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Shin-Hua Lin

Ling-En Hsiao

Chi-Ling Pan

Wei-wen Yu
Missouri University of Science and Technology, wwy4@mst.edu

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DESIGN OF AUTOMOTIVE STRUCTURAL COMPONENTS USING HIGH STRENGTH SHEET STEELS

STRUCTURAL STRENGTH OF COLD-FORMED STEEL I-BEAMS AND HAT SECTIONS SUBJECTED TO WEB CRIPPLING LOAD

by

Shin-Hua Lin
Ling-En Hsiao
Chi-Ling Pan

Research Assistants

Wei-Wen Yu

Project Director

A Research Project Sponsored by the American Iron and Steel Institute

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Department of Civil Engineering
University of Missouri-Rolla
Rolla, Missouri

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I. INTRODUCTION

When cold-formed steel beam webs are subjected to partial edge loading, they may fail by web crippling rather than bending of the beam. Web crippling is caused by a highly localized intensity of the load or reaction. Because of the complexity of the web crippling behavior, empirical expressions are presently used for the design of cold-formed steel beams in buildings and automotive structural components to prevent web crippling.[1,2,3]

The research on the structural behavior of cold-formed steel beam webs subjected to web crippling has been conducted at Cornell University and the University of Missouri-Rolla (UMR) under the sponsorship of the American Iron and Steel Institute (AISI).[4,5] Since 1982, additional work has been performed at the University of Missouri-Rolla, Inland Steel Company, and Ford Motor Company to investigate the web crippling strength of automotive structural components using high strength sheet steels.[6-9] The research findings of the UMR study were summarized in the Eighth Progress Report.[7]

In the UMR Fifth and Eighth Progress Reports, it was noted that if the I-beam specimens are subjected to the end one-flange loading without connecting the beam flange to the bearing plate, the failure of all sections used in the pilot tests occured by cross-bending of the flange about the connector location as shown in Fig. 1 instead of the conventional web crippling. This type of failure will be referred to as a "flange cross-bending" mode of failure in this report. It seems to be dependent primarily on the bend radius, the thickness of the web, the location of connectors and other parameters. Figure 2 shows the failure of an I-beam subjected to end one-flange loading. The tested loads for the specimens having the "flange cross-bending" type of failure were lower than those caused by the conventional web crippling.

The purpose of this brief study reported herein was to review the test results described in Ref. 6 for the "flange cross-bending" type of failure of cold-formed steel I-beams using high strength sheet steels and to develop some new design criteria, if possible. Because of the limited number of test results, the present investigation can only be treated as a preliminary study of the problem. An extensive experimental work will be needed for the development of general design criteria.

Section II contains a review of the experimental research results described in Ref. 6. In Section III, an analytical study of this type of failure mode for cold-formed steel I-beams is presented by using the finite element method. The development of an empirical expression for predicting the ultimate load is discussed in Section IV. Also included in this section is the comparison of test results and predicted values based on the newly developed equations for "flange cross-bending" failure.

In addition to the study of the web crippling strength of I-beams, this report also evaluates the results of 157 beam tests using hat sections. These tests were conducted recently at the Research Laboratories of Inland Steel Company. Section V includes the information on beam specimens[10] and comparisons of the tested and predicted failure loads on the basis of the design recommendations proposed in Ref. 7.

Finally, conclusions are drawn in Section VI.

II. EXPERIMENTAL RESULTS OF I-BEAMS

In this brief study, consideration was given only to cold-formed steel I-beam specimens subjected to end one-flange loading. Because the flanges of specimens were not connected to bearing plates, "flange cross-bending" type of failure occured in the tests. The experimental results obtained by Santaputra were reported in Ref. 6.

A. Test Specimens and Setup

A total of 18 I-beam test specimens were used to study the "flange cross-bending" failure under end one-flange loading. These I-beam specimens as shown in Fig. 3 were fabricated from two channels connected back to back with the aid of self-tapping screws(14 x 3/4 Tek Screws) at a distance of 1/2 in. from top and bottom flanges. This is the minimum clearance of the electric drill used for driving the screws. The self-tapping screws were spaced along the beam length at a constant distance of 2 in. from center to center. The screws were driven from alternate sides of webs during fabrication in order to minimize the initial imperfection of webs.

The dimensions of the I-beam specimens used in this investigation are listed in Table 1. From this table, it is noted that two identical tests were conducted for each type of specimens. Three different types of sheet steels(80DK, 80XF and 100XF) were used in this study. The typical stress-strain curves for these materials can be found in References 11 and 12. The test setup used in Ref. 6 is shown in Fig. 4. During the test, compression flanges of I-beam specimens were braced against lateral movement to prevent twisting of the section.

B. Test Results

The nature of the failure for each specimen was carefully inspected throughout the testing. It was found that the conventional web crippling did not occur in these I-beam specimens under this type of loading condition. A totally different failure mode was observed when compared with the conventional web crippling failure mode. All failures occured at the junction of the web and flange as shown in Fig. 1. The failure seems to be caused by the cantilever action of the flange about the screw location. Thus, the bend radius, the location of screws and the thickness of material are important parameters. Because of the premature failure, the conventional web crippling failure could not be developed in the webs.

C. Discussions

The dimensions of specimens and the test results obtained for the cold-formed steel I-sections with a "flange cross-bending" type of failure are listed in Table 1. All symbols used for cross-sectional dimensions are shown in Fig. 3. The sectional properties and important parameters for each specimen are listed in Table 2, in which t is the thickness of the I-section, F_y is the yield strength, R is the inside bend radius, N is the bearing length, e is the clear distance between edges of the adjacent opposite bearing plates measured along the length of beam, and h is the clear distance between flanges measured along the plane of the web.

The comparisons of the tested failure loads and predicted ultimate loads based on the AISI 1981 Guide[2] are presented in Table 3 under the ratio of P_{test}/P_{AISI}. The discrepancies are due to the fact that the 1981

Guide is used for the conventional type of web crippling and is not for the flange cross-bending.

III. FINITE ELEMENT ANALYSIS OF I-BEAMS

In order to study the "flange cross-bending" failure of cold-formed steel I-sections, a finite element analysis has been employed. The finite element program entitled "Automative Dynamic Incremental Nonlinear Analysis" (ADINA)[13,14] was used in this study. In this investigation, emphasis was concentrated on the I-beam specimens fabricated from two channels. These I-sections have a constant distance of 1/2 in. between flanges and the location of screw lines. Only the end one-flange loading condition was considered.

ADINA is a computer program for the static and dynamic displacement and stress analysis of solids, structures and fluid-structure systems. The program can be employed to perform linear and nonlinear analysis. Program ADINA is an out-of-core solver, i.e., the equilibrium equations are processed in blocks, so very large finite element systems can be considered.

A. Finite Element Model

In the finite element analysis, a parabolic 9-node thin shell element with an Updated Lagrangian formulation was employed. This element may be used for very large displacements and rotations but small strain. A typical element having 5 degrees of freedom at each node (3 translations and 2 rotations) is shown in Fig. 5. The stress-strain relationships used for the finite element analysis were treated as elastic-linear strain hardening type (Fig. 6) and the value of tangent modulus, E_t, was assumed to be zero. In order to take the symmetry of the I-beam into account, only a portion of the test specimen was considered in the analysis as shown in Fig. 7.a.

The boundary conditions of the finite element model were chosen carefully until its situation is close to the actual tested case. Because two identical tests were conducted for the specimens described in Section II, the average value of these duplicate test data, as listed in Table 1, was used in this finite element analysis. Figure 7.b shows a typical finite element model which contains a total of 165 nodes and 35 elements. The loads are applied at nodes 91 through 99.

B. Finite Element Implementation

A total of nine finite element model analyses were studied in this investigation. The comparisons between the tested failure loads and the analytical values computed from the finite element program are presented in Table 4. As indicated in this table, the predictions using the finite element analyses are lower than the tested failure loads with one exception. The average value of the P_{test}/P_{FE} ratios for nine test models is 1.113 with a standard deviation of 0.097. In the above expression, P_{FE} is the computed ultimate load using the finite element analysis.

The underestimation of the analytical values may be due to the fact that during the test, the contact point between the bearing plate and the specimen moved toward the web as the load increased. However, in the finite element model, the applied load was stationary. The shifting of the loading point was caused by the rotation of the web-flange junction. As a result, the out-of-plane bending caused by the eccentric load applied in the actual test was smaller than that used in the finite element model.

C. Discussions

Even though the predictions from the ADINA finite element program slightly underestimate the test results, it seems to be a reasonable analytical method to deal with this problem. It should be noted that because of the complicated boundary conditions at the curved part between the flange and the connected line of I-beams, it may be difficult to accurately determine the failure load by using this analytical study.

According to the comparisons of the predicted ultimate loads and the available tested failure loads, the predications are slightly conservative for all but one of the test models. Because of the limited number of test results, the finite element model analysis was used only for a parametric study. The development of the new design equation is discussed in the next section.

IV. DEVELOPMENT OF NEW EQUATIONS FOR I-BEAMS

As discussed in Section II, the AISI design provisions for web crippling included in the 1981 Guide for preliminary design of sheet steel automotive structural components are not applicable for the "flange cross-bending" failure of I-sections subjected to end one-flange loading. The premature failure is dependent on the bend radius, the location of screws, the thickness of material, and other factors. A new design equation is needed to predict the failure load for this case.

A. I-Sections Subjected to End One-Flange Loading

Nondimensional parameters such as N/t and R/t and the parameter t^2F_y are used for the prediction of web crippling loads for cold-formed steel beams (t being the web thickness, F_y being the yield strength of steel, N being the actural length of bearing, and R being the bend radius). These parameters are presently included in the AISI 1986 Specification and are also used in the development of the new equation. In addition to these parameters, the ratios of e/h and B/N are considered in the new formula. The definitions of e and B are discussed below.

In general, the form of the new equation for determining the ultimate load for flange cross-bending of I-beams may be written as

$$(P_{ult})_I = t^2F_y \, f(N/t, R/t, B/N, e/h) \tag{1}$$

in which h is the depth of the web, e is the clear distance between opposite bearing plates and B is the flange width of the I-section. A nonlinear least square regression technique was used for determining the relationships between different parameters in the above empirical formula. This equation was developed on the basis of the available test data obtained from Ref. 6 and the ADINA analytical results. Because the modulus of elasticity, E, and tangent modulus, E_t are not considered in the predicted formula, the value of E_t was assumed to be equal to zero as discussed in Section III.A. The overall ranges of parameters used in this study are shown below.

Parameter	Max. Limit	Range
t, in.	0.1	0.048 to 0.082
R/t	4.6	2.67 to 4.56
N/t	42.0	24.39 to 41.67
B/N	2.7	1.61 to 2.66
e/h	1.3	1.16 to 1.32
F_y, ksi	110	58.2 to 113.1

The following equation was developed to predict the ultimate loads for cold-formed steel I-sections using high strength sheet steels, corresponding to the "flange cross-bending" type of failure when these sections are subjected to end one-flange loading without connecting the flanges to bearing plates:

$$(P_{ult})_I = 0.03t^2F_y(1+0.223F_{yc})\left[1+0.0683N/t+0.000197(N/t)^2\right]$$
$$\times\left[(60.305/\sqrt{R/t})-1\right](1+1.215\sqrt{B/N})(1-0.1628\sqrt{e/h}) \qquad (2)$$

In the above equation, $F_{yc} = (90-F_y)/90$.

B. Proposed Design Recommendations

Based on the equation developed in Section IV.A, Eq. (3) is proposed to prevent the "flange cross-bending" type of failure for cold-formed steel I-sections with flanges not connected to a bearing plate. This equation applies only to I-beams subjected to end one-flange loading when $t \leq 0.1$ in., $F_y \leq 110$ ksi, $R/t \leq 4.6$, $N/t \leq 42$, $B/N \leq 2.7$ and $e/h \leq 1.3$. These limits are based on the ranges of parameters used in the beam tests.

$$(P_{ult})_I = 0.03t^2F_y \, C'_1C'_2C'_3C'_4C'_5 \tag{3}$$

where

$$C'_1 = (1+0.223F_{yc}) \tag{4}$$

$$C'_2 = \left[1+0.0683(N/t)+0.000197(N/t)^2\right] \tag{5}$$

$$C'_3 = \left[(60.305/\sqrt{R/t})-1\right] \tag{6}$$

$$C'_4 = (1+1.215\sqrt{B/N}) \tag{7}$$

$$C'_5 = (1-0.1628\sqrt{e/h}) \tag{8}$$

In the equation for C'_1, $F_{yc} = (90-F_y)/90$.

C. Comparisons of Tested and Computed Loads Based on the Newly Developed Formula

The following discussion presents comparisons of the tested results and the computed ultimate loads based on the newly developed formula (Eq. 3). Table 3 shows the comparisons of the tested and predicted loads for 18 tests used in this investigation. It can be seen from Table 3 that an average value of P_{test}/P_{comp} is 1.001 with a standard deviation of 0.107, where P_{comp} is the predicted value based on the newly developed equation. Also included in this table are the comparisons of the tested loads and the computed loads obtained from the 1981 AISI Guide for the preliminary design of automotive structural components.

Figure 8 shows the effect of F_y on the ratio of P_{test}/P_{comp}. The comparison shows good agreement between the tested and predicted failure loads.

D. Discussions

The above comparison shows that the existing design criteria are not prepared for the I-sections governed by the "flange cross-bending" type of failure. The proposed design recommendations can provide good estimation of the ultimate loads for cold-formed steel I-sections using high strength sheet steels with flanges that are not connected to bearing plates when they are subjected to end one-flange loading.

V. INLAND EXPERIMENTAL RESULTS OF HAT SECTIONS

Recently, numerous hat sections have been tested at the Research Laboratories of Inland Steel Company for the purpose of investigating the web crippling strength of cold-formed steel beams. The results of 157 beam tests are compared with the design formulas proposed in Ref. 7.

A. Test Specimens and Setup

The test specimens used for this comparison were fabricated from different types of steel sheets. The material designations and the tested yield strengths (F_y = 92.0 - 179.0 ksi) are listed in Table 5. The specimen numbers listed in the last column of the table are the designations used in Ref. 10.

Table 6 gives the dimensions of hat sections used in the Inland tests. All symbols (t, B1, B2, D1, D2, and R) are defined in Fig. 9. Based on these dimensions, the design parameters (h/t, N/h, e/h, N/t, and R/t) have been computed and are presented in Table 7.

B. Test Results

All specimens were tested as simply supported beams under two concentrated loads as shown in Fig. 10. For all tests, the span length L was 32.25 inches and the total length of the specimen was 43 inches. Four 2-inch bearing plates were used at both end reactions and under the applied loads. The tested failure loads are presented in Table 8 under the column title "P_{test}".

C. Comparisons of Tested and Computed Loads Based on the Design Formulas Proposed in Ref. 7

For the purpose of comparison between the tested and computed ultimate loads, the failure loads of these 157 Inland tests were predicted by using the computer program given in Appendix A of this report. The types of failure modes considered in this investigation are bending, combined bending and shear in webs, web crippling, and combined bending and web crippling. All symbols used in Table 8 are defined as follows:

P_m = predicted load based on bending moment, kips

P_{cy} = predicted load based on web crippling due to overstressing, kips

P_{mc} = predicted load for combined bending and web crippling, kips

P_{cb} = predicted load based on web crippling due to web buckling, kips

P_{ms} = predicted load for combined bending and shear in webs, kips

P_{test} = tested failure load, kips

P_{comp} = computed filure load which is the smallest of P_{mc}, P_{cb}, and P_{ms}

The governing failure modes are defined as follows:

B = web crippling due to web buckling

M = bending moment

MC = combined bending and web crippling due to overstressing

MS = combined bending and shear in webs

The values of P_{cy} and P_{cb} were computed according to the design equations proposed in Table 6.1 of the Eighth Progress Report.[7] The value of P_{mc} was determined from Eq. (6.40) of Ref. 7.

D. Discussions

A review of the P_{test}/P_{comp} ratios indicates that for most of the Inland recent tests, the proposed design equations provide reasonable predicted failure loads. The effect of F_y on the ratio P_{test}/P_{comp} for 157 Inland tests are shown graphically in Fig. 11. The tested and computed loads are compared in Fig. 12.

VI. CONCLUSIONS

The "flange cross-bending" type of failure may occur in cold-formed steel I-sections subjected to end one-flange loading, if the flange is not connected to the bearing plate. This premature failure is mainly dependent on the bend radius, the thickness of the web, and the cantilever action of the flange bending about the connection line in the web. Based on a limited amount of test data for this type of failure, a preliminary study was carried out at the University of Missouri-Rolla to investigate the structural behavior of the aforementioned failure by using the finite element method.

The purpose of this investigation was to establish the parameters involved in this problem and to develop new design criteria for preventing this type of failure. The investigation of this type of failure mode and the structural strengths of 18 I-beams were studied in Section II. Details of the test specimens and test results are also presented in this section.

In the analytical study discussed in Section III, a finite element program (ADINA), which is available at UMR, was used to predict the ultimate loads of test specimens. A 9-node parabolic thin shell element was used as the typical element in the analysis with both geometric and material nonlinearities. The finite element analytical method slightly underestimates the failure loads.

A new design equation was developed to determine the ultimate load for cold-formed steel I-beams using high strength sheet steels when they are subjected to end one-flange loading with flanges not connected to bearing plates. The tested and computed ultimate loads for the "flange cross-bending" failure of I-beams were compared in Section IV.

It should be noted that the new formula was developed on the basis of a limited number of test results for those high strength cold-formed steel I-beams without connecting the flanges to bearing plates when they are subjected to end one-flange loading. The new design equation developed herein can only be used for the parameters within the ranges indicated in Section IV. Because this study can only serve as a preliminary investigation, an extensive study is needed for the development of general design criteria.

In addition to the study of "flange cross-bending" of I-beams, Section V presents the results of 157 beam tests using hat sections. These tests were conducted at the Research Laboratories of Inland Steel Company in East Chicago, Indiana. The tested failure loads are compared with the predicted values according to the design formulas proposed in Ref. 7.

VII. ACKNOWLEDGMENTS

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IX. NOTATION

The following symbols are used in this report:

B = failure mode due to web buckling

B = flange width of the I-section

B1,B2 = dimensions of hat section, see Fig. 9

$C'_1, C'_2, C'_3, C'_4, C'_5$ = coefficients, see Eq. (3)

D1,D2 = dimensions of hat section, see Fig. 9

e = clear distance between edges of the adjacent opposite bearing plates measured along the length of beam

E = initial modulus of elasticity

E_t = tangent modulus

F_y = yield strength

F_{yc} = $(90-F_y)/90$

h = clear distance between flanges measured along the plane of the web

L = span length

M = failure mode due to bending moment

MC = failure mode due to combined bending and web crippling

MS = failure mode due to combined bending and shear in webs

N = bearing length

P_{AISI} = predicted failure load based on the AISI 1981 Guide

P_{cb} = predicted load based on web crippling due to web buckling, kips

P_{comp} = computed filure load which is the smallest of P_{mc}, P_{cb}, and P_{ms}

P_{cy} = predicted load based on web crippling due to overstressing, kips

P_{FE} = computed ultimate load from finite element analysis

P_{m} = predicted load based on bending moment, kips

P_{mc} = predicted load for combined bending and web crippling, kips

P_{ms} = predicted load for combined bending and shear in webs, kips

P_{test} = tested failure load, kips

$(P_{ult})_I$ = predicted ultimate load determined from Eq. (3)

R = inside bend radius

t = thickness of the section

TABLE 1

Dimensions of Specimens and Tested Failure Loads

for I-Sections Subjected to End One-Flange Loading [6]

Specimen No.	Cross-Sectional Dimensions (in.)				Span Length (in.)	Failure Load,(kips) P_{test}
	t	B	D1	R		
1-IE-11	0.048	3.230	3.023	0.219	15.0	1.012
1-IE-12	0.048	3.227	3.071	0.219	15.0	---
1-IE-1	0.048	3.228	3.047	0.219	15.0	1.012 *
1-IE-21	0.048	4.261	4.048	0.219	18.0	1.325
1-IE-22	0.048	4.266	4.022	0.219	18.0	1.350
1-IE-2	0.048	4.263	4.035	0.219	18.0	1.338 *
1-IE-31	0.048	5.279	5.044	0.219	21.0	1.250
1-IE-32	0.048	5.237	5.080	0.219	21.0	1.238
1-IE-3	0.048	5.258	5.062	0.219	21.0	1.244 *
2-IE-11	0.082	3.281	3.130	0.219	15.0	3.788
2-IE-12	0.082	3.283	3.152	0.219	15.0	3.750
2-IE-1	0.082	3.282	3.141	0.219	15.0	3.769 *
2-IE-21	0.082	4.240	4.152	0.219	18.0	4.400
2-IE-22	0.082	4.304	4.128	0.219	18.0	4.275
2-IE-2	0.082	4.272	4.140	0.219	18.0	4.338 *
2-IE-31	0.082	5.301	5.102	0.219	21.0	3.762
2-IE-32	0.082	5.347	5.098	0.219	21.0	3.806
2-IE-3	0.082	5.324	5.100	0.219	21.0	3.784 *
3-IE-11	0.062	3.264	3.190	0.188	15.0	2.988
3-IE-12	0.062	3.267	3.102	0.188	15.0	2.925
3-IE-1	0.062	3.265	3.146	0.188	15.0	2.957 *
3-IE-21	0.062	4.260	4.111	0.188	18.0	3.125
3-IE-22	0.062	4.355	4.072	0.188	18.0	3.400
3-IE-2	0.062	4.307	4.092	0.188	18.0	3.262 *
3-IE-31	0.062	5.268	5.090	0.188	21.0	2.750
3-IE-32	0.062	5.249	5.093	0.188	21.0	2.912
3-IE-3	0.062	5.258	5.091	0.188	21.0	2.831 *

Note: 1. --- Test data is not given in Ref. 6.
2. * Average value of two identical test specimens was used for the finite element analysis.
3. For definition of symbols, see Fig. 3.

TABLE 2

Parameters and Sectional Properties of I-Beams Used for End One-Flange Loading Condition [6]

Specimen No.	Material	t (in.)	F_y (ksi)	R/t	N/t	B/N	e/h	h/t
1-IE-11	80DK	0.048	58.2	4.562	41.70	1.615	1.195	61.0
1-IE-12	80DK	0.048	58.2	4.562	41.70	1.614	1.176	62.0
1-IE-21	80DK	0.048	58.2	4.562	41.70	2.131	1.266	82.3
1-IE-22	80DK	0.048	58.2	4.562	41.70	2.133	1.273	81.8
1-IE-31	80DK	0.048	58.2	4.562	41.70	2.640	1.313	103.1
1-IE-32	80DK	0.048	58.2	4.562	41.70	2.619	1.305	103.8
2-IE-11	80XF	0.082	88.3	2.671	24.40	1.641	1.179	36.2
2-IE-12	80XF	0.082	88.3	2.671	24.40	1.642	1.173	36.4
2-IE-21	80XF	0.082	88.3	2.671	24.40	2.120	1.255	48.6
2-IE-22	80XF	0.082	88.3	2.671	24.40	2.152	1.262	48.3
2-IE-31	80XF	0.082	88.3	2.671	24.40	2.651	1.317	60.2
2-IE-32	80XF	0.082	88.3	2.671	24.40	2.674	1.317	60.2
3-IE-11	100XF	0.062	113.1	3.032	32.30	1.632	1.140	49.5
3-IE-12	100XF	0.062	113.1	3.032	32.30	1.634	1.176	48.0
3-IE-21	100XF	0.062	113.1	3.032	32.30	2.130	1.254	64.3
3-IE-22	100XF	0.062	113.1	3.032	32.30	2.178	1.266	63.7
3-IE-31	100XF	0.062	113.1	3.032	32.30	2.634	1.309	80.1
3-IE-32	100XF	0.062	113.1	3.032	32.20	2.625	1.309	80.1

TABLE 3

Comparisons of Tested and Predicted Failure Loads for I-Beams under End One-Flange Loading Based on the AISI 1981 Guide and Newly Developed Formula

Specimen No.	P_{test} (kips)	P_{AISI} (kips)	P_{comp} (kips)	$\frac{P_{test}}{P_{AISI}}$	$\frac{P_{test}}{P_{comp}}$
1-IE-11	1.012	2.629	1.036	0.385	0.978
1-IE-12	---	2.631	1.035	---	---
1-IE-21	1.325	2.698	1.122	0.491	1.181
1-IE-22	1.350	2.697	1.121	0.501	1.204
1-IE-31	1.250	2.766	1.198	0.452	1.043
1-IE-32	1.238	2.768	1.196	0.447	1.035
2-IE-11	3.788	10.097	3.762	0.375	1.007
2-IE-12	3.750	10.099	3.764	0.371	0.996
2-IE-21	4.400	10.256	4.047	0.429	1.087
2-IE-22	4.275	10.252	4.064	0.417	1.052
2-IE-31	3.762	10.405	4.329	0.362	0.869
2-IE-32	3.806	10.405	4.341	0.366	0.877
3-IE-11	2.988	7.951	2.973	0.376	1.005
3-IE-12	2.925	7.936	2.964	0.369	0.987
3-IE-21	3.125	8.098	3.197	0.386	0.977
3-IE-22	3.400	8.092	3.217	0.420	1.057
3-IE-31	2.750	8.256	3.410	0.333	0.807
3-IE-32	2.912	8.256	3.406	0.353	0.855
Mean Value				0.402	1.001
Standard Deviation				0.048	0.107

Notes:

1. P_{test} is the tested failure load as listed in Table 1.
2. P_{AISI} is the computed ultimate load based on Eq. 3.4.7b1 of the AISI 1981 Guide.
3. P_{comp} is the predicted ultimate load based on the newly developed formula.

TABLE 4

Comparisons of Tested Failure Loads and Predicted Ultimate Loads Using Finite Element Method for End One-Flange Loading

Specimen No.	P_{test} (kips)	P_{FE} (kips)	$\frac{P_{test}}{P_{FE}}$
1-IE-1	1.01	0.93	1.086
1-IE-2	1.34	1.08	1.241
1-IE-3	1.24	1.17	1.060
2-IE-1	3.77	3.24	1.164
2-IE-2	4.34	3.56	1.221
2-IE-3	3.78	3.78	1.000
3-IE-1	2.96	2.59	1.143
3-IE-2	3.26	2.84	1.150
3-IE-3	2.83	2.98	0.951
Mean Value			1.113
Standard Deviation			0.097

Note: P_{FE} is the predicted ultimate load based on the finite element analysis.

TABLE 5

Material Properties of Inland Specimens

Specimen No.	Material Designation	F_y (ksi)	Source Specimen No.
1	--	92.0	39
2	--	92.0	31
3	--	92.0	41
4	--	92.0	33
5	--	92.0	28
6	--	92.0	27
7	--	92.0	9
8	--	92.0	26
9	--	92.0	16
10	--	92.0	29
11	--	92.0	42
12	--	92.0	34
13	--	92.0	38
14	--	92.0	37
15	--	92.0	24
16	--	92.0	17
17	--	92.0	7
18	--	92.0	5
19	--	92.0	21
20	--	92.0	13
21	--	92.0	14
22	--	92.0	12
23	--	92.0	10
24	--	92.0	35
25	--	92.0	30
26	--	92.0	32
27	--	92.0	23
28	--	92.0	1
29	--	92.0	2
30	--	92.0	3
31	--	92.0	8
32	--	92.0	4
33	--	92.0	19
34	--	92.0	18
35	M-190	179.0	40
36	M-190	179.0	20
37	M-190	179.0	36
38	M-190	179.0	22
39	M-190	179.0	11
40	M-190	179.0	25

TABLE 5 (cont'd)

Material Properties of Inland Specimens

Specimen No.	Material Designation	F_y (ksi)	Source Specimen No.
41	M-190	179.0	15
42	RA-120	129.0	4
43	RA-120	129.0	9
44	RA-120	129.0	18
45	RA-120	129.0	25
46	RA-120	129.0	19
47	RA-120	129.0	17
48	RA-120	129.0	15
49	RA-120	129.0	20
50	RA-120	129.0	8
51	RA-120	129.0	3
52	RA-120	129.0	1
53	RA-120	129.0	7
54	RA-120	129.0	24
55	RA-120	129.0	23
56	RA-120	129.0	12
57	RA-120	129.0	11
58	RA-120	129.0	21
59	RA-120	129.0	10
60	RA-120	129.0	26
61	RA-120	129.0	6
62	RA-120	129.0	22
63	RA-120	129.0	16
64	RA-120	129.0	13
65	M-160	160.0	137
66	M-160	160.0	106
67	M-160	160.0	136
68	M-160	160.0	124
69	M-160	160.0	131
70	M-160	160.0	138
71	M-160	160.0	125
72	M-160	160.0	128
73	M-160	160.0	139
74	M-160	160.0	130
75	M-160	160.0	108
76	M-160	160.0	111
77	M-160	160.0	122
78	M-160	160.0	118
79	M-160	160.0	141
80	M-160	160.0	144

TABLE 5 (cont'd)

Material Properties of Inland Specimens

Specimen No.	Material Designation	F_y (ksi)	Source Specimen No.
81	M-160	160.0	87
82	M-160	160.0	90
83	M-160	160.0	84
84	M-160	160.0	85
85	M-160	160.0	143
86	M-160	160.0	107
87	M-160	160.0	95
88	M-160	160.0	121
89	M-160	154.0	97
90	M-160	154.0	99
91	M-160	154.0	133
92	M-160	154.0	65
93	M-160	154.0	105
94	M-160	154.0	146
95	M-160	154.0	126
96	M-160	154.0	110
97	M-160	154.0	101
98	M-160	154.0	81
99	M-160	154.0	100
100	M-160	154.0	74
101	M-160	154.0	132
102	M-160	154.0	91
103	M-160	154.0	75
104	M-160	154.0	120
105	M-160	154.0	129
106	M-160	154.0	83
107	M-160	154.0	79
108	M-160	154.0	72
109	M-160	154.0	93
110	M-160	154.0	98
111	M-160	154.0	80
112	M-160	154.0	77
113	M-190	171.0	43
114	M-190	171.0	55
115	M-190	171.0	52
116	M-190	171.0	50
117	M-190	171.0	39
118	M-190	171.0	44
119	M-190	171.0	67
120	M-190	171.0	62

TABLE 5 (cont'd)

Material Properties of Inland Specimens

Specimen No.	Material Designation	F_y (ksi)	Source Specimen No.
121	M-190	171.0	41
122	M-190	171.0	40
123	M-190	171.0	34
124	M-190	171.0	47
125	M-190	171.0	42
126	M-190	171.0	35
127	M-190	171.0	58
128	M-190	171.0	60
129	M-190	171.0	49
130	M-190	171.0	51
131	M-190	171.0	38
132	M-190	171.0	56
133	M-190	171.0	53
134	M-190	171.0	61
135	M-190	171.0	59
136	M-190	167.0	25
137	M-190	167.0	24
138	M-190	167.0	19
139	M-190	167.0	23
140	M-190	167.0	13
141	M-190	167.0	16
142	M-190	167.0	5
143	M-190	167.0	22
144	M-190	167.0	27
145	M-190	167.0	9
146	M-190	167.0	12
147	M-190	167.0	14
148	M-190	167.0	17
149	M-190	167.0	20
150	M-190	167.0	10
151	M-190	167.0	26
152	M-190	167.0	37
153	M-190	167.0	8
154	M-190	167.0	21
155	M-190	167.0	28
156	M-190	167.0	33
157	M-190	167.0	15

TABLE 6

Dimensions of Inland Specimens

Specimen No.	t (in.)	B1 (in.)	B2 (in.)	D1 (in.)	D2 (in.)	R (in.)	L (in.)
1	0.028	1.09	3.27	1.58	0.51	0.26	32.25
2	0.028	1.10	3.29	1.57	0.53	0.26	32.25
3	0.028	1.11	3.31	1.58	0.52	0.26	32.25
4	0.028	1.85	4.06	1.57	0.52	0.26	32.25
5	0.028	2.05	4.25	1.57	0.55	0.26	32.25
6	0.028	2.59	4.79	1.57	0.52	0.26	32.25
7	0.028	2.64	4.84	1.54	0.57	0.26	32.25
8	0.028	2.64	4.83	1.54	0.56	0.26	32.25
9	0.028	3.36	5.52	1.50	0.51	0.26	32.25
10	0.028	3.37	5.55	1.56	0.50	0.26	32.25
11	0.028	3.37	5.57	1.56	0.51	0.26	32.25
12	0.028	1.12	3.32	2.56	0.55	0.26	32.25
13	0.028	1.12	3.29	2.56	0.53	0.26	32.25
14	0.028	1.14	3.31	2.54	0.54	0.26	32.25
15	0.028	1.85	4.05	2.59	0.50	0.26	32.25
16	0.028	1.88	4.08	2.56	0.50	0.26	32.25
17	0.028	1.90	4.10	2.57	0.51	0.26	32.25
18	0.028	2.62	4.74	2.51	0.56	0.26	32.25
19	0.028	2.62	4.77	2.58	0.58	0.26	32.25
20	0.028	2.62	4.76	2.61	0.59	0.26	32.25
21	0.028	3.39	5.57	2.59	0.49	0.26	32.25
22	0.028	3.40	5.60	2.55	0.52	0.26	32.25
23	0.028	3.42	5.60	2.55	0.52	0.26	32.25
24	0.028	1.13	3.35	3.54	0.55	0.26	32.25
25	0.028	1.14	3.37	3.54	0.55	0.26	32.25
26	0.028	1.16	3.34	3.53	0.53	0.26	32.25
27	0.028	2.39	4.58	3.55	0.56	0.26	32.25
28	0.028	2.59	4.67	3.54	0.53	0.26	32.25
29	0.028	2.59	4.79	3.54	0.54	0.26	32.25
30	0.028	2.60	4.80	3.57	0.52	0.26	32.25
31	0.028	2.66	4.86	3.55	0.56	0.26	32.25
32	0.028	3.38	5.58	3.55	0.50	0.26	32.25
33	0.028	3.39	5.61	3.54	0.48	0.26	32.25
34	0.028	3.39	5.57	3.59	0.50	0.26	32.25
35	0.035	1.11	3.41	1.59	0.52	0.27	32.25
36	0.035	1.13	3.39	1.60	0.54	0.27	32.25
37	0.035	1.16	3.43	1.58	0.52	0.27	32.25
38	0.035	1.90	4.19	2.56	0.53	0.27	32.25
39	0.035	1.90	4.10	2.57	0.53	0.27	32.25
40	0.035	1.92	4.15	2.55	0.55	0.27	32.25

TABLE 6 (cont'd)

Dimensions of Inland Specimens

Specimen No.	t (in.)	B1 (in.)	B2 (in.)	D1 (in.)	D2 (in.)	R (in.)	L (in.)
41	0.035	2.69	4.92	3.54	0.53	0.27	32.25
42	0.066	1.13	3.42	1.56	0.51	0.28	32.25
43	0.066	1.93	4.17	1.59	0.54	0.28	32.25
44	0.066	2.47	4.78	1.57	0.51	0.28	32.25
45	0.066	2.70	4.96	1.56	0.55	0.28	32.25
46	0.066	2.71	4.96	1.56	0.54	0.28	32.25
47	0.066	3.45	5.71	1.55	0.50	0.28	32.25
48	0.066	3.45	5.70	1.56	0.53	0.28	32.25
49	0.066	1.27	3.57	2.53	0.52	0.28	32.25
50	0.066	1.11	3.37	2.55	0.54	0.28	32.25
51	0.066	1.12	3.38	2.55	0.54	0.28	32.25
52	0.066	1.99	4.26	2.55	0.53	0.28	32.25
53	0.066	1.98	4.25	2.61	0.52	0.28	32.25
54	0.066	2.72	4.98	2.56	0.54	0.28	32.25
55	0.066	2.72	4.94	2.58	0.53	0.28	32.25
56	0.066	3.47	5.74	2.54	0.52	0.28	32.25
57	0.066	3.96	6.22	2.55	0.52	0.28	32.25
58	0.066	1.21	3.50	3.53	0.54	0.28	32.25
59	0.066	1.97	4.27	3.55	0.55	0.28	32.25
60	0.066	1.95	4.21	3.58	0.55	0.28	32.25
61	0.066	2.70	5.00	3.56	0.52	0.28	32.25
62	0.066	2.71	5.00	3.56	0.53	0.28	32.25
63	0.066	3.93	6.19	3.57	0.51	0.28	32.25
64	0.066	3.94	6.19	3.57	0.54	0.28	32.25
65	0.044	1.16	3.45	1.60	0.55	0.27	32.25
66	0.044	1.16	3.43	1.62	0.52	0.27	32.25
67	0.044	1.91	4.15	1.62	0.53	0.27	32.25
68	0.044	1.89	4.13	1.63	0.54	0.27	32.25
69	0.044	2.64	4.88	1.63	0.55	0.27	32.25
70	0.044	2.62	4.85	1.65	0.53	0.27	32.25
71	0.044	3.40	5.61	1.62	0.51	0.27	32.25
72	0.044	3.40	5.62	1.62	0.53	0.27	32.25
73	0.044	1.24	3.49	2.59	0.52	0.27	32.25
74	0.044	1.25	3.47	2.60	0.54	0.27	32.25
75	0.044	1.95	4.22	2.58	0.54	0.27	32.25
76	0.044	2.00	4.22	2.59	0.54	0.27	32.25
77	0.044	2.74	4.98	2.58	0.54	0.27	32.25
78	0.044	2.75	4.98	2.59	0.55	0.27	32.25
79	0.044	3.50	5.75	2.59	0.50	0.27	32.25
80	0.044	3.50	5.74	2.60	0.49	0.27	32.25

TABLE 6 (cont'd)

Dimensions of Inland Specimens

Specimen No.	t (in.)	B1 (in.)	B2 (in.)	D1 (in.)	D2 (in.)	R (in.)	L (in.)
81	0.044	1.19	3.42	3.63	0.51	0.27	32.25
82	0.044	1.18	3.43	3.65	0.53	0.27	32.25
83	0.044	1.97	4.19	3.57	0.54	0.27	32.25
84	0.044	1.98	4.26	3.59	0.53	0.27	32.25
85	0.044	2.69	4.93	3.63	0.52	0.27	32.25
86	0.044	2.68	4.95	3.64	0.53	0.27	32.25
87	0.044	3.43	5.66	3.61	0.50	0.27	32.25
88	0.044	3.46	5.71	3.63	0.50	0.27	32.25
89	0.048	1.19	3.46	1.62	0.53	0.27	32.25
90	0.048	1.20	3.42	1.62	0.56	0.27	32.25
91	0.048	1.90	4.13	1.62	0.55	0.27	32.25
92	0.048	1.90	4.11	1.63	0.53	0.27	32.25
93	0.048	2.65	4.88	1.64	0.54	0.27	32.25
94	0.048	2.66	4.90	1.65	0.55	0.27	32.25
95	0.048	3.41	5.67	1.61	0.51	0.27	32.25
96	0.048	3.40	5.64	1.64	0.52	0.27	32.25
97	0.048	1.17	3.40	2.62	0.57	0.27	32.25
98	0.048	1.14	3.35	2.63	0.55	0.27	32.25
99	0.048	1.99	4.22	2.60	0.54	0.27	32.25
100	0.048	2.00	4.24	2.61	0.54	0.27	32.25
101	0.048	1.97	4.19	2.65	0.54	0.27	32.25
102	0.048	2.77	4.98	2.59	0.53	0.27	32.25
103	0.048	2.78	4.99	2.60	0.54	0.27	32.25
104	0.048	3.51	5.75	2.56	0.51	0.27	32.25
105	0.048	3.49	5.76	2.62	0.51	0.27	32.25
106	0.048	1.27	3.51	3.57	0.54	0.27	32.25
107	0.048	1.25	3.48	3.59	0.54	0.27	32.25
108	0.048	1.97	4.21	3.61	0.54	0.27	32.25
109	0.048	2.71	4.96	3.55	0.54	0.27	32.25
110	0.048	2.71	4.95	3.60	0.55	0.27	32.25
111	0.048	3.43	5.69	3.59	0.50	0.27	32.25
112	0.048	3.46	5.65	3.63	0.53	0.27	32.25
113	0.047	1.20	3.44	1.61	0.53	0.27	32.25
114	0.047	1.19	3.47	1.62	0.53	0.27	32.25
115	0.047	1.93	4.22	1.61	0.54	0.27	32.25
116	0.047	1.93	4.20	1.62	0.52	0.27	32.25
117	0.047	2.66	4.92	1.62	0.54	0.27	32.25
118	0.047	2.67	4.93	1.62	0.53	0.27	32.25
119	0.047	3.40	5.66	1.63	0.51	0.27	32.25
120	0.047	3.40	5.70	1.65	0.49	0.27	32.25

TABLE 6 (cont'd)

Dimensions of Inland Specimens

Specimen No.	t (in.)	B1 (in.)	B2 (in.)	D1 (in.)	D2 (in.)	R (in.)	L (in.)
121	0.047	1.26	3.49	2.59	0.55	0.27	32.25
122	0.047	1.26	3.52	2.60	0.54	0.27	32.25
123	0.047	2.01	4.25	2.58	0.52	0.27	32.25
124	0.047	2.01	4.25	2.58	0.52	0.27	32.25
125	0.047	2.77	5.01	2.58	0.52	0.27	32.25
126	0.047	2.76	5.00	2.60	0.52	0.27	32.25
127	0.047	3.48	5.75	2.59	0.50	0.27	32.25
128	0.047	3.51	5.81	2.59	0.50	0.27	32.25
129	0.047	1.26	3.51	3.57	0.55	0.27	32.25
130	0.047	1.27	3.56	3.59	0.53	0.27	32.25
131	0.047	1.99	4.25	3.56	0.54	0.27	32.25
132	0.047	2.01	4.27	3.57	0.53	0.27	32.25
133	0.047	2.74	5.04	3.57	0.55	0.27	32.25
134	0.047	3.50	5.77	3.59	0.50	0.27	32.25
135	0.047	3.46	5.71	3.60	0.51	0.27	32.25
136	0.059	1.27	3.63	1.58	0.56	0.28	32.25
137	0.059	1.30	3.68	1.58	0.56	0.28	32.25
138	0.059	1.96	4.19	1.60	0.55	0.28	32.25
139	0.059	1.97	4.22	1.63	0.53	0.28	32.25
140	0.059	2.70	4.95	1.64	0.53	0.28	32.25
141	0.059	2.70	4.96	1.65	0.55	0.28	32.25
142	0.059	3.41	5.60	1.61	0.52	0.28	32.25
143	0.059	1.25	3.49	2.59	0.56	0.28	32.25
144	0.059	1.22	3.49	2.60	0.56	0.28	32.25
145	0.059	2.00	4.29	2.56	0.54	0.28	32.25
146	0.059	2.01	4.24	2.60	0.54	0.28	32.25
147	0.059	2.74	4.99	2.61	0.52	0.28	32.25
148	0.059	3.47	5.76	2.60	0.56	0.28	32.25
149	0.059	3.47	5.69	2.60	0.55	0.28	32.25
150	0.059	1.26	3.52	3.55	0.53	0.28	32.25
151	0.059	1.28	3.57	3.55	0.51	0.28	32.25
152	0.059	1.99	4.24	3.59	0.56	0.28	32.25
153	0.059	1.99	4.24	3.60	0.58	0.28	32.25
154	0.059	2.73	5.01	3.57	0.54	0.28	32.25
155	0.059	2.75	4.99	3.60	0.56	0.28	32.25
156	0.059	3.52	5.79	3.62	0.58	0.28	32.25
157	0.059	3.41	5.64	3.65	0.52	0.28	32.25

TABLE 7

Parameters and Sectional Properties of Inland Specimens

Specimen No.	t	h/t	N/h	e/h	N/t	R/t
1	0.028	54.4285	1.3123	5.3314	71.4286	9.4286
2	0.028	54.0714	1.3210	5.3666	71.4286	9.4286
3	0.028	54.4285	1.3123	5.3314	71.4286	9.4286
4	0.028	54.0714	1.3210	5.3666	71.4286	9.4286
5	0.028	54.0714	1.3210	5.3666	71.4286	9.4286
6	0.028	54.0714	1.3210	5.3666	71.4286	9.4286
7	0.028	53.0000	1.3477	5.4751	71.4286	9.4286
8	0.028	53.0000	1.3477	5.4751	71.4286	9.4286
9	0.028	51.5714	1.3850	5.6267	71.4286	9.4286
10	0.028	53.7143	1.3298	5.4023	71.4286	9.4286
11	0.028	53.7143	1.3298	5.4023	71.4286	9.4286
12	0.028	89.4285	0.7987	3.2448	71.4286	9.4286
13	0.028	89.4285	0.7987	3.2448	71.4286	9.4286
14	0.028	88.7142	0.8052	3.2709	71.4286	9.4286
15	0.028	90.5000	0.7893	3.2064	71.4286	9.4286
16	0.028	89.4285	0.7987	3.2448	71.4286	9.4286
17	0.028	89.7857	0.7955	3.2319	71.4286	9.4286
18	0.028	87.6428	0.8150	3.3109	71.4286	9.4286
19	0.028	90.1428	0.7924	3.2191	71.4286	9.4286
20	0.028	91.2142	0.7831	3.1813	71.4286	9.4286
21	0.028	90.5000	0.7893	3.2064	71.4286	9.4286
22	0.028	89.0714	0.8019	3.2578	71.4286	9.4286
23	0.028	89.0714	0.8019	3.2578	71.4286	9.4286
24	0.028	124.4285	0.5741	2.3321	71.4286	9.4286
25	0.028	124.4285	0.5741	2.3321	71.4286	9.4286
26	0.028	124.0714	0.5757	2.3388	71.4286	9.4286
27	0.028	124.7857	0.5724	2.3254	71.4286	9.4286
28	0.028	124.4285	0.5741	2.3321	71.4286	9.4286
29	0.028	124.4285	0.5741	2.3321	71.4286	9.4286
30	0.028	125.5000	0.5692	2.3122	71.4286	9.4286
31	0.028	124.7857	0.5724	2.3254	71.4286	9.4286
32	0.028	124.7857	0.5724	2.3254	71.4286	9.4286
33	0.028	124.4285	0.5741	2.3321	71.4286	9.4286
34	0.028	126.2142	0.5659	2.2991	71.4286	9.4286
35	0.035	43.4285	1.3158	5.3454	57.1429	7.6429
36	0.035	43.7143	1.3072	5.3105	57.1429	7.6429
37	0.035	43.1428	1.3245	5.3808	57.1429	7.6429
38	0.035	71.1428	0.8032	3.2631	57.1429	7.6429
39	0.035	71.4285	0.8000	3.2500	57.1429	7.6429
40	0.035	70.8571	0.8065	3.2762	57.1429	7.6429

TABLE 7 (cont'd)

Parameters and Sectional Properties of Inland Specimens

Specimen No.	t	h/t	N/h	e/h	N/t	R/t
41	0.035	99.1428	0.5764	2.3415	57.1429	7.6429
42	0.066	21.6364	1.4006	5.6898	30.3030	4.2879
43	0.066	22.0909	1.3717	5.5727	30.3030	4.2879
44	0.066	21.7879	1.3908	5.6502	30.3030	4.2879
45	0.066	21.6364	1.4006	5.6898	30.3030	4.2879
46	0.066	21.6364	1.4006	5.6898	30.3030	4.2879
47	0.066	21.4848	1.4104	5.7299	30.3030	4.2879
48	0.066	21.6364	1.4006	5.6898	30.3030	4.2879
49	0.066	36.3333	0.8340	3.3882	30.3030	4.2879
50	0.066	36.6364	0.8271	3.3602	30.3030	4.2879
51	0.066	36.6364	0.8271	3.3602	30.3030	4.2879
52	0.066	36.6364	0.8271	3.3602	30.3030	4.2879
53	0.066	37.5455	0.8071	3.2789	30.3030	4.2879
54	0.066	36.7879	0.8237	3.3464	30.3030	4.2879
55	0.066	37.0909	0.8170	3.3190	30.3030	4.2879
56	0.066	36.4848	0.8306	3.3742	30.3030	4.2879
57	0.066	36.6364	0.8271	3.3602	30.3030	4.2879
58	0.066	51.4848	0.5886	2.3911	30.3030	4.2879
59	0.066	51.7879	0.5851	2.3771	30.3030	4.2879
60	0.066	52.2424	0.5800	2.3564	30.3030	4.2879
61	0.066	51.9394	0.5834	2.3702	30.3030	4.2879
62	0.066	51.9394	0.5834	2.3702	30.3030	4.2879
63	0.066	52.0909	0.5817	2.3633	30.3030	4.2879
64	0.066	52.0909	0.5817	2.3633	30.3030	4.2879
65	0.044	34.3636	1.3228	5.3737	45.4545	6.1818
66	0.044	34.8182	1.3055	5.3035	45.4545	6.1818
67	0.044	34.8182	1.3055	5.3035	45.4545	6.1818
68	0.044	35.0454	1.2970	5.2691	45.4545	6.1818
69	0.044	35.0454	1.2970	5.2691	45.4545	6.1818
70	0.044	35.5000	1.2804	5.2017	45.4545	6.1818
71	0.044	34.8182	1.3055	5.3035	45.4545	6.1818
72	0.044	34.8182	1.3055	5.3035	45.4545	6.1818
73	0.044	56.8636	0.7994	3.2474	45.4545	6.1818
74	0.044	57.0909	0.7962	3.2345	45.4545	6.1818
75	0.044	56.6364	0.8026	3.2604	45.4545	6.1818
76	0.044	56.8636	0.7994	3.2474	45.4545	6.1818
77	0.044	56.6364	0.8026	3.2604	45.4545	6.1818
78	0.044	56.8636	0.7994	3.2474	45.4545	6.1818
79	0.044	56.8636	0.7994	3.2474	45.4545	6.1818
80	0.044	57.0909	0.7962	3.2345	45.4545	6.1818

TABLE 7 (cont'd)

Parameters and Sectional Properties of Inland Specimens

Specimen No.	t	h/t	N/h	e/h	N/t	R/t
81	0.044	80.5000	0.5647	2.2939	45.4545	6.1818
82	0.044	80.9545	0.5615	2.2810	45.4545	6.1818
83	0.044	79.1363	0.5744	2.3334	45.4545	6.1818
84	0.044	79.5909	0.5711	2.3201	45.4545	6.1818
85	0.044	80.5000	0.5647	2.2939	45.4545	6.1818
86	0.044	80.7273	0.5631	2.2874	45.4545	6.1818
87	0.044	80.0454	0.5679	2.3069	45.4545	6.1818
88	0.044	80.5000	0.5647	2.2939	45.4545	6.1818
89	0.048	31.7500	1.3123	5.3314	41.6667	5.7083
90	0.048	31.7500	1.3123	5.3314	41.6667	5.7083
91	0.048	31.7500	1.3123	5.3314	41.6667	5.7083
92	0.048	31.9583	1.3038	5.2966	41.6667	5.7083
93	0.048	32.1667	1.2953	5.2623	41.6667	5.7083
94	0.048	32.3750	1.2870	5.2284	41.6667	5.7083
95	0.048	31.5416	1.3210	5.3666	41.6667	5.7083
96	0.048	32.1667	1.2953	5.2623	41.6667	5.7083
97	0.048	52.5833	0.7924	3.2191	41.6667	5.7083
98	0.048	52.7916	0.7893	3.2064	41.6667	5.7083
99	0.048	52.1667	0.7987	3.2448	41.6667	5.7083
100	0.048	52.3750	0.7955	3.2319	41.6667	5.7083
101	0.048	53.2083	0.7831	3.1813	41.6667	5.7083
102	0.048	51.9583	0.8019	3.2578	41.6667	5.7083
103	0.048	52.1667	0.7987	3.2448	41.6667	5.7083
104	0.048	51.3333	0.8117	3.2975	41.6667	5.7083
105	0.048	52.5833	0.7924	3.2191	41.6667	5.7083
106	0.048	72.3750	0.5757	2.3388	41.6667	5.7083
107	0.048	72.7916	0.5724	2.3254	41.6667	5.7083
108	0.048	73.2083	0.5692	2.3122	41.6667	5.7083
109	0.048	71.9583	0.5790	2.3523	41.6667	5.7083
110	0.048	73.0000	0.5708	2.3188	41.6667	5.7083
111	0.048	72.7916	0.5724	2.3254	41.6667	5.7083
112	0.048	73.6250	0.5659	2.2991	41.6667	5.7083
113	0.047	32.2553	1.3193	5.3595	42.5532	5.8191
114	0.047	32.4681	1.3106	5.3244	42.5532	5.8191
115	0.047	32.2553	1.3193	5.3595	42.5532	5.8191
116	0.047	32.4681	1.3106	5.3244	42.5532	5.8191
117	0.047	32.4681	1.3106	5.3244	42.5532	5.8191
118	0.047	32.4681	1.3106	5.3244	42.5532	5.8191
119	0.047	32.6808	1.3021	5.2897	42.5532	5.8191
120	0.047	33.1064	1.2853	5.2217	42.5532	5.8191

TABLE 7 (cont'd)

Parameters and Sectional Properties of Inland Specimens

Specimen No.	t	h/t	N/h	e/h	N/t	R/t
121	0.047	53.1064	0.8013	3.2552	42.5532	5.8191
122	0.047	53.3191	0.7981	3.2422	42.5532	5.8191
123	0.047	52.8936	0.8045	3.2683	42.5532	5.8191
124	0.047	52.8936	0.8045	3.2683	42.5532	5.8191
125	0.047	52.8936	0.8045	3.2683	42.5532	5.8191
126	0.047	53.3191	0.7981	3.2422	42.5532	5.8191
127	0.047	53.1064	0.8013	3.2552	42.5532	5.8191
128	0.047	53.1064	0.8013	3.2552	42.5532	5.8191
129	0.047	73.9574	0.5754	2.3375	42.5532	5.8191
130	0.047	74.3830	0.5721	2.3241	42.5532	5.8191
131	0.047	73.7447	0.5770	2.3442	42.5532	5.8191
132	0.047	73.9574	0.5754	2.3375	42.5532	5.8191
133	0.047	73.9574	0.5754	2.3375	42.5532	5.8191
134	0.047	74.3830	0.5721	2.3241	42.5532	5.8191
135	0.047	74.5957	0.5705	2.3175	42.5532	5.8191
136	0.059	24.7796	1.3680	5.5575	33.8983	4.7373
137	0.059	24.7796	1.3680	5.5575	33.8983	4.7373
138	0.059	25.1186	1.3495	5.4825	33.8983	4.7373
139	0.059	25.6271	1.3228	5.3737	33.8983	4.7373
140	0.059	25.7966	1.3141	5.3384	33.8983	4.7373
141	0.059	25.9661	1.3055	5.3035	33.8983	4.7373
142	0.059	25.2881	1.3405	5.4457	33.8983	4.7373
143	0.059	41.8983	0.8091	3.2868	33.8983	4.7373
144	0.059	42.0678	0.8058	3.2736	33.8983	4.7373
145	0.059	41.3898	0.8190	3.3272	33.8983	4.7373
146	0.059	42.0678	0.8058	3.2736	33.8983	4.7373
147	0.059	42.2373	0.8026	3.2604	33.8983	4.7373
148	0.059	42.0678	0.8058	3.2736	33.8983	4.7373
149	0.059	42.0678	0.8058	3.2736	33.8983	4.7373
150	0.059	58.1695	0.5828	2.3674	33.8983	4.7373
151	0.059	58.1695	0.5828	2.3674	33.8983	4.7373
152	0.059	58.8475	0.5760	2.3401	33.8983	4.7373
153	0.059	59.0170	0.5744	2.3334	33.8983	4.7373
154	0.059	58.5085	0.5794	2.3537	33.8983	4.7373
155	0.059	59.0170	0.5744	2.3334	33.8983	4.7373
156	0.059	59.3559	0.5711	2.3201	33.8983	4.7373
157	0.059	59.8644	0.5663	2.3004	33.8983	4.7373

TABLE 8

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the Design Recommendations Proposed in Ref. 7

Specimen No.	P_m (kips)	P_{cy} (kips)	P_{mc} (kips)	P_{cb} (kips)	P_{ms} (kips)	P_{test} (kips)	Predicted Failure Mode	$\frac{P_{test}}{P_{comp}}$
1	1.143	2.741	1.084	1.639	1.201	1.01	MC	0.931
2	1.139	2.741	1.083	1.639	1.198	0.98	MC	0.905
3	1.158	2.741	1.095	1.639	1.215	1.01	MC	0.923
4	1.319	2.741	1.196	1.639	1.383	0.97	MC	0.811
5	1.331	2.741	1.202	1.639	1.395	1.01	MC	0.840
6	1.355	2.741	1.218	1.639	1.420	1.00	MC	0.821
7	1.319	2.741	1.196	1.639	1.388	1.01	MC	0.844
8	1.318	2.741	1.197	1.639	1.388	1.00	MC	0.836
9	1.284	2.741	1.177	1.639	1.360	1.02	MC	0.867
10	1.360	2.741	1.221	1.639	1.426	1.00	MC	0.819
11	1.361	2.741	1.221	1.639	1.428	0.99	MC	0.811
12	2.281	2.741	1.629	2.502	2.074	1.40	MC	0.859
13	2.277	2.741	1.628	2.502	2.071	1.28	MC	0.786
14	2.274	2.741	1.626	2.489	2.072	1.37	MC	0.843
15	2.566	2.741	1.732	2.521	2.277	1.41	MC	0.814
16	2.535	2.741	1.722	2.502	2.260	1.44	MC	0.836
17	2.549	2.741	1.727	2.508	2.268	1.43	MC	0.828
18	2.517	2.741	1.715	2.470	2.256	1.40	MC	0.816
19	2.603	2.741	1.744	2.515	2.304	1.41	MC	0.808
20	2.636	2.741	1.754	2.533	2.321	1.40	MC	0.798
21	2.647	2.741	1.760	2.521	2.333	1.37	MC	0.779
22	2.603	2.741	1.746	2.496	2.310	1.38	MC	0.791
23	2.601	2.741	1.745	2.496	2.308	1.38	MC	0.791
24	3.347	2.741	1.963	2.862	2.448	1.66	MC	0.846
25	3.361	2.741	1.966	2.862	2.453	1.66	MC	0.844
26	3.362	2.741	1.969	2.861	2.457	1.64	MC	0.833
27	3.691	2.741	2.048	2.863	2.569	1.69	MC	0.825
28	3.666	2.741	2.042	2.862	2.564	1.67	MC	0.818
29	3.693	2.741	2.049	2.862	2.574	1.69	MC	0.825
30	3.725	2.741	2.054	2.865	2.573	1.64	MC	0.798
31	3.709	2.741	2.051	2.863	2.575	1.66	MC	0.809
32	3.733	2.741	2.058	2.863	2.583	1.69	MC	0.821
33	3.725	2.741	2.055	2.862	2.584	1.68	MC	0.817
34	3.770	2.741	2.066	2.867	2.580	1.62	MC	0.784
35	2.811	7.764	2.794	2.561	2.902	2.47	B	0.964

TABLE 8 (cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the Design Recommendations Proposed in Ref. 7

Specimen No.	P_m (kips)	P_{cy} (kips)	P_{mc} (kips)	P_{cb} (kips)	P_{ms} (kips)	P_{test} (kips)	Predicted Failure Mode	$\frac{P_{test}}{P_{comp}}$
36	2.860	7.764	2.832	2.561	2.947	2.56	B	1.000
37	2.857	7.764	2.831	2.561	2.955	2.56	B	1.000
38	5.828	7.764	4.362	3.896	5.010	3.40	B	0.873
39	5.822	7.764	4.358	3.906	5.001	3.53	B	0.904
40	5.784	7.764	4.341	3.885	4.987	3.50	B	0.901
41	8.294	7.764	5.235	4.604	5.365	4.53	B	0.984
42	3.425	25.027	3.425	9.107	4.128	5.04	M	1.471
43	5.149	25.027	5.149	9.107	6.216	5.28	M	1.025
44	5.533	25.027	5.533	9.107	6.697	5.10	M	0.922
45	5.560	25.027	5.560	9.107	6.743	5.04	M	0.906
46	5.563	25.027	5.563	9.107	6.747	5.16	M	0.927
47	5.734	25.027	5.734	9.107	6.967	5.40	M	0.942
48	5.775	25.027	5.775	9.107	7.007	5.16	M	0.894
49	7.874	25.027	7.874	13.510	8.680	7.98	M	1.013
50	7.419	25.027	7.419	13.587	8.175	7.86	M	1.059
51	7.453	25.027	7.453	13.587	8.211	7.74	M	1.039
52	10.330	25.027	9.968	13.587	11.292	8.16	MC	0.819
53	10.664	25.027	10.173	13.809	11.590	7.56	MC	0.743
54	11.111	25.027	10.480	13.625	12.103	8.52	MC	0.813
55	11.208	25.027	10.545	13.699	12.187	8.28	MC	0.785
56	11.342	25.027	10.634	13.549	12.363	7.62	MC	0.717
57	11.538	25.027	10.758	13.587	12.559	7.74	MC	0.719
58	13.152	25.027	11.580	16.234	13.214	10.02	MC	0.865
59	16.768	25.027	13.442	16.273	16.468	9.66	MC	0.719
60	16.849	25.027	13.476	16.329	16.491	10.38	MC	0.770
61	17.891	25.027	13.958	16.292	17.423	10.14	MC	0.726
62	17.894	25.027	13.960	16.292	17.426	10.20	MC	0.731
63	18.603	25.027	14.258	16.310	18.011	10.68	MC	0.749
64	18.612	25.027	14.269	16.310	18.017	10.20	MC	0.715
65	3.189	11.816	3.189	4.047	3.511	3.36	M	1.054
66	3.247	11.816	3.247	4.047	3.565	3.48	M	1.072
67	3.924	11.816	3.924	4.047	4.299	3.36	M	0.856
68	3.951	11.816	3.951	4.047	4.323	3.48	M	0.881
69	4.099	11.816	4.099	4.047	4.482	3.54	B	0.875
70	4.167	11.816	4.167	4.047	4.544	3.48	B	0.860

TABLE 8 (cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the Design Recommendations Proposed in Ref. 7

Specimen No.	P_m (kips)	P_{cy} (kips)	P_{mc} (kips)	P_{cb} (kips)	P_{ms} (kips)	P_{test} (kips)	Predicted Failure Mode	$\frac{P_{test}}{P_{comp}}$
71	4.128	11.816	4.128	4.047	4.521	3.72	B	0.919
72	4.128	11.816	4.128	4.047	4.520	3.72	B	0.919
73	6.900	11.816	5.719	6.176	6.501	5.04	MC	0.881
74	6.949	11.816	5.743	6.191	6.539	5.04	MC	0.878
75	7.758	11.816	6.140	6.160	7.206	5.16	MC	0.840
76	7.793	11.816	6.162	6.176	7.231	5.34	MC	0.867
77	7.971	11.816	6.244	6.160	7.376	5.40	B	0.877
78	8.004	11.816	6.259	6.176	7.398	5.40	B	0.874
79	8.115	11.816	6.312	6.176	7.486	5.28	B	0.855
80	8.147	11.816	6.326	6.191	7.506	4.98	B	0.804
81	10.268	11.816	7.186	7.333	8.215	6.60	MC	0.918
82	10.319	11.816	7.207	7.349	8.225	6.48	MC	0.899
83	11.324	11.816	7.553	7.285	8.787	6.42	B	0.881
84	11.439	11.816	7.596	7.302	8.820	6.60	B	0.904
85	11.799	11.816	7.711	7.333	8.939	6.90	B	0.941
86	11.858	11.816	7.732	7.341	8.954	6.96	B	0.948
87	11.842	11.816	7.727	7.318	8.979	6.72	B	0.918
88	11.928	11.816	7.754	7.333	8.995	6.72	B	0.916
89	3.431	14.216	3.431	4.817	3.846	4.02	M	1.172
90	3.435	14.216	3.435	4.817	3.852	4.08	M	1.188
91	4.226	14.216	4.226	4.817	4.732	3.84	M	0.909
92	4.260	14.216	4.260	4.817	4.765	3.96	M	0.930
93	4.495	14.216	4.495	4.817	5.017	4.14	M	0.921
94	4.538	14.216	4.538	4.817	5.057	4.08	M	0.899
95	4.481	14.216	4.481	4.817	5.020	4.26	M	0.951
96	4.589	14.216	4.589	4.817	5.121	4.20	M	0.915
97	7.148	14.216	6.340	7.390	6.996	5.88	MC	0.927
98	7.093	14.216	6.302	7.409	6.937	5.64	MC	0.895
99	8.472	14.216	7.073	7.353	8.198	6.12	MC	0.865
100	8.532	14.216	7.093	7.372	8.238	6.24	MC	0.880
101	8.699	14.216	7.163	7.445	8.336	6.12	MC	0.854
102	8.693	14.216	7.192	7.334	8.402	6.24	MC	0.868
103	8.745	14.216	7.210	7.353	8.435	6.18	MC	0.857
104	8.686	14.216	7.195	7.277	8.431	6.06	MC	0.842
105	8.999	14.216	7.323	7.390	8.628	6.18	MC	0.844

TABLE 8 (cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the Design Recommendations Proposed in Ref. 7

Specimen No.	P_m (kips)	P_{cy} (kips)	P_{mc} (kips)	P_{cb} (kips)	P_{ms} (kips)	P_{test} (kips)	Predicted Failure Mode	$\frac{P_{test}}{P_{comp}}$
106	11.271	14.216	8.230	8.662	9.572	7.32	MC	0.889
107	11.267	14.216	8.226	8.682	9.554	7.26	MC	0.883
108	12.829	14.216	8.816	8.701	10.432	7.20	B	0.828
109	12.942	14.216	8.855	8.643	10.554	7.56	B	0.875
110	13.145	14.216	8.932	8.691	10.610	7.80	B	0.897
111	13.267	14.216	8.969	8.682	10.685	7.32	B	0.843
112	13.395	14.216	9.015	8.720	10.707	7.80	B	0.895
113	3.713	14.971	3.713	4.618	4.119	4.56	M	1.228
114	3.738	14.971	3.738	4.618	4.140	4.56	M	1.220
115	4.489	14.971	4.489	4.618	4.969	4.56	M	1.016
116	4.526	14.971	4.526	4.618	5.004	4.56	M	1.008
117	4.690	14.971	4.690	4.618	5.183	4.44	B	0.961
118	4.693	14.971	4.693	4.618	5.186	4.56	B	0.987
119	4.816	14.971	4.816	4.618	5.313	4.74	B	1.026
120	4.915	14.971	4.915	4.618	5.405	4.68	B	1.013
121	7.931	14.971	6.836	7.036	7.554	6.72	MC	0.983
122	7.995	14.971	6.931	7.054	7.597	6.96	MC	1.004
123	8.960	14.971	7.395	7.017	8.437	7.08	B	1.009
124	8.960	14.971	7.394	7.017	8.437	6.96	B	0.992
125	9.211	14.971	7.522	7.017	8.645	7.20	B	1.026
126	9.315	14.971	7.559	7.054	8.704	7.20	B	1.021
127	9.396	14.971	7.611	7.036	8.783	7.20	B	1.023
128	9.416	14.971	7.620	7.036	8.799	7.20	B	1.023
129	11.911	14.971	8.690	8.307	9.757	8.52	B	1.026
130	12.055	14.971	8.738	8.326	9.816	8.52	B	1.023
131	13.191	14.971	9.172	8.298	10.435	8.64	B	1.041
132	13.242	14.971	9.193	8.307	10.449	8.28	B	0.997
133	13.584	14.971	9.314	8.307	10.614	9.12	B	1.098
134	13.782	14.971	9.376	8.326	10.684	8.76	B	1.052
135	13.806	14.971	9.392	8.335	10.682	9.12	B	1.094
136	4.475	25.203	4.475	7.278	5.215	5.76	M	1.287
137	4.553	25.203	4.553	7.278	5.305	5.76	M	1.265
138	5.770	25.203	5.770	7.278	6.718	6.00	M	1.040
139	5.942	25.203	5.942	7.278	6.891	6.24	M	1.050
140	6.328	25.203	6.328	7.278	7.329	6.24	M	0.986

TABLE 8 (cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the Design Recommendations Proposed in Ref. 7

Specimen No.	P_m (kips)	P_{cy} (kips)	P_{mc} (kips)	P_{cb} (kips)	P_{ms} (kips)	P_{test} (kips)	Predicted Failure Mode	$\frac{P_{test}}{P_{comp}}$
141	6.383	25.203	6.383	7.278	7.382	6.24	M	0.978
142	6.295	25.203	6.295	7.278	7.322	6.00	M	0.953
143	9.462	25.203	9.360	11.018	9.859	9.36	MC	1.000
144	9.421	25.203	9.380	11.047	9.808	9.60	MC	1.023
145	11.461	25.203	10.672	10.930	11.870	9.48	MC	0.888
146	11.693	25.203	10.817	11.047	12.057	9.72	MC	0.899
147	12.283	25.203	11.168	11.075	12.616	9.84	B	0.888
148	12.485	25.203	11.299	11.047	12.818	9.84	B	0.891
149	12.433	25.203	11.271	11.047	12.772	9.84	B	0.891
150	15.483	25.203	12.589	13.025	14.096	11.52	MC	0.915
151	15.608	25.203	12.652	13.025	14.190	12.36	MC	0.977
152	18.575	25.203	14.019	13.085	16.266	12.24	B	0.935
153	18.646	25.203	14.049	13.099	16.302	12.24	B	0.934
154	19.184	25.203	14.272	13.055	16.693	12.36	B	0.947
155	19.353	25.203	14.339	13.099	16.768	12.36	B	0.944
156	19.859	25.203	14.543	13.128	17.069	12.96	B	0.987
157	19.945	25.203	14.581	13.171	17.085	12.60	B	0.957
Mean Value:								0.916
Standard Deviation:								0.116

** NOTE : Failure Mode
B - represent web buckling
M - represent bending moment
MC - represent combined bending and web crippling
MS - represent combined bending and shear

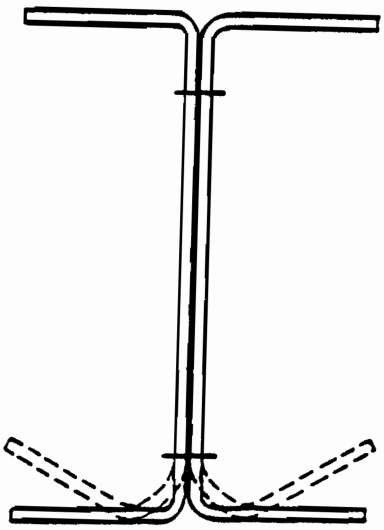


Fig. 1 Sketch Showing Failure at Web-Flange Junction

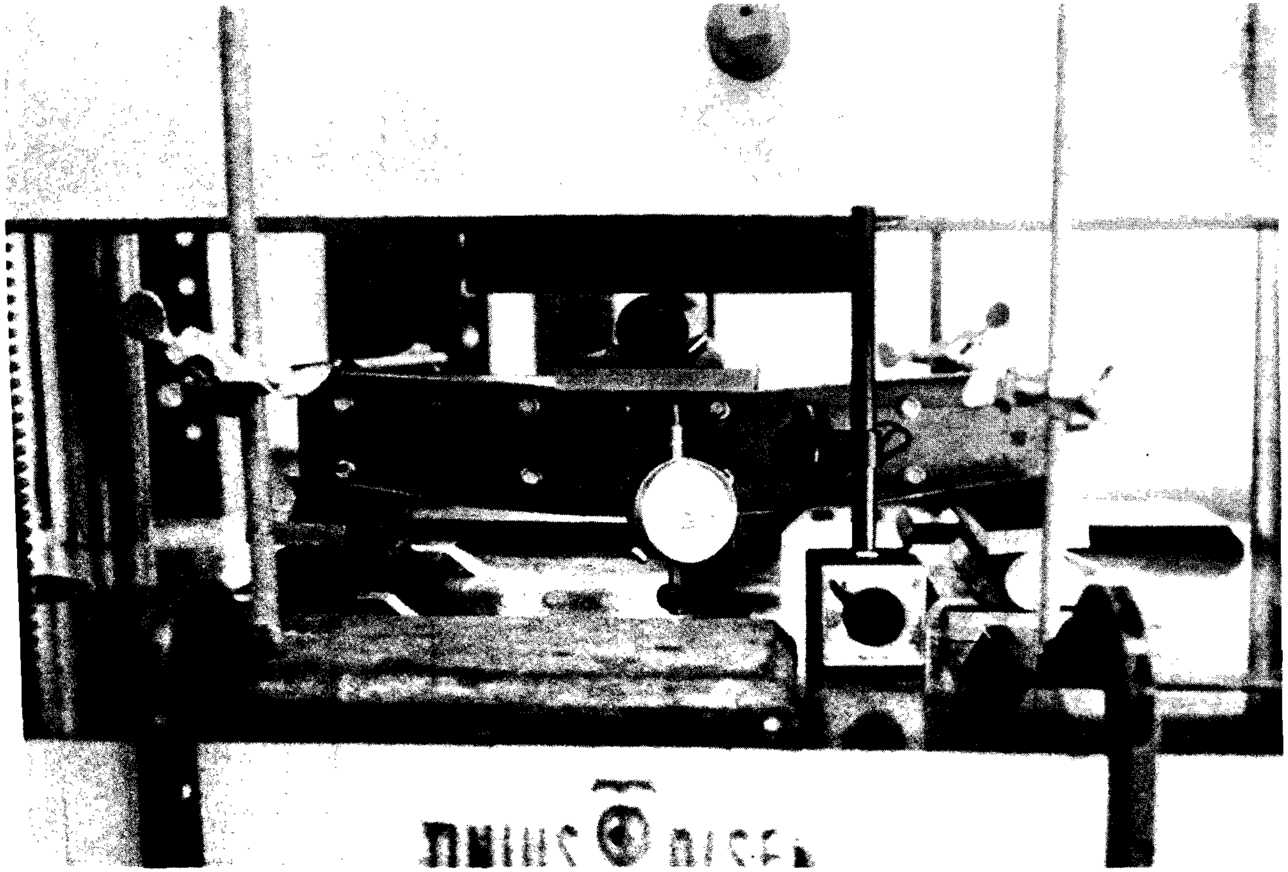


Fig. 2 Photograph Showing Failure of an I-Beam Subjected to End One-Flange Loading

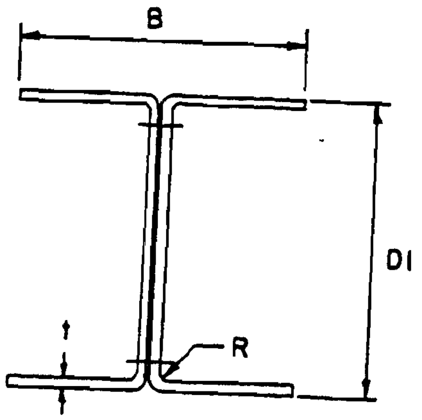


Fig. 3 I-Sections Used in the Experimental Study

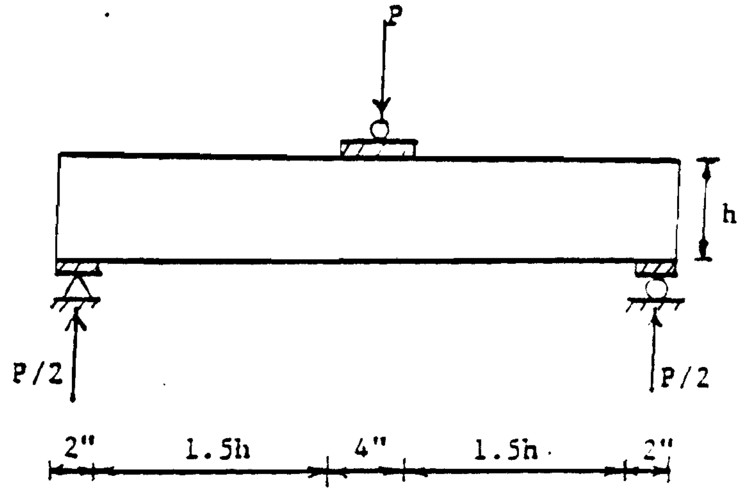


Fig. 4 Test Setup for Web Crippling under End One-Flange Loading

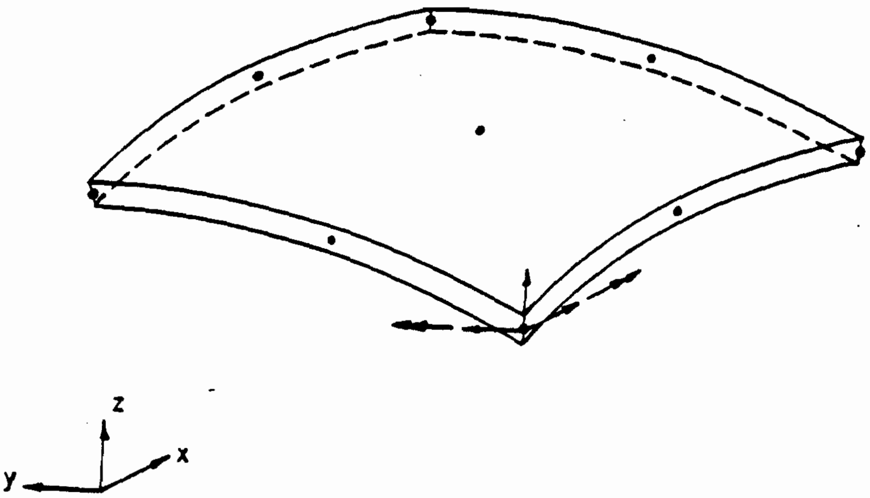


Fig. 5 A Typical 9-Node Thin Shell Element with 5 D.O.F. at Each Node

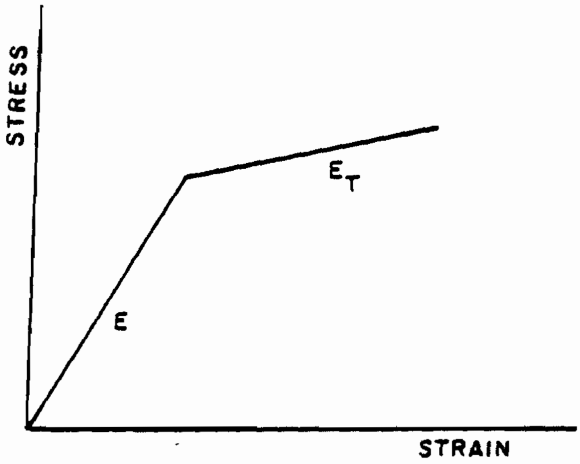
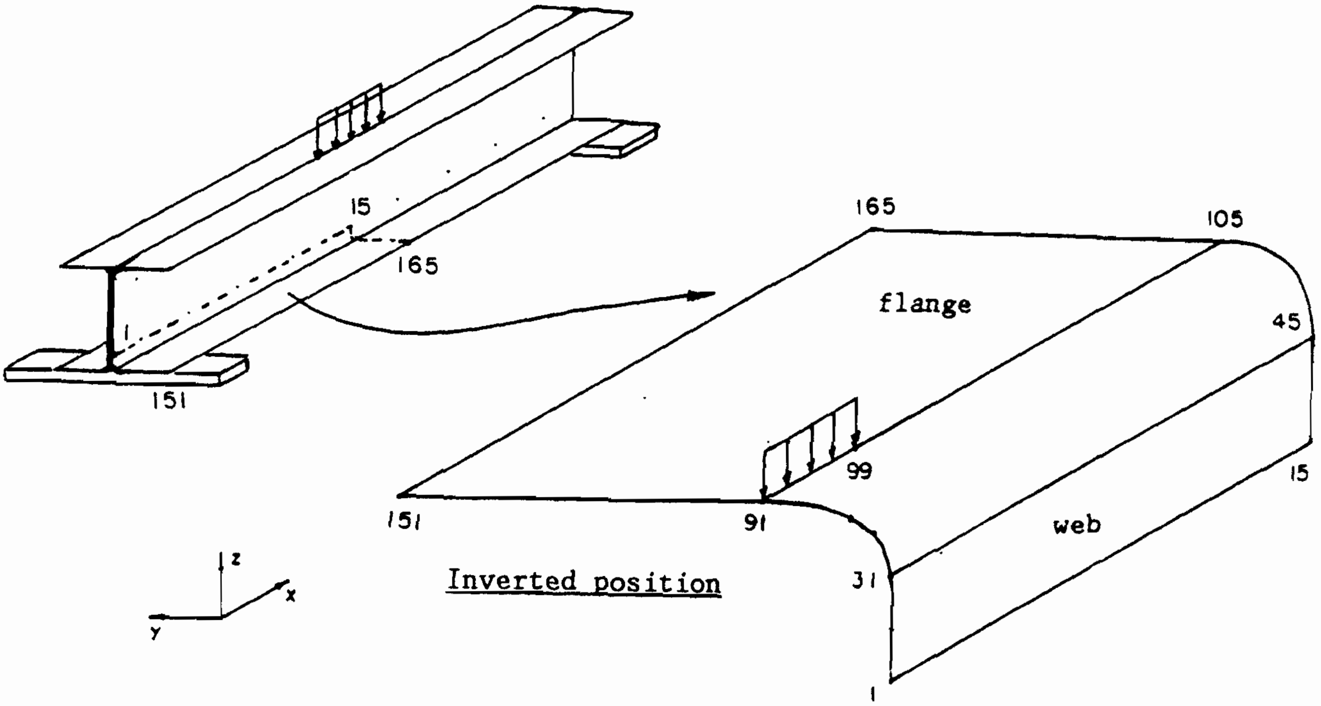
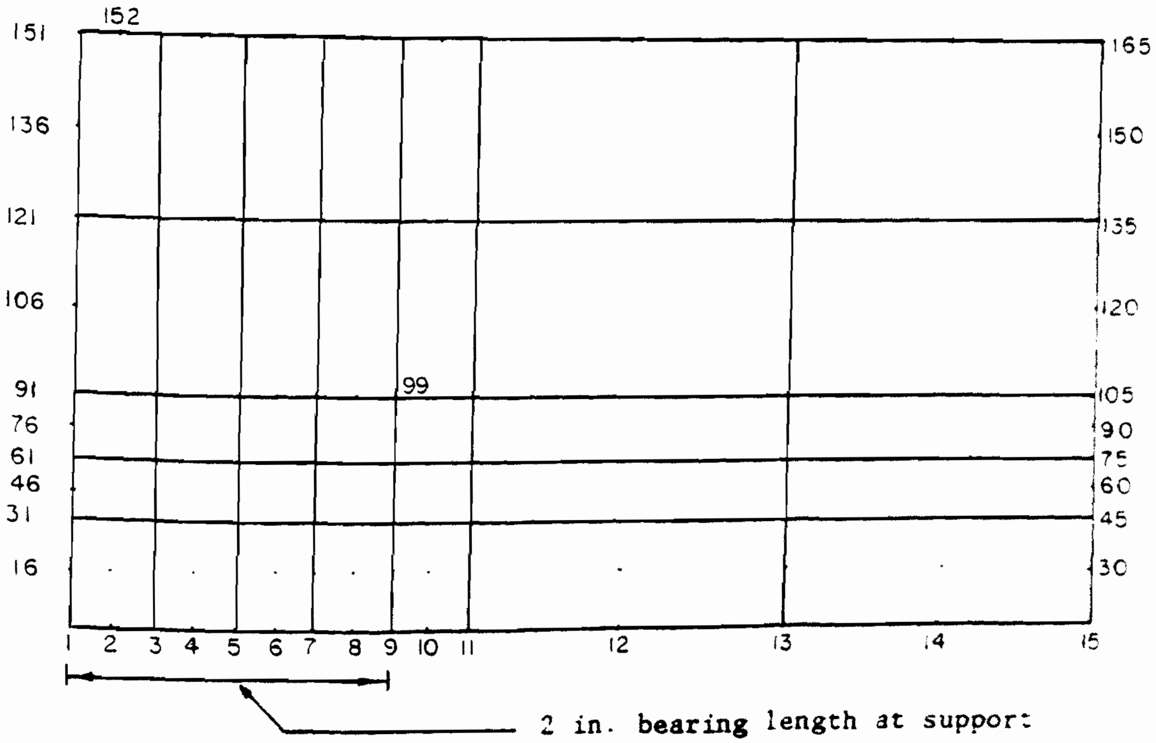


Fig. 6 Stress-Strain Relationships of the Elastic-Linear Strain Hardening Material



(a) Analyzed Portion of the Test Specimen



(b) Finite Element Mesh Used in This Study

Fig. 7 Finite Element Model of an I-Beam Subjected to End One-Flange Loading

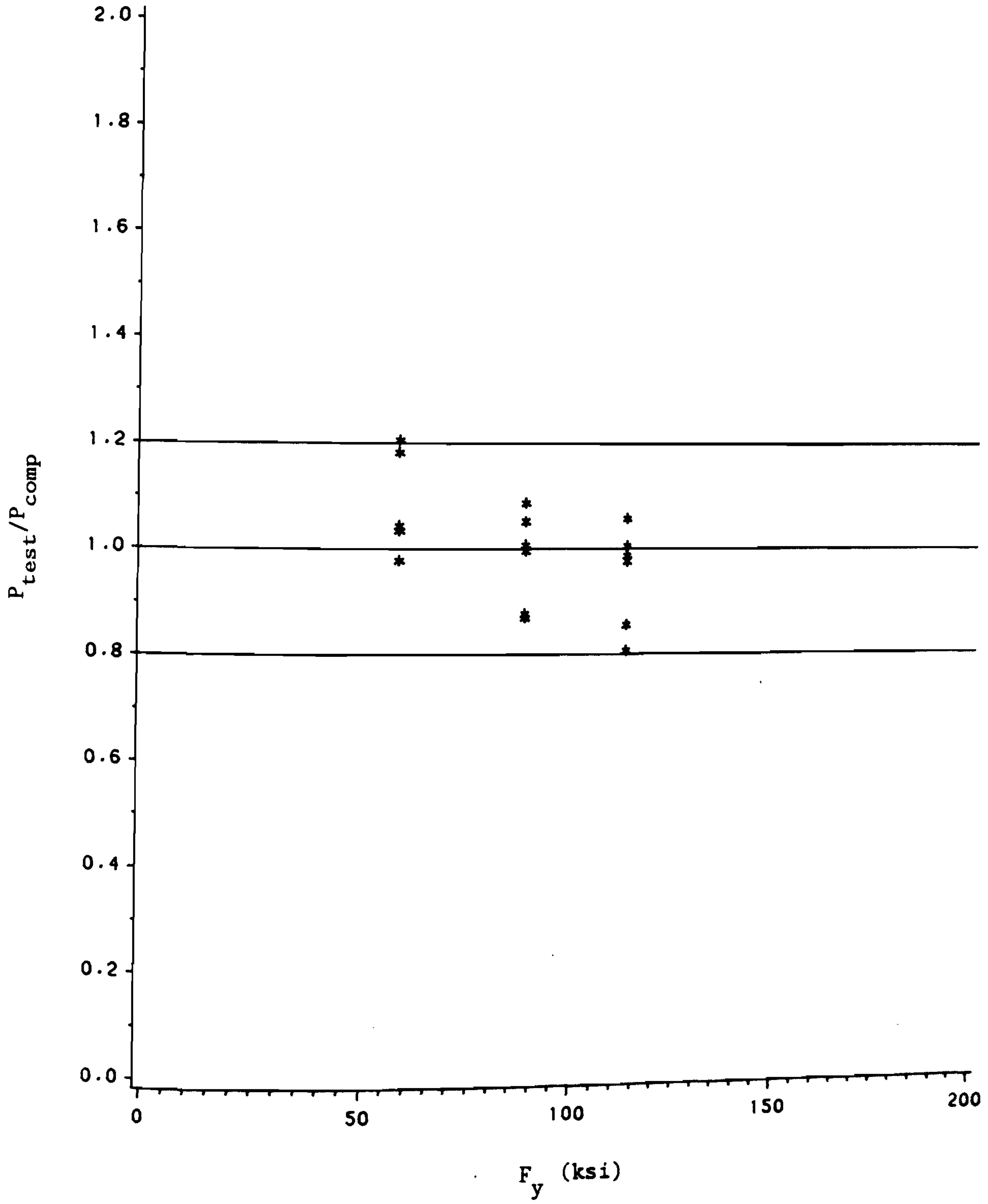


Fig. 8 Effect of F_y on the Ratio of P_{test}/P_{comp} for I-Beams Subjected to End One-Flange Loading Based on the New Design Formula

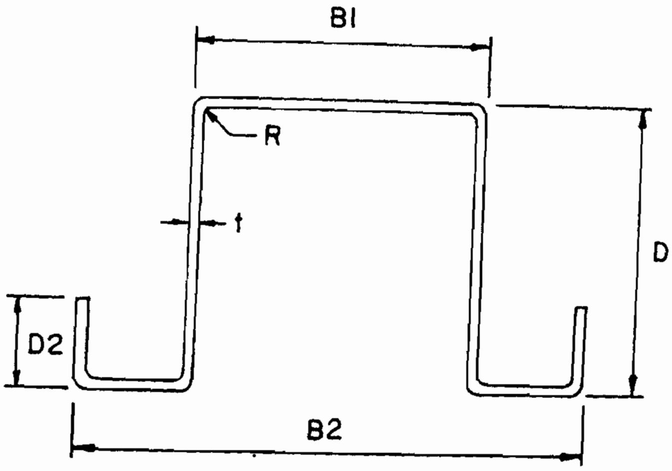


Fig. 9 Hat Sections Used for Inland Tests

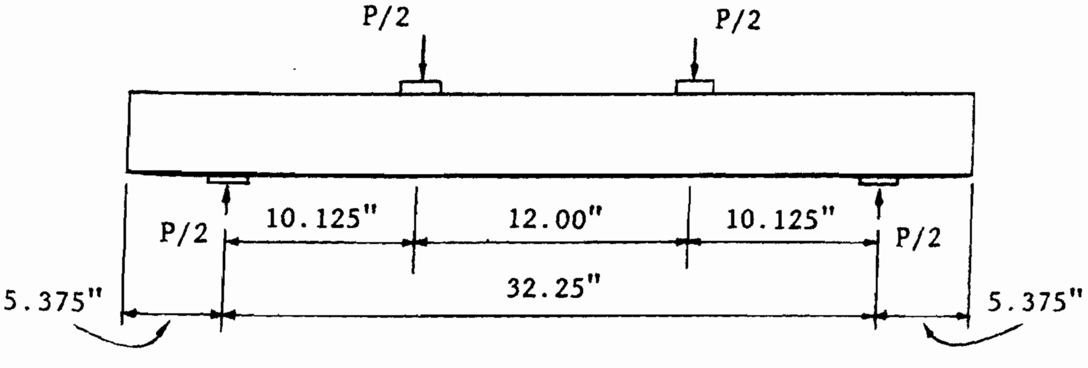


Fig. 10 Test Arrangement for Inland Tests[10]

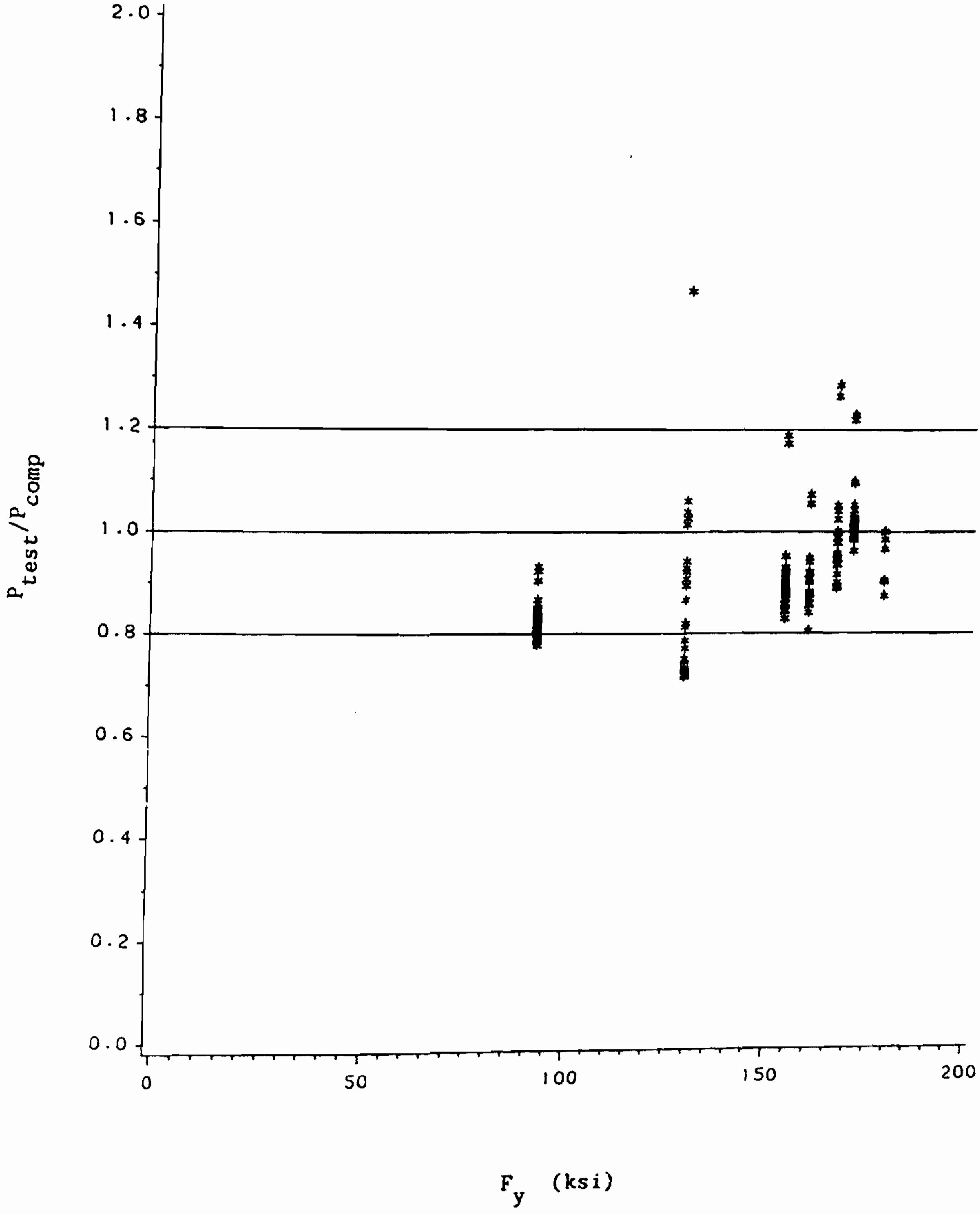


Fig. 11 Effect of F_y on the Ratio of P_{test}/P_{comp} for Inland Tests Based on the Proposed Design Recommendations

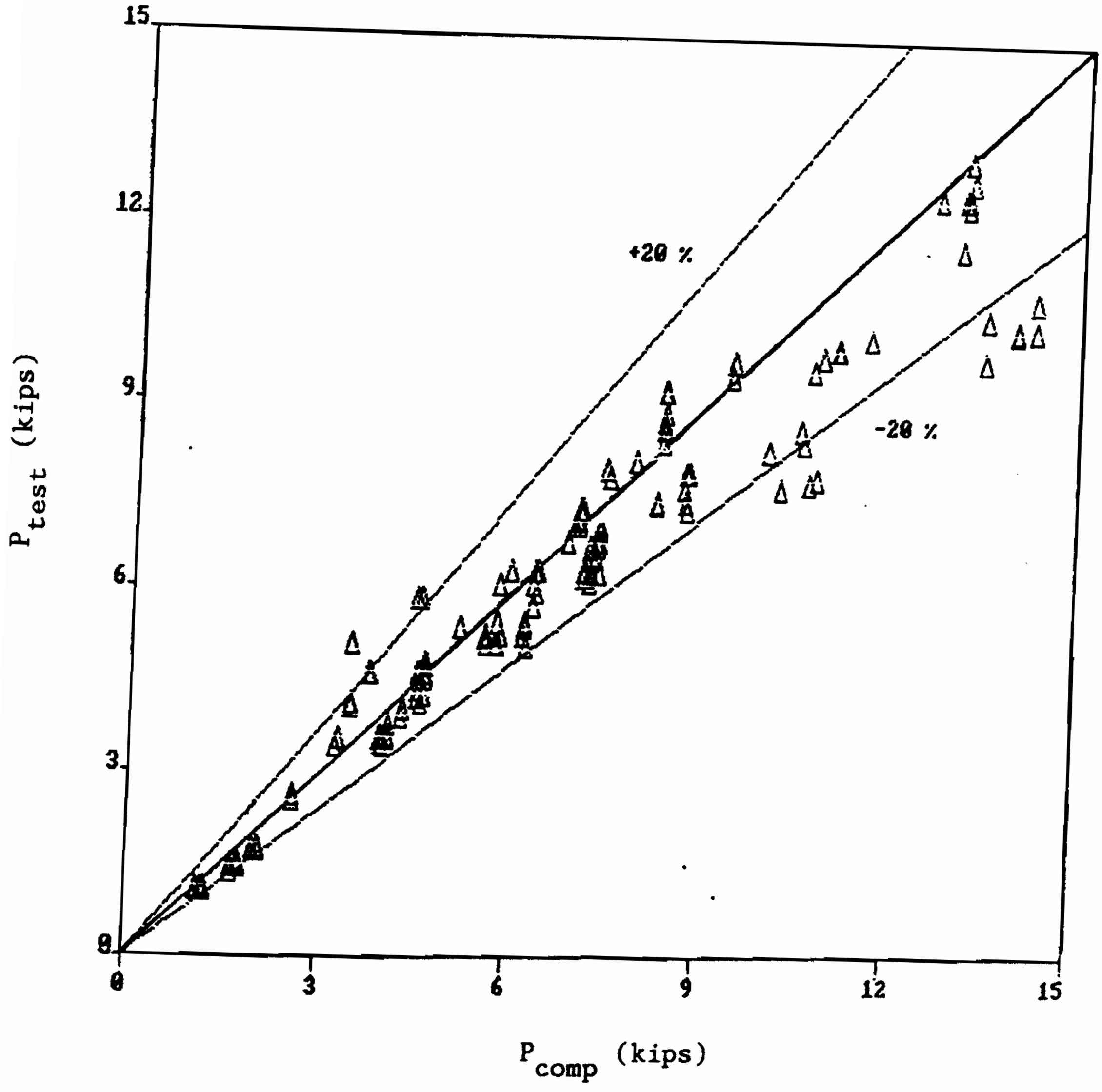


Fig. 12 Tested Load, P_{test}, vs. Computed Load, P_{comp}, for Inland Tests Based on the Design Recommendations Proposed in Ref. 7

APPENDIX A

COMPUTER PROGRAM USED IN THE PREDICTIONS OF FAILURE LOADS BASED ON THE DESIGN RECOMMENDATIONS PROPOSED IN REF. 7

```
C***********************************************************************
C*   THIS PROGRAM PREDICTS THE ULTIMATE LOADS FOR INLAND TEST DATA   *
C*        BASED ON THE DESIGN RECOMMENDATIONS PROPOSED IN REF. 7     *
C***********************************************************************
C
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT
      DIMENSION PC(200),PM(200),PMC(200),PTEST(200),RATIO(200),
     /PMS(200),PS(200),PBW(200),PCB(200),PMM(200),LS(200)
C
C.....NN=TOTAL NUMBER OF TEST DATA
C
      READ(5,*)NN
      WRITE(6,1003)
      DO 60 I=1,NN
      READ(5,*)LS(I),HH,WW,WW1,WW2,DD1,DD2,R,T,BRG,FY,FU,SPAN,PTEST(I)
      D1=HH
      B1=WW+2.0*(R+T)
      B2=B1+WW1+WW2+4.0*R+2.0*T
      D2=(DD1+DD2)/2.0
      H=D1-2.*T
      TH=H/T
      IF(TH.LT.110.)TH=110.
      EH=5.125/H
      IF(EH.GT.5.0)EH=5.0
      TR=R/T
      IF(TR.GT.7.0)TR=7.0
      TN=BRG/T
      IF(TN.GT.100.0)TN=100.0
      HN=BRG/H
      IF(HN.GT.0.4)HN=0.4
C
C.....CALCULATE FLEXURAL YIELD MOMENT
C
      CALL MY1
C
C.....CALCULATE MOMENT,SHEAR,COMBINE MOMENT & SHEAR IN WEB
C
      CALL WEB(SPAN,SMP,SMP1,SP,SP1,BWP,BWP1)
      PS(I)=SP
      PBW(I)=BWP
      PMS(I)=SMP
      PC(I)=4.*7.80*T**2.*FY*(1.+0.2167*TN**0.5)*(1.-0.0814*TR)
      PCB(I)=4.*820.*T**2.*(1.+2.4*HN)*(1.-0.0017*TH)*(1.-0.12*EH)
C
C.....FOR RAM LOAD-MOMENT = 1/6*(P*L)
C
      PM(I)=XM/5.0625
C
C.....COMPARE FLEXURAL MOMENT TO MOMENT IN WEB
C
      IF(PM(I).GT.PBW(I)) PM(I)=PBW(I)
C
C.....COMBINED MOMENT AND WEB CRIPPING
```

```
C
C     PMC(I)=1.42*PM(I)*PC(I)/(PC(I)+1.10*PM(I))
      ASSUMP=PTEST(I)
 3000 AA=(ASSUMP/PBW(I))+1.045*(ASSUMP/PC(I))
      AAA=ABS(1.-1.341/AA)
      IF(AAA.LT.0.005) GO TO 4000
      ASSUMP=ASSUMP+0.2*ASSUMP*(1.341-AA)
      GO TO 3000
 4000 PMC(I)=ASSUMP
      IF(PMC(I)/PC(I).LT.0.3263) PMC(I)=PBW(I)
      IF(PMC(I)/PBW(I).LT.0.296) PMC(I)=PC(I)
      IF(PMC(I).GT.PM(I)) PMC(I)=PM(I)
      IF(PMC(I).GT.PC(I)) PMC(I)=PC(I)
      PMM(I)=PMC(I)
      IF(PMC(I).GT.PCB(I)) PMC(I)=PCB(I)
C...  AA=PS(I)
      AA=PCB(I)
C...  BB=PMC(I)
      BB=PMM(I)
      CC=PMS(I)
C
C.....SELECT SMALLEST FAILURE LOAD
C
      CALL SELECT(AA,BB,CC,NF)
      GO TO (101,102,103),NF
C101  RATIO(I)=PS(I)/PTEST(I)..........
 101  RATIO(I)=PCB(I)/PTEST(I)
      RATIO(I)=1./RATIO(I)
      WRITE(6,800)I,PM(I),PC(I),PMM(I),PCB(I),PMS(I),PTEST(I),
     /            RATIO(I)
      GO TO 60
C102  RATIO(I)=PMC(I)/PTEST(I).........
 102  RATIO(I)=PMM(I)/PTEST(I)
      RATIO(I)=1./RATIO(I)
      IF(PM(I).EQ.PMM(I))GO TO 67
      WRITE(6,808)I,PM(I),PC(I),PMM(I),PCB(I),PMS(I),PTEST(I),
     /            RATIO(I)
      GO TO 60
 67   WRITE(6,818)I,PM(I),PC(I),PMM(I),PCB(I),PMS(I),PTEST(I),
     /            RATIO(I)
      GO TO 60
 103  RATIO(I)=PMS(I)/PTEST(I)
      RATIO(I)=1./RATIO(I)
      WRITE(6,828)I,PM(I),PC(I),PMM(I),PCB(I),PMS(I),PTEST(I),
     /            RATIO(I)
C
 60   CONTINUE
C
 800  FORMAT(1X,I3,6F9.3,5X,'B ',F9.3)
 808  FORMAT(1X,I3,6F9.3,5X,'MC',F9.3)
 818  FORMAT(1X,I3,6F9.3,5X,'M ',F9.3)
 828  FORMAT(1X,I3,6F9.3,5X,'MS',F9.3)
 1003 FORMAT(/2X,'SPC',4X,'PM',7X,'PC',7X,'PMC',6X,'PB',6X,'PMS',6X,
```

```
     /         'PTEST',4X,'MODE',3X,'PTEST/PCOM'/)
C
      STOP
      END
C
C
C--------------------------------------------------------------------
C
      SUBROUTINE MY1
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT
      W=B1-2.*(R+T)
      W1=(B2-B1)/2.-T-2.*R
      D3=D1-2.*(R+T)
      D4=D2-(R+T)
      R1=R+T/2.
      U1=1.57*R1
      C1=0.637*R1
      WT=W/T
      H1=2.*D4
      H2=4.*U1
      H3=2.*W1
      H4=2.*D3
      H5=2.*U1
      HL=H1+H2+H3+H4+H5
      Y1=D1-R-T-D4/2.
      Y2=D1-R-T+C1
      Y3=D1-T/2.
      Y4=D1/2.
      Y5=R+T-C1
      HY1=H1*Y1
      HY2=H2*Y2
      HY3=H3*Y3
      HY4=H4*Y4
      HY5=H5*Y5
      HYL=HY1+HY2+HY3+HY4+HY5
      HYY1=HY1*Y1
      HYY2=HY2*Y2
      HYY3=HY3*Y3
      HYY4=HY4*Y4
      HYY5=HY5*Y5
      HYYL=HYY1+HYY2+HYY3+HYY4+HYY5
      XI0=2.*(D3**3.+D4**3.)/12.+6.*0.149*R1**3.
      CALL TRIAL(W,D1,T,FY,WT,HL,HYL,HYYL,XI0,XI,XM,XS,ASSUMF,YCG)
      RETURN
      END
C
C...................................................................
C
      SUBROUTINE TRIAL(W,D1,T,FY,WT,HL,HYL,HYYL,XI0,XI,XM,XS,ASSUMF,YCG)
      ASSUMF=FY
 100  SF=SQRT(ASSUMF)
      WTLIM=221./SF
      IF(WT.GT.WTLIM)GO TO 110
```

```
      BE=W
      GO TO 120
 110  BE=326./SF*(1.-71.3/WT/SF)*T
 120  HT=HL+BE
      HYT=HYL+BE*T/2.
      HYYT=HYYL+BE*T/2.*T/2.
      YCG=HYT/HT
      IF(YCG.GE.D1/2.)GO TO 200
      F=FY*YCG/(D1-YCG)
      TOL=1.-F/ASSUMF
      ATOL=ABS(TOL)
      IF(ATOL.LE.0.005)GO TO 300
      ASSUMF=F
      GO TO 100
 200  XI=(HYYT+XI0-HT*YCG**2.)*T
      XS=XI/YCG
      GO TO 400
 300  XI=(HYYT+XI0-HT*YCG**2.)*T
      XS=XI/(D1-YCG)
 400  XM=FY*XS
      RETURN
      END
C
C...........................................................
C
      SUBROUTINE WEB(SPAN,PMS,PMS1,PS,PS1,PBW,PBW1)
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT
      H=D1-2.*T
      HT=H/T
      SF=SQRT(FY)
C
C.....BENDING IN WEB
C
      FBWU1=640000./(HT)**2.
      IF(FBWU1.GT.FY) FBWU1=FY
      FBWU=(1.21-0.00034*HT*SF)*FY
      CFBWU=FBWU
      IF(FBWU.GT.FY) FBWU=FY
C
C.....SHEAR IN WEB
C
      SFY=0.577*FY
      HTLIM=237.*SQRT(5.34/FY)
      IF(HT.GT.HTLIM) GO TO 10
      FVU=110.*SQRT(5.34*FY)/HT
      CFVU=FVU
      IF(FVU.GT.SFY) FVU=SFY
      GO TO 20
 10   FVU=26660.*5.34/HT**2.
      CFVU=FVU
 20   HTLIM1=648./SF
      IF(HT.GT.HTLIM1) GO TO 30
      FVU1=219.*SF/HT
```

```
      IF(FVU1.GT.SFY) FVU1=SFY
      GO TO 40
 30   FVU1=142000./HT**2.
C
C.....SHEAR IN WEB
C
 40   PS=4.*H*T*FVU
      PS1=4.*H*T*FVU1
C
C.....BENDING IN WEB
C
      PBW=FBWU*XI/(YCG-T)/5.0625
      PBW1=FBWU1*XI/(YCG-T)/5.0625
C
C.....COMBINE BENDING AND SHEAR
C
      BWEB=(5.0625*(YCG-T)/XI/CFBWU)**2.
      BWEB1=(5.0625*(YCG-T)/XI/FBWU1)**2.
      SWEB=(0.25/H/T/CFVU)**2.
      SWEB1=(0.25/H/T/FVU1)**2.
      PMS=SQRT(1./(BWEB+SWEB))
      PMS1=SQRT(1./(BWEB1+SWEB1))
      RETURN
      END
C
C.....................................................................
C
      SUBROUTINE SELECT(A,B,C,NF)
      IF(A-B) 10,10,40
 10   IF(A-C) 20,20,30
 20   NF=1
      GO TO 100
 30   NF=3
      GO TO 100
 40   IF(B-C) 50,50,30
 50   NF=2
 100  RETURN
      END
```