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Mr. Riddle



Welded Built-Up Columns

**HEAT INPUT
THERMAL AND RESIDUAL STRESSES
IN WELDED STRUCTURAL PLATES**

by
Lambert Tall

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Fritz Laboratory Report No. 249.12

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HEAT INPUT, THERMAL AND RESIDUAL STRESSES
IN WELDED STRUCTURAL PLATES

by

Lambert Tall

Presented at the Fundamental Research
Symposium on Transient Heat Flow,
Sponsored Jointly by the American
Welding Society and the Welding
Research Council, Dallas, Texas,
September 1961

This work has been carried out as a part of an
investigation sponsored jointly by the Column
Research Council, the Pennsylvania Department
of Highways, the U. S. Department of Commerce
Bureau of Public Roads and the National Science
Foundation

Fritz Engineering Laboratory
Department of Civil Engineering
Lehigh University
Bethlehem, Pennsylvania

August 1962

Fritz Laboratory Report No. 249.12

A B S T R A C T

The relationship is shown between the heat input into a steel plate due to a weld, and the resulting distributions of temperature and of thermal and residual stresses.

The residual stress distribution set up in welded structural plates which are components of a welded built-up column influence the strength of the column. Increased column strength may be possible from reduced heat inputs when welding.

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1. I N T R O D U C T I O N

This paper presents some results of a theoretical and experimental investigation^(1,2) into the residual stress distribution set up in steel plates welded either at the center or at the edge. The investigation is one phase of a general study on the effect of residual stresses on the strength of welded built-up columns⁽³⁾. The general study was concerned only with bars and universal mill plates of ASTM Designation A7 structural steel.

Welding is usually associated with mechanical techniques and metallurgical conditions. But, to the structural engineer, there is another aspect to welding: this is the effect of welding on the strength of the structure.

A transient heat flow is a flow of heat which exists for a short time. However, no matter for how short or for how long a time the heat flows, provided the heat generated in that time is substantial, then the effects of a transient heat flow can be very serious for the strength of welded structural members. The heat generated from even a minor spot weld is quite sufficient to produce the plastic deformations which are necessary for residual stresses to be formed.

Much attention in the past has been paid to the problem of residual stresses in the weld and to the problem of removing them. Very little attention, however, has been paid to the problem of residual stresses caused by welding of a structural member. Such stresses can be quite high and in some cases may reduce column strength by as much as 50% from the strength of comparable rolled or riveted columns (3,4).

This paper will indicate how the placing of a weld on a plate making up a welded column will result in thermal and residual stresses and how it may be possible to reduce these stresses to gain column strength.

2. W E L D E D B U I L T - U P S H A P E S

Welded built-up members are being used more frequently in steel construction. The residual stress distribution inherent in the cross section of a column plays a major role in the strength characteristics. (5,6) Although welded shapes have residual stress magnitudes and distributions different from those of rolled shapes, design formulas prepared for rolled structural shapes are being applied to welded columns. The present research is being conducted to compare the behavior of welded columns with rolled columns.

An infinite variety of welded built-up shapes can be fabricated; fortunately, only two shapes are basic, that is, the H-shape and the box-shape. Consider the residual stress distributions for these two shapes as shown in Fig. 1. At the weld, the residual stresses are tensile, while at the flange tips for the H-shape, and at the box-center for the box-shape, there are compressive residual stresses. The tensile residual stresses are at the yield point of the material⁽¹⁾, whereas the compressive residual stresses are somewhat smaller in magnitude. When such shapes are loaded in compression, yielding will first take place in those parts of the section which are already in compression due to compressive residual stresses. For the H-shape, the

flange tips will yield first, leaving only a central core to resist bending, that is, there is a drastic reduction in strength. For the box-shape, the situation is not quite as serious, since when yielding takes place, there is still elastic material far from the neutral axis and the load carrying capacity is not so markedly reduced. These elastic areas are shown shaded in Fig. 1.

The residual stress distribution shown for the complete section is more or less the same as it would be for the individual plates welded, as indicated in Fig. 2. (3) That is, the welded plates may be regarded as component parts of welded built-up section, so that, if individual welded plates are studied, much can be learned about the welded shapes themselves. In other words, studies of residual stresses in welded plates lead directly to column strength.

3. H E A T I N P U T

The heat input is that portion of the total heat emitted which actually enters the plate and is a function of the electrode type, its voltage and amperage, and its electrical properties, as well as the radiation from the surface of the plate and from the deposited weld. The total heat emitted by an electrode during arc welding is

$$Q = A \cdot V \cdot t$$

where

A = current in amperes

V = voltage

t = time in seconds

Q = total heat generated in watts-sec
(or in 0.24 calories)

There are losses in heat energy to the atmosphere, losses in forming and maintaining the arc, losses in conduction and so on. Hence, not all the heat generated is effective in causing thermal stresses. Rosenthal^(7,8), on the basis of a theoretical study and experimental verification for two edge-welded plates, has suggested that 65% of the total heat goes into the plate and is influential towards the formation of thermal and residual stresses. Jackson and Shrubbsall⁽⁹⁾, in a study concerned with the distribution of energy during electric welding, showed that a variation occurred for all

factors dependent upon the current. It was shown that for a current of approximately 200 amps, 20 - 40% of the energy went into the melting of base metal and the melting of the electrode. Since the heat loss from the surface is small in proportion to other losses⁽¹⁾, the final heat input into the plate may be approximately that obtained by Rosenthal in his investigation. These results were obtained indirectly since it is not possible to measure heat input directly.

The conclusions of this investigation⁽¹⁾ have indicated that this value of 35% heat losses may not necessarily hold true where thermal and residual stresses are concerned, or where welds other than edge welds are concerned. These conclusions are also based on indirect methods; in this case, comparing the experimentally measured residual stress distribution with the theoretically computed distribution based on varying heat inputs. The investigation studied three center-welded and one edge-welded plate, and indicated that, for V-grooved center-welded plates, 95% of the total heat emitted was influential in setting up thermal and residual stresses, whereas for the edge-welded plate 40% was the corresponding figure. This is discussed further in Section 4.

The results of this study⁽¹⁾ appear to indicate that the heat energy involved in melting and fusion^(8,9) is not a heat loss as far as the formation of residual stresses is concerned.

4. TEMPERATURE DISTRIBUTION,
THERMAL AND RESIDUAL
STRESSES

The distribution of temperature in a heated plate depends upon many factors, such as thickness of plate, size of plate, speed of welding, position of weld and the thermal properties of the plate. (1)

The temperature at a point in a plate due to a weld is linearly proportional to the heat input. This is indicated in Fig. 3: for instance, at a section 2" from the weld the temperature is approximately 100 °F for the light weld and approximately 200 °F for the heavy weld.

The heat input and the resulting temperature distribution produce thermal stresses; the thermal stress when the plate has cooled is called the residual stress. Thermal and residual stresses can be computed from a knowledge of the heat input and temperature distribution, but the computation is time-consuming. (1)

Figure 4 indicates how thermal stresses vary with heat input. Computed thermal stresses are shown for time = 0, 25 and 300 seconds for an edge welded plate; in one case the heat input is half the other, that is, corresponding to the light weld and to the heavy weld respectively. Thermal stresses are limited by the yield stress of the material at

the particular temperature existing.⁽¹⁾ The yield stress is a function of temperature, in general, the higher the temperature the lower the yield stress. Initially, the temperature around the weld is so high that the material is plastic, and stresses cannot exist there. This is shown for both heat inputs for time = 0 and time = 25 seconds in Fig. 4. At time = 300 seconds the temperature is higher for the heavy weld than for the light weld, and so a lower thermal stress will exist at the weld for the heavy weld.

It is interesting to compare in Fig. 4 the effects of the transient heat flow on the thermal stress distribution away from the weld for intervals of time soon after welding. For both welds, for time = 0 and time = 25 seconds, the thermal stress distribution is independent of the heat input from about 2 1/2" to 12" distance from the weld.

The variation of heat input has an effect on thermal stresses, but the effect is not linear as it was for temperature; for times very soon after welding, the variation of heat input plays no role in thermal stress formation at sections away from the weld.

Figure 5(a) illustrates the effect of heat input on the computed residual stress distribution and also presents experimental results for a 1/4" weld. The computed curves are for various proportions of the theoretical total heat

generated by the welding of the experimental plate. The heat input giving best correlation with experiment is 40%, that is, 60% losses, as shown in both Fig. 5(a) and Fig. 5(b). On the basis of this comparison, the 40% heat input corresponds to the 1/4" weld, and hence the 60% and 120% heat inputs correspond to 3/8" and 3/4" welds respectively.

The computed curves for residual stress show that the heat input does not have a linear relationship with residual stress as it does with temperature. The residual stress distribution is the final result of a step-by step computation of thermal stresses through the complete history of heating and cooling of the plate, so that a linear relationship is not possible.

Figure 6 presents some experimental results of residual stress distributions in welded plates. (2) It is seen again that although the greater heat inputs result in greater residual stresses, the relationship is not linear.

In general, the smaller the compressive residual stress in the cross section, the stronger the welded column. (3) As shown above, smaller heat inputs result in smaller residual stresses. Hence it is expected that smaller heat inputs, achieved by smaller currents and voltages, would produce columns of greater strength. Future studies of the strength of welded columns will have to consider welding conditions as a factor.

5. S U M M A R Y

1. The deposition of a weld on a steel plate creates a heat input which results in thermal and residual stresses being formed.
2. The welding residual stresses in steel plates which are components of a welded built-up column influence the strength of the column.
3. The results of a limited study appear to indicate that the heat energy involved in melting and fusion is not a heat loss as far as the formation of residual stresses is concerned.
4. The magnitude of the heat input influences the temperature distribution linearly; there is a direct but not linear effect on thermal and residual stresses.
5. In general, the smaller the compressive residual stress in the cross section, the stronger the welded column. To achieve smaller residual stress magnitudes, the heat input must be smaller, that is, current and voltage at welding should be decreased.

6. A C K N O W L E D G E M E N T S

This report presents a part of the theoretical and experimental investigation made during the course of a research program on the influence of residual stress on the strength of welded built-up columns.

The investigation was conducted at Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pennsylvania. The Pennsylvania Department of Highways and the U. S. Department of Commerce Bureau of Public Roads, the National Science Foundation and the Engineering Foundation through the Column Research Council sponsored jointly the research program.

7. FIGURES

ELASTIC SECTION
AFTER YIELDING

WELDED
SHAPE

RESIDUAL STRESS
DISTRIBUTION

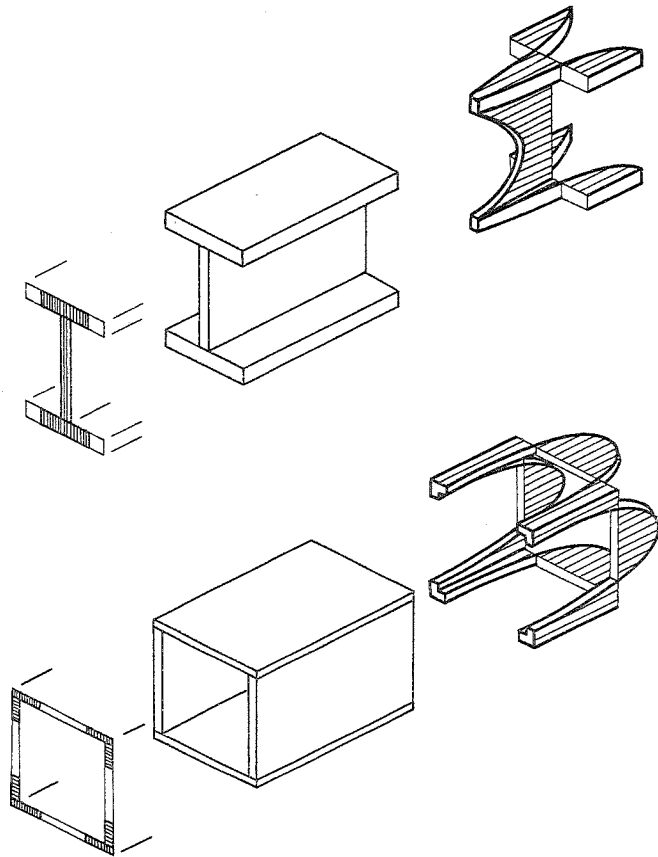


FIG. 1. WELDED SHAPES

WELDED
SHAPE

COMPONENT
WELDED PLATES

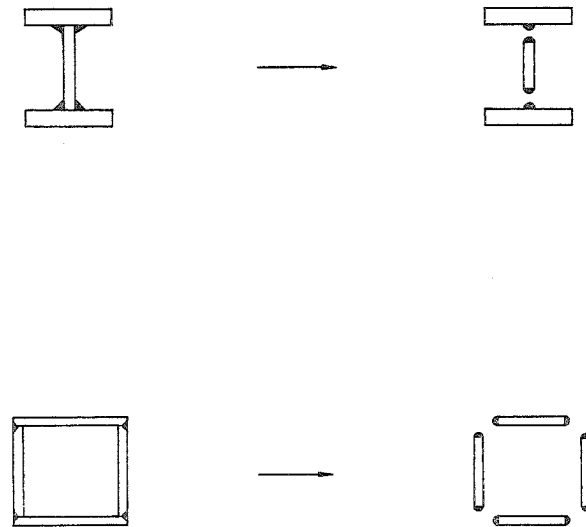


FIG. 2. COMPONENT WELDED PLATES

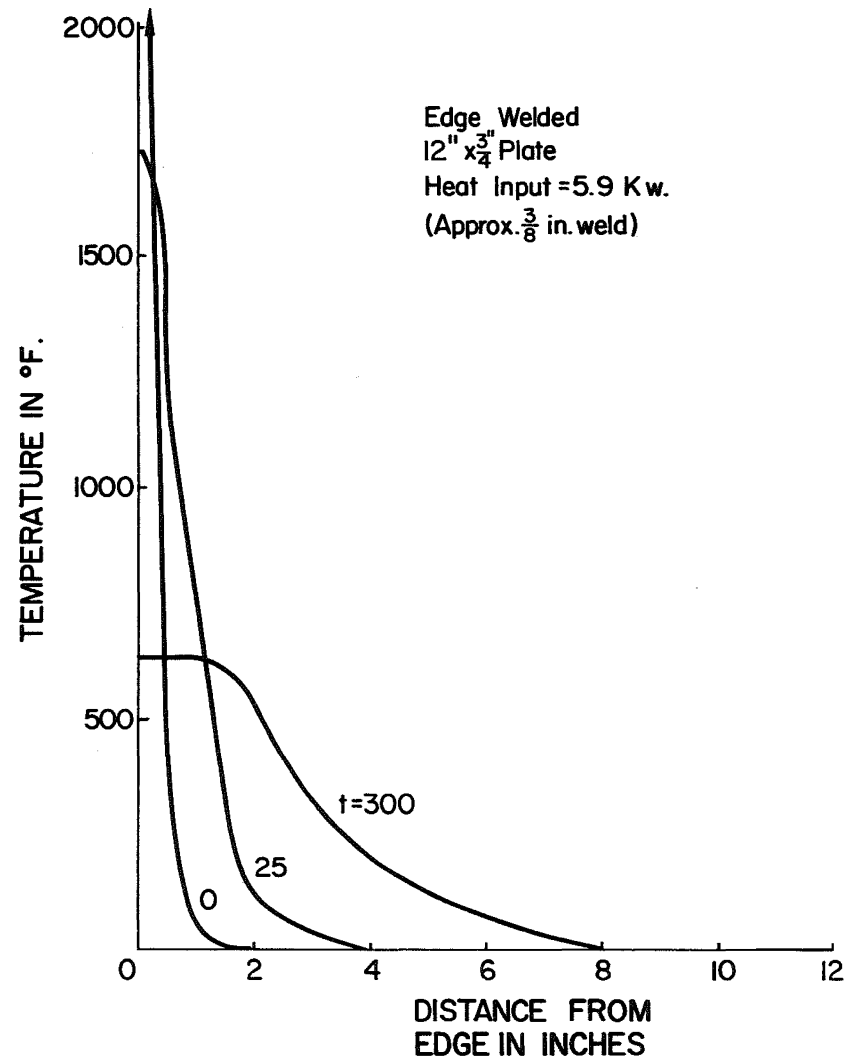
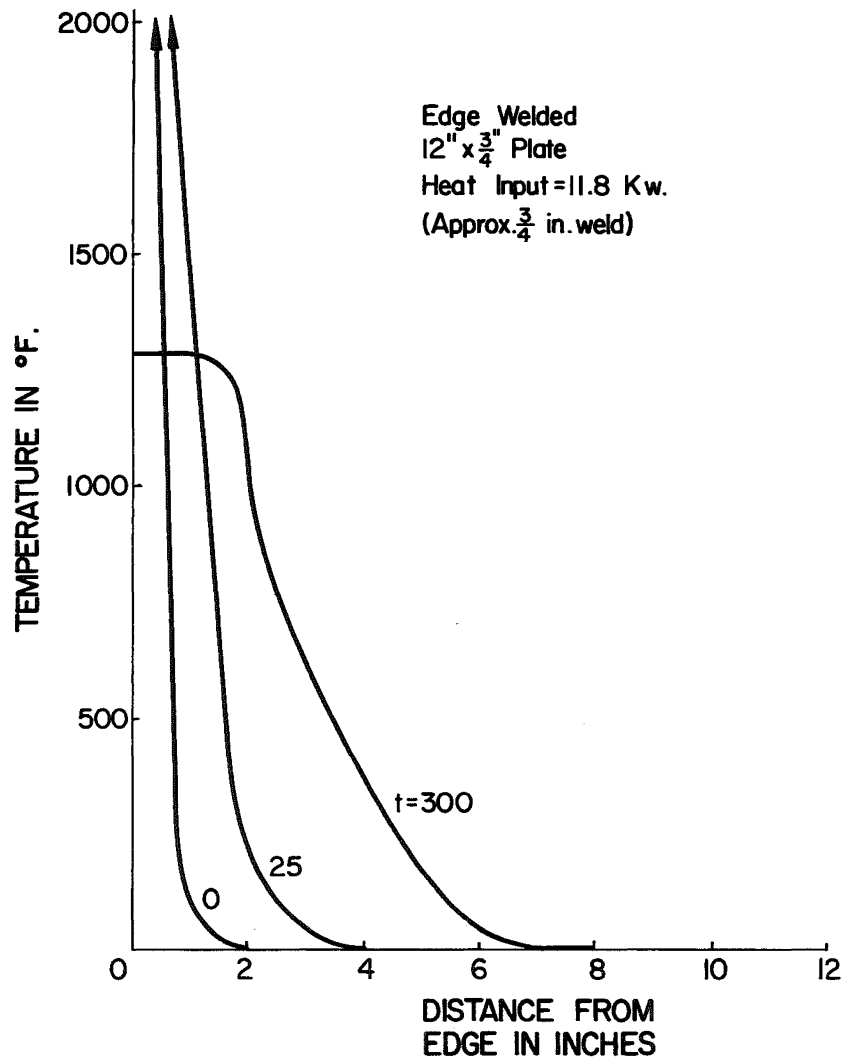


FIG. 3. HEAT INPUT AND TEMPERATURE DISTRIBUTION (COMPUTED)

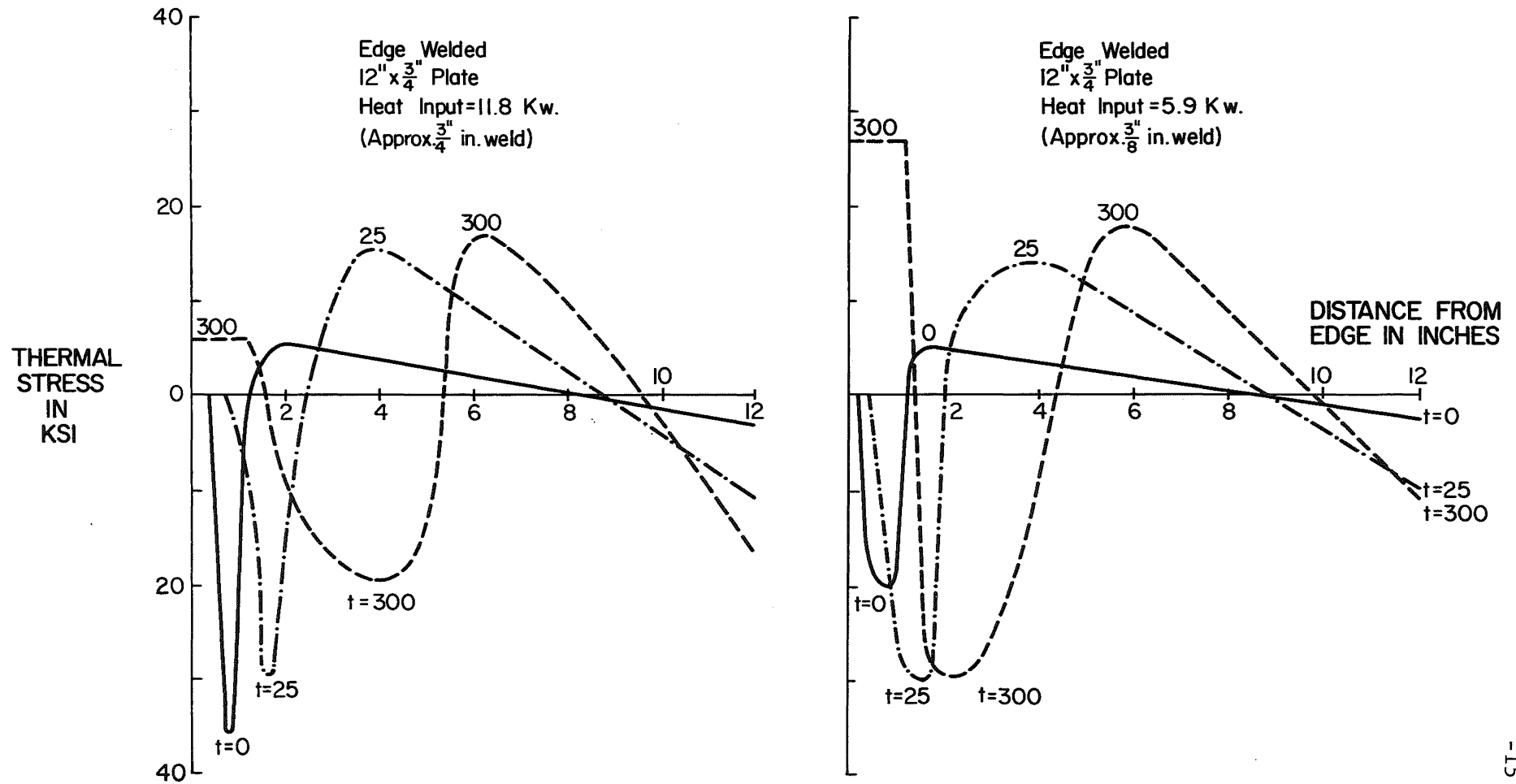


FIG. 4. HEAT INPUT AND THERMAL STRESS (COMPUTED)

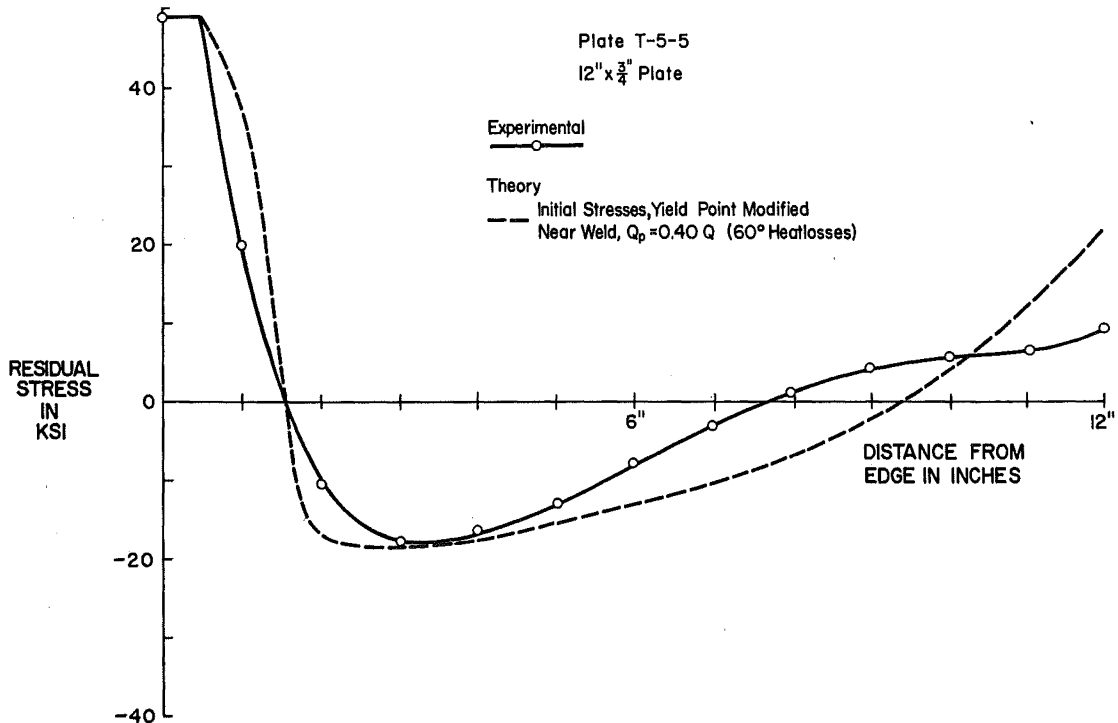
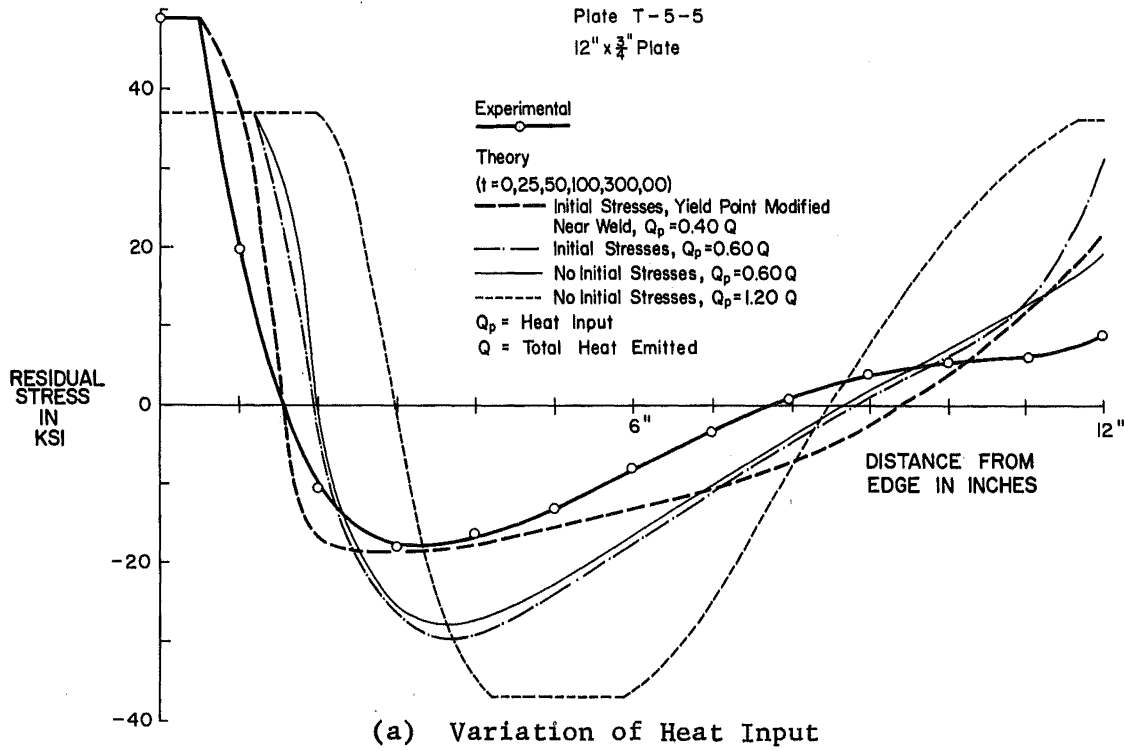


FIG. 5. HEAT INPUT AND RESIDUAL STRESS

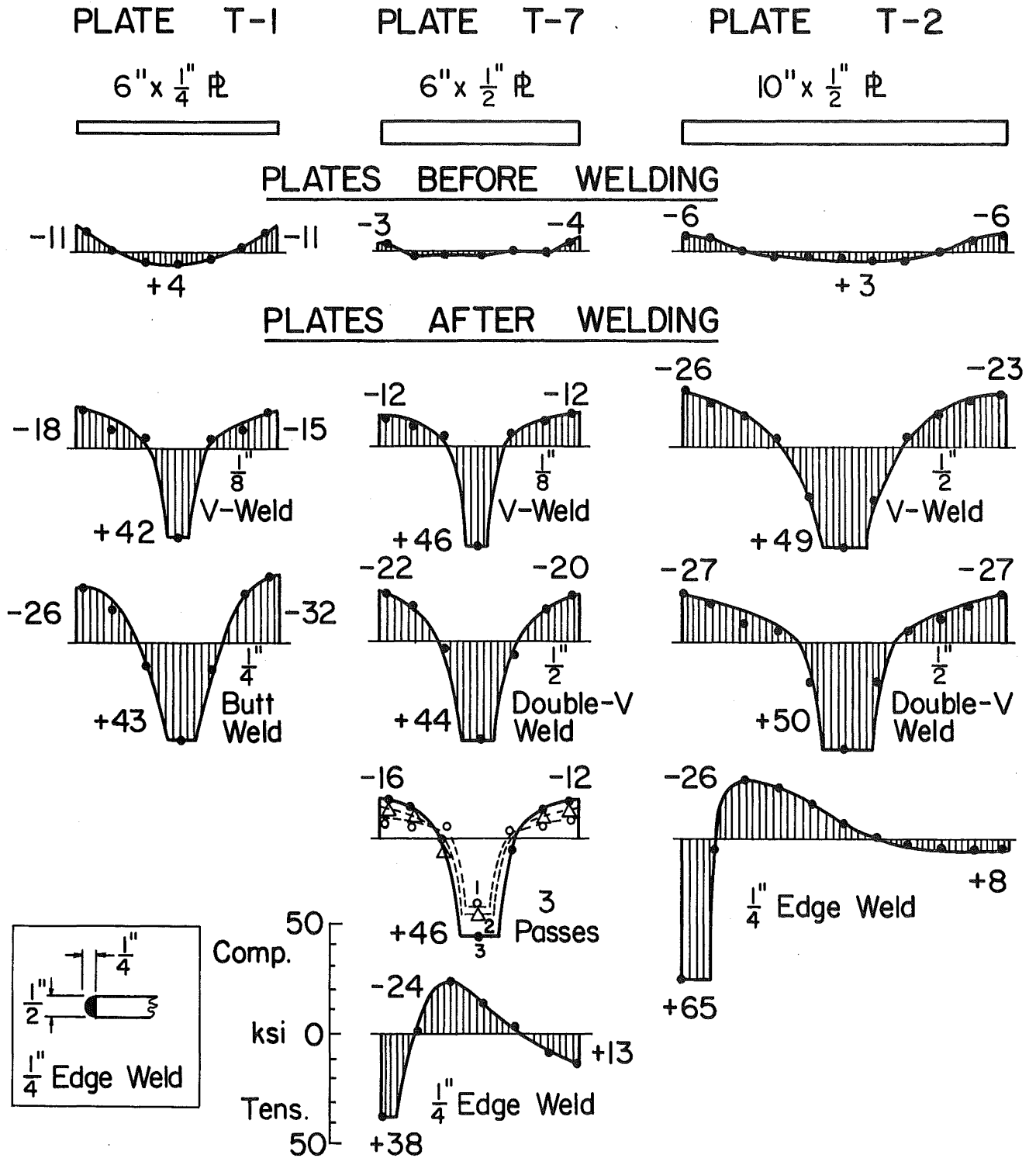


FIG. 6. TYPICAL RESIDUAL STRESS DISTRIBUTIONS

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LEHIGH UNIVERSITY
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249/G2A

September 6, 1962

Mr. John A. Gilligan, Chairman
Task Group 1, CRC
U. S. Steel Corporation
525 William Penn Place
Pittsburgh 30, Pennsylvania

Dear Mr. Gilligan,

Enclosed is Fritz Laboratory Report No. 249.12, "Heat Input, Thermal and Residual Stresses in Welded Structural Plates", by Lambert Tall.

This paper presents some results of the theoretical and experimental investigation into the residual stress distribution set up in steel plates welded either at the center or at the edge.

The report was presented at the Fundamental Research Symposium on Transient Heat Flow, sponsored jointly by the American Welding Society and the Welding Research Council in Dallas, Texas, in September 1961.

We are anxious to have your comments on the report prior to submitting it for publication. If you do have suggestions, could we please hear from you by September 21, 1962.

Your early attention will be appreciated.

Sincerely yours,



Lambert Tall

LT:tc

Enc: Report 249.12

cc: Members, Task Group 1, CRC
Members, Executive Committee, CRC
Pennsylvania Department of Highways
Messrs., C. D. Jensen, P. D. Muffley
Bureau of Public Roads, T. L. Stinson