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Pin Connections for Cold-Formed Steel with Spreadsheet

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2012

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Light Gauge Steel Research Group
Department of Civil Engineering
Santa Clara University

Design Provisions for Aerosmith, Inc. Steel Pins

Report No.: LGSRG-2-96

by

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February 28, 1996

An Applied Research Program
Sponsored by Aerosmith, Inc.

Santa Clara, California 95053

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1.0 INTRODUCTION

The purpose of the test program described in this report was to develop, through testing and a review of the literature, design values and recommendations for the withdrawal (tension) and shear strength of steel pin connections in light gauge steel-to-steel connections. The tests included a wide combination of steel thickness (covering most residential applications).

2.0 SCOPE

Lap shear and withdrawal tests were conducted for different combinations of steel thickness (gauge) and two sizes of steel pins (0.100 in. and 0.144 in. diameters). The overall scope of the test program is summarized in Tables 1 through 4. For each configuration listed in the tables, a set of three tests were performed in an effort to provide reliable test data.

Table 1 Lap shear tests using 0.100 in. diameter helical thread pins

		Main Plate[1]				
		22 ga.	20 ga.	18 ga.	16 ga.	14 ga.
Holding Plate[2]	20 ga.		O	O	O	
	18 ga.		O	O	O	
	16 ga.	O	O	O	O	
	14 ga.		O			O
	12 ga.		O			

[1] plate in contact with head of the steel pin
[2] plate on side with tip of the steel pin

Table 2 Withdrawal (tension) tests using 0.100 in. diameter helical thread pins

		Main Plate[1]				
		22 ga.	20 ga.	18 ga.	16 ga.	14 ga.
Holding Plate[2]	20 ga.		O	O	O	
	18 ga.		O	O	O	
	16 ga.	O	O	O	O	
	14 ga.		O			O
	12 ga.		O			

[1] plate in contact with head of the steel pin
[2] plate on side with tip of the steel pin

Based on the data provided by Aerosmith, Inc., the nominal thickness and strength of the steels used in the test program were interpreted and the values are summarized in Table 5. Tension coupon testing was not part of the scope of this project. The values given in Table 5 are based on data taken from Working Draft #4 of NAHB's prescriptive design recommendations for cold-formed steel framing, the Metal Stud Manufacturers Association (MSMA) member catalog, and ASTM Standard A653.

Table 3 Lap shear tests using 0.144 in. diameter helical thread pins

		Main Plate[1]			
		20 ga.	18 ga.	16 ga.	14 ga.
Holding Plate[2]	20 ga.	O			
	18 ga.	O	O		
	16 ga.	O	O	O	
	14 ga.		O	O	O
	12 ga.		O	O	O

[1] plate in contact with head of the steel pin
[2] plate on side with tip of the steel pin

Table 4 Withdrawal (tension) tests using 0.144 in. diameter helical thread pins

		Main Plate[1]			
		20 ga.	18 ga.	16 ga.	14 ga.
Holding Plate[2]	20 ga.	O			
	18 ga.	O	O		
	16 ga.	O	O	O	
	14 ga.		O	O	O
	12 ga.		O	O	O

[1] plate in contact with head of the steel pin
[2] plate with tip of the steel pin

Table 5 Nominal thickness and minimum yield and tensile strength values

Designation (mils)	Min. Thickness, in (mm)	Reference Gauge	Yield Strength[1], ksi	Min. Tensile Strength[1], ksi
18	0.0179 (0.455)	25	33	45
27	0.0269 (0.683)	22	33	45
33	0.0329 (0.836)	20	33	45
43	0.0428 (1.087)	18	33	45
54	0.0538 (1.367)	16	50	65
68	0.0677 (1.720)	14	50	65
97	0.0966 (2.454)	12	50	65

[1] assumed based on literature

3.0 TEST SETUP and PROCEDURE

3.1 Lap Shear Tests

All shear test specimens consisted of a single lap joint with two pins aligned in the direction of the applied shear load. The width dimension of the shear specimen was such that failure by yield in the gross section or fracture across the net section was not possible before failure at the connection. Figure 1 shows a schematic of the typical test specimen and physical dimensions are given in Appendix A. The lap shear tests were conducted in a 10 kip Applied Testing Systems universal testing machine. Figure 2 shows the overall test setup. The specimens were loaded to failure at a rate of 0.2 in. per minute, based on the free running crosshead speed. Data recorded during the test included the applied load and the relative displacement across the joint. Displacement at the joint was measured using a system of two transducers (dcdt) across the lap.

Each lap shear specimen was given a designation identifying the main plate, the holding (substrate) plate, and the diameter of the steel pin used. For example S20-18-100 implied a lap shear test (S), the main plate is 20 gauge (20), and the holding plate is 18 gauge (18).

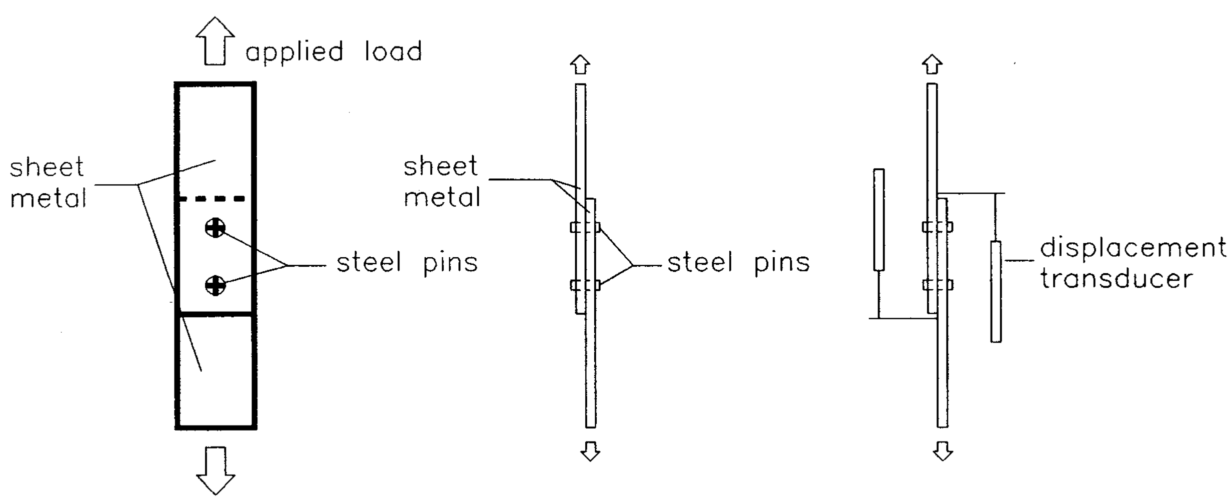


Figure 1 Typical lap shear test specimen

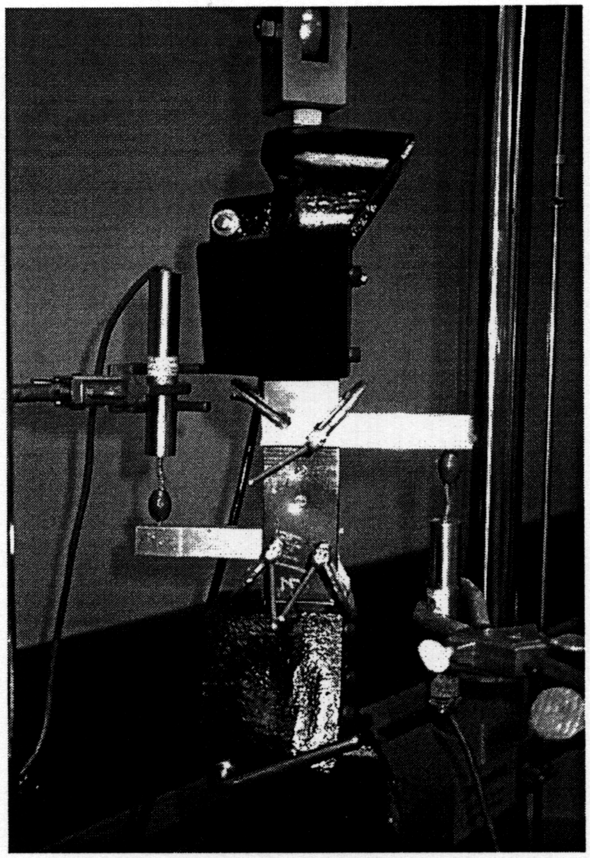


Figure 2 Overall test setup for lap shear test

3.2 Withdrawal (Tension) Tests

The tension test specimen comprised two plates bent to form channel sections. The web of the channel sections were attached back to back with a single pin (see Figure 3). The physical dimensions of the test specimens are given in Appendix A. Load was applied perpendicular to the connected web elements, through the flanges, at a free running crosshead speed of 0.2 in. per minute (in the universal testing machine). Each specimen was tested to destruction. Data recorded during the test included the applied load and the stroke of the test machine (this was a relative measure of the joint displacement). Figure 4 shows the overall test setup. To limit bending in the web of the channel section, an attempt was made to fit the tubular section tightly against the web of the channel. In many cases, however, a close fit at the web could not be achieved, thus, there was some bending in the web.

Each withdrawal (tension) specimen was given a designation identifying the main plate, the holding (substrate) plate, and the diameter of the steel pin used. For example T20-18-144 implied a withdrawal (tension) test (T), the main plate is 20 gauge (20), and the holding plate is 18 gauge (18).

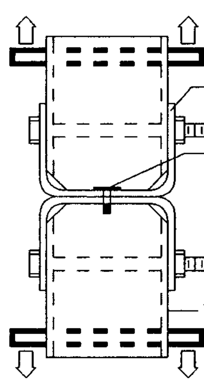


Figure 3 Typical withdrawal (tension) test specimen

4.0 TEST RESULTS

In the lap shear tests, the displacement across the connection was relatively small up to the maximum load. As the maximum resistance in the lap shear connection was reached the displacement at the joint increased rapidly. This increase in displacement was derived from two

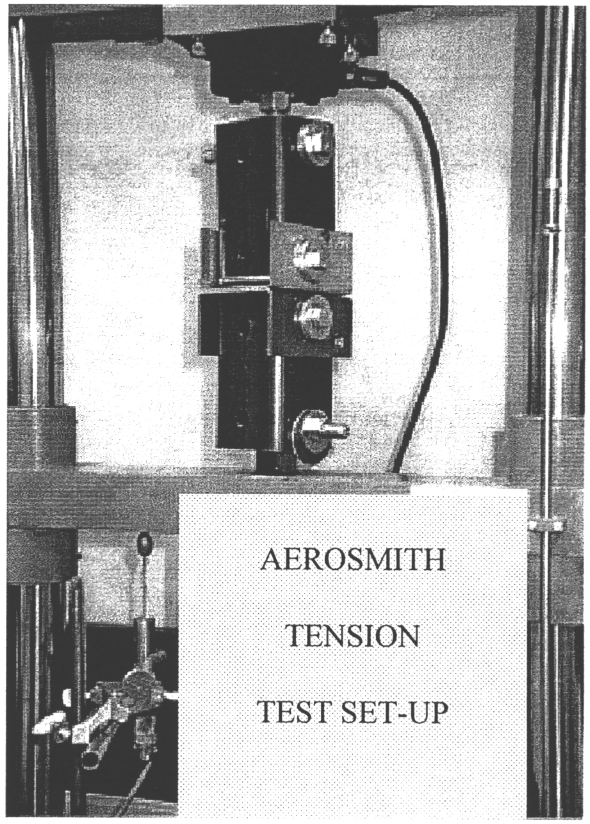


Figure 4 Overall test setup for withdrawal (tension) test

sources: (i) pin slip in the holding plate and (ii) deformation in the main plate (at the head of the pin). In the withdrawal test, the main source of displacement across the joint was pin slip (apart from bending of the channel web). In none of the withdrawal tests did the head of the pin pull through the main plate. Figures 5 (a and b) and 6 show the overall failure modes for the lap shear and withdrawal tests, respectively.

The nominal maximum loads for each configuration tested are given in Tables 6 through 9. Appendix B gives the test data for each specimen. For each set of three tests (Appendix B), the nominal strength was determined as the lower of the average of the three maximum values, if the three values were within 10% of the average, or the lowest of the three values if one of the three values was not within 10% of the average. Tables 6 and 7 give the overall results for the shear and withdrawal (tension) tests using the 0.100 in. diameter pins. Tables 8 and 9 give the same results for the tests with 0.144 in. diameter pins. For the 0.100 in. diameter pins, Figures 7 and 8 show the relationship between the applied load and the thickness of the holding and main plates (t2 and t1, respectively) for the lap shear and withdrawal tests. Similar relationships for the 0.144 in. diameter pins are shown in Figures 9 and 10. The holding plate thickness appeared to be the main parameter governing the nominal strength of the connection. No relationship was evident between the strength of the connection and the thickness of the main plate, except, when t2/t1 was greater than 3.0.

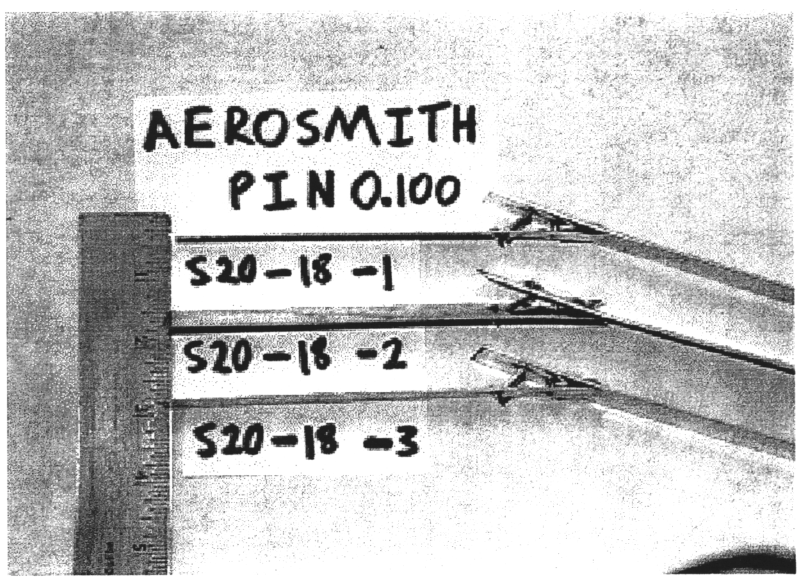


Figure 5a Typical mode of failure for lap shear test

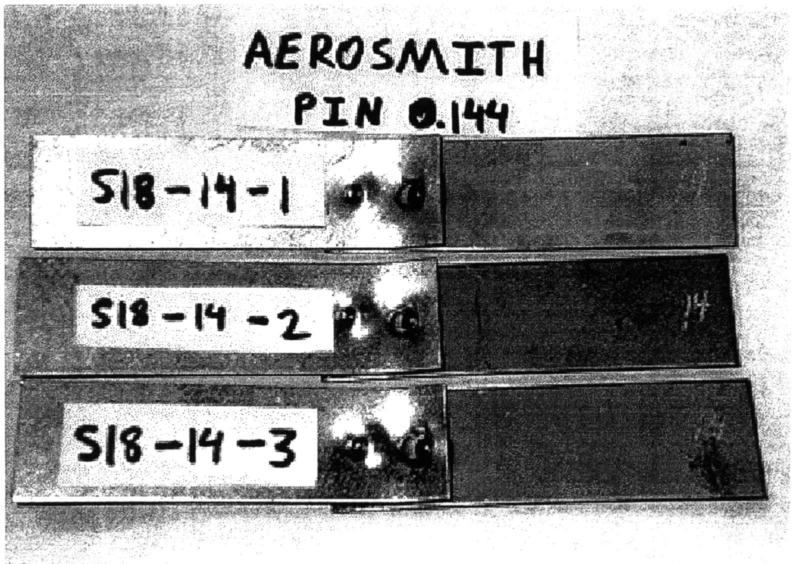


Figure 5b Typical mode of failure for the lap shear test

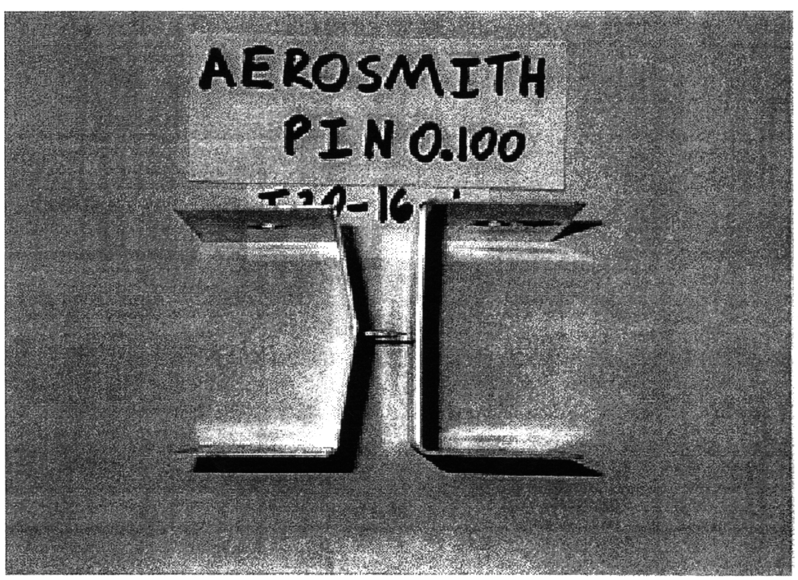


Figure 6 Typical mode of failure for the withdrawal (tension) test

Table 6 Overall test results for shear using 0.100 in. diameter steel pins

Specimen	Failure Load (per pin), lb.	Main Plate t_1, in.	Holding Plate t_2, in.	Pin Diameter, in.	*Tensile Strength* F_{u1}, *ksi*	*Tensile Strength* F_{u2}, *ksi*
S22-16	669.83	0.0329	0.0538	0 .100	45	65
S20-20	402.32	0.0329	0.0329	0.100	45	45
S20-18	582.52	0.0329	0.0428	0.100	45	45
S20-16	746.04	0.0329	0.0538	0.100	45	65
S20-14	929.25	0.0329	0.0677	0.100	45	65
S20-12	921.12	0.0329	0.0966	0.100	45	65
S18-20	444.94	0.0428	0.0329	0.100	45	45
S18-18	619.82	0.0428	0.0428	0.100	45	45
S18-16	811.49	0.0428	0.0538	0.100	45	65
S16-20	485.91	0.0538	0.0329	0.100	65	45
S16-18	699.65	0.0538	0.0428	0.100	65	45
S16-16	865.47	0.0538	0.0538	0.100	65	65
S14-14	1,120.21	0.0677	0.0677	0.100	65	65

Table 7 Overall test results for withdrawal (tension) using 0.100 in. diameter steel pins

Specimen	Failure Load (per pin), lb.	Main Plate t_1, in.	Holding Plate t_2, in.	Pin Diameter, in.	*Tensile Strength* F_{u1}, *ksi*	*Tensile Strength* F_{u2}, *ksi*
T22-16	340.88	0.0329	0.0538	0.100	45	65
T20-20 (repeat)	131.02	0.0329	0.0329	0.100	45	45
T20-20	104.98	0.0329	0.0329	0.100	45	45
T20-18	190.06	0.0329	0.0428	0.100	45	45
T20-16	255.54	0.0329	0.0538	0.100	45	65
T20-14	438.38	0.0329	0.0677	0.100	45	65
T20-12	524.94	0.0329	0.0966	0.100	45	65
T18-20	139.24	0.0428	0.0329	0.100	45	45
T18-18	251.77	0.0428	0.0428	0.100	45	45
T18-16	371.79	0.0428	0.0538	0.100	45	65
T16-20	69.94	0.0538	0.0329	0.100	65	45
T16-18	244.92	0.0538	0.0428	0.100	65	45
T16-16	321.81	0.0538	0.0538	0.100	65	65
T14-14	439.17	0.0677	0.0677	0.100	65	65

Table 8 Overall test results for shear using 0.144 in. diameter steel pins

Specimen	Failure Load (per pin), lb.	Main Plate t_1, in.	Holding Plate t_2, in.	Pin Diameter, in.	*Tensile Strength* F_{u1}, *ksi*	*Tensile Strength* F_{u2}, *ksi*
S20-20	452.64	0.0329	0.0329	0.144	*45*	*45*
S20-18	670.82	0.0329	0.0428	0.144	*45*	*45*
S20-16	868.92	0.0329	0.0538	0.144	*45*	*65*
S18-18	743.78	0.0428	0.0428	0.144	*45*	*45*
S18-16	980.23	0.0428	0.0538	0.144	*45*	*65*
S18-14	1,252.58	0.0428	0.0677	0.144	*45*	*65*
S18-12	1,522.51	0.0428	0.0966	0.144	*45*	*65*
S16-16	977.41	0.0538	0.0538	0.144	*65*	*65*
S16-14	1,325.51	0.0538	0.0677	0.144	*65*	*65*
S16-12	1,917.64	0.0538	0.0966	0.144	*65*	*65*
S14-14	1,392.88	0.0677	0.0677	0.144	*65*	*65*
S14-12	2,147.73	0.0677	0.0966	0.144	*65*	*65*

Table 9 Overall test results for withdrawal (tension) using 0.144 in. diameter steel pins

Specimen	Failure Load (per pin), lb.	Main Plate t_1, in.	Holding Plate t_2, in.	Pin Diameter, in.	*Tensile Strength* F_{u1}, *ksi*	*Tensile Strength* F_{u2}, *ksi*
T20-20	241.15	0.0329	0.0329	0.144	*45*	*45*
T20-18	421.23	0.0329	0.0428	0.144	*45*	*45*
T20-16	545.17	0.0329	0.0538	0.144	*45*	*65*
T18-18	426.01	0.0428	0.0428	0.144	*45*	*45*
T18--16	557.39	0.0428	0.0538	0.144	*45*	*65*
T18-14	669.44	0.0428	0.0677	0.144	*45*	*65*
T18-12	1,010.05	0.0428	0.0966	0.144	*45*	*65*
T16-16	596.36	0.0538	0.0538	0.144	*65*	*65*
T16-14	613.2	0.0538	0.0677	0.144	*65*	*65*
T16-12	902.72	0.0538	0.0966	0.144	*65*	*65*
T14-14	659.51	0.0677	0.0677	0.144	*65*	*65*
T14-12	894.39	0.0677	0.0966	0.144	*65*	*65*

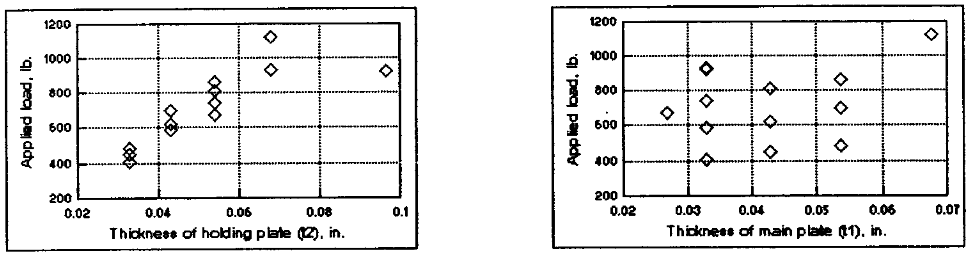


Figure 7 Comparison of pin shear load versus t_1 and t_2 for 0.100 in. steel pins

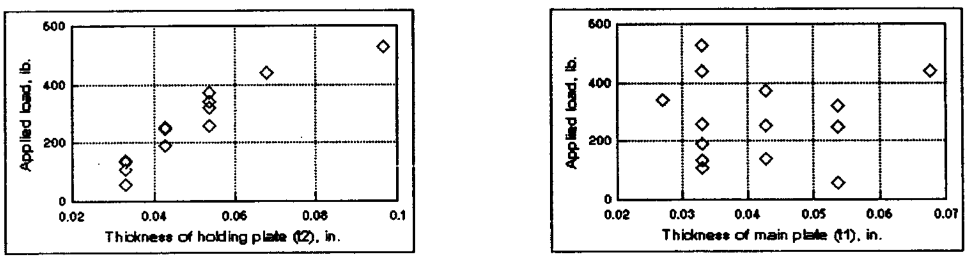


Figure 8 Comparison of pin withdrawal load versus t_1 and t_2 for 0.100 in. steel pins

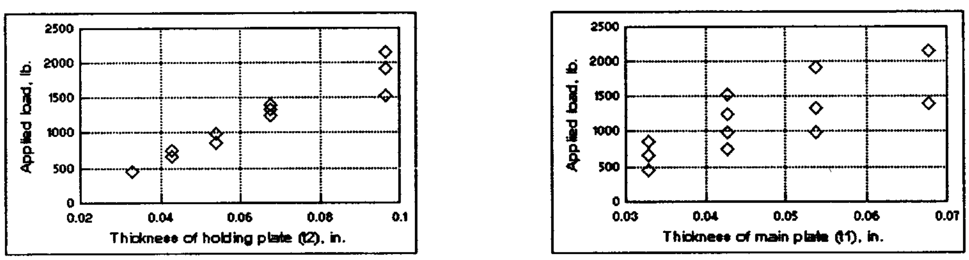


Figure 9 Comparison of pin shear load versus t_1 and t_2 for 0.144 in. steel pins

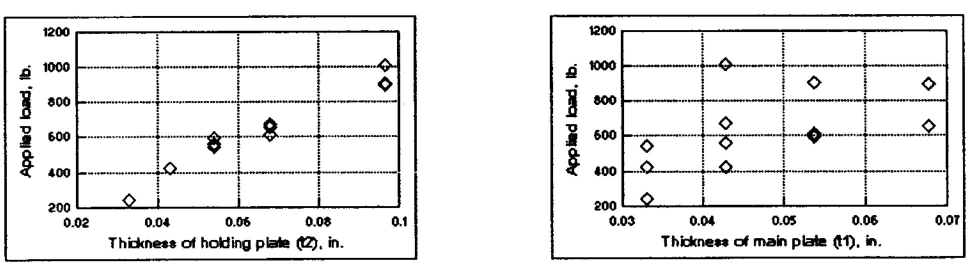


Figure 10 Comparison of pin withdrawal load versus t_1 and t_2 for 0.144 in. steel pins

5.0 DISCUSSION

A comparison of the nominal measured shear values with computed values based on the AISI design equations for screws (Tables 10 and 11 for 0.100 in. and 0.144 in. diameter pins, respectively) shows that the AISI screw equations (equations (1) through (5)) may be very conservative for the Aerosmith pins in shear (using the assumed material properties in Table 5). Based on the test data, the equations (6) and (7) are recommended for computing the capacity of the lap shear steel pin connection.

Table 10 Measured vs. predicted shear connection capacities for 0.100 in. diameter pins

Specimen	Measured Capacity, lb.	Predicted Capacity (LGSRG), lb.	Predicted Capacity (AISI), lb.
S22-16	669.83	618.19	326.84
S20-20	402.32	370.13	356.66
S20-18	582.52	422.16	399.74
S20-16	746.04	683.66	399.74
S20-14	929.25	766.91	399.74
S20-12	921.12	916.09	399.74
S18-20	444.94	422.16	356.66
S18-18	619.82	481.5	520.02
S18-16	811.49	779.77	520.02
S16-20	485.91	473.31	356.66
S16-18	699.65	539.84	520.02
S16-16	865.47	874.25	944.19
S14-14	1,120.21	1,100.13	1,188.14

Table 11 Measured vs. predicted shear connection capacities for 0.144 in. diameter pins

Specimen	Measured Capacity lb.	Predicted Capacity (LGSRG) lb.	Predicted Capacity (AISI) lb.
S20-20	452.64	532.98	427.99
S20-18	670.82	607.9	575.62
S20-16	868.92	984.48	575.62
S18-18	743.78	693.36	635.05
S18-16	980.23	1,122.87	748.83
S18-14	1,252.58	1,259.6	748.83
S18-12	1,522.51	1,504.62	748.83
S16-16	977.41	1,258.92	1,292.76
S16-14	1,325.51	1,412.22	1,359.63
S16-12	1,917.64	1,686.92	1,359.63
S14-14	1,392.88	1,584.18	1,710.91
S14-12	2,147.73	1,892.34	1,710.91

AISI equations for lap shear screw connections:

For $t_2/t_1 \leq 1.0$, the nominal strength per fastener is the smallest of

$$P_{ns} = 4.2(t_2^3 d)^{1/2} F_{u2} \quad \text{..........} \quad (1)$$
$$P_{ns} = 2.7 t_1 d F_{u1} \quad \text{..........} \quad (2)$$
$$P_{ns} = 2.7 t_2 d F_{u2} \quad \text{..........} \quad (3)$$

For $t_2/t_1 > 2.5$, the nominal strength per fastener is taken as the smaller of

$$P_{ns} = 2.7 t_1 d F_{u1} \quad \text{..........} \quad (4)$$
$$P_{ns} = 2.7 t_2 d F_{u2} \quad \text{..........} \quad (5)$$

Interpolate between the two limits of t_2/t_1.

Recommended equations for lap shear steel pin connections:

For $t_2/t_1 \leq 3.0$, the nominal strength per fastener may be taken as

$$P_{ns} = 2.5(t_1 t_2)^{1/2} d F_{u2} \quad \text{..........} \quad (6)$$

For $t_2/t_1 > 3.0$, the nominal strength per fastener may be taken as

$$P_{ns} = 2.7 t_1 d F_{u1} \quad \text{..........} \qquad (7)$$

For the withdrawal tests, Tables 12 an 13 (0.100 in. and 0.144 in. diameter pins, respectively) show that the AISI screws equation gives a relative good prediction of the withdrawal capacity of the steel pin connection.

AISI equation for screw pull-out in withdrawal connections (equation may also be used for steel pin):

$$P_{not} = 0.85 t_2 d F_{u2}$$

Table 12 Measured vs. predicted withdrawal connection capacities for 0.100 in. diameter pins

Specimen	Measured Capacity lb.	Predicted Capacity (AISI) lb.
T22-16	340.88	297.25
T20-20 (r)	131.02	125.84
T20-20	104.98	125.84
T20-18	190.06	163.71
T20-16	255.54	297.25
T20-14	438.38	374.04
T20-12	524.94	533.72
T18-20	139.24	125.84
T18-18	251.77	163.71
T18-16	371.79	297.25
T16-20*	69.94	125.84
T16-18	244.92	163.71
T16-16	321.81	297.25
T14-14	439.17	374.04

* value unexpectedly low

Table 13 Measured vs. predicted withdrawal connection capacities for 0.144 in. diameter pins

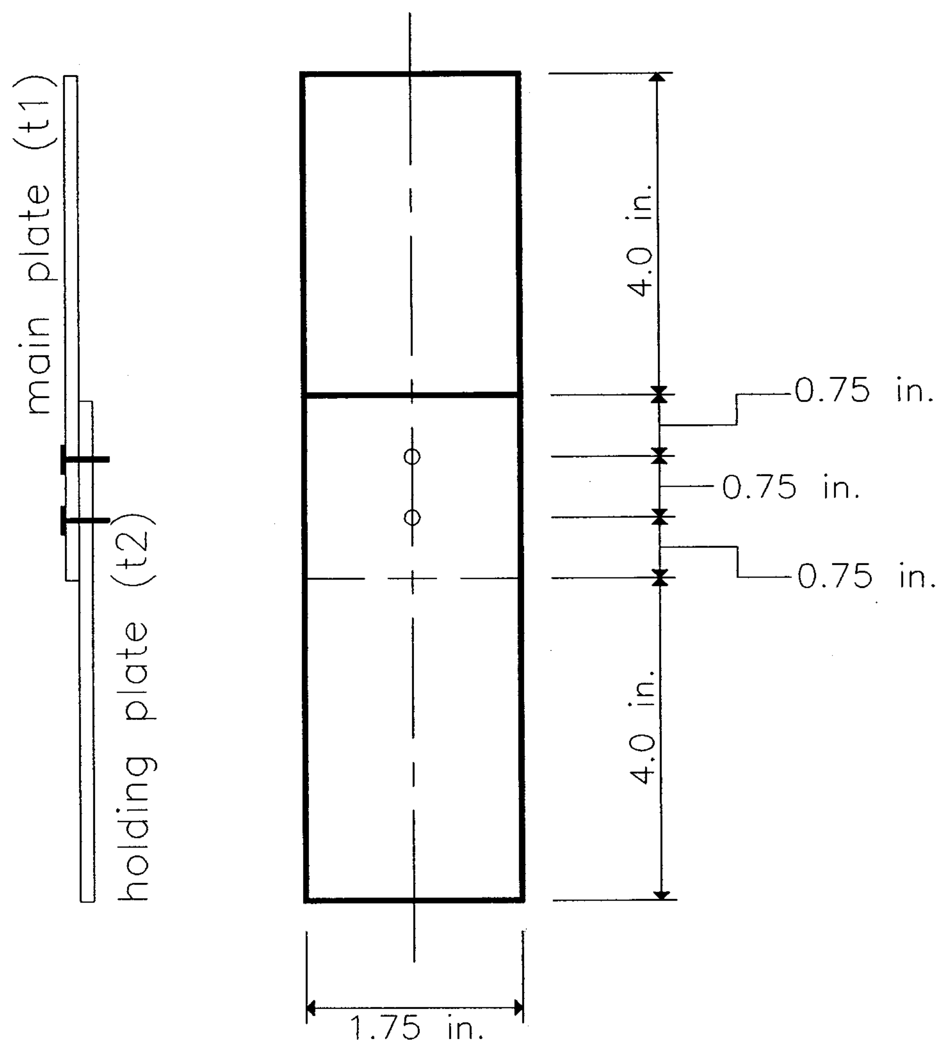
Specimen	Measured Capacity, lb.	Predicted Capacity (AISI), lb.
T20-20	241.15	181.21
T20-18	421.23	235.74
T20-16	545.17	428.03
T18-18	426.01	235.74
T18--16	557.39	428.03
T18-14	669.44	538.62
T18-12	1,010.05	768.55
T16-16	596.36	428.03
T16-14	613.2	538.62
T16-12	902.72	768.55
T14-14	659.51	538.62
T14-12	894.39	768.55

6.0 CONCLUSION

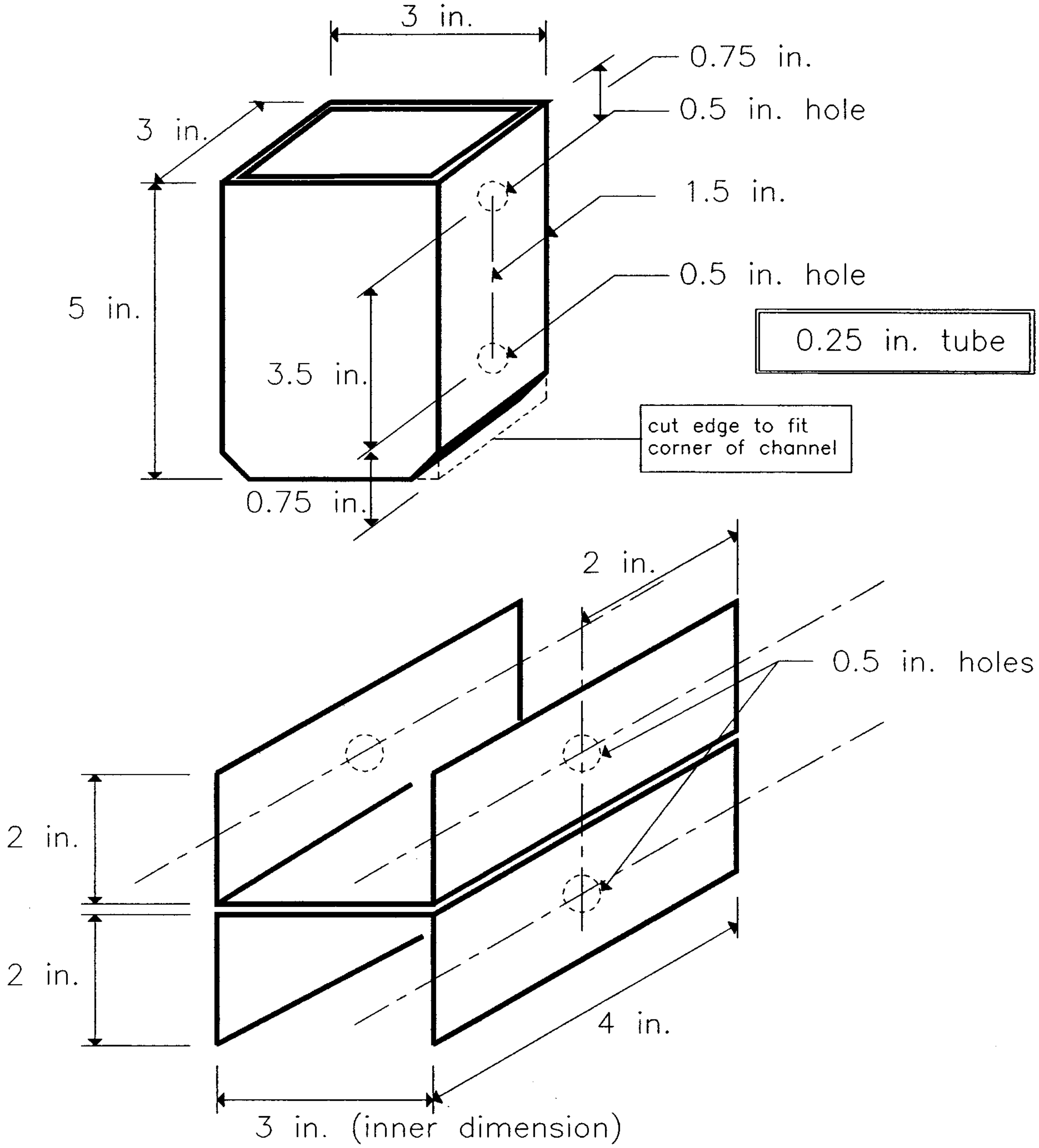
Results from a comprehensive series of lap shear and withdrawal (tension) light gauge metal-to-metal connections tests were presented for Aerosmith, Inc.'s 0.100 in. and 0.144 in. diameter helical thread pins. The test data cover a wide combination of main and holding (substrate) plates thickness that may be used in the field. Overall, the measured results are very good compared with the predicted values based on the AISI screw equations.

APPENDIX A

Lap Shear Specimen Dimensions



Tension Specimen Dimensions



APPENDIX B

Lap shear tests: 0.100 in. diameter pins

S22-16-1	675.17	
S22-16-2	641.71	**669.83**
S22-16-3	692.62	
S20-20-1	411.19	
S20-20-2	390.64	**402.32**
S20-20-3	405.13	
S20-18-1	579.34	
S20-18-2	580.18	**582.52**
S20-18-3	588.03	
S20-16-1	760.72	
S20-16-2	732.21	**746.04**
S20-16-3	745.19	
S20-14-1	932.70	
S20-14-2	934.21	**929.25**
S20-14-3	920.83	
S20-12-1	881.32	
S20-12-2	937.96	**921.12**
S20-12-3	944.09	
S18-20-1	413.50	
S18-20-2	473.24	**444.94**
S18-20-3	448.07	

S18-18-1	589.72	
S18-18-2	655.02	**619.82**
S18-18-3	614.71	
S18-16-1	812.50	
S18-16-2	771.79	**811.49**
S18-16-3	850.18	
S16-20-1	450.78	
S16-20-2	538.64	**485.91**
S16-20-3	468.30	
S16-18-1	689.27	
S16-18-2	703.69	**699.65**
S16-18-3	706.00	
S16-16-1	829.23	
S16-16-2	870.25	**865.47**
S16-16-3	896.94	
S14-14-1	1142.60	
S14-14-2	1137.34	**1,120.21**
S14-14-3	1080.70	

Withdrawal tests: 0.100 in. pins

T22-16-1	316.56	
T22-16-2	367.54	**340.88**
T22-16-3	338.54	
T20-20-5 (r)	111.04	
T20-20-6 (r)	126.33	
T20-20-7 (r)	159.00	**131.02**
T20-20-8 (r)	137.81	
T20-20-9 (r)	120.92	
T20-20-1	184.80	
T20-20-2	104.98	**104.98**
T20-20-3	143.06	
T20-18-1	190.06	
T20-18-2	204.56	**190.06**
T20-18-3	243.44	
T20-16-1	308.12	
T20-16-2	255.54	**255.54**
T20-16-3	276.10	
T20-14-1	434.28	
T20-14-2	480.02	**438.38**
T20-14-3	400.84	
T20-12-1	539.28	
T20-12-2	712.14	**524.94**
T20-12-3	524.94	

T18-20-1	171.26	
T18-20-2	139.24	**139.24**
T18-20-3	173.34	
T18-18-1	252.52	
T18-18-2	255.54	**251.77**
T18-18-3	247.26	
T18-16-1	348.42	
T18-16-2	373.60	**371.79**
T18-16-3	393.34	
T16-20-1	90.48	
T16-20-2	69.94	**69.94**
T16-20-3	155.96	
T16-18-1	243.44	
T16-18-2	259.36	**244.92**
T16-18-3	231.96	
T16-16-1	350.64	
T16-16-2	291.38	**321.81**
T16-16-3	323.40	
T14-14-1	435.24	
T14-14-2	435.88	**439.17**
T14-14-3	446.40	

Lap shear tests: 0.144 in. pins

S20-20-1	467.11	
S20-20-2	474.67	**452.64**
S20-20-3	416.13	
S20-18-1	653.42	
S20-18-2	687.68	**670.82**
S20-18-3	671.35	
S20-16-1	888.97	
S20-16-2	852.80	**868.92**
S20-16-3	864.99	
S18-18-1	753.15	
S18-18-2	735.31	**743.78**
S18-18-3	742.88	
S18-16-1	1008.77	
S18-16-2	986.31	**980.23**
S18-16-3	945.60	
S18-14-1	1250.29	
S18-14-2	1246.47	**1,252.58**
S18-14-3	1260.97	

S18-12-1	1545.82	
S18-12-2	1538.25	**1,522.51**
S18-12-3	1483.45	
S16-16-1	1008.77	
S16-16-2	991.47	**977.41**
S16-16-3	931.98	
S16-14-1	1303.11	
S16-14-2	1363.96	**1,325.51**
S16-14-3	1309.46	
S16-12-1	1806.77	
S16-12-2	1934.34	**1,917.64**
S16-12-3	2011.81	
S14-14-1	1392.88	
S14-14-2	1518.82	**1,392.88**
S14-14-3	1891.02	
S14-12-1	2128.59	
S14-12-2	2149.94	**2,147.73**
S14-12-3	2164.67	

Withdrawal tests: 0.144 in. pins

T20-20-1	250.28	
T20-20-2	228.30	**241.15**
T20-20-3	244.86	
T20-18-1	426.00	
T20-18-2	423.78	**421.23**
T20-18-3	413.90	
T20-16-1	566.68	
T20-16-2	528.76	**545.17**
T20-16-3	540.08	
T18-18-1	432.22	
T18-18-2	424.42	**426.01**
T18-18-3	421.38	
T18--16-1	515.86	
T18-16-2	585.00	**557.39**
T18-16-3	571.30	
T18-14-1	691.58	
T18-14-2	689.20	**669.44**
T18-14-3	627.54	
T18-12-1	963.84	
T18-12-2	1078.07	**1,010.05**
T18-12-3	988.23	

T16-16-1	581.18	
T16-16-2	601.72	**596.36**
T16-16-3	606.18	
T16-14-1	613.20	
T16-14-2	750.04	**613.2**
T16-14-3	686.32	
T16-12-1	903.78	
T16-12-2	899.16	**902.72**
T16-12-3	905.22	
T14-14-1	614.48	
T14-14-2	656.54	**659.51**
T14-14-3	707.52	
T14-12-1	936.44	
T14-12-2	853.60	**894.39**
T14-12-3	893.12	