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COLD-FORMED STEEL SERIES

FINAL REPORT

TENSILE STRENGTH OF WELDED CONNECTIONS

by

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A Research Project Sponsored by the American Iron and Steel Institute

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PREFACE

The tensile strength of an arc spot weld is given only limited attention in the current edition of the AISI Specification for the Design of Cold-Formed Steel Structural Members. To broaden the design engineer's understanding of the behavior of arc spot welds, and to expand the specification's application for arc spot welds, the American Iron and Steel Institute, in 1989, initiated a research study at the University of Missouri-Rolla.

The UMR research consisted of a comprehensive literature review, and experimental study which comprised of over 260 individual connection test specimens. The test specimen selectin enabled the investigation of the key parameters that influence the behavior of an arc spot weld connection. In addition to individual connection tests, the behavior of the connection within a full panel was also experimentally studied. This report provides a detailed discussion of the various test specimen configurations, test procedure, test results, and proposed design recommendations.

I. INTRODUCTION

A. General

In building construction, arc spot welds, commonly called puddle welds, are widely used for connecting 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 structural member.

An arc spot weld will be subjected to different stress conditions as a result of imposed loading conditions. For example, wind load acting on a structural system may impose a shear force on the weld when the roof deck is functioning as a structural diaphragm. The same wind load may exert a tension force on the weld resulting from the uplift forces applied to the roof system.

For cold-formed steel design, both the Structural Welding Code - Sheet Steel AWS D1.3-89 (AWS 1989) , and the American Iron and Steel Institute Specification for the Design of Cold-Formed Steel Structural Members (AISI 1986) only provide design information for arc spot welds subjected to shear. Additional design guidance is needed for predicting the tensile strength of arc spot weld connections.

The Addendum to the AISI Specification (AISI 1989), contains a design guideline, which is based on studies by Albrecht (1988) and Yu (1989). This design guideline is also being used by the Canadian Standard (CSA 1989).

To fill a void in the present design specification for cold-formed steel structural members and their connections, additional, comprehensive design information needs to be developed. Thus, a research project entitled "Uplift Strength of Welded Connections" was initiated in 1989 by the American Iron and Steel Institute at the University of Missouri-Rolla.

B. Objective of Study

The objective of the research to be discussed herein has been to study, experimentally, the tensile strength of arc spot welded connections. The findings obtained from this study will provide the needed background information to enable the formulation of more comprehensive design guidelines.

C. Scope of Study

This study consisted of both an analytical and an experimental investigation of the behavior of arc spot welds subjected to tension load. The intent of the study was to gain a better understanding of the behavior of arc spot welds subjected to a tension load and develop a general design provision for the arc spot weld connection in tension. The first task was to review the available literature regarding the behavior of arc spot welds in tension. This review is summarized in Section II of this report.

Major parameters that were perceived to have an influence on the tension capacity of an arc spot welded connection were experimentally studied. The test specimens reflected a range of mechanical properties for sheet steels, typical in-place sheet connections, and variations in deck geometry. Small scale tests were conducted using a test fixture which is recommended in an AISI standard test procedure (AISI 1990). Both stick and automatic weld procedures were investigated. Also, the behavior of the full-panel was studied, and compared with the small scale tests. The findings obtained from this experimental study are summarized in Section III.

Analytical studies were conducted to evaluate trends in behavior, and to develop design recommendations. Section IV contains the design recommendations.

Finally, Section V summarizes the investigation and the conclusions that were reached.

II. LITERATURE REVIEW

A review of the literature uncovered a very limited amount of information on the capacity of arc spot welds under tension. The findings of this review are summarized in the subsequent discussion.

The design documents in the United States, i.e., the Structural Welding Code - Sheet, AWS D1.3-89 (AWS 1989), and the Specification for the Design of Cold-Formed Steel Structural Members (AISI 1986) do not address the structural integrity of arc spot welds in tension. These documents do, however, provide a very thorough coverage of other limit states for arc spot welds. The basis for these existing arc spot weld design provisions is given by Pekoz and McGuire (1979).

In a report entitled "Strength of Arc-Spot Weld in Sheet Steel Construction", Fung (1978) documented the activities and findings of an experimental study to determine the capacity of an arc spot weld in either shear or tension. No attempt was made to establish the capacity of an arc spot weld in combined shear and tension. Based on the experimental findings, recommended design capacities for 0.75-in. 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 (CSA 1984):

$$P_{nt} = 224.82\ (142.24\ t - 1) \qquad (1)$$

where t = sheet thickness in inches, exclusive of coating.

Additional analysis of Fung's data was performed by Albrecht (1988). As given by Albrecht, the test specimens represented a variation in the parameters considered to be significant contributors to the connection strength. These parameters are summarized in Table 1. The test specimens were assembled using specified weld diameters of 0.50, 0.75, and 1.00-in. The majority of the welds were to have a specified diameter of 0.75-in. Albrecht recommended the following design expression for the nominal strength in tension of an arc spot weld, P_{nt}:

$$P_{nt} = 0.90\ t\ d_a\ F_u \tag{2}$$

in which d = visible diameter of the outer surface of the spot weld, d_a = average diameter of the arc spot weld at mid-thickness of t [where d_a = (d - t) for a single sheet], t = sheet thickness (exclusive of coating), F_u = tensile strength of steel sheet. Because of test specimen limitations, Equation 1 is applicable only if $F_{xx} \geq 60$ ksi, and $F_u \leq 60$ ksi (F_{xx} = stress level designation in AWS electrode classification).

A statistical evaluation of Fung's data (1978) was conducted at the University of Missouri-Rolla (Yu 1989). To achieve an acceptable safety index, or corresponding factor of safety of 2.5, the following equation was recommended:

$$P_{nt} = 0.66\ t\ d_a\ F_u \tag{3}$$

Fung's data is the basis for the following equation, which has been adopted for the 1989 edition of the Canadian Standard (CSA 1989):

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

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

$$P_{nt} = 0.70\ t\ d_a\ F_u \tag{5}$$

Blodgett (1990) recognized that only 1/3 to 1/2 of the circumference of a weld is effective in resisting a tension load, and therefore, derived the following prediction equation:

$$P_{nt} = [d\ t\ F_u\ /\ (F_u - 9.45)]\ \mathrm{Cos}^{-1}\ (1 - 4\ t\ /\ d) \tag{6}$$

in which all parameters have been previously defined.

III. EXPERIMENTAL STUDY

The objective of the experimental study was to evaluate the strength of an arc spot weld in tension. Particular emphasis was given to choosing connection parameters such that the existing data base, as developed by Fung (1978), would be expanded. Therefore, the test specimens chosen had a larger range of mechanical properties, a thinner material, and a variation in cross-section geometry. Also, care was taken to simulate in-place conditions, i.e., single sheet connections, double sheet connections, and lapped sheet connections. Both stick weld and automatic weld processes were investigated. To verify that the single connection tests reflect the actual behavior of a full panel, full panel tests were also conducted.

This Section will discuss preparation of the test specimens, testing of the specimens, and results of the tests. The discussion will first discuss the single connection tests, and then the full panel tests.

A. Single Connection Tests

1. Preparation of Test Specimens

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 sheet, arc spot welded to a steel plate. The sheet was cut from a type B roof deck provided by a deck manufacturer. Figures 1 and 2a show the cross section of a typical test specimen.

Two welding processes were used to fabricate the test specimens, i.e., a manual, or stick, process and an automatic process. The manual welding was done by a local welding supplier using a SMAW 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. The automatic welder was provided by OTC America in Charlotte, NC. For both welding processes, an E70 electrode was used to fabricate the test specimens.

The test specimen was bolted to a test fixture which was based on the suggested tension test configuration as given in the AISI document Test Methods for Mechanically Fastened Cold-Formed Steel Connections (AISI 1990). A schematic view of the test assembly is given by Fig. 3. Figures 2a and 2b show the test assembly in the Tinius Olson universal testing machine.

2. Testing of Specimens

a. Tensile Coupon Tests

Two grades of 0.029-in. thick galvanized sheet steel were used to fabricate the deck sections from which the test specimens were cut. 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. Table 2 lists the test results for base thickness, yield point, tensile strength, and elongation measured for a 2-in. gage length. The test specimens will be segregated as GC, for the grade C steel sheet, or GE material, for the grade E sheet. Table 3 summarizes information on the coating weight for each material type. This information was generated in accordance with ASTM A90 procedures. The material properties for the GX material will be discussed in Section B.c.vi, where as DH and BR material will be discussed in Section B.c.vii.

b. Testing of Weld Specimens

The test fixture for the single connection tests has been previously discussed and is shown in Figs. 2 and 3.

Each specimen was subjected to a direct tension load as shown by Figs. 2 and 3, and loaded to failure. Figure 4 shows the typical behavior of a test specimen under load, and Fig. 5 illustrates typical failure patterns. The failure load, sheet thickness, visible diameter, and weld time was recorded for each test specimen (Tables 4 through 34). Also listed in the tables is the value of d_a, the average diameter of the arc spot weld at mid thickness t. During each test, in addition to noting the failure load, the failure mode was also recorded. Because of the thin material, 0.029-in., the primary failure mode was tearing of the sheet around the perimeter of the weld (Fig. 5). In isolated situations, if another failure mode was observed, it is so indicated in the Tables. Section B.c.vi discusses the testing and evaluation for the thicker GX material, and Section B.c.vii contains a discussion of the results for the thinner DH and BR sheet.

Specimens were tested under a symmetrical loading, i.e., load applied at all four load points (Fig. 3). An eccentric load condition was also considered with load applied at two load points, i.e., points 1 and 2, or 3 and 4. The intent was to simulate the loading of a weld at the interior and the perimeter of a roof deck system.

c. Evaluation of Test Results

As indicated by the titles of Tables 4 through 34, the data has been presented by loading condition, material type, weld process, and use of washers. Each of these conditions will be discussed in the following presentation.

i. Symmetrical Loading

This is the most prevalent load condition in a welded steel deck roof system, because it represents all connection conditions except at the perimeter of the roof system.

For this loading condition, the following summarizes the number of tests for each material type and each weld process:

Material	Weld Type	No. of Tests	Table
GC	Manual	13	4
GC	Automatic	21	5
GE	Manual	14	6
GE	Automatic	22	7

Figures 6 and 7 present the relationship between the tested failure load, P_u, and the ratio of the plate thickness to the sheet thickness, T/t. Based on the dispersion of the data, it appears that, for the range of T/t ratios used in the tests, the capacity of an arc spot weld connection is independent of the thickness of the attachment plate. For a field application, this implies that the connection capacity will not be a function of the thickness of the deck's supporting member. This finding is consistent with that of Fung (1978).

Because of the conditions that exist during welding, the automatic weld process would, generally, be expected to provide a higher quality weld. The variation in tested strength with average diameter, d_a, is shown graphically by Figs. 8 and 9.

A comparison of the appropriate figures indicates that for the respective stick and automatic weld specimens, little difference exists in the obtained failure load. Thus, under controlled conditions both the stick and automatic weld processes yield quality welds of virtually equal strength.

An analytical model to represent the strength of the sheet in a welded connection subjected to tension load would take the form of Eq. 7:

$$P_n = K' \; C \; t \; \tau_u \tag{7}$$

where C = circumference of the arc spot weld, t = base thickness of sheet, τ_u = shear tensile strength of the sheet, and K' = factor to reflect the nonlinear stress distribution around the circumference of the weld. Expressing C as a function of the diameter of the arc spot weld, $\tau_u = F_u / \sqrt{3}$ results in the following expression:

$$P_n = K' \; (F_u \,/\, \sqrt{3}) \; t \; d_a \tag{8}$$

where F_u = tensile strength of the sheet, and d_a has been previously defined. Equation 8 takes the form of Eq. 2, as developed by Albrecht (1989).

The relationship between P_u and the quantity $t \; d_a \; F_u$ is given by Fig. 10. All available data, Tables 4 through 7 and Fung' data, are depicted on Fig. 10.

Certainly, as the value of the quantity $t\ d_a\ F_u$ increased, the connection strength increased.

Additional analysis of the data of Fig. 10 indicated that the material's tensile strength, has an influence on the tested load capacity. This phenomenon is shown by the plot of $P_u/(t\ d_a\ F_u)$ versus F_u, Fig. 11. The distribution of the data would indicate that the behavior of a lower strength sheet is different than that of a higher strength. This is attributed to the higher ductility exhibited by the lower strength sheet. During a test, it was observed that the GC specimens experienced more distortion prior to failure than did the GE specimens.

Based on the behavior demonstrated by the distribution of the test data on Fig. 11, an additional F_u relationship is required to more accurately model the behavior of the test specimens. To maintain a non-dimensional equation format, Fig. 12 presents the relationship between $P_u/(t\ d_a\ F_u)$ and F_u/E, where E is the modulus of elasticity of steel, 29500 ksi. Based on a statistical analysis to achieve a target reliability index of approximately 3.5 (Hsiao, Yu, and Galambos 1989) and a regression analysis, the following equations were determined:

$$\text{when } F_u/E < 0.00187 \quad P_n = [6.59 - 3150\ (F_u/E)]\ t\ d_a\ F_u \leq 1.46\ t\ d_a\ F_u \tag{9}$$

$$\text{when } F_u/E \geq 0.00187 \quad P_n = 0.70\ t\ d_a\ F_u \tag{10}$$

for which all parameters have been previously defined.

A measure of the accuracy of the above equations to predict the failure load can be developed by comparison between the tested load capacity, P_u, and the calculated load capacity, P_n (Eqs. 9 or 10). This is shown graphically by Fig. 13. For the test specimens presented in Tables 4 through 7, the ratio of P_u/P_n for symmetrical loading has a mean value of 1.18, a standard deviation of 0.285, and a coefficient of variation of 0.242. Recognizing the variability in fabrication of an arc spot weld connection, this is considered to be acceptable.

The multipliers to the basic strength parameters, td_aF_u, reflect both the constants of the circumference equations, π, the relationship between the ultimate strengths in tension and shear, and the nonlinear variation of the applied stress, K'. The nonlinear stress distribution occurs because only a portion of the circumference of the weld is effectively resisting the tension load. Thus a higher stress will occur on the weld at the point closest to the web elements of the deck cross section.

The tension capacity for the test specimens listed in Tables 4 through 7 were also evaluated using Eq. 6. The ratio of P_u/P_{nt}, where P_{nt} is based on Eq. 6, has a mean value of 1.331 with a corresponding standard deviation of 0.482 and coefficient of variation of 0.362.

ii. Eccentric Load

At the perimeter of a steel deck roof system, the arc spot weld connection may experience an eccentric load condition. This was simulated in the test program by applying load to only two load points, as previously described.

Tables 8 through 11 summarizes the GC and GE specimens tested under an eccentric load condition.

A measure of the variation in strength for a symmetrically loaded and eccentrically loaded connection is the comparison of the tested failure load, as listed in Tables 8 - 11, and the calculated load for a symmetric connection, Eqs. 9 or 10. The corresponding value for P_u, P_n, and the ratio of P_u/P_n is given in Tables 12 and 13 for GC and GE test specimens.

As listed in Tables 12 and 13, for both GC and GE material, the mean and coefficient of variation values for the ratio of P_u/P_n are from 0.59 to 0.66, and 0.136 to 0.279. Thus, the difference in material strength had little influence on the mean load capacity for an eccentric loading condition. Therefore, the reduced capacities can be attributed to the pealing action of the sheet along a small segment of the circumference of the weld.

The low values of P_u/P_n would indicate that the engineer would need to either design for a reduction in load capacity of approximately 40% for perimeter weld connections, reinforce the perimeter weld connections, or increase the number of the perimeter weld connections.

One possible reinforcement would be to use weld washers at perimeter connections. Generally, weld washers are only used on thinner sheets, less than 0.028-in. thick. However, a series of tests was conducted to determine if a weld washer could serve as an acceptable reinforcement to increase the strength of perimeter weld connections. Tables 14 through 19 list the specimens in this study. Both round and rectangular weld washers were used in the study. The rectangular washers, 1-3/8 x 2-1/4 x 0.077-in, were fabricated from sheet steel and prepunched with either a 3/8" or 1/2" diameter hole. The round weld washers were commercially available washers chosen to be compatible with the desired nominal weld diameter. The following summarizes the dimensions of the round washers:

Weld Dia. (in.)	Washer Inside Dia. (in.)	Washer Outside Dia. (in.)	Washer Thickness (in.)
3/8	7/16	13/16	0.075
5/8	9/16	1-3/8	0.074
7/8	15/16	1-3/4	0.131

The contribution of the weld washer to the capacity of the weld connection can be quantified by comparing the tested failure load, P_u, to the computed load capacity, P_n, using Eqs. 9 or 10. For each test specimen, the corresponding value of P_u, P_n, and the ratio of P_u/P_n is listed in Tables 20 and 21 for GC and GE material.

For GC material (Table 20), the mean value of the P_u/P_n ratio for connections fabricated by the automatic weld process using round washers was calculated to be 0.776, with a corresponding standard deviation of 0.107. The coefficient of variation is 0.139. For GC specimens fabricated by the stick weld process, the P_u/P_n ratio was determined to be 1.119 with a standard deviation and coefficient of variation of 0.205 and 0.183.

Several observations can be made regarding the aforementioned results for GC material. First, the presence of a weld washer increased the load carrying capacity for both stick and automatic welds; this can be observed by comparison of the tested to computed load ratio from Tables 12 and 20. For the weld connections fabricated by using the stick process, the use of washers enabled the calculated load capacity to be achieved, $P_u/P_n = 1.119$. Also, although the connections that were assembled by the automatic weld process did not achieve an average capacity equivalent to the computed capacity, it must be mentioned that this weld was difficult to make with the automatic equipment employed, and therefore, the quality of the welds may be suspect. It is expected that a better performance can be achieved by using an improved welding procedure.

The ratio of P_u/P_n for the GE material using weld washers as summarized in Table 21, indicates that the type of washer, i.e., rectangular or round, had virtually no effect on the ability of the reinforced weld to develop the calculated load capacity. For the round washers the mean value is 0.973 versus 0.929 for the rectangular washers.

By comparing the average load ratios for the unreinforced welds (Table 13) with the average load ratios from Table 21, for the reinforced welds, it is evident that the use of a weld washer played a major role in improving the tension strength of the weld connection.

iii. Symmetric Load With Washers

To provide some indication of the possible increase in tension strength for a reinforced, arc spot weld connection subjected to a symmetric loading, a small number of tests were conducted. Tables 22 and 23 give the key geometry parameters, and Table 24 lists the tested load, calculated load, and load ratio for each specimen.

As presented in Table 24, the ratio of P_u/P_n for the test specimens, having a washer with a 0.375-in. prepunched hole, specimens GE134W and GE135W, achieved a mean load ratio of 2.64.

Four specimens, GE130W to GE133W, failed by tension failure of the weld, at loads greater than twice the calculated sheet failure load (Table 24). If the tension stress distribution is assumed to be uniform on the cross section of the weld, the nominal failure load can be estimated by the following expression:

$$P_n = A_e \ F_{xx} \qquad (11)$$

where F_{xx} = electrode stress level designation in AWS electrode classification, and $A_e = \pi \ d_e^2 / 4$. The effective weld diameter of the fused area, d_e, is defined by the following (AISI 1986):

$$d_e = 0.7 \ d - 1.5 \ t \leq 0.55 \ d \qquad (12)$$

for which t = the sheet thickness plus the weld washer thickness, and d = visible diameter of the weld.

Table 25 summarizes the value for Eq. 11, as well as the corresponding ratio of P_u/P_n, for each specimen GE130W to GE133W. As the ratio indicates, Eq. 11 provides a good prediction for the tension failure of the weld.

For specimens GE140W to GE143W, a prepunched washer was also used, but the hole diameter was 0.5-in. Although the tested failure loads were equal to, or greater than the computed maximum load, these results show that the prepunched hole diameter must be matched with the specified weld diameter. The same automatic weld settings were used for the specimens having the 0.375-in. and 0.50-in. diameter prepunched holes, but better connection strength was obtained for the 0.375-in. specimens. This condition is more critical for an automatic weld process than for a stick weld process, because in the case of a stick weld process, if a prepunched hole is used, the welder will, in all likelihood just fill the hole, regardless of the specified weld diameter.

iv. Nested Sheet Connections

Deck sections are typically nested together and welded to achieve continuity of the floor, or roof system. Nested connections may consist of two sheets interconnected either as shown by Fig. 14, or more commonly connected as shown in Fig. 15. A limited number of tests were conducted to gain insight into the tension capacity of nested connections as shown by Figs. 14 and 15, when subjected to a symmetric load condition.

Table 26 summarizes the geometry and tested load capacity for the case of two sheets nested together (Fig. 14). A measure of the capacity of such a connection can be obtained by comparison of the test failure load, P_u, with the calculated load, P_n (Eq. 9 or 10). The evaluation of Eqs. 9 and 10 are based on using the sum of the sheet thicknesses for the parameter t, i.e., t was taken as 2 times 0.029-in. For the specimens in question, the ratio of P_u/P_n is given in Table 27. The strength ratio for the GC specimens varies from 0.985 to 1.511 with a mean of 1.216, where as the strength ratio for the GE specimens ranges from 0.853 to 1.205 with a mean of 1.088. This would indicate that the tension capacity of a multiple sheet connection (Fig. 14) can be adequately estimated by adding the strength of each single sheet that is present in the connection.

For the more common sheet lap connection (Fig. 15), test specimens were designed to provide information on the strength of the connection as the unstiffened flange element (L on Fig. 15) of the deck varies in length. The flange length, L, varied in length from 0.5-in. to 1.5-in., as summarized in Table 28. The ratio of P_u/P_n provides an indication of the load capacity of the lap connection, as compared to the basic sheet to supporting member connection (Fig. 1). The numerical values for the P_u/P_n ratios are listed in Table 29, where P_n is evaluated by either Eq. 9 or 10. The strength of the lap connection is very sensitive to the amount of weld that is provided for the top sheet of the lap, L. Also listed in Table 28 is the measured weld encroachment, d', into length L. Figure 16 graphically illustrates the influence of the weld encroachment on the strength ratio. As the ratio of d'/d_a increases, there appears to be an increase in the ratio of P_u/P_n.

However, even for d'/d_a of unity, the tested connection strength did not achieve, on the average, the value of the calculated connection strength. This is attributed to the eccentric load application. For each test specimen, the failure was manifested as a tearing of the top sheet, i.e., the unstiffened flange, of the connection. The bottom flange and weld remained intact.

v. Variation in Flange Width

A series of tests were conducted to determine if the width of the attached stiffened flange of the deck had a measurable effect on the tension capacity of an arc weld connection. For the specimens summarized in Tables 4 through 7, the stiffened flange width was 1.75-in. for the GC specimens and 1.6875-in. for the GE specimens. By inverting the B deck, a larger connected element of 3.375-in. was obtained. Table 30 lists the geometry and tested failure load for each specimen. Because Eqs. 9 and 10 were developed using the tested capacities for the GC and GE decks, having a narrow stiffened flange width, a comparison of the P_u values given in Table 30 with the P_n computed by using Eq. 9 or 10 will provide an indication of the influence of the connected stiffened flange on the tension capacity of the weld connection. The ratio of P_u/P_n is given in Table 31 for the test specimens in question. For both the GC and GE materials, the tested capacities compared well with the computed values; the mean values were 1.164 and 1.209, respectively. Therefore, it appears that the tension capacity of an arc spot weld connection in a deck section, is independent of the width of the attached stiffened flange.

vi. Thicker Sheet

This study has focused primarily on thinner sheet, 0.029-in. in thickness, because test data was available for sheets thicker than 0.031-in. (Fung 1978). Equations 9 and 10 were developed using both the data from this study of thinner sheet and the data generated by Fung.

A limited number of tests were conducted, using thicker sheet, to verify Eqs. 9 and 10, and to study the effect of an eccentric load on the behavior of weld connections with thicker sheet. Single connection test specimens were cut from a composite deck profile and tested as previously described (Figs 1-3).

The material properties of the sheet were evaluated using standard ASTM A370 procedures. The tested properties for this thicker, 0.0625-in, material, designated as type GX, are summarized in Table 2.

Both concentric and eccentric load applications were investigated. Tables 32 and 33 summarize the specimen geometry and tested failure load for all of the test specimens.

The concentrically loaded specimens produced a mean value for the ratio of P_u/P_n of 0.955 (Table 34). This indicates that the prediction equations (Eqs. 9 and 10) are capable of adequately estimating the strength of a concentrically loaded, weld connection with thicker sheet.

Also listed in Table 34 is the ratio of P_u/P_n for the specimens subjected to an eccentric load. Specimens GX1 through GX6 were fabricated without washers.

As indicated by the ratio of P_u/P_n, Eqs. 9 and 10 also overestimates the load capacity of thicker sheet connections subjected to an eccentric load. The mean value of the strength ratio is 0.496, which is slightly lower than the same ratio obtained for the thinner sheet (Tables 12 and 13).

It was shown that for the 0.029-in. thick sheet, the computed weld strength could be achieved by reinforcing the connection with a weld washer. A small number of tests were conducted with a reinforced weld connection for the 0.0625-in sheet, even though the weld washer is not required by the Specification. For Specimens GXW1 through GXW6, having a reinforced weld connection subjected to an eccentric load, the mean value for the ratio of P_u/P_n is 0.849. The lower numerical values for the strength ratios may be attributed to the inability to accurately measure the visible diameter of the weld for the reinforced connections. For all specimens round washers, as described previously, were used.

vii. Thinner Sheet

A limited number of tests were conducted to determine the the validity of using Eqs. 9 and 10 for thinner sheet, i.e., nominally 0.180-in.

Single connection test specimens were cut from two different deck profiles that were formed from nominally 28 gage sheet steel. The material properties of the sheets were determined using ASTM A370 procedures, and are listed in Table 2 as DH and BR materials.

The test specimens were subjected to a concentric load as previously described. Because of the relative thin sheet steel, both AISI and AWS require the use of a weld washer. However, to define the limit of the proposed design equations, Eqs. 9 and 10, tests were conducted both with and without the use of a weld washers. Each test specimen geometry and failure load are summarized in Tables 35 through 38. The washers were commercially available, round washers were chosen to be compatible with the specified nominal weld diameter (see Section B.c.ii).

For the test specimens without washers, poor correlation was observed between the tested failure load and the computed failure load (Tables 39 and 41). However, the test specimens that were fabricated using a weld washer showed adequate tensile stength, as indicated by the ratios of P_u/P_n listed in Tables 40 and 42. Therefore, if a weld washer is provided as prescribed by both the AISI and AWS Specifications, the strength prediction equations, Eqs. 9 and 10, can be expected to provide a conservative estimate of the tensile strength of an arc spot welded connection in thinner material.

B. Full Panel Tests

Although the single connection test specimens were fabricated using actual sheet cut from a deck profile, the question still remains, does the single connection test provide an acceptable model for the entire panel assembly. To gain insight into the behavior of a full panel assembly, and to develop some degree of confidence that the results obtained from the single connection tests accurately model the assembly strength, several tests were conducted using a full panel.

1. Preparation of Test Specimens

Six full panel tests were conducted. Four of the tests were constructed to achieve a failure at the interior weld; the remaining two tests were designed to simulate a failure of an edge, or perimeter weld. Each test specimen, as depicted by Figs. 17, 18 and 19, consisted of a single sheet continuous over two spans, welded to supporting W shape members. The sheet was attached, in accordance with the manufacturer's published literature, 18-in. on center. To model the edge boundary condition for the continuity of the sheets, a standard side lap was included along one of the perimeter edges (Fig. 19). All welds were made using the automatic weld process. Summarized in Table 43 are the panel and weld geometries for each test specimen.

2. Testing of Specimens

Design wind uplift loads are assumed to act uniformly over the surface of the roof. Therefore, to simulate the uniform wind load application, the fabricated test assembly was inverted over a vacuum chamber (Fig. 18).

During a test, load was applied in a steady, uniform manner until failure was achieved. The failure load for each test specimen is listed in Table 43. This load was calculated by using the measured failure pressure obtained from a manometer inserted in the side of the chamber. The failure load was calculated as the interior reaction assuming the panel was a two span continuous beam with a tributary width equal to the weld spacing of 18-in. Failure was defined as a sudden drop in load resulting from failure of the entire panel.

3. Evaluation of Test Results

The goal of this series of tests was to develop confidence that the results obtained from the single connection tests gave a reasonable prediction of the in-place panel connection behavior. A comparison of the calculated load capacity, Eq. 9 or 10, to the recorded full panel failure load, is a measure of the accuracy of the single connection tests to predict the load capacity of the full panel. Table 43 contains the ratio of the test failure load to the calculated failure load, P_u/P_n, for each test specimen.

For specimens fabricated using GC material, Specimens No. GC1-F and GC2-F, the ratio of P_u/P_n was 1.38 and 1.18. These values would indicate that the load calculation equations, which are based on single connection tests, are reasonable indicators of the capacity of a full panel specimen, for the assumed tributary area.

Specimens GE1-F and GE2-F, fabricated from the GE material, developed P_u/P_n ratios of 0.84 and 0.75. Because the prediction equations provided favorable results for GC specimens, the unconservative nature of the load ratios for GE material may be due to several factors.

First, the lack of ductility inherent in the material may be contributing to the poor predictions. The failure was a very sudden failure, and the distortion of the panel was less for the GE material than observed for the GC material. For a ductile material, the full panel, continuous over multiple supports, is capable of a redistribution of forces, however, the full-hard, GE material is unable to provide redistribution because of a lack of ductility.

A second consideration could be a change in material characteristics of the GE material. The welding process may be stress relieving the material properties in the area of the weld; this would cause a reduction in the connection strength.

Test specimens GC3-F and GE3-F were constructed to study the edge, or perimeter weld, condition. Results obtained from the single connection tests indicted that this weld, because it is subjected to an eccentric load, experiences about 40% to 50% loss in load capacity due to the asymmetric tearing of the sheet around the weld. As indicated by the ratio of P_u/P_n in Table 43, specimens GC3-F and GE3-F also exhibited a reduction of approximately 50%.

IV. DESIGN RECOMMENDATIONS

Based on the findings of this study, two limit states were identified for an arc spot weld connection subject to a tension load, i.e., tearing of the sheet around the weld, and tension failure of the weld cross section. Therefore, the following design recommendations are proposed:

For the limit state of tearing of the sheet, the nominal tension load, P_n, on each arc spot weld between sheet and supporting member shall not exceed:

When $F_u/E < 0.00187$ $\quad P_n = [6.59 - 3150\,(F_u/E)]\ t\ d_a\ F_u \leq 1.46\ t\ d_a\ F_u$ (13)

When $F_u/E \geq 0.00187$ $\quad P_n = 0.70\ t\ d_a\ F_u$ (14)

The following additional limitations for use with Eqs. 13 and 14 shall apply:

$e_{min} \geq d$

$F_{xx} \geq 60$ ksi

$F_u < 82$ ksi

$t \geq 0.028$ in

The maximum tensile strength of the sheet is taken as 82 ksi to reflect the poor performance of the GE material in the full panel tests (Table 43), and the minimum specified tensile strength of grade E material. From Table 43, a mean value of 0.796 was obtained for the ratios of P_u/P_n for test specimens GE1-F and GE2-F. Therefore, a 20 percent reduction was applied to the tested F_u of 99.83 ksi (0.8 x 99.83 ksi = 79.86 ksi). The minimum specified tensile strength for A446 Grade E sheet is 82 ksi.

Equations 13 and 14 assume a concentrically loaded connection. For eccentric load conditions, as would occur at the perimeter of the deck system, the capacity shall be reduced by 50%. In lieu of a strength reduction, the weld connection may be reinforced by a weld washer, or equivalent; in such case the connection must be shown by test to develop the assumed design capacity. Weld washers shall be used when the thickness of the sheet is less than 0.028-in. Weld washers shall have a thickness between 0.05 and 0.08-in. with a minimum prepunched hole of 3/8-in. diameter.

For connections having multiple sheets, the strength can be determined by using the sum of the sheet thicknesses for the parameter t in the evaluation of Eqs. 13 and 14.

At the side lap connections within a deck system, the strength of the weld connection as computed by Eq. 13 and 14 shall be reduced by 30% for $d'/d_a > 0.30$.

For the limit state of tension on the effective cross section of the weld, the nominal tension load, P_n, on each arc spot weld between sheet and supporting member shall not exceed:

$$P_n = A_e F_{xx} \tag{15}$$

where

$A_e = \pi d_e^2 / 4$

$d_e = 0.7 d - 1.5 t \leq 0.55 d$

V. 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 70 single connection tests indicate that the primary parameters that influence the tension strength of the sheet in an arc spot weld connection are the thickness of the sheet, the diameter of the weld, and the tensile strength of the sheet. Although the load application for the 70 test specimens was concentric with respect to the center of weld, the distortion of the sheet during loading results in a non-uniform stress around the perimeter of the weld. A predication equation for the strength of the connection has been presented. The equation recognizes the three significant parameters as well as the variation in stress around the perimeter of the weld.

Based on tests using thin sheet, nominally 28 gage (0.018-in.), it was determined that the prediction will overestimate the tension stength of the connection, unless a weld washer is used during fabrication. This is consistent with the current requirements of both the AISI and AWS Specifications.

Also, the tension capacity of an arc spot weld connection appears to be independent of the width of the stiffened flange of the deck attached to the supporting member.

Based on the test results, it was determined that the tension capacity of an arc spot weld is independent of the thickness of the attachment plate. This implies that the connection capacity will not be a function of the thickness of the deck's supporting member.

Both a manual and automatic weld process was utilized in the study. Because of the controlled conditions that existed during this study, the manual and automatic weld processes yielded welds of virtually equal quality.

Results from 40 weld connections, loaded in an eccentric manner, indicate that the tension capacity of the connection can be reduced by as much as 50%, when compared with the calculated load capacity for a concentric load. Thus for perimeter welds in a floor system, or such applications where the weld will be subjected to an eccentric tension load, the design strength must be reduced.

For the eccentric load condition, in lieu of reducing the load capacity, it has been shown that reinforcement can be added to the connection to enable the calculated strength to be achieved.

For connections having multiple sheets welded to a supporting member, the strength can be adequately determined by combining the strengths of the individual sheet connections.

At a lap connection between two deck sections, the length of the unstiffened flange, and the extent of encroachment of the weld into the unstiffened flange, has a measurable influence on the strength of the weld connection.

Based on a limited number of test specimens that failed by tension of the weld, a design provision was proposed. The strength of the weld was determined to be a function of the tension strength of the weld electrode and the fused area of the weld.

Favorable results obtained from a limited number of full panel tests using Grade C sheet steel demonstrate that the single connection tests provide a valid model for the full assembly behavior. However, the test specimens fabricated using Grade E sheet steel developed slightly unconservative correlation with single connection tests.

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Table 1
Canadian Test Parameters

Sheet Thickness (In.)	Plate Thickness (In.)	F_u (Ksi)	F_{xx} (Ksi)
0.031--.072	0.125-1.0	50-68.5	60

Table 2
Material Properties

Material Type	Sheet Thickness (in)	Yield Strength (ksi)	Tensile Strength (ksi)	Elongation* (%)
GC	0.0290	39.12	47.99	15
GE	0.0290	99.43	99.83	3
GX	0.0625	36.36	45.02	31
DH	0.0180	63.75	65.40	2
BR	0.0185	112.70	115.78	5

*2-in. gage length

Table 3
Coating Weight

Material	Weight of Coating (oz./ft^2)
GC	0.76
GE	0.41
GX	1.63

Table 4
GC Specimens
Symmetric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GC1	0.029	0.50	0.454	0.425	5	955.0
GC2	0.029	0.50	0.480	0.451	6	858.0
GC3	0.029	0.50	0.487	0.458	6	1122.5
GC4	0.029	0.50	0.558	0.529	8	1152.5
GC5	0.029	0.50	0.444	0.415	5	930.0
GC6	0.029	0.50	0.812	0.783	14	1232.5
GC7	0.029	0.50	0.502	0.473	5	825.0
GC8	0.029	0.50	0.543	0.514	7	1021.0
GC9	0.029	0.50	0.630	0.601	9	1845.0
GC10	0.029	0.25	0.724	0.695	13	1377.5
GC11	0.029	0.25	0.447	0.418	5	1227.5
GC12	0.029	0.25	0.566	0.537	8	1396.5
GC13	0.029	0.25	0.824	0.795	15	1897.0

Table 5
GC Specimens
Symmetric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GC18A	0.029	0.50	0.396	0.367	1	635
GC20A	0.029	0.25	0.541	0.512	2	1417.5
GC26A	0.029	0.50	0.378	0.349	1	940
GC28A	0.029	0.50	0.552	0.523	2	1368
GC30A	0.029	0.25	0.391	0.362	1	935
GC31A	0.029	0.25	0.582	0.553	2	1085
GC32A	0.029	0.50	0.399	0.370	1	925
GC33A	0.029	0.50	0.560	0.531	2	750
GC34A	0.029	0.25	0.641	0.612	3	1410
GC35A	0.029	0.25	0.754	0.725	4	1175
GC36A	0.029	0.50	0.583	0.554	3	1415
GC37A	0.029	0.50	0.674	0.645	4	1705
GC38A	0.029	0.25	0.702	0.673	3.5	1232.5
GC39A	0.029	0.50	0.693	0.664	3.5	1198
GC40A	0.029	0.25	0.667	0.638	3	1352.5
GC41A	0.029	0.25	0.710	0.681	4	1340
GC42A	0.029	0.25	0.654	0.625	3.5	1252.5
GC43A	0.029	0.50	0.584	0.555	3	1267
GC44A	0.029	0.50	0.753	0.724	4	1385
GC45A	0.029	0.50	0.701	0.672	3.5	1290
GC47A	0.029	0.50	0.614	0.585	2	1895

Table 6
GE Specimens
Symmetric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE1	0.029	0.50	0.459	0.430	4	887.5
GE2	0.029	0.50	0.418	0.389	4	985
GE3	0.029	0.50	0.431	0.402	4	1026
GE4	0.029	0.50	0.834	0.805	17	2080
GE5	0.029	0.50	0.444	0.415	4	1090
GE6	0.029	0.50	0.640	0.611	8	1210
GE7	0.029	0.25	0.437	0.408	5	1139
GE8	0.029	0.25	0.607	0.578	7	1422.5
GE9	0.029	0.50	0.614	0.585	8	1490
GE10	0.029	0.25	0.800	0.771	14	2080
GE11	0.029	0.25	0.411	0.382	4	1222.5
GE12	0.029	0.25	0.563	0.534	8	1715
GE13	0.029	0.25	0.818	0.789	7	1974
GE14	0.029	0.25	0.577	0.548	7	1807.5

Table 7
GE Specimens
Symmetric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE25A	0.029	0.25	0.377	0.348	1	745
GE27A	0.029	0.25	0.570	0.541	2	1645
GE29A	0.029	0.25	0.321	0.292	1	725
GE31A	0.029	0.25	0.559	0.530	2	1315
GE33A	0.029	0.50	0.278	0.249	1	487
GE35A	0.029	0.50	0.545	0.516	2	901
GE37A	0.029	0.50	0.387	0.358	1	905
GE38A	0.029	0.50	0.563	0.534	2	1622
GE39A	0.029	0.25	0.395	0.366	1	982
GE40A	0.029	0.25	0.666	0.637	3	1585
GE41A	0.029	0.25	0.756	0.727	4	1436
GE42A	0.029	0.50	0.652	0.623	3	1445
GE43A	0.029	0.50	0.699	0.670	4	1225
GE44A	0.029	0.25	0.703	0.674	3.5	1598
GE45A	0.029	0.50	0.669	0.640	3.5	1218
GE46A	0.029	0.25	0.674	0.645	3	1605
GE47A	0.029	0.25	0.693	0.664	4	1590
GE48A	0.029	0.25	0.650	0.621	3.5	1555
GE49A	0.029	0.50	0.648	0.619	3	1560
GE50A	0.029	0.50	0.714	0.685	4	1392
GE51A	0.029	0.50	0.710	0.681	3.5	1285
GE52A	0.029	0.50	0.593	0.564	2	1361

Table 8
GC Specimens
Eccentric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GC100	0.029	0.25	0.555	0.526	2	450
GC101	0.029	0.25	0.538	0.509	2	520
GC103	0.029	0.25	0.592	0.563	2	693
GC105	0.029	0.25	0.354	0.325	1	450
GC106	0.029	0.25	0.387	0.358	1	445
GC107	0.029	0.25	0.563	0.534	2	838
GC108	0.029	0.25	0.572	0.543	2	750
GC109	0.029	0.25	0.625	0.596	3	830
GC110	0.029	0.25	0.664	0.635	3	890
GC111	0.029	0.25	0.760	0.731	4	600
GC112	0.029	0.25	0.707	0.678	4	640

Table 9
GC Specimens
Eccentric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GC115	0.029	0.25	0.47	0.441	5	600
GC116	0.029	0.25	0.467	0.438	8	600
GC117	0.029	0.25	0.626	0.597	9	665
GC118	0.029	0.25	0.632	0.60	9	890
GC119*	0.029	0.25	0.843	0.814	17	985
GC120	0.029	0.25	0.906	0.877	15	1435

* Capacity controlled by the bolted connection.

Table 10
GE Specimens
Eccentric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE100	0.029	0.5	0.535	0.506	2	805
GE101	0.029	0.5	0.554	0.525	2	488
GE103	0.029	0.5	0.561	0.532	2	865
GE104	0.029	0.5	0.546	0.517	2	830
GE105	0.029	0.5	0.365	0.336	1	420
GE106	0.029	0.5	0.328	0.299	1	183
GE107	0.029	0.5	0.562	0.533	2	730
GE108	0.029	0.5	0.552	0.523	2	945
GE109	0.029	0.5	0.633	0.604	3	600
GE110	0.029	0.5	0.639	0.610	3	620
GE111	0.029	0.5	0.717	0.688	4	720
GE112	0.029	0.5	0.708	0.679	4	695

Table 11
GE Specimens
Eccentric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE115	0.029	0.25	0.533	0.504	4	887
GE116	0.029	0.25	0.551	0.522	5	900
GE117	0.029	0.25	0.713	0.684	12	850
GE118	0.029	0.25	0.772	0.743	17	725
GE119	0.029	0.25	0.887	0.858	17	945
GE120	0.029	0.25	0.938	0.909	17	835

Table 12
GC Specimens
Eccentric Load
Without Washers

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
ECCENTRIC LOAD - AUTO WELD					
GC100	0.029	47.99	450	1072.91	0.419
GC101	0.029	47.99	520	1038.23	0.501
GC103	0.029	47.99	693	1148.38	0.603
GC105	0.029	47.99	450	662.92	0.679
GC106	0.029	47.99	445	730.23	0.609
GC107	0.029	47.99	838	1089.23	0.769
GC108	0.029	47.99	750	1107.59	0.677
GC109	0.029	47.99	830	1215.69	0.683
GC110	0.029	47.99	890	1295.24	0.687
GC111	0.029	47.99	600	1491.06	0.402
GC112	0.029	47.99	640	1382.95	0.463
				Mean =	0.590
				Standard Deviation =	0.119
				COV =	0.201
ECCENTRIC LOAD STICK WELD					
GC115	0.029	47.99	600	899.53	0.667
GC117	0.029	47.99	665	1217.73	0.546
GC118	0.029	47.99	890	1229.97	0.724
GC119	0.029	47.99	985	1660.36	0.593
GC120	0.029	47.99	1435	1788.86	0.802
				Mean =	0.666
				Standard Deviation =	0.091
				COV =	0.136

Table 13
GE Specimens
Eccentric Load
Without Washers

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
ECCENTIC LOAD AUTO WELD					
GE100	0.029	99.83	805	1025.43	0.785
GE101	0.029	99.83	488	1063.94	0.459
GE103	0.029	99.83	865	1078.12	0.802
GE104	0.029	99.83	830	1047.73	0.792
GE105	0.029	99.83	420	680.92	0.617
GE106	0.029	99.83	183	605.94	0.302
GE107	0.029	99.83	.730	1080.15	0.676
GE108	0.029	99.83	945	1059.89	0.892
GE109	0.029	99.83	600	1224.04	0.490
GE110	0.029	99.83	620	1236.20	0.501
GE111	0.029	99.83	720	1394.27	0.516
GE112	0.029	99.83	695	1376.03	0.505
				Mean =	0.611
				Standard Deviation =	0.170
				COV =	0.279
ECCENTRIC LOAD STICK WELD					
GE115	0.029	99.83	887	1021.38	0.868
GE116	0.029	99.83	900	1057.86	0.851
GE117	0.029	99.83	850	1386.16	0.613
GE118	0.029	99.83	725	1505.73	0.481
GE119	0.029	99.83	945	1738.78	0.543
GE120	0.029	99.83	835	1842.13	0.453
				Mean =	0.635
				Standard Deviation =	0.167
				COV =	0.263

Table 14
GC Specimens
Eccentric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GC115W*	0.029	0.25	0.375	0.346	8	1010
GC117W	0.029	0.25	0.625	0.596	20	1420
GC118W	0.029	0.25	0.625	0.596	20	1190
GC119W*	0.029	0.25	0.875	0.846	44	1550

All specimens used round weld washers
* Capacity controlled by the bolted connection.

Table 15
GC Specimens
Eccentric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GC121W	0.029	0.25	0.375	0.346	1.5	440
GC122W	0.029	0.25	0.375	0.346	1.5	540
GC123W	0.029	0.25	0.625	0.596	3	1125
GC124W	0.029	0.25	0.625	0.596	3	960

All specimens used round weld washers

Table 16
GE Specimens
Eccentric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE115W	0.029	0.25	0.375	0.346	8	650
GE116W	0.029	0.25	0.375	0.346	8	840
GE117W^	0.029	0.25	0.625	0.596	23	1000

All specimens used round washers

^ Bolted connection failed prior to sheet or weld

Table 17
GE Specimens
Eccentric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE113W	0.029	0.25	0.426	0.397	2	900
GE114W	0.029	0.25	0.436	0.407	2	782
GE123W	0.029	0.25	0.625	0.596	3	650
GE124W	0.029	0.25	0.625	0.596	3	990

All specimens used round washers

Table 18
GE Specimens
Eccentric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE125W	0.029	0.25	0.517	0.488	2	950
GE126W	0.029	0.25	0.631	0.602	3	1075
GE127W	0.029	0.25	0.441	0.412	1.5	730
GE128W	0.029	0.25	0.495	0.466	2	920
GE129W	0.029	0.25	0.666	0.637	3	990

All specimens used rectangular washers with 3/8" prepunched hole

Table 19
GE Specimens
Eccentric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE136W	0.029	0.25	0.569	0.54	3	1110
GE137W	0.029	0.25	0.637	0.608	3	1075
GE138W~	0.029	0.25	0.516	0.487	2	750
GE139W~	0.029	0.25	0.472	0.443	2	475

All specimens used rectangular washer with 1/2" diameter prepunched hole
~ 3/8" diameter weld used in 1/2" diameter weld washer hole

Table 20
GC Specimens
Eccentric Load
With Washers

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
AUTOMATIC WELD					
GC121W	0.029	47.99	440	705.75	0.623
GC122W	0.029	47.99	540	705.75	0.765
GC123W	0.029	47.99	1125	1215.69	0.925
GC124W	0.029	47.99	960	1215.69	0.790
				Mean =	0.776
				Standard Deviation =	0.107
				COV =	0.139
STICK WELD					
GC115W	0.029	47.99	1010	705.75	1.431
GC117W	0.029	47.99	1420	1215.69	1.168
GC118W	0.029	47.99	1190	1215.69	0.979
GC119W	0.029	47.99	1550	1725.63	0.898
				Mean =	1.119
				Standard Deviation =	0.205
				COV =	0.183

Table 21
GE Specimens
Eccentric Load
With Washers

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
Automatic Weld, Round Washers					
GE113W	0.029	99.83	900	804.54	1.119
GE114W	0.029	99.83	782	824.80	0.948
GE123W	0.029	99.83	650	1207.82	0.538*
GE124W	0.029	99.83	990	1207.82	0.820
Stick Weld, Round Washers					
GE115W	0.029	99.83	650	701.19	0.927
GE116W	0.029	99.83	840	701.19	1.198
GE117W	0.029	99.83	1000	1207.82	0.828
				Mean =	0.973
Automatic Weld, Rectangular Washer					
GE125W	0.029	99.83	950	988.96	0.961
GE126W	0.029	99.83	1075	1219.98	0.881
GE127W	0.029	99.83	730	834.94	0.874
GE128W	0.029	99.83	920	944.37	0.974
GE129W	0.029	99.83	990	1290.91	0.767*
Automatic Weld, Rectangular Washer					
GE136W	0.029	99.83	1110	1094.34	1.014
GE137W	0.029	99.83	1075	1232.14	0.872
GE138W	0.029	99.83	750	986.93	0.760*
GE139W	0.029	99.83	475	897.76	0.529*
				Mean =	0.929

* Questionable test results, excluded from calculation of mean value

Table 22
GE Specimens
Concentric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE130W*	0.029	0.25	0.647	0.618	3	4250
GE131W*	0.029	0.25	0.496	0.467	2	1965
GE132W*	0.029	0.25	0.486	0.457	2	2120
GE133W*	0.029	0.25	0.463	0.434	2	2035
GE134W	0.029	0.25	0.627	0.598	3	3325
GE135W	0.029	0.25	0.645	0.616	3	3175

All specimens used washer with 3/8" prepunched hole
* Weld failed prior to sheet tearing

Table 23
GE Specimens
Concentric Loading
Using Automatic Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GE140W	0.029	0.25	0.565	0.536	3	1520
GE141W	0.029	0.25	0.551	0.522	3	1550
GE142W	0.029	0.25	0.451	0.422	2	850
GE143W	0.029	0.25	0.438	0.409	2	1055

All specimens used washer with 1/2" diameter prepunched hole

Table 24
Concentric Load
With Washers

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
GE130W	0.029	99.83	4250	1252.40	3.393
GE131W	0.029	99.83	1965	946.40	2.076
GE132W	0.029	99.83	2120	926.13	2.289
GE133W	0.029	99.83	2035	879.52	2.314
GE134W	0.029	99.83	3325	1211.88	2.744
GE135W	0.029	99.83	3175	1248.35	2.543
GE140W	0.029	99.83	1520	1086.23	1.399
GE141W	0.029	99.83	1550	1057.86	1.465
GE142W	0.029	99.83	850	855.20	0.994
GE143W	0.029	99.83	1055	828.86	1.273

Table 25
GE Specimens
Concentric Loading
Using Automatic Weld Process
Tension Failure of Weld

Specimen Number	Washer Thickness (in)	F_{xx} (ksi)	d_e (in)	A (in)	P_n (kips)	P_u/P_n
GE130W	0.077	70	0.2939	0.0678	4.746	0.895
GE131W	0.077	70	0.1882	0.0278	1.946	1.010
GE132W	0.077	70	0.1812	0.0258	1.804	1.175
GE133W	0.077	70	0.1651	0.0214	1.498	1.359

Table 26
Nested Sheet Specimens
Symmetric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GC 200D	0.029	0.25	0.531	0.502	2	1900
GC 201D	0.029	0.25	0.500	0.471	2	2190
GC 202D	0.029	0.25	0.719	0.690	3	4075
GC 203D	0.029	0.25	0.813	0.784	4	4150
GC 204D	0.029	0.25	0.640	0.611	3	2655
GC 205D	0.029	0.25	0.766	0.737	4	2850
GC 206D	0.029	0.25	0.680	0.651	3	3750
GC 207D	0.029	0.25	0.785	0.756	3	3525
GC 208D	0.029	0.25	0.885	0.856	4	3750
GC 209D	0.029	0.25	0.812	0.783	4	3975
GC 210D	0.029	0.25	0.779	0.750	4	3375
GE 200D	0.029	0.25	0.625	0.596	2	1960
GE 201D	0.029	0.25	0.524	0.495	2	2560
GE 202D	0.029	0.25	0.647	0.618	3	2875
GE 203D	0.029	0.25	0.698	0.669	3	2800
GE 204D	0.029	0.25	0.763	0.734	4	3025
GE 205D	0.029	0.25	0.718	0.689	4	2875
GE 206D	0.029	0.25	0.539	0.510	2	1925

Table 27
Nested Sheet Specimens
Symmetric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
GC 200D	0.029	47.99	1900	1929.61	0.985
GC 201D	0.029	47.99	2190	1803.14	1.215
GC 202D	0.029	47.99	4075	2696.55	1.511
GC 203D	0.029	47.99	4150	3080.03	1.347
GC 204D	0.029	47.99	2655	2374.27	1.118
GC 205D	0.029	47.99	2850	2888.29	0.987
GC 206D	0.029	47.99	3750	2537.45	1.478
GC 207D	0.029	47.99	3525	2965.80	1.189
GC 208D	0.029	47.99	3750	3373.95	1.112
GC 209D	0.029	47.99	3975	3075.95	1.292
GC 210D	0.029	47.99	3375	2941.32	1.147
					Mean = 1.216
GE 200D	0.029	99.83	1960	2298.11	0.853
GE 201D	0.029	99.83	2560	1888.74	1.355
GE 202D	0.029	99.83	2875	2387.28	1.204
GE 203D	0.029	99.83	2800	2593.98	1.079
GE 204D	0.029	99.83	3025	2857.43	1.059
GE 205D	0.029	99.83	2875	2675.05	1.075
GE 206D	0.029	99.83	1925	1949.54	0.987
					Mean = 1.088

Table 28
Sheet Lap Connection
Symmetric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Flange* Length, L (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)	d' (In.)
GC 400	0.029	0.50	0.577	0.548	10	700	0.286
GC 401	0.029	0.50	0.421	0.392	8	675	0.192
GC 402	0.029	0.50	0.629	0.6	12	900	0.273
GC 403	0.029	0.50	0.519	0.49	8	700	0.197
GC 404	0.029	0.50	0.419	0.39	4	550	0.068
GC 405	0.029	0.50	0.334	0.305	3	50	0.098
GE 400	0.029	0.50	0.328	0.299	5	150	0.142
GE 401	0.029	0.50	0.496	0.467	8	500	0.258
GE 402	0.029	0.50	0.565	0.536	9	875	0.188
GE 403	0.029	0.50	0.442	0.413	6	475	0.326
GE 404	0.029	0.50	0.721	0.692	12	1025	0.209
GE 405	0.029	0.50	0.723	0.694	15	1050	0.389
GCS1	0.029	1.00	0.506	0.477	5	600	0.455
GCS2	0.029	1.00	0.499	0.470	5	875	0.425
GCS3	0.029	1.125	0.713	0.684	10	1075	0.720
GCS4	0.029	1.125	0.700	0.671	12	675	0.679
GCS5	0.029	1.00	0.630	0.601	8	375	0.252
GCS6	0.029	1.00	0.632	0.603	9	650	0.499
GCL1**	0.029	1.50	0.560	0.531	4	0	-
GCL2	0.029	1.50	0.496	0.467	5	925	0.496
GCL3	0.029	1.50	0.642	0.613	8	1800	0.642
GCL4	0.029	1.50	0.590	0.561	6	975	0.590
GCL5	0.029	1.50	0.668	0.639	11	1075	0.668
GCL6	0.029	1.50	0.739	0.710	13	1450	0.739
GES1	0.029	0.875	0.459	0.430	4	650	0.310
GES2	0.029	0.875	0.468	0.439	4	725	0.293
GES3	0.029	1.125	0.565	0.536	6	825	0.565
GES4	0.029	0.875	0.495	0.466	6	750	0.263
GES5	0.029	1.125	0.665	0.636	9	950	0.556
GES6	0.029	1.125	0.609	0.580	9	1075	0.550
GEL1	0.029	1.500	0.505	0.476	4	1075	0.505
GEL2	0.029	1.500	0.506	0.477	4	1450	0.506
GEL3	0.029	1.500	0.613	0.584	6	1800	0.613
GEL4	0.029	1.500	0.621	0.592	7	1050	0.621
GEL5	0.029	1.500	0.786	0.757	9	1100	0.786
GEL6	0.029	1.500	0.793	0.764	9	1400	0.793

*Length of unstiffened flange at lap connection
**Bad weld, no fusion

Table 29
Sheet Lap Connection
Symmetric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
GC 400	0.029	47.99	700	1117.78	0.626
GC 401	0.029	47.99	675	799.58	0.844
GC 402	0.029	47.99	900	1223.85	0.735
GC 403	0.029	47.99	700	999.48	0.700
GC 404	0.029	47.99	550	795.50	0.691
GC 405	0.029	47.99	50	622.12	0.080
GE 400	0.029	99.83	150	605.94	0.248
GE 401	0.029	99.83	500	946.40	0.528
GE 402	0.029	99.83	875	1086.23	0.806
GE 403	0.029	99.83	475	836.96	0.568
GE 404	0.029	99.83	1025	1402.37	0.731
GE 405	0.029	99.83	1050	1406.43	0.747
GCS1	0.029	47.99	600	972.96	0.617
GCS2	0.029	47.99	875	958.68	0.912
GCS3	0.029	47.99	1075	1395.19	0.771
GCS4	0.029	47.99	675	1368.67	0.493
GCS5	0.029	47.99	375	1225.89	0.306
GCS6	0.029	47.99	650	1229.97	0.528
GCL2	0.029	47.99	925	952.56	0.971
GCL3	0.029	47.99	1800	1250.37	1.440
GCL4	0.029	47.99	975	1144.30	0.852
GCL5	0.029	47.99	1075	1303.40	0.825
GCL6	0.029	47.99	1450	1448.22	1.001
GES1	0.029	99.83	650	871.42	0.746
GES2	0.029	99.83	725	889.66	0.815
GES3	0.029	99.83	825	1086.23	0.760
GES4	0.029	99.83	750	944.37	0.794
GES5	0.029	99.83	950	1288.89	0.737
GES6	0.029	99.83	1075	1175.40	0.915
GEL1	0.029	99.83	1075	964.64	1.114
GEL2	0.029	99.83	1450	966.66	1.500
GEL3	0.029	99.83	1800	1183.51	1.521
GEL4	0.029	99.83	1050	1199.72	0.875
GEL5	0.029	99.83	1100	1534.10	0.717
GEL6	0.029	99.83	1400	1548.28	0.904

Table 30
Wide Sheet Flange
Symmetric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (In.)	Plate Thickness (In.)	Visible Diameter (In.)	d_a (In.)	Weld Time (Sec.)	P_u (lbs.)
GC 320	0.029	0.25	0.510	0.481	5	1050
GC 321	0.029	0.25	0.523	0.494	5	925
GC 322	0.029	0.25	0.634	0.605	7	1175
GC 323	0.029	0.25	0.631	0.602	7	1625
GC 324	0.029	0.25	0.752	0.723	10	1700
GC 325	0.029	0.25	0.744	0.715	12	1925
GE 320	0.029	0.25	0.496	0.467	5	1300
GE 321	0.029	0.25	0.472	0.443	6	1050
GE 322	0.029	0.25	0.592	0.563	7	2025
GE 323	0.029	0.25	0.633	0.604	7	1375
GE 324	0.029	0.25	0.895	0.866	14	1600
GE 325	0.029	0.25	0.753	0.724	9	1325

*Flange width of welded portion of sheet was 3 3/8-in.

Table 31
Wide Sheet Flange
Symmetric Loading
Using Stick Weld Process

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
GC 320	0.029	47.99	1050	981.12	1.070
GC 321	0.029	47.99	925	1619.56	0.571
GC 322	0.029	47.99	1175	1234.05	0.952
GC 323	0.029	47.99	1625	1227.93	1.323
GC 324	0.029	47.99	1700	1474.74	1.153
GC 325	0.029	47.99	1925	1458.42	1.320
				Mean =	1.164
GE 320	0.029	99.83	1300	946.40	1.374
GE 321	0.029	99.83	1050	897.76	1.170
GE 322	0.029	99.83	2025	1140.95	1.775
GE 323	0.029	99.83	1375	1224.04	1.123
GE 324	0.029	99.83	1600	1754.99	0.912
GE 325	0.029	99.83	1325	1467.22	0.903
				Mean =	1.209

Table 32
GX Specimens
Concentric Loading
Stick Weld Process

Specimen No.	Sheet Thickness (in.)	Plate Thickness (in.)	Visible Diameter (in.)	d_a (in.)	Weld Time (Sec.)	P_u (lbs)
GX20	0.0625	0.25	0.633	0.5705	4	2100
GX21	0.0625	0.25	0.567	0.5045	4	2150
GX22	0.0625	0.25	0.798	0.7355	7	1975
GX23	0.0625	0.25	0.697	0.6345	8	3225
GX24	0.0625	0.25	0.942	0.8795	12	4050
GX25	0.0625	0.25	0.931	0.8685	14	2800

Table 33
GX Specimens
Eccentric Loading
Stick Weld Process

Specimen No.	Sheet Thickness (in.)	Plate Thickness (in.)	Visible Diameter (in.)	d_a (in.)	Weld Time (Sec.)	P_u (lbs)
GX1	0.0625	0.25	0.647	0.5845	6	950
GX2	0.0625	0.25	0.587	0.5245	4	1100
GX3	0.0625	0.25	0.684	0.6215	5	1550
GX4	0.0625	0.25	0.682	0.6195	5	1400
GX5	0.0625	0.25	1.091	1.0285	11	2025
GX6	0.0625	0.25	0.989	0.9265	10	1650
GXW1*	0.0625	0.25	0.5	0.4375	4	1875
GXW2	0.0625	0.25	0.5	0.4375	4	1700
GXW3	0.0625	0.25	0.75	0.6875	10	2025
GXW4	0.0625	0.25	0.75	0.6875	9	2300
GXW5	0.0625	0.25	1	0.9375	20	3000
GXW6	0.0625	0.25	1	0.9375	20	3050

* Connection for GXW specimens was reinforced with a round washer

Table 34
GX Specimens
Stick Weld Process

Specimen No.	Sheet Thickness (in.)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
GX1	0.0625	45.02	950	2401.17	0.396
GX2	0.0625	45.02	1100	2154.69	0.511
GX3	0.0625	45.02	1550	2553.17	0.607
GX4	0.0625	45.02	1400	2544.95	0.550
GX5	0.0625	45.02	2025	4225.16	0.479
GX6	0.0625	45.02	1650	3806.13	0.434
				Mean =	0.496
GXW1	0.0625	45.02	1875	1797.28	1.043
GXW2	0.0625	45.02	1700	1797.28	0.946
GXW3	0.0625	45.02	2025	2824.30	0.717
GXW4	0.0625	45.02	2300	2824.30	0.814
GXW5	0.0625	45.02	3000	3851.32	0.779
GXW6	0.0625	45.02	3050	3851.32	0.792
				Mean =	0.849
GX20	0.0625	45.02	2100	2343.66	0.896
GX21	0.0625	45.02	2150	2072.52	1.037
GX22	0.0625	45.02	1975	3021.49	0.654
GX23	0.0625	45.02	3225	2606.57	1.237
GX24	0.0625	45.02	4050	3613.05	1.121
GX25	0.0625	45.02	2800	3567.86	0.785
				Mean =	0.955

Table 35
28 ga. DH Sheet Specimens
Symmetric Loading
Using Stick Weld Process
Without Washers

Specimen No.	Sheet Thickness (In)	Plate Thicknes (In)	Visible Diameter (In)	d_a (In)	P_u (lbs)
DH1	0.018	0.25	0.660	0.642	475
DH2	0.018	0.25	0.688	0.670	425
DH3	0.018	0.25	0.719	0.701	350
DH4	0.018	0.25	0.467	0.449	325
DH5	0.018	0.25	0.641	0.623	325
DH6	0.018	0.25	0.657	0.639	200
DH7	0.018	0.25	0.509	0.491	425
DH8	0.018	0.25	0.564	0.546	650
DH9	0.018	0.25	0.575	0.557	300
DH10	0.018	0.25	0.592	0.574	450
DH11	0.018	0.25	0.588	0.567	275
DH12	0.018	0.25	0.628	0.610	800
DH13	0.018	0.25	0.712	0.694	525

Table 36
28 ga. DH Sheet Specimens
Symmetric Loading
Using Stick Weld Process
With Washers

Specimen No.	Sheet Thickness (In)	Plate Thicknes (In)	Visible Diameter (In)	d_a (In)	P_u (lbs)
DH1W	0.018	0.25	0.460	0.442	850
DH2W	0.018	0.25	0.538	0.519	850
DH3W	0.018	0.25	0.610	0.592	875

Table 37
28 ga. BR Sheet Specimens
Symmetric Loading
Using Stick Weld Process
Without Washers

Specimen No.	Sheet Thickness (In)	Plate Thicknes (In)	Visible Diameter (In)	d_a (In)	P_u (lbs)
BR1	0.0185	0.25	0.821	0.803	375
BR2	0.0185	0.25	0.691	0.672	350
BR3	0.0185	0.25	0.678	0.659	225
BR4	0.0185	0.25	0.642	0.624	275
BR5	0.0185	0.25	0.699	0.680	400
BR6	0.0185	0.25	0.738	0.719	400
BR7	0.0185	0.25	0.610	0.591	400
BR8	0.0185	0.25	0.617	0.598	300

Table 38
28 ga. BR Sheet Specimens
Symmetric Loading
Using Stick Weld Process
With Washers

Specimen No.	Sheet Thickness (In)	Plate Thicknes (In)	Visible Diameter (In)	d_a (In)	P_u (lbs)
BR9W	0.0185	0.25	0.477	0.458	1375
BR10W	0.0185	0.25	0.581	0.562	1375
BR11W	0.0185	0.25	0.556	0.537	1750
BR12W	0.0185	0.25	0.502	0.484	1400

Table 39
28 ga. DH Sheet Specimens
Symmetric Loading
Using Stick Weld Process
Without Washers

Specimen No.	Sheet Thickness (In)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
DH1	0.018	65.4	475	529	0.899
DH2	0.018	65.4	425	551	0.770
DH3	0.018	65.4	350	558	0.606
DH4	0.018	65.4	325	370	0.878
DH5	0.018	65.4	325	513	0.633
DH6	0.018	65.4	200	526	0.380
DH7	0.018	65.4	425	405	1.050
DH8	0.018	65.4	650	450	1.446
DH9	0.018	65.4	300	459	0.654
DH10	0.018	65.4	450	473	0.952
DH11	0.018	65.4	275	469	0.586
DH12	0.018	65.4	800	503	1.592
DH13	0.018	65.4	525	571	0.919
				Mean	0.874
				Std Dev	0.328
				Cov	0.375

Table 40
28 ga. DH Sheet Specimens
Symmetric Loading
Using Stick Weld Process
With Washers

Specimen No.	Sheet Thickness (In)	F_u (ksi)	P_u (lbs)	P_n (lbs)	P_u/P_n
DH1W	0.018	65.4	850	363	2.336
DH2W	0.018	65.4	850	428	1.987
DH3W	0.018	65.4	875	487	1.795
				Mean	2.040
				Std Dev	0.224
				Cov	0.110

Table 41
28 ga. BR Sheet Specimens
Symmetric Loading
Using Stick Weld Process
Without Washer

Specimen No.	Sheet Thickness (In)	F_u (psi)	P_u (lbs)	P_n (lbs)	P_u/P_n
BR1	0.0185	115782.8	375	1203.3	0.312
BR2	0.0185	115782.8	350	1007.6	0.347
BR3	0.0185	115782.8	225	988.1	0.228
BR4	0.0185	115782.8	275	934.9	0.294
BR5	0.0185	115782.8	400	1019.6	0.392
BR6	0.0185	115782.8	400	1078.1	0.371
BR7	0.0185	115782.8	400	886.1	0.451
BR8	0.0185	115782.8	300	896.6	0.335
				Mean	0.341
				Std Dev	0.063
				Cov	0.184

Table 42
28 ga. BR Sheet Specimens
Symmetric Loading
Using Stick Weld Process
With Washer

Specimen No.	Sheet Thickness (In)	F_u (psi)	P_u (lbs)	P_n (lbs)	P_u/P_n
BR9W	0.0185	115782.8	1375	686.7	2.002
BR10W	0.0185	115782.8	1375	842.7	1.632
BR11W	0.0185	115782.8	1750	805.2	2.173
BR12W	0.0185	115782.8	1400	725.0	1.931
				Mean	1.935
				Std Dev	0.196
				Cov	0.101

Table 43
Full Panel Tests

Specimen No.	Sheet Thickness (in.)	Visible Diameter (in.)	d_a (in.)	Weld Time (sec.)	P_u (lbs)	P_u/P_n
Full Panel Tests (failure at center weld, perimeter welds reinforced)						
GC1-F	0.029	0.575	0.546	2	1532	1.376
GC2-F	0.029	0.6875	0.6585	2	1582	1.178
GE1-F	0.029	0.556	0.527	2	898	0.841
GE2-F	0.029	0.53	0.501	2	762	0.751
Full panel tests (failure at perimeter weld of center support)						
GC3-F	0.029	0.54	0.511	2	507	0.486
GE3-F	0.029	0.52	0.491	2	476	0.478

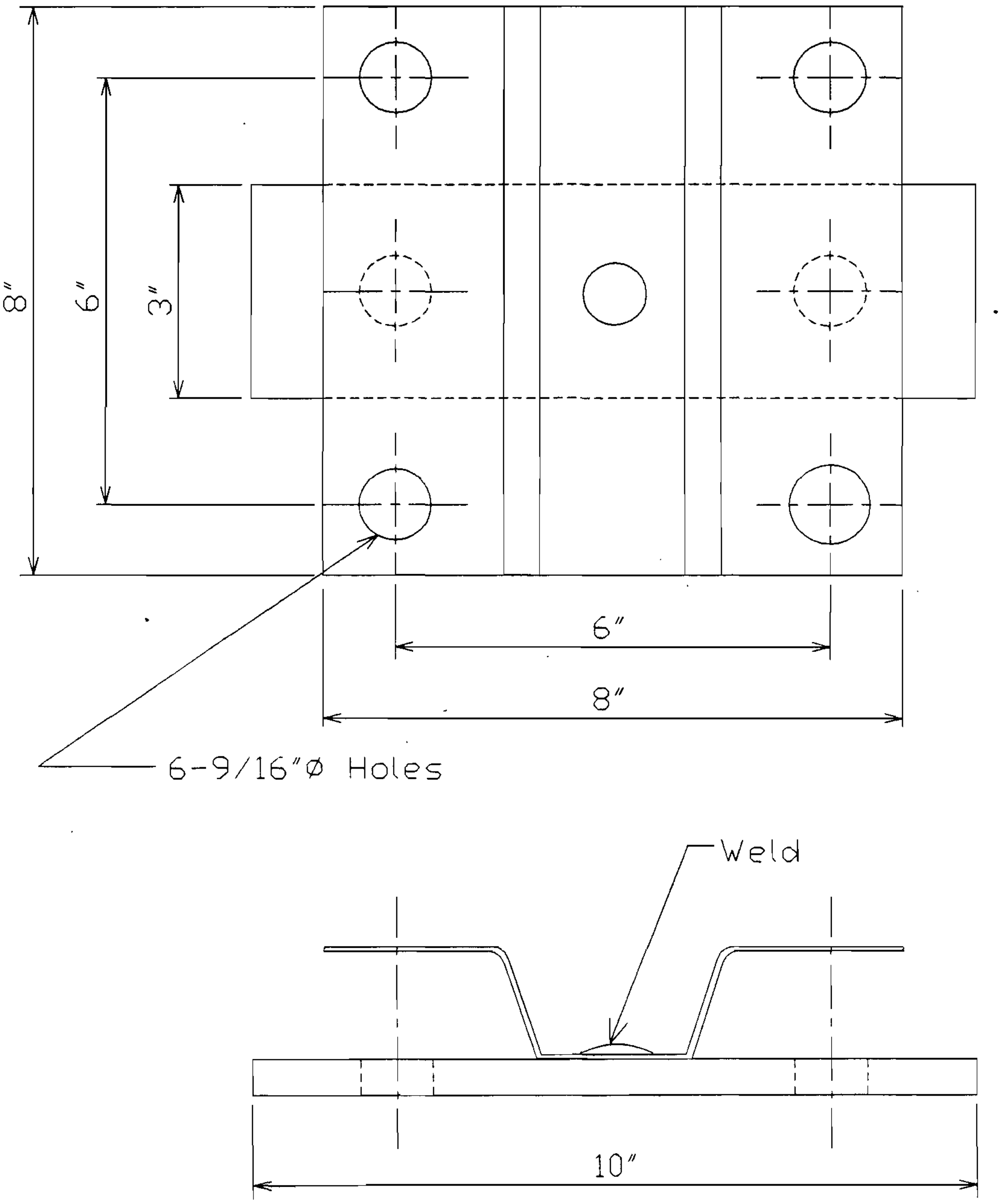
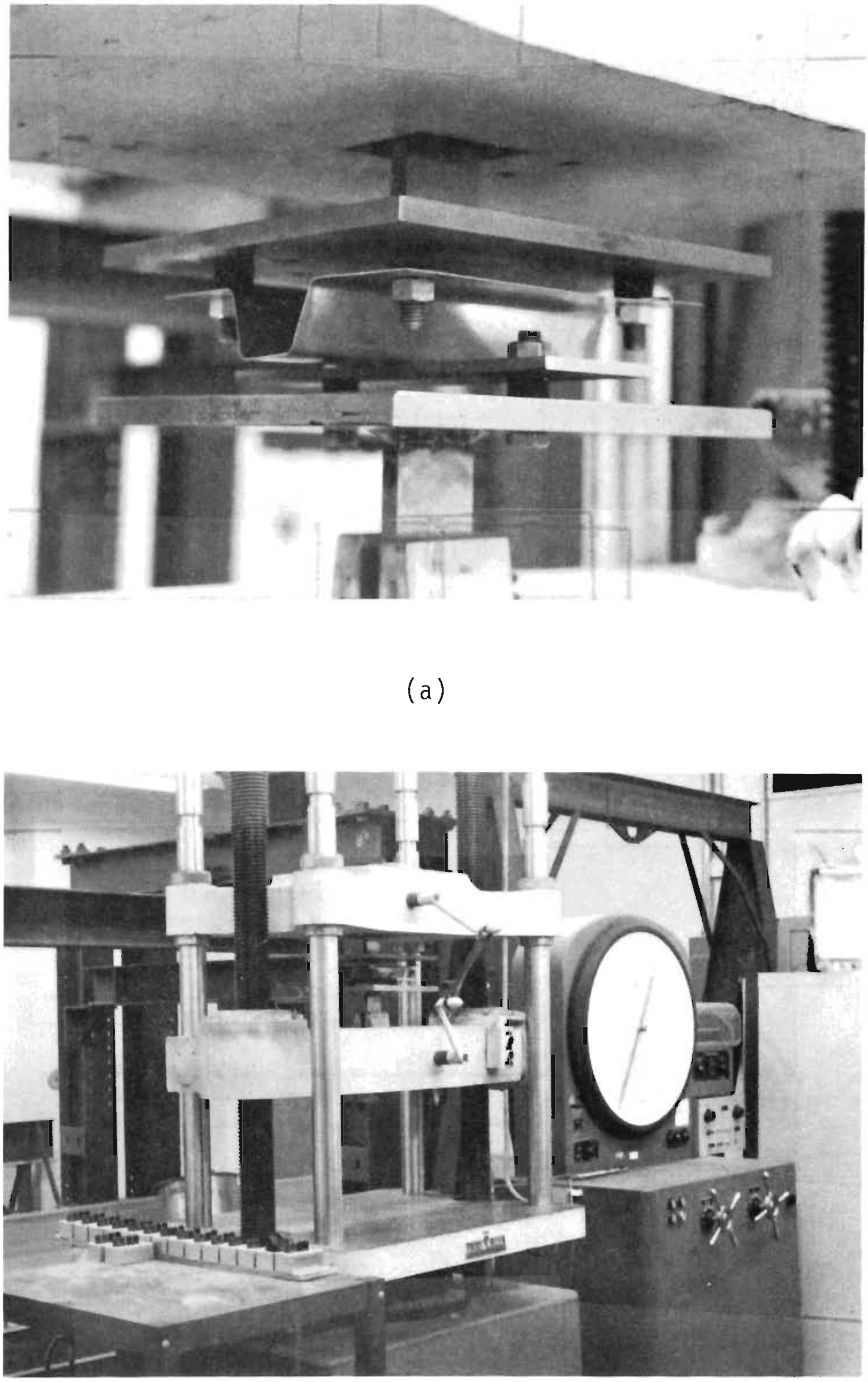


Fig. 1 Typical Test Specimen Cross-Section



(a)

(b)

Fig. 2 Test Specimen and Test Fixture

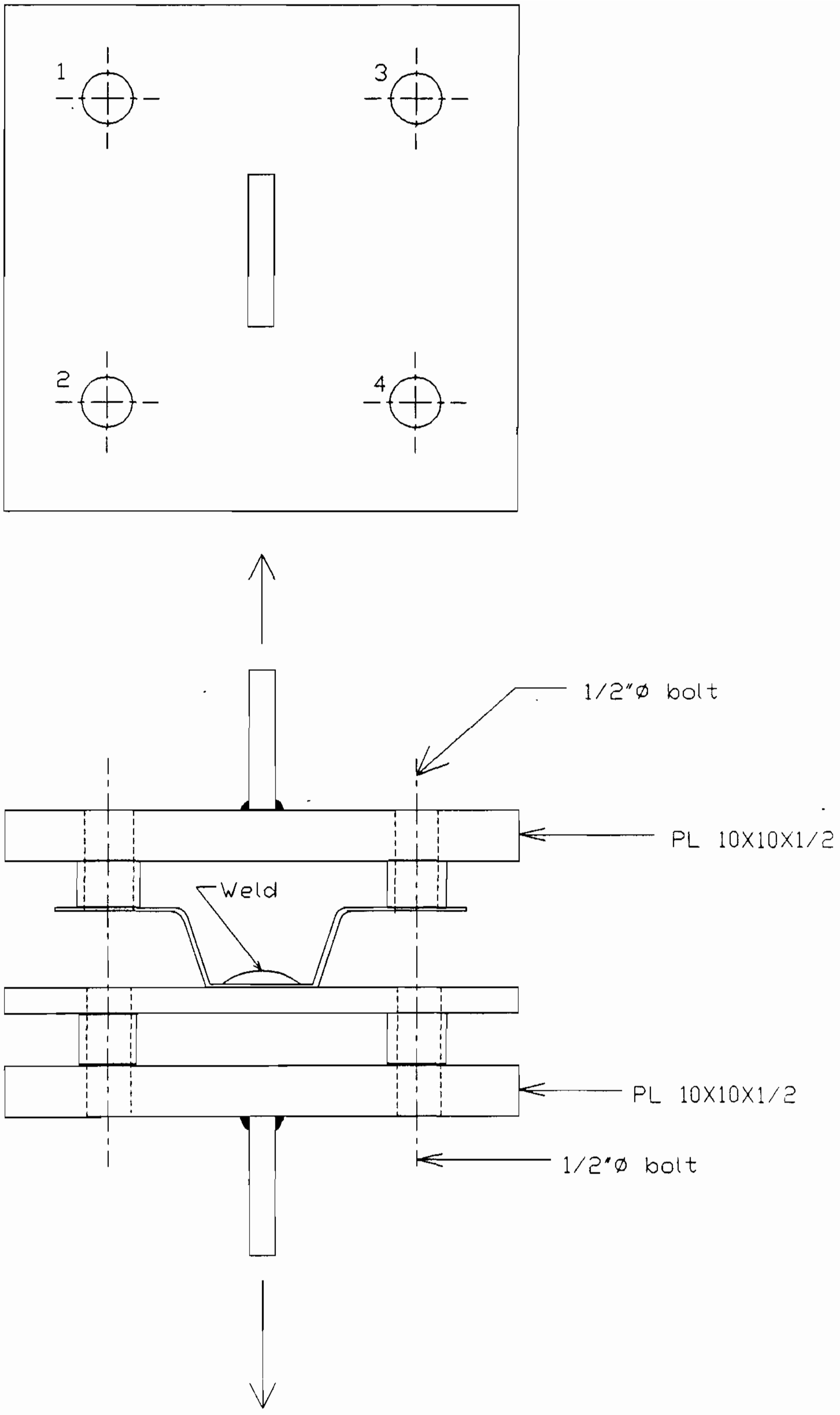
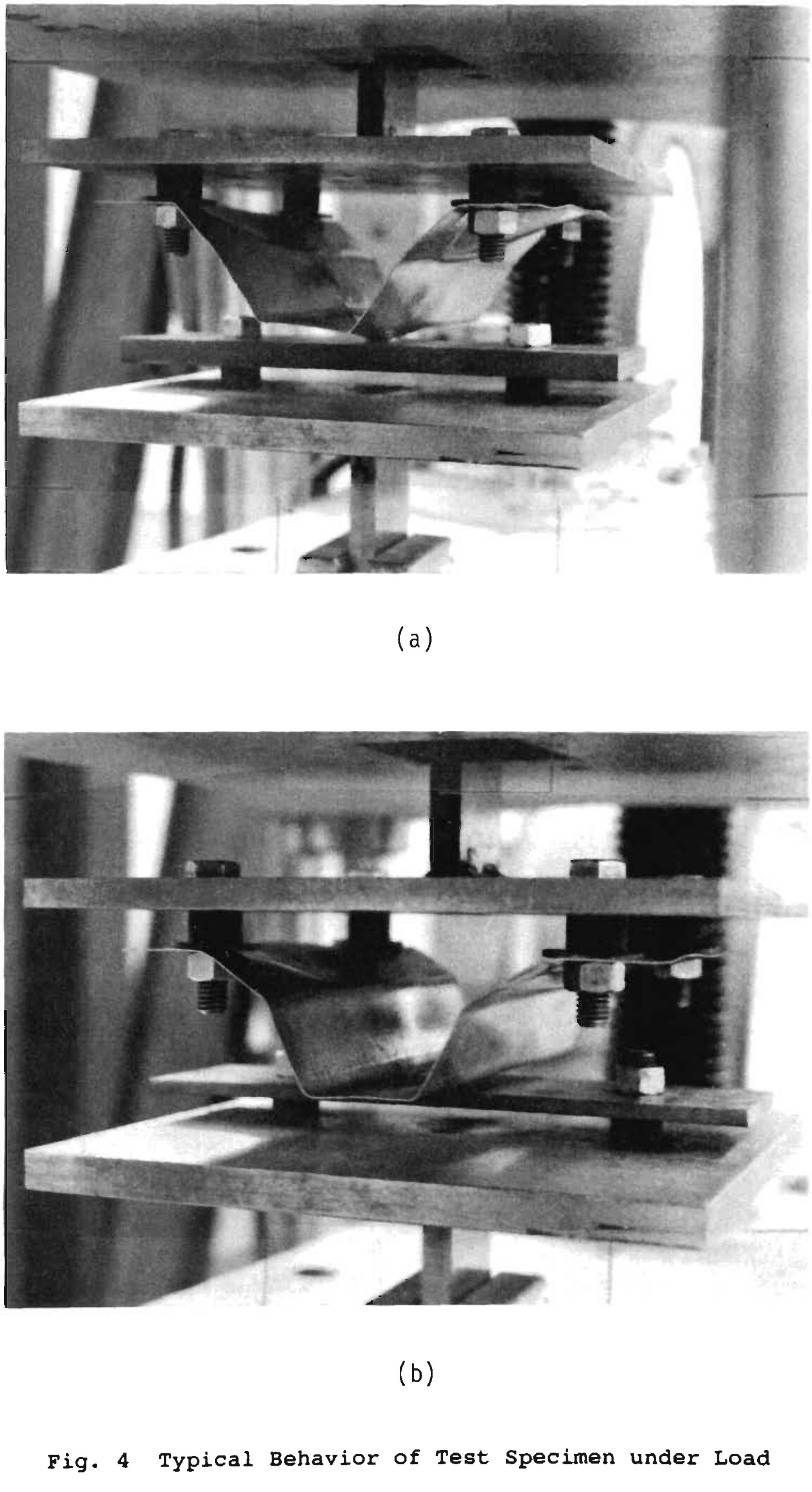


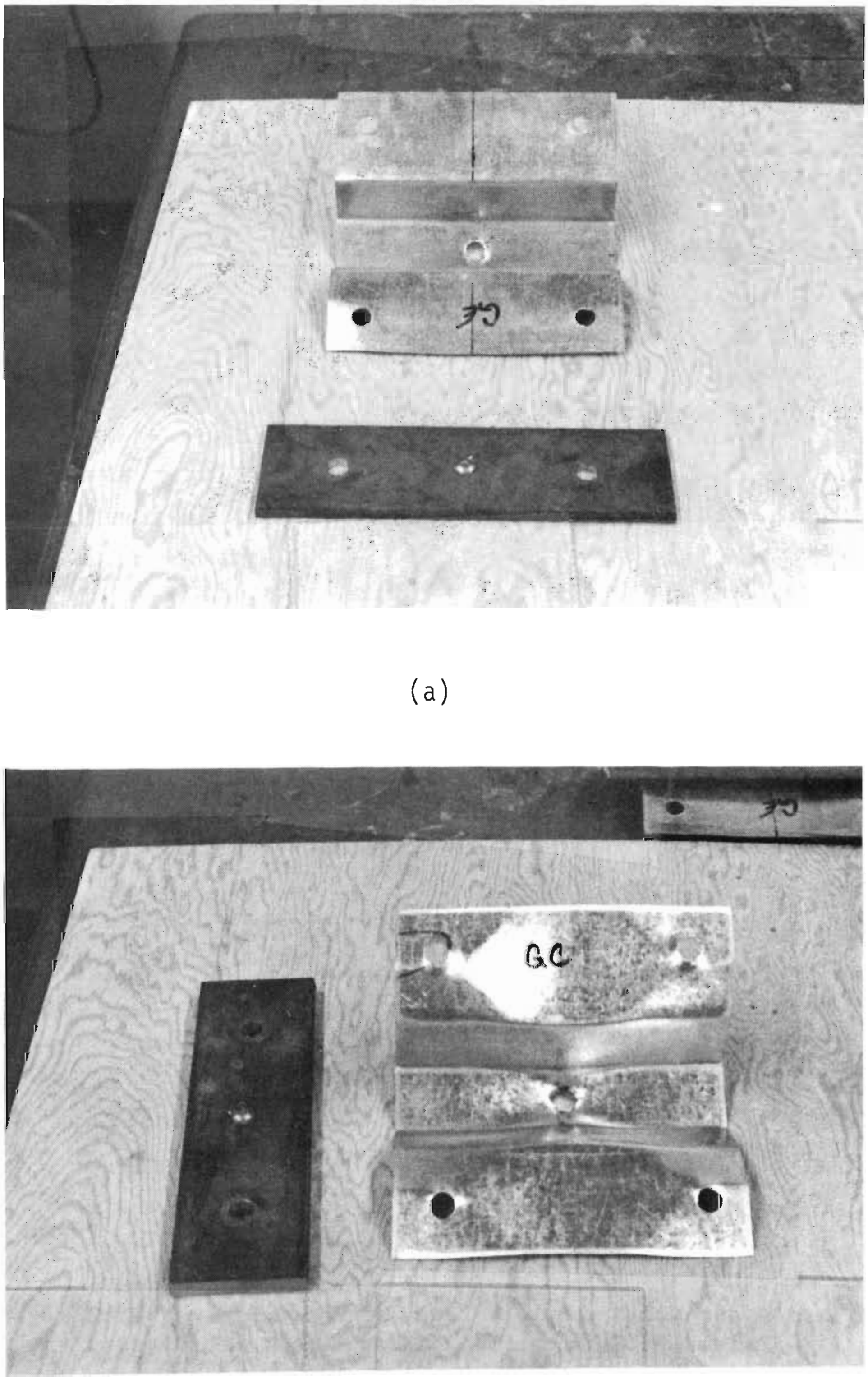
Fig. 3 Test Assembly



(a)

(b)

Fig. 4 Typical Behavior of Test Specimen under Load



(a)

(b)

Fig. 5 Typical Failure Modes

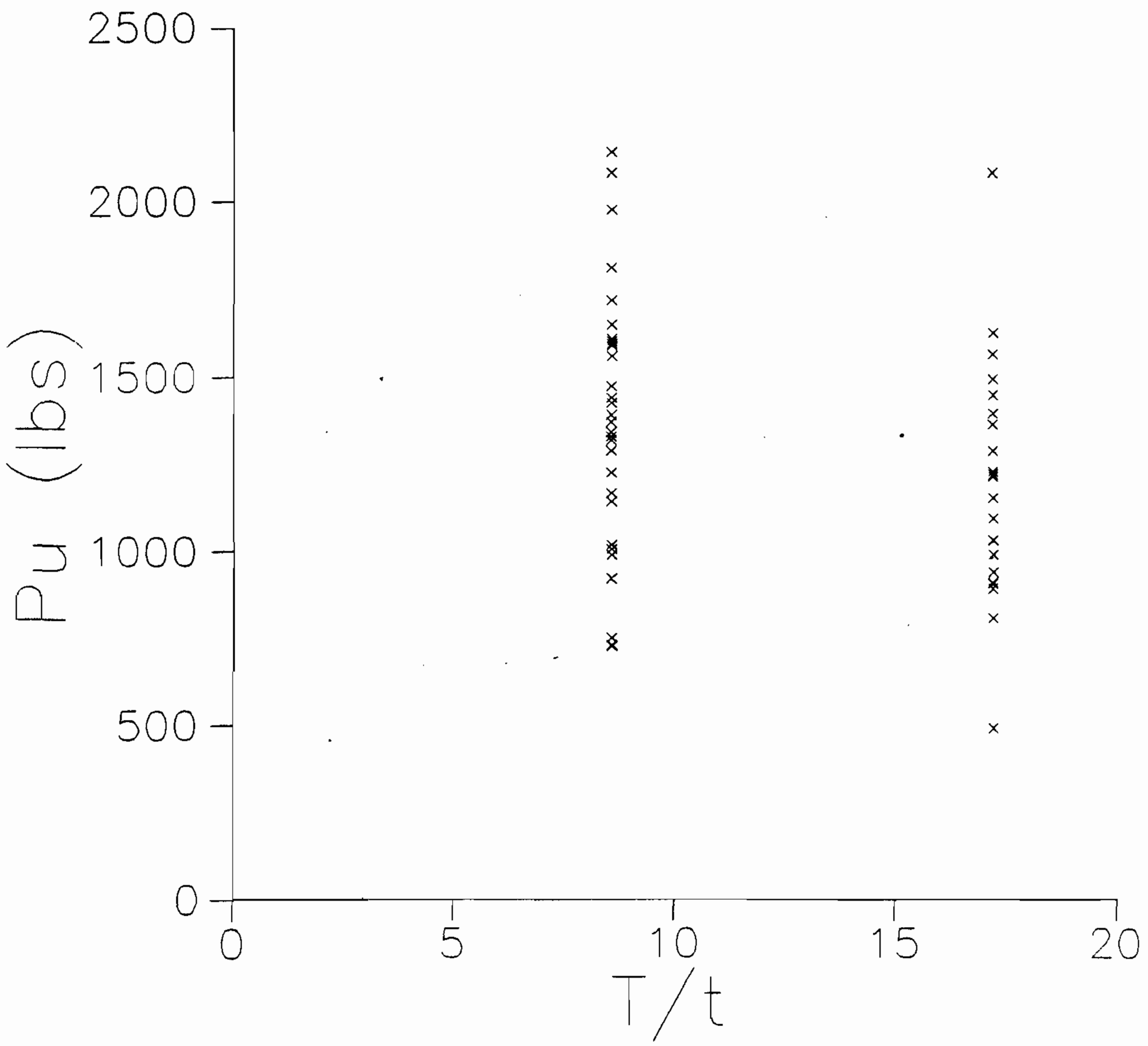


Fig. 6 Effect of Plate Thickness to Sheet Thickness Ratio on Failure for Symmetrical Loading of GC Material

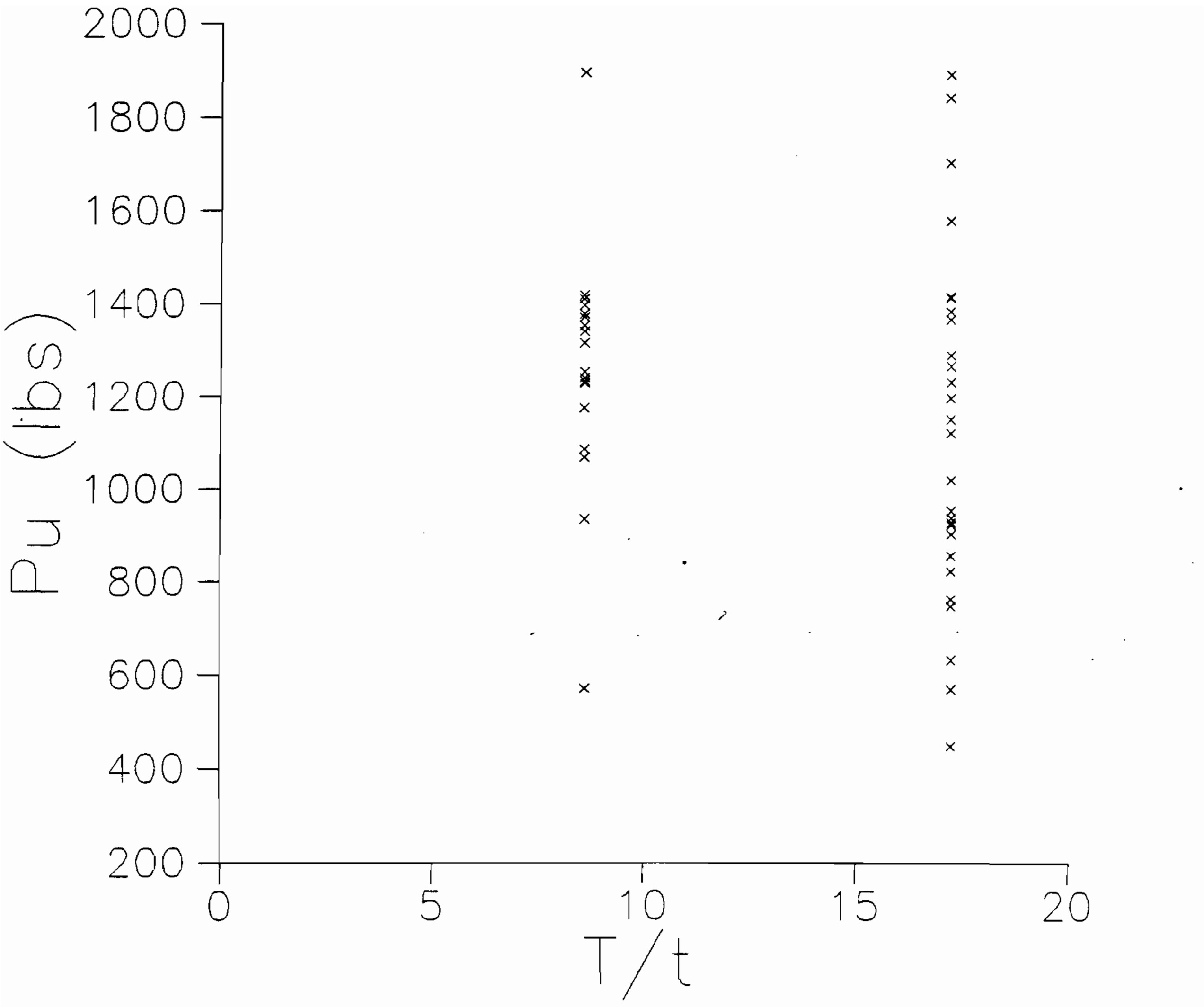


Fig. 7 Effect of Plate Thickness to Sheet Thickness Ratio on Failure for Symmetrical Loading of GE Material

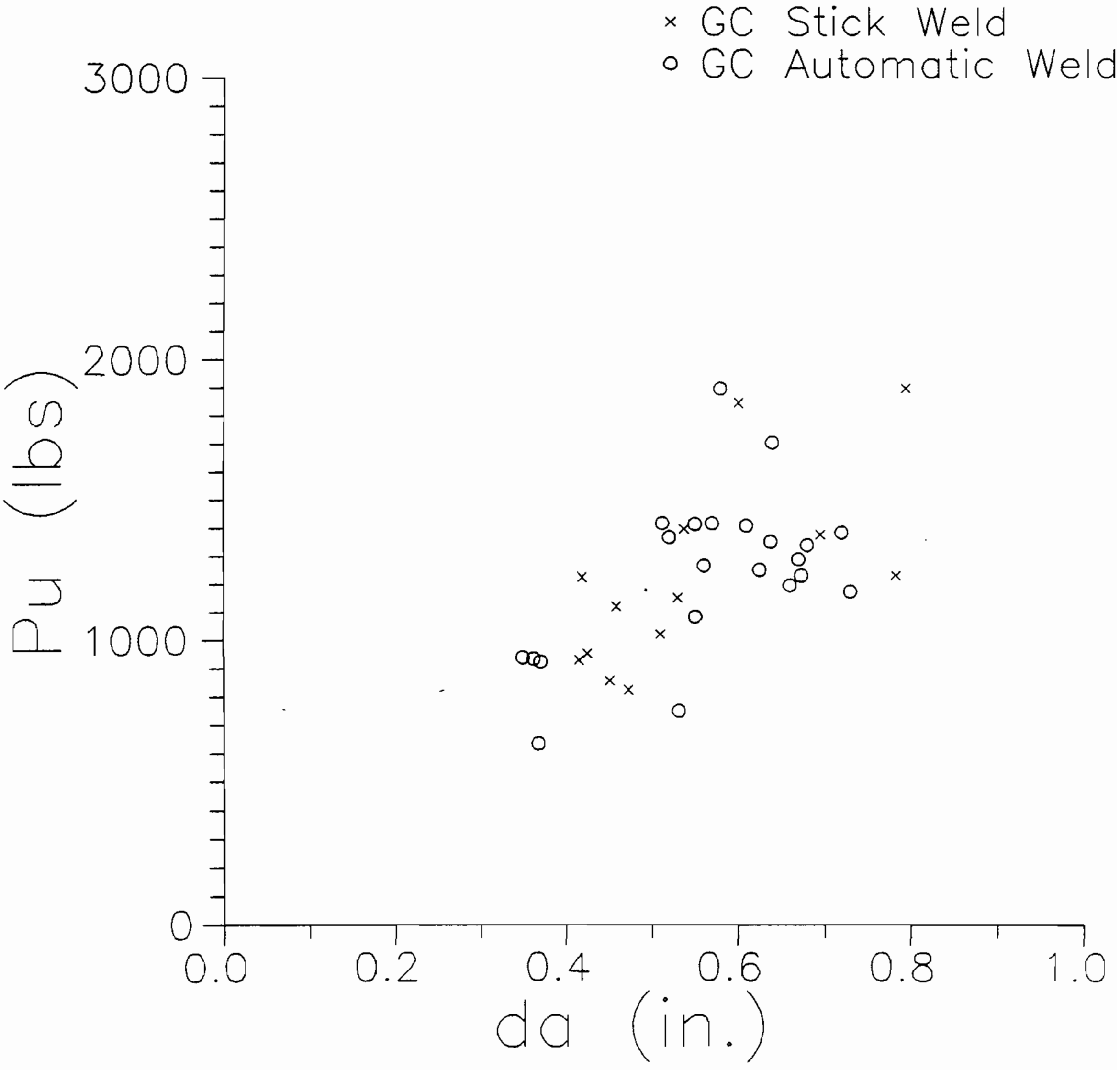


Fig. 8 Relationship Between P_u and d_a for Stick Weld and Automatic Weld Processes for GC Material

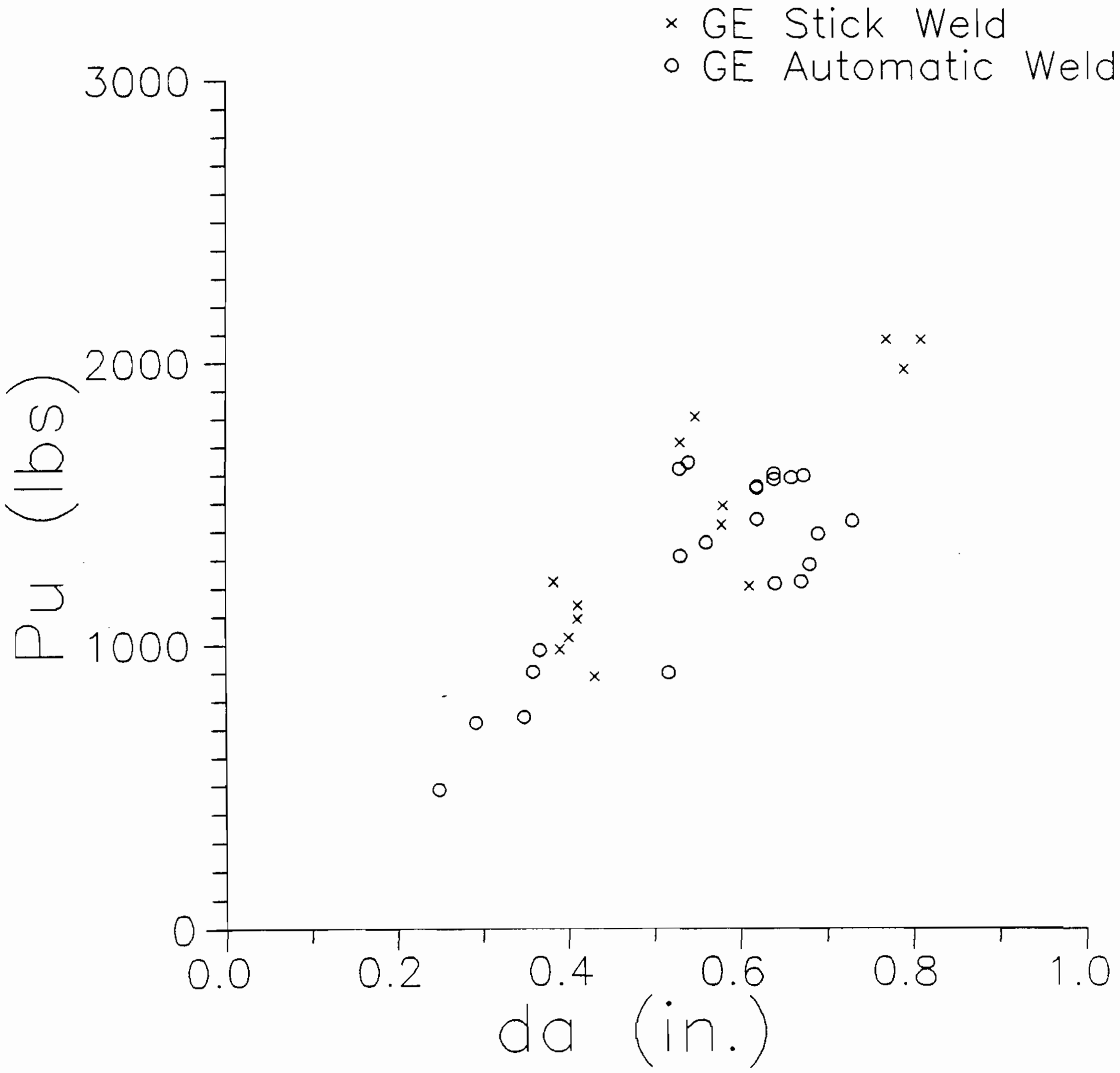


Fig. 9 **Relationship Between P_u and d_a for Stick Weld and Automatic Weld Processes for GE Material**

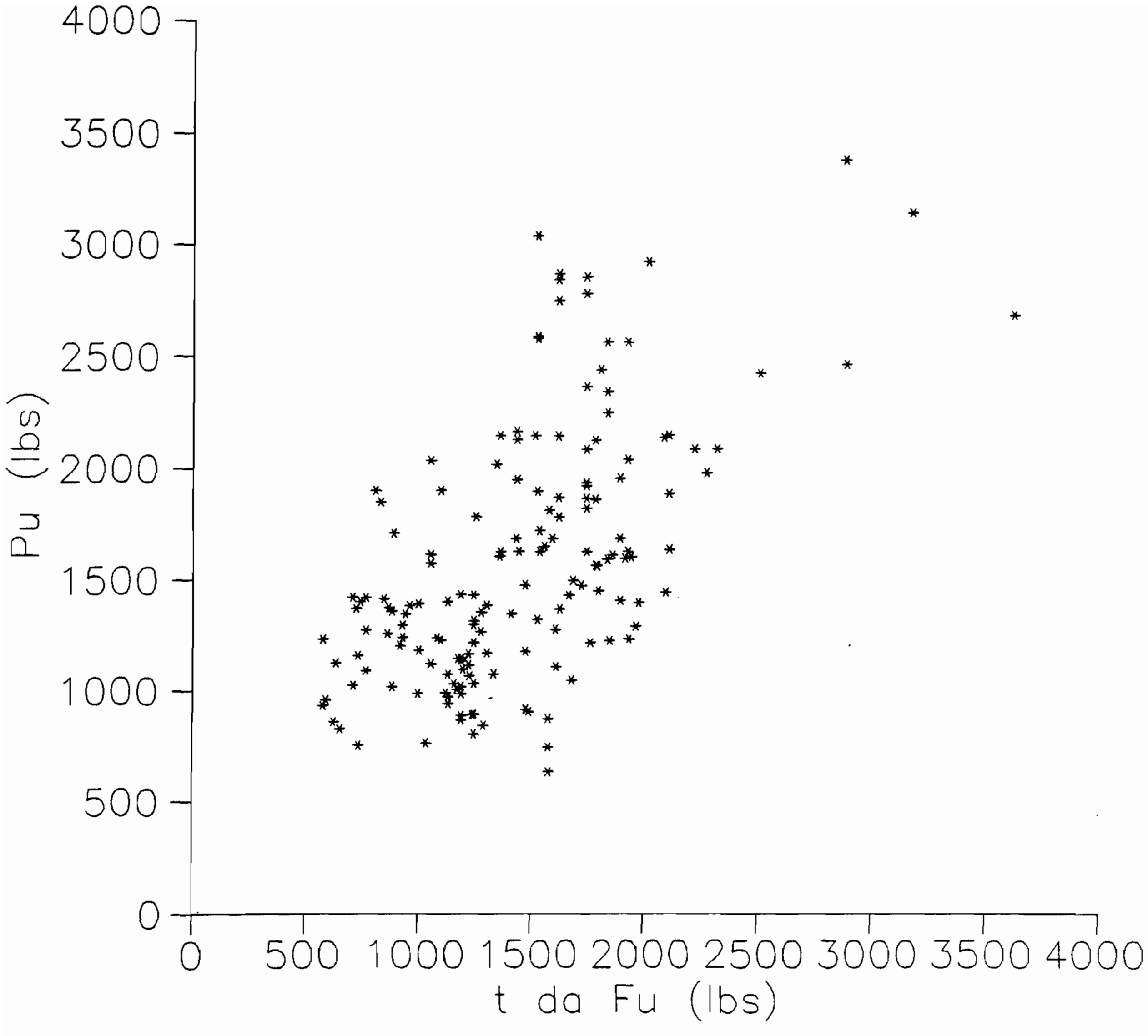


Fig. 10 Relationship Between P_u and td_aF_u for All Available Test Data

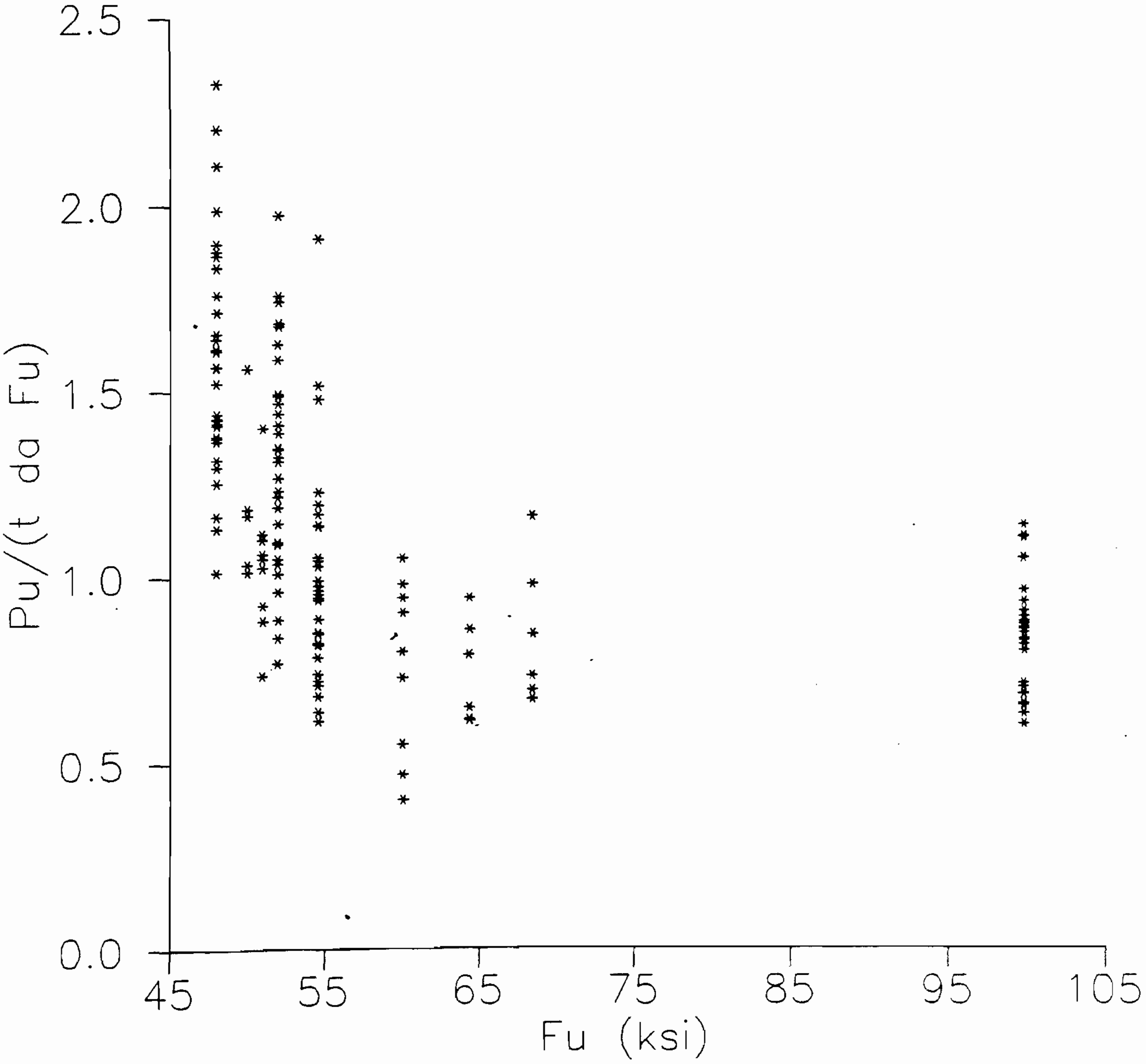


Fig. 11 Influence of F_u on Connection Strength

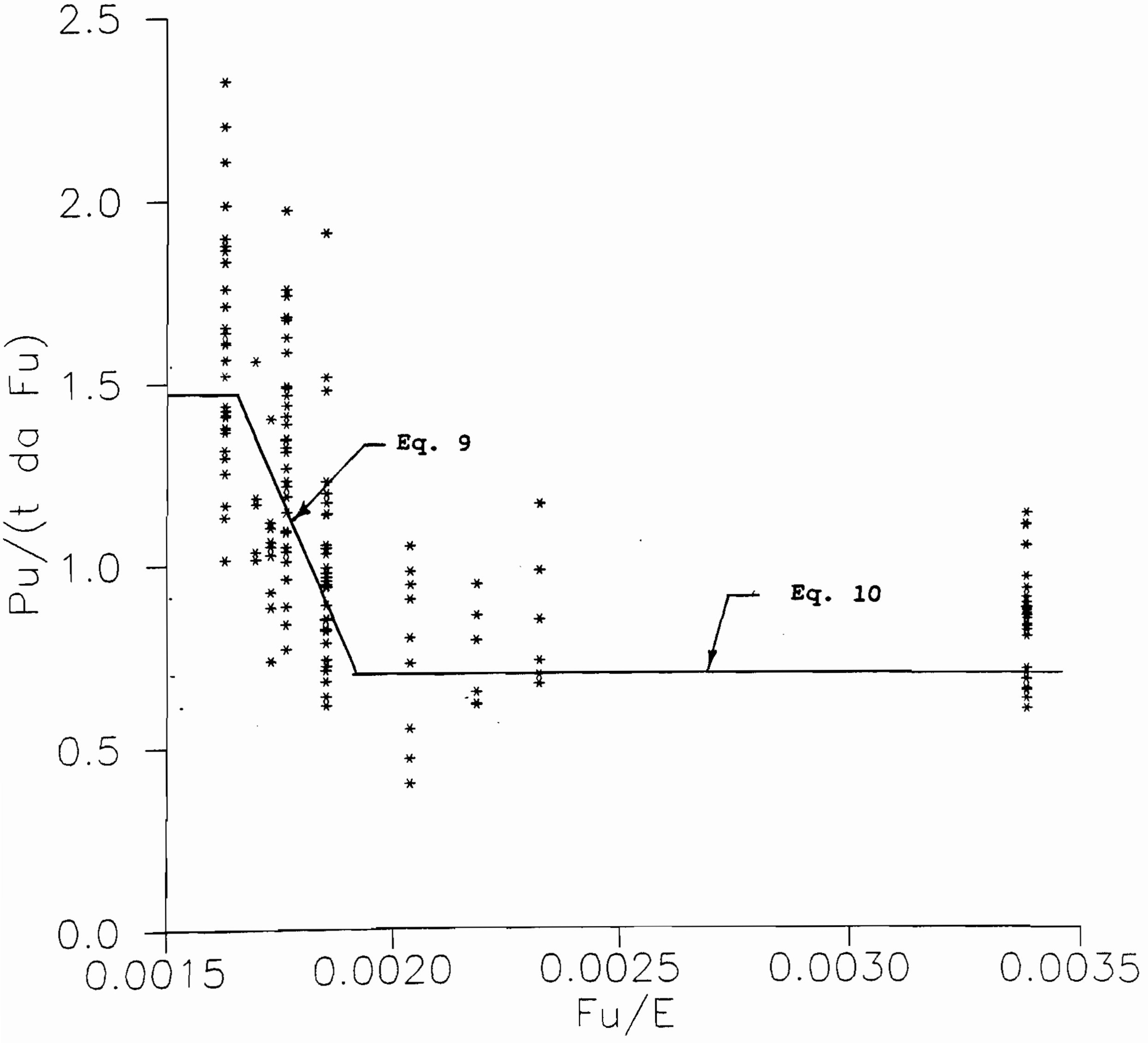


Fig. 12 Relationship Between F_u/E and Connection Strength

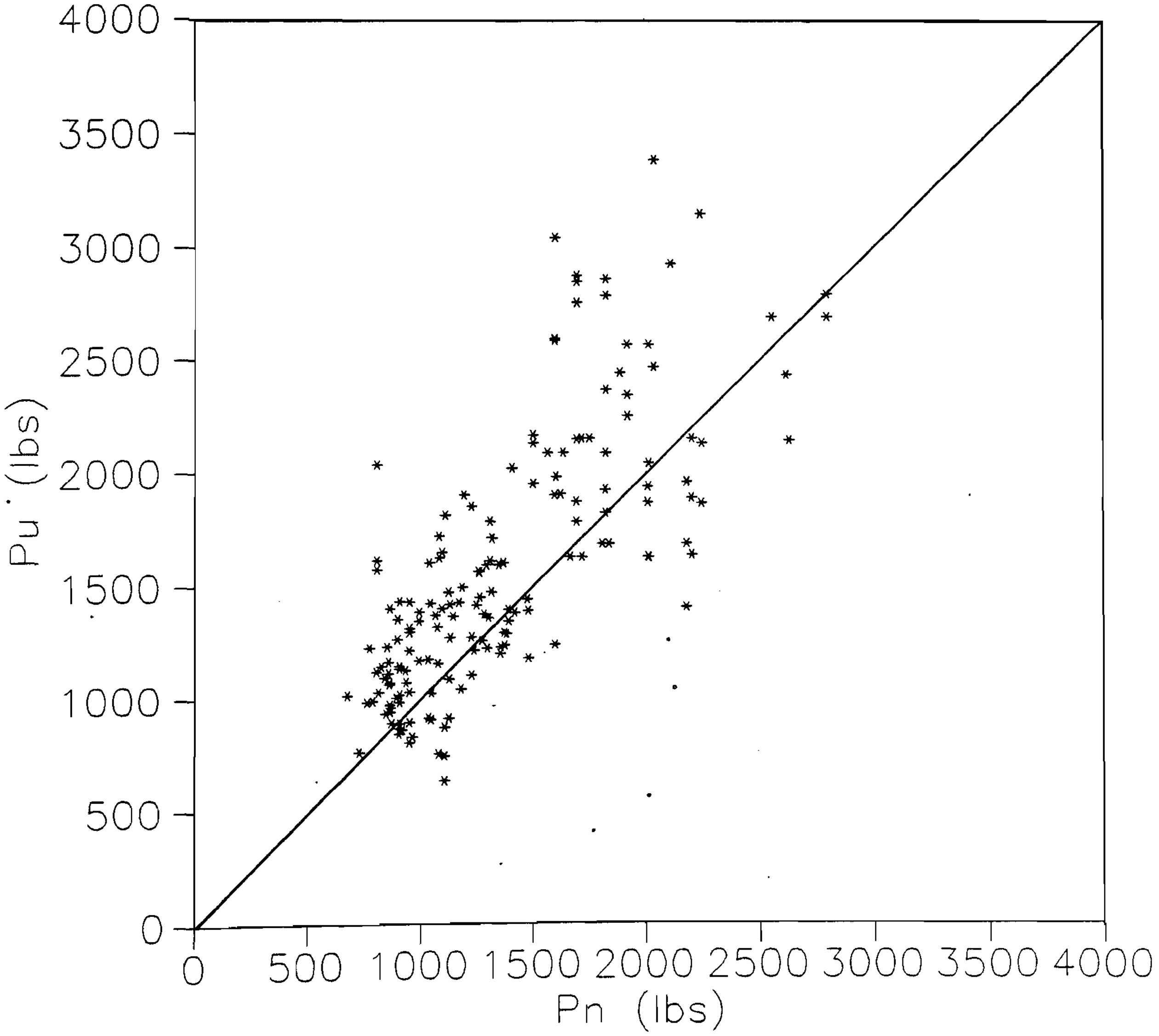


Fig. 13 Relationship Between P_u and P_n

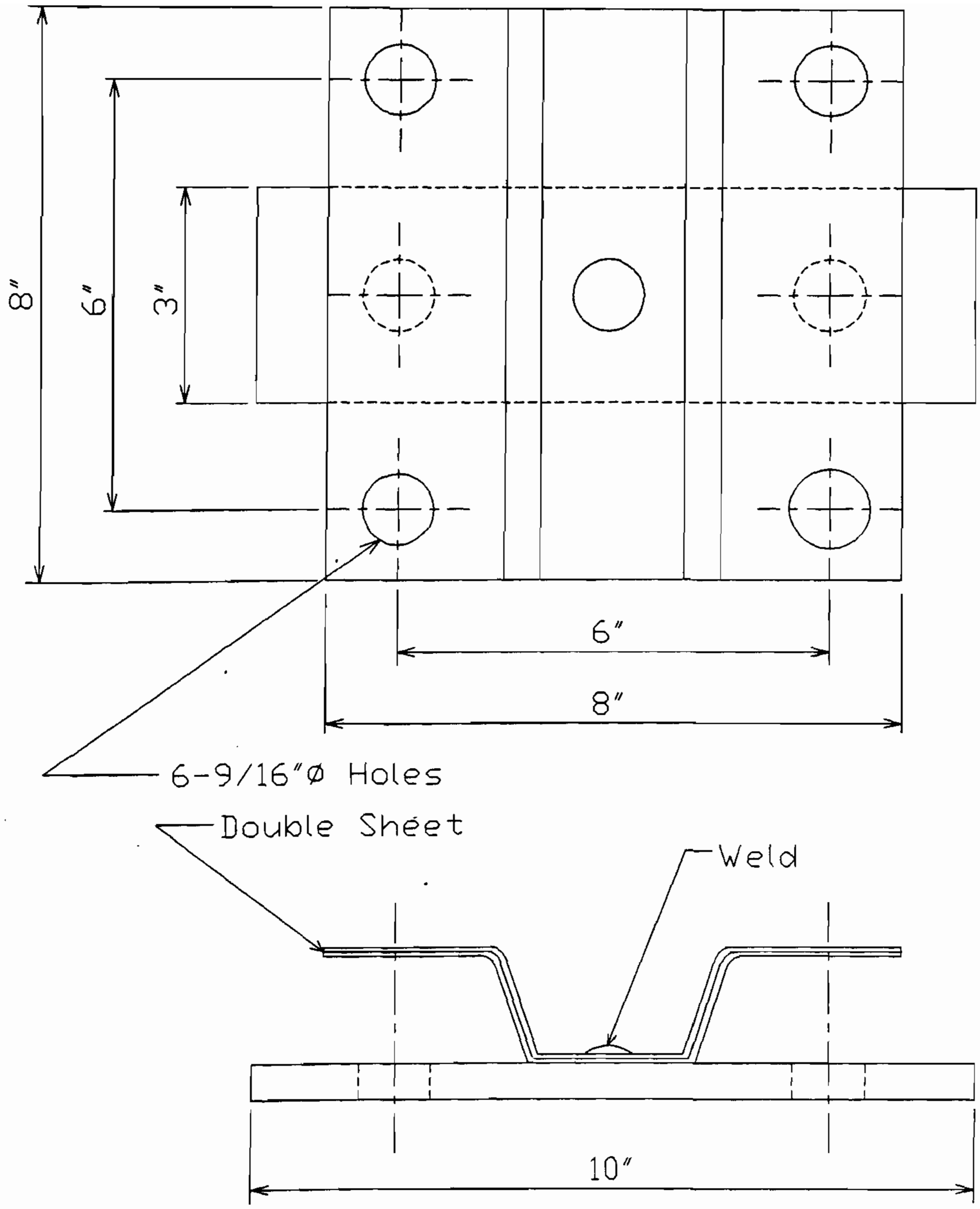


Fig. 14 Cross-Section of Double Sheet Specimens

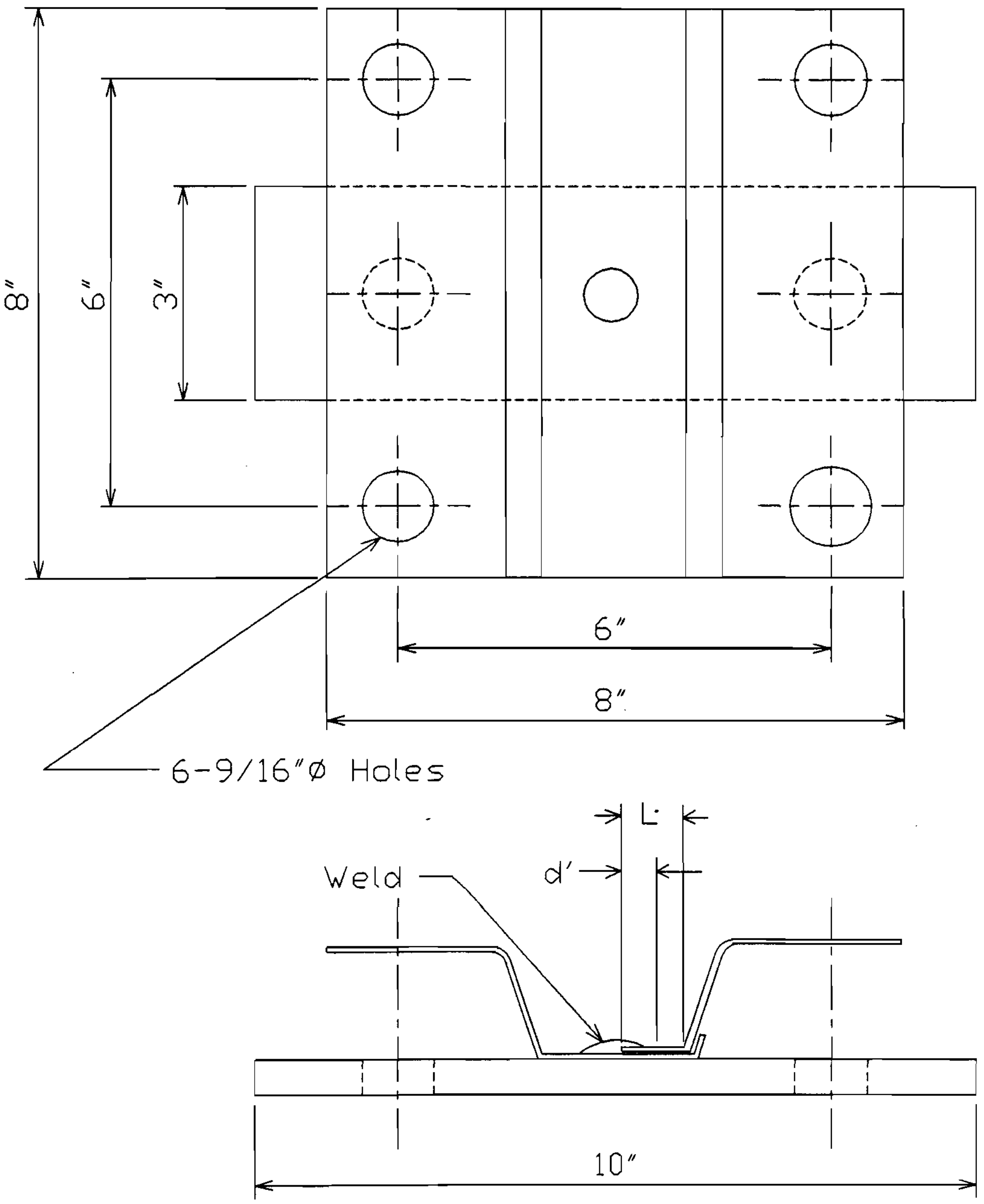


Fig. 15 Cross-Section of Lap Connection Specimens

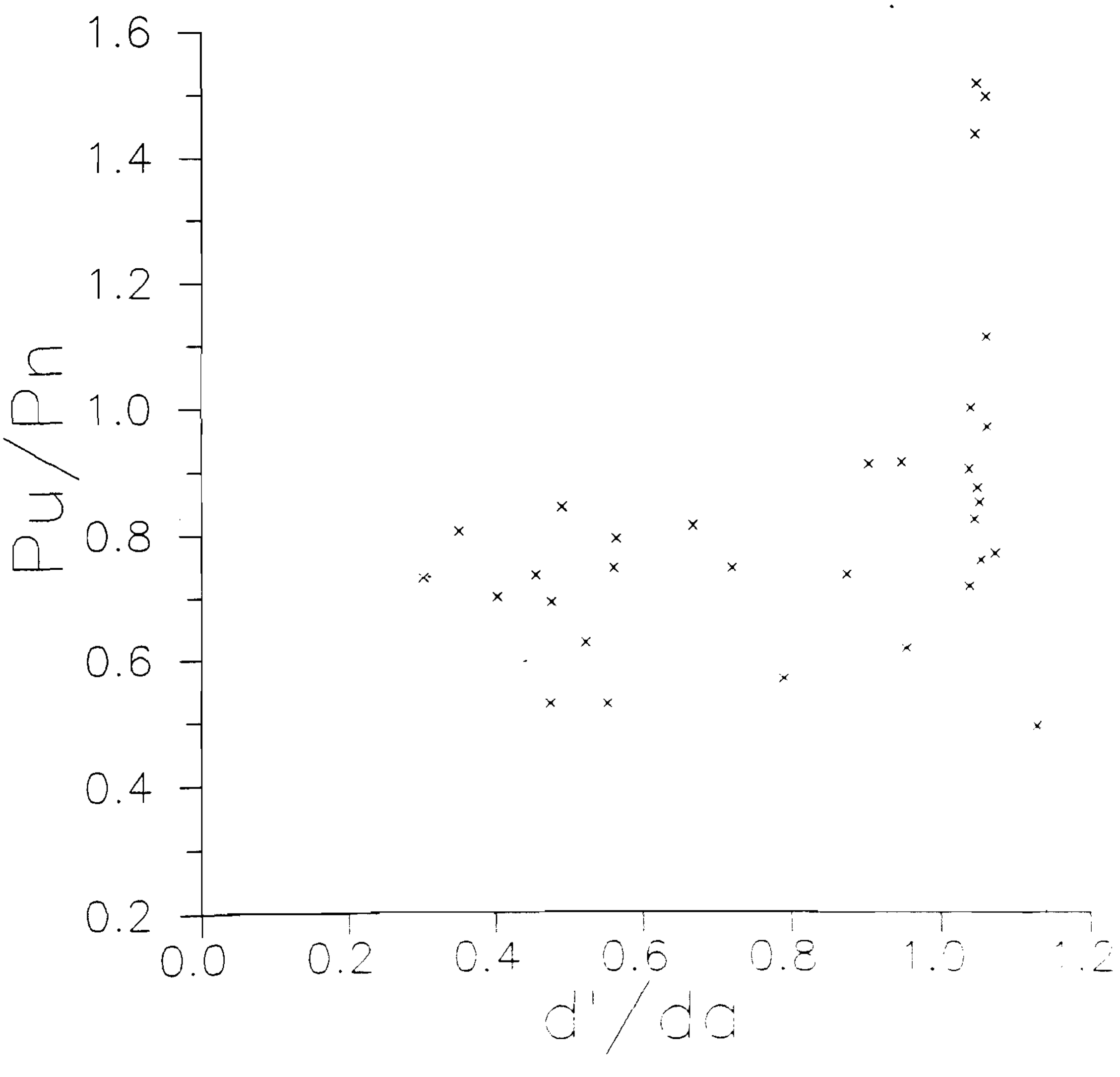


Fig. 16 Influence of Weld Position on Strength of Lap Connection

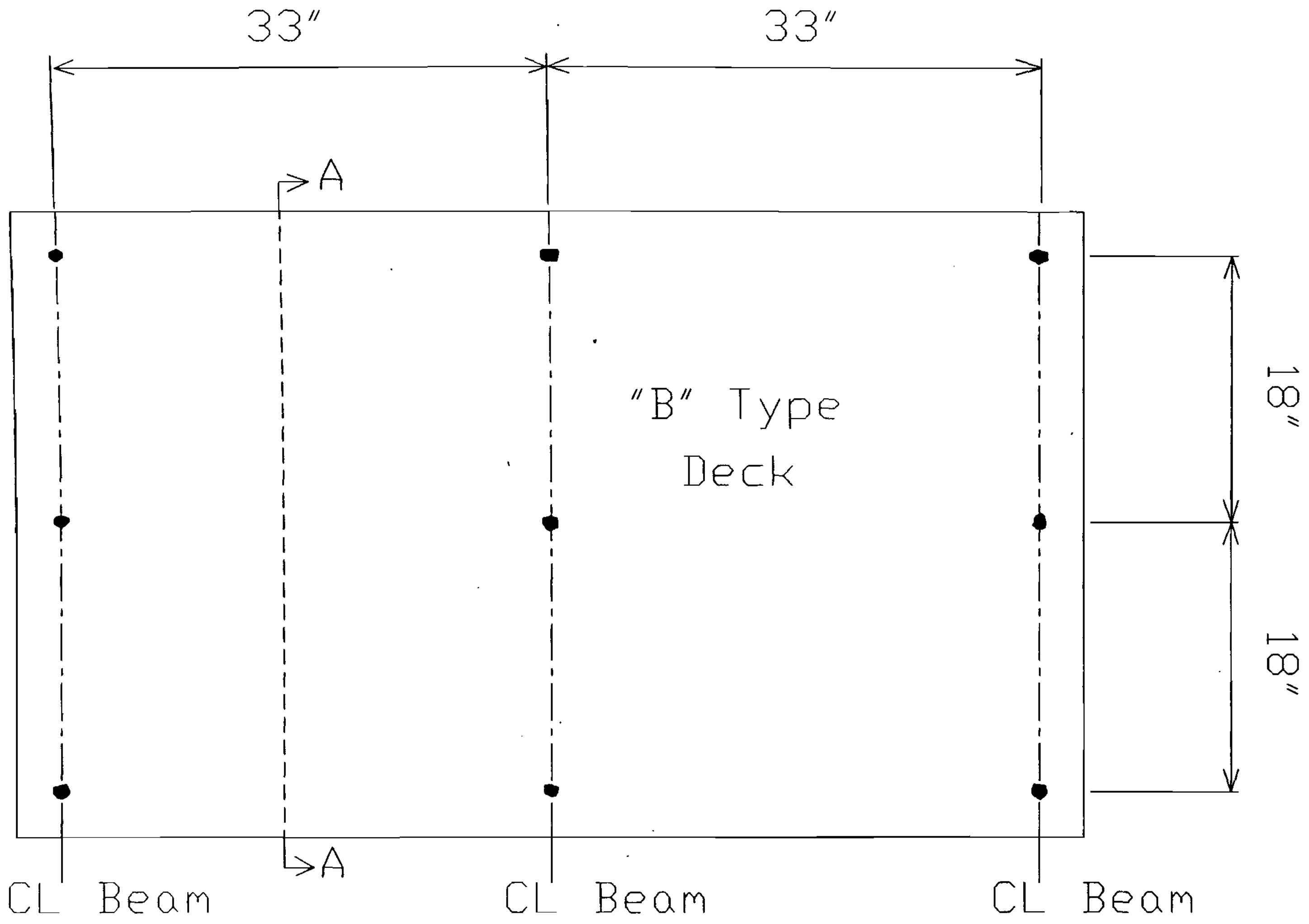


Fig. 17 Plan View of Full Panel Test Setup

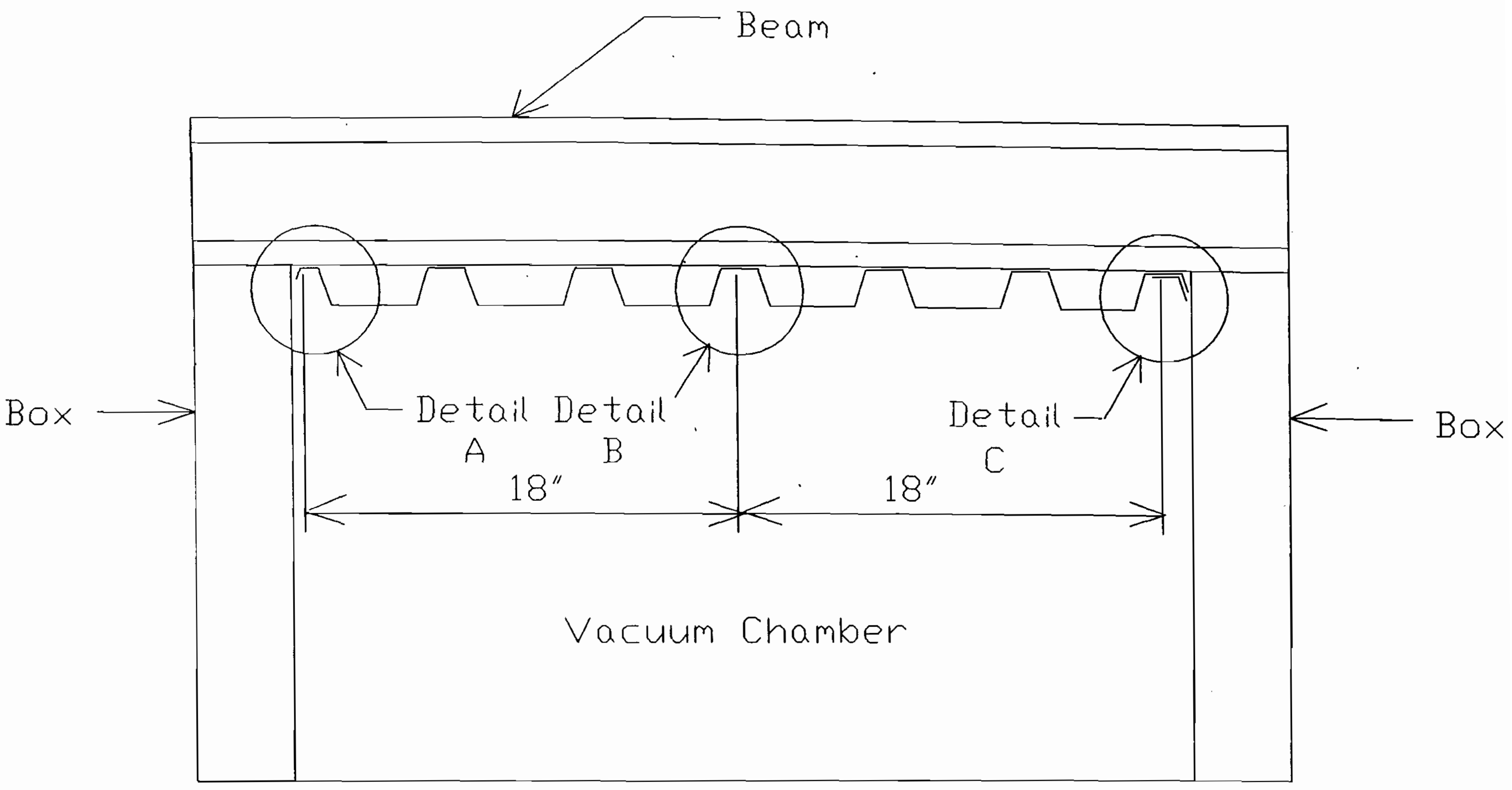


Fig. 18 Section A-A of Fig. 17

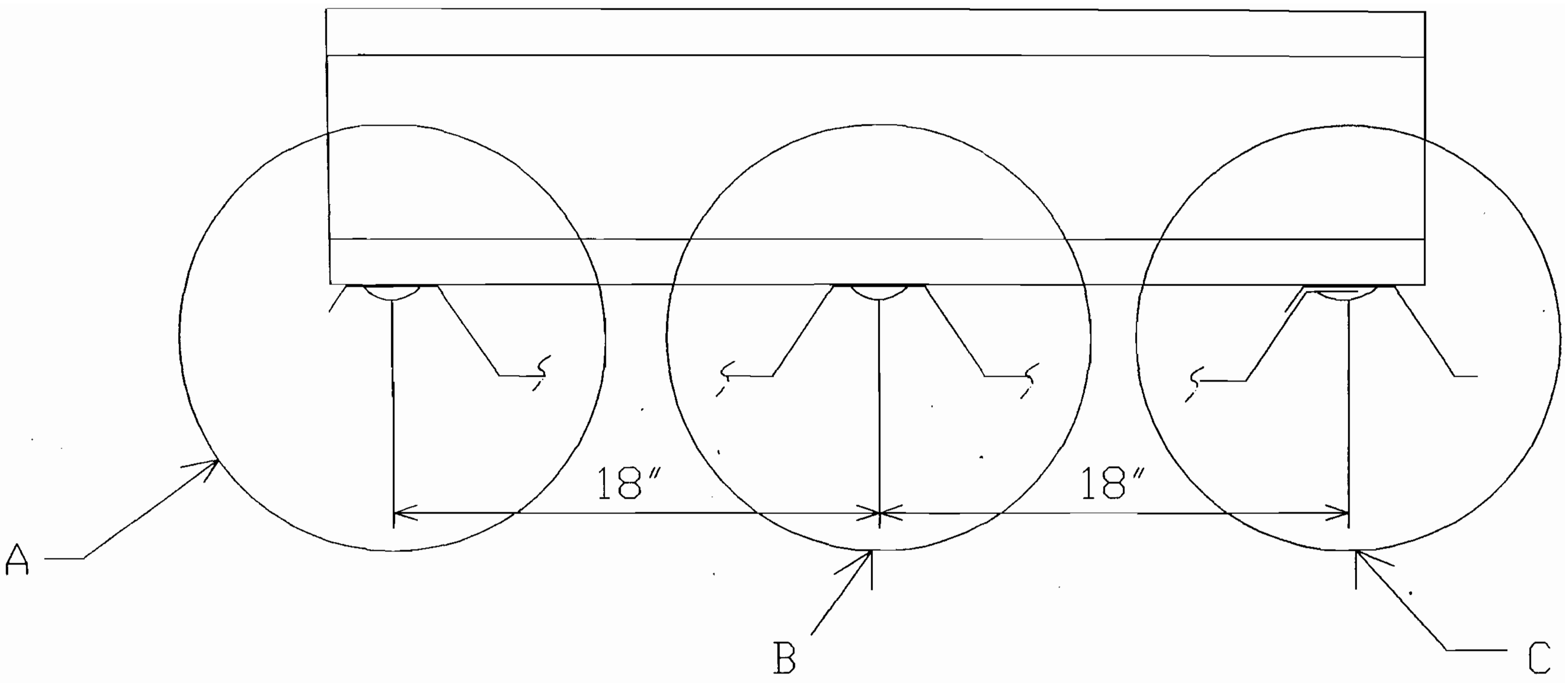


Fig. 19 Typical Connection Details of Fig. 18