THE UNIVERSITY OF MANITOBA

STATICAL BEHAVIOUR OF CROPPED-WEB JOINTS FOR TRUSSES WITH ROUND TUBULAR MEMBERS.

by

J. B. CIWKO

A Thesis
PRESENTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
DEPARTMENT OF CIVIL ENGINEERING

WINNIPEG, MANITOBA
CANADA

OCTOBER 1980

STATICAL BEHAVIOUR OF CROPPED-WEB JOINTS FOR TRUSSES WITH ROUND TUBULAR MEMBERS

BY

JOSEPH BARRY MICHAEL CIWKO

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

The static behaviour of 61 isolated cropped-web tubular truss joints is described. The effects of various parameters on joint strength, flexibility and ductility are investigated and reported. A statistical approach is used to generate empirical equations for the estimation of the joint strength and the joint flexibility. The ultimate strengths of statically loaded cropped-web joints are comparable to those of similar profiled-web joints. Cropped-web joints with round chords are less flexible than similar cropped-web joints involving square chords. Recommendations for design and further research are provided.

ACKNOWLEDGEMENT

The guidance and patience of Dr. G. A. Morris for the duration of this study are gratefully acknowledged.

The author would like to thank Mr. J. Clark, Mr. E. Lemke, Mr. M. McVey, Mr. W. Wiles, Mr. D. Wiebe, and Mr. L. Wilkins for their invaluable time and assistance in the testing phase of this study.

Financial assistance was provided by the University of Manitoba and the Steel Company of Canada, Limited. Material for all test specimens was provided by the Steel Company of Canada, Limited.

Finally, the author would like to thank his parents and friends for their help and encouragement.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

Figure Page

LIST OF SYMBOLS

b_o	Outside width of rectangular chord.
d_o, d_1, d_2	Outside diameters of the chord, compression web and tension web, respectively.
d	Diameter of compression web or tension web when equal in size.
e	Joint eccentricity.
E	Modulus of elasticity (200,000 MPa or 30,000 ksi)
f_c	Compression joint flexibility.
f_t	Tension joint flexibility.
g	Joint gap.
h_o	Outside depth of rectangular chord.
J_r	Factored joint resistance.
J_u	Ultimate joint load.
K	Effective length factor.
kips	1 kip = 1000 lbs.
kN	Kilo-newton.
L_o, L_1, L_2	Lengths of the chord, compression web and tension web, respectively.
m	Meter
mm	Millimeter.
N	Newton.
N_o, N_1, N_2	Axial loads in the chord, compression web and tension web, respectively.
N_{1b}	Buckling strength of the compression web.
N_{oe}, N_{1e}, N_{2e}	Axial yield loads of the chord, compression web and tension web, respectively.

N_{ou}, N_{1u}, N_{2u}	Axial ultimate loads of the chord, compression web and tension web, respectively.
O_v	Web overlap.
p	Length of the cropped edge of the tension web.
Pa	Pascal.
q	Overlap length of the compression web.
r	Radius of gyration of the compression web.
R_m	Mean resistance from tests.
R_n	Nominal resistance as expressed by the design criteria.
t_o, t_1, t_2	Wall thicknesses of the chord, compression web and tension web, respectively.
t	Wall thickness of the compression web or tension web when equal in size.
V_F	Coefficient of variation of the test/predicted results, the fabrication, or the manufacturing.
V_m	Coefficient of variation of the material yield strength.
V_p	Coefficient of variation of the professional assumptions.
α	Statistical significance level.
β	Safety index.
γ	Numerical factor equal to 0.55.
δ_1, δ_2	Chord deformation along the axes of the compression and tension webs, respectively.
Δ_j	Mid-span truss deflection due to joint deformation.
Δ_m	Mid-span truss deflection due to member deformation.
λ	Statistical confidence level.
ν_1	Number of independent variables used in a given run of the regression program.

ν_1	Degrees of freedom in a given run of the regression program.
σ_{oe}, σ_{1e}, σ_{2e}	Yield stresses of the chord, compression web and tension web, respectively.
σ_{ou}, σ_{1u}, σ_{2u}	Ultimate stresses of the chord, compression web and tension web, respectively.
ϕ	Capacity reduction factor.

CHAPTER I

INTRODUCTION

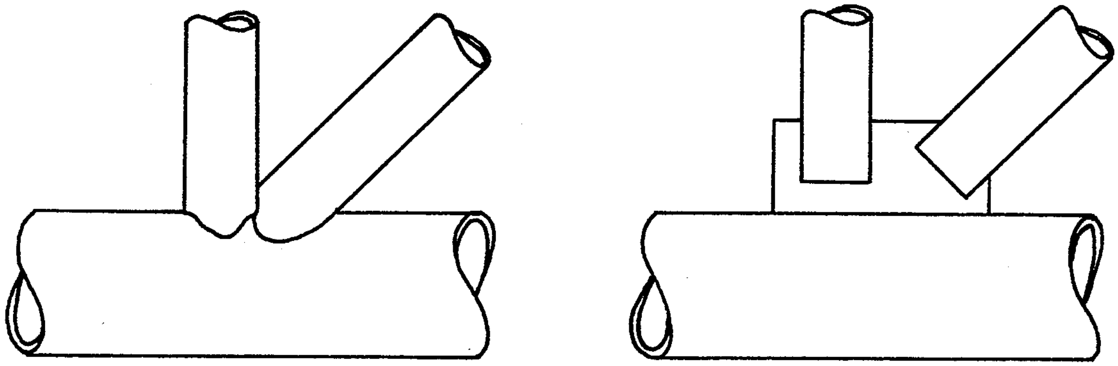
1.1) General

During the past 20 years, interest has increased in the use of hollow structural sections (HSS) in truss construction.

Hollow structural sections possess several strong advantages compared to conventional sections. They have high resistance to buckling and twisting. This generally results in weight savings in the order of 20 per cent. They expose less surface area than do conventional sections of similar weight and size. Thus they reduce the maintenance or protective covering required. The strength of a HSS member can be increased without changing its external dimensions, by filling it with grout or by selecting a section with a greater wall thickness. HSS members offer relatively small resistance to wind or wave action and, as well, they produce asthetically pleasing structures.

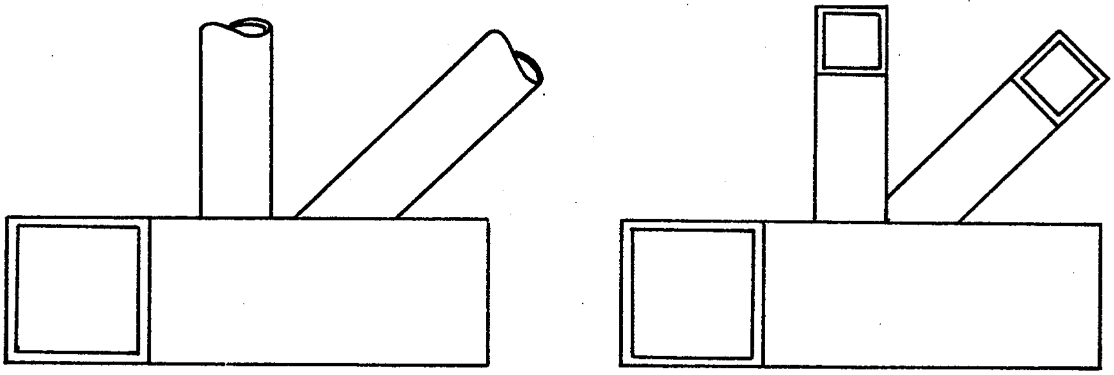
Although HSS are excellent in many respects, their primary drawback in trusses relates to the joints or connections. Figure 1.1 illustrates several forms of tubular truss joints. Complex profiling and difficulties in welding or bolting may be encountered at the joint, particularly when circular hollow sections (CHS) are involved. Improved welding techniques along with the advent of automatic profiling machines have reduced these problems to some extent, but still the fabrication costs of such joints remain high.

The use of gusset plates as an alternative to profiling has been



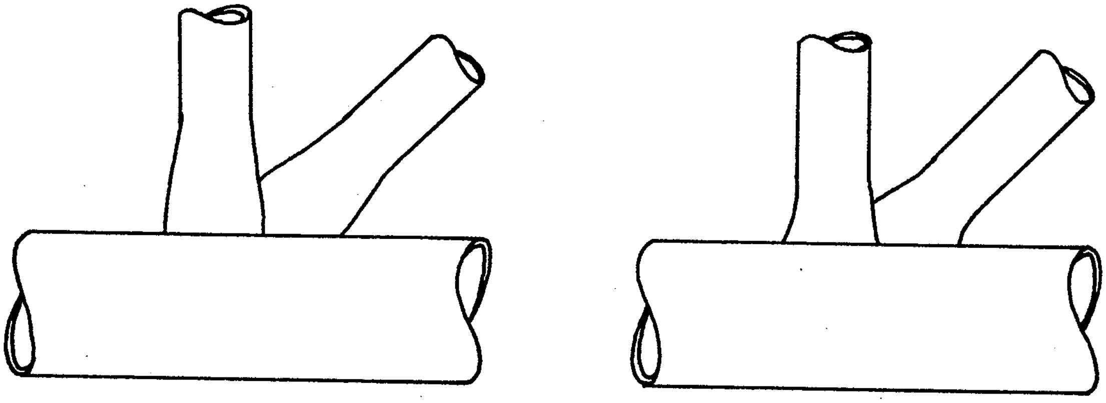
a) Profiled-web joint

b) Joint with gusset plate



c) Sawn-web gap joint

d) Sawn-web lap joint



e) Flattened-web joint

f) Cropped-web joint

Fig. 1.1 - Tubular truss joints.

investigated by several researchers. However, gusset plates have been found to be somewhat less effective than direct connections between members.

An economical alternative to member profiling is the process of end-flattening. It results in simplified welds and does not require additional material. Generally, this technique requires two steps for member preparation; namely, cutting and end-flattening. However, a more efficient form of end-flattening is end-cropping, a process of simultaneously cutting and flattening the member in one operation. Flattened member ends are particularly economical for joints between round tubular webs and round tubular chords, where profiling is otherwise unavoidable.

Because the behaviour of trusses with end-cropped webs has not been researched extensively, the use of such joints has been very limited. However, the available research indicates this type of member end preparation to be a safe, economical alternative to profiling, providing the loading is static.

1.2) Tubular Truss Joint Research

To date, research on tubular truss joints has covered several common truss geometries involving various web-chord combinations of circular, square, and rectangular hollow structural sections. Both isolated joint specimens and full scale trusses have been investigated and reasonably consistent results have been obtained. Furthermore, various techniques of web member end preparation have been investigated. Although the bulk of the research has been experimentally based, several attempts at theoretical investigations have been partially successful in duplicating the experimental results.

1.2.1) Joint Performance

To evaluate the behaviour of a joint, a measure of performance must be established. The most frequently used measure of joint performance is the ultimate strength, although joint stiffness and ductility have also been used. The latter, however, have generally eluded a common definition and they are more difficult to quantify.

For ease of comparison, researchers usually have expressed the ultimate strengths of tubular truss joints in non-dimensional form. The most common forms are joint efficiency and joint load factor. Joint efficiency has been defined as: the ratio of the failure load for the joint to (a) the ultimate strength of the tension web (Bouwkamp 1968), or (b) the yield strength of the first member to yield (Jamm et al. 1952, and Eastwood et al. 1970). Joint load factor has been defined as the ratio of the failure load for the joint to the design load of the compression or tension web (Eastwood et al. 1970).

Other parameters which have been used to express joint strength include the following:

a) $J_u/t_o\sigma_{oe}$, (Eastwood et al 1970), although it is not dimensionless.

b) $J_u/t_o^2\sigma_{oe}$, (Kurobane et al 1969, Togo 1969)

c) $J_u/t_o^{0.5}b_o^{1.5}\sigma_{oe}$, (Wardenier 1977)

d) $J_u/t_ob_o\sigma_{oe}$, (Thiensiripipat 1979).

In these expressions, J_u is the ultimate load perpendicular to the chord, t_o is the chord thickness, $d_o(b_o)$ is the chord diameter (width), and σ_{oe} is the chord yield strength. These forms have been more successful than joint efficiency or joint load factor in relating strength to the joint geometry and material characteristics.

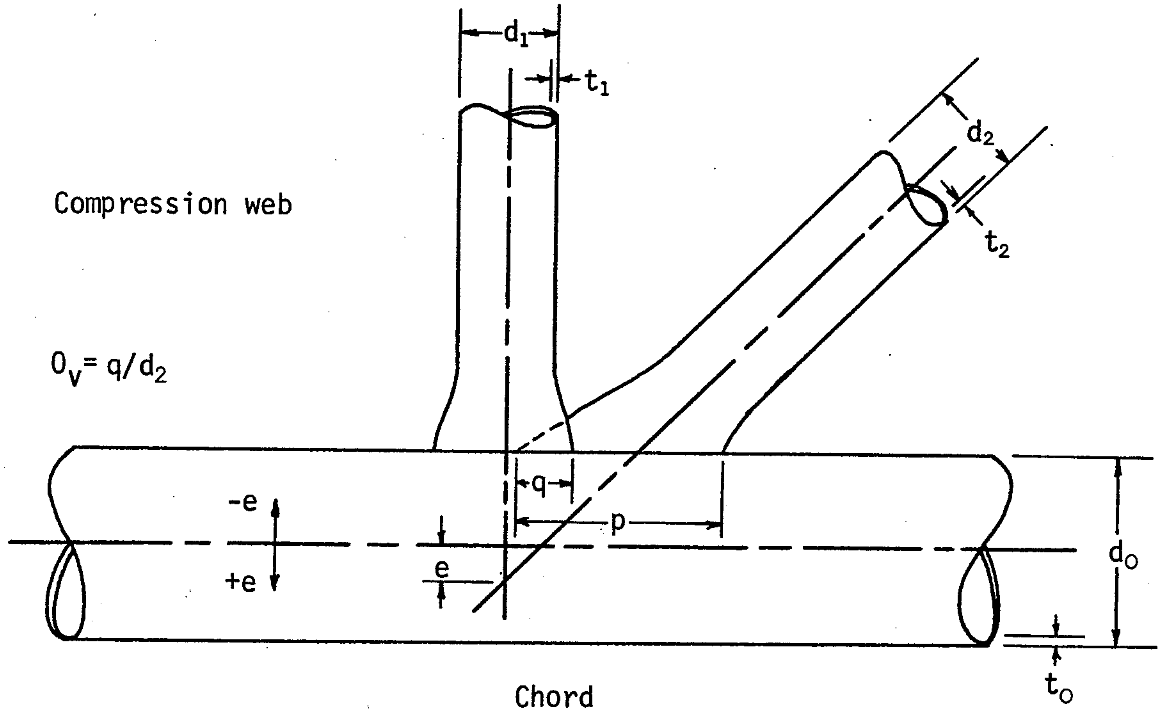
The stiffness of a tubular truss joint has been defined as the slope of the approximately straight-line portion of the load-deformation diagram. Because the joint behaves non-linearly in many cases, the joint stiffness tends to be sensitive to the load level at which it is calculated. This tends to make it an unsatisfactory measure of performance. The joint stiffness has been used to estimate the approximate additional truss deflection due to joint deformation (Thiensiripipat 1979).

Joint ductility is a measure of the load-carrying capacity of a joint after initial yielding has occurred. It has been found that the favourable stress redistribution characteristics of tubular truss joints make them quite ductile (Anderson 1961 and Eastwood et al. 1970).

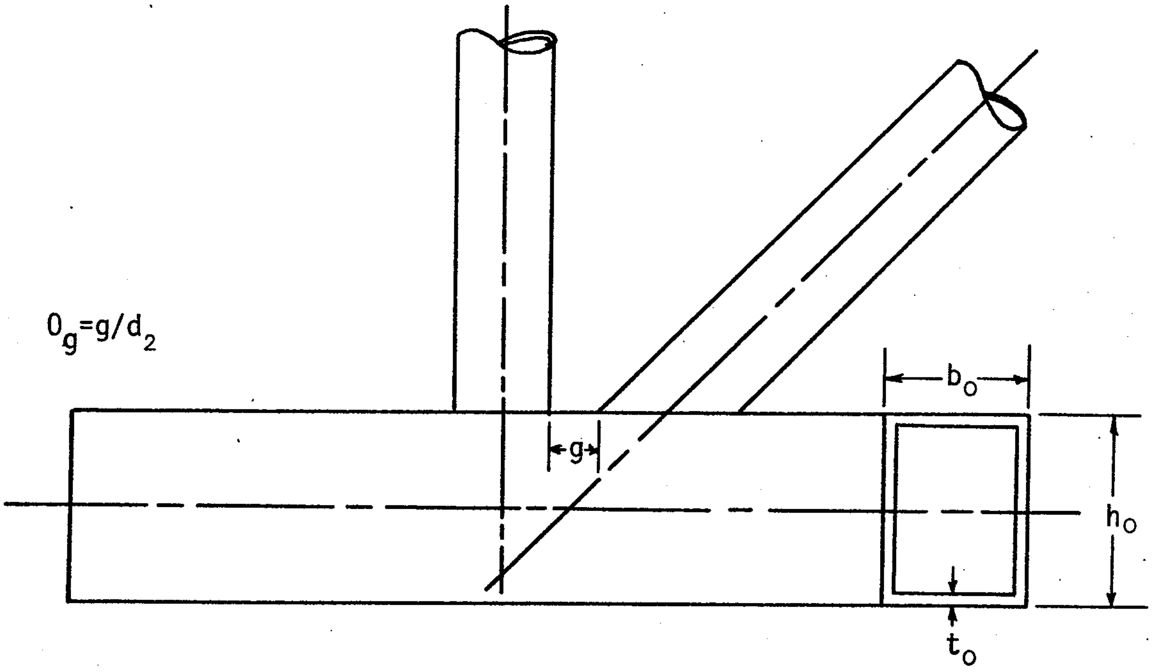
1.2.2) Parameters Affecting Performance

The three most significant of the several parameters which have been found to influence the performance of a tubular truss joint are the chord thickness to diameter (width) ratio, t_o/d_o or t_o/b_o, the web diameter (width) to chord diameter (width), d/d_o or d/b_o, and the web lap, $O_v=q/d_2$, or gap, $O_g=g/d_2$. The aforementioned parameters are illustrated in Figure 1.2.

Research has shown that joint strength and stiffness increase with an increase in the chord thickness to diameter (width) ratio, particularly for gap joints. This is because of the increased bending and



a) Overlap joint with circular chord.



b) Gap joint with rectangular chord.

Fig. 1.2 - Joint properties.

load transfer capacity of the chord wall. There is also a decrease in joint ductility, since failure tends to occur in the members before yielding of the chord is achieved. The resulting load-deformation curves indicate a brittle type of failure.

An increase in the web diameter (width) to chord diameter (width) ratio has been found to improve the load distribution on the chord face and to reduce the rotational deformation of the joint. This results in an increase in strength and stiffness and a reduction in ductility. The reason is that, when the web to chord diameter (width) is large, more load is transferred to the side walls of the chord and thus the plastic deformation of the joint is reduced.

A web lap has been found to be more advantageous than a web gap. The former permits a direct transfer of web forces through the web interconnection. This results in increased joint strength and stiffness. A decrease in web gap or an increase in web lap usually produces an increase in strength and stiffness and a decrease in joint ductility. Gap joints have been found to be more ductile than lap joints.

Several investigators have used joint eccentricity, defined as the perpendicular distance the intersection of the web axis lies from the chord axis (see Figure 1.2a), as a joint parameter. This, however, gives an indication of the moment in the chord at and due to the joint, rather than a measure of the web interconnection. The latter influences the joint strength, stiffness, and ductility more significantly than eccentricity. Eastwood et al. (1970) indicated that the chord moments due to joint eccentricity could be accounted for using conventional design techniques. In addition, Jamm et al. (1952) stated that joint eccentricity would not be a problem provided the web axes intersected within the middle half of the chord diameter.

1.2.3) Failure Modes

The failure of a tubular truss joint usually has been assumed to coincide with the point of maximum load carrying capacity. Eastwood et al. (1970), however, arbitrarily defined it as corresponding to a rate of deformation in the loading ram of 0.45 inches per minute without any increase in load. The two definitions produce comparable ultimate loads, since deflection usually becomes excessive immediately before the maximum load is reached.

Various failure modes have been reported; however, the general mechanism of failure is as follows. The chord face undergoes deformation as a result of the web loading. This in turn subjects the webs to end moments which usually induce compression web buckling or tension web tearing in the heat affected zone near the web member interconnection.

Other failure modes which have been observed include tension web fracture, shearing through the web interconnection, chord wall tearing, and buckling of the chord member.

1.3) Objectives and Limitations

The objective of this study was to measure experimentally the static load-deformation behaviour of Pratt-type truss joints involving round chords and round cropped webs.

This study was limited to an experimental investigation of 61 isolated Pratt type joints. No analytical study was attempted. The tension and compression webs for any given joint specimen were of the same size. The maximum sizes of the members in the specimens were limited by the capacity of the loading assembly (889 kN, 200 kips). The influence of three geometric parameters; the chord thickness to diameter ratio (t_o/d_o), the web diameter to chord diameter ratio (d_1/d_o) and the web lap (O_V), on the load-deformation behaviour of the joints was investigated. All other parameters were kept as nearly constant as possible.

There was no preload applied to the chord. Previous investigators (Bouwkamp 1968, Mee 1969, Eastwood et al 1969) have indicated that chord preload did not significantly affect the ultimate loads of the joints. However, recent tests of end-cropped joints which have been incorporated into trusses (Ghosh 1979) suggest that large axial stresses in the chord do influence joint behaviour.

CHAPTER 2

TEST PROGRAM

In this chapter, the selection of geometry and joint parameters for the test specimens are discussed. In addition, the fabrication techniques, the specimen measurements, the test apparatus and the test procedure are described.

2.1) Specimen Design

A Pratt-type joint, shown in Figure 2.1, was chosen for the specimen geometry. It is widely employed and, more important, it produces the most severe case of loading on the chord face. Thus, design criteria developed for the Pratt joint may be conservatively applied to other joint geometries. Furthermore, several investigators in the past have used Pratt-type joints, thus facilitating comparison of results.

The specimen web and chord members were chosen to provide five different values for each of the parameters, t_o/d_o and d_1/d_o. In addition, three values of web lap were chosen for various combinations of t_o/d_o and d_1/d_o.

The joints were designed as isolated specimens modelling a Pratt-type truss, 1.83 m (6 feet) in depth, with the tension diagonals oriented at 45 degrees (see Figure 2.1). It was assumed that a statically loaded truss would deform with inflection points at the mid-lengths of the members, as indicated in Figure 2.2, if out of plane buckling were prevented. Thus, a typical specimen, shown in Figure 2.3,

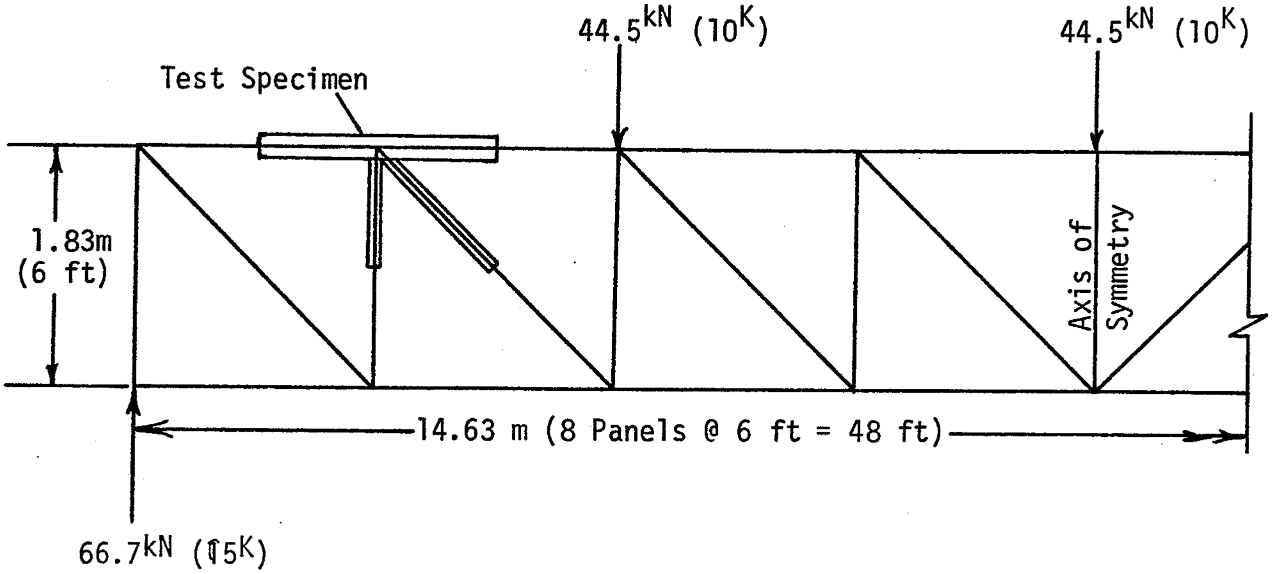


Fig. 2.1 - Pratt truss and test specimen.

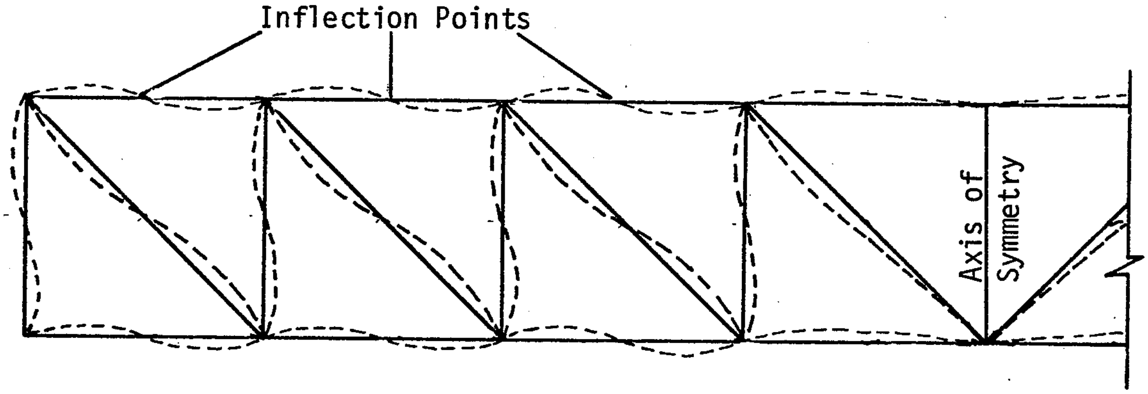
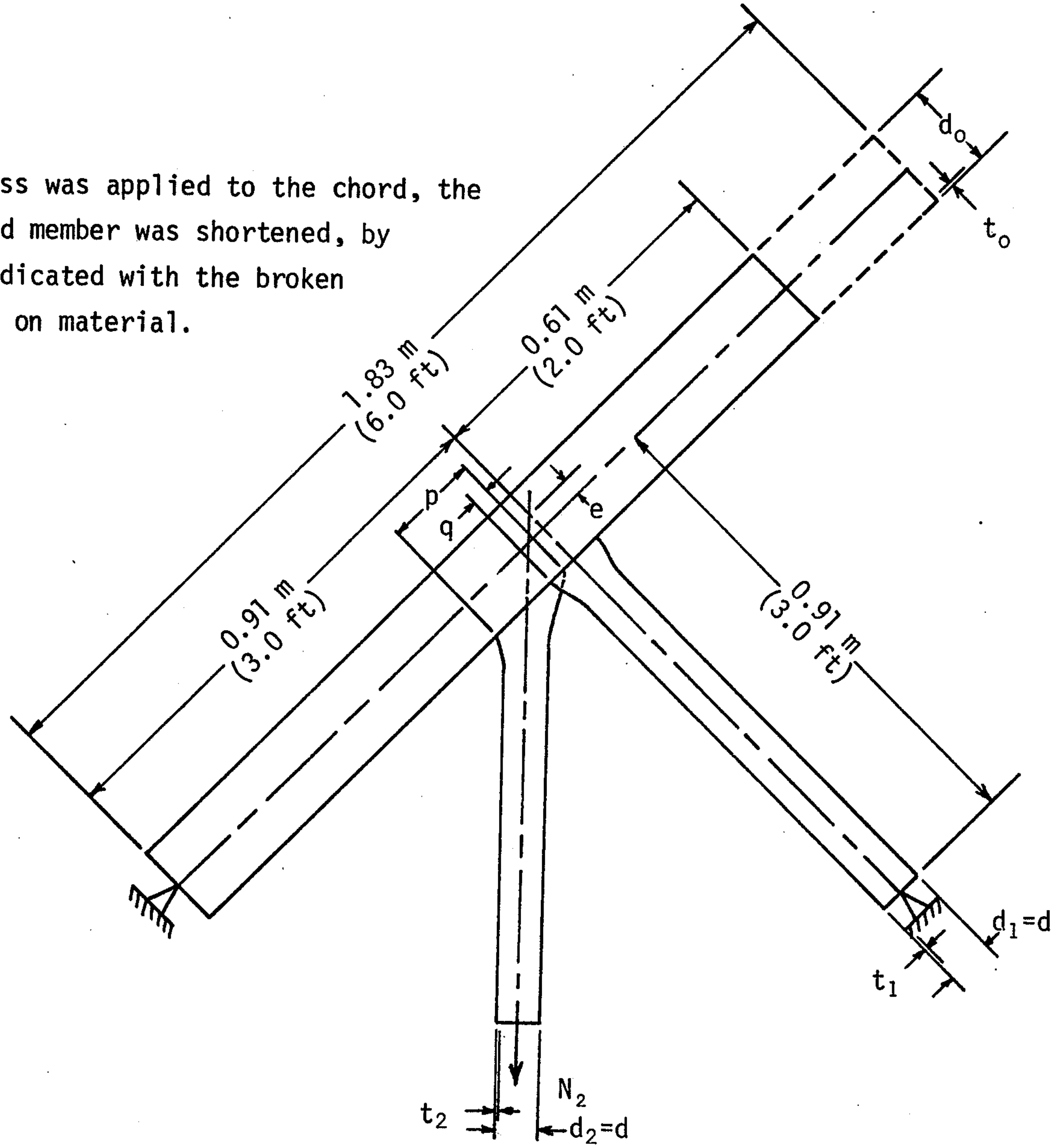


Fig. 2.2 - Assumed elastic deformation considering bending of members only.



As no prestress was applied to the chord, the specimen chord member was shortened, by the amount indicated with the broken line, to save on material.

Fig. 2.3 - Typical test specimen.

had members extending from the joint in question halfway to the adjacent truss panel joints. The joint welds were designed in accordance with the member design loads in the prototype truss.

The specimen parameters (t_o/d_o, d_1/d_o, and O_v), the compression web slenderness ratio (L_1/r_1), the joint eccentricity to chord diameter ratio (e/d_o), and specified size of the web-chord fillet weld are indicated in table 2.1. Table 2.2 lists the specimen member sizes and material properties. Several specimens embody extreme values of t_o/d_o which would not be used in practice. However, these were included with the intention of assembling complete information concerning the influence of the t_o/d_o ratio on joint performance.

2.2) Specimen Designation

The specimen designation was derived from the three major parameters found to affect joint performance in tubular trusses. The designation is as follows. The first character is a digit, ranging from 1 to 6, referring to a specific t_o/d_o ratio. This is followed by an alphabetic character, D, E, F, G, or H, identifying an approximate d_1/d_o ratio. Finally, the last two characters are digits, either 00, 50, or 75, which represent the lap of the web members expressed as a percentage of the tension web diameter.

2.3) Fabrication

The cropping, cutting, fitting, and tack welding of all specimens were carried out in the Civil Engineering Laboratories at the University of Manitoba.

TABLE 2.1

SPECIMEN PROPERTIES

Specimen	t_o/d_o	d_1/d_o	L_1/r_1	O_v	e/d_o	Weld Size (in.)	(mm)
1D00	0.0174	0.355	90.0	0	0.149	1/4	6.35
1D50	0.0177	0.357	90.0	50	-0.032	1/4	6.35
1D75	0.0176	0.356	90.0	75	-0.122	1/4	6.35
2D00	0.0278	0.360	90.0	0	0.149	1/4	6.35
2D50	0.0277	0.359	90.0	50	-0.032	1/4	6.35
2D75	0.0279	0.359	90.0	75	-0.122	1/4	6.35
3D00	0.0403	0.359	90.0	0	0.149	1/4	6.35
3D50	0.0403	0.360	90.0	50	-0.032	1/4	6.35
3D75	0.0401	0.359	90.0	75	-0.122	1/4	6.35
4D00	0.0395	0.363	133	0	0.144	3/16	4.76
4D50	0.0419	0.363	133	50	-0.044	3/16	4.76
4D75	0.0391	0.363	133	75	-0.098	3/16	4.76
5D00	0.0496	0.364	133	0	0.144	3/16	4.76
5D50	0.0496	0.364	133	50	-0.044	3/16	4.76
5D75	0.0498	0.365	133	75	-0.098	3/16	4.76
6D00	0.0681	0.364	133	0	0.144	3/16	4.76
6D50	0.0690	0.365	133	50	-0.044	3/16	4.76
6D75	0.0698	0.366	133	75	-0.098	3/16	4.76
1E00	0.0176	0.430	75.0	0	0.270	5/16	7.94
1E50	0.0177	0.432	75.0	50	0.051	5/16	7.94
1E75	0.0178	0.432	75.0	75	-0.054	5/16	7.94
2E00	0.0279	0.434	75.0	0	0.270	5/16	7.94
2E50	0.0275	0.430	75.0	50	0.051	5/16	7.94
2E75	0.0276	0.434	75.0	75	-0.054	5/16	7.94
3E00	0.0404	0.434	75.0	0	0.270	5/16	7.94
3E50	0.0404	0.434	75.0	50	0.051	5/16	7.94
3E75	0.0402	0.435	75.0	75	-0.054	5/16	7.94
4E00	0.0397	0.424	113	0	0.256	3/16	4.76
4E50	0.0391	0.424	113	50	0.044	3/16	4.76
4E75	0.0392	0.423	113	75	-0.067	3/16	4.76
5E00	0.0501	0.426	113	0	0.256	3/16	4.76
5E50	0.0501	0.426	113	50	0.044	3/16	4.76
5E75	0.0504	0.425	113	75	-0.067	3/16	4.76
6E00	0.0692	0.425	113	0	0.256	3/16	4.76
6E50	0.0703	0.426	113	50	0.044	3/16	4.76
6E75	0.0701	0.424	113	75	-0.067	3/16	4.76

TABLE 2.1 (continued)

Specimen	t_o/d_o	d_1/d_o	L_1/r_1	O_v	e/d_o	Weld Size	
						(in.)	(mm)
2F50	0.0279	0.530	60.5	50	0.209	5/16	7.94
2F75	0.0279	0.529	60.5	75	0.078	5/16	7.94
3F50	0.0399	0.529	60.5	50	0.209	5/16	7.94
3F75	0.0401	0.529	60.5	75	0.078	5/16	7.94
4F00	0.0391	0.525	90.0	0	0.456	1/4	6.35
4F50	0.0411	0.526	90.0	50	0.191	1/4	6.35
4F75	0.0417	0.529	90.0	75	0.060	1/4	6.35
5F50	0.0530	0.529	90.0	50	0.191	1/4	6.35
5F75	0.0526	0.528	90.0	75	0.060	1/4	6.35
6F50	0.0670	0.527	90.0	50	0.191	1/4	6.35
6F75	0.0667	0.528	90.0	75	0.060	1/4	6.35
4G00	0.0391	0.636	75.0	0	0.633	5/16	7.94
4G50	0.0389	0.637	75.0	50	0.313	5/16	7.94
4G75	0.0390	0.635	75.0	75	0.153	5/16	7.94
5G50	0.0531	0.637	75.0	50	0.313	5/16	7.94
5G75	0.0528	0.640	75.0	75	0.153	5/16	7.94
6G50	0.0690	0.639	75.0	50	0.313	5/16	7.94
6G75	0.0692	0.639	75.0	75	0.153	5/16	7.94
4H00	0.0410	0.781	60.5	0	0.933	5/16	7.94
4H50	0.0409	0.781	60.5	50	0.544	5/16	7.94
4H75	0.0416	0.780	60.5	75	0.351	5/16	7.94
5H50	0.0501	0.781	60.5	50	0.544	5/16	7.94
5H75	0.0495	0.781	60.5	75	0.351	5/16	7.94
6H50	0.0670	0.780	60.5	50	0.544	5/16	7.94
6H75	0.0665	0.781	60.5	75	0.351	5/16	7.94

Definition of symbols.

t_o = chord thickness.

d_o = chord diameter.

d_1 = compression web diameter.

L_1 = compression web length in prototype truss.

r_1 = radius of gyration of compression web.

O_v = web lap.

e = joint eccentricity.