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Behavior of Arc Spot Weld Connections in Tension

By R. A. LaBoube,[1] Member, ASCE, and W. W. Yu,[2] Fellow, ASCE

Abstract: Arc spot welds, commonly called puddle welds, are widely used for connecting cold-formed steel roof decks to their supporting members. These support members are typically hot-rolled steel beams or girders, or the top chord of open-web steel joists. A comprehensive experimental study of the tension strength of arc spot weld connections used to affix a cold-formed steel roof deck to its support member was conducted. The study investigated the key parameters that influence the connection strength: steel thickness, tensile strength, and ductility; type of weld process, automatic or manual; cross section of the roof deck; loading condition, symmetrical or eccentric load; and geometry of connection. Based on the experimental results obtained from over 260 connection tests, equations have been developed that predict the tension capacity of an arc spot weld connection. These equations are easily applied, and lend themselves to use by structural designers.

Introduction

In the United States, arc spot welds, commonly called puddle welds, are widely used for connecting cold-formed steel roof decks to support members. These support members are typically hot-rolled steel beams or girders, or open-web steel joists. The arc spot weld is formed by burning a hole through the sheet and then filling the hole with weld metal, thus fusing the sheet to the support member. This two-step in-place procedure is done in one continuous operation.

To expand the application of the design specifications for cold-formed steel structural members and their connections (*Specification* 1986; "Structural" 1989), a research project entitled on the uplift strength of welded connections was initiated in 1989 by the American Iron and Steel Institute (AISI) at the University of Missouri-Rolla (UMR).

Literature Review

A review of the literature uncovered a very limited amount of information on the capacity of arc spot weld connections in tension.

Fung (1978) documented an experimental study that determined the capacity of an arc spot weld in either shear or tension. Based on the experimental findings, recommended design capacities for 19-mm diameter welds were suggested.

Based on Fung's test results, the following equation was developed and included in the 1984 edition of the Canadian standard ("Cold-formed" 1984):

$$P_{nt} = (5.6t - 1)10^3 \qquad (1)$$

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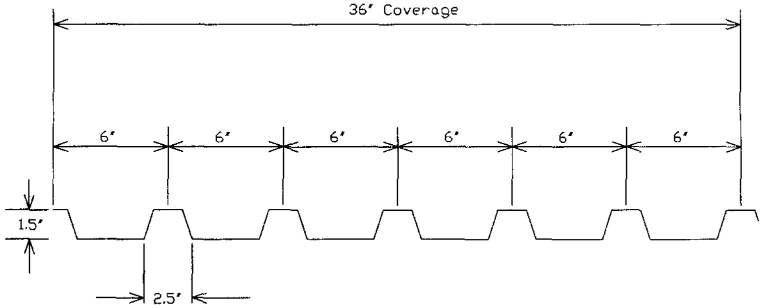

FIG. 1. Typical Panel Geometry

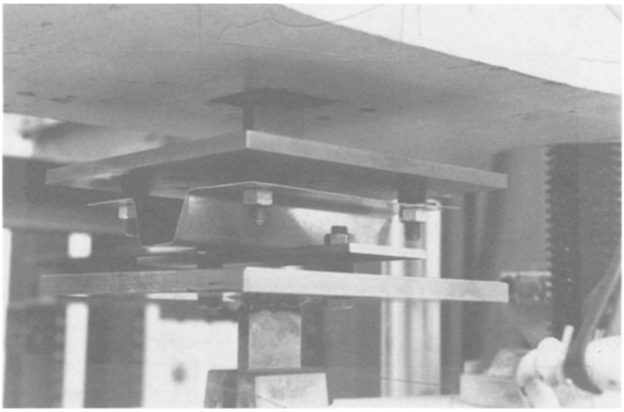

FIG. 2. Test Specimen and Test Fixture

where P_{nt} = connection tensile strength, N; and t = sheet thickness, mm, exclusive of coating.

Additional analysis of Fung's data was performed by Albrecht (1988) who recommended the following design expression for the nominal strength in tension of an arc spot weld, P_{nt}:

$$P_{nt} = 0.90td_aF_u \quad (2)$$

where d = visible diameter of the outer surface of the spot weld; d_a = average diameter of the arc spot weld at midthickness of sheet [where d_a = $(d - t)$ for a single sheet]; t = sheet thickness (exclusive of coating); F_u = tensile strength of steel sheet.

A statistical evaluation of Fung's data was conducted at the University of Missouri-Rolla (W. W. Yu, private committee correspondence, 1989). To achieve an acceptable safety index, or corresponding factor of safety of 2.5, the following equation was recommended:

$$P_{nt} = 0.66td_aF_u \quad (3)$$

Fung's data is also the basis for the following equation, which has been adopted for the 1989 edition of the Canadian standard ("Cold-formed" 1989):

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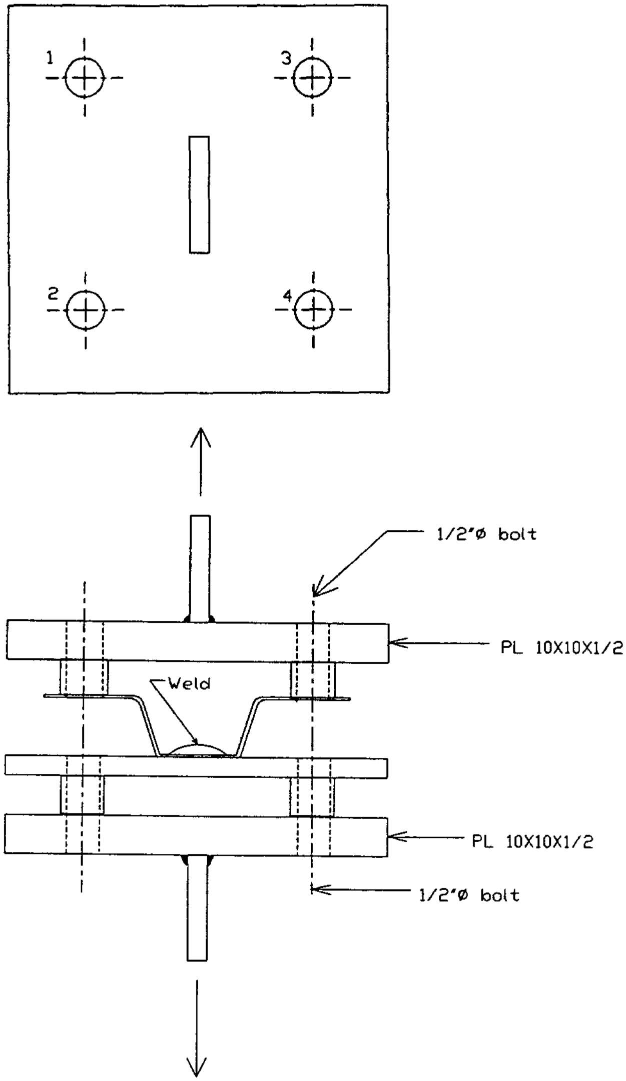

FIG. 3. Test Assembly

$$P_{nt} = 0.67t(d - t)F_u \quad (4)$$

The addendum to the AISI *Specification for the Design of Cold-Formed Steel Structural Members* (1989) adopted the following equation, which is based on (3):

$$P_{nt} = 0.70td_aF_u \quad (5)$$

Experimental Study

The objective of the UMR study was to evaluate the strength of an arc spot weld connection in tension. Particular emphasis was given to choosing

TABLE 1. Material Properties

Material type (1)	Sheet thickness (cm) (2)	Yield strength (MPa) (3)	Tensile strength (MPa) (4)	Elongation[a] (%) (5)
GC	0.737	269.7	330.9	15
GE	0.737	685.6	688.3	3
DH	0.457	439.6	450.9	2
BR	0.470	777.1	798.3	5

[a]5.1-cm gauge length.

connection parameters such that the existing data base, as developed by Fung (1978), would be expanded. Therefore, the UMR test specimens had a larger range of mechanical properties, a thinner sheet thickness, and a variation in cross-section geometry. Also, care was taken to simulate in-place conditions, e.g., single-sheet connections and multiple-sheet connections. Both manual weld and automatic weld processes were investigated. This paper will discuss the findings of the connection tests.

Test Specimen

The test specimen geometry was chosen to simulate the in-place geometry and behavior of a steel deck roof system when subjected to a wind uplift loading.

Each test specimen consisted of a section of deck profile, arc spot welded to a steel plate. The sheet was cut from typical roof deck profiles (Fig. 1). Figs. 2 and 3 show the cross section of a typical test specimen.

Two welding processes were used to fabricate the test specimens, i.e., a manual process and an automatic process. The manual welding was done by a local welding supplier using a gas metal arc weld (GMAW) process. The automatic weld process was done in the university test laboratory using an inverter-controlled, CO_2 automatic puddle-welding system for steel decks. For both welding processes, a 483-MPa (70-ksi) tensile strength electrode was used to fabricate the test specimens.

The test specimen was bolted to a test fixture that was based on the suggested tension test configuration as given in AISI ("Test" 1992). A schematic view of the test assembly is given by Fig. 3. Fig. 2 shows the test assembly in the Tinius Olson universal testing machine.

Test Program

The test program included the study of arc spot weld connections subjected to either concentric or eccentric loading. The connections were fabricated using both single and multiple sheets.

Concentric Loading

The test specimens were cut from two grades of galvanized sheet steel deck sections 0.74 mm (0.029 in.) thick. These materials were specified as ASTM A446 grade C and ASTM A446 grade E. The actual mechanical properties of the sheet were established by standard tensile tests in accordance with ASTM A370. See material types GC and GE of Table 1.

Each test specimen was subjected to a direct tension load, as shown by

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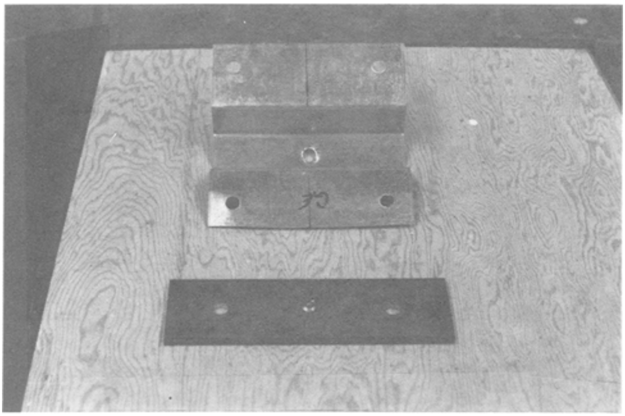

FIG. 4. Typical Failure Mode

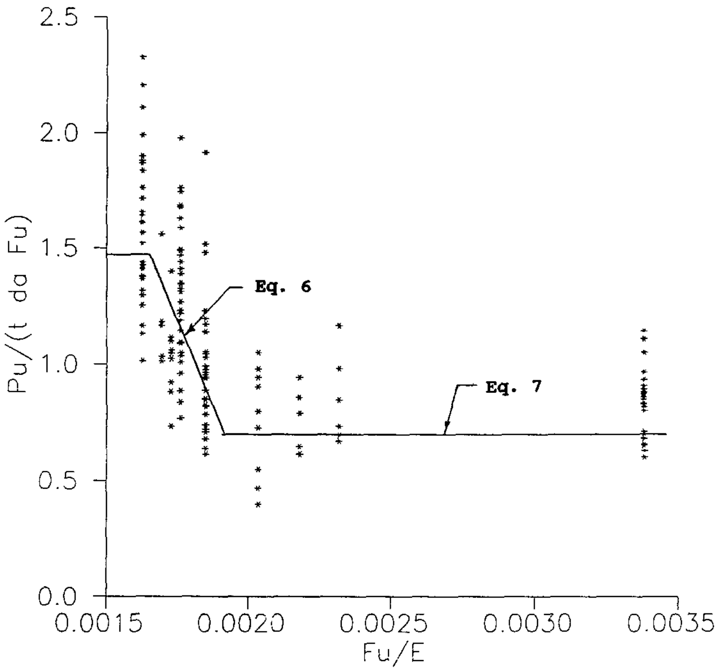

FIG. 5. Relationship Between F_u/E and Connection Strength

Figs. 2 and 3, until failure. Fig. 4 illustrates a typical failure pattern, which was sheet tearing around the weld perimeter. The failure load, sheet thickness, visible diameter, and weld time was recorded for each test specimen (LaBoube and Yu 1991b).

Specimens were tested under a concentric loading, i.e., load applied at all four load points (Fig. 3). The intent was to simulate the loading of a

TABLE 2. GC Specimens Eccentric Load

Specimen number (1)	Sheet thickness (cm) (2)	F_u (MPa) (3)	P_u (kN) (4)	P_n (kN) (5)	P_u/P_n (6)
(*a*) Eccentric Load—Automatic Weld[a]					
GC100	0.737	330.9	2.00	4.77	0.419
GC101	0.737	330.9	2.31	9.62	0.501
GC103	0.737	330.9	3.08	5.11	0.603
GC105	0.737	330.9	2.00	2.95	0.679
GC106	0.737	330.9	1.98	3.25	0.609
GC107	0.737	330.9	3.73	4.86	0.769
GC108	0.737	330.9	3.34	4.93	0.677
GC109	0.737	330.9	3.69	5.41	0.683
GC110	0.737	330.9	3.96	5.76	0.687
GC111	0.737	330.9	2.67	6.63	0.402
GC112	0.737	330.9	2.85	6.15	0.463
(*b*) Eccentric Load—Manual Weld[b]					
GC115	0.737	330.9	2.67	4.00	0.667
GC117	0.737	330.9	2.96	5.42	0.546
GC118	0.737	330.9	3.96	5.47	0.724
GC119	0.737	330.9	4.38	7.39	0.593
GC120	0.737	330.9	6.39	7.96	0.802

[a]Mean = 0.590; standard deviation = 0.119; and coefficient of variation = 0.201.
[b]Mean = 0.666; standard deviation = 0.091; and coefficient of variation = 0.136.

weld at the interior of a roof deck system. A total of 70 connection tests were conducted for this load application.

As indicated by (3), a relationship exists between the failure load, P_u, and the quantities t, d_a, and F_u. However, additional analysis of the data revealed that the sheet material's tensile strength has an additional influence on the tested load capacity. This phenomenon is shown by the plot of $P_u/(td_aF_u)$ versus F_u/E (Fig. 5), where E is the modulus of elasticity of steel. The distribution of the data would indicate that the behavior of a lower-strength sheet is different than that of a higher-strength sheet. This is attributed to the higher ductility exhibited by the lower-strength sheet.

Based on a statistical analysis to achieve a target reliability index of approximately 3.5 (LaBoube and Yu 1991b) and a regression analysis, the following equations were derived.

- When $F_u/E < 0.00187$:

$$P_n = \left[6.59 - 3150\left(\frac{F_u}{E}\right)\right] td_aF_u \leq 1.46td_aF_u \quad (6)$$

- When $F_u/E \geq 0.00187$:

$$P_n = 0.70td_aF_u \quad (7)$$

for which all parameters have been previously defined.

TABLE 3. GC Specimens Eccentric Load

Specimen number (1)	Sheet thickness (cm) (2)	F_u (MPa) (3)	P_u (kN) (4)	P_n (kN) (5)	P_u/P_n (6)
(*a*) Eccentric Load—Automatic Weld[a]					
GE100	0.737	688.3	3.58	4.56	0.785
GE101	0.737	688.3	2.17	4.73	0.459
GE103	0.737	688.3	3.85	4.80	0.802
GE104	0.737	688.3	3.69	4.66	0.792
GE105	0.737	688.3	1.87	3.03	0.617
GE106	0.737	688.3	0.81	2.70	0.302
GE107	0.737	688.3	3.25	4.81	0.676
GE108	0.737	688.3	4.21	4.72	0.892
GE109	0.737	688.3	2.67	5.45	0.490
GE110	0.737	688.3	2.76	5.50	0.501
GE111	0.737	688.3	3.20	6.20	0.516
GE112	0.737	688.3	3.09	6.12	0.505
(*b*) Eccentric Load—Manual Weld[b]					
GE115	0.737	688.3	3.95	4.55	0.868
GE116	0.737	688.3	4.01	4.71	0.851
GE117	0.737	688.3	3.78	6.17	0.613
GE118	0.737	688.3	3.23	6.70	0.481
GE119	0.737	688.3	4.21	7.74	0.543
GE120	0.737	688.3	3.72	8.20	0.453

[a]Mean = 0.611; standard deviation = 0.170; and coefficient of variation = 0.279.
[b]Mean = 0.635; standard deviation = 0.167; and coefficient of variation = 0.263.

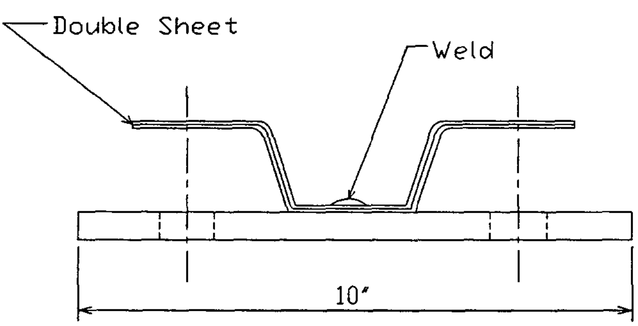

FIG. 6. Cross Section of Multiple Sheet Specimens

A measure of the accuracy of (6) and (7) to predict the failure load can be developed by comparison between the tested load capacity P_u and the calculated load capacity P_n [(6) or (7)]. The ratio of P_u/P_n has a mean value of 1.18, a standard deviation of 0.285, and a coefficient of variation of 0.242. Recognizing the variability of an arc spot weld connection, this is considered to be acceptable. These statistical data are similar to those used for shear strength of arc spot welds (*Commentary* 1991).

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TABLE 4. Multiple-Sheet Specimens

Specimen number (1)	Sheet thickness (cm) (2)	F_u (MPa) (3)	P_u (kN) (4)	P_n (kN) (5)	P_u/P_n (6)
GC 200D[a]	0.737	330.9	8.46	8.57	0.985
GC 201D[a]	0.737	330.9	9.75	8.02	1.215
GC 202D[a]	0.737	330.9	18.13	12.00	1.511
GC 203D[a]	0.737	330.9	18.47	13.71	1.347
GC 204D[a]	0.737	330.9	11.81	10.57	1.118
GC 205D[a]	0.737	330.9	12.68	12.86	0.987
GC 206D[a]	0.737	330.9	16.69	11.29	1.478
GC 207D[a]	0.737	330.9	15.69	13.20	1.189
GC 208D[a]	0.737	330.9	16.69	15.01	1.112
GC 209D[a]	0.737	330.9	17.69	13.69	1.292
GC 210D[a]	0.737	330.9	15.02	13.09	1.147
GE 200D[b]	0.737	688.3	8.72	10.23	0.853
GE 201D[b]	0.737	688.3	11.39	8.40	1.355
GE 202D[b]	0.737	688.3	12.79	10.62	1.204
GE 203D[b]	0.737	688.3	12.46	11.54	1.079
GE 204D[b]	0.737	688.3	13.46	12.74	1.059
GE 205D[b]	0.737	688.3	12.79	11.90	1.075
GE 206D[b]	0.737	688.3	8.57	8.68	0.987

[a]Mean = 1.216; standard deviation = 0.168; and coefficient of variation = 0.138.
[b]Mean = 1.088; standard deviation = 0.147; and coefficient of variation = 0.135.
Note: All welds were made using a manual weld process.

Eccentric Loading

At the perimeter of a steel deck roof system, an arc spot weld may experience an eccentric load condition. This was simulated in the test program by applying load to only two load points, i.e., load points 1 and 2 or 3 and 4 of Fig. 3.

A measure of the variation in strength between a symmetrically loaded and eccentrically loaded connection can be obtained by the ratio of P_u/P_n, where P_u is the tested eccentric load, and P_n is the calculated concentric failure load using (6) and (7). For the 34 test specimens subjected to an eccentric load (Tables 2 and 3), the mean value for the ratio of P_u/P_n ranged from 0.590 to 0.666, which indicates a strength reduction of about 40% when compared to the behavior of a concentrically loaded connection.

Multiple-Sheet Connections

Deck sections are typically nested together and welded to achieve continuity of the floor or roof system. A limited study of the tension strength of a concentrically loaded arc spot weld connection consisting of two sheets nested and welded to a support member was conducted (Fig. 6). By adding the strength of each single sheet, P_n as calculated by (6) and (7), good correlation was obtained with the tested connection strength, P_u (Table 4).

Thinner-Sheet Connections

A limited number of tests, using the concentric load condition, were conducted to determine the validity of (6) and (7) for thinner sheets, i.e.,

TABLE 5. Thinner-Sheet Specimens No Weld Washer

Specimen number (1)	Sheet thickness (cm) (2)	F_u (MPa) (3)	P_u (kN) (4)	P_n (kN) (5)	P_u/P_n (6)
DH1[a]	0.457	450.9	2.11	2.35	0.899
DH2[a]	0.457	450.9	1.89	2.45	0.770
DH3[a]	0.457	450.9	1.56	2.48	0.606
DH4[a]	0.457	450.9	1.45	1.65	0.878
DH5[a]	0.457	450.9	1.45	2.28	0.633
DH6[a]	0.457	450.9	0.89	2.34	0.380
DH7[a]	0.457	450.9	1.89	1.80	1.050
DH8[a]	0.457	450.9	2.89	2.00	1.446
DH9[a]	0.457	450.9	1.34	2.04	0.654
DH10[a]	0.457	450.9	2.00	2.10	0.952
DH11[a]	0.457	450.9	1.22	2.09	0.586
DH12[a]	0.457	450.9	3.56	2.24	1.592
DH13[a]	0.457	450.9	2.34	2.54	0.919
BR1[b]	0.470	798.3	1.67	5.35	0.312
BR2[b]	0.470	798.3	1.56	5.46	0.347
BR3[b]	0.470	798.3	1.00	4.40	0.228
BR4[b]	0.470	798.3	1.22	4.16	0.294
BR5[b]	0.470	798.3	1.78	4.53	0.392
BR6[b]	0.470	798.3	1.78	4.80	0.371
BR7[b]	0.470	798.3	1.78	3.94	0.451
BR8[b]	0.470	798.3	1.34	3.99	0.335

[a]Mean = 0.874; standard deviation = 0.328; and coefficient of variation = 0.375.
[b]Mean = 0.341; standard deviation = 0.063; and coefficient of variation = 0.184.

TABLE 6. Thinner-Sheet Specimens with Weld Washer

Specimen number (1)	Sheet thickness (cm) (2)	F_u (MPa) (3)	P_u (kN) (4)	P_n (kN) (5)	P_u/P_n (6)
DH1W[a]	0.457	450.9	3.78	1.61	2.336
DH2W[a]	0.457	450.9	3.78	1.90	1.987
DH3W[a]	0.457	450.9	3.89	2.17	1.795
BR9W[b]	0.470	798.3	6.12	3.06	2.002
BR10W[b]	0.470	798.3	6.12	3.75	1.632
BR11W[b]	0.470	798.3	7.79	3.58	2.173
BR12W[b]	0.470	798.3	6.23	3.23	1.931

[a]Mean = 2.040; standard deviation = 0.224; and coefficient of variation = 0.110.
[b]Mean = 1.935; standard deviation = 0.196; and coefficient of variation = 0.101.

nominally 0.46 mm (0.18 in.). This material is identified as either DH or BR material in Table 1. A comparison of the tested failure load P_u and the computed failure load from (6) and (7), P_n indicates that a weld washer was required in order to achieve the computed failure load. Table 5 summarizes the test results for specimens without weld washers, while Table 6 demonstrates the enhanced strength provided by the use of a weld washer.

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TABLE 7. Sheet Lap Connection Symmetrical Loading

Specimen number (1)	d'/L (2)	F_u (MPa) (3)	P_u (kN) (4)	P_n (kN) (5)	P_u/P_n (6)
GC 400[a]	0.572	330.9	3.12	4.98	0.626
GC 401[a]	0.384	330.9	3.00	3.56	0.844
GC 402[a]	0.546	330.9	4.01	5.45	0.735
GC 403[a]	0.394	330.9	3.12	4.48	0.700
GC 404[a]	0.173	330.9	2.45	3.54	0.691
GE 400[b]	0.284	688.3	0.67	2.70	0.248
GE 401[b]	0.516	688.3	2.23	4.21	0.528
GE 402[b]	0.376	688.3	3.89	4.83	0.806
GE 403[b]	0.652	688.3	2.11	3.72	0.568
GE 404[b]	0.418	688.3	4.56	6.24	0.731
GE 405[b]	0.778	688.3	4.67	6.26	0.747
GCS1[c]	0.455	330.9	2.67	4.33	0.617
GCS2[c]	0.425	330.9	3.89	4.27	0.912
GCS3[c]	0.640	330.9	4.78	6.21	0.771
GCS4[c]	0.603	330.9	3.00	6.09	0.493
GCS5[c]	0.252	330.9	1.67	5.46	0.306
GCS6[c]	0.499	330.9	2.89	5.47	0.528
GCL2[d]	0.331	330.9	4.12	4.24	0.971
GCL3[d]	0.428	330.9	8.01	5.56	1.440
GCL4[d]	0.393	330.9	4.34	5.09	0.852
GCL5[d]	0.445	330.9	4.78	5.80	0.825
GCL6[d]	0.492	330.9	6.45	6.44	1.001
GES1[e]	0.354	688.3	2.89	3.88	0.746
GES2[e]	0.335	688.3	3.23	3.96	0.815
GES3[e]	0.502	688.3	3.67	4.83	0.760
GES4[e]	0.301	688.3	3.34	4.20	0.794
GES5[e]	0.494	688.3	4.23	5.74	0.737
GES6[e]	0.489	688.3	4.78	5.23	0.915
GEL1[f]	0.337	688.3	4.78	4.29	1.114
GEL2[f]	0.337	688.3	6.45	4.30	1.500
GEL3[f]	0.409	688.3	8.01	5.26	1.521
GEL4[f]	0.414	688.3	4.67	5.34	0.875
GEL5[f]	0.524	688.3	4.90	6.83	0.717
GEL6[f]	0.529	688.3	6.23	6.89	0.904

[a]Mean = 0.719; standard deviation = 0.072; and coefficient of variation = 0.100.
[b]Mean = 0.605; standard deviation = 0.188; and coefficient of variation = 0.311.
[c]Mean = 0.605; standard deviation = 0.196; and coefficient of variation = 0.324.
[d]Mean = 1.020; standard deviation = 0.221; and coefficient of variation = 0.217.
[e]Mean = 0.795; standard deviation = 0.060; and coefficient of variation = 0.075.
[f]Mean = 1.105; standard deviation = 0.309; and coefficient of variation = 0.280.
Notes: See Fig. 7 for definition of L and d'; sheet thickness for all specimens = 0.737 cm; and all welds made by a manual process.

Lap Connections

Deck sections are commonly lapped and welded to achieve continuity of adjacent sections. Thirty-six tests were performed to evaluate the behavior of the side-lap weld when subjected to a tension force. The test data (Table

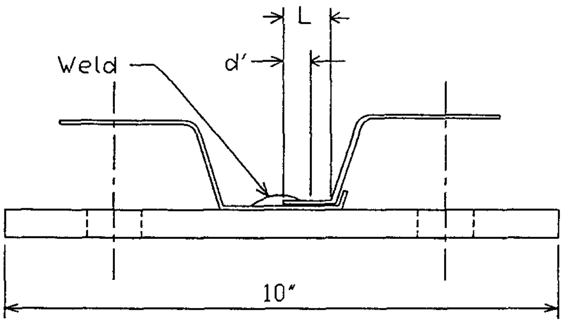

FIG. 7. Cross Section of Lap Connection Specimens

7) would indicate that there is no clear trend regarding the strength of the side-lap connection as the length of weld encroachment d' increases into the length of the flange, L (Fig. 7). The mean value ratio of P_u/P_n ranged from 0.600 to 1.105 for different material strengths and connection details. The poor performance is attributed to the eccentric load application. For each test specimen, the failure resulted from tearing of the top from the weld; the bottom sheet and weld remained intact.

Summary and Conclusions

The objective of this investigation was to study experimentally the tensile strength of arc spot weld connections and to develop appropriate design recommendations.

Results from over 260 connection tests indicate that the primary parameters that influence the tension strength of an arc spot weld connection are the thickness of the sheet, the diameter of the weld, and the tensile strength of the sheet. A prediction equation for the strength of the connection when subjected to a concentric load condition has been presented.

For design situations when the load is applied eccentric to the connection, reductions in strength by as much as 40% were discovered.

Both a manual and an automatic weld process were used in the study. Because of the controlled conditions that existed for this study, the manual and automatic weld processes yielded welds of virtually equal quality.

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Appendix I. References

Albrecht, R. E. (1988). "Developments and future needs in welding cold-formed steel." *Proc. of the Ninth Int. Specialty Conf. on Cold-Formed Steel Structures*, Univ. of Missouri-Rolla, Rolla, Mo.

"Cold-formed structural members." (1984). *CAN3-S136-M84*, Canadian Standards Association, Rexdale, Canada.

"Cold-formed structural members." (1989). *CAN3-S136-M89*, Canadian Standards Association, Rexdale, Canada.

Commentary on the load and resistance factor design specification for the design of cold-formed steel structural members. (1991). American Iron and Steel Inst., Washington, D.C.

Fung, C. (1978). "Strength of arc-spot weld in sheet steel construction." *Final Report on CSICC Industry Research Project 175*, Westeel-Rosco Ltd., Toronto, Ontario Canada.

LaBoube, R. A., and Yu, W. W. (1991a). "Tensile strength of cold-formed steel welded connections." *Proc. of Int. Conf. on Steel and Aluminum Structures*, Elsevier Appl. Sci., New York, N.Y.

LaBoube, R. A., and Yu, W. W. (1991b). "Uplift strength of welded connections." *Final Report, Civil Engineering Studies 91-3*, Univ. of Missouri-Rolla, Rolla, Mo.

Specification for the design of cold-formed steel structural members. (1986). American Iron and Steel Inst., Washington, D.C.

Specification for the design of cold-formed steel structural members. (1989). American Iron and Steel Inst., Washington, D.C.

"Structural welding code sheet steel." (1989). *AWS D1.3-89*, second Ed., American Welding Society, Miami, Fla.

"Test procedure for mechanically fastened cold-formed steel connections." (1992). *Cold-Formed Steel Design Manual*, American Iron and Steel Inst., Washington, D.C.

Appendix II. Notation

The following symbols are used in this paper:

d = visible diameter of outer surface of spot weld;
d_a = average diameter of arc spot weld;
E = modulus of elasticity of steel;
F_u = tensile strength of steel sheet;
P_n = nominal tensile strength of connection;
P_{nt} = connection tensile strength;
P_u = tested failure load; and
t = sheet thickness exclusive of coating.

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