

A PRELIMINARY INVESTIGATION INTO THE BEHAVIOUR OF
VARIOUS FLATTENED-END TRUSS CONNECTION CONFIGURATIONS

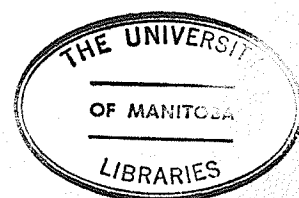
A THESIS
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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE
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NOTATION

$b_i A$	-	Area of Member i
d	-	Web Tube Diameter
D	-	Chord Tube Diameter; For Rectangular Tubes D Is The Diagonal Distance Between Tube Corners
e	-	Joint Eccentricity; Measure of Distance From Chord Axis That The Web Tube Axes Intersect
K	-	Effective Length Factor
ℓ	-	Effective Length of Member
L	-	Total Member Length
P_B	-	Joint Failure Load ⁽³¹⁾
P_m	-	Joint Failure Load With $e = 0$ And Bending Buckling And Stress Concentration Considered
r	-	Radius of Gyration of H.S.S. Sections
t	-	Web Tube Thickness
t_p	-	Thickness of Stiffening Plate
T	-	Chord Tube Thickness
β	-	Ratio of Web Tube Diameter To Chord Tube Diameter (d/D)
ϕ	-	Diameter
σ_b	-	Tensile Strength of Steel

CHAPTER 1

INTRODUCTION

1.1 Introduction

In structural steel work, it has generally been found that the use of Hollow Structural Sections (H.S.S.) leads to a more economical and lighter design than conventional rolled sections when members are subjected to biaxial bending. The superior performance of H.S.S. when subjected to axial load, makes their use desirable in trusses where all welded construction and intricate joint details result in an aesthetically pleasing structure. In recent years, a larger selection of members has become more readily available, and as better fabrication procedures are devised, H.S.S. sections are becoming increasingly popular.

The major drawback to the use of H.S.S. is the relatively high cost of fabrication of connections. The automatic tube-cutting machine has greatly simplified the member end preparation required for connections in trusses using round H.S.S. for both web and chord members. Since the introduction of rectangular H.S.S., the necessary profiling has been reduced to simple mitring, depending on the combination of sections used and the joint geometry.

However, the cost of connections is still quite high when compared with those required for standard I and WF shapes, and the required welding is still much more involved than the relatively simple straight fillet welds required for the popular standard steel shapes.

A recent proposal to reduce connection cost and simplify connection design and fabrication is end flattening. This connection technique has been used in the past for light bracing and other secondary members. It has the advantages of requiring simple fillet welds along straight lines, and no profiling. In situations where an acetylene profiling machine is unavailable, end flattening allows connections to be made between round members and reduces preparation and fabrication time. The procedure allows simple connections, of the type used for standard rolled shapes, to be used with H.S.S.

Photos 1.1, 1.2 and 1.3 show profiled tubes and some typical profiled connections between round H.S.S. tubes. Photo 1.4 shows a typical round to square H.S.S. connection.

1.2 Literature Review

1.2.1 Conventional H.S.S. Connections

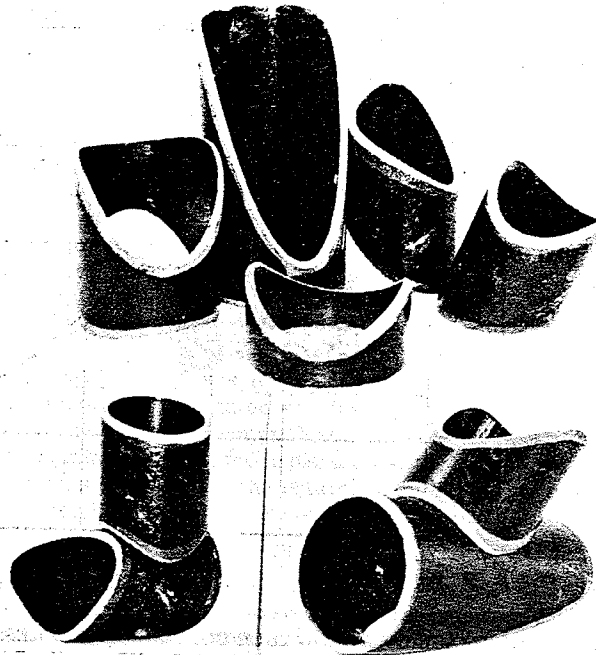


Photo 1.1 Some Profiled H.S.S. Tubes and Typical Joints

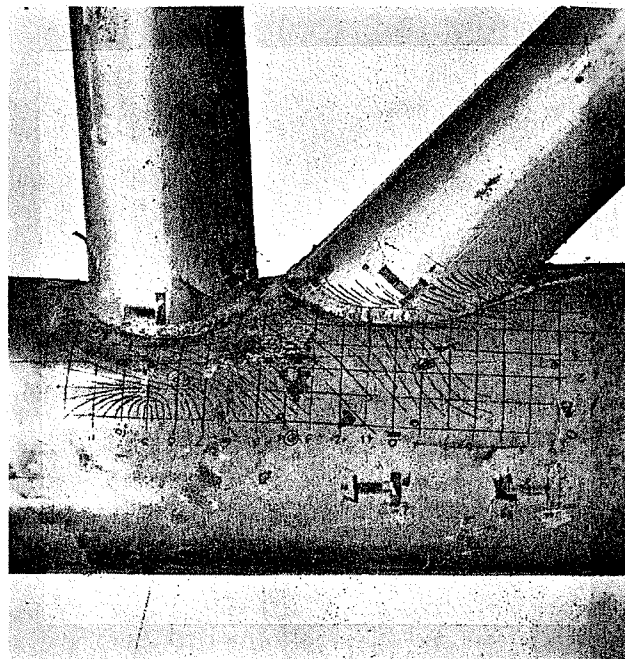


Photo 1.2 A Typical Profiled Joint Between Round H.S.S. Tubes With A Gap

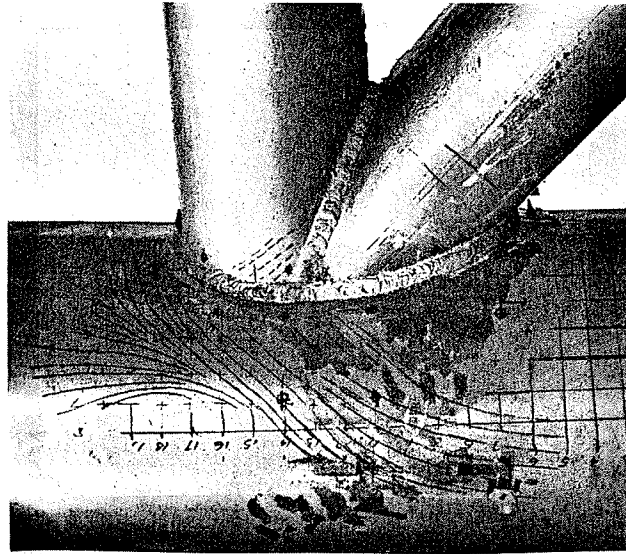


Photo 1.3 A Typical Profiled Joint Between Round
H.S.S. Tubes With The Web Members
Overlapping

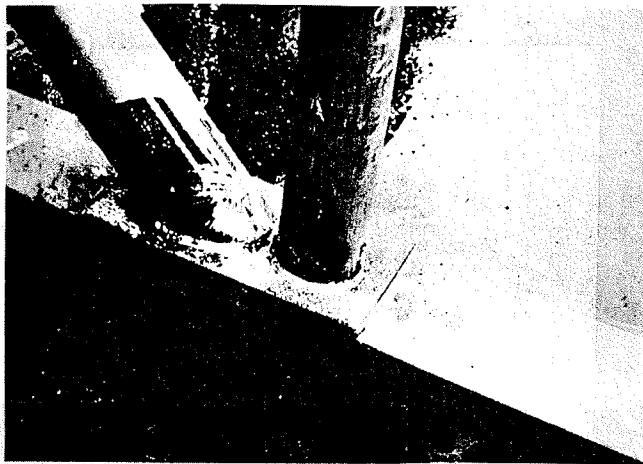


Photo 1.4 A Mitred Connection of Round Web Tubes
To a Square Stiffened Chord

Generally, it has been shown that three main parameters govern H.S.S. static connection strength^(2, 6, 9 11, 14, 16, 17, 19, 27, 32). These parameters are:

- (a) the ratio of branch width to chord width (β);
- (b) the ratio of chord thickness to chord diameter (T/D); and
- (c) the eccentricity of the joint (which is a measure of the distance of the intersection of the web member axes relative to the chord axis) or the gap between web members. Negative eccentricity usually indicates a lapped joint since the web members' center-lines meet on the web side of the chord center-line while for positive eccentricity the web member center-lines meet on the side opposite the web members.

Initially, investigators found that varying the eccentricity (e) between $+D/4$ and $-D/4$ resulted in an increase of joint efficiency of from 50 percent to 108 percent of the tension member strength. Joint efficiency is a measure of the ultimate joint strength relative to the yield strength of the tension member incident on that joint. However, most early tests involved members with large β ratios and the corresponding large web sections over-emphasized the value of eccentricity as a joint parameter. When smaller web members were used, even with negative eccentricities, the gap between tension and compression members resulted in low joint efficiency, since a gap between the web members forced the web loads to be trans-

ferred through the face of the chord member. The large deformations of the chord face associated with this form of load transfer led to premature failure of the chord. It was this transfer of forces between web members, not through the chord face, that resulted in higher joint strength. It was also found that the secondary stresses caused by joint eccentricities of up to $\pm D/2$ could be neglected, since the moments produced were relatively small for the normal range of H.S.S. sizes.

The effect of varying the member β ratio is to effectively change the joint flexibility. A low value of β yields a more flexible joint with a low plastic yield point, but a large capacity for stress redistribution and therefore high ductility, while a high β ratio results in a higher yield point, but lower ductility.

Bouwkamp⁽¹¹⁾ found that as the T/D ratio was increased, the thicker chord wall relieved the radial bending stresses in the web tube walls and resulted in a stronger joint. Further, he found that the effects of varying d/D and T/D ratios became less and less significant as the degree of overlap was increased. This was substantiated by Eastwood et al⁽¹⁴⁾ who found that for D/T less than 25, the influence of these parameters was reduced, and was significant only when load was transferred through

the chord face. The work of Eastwood et al also showed that if load is to be transferred through the chord face, deflections can be reduced by increasing the β ratio; that is, by increasing the stiffness of the joint and forcing load transfer to occur in the side walls of the chord.

Shinouda⁽²⁷⁾ found that by increasing the joint stiffness, joint, and therefore total truss, deflections could be reduced and a more uniform stress distribution between members obtained.

1.2.1.1 Circular Chords

Connections of round web members to round chord members are probably the most complex in terms of end preparation. For joints where the web members overlap, it is necessary to have a tube profiling machine since the web tubes must be profiled in two planes. In situations where a tube profiling machine is not available, a joint of this type would be almost impossible to fabricate by hand. Photo 1.3 shows this type of joint.

Thus, although this type of joint is very sound structurally, it requires very careful preparation, and if an acetylene tube profiling machine is unavailable, the joint is very difficult to construct.

In design curves of T/D and d/D (β) ratios published

in the H.S.S. Connection Design Manual published by The Steel Company of Canada⁽¹³⁾, it was found that joint efficiencies are highest in the range of d/D ratios from 0.35 to 0.5 with 100 percent efficiency occurring at a T/D ratio of 0.05, for non-eccentric joints between round web and round chord members. Bouwkamp⁽¹¹⁾ is in agreement with the results presented in the Stelco Connection Design Manual⁽¹³⁾. He found further that superior strength characteristics were displayed for joints with negative eccentricity especially for values of T/D between .01 and .03 and d/D values between .3 and .5. It is concluded, therefore, that a joint with negative eccentricity virtually guarantees load transfer between the web members, and hence large efficiencies.

For joints with a gap between the web members, larger d/D and T/D ratios reduce the local bending stresses around the joint and increase the overall strength of the connection. For such gap joints, these parameters are more pronounced, since all of the load is transferred by the chord face.

1.2.1.2 Rectangular Chords

The problems involved when round web members are attached to square chords usually stem from the fact that the web tubes are welded to the relatively flexible face of

the rectangular member. This type of connection can lead to very large local deformations of the chord face, unless stiffening plates are attached to the chord, or the web tubes interact. For joints that use stiffening plates, Shinouda⁽²⁷⁾ found that stiffening plates produced high localized stresses in the tube walls at the ends of the plates when all four sides of the stiffening plate were welded to the chord. He also found that the ultimate joint load was the same whether two or four sides of the plate were welded to the chord. That is, the high stresses did not affect the ultimate capacity of the joint. For increases in the chord axial load above the design value, a load reduction proportional to the inverse of the stiffening plate thickness (t_p) occurred.

A further problem encountered with square chords, is that significant deformation of the chord occurs at loads very much below the elastic limit of the members. Thus, elastic design cannot be used in selection of members for this type of joint. Eastwood and Wood⁽¹⁵⁾ found that the ultimate load carried by a gap joint was a function of the chord thickness. Design tables and charts have been compiled to relate the maximum vertical load that can safely be applied to the rectangular chord member, and to the parameters T/D and d/D .

1.2.2 Flattened-End Connections

Jamm et al⁽¹⁹⁾ have claimed that 100 percent efficiency is achievable in truss connections involving flattened-end H.S.S. members. Hlavacek, however, has found joint efficiency to be 20 percent lower than that for profiled joints. Washio and Kurobane⁽³¹⁾ found joint efficiencies for truss joints involving flattened-end H.S.S. members to range from approximately 45 percent to 50 percent. This figure must be viewed as very approximate since the effective lengths of the members involved were not reported, and the study was only a preliminary investigation of experimental techniques.

In tests conducted at the Commonwealth Experimental Building Station in Australia, Anderson⁽¹⁾ found that the ultimate load capacity of cropped-end connections was equal to the capacity of profiled-end connections. However, the circumferential stresses around the cropped-end members were in general much higher than those for the profiled-end members. Hlavacek⁽¹⁷⁾ found similar results for joints between flattened-end members. Anderson concluded that the redistribution of overstress, non-elastic chord wall behaviour before failure, the longer length of normal axial load distribution, direct load transfer between web members, and the effect of negative eccentricity in reducing stress

intensification in cropped-end members do not adversely affect the ultimate load carrying capacity of the joint.

1.2.3 Boundary Conditions For Test Specimens

In investigating the behaviour of truss connections, the test specimen normally consists of a single joint between two web members and a chord member. To simulate conditions in an actual truss, member segments extending from the joint in question, half way to the adjacent joints are used and appropriate boundary conditions are imposed at the member ends.

Eastwood, Wood et al⁽¹⁵⁾ investigated the effects of five boundary conditions, ranging from pins to rollers, for the far ends of the members. They concluded that the boundary conditions had only a minor effect on joint behaviour and used pinned conditions (which simulate conditions in a truss with relatively stocky members) for the majority of their work. Bouwkamp⁽¹¹⁾, Toprac⁽³⁾ and Washio and Kurobane⁽³¹⁾ used similar boundary conditions.

1.2.4 Effect of Slenderness Ratio

In tests conducted on profiled members in H.S.S. trusses by Mouty⁽²³⁾, it was found that for web members, an effective length of $0.7L$ was conservative for design purposes. These results are not, of course, directly

applicable to members with flattened ends. In tests conducted at the University of Manitoba⁽³⁸⁾, slender tubular columns with end connections which simulated the effects of circular truss chords were tested. Three different end preparation procedures (profiling, shearing, flattening and sawing) were used.

It was found that the profiled joint had the lowest effective length factor, followed by the completely flattened-end column and then the sheared-end column, whose effective length factor was approximately 10 percent greater than that for the specimen with profiled ends.

1.2.5 Techniques of End Flattening

The two most commonly used end preparation techniques are flattening followed by sawing, and shearing, with the shearing action producing the flattening. The two methods are simple and economical, but care must be taken to ensure the correct angle of cutting, especially in the shearing process.

Problems arise also due to cracking of the tube parallel to its axis.

Cracking can occur at any orientation of the tube seam relative to the direction of flattening. This problem is more pronounced for small diameter tubes and tubes with

thick walls since the local bending is more extreme for these tubes than with larger diameter tubes. Boulos⁽⁷⁾ suggested preheating before flattening, but this requires extra time and expense, and will probably result in a more costly joint. Another solution to the problem is closing the cracks by welding. This repair can be done at little extra cost during the welding of the joint in either the fabrication shop or on site.

This cracking problem is more pronounced for hot-rolled sections than cold-formed sections, and probably relates to material properties and cold working of the sections.

1.3 Scope of Study

This study represents an initial phase of an investigation of the load-deformation behaviour of truss joints between tubular members with flattened ends.

The objective of the present investigation was to evaluate the relative merits of four types of flattened-end connections under static loading, to determine which of the connection types merited further, more detailed, study. No attempt was made in this initial study to evaluate the effects of various joint parameters, but rather to simply compare joints with significantly different geometries.

A significant aspect of the investigation concerned the design of the loading equipment and the development of appropriate measurement techniques.

1.4 Assumptions and Limitations

Due to the nature of the initial project, the test program was limited to static tests using a non-spring-loaded prestressing bar. The prestressing bar was simply stressed to apply a given compression load in the chord. This prestress load would drop due to elastic shortening of the chord when external load was applied. If the bar had had large springs between the specimen loading plate and the prestressing bar bearing plate, the spring would have expanded as the chord shortened and the prestressing load could have been held constant during the test.

Another factor that may affect joint behaviour slightly is the loading simulation. In this study, the compression members were supported by pin supports which simulate conditions in a stocky truss rather than rollers which simulate a more flexible truss condition.

The study was limited to an experimental determination of joint behaviour with no attempt to predict this behaviour analytically. However, other researchers have

attempted to correlate experimental and analytical investigations in the interpretation of joint performance, and these results are presented in the next chapter.

CHAPTER 2

BEHAVIOUR OF HOLLOW STRUCTURAL SECTION JOINTS

2.1 Methods of Analysis

Many investigators have proposed analysis techniques to aid in the understanding of the stress distribution around joints, and also to aid in the design of these joints. Von Obering and Jamm⁽²⁴⁾ and Blockley and Eastwood⁽⁵⁾ have used classical theories (plate on an elastic foundation and thin plate theory) with some success for the analysis of joints in tubular members. Bouwkamp⁽¹⁰⁾ has compared deflections and stresses obtained using photo-elastic techniques with those predicted using the Bijlaard theory and with the results of a computer simulation by Scordelis⁽²⁶⁾. He found that the photo-elastic and analytical procedures showed promise for finding the stress condition in the joint. The Bijlaard theory applies for pressure vessels with the plugs cut out at the joints. This intensifies loading stresses at the joint and results in a lower joint capacity.

Jubb and Redwood⁽²⁰⁾ analyzed the stresses induced in the chord face using a yield line analysis, in the same manner that concrete slabs are analyzed. They found that it

is a simple and useful method of analyzing a joint, but requires more extensive tables relating joint eccentricity, β ratio and the ratio of beam depth to column width for complete analysis.

Scordelis and Bouwkamp⁽²⁶⁾ have written a computer program, based on classical thin shell theory, for the analysis of a simply supported circular cylindrical shell, representing a section of a tubular chord member. Utilizing the five loading cases shown in Figure 2.1, any combination of web to chord connection can be analyzed.

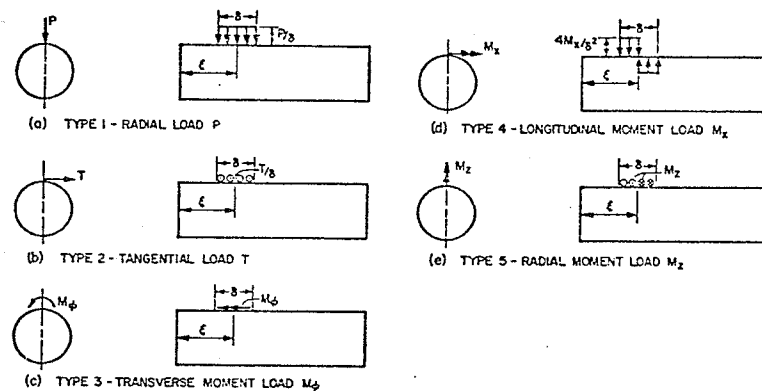


Figure 2.1 Loading Types⁽²⁶⁾

Comparing stress and displacement results with those obtained experimentally, it was found that the computer analysis compared favourably to the results of Bijlaard and Kempner, Sheng and Pohle.

Greste⁽¹⁷⁾ developed a program to automatically generate a finite-element mesh to analyze Pratt type joints by the finite-element method. By considering symmetry, computing machine functions, the degrees of freedom related to the basic elements used and substructuring of specimens, Greste was able to produce a very efficient program to produce meshes of variable fineness for use with a finite element analysis program.

Although he concentrated on N type joints (this work was done in conjunction with that of Bouwkamp), the program is general and can be applied to any joint configuration.

In comparing the stresses obtained experimentally and from the finite element program, it was found that the results were in very good agreement, and that values of stresses tended to converge rapidly as the fineness of the mesh was increased.

Of the four meshes proposed, (coarse, medium, fine and Xfine), Greste found that for most purposes the medium mesh could be used, while the fine mesh was more

than adequate for analytical studies.

Becker, Gerberich and Bouwkamp⁽⁴⁾ formed a model to analyze the fatigue failure of joints under cyclic loading by considering fracture mechanics and crack initiation and propagation. They devised models based on a two-dimensional notch crack and a three dimensional semi-elliptical crack, with which they were able to predict the life expectancy of joints. Their model was in good agreement with other experimental findings.

Current work on analysis techniques is directed toward increasing the correlation between experimental and analytical values of the tube stresses and deflections. As yet, there is no simple way to check the adequacy of joints other than destructive testing, but as programs are written for more complex fourier analyses, the level of competence will increase in this area of design.

Several investigators cite failure theories based on classical methods which are familiar to most people. The more contemporary theories such as fracture mechanics and crack initiation and propagation as advanced by Becker et al⁽⁴⁾ are at present applicable only for special joint configurations.

While analytical studies can accurately predict the elastic load-deformation behaviour of some joints, the only reliable means of establishing the actual joint response to

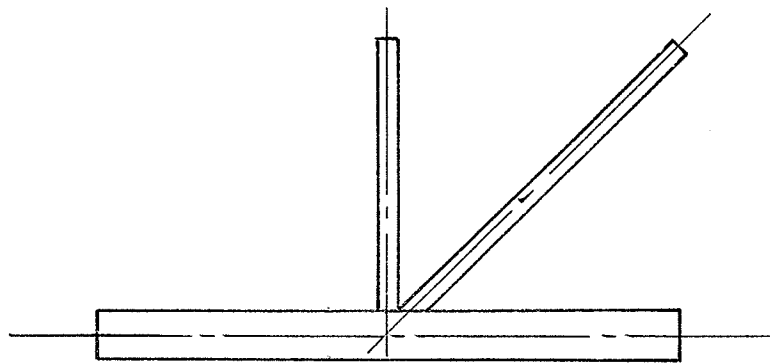
static loading is by experimentation.

In the experimental investigation of conventional profiled joints and mitred joints between round web members and square chords, several parameters have been recognized as playing a significant part in influencing the performance of the joints. Some of these properties are eccentricity (e), T/D ratio and d/D ratio or β ratio. These properties are defined below.

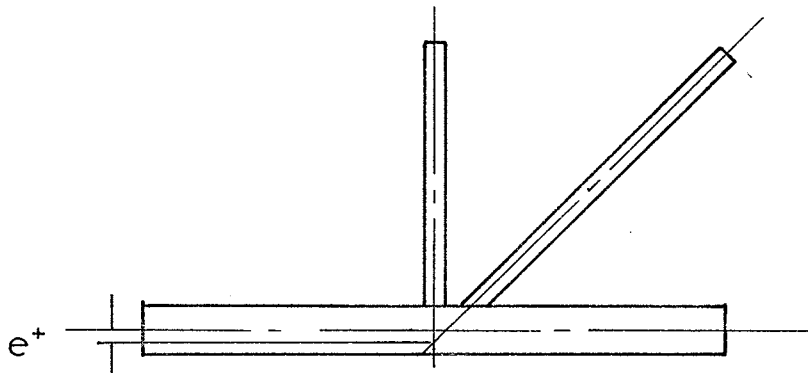
- (i) Eccentricity, (e), is the distance above or below the centroidal axis of the chord at which the axes of the web tubes intersect. Figure 2.2 illustrates eccentricity.
- (ii) T/D is the ratio of chord thickness to chord diameter. As the T/D ratio is increased, joint efficiency increases.
- (iii) d/D is the ratio of web tube diameter to chord tube diameter. For any value of T/D there is a value of d/D that gives an optimum value of efficiency.

In addition, for connections involving flattened end members, some parameters such as the degree and length of flattening are introduced. Jamm et al⁽¹⁹⁾ state that 100 percent efficiency can be developed when the web tubes are flattened to between $D/4$ and $D/5$. Hlavacek⁽¹⁸⁾ found that joint efficiency decreased by less than 20 percent for completely flattened web tubes in similar joints.

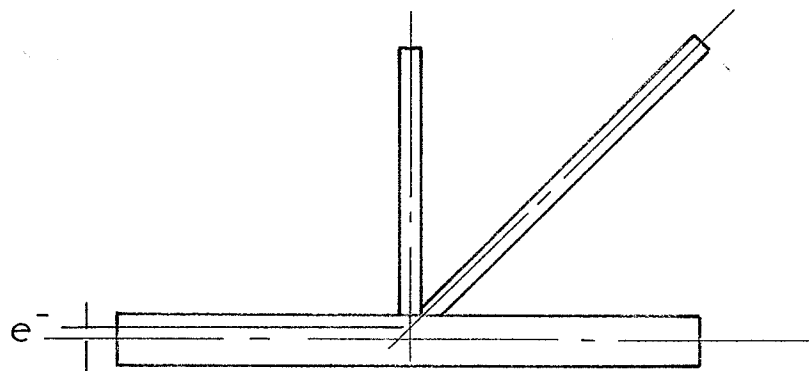
Consideration should be given to the stress distri-



a) ZERO ECCENTRICITY



b) POSITIVE ECCENTRICITY



c) NEGATIVE ECCENTRICITY

FIGURE 2.2

bution in the wall of the chord member due to the stress transfer in the decreased developed area of the web members. This could cause large chord wall deformations at loads greatly below the elastic limit and, consequently, before the structure reaches its useful limit, based on the structural adequacy of the members. Anderson⁽¹⁾, however, found that for joints with a web member overlap the stresses around the joint do not adversely affect joint performance, regardless of the degree of flattening. For mitred joints between round web tubes and square chords, Eastwood and Wood⁽¹⁵⁾ found that the stress distribution around the joint, for a static loading condition, gave no indication of joint performance. They concluded that the parameters that alter joint performance are those that change the joint stiffness and ultimate capacity. These parameters are the eccentricity, T/D and β ratios.

2.2 Failure Criteria

Excessive deformation is probably the best criterion of the useful life of a member, since plastic deformation before failure can be very large. With such large deformation, the structure can become unusable before ultimate failure has occurred. In tubular trusses with end flattened web members, plastic deformations are usually noticed particularly early around the joints.

Blockley et al⁽⁶⁾ defined failure, in tests similar to those described in this study, as a movement of the loading ram of 0.045 inches per minute, under no load increase. Attempts to relate the maximum allowable truss deflection to failure were abandoned, since it was found to be too difficult to relate joint deformation, elastic member shortening and the limiting truss deformations because the panel sizes and the joint geometry were variable. An arbitrary value of 0.05 inch deflection of the chord face under the compression member was chosen as being equivalent to joint failure.

Anderson⁽¹⁾, Bouwkamp⁽¹¹⁾ and Beale and Toprac⁽³⁾ used ultimate failure criteria such as buckling, tension failures and weld failures in the evaluation of their test joints.

In the present study, the excessive deformation criterion will be used to define the useful limit of the connection. Although ultimate failure criteria, such as member buckling, fracture, etc. will also be examined, it was felt that because end flattening results in larger joint deformations, an excessive deformation failure would give a better indication of the useful life of the structure. Other types of failure are also possible. For small web sections, the effective length (KL) may be fairly large, and the web compression member

may buckle elastically before the deformation of the chord face becomes critical. This buckling may be simple Euler Buckling, or it may be similar to web crippling in standard rolled shapes. A localized web crippling failure may be more prevalent in specimens where there is no web tube interaction; that is where web loads are transferred through the chord face only.

Another possibility is punching through the chord face in either tension or compression. This problem is most prevalent for joints with very small T/D ratios where large web members forces are involved.

2.3 Joint Efficiency

Several investigators^(8, 11, 12, 14 and 19) have defined the joint efficiency as the ratio of the failure load for the joint to the tensile strength of the diagonal member or the yield strength of the first member to yield.

This definition is simpler to use than others, such as that proposed by Washio and Kurobane⁽³¹⁾, and is widely accepted as a standard means of defining joint capacity with respect to the tensile capacity of the diagonal web member.

The numerical calculation of joint efficiency is not the only means of evaluating the structural performance

of truss joints. A qualitative evaluation of other factors involved in the overall response of the connections to loading is also possible. These other considerations cannot be neglected due to the nature of the joints being tested. Problems such as Euler Buckling, local buckling or other problems related to end flattening can occur at loads very much below the tensile capacity of the diagonal web member, and very low values of apparent joint efficiency may result.

In this study, measurements of the overall specimen displacements, rotations and the relative displacements of the web members to the chord tube will be taken. These measurements will give an accurate record of the test joint response to static loading. In addition to deflection measurement, some specimens will be strain gauged in order to measure the distribution of member stresses.

CHAPTER 3

DESIGN AND FABRICATION OF TEST SPECIMENS

3.1 Introduction

The design of the series of test specimens was influenced by several factors.

Firstly, it was felt desirable to facilitate comparisons between results obtained in this study and those obtained by others. Secondly, several different joint geometries involving different directions of web member end flattening and both circular and square chord members were to be investigated. It was desired, also to determine, if possible, the effects of different methods of end flattening on joint behaviour. Finally, in selecting member sizes, consideration was given to ranges of available sizes, ease of fabrication and size and capacity of loading equipment.

A total of 10 specimens, involving two methods of end flattening, four different geometries and both square and circular chord sections were tested.

3.1.1 Specimen Design

A number of studies (1, 2, 5, 6, 11, 14, 15, 16 and 19) of the behaviour connections in tubular trusses have been based on a Pratt truss geometry. Consequently, to facilitate

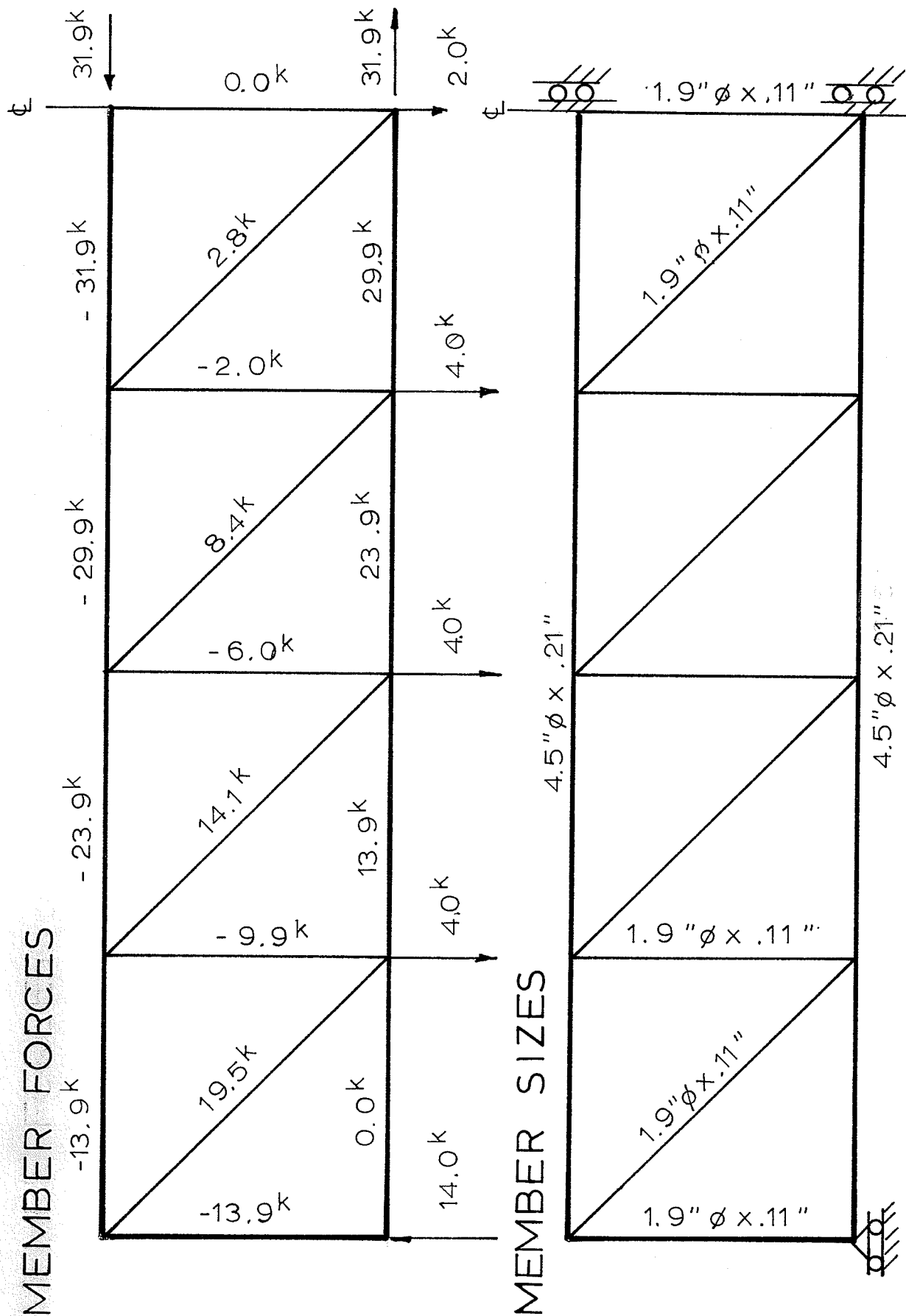


FIGURE 3.1. TRUSS MODEL

comparisons of results obtained in this study with those of the previous studies, the Pratt truss geometry was selected.

In order to obtain meaningful comparisons of joint behaviour for the several joint configurations considered, the test specimens were designed to portray relatively severe loading and geometric conditions. A full scale truss was considered and then scaled down to obtain the design shown in Figure 3.1. Because of its relatively severe web member loading, the compression chord panel point adjacent to the end vertical was selected as a model for the test specimens. A high strength prestressing bar was designed to provide the necessary chord compressive force.

In proportioning the joint, small web members were matched with large diameter thin-walled chord tubes. It was hoped that these member sizes would result in relatively low values of joint efficiency and hence represent severe test conditions. Unfortunately, the proposed chord section was unavailable, and a tube with a thicker wall was substituted for some of the specimens.

A second consideration in the design of the specimens was the methods of end preparation available. The two most commonly used methods of end preparation currently in

use; shearing, and flattening and sawing, were used in this test program.

Shearing has been found to require a minimum of fabrication time although care must be taken to ensure symmetrical flattening and correct orientation of the sheared planes.

End flattening and sawing is favoured by some fabricators who have developed special equipment to reduce the preparation time and thus reduce costs. Proper attention must be paid in the flattening of the tubes so that distortion, as illustrated in Photo 3.1, is reduced.

Since the purpose of this study was to investigate a variety of flattened-end joint configurations, both circular and rectangular chord tubes and directions of flattening parallel and perpendicular to the truss plane were used. Similarly, the degree of flattening was varied from full flattening to partial flattening with a gap of $\frac{1}{2}$ inch between the tube walls.

As was done in previous studies, it was assumed that, during loading, truss members tend to deform approximately as shown in Figure 3.2 with points of inflection approximately at the mid-length of each member. The test specimen was consequently designed to consist of a chord member and two web members, all extending from the joint in

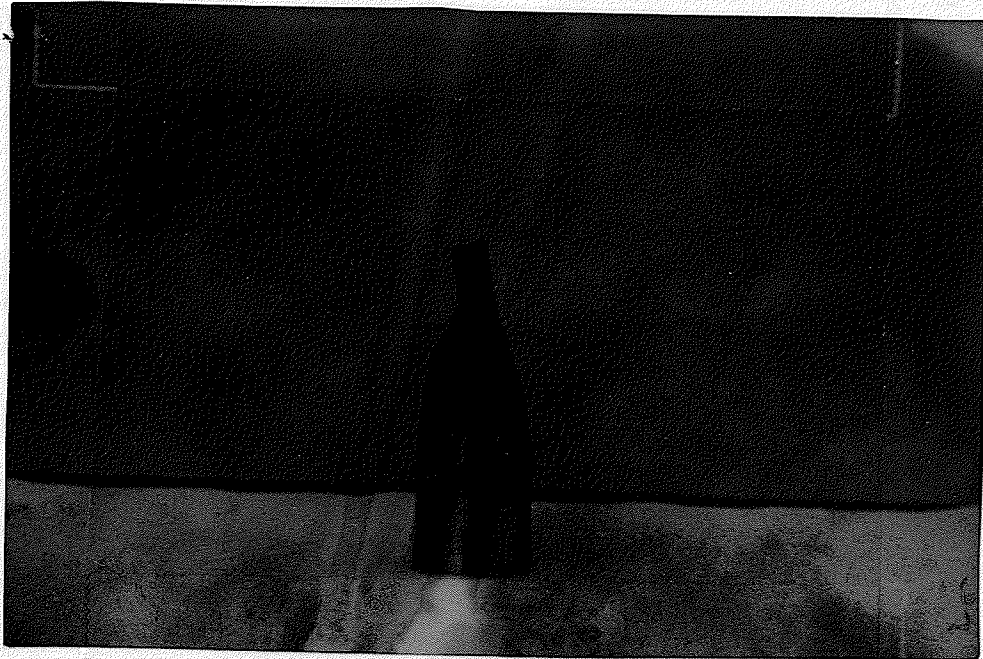


Photo 3.1 Distortion Due To Uneven Flattening



Photo 3.2 Specimen 2B1 Showing Overlapping Web Members

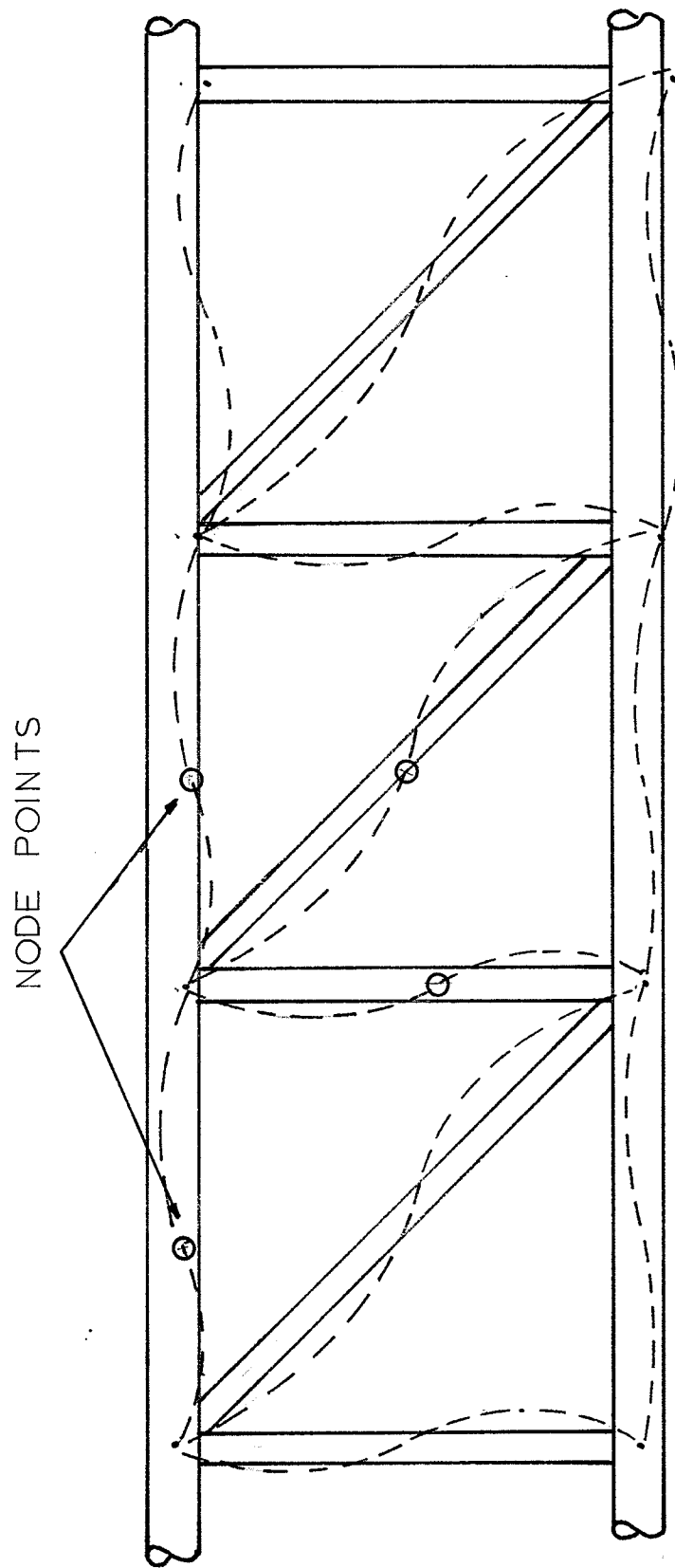


FIGURE 3.2 DEFLECTED TRUSS SHAPE

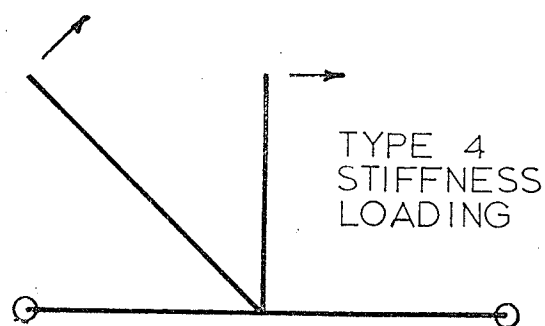
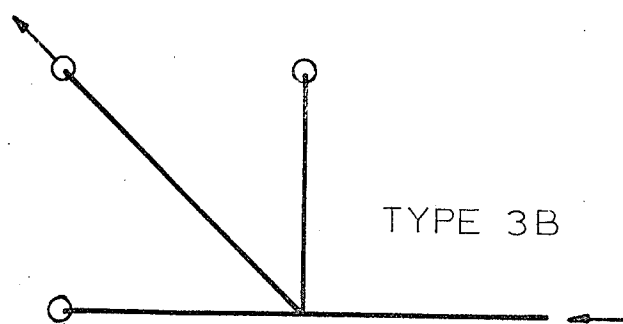
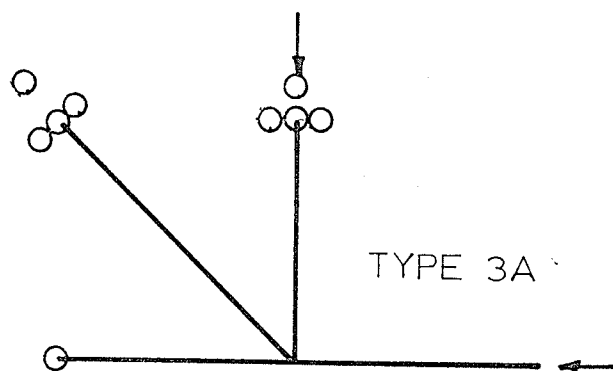
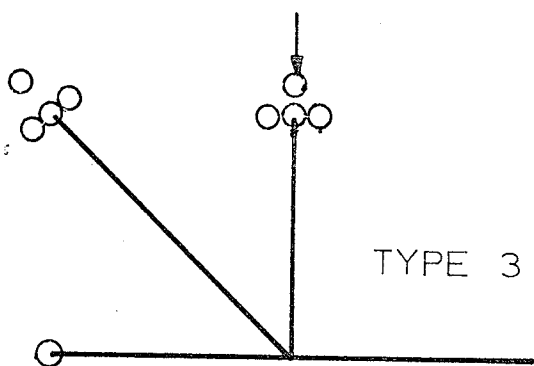
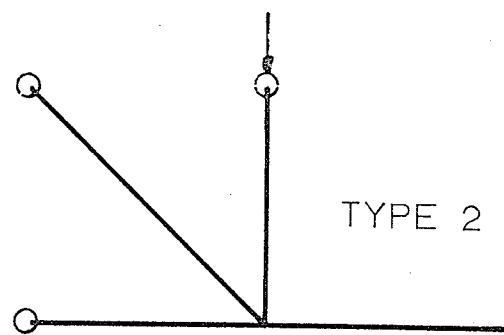
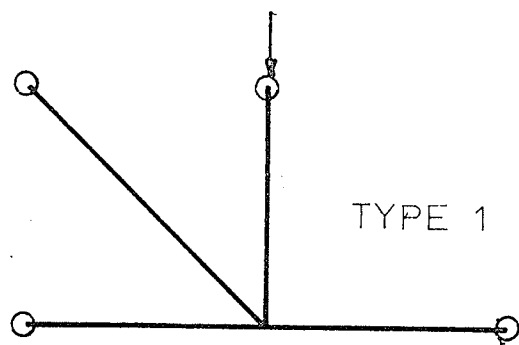


FIGURE 3.3
LOADING CONFIGURATION

ROCKER ○
ROLLER ○○○
LOADING ←

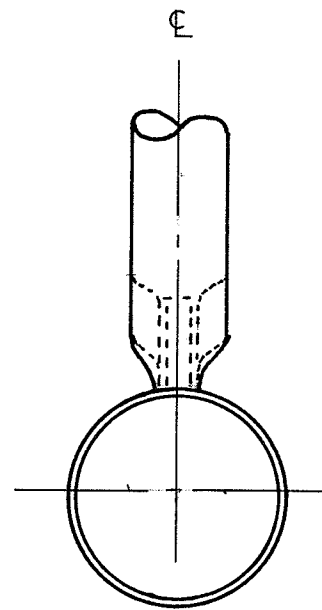
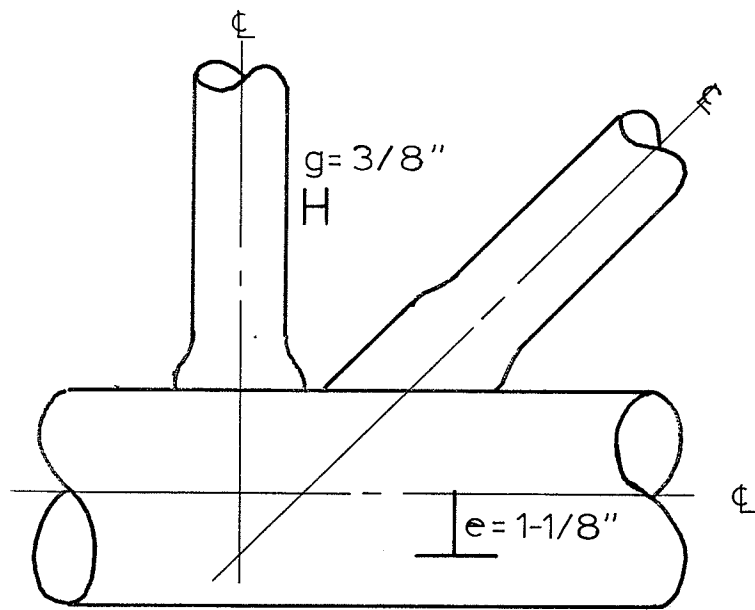
question, half way to the adjacent panel points.

The secondary member end moments, which result from the continuity between truss members, range from very small values for trusses with long, slender members, to relatively large values for trusses with stocky members. Eastwood, Wood et al⁽¹⁵⁾ employed several types of member end conditions, involving either pins or rollers, to simulate conditions in an actual truss. After finding that the member end conditions exerted only a minor influence on the joint behaviour, they used the relatively simple pin connections for most of their work.

For this study, the chord and compression web member supports were designed as pin, or rocker, supports, with virtually no provision for transverse member displacement, while the tension member was applied through a pin connection. Hence, the joints should simulate the relatively severe conditions at a joint in a truss with stocky members.

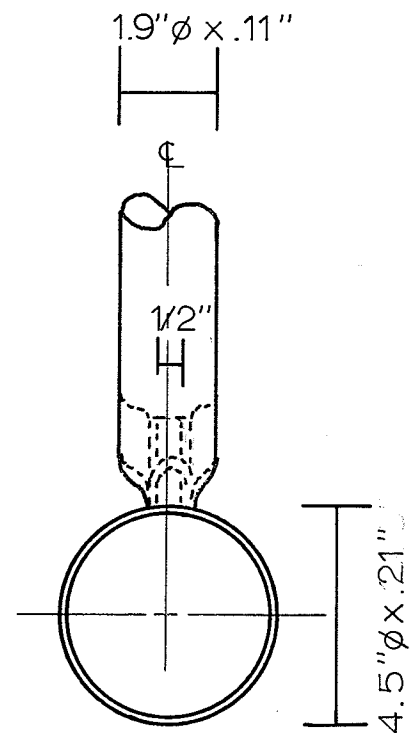
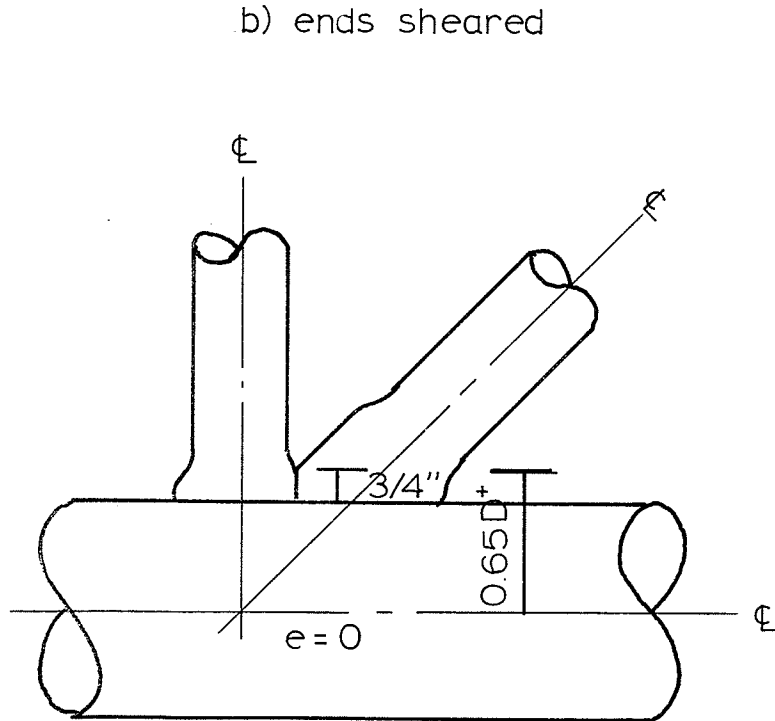
3.2 Specimen Designation

Figure 3.4 illustrates the four joint configurations used in this test series. A three character designation was used to identify the various specimens. The first character specifies the joint geometry by using the digits from 1 to 4. The second character, letters A, B or C, designates the method



TYPE 1

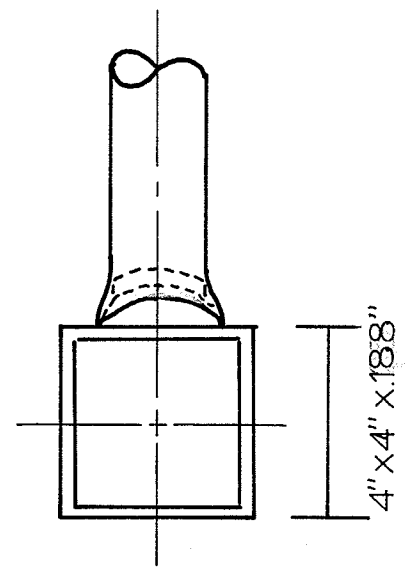
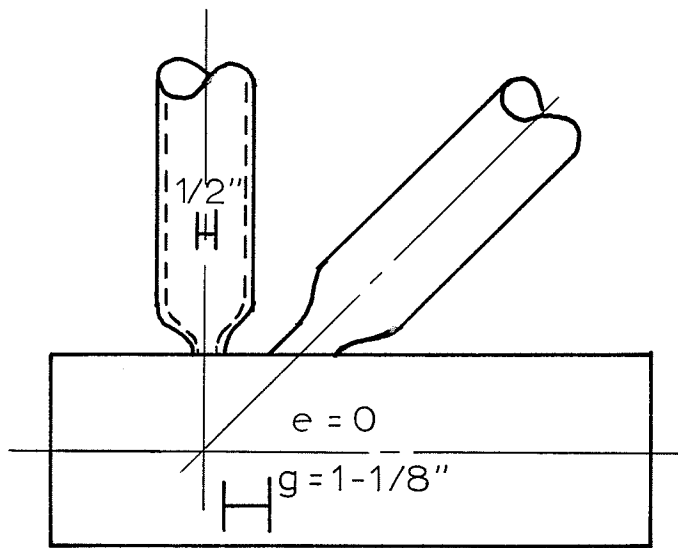
- a) ends flattened and profiled
- b) ends sheared



TYPE 2

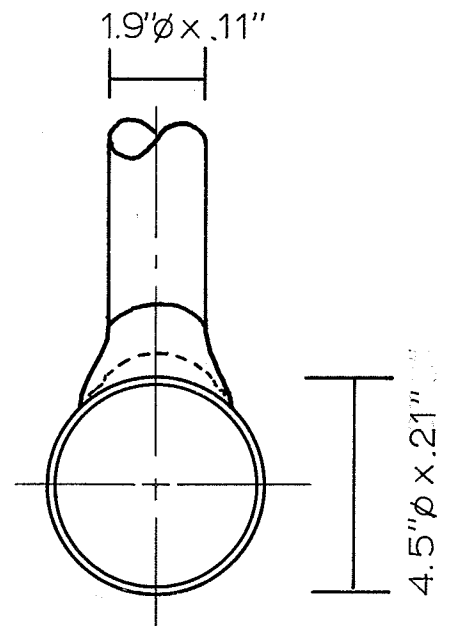
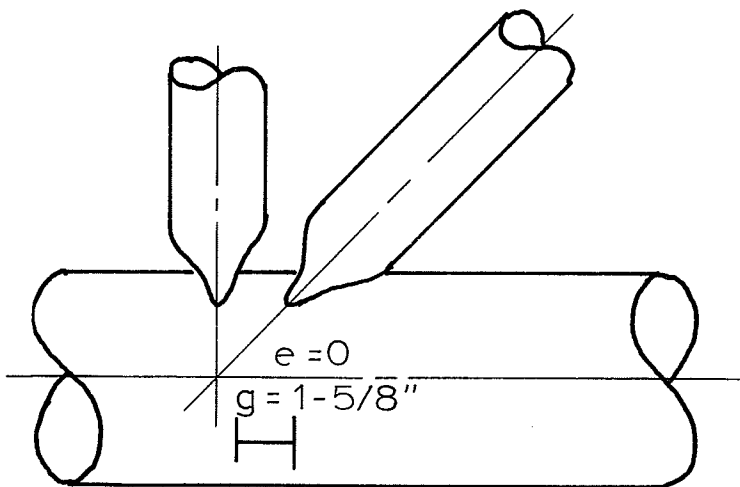
- a) ends flattened and profiled
- b) ends sheared

FIGURE 3.4 TEST JOINTS



TYPE 3

ends flattened and profiled perpendicular
to chord direction
(square chord)



TYPE 4

ends flattened and profiled perpendicular
to chord direction
(round chord)

Scale 1/4" = 1"

3.4(b)

of end preparation. For types 1 and 2, A indicates flattening of the tube to a $\frac{1}{2}$ inch gap and cutting, and B indicates shearing. For types 3 and 4, A indicates complete flattening and sawing. As the specimens were fabricated in pairs, the third character, the digit 1 or 2, distinguishes each specimen of the pair.

Thus, 2B2 indicates a type 2 specimen with sheared web tubes.

The type 1 specimens had round chord members with the flattened members attached to the chords parallel to the direction of flattening, as shown in Photos 3.3 and 3.4. The type 1A specimens were prepared by flattening and cutting. A $\frac{1}{2}$ inch gap between the flattened tube walls was used.

The type 1B specimens used sheared tubes. Shearing fully flattened the tubes, as shown in Photos 3.11 and 3.14.

The type 1 specimens incorporated a positive eccentricity of $D/4$ so that the gap between the web members would force the member loads to be transferred through the chord tube face.

The type 1 joints, because of their simple end preparation and straight fillet welding, were the easiest to fabricate. The preparation of the web members for the type 2 joints was the same as that for the type 1 joints.

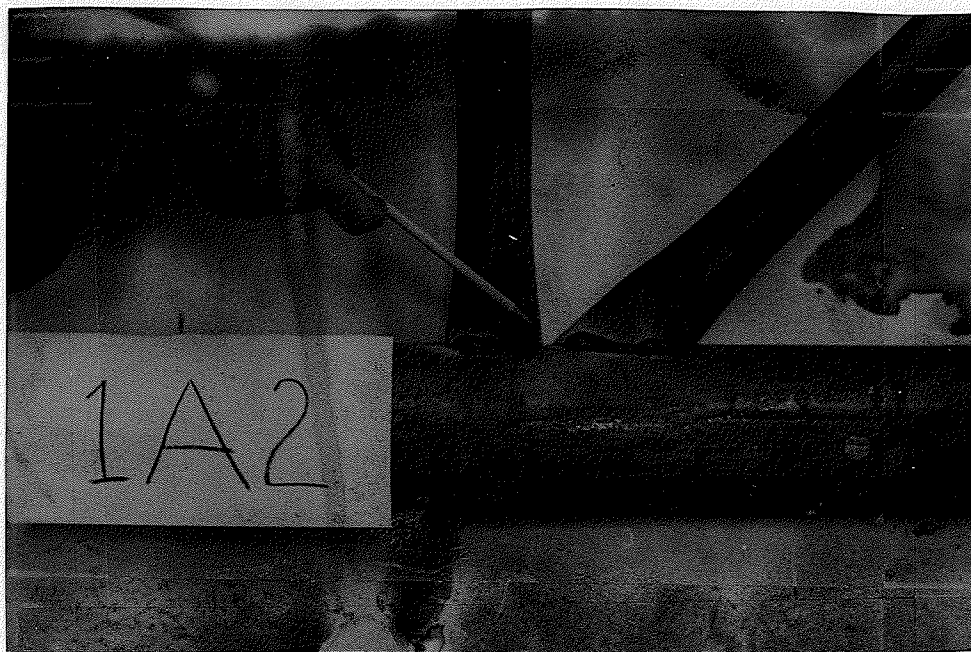


Photo 3.3 Type 1A Joint Configuration



Photo 3.4 Type 1B Joint Orientation

However, the type 2 joints had zero eccentricity so that the web tubes required further preparation to allow for the web member overlap as shown in Photo 3.5 and 3.11. The type 2 joint was investigated because it was anticipated that its larger fabrication cost might be offset by significantly better structural performance.

The type 3 specimens used square chords with zero eccentricity and the flattened web tubes attached perpendicular to the chord tube. Photos 3.6 and 3.26 show details of the specimen configuration. For the type 3 and type 4 specimens, the web tubes were fully flattened and cut by hacksaw or acetylene torch. It was felt that the localized chord loading, for the type 3 specimen, might be less severe than that for a conventional mitred joint with relatively small web members.

Joint type 4 was similar to joint type 3, except that it had round chord members. Photos 3.7 and 3.13 show the web tube orientation and profiling of this joint.

Joint type 4, while requiring profiling, involves the profiling of a flattened tube, which requires only the cutting of circular arcs on flat surfaces. The cuts can be made by hand using simple templates. This joint may prove to be a good alternate to joints between large chords and very small web members which place a large point load on a relatively plane surface. The type 4 joint may increase the

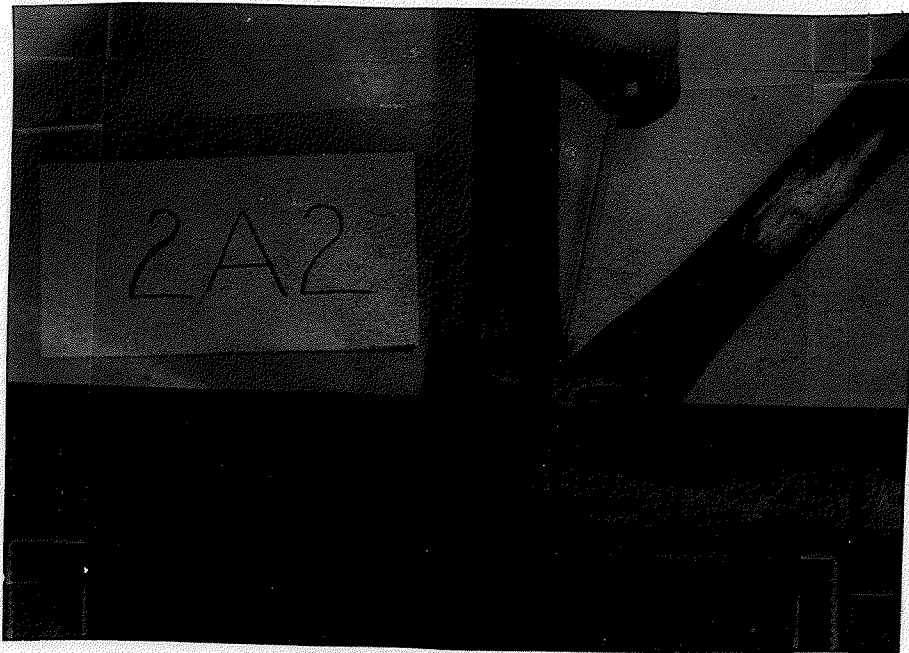


Photo 3.5 Web Member Overlap Before Welding

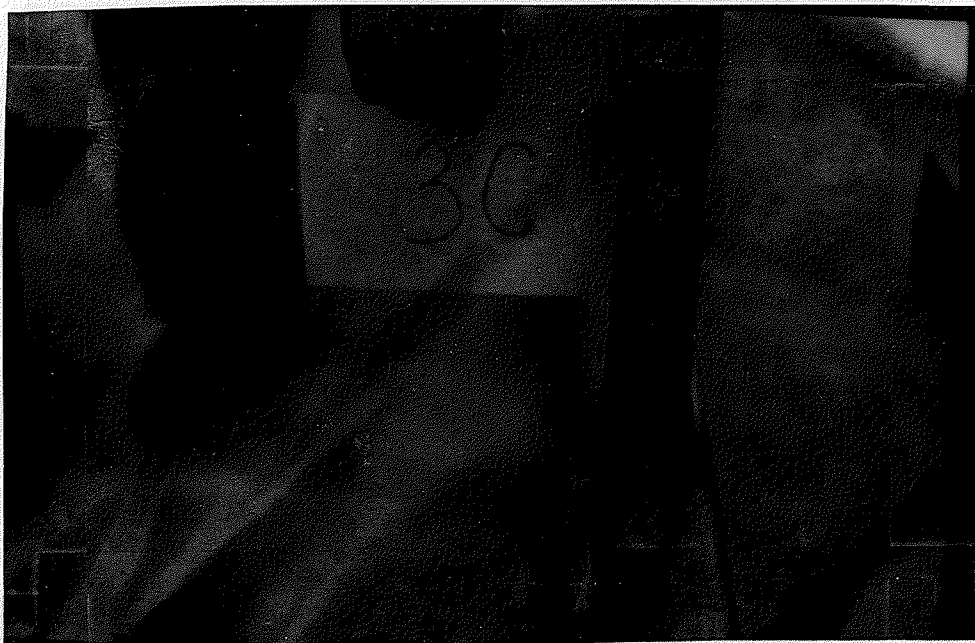


Photo 3.6 End View Of Type 3 Specimen

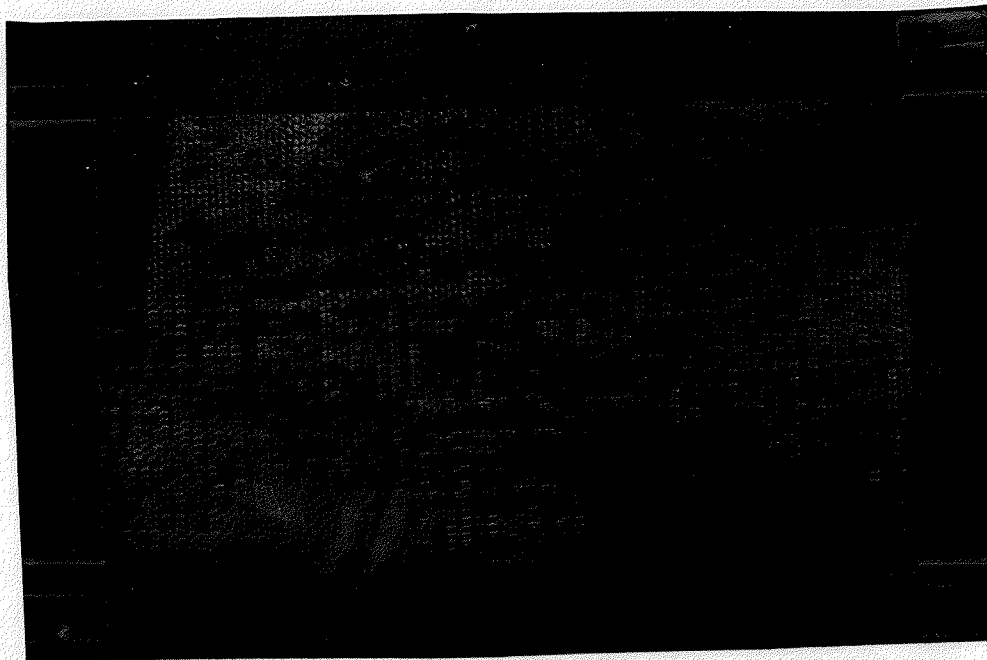


Photo 3.7 Type 4 Joint Configuration



Photo 3.8 Side View Of Web Member Preparation

TABLE 3.1
Specimen Properties

Type	Chord Size (Nominal)	Chord Size (Measured)	Web Size	e	t/D (Nominal)	t/D (Measured)	B=d/D Nominal	B=d/D Measured	Gap	Overlap	Web Member End Preparation	d/2 gap flattened members
1a	4.5"φ x .21	4.534"φ x .193 4.542"φ x .196	1.9"φ x .11	D/4 = +1 1/8"	.047	.0425 .0433	.423	.419 .418	3/8"	0	Flattened & Sawed	
1b	4.5"φ x .21	4.530"φ x .198	1.9"φ x .11	D/4 = +1 1/8"	.047	.0437	.423	.419	3/8"	0	Sheared	
2a	4.5"φ x .21	4.539"φ x .196 4.534"φ x .193	1.9"φ x .11	0	.047	.0433 .0426	.423	.419 .417	0	3/4"	Flattened & Sawed	0.65/D Overlap (as proposed by Zimmer- man et al (19)
2b	4.5"φ x .21	4.543"φ x .198	1.9"φ x .11	0	.047	.0436	.423	.419	0	3/4"	Sheared	0.65/D Overlap (as proposed by Zimmer- man et al (19)
3a	4"x4"x.188"	---	1.9"φ x .11	0	.0442	---	.335	---	1 1/8"	0	Flattened & Sawed	
4a	4.5"φ x .21	4.530"φ x .192 4.542"φ x .197	1.9"φ x .11	0	.047	.0424 .0434	.423	.417 .419	1 5/8"	0	Flattened & Sawed	May require as much profiling as unfla- ttened joints. Used only to compare with Type 3 joints.

severity of the load in the web member, but distributes the load to the sides of the circular member in much the same way as the type 3 joint spreads the web member load to the vertical sides of the square chord.

3.3 End Preparation and Fabrication

Most of the end preparation and fabrication of the test specimens was performed in the University of Manitoba Civil Engineering Machine Shop or Civil Engineering Laboratory where the required flattening and cutting equipment were readily available. Other operations were conducted at the Dominion Bridge Fabrication Shop and the Lincoln Electric Welding Research Laboratory in Winnipeg.

3.3.1 Preparation of Type 1A, 2A, 3A and 4A Web Members

The flattening required for the type 1A, 2A, 3A and 4A specimens was done in the Civil Engineering Laboratory using a Riehle 60,000 pound testing machine as shown in Photo 3.8.

The web member gap of $d/4$, as specified in Figure 3.4, was obtained by placing a $\frac{1}{2}$ inch by $1\frac{1}{2}$ inch plate in the pipe to be flattened. Jamm et al⁽¹⁹⁾ suggested a $D/4$ gap of $\frac{1}{4}$ of the chord diameter to reduce the stresses applied to the chord tube. In this study, however, the gap was reduced

to $\frac{1}{4}$ of the web member diameter in order to examine the influence of higher stresses on the chord tube. After the tube was flattened and the $\frac{1}{2}$ inch by $1\frac{1}{2}$ inch plate removed, the web tube was cut to the minimum length required to develop full flattening. The completely flattened web members used in type 3 and type 4 specimens were prepared in the same way, but without the separating plate.

After the flattening was done, the type 1, 2 and 3 specimens were cut to provide the required joint geometry as shown in Figure 3.4. This operation was done using a mechanical hacksaw in the Civil Engineering Machine Shop. Typically, however, steel fabricators use abrasive saws for this type of operation, thus further reducing preparation time without adversely affecting the finished fit of the joint or the material properties.

Photos 3.9 and 3.10 show the web tubes after they have been flattened and cut for the type 1 and 3 specimens, while Photo 3.11 shows the finished diagonal member end preparation for the type 2 specimens.

Final preparation of the type 4 web members was done by acetylene cutting and grinding after the required profiling was determined for the tubes. The grinding was necessary to obtain a good fit of the tubes after the tubes were initially cut by a hand-held torch. These

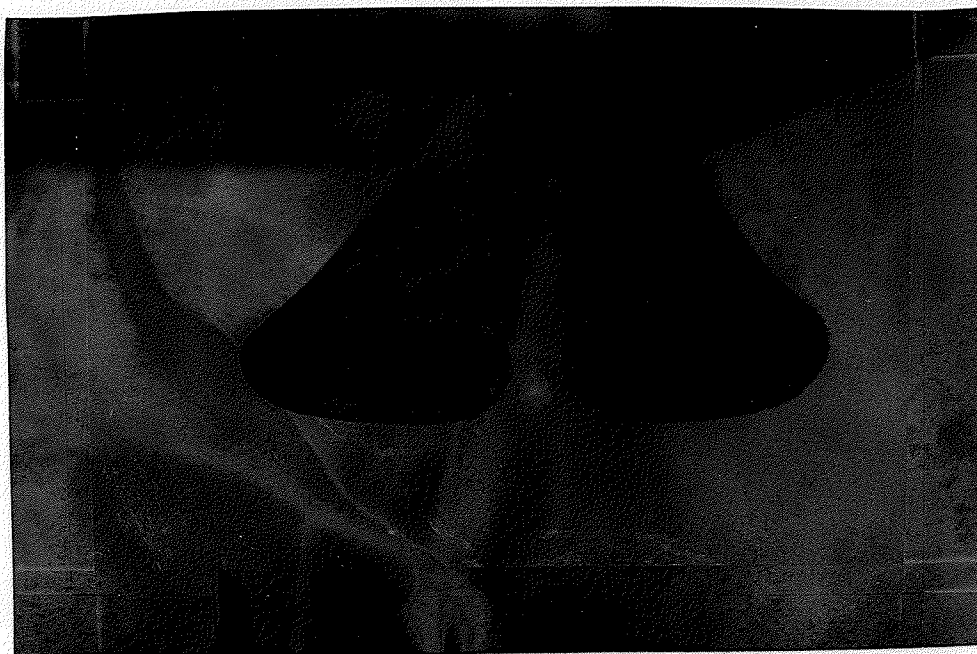


Photo 3.9 Type 1A Web Compression Member Flattening



Photo 3.10 Type 3 Web Compression Member
Flattening

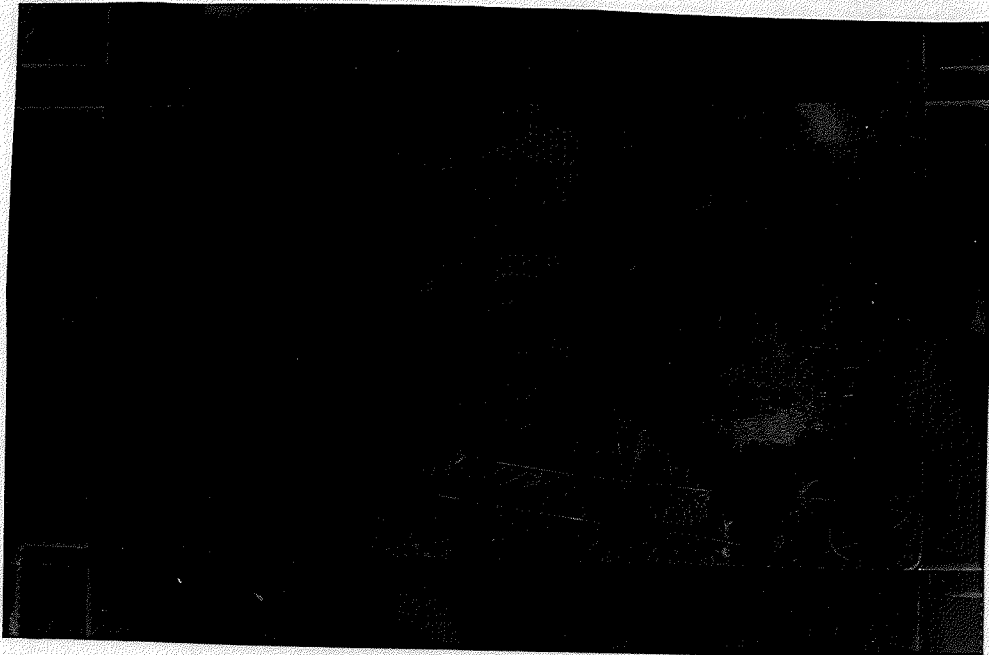


Photo 3.11 Type 2 Diagonal Web Member Preparation

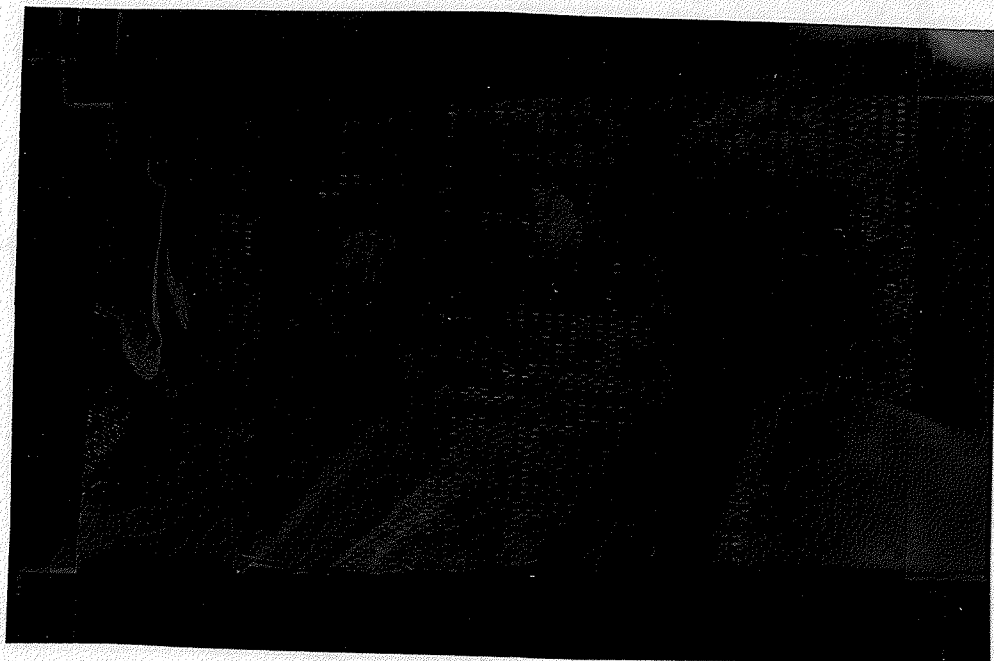


Photo 3.12 Type 4 Web Tube Preparation

operations were reasoned to be typical of conditions produced by the automatic acetylene cutting tools used by larger steel fabricators.

Photo 3.12 shows a type 4 web member after final profiling has been done, and Photo 3.13 shows the web tube fitted to a round chord after initial tack welding has been completed.

Observations of the flattening of hot-rolled hollow structural sections and cold-formed hollow structural sections revealed a very marked difference in material performance. Hot-rolled hollow structural sections cracked along the seam at almost any orientation of the seam to the flattened force, whereas cold-formed hollow structural sections did not. In only one instance did a cold-formed section crack on the tube seam, and that occurred when the seam coincided with the point of maximum curvature as in Photo 3.14.

This performance when undergoing bending indicates that a more ductile hot-rolled hollow structural section tube may be preferable to the currently used materials.

3.3.2 Preparation of Type 1B and 2B Web Members

Difficulties were encountered at the Dominion Bridge Fabricating Shop when shearing the web members for

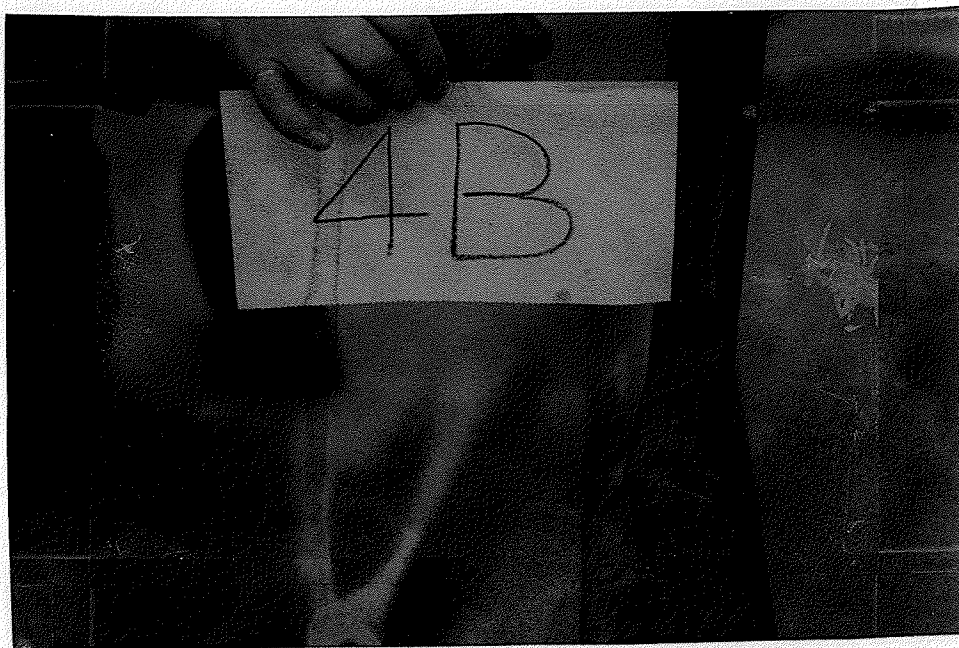


Photo 3.13 End View Of Type 4 Specimen



Photo 3.14 Crack In Seam Of Flattened H.S.S.

specimens type 1B and 2B. Due to the non-production use of the shear, it was noted that some of the inclined tension web members had been sheared at between 3 and 7 degrees from the specified angle of 45 degrees to the tube axis. These tubes had to be refinished, and the Photo 3.15 of specimen 2B1 shows the most severe misfit observed. The vertical web members also were deformed slightly in some cases, with a distinct kink appearing in the sheared face. This distortion was not excessive and the weldment readily rectified this situation. Another problem encountered was the difficulty of holding the pipes in the shear. For this reason, the operator used a template to hold the pipe. Unfortunately, this template held the tube at an angle of 60 to 65 degrees to the shearing plane causing the distorted end preparation as shown in Photo 3.16.

It is felt, however, that guides designed for an operation of this sort and better protective devices to prevent the prepared tubes from snapping back would increase the uniformity in end preparation.

Photo 3.17 compares the finishing produced by the three end preparation methods (i.e. $\frac{1}{2}$ inch gap in flattened tube, fully flattened tube and sheared tube).

Photo 3.18 shows the finished tension diagonal tube. Photo 3.19 is an end view of specimen 1B1 after tack

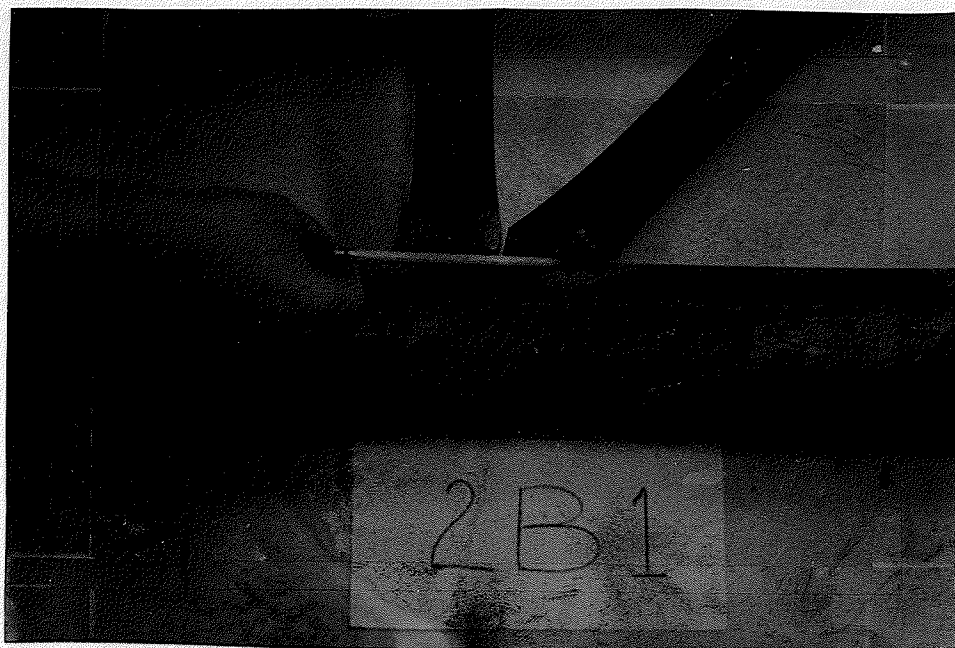


Photo 3.15 Damaged Diagonal Web Member

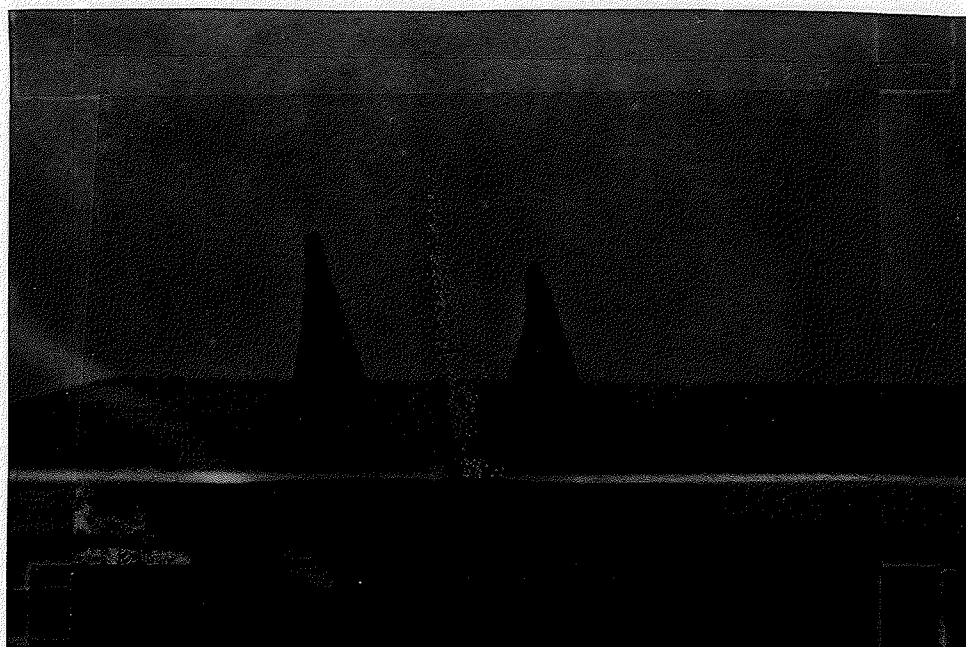


Photo 3.16 Sheared Tube Ends



Photo 3.17 End View Of Three Types Of End
Preparation

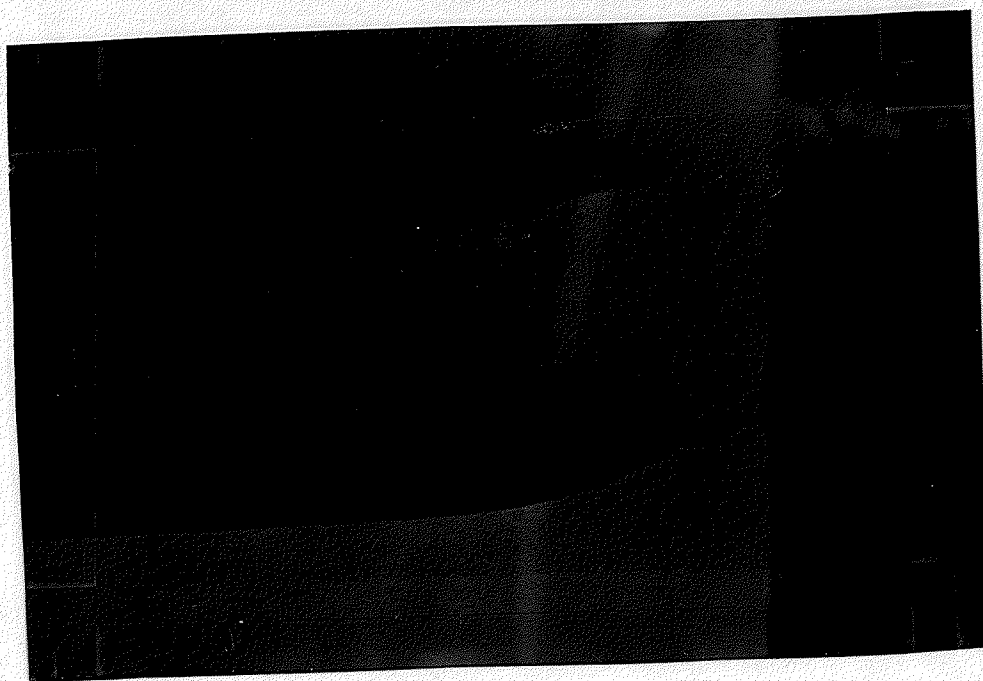


Photo 3.18 Sheared Tension Tubes

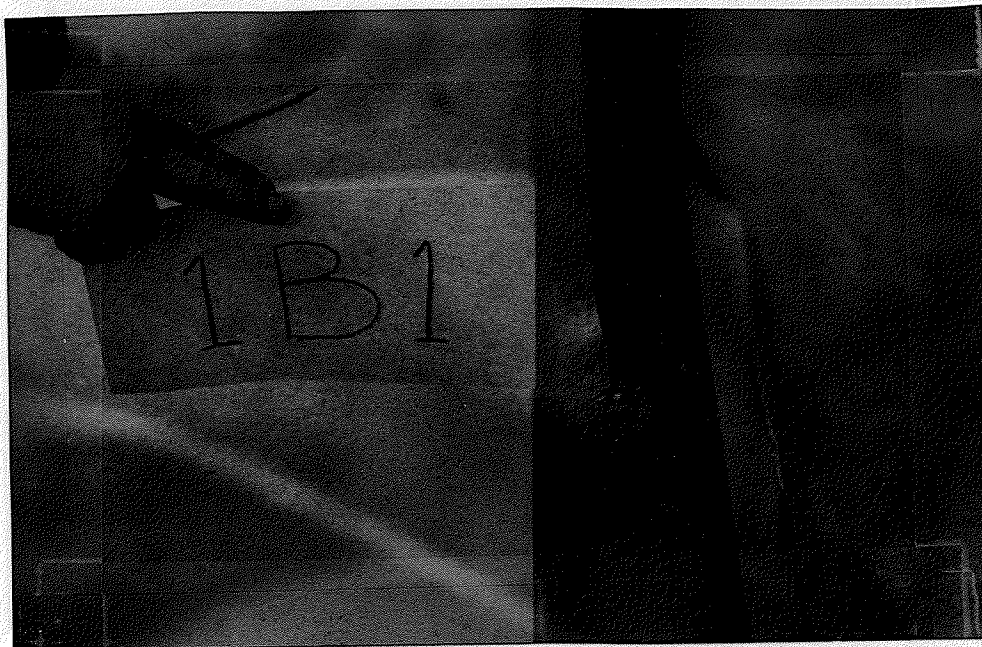


Photo 3.19 End View Of Type 1B Specimen



Photo 3.20 Crack In Flattened Face Of H.S.S.

welding showing the narrow plane of contact between the web tubes and the chord.

3.3.3 Problems of End Preparation

The main difficulty encountered in the flattening of the web tubes was cracking of the tubes along the welded seam. This cracking was observed in most specimens and occurred at almost any position of the seam on the flattened end, as shown in Photos 3.20 and 3.21 for flattened tubes and Photos 3.22 and 3.23 for sheared tubes.

Two remedies to this problem are preheating, which is expensive and time consuming and not always necessary, or closing by welding, which is also expensive and time consuming. Depending on the length of crack and the type of end preparation, most of the damage can be cut off, and a minimum length left to be repaired. This selection, however, involves close inspection that again is expensive and time consuming.

An example of this type of problem is shown in Photos 3.23 and 3.24 before and after welding of the cracked seam.

3.3.4 Specimen Fabrication

After the materials were prepared, the joints were fitted up and tack welded before final weldments were made.



Photo 3.21 Crack At Point Of Maximum Curvature
In Flattened H.S.S.



Photo 3.22 Crack In Flattened Face Of Sheared
H.S.S.

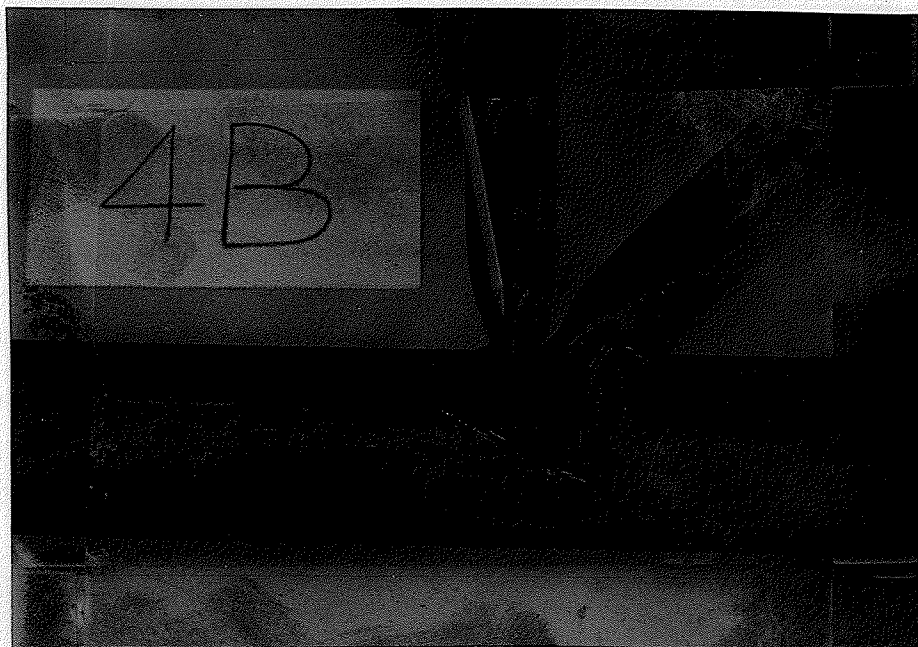


Photo 3.23 Crack In Web Compression Member Before Repair

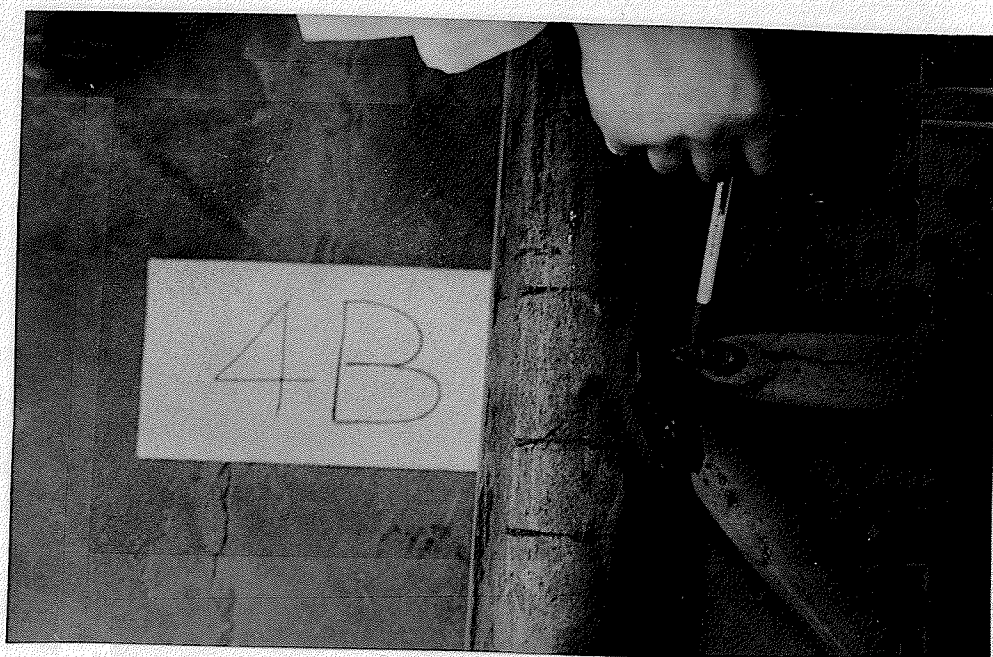


Photo 3.24 Crack In Specimen 4B After Repair

Photo 3.25 shows an assembled specimen prepared for final welding. This preparation was done in the Civil Engineering Laboratory by technicians from the Civil Engineering Department.

3.3.4.1 Final Specimen Welding

All final welding of all specimens was done by the same qualified welder under identical conditions.

A Lincoln Welder set at 150 amps AC and a 5/32 inch Lincoln Type 57 (6013) Electrode were used for all welds.

In some cases, especially for the type 3 and 4 specimens, where a poor fit was obtained, the filling of defects was done using a 6011 1/8 inch electrode at 100 amps AC.

As a result of experience gained in the welding of the specimens, the following recommendations are made for the fabrication of further specimens:

- (a) A better fit should be obtained by improving the bevelling of types 3 and 4 specimens;
- (b) Careful attention should be paid to the end preparation of types 1 and 2; and
- (c) Care should be taken to maintain sufficient clearances for welding in connections of the type illustrated in Photo 3.26.

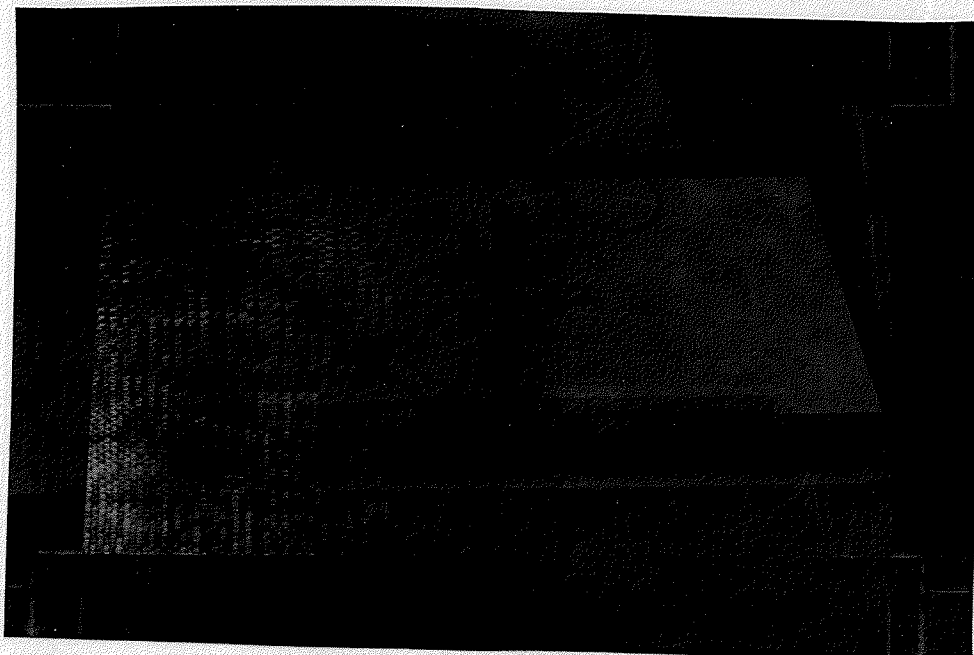


Photo 3.25 View Of Final Fitting Of Specimen
And Joint Template



Photo 3.26 Joint 3A1 Configuration

CHAPTER 4

TEST PROCEDURE

4.1 Test Equipment

The test equipment was designed with a view to simplifying fabrication and allowing an unobstructed view of specimen during testing.

4.1.1 Loading Frame

The loading frame, illustrated in Figure 4.1 and Photo 4.1, consisted of two W21 x 68 beams supporting two reaction assemblies inclined at 45 degrees to the horizontal. Each reaction assembly had a two inch diameter semi-cylindrical bearing surface with a $\frac{1}{4}$ inch diameter centering pin to receive the chord and compression web member of the specimen. One of the reaction assemblies had provision for both horizontal adjustment and adjustment of the bearing surface parallel to the sloping face.

The 12 inch deep built up jacking beam was bolted to the main beam and permitted horizontal adjustment by increments of three inches. A three inch diameter hole through the jacking beam allowed a loading yoke to pass through the beam in order to apply load to the test specimen.

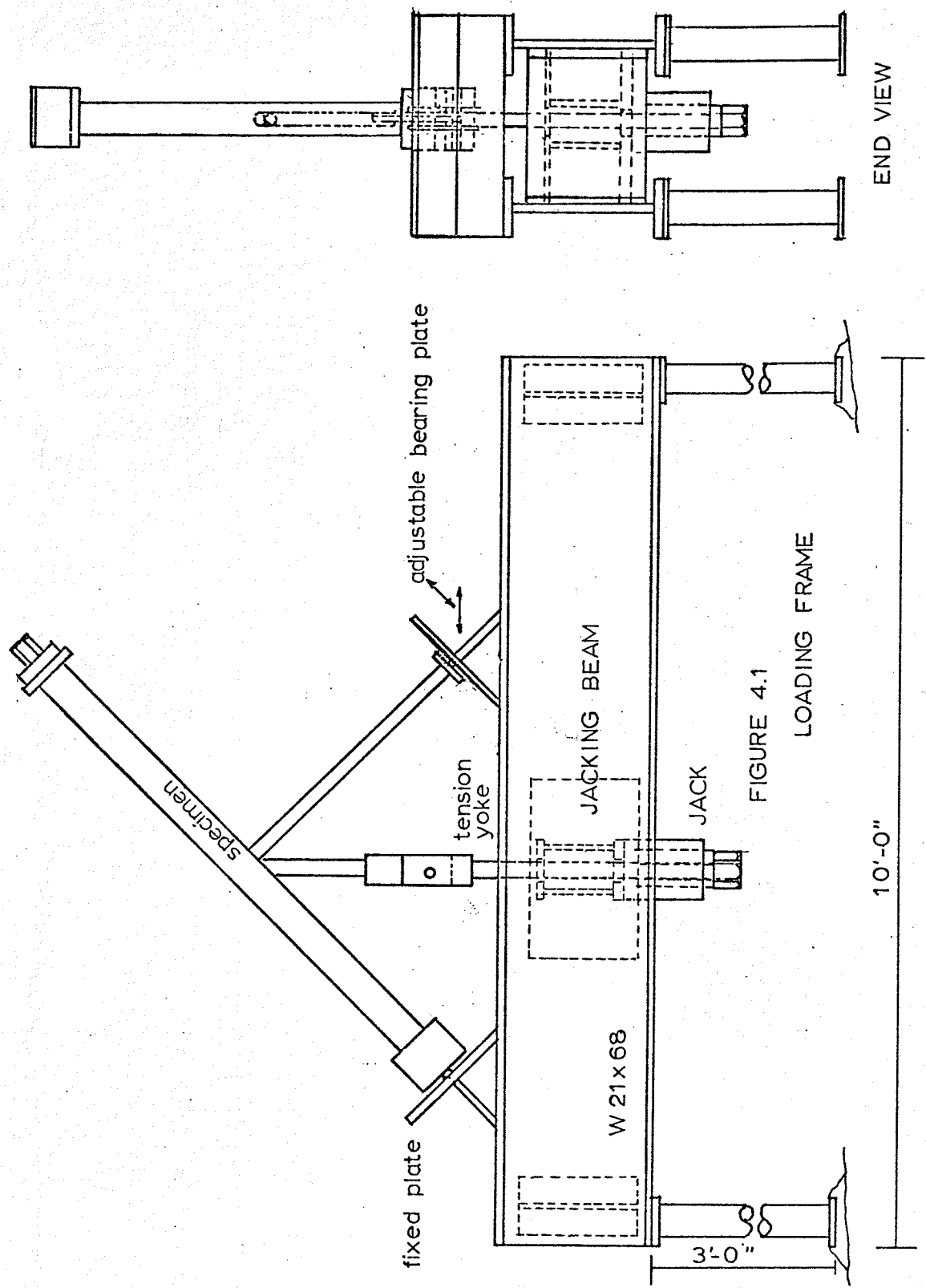


FIGURE 4.1
LOADING FRAME

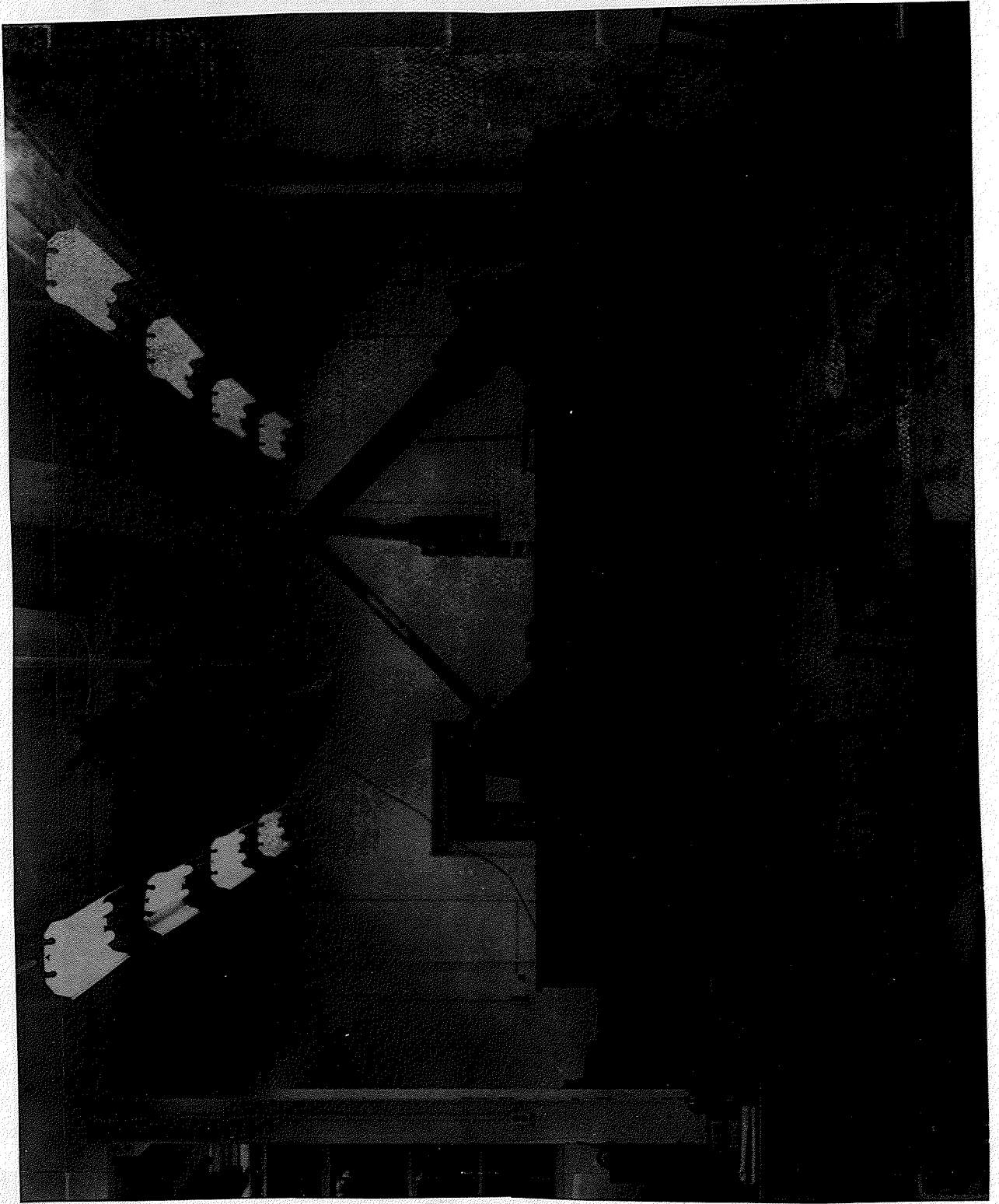


Photo 4.1 Loading Frame

Shim plates were used to provide even bearing of the compression members, after it was found that some of the web compression member bearing plates were not properly aligned. The shims also prevented bending in the plane perpendicular to the specimen, due to uneven bearing.

4.1.2 Prestressing System

In order to apply the minor compression load in the chord of the test specimen, a threaded post-tensioning bar was inserted along the centroidal axis of the chord member, as shown in Figure 4.2. The bar had an ultimate stress capacity of 400 ksi, was $1\frac{1}{4}$ inches in diameter and had an area of 1.23 inches squared. Eight strain gauges were applied to the bar, for the purpose of monitoring the load applied to the chord member.

Two sets of mutually perpendicular strain gauges were connected in the half bridge configuration to compensate for possible temperature and bending effects. The gauge factor was 2.08. A Budd Strain Indicator was used.

Six calibration tests were conducted for loads up to 80.0 kips, and the resulting calibration curve is shown in Figure A-1.

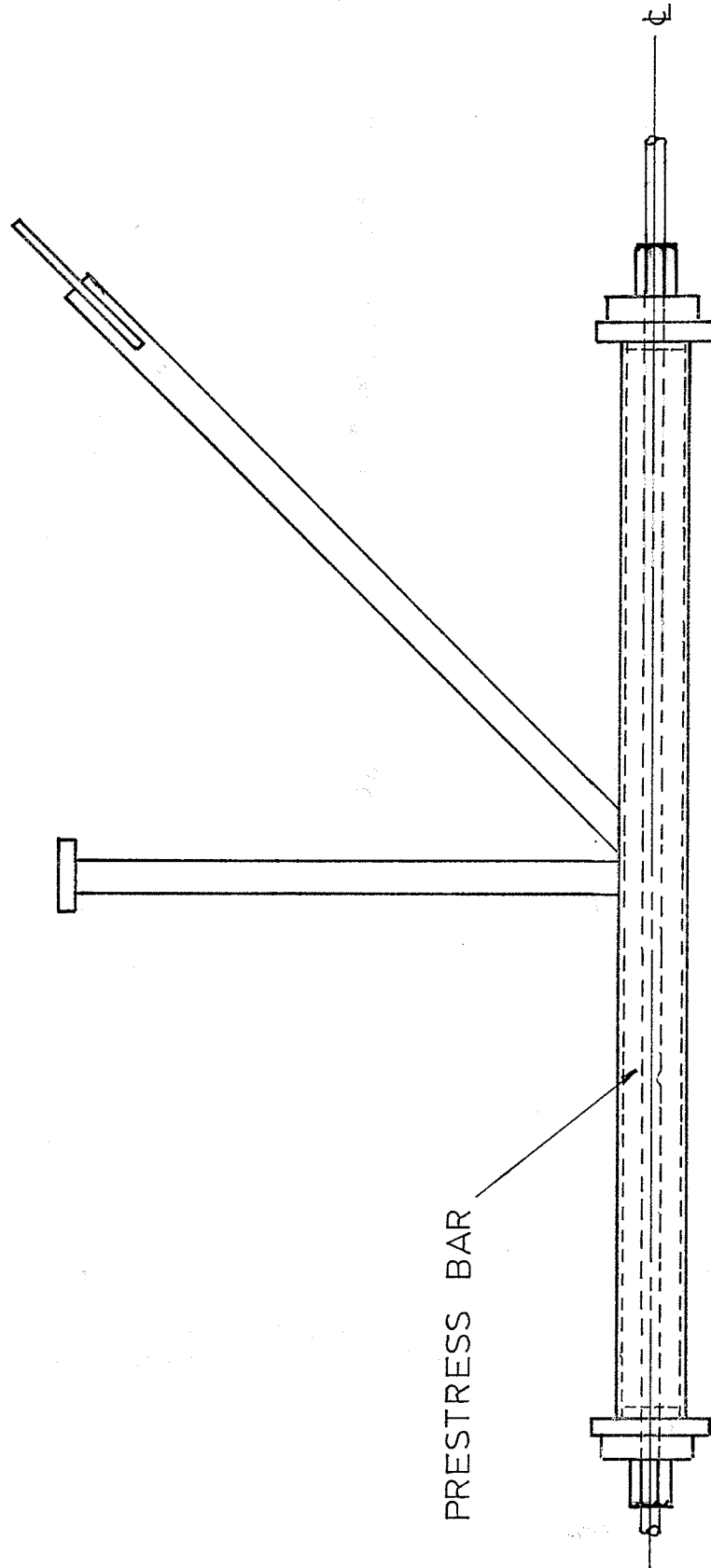


FIGURE 4.2 TYPICAL SPECIMEN WITH PRESTRESSING BAR
IN POSITION

4.1.3 Jacking System

The load was applied to the tension web member by means of a 200 kip simplex hollow core jack. Two pressure gauges connected to the hydraulic cylinder measured the applied load.

The gauges were of 2,000 and 10,000 psi capacity, and were attached in series to the hydraulic system. The smaller capacity pressure gauge was used to give a more sensitive reading of pressure at low applied loads, while the 10,000 psi gauge indicated applied jack loads up to 200 kips; well above the expected failure load.

Although the load applied by the jack could be calculated from the line pressure and pressure face of the jack, it was felt that calibration of the jacking system was desirable to give pressure values without corrections for pressure losses or varying frictional resistance of the Riehle testing machine. While the calibration conditions corresponded to quite small displacements of the jack loading ram, it was felt that they simulated the joint testing conditions reasonably well, particularly within the elastic ranges of the specimens. The calibration was performed by applying load to the jack in a hydraulic cylinder.

The calibration of the system was carried out for

loads up to 80 kips. The average pressures obtained from four calibration tests are recorded in Table A-2.

A loading yoke made from $\frac{1}{2}$ inch by 4 inch plate and a cold worked 2 inch diameter steel bar was threaded through the jack and the loading frame jacking beam. It was attached by a pinned-joint to the specimen tension member.

4.2 Instrumentation

The two primary quantities to be measured were joint deformations and member strains in the vicinity of the joint. Two different techniques were tried for measuring the most significant deformation quantities; the radial deformations of the chord at the joint. The purpose of the strain measurements was to determine elastic longitudinal stress distributions around the web and chord members in the vicinity of the joint.

4.2.1 Displacement Measurements

For the initial test, that involving specimen 1A2, an attempt was made to measure the chord deformations by means of calipers. Caliper readings of the outside diameter in the plane of the truss, were taken at 8 different points in the vicinity of the joint. Because of the limited accuracy obtainable with the calipers and the difficulty of

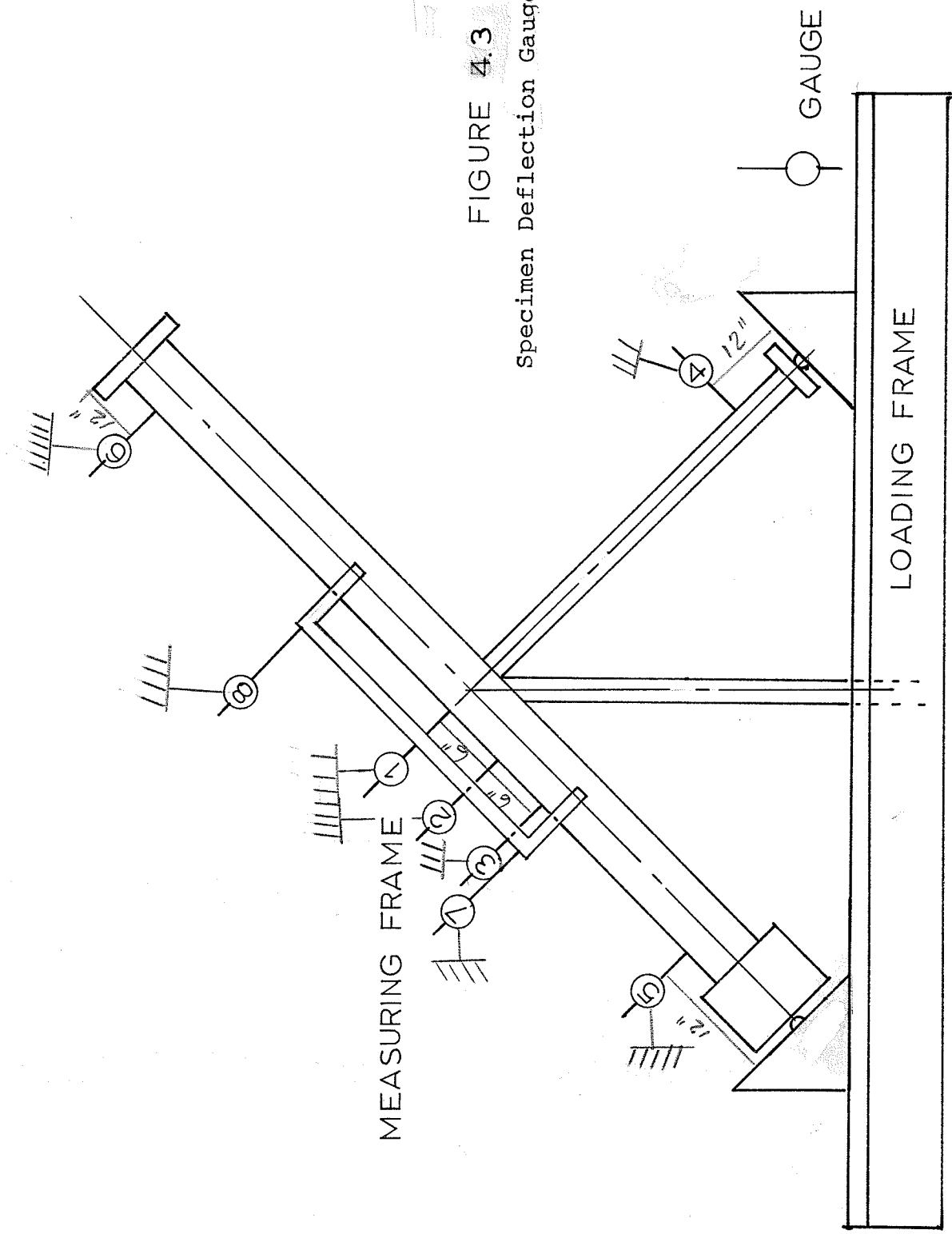


FIGURE 4.3
Specimen Deflection Gauge Locations

taking the readings at the correct points on the circular chord member, this measurement procedure was found to be unsuitable.

For subsequent tests, the more elaborate deformation measuring apparatus shown in Photo 4.2 was used.

It consisted of a twenty-four inch long aluminum frame with U-shaped yokes that were fastened to the specimen by means of set screws positioned in punch marks on the chord center line. Pairs of dial gauges mounted on magnetic bases were attached to steel strips that were screwed to each side of the aluminum frame. Aluminum collars were similarly attached to the web members by set screws. Fine wires connected the four dial gauge stems to the collars and measured the displacements of the web collars relative to the measuring frame. In order to obtain the axial displacements of the web members relative to the chord center line, it was necessary to apply two types of corrections.

Firstly, the elastic axial deformation of the portion of each web member between the collar and the chord face had to be deducted from the dial gauge reading. This axial deformation was based on the average axial stress for the web member.

Secondly, the dial gauge readings had to be

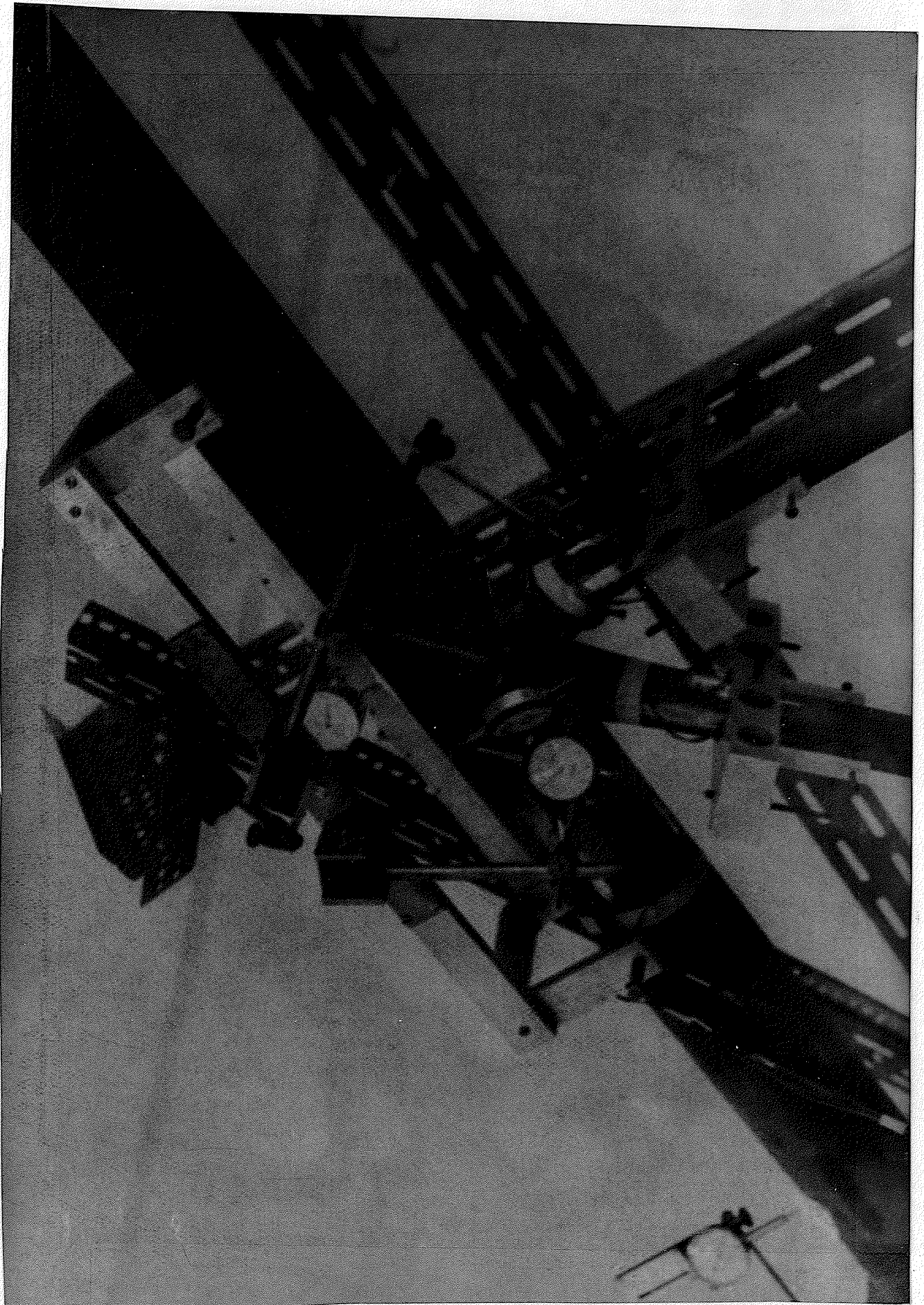


Photo 4.2 Aluminum Measuring Frame And Collars
With Dial Gauges In Position

corrected for the effects of bending of the chord member within the twenty-four inch length of the measuring frame. This was done by determining the chord displacements normal to its axis at the joint and the two points where the measuring frame attached to the chord.

Two different techniques were tried for determining the necessary chord displacements. For specimens 2B2 and 1B2, dial gauges measured chord displacements at both ends and at the joint. The overall chord bending was then prorated down to obtain an approximation to that occurring within the twenty-four inch length of the measuring frame.

When this procedure proved to be somewhat unsatisfactory, displacement measurements were made at the two ends of the measuring frame and at the joint.

The dial gauges used throughout the test series were Mercer or Kyoto spring-loaded deflection gauges sensitive to one-thousandth of an inch deflection over a range of one inch.

Photo 4.3 shows a typical specimen in the loading frame with the deflection gauges in position.

4.2.2 Strain Measurements

In order to obtain longitudinal stress distributions

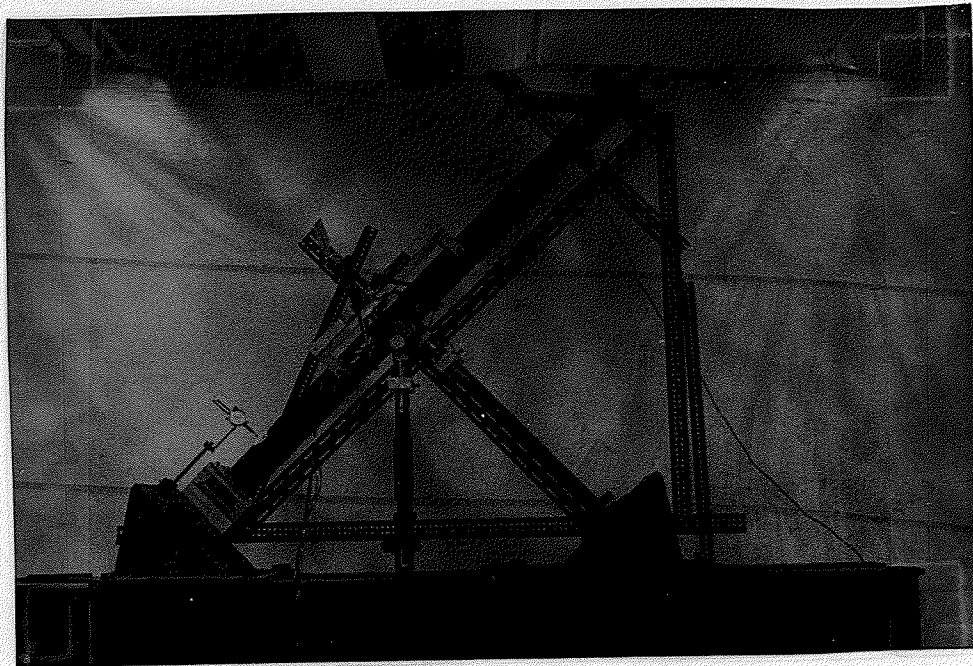


Photo 4.3 View of Specimen Showing Dial Gauges

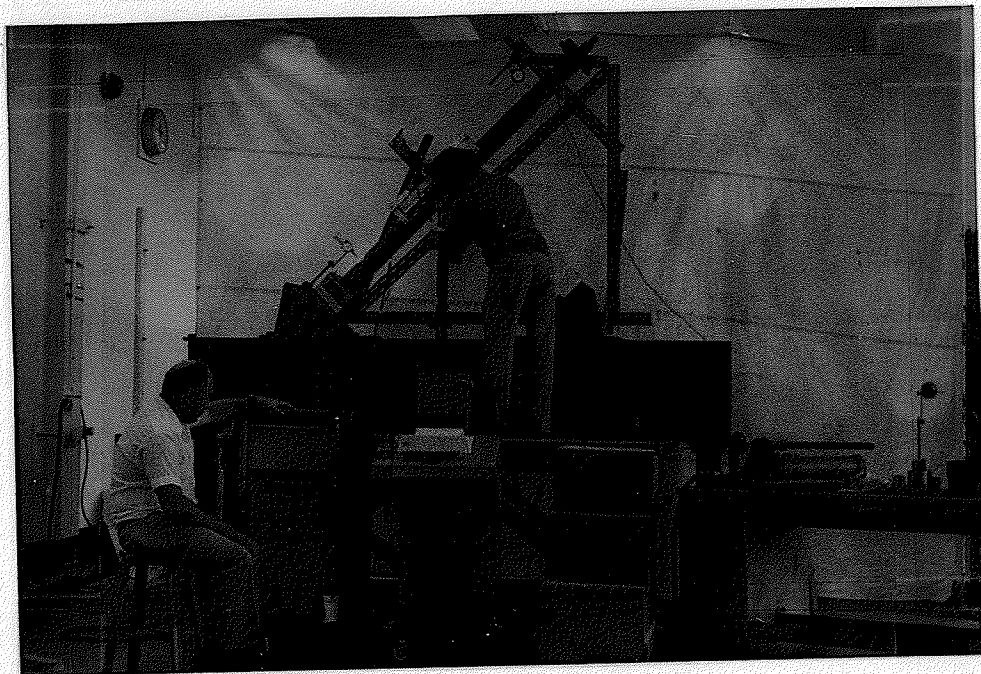


Photo 4.4 Test Setup Showing Hewlett-Packard
Data Acquisition System

around the web and chord members foil strain gauges were applied to specimens 2B2, 1B2 and 1A1 as illustrated in Figures 4.4, 4.5 and 4.6.

The gauges properties were:

Length	6mm;
Gauge Factor	$2.00 \pm .5$; and
Resistance	$120 \pm .15$ ohms.

The Hewlett-Packard Model 1745 Acquisition System shown in Photo 4.4, was used to obtain a printed and a punched paper tape record of the gauge readings. A computer program was used to convert the voltage readings from the Hewlett-Packard apparatus to strain readings.

4.3 Test Procedure

Initial preparation of the specimen included establishing punch marks on the chord and web tubes for the purpose of locating the measuring frame and collars on the specimen. The threaded post-tensioning bar was then threaded through the chord member. The prestressing bar was located by means of end plates with stops machined to the internal dimensions of the chord tube. This assured accurate location of the bar.

The bar was then tensioned to approximately 17 kips

FIGURE 4.4
STRAIN GAUGE LOCATION
SPECIMEN NO. 2B2

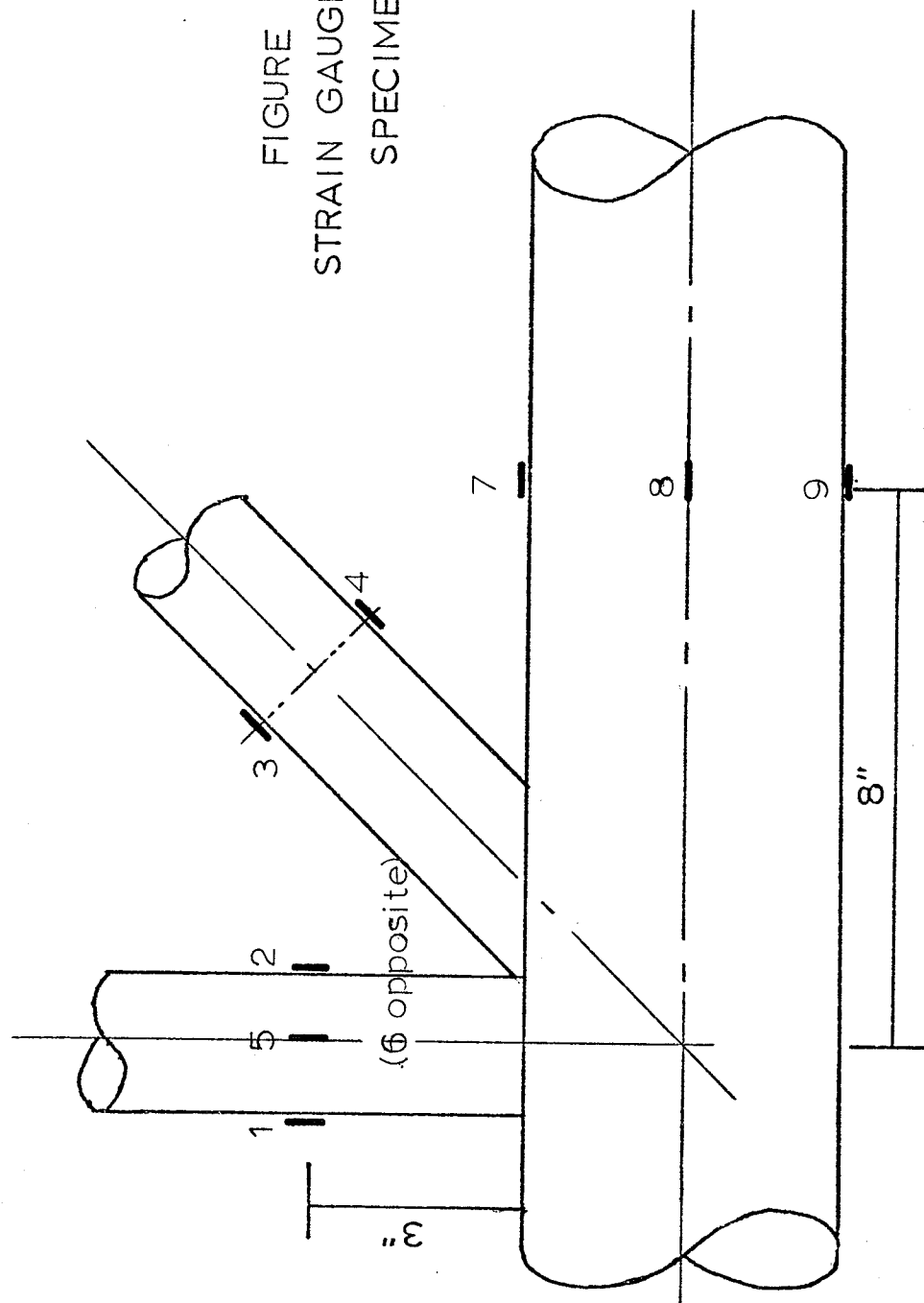


FIGURE 4.5

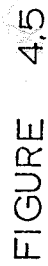
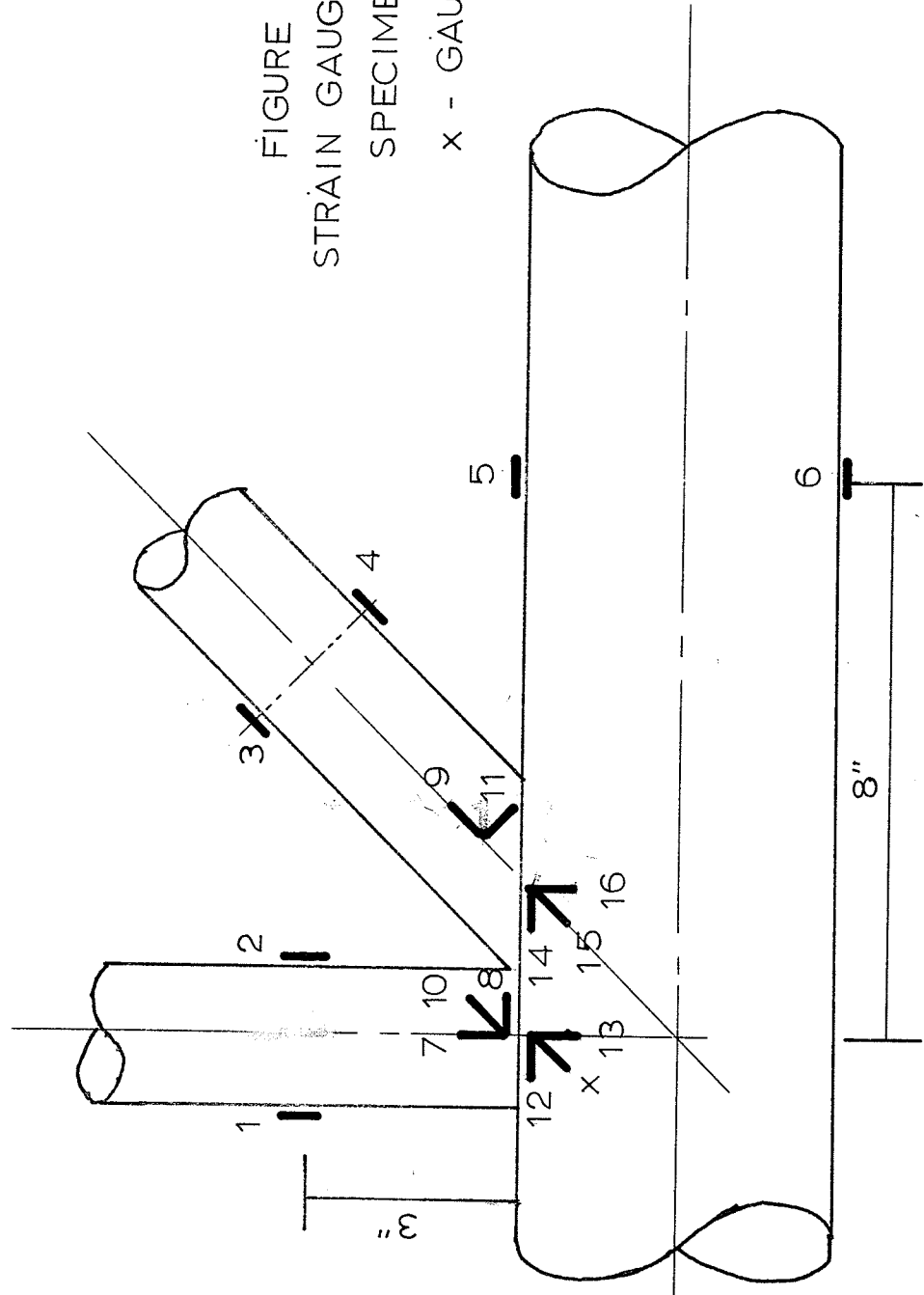


FIGURE 54.6
 STRAIN GAUGE LOCATION
 SPECIMEN NO. 1A1
 x - GAUGE DAMAGED



so that the load would drop to approximately 14 kips, due to elastic chord shortening, at approximately the expected failure load. This procedure was necessary since elastic shortening of the chord due to the externally applied loads caused a loss of prestress force. The prestressed specimen was then lifted onto the loading frame and the tension yoke and jack attached.

After the specimen was positioned in the loading frame, the dial gauges were located and the Hewlett-Packard Data Acquisition equipment was connected to the strain gauges. An initial load was applied to the diagonal web member and the alignment of the test specimen and the operation of all dial gauges checked. The load was then released, initial gauge readings checked and gauges reset, if necessary.

Load was then applied to the specimen until failure occurred. After each increment of load, all dial gauge readings were recorded, the prestressing load was noted and the strain gauges electronically monitored.

Careful observation was made of the specimen, and any signs of distress, such as tube splitting, weld cracking or tearing and elastic buckling were noted with photographs being taken in several instances to show typical behaviour of the test specimens.

Load applied to the specimen was increased, as recorded in the test log, until failure was observed. The failure mode, excessive deformation, elastic buckling and other failure criteria, and load, were established and noted at this time. The dial gauges were then removed and the load increased until ultimate failure occurred.

The load was then released and the specimen removed from the loading frame and dismantled. The failed specimen was then carefully inspected for other signs of distress. Photographs of the failed member were taken and the mode of failure recorded.

CHAPTER 5

TEST RESULTS

5.1 Introduction

The significant characteristics of flattened-end joint behaviour are considered to be joint stiffness, joint efficiency, load at the onset of plastic deformation and ultimate failure load.

Many of these characteristics are readily illustrated in load-deformation diagrams. Hence for the specimens tested, plots of load versus tension member travel relative to the chord face in the direction of the tension member and load versus compression member travel are presented.

Joint efficiency was calculated for each specimen on the basis of the measured ultimate load, or the load corresponding to a large deformation failure (0.05 inch deflection of the compression tube into the chord face) in specimens where this criteria governed.

As a further indication of joint behaviour the displacement of the unloaded face of the chord, normal to the chord axis, is presented for each specimen. This latter plot gives a further relative measure of the load-deformation

behaviour for the various specimens.

Measurements were taken for specimens 2B2, 1B2 and 1A1 of the joint and member strains. These findings are presented in the form of applied load versus strain reading.

5.2 Material Properties

The materials used were either hot-rolled round hollow structural sections conforming to CSA specification G40.16 (1969) or cold-formed seamless square hollow structural sections conforming to CSA specification G40.17 (1969).

Table 5.1 is a test report on the composition, yield point and ultimate strength of the various materials used.

In addition, two tension specimens were cut from the web tube material as a check on the material properties.

Tables A-4 and A-5 present the results of the tension tests and Figure 5.1 shows the plot of these results. From the stress-strain curves, the average yield point stress was found to be 53,200 psi and the average ultimate stress was 77,300 ksi. These values are in good agreement with the values in Table 5.1 and the values found from the tests were used in calculations of ultimate tensile capacities of the

TABLE 5.1

Metallurgical Report On Hollow Structural Sections

THE STEEL COMPANY OF CANADA, LIMITED
TEST REPORT - MONTREAL METALLURGICAL DEPARTMENT

M543A (6-70)

REPORT NO.		DATE	CUSTOMER									
73-113		Jan. 26/73	University of Manitoba - Winnipeg, Man. Attn. Mr. G. Morris									
CUSTOMER'S ORDER NO.		MILL ORDER NO.	SPECIFICATION									
1/15/73		KP-94353	C.S.A. G-4016 Gr. 50 HSS									
p.p. 1 to 7			INSPECTED BY STELCO UNLESS OTHERWISE INDICATED									
	HEAT NO.	C	P	S	Mn	Si	Cu	Cr	Ni	Mo	CB	
1	620316	18	002	019	67	08					02	
2	611472	21	002	019	67	05					02	
3	622051	19	002	024	72	08					01	
4	612810	20	003	020	78	06					04	
5	621877	22	002	021	65	07					01	
6	620486	16	005	028	44	07					02	
7	612344	17	002	037	77	07						
8	612344	17	002	037	77	07						
9												
10												

TABLE 5.1 continued

	SIZE ROLLED	SAMPLE DIMENSIONS	AREA	YIELD POINT P.S.I.	ULTIMATE STR. P.S.I.	ELONG % IN INCHES	REDUCED DIMENSIONS	RED. OF AREA %	FRACT.	BEND
1	4.500 x 210		380	51310	75260	40 - 2			1/4C	OK
2	1.900 x 100		657	56320	78840	44 - 2			3/4C	OK
3	1.900 x 188		918	54190	75160	28 - 2				
4	2.375 x 125		883	53220	72480	28 - 8				
5	2.375 x 165		1.207	58820	78710	27 - 8				
6	3.500 x 188		361	51250	70080	26 - 8				
7	3.500 x 250		479	60750	78910	44 - 2				
8										
9										
10										
TESTED BY					APPROVED BY					
					W. Balaz					
REMARKS:										

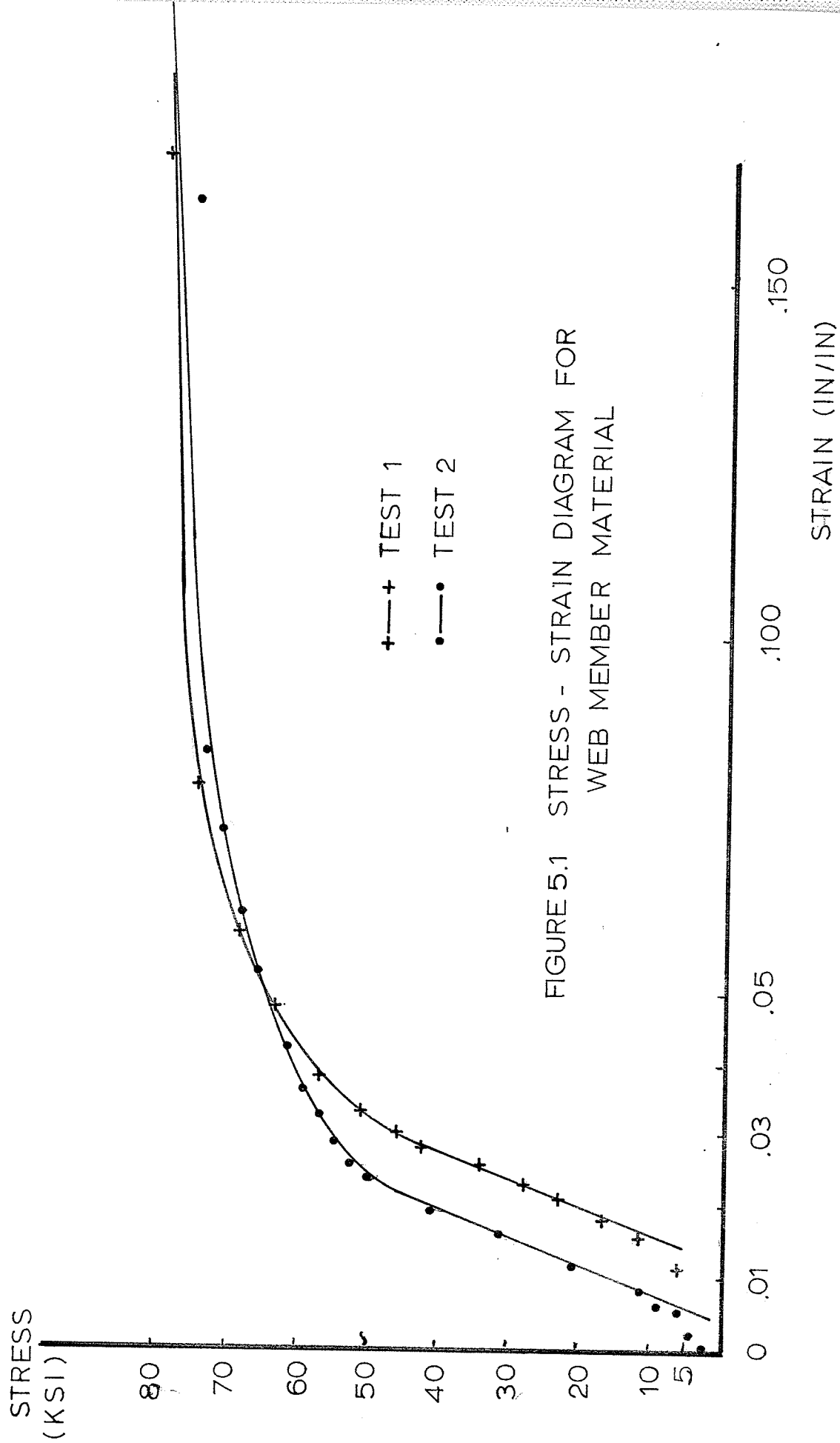


FIGURE 5.1 STRESS - STRAIN DIAGRAM FOR
WEB MEMBER MATERIAL

diagonal web members and overall joint efficiencies.

Using a material tensile strength of 77.3 ksi, the ultimate strength of the tension web member was found to be $77.3 \times .619 = 46.7$ kips.

The square chord material was obtained from a local distributor. Mill reports were unavailable due to the small quantities used, and because the material properties for the chord section had little influence on joint efficiency, tension tests were not run. The specified yield strength of the material was 50 ksi, and a resistance welding process was used in producing the tube.

5.3 Results of Joint Tests

5.3.1 Specimen 1A1

Specimen 1A1 failed at a load of approximately 38 kips, due to buckling of the compression member. The calculated joint efficiency was $38.0/46.7 = 81\%$.

Table 5.2 lists the dial gauge readings of the web member axial deformations from which the tension and compression member travel corrected for elastic web tube shortening and chord tube bending are obtained. This table also lists the overall specimen deflection parallel to the web compression member as well as the deflection at both ends of the aluminum measuring frame. The latter values

TABLE

5.2

TEST SPECIMEN IAI

DATE July 19, 1973

LOAD (KIPS)	TENSION MEMBER TRAVEL (IN.)		AVERAGE TENSION MEMBER TRAVEL	COMPRESSION MEMBER TRAVEL		AVERAGE MEMBER TRAVEL	PRESTRESS LOAD (KIPS)
	A	B		A	B		
0.0	DEFECTIVE	0.200	0.000	DEFECTIVE	0.780	0.000	17.1
5.0	GAUGE	0.208	0.005	GAUGE	0.775	0.002	16.5
10.0		0.212	0.007		0.771	0.002	16.3
12.5		0.215	0.008		0.770	0.002	16.0
15.0		0.217	0.009		0.768	0.002	15.75
17.5		0.218	0.009		0.767	0.003	15.6
20.0		0.220	0.009		0.765	0.003	15.4
22.5		0.222	0.011		0.764	0.004	15.25
25.0		0.226	0.011		0.761	0.004	15.0
27.5		0.229	0.013		0.758	0.004	14.75
30.0		0.234	0.015		0.754	0.007	14.7
31.0		0.235	0.016		0.753	0.007	14.6
32.0		0.236	0.017		0.752	0.007	14.5
33.0		0.239	0.018		0.748	0.007	14.4
34.0		0.243	0.021		0.741	0.012	14.2
35.0		0.250	0.026		0.733	0.018	14.1
36.0		0.261	0.035		0.724	0.023	14.0
37.0		0.275	0.049		0.712	0.035	13.95
38.0		0.287	0.059		0.695	0.047	13.9
38.0 ⁺		COMPRESSION MEMBER BUCKLING					

TABLE 2
SPECIMEN 1A1

LOAD	TRANSVERSE DISPLACEMENT OF JOINT	MEASURING FRAME DEFLECTION	
		LOW END	HIGH END
0.0	0.000	0.000	0.000
5.0	0.027	0.021	0.030
10.0	0.046	0.036	0.052
12.5	0.055	0.043	0.061
15.0	0.062	0.048	0.068
17.5	0.067	0.052	0.073
20.0	0.073	0.058	0.079
22.5	0.078	0.062	0.083
25.0	0.086	0.069	0.090
27.5	0.092	0.074	0.096
30.0	0.101	0.081	0.102
31.0	0.104	0.084	0.105
32.0	0.105	0.085	0.106
33.0	0.112	0.091	0.112
34.0	0.123	0.100	0.121
35.0	0.135	0.110	0.132
36.0	0.148	0.120	0.145
37.0	0.163	0.132	0.163
38.0	0.185	0.148	0.187

were used to correct the readings of the web member travel.

When the applied load reached a value of 38 kips the joint was deforming plastically and was incapable of sustaining any load increase.

Because of the one-half inch gap between the walls of the flattened web tubes, the loaded width of the chord member at the joint was relatively large and the local deformation was not apparent until the load approached 38 kips.

In addition to the curves of overall joint displacement and web tube displacement shown in Figures 5.2 to 5.4, plots of joint and member strain are presented in Figures 5.6 to 5.8. The locations of the sixteen strain gauges used to monitor the specimen strains are shown in Figure 4.6.

5.3.2 Specimen 1A2

In the testing of specimen 1A2, the change in the chord diameter at seven points along the chord over a two foot length centered at the point of intersection of the three members was measured.

Figure 5.9 shows that no deformation of the chord was measured at loads below 35.0 kips. This was due to the poor accuracy obtained in reading the calipers, which could

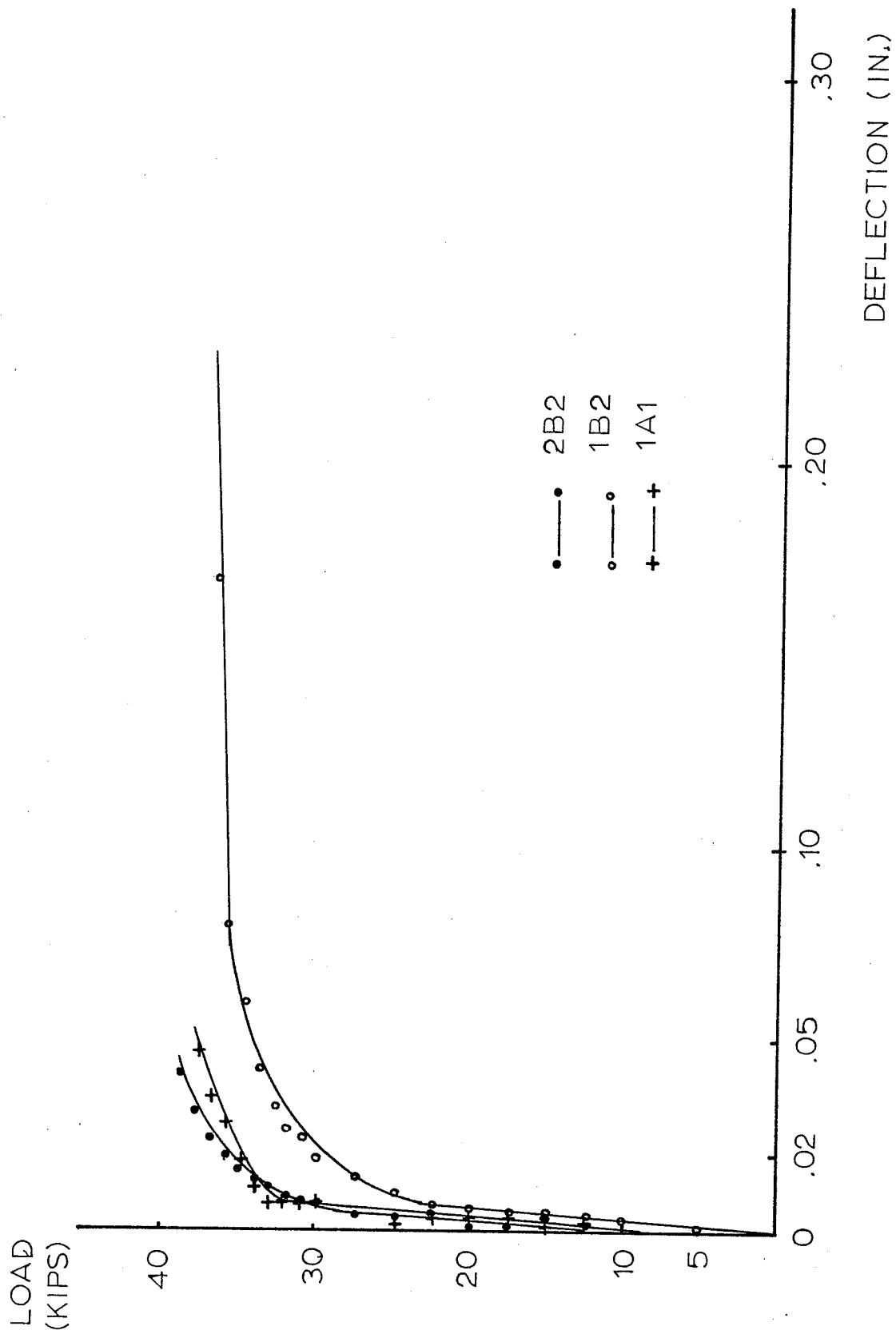


FIGURE 5.2 COMPRESSION MEMBER TRAVEL

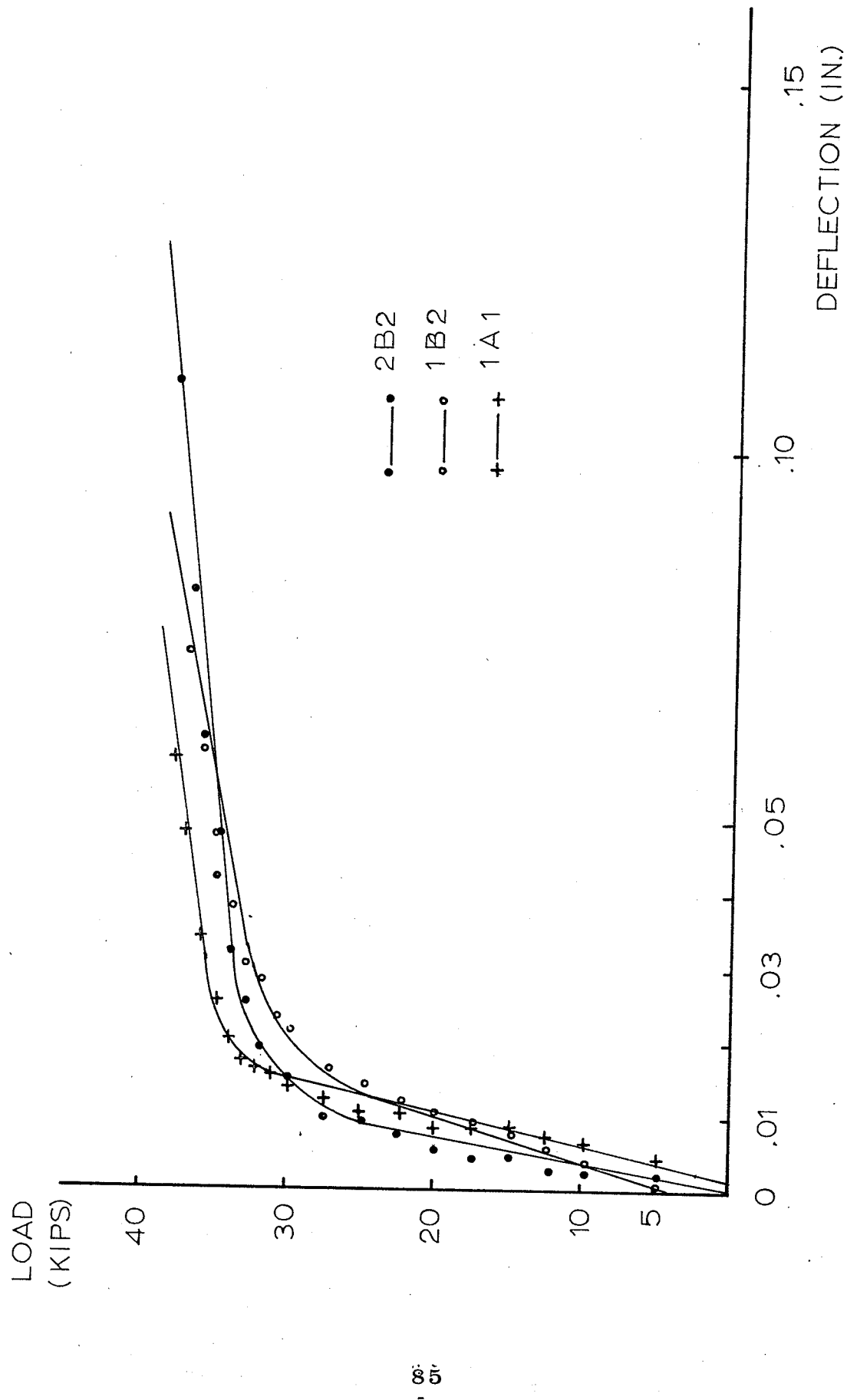


FIGURE 5.3 TENSION MEMBER TRAVEL

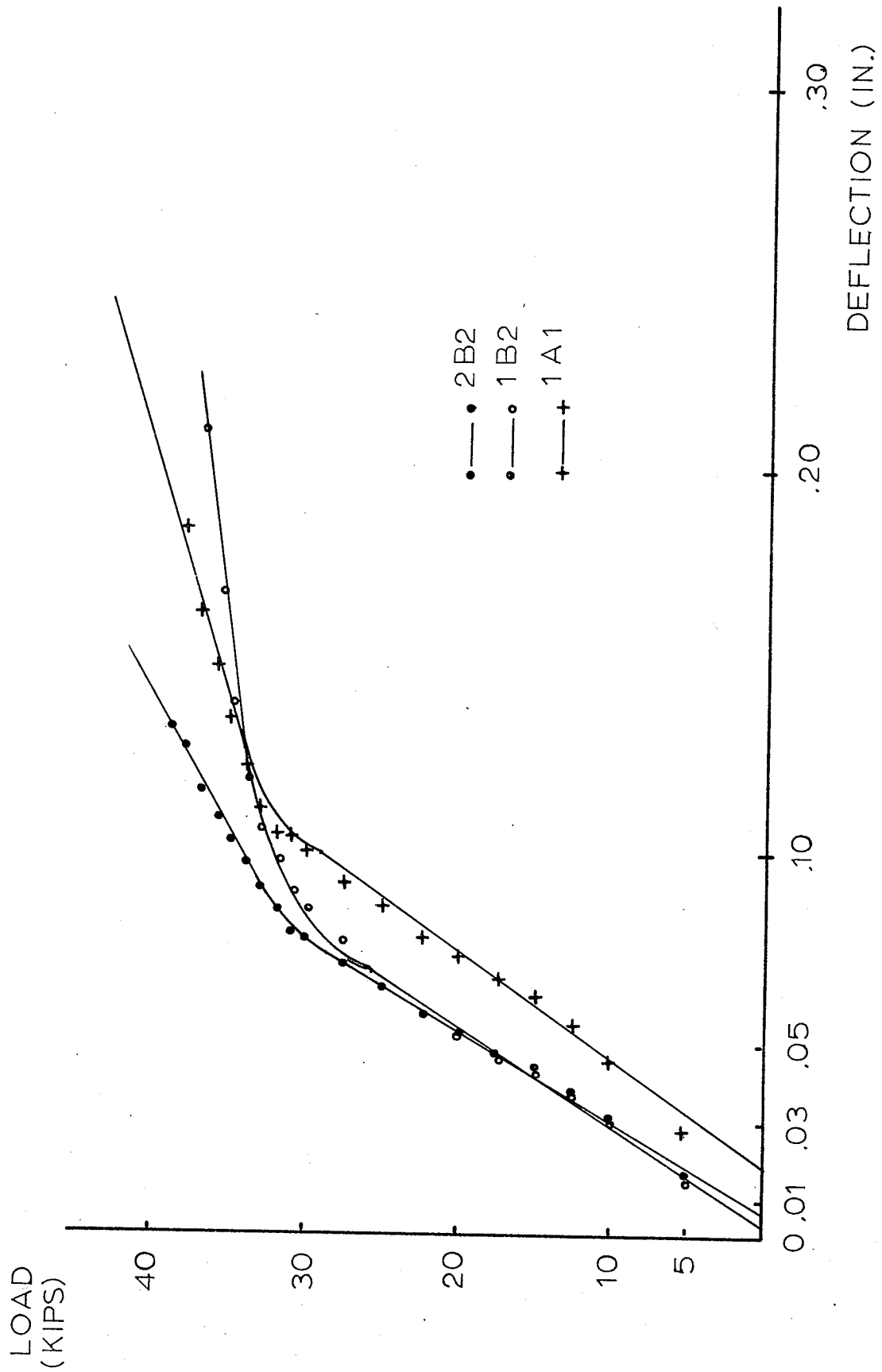


FIGURE 5.4 JOINT DISPLACEMENT NORMAL TO AXIS OF CHORD

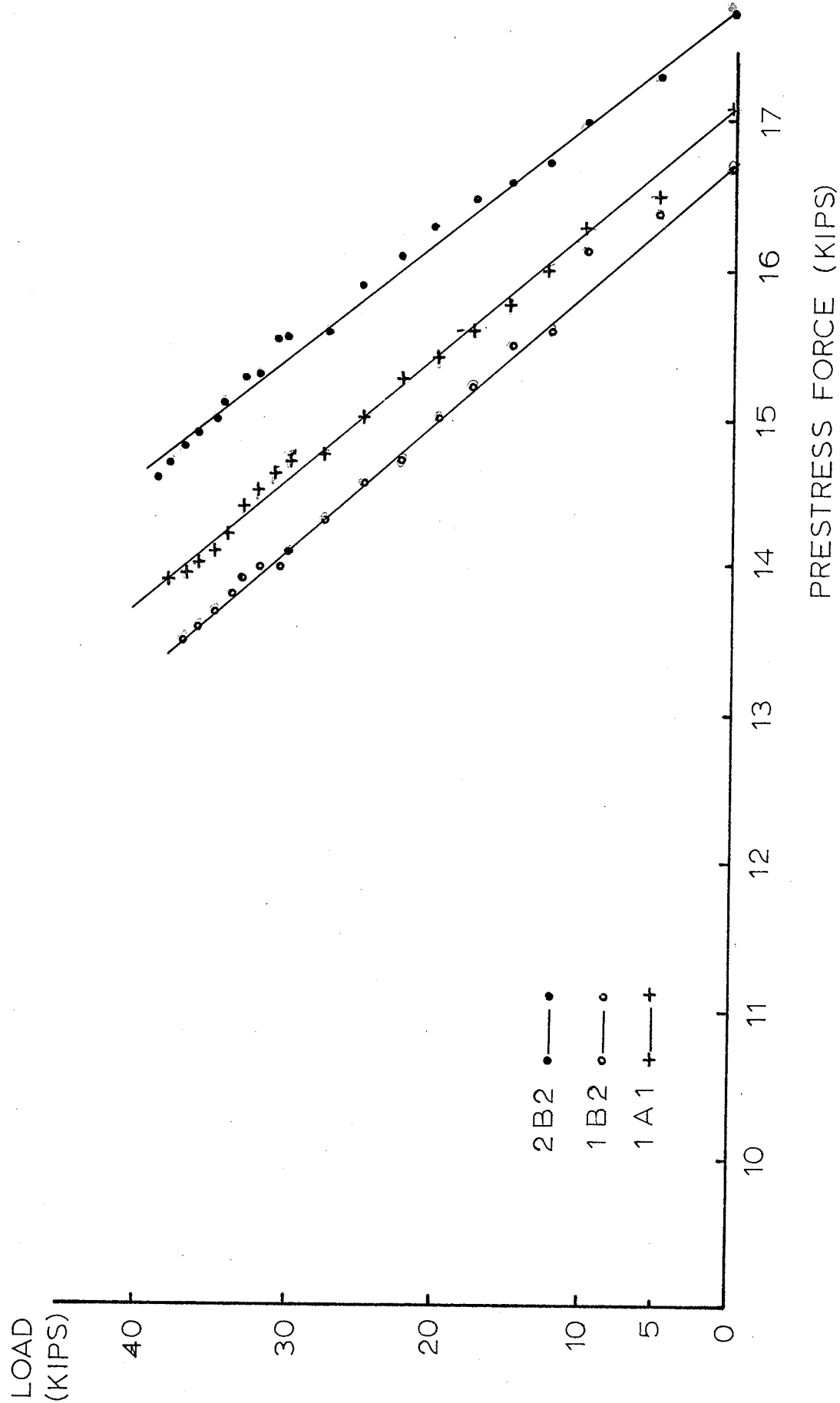


FIGURE 5.5 LOSS OF PRESTRESS

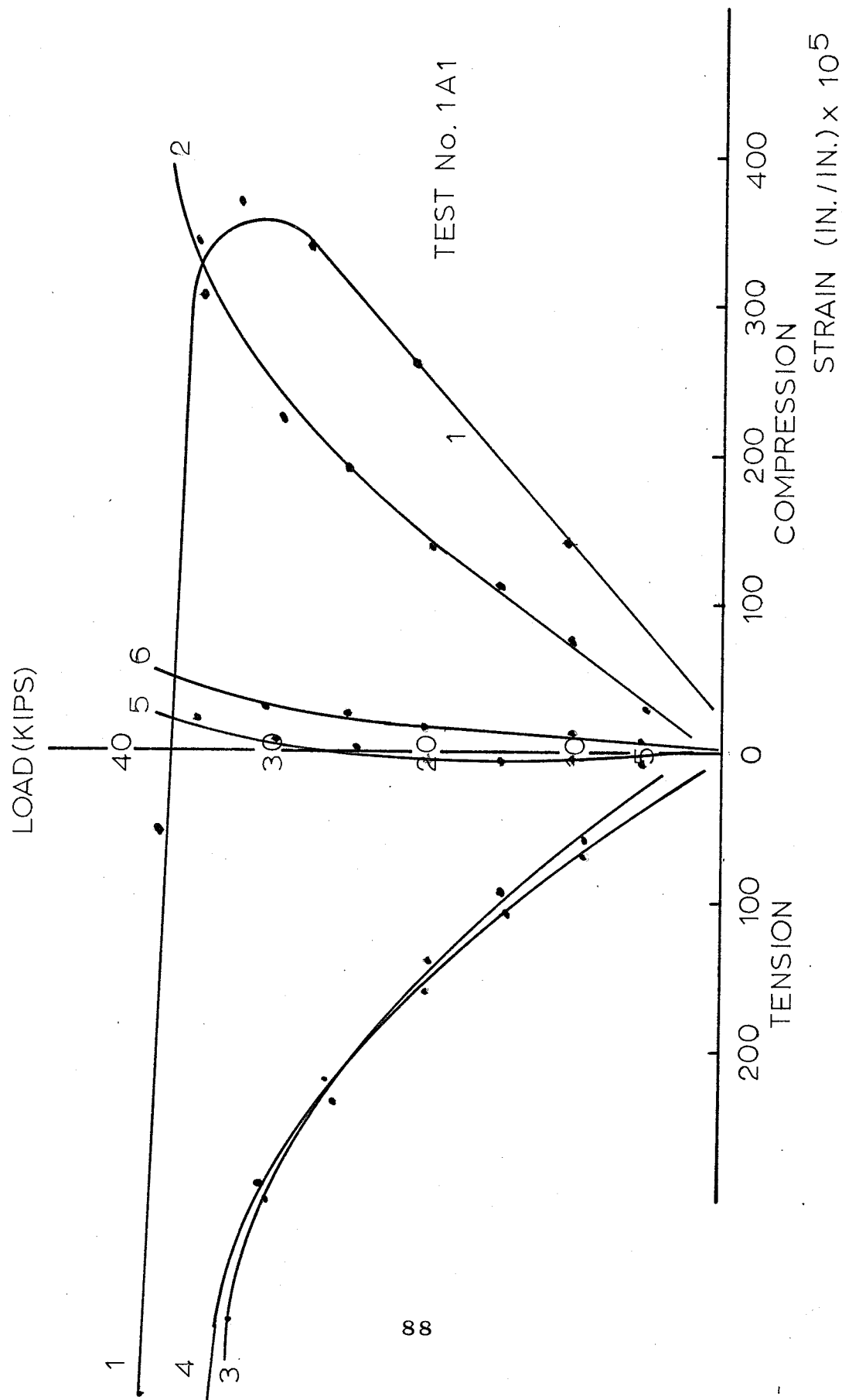


FIGURE 5.6 MEMBER STRAIN

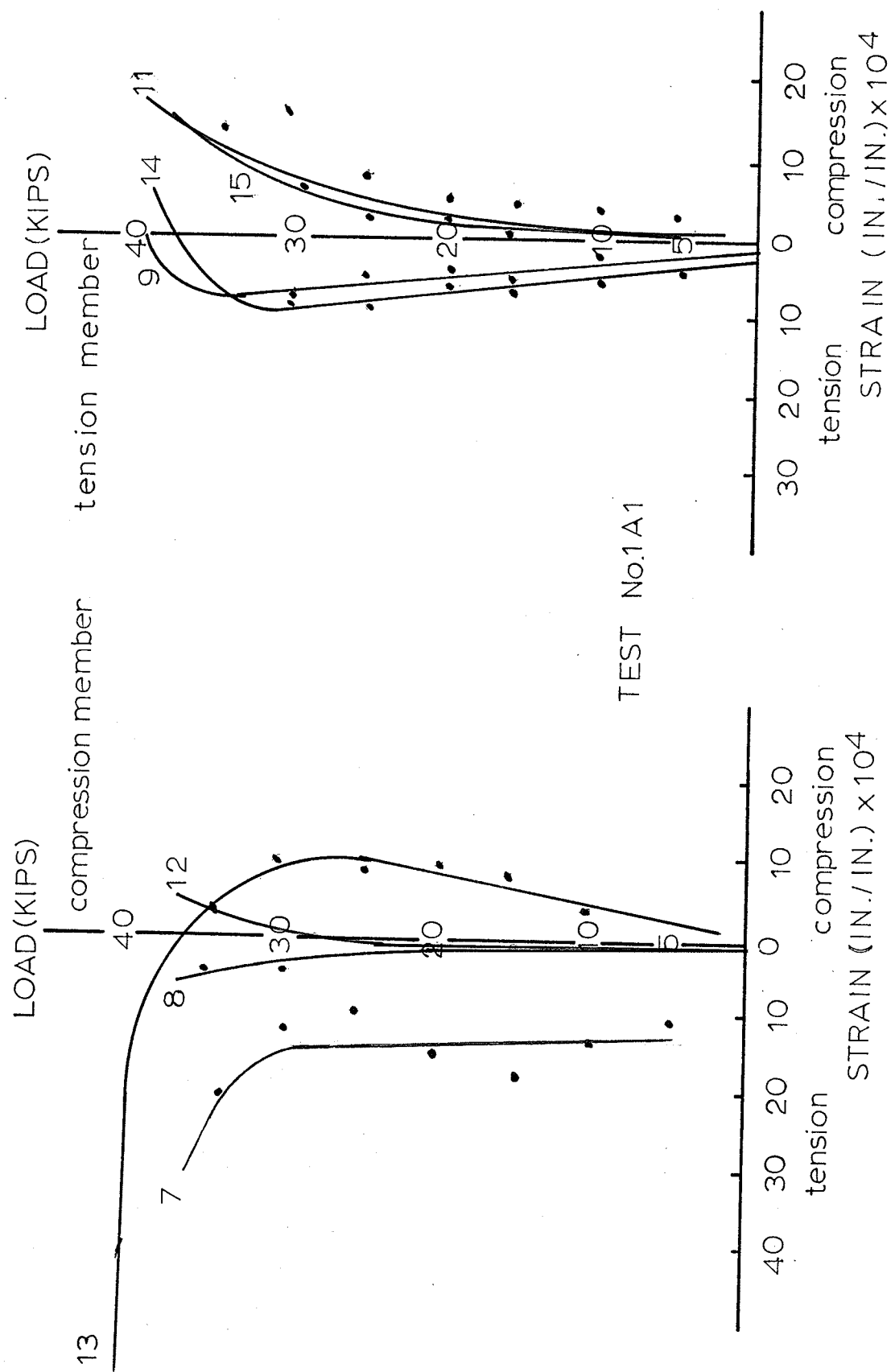


FIGURE 5.7 JOINT STRAIN

FIGURE 5.8 JOINT STRAIN

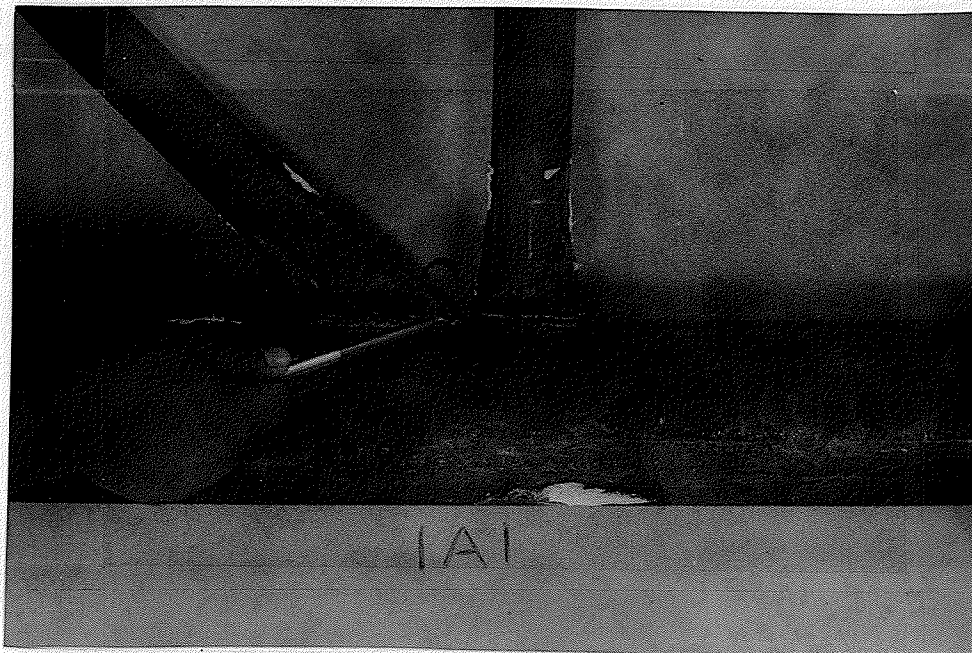


Photo 5.1 View of Type 1A1 Specimen After Testing

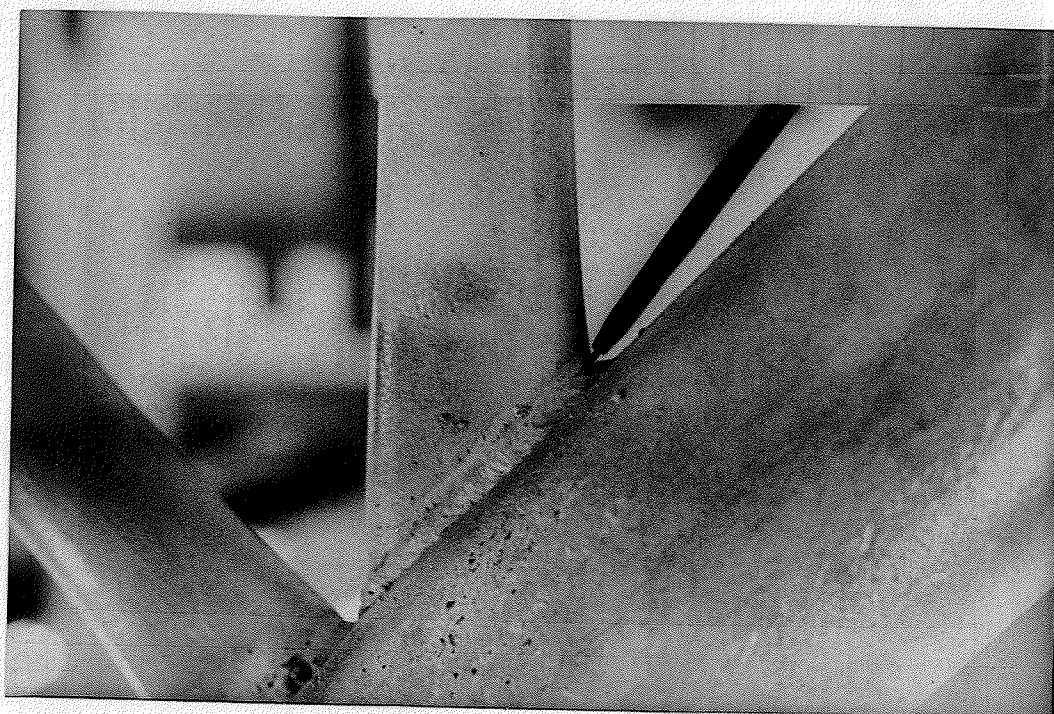


Photo 5.2 Crack In Notch of Weld In Specimen 1A2

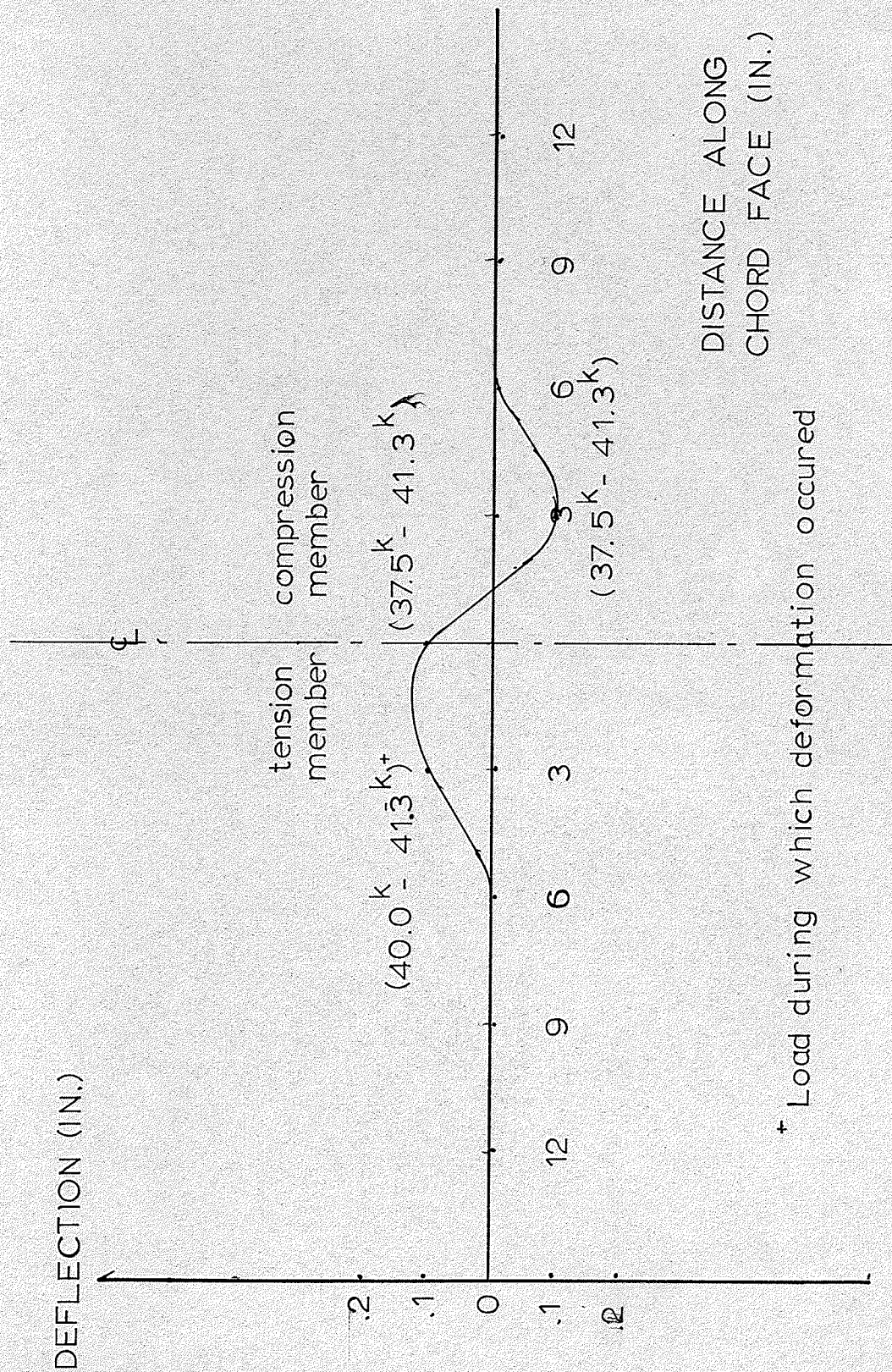


FIGURE 5.9 DEFORMATION OF CHORD FACE
FOR SPECIMEN 1A2

be easily disturbed and would thus give unreliable readings of deformation. Another problem in using the calipers was the difficulty of applying the gauge to the same spot consistently. This tended to produce readings that vary rapidly as the distance from the measuring point increased.

Monitoring the values of strain in the prestressing bar, showed that the application of load to the tension member reduced the force in the prestressing bar due to the elastic shortening of the chord. In order to remedy this problem in subsequent tests, the prestress bar was overstressed by approximately 3.0 kips so that the precompression would drop to approximately the required force at the anticipated failure load.

Figure 5.9 shows the deformation of the chord face along the gauged length as load was increased to ultimate failure.

The specimen failed at an applied load of approximately 41 kips due to elastic buckling of the web compression member as shown in Photo 5.3. Failure was accompanied by a crack in the acute angle of the tension weld as shown in Photo 5.2.

Joint efficiency was calculated at $41.3/46.7 = 89\%$ of the ultimate tension member yield strength.

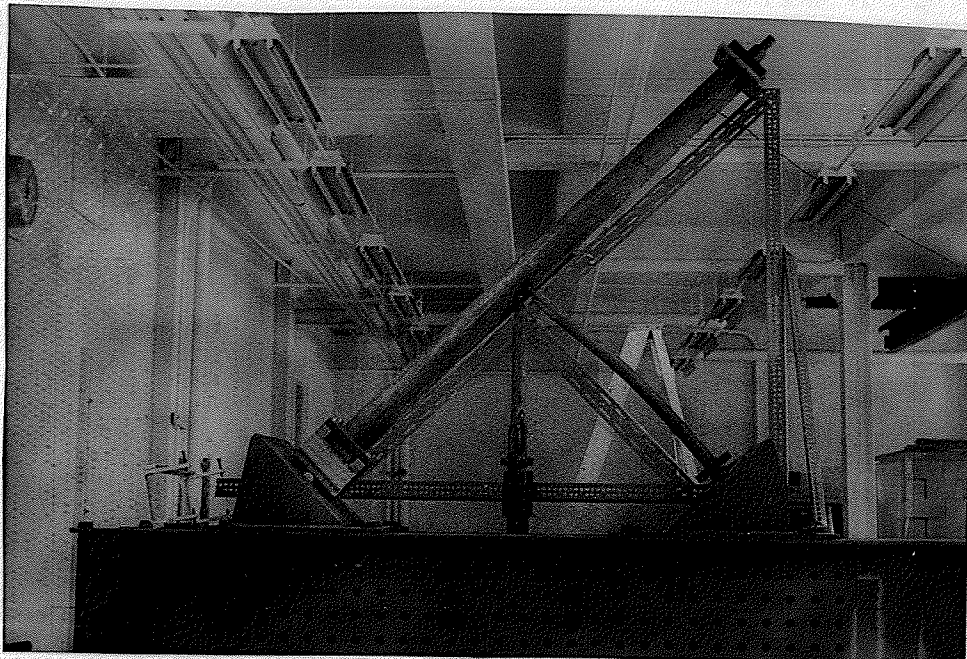


Photo 5.3 Typical Compression Tube Buckling Failure

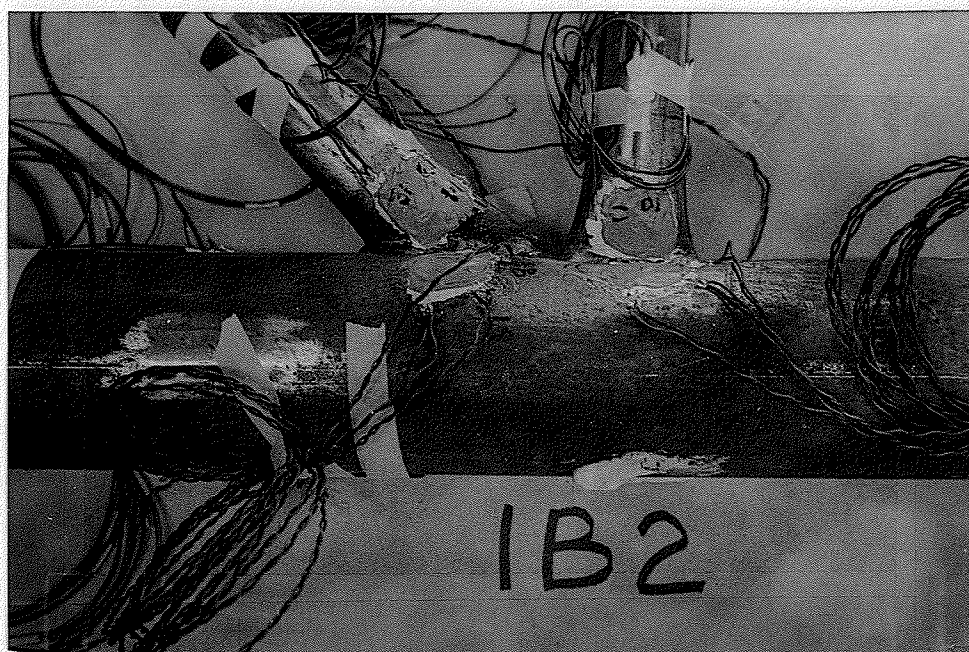


Photo 5.4 View of Specimen 1B2 After Failure

5.3.3 Specimen 1B2

The results of specimen 1B2 are recorded in Table 5.3. In this test, in addition to the dial gauges, twenty strain gauges, located as shown in Figure 4.5, were used to obtain strain measurements in and around the test joint.

The specimen exhibited large deformations of the chord face, that first became noticable at approximately 32 kips. The specimen failed at approximately 34.5 kips, due to excessive travel of the web compression member into the chord face. This resulted in an efficiency of $34.5/46.7 = 74\%$ with respect to the ultimate strength of the web tension member. As load was applied above 35 kips, the deformations increased until the specimen failed due to buckling of the web compression member at a load of 37.75 kips.

The plot of tension member travel shows the joint initially becoming plastic at about 27.5 kips, which is about the same load range that the compression member travel graph indicates initiation of plastic activity.

Figure 5.10 shows the graph of the strains recorded in Table A-7 for gauges 1 through 9. The plots for the gauges 1 through 9 behave as one would expect; gauges on the compression member approached plastic strains at approximately 30 kips and achieve full plastic strain at about 34 kips when buckling is imminent; gauges on the tension

TABLE 5.3

TEST SPECIMEN 1B2

DATE July 18, 1973

LOAD (KIPS)	TENSION MEMBER TRAVEL (IN.)		AVERAGE TENSION MEMBER TRAVEL	COMPRESSION MEMBER TRAVEL		AVERAGE MEMBER TRAVEL	PRESTRESS LOAD (KIPS)
	A	B		A	B		
0.0	.198	.207	0.000	.800	.797	0.000	16.7
5.0	.193	.218	0.001	.799	.792	0.001	16.4
10.0	.195	.224	0.004	.797	.789	0.003	16.15
12.5	.197	.227	0.006	.796	.786	0.004	15.6
15.0	.199	.229	0.008	.794	.784	0.005	15.5
17.5	.200	.232	0.009	.793	.782	0.005	15.2
20.0	.202	.234	0.011	.792	.780	0.006	15.0
22.5	.204	.237	0.012	.790	.777	0.007	14.7
25.0	.207	.241	0.015	.787	.773	0.010	14.55
27.5	.211	.245	0.017	.782	.768	0.014	14.3
30.0	.217	.250	0.022	.776	.763	0.019	14.1
31.0	.219	.252	0.024	.773	.759	0.022	14.0
32.0	.224	.256	0.029	.767	.754	0.027	14.0
33.0	.228	.260	0.031	.762	.749	0.032	13.9
34.0	.235	.267	0.039	.751	.738	0.042	13.8
35.0	.244	.278	0.049	.735	.721	0.059	13.7
36.0	.253	.291	0.060	.714	.702	0.079	13.6
37.0	.262	.311	0.073	.675	.658	0.169	13.5
37.75			COMPRESSION	MEMBER BUCKLING			

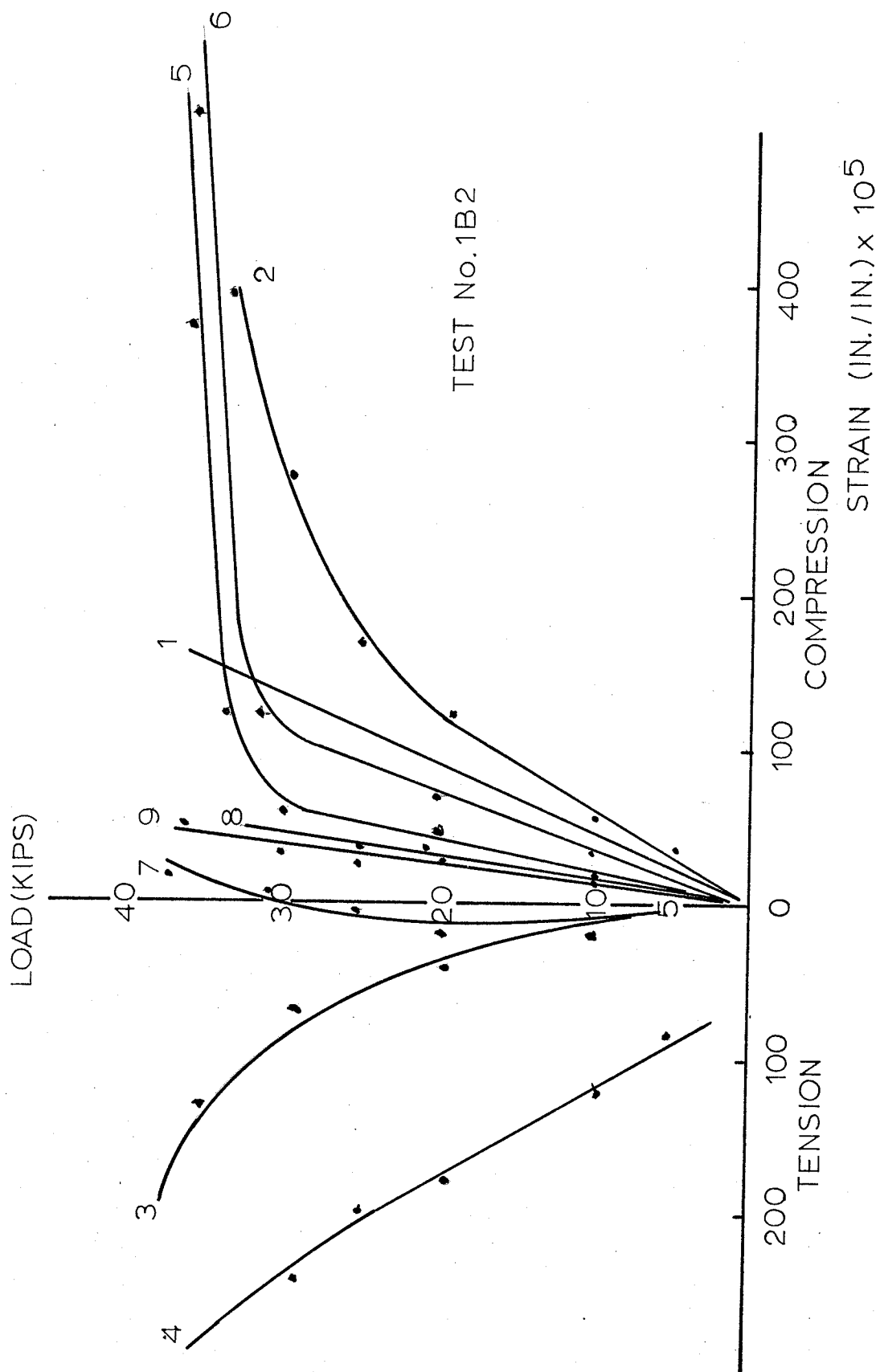


FIGURE 5.10 MEMBER STRAIN

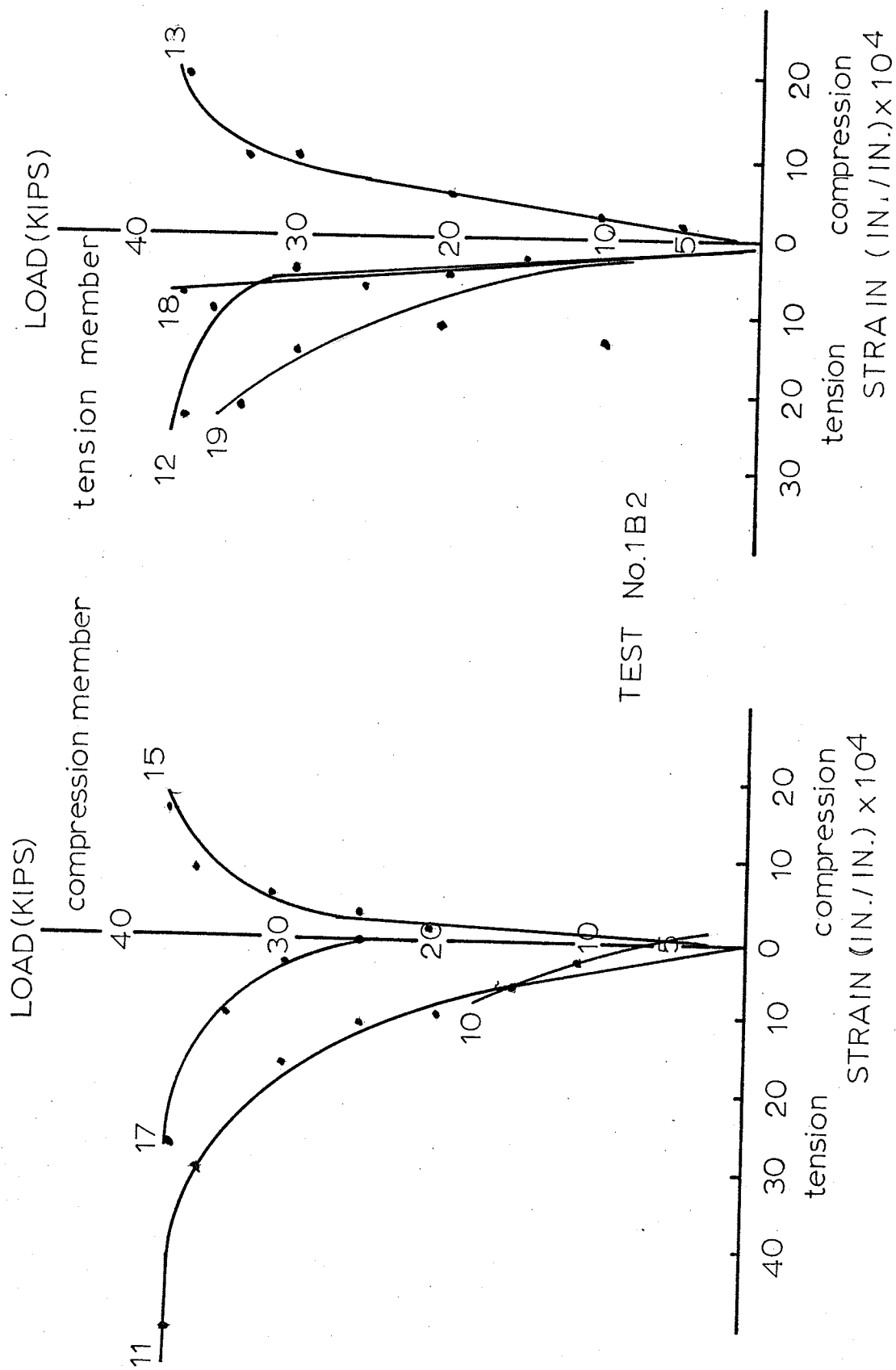


FIGURE 5. 11 JOINT STRAIN

FIGURE 5.12 JOINT STRAIN

member approached the plastic strain region as failure occurred; strains for the gauges on the chord reflected a low state of stress.

The plot for the gauges located at the base of the compression member (Figure 5.10) indicates that the strains in directions parallel and perpendicular to the chord at the base of the compression member were tensile. This is probably due to the load transfer, through the chord face, between the web members. Unfortunately, gauge 10 was damaged at a low strain and did not permit better evaluation of the state of stress in the compression member.

For the gauges on the web tension member, the gauges parallel to that member, and gauge 18 revealed tensile strains, which were expected. Gauge 13 showed compressive strains, which were verified by gauge 14. This probably indicates a slightly eccentric loading.

5.3.4 Specimen 2A1

Table 5.4 shows the test data for specimen 2A1. Plots of load versus compression member travel, load versus tension member travel and load versus overall deflection show the test specimen to be fairly rigid with all the curves just moving into the plastic range when premature failure

TABLE 5.4

TEST SPECIMEN 2A1

DATE May 31, 1973

LOAD (KIPS)	TENSION MEMBER TRAVEL (IN.)		AVERAGE TENSION MEMBER TRAVEL	COMPRESSION MEMBER TRAVEL		AVERAGE MEMBER TRAVEL	PRESTRESS LOAD (KIPS)
	A	B*		A	B		
0.0	.200	.100	0.0	.900	.500	0.0	17.0
5.0	.199	.101	0.001	.900	.496	0.000	16.5
0.0	.199	.101	0.0	.900	.498	0.0	17.0
5.0	.199	.101	0.0	.898	.496	0.000	16.5
10.0	.205	.101	0.002	.897	.494	0.000	16.0
12.5	.207	.101	0.003	.895	.494	0.0	15.7
15.0	.210	.104	0.005	.893	.493	0.0	15.5
17.5	.212	.104	0.006	.892	.493	0.0	15.1
20.0	.216	.104	0.009	.891	.492	0.0	15.0
22.5	.220	.104	0.012	.889	.491	0.0	14.8
25.0	.225	.104	0.016	.887	.490	0.001	14.7
27.5	.230	.104	0.020	.885	.489	0.001	14.5
30.0	.236	.105	0.025	.883	.488	0.002	14.0
31.0	.239	.105	0.030	.882	.488	0.002	13.9
32.0	.244	.105	0.034	.881	.487	0.003	13.8
33.0	.248	.105	0.038	.879	.487	0.003	13.75
34.0	.251	.110	0.040	.877	.487	0.004	13.7
35.0	.254	.116	0.043	.874	.486	0.005	13.6
36.0	.264	.119	0.053	.872	.485	0.007	13.5
36.5			TENSION MEMBER LOADING PLATE FAILURE				
			* DEFECTIVE GAUGE				

TABLE 58.4

SPECIMEN 2A1

LOAD	DEFLECTION GAUGES					PROJECTED DEFLECTION GAUGE NO.1
	TRANSVERSE DISPLACEMENT OF JOINT	NO. 2	NO. 3	NO. 4	NO. 5	
0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	0.004	0.010	0.0	0.0018	0.0032	0.0093
0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	0.0	0.005	0.0	-0.0008	0.0009	0.0026
10.0	0.008	0.013	0.001	0.0016	0.0055	0.0160
12.5	0.010	0.017	0.004	0.0027	0.0078	0.0227
15.0	0.013	0.018	0.005	0.0036	0.0105	0.0307
17.5	0.016	0.018	0.008	0.0044	0.0126	0.0366
20.0	0.024	0.020	0.011	0.0053	0.0158	0.0459
22.5	0.029	0.022	0.012	0.0062	0.0184	0.0535
25.0	0.034	0.026	0.014	0.0075	0.0211	0.0614
27.5	0.041	0.031	0.020	0.0094	0.0244	0.0710
30.0	0.047	0.035	0.023	0.0110	0.0272	0.0790
31.0	0.051	0.038	0.029	0.0118	0.0288	0.0837
32.0	0.053	0.039	0.030	0.0127	0.0303	0.0880
33.0	0.058	0.043	0.033	0.0140	0.0319	0.0923
34.0	0.061	0.046	0.037	0.0157	0.0347	0.1010
35.0	0.068	0.056	0.042	0.0176	0.0372	0.1080
36.0	0.070	0.054	0.044	0.0201	0.0389	0.1130

due to tearing of the tension member at the loading plate occurred.

The measured deflections of the web members relative to the chord face were very small with the tension member deforming the face by approximately .05 inches and the compression member deforming the face less than .01 inches. The overall specimen deflection was limited to .07 inches by the rigidity of the joint.

The lack of excessive chord face deformation was probably due to the one-half inch gap between the walls of the flattened web tube and to the transfer of load between web members above the chord face.

Attempts to correlate a rigid body rotation to the gauge 1 overall deflection failed indicating the possibility of impending deformation due to bending.

Because a premature failure occurred at the point where the tension web member was welded to the plate through which the load was applied, the subsequent specimens were reinforced at this point to preclude similar failures.

Joint 2A1 was evaluated as being $36.5/46.7 = 78\%$ efficient.

5.3.5 Specimen 2A2

The results of the test on specimen 2A2 are



Photo 5.5 Joint 2A1 Detail

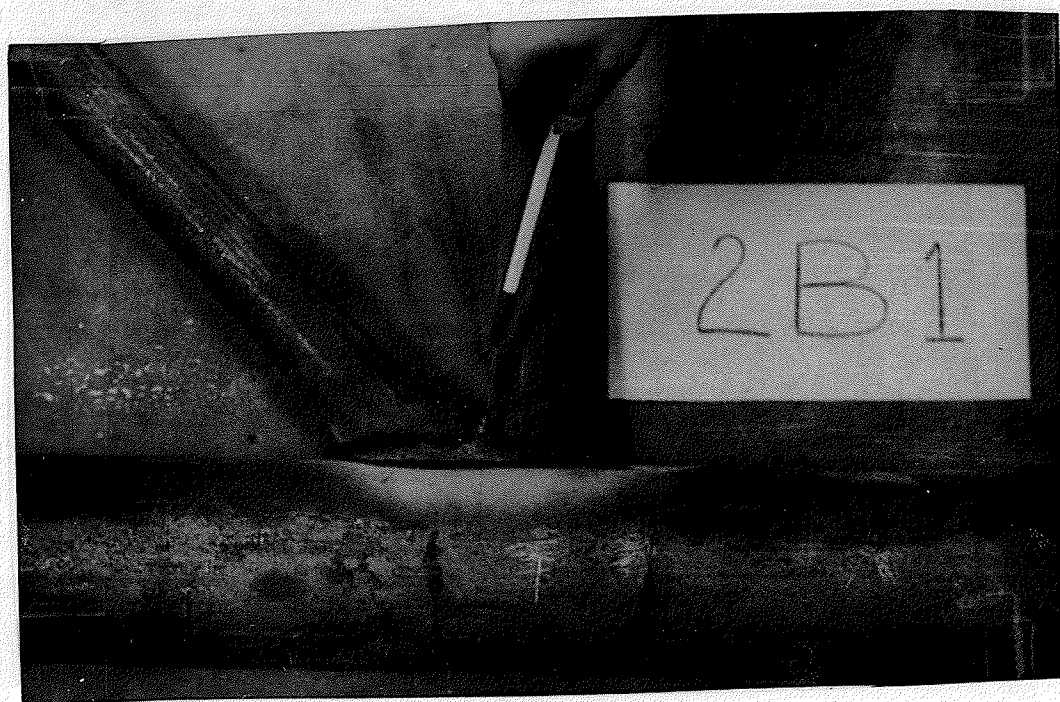


Photo 5.6 Specimen 2B Joint Detail

DATE May 31, 1973

TABLE 5.5

[illegible]

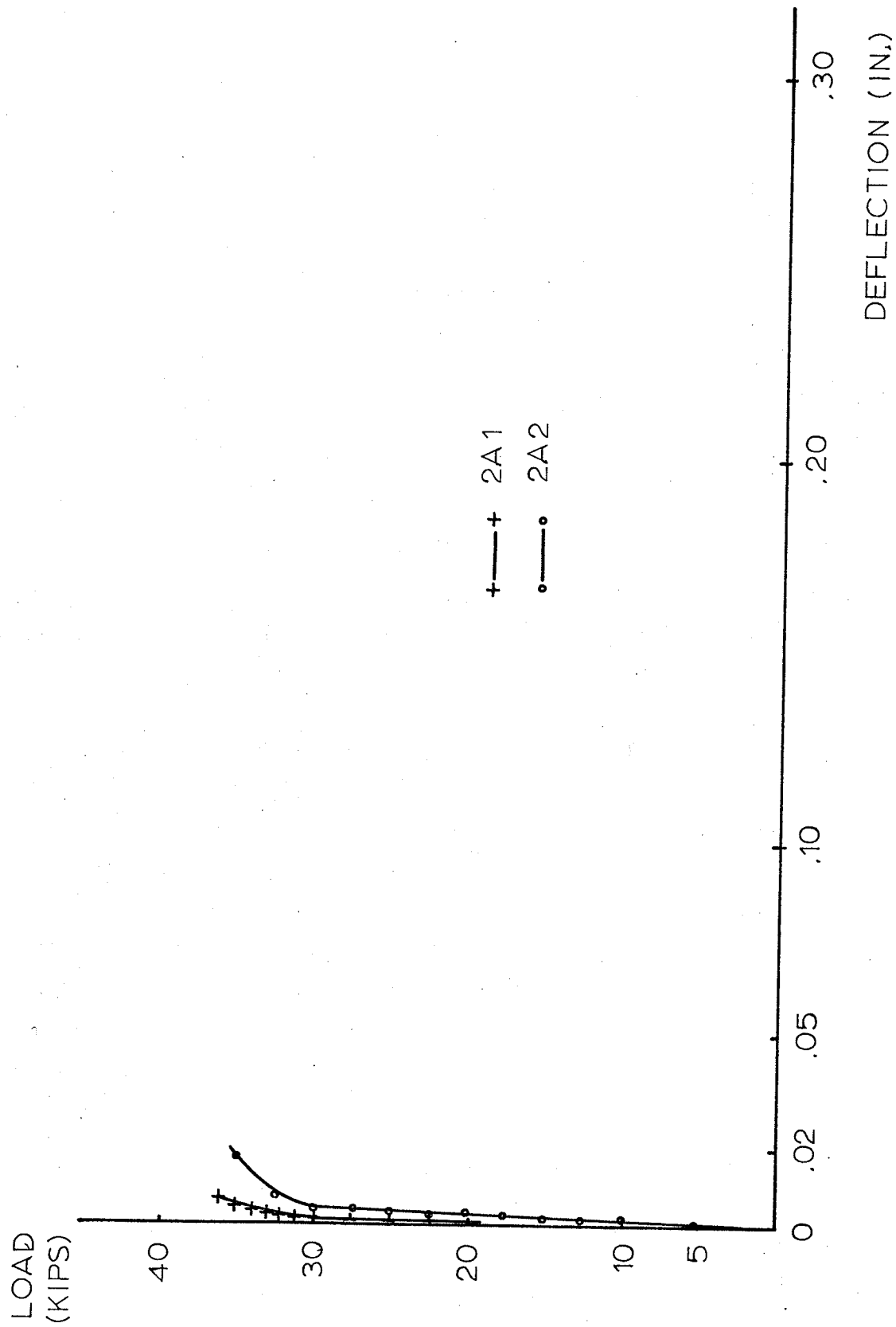


FIGURE 5.13 COMPRESSION MEMBER TRAVEL

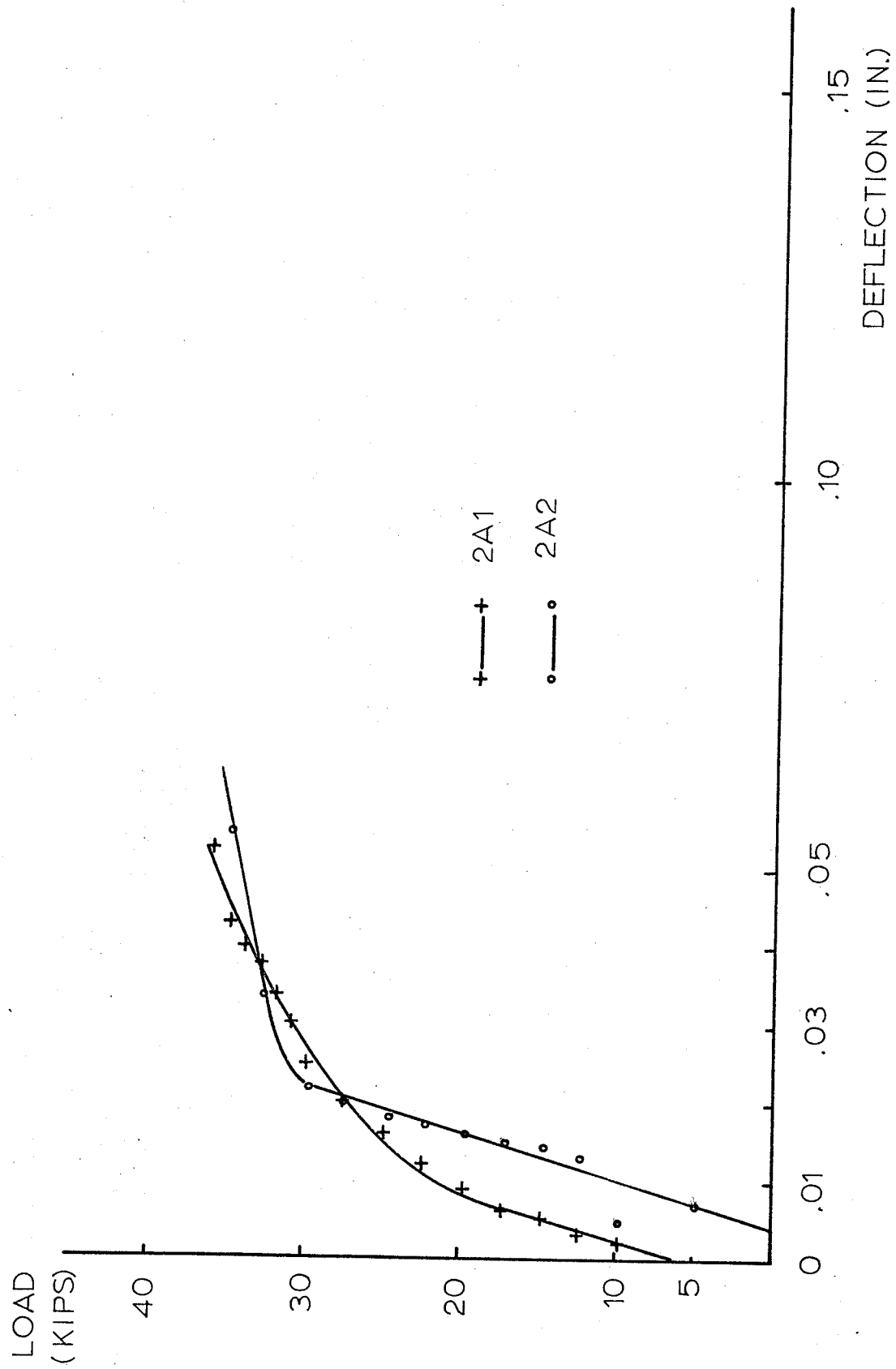


FIGURE 5.14 TENSION MEMBER TRAVEL

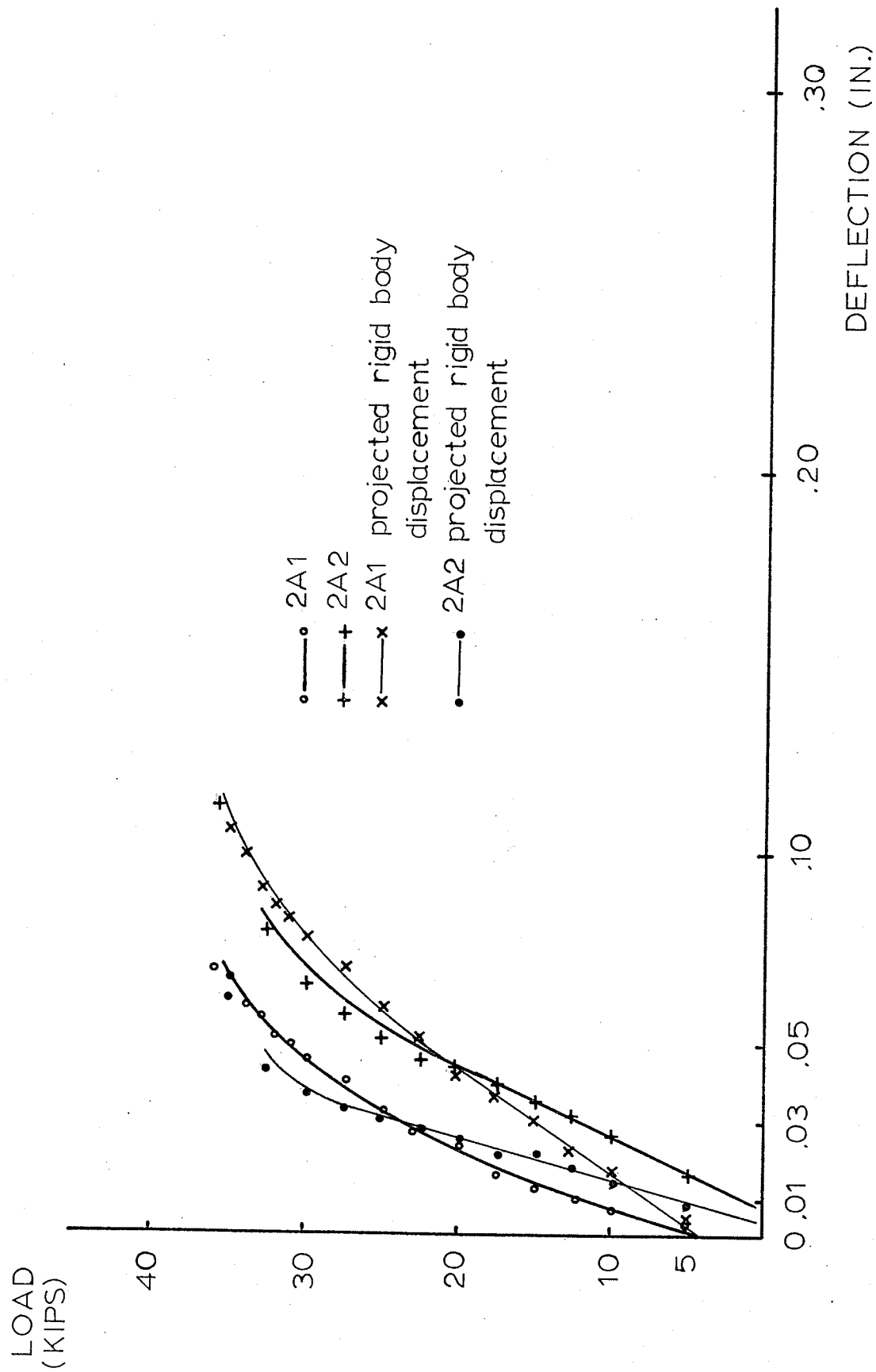


FIGURE 5.15 TRANSVERSE DISPLACEMENT OF JOINT

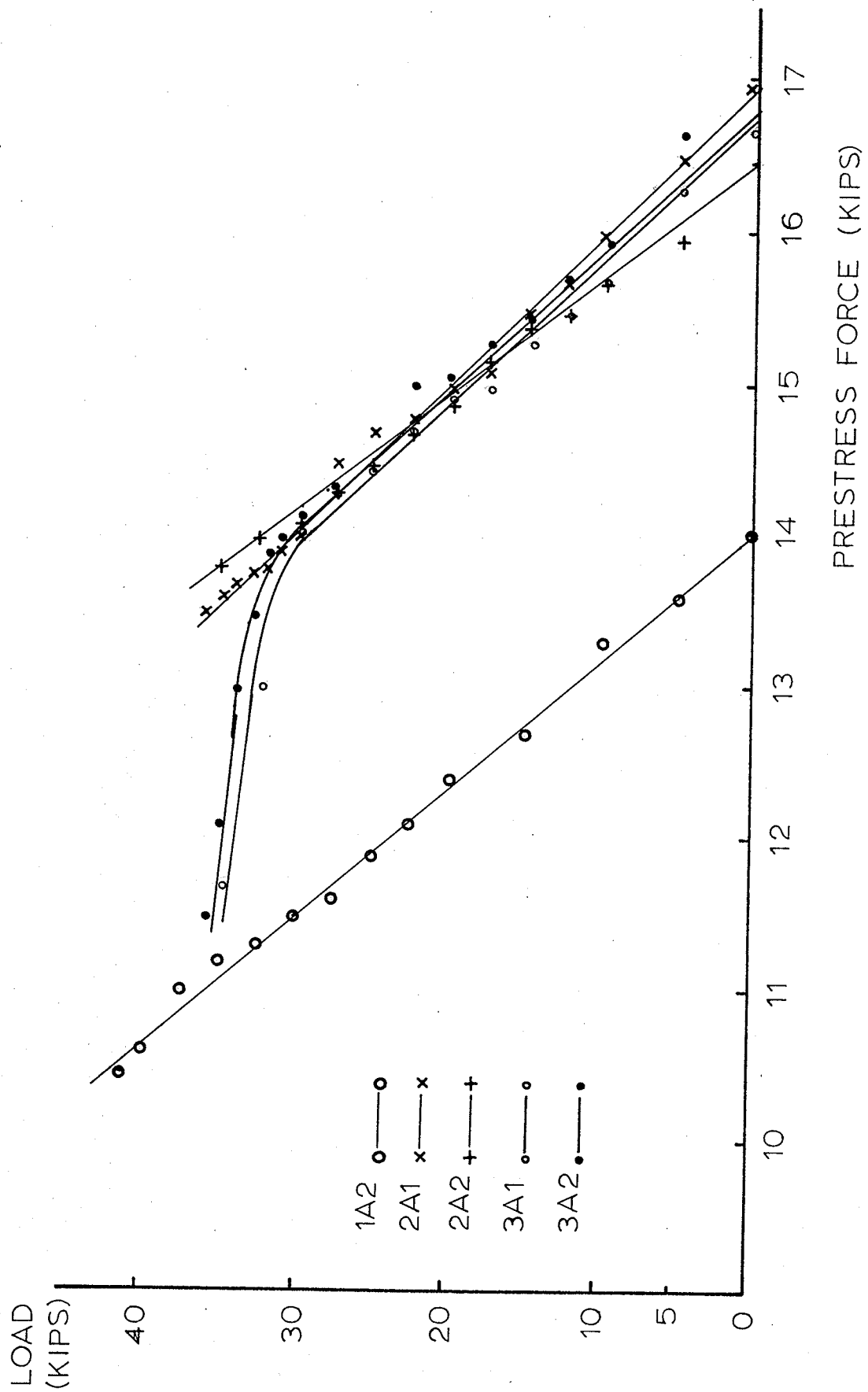


FIGURE 5.16 LOSS OF PRESTRESS

tabulated in Table 5.9.

The behaviour of this specimen was almost identical to that of specimen 2A1 with slightly larger web member deflections relative to the chord face, as can be seen in Figure 5.13 and 5.14. The overall specimen deflection was somewhat larger as is shown in Figure 5.15, but this may have been due to an initial movement of the gauge, as the curves are similar except for the initial values read.

Since the two tests (i.e. 2A1 and 2A2) were very similar and, the failure modes were identical, further explanation of this joint's behaviour is not required.

Joint 2A2 was found to have $39.5/46.7 = 85\%$ efficiency.

5.3.6 Specimen 2B2

Table 5.6 presents the results of specimen 2B2. In addition to the dial gauges, nine strain gauges were applied to the specimen, as shown in Figure 4.4 and the resulting strains were calculated by a computer program.

In addition to the strain gauges, dial gauges were positioned at the reaction end of the chord and the free end of the chord so that any movement of the measuring frame, relative to the chord tube center line, could be measured.

TABLE 5.6

TEST SPECIMEN 2B2

DATE July 16, 1973

LOAD (KIPS)	TENSION MEMBER TRAVEL (IN.)		AVERAGE TENSION MEMBER TRAVEL	COMPRESSION MEMBER TRAVEL		AVERAGE MEMBER TRAVEL	PRESTRESS LOAD (KIPS)
	A	B		A	B		
0.0	.200	.201	0.000	.900	.597	0.000	17.75
5.0	.200	.206	0.002	.901	.594	0.000	17.3
10.0	.201	.211	0.003	.900	.590	0.000	17.0
12.5	.201	.214	0.003	.899	.588	0.000	16.75
15.0	.202	.217	0.005	.899	.586	0.001	16.6
17.5	.202	.219	0.005	.898	.584	0.001	16.5
20.0	.204	.221	0.006	.898	.582	0.001	16.3
22.5	.205	.223	0.008	.897	.579	0.004	16.1
25.0	.208	.226	0.010	.896	.577	0.003	15.9
27.5	.210	.229	0.011	.895	.574	0.004	15.6
30.0	.214	.234	0.016	.893	.569	0.007	15.55
31.0	.216	.235	0.016	.892	.567	0.007	15.5
32.0	.220	.239	0.020	.891	.565	0.009	15.3
33.0	.226	.244	0.026	.899	.562	0.011	15.25
34.0	.234	.252	0.033	.887	.558	0.013	15.1
35.0	.244	.263	0.043	.885	.555	0.016	15.0
36.0	.261	.284	0.062	.882	.549	0.020	14.9
37.0	.279	.308	0.082	.878	.544	0.024	14.85
38.0	.309	.334	0.110	.873	.535	0.031	14.7
39.0	.346	.363	0.143	.866	.521	0.041	14.6
41.6							
			COMPRESSION MEMBER BUCKLING				

LOAD	TRANSVERSE DISPLACEMENT OF JOINT	CHORD	
		PINNED-END (lower end)	FREE-END (upper end)
0.0	0.000	0.000	0.000
5.0	0.017	0.007	0.028
10.0	0.031	0.015	0.039
12.5	0.038	0.018	0.050
15.0	0.044	0.022	0.058
17.5	0.048	0.024	0.067
20.0	0.053	0.027	0.076
22.5	0.058	0.029	0.085
25.0	0.065	0.032	0.094
27.5	0.071	0.035	0.104
30.0	0.078	0.039	0.115
31.0	0.080	0.040	0.119
32.0	0.086	0.043	0.125
33.0	0.091	0.045	0.132
34.0	0.097	0.048	0.139
35.0	0.103	0.050	0.149
36.0	0.109	0.053	0.158
37.0	0.117	0.057	0.169
38.0	0.128	0.062	0.186
39.0	0.134	0.068	0.211



Photo 5.7 View Of Deformation Of Specimen 2B2
After Loading

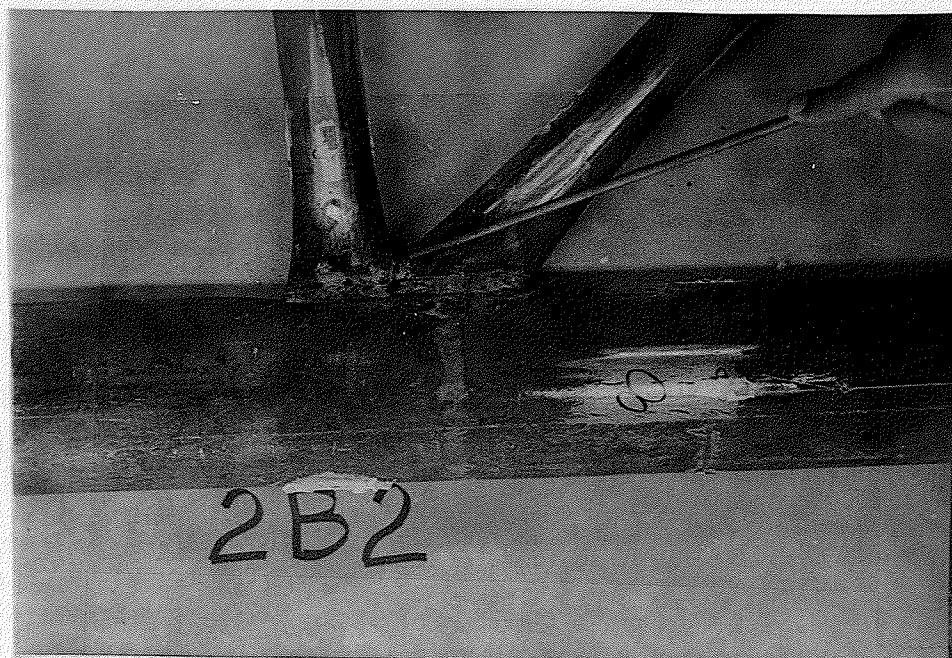


Photo 5.8 View Of Specimen 2B2 Showing Crack
Of Interconnecting Weld

Figure 5.2 shows the compression member travel for the test specimen. Subsequent to failure, it was observed that the behaviour of the joint was just becoming fully plastic and probably would have failed due to excessive deformation below 40 kips, since the chord deformation was becoming quite noticable. This awareness of "plastic-flow" was heightened by the relatively large tension member travel as is shown in Figure 5.3.

The overall deflection of the joint also showed the specimen to be on the verge of plastic behaviour, while the chart of prestress loss shows a slight curvature to suggest imminent plastic behaviour.

Joint efficiency was calculated at $41.6/46.7 = 89\%$.

During the test at approximately 34 kips, the weld joining the tension and compression members cracked and started to open. At this point, the web member travel started to increase, and chord deformation became significant.

The gauges were removed at a load of 39 kips, as it was feared there would be a sudden failure. Load was applied until the compression member buckled at an applied load of 41.6 kips.

Figure 5.17 shows the plots of the nine strain

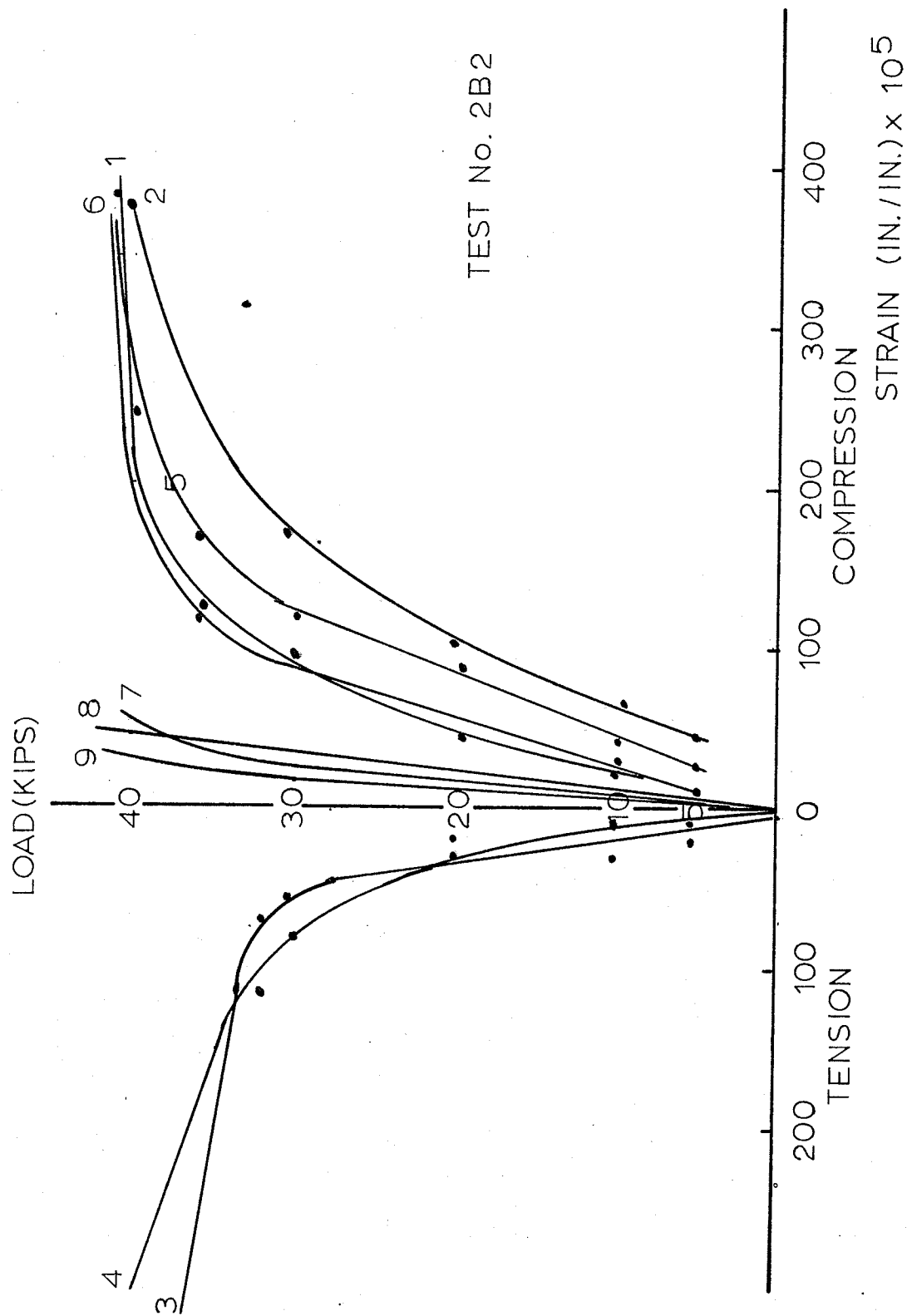


FIGURE 5.17 MEMBER STRAIN

gauges used in this test.

From these results, it can be seen that the web compression member underwent plastic strain beginning at approximately 38 ksi. At approximately 45 ksi the strain readings indicated that the compression member was almost fully plastic. The web tension member began to undergo plastic strain at approximately 45 ksi and was fully plastic at approximately 57 ksi.

The load-strain plot for the chord indicates that the chord material was in the elastic behaviour range. This is quite reasonable since the chord was not highly stressed.

5.3.7 Specimen 3A1

The test of specimen 3A1 was the first test in which use was made of the measuring frame and collar apparatus. In addition to these displacement measurements, gauges number 1 to 5, as shown in Figure 4.4, measured the chord displacement at the joint (gauges 1, 2, and 3), the rotation of the chord tube (gauge 5), and the web tube (gauge 4). These gauges permitted a comparison of the projected rigid body displacements measured by gauges 5 and 1, to the actual displacement of gauge 1, as well as allowing the rotation of the compression members to be estimated.

Table 5.7 shows the results of test 3A1. The

TABLE 5.7

LOAD	DEFLECTION GAUGES					CHORD ROTATION (DEG.)	PROJECTED DEFLECTION GAUGE NO.1
	TRANSVERSE DISPLACE- MENT OF JOINT	NO. 2	NO. 3	NO. 4	NO. 5		
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	0.0	-0.0001	0.0	0.0	0.007	0.4	0.019
0.0	0.0	0.001	0.0	-0.001	0.001	0.0	0.0
5.0	0.0	0.0	0.0	0.0	0.007	0.4	0.019
10.0	0.0	0.0	0.0	0.001	0.011	0.6	0.031
12.0	0.0001	0.0	0.001	0.001	0.013	0.7	0.037
15.0	0.0046	0.0032	0.010	0.001	0.017	0.9	0.048
17.5	0.0146	0.0032	0.011	0.001	0.019	1.0	0.054
20.0	0.0154	0.0032	0.012	0.001	0.023	1.3	0.066
22.5	0.0239	0.0032	0.014	0.001	0.027	1.5	0.077
25.0	0.0494	0.0067	0.022	0.0	0.033	1.8	0.094
27.5	0.0691	0.0265	0.045	0.0	0.042	2.25	0.119
30.0	0.1120	0.0459	0.070	0.0	0.042	2.25	0.119
32.5	0.1659	0.1024	0.112	0.004	0.071	3.85	0.202
35.0	0.2684	0.1090	0.162	0.022	0.098	5.5	0.289

ultimate failure was due to buckling of the web compression member at 36.5 kips. The initial failure was due to excessive deformation of the square chord tube under the compression member at a load of approximately 27 kips as illustrated in Figure 5.19. At the initial failure, the joint showed marked plastic deformation which increased until the joint failed. Photos 5.9 and 5.10 show the deformed joint after testing.

Figure 5.18 shows the overall displacement of the joint as measured by gauge 1 during a plastic load deflection curve similar to the stress-strain curves found when the web materials were subjected to a tension test.

The attempt to correlate the deflection of gauge 1 to a rigid body rotation projected from the displacements of gauge 5 shows that the loading condition causes a bending moment in the chord which results in displacements larger than a rigid body displacement.

Figure 5.16 shows the loss of prestress as the applied load is increased. The loss of load follows a curve that decreases due to the elastic shortening of the chord up to approximately 27 kips, then falls off rapidly as the joint becomes plastic and the deformations of the chord face increase.

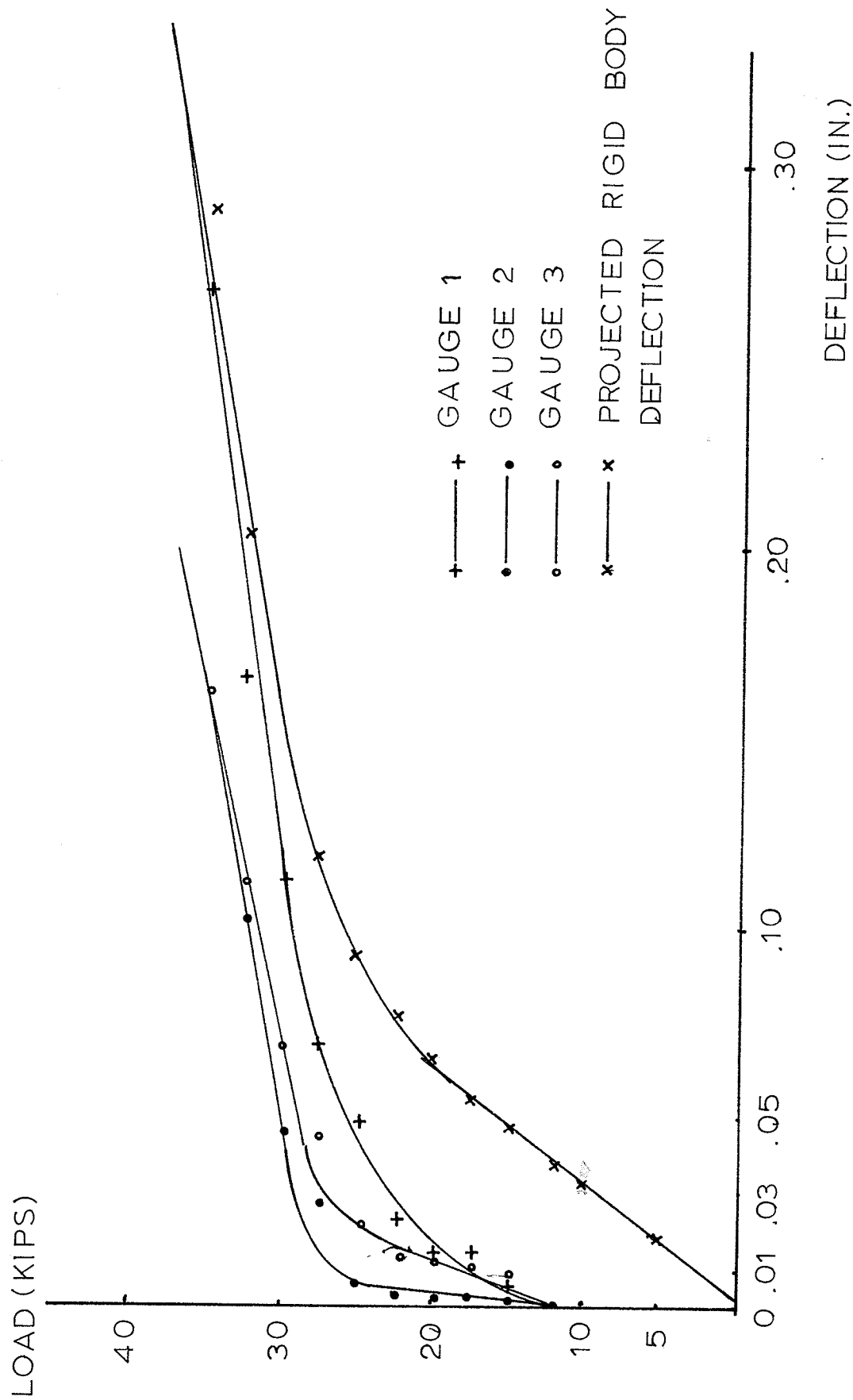


FIGURE 5.18 SPECIMEN DEFLECTION AT THE NODE POINT

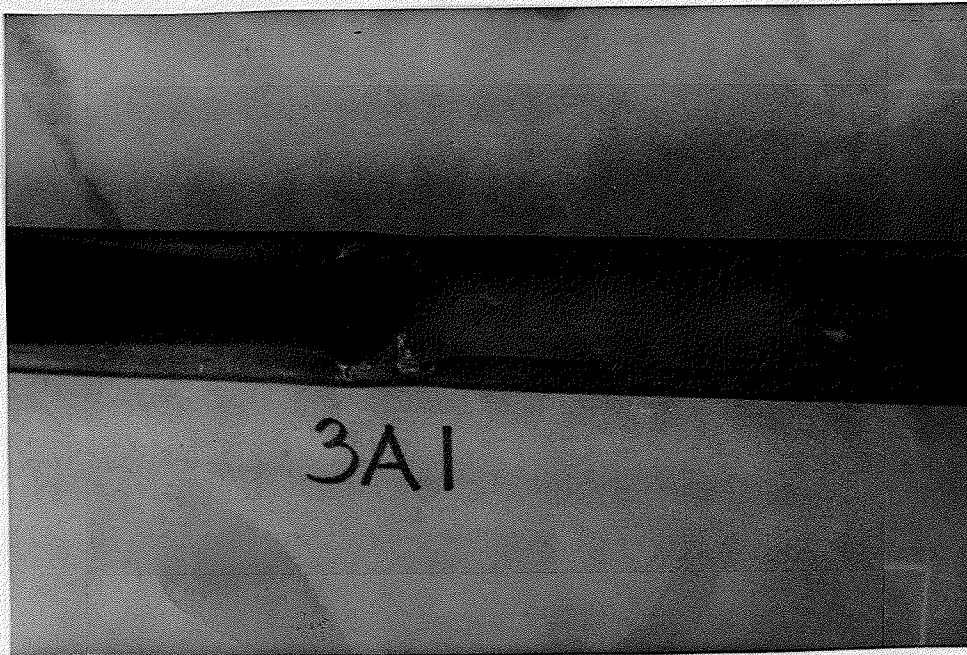
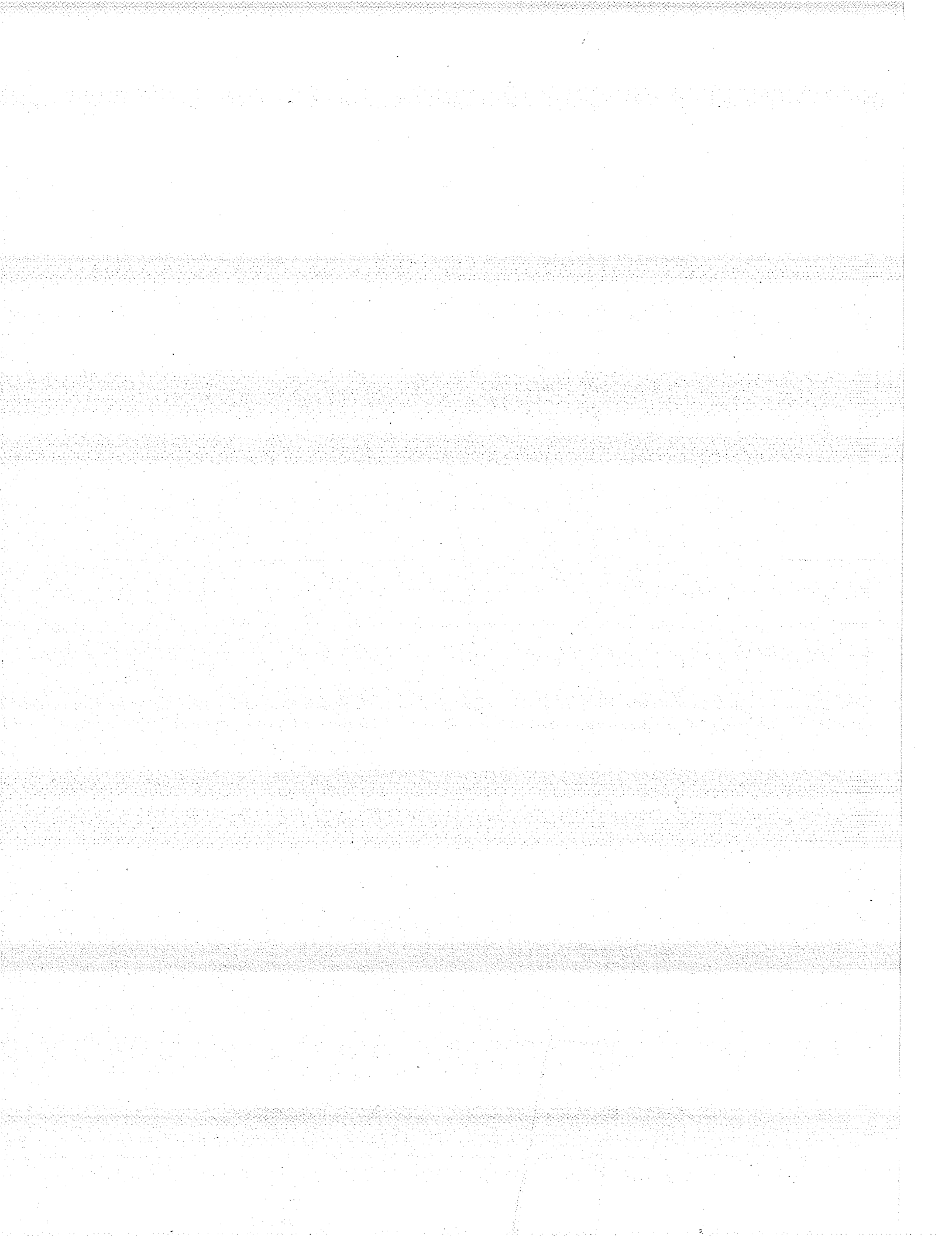


Photo 5.9 Top View Of Deformed Specimen



Photo 5.10 Side View Of Deformed Specimen



efficiency is $27.5/46.7 = 59\%$ of the load.

3A2
shows the test data recorded for compared favourably with the test 3A1 as is shown in Figure 5.19 through

showing compression member travel into es extremely well with the results for failure occurred at approximately 29.5 kips formation, and ultimate failure occurred tension member failure just above the otos 5.11 and 5.12.

on member travel agrees closely with 3A1 and are approximately 12 percent nt is becoming plastic.

l gauge 1 deflections and prestress y similar to those found for joint 3A1 further interpretation.

ciency for test 3A2 was calculated at ough failure occurred in the tension

5.0	.104	.291	0.0	.794	.531	0.002	16.7
10.0	.112	.291	0.002	.791	.526	0.004	16.0
12.5	.116	.290	0.003	.789	.523	0.005	15.7
15.0	.121	.290	0.004	.786	.520	0.007	15.5
17.5	.125	.291	0.006	.783	.517	0.009	15.3
20.0	.131	.294	0.009	.778	.512	0.013	15.1
22.5	.138	.298	0.014	.772	.504	0.019	15.0
25.0	.147	.303	0.020	.761	.492	0.028	14.7
27.5	.157	.309	0.027	.749	.477	0.040	14.5
28.5	.160	.310	0.029	.745	.472	0.045	14.3
30.0	.171	.318	0.037	.726	.449	0.059	14.1
31.0	.178	.323	0.043	.712	.444	0.074	14.0
32.0	.190	.332	0.052	.687	.408	0.103	13.9
33.0	.203	.340	0.063	.657	.378	0.134	13.5
34.0	.226	.350	0.079	.611	.327	0.186	13.0
35.0	.256	.370	0.104	.574	.280	0.228	12.1
36.0	.295	.414	0.150	.521	.229	0.280	11.5
36.5			TENSION MEMBER FAILURE				

TABLE 5.8.6

10.0	0.0054	0.0001	0.001	0.0	0.007	0.7	0.024
12.5	0.0146	0.0	0.001	0.0	0.010	1.0	0.034
15.0	0.0312	GAUGE	0.001	0.0	0.013	1.5	0.045
17.5	0.0437	FOULED	0.001	0.0	0.016	1.7	0.055
20.0	0.0537		0.002	0.002	0.020	2.0	0.069
22.5	0.0571		0.003	0.003	0.026	2.7	0.090
25.0	0.0626		0.004	0.004	0.032	3.0	0.110
27.5	0.0822		0.005	0.005	0.039	3.5	0.134
28.5	0.0833		0.005	0.005	0.041	4.0	0.141
30.0	0.1128		0.018	0.005	0.051	5.0	0.176
31.0	0.1230		0.026	0.006	0.057	5.5	0.196
32.0	0.1515		0.039	0.005	0.068	6.1	0.234
33.0	0.1814		0.057	0.004	0.080	7.7	0.275
34.0	0.1836		0.077	0.001	0.096	9.0	0.330
35.0	0.2725		0.101	-0.004	0.111	10.2	0.382
36.0	0.3235		0.121	-0.030	0.127	12.0	0.437

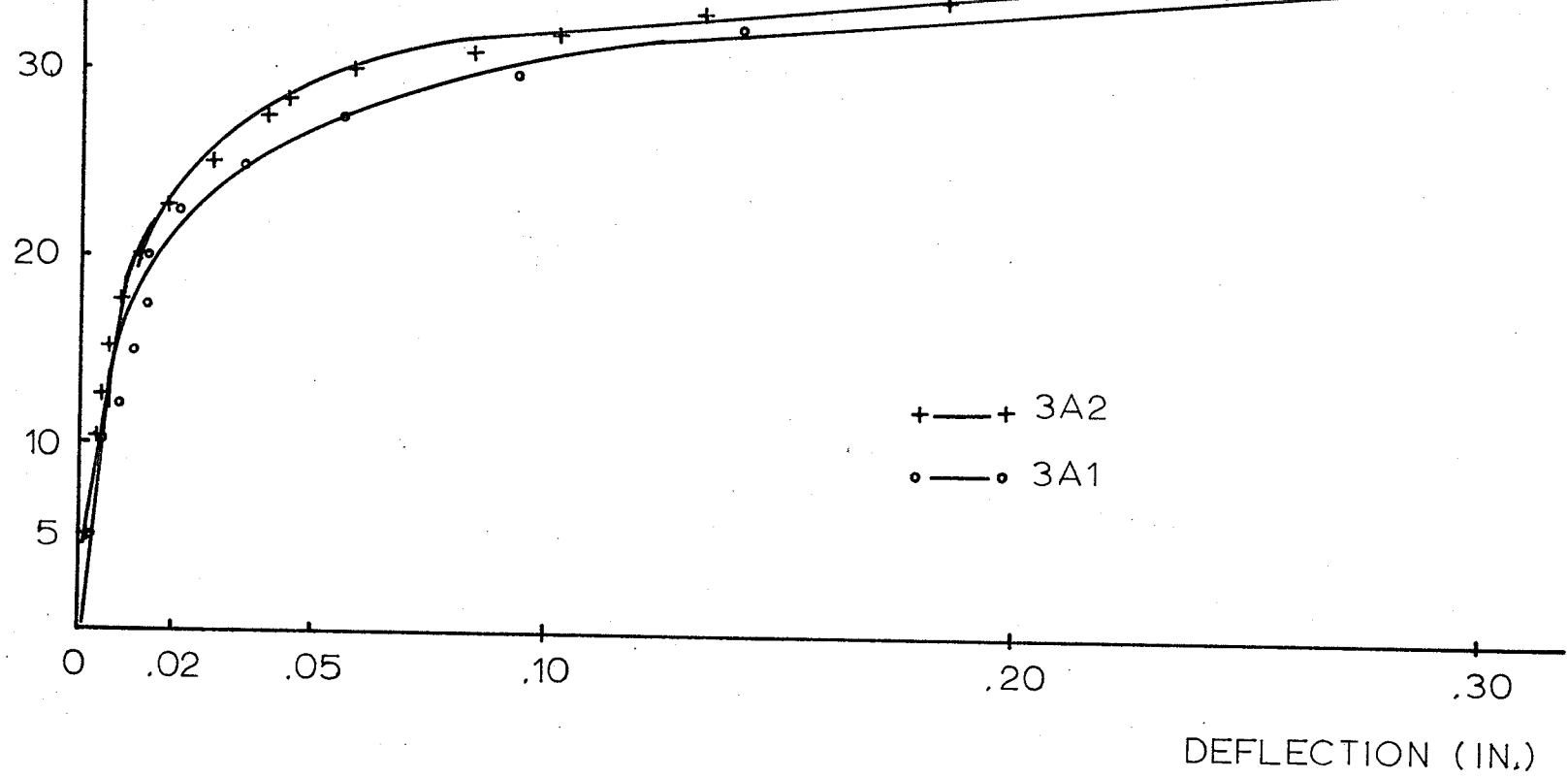


FIGURE 5.19 COMPRESSION MEMBER TRAVEL

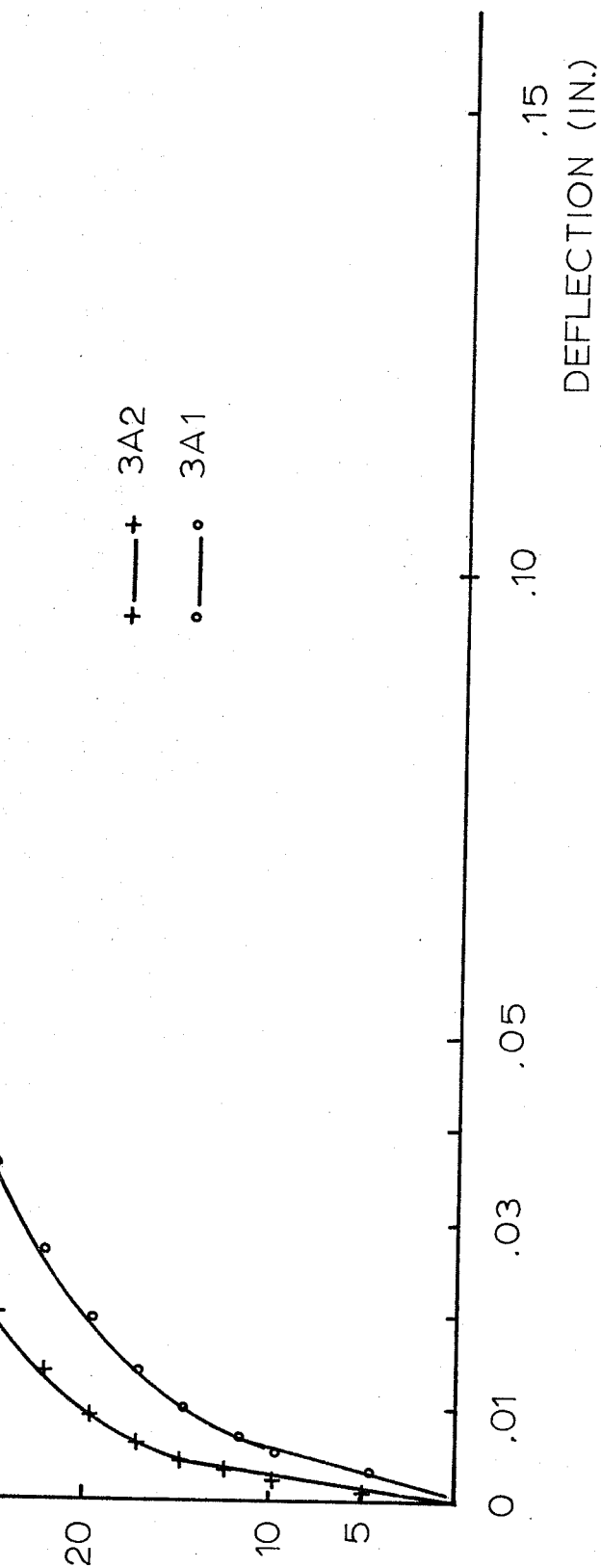


FIGURE 5.20 TENSION MEMBER TRAVEL

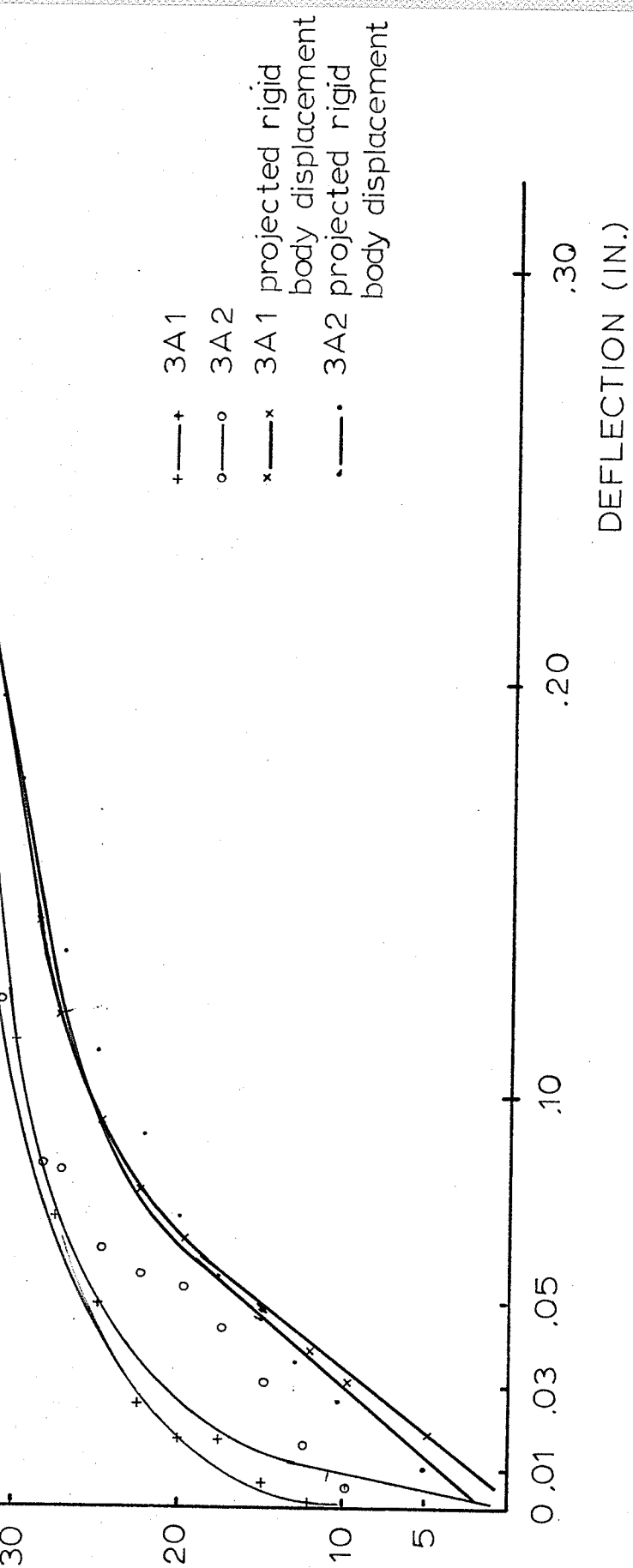


FIGURE 5.21 TRANSVERSE DISPLACEMENT OF JOINT (3A1, 3A2)

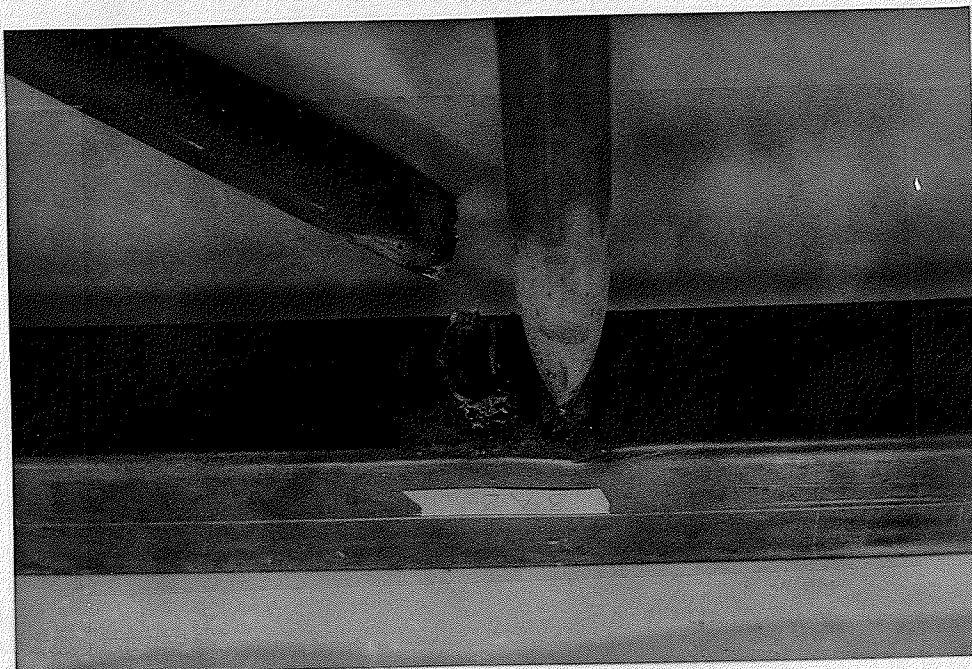


Photo 5.11 View Of Joint 3A2 After Failure

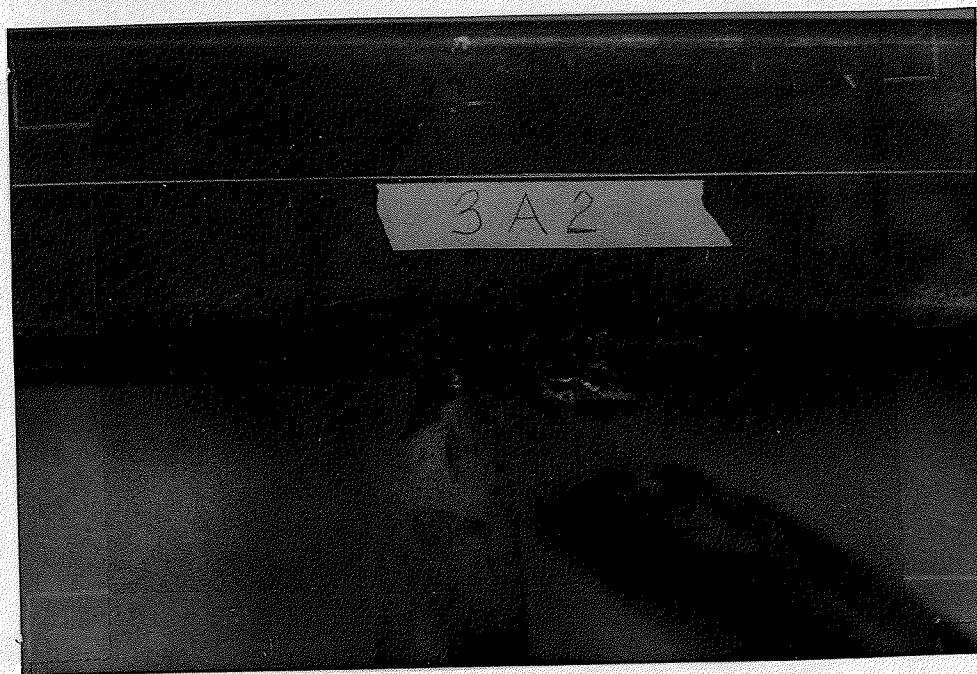


Photo 5.12 Side View Of Joint 3A2 Showing Deformation

TABLE 5.9

TEST SPECIMEN 4A1

DATE July 9, 1973

LOAD (KIPS)	TENSION MEMBER TRAVEL (IN.)		AVERAGE TENSION MEMBER TRAVEL	COMPRESSION MEMBER TRAVEL		AVERAGE MEMBER TRAVEL	PRESTRESS LOAD (KIPS)
	A	B		A	B		
0.0	.200	.200	0.000	.800	.800	0.000	17.2
5.0	.201	.206	0.003	.797	.800	0.001	16.7
0.0	.200	.201	0.000	.798	.800	0.000	17.2
5.0	.200	.206	0.002	.798	.800	0.000	16.7
10.0	.201	.208	0.001	.796	.800	0.000	16.4
12.5	.202	.210	0.002	.794	.799	0.000	16.25
15.0	.203	.211	0.003	.793	.798	0.000	16.0
17.5	.205	.212	0.003	.791	.797	0.000	15.8
20.0	.207	.212	0.003	.790	.796	0.000	15.5
22.5	.209	.214	0.004	.789	.794	0.001	15.4
25.0	.211	.215	0.005	.786	.793	0.002	15.2
27.5	.213	.217	0.007	.784	.790	0.003	15.0
30.0	.217	.218	0.009	.782	.788	0.005	14.7
31.0	.219	.218	0.009	.780	.787	0.007	14.6
32.0	.222	.219	0.010	.778	.784	0.009	14.5
33.0	.227	.219	0.013	.776	.782	0.010	14.4
34.0	.234	.218	0.015	.773	.779	0.013	14.3
35.0	.244	.216	0.019	.767	.777	0.016	14.0
35.5			COMPRESSION MEMBER BUCKLING				

TABLE 5.92

SPECIMEN 4A1

LOAD	DEFLECTION GAUGES				PROJECTED DEFLECTION GAUGE NO. 1
	TRANSVERSE DISPLACEMENT OF JOINT	NO. 3	NO. 4	NO. 5	
0.0	0.000	0.000	0.000	0.000	0.000
5.0	0.003	0.003	0.003	0.009	0.002
0.0	0.000	0.000	0.000	0.000	0.000
5.0	0.000	0.001	0.000	0.008	0.002
10.0	0.009	0.011	0.001	0.012	0.031
12.5	0.018	0.012	0.001	0.015	0.039
15.0	0.030	0.014	0.001	0.018	0.047
17.5	0.047	0.036	0.002	0.020	0.052
20.0	0.049	0.038	0.002	0.023	0.060
22.5	0.050	0.042	0.002	0.026	0.068
25.0	0.057	0.043	0.003	0.029	0.076
27.5	0.066	0.051	0.003	0.031	0.081
30.0	0.070	0.051	0.002	0.035	0.092
31.0	0.073	0.053	0.001	0.036	0.094
32.0	0.083	0.063	-0.001	0.037	0.097
33.0	0.087	0.062	-0.005	0.040	0.105
34.0	0.091	0.067	-0.012	0.042	0.110
35.0	0.106	0.080	-0.051	0.046	0.121

member buckling.

5.3.10 Specimen 4A2

Figures 5.22 through 5.25 indicate that results of specimen 4A2 are similar to those for specimen 4A1.

However, unlike specimen 4A1, failure occurred in the tension member at the joint, as shown in Photos 5.13 and 5.14. The numerical evaluation of efficiency gives a value of $39.0/46.7 = 84\%$, despite the fact that failure did occur in the tension member. This reduction in capacity of the tension member was probably due to a slightly eccentric loading that would initiate a premature yielding at some point in the tension tube.

Because of the similarities between this test and that for specimen 4A1 no further evaluation of the results for specimen 4A2 is included.

TABLE 5.10

TEST SPECIMEN 4A2

DATE July 10, 1973

LOAD (KIPS)	TENSION MEMBER TRAVEL (IN.)		AVERAGE TENSION MEMBER TRAVEL	COMPRESSION MEMBER TRAVEL		AVERAGE MEMBER TRAVEL	PRESTRESS LOAD (KIPS)
	A	B		A	B		
0.0	.200	.150	0.000	.600	.800	0.000	16.5
5.0	.201	.154	0.002	.599	.795	0.001	15.9
0.0	.200	.151	0.000	.600	.799	0.000	16.4
5.0	.200	.154	0.001	.600	.795	0.000	16.0
10.0	.202	.157	0.001	.599	.792	0.001	15.5
12.5	.204	.158	0.003	.598	.791	0.002	15.3
15.0	.206	.159	0.003	.597	.789	0.003	15.1
17.5	.208	.161	0.004	.596	.788	0.003	14.9
20.0	.209	.162	0.004	.595	.787	0.003	14.6
22.5	.211	.164	0.005	.593	.785	0.004	14.5
25.0	.213	.167	0.007	.592	.783	0.004	14.25
27.5	.214	.169	0.008	.590	.782	0.005	14.0
30.0	.217	.172	0.010	.588	.779	0.005	13.75
31.0	.218	.174	0.012	.587	.778	0.006	13.75
32.0	.219	.176	0.012	.585	.777	0.008	13.7
33.0	.220	.181	0.015	.583	.775	0.009	13.6
34.0	.221	.188	0.019	.581	.773	0.012	13.5
35.0	.226	.195	0.024	.578	.771	0.014	13.4
39.0			TENSION MEMBER FAILED AT JOINT				

TABLE 5.10

SPECIMEN 4A2

LOAD	DEFLECTION GAUGES				PROJECTED DEFLECTION GAUGE NO. 1
	TRANSVERSE DISPLACEMENT OF JOINT	NO. 3	NO. 4	NO. 5	
0.0	0.000	0.000	0.000	0.000	0.000
5.0	0.004	0.000	0.004	0.001	0.004
0.0	0.000	0.000	0.000	0.000	0.000
5.0	0.011	0.000	0.001	0.001	0.004
10.0	0.023	0.022	0.005	0.007	0.031
12.5	0.025	0.027	0.007	0.010	0.044
15.0	0.033	0.032	0.008	0.014	0.061
17.5	0.035	0.034	0.010	0.017	0.075
20.0	0.040	0.038	0.011	0.020	0.088
22.5	0.048	0.046	0.013	0.023	0.101
25.0	0.058	0.050	0.016	0.026	0.114
27.5	0.060	0.054	0.018	0.031	0.136
30.0	0.064	0.058	0.021	0.034	0.149
31.0	0.067	0.060	0.021	0.035	0.153
32.0	0.068	0.068	0.023	0.037	0.162
33.0	0.074	0.070	0.024	0.039	0.171
34.0	0.081	0.073	0.026	0.041	0.180
35.0	0.086	0.077	0.027	0.044	0.193

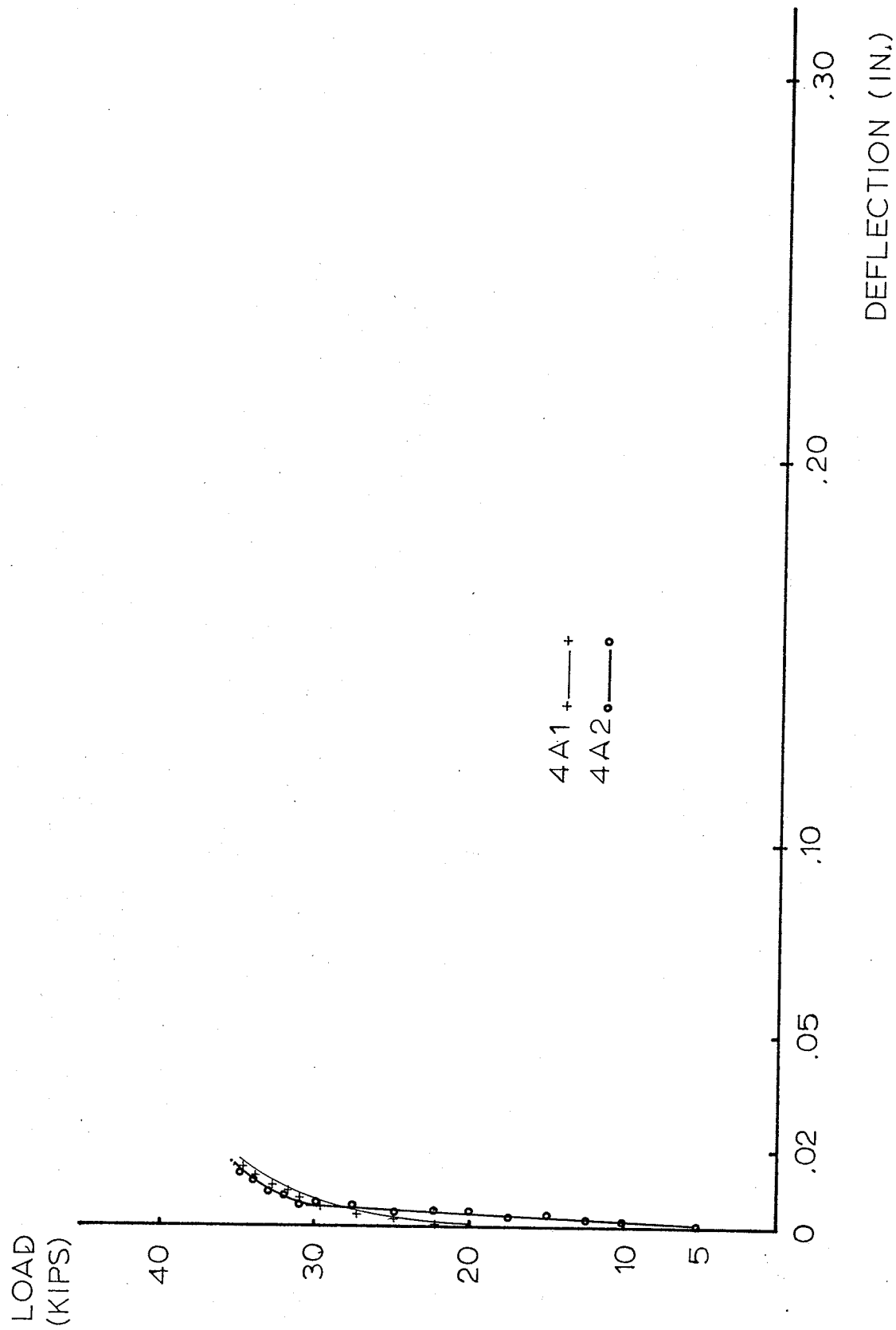


FIGURE 5. 22 COMPRESSION MEMBER TRAVEL

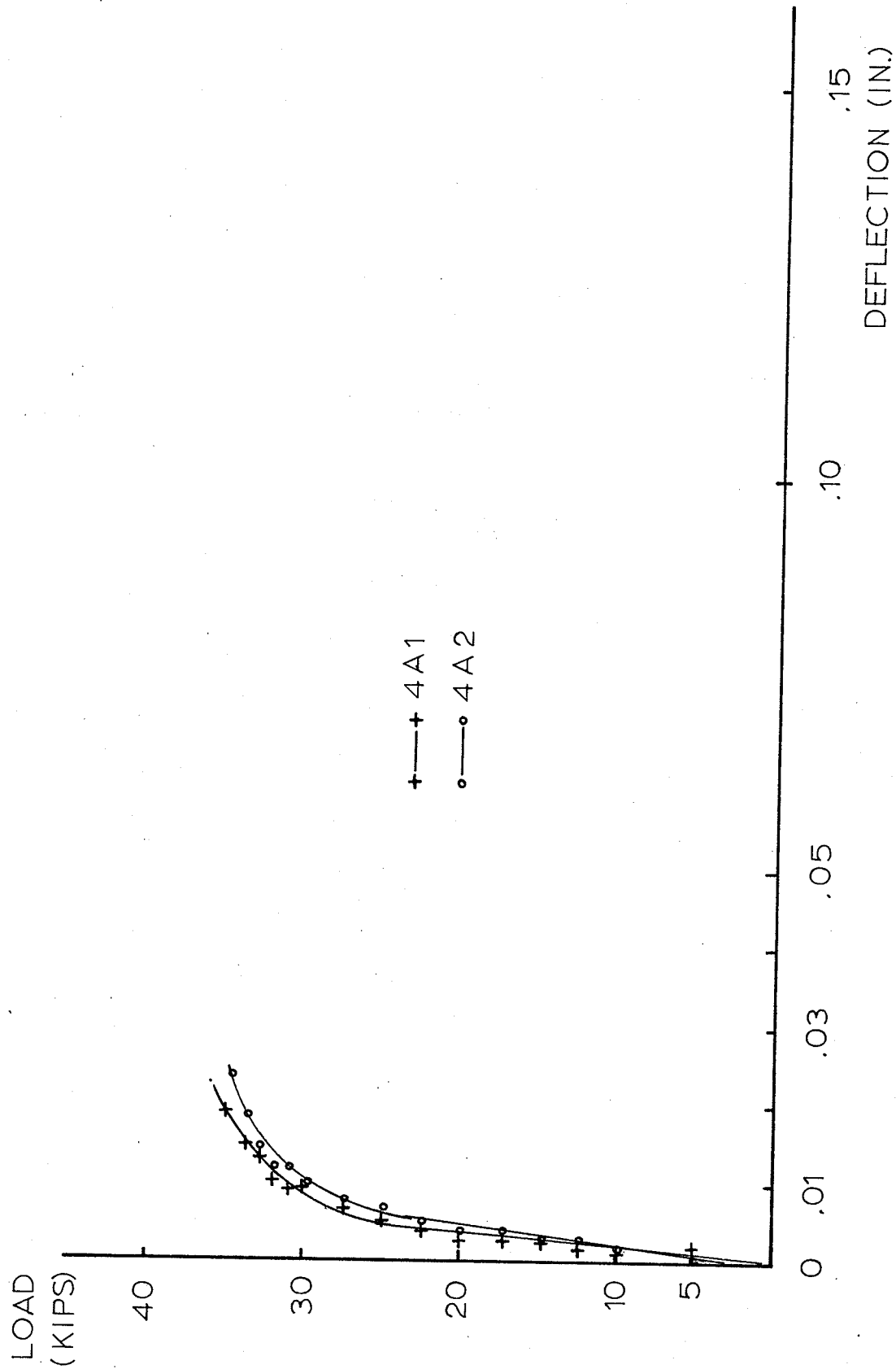


FIGURE 5.23 TENSION MEMBER TRAVEL

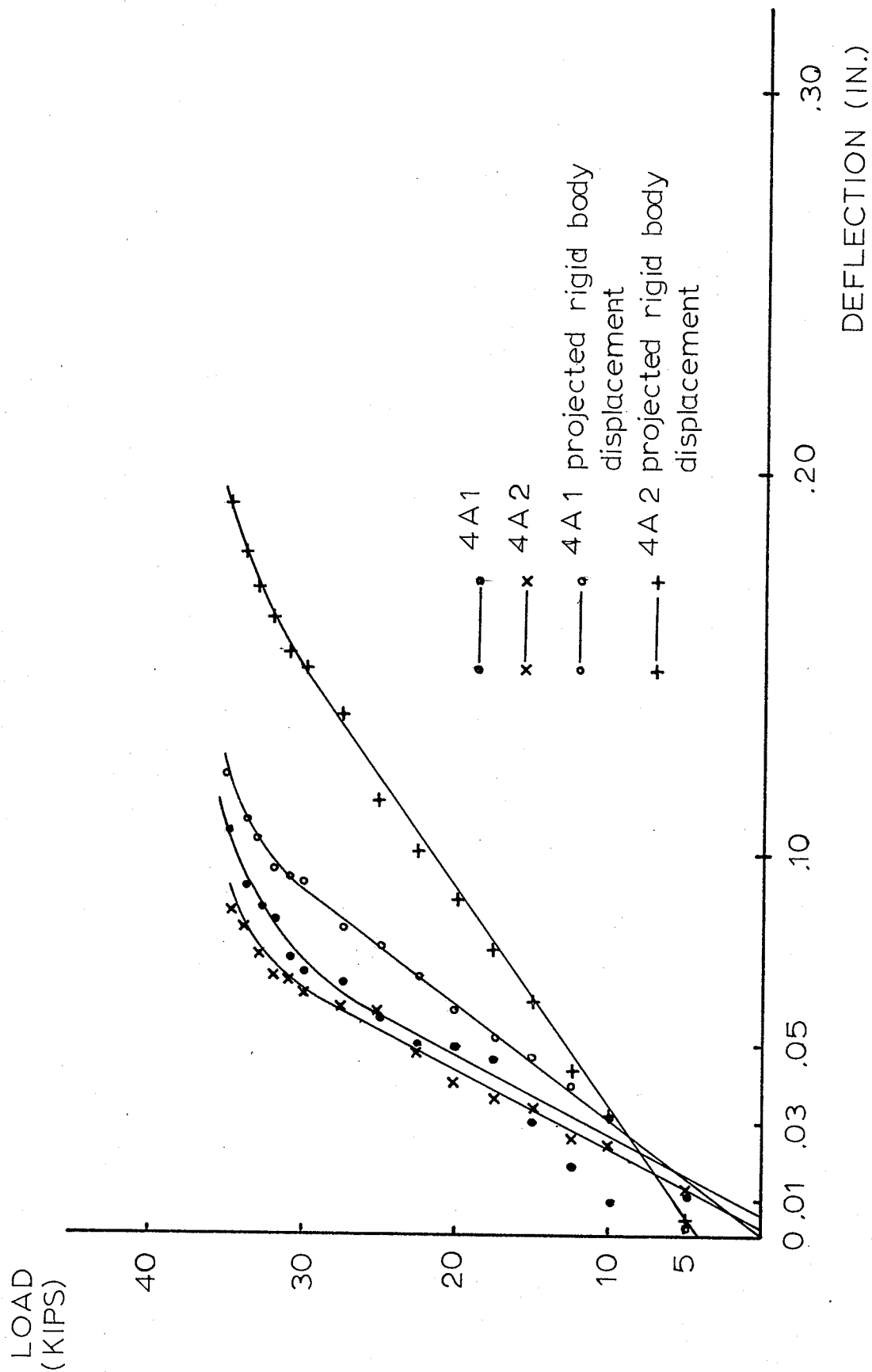


FIGURE 5.24 TRANSVERSE DISPLACEMENT OF JOINT (4A1, 4A2)

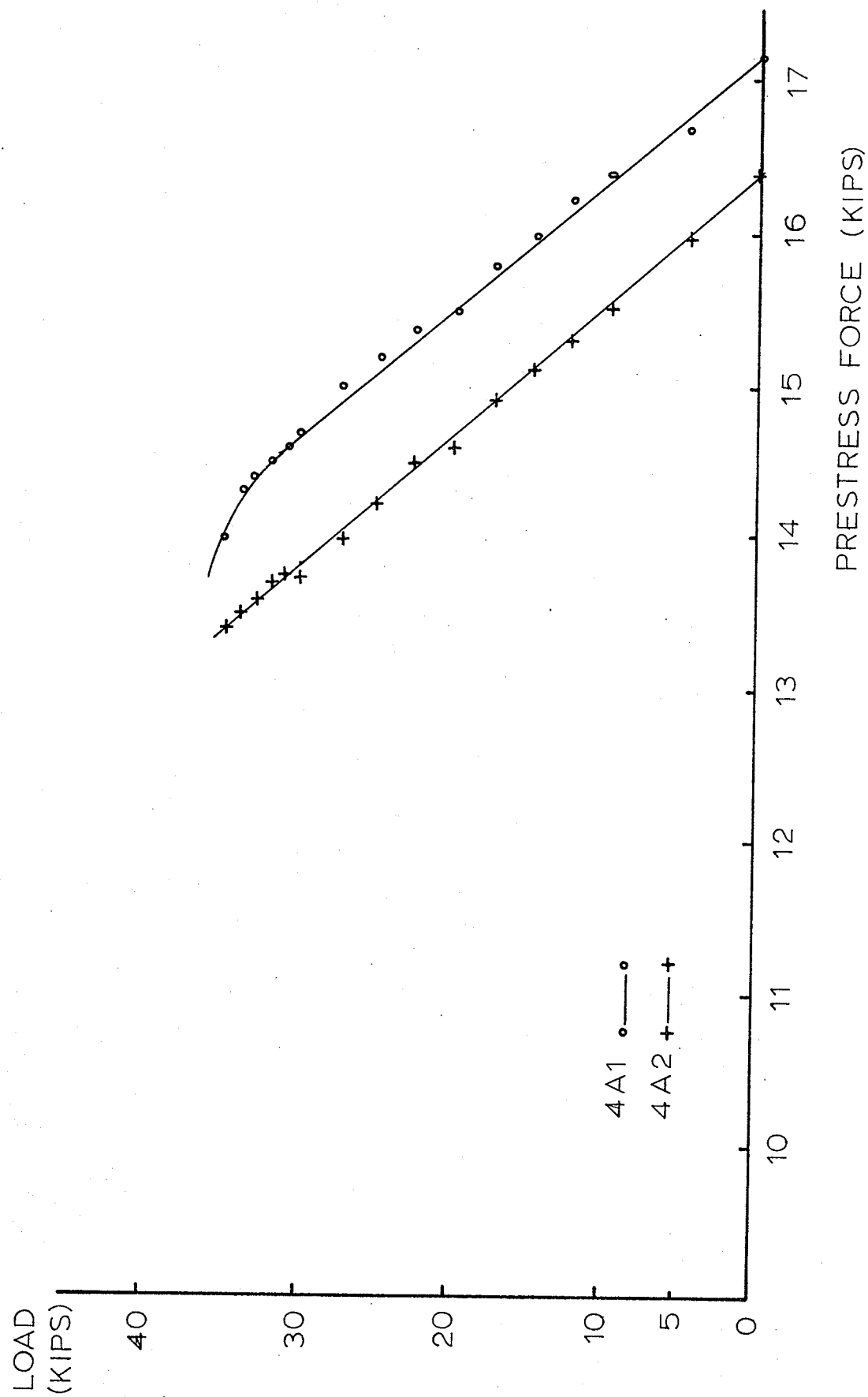


FIGURE 5.25 LOSS OF PRESTRESS



Photo 5.13 View of Specimen 4A2 After Failure

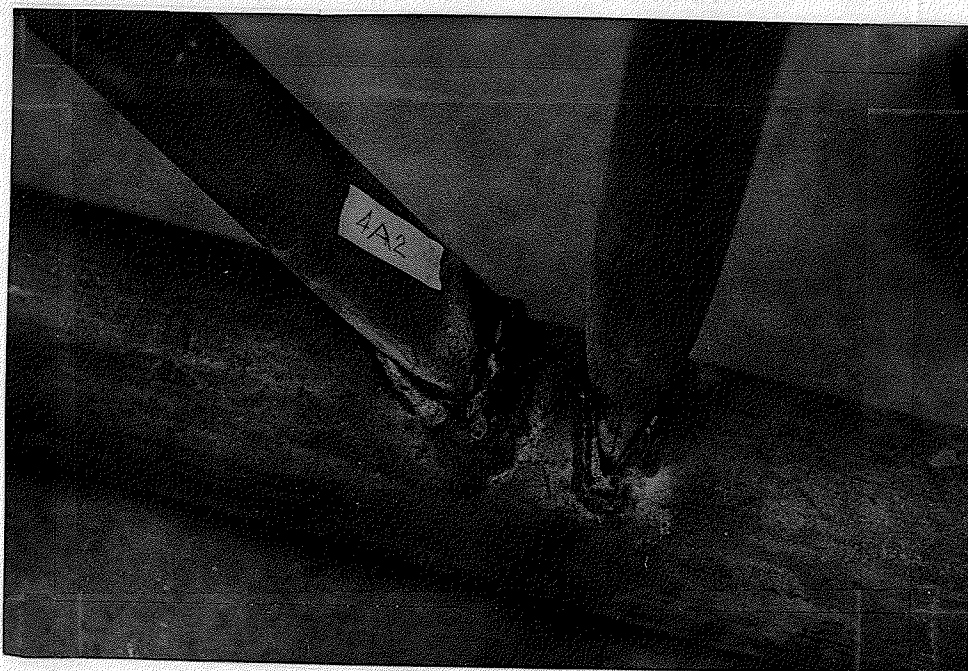


Photo 5.14 Side View of Joint 4A2 After Testing

CHAPTER 6

DISCUSSION

6.1 Discussion of Experimental Results

6.1.1 Specimen 1A1

Specimen 1A1 failed due to compression member buckling at a load of 38.0 kips, giving the joint a calculated efficiency of 81 percent.

The table of results shows the joint to be on the verge of a large deformation failure when the ultimate failure of the joint occurred. The joint seemed to be fairly rigid since plastic deformations were not apparent until the applied load had reached approximately 33 kips as shown in Figures 5.2, 5.3 and 5.4. The plot of loss of prestress force indicates the loss of chord tube precompression to be due to elastic shortening of the chord.

The strain gauges measuring member strains responded as expected to the loading situation. As the buckling failure became imminent, gauge 1 started to record a decrease in compressive stresses until buckling occurred, at which time gauge 1 read large tensile strains.

The plots of strains for the gauges at the joint indicate responses similar to those recorded for specimen 1B2.

The results of the tests are in good agreement with the qualitative evaluation of the test specimens based on the test done by White and Fang⁽³¹⁾.

In all tests where the specimen failed by buckling, the compression members buckled in the same direction. This was probably due to the local joint rotation, as shown in Figure 6.1. This rotation was probably also responsible for tension failures of the sort shown in Photo 5.14, for specimen 4A2.

These failures might also have been initiated by a slightly eccentric loading, causing moment in the web compression member as shown in Figure 6.1(b).

6.1.2 Specimen 1A2

Since the measuring system used for specimen 1A2 was not adequate, the joint can only be evaluated qualitatively.

The calculated joint efficiency was 88%. Observation of the joint after failure had occurred, showed no apparent signs of a deformation failure.

Although this specimen had a positive eccentricity of 1 1/8 inches, a gap joint, no chord member distress was evident. This was probably due to the 1/2 inch gap between the flattened tube walls of the web member which gave a more even stress distribution than would be obtained with completely flattened web tubes.

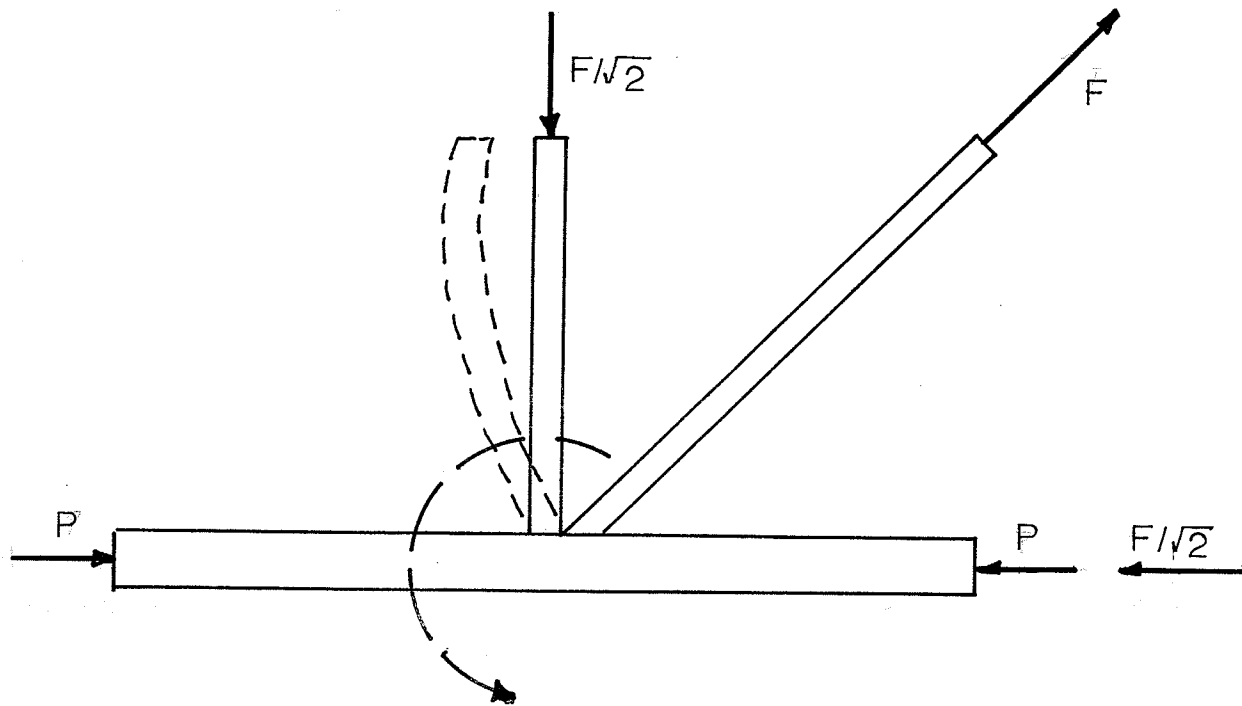
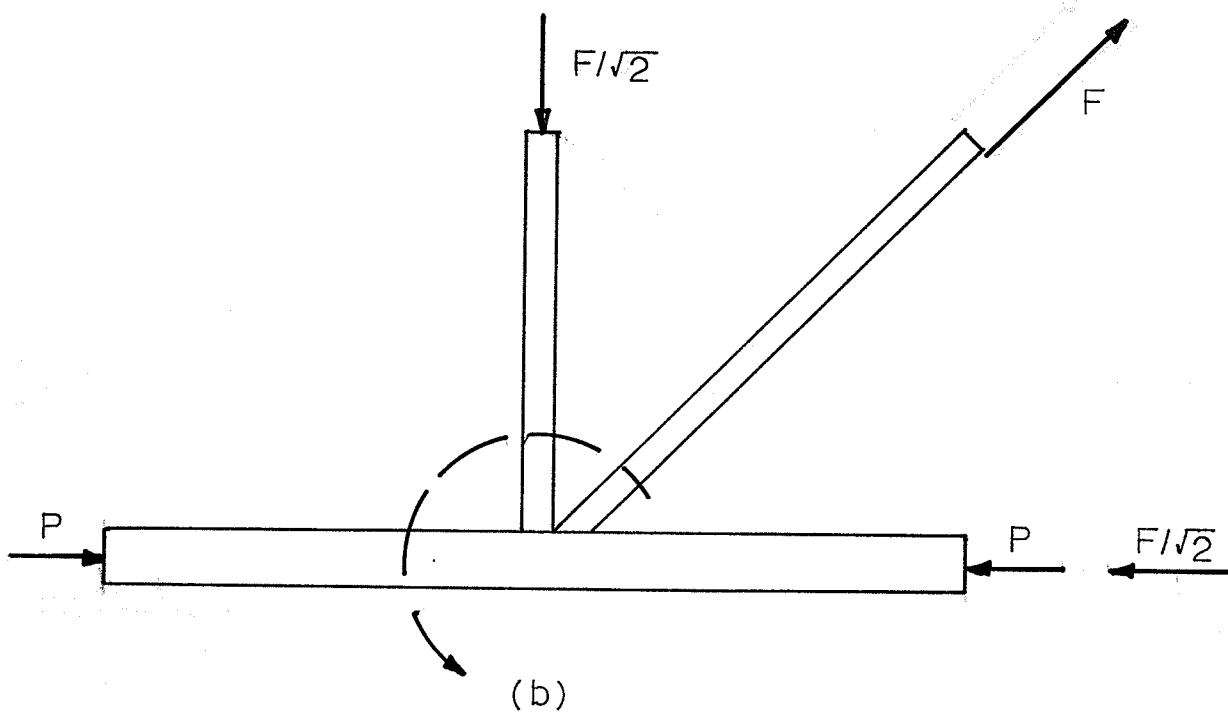


FIGURE 6.1 RELATIVE JOINT ROTATION



JOINT ROTATION DUE TO ECCENTRICALLY APPLIED LOAD

Because of the inadequate measuring system, no localized joint deformation was measurable until the applied loads were quite large.

6.1.3 Specimen 1B2

Specimen 1B2 failed at 34.5 kips due to excessive deformation of the chord tube under the web compression member. This joint's efficiency, calculated on the basis of the 0.05 inch deformation limit, was 74%. Graphs of member travel and specimen deflection show the specimen to have undergone quite substantial plastic deformations when the ultimate buckling failure occurred at 37.75 kips. The deformations approached .17 inches under the compression member and .21 inch total joint deflection.

The strain gauges applied to the specimen members indicated the strains increased fairly uniformly as the applied load was increased. Figure 5.11 shows that these strains increased linearly to an applied load of approximately 30 kips when buckling of the web compression occurred. The strain gauge on the internal chord face shows a reversal of strain from tension to compression. This is probably due to a slight misalignment of the prestressing bar causing the slight tensile strain recorded by the gauge.

The strain gauges located at the joint of the

specimen recorded the strains shown in Figures 5.11 and 5.12.

The recorded strains under the compression tube show gauges 10 and 17 to be in tension. This shows the same stress reversal phenomenon as described by Eastwood et al⁽¹⁵⁾ for joints between round web members and square chord members. Eastwood noted that this reversal of stress was most apparent for β ratios greater than 0.4, which is in the range of β considered in this series of tests. This stress distribution may be due to the mechanics of the load transfer and deformation of the joint. As load is increased in the joint, the compression member tends to rotate toward the tension member due to the larger and larger chord tube deformation. In order to resist a buckling failure, the face of the compression tube furthest from the tension diagonal must act in tension.

The strain distribution near the tension diagonal is fairly straightforward. The stresses recorded by gauges 12, 18 and 19 are tensile, indicating a bulging out of the chord tube, while gauge 13 indicates a compressive strain. This compressive strain indicates that the chord member is acting to resist the load applied to the joint by the tension member.

6.1.4 Specimen 2A1 and 2A2

Specimens 2A1 and 2A2 appear to be very rigid as

is shown in Figures 5.13, 5.14 and 5.15. This rigidity is due to the $\frac{1}{2}$ inch gap between the faces of the flattened tubes which reduced local chord tube stresses and the web member overlap that allows a direct transfer of load between the web members.

Ultimate failure occurred at 36.5 kips for specimen 2A1 and 39.5 kips for specimen 2A2. Both joints failed prematurely at the loaded end of the tension member. This failure was due to weld notches at the base of the tension member loading plate. Apparent joint efficiency was 81% based on the ultimate failure load, but the joint behaviour and deflection curves indicate it would have been much higher if the joint had not failed prematurely.

The plots of compression member travel and overall joint deflection indicate the test specimens to be on the verge of plastic deformation when the premature failure occurred. The graph of tension member travel was already into the plastic range, indicating the joint to have some ductility. Further investigations involving this joint are recommended, to evaluate the ductility of the joint so that its suitability can be more carefully reviewed.

6.1.5 Specimen 2B2

The plots of member strain for specimen 2B2 indicate the strains to increase in the members as the loading increases.

The strains increased almost linearly until buckling of the web compression member occurred, at which time the strains showed a large increase in magnitude.

The deflection readings and graphs show that the chord face deformations were very close to the value of 0.05 inches when failure occurred due to buckling of the compression tube. Extrapolation of the average compression member travel indicates that this failure could be expected to occur at approximately 40 kips, slightly below the 41.6 kip load at which compression member buckling occurred. Photo 5.7 shows the chord tube deformation. In addition to the compression tube buckling and large deformations, a crack, shown in Photo 5.8, developed in the interconnecting weld between the web members. This weld failure may indicate an inadequate weld or an eccentric loading condition which would cause a greater tensile stress at the interconnecting weld.

The specimen failed at a load of 41.6 kips giving a calculated efficiency value of 89%. The curves of member travel and overall specimen deflection show the member to be undergoing plastic deformation which was initiated at approximately 30 kips.

This joint performed very well and is a likely choice for further, more intense, study.

6.1.6 Specimens 3A1 and 3A2

These specimens behaved almost exactly alike as shown by the plots of tension and compression member travel. Initial failure occurred at approximately 27.5 kips due to excessive chord tube deformation under the web compression member. Ultimate failure occurred at 36.5 kips in both tests. Specimen 3A1 failed due to compression member buckling while specimen 3A2 failed due to tearing of the tension member at the joint. Photos 5.9 to 5.10 show the joint deformations of the two specimens and the ultimate failure mode of specimen 3A2.

This type of joint is especially flexible due to the relatively concentrated loading on the flat face of the chord member. This flexibility is reflected by the overall deflection curve in Figure 5.21 which shows that plastic behaviour of the joint started extremely early in the life of the specimen. Joint efficiency is only 59%, which is not surprising for this configuration. A better load transfer condition for this specimen would be achieved if the flattened web tube were of the same width as the chord tube. A configuration of this type would transfer more load directly into the chord side walls and thus reduce stresses on the connected face and improve the overall joint performance.

The low value of joint efficiency confirms an

earlier qualitative evaluation of the performance of the joint in that deformations of the chord face are exceedingly large. This distortion at chord loads greatly below the elastic limit of the material raises serious doubt regarding connections between flattened-end members and rectangular H.S.S. Although the joint efficiency is low, this joint type is very easy to fabricate and weld.

6.1.7 Specimen 4A1 and 4A2

The plots of compression member travel, tension member travel and overall joint deflection for these two specimens, shown in Figures 5.22 and 5.24, reveal the joint to be very rigid. However, all of the curves show plastic deformations to be incipient.

Joint 4A1 failed at 35.5 kips due to compression tube buckling, while specimen 4A2 failed at 39.0 kips due to tearing of the diagonal tension member near the joint as shown in Photos 5.13 and 5.14. Joint efficiencies were 76% for joint 4A1 and 83% for joint 4A2 although failure occurred in the web tube.

The early buckling failure associated with specimen 4A1 may have been due to misalignment of the web compression member due to welding distortion. This failure emphasizes the necessity of careful fitting up of the web members, and welding procedures in the fabrication of the test specimens.

The failure of specimen 4A2 may also have been caused by a misalignment of the web members due to welding distortion, which could have caused a slightly eccentrically applied load and higher tensile stresses at one point in the tension diagonal. It must be noted that the type 3 and 4 joints may be the most difficult to fit up due to the orientation of the web members.

6.2 Discussion of Joint Behaviour

6.2.1 Load-Deflection Criteria

Figures 6.2, 6.3 and 6.4 are plots of the load deflection curves for the web compression member and the web tension member, and the overall specimen deflection. These curves allow the different joint configurations to be evaluated with regard to relative deflections and joint ductility.

The type 3A joint consistently displayed large deformations at very low loads. These large deflections are due to the application of the web tube loads to the flexible face of the square chord member. The distortion

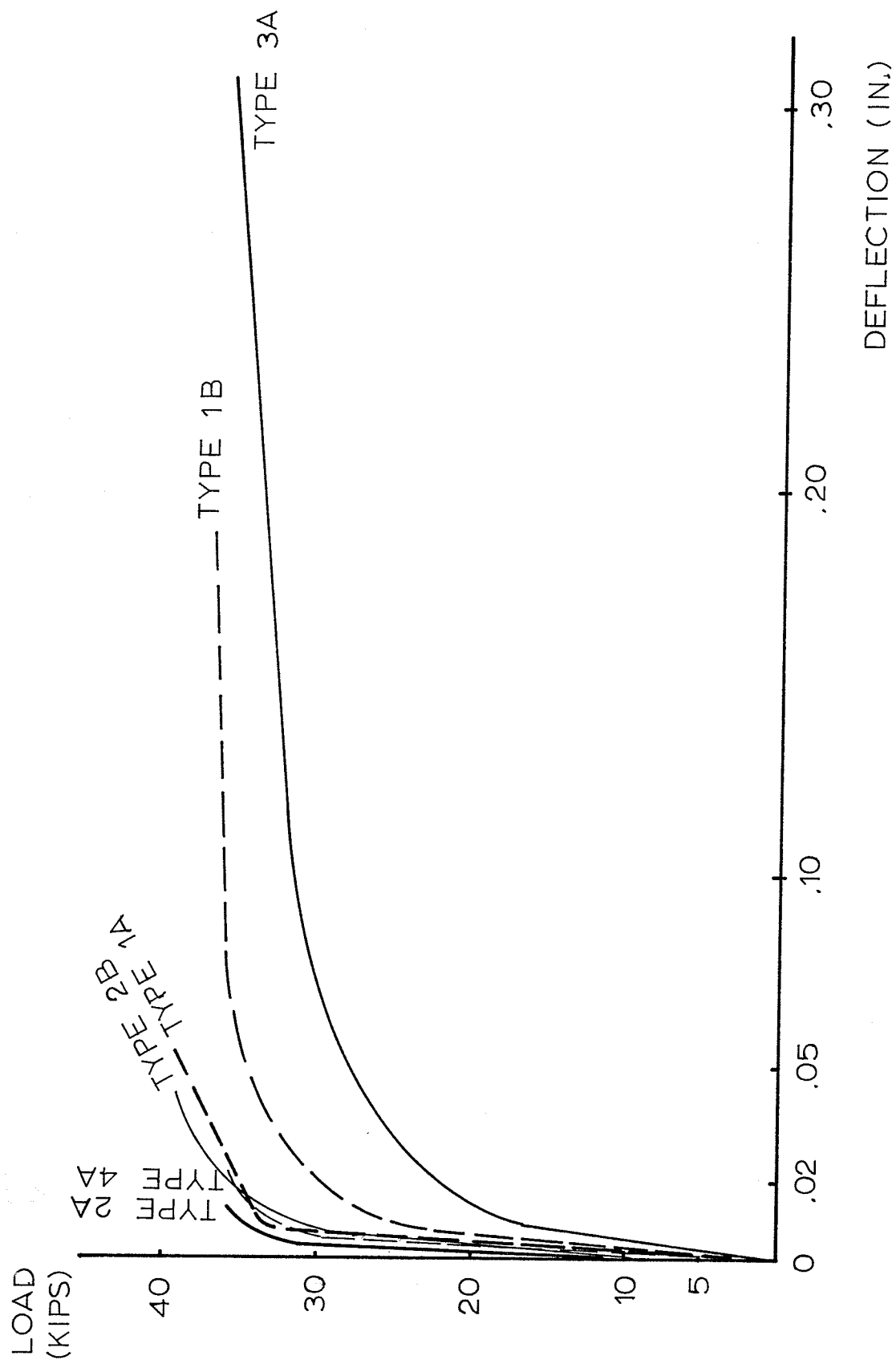


FIGURE 6.2 COMPRESSION MEMBER TRAVEL

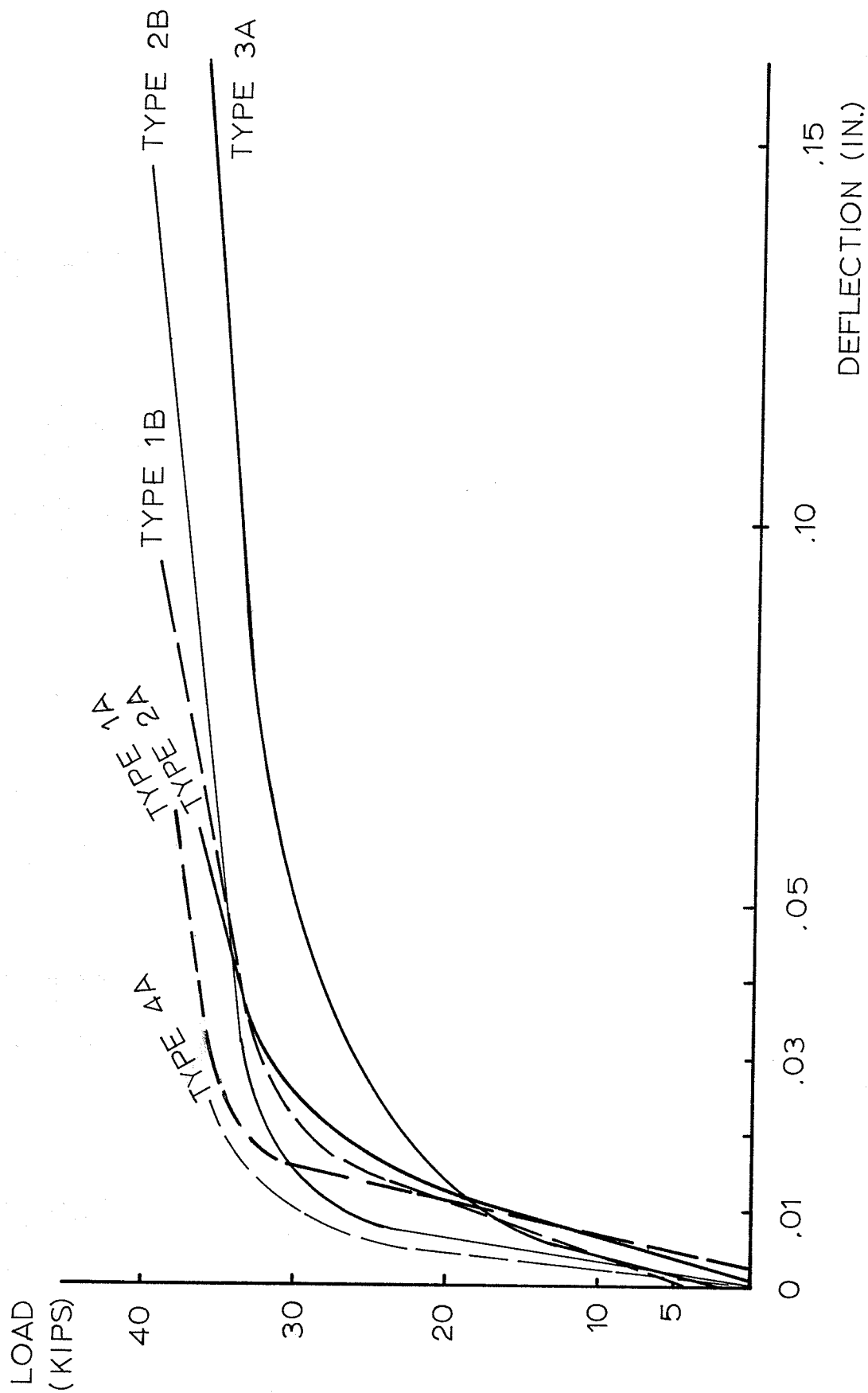


FIGURE 6.3 TENSION MEMBER TRAVEL

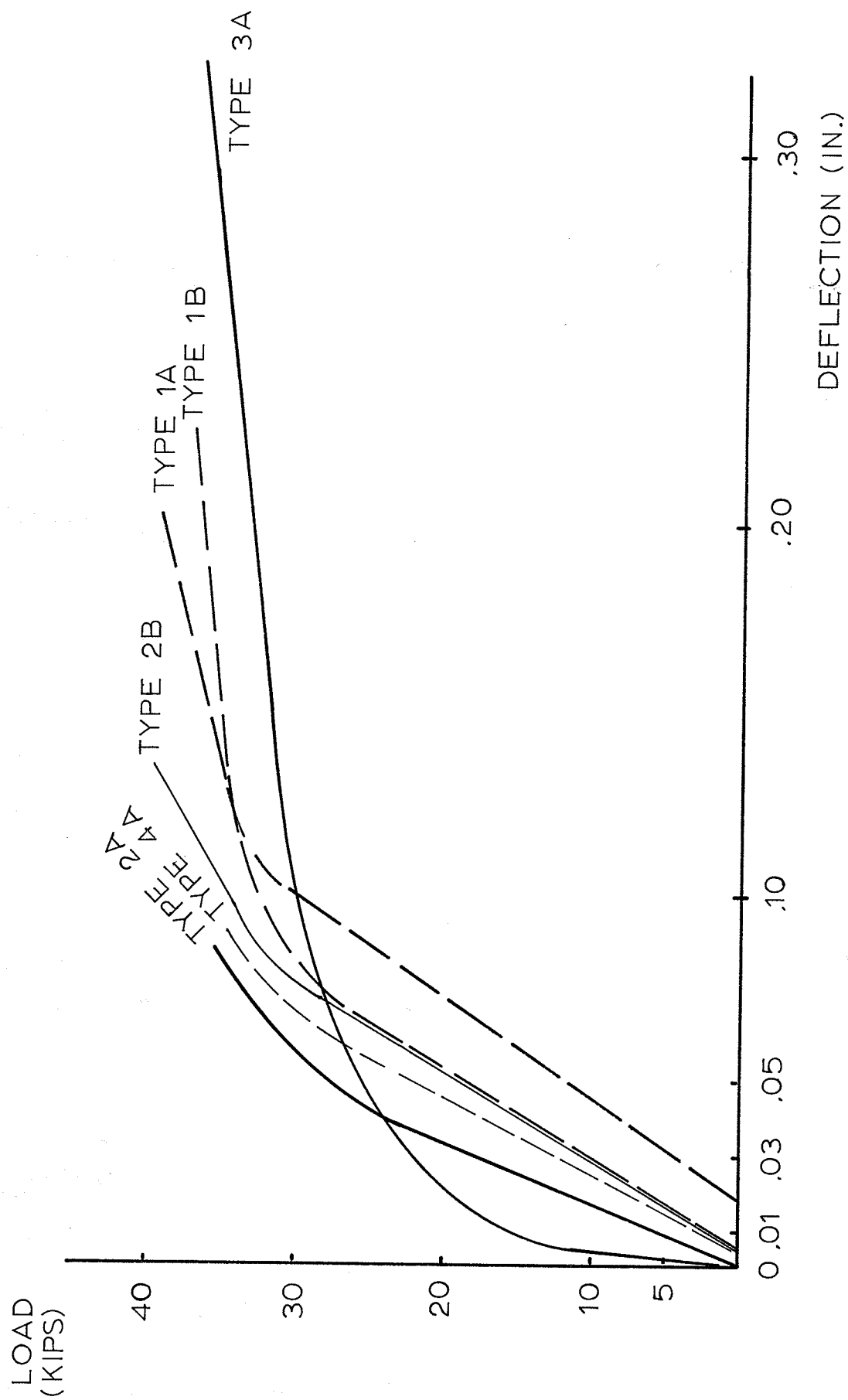


FIGURE 6.4 JOINT DISPLACEMENT PARALLEL TO
WEB COMPRESSION MEMBER

of the chord tube first became discernible at about 20 to 25 kips applied load, extremely early in the specimen life. It was felt for this specimen that the failure criterion of .05 inch deflection under the compression tube might have been too liberal. There is no doubt that the deformation observed would make a structure using this joint configuration unusable long before the ultimate collapse of the structure.

The stiffest joints appear to be the 2A and 4A types. These joints exhibited the lowest joint deformation under the compression member and the lowest overall joint deflection. The rigidity of the type 2A joint is due to the large area of chord that resists the applied loads and the vertical shear transmitted directly between the members. This joint type seems to be a very successful one since it involves straight welds in the fabrication and straight cuts in the preparation of the web members. One aspect that may limit the desirability of using this configuration is the $\frac{1}{2}$ inch gap between the flattened tube walls. This feature leads to a reduced localized stress distribution on the chord tube, but may be difficult to produce economically.

The type 4 joint owes its rigidity to the orientation of the web members which distribute the load from the web members over an arc on the surface of the chord tube, rather than along a line in the plane of the truss. This

joint type requires some profiling of the web tubes, but the preparation consists only of circular arcs in a single plane rather than the more involved profiling required for conventional round to round connections. The type 4 specimen was similar to the type 3 specimen with the exception of the chord tube. Although the joint parameters are very similar, the relative rigidities are very dissimilar. This is due mainly to the rigidity inherent in the chord tubes and the transfer of load into the side walls of the tubes.

The type 4 specimen, although it was probably the best specimen type in terms of load-deflection behaviour, would be rather expensive to fabricate because of the profiling required and the difficult welding involved.

The type 1A and 2B specimens behave similarly to the type 2A and 4A joint configurations with respect to compression member travel and overall specimen deflection. The deformations related with the type 1A and 2B joints are approximately 10 to 15% larger than the type 2A and 4A deflections, but the 1A and 2B joints display higher ultimate loads at these deformations and larger capacity for the redistribution of stresses due to the ductility of the joints. These joint types merit further investigation based on the load-deflection behaviour of the joints.

The load-deflection behaviour of the type 1B specimen is similar to that of the type 3A specimen. The ultimate loads and initial failure loads are higher and the deflections about 30% less than for the 3A configuration. The use of a gap joint in conjunction with completely flattened web tubes or sheared web tubes results in joints that do not perform adequately compared to overlapped joints using the same end preparation.

6.2.2 Ultimate Load and Efficiency Criteria

Table 6.1 compiles the Initial and Ultimate loads and failure modes and the calculated joint efficiencies. Initial failure in this context is equivalent to an excessive deformation failure.

This table reveals the type 1A and 2B specimen types to have the highest ultimate loads and joint efficiencies. At ultimate failure, both specimen types were on the verge of an excessive deformation failure. These two configurations exhibit a balanced type of failure that indicates an optimum design. In addition, both joints displayed a large amount of plastic deformation which gives early warning of impending failure.

The type 2A and 4A configurations display a lower joint efficiency than the 1A and 2B pattern although the former are much more rigid than the latter when load

TABLE 6.1

Joint Efficiency

Specimen Number	Initial Failure Load (kips)	Initial Failure Mode	Ultimate Failure Load (kips)	Ultimate Failure Mode	Joint Efficiency (percent)
1A1	38.0	Chord Face Deformation (extrapolated from Table 5.)	38.0	Compression Tube Buckling	81%
1A2			41.3	Tension Member Yielding Along With Compression Tube Buckling and Weld Distress	88%
1B2	34.5	Chord Face Deformation	37.75	Compression Tube Buckling	73%
2A1			36.5	Tension Tube Failure At Loading Plate	78%
2A2			39.5	Tension Tube Failure At Loading Plate	84%
2B2	40.0	Chord Face Deformation (extrapolated from Table 5.)	41.6	Compression Tube Buckling	89%
3A1	26.7	Chord Face Deformation	36.5	Compression Tube Buckling	57%
3A2	29.0	Chord Face Deformation	36.5	Tension Tube Failure Above Joint	62%
4A1			35.5	Compression Tube Buckling	76%
4A2			39.0	Tension Tube Failure Above Joint	83%

deflection criteria are compared. This decrease in efficiency is due to the lack of ability of the 2A and 4A specimens to deform and thus redistribute the web loads more evenly over the chord member. Although the type 2A specimens failed prematurely due to faulty loading plate welds, the specimen behaved similarly to the type 4 specimens with regard to load deflection behaviour.

The least efficient joint configurations were the type 1B and 3A series. Both these configurations failed due to excessive deformation before the ultimate mode of failure occurred, the 1B configuration 10% below the ultimate load and the 3A type 30% below the ultimate load.

6.3 Comparison of Joint Behaviour

The type 3 and 4 joints display the two extremes in joint behaviour, that is very flexible versus very rigid, and neither joint concretely indicates that further research will change this evaluation.

The series 3 joints are too flexible. Better joints between round web members and square chords can be formed by using mitred web tubes with or without an interconnection between the web members. This type of joint results in less end preparation and a better joint response, although the welding may be more intricate than for the type 3 specimens.

The type 4 specimen behaves quite well when compared to the other test specimens. The problem with this joint is in the fact that profiling of the flattened tubes is still required. This leads to an increase in joint costs, complexity and welding time. The fact that other joints were ideally suited to flattened-end preparation behave equally as well with regard to load-deflection behaviour and better with regard to efficiency and ultimate load capacity than the series 4 joints, tends to make use of this specimen type less desirable.

The series 2A connection reacted very similarly to the type 4A series with regard to load-deformation behaviour and ultimate joint capacity. Unfortunately, the joint failed prematurely, but still displayed a fairly high efficiency and very good load-deflection behaviour before failure occurred. A drawback to the use of this joint is the required gap in the flattened tube. This gap is desirable in that it reduces the localized stresses associated with the load transfer between the web and chord members, but may require more time and care in its end preparation. The type 2B specimen, however, makes use of sheared web tubes which eliminates the extra work required for the 2A specimen. This joint behaves almost as well as the 2A joint when load deflection criteria are compared and shows an increase in overall joint efficiency of nearly 10%. This increased efficiency is due to the ability of the joint to deform more

easily and redistribute the loading stresses. In view of these comparisons it seems that a joint with completely flattened and sawn or sheared web tubes behaves as well as, if not better than, a similar joint with a gap between the flattened web tube walls.

The type 1A joint behaves similarly to the type 2B joint in terms of load-deflection, efficiency and ultimate load criteria. This joint makes use of the same web tube preparation as the 2A specimen, but incorporates a positive joint eccentricity into the joint. This results in a 3/8 inch gap between the web members and forces all the load transfer to take place in the chord tube. Although the joint involves less intricate welding, the web tube preparation detracts slightly from the desirability of using this type of joint configuration.

Finally, the type 1B joint behaved similarly to the type 3 series specimen in that it failed due to excessive deformation. This joint had the same eccentricity and gap between the web members as the type 1A joint, but the sheared tube preparation resulted in higher stresses at the chord tube face during load transfer. The joint exhibited large deformations early in its life giving the joint an efficiency value of 75 percent. These considerations tend to make this joint undesirable when joints with a gap between web members are used.

6.4 Stress Distribution Around The Joint

Observations of the load deflection curves for joint types 2A and 2B indicates that the increased chord face stresses for the type 2B joint do not alter the response to loading or efficiency of the joint appreciably. This behaviour arises from the fact that a substantial part of the load transfer occurs directly between the web members.

These observations are in agreement with the findings of Anderson⁽¹⁾ who found for joints with a web tube overlap, that the increased stresses associated with a completely flattened tube do not seem to decrease the joint capacity.

This, however, is not the case for joints that have a gap between the web members. Strain gauges applied near the joints of the type 1A and 1B specimens reveal the stresses at the base of the tension member to be higher for the type 1B joint than for the 1A configurations. This difference is due to the totally flattened tubes used in the 1B joint. The stress distribution under the compression tubes is about the same for both joints. From the load-deflection response and the efficiency values calculated for the 1A and 1B joints, it was found that the type 1B joint tended to deform plastically much earlier in the specimen life than the 1A

joint and the efficiency was approximately 11 percent less for the 1A specimen.

This consideration tends to make the use of overlapping web members in joints more desirable than the use of gap joints. Consequently, if only overlapping joints are considered, totally flattened or sheared tubes can be used with confidence.

6.5 Ease of Fabrication

When considering ease of fabrication in the preparation of the flattened-end connections used, welding of the specimen is an important factor. The welding was found to be extremely quick and easy for the type 1 and 2 specimens. This was because of the fit of the members and the clear view presented to the welder. The type 3 and 4 joints were more difficult to weld because of the orientation of the web tubes and the amount of filling required to produce a good weld.

The preparation of the web tubes was most easily accomplished by shearing. If proper care is taken to ensure accurate end preparation, no problems should occur with respect to fit, orientation of the sheared planes at the ends of the tube and welding. While flattening and sawing takes slightly longer than shearing, the results are the

same. Although, flattening and sawing may be more precise in aligning the flattened planes of the tube, the performance of the joint is not altered.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The load deformation behaviour has been experimentally examined for connections involving flattened-end hollow structural sections for a Pratt type truss. Four different joint geometries involving both circular and rectangular chord tubes have been investigated in this program; the first phase of a more extensive study to recommend design criteria for this connection type.

7.1 Conclusions

From considerations of load-deflection behaviour and joint efficiency, four joint configurations appear to be worthy of further investigation. These joints were types 1A, 2A, 2B and 4A, all of which involved circular web and chord sections.

The type 4A specimen, which involved web tubes flattened in the direction perpendicular to the chord, exhibited a very stiff load-deflection behaviour due to the orientation of the flattened web tubes. This caused the specimen to fail just after plastic deformations started to occur. It was felt that this lack of ductility was undesirable for flattened-end connections. This consideration along with considerations of end preparation

and welding caused this specimen to be judged less advantageous for general use than some of the other joint configurations tested.

The type 1A and 2A specimens which had a $\frac{1}{2}$ inch gap between the flattened web tube walls and an eccentricity of $+D/4$ for the type 1A and zero eccentricity for the type 2A joint behaved very well with regard to structural response, joint efficiency and ultimate joint capacity. A slight problem arose because of the $\frac{1}{2}$ inch gap between the flattened walls of the web tube. This feature required extra time to be spent in end preparation and reduced the ductile capacity of the type 2A joint. The type 1A joint had a small gap between the web tubes, which allowed good ductile joint behaviour. However, considerations of fabrication and comparison of the type 1A joint with the type 2B joint, tend to favour use of the 2B configuration rather than the type 1A or 2A specimens.

The type 2B specimen involved completely flattened web tubes and an overlap between the web members. The web tube ends for this specimen were prepared by shearing, although flattening and then sawing are a suitable alternative to this operation. This joint type revealed the highest joint efficiency value of any of the specimens considered in this preliminary program. In terms of end

preparation, welding, structural adequacy, and chord deformations, the joint compares favourably in all aspects with the other joints tested.

From considerations of strain distribution around the joints in tests 1A1 and 1B2, and the performance of the type 2A and 2B specimens it can be concluded that joints with overlapping web members behave better than comparable joints with a gap between these members especially when the web tubes are completely flattened. Observation of the member strains did not clearly indicate a variation of stress around the web tubes. However, observations of the failure of specimens 4A2 and 3A2 indicate an increased tensile stress at the toe of the diagonal web member. This was apparent since the tension failures for these specimens were initiated at the toe of the member, as shown in Photo 5.14.

The method of end preparation for completely flattened tubes does not appear to alter the joint response to loading. The use of a gap between the flattened faces of the web tubes does, however, result in a stiffer joint for which deflection is substantially reduced.

The possibility of local buckling of the web tubes near the joint does not appear to be a problem since the weld used in the tests conducted was large enough to provide

even bearing on the chord tube.

The ductility of the various specimens ranged from very ductile as exhibited by the type 3 joint which deformed plastically at very low applied loads to very stiff as was exhibited by the type 4 specimen. Generally, these two extremes are not suitable for use. The types 1 and 2 specimens had ductilities ranging from very flexible for type 1B, which responded similarly to the type 3 specimen, to fairly rigid as displayed by the type 2A specimen. From observations of the 2B and 1A specimens, it has been found that ultimate failure coincided with a large deflection failure. These joints indicate a fairly ductile behaviour that is quite desirable with the view of structural performance in mind.

From the above considerations, it can be concluded that completely flattened-end preparation is both economically and structurally feasible when an overlap of web tubes is incorporated into the joint. For connections that do not have this interconnection of web members, however, complete flattening of the web tubes leads to an early large deformation failure.

7.2 Recommendations

In order to establish design rules for flattened-

end connections for joints between round web members and round chord sections, more detailed research must be conducted over a wide range of joint parameters.

It is recommended on the basis of this investigation that joint type 2B be investigated further varying such parameters as T/D , d/D and eccentricity since it is well suited to this type of joint based on efficiency, load-deformation, ease of fabrication, ultimate load and ductility criteria. By substituting flattening and sawing for shearing in the preparation of the web tubes, the fabrication and testing of these joints can be done entirely at the University of Manitoba with a substantial saving in time without any adverse joint reaction.

It is recommended that the following suggestions be implemented in future phases of this study so that information pertinent to design criteria may be gained.

A larger range of T/D and d/D ratios should be investigated. This can be accomplished by using chord tubes up to $6 \frac{5}{8}$ inches in diameter and web tubes from 2 to $4 \frac{1}{2}$ inches in diameter.

Joint eccentricity should be varied from some minimum web tube overlap say $\frac{3}{4}$ of an inch, to a fully overlapped condition of the web tubes so that the effect of web member interaction on the performance of the joint

can be evaluated.

More research on the effect of flattening the ends of tubes must be done in order to evaluate the effects of end flattening on slenderness ratios (Kl/r) of compression members. This program would involve tests on flattened end columns similar to those tested by Muzyk⁽³⁸⁾ so that elastic buckling curves could be plotted. These tests would involve a range of Kl/r ratios for the columns which would include both stub columns and slender columns.

It may also be useful to determine the loads that can be safely applied to the face of the chord tube by a flattened-end member by conducting tests on T-sections similar to those done by Toprac et al⁽³⁾. Toprac tested tee connections for profiled tube joints in order to evaluate the maximum load that could be applied to a hollow member.

Finally, in order to gain insight into fatigue strengths, it may be advantageous to measure strains at the joint so that a comparison of stresses between conventionally profiled joints and flattened-end joints can be obtained.

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TABLE A-1
CALIBRATION OF PRESTRESS BAR

LOAD (k)	STRAIN (MICRO IN/IN) $\times 10^4$	AVERAGE STRAIN	LOAD (k)	STRAIN (MICRO IN/IN) $\times 10^4$	AVERAGE STRAIN
0.0	2	2	6.0	217	217
	2				
	2				
	2				
	2				
	2				
1.0	40	40	7.0	251	252
	42				
	38				
	39				
	45				
	40				
2.0	76	77	8.0	285	289
	80				
	77				
	76				
	79				
	77				
3.0	115	113	9.0	319	323
	116				
	113				
	113				
	115				
	110				
4.0	150	150	10.0	355	357
	151				
	148				
	147				
	150				
	145				
5.0	183	183	11.0	388	390
	186				
	182				
	183				
	184				
	180				
			12.0	442	426
		426			
		426			
		428			
				420	

TABLE A-1 continued

LOAD (k)	STRAIN (MICRO IN/IN) $\times 10^4$	AVERAGE STRAIN	LOAD (k)	STRAIN (MICRO IN/IN) $\times 10^4$	AVERAGE STRAIN
13.0	456 460 460 461	460	21.0	735 735 732 732	733
14.0	495 496 492 494	494	22.0	770 771 765 767	767
15.0	526 528 528 529	528	23.0	804 805 800 802	802
16.0	564 564 560 562	562	24.0	838 838 834 836	837
17.0	594 598 598 598	597	25.0	872 874 868 871	871
18.0	628 630 632 633	631	26.0	906 908 903 904	905
19.0	662 665 667 668	666	27.0	940 942 937 939	939
20.0	702 702 697 698	700	28.0	975 976 973 974	974

TABLE A-1 continued

LOAD (k)	STRAIN (MICRO IN/IN) $\times 10^4$	AVERAGE STRAIN	LOAD (k)	STRAIN (MICRO IN/IN) $\times 10^4$	AVERAGE STRAIN
29.0	1009 1011 1007 1008	1009	37.0	1285 1286 1283 1284	1284
30.0	1044 1047 1040 1044	1044	38.0	1317 1319 1317 1319	1318
31.0	1078 1080 1075 1078	1078	39.0	1355 1356 1352 1355	1353
32.0	1112 1116 1113 1110	1113	40.0	1386 1389 1389 1391	1389
33.0	1143 1147 1147 1150	1147	41.0	1424 1425 1420 1424	1423
34.0	1182 1185 1178 1182	1182	42.0	1458 1455 1456 1458	1456
35.0	1216 1217 1213 1215	1215	43.0	1493 1494 1490 1492	1492
36.0	1250 1249 1253 1252	1250	44.0	1528 1528 1527 1525	1527

TABLE A-1 continued

LOAD (k)	STRAIN (MICRO IN/IN) $\times 10^4$	AVERAGE STRAIN	LOAD (k)	STRAIN (MICRO IN/IN) $\times 10^4$	AVERAGE STRAIN
45.0	1563 1565 1559 1562	1563	53.0	1838 1838 1842 1843	1840
46.0	1596 1594 1598 1599	1596	54.0	1872 1877 1876 1873	1874
47.0	1633 1635 1629 1630	1632	55.0	1907 1908 1910	1908
48.0	1668 1667 1665 1666	1666	56.0	1941 1946 1945	1944
49.0	1698 1700 1703 1703	1701	57.0	1977 1982 1982	1980
50.0	1734 1734 1738 1734	1735	58.0	2016 2016 2012	2015
51.0	1765 1768 1772 1766	1767	59.0	2048 2051 2051	2050
52.0	1804 1803 1806 1806	1805	60.0	2082 2085 2086	2084

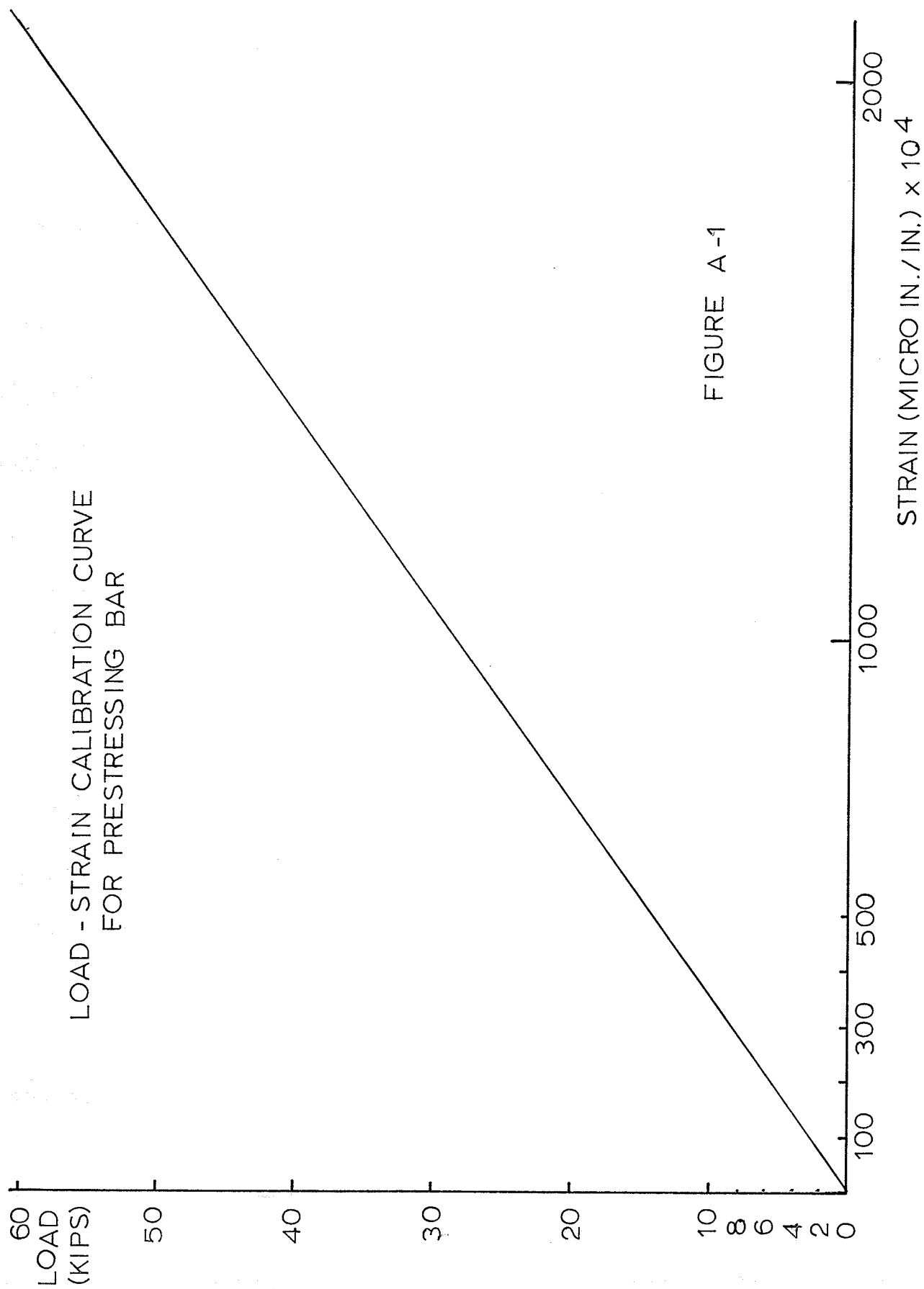


FIGURE A-1

TABLE A-2

CALIBRATION OF PRESSURE GAUGES

LOAD	2000 psi GAUGE	10000 psi GAUGE	LOAD	2000 psi GAUGE	10000 psi GAUGE
1	62.5	---	29	1470	1340
2	100	---	30	1510	1370
3	155	---	31	1550	1400
4	200	---	32	1610	1450
5	250	---	33	1635	1500
6	300	---	34	1700	1550
7	355	---	35	1745	1580
8	405	---	36	1790	1630
9	450	---	37	1840	1700
10	495	---	38	1880	1750
11	530	---	39	1940	1790
12	570	400	40	1970	1800
13	620	450	42.5		1950
14	670	500	45		2075
15	730	550	47.5		2180
16	770	600	50		2350
17	800	650	52.5		2450
18	855	700	55		2580
19	925	750	57.5		2700
20	980	850	60		2750
21	1030	900	62.5		2850
22	1090	970	65		2950
23	1150	1030	67.5		3075
24	1220	1100	70		3200
25	1270	1140	72.5		3300
26	1310	1190	75		3425
27	1355	1220	77.5		3525
28	1395	1260	80		3650

TABLE A-3

MEASURED CHORD TUBE DIMENSIONS

SPECIMEN NUMBER	MEASURED CHORD TUBE DIAMETER	AVERAGE CHORD TUBE DIAMETER	MEASURED CHORD TUBE THICKNESS	AVERAGE CHORD TUBE THICKNESS
1A1	4.518		0.196	
	4.542		0.188	
	4.540		0.189	
	4.535		0.197	
			0.200	
			0.188	
			0.193	
		4.534	0.193	0.193
2B2	4.541		0.205	
	4.539		0.200	
	4.542		0.196	
	4.544		0.198	
			0.198	
			0.196	
			0.195	
		4.543	0.195	0.198
1A2	4.543		0.205	
	4.539		0.200	
	4.542		0.196	
	4.544		0.198	
			0.198	
			0.196	
			0.195	
		4.542	0.195	0.196
4A2	4.521		0.193	
	4.534		0.189	
	4.528		0.191	
	4.537		0.189	
			0.200	
			0.189	
			0.198	
		4.530	0.191	0.192

Table A-3 continued

SPECIMEN NUMBER	MEASURED CHORD TUBE DIAMETER	AVERAGE CHORD TUBE DIAMETER	MEASURED CHORD TUBE THICKNESS	AVERAGE CHORD TUBE THICKNESS
4A1	4.551		0.200	
	4.543		0.192	
	4.534		0.191	
	4.539		0.198	
			0.199	
			0.197	
			0.197	
		4.542	0.200	0.197
1B1	4.530		0.195	
	4.530		0.196	
	4.528		0.195	
	4.531		0.195	
			0.195	
			0.187	
			0.193	
		4.530	0.195	0.198
2A1	4.540		0.197	
	4.537		0.197	
	4.541		0.189	
	4.536		0.200	
			0.197	
			0.198	
			0.191	
		4.539	0.199	0.196
2A2	4.543		0.188	
	4.530		0.187	
	4.530		0.199	
	4.532		0.191	
			0.193	
			0.196	
			0.189	
		4.534	0.199	0.193

TABLE A-4

Tension Test on Hot Rolled H.S.S. Web Tube Material

Test #1

LOAD (lb)	STRESS (psi)	STRAIN (in/in)
0		
250	5,730	0.0113
500	11,460	0.0156
750	17,190	0.0185
1000	22,950	0.0211
1250	28,650	0.0234
1500	34,400	0.0258
1750	40,250	0.0280
2000	45,900	0.0303
2250	51,600	0.0335
2500	57,400	0.0388
2750	63,150	0.0484
3000	68,800	0.0587
3250	74,500	0.0793
3460	79,500	0.1685

Area = 0.0436 in²
Specimen Length = 4.688 in.

TABLE A-5

Tension Test on Hot Rolled H.S.S. Web Tube Material

Test #2

LOAD (lb)	STRESS (psi)	STRAIN (in/in)
100	2,280	0.0000
200	4,575	0.0029
300	6,850	0.0051
400	9,140	0.0065
500	11,420	0.0080
600	13,710	0.0091
700	15,970	0.0102
800	18,270	0.0112
900	20,550	0.0120
1000	22,800	0.0128
1100	25,100	0.0138
1200	27,400	0.0146
1300	29,650	0.0154
1400	31,950	0.0159
1500	34,250	0.0168
1600	36,500	0.0177
1700	38,800	0.0185
1800	41,100	0.0194
1900	43,400	0.0204
2000	45,750	0.0215
2100	47,900	0.0226
2200	50,200	0.0238
2300	52,500	0.0261
2400	54,750	0.0288
2500	57,100	0.0326
2600	59,300	0.0366
2700	61,600	0.0422
2800	64,000	0.0480
2900	66,300	0.0528
3000	68,500	0.0613
3100	70,750	0.0728
3200	73,000	0.0840
3290	75,100	0.1622

Area = 0.0438 in²
Specimen Length = 4.753 in