Screw and Pin Fastener Tests for Cold-Formed Steel

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Abstract

Because of limited available information on strength and ease of installation of specific fasteners for a particular application to a steel deck diaphragm, a preliminary testing program comparing the shear strength of commercially available screws and gas-actuated shot pins was conducted by J. R. Harris and Company at the University of Colorado Denver in 2018. A test was designed to explore the behavior and capacity of various fasteners, securing two and three pieces of sheet steel of various thicknesses together. Specimens were fabricated and load tested, with the sheet steel pieces in tension, so the fasteners were subject to shear. Four fasteners, in two rows of two, were used for all tests, with different end distances also being studied. Most of the tests were monotonic tension, and those results were used to develop a cyclic testing protocol for the best performing screw and shot pin.

Most limit states encountered were limited by tilting of the screw against the sheet steel in bearing, leading to a ductile failure. Fastener shear was encountered in a small percentage of cases. Results are compared to each other and to AISI calculated values.

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Introduction

A future study to evaluate the performance of a new cold-formed steel (CFS) diaphragm for seismic applications required the selection of an appropriate fastener to secure the deck to the structural members. The testing program described below was developed to evaluate three (3) gas actuated shot pins and five (5) sheet metal screws to determine the optimum fasteners for attaching CFS deck panel to CFS structural members. This paper is intended to add to the body of knowledge on this topic as reported in part by (AISI 2006) and (Hong and Moen 2015).

Fastener shear capacity was tested by placing specimens under both a monotonic tension load and a cyclic loading protocol. All the fasteners studied were physically suitable for the intended application, and all are readily available commercially. Figure 1 is a photograph of the three pins tested; the grid shown is 0.25“ (6.4mm). Table 1 provides the specifications for each pin.

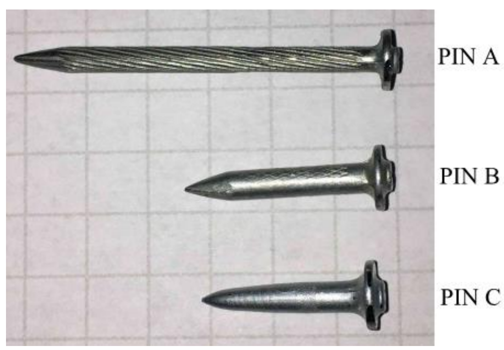

Figure 1. Photograph of the three pins tested.

Table 1. Pin Specification

Name	Length	Diameter	Surface
Pin A	1-1/2“ (37mm)	0.108“ (2.74mm)	Rough spiral knurling
Pin B	13/16“ (20 mm)	0.120“ (3.05mm)	Ligh cross hatch knurling
Pin C	11/16“ (18 mm)	0.120“ (3.05mm)	Smooth

Figure 2, is a photograph of the five screws tested; the grid shown is 0.25“ (6.4mm). Table 2 provides the specifications for each screw.

Figure 2. Photograph of the five screws tested.

Table 2. Self-Drilling Screw Specifications

Name	Length	Diameter	Thread pitch (thread/in)	Drill tip size
Screw A	1-5/8” (41mm)	#12 – 0.21” (5.3mm)	24	#5 (modified)
Screw B	1” (25mm)	#12 – 0.21” (5.3mm)	14	#2
Screw C	7/8” (22mm)	#12 – 0.21” (5.3mm)	24	#4
Screw D	3/4" (19mm)	#10-0.19” (4.8mm)	16	#3
Screw E	3/4" (19mm)	#12 – 0.21” (5.3mm)	14	#3

For simplicity, in the remainder of the paper a particular fastener will be referred to by its designation in the previous tables.

Testing Procedure

The testing procedure was adapted from AISI S905, "Test Methods for Mechanically fastened Cold-Formed Steel Connections" (AISI S905, 2012). It used nested 6" (152mm) nominal CFS studs instead of CFS sheets. Figure 3 shows the test setup with a specimen.

Monotonic loading tests were conducted by increasing the displacement in tension at 0.006 in/s (.15 mm/s) and recording both displacement and the induced force data. Cyclic tests followed a modified displacement protocol in accordance with FEMA 461 (FEMA 2007). Displacement settings increased in steps from zero to one inch in both tension and compression with 6 cycles at the first displacement step in the linear-elastic region for the specimen.
All subsequent steps had two cycles. Table 3 shows the positive and negative displacements for each step of the cyclic loading protocol.

Table 3. Displacements Steps for Cyclic Protocol.

Step	±∆ in (mm)	Step	±∆ in (mm)	Step	±∆ in (mm)	Step	±∆ in (mm)
1	0.015 (0.38)	6	0.081 (2.06)	11	0.375 (9.53)	16	0.750 (19.05)
2	0.021 (0.53)	7	0.113 (2.87)	12	0.450 (11.43)	17	0.825 (20.96)
3	0.029 (0.74)	8	0.158 (4.01)	13	0.525 (13.34)	18	0.900 (22.86)
4	0.041 (1.04)	9	0.221 (5.61)	14	0.600 (15.24)	19	0.975 (24.77)
5	0.058 (1.47)	10	0.300 (7.62)	15	0.675 (17.15)	20	1.000 (25.40)

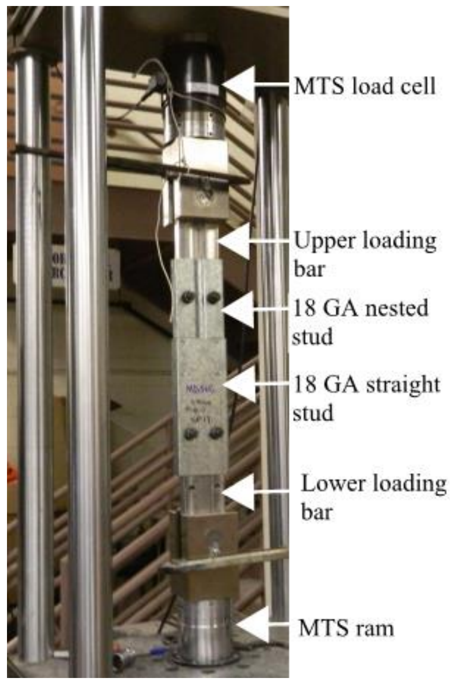

Figure 3. Photograph of a specimen loaded into the testing machine, a 220 kip (980 kN) MTS Model 810, capable of monotonic and cyclic testing in tension and compression.

The specimens were fabricated by nesting a section of commercially produced 18 GA reduced C-stud 6” (152 mm) inside a straight C-stud. The two sections were fastened together using four (4) fasteners in a rectangular pattern. Two different end distances for the fasteners were used: 2” (50.8mm) and 3/8” (9.5mm). One specimen of each fastener type was tested with an additional 14 GA sheet to simulate conditions found in the diaphragm application where three layers of CFS must be penetrated. The primary purpose of testing with the 14 GA sheet was to determine the capability of the fastener in penetrating the three layers of CFS. Figure 4 illustrates the reduced (nested) stud in straight stud cross section, both with and without the 14 GA plate. Figures 5 and 6 show the fastener patterns used. The same pattern was used for both pin and screw connections.

Three monotonic tests were conducted on specimens with 2” (50.8mm) end distances for each of the eight types of fasteners (plus an additional one for screw E). For screws A, B, and C three monotonic and two cyclic tests were conducted on specimens with 3/8” (9.5mm) end distance. Pin B had three monotonic tests with 3/8” (9.5mm) end distance and Pin C had two cyclic tests with 3/8” end distance.

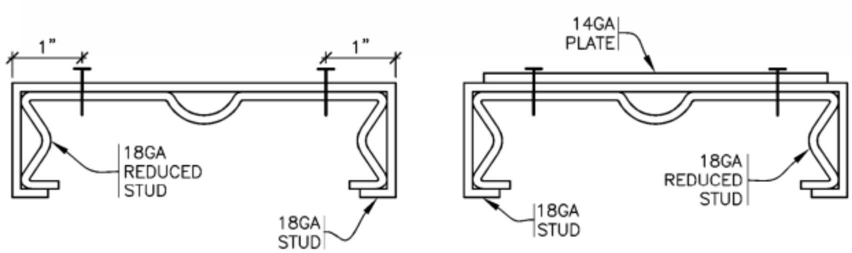

Figure 4. Cross-section of test specimen showing reduced stud in straight stud (left) and also with 14 GA plate (right).

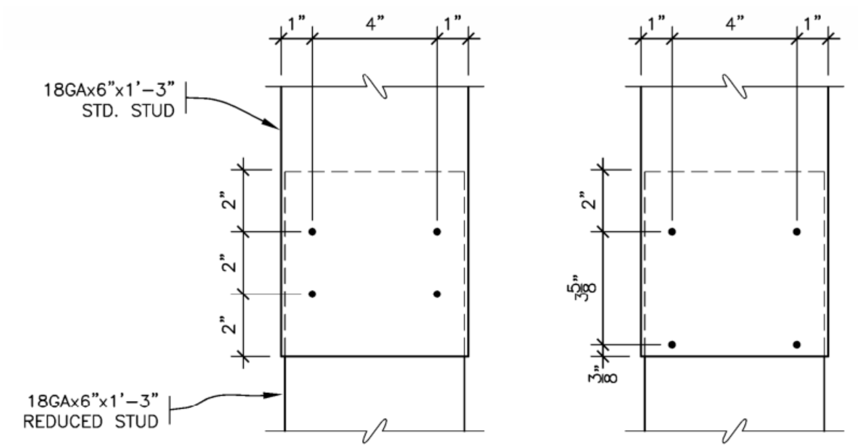

Figure 5. Fastener test patterns showing 2” (50.8mm) and 3/8” (9.5mm) end distances. All the specimens with the additional 14 GA sheet were prepared with the 2” (50.8mm) end distance.

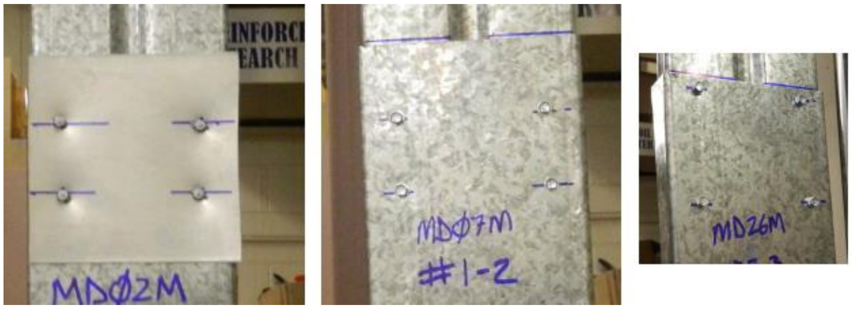

Figure 6. Photograph showing specimen with 14 GA plate, 2” end distance, and 3/8” end distance.

Calculated Predictions

Calculations in accordance with AISI S100-16 (AISI 2016) were made for the screws based on tilting and bearing failure described by equations J4.3.1-1 and J4.3.1-2 for screws. The results are based on the use of four (4) fastners. The analytical value for the specimens with #12 screws is 5.6 kip (24.9 kN). There were no calculated values for the pins because the AISI S100-16 equations for pins are intended for use where the sheet metal is attached to thicker steel members instead of sheet metal to sheet metal, the subject of these tests.

Test Results

The test results are summarized in Table 4 for the pin fasteners and Table 5 for the screw fasteners. In the tables below, the peak forces were averaged where multiple tests were conducted. The primary failure mode is also recorded.

The primary failure observed was a tension failure of the fastener through tilting and subsequent pull-out from the base material. In all cases bearing failure in the base metal was observed but secondary to the tilting of the fastener. In two specimens (screw B and screw D) with the 14 GA plate, shear of all four fasteners was observed.

Screw B, which had the smallest drill point had the best results for 18 GA/18 GA connections but failed in shear when the 14 GA sheet was added. The small drill point necessitated considerable extra effort to install through the three layers of 14 GA/18 GA/18 GA. Screw D, the smallest diameter tested, failed in shear under cyclic loading but failed by tilting and subsequent pull-out under monotonic loading.

Table 4. Summary of pin test results. All results are for tests with four (4) pins arranged as shown in Figure 6.

Fastener	**Test type**	**Max avg load kip (kN)**	**Primary failure mode**
Pin A	18GA/18GA	2.6 (11.6)	Tilting & Bearing
Pin B	w/ 14GA PL	2.7 (12.0)	Tilting & Bearing
	18GA/18GA	2.4 (10.7	Tilting & Bearing
Pin C	w/ 14GA PL	3.2 (14.2)	Tilting & Bearing
	18GA/18GA	2.6 (11.6)	Tilting & Bearing
	cyclic	2.4 (10.7)	Tilting & Bearing

Table 5. Summary of screw test results. All results are for tests with four (4) screws arranged as shown in Figure 6.

Fastener	**Test type**	**Max avg load kip (kN)**	**Primary failure mode**
Screw A	w/ 14GA PL	7.7 (34.2)	Tilting & Bearing
	18GA/18GA	5.2 (23.1)	Tilting & Bearing
Screw B	w/ 14GA PL	4.4 (19.6)	Fastener Shear
	18GA/18GA	6.7 (29.8)	Tilting & Bearing
Screw C	w/ 14GA PL	7.9 (35.1)	Tilting & Bearing
	18GA/18GA	5.4 (24.0)	Tilting & Bearing
	cyclic	4.8 (21.4)	Tilting & Bearing
Screw D	w/ 14GA PL	5.1 (22.7)	Fastener Shear
	18GA/18GA	4.8 (21.4)	Tilting & Bearing
	cyclic	4.1 (18.2)	Fastener Shear
Screw E	18GA/18GA	4.8 (21.4)	Tilting & Bearing
	cyclic	4.1 (18.2)	Tilting & Bearing

The test results with the analytical calculated capacities are shown on a graph in Figure 7 below.

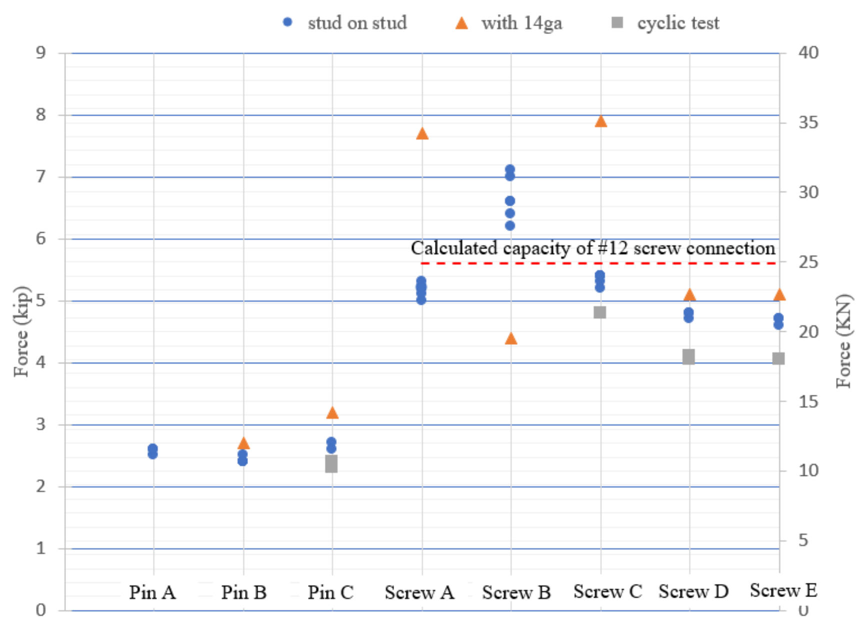

Figure 7. Consolidated graph of test results for pins and screws for 18 GA on 18 GA specimens, specimens with an additional 14 GA plate, and cyclic tests.

Analysis

The capacity of the pins was about half that of the screws. Additionally there was difficulty in getting a consistent installation where the pin head was seated flush to the CFS. These issues eliminated them as a candidate to be used in future diaphragm testing. The susequent analysis focuses on Screw C.

For the purpose of comparing the results from the cyclic test to those of the monotonic tests, the peak values for each cycle in the tension region were used to create a backbone curve, shown in Figure 8.

For 18 GA to 18 GA connections, screws were found to exhibit lowest capacities under cyclic loading conditions. Capacities were found to be highest of all when a 14 GA sheet was on top of the 18 GA to 18 GA connection (except for screw B, where the failure was shear of the screws), even though the 14 GA sheet was nominally not loaded in the test.

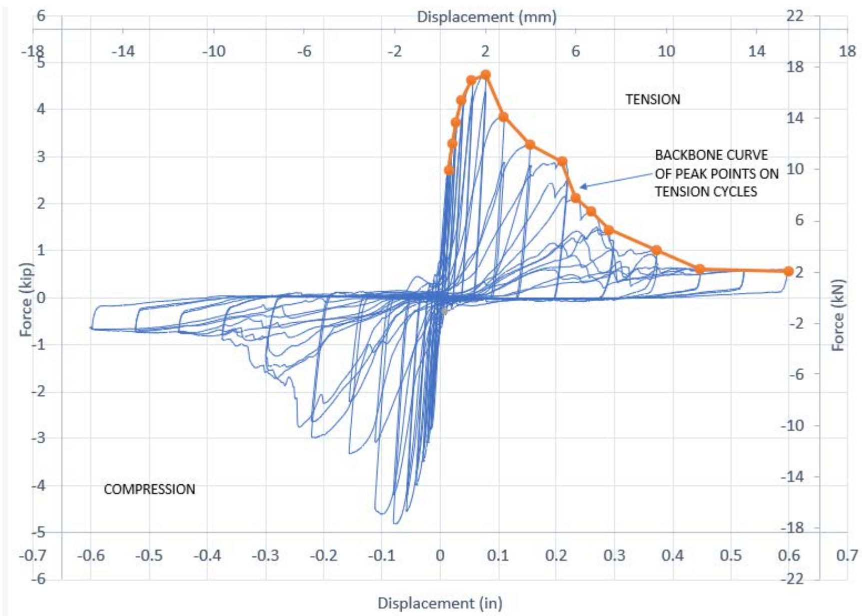

Figure 8. Load-Displacement hysteresis for cyclic loading for Screw C connection. The peak points on the tension cycles have been indicated as a backbone curve. This backbone curve is presented in Figure 9.

The graph of the results for Screw C comparing the tests with the additional 14 GA sheet, 18 GA to 18 GA plus the tension backbone of the cyclic test to each other, along with the analytical value, are given in Figure 9.

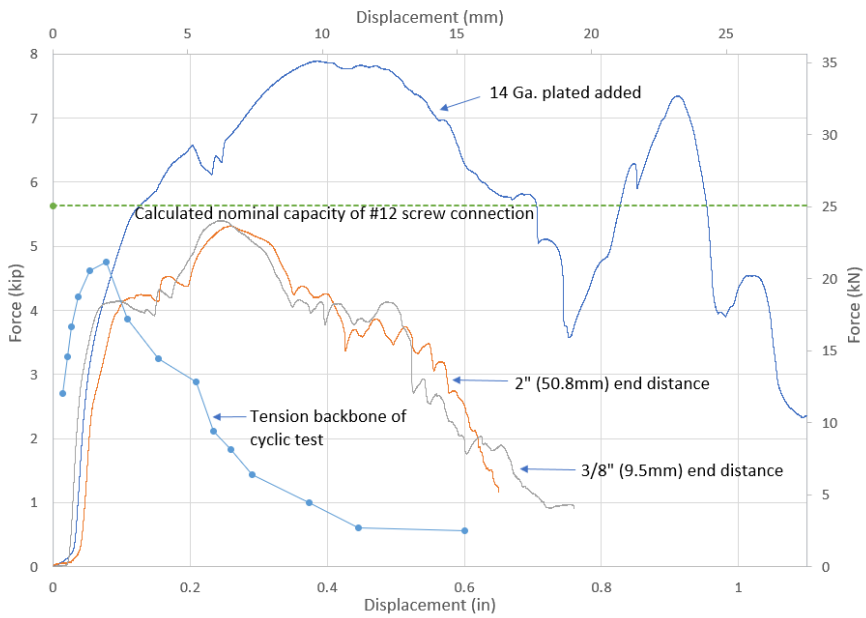

Figure 9. Comparison of tests for Screw C connection. The graphs show results for the backbone curve of a cyclic test from Figure 8, for the different end distances, and the addition of a 14 GA plate.

From Figure 9, it can be seen that the response from a four (4) screw pattern with 2” (50.8mm) end distance was virtually the same as that from a similar pattern with 3/8” (9.5mm) end distance. Addition of a 14 GA plate significantly improved the response. The peak response under cyclic loading showed a relatively small reduction in strength and a relatively large reduction in post-peak strength and ductility.

The typical failure mode for monotonic loading for screws was very local deformation of the 18 GA metal and tilting of the screws. The typical failure mode for cyclic loading was very local deformation of the 18 GA metal and tilting (both ways) of screws. The screws tended to “walk” out of their holes with the appearance of “unscrewing” themselves.

The photographs in Figures 10 and 11 illustrate the typical failures observed.

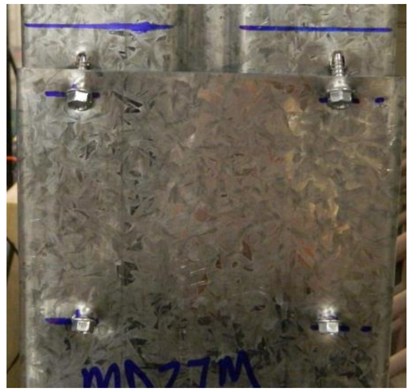

Figure 10. Photograph of typical failure with screws from the front side of specimen. The photo is for the case of 3/8” (9.5mm) end distance, but is representative of failure for both screw patterns. This is a monotonic test specimen.

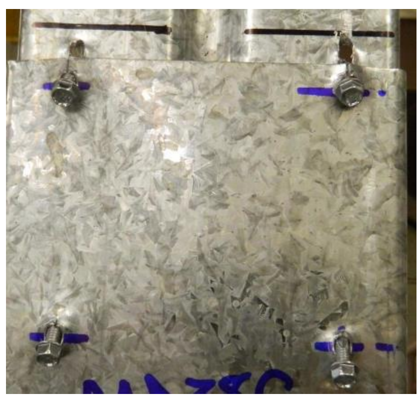

Figure 11. Photograph of typical failure with screws from the front side of specimen. Screws have backed out and torn through base metal. This is a cyclic test specimen.

Conclusions and Recomendations

- Screws consistently outperformed pins in absolute value and closely approached their calculated nominal capacities.

- A third ply of sheet metal between the fastener head and the sheet metal to be connected added significant ductility and capacity to the connection.

- End distances as small as 0.375″ (9.5mm) had almost identical results as those with 2″ (50.8mm) end distance.

- A drill tip on sheet metal screws that is smaller in diameter achieved higher capacities than those with a larger diameter drill tip.

- Fine thread screws produced peak resistances at smaller displacements than coarse thread screws and had a more gradual decline in capacity. Coarse thread screws maintained a peak resistance for a longer displacement but had steeper declines in resistance.

- Cyclic loading decreased the ductility and capacity of the fasteners.

- Pins proved to be unsuitable due to lower capacities, with little to no bonding to the base material to prevent the fastener from walking out. They were also unable to reliably penetrate the three layers of cold formed steel used in this test.

References

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