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Welded and Rolled T-I Columns

RESIDUAL STRESSES IN T-1 CONSTRUCTIONAL ALLOY STEEL PLATES

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TABLE OF CONTENTS

ABSTRACT

This paper presents the results obtained and conclusions made in an experimental investigation of residual stresses due to welding and cutting in welded and unwelded T-1 steel plates.

Welded and unwelded specimens having either sheared or flame cut edges were tested. The residual stress pattern and magnitudes are presented for a wide range of plate and weld sizes. The effect of different types of electrode, number of passes, weld size and, mainly, the geometry of the plate is discussed.

A knowledge of the residual stress pattern and magnitude in plates makes it possible to estimate the residual stresses in shapes built-up from plates by welding. The strength of a column depends on the residual stress distribution and magnitude; therefore knowing these, and other properties the strength of the column can be estimated.

1. INTRODUCTION

A research project on "Welded Built-Up and Rolled Heat Treated T-1 Columns" is in progress at Fritz Engineering Laboratory, Lehigh University, under the guidance of Task Group 1 of the Column Research Council. The following report presents the results of the experimental investigation in one phase of the Project: "Residual Stresses in Welded T-1 Plates."

The overall study is also concerned with the residual stresses in welded built-up and rolled heat treated T-1 steel columns.

T-1 constructional alloy steel*, is a low carbon, quenched and tempered steel, introduced by the United States Steel Corporation in 1953. It has exceptional strength and toughness, combined with good weldability. Procedures for proper welding, and selection of electrodes for this steel are summarized in Ref. 1. T-1 steel is furnished with a minimum yield strength of 100 ksi and a tensile strength in the range of 115 to 135 ksi for plate thicknesses between 3/16" to 2-1/2", inclusive. The modulus of elasticity is approximately 30,000 ksi. Detailed information on mechanical properties, chemical composition and processing of T-1 steel is given in Ref. 2.

PURPOSE AND SCOPE

Residual stresses occur in almost all structural steel members as a result of plastic deformations which take place during or after various fabrication operations. Rolled sections contain residual

* T-1 constructional alloy steel meets the requirements of ASTM A514 steel.

stress due to uneven cooling after rolling. The rate of cooling at the central section of the flange in wide-flange shapes is considerably slower than the rate at the edges. This faster cooling rate at the edges normally causes compressive residual stresses at the edges and tensile residual stresses at the center of the flange.[3] Rolled sections often require cold straightening which induces strains beyond the yield strain in some parts of the section, and thereby causes residual stresses. Cambering leaves a pattern of residual stress similar to the pattern due to cold straightening, but different from the pattern left by uneven cooling[4,5]. Another important cause of residual stresses is the process of welding. The residual stresses introduced by welding resemble in pattern those due to uneven cooling, and are caused by the local heat input and resulting plastic deformation during cooling[4]. The formation of residual stress due to welding is a complicated process because of the large number of factors involved, such as material properties, type of welds, welding procedure and the geometry of the shape[6,7]. The geometry of the shape has been shown to be one of the main factors[6].

When plates are welded together to form a column or any other structural member, residual stresses are formed due to the welding, and these residual stresses may decrease the strength of the section considerably. The strength of a compression member in general depends on the average stress-strain relationship for the member which in turn depends on the magnitude and distribution of residual stress[4,8,9]. The compressive residual stresses reduce the buckling strength of the member by causing early local yielding at certain parts of the cross section. It is known[4] that the presence of residual stresses is the major factor affecting the strength of centrally loaded columns of low to medium slenderness ratios, L/r, depending on the strength of the steel* so that the design curves for column strength need to be modified to take account of residual stress.

It is essential, therefore, to have an accurate knowledge of the residual stress distribution and magnitude for various plate thickness and widths, and for different weld types and sizes**.

This paper gives the experimental results of tests performed on a large number of plates with various geometric properties. Table 1 gives the sizes of the plates and the tests conducted. Tables 2 and 3 show the geometry of the plates and additional related information on tests and welding.

PREVIOUS STUDIES AND EXPERIMENTS

The analytical methods for the determination of the magnitude and distribution of residual stresses in welded plates are extremely complicated and are not exact. However, a number of theoretical studies have been made, based on simplifying assumptions. Ref. 10, has a complete summary of theoretical and experimental work on this subject.

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* $40 < L/r < 120$ for ASTM A7 steel[4], $30 < L/r < 60$ for T-1 steel.

** The weld sizes are defined in Fig. 1, and the individual dimensions are given in Table 3.

Although residual stresses have been studied extensively, Ref. 10 was the first to present definite conclusions on the studies conducted on plates with varying geometry. A wide range of welded and unwelded ASTM A7 steel plates were tested and conclusive results were presented. Also, the results of a theoretical study were presented in Ref. 6 for the same plate geometries, employing a simple step-by-step method which takes into account the complete history of the cooling of the piece and the variation of material properties.

There was not, however, any study on residual stresses in higher strength (over 100 ksi) steel plates, welded or unwelded, and the tests reported in this paper were conducted to obtain the data for plates of T-1 constructional alloy steel.

2. DESCRIPTION OF TESTS

TYPES OF PLATES AND WELDS

The plate sizes tested were selected so as to represent the component parts of commonly used built-up members. The plates chosen encompassed a range larger than any hitherto tested in any single program. Tables 1, 2 and 3 give the summary of the plate dimensions and the tests conducted.

Generally universal mill plates are cold-straightened at the mill to be within specified tolerances. This cold-straightening results in residual stresses at some locations, and these locations should be excluded from the program. For structural carbon steel, ASTM A7 steel, the locations affected by cold-straightening are easily spotted by the flaking of mill scale. This is not true for T-1 steel. An attempt was made to identify cold-straightened locations by observing yield lines and plates containing such yield lines were not tested.

The plates were cut to specified sizes from wide plates. The usual cutting procedure is by flame cutting, however, for thin plates (up to 1/2" thickness) shearing is also applied. Both cutting procedures leave some residual stress in the plate. For comparison of the effect of different cutting procedures on the magnitude and distribution of residual stress, both flame-cut edge and sheared edge plates were tested. Tests T-1 to T-9 inclusive were on plates cut by flame cutting and Tests T-10 and T-11 were on plates cut by shearing.

The plates tested included unwelded plates, center welded plates and plates welded along one or both edges, the latter two simulating the components of welded built-up H and box shapes, as shown in Fig. 1. Manual shielded metal-arc welding, and automatic submerged arc welding processes were employed. The electrodes used for most of the manual welds were E70 series, which are commonly used in industry and, correspondingly, the wire and flux combination used was L70 and L840 used for automatic submerged-arc welding.

For determination of possible difference in magnitude and distribution of residual stress due to the use of different electrode types, a higher strength electrodes also was used. Automatic welding, using L100 series with a 709 flux, was performed on plates T-5-5 and T-5-6 of Test 5. Either single or double V-grooves were used for the center welded plates. Of the eighteen center welded plates, ten were welded by an automatic welding process, and eight by a manual welding process. Two of these plates, T-6-10 and T-6-12, were welded with double V-groove. Table 3 gives the types of welding employed, and Table 4 shows the electrode types used for each plate. Nineteen plates were welded on one or both edges. Thirteen plates of this group were welded by automatic welding and six plates by manual welding process. Plates T-6-8, T-5-10, T-7-6, T-8-4, and T-9-6 were welded on both edges to simulate H and box shape components. All of the plates mentioned above were cut from rolled plates by commonly used flame cutting procedure. In addition, eleven sheared plates were tested to observe any possible differences in the residual stress magnitude and distribution due to different cutting procedures; 1/4" x 4" and 1/2" x 6" plates of tests T-10 and T-11 respectively. Three plates were center welded and two plates were single-edge welded; both manual and automatic welding processes were employed. (Tables 3 and 4).

The plates were welded by professional welders in the welding shop of a large industrial plant and the information related to welding such as voltage, amperage, speed of electrode travel, type of electrode, number and position of beads was recorded. Table 4 gives the detailed information on the welding procedures used.

In Test 3, the plate was center welded by manual arc welding along the length and the residual stress measurements were taken in four places to check the variation in magnitude and distribution along the length of the plate. (Figure 2 shows the layout for plate T-3).

RESIDUAL STRESS MEASUREMENTS

All the plates were sufficiently long* so that a uniform state of stress existed in the portions where the residual stresses were measured. The method of "sectioning" was used for the measurement of residual strains, because it is simple and gives the average strains[5] within the gage length. Longitudinal strains were measured over a 10" gage length by a 1/10,000" Whittemore strain gage on a series of previously laid out holes across the width of the plate. Figure 3 shows a typical layout of the holes. The personal factor on measuring the strains with the Whittemore gage was found to be negligible, after comparison of independent measurements made by two different investigators.

* At least three times of the width plus the gage length.

The strain readings were from both top and bottom faces of the plates, except plates of 1/4" thickness which were measured on the top face only, because they are in the category of "thin plates" which are expected to have the same residual stress distribution throughout the thickness of the plate[10]. The spacing of the gage holes was arranged to give more readings in regions of stress variation than in regions of constant stress. Both ends of the 10" gage length were at a distance of 1/2" from the cut edges. A standard 10" steel bar was used to compensate for the effect of temperature changes on the strains during the readings. The residual strains were obtained after measuring the stress-relieved, sawed strips, containing the gage holes. Figure 4 shows the sawed strips, the Whittemore gage, and the temperature bar.

The residual stress was then determined by the simple formula

$$\sigma_r = E \left[(R_1 - R_2) - (T_1 - T_2) \right]$$

where

σ_r is the average residual stress along the 10" gage length (ksi)

R_1 is the non-dimensionalized distance between gage holes before sectioning (in/in)

R_2 is the non-dimensionalized distance between gage holes after sectioning (in/in)

T_1 is the non-dimensionalized distance between the holes in the temperature compensating bar at the time of R_1 readings (in/in)

T_2 is the non-dimensionalized distance between the holes in temperature compensating bar at the time of R_2 readings (in/in)

E modulus of elasticity of steel (ksi)

Positive results indicate tensile residual stresses and negative results indicate compressive residual stresses.

It should be noted, however, that only the longitudinal residual stresses are obtained by this method.

MECHANICAL PROPERTY TESTS

A number of tension tests were conducted on coupons, cut from the plates before and after welding, to ascertain the material properties. Small coupons made of weld metal were tested to obtain the yield stress level* of the weld metal. The dimensions of the tensile coupons were in accordance with ASTM specifications[11]. Table 5 shows the plates tested and Fig. 5 shows a typical layout for procurement of the test specimens.

* See Definitions

3. TEST RESULTS AND DISCUSSIONS

The results obtained for some of the tension coupon tests are presented in Table 6, and typical load-strain relationships for weld metal and for a T-1 steel tension coupon are shown in Figs. 6 and 7, respectively. According to the test results, the static yield stress level* was 110 ksi, and the modulus of elasticity, E, was 30,000 ksi.

The results indicate that for most of the plates, the residual stresses at the top and bottom faces were little different but the difference was so small compared to the yield strength of the material, that the average value could be used. (Figs. 10 through 18). The results obtained are presented in a tabular form in Tables 7, 8 and 9, where the values of residual stresses are the averages of both top and bottom faces of a plate. The sheared edge plates, test T-11, Fig. 11, contained large compressive and tensile residual stresses on top and bottom faces, respectively. Because it is sometimes essential to have a knowledge of the pattern and magnitude for individual faces, the top and bottom stresses were not averaged. The "thin" plates of tests T-1 and T-10 were considerably bent after sectioning, therefore, the results were adjusted to compensate for the effect of curvature.

The results obtained from this experimental study are presented in three parts. Residual stress in as-cut plates, in center welded plates and in edge welded plates.

* See Definitions

AS-CUT PLATES

For as-cut plates, the residual stresses result from cutting (flame cutting or shearing) and other fabrication processes. The residual stresses obtained for flame cut plates are shown in Fig. 8, 10 and 12 to 18 inclusive, and a tabular representation is given in Table 7. The maximum compressive residual stress was in the range of 3 ksi to 10 ksi, the average being approximately 6 ksi. The average maximum compressive residual stress for plates wider than 12" was approximately 4 ksi. This average compressive stress extended across 60 to 95% of the plate width. The maximum tensile residual stress was at the edges and ranged from 26 ksi to 86 ksi. Two plates 24" x 1" (T-9-3, and T-9-5), showed a peculiar pattern as given in Fig. 18. The shape of these curves probably resulted from cold work. Table 7 also presents the distances where the compressive and tensile residual stresses occured along the width of the plate.

The plates with sheared edges presented an entirely different residual stress pattern as can be seen in Figs. 9 and 11. The results obtained from the 4" x 1/4" plates are shown in Fig. 9 . These are the values calculated from measuring strains on one face, and they are adjusted to exclude the effect of curvature. In the 6" x 1/2" plates there is a very different appearance between the residual stress patterns of the top and the bottom faces, as seen from Fig. 11, at the sheared edges.

CENTER WELDED PLATES

The distribution of residual stress across the widths of the center welded plates as measured on top and bottom faces are shown in Figs. 10 through 18, and for plates measured on one face only in Figs. 8 and 9. The salient dimensions of the residual stress distribution are enumerated in Table 8 for most of the plates. They are based on the averages of the magnitude of residual stress measured on both top and bottom faces. The resulting curve and the notations used in the table are shown on top of Table 8. Tensile residual stresses were observed at the flame cut edges and at the weld. The compressive residual stress reached a maximum of about 24 ksi in plates welded by automatic welding and a lower value of 16 ksi for plates welded manually. The average compressive residual stress ranged from 6 ksi to 18 ksi.

The highest tensile residual stress for the plates of Tests T-2 through T-9 was found to be about 84 ksi at the weld for plate 2 of Test T-5 (Fig. 14), having a 1/4" automatic weld. The residual stress distribution in plates with flame cut edges 4" x 1/4" are shown in Fig. 8.

The results obtained from center welded sheared edge plates are shown in Figs. 9 and 11. The maximum compressive residual stress averaged about 19 ksi for the various plates investigated, being equal to 22 ksi for automatic welding, and a lesser value for manual welding.

The effect of different electrode strength on the magnitude and pattern of residual stress was studied on a 12" x 1/2" plate. The plates were welded automatically with a high strength electrode of the L100 series and 709 flux. As seen from Fig. 14 there is no important difference in pattern or magnitude of residual stress in plate T-5-4 welded automatically with an L70 electrode, and in plate T-5-5 welded automatically with an L100 electrode. Therefore, it was concluded that no important effect on the resulting residual stress resulted from the use of an electrode having 30 ksi higher tensile strength. Some of the plates of Test T-5 and T-6 had different weld sizes. This was done to study the effect of different weld sizes on residual stress in plates with the same geometry. Figures 14 and 15 show that the effect of different weld sizes is small. The magnitude and distribution of residual stress resulting from larger weld did not differ from that resulting from smaller weld except for a reduction of tensile residual stress at the flame cut edges for the larger weld.

Although no data are available to allow a direct comparison of the effect of number of weld passes on the residual stresses in plates of the same size welded in the same way, the available results suggest that the effect would be small. Plates T-6-10 and T-6-12 were welded with a double V-groove and the comparison of the results with those obtained for plates T-6-6 and T-6-8 welded with a single V-groove of the same size weld showed no significant difference in the residual stress pattern and magnitudes. (Fig. 15).

EDGE WELDED PLATES

The residual stress patterns measured experimentally are shown in Figs. 8 through 18. The salient dimensions of the residual stress distributions for most of the plates are presented in Table 9. The notations used in Table 9 are explained in its inset figure. The maximum compressive residual stress obtained from flame cut plates of tests T-2 through T-9 was 20 ksi in plate T-4-6 (Fig. 13), the average being approximately 10 ksi. The average compressive residual stress in most of the wider plates of tests T-7, T-8 and T-9 (Figs. 16, 17, 18) was 6 ksi. The tensile residual stresses at the welded edges were comparatively high, reaching the yield strength in the weld for the 1/2" automatic weld on Plates T-6-16 and T-9-6 (Figs. 15 and 18), and was approximately 80 ksi for most of the plates.

Some stress reversals were observed in plates T-9-4 and T-9-6 (Fig. 18) probably due to the cold-straightening of these plates.

The residual stress pattern for the sheared edge plates are shown in Figs. 9 and 11. The tensile residual stress at the welded edge was as high as 85 ksi for Plate T-11-8. However, the characteristic residual stress in the sheared edge plates exists at the non-welded edges; that is, high compressive residual stresses on one face and high tensile residual stresses on the other face of the plate. Although individual stress values as high as 37 ksi were observed, a negligible average value resulted.

As shown in Figs. 14 and 15, no important difference in magnitudes and patterns of residual stresses resulted from the use of different electrode types on plates of Tests T-5 and T-6. Plate T-5-6 was welded automatically with a high strength electrode of the L100 series with 709 flux. Comparing these results with those obtained for plate T-5-10 which had the same weld size, but was welded with the L70 electrode, shows that the patterns and magnitudes of residual stress formed in these plates were similar. (Fig. 14).

From the results obtained it appeared that the distribution of the residual stress in T-1 steel plates may be represented by straight lines. (Figs. 8 through 18). Also, the residual stress distribution in plates non-welded, center welded and welded on both edges may be considered as symmetrical about the center line for practical purposes. (Figs. 8 through 18).

4. COMPARISON WITH THE RESULTS OBTAINED FROM ASTM A7 STEEL

An extensive investigation was carried out in Fritz Engineering Laboratory, Lehigh University, to determine the residual stresses in manually welded ASTM A7 steel plates. Reference 10 presents the results of that study.

It would be of interest to compare the results obtained for A7 steel plates with those obtained for T-1 steel plates, since the comparison might give some knowledge on the difference in behavior of compression members built-up from these steels. However, the A7 steel plates included in the previous study had rolled edges, (universal mill plates), whereas the plates in this study had mainly flame cut edges. Furthermore, plates with identical geometry were not tested in the two programs. Thus no direct comparison of plates of the two steels is possible.

The residual stresses introduced due to flame cutting or shearing of the edges in T-1 steel plates are different from those found in universal mill plates of A7 steel. Representative patterns of residual stresses in the unwelded plates are shown in Fig. 19. Although there is a significant difference, it is probably due more to different edge treatment of the plates than to the different steels.

Typical results of edge welded plates of both steels are shown in Fig. 20. The most significant difference is the patterns of distribution of stresses. T-1 steel shows rather constant distribution of compressive residual stress and abrupt change from compressive residual stresses to tensile residual stresses near the edge. The distribution in A7 steel plates are reasonably smooth throughout. Most of the A7 steel plates welded at one edge, had tensile residual stresses at both welded and unwelded edges and the tensile residual stress existed over a large percentage of total width, including the sections which had contained compressive residual stresses in the unwelded state. The peak value of the compressive residual stresses in A7 steel plates is higher than those in T-1 steel plates of similar geometry. However, such large magnitudes take place at a point covering only a small portion of the total width. In general, the magnitude of compressive residual stress is slightly higher in T-1 steel plate over most of the width of the plate. A good average of the difference is 2 to 3 ksi for the plates between 4 to 8 inches wide and less than 2 ksi for the wider plates. The portion of the width under compressive residual stress is 30 to 50% of the total width in A7 steel plates whereas it is about 60 to 80% of the total width in T-1 steel plates.

The tensile residual stress at the weld ranged from 40 to 60 ksi for A7 steel plates, welded by E60XX electrodes. The magnitude in T-1 steel plates was higher and ranged from 60 to 110 ksi.

Similar results have been observed in center welded plates. Fig. 21 represents the results. The compressive residual stress in center welded A7 steel plates was not constant and showed the peak at the edges for narrow plates from 4 to 12 inches wide. For wider plates this peak value was observed somewhere between the weld metal and the edges. Again the peak value of compressive residual stress were often larger than those in T-1 steel plates. However, the average value as well as the portion of area under compressive residual stress were relatively small in A7 steel plates. The distribution of stress in A7 steel plates was smooth and may be closely approximated by a parabola, especially for narrow plates. However, this was not true in T-1 steel plates. Even for the narrower plates of T-1 steel (6 inches wide), the compressive residual stress is rather constant and the change from compressive to tensile stress was abrupt. The pattern may be closely approximated by straight lines rather than by a parabola. This difference in pattern was one of the significant results found in this investigation.

Because the compressive residual stress in T-1 steel plates constitutes a much smaller fraction of the yield strength than the residual stresses in A7 steel plates, the effect of residual stress on the strength of welded T-1 steel compression members should be smaller than the effect of residual stresses on strength of compression members of A7 steel.

5. SUMMARY AND CONCLUSIONS

This report presents the results of an experimental investigation to determine the magnitude and distribution of residual stresses in welded (both automatically and manually) and unwelded plates of T-1 Constructional Alloy quenched and tempered steel. The plates investigated vary in width from 4 to 24 inches and in thickness from 1/4 to 1 inch. The results of this study will be used in the determination of the influence of residual stress on the strength of welded built-up compression members.

1. The distribution of residual stress in T-1 steel plates, whether due to cutting of the edges in the unwelded plates, or due to welding in welded plates, may be represented by straight lines. In contrast the distribution in A7 steel plates is approximately parabolic[10]. (Section 4, Figs. 8 through 21).
2. Because there is a little difference between the residual stress distributions at the top and bottom faces of the plates, the average value gives a good representation of the residual stress in the plate (Section 3, Figs. 10, 12 through 18).
3. The distribution of residual stress in plates center welded, unwelded and welded on both edges are approximately symmetrical about the center line. (Section 3, Figs. 10 through 18).

4. Electrode strength has little effect on the residual stress distribution of plates having the same geometry. (Section 3, Fig. 14).
5. Manual and automatic welding resulted in residual stresses of a similar pattern. However, slightly higher magnitudes of stress was observed for the automatically welded plates. (Section 3, Figs. 10, 12 through 18).
6. With uniform welding conditions the distribution and magnitude of residual stress is constant along the longitudinal direction of a welded plate. (Section 3, Fig. 12).
7. Flame cutting produces a residual stress distribution similar to that due to edge welding but at lower magnitudes. (Section 3, Figs. 10, 12 through 18).
8. Near the weld or near a flame-cut edge the transition in residual stress from tensile to compressive is a straight line having a very steep slope. In contrast the transition in plates of A7 steel was more gentle. (Section 4, Figs. 10, 12 through 21).
9. Plates with the same geometry, but different weld sizes have residual stresses similar in pattern, but with slightly higher magnitudes for larger welds. (Section 3, Fig. 10, 12 through 18).

10. The number of weld passes seems to have no significant effect on the shape and magnitude of residual stress in plates having the same geometry. (Section 3).
11. The results of this experimental study make it possible to estimate the residual stress pattern and magnitude in T-1 steel plates, welded and unwelded. (Tables 7, 8 and 9).
12. Shearing results in the formation of residual stresses which are totally different in pattern from those resulting from flame cutting. Individual faces of unwelded plates with sheared edges have different residual stress patterns, and residual stresses at the individual faces have the same magnitude but opposite sign. (Section 3, Figs. 9 and 11).

6. ACKNOWLEDGMENTS

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The project is sponsored by the United States Steel Corporation. Charles G. Schilling of that corporation made many valuable comments, both in the course of the program, and in the preparation of this report. Task group 1 of the Column Research Council of the Engineering Foundation acted in an advisory capacity under the chairmanship of John A. Gilligan.

The report was typed with care by Miss Marilyn Courtright.

7. NOMENCLATURE

b = width of the plate

t = thickness of the plate

E = modulus of Elasticity (ksi)

T = depth of weld

L/r = slenderness ratio

S = plate welded along single edge

D = plate welded along both edges

V = single - Vee groove

2-V = double - Vee groove

Z_i = distances in inches used to show the distribution of residual stress along the length: as shown in the figures of tables 7, 8 and 9.

σ_{ri} = magnitudes of residual stress in ksi, at locations shown in the figures of tables 7, 8 and 9.

σ_{ys} = static yield stress level (zero strain rate).

8. DEFINITION OF TERMS

Residual Stresses

Stresses formed as a result of permanent deformations during the fabrication or manufacture.

Yield Point

The first stress in a material, less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress[11].

Yield Strength

The stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain[11].

Yield Stress Level

The average stress during yielding in the plastic range. It remains fairly constant for structural steel, provided the strain rate remains constant.

Static Yield Stress Level

The average stress during actual yielding in the plastic range with zero strain rate.

9. TABLES AND FIGURES

TABLE 1 PLATE SIZES TESTED

Plates With Flame Cut Edges

t \ b	4	6	8	12	16	20	24
1/4	xo						
3/8						xo	
1/2		xo+	o	xo+*	xo+		
1			xo+	xo+*			xo

Plates With Sheared Edges

t \ b	4	6
1/4	xo+	
1/2		xo+

t Thickness of plate

b Width of plate

x Residual Stress before Welding

o Residual Stress after Welding

+ Coupon Tests before Welding

* Coupon Tests after Welding

TABLE 2 DATA GROUPED ACCORDING TO PLATE WIDTH

Test No.	Plate Size		Residual Stresses Measured		Type and Depth Of Welding (T), (in)			Coupon Tests		Weld Type	
	b (in)	t (in)	Before Welding	After Welding	Single -V	Double -V	Edge	Before Welding	After Welding	Aut.	Man.
Flame Cut Edge											
T-1	4	1/4	X	X	1/8	-	1/8	-	-	-	X
T-2	6	1/2	X	X	1/4	-	1/4	X	X	X	X
T-3	8	1/2	-	X	1/4	-	-	-	-	-	X
T-4	8	1	X	X	1/4	-	1/4	X	X	X	X
T-5	12	1/2	X	X	1/2,1/4	-	1/4,1/2	X	X	X	-
T-6	12	1	X	X	1/2,1	1	1/2,1/4	X	X	X	X
T-7	16	1/2	X	X	1/2	-	1/2	X	X	X	-
T-8	20	3/8	X	X	-	-	3/8	-	-	X	-
T-9	24	1	X	X	1/2	-	1/2	-	-	X	-
Sheared Edge											
T-10	4	1/4	X	X	1/8	-	1/8	-	-	-	X
T-11	6	1/2	X	X	1/4	-	1/4	X	-	X	X

TABLE 3 INFORMATION OF THE WELDING OF THE PLATES

Plates With Flame Cut Edges

Center Welded Plates					Edge Welded Plates				
Plate No.	Geometry (in.)	Type of Weld		Weld Size (in.)	Plate No.	Geometry (in.)	Type of Weld		Weld Size (in.)
		Aut.	Man.				Aut.	Man.	
T-1-2	4 x 1/4	-	X	1/8	T-1-4	4 x 1/4	-	X	1/8
-6	4 x 1/4	-	X	1/8	-7	4 x 1/4	-	X	1/8
T-2-2	6 x 1/2	-	X	1/4	T-1-6	6 x 1/2	-	X	1/4
-4	6 x 1/2	X	-	1/4	-8	6 x 1/2	X	-	1/4
T-3	8 x 1/2	-	X	1/4	-	-	-	-	-
T-4-2	8 x 1	-	X	1/4	T-4-6	8 x 1	-	X	1/4
-4	8 x 1	X	-	1/4	-8	8 x 1	X	-	1/4
T-5-2	12 x 1/2	X	-	1/4	T-5-6	12 x 1/2	X	-	1/2 (L100)
-4	12 x 1/2	X	-	1/2	-8	12 x 1/2	X	-	2 x 1/4
-5	12 x 1/2	X	-	1/2 (L100)	-10	12 x 1/2	X	-	2 x 1/2
T-6-2	12 x 1	-	X	1/2	T-6-14	12 x 1	-	X	1/2
-4	12 x 1	X	-	1/2	-16	12 x 1	X	-	1/2
-6	12 x 1	-	X	1	-18	12 x 1	-	X	1
-8	12 x 1	X	-	1	-20	12 x 1	X	-	1
-10	12 x 1	-	2VX	2V-1	-	-	-	-	-
-12	12 x 1	2VX	-	2V-1	-	-	-	-	-
T-7-2	16 x 1/2	X	-	1/2	T-7-4	16 x 1/2	X	-	1/2
-	-	-	-	-	-6	16 x 1/2	X	-	2 x 1/2
-	-	-	-	-	T-8-2	20 x 3/8	X	-	3/8
					-4	20 x 3/8	X	-	2 x 3/8
T-9-2	24 x 1	X	-	1/2	T-9-4	24 x 1	X	-	1/2
					-6	24 x 1	X	1	2 x 1/2

Plates With Sheared Edges

Center Welded Plates					Edge Welded Plates				
Plate No.	Geometry (in.)	Type of Weld		Weld Size (in.)	Plate No.	Geometry (in.)	Type of Weld		Weld Size (in.)
		Aut.	Man.				Aut.	Man.	
T-10-2	4 x 1/4	-	X	1/8	T-10-4	4 x 1/4	-	X	1/8
T-11-2	6 x 1/2	-	X	1/4	T-11-6	6 x 1/2	-	X	1/4
-4	6 x 1/2	X	-	1/4	-8	6 x 1/2	X	-	1/4

All center welded plates are welded with single Vee groove, unless otherwise specified

2V - Double Vee Groove

TABLE 4 RECORDS OF WELDING

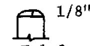
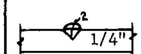
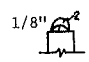
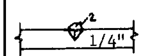
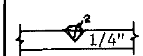
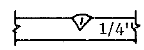
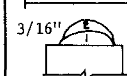
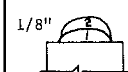
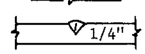
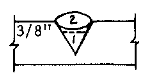
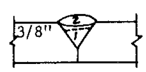
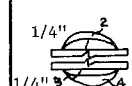
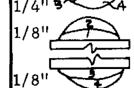
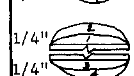
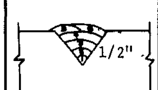
Plate No.	Pass	Volts	Amps	Electrode Travel (in/min)	Electrode Melt-Off (in/min)	Electrode Type	Type of Weld	Place of Weld	Flux	Beads
T-1-2	1	18	170	5.8	10.5	E7018(1/8"D)	M	C	-	
T-1-4	1	18	125	24.0	9.55	"	M	E	-	
T-1-6	1	18	170	7.0	10.4	"	M	C	-	As T-1-2
T-1-7	1	18	125	24.0	9.55	"	M	E	-	As T-1-4
T-2-2	1	20-22	130	8.0	9.9	"	M	C	-	
	2	20-22	210	8.8	8.5	E7018(3/16"D)	M	C	-	
T-2-4	1	32	350	12.0	120.0	L70(W)5/64"	A	C	L840	
T-2-6	1	22	160	9.2	10.4	E7018(5/32")	M	E	-	
	2	22	160	9.3	10.6	"	M	E	-	
T-2-8	1	28	300	30.0	111.1	L70(W)5/64"	A	E	L840	
	2	28	300	30.0	111.1	"	A	E	"	
T-3	1	20-22	130	6.6	10.2	E7018(1/8"D)	M	C	-	
	2	20-22	210	8.8	8.6	E7018(3/15"D)	M	C	-	
T-4-2	1	20-22	130	6.8	9.8	E7018(1/8"D)	M	C	-	
	2	20-22	210	9.2	8.6	E7018(E/16"D)	M	C	-	
T-4-4	1	32	350	15.0	120.0	L70(W)5/64"	A	C	L840	
T-4-6	1	22	160	9.0	10.4	E7018(1/8"D)	M	E	-	
	2	22	160	8.0	9.8	E7018(1/8"D)	M	E	-	
T-4-8	1	28	300	30.0	111.1	L70(W)5/64"	A	E	L840	
	2	28	300	30.0	111.1	"	"	"	"	
T-5-2	1	32	350	12.0	120.0	L70(W)5/64"	A	C	L840	
T-5-4	Tack Welds	20-22	130	4.9	9.8	E11018(1/8"D)	M	C	-	
	1	32	350	12.0	120.0	L70(W)5/64"	A	C	L840	
	2	32	350	12.0	120.0	"	A	C	L840	
T-5-5	Tack Welds	20-22	130	5.8	8.7	E11018(1/8"D)	M	C	-	
	1	32	400	18.0	120.0	L100(W)1/8"D	A	C	709-5	
	2	32	500	18.0	120.0	"	A	C	709-5	
T-5-6	1,2	30	350	24.0	44.4	L100(W)1/8"	A	E	709	
	3,4	30	350	24.0	44.4	L100(W)1/8"	A	E	709	
T-5-8	1,2	28	300	30.0	111.1	L70(W)5/64"	A	E	L840	
	3,4	28	300	30.0	111.1	L70(W)5/64"	A	E	L840	
T-5-10	1,2	28	300	21.0	111.1	L70(W)5/64"	A	E	L840	
	3,4	28	300	21.0	111.1	L70(W)5/64"	A	E	L840	
T-6-2	1	18	140	6.0	11.0	E7018(1/8"D)	M	C	-	
	2	18	170	6.0	10.3	"	M	C	-	
	3	20	210	4.6	9.4	"	M	C	-	
	4	20	210	5.6	9.7	"	M	C	-	
	5	20	210	7.5	10.5	"	M	C	-	
	6	20	210	7.0	10.1	E7018(1/8"D)	M	C	-	

TABLE 4 RECORDS OF WELDING (Continued)

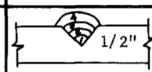
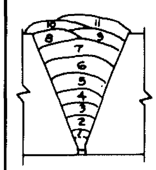
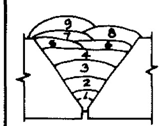
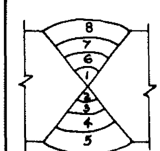
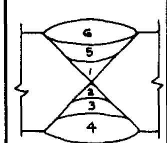
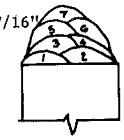
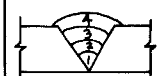
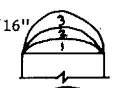
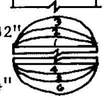
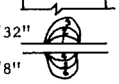
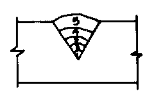
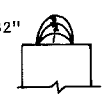
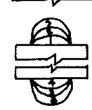
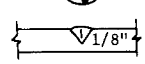
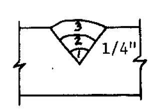
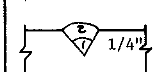
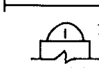
Plate No.	Pass	Volts	Amps	Electrode Travel (in/min)	Electrode Melt-Off (in/min)	Electrode Type	Type of Weld	Place of Weld	Flux	Beads
T-6-4	1,2	32	375	15.0	150.9	L70(W)5/64"	A	C	L840	
	3,4	32	375	15.0	150.9	L70(W)5/64"	A	C	L840	
T-6-6	Tack Welds	22	140	-	-	E7018(1/8")	M	C		
	1	22	140	5.3	9.7	E7018(1/8")	M	C	-	
	2	20	170	4.9	10.7	E7018(5/32")	M	C		
	3	20	210	4.6	9.7	E7018(3/16")	M	C		
	4	20	210	7.0	9.3	"	M	C		
	5	20	210	7.3	9.1	"	M	C		
	6	20	210	6.7	9.3	"	M	C		
	7	20	210	7.3	9.8	"	M	C		
	8	20	210	6.1	9.6	"	M	C		
	9	20	210	8.0	9.5	"	M	C		
	10	20	210	6.8	9.9	"	M	C		
	11	20	210	6.5	10.1	E7018(3/16")	M	C		
T-6-8	1,2,3	32	400	16.0	179.8	L70(W)5/64"	A	C	L840	
	4,5,6	31	375	12.0	152.6	L70(W)5/64"	A	C	L840	
	7,8,9	31	375	12.0	152.6	L70(W)5/64"	A	C	L840	
	Tack Welds	22	140	-	-	E7018(1/8")	M	C	-	
T-6-10	Tack Welds	20	140	-	-	E7018(1/8")	M	2V-C		
	1	20	140	6.4	10.3	E7018(1/8")	M	2V-C		
	2	20	140	6.2	10.7	E7018(1/8")	M	2V-C		
	3	20	170	6.4	10.7	E7018(5/32")	M	2V-C		
	4	18	210	5.9	10.4	E7018(3/16")	M	2V-C		
	5	18	210	5.9	10.3	E7018(3/15")	M	2V-C	-	
	6	18	170	5.7	10.6	E7018(5/32")	M	2V-C	-	
	7	18	210	6.1	9.8	E7018(3/16")	M	2V-C	-	
	8	18	210	5.5	10.1	E7018(3/16")	M	2V-C	-	
T-6-12	Tack Welds	18	140	-	-	E7018(1/8")	M	-	-	
	1	32	325	18.0	130.6	L70(W)5/64"	A	2V-C	L840	
	2,3,4	32	400	16.0	179.8	L70(W)5/64"	A	2V-C	L840	
	5,6	32	400	16.0	179.8	L70(W)5/64"	A	2V-C	L840	

Plate No.	Pass	Volts	Amps	Electrode Travel (in/min)	Electrode Melt-Off (in/min)	Electrode Type	Type of Weld	Place of Weld	Flux	Beads
T-6-14	1	22	160	3.1	9.6	E7018(5/32")	M	E	-	1/4" 
	2	22	160	8.1	10.3	E7018(5/32")	M	E	-	
T-6-16	1,2,3	30	300	20.0	105.8	L70(W)5/64"	A	E	L840	3/16" 
T-6-18	1	22	160	5.0	10.3	E7018(5/32")	M	E	-	
	2	22	160	4.8	10.0	E7018(5/32")	M	E	-	7/16" 
	3	22	160	5.8	10.3	"	M	E	-	
	4	22	160	5.8	10.3	"	M	E	-	
	5	22	160	6.2	10.8	"	M	E	-	
	6	22	160	6.2	10.8	"	M	E	-	
	7	22	160	4.6	10.4	E7018(5/32")	M	E	-	
T-6-20	1 to 11	30	300	20.0	105.8	L70(W)5/64"	A	E	L840	
T-7-2	1	32	375	18.0	152.6	L70(W)5/64"	A	C	L840	
	2,3,4	32	375	15.0	152.6	L70(W)5/64"	A	C	L840	
	Tack Welds	22	140	-	-	E7018(1/8")	M	C	-	
T-7-4	1,2,3	32	300	26.0	106.0	L70 5/64"	A	E	L840	3/16" 
T-7-6	1,2,3	32	300	26.0	106.0	L70 5/64"	A	E	L840	7/32"  1/4"
	4,5,6	32	300	26.0	106.0	L70 5/64"	A	E	L840	
T-8-2	1,2	30	300	36.0	94.7	L70 5/64"	A	E	L840	1/8" 
T-8-4	1,2	30	300	36.0	94.7	L70(W)5/64"	A	E	L840	5/32"  1/8"
	3,4	30	300	36.0	94.7	L70(W)4/64"	A	E	L840	
T-9-2	1,2	32	375	15.0	150.9	L70(W)5/64"	A	E	L840	
	3,4,5	32	375	15.0	150.9	L70(W)f/64"	A	E	L840	
T-9-4	1	30	300	32.0	94.7	L70(W)5/64"	A	E	L840	7/32" 
	2	30	300	28.0	94.7	L70(W)5/64"	A	E	L840	
	3	30	300	26.0	94.7	L70(W)5/64"	A	E	L840	
T-9-6	1,2,3	30	300	26.0	94.7	L70(W)5/64"	A	E	L840	
	4,5,6	30	300	26.0	94.7	L70(W)5.64"	A	E	L840	
T-10-2	1	20	140	6.7	106.25	E7018(1/8"D)	M	C	-	 1/8"
T-10-4	1	18	125	30.0	12.0	E7018(1/8)	M	E	-	 1/8"
T-11-2	1	20	140	6.2	10.8	E7018(1/8)	M	C	-	 1/4"
	2	18	170	7.7	9.6	E7018(5/32"	M	C	-	
	3	18	170	6.8	10.0	E7018(5/32")	M	C	-	
T-11-4	1	32	375	13.0	150.9	L70(W)5/64"	A	C	L840	 1/4"
	2	32	375	13.0	150.9	L70(W)5/64"	A	C	L840	
T-11-6	1	18	110	10.1	9.3	E7018(1/8"	M	E	-	 1/4"

Test No.	Plate No.	Plate Thickness (in)	Coupon No.
T-1	-	-	-
T-2	T-2-1	1/2	T-2-1-1
			T-2-1-2
			T-2-1-3
	T-2-2		T-2-2-1
			T-2-2-2
			T-2-2-3
	T-2-3		T-2-3
	T-2-4		T-2-4
	T-2-5		T-2-5
	T-2-6		T-2-6-1
			T-2-6-2
			T-2-6-3
	T-2-7		T-2-7
	T-2-8		T-2-8
T-3	-	-	-
T-4	T-4-1	1	T-4-1-1
			T-4-1-2
			T-4-1-3
	T-4-2		T-4-2-1
			T-4-2-2
			T-4-2-3
	T-4-3	1	T-4-3
	T-4-4		T-4-4
	T-4-5		T-4-5
	T-4-6		T-4-6-1
			T-4-6-2
			T-4-6-3
	T-4-7		T-4-7
	T-4-8		T-4-8
T-5	T-5-1	1/2	T-5-1
	T-5-2		T-5-2
	T-5-3		T-5-3
	T 5-4		T-5-4-1
			T-5-4-2
			T-5-4-3
	T-5-5		T-5-5
	T-5-6		T-5-6
	T-5-7		T-5-7-1
			T-5-7-2
			T-5-7-3
	T-5-8		T-5-8
	T-5-9		T-5-9
	T-5-10		T-5-10-1
			T-5-10-2
			T-5-10-3

TABLE 5 LIST OF TENSION COUPONS INCLUDED IN THE STUDY

Test No.	Plate No.	Plate Thickness (in)	Coupon No.
T-6	T-6-7	1	T-6-7
	T-6-8		T-6-8
	T-6-9		T-6-9*
	T-6-10		T-6-10*
	T-6-11		T-6-11**
	T-6-12		T-6-12**
T-7	T-7-1	1/2	T-7-1
	T-7-2		T-7-2
	T-7-3		T-7-3
	T-7-4		T-7-4
T-8	-	-	-
T-9	-	-	-
T-10	T-10-1	1/4	T-10-1
	T-10-3		T-10-3
T-11	T-11-1	1/2	T-11-1
	T-11-5		T-11-5

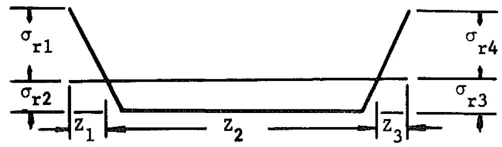
* Round Coupon
** Small Coupon

TABLE 5 LIST OF TENSION COUPONS INCLUDED IN THE STUDY (Continued)

Plate No.	Coupon No.	σ_{ys} (ksi)
T-2-1	T-2-1-1	109.3
	T-2-1-2	111.2
	T-2-1-3	110.6
T-2-6	T-2-6-1	110.0
	T-2-6-2	110.0
	T-2-6-3	110.0
T-2-3	T-2-3	111.2
T-2-5	T-2-5	108.7
T-2-7	T-2-7	111.0
T-2-8	T-2-8	111.0
T-5-1	T-5-1	110.6
T-5-2	T-5-2	112.0
T-5-3	T-5-3	110.9
T-5-5	T-5-5	111.0
T-5-9	T-5-9	111.8
T-5-10	T-5-10	112.2

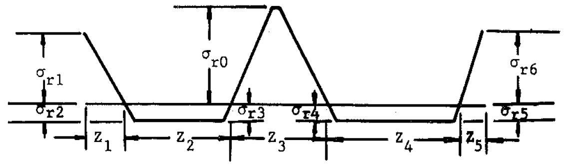
TABLE 6 RESULTS OF TENSION COUPON TESTS

TABLE 7 RESIDUAL STRESS DISTRIBUTION IN AS-CUT UN-WELDED PLATES



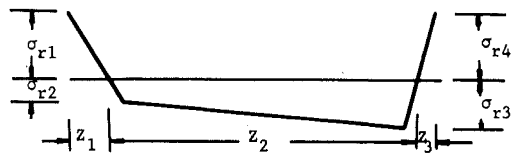
Test No.	Plate No.	Plate Size (in.)	Residual Stress in ksi				Distances in in.		
			σ_{r1}	σ_{r2}	σ_{r3}	σ_{r4}	z_1	z_2	z_3
T-1	-	-	-	-	-	-	-	-	-
T-2	1	6 x 1/2	76.0	8.03	5.28	72.6	0.85	4.3	0.85
	3		81.4	6.05	6.05	86.9	0.90	4.2	0.90
	5		85.8	6.05	6.05	79.2	0.90	4.2	0.90
	7		89.1	6.05	6.05	83.6	0.90	4.2	0.90
T-3	-	-	-	-	-	-	-	-	-
T-4	1	8 x 1	25.3	4.99	4.99	29.7	0.90	6.3	0.80
	3		31.9	7.70	7.70	49.5	1.00	6.0	1.00
	5		34.1	4.40	3.96	37.4	0.90	6.2	0.90
	7		28.6	4.40	3.96	30.8	0.85	6.2	0.95
T-5	1	12 x 1/2	41.8	6.60	3.63	36.3	0.90	10.2	0.90
	3		37.4	2.64	4.73	46.2	0.90	10.2	0.90
	7		40.7	3.96	3.19	40.7	0.90	10.2	0.90
	9		42.9	5.39	3.41	36.3	0.90	10.2	0.90
T-6	1	12 x 1	30.8	4.51	4.51	30.8	0.80	10.5	0.70
	3		42.9	3.96	3.96	40.7	0.70	10.6	0.70
	5		37.4	3.96	3.96	40.7	0.70	10.6	0.70
	7		42.9	2.97	2.97	51.7	0.80	10.6	0.60
	9		38.5	3.52	3.52	34.1	0.70	10.6	0.70
	11		45.1	3.52	3.52	44.1	0.70	10.6	0.70
	13		36.3	3.52	3.52	36.3	0.70	10.6	0.70
	15	12 x 1	36.3	2.97	2.97	42.9	0.70	10.6	0.70
	17		31.9	2.97	2.97	36.3	0.70	10.6	0.70
	19		50.6	3.96	3.96	36.3	0.70	10.6	0.70
T-7	1	16 x 1/2	48.4	1.98	2.97	48.4	0.70	14.60	0.70
	3		57.2	4.51	1.98	47.3	0.70	14.6	0.70
T-8	1	20 x 3/8	61.6	3.96	3.96	59.5	0.70	18.6	0.70
	3		67.1	3.74	3.63	58.3	0.80	18.5	0.70
T-9	1	24 x 1	46.2	3.96	1.98	30.8	0.70	22.60	0.70
	3		31.9	5.94	5.06	31.9	0.60	22.9	0.50
	5		27.5	5.94	11.0	38.5	0.60	22.8	0.60

TABLE 8 RESIDUAL STRESS DISTRIBUTION IN CENTER WELDED PLATES



Test No.	Plate No.	Size (in x in)	Residual Stresses (ksi)							Distances (in)				
			σ_{r0}	σ_{r1}	σ_{r2}	σ_{r3}	σ_{r4}	σ_{r5}	σ_{r6}	z_1	z_2	z_3	z_4	z_5
T-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T-2	2	6 x 1/2	39.9	62.0	16.0	14.0	13.0	12.0	55.9	0.70	1.65	1.40	1.65	0.60
	4	6 x 1/2	78.0	44.9	24.0	22.0	18.0	13.9	39.1	0.40	1.80	1.65	2.00	0.15
T-3	A	8 x 1/2	65.7	26.4	14.5	9.02	9.02	12.7	23.5	0.20	2.50	2.30	2.80	0.20
	B	8 x 1/2	69.7	28.3	12.4	9.60	9.60	10.8	27.8	0.18	2.62	2.60	2.42	0.18
	C	8 x 1/2	70.2	31.2	8.03	7.81	7.04	7.70	29.2	0.20	2.60	2.50	2.55	0.15
	D	8 x 1/2	66.1	31.0	12.0	12.0	12.0	12.0	31.7	0.15	2.65	2.40	2.60	0.20
T-4	2	8 x 1	19.1	22.6	7.04	7.26	7.81	7.04	25.0	0.80	2.50	1.40	2.40	0.90
	4	8 x 1	30.3	27.1	7.81	9.02	11.0	10.5	31.2	0.80	2.40	1.60	2.40	0.80
T-5	2	12 x 1/2	87.8	31.5	16.1	16.1	15.0	14.1	19.6	0.80	4.20	2.20	4.10	0.70
	4	12 x 1/2	76.8	36.5	14.9	16.0	16.5	16.5	49.2	0.80	4.20	2.30	3.80	0.80
	5	12 x 1/2	79.5	53.5	14.9	11.9	11.9	14.9	40.8	0.80	4.30	1.90	4.20	0.80
T-6	2-A	12 x 1	31.1	27.1	9.82	6.1	10.0	8.03	24.1	0.60	4.40	1.60	4.70	0.70
	2-B	12 x 1	49.3	24.3	8.10	7.04	9.35	7.04	13.75	0.60	4.50	1.60	4.70	0.60
	4-A	12 x 1	26.95	35.1	10.0	10.0	11.9	10.0	27.9	0.70	4.40	1.80	4.40	0.70
	4-B	12 x 1	65.01	34.3	34.3	10.0	10.0	9.02	9.02	32.0	0.60	1.80	4.40	0.70
	6-A	12 x 1	51.6	25.6	11.9	13.9	10.0	11.9	7.15	0.60	4.40	2.00	4.40	0.60
	6-B	12 x 1	49.2	22.2	14.41	11.9	10.0	10.0	14.3	0.60	4.50	1.80	4.50	0.60
	8-A	12 x 1	49.7	20.6	14.0	14.0	14.0	17.1	14.1	0.60	5.40	1.00	4.50	0.50
	8-B	12 x 1	61.2	24.9	14.1	14.1	11.9	11.9	35.0	0.60	5.00	1.40	4.40	0.60
	10-A	12 x 1	46.2	20.5	15.8	6.05	8.03	11.9	15.1	0.50	4.60	1.80	4.70	0.40
	10-B	12 x 1	34.5	24.8	9.8	8.03	8.03	10.6	20.0	0.60	5.00	1.20	4.60	0.60
	12-A	12 x 1	47.4	23.0	20.0	10.6	10.0	24.6	5.06	0.60	4.50	1.80	4.60	0.50
	12-B	12 x 1	42.9	25.1	10.0	10.0	10.0	16.0	35.3	0.60	4.50	1.80	4.50	0.60
T-7	2	16 x 1/2	69.5	38.0	10.0	10.0	10.0	10.0	40.3	0.60	6.40	1.90	6.50	0.60
T-8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T-9	2-A	24 x 1	60.1	44.0	7.04	6.05	4.95	8.60	18.5	0.70	10.4	1.80	10.5	0.60
	2-B	24 x 1	71.5	37.8	6.05	4.95	4.95	6.05	22.4	0.60	10.5	1.80	10.4	0.70

TABLE 9 RESIDUAL STRESS DISTRIBUTION IN EDGE WELDED PLATES



Test No.	Plate No.	Size (in x in)	Residual Stress in ksi				Distances (in)			Weld
			σ_{r1}	σ_{r2}	σ_{r3}	σ_{r4}	z_1	z_2	z_3	
T-1	-	-	-	-	-	-	-	-	-	-
T-2	6	6 x 1/2	78.1	15.1	2.97	86.0	0.8	4.20	1.0	S
	8		92.0*	2.97	16.0	85.0	0.8	4.20	1.0	S
T-4	6	8 x 1	99.0*	8.5	8.0	44.0	1.2	5.1	1.70	S
	8		78.0*	7.26	11.55	33.0	0.80	6.4	0.80	S
T-5	6-A	12 x 1/2	74.8	8.03	6.05	88.2**	1.00	10.1	0.90	D
	6-B		62.8	10.5	1.0	100.0**	0.90	10.1	1.00	S
	8-A		100.0*	6.05	6.05	98.6*	1.0	10.0	1.00	D
	8-B		93.5*	6.26	1.10	99.0*	0.90	10.2	0.90	S
	10-A		82.4*	8.80	10.0	73.6*	0.90	10.2	0.90	D
	10-B		75.9*	9.75	1.0	101.0*	0.90	9.1	1.00	S
T-6	14	12 x 1	-	-	-	-	-	-	-	-
	16-A		90.0*	6.05	4.06	42.8	0.60	11.2	0.20	S
	16-B		125.0*	7.02	2.96	42.8	0.70	11.0	0.30	S
	18		-	-	-	-	-	-	-	-
	20-A		95.0*	13.6	1.0	48.4	0.70	10.5	0.80	S
	20-B		98.0*	14.3	1.0	48.0	0.70	11.0	0.30	S
T-7	4	16 x 1/2	82.5*	10.6	1.0	50.5	0.70	14.6	0.70	S
	6		84.0*	6.71	6.27	83.6*	0.90	14.2	0.90	D
T-8	2	20 x 3/8	82.5*	6.05	4.40	60.5	0.70	18.3	1.00	S
	4		81.3*	5.61	5.50	81.4*	1.00	18.2	0.8	D
T-9	4-A	24 x 1	35.0	5.08	6.60	81.5*	0.7	22.6	0.7	S
	4-B		39.0	12.3	5.72	115.95*	0.60	22.7	0.70	S
	6-A		111.0*	5.50	5.50	124.0*	0.70	22.6	0.70	D
	6-B		109.0*	3.96	6.05	121.0*	0.80	22.6	0.60	D

S - Welded on one edge only
D - Welded on both edges
* - Residual stress at the welded edge
** - Residual stress at the edge welded with L100 electrode

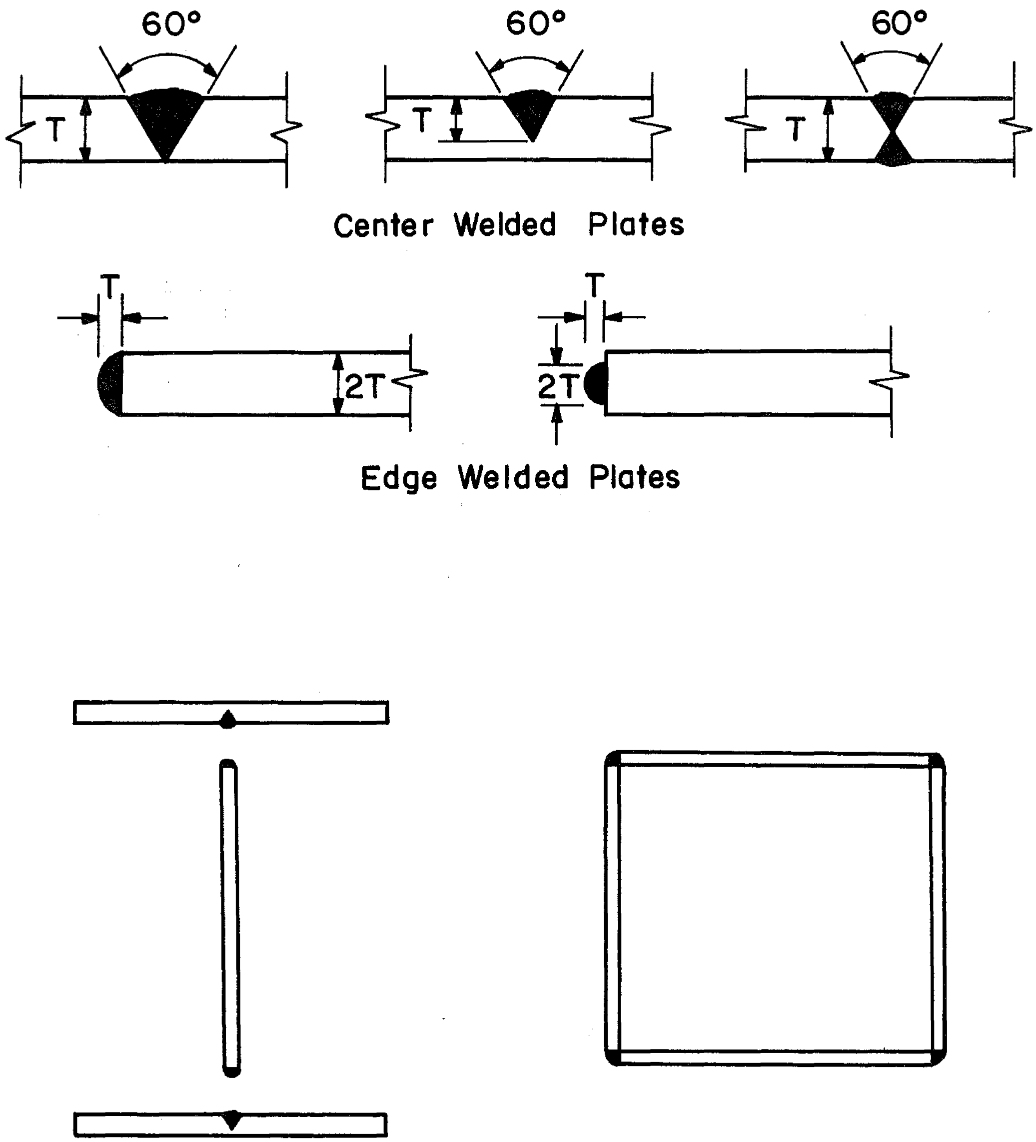


FIG. 1 TYPES AND SIZES OF WELDS USED TO SIMULATE CONDITIONS PREVAILING IN H- AND BOX-SHAPES

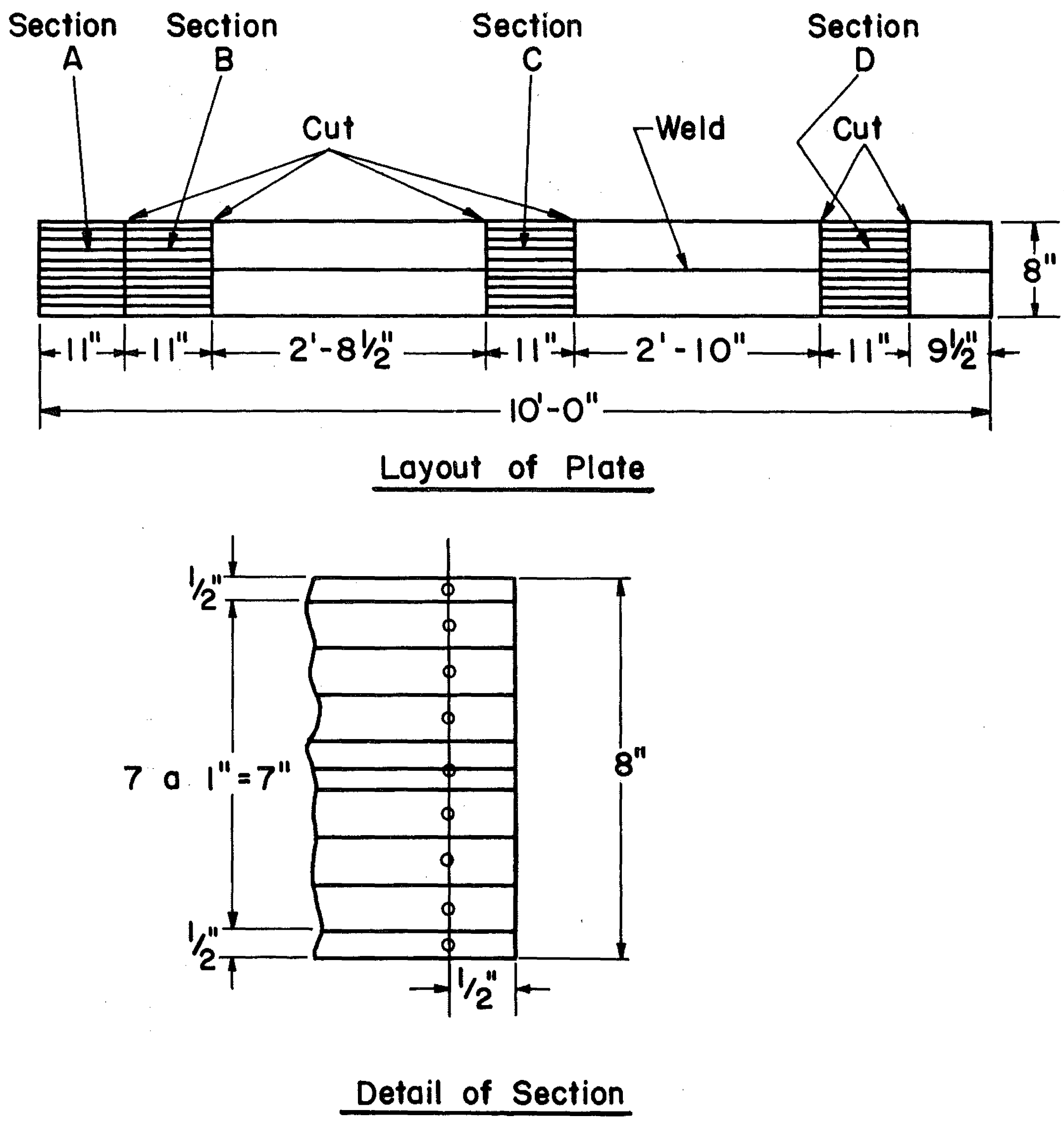
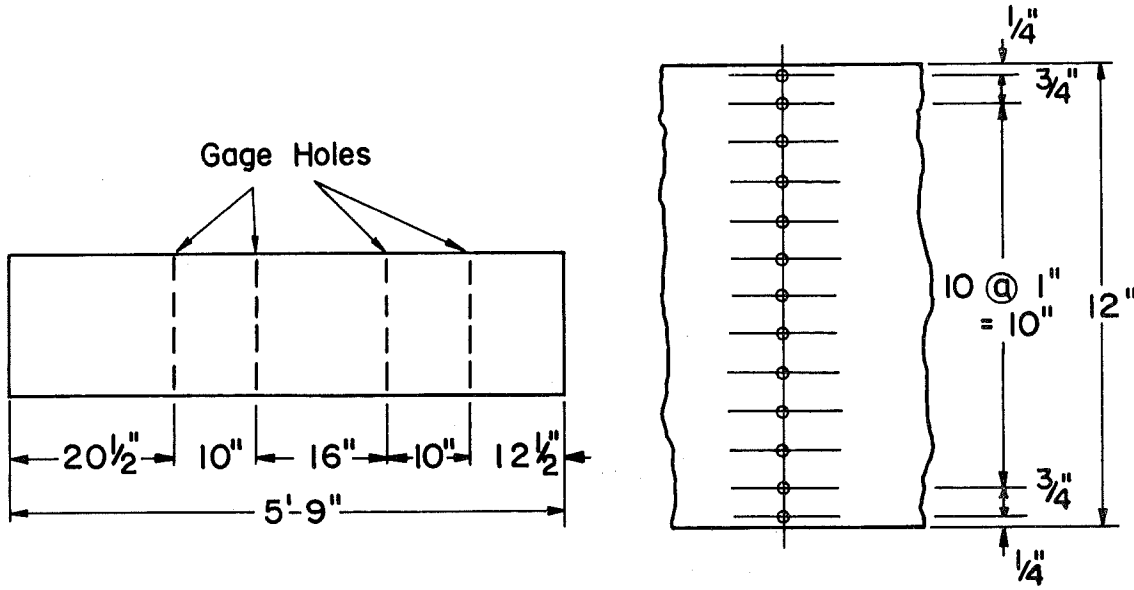
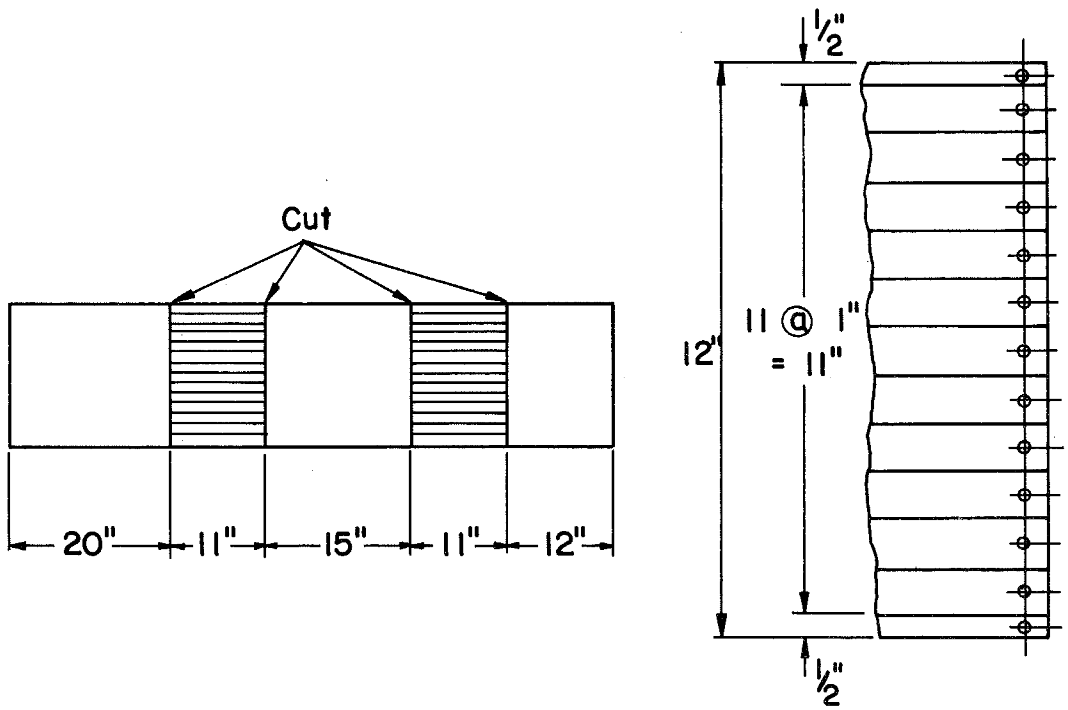


FIG. 2 LAYOUT OF A PLATE WELDED ALONG THE CENTERLINE

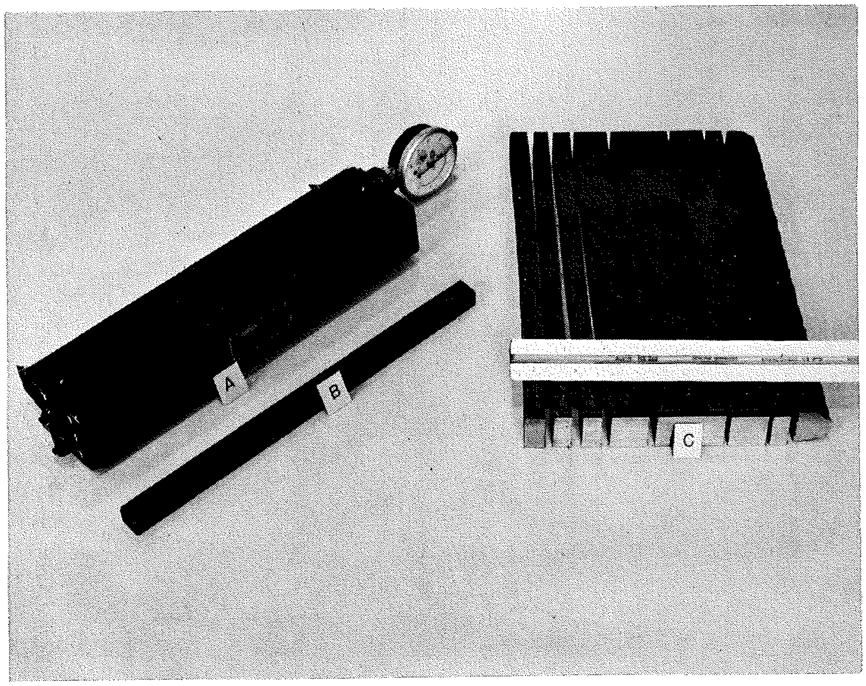


(a) Marking



(b) Sectioning

FIG. 3. TYPICAL LAYOUT FOR MARKING AND SECTIONING



A. Whittemore Gage
B. 10" temperature bar
C. Typical sawed strips containing gage holes

FIG. 4 EQUIPMENT USED FOR RESIDUAL STRESS MEASUREMENTS

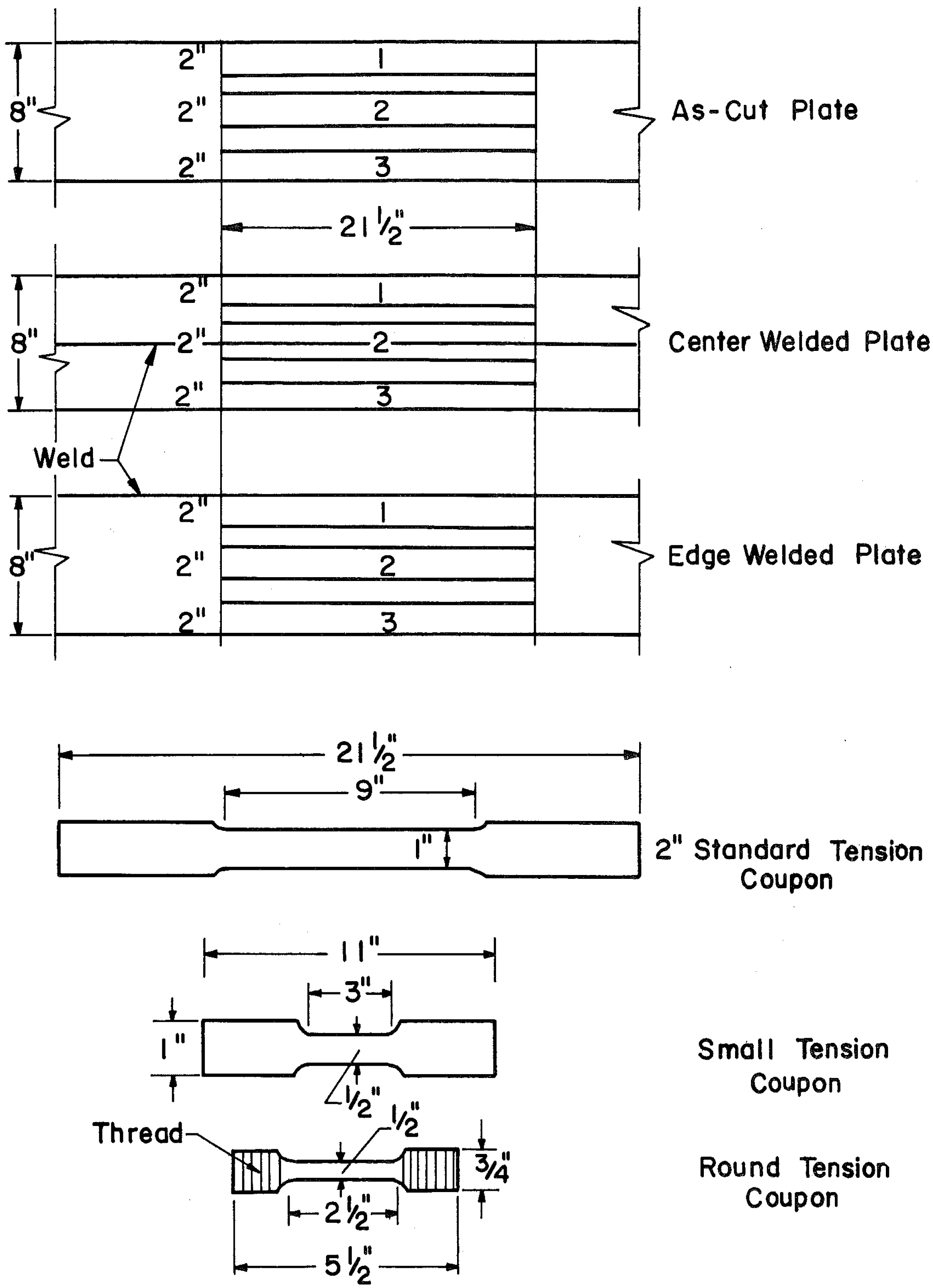


FIG. 5 LAYOUT FOR TENSION COUPONS

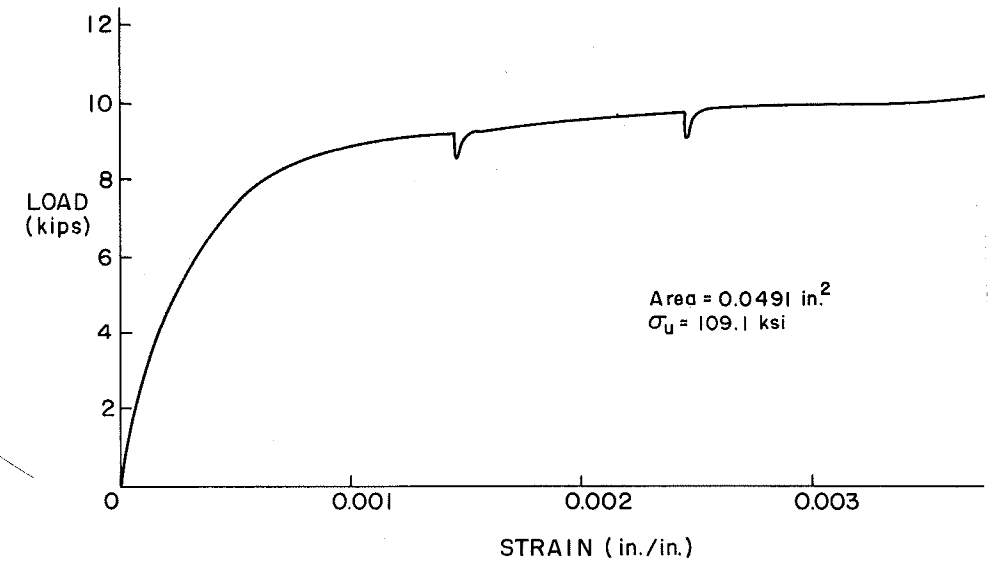


FIG. 6 LOAD-STRAIN RELATIONSHIP OF WELD METAL

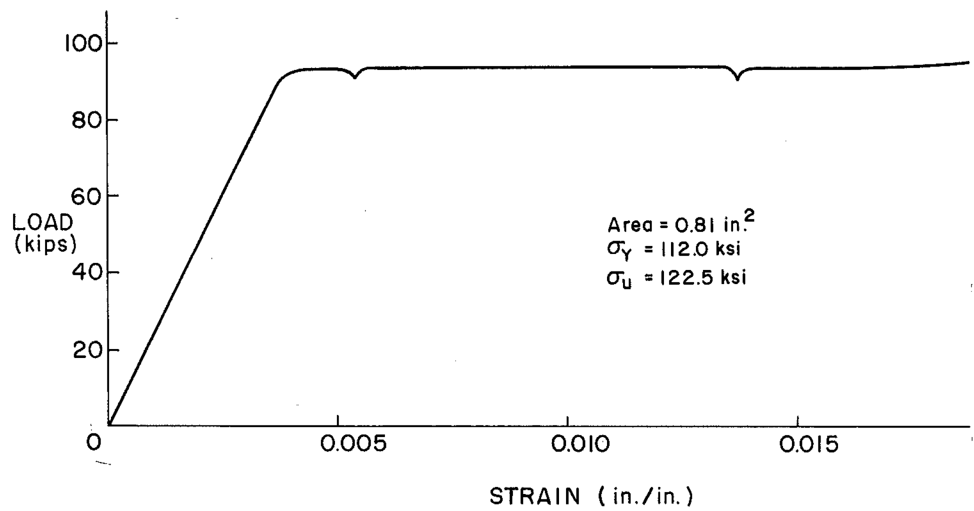


FIG. 7 LOAD-STRAIN RELATIONSHIP OF A TYPICAL TENSILE COUPON OF T-1 STEEL

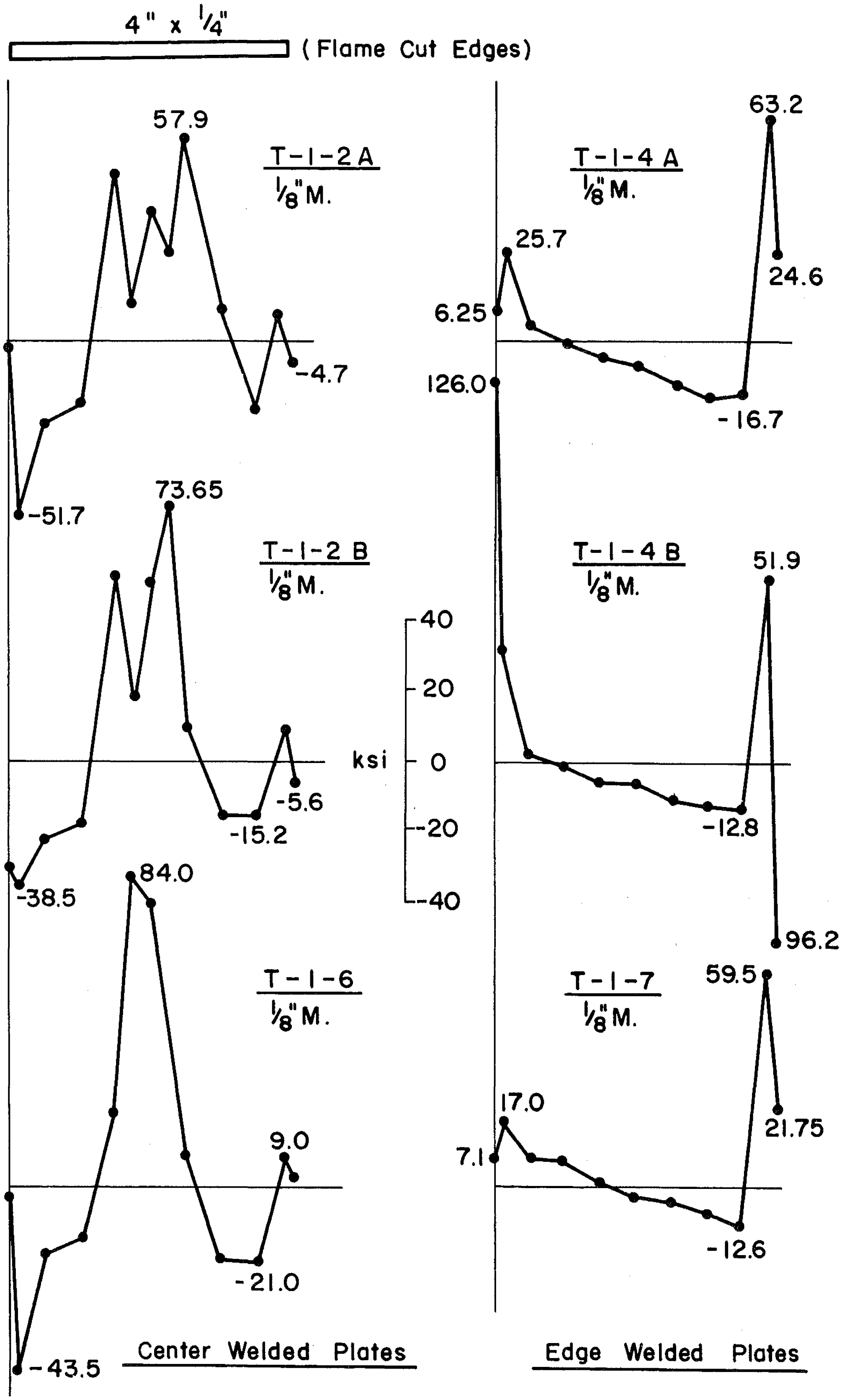


FIG. 8 RESIDUAL STRESSES IN 4" x 1/4" PLATES (T-1)

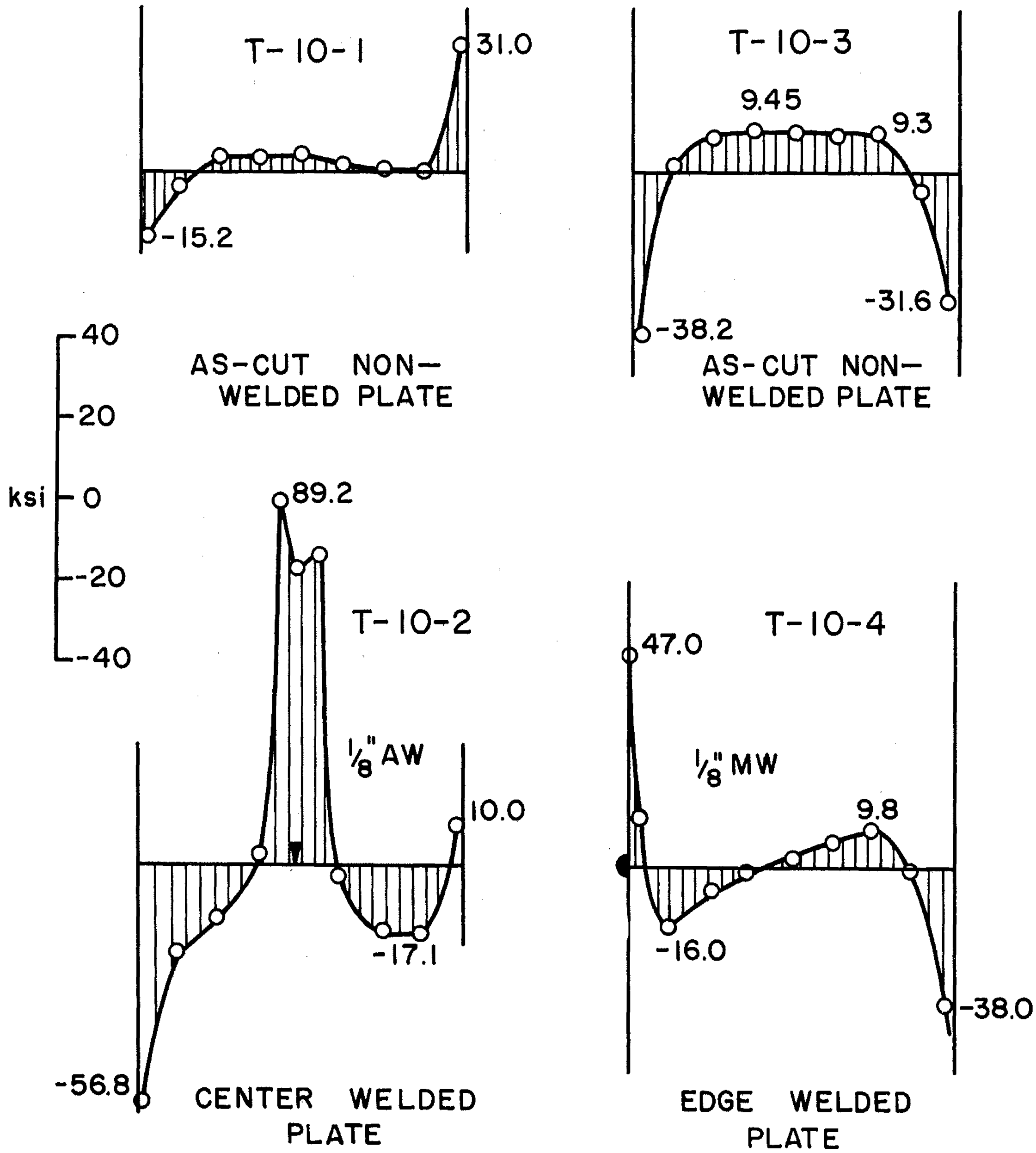


FIG. 9 RESIDUAL STRESSES IN 4" x 1/4" SHEARED EDGE PLATES (T-1)

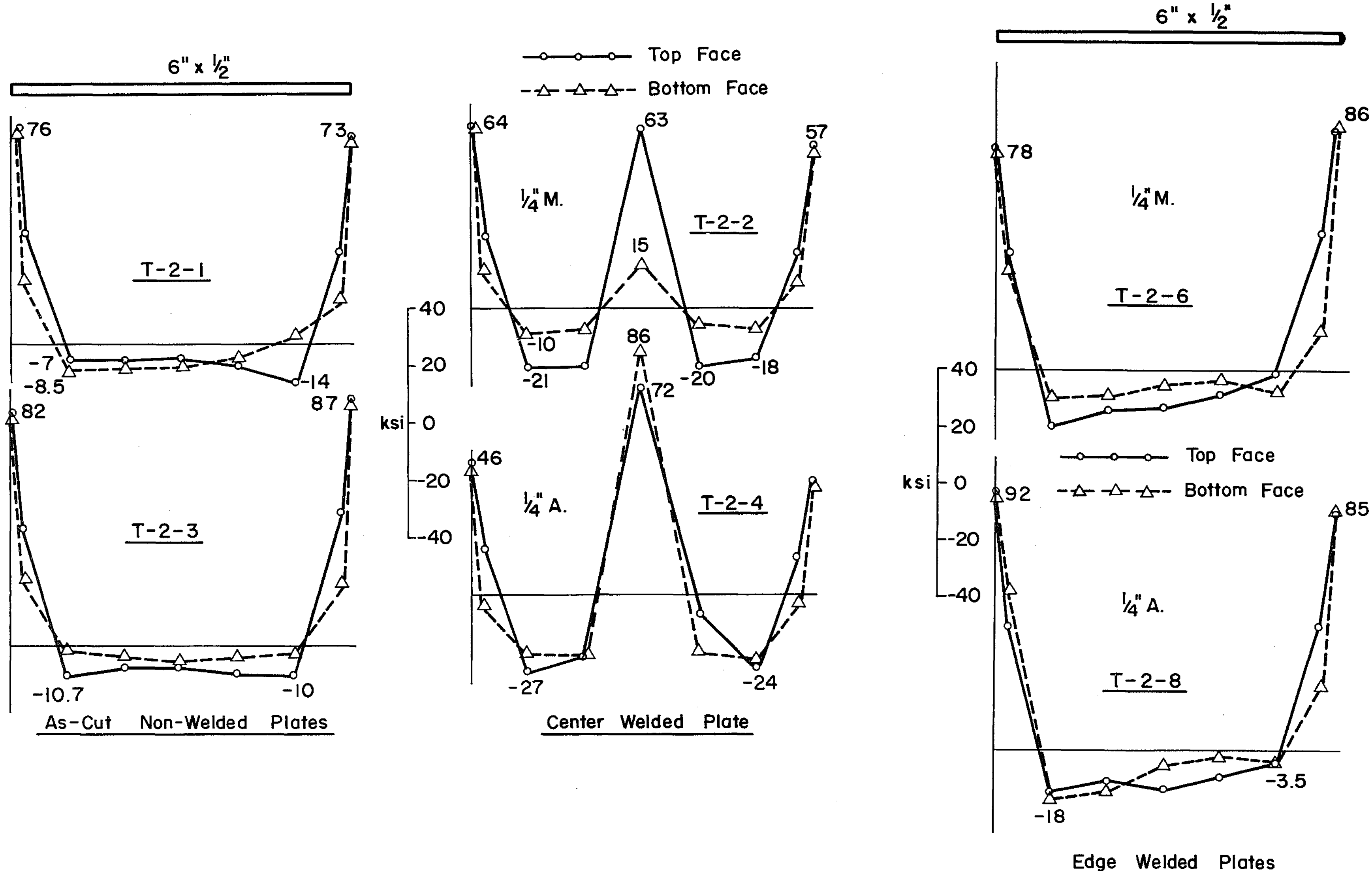


FIG. 10 RESIDUAL STRESSES IN 6" x 1/2" FLAME CUT PLATES (T-2)

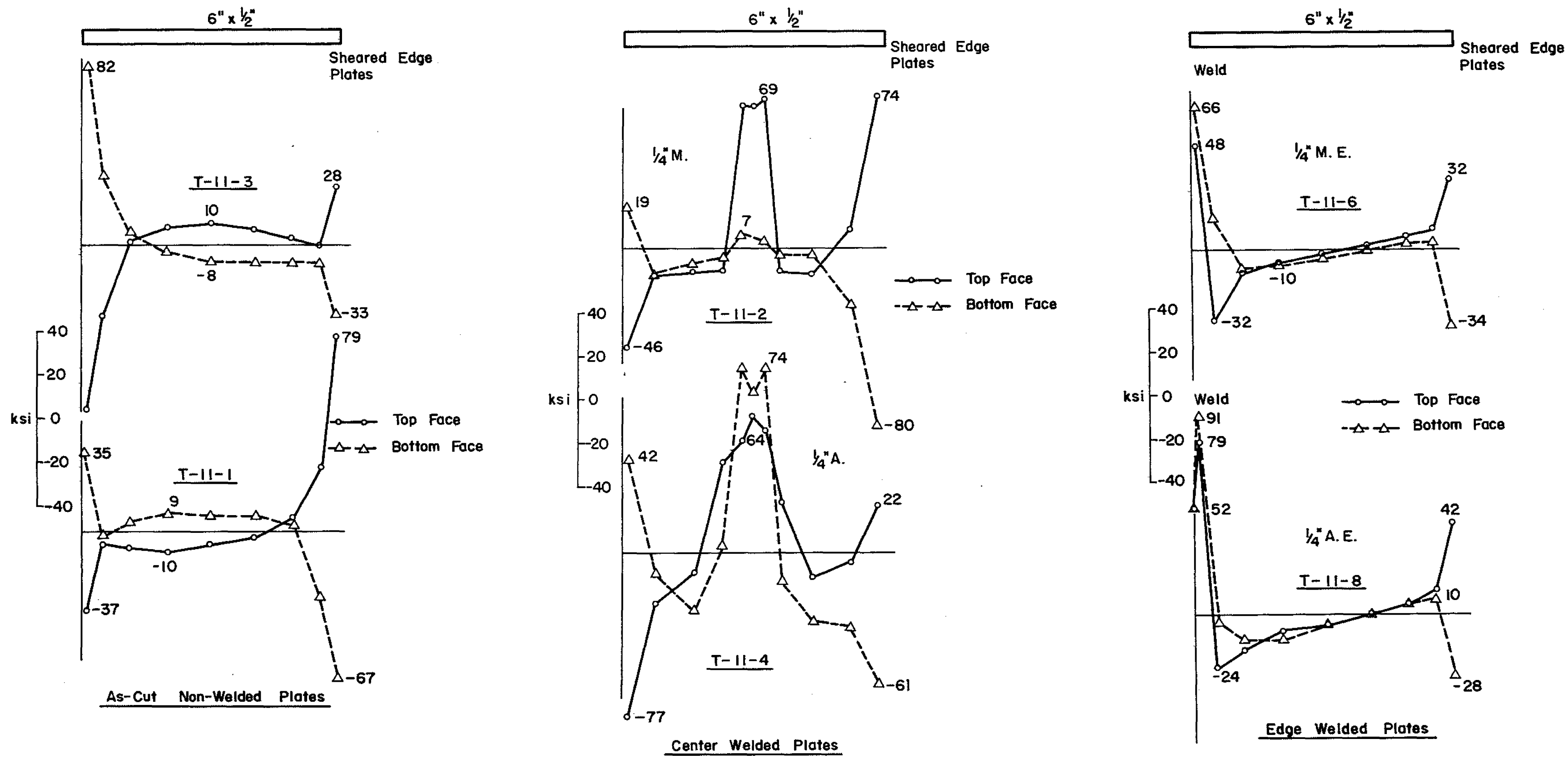


FIG. 11 RESIDUAL STRESSES IN 6" x 1/2" SHEARED EDGE PLATES (T-11)

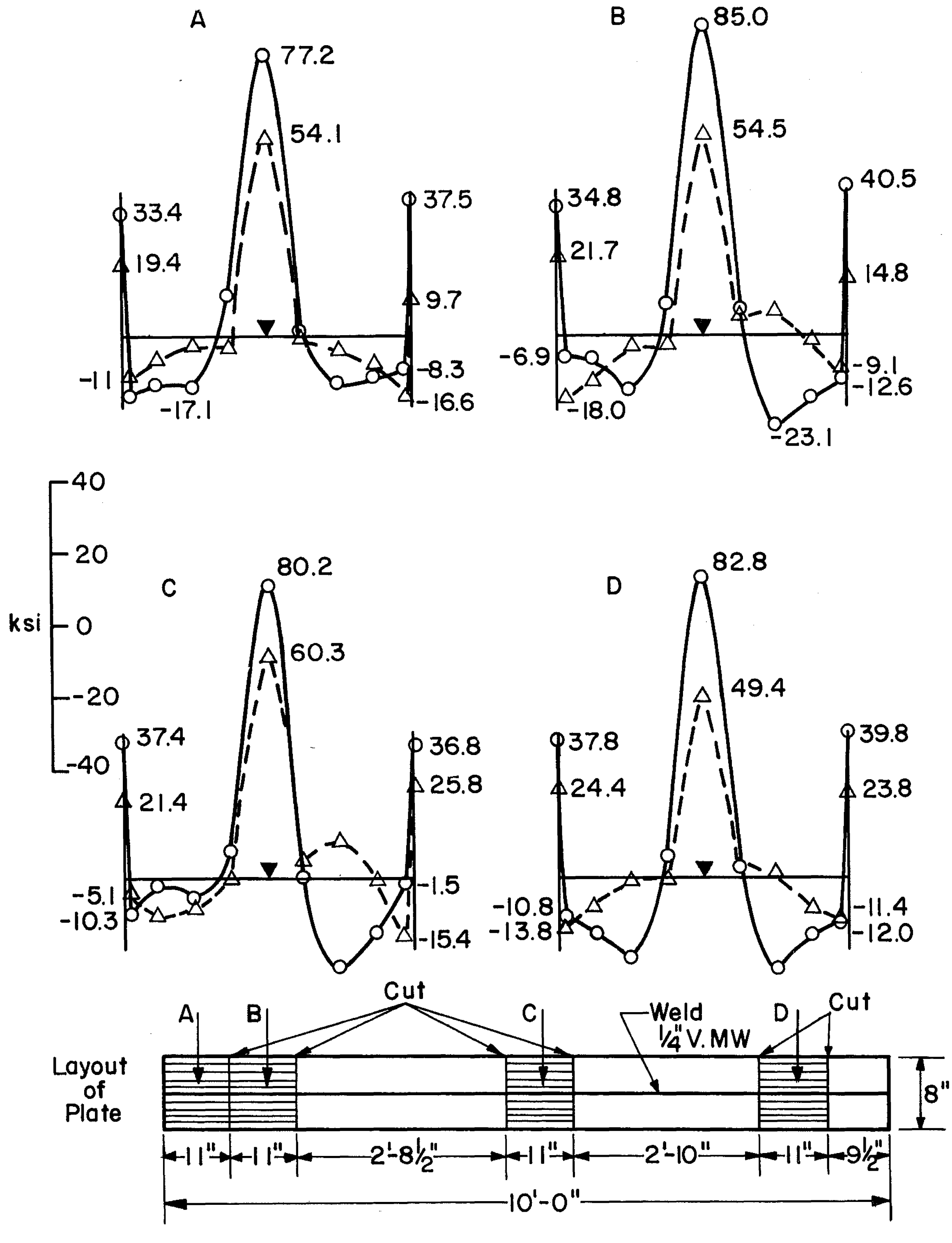


FIG. 12 VARIATION OF RESIDUAL STRESSES IN 8" x 1/2" PLATES ALONG THE CENTERLINE (T-3)

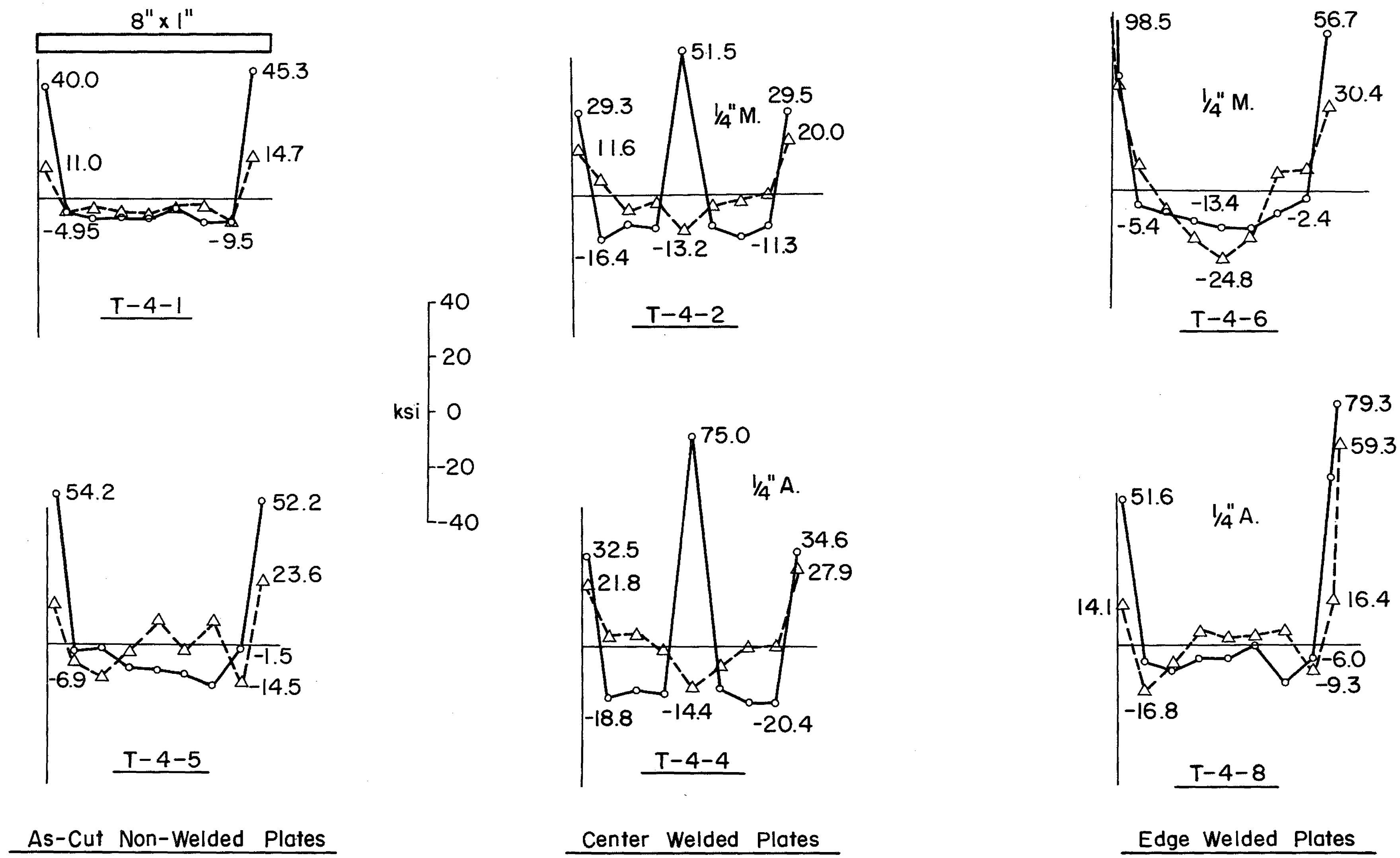
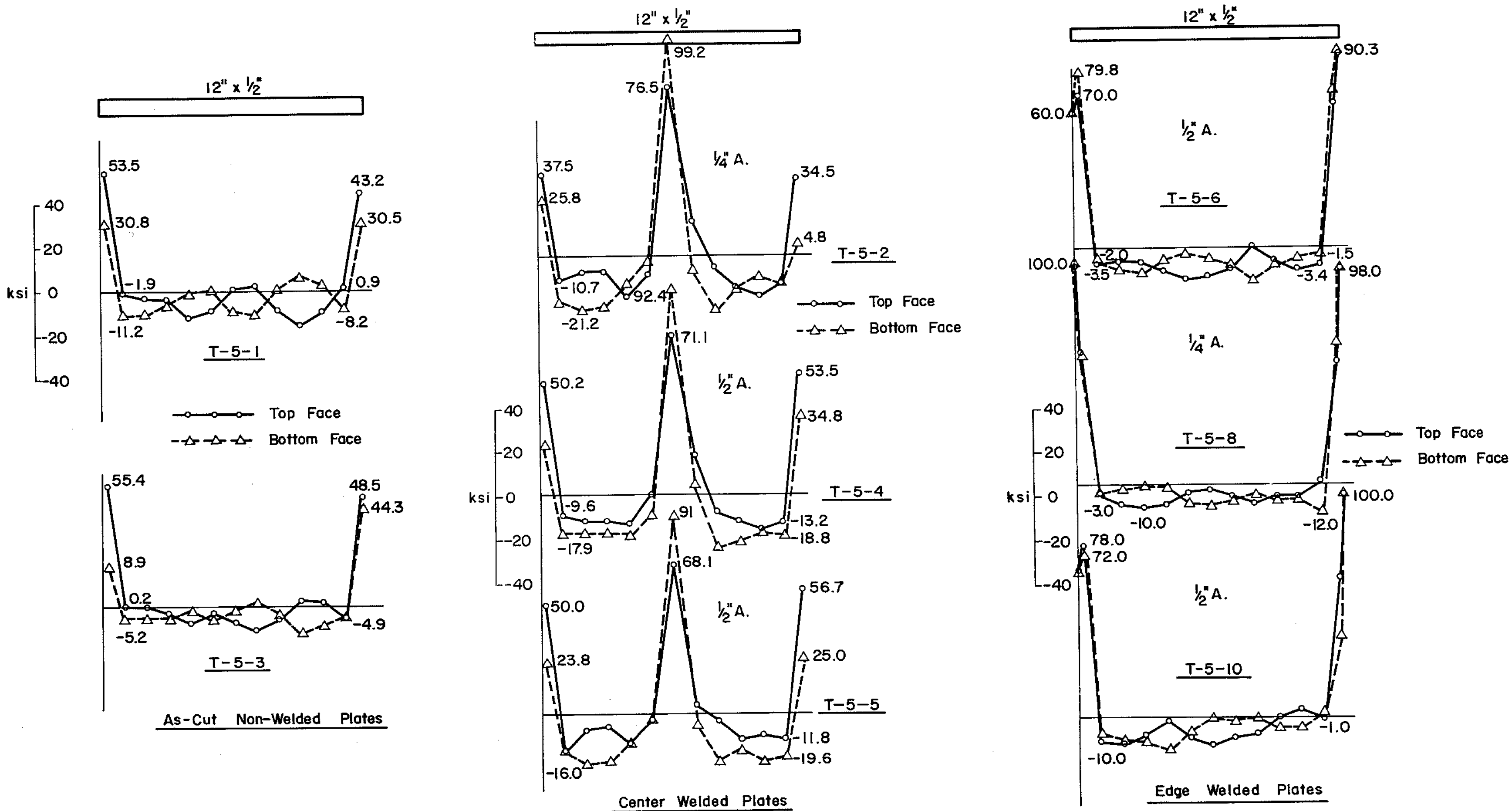


FIG. 13 RESIDUAL STRESSES IN 8" x 1" PLATES (T-4)



290.4 FIG. 14 RESIDUAL STRESSES IN 12" x 1/2" PLATES (T-5)

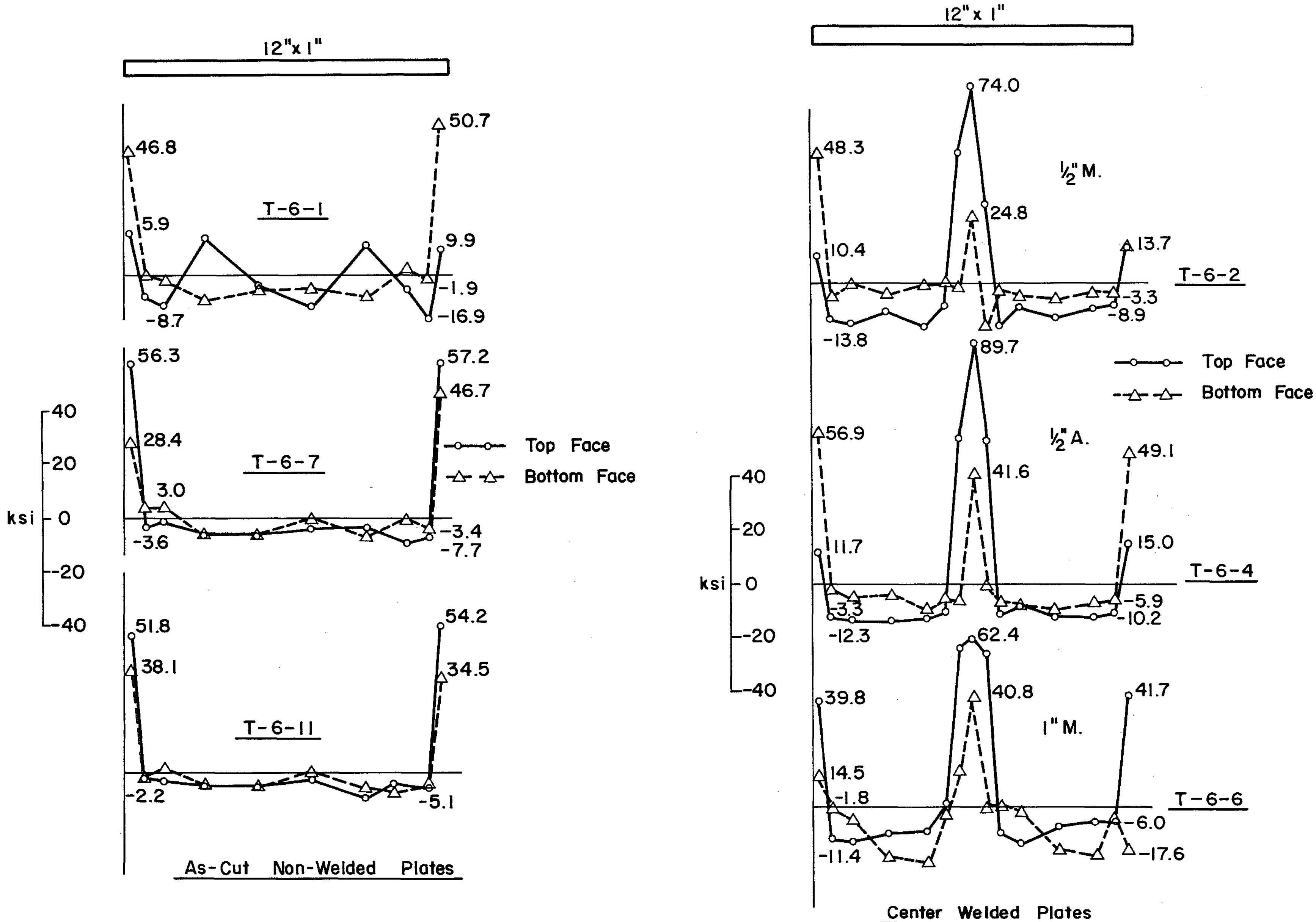


FIG. 15 RESIDUAL STRESSES IN 12" x 1" PLATES (T-6)

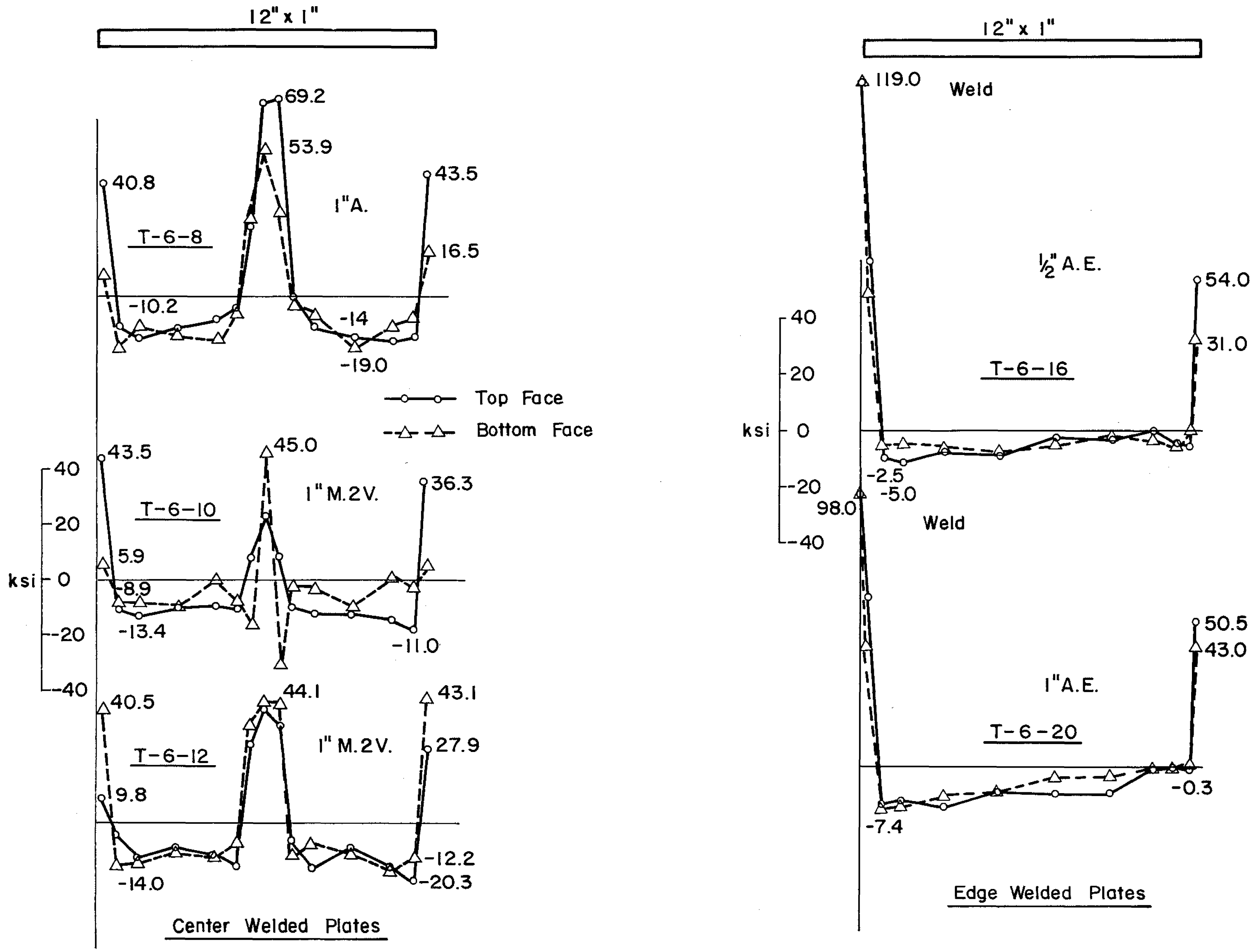


FIG. 15 RESIDUAL STRESSES IN 12" x 1" PLATES (T-6) (Cont'd)

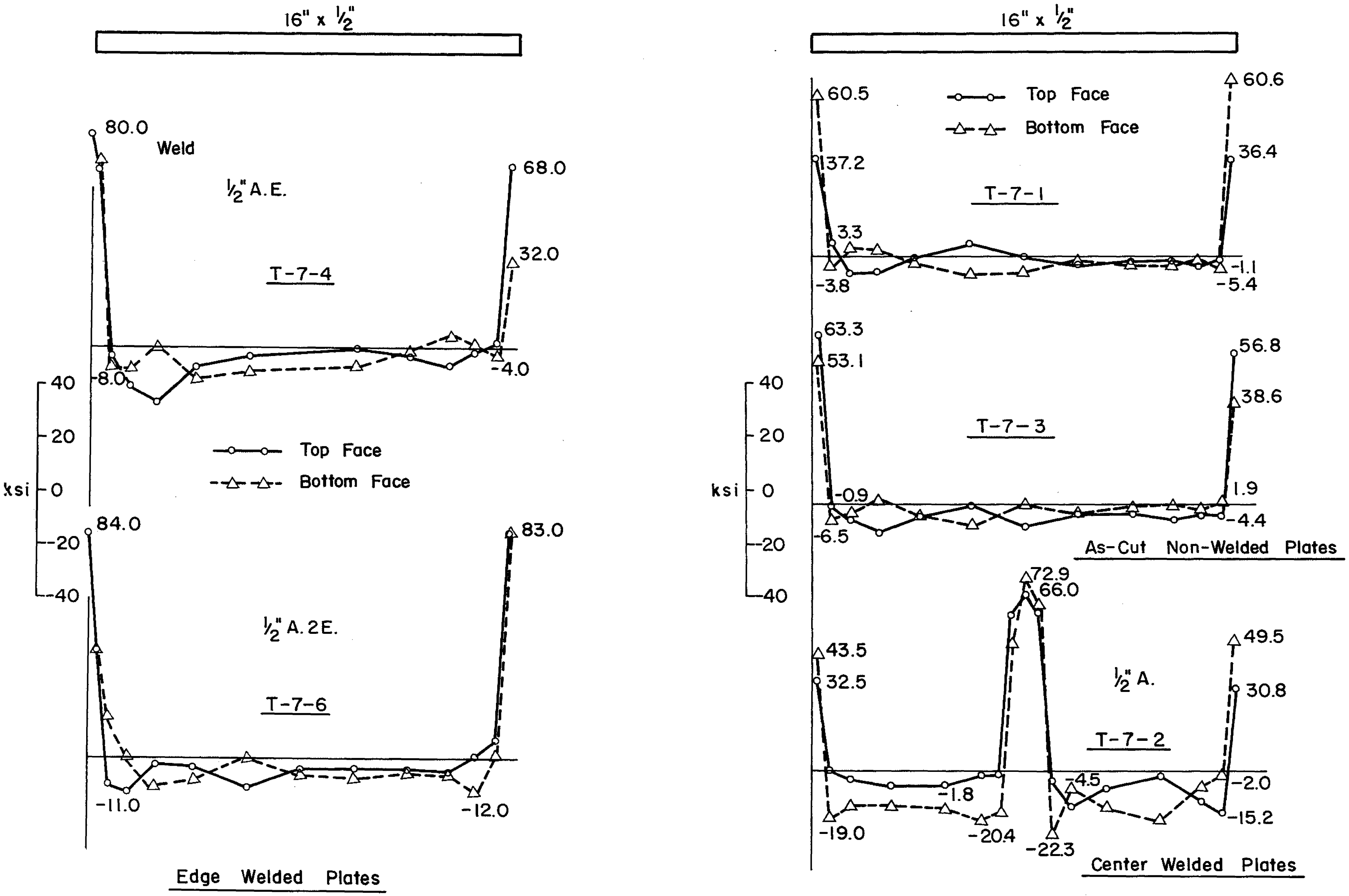
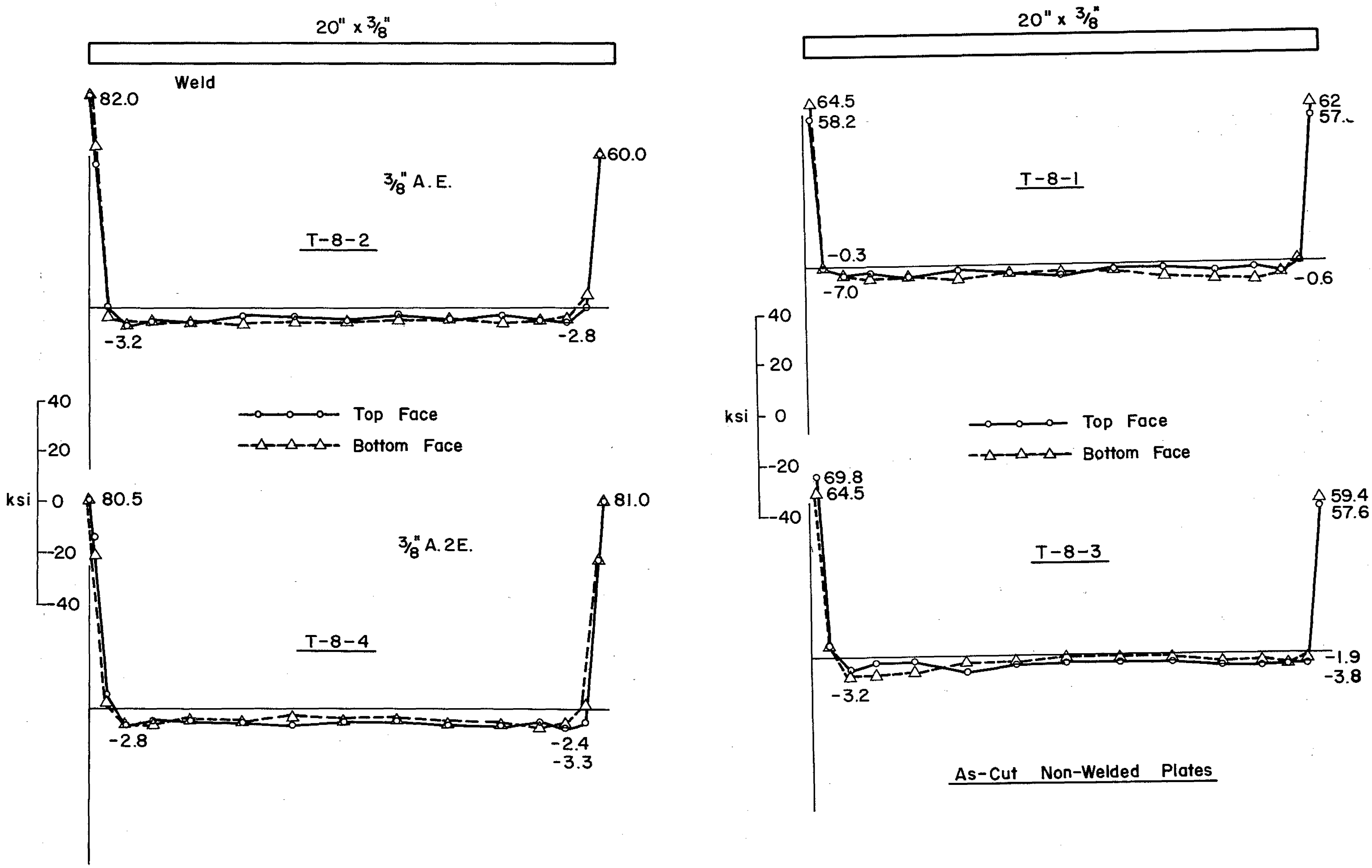


FIG. 16 RESIDUAL STRESSES IN 16" x 1/2" PLATES (T-7)



290.4 FIG. 17 RESIDUAL STRESSES IN 20" x 3/8" PLATES (T-8)

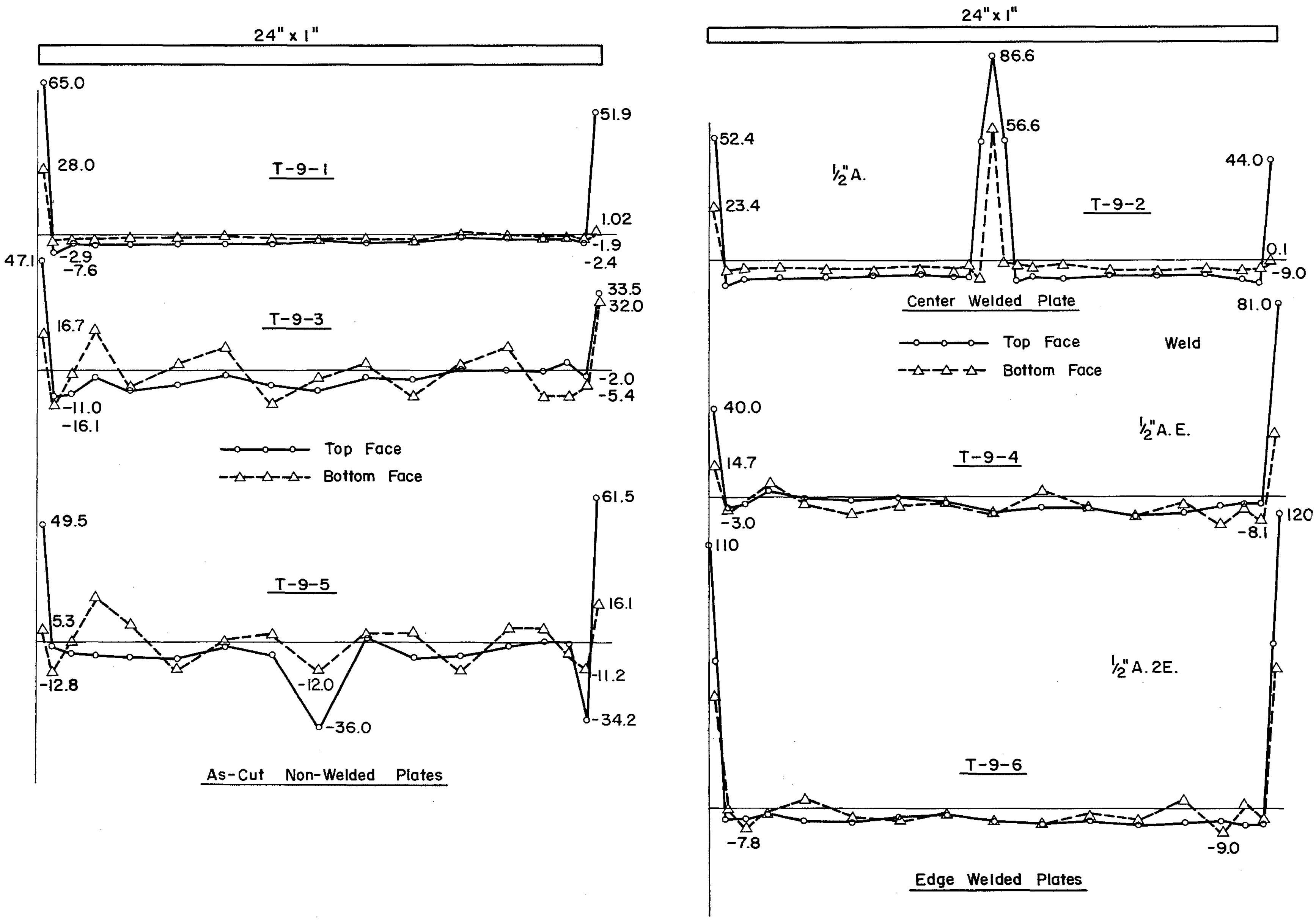


FIG. 18 RESIDUAL STRESSES IN 24" x 1" PLATES

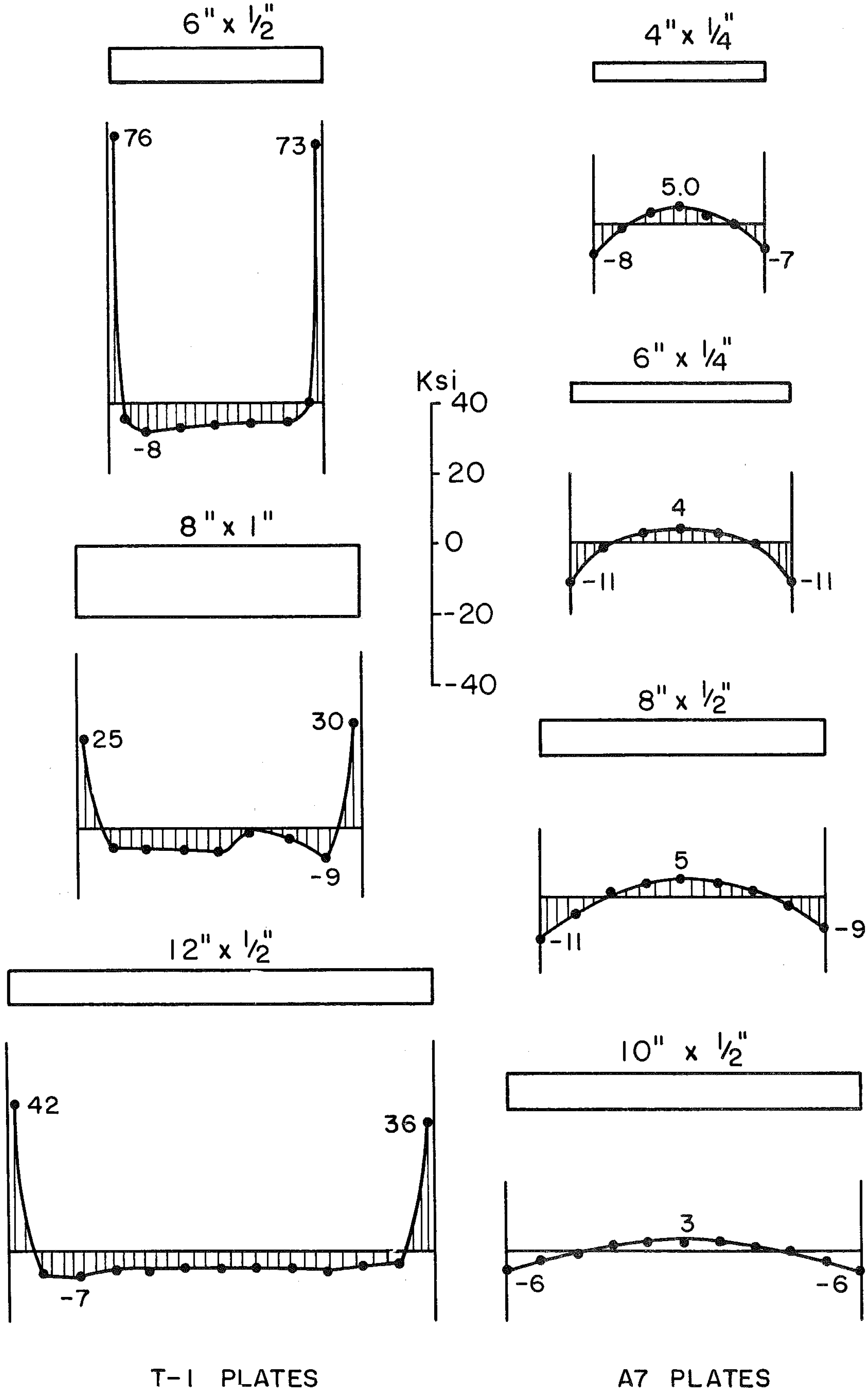


FIG. 19 RESIDUAL STRESSES IN UN-WELDED T-1 AND A-7 STEEL PLATES

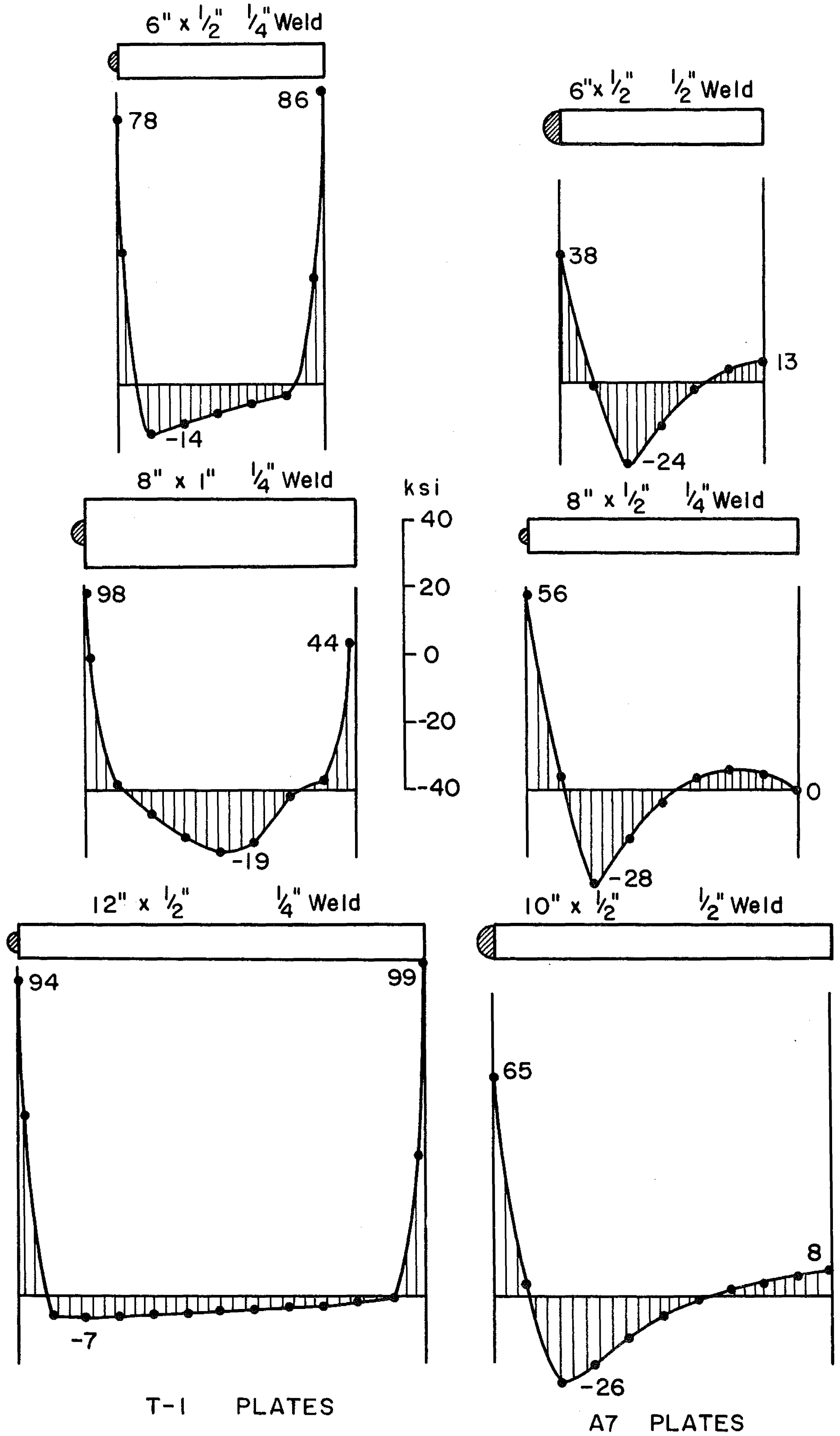


FIG. 20 RESIDUAL STRESSES IN EDGE WELDED T-1 AND A7 STEEL PLATES

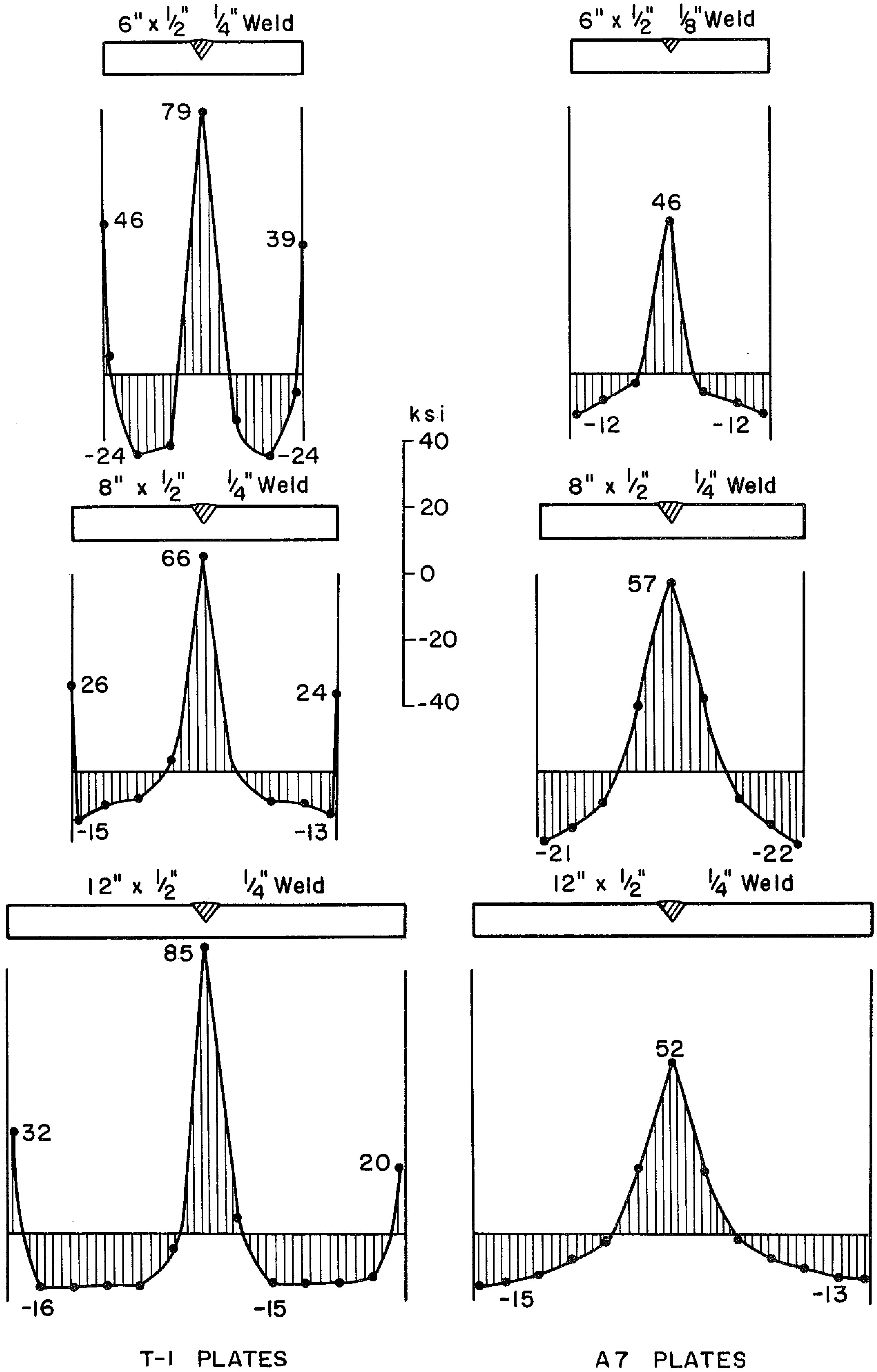


FIG. 21 RESIDUAL STRESSES IN CENTER WELDED T-1 AND A7 STEEL PLATES

10. REFERENCES

1. HOW TO WELD USS "T-1" STEEL, USS Publication #ADUCO 01006, 1962

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