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Strength and Stiffness of Conventional Bridging Systems for Cold-Formed Cee Studs

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Abstract

An experimental testing program has been carried out on typical bridging components and connections used in North American practice to provide bracing to cold-formed lipped cee-studs, in order to determine the in-plane and out-of-plane strength and stiffness of the bridging components and connections. Bridging systems tested included cold-formed bridging channels directly welded to the stud, bridging channels connected to the stud web through a welded connection to a clip angle, and bridging channels connected to the stud web through a screwed connection to a clip angle. Bridging connections were loaded axially (into the stud web) and laterally (parallel to the stud web). Separate analysis of the test results indicates that conventional bridging used in current North American practice has adequate stiffness and strength to brace axially loaded and curtain wall steel studs.

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Introduction

A total of 54 full-scale bridging specimens were tested to evaluate the strength and stiffness of typical industry bridging. (Green, et.al. 2004) The tests were conducted on 3'-6" long cee-stud sections. Three types of typical industry bridging were tested. The specimens were divided into two groups based on the direction of loading namely, in-plane loading and out-of-plane loading. Twenty-eight specimens were tested in the out-of-plane loading group while twenty-six specimens were tested in the in-plane loading group.

Test Specimens

The 3'-6" long cee-stud sections were cut from 20'-6" long as delivered studs such that the elevation to the center of the web punchout was maintained at 1'-11". Material properties are as shown in Table 1. The test specimens were identified using the following modified SSMA nomenclature:

DDD S FFF-TT-N CC

where:	DDD	=	Overall stud depth (362 = 3.62"; 600 = 6.00"; 800 = 8.00")
	S	=	Lipped stud section
	FFF	=	Flange width (125 = 1.25"; 162 = 1.62")
	TT	=	Nominal steel thickness (mils; 1 mil = 0.001")
	N	=	Number of the test specimen in each series of stud
	CC	=	Bridging connection type (SS, WW, DW)

Figs. 1(a) through (c) show the types of bridging connections tested and they are described below:

<u>Type-1 Screwed-Screwed (SS) Connection</u>: The clip angle was screwed to the bridging channel with two #10 self-drilling screws and screwed to the web of the stud as shown in Fig. 1a.

<u>Type-2 Welded-Welded (WW) Connection</u>: The bridging channel was welded at its flange-web junction to the clip, as shown in Fig. 1b. The clip angle was then positioned along the centerline of the web and fillet welded on the edges of

the in-line leg. The bridging channel was slid through the punchout and then fillet welded to the outstanding leg of the clip angle. The welding specifications used were – Metal alloy: ER7056, Heat: 1026° F, Shielding gas: Argon-CO2 (75%-25%).

Type-3 Direct-Welded (DW) Connection: The bridging channel was slid through the web punchout and the flanges welded to the web of the stud, as shown in Fig. 1c. The welding specification used was the same as in the Type-2 connection.

Test Fixture

The test fixture used to secure the specimens for the bridging tests is shown in Figs. 2 and 3. The load was applied to the bridging channel by a manually operated screw-driven actuator, fixed to the actuator armature. One end of the actuator was connected to an S-beam load cell, and the other end was connected to the vertical channel of the actuator armature by a 3/4" diameter SAE Grade 5 bolt. A plate-coupler was introduced between the bridging and the S-beam load cell that allowed the load to be transmitted to the bridging channel through the plate-coupler. The joint between the actuator and the vertical channel of the actuator armature was free to rotate horizontally, while the joint between the plate-coupler and the bridging channel was free to rotate vertically.

Instrumentation

The instruments used for the out-of-plane loading tests are shown in Fig. 4 and for the in-plane loading tests in Fig. 5. For both loading conditions, three linear string type potentiometers were used to capture the spatial movement of the bridging where it is connected to the load actuator, each measuring the X, Y and Z displacements, respectively. Five additional linear potentiometers were used to measure the displacement of the bridging connection and the stud web, two on the front side and two on the back side, with an additional one on the back side located approximately one foot above the location of the bridging connection to the stud web.

Out-of-Plane Loading Test

The specimen mounting-frame and the actuator armature were aligned and anchored to the floor. The test specimen was placed in the specimen mounting-frame and aligned horizontally and vertically. The specimen was secured on the front and on the back by four rigid hot-rolled steel members, to isolate the web for testing.

In-Plane Loading Test

The specimen mounting-frame and the actuator armature were placed in line with the bridging channel of the stud specimen and anchored to the floor. The test specimen was placed in the specimen mounting-frame and aligned horizontally and vertically. The specimen was then secured on the front and on the back by four rigid hot-rolled steel members, to isolate the web for testing.

Bridging Test Results

The results of all the 54 experimental tests are presented in Tables 2 and 3. The maximum load attained and the corresponding connection deformations, for each of the loading tests, are given in these tables.

Observations of the Experimental Tests

1. SS type connection: It was observed that the deformation of the stud web was comparatively less than either the pullout of the screw or the deformation of the clip angle. With increasing thickness of the stud, the load required to fail the connection by pullout increased. This is because the area of contact between the screw and the stud increases with increasing thickness. When the clip angle deformed by forming a yield line at the level of the web screws, the axis of the screws was no longer horizontal, leading to an increase in stiffness of the connection. For this to occur, the connection had to undergo sufficient deformation hence failure was considered to have occurred at the load at which this effect of stiffening was observed. In some tests, the axial tension in the screws attached to the web exceeded the capacity of the screw and caused sudden failure. In a few specimens, the single shear across the cross-section of the screws attached to the bridging channel was the cause of sudden failure.
2. WW type connection: On application of the out-of-plane load, the right half of the clip angle started to pull on the stud web causing tension on the weld, and the left half started to push on the web causing compression on the web. In all the tests with WW type connections, the failure occurred at the

connection of the clip angle to the stud web. This was because the lever arm between the resultant tension to the resultant compression was greater than the lever arm between the welds holding the bridging channel to the clip angle. When the load reached either the weld strength or the tearing strength of the clip angle, the connection failed.

3. DW type connection: In this connection type, the weld holding the bridging channel to the stud was as long as the flange width of the bridging channel. With application of the load, the load path from the bridging to the stud web was across the small length of weld, which caused local deformation of the web plate around the punchout. In most cases the failure occurred by tearing of the weld.

Observed Bridging Connection Failures

In the out-of-plane loading and the in-plane tests, the following types of failure were observed for each type of bridging connection:

1. SS Type connection:
   - Single screw pullout without distortion of the angle (see Figs. 6a, b)
   - Single screw pullout with distortion of the angle (see Figs. 7a, b)
   - Tensile failure of the screw connecting to the stud web (see Fig. 8)
   - Shearing of screw connecting the bridging channel to the angle (see Fig. 9)
2. WW Type connection:
   - Tearing of the angle leg welded to the cee-stud (see Figs. 10a, b)
   - Tearing of the weld between the angle and the cee-stud (see Fig. 11)
3. DW Type connection:
   - Tearing of weld between the bridging channel and the cee-stud (see Fig. 12)
   - Tearing of cee-stud web around the weld material (see Fig. 13)

Total Bridging Connection Stiffness

The stiffness of the bridging connections are calculated for both the out-of-plane loading tests and the in-plane loading tests and are given in Tables 2 and 3, respectively. For flexural buckling in first mode, the in-plane connection stiffness is to be used in calculating the total actual stiffness of the bracing system. For torsional buckling in either first or second mode, the out-of-plane connection stiffness is to be used in calculating the total actual stiffness of the bracing system. The total actual stiffness of the bridging system is calculated using Eq. 1.

$$\frac{1}{\beta_{act}} = \frac{1}{\beta_{conn}} + \frac{1}{\beta_{brace}} \qquad \text{Eq.1}$$

where: β_{conn} = connection stiffness
β_{brace} = stiffness of the brace

In the case of flexural-torsional buckling the bridging connection stiffness is to be determined as an equivalent stiffness. This equivalent stiffness is used in Eq. 1 to obtain the total actual stiffness of the bracing system.

Summary and Conclusions

Industry typical bridging details were tested to determine the stiffness and strength of those details. Separate analysis of the test results indicates that conventional bridging used in current North American practice has adequate stiffness and strength to brace axially loaded and curtain wall steel studs.

Acknowledgements

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Reference

Green, P.S., Sputo, T., and Urala, V. (2004), "Lateral-Torsional Bracing of Cold-Formed Cee-Studs," Final Report Submitted to the American Iron and Steel Institute, P.O. No. CM-261, Department of Civil and Coastal Engineering, University of Florida, Gainesville, FL

Table 1 As-Built Material Properties from the Tension Coupon Tests

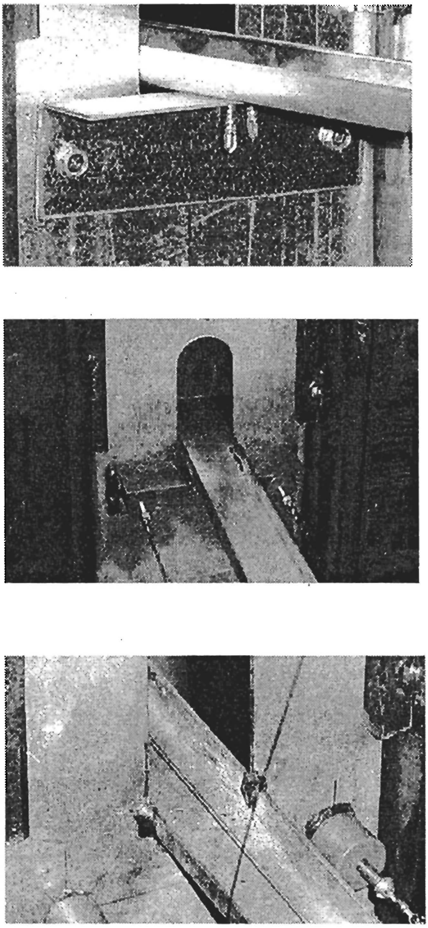
Specimen ID						Yield Stress (0.2% offset)	Upper Yield Stress	Lower Yield Stress	Ultimate Stress
TC	D		B	t		ksi	ksi	ksi	ksi
TC	362	S	125	33		-	47.26	46.40	54.68
TC	362	S	125	33		48.51	49.17	48.59	55.88
TC	362	S	125	33		48.55	49.17	49.40	55.89
Average						48.53	48.53	48.13	55.48
TC	362	S	162	43		46.65	46.90	46.43	57.62
TC	362	S	162	43		46.73	46.84	46.13	57.64
TC	362	S	162	43		47.98	48.31	47.22	58.60
TC	362	S	162	43		46.80	47.83	47.25	58.94
Average						47.04	47.47	46.76	58.20
TC	362	S	162	68		50.12	51.91	51.72	66.62
TC	362	S	162	68		51.75	51.78	51.24	67.34
TC	362	S	162	68		54.15	54.35	53.96	69.43
Average						52.01	52.68	52.30	67.80
TC	600	S	125	33		23.82	-	-	45.22
TC	600	S	125	33		26.97	-	-	45.56
TC	600	S	125	33		26.73	-	-	44.93
TC	600	S	125	33		18.61	-	-	35.70
TC	600	S	125	33		-	-	-	36.88
Average						24.03	-	-	45.24
TC	600	S	162	43		45.12	45.48	44.06	53.03
TC	600	S	162	43		46.65	47.49	48.37	55.65
TC	600	S	162	43		46.75	47.28	45.86	55.65
TC	600	S	162	43		46.43	47.79	47.16	55.18
Average						46.24	47.01	46.36	54.88
TC	600	S	162	43		50.27	50.81	50.63	59.21
TC	600	S	162	43		50.34	51.58	51.24	59.56
Average						50.30	51.19	50.94	59.38
TC	600	S	162	97		60.40	60.70	59.23	70.38
TC	600	S	162	97		61.10	62.05	59.31	70.28
TC	600	S	162	97		59.10	59.87	58.30	69.96
Average						60.20	60.87	58.94	70.21
TC	800	S	162	43		-	40.65	40.20	55.03
TC	800	S	162	43		-	40.50	40.20	54.47
TC	800	S	162	43		-	40.88	40.30	55.20
Average						-	40.68	40.23	54.90
TC	800	S	162	97		42.12	45.62	44.39	66.79
TC	800	S	162	97		43.32	44.55	44.51	68.00
TC	800	S	162	97		42.06	47.01	46.56	67.69
Average						42.50	45.73	45.15	67.49

Table 2 Out-of-Plane Loading Bridging Test Results

Serial Number	Stud Designation						Applied Load	Displacement of		Torsional Stiffness
								R_{FRONT}	R_{BACK}	
							T_{max}	Δ_{RB}	Δ_{RF}	K_T
	D	S	B	t	N	B	lbs.	in.	in.	lbs./in.
1	362	S	125	33	1	SS	57.37	0.184	-0.008	311
2	362	S	125	33	2	SS	71.10	0.208	-0.005	342
3	362	S	162	43	1	SS	69.19	0.073	0.014	945
4	362	S	162	43	2	SS	63.05	0.098	0.002	640
5	362	S	162	68	1	SS	128.91	0.067	0.003	1925
6	362	S	162	68	2	SS	102.39	0.059	-0.002	1731
7	362	S	162	68	1	WW	138.81	0.028	0.009	4908
8	362	S	162	68	2	WW	150.23	0.031	0.008	4917
9	362	S	162	68	1	DW	166.15	0.04	0.027	4491
10	362	S	162	68	2	DW	149.83	0.036	0.031	4149
11	600	S	125	33	1	SS	113.91	0.31	0.024	370
12	600	S	125	33	2	SS	83.59	0.200	0.019	418
13	600	S	162	43	1	SS	66.09	0.109	-0.008	605
14	600	S	162	43	2	SS	137.95	0.202	-0.009	682
15	600	S	162	97	3	SS	280.33	0.061	0.001	4564
16	600	S	162	97	4	SS	272.34	0.067	0.002	4094
17	600	S	162	97	1	WW	380.67	0.044	0.014	8747
18	600	S	162	97	2	WW	421.57	0.067	0.021	6276
19	600	S	162	97	1	DW	199.59	0.047	0.041	4267
20	600	S	162	97	2	DW	156.88	0.042	0.019	3753
21	800	S	162	43	1	SS	161.23	0.150	0.002	1075
22	800	S	162	43	2	SS	145.14	0.129	0.000	1128
23	800	S	162	97	1	SS	255.75	0.029	0.004	8735
24	800	S	162	97	2	SS	273.51	0.039	0.003	7049
25	800	S	162	97	1	WW	291.13	0.015	0.002	20036
26	800	S	162	97	2	WW	388.28	0.026	0.014	14797
27	800	S	162	97	1	DW	207.52	0.038	0.030	5503
28	800	S	162	97	2	DW	162.02	0.031	0.020	5272

Table 3 In-Plane Loading Bridging Test Results

Serial Number	Stud Designation						Applied Load	Displacement of		Flexural Stiffness
								L_{FRONT}	R_{FRONT}	
							T_{max}	Δ_{LF}	Δ_{RF}	K_F
	D	S	B	t	N	B	lbs.	in.	in.	lbs./in.
1	362	S	125	33	3	SS	391.94	0.219	0.229	1752
2	362	S	125	33	4	SS	431.48	0.321	0.174	1743
3	362	S	162	43	3	SS	545.56	0.130	0.088	5005
4	362	S	162	43	4	SS	491.00	0.122	0.089	4650
5	362	S	162	68	3	SS	937.28	0.087	0.092	10496
6	362	S	162	68	4	SS	889.78	0.092	0.054	12225
7	362	S	162	68	3	WW	1503.76	0.118	0.127	12263
8	362	S	162	68	4	WW	1462.17	0.121	0.127	11817
9	362	S	162	68	3	DW	3064.03	0.31	0.307	9883
10	362	S	162	68	4	DW	2642.63	0.349	0.401	7054
11	600	S	125	33	3	SS	425.80	0.29	0.223	1658
12	600	S	125	33	4	SS	302.94	0.174	0.186	1684
13	600	S	162	43	4	SS	640.80	0.131	0.125	5001
14	600	S	162	43	5	SS	587.06	0.214	0.381	5001
15	600	S	162	97	1	SS	1514.38	0.131	0.147	10902
16	600	S	162	97	2	SS	1172.38	0.105	0.130	9996
17	600	S	162	97	3	WW	1169.53	0.163	0.200	6444
18	600	S	162	97	4	WW	1653.71	0.212	0.230	7477
19	600	S	162	97	3	DW	-	-	-	-
20	600	S	162	97	4	DW	3159.07	0.469	0.464	6772
21	800	S	162	43	3	SS	275.60	0.073	0.093	3307
22	800	S	162	43	4	SS	522.66	0.137	0.151	3632
23	800	S	162	97	3	SS	848.35	0.032	0.037	24651
24	800	S	162	97	3a	SS	1402.04	0.064	0.030	29965
25	800	S	162	97	3	WW	1238.18	0.143	0.148	8493
26	800	S	162	97	4	WW	1101.97	0.151	0.111	8417
27	800	S	162	97	3	DW	2908.04	0.526	0.553	5390
28	800	S	162	97		DW	-	-	-	-



(a)

(b)

(c)

Fig. 1 Bridging Connections (a) SS (b) WW (c) DW

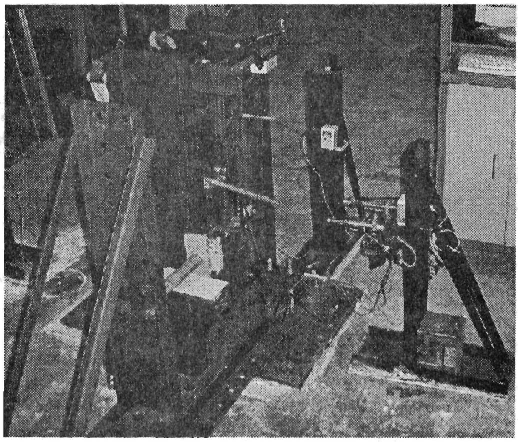


Fig. 2 Overall View of the Out-of-Plane Bridging Test Setup

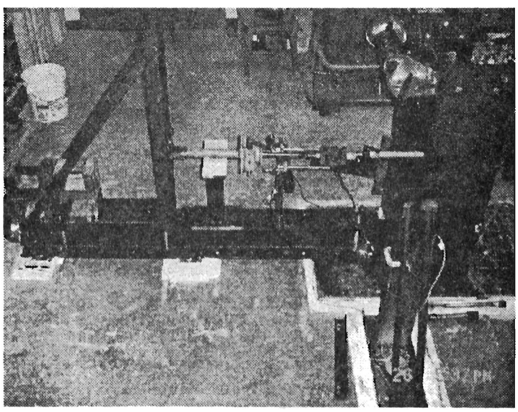


Fig. 3 Overall View of the In-Plane Bridging Test Setup

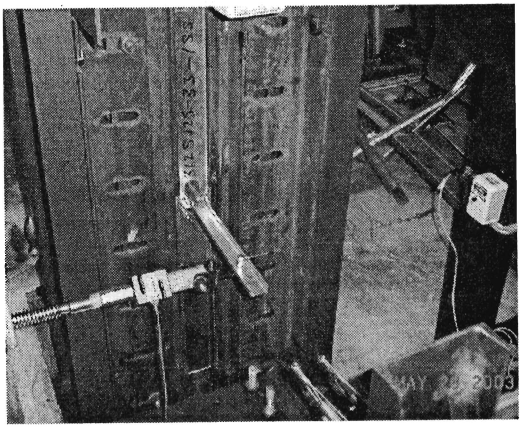


Fig. 4 Out-of-Plane Loading Test Instrumentation

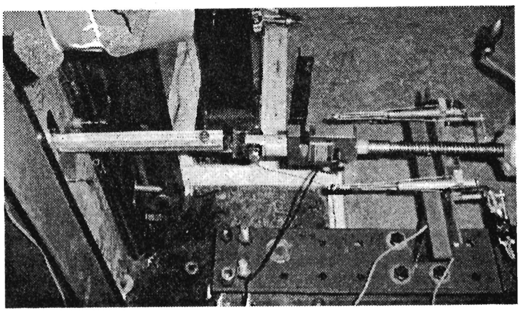
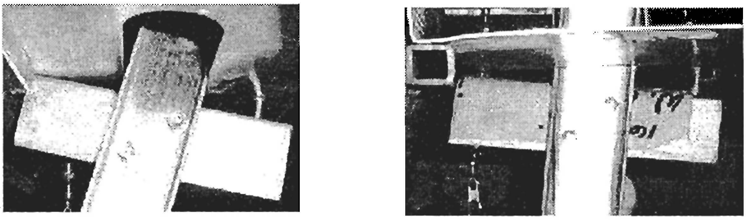


Fig. 5 In-plane Loading Test Instrumentation



(a) Out-of-plane loading (b) In-plane loading

Fig. 6 Observed Failure in SS Type connection due to Screw Pullout

(a) Out-of-plane loading (b) In-plane loading

Fig. 7 Observed Failure in SS Type connection due to Clip Angle Deformation

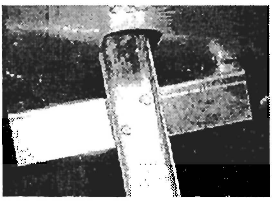


Fig. 8 Observed Failure in SS Type Connection due to Tension Failure of Screw

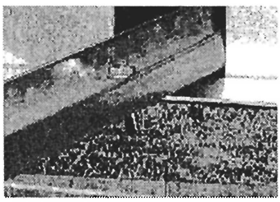
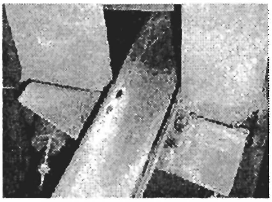
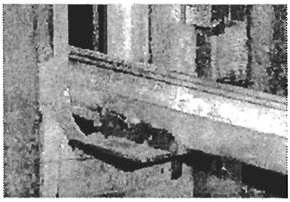


Fig. 9 Observed Failure in SS Type Connection due to Single Shear Failure of Screw



(a) Out-of-Plane Loading



(b) In-Plane Loading

Fig. 10 Clip Angle Tearing Failure in WW Type Connection

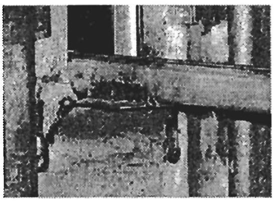


Fig. 11 Weld Tearing Failure in WW Type Connection

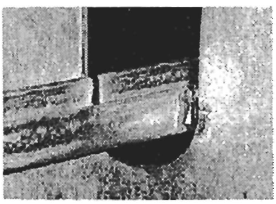


Fig. 12 Tearing of Weld Failure in the DW Type Connection

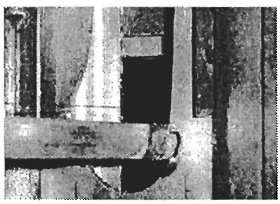


Fig. 13 Tearing of Stud Web Failure in the DW Type Connection