Wei-Wen Yu International Specialty Conference
on Cold-Formed Steel Structures 2018

Sidelap and Structural Fastener Tests for Steel Deck Diaphragms

Yifei Shi[1], Shahab Torabian[2], Benjamin W. Schafer[3],
W. Samuel Easterling[4], Matthew R. Eatherton[5]

Abstract

Steel deck diaphragm systems, which are commonly used for roof construction in steel-framed buildings, consist of many parts such as corrugated steel deck sheets, sidelap fasteners between adjacent sheets, structural fasteners from the sheets to the supporting beams or joists, chord elements, and collectors. Load-deformation behavior of a steel deck diaphragm system is typically dominated by sidelap and structural fastener limit states. To understand and accurately model the behavior of steel deck diaphragm systems, it is therefore necessary to characterize the behavior of the individual fasteners. The effect of local geometry and detailing at these fasteners such as how the sheets fit together, fastener proximity to the sheet edge, and fastener location relative to the corrugation is not well understood

This paper presents a testing program including 80 specimens with single fasteners in flat steel deck sheets (not corrugated) that remove the effects of corrugation and edge distance. The testing program included two types of sidelap fasteners (#10 screws, #12 screws), four types of structural fasteners (powder actuated fasteners, pneumatic power actuated fasteners, arc seam welds, #12 screws), as well as other variations such as number of deck plies for structural fasteners (1 ply to support, 2 ply, and 4 ply), deck thickness (22 gage, 20 gage and 18 gage), and loading (monotonic and cyclic). A companion suite of 60 monotonic and cyclic tests were conducted with deck geometry and detailing representative of typical construction. By comparing results between these two sets of tests, the effect of deck geometry and fastener location was isolated.

[1] Graduate Research Assistant, Virginia Tech, yifei@vt.edu
[2] Post-Doctoral Research Assistant, Johns Hopkins University, torabian@jhu.edu
[3] Professor, Johns Hopkins University, schafer@jhu.edu
[4] Professor, Virginia Tech, seaster@exchange.vt.edu
[5] Associate Professor, Virginia Tech, meather@vt.edu

Introduction

The roofs of steel buildings typically use long corrugated steel deck sheets as structural support between joists or beams. These long deck sheets are attached together at their sides with fasteners or crimping referred to as sidelap connectors and attached down to the supporting steel members with fasteners or welds referred to as structural connectors. The attached steel deck sheets not only resist gravity loads, but also combine to form a roof diaphragm system that acts to transfer lateral loads to and between the elements of the vertical lateral force resisting system. The behavior of steel deck diaphragms when subjected to lateral loads, have been shown to be dominated by the localized behavior of and around the sidelap and structural fasteners.

There have been a number of experimental programs that examine the behavior of sidelap and structural fasteners in corrugated steel deck (e.g. Rogers and Tremblay 2003). Some of these testing programs have shown that the response of the fastener is sensitive to its placement relative to the corrugation, in particular how close the fastener is to the cold-worked corner of the corrugation (Torabian and Schafer 2018). It is unclear, therefore, how much the behavior of the connector is related to the local material and geometric effects of the corrugation and how much of the behavior of the connector is related to the action of the fastener in a light-gage sheet of steel.

Standards such as AISI S100 (AISI 2012) provide design formulas for connectors in light-gage sheet steel and these procedures are based largely on tests of connectors in flat sheets of steel (e.g. see Pekoz 1990). A link is needed to bridge the gap between the tests on sidelap and structural fasteners with corrugated deck and tests on flat sheet steel. To fill this gap, an experimental program was conducted on isolated single fasteners in flat sheets of deck material with similar fastener types and sizes as those studied in a companion project that examined behavior of these fasteners in corrugated steel roof deck.

The test setup used in this experimental program was designed to produce controlled and relatively simple boundary conditions around the fasteners that are expected to be more repeatable than the other typical deck fastener tests. The testing program included two types of sidelap fasteners (#10 screws, #12 screws), four types of structural fasteners (powder actuated fasteners, pneumatic power actuated fasteners, arc seam welds, #12 screws), variation in the number of deck plies to simulate structural fasteners in end lap conditions (1 ply to support, 2 ply to support, and 4 ply to support), two deck thicknesses (22 gage, 20 gage and 18 gage), and two types of loading (monotonic and cyclic). A total of 80 specimens were tested. Results from the tests are compared to each other and compared to a set of 60 companion tests with similar fasteners conducted with deck geometry and detailing representative of typical construction.

Testing Plan and Test Matrix

Figure 1 shows the test setup used in the experimental program. Flat sheets of steel deck material were obtained before they were corrugated, and cut to 6 in. width for the specimens. Sidelap specimens used deck sheets at the top and bottom while structural fastener specimens used deck sheets at the top and thicker steel plate at the bottom as will be described later in this section.

The fixtures were used in a previous experimental program investigating the behavior of fasteners in cold-formed steel studs and joists (Tao et al. 2016). As shown in Figure 1, the top fixture is U-shaped and the bottom fixture is likewise U-shaped with the U facing up. In any test with a single shear plane, there is an eccentricity between the axial force in the two sheets which creates a small moment. In axial tension test configurations where there is no restraint, the sheets will bend out-of-plane and the fasteners are subjected to combined shear and tension. In this test setup, the goal of the U-shaped fixtures is to keep the sheets flat and in contact and by restraining the out-of-plane movement resist the small moment that develops. Also, the goal of the fixtures is to restrain out-of-plane buckling of the sheets during compression excursions of the cyclic loading.

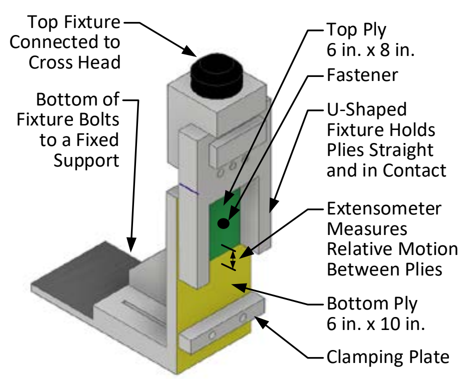


Figure 1. Test Setup

As shown schematically in Figure 1, an extensometer was used to measure relative motion of the two plies. Other instrumentation included actuator load and actuator displacement. Timelapse videos were also obtained for each specimen to help document failure modes.

Table 1. Test Matrix.

Number of Tests	Series Name	Configuration	Deck Material (gage)	Structural Support Steel (thickness)	Fastener	Loading
2	18-SL-S10-M	Sidelap	18	-	#10 Screw	Monotonic
2	18-SL-S10-C	Sidelap	18	-	#10 Screw	Cyclic
2	22-SL-S10-M	Sidelap	22	-	#10 Screw	Monotonic
2	22-SL-S10-C	Sidelap	22	-	#10 Screw	Cyclic
2	18-SL-S12-M	Sidelap	18	-	#12 Screw	Monotonic
2	18-SL-S12-C	Sidelap	18	-	#12 Screw	Cyclic
2	22-SL-S12-M	Sidelap	22	-	#12 Screw	Monotonic
2	22-SL-S12-C	Sidelap	22	-	#12 Screw	Cyclic
2	18-ST-1P-H-M	1 ply to support	18	3/16 in.	Powder PAF	Monotonic
3	18-ST-1P-H-C	1 ply to support	18	3/16 in.	Powder PAF	Cyclic
2	22-ST-1P-H-M	1 ply to support	22	3/16 in.	Powder PAF	Monotonic
3	22-ST-1P-H-C	1 ply to support	22	3/16 in.	Powder PAF	Cyclic
2	18-ST-1P-PN-M	1 ply to support	18	3/16 in.	Pneumatic PAF	Monotonic
3	18-ST-1P-PN-C	1 ply to support	18	3/16 in.	Pneumatic PAF	Cyclic
2	22-ST-1P-PN-M	1 ply to support	22	3/16 in.	Pneumatic PAF	Monotonic
3	22-ST-1P-PN-C	1 ply to support	22	3/16 in.	Pneumatic PAF	Cyclic
2	18-ST-1P-W-M	1 ply to support	18	3/16 in.	Arc Seam Weld	Monotonic
3	18-ST-1P-W-C	1 ply to support	18	3/16 in.	Arc Seam Weld	Cyclic
2	22-ST-1P-W-M	1 ply to support	22	3/16 in.	Arc Seam Weld	Monotonic
3	22-ST-1P-W-C	1 ply to support	22	3/16 in.	Arc Seam Weld	Cyclic
2	18-ST-1P-S12-M	1 ply to support	18	3/16 in.	#12 Screw	Monotonic
3	18-ST-1P-S12-C	1 ply to support	18	3/16 in.	#12 Screw	Cyclic
2	22-ST-1P-S12-M	1 ply to support	22	3/16 in.	#12 Screw	Monotonic
3	22-ST-1P-S12-C	1 ply to support	22	3/16 in.	#12 Screw	Cyclic
3	22-ST-2P-H-C	2-ply to support	22	3/16 in.	Powder PAF	Cyclic
3	22-ST-2P-PN-C	2-ply to support	22	3/16 in.	Pneumatic PAF	Cyclic
3	22-ST-2P-W-C	2-ply to support	22	3/16 in.	Arc Seam Weld	Cyclic
3	22-ST-2P-S12-C	2-ply to support	22	3/16 in.	#12 Screw	Cyclic
3	22-ST-4P-HT-C	4-ply to support	22	3/16 in.	Powder PAF	Cyclic
3	22-ST-4P-PN-C	4-ply to support	22	3/16 in.	Pneumatic PAF	Cyclic
3	22-ST-4P-W-C	4-ply to support	22	3/16 in.	Arc Seam Weld	Cyclic
3	22-ST-4P-S12-C	4-ply to support	22	3/16 in.	#12 Screw	Cyclic
80	**Specimens Total**					

The test matrix is given in Table 1 as organized into 32 groups which are shown as rows in the table. The first eight groups are specimens with sidelap fasteners. With two specimens for each combination of fastener type, #10 screw and #12 screw, and deck thickness, 18 gage and 22 gage, there were 16 sidelap specimens total. The next sixteen groups are specimens with one of the following four structural fasteners: Hilti HSN 24, Pneutek K64062 fastener, 3/8 in. x 1 in. arc seam weld, and #12 screw. With 2 monotonic and 3 cyclic tests for every combination of structural fastener and deck thickness, a total of 40 single ply structural fasteners were tested. The last eight groups are specimens with structural fasteners applied through either two or four plies of 22 gage steel deck. With 24 two-ply or four-ply specimens, the total number of specimens in the testing program was 80.

To understand what each specimen configuration is meant to simulate, it is necessary first to identify the differences between nestable and interlock deck. As shown in Figure 2a, the nestable deck has an overlap between deck sheets and sidelap fasteners such as screws would be installed through both plies at the corner of the trough. The interlock deck shown in Figure 2b is more typical in the Western United States and uses mechanical crimping or top seam welds for the sidelap connection.

The sidelap specimens shown in Figure 2c represents a sidelap connection between sheets of nestable deck as shown in Figure 2d. The specimens use flat deck material for both plies without corrugation so the effects of corrugation and edge distance are excluded. In the structural fastener specimens shown in Figure 2e, a piece of deck material is connected to a 3/16 in. thick steel plate which simulates the top flange of a joist or beam as shown in Figure 2f. The two-ply specimens shown in Figure 2f simulate an end lap of either nestable or interlock deck (see Figure 2g) where the fastener has to penetrate two plies of deck material to connect to the structural support.

The two-ply specimens simulate shear between the two sheets but load is not applied through the 3/16 in. structural ply (in the specimens a 2 in. x 2 in. square) which represents end laps on joists or beams that are not collectors such as shown in Figure 2h. Similarly, the four-ply specimens shown in Figure 2i, simulate a condition where shear forces are transferred between sheets but not to the support. In the four-ply case, the specimen simulates the corner of a nestable deck (see Figure 2j) wherein the fastener has to penetrate four plies to get to the structural support. The deck sheets are assumed to be laid from left to right starting from the upper left in Figure 2j, i.e. sheets are installed in the order: 3, 4, 1, 2. The primary shear deformations are assumed to act along the longitudinal axis of the deck sheet and thus in the specimen (Figure 2i), sheets 2 and 4 are pulled up while sheets 1 and 3 are pulled down as a group.

The cyclic displacement protocol from FEMA 461 (FEMA 2007) was used, which has two cycles at each displacement step and a factor of 1.4 to relate the displacement amplitude of one displacement step relative to the previous. For each configuration, monotonic tests were conducted first and peak load, P_{max}, and elastic stiffness, K_e (secant stiffness at 0.2 P_{max}) were obtained. The displacement associated with inelasticity was then approximated as Δ_a=0.8 P_{max} / K_e. Consistent with the FEMA 461 displacement protocol, six cycles (three displacement steps) were included before reaching the lowest damage limit state which was taken as Δ_a. Monotonic tests used a constant displacement rate of 0.10 in/min (approximately 3 mm/min), in accordance with AISI S905-13. (AISI 2013).

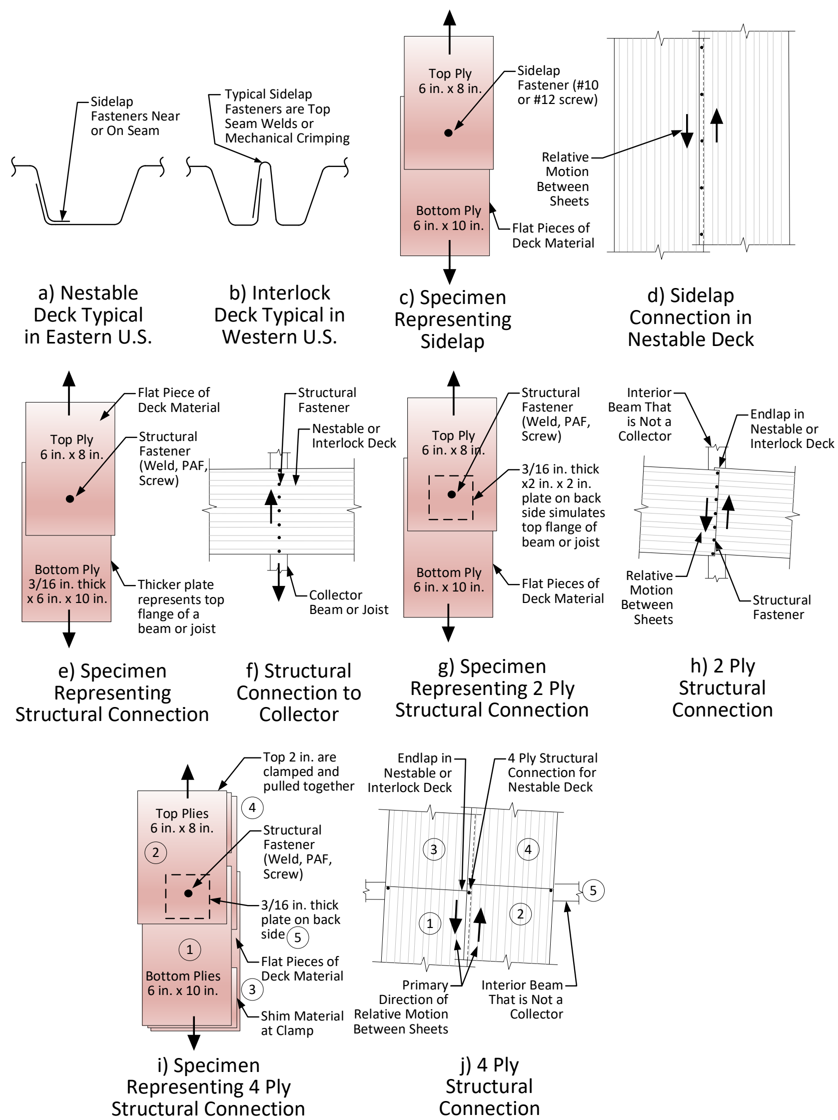


Figure 2. Tested Configurations

Materials and Fastener Installation Details

A typical screw installation is shown in Figure 3a. All screws were self-drilling with the #10 and #12 screws for sidelaps being 10-16x3/4 HWH #2 F.P. and 12-14x1 HWH #1 F.P., respectively. The #12 screws for structural fasteners used a finer 24 threads per inch pitch and were S-MD 12-24x7/8 HWH #4. A Hilti ST 1800 adjustable torque screwdriver was used to install the screws and the torque setting was adjusted accordingly for each type of specimen. More details are available in Shi et al. (2018).

The pneumatic power actuated structural fasteners, see Figure 3b, were the Pneutek K64062 for specimens with one-ply to the support and Pneutek K64075 for specimens with two-ply and four-ply to support conditions. An appropriate Pneutek tool was used with air pressure equal to 180 psi, 200 psi, 200 psi, and 220 psi for one-ply 22 gage, one-ply 18 gage, two-ply 22 gage, and four-ply 22 gage structural fasteners, respectively.

a) Screw | b) Pneumatic Power Actuated Fastener | c) Arc Seam Weld | d) Powder Actuated Fastener

Figure 3. Picture of Each Type of Fastener Tested

Arc seam welds, such as shown in Figure 3c, were made with SMAW process and E6022 electrodes by a certified welder with experience making deck welds. The target dimensions were 3/8 in. x 1 in. visible weld. Besides being relatively clean, no surface preparation was conducted and surface coatings such as galvanizing or thin coat of white primer were left undisturbed prior to welding. Plies were clamped together and in the case of the two-ply and four-ply specimens, a hammer was used to hit the specimens in the location of the weld to put the plies in contact. The welding time, length of electrode used, and weld dimensions were recorded. The average weld time was 17 seconds with an average visible weld length of 1.2 in. The length of electrode used was 1.9 in., 2.3 in., 2.7 in., and 3.5 in. for 18 gage one-ply, 22 gage one-ply, 22 gage two-ply, and 22 gage four-ply, respectively.

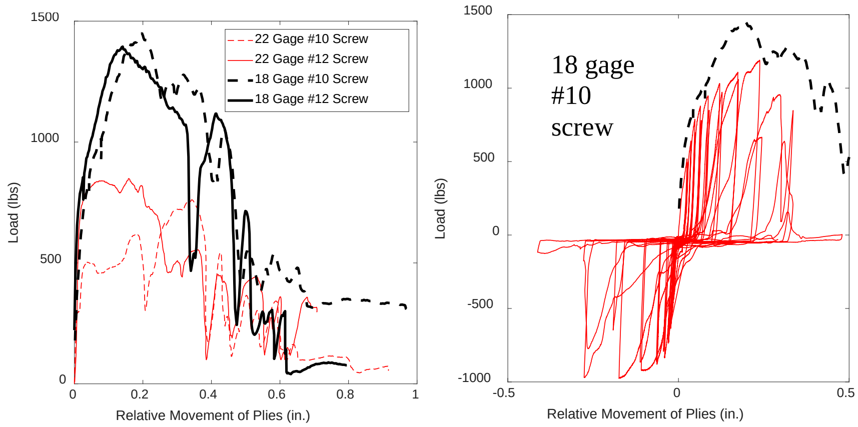
Figure 3d shows a typical Hilti HSN24 power actuated fastener. The Hilti DX460 SM tool was used for installation with red cartridge and power level of 2.5 for one-ply structural specimens. For two-ply and four-ply structural specimens, the black cartridge was used with power level of 1.5 and 2.0, respectively. All powder actuated fastener installations were verified by checking that: 1) the fastener clamped the steel deck down to the base steel, and 2) the nail head stand-off was within the acceptable range using the Hilti "Power adjustment guide".

Results and Discussion

Figure 4a shows a comparison of the load-deformation behavior of a typical monotonic sidelap specimen for each of the two screw sizes and deck thicknesses. A summary of results of all groups of tests is given in Table 2. For all of the sidelap specimens, the failure mode was tilting of the screw (see Figure 6a) and then pull-out wherein the threads would pull through the deck sheet one at a time. The titling / pull-out failure mode is evident in the load-deformation behavior as the initial flattening (22 gage) or reduction in stiffness (18 gage) is associated with tilting and the sharp drops in strength with subsequent recovery of load are associated with one thread being pulled through the deck and the next thread coming into bearing.

Figure 4a shows that the thinner 22 gage deck exhibited more severe reduction in stiffness during tilting (stiffness approaches zero) and that the #12 screw developed more strength than the #10 screw, reaching an average of 40% larger strength as given in Table 2. The resistance to tilting was not as sensitive to screw size for the thicker 18 gage deck. Figure 4a and Table 2 show that there was little difference in strength between the #12 and #10 sidelap screws in 18 gage deck. The reduction in stiffness was also considerably less severe in 18 gage deck and did not appear to be affected by screw size.

There were also key differences in the cyclic behavior. Figure 4b shows monotonic and cyclic response for typical sidelap specimens with #10 screws in 18 gage deck. As is typical for many structural systems, cyclic loading causes cyclic damage and a reduction in the strength compared to monotonic loading. Table 2 demonstrates this trend for both #10 and #12 sidelap screws in 18 gage deck with approximately 17% reduction in peak strength for cyclic loading compared to monotonic. However, for 22 gage deck, the reverse is true and the cyclic loading results in an average of 8% increased peak loads as compared to monotonic. It is possible with the thinner deck, that the reversed loading resets the fastener in the hole such that it reaches higher load before pull-out of the thread or the increased strength could be related to cyclic hardening. Regardless, it is not well understood why this happened for thinner deck and not thicker deck.



a) Monotonic Tests b) Comparison of Monotonic and Cyclic

Figure 4. Typical Results from Sidelap Tests

Figure 5 shows typical monotonic and cyclic results for structural specimens while Figure 6 shows pictures of typical failure modes and Table 2 tabulates the results. The failure mode for screw structural fasteners in 22 gage deck was typically tilting / pull-out for monotonic tests, but shifted to bearing for cyclic tests (see Figure 6b). The failure mode for 18 gage deck was screw shear failure for monotonic (see Figure 6c), but also shifted to bearing failure for cyclic tests. The shift to bearing failure for cyclic tests of 18 gage deck caused a reduction in average peak load, whereas the shift from tilting to bearing failure for cyclic tests of 22 gage resulted in an increase in peak load.

As demonstrated by comparing Figure 5b and 5c, the power actuated fasteners (PAF) had similar behavior in monotonic and cyclic structural specimens regardless of whether they were powder PAF or pneumatic PAF. All of these specimens failed due to bearing of the deck sheet as shown in Figures 6d and 6e for powder PAF and pneumatic PAF, respectively. The specimens held relatively constant strength during cyclic loading as the PAF head plowed through the adjacent deck material. Both types of fasteners exhibited some cyclic degradation compared to monotonic behavior.

The arc seam welds (Figure 5d) were capable of developing significantly larger strength, between two to four times larger than other fasteners, although there was more variability in the results. Three types of failure modes were observed including a) tearing of the sheet around the weld (Figure 6g) which resulted in the most strength, b) fracture of the deck sheet around the weld (Figure 6h) at a considerably smaller load, and c) shear failure of the weld itself was observed for some specimens and was associated with smaller strength. The performance of welds for decking attachment have been shown to be sensitive to welding time and it has been observed that typical deck field welding does not produce sufficient welding time (Snow and Easterling 2008).

In some cases, the fastener was so strong, the deck sheet buckled as shown in Figure 6f. In these cases, the peak compression forces were not included in the average cyclic peak load given in Table 2, but it was assumed that the peak tension force was still representative of tension strength.

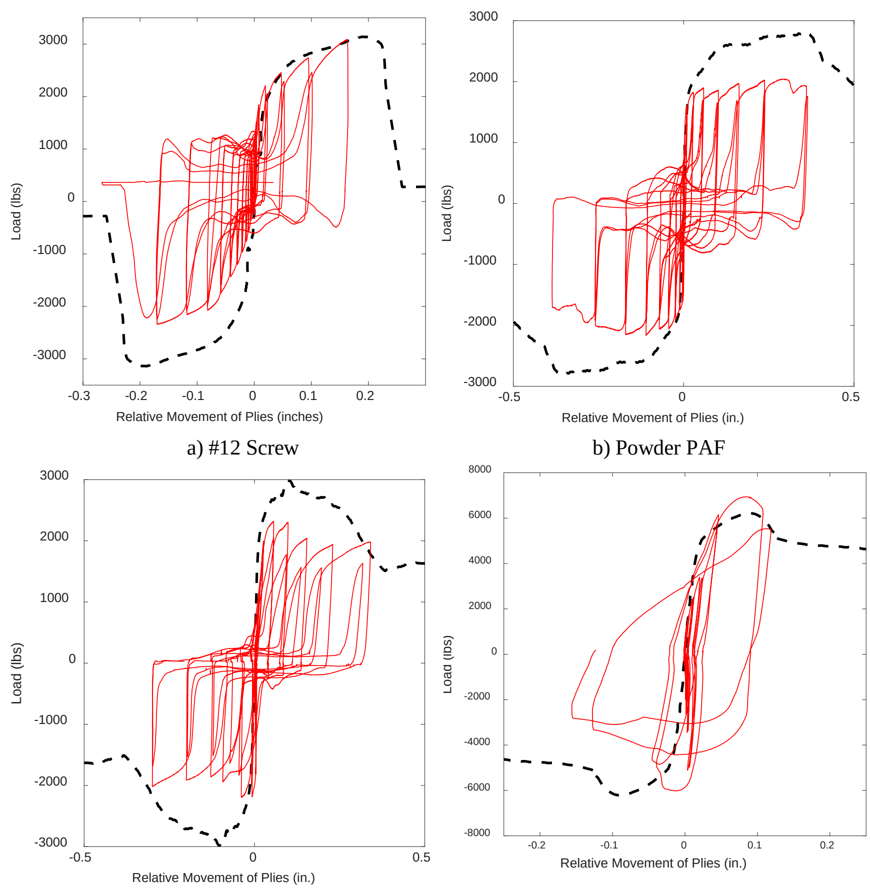


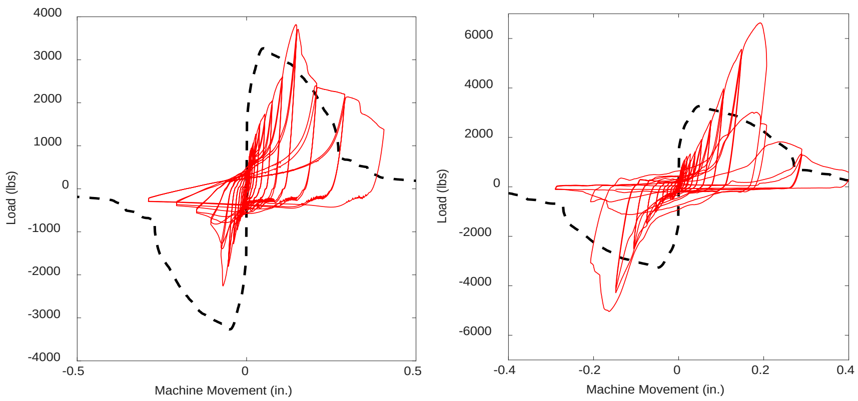
Figure 5. Typical Results from Structural Fastener Tests

a) Sidelap Screw Tilting and Pullout | b) Structural Screw Bearing | c) Structural Screw Shear | d) Powder PAF Bearing

e) Pneumatic PAF Bearing | f) Buckling of Deck Sheet | g) Tearing of Sheet Around Weld | h) Shear Failure of Weld

Figure 6. Typical failure modes

The effect of multiple plies on the strength of an arc seam weld is demonstrated in Figure 7 wherein the strength of the weld in two plies is approximately the same as one ply and the strength of the weld in four plies is approximately twice that of one ply because two plies are being pulled in each direction. However, the general trends as given in Table 2 show that the two-ply configuration resulted in less strength than one-ply configuration. It is hypothesized that the fasteners are not as effective when applied through multiple plies. For the four-ply configuration, the specimens should develop twice the strength of the one-ply or two-ply configurations if the fastener is equally effective because there are two deck sheets being pulled each direction. The four-ply powder PAF and pneumatic PAF saw four-ply strength that was bigger than two times the one-ply or two-ply strength implying they are more effective per sheet with the addition of more plies. Conversely, the four-ply configuration with #12 screws was less than two times the one-ply or two-ply strength, implying they were less effective per sheet with the addition of more plies.



a) Cyclic 2 Ply vs. 1 Ply Monotonic   b) Cyclic 4 Ply vs. 1 Ply Monotonic

Figure 7. Effect of Multiple Plies

Table 2. Selected Results from Testing Program

Row	Specimen Series	Deck (gage)	Fastener[1]	Average Monotonic Peak Load[2] (kips)	Average Cyclic Peak Load[3] (kips)
1	18-SL-S10	18	#10 Screw Sidelap	1.40	1.12
2	22-SL-S10	22	#10 Screw Sidelap	0.65	0.71
3	18-SL-S12	18	#12 Screw Sidelap	1.43	1.24
4	22-SL-S12	22	#12 Screw Sidelap	0.89	0.93
5	18-ST-1P-H	18	Pwdr PAF Struct.	2.65	2.27
6	22-ST-1P-H	22	Pwdr PAF Struct.	1.70	1.67
7	18-ST-1P-PN	18	Pneum. PAF Struct.	3.00	2.32
8	22-ST-1P-PN	22	Pneum. PAF Struct.	1.52	1.34
9	18-ST-1P-W	18	Weld Structural	6.56	6.26
10	22-ST-1P-W	22	Weld Structural	2.52	3.89
11	18-ST-1P-S12	18	#12 Screw Struct.	2.94	2.65
12	22-ST-1P-S12	22	#12 Screw Struct.	1.79	1.92
13	22-ST-2P-H	2ply 22	Pwdr PAF Struct.	-	1.51
14	22-ST-2P-PN	2ply 22	Pneum. PAF Struct.	-	1.68
16	22-ST-2P-S12	2ply 22	#12 Screw Struct.	-	1.65
17	22-ST-4P-H	4ply 22	Pwdr PAF Struct.	-	3.47
18	22-ST-4P-PN	4ply 22	Pneum. PAF Struct.	-	3.62
20	22-ST-4P-S12	4ply 22	#12 Screw Struct.	-	3.01

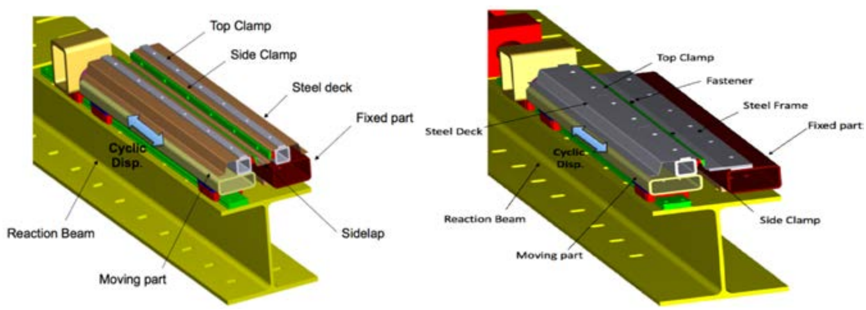
[1] Pwdr PAF = Hilti HSN24 Powder Actuated Fasteners
Pneum. PAF = Pneutek Pneumatic Power Actuated Fasteners

[2] Peak loads are reported as the average of 2 monotonic specimens

[3] Peak loads are reported as the average of positive peak and negative peak for 2 cyclic specimens for sidelap fasteners or 3 cyclic specimens for structural fasteners. For cyclic specimens that experienced sheet buckling, only positive (tension) peaks were included.

Comparison to Companion Test Program

Figure 8a and 8b shows the test setup for sidelap and structural fasteners in the companion test program (Torabian et al. 2018). Specimens used corrugated deck and fasteners were installed in locations consistent with field conditions; that is, structural fasteners for nestable deck were in the corner of the trough near the edge of the deck sheet. See Torabian et al. (2018) for more details about the test setup and test matrix.



a) Sidelap Testing Setup b) Structural Fastener Testing Setup

Figure 8. Picture of Each Type of Fastener Tested

Table 3 tabulates the comparison between the isolated fastener tests in flat deck sheets described in this paper (labeled as Virginia Tech) and the fastener tests with configurations that simulate realistic field boundary conditions (labeled as Johns Hopkins).

Table 3. Comparing Results with Tests Having Realistic Boundary Conditions

		Virginia Tech[1]		Johns Hopkins[2]	
Row	Specimen Series	Average Monotonic Peak Load (kips)	Average Cyclic Peak Load (kips)	Average Monotonic Peak Load (kips)	Average Cyclic Peak Load (kips)
1	22-SL-S10	0.65	0.71	0.95	0.83
2	18-SL-S12	1.43	1.24	1.43	1.40
3	18-ST-1P-H	2.65	2.27	2.04	2.11
4	22-ST-1P-H	1.70	1.67	1.85	1.82
5	18-ST-1P-W	6.56	6.26	7.70	7.43
6	22-ST-1P-W	2.52	3.89	4.24	4.10

[1] Specimens designed to simulate controlled boundary conditions in a flat sheet of deck
[2] Specimens designed to simulate realistic field boundary conditions

With the exception of the power actuated fasteners applied in 18 gage deck, all other groups saw an increase in strength with corrugations. The PAF in 18 gage deck (series 18-ST-1P-H) showed a 23% and 7% decrease in peak load going from a flat deck sheets to the corrugated deck sheets for monotonic and cyclic loading, respectively. Over all fasteners and series listed in Table 3, the specimens with corrugations and more realistic boundary conditions resulted in an average of 14% larger peak load. It is hypothesized that the stiffening of the material at the corner of the corrugation may reduce the tilting of screws and the resist the bearing of other fasteners better than the flat deck sheets. There may also be an effective higher yield stress at the corners due to cold-working.

Conclusions

A testing program was conducted on a total of 80 sidelap and structural fastener specimens representing typical connections in steel roof deck diaphragm systems. The test setup was designed to create controlled boundary conditions and eliminate the effects of deck corrugation and fastener edge distance. The test program had two goals: 1) to examine the effect of deck corrugation and edge distance by comparing to a set of companion tests that included these effects, and 2) use this simpler, more controlled type of test setup to explore the effect of other parameters such as multiple deck plies and other fastener types.

Some of the findings include the following: 1) The strength of sidelap screw specimens with thicker deck was not as sensitive to screw size as it was for thinner deck. 2) In general, cyclic loading resulted in smaller strength than monotonic which is expected due to cyclic degradation. However, there were some exceptions like screws in 22 gage deck (both sidelap and structural). While this is not well understood, the increase strength may be related to shifting the failure mode from tilting to bearing in cyclic tests. 3) The power actuated fasteners (PAF), both powder or pneumatic, failed due to bearing and resisted relatively constant load during cyclic tests as the fastener head plowed through the deck material. 4) Arc seam welds were found to be capable of generating two to four times more strength than other fasteners, but there was more variability with three failure modes, some of which exhibited low strength. 5) In general, the effect of a two-ply configuration representative of an end lap connection to a support, results in slightly reduced strength as compared to a one-ply to support configuration. 6) For the four-ply configurations representing the corner of a sheet in the end lap of a nestable deck, the strength per ply was greater than one-ply configurations for PAF, but less for screw structural fasteners. 7) By comparing to the companion tests, it was found that there was an average of 14% increase in strength with corrugations and relatistic boundary conditions, although there was much variability between groups.

This paper represents preliminary analysis of the test data and further examination of the data with particular emphasis on ductility and energy dissipation is planned. Also, more in-depth analysis comparing the results to the companion tests is underway.

Acknowledgements

This work was part of the Steel Diaphragm Innovation Initiative (SDII) which is funded by AISI, AISC, SDI, SJI, and MBMA and is part of the Cold-Formed Steel Research Consortium (CFSRC). This material is based upon work supported by the National Science Foundation under grant No. 1562669. In-kind funding was provided by Verco, Hilti, and Pneutek. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or other sponsors. The authors received valuable advice from Pat Bodwell and Jerry Hajjar.

References

AISI-S100-12 (2012) *North American Specification for the Design of Cold-Formed Steel Structural Members*. American Iron and Steel Institute, Washington, D.C. ANSI/AISI-S100-12.

AISI S907-13 (2013) *Test standards for Cantilever Test Method for Cold-Formed Steel Diaphragms*, Washington DC, American Iron and Steel Institute.

FEMA (2007) *FEMA 461 Interim Protocols for Determining Seismic Performance Characteristics of Structural and Nonstructural Components Through Laboratory Testing*, Federal Emergency Management Agency (FEMA).

Pekoz, T.B. (1990) "Design of Cold-Formed Steel Screw Connections", *Proceedings of the Tenth International Specialty Conference on Cold-Formed Steel Structures*, University of Missouri-Rolla, Rolla, MO.

Rogers, C.A., and Tremblay, R. (2003) "Inelastic Seismic Response of Frame Fasteners for Steel Roof Deck Diaphragms", *Journal of Structural Engineering*, Vol. 129, No. 12, pp. 1647-1657.

Shi, Y., and Eatherton, M.R. (2018) *Monotonic and Cyclic Behavior of Isolated Steel Deck Diaphragm Fasteners*, CFSRC Report No. TBD

Snow, G.L., and Easterling, W.S. (2008) "Strength of Arc Spot Welds Made in Single and Multipel Steel Sheets" *Proceedings of the Nineteenth International Specialty Conference on Cold-Formed Steel Structures*, MO. Univ. of Science and Tech.

Tao, F., Chatterjee, A., and Moen, C. D. (2017) *Monotonic and Cyclic Response of Single Shear Cold-Formed Steel-to-Steel and Sheathing-to-Steel Connections*, Virginia Tech Structural Engineering Report No. CE/VPI-ST-16/01.

Torabian, S., Schafer, B.W.(2017). *Cyclic performance and characterization of steel deck connections*, NBM Technologies Inc. Internal Report