cycle time is the time selected for the electrical source to conduct through the materials under applied force. Each cycle time is equivalent to 1/60 of a second.

The connection tests were tensioned on an INSTRON 4482 universal testing machine. The tests were conducted in displacement control at a constant rate of 0.05 in/min. Sheathing-to-stud connection test setup for HWH screw and SW are seen in Figures 7 and 8 respectively. Three connection tests were conducted for each setting and the average test results are shown in Table 2 and Table 3. Multiple spot-welded settings were tested to obtain best SW connections. For sheet-to-sheet configuration, the dual heads created two welds therefore the results are to be divided by two. It was concluded that high voltage and low cycle time caused the sheet to burn therefore it impacted the surface of the connection area poorly and did not create welds. The best connection with high strength was achieved with high voltage of 9.0 volts and high cycle time of 60.

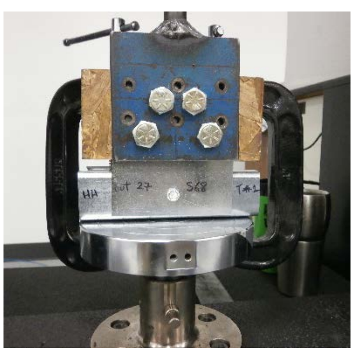

Figure 7 - HWH connection test

Figure 8 - SW connection test

Table 2 - Sheet-to-sheet connection test results

SW volt-cycle time	Peak Load (lbs)	Extension at peak (in.)	Peak Load/2 (lbs)
SW 4.5-40	784	0.303	392
SW 5.5-55	1254	0.099	627
SW 6.0-60	1392	0.100	696
SW 7.0-55	1187	0.108	594
SW 8.9-60	1801	0.115	901
SW 9.0-55	1554	0.099	777
SW 9.0-60	1630	0.094	815

Table 3 - Sheet-to-stud connection results

SW volt-cycle time	Peak Load (lbs)	Extension at peak (in.)
SW 4.5-40	538	0.186
SW 9.0-60	1193	0.377

Figure 9 and Figure 10 shows a comparison of sheet-to-sheet and sheet-to-stud connection test results, respectively. Connection 1 reports the No. 12 HWH screw and Connection 2 reports the spot-weld connection with 9 volts and 60 cycle time. The spot-welds lost connection between two surfaces upon failure which resulted into instant connection loss. For sheet-to-sheet, the SW showed higher strength and in sheet-to-stud connection, the SW failed at a lower strength compared to the screw connection. Also, the SW had higher initial stiffness in comparison to the screw connections.

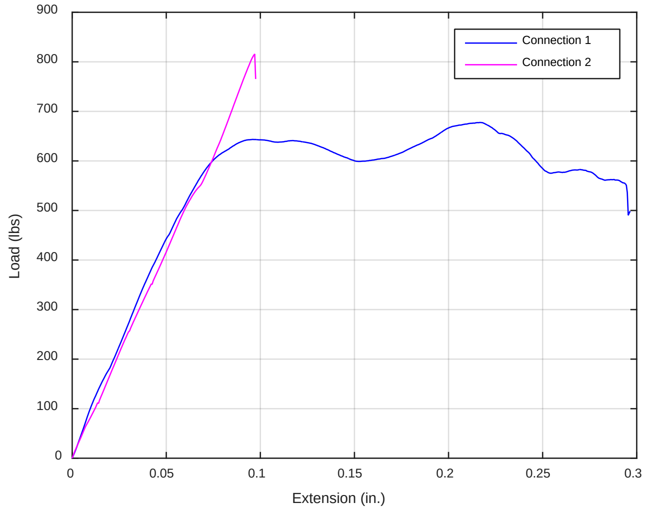

Figure 9 - Sheet-to-sheet connections

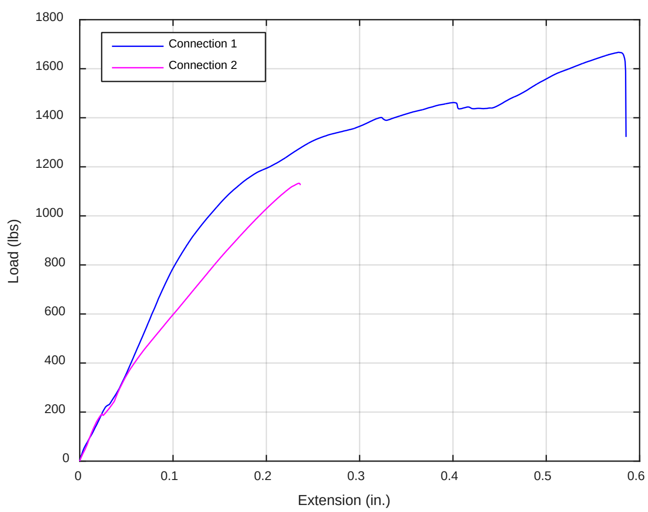

Figure 10 - Sheet-to-stud connections

SW Shear Wall Test Results

Specimen 3 is shear wall with SW 7.0-35 sheathing connection and specimen 4 is shear wall with SW 9.0-60 sheathing connections. Specimen 3 failed prematurely due to weak sheathing connections. Almost all spot-welds were disconnected in an unzipping act seen in Figure 11. Most shear walls fail at cycle 35-38 but shear walls with SW connections failed at an earlier cycle 21-25. Table 4 summarizes specimen 3 and specimen 4 results. The nominal shear strength of specimen 4 increased by 172% in comparison to specimen 3, though still failed prematurely and the frame was undamaged.

Figure 11 - SW sheathing connection failure

Table 4 - Spot-welded shear wall test results

Specimen #	Average peak load (lbs)	Average disp (in.)
3	2709	0.255
4	7357	0.630

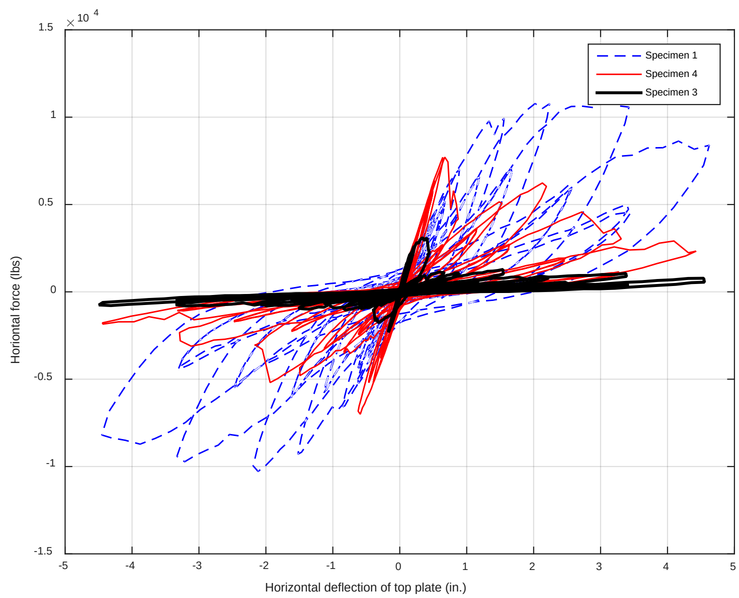

Figure 12 - SW hysteresis curves

Figure 12 shows the hysteresis curve of the two SW tests and Specimen 1. Even though changing the SW voltage and cycle time improved the shear wall performance greatly, it was not comparable to the self-drilling screw connections. Shear walls with SW sheathing connections presented higher initial stiffness but lower shear resistance and ductility in comparison to shear walls with screw sheathing connections. Thus, the spot-welded sheathing connections were not a feasible connection method.

Conclusion

A total of four shear wall specimens and seven connection specimens were tested for this research paper. The primary objective of this paper was to determine the effect of the sheathing overlapping and to investigate a new sheathing connection method – spot weld. Shear wall with one rib overlapping was compared to shear wall with double ribs overlapping. The results showed less than 10% difference in peak load and displacement between the two configurations. Therefore, overlapping sheets by two corrugations is acceptable which results into less labor and construction time of the shear wall system. A series of connection tests were performed to obtain the optimal setting for a dual-head spot-welding connections. Two shear walls with different spot-weld voltage and cycle time were tested. Results indicated premature failure of both specimens due to weak sheet-to-stud connections. The spot-weld sheathing connection is not recommended for CFS shear wall applications.

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