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Design of automotive structural components using high strength sheet steels-strength of beam webs

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DESIGN OF AUTOMOTIVE STRUCTURAL COMPONENTS USING HIGH STRENGTH SHEET STEELS

STRENGTH OF BEAM WEBS

by

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A Research Project Sponsored by American Iron and Steel Institute

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I. INTRODUCTION

In February 1981, the "Guide for Preliminary Design of Sheet Steel Automotive Structural Components" was issued by American Iron and Steel Institute (AISI) for assisting automotive structural designers to achieve weight reduction through the efficient utilization of carbon and high strength steels.[1] These design recommendations were based primarily on the 1968 Edition of the AISI "Specification for the Design of Cold-Formed Steel Structural Members"[2] but contained the following major differences with regard to the AISI Specification, which was written for the design of buildings:[1,4]

a. The design expressions presented in the Guide are based on an ultimate strength basis.

b. The range of applicability is restricted in some instances because of some simplified expressions in the Guide.

c. The design expressions are extended to materials with yield strengths ranging up to 80 ksi.

The AISI Specification was revised in 1980.[3] Some of the design criteria were revised and others were added in keeping with technical developments and the results of continued research programs sponsored by the American Iron and Steel Institute. The significant changes made in the 1980 Edition of the AISI Specification for building design are related to the following subjects: materials, webs of flexural members, inelastic reserve capacity of flexural members, arc welds, bolted connections, wall studs, channels and Z-sections used as beams, and tests for special cases.[3] The design of automotive components may be affected by the revisions concerning webs of flexural members and inelastic reserve capacity of flexural members.

Since early 1982, a research project entitled "Structural Design of Automotive Structural Components Using High Strength Sheet Steels" has been conducted at the University of Missouri-Rolla under the sponsorship of American Iron and Steel Institute. The primary objectives of the project are:

a. to determine the characteristics of high strength automotive sheet steels that may influence the performance of the steels in structural application,

b. to determine if the existing design procedures are appropriate, and

c. to develop new design procedures if necessary.

In order to achieve the above objectives, the following three phases of research work were planned for the project:

I. Preliminary Study
II. Structural Research
III. Development of Design Criteria

The preliminary study (Phase I) included a review of the literature dealing with automotive structures, a study of typical mechanical properties and stress-strain curves for a selected group of high strength sheet steels, and a critical review of various AISI specifications for the design of cold-formed steel members. Phase I was completed in January 1983.[5]

The present report deals with a part of Phase II. It contains the results of a brief study of the load-carrying capacities of hat sections used as flexural members in automotive structures. This study was based on the tests conducted by Levy[6] and Vecchio[7] for the following design considerations:

1. Moment resisting capacity
2. Bending capacity of webs
3. Shear capacity of webs
4. Combined bending and shear in webs
5. Web crippling
6. Combined bending and web crippling

In Section II, the provisions of the 1981 Guide and the 1980 Specification are reviewed for each of the design considerations mentioned above. Section III contains an evaluation of the available experimental results and a discussion of the validity of current AISI design procedures. A modification of the design expressions for web crippling of beams cold-formed from high strength steels is given in Section IV, and topics for future study are proposed in Section V.

II. CURRENT AISI DESIGN PROVISIONS

As stated in Section I, the 1981 Guide is based primarily on the 1968 Edition of the AISI Specification, and the current edition of the Specification was published in 1980. Included in this section is a review of the AISI design provisions required by the 1981 Guide and the 1980 Specification. It should be noted that this review is limited only to the following topics, which are used to evaluate beam strength:

1. Properties of stiffened compression elements
2. Flexural members
    - Maximum flat-width ratio
    - Maximum web-depth ratio
    - Maximum tensile stress
    - Maximum compressive stress
    - Bending stresses in webs
    - Shear stresses in webs
    - Combined bending and shear stresses in webs
    - Web crippling for interior one-flange loading
    - Combined bending and web crippling
3. Inelastic reserve capacity of flexural members

All expressions presented in the following sections are based on ultimate strength and are intended for use as hat sections having single unreinforced webs. The beams have stiffened compression flanges without intermediate stiffeners. Additional requirements for other cases may be obtained from the 1981 Guide and the 1980 Specification.

II.1 AISI 1981 Guide for Preliminary Design of Sheet Steel Automotive

Structural Components

II.1.1 Properties of Stiffened Compression Elements

Section 2.3.1.1 of the 1981 Guide states that stiffened compression elements are fully effective (b = w) up to

$$(w/t)_{lim} = 221/\sqrt{f} \tag{1}$$

For stiffened compression elements with $w/t > (w/t)_{lim}$

$$\frac{b}{t} = \frac{326}{\sqrt{f}}\left[1 - \frac{71.3}{(w/t)\sqrt{f}}\right] \tag{2}$$

where b = effective design width, in.

w = flat width of the stiffened element, in.

t = thickness of the element, in.

f = actual stress in the compression element computed on the basis of the effective design width, ksi

II.1.2 Flexural Members

According to Sections 2.3.3 and 3.4 of the 1981 Guide, the following requirements are included for the design of beams:

II.1.2.1 Maximum Allowable Flat-Width Ratio

$$(w/t)_{max} = 500 \tag{3}$$

II.1.2.2 Maximum Allowable Web-Depth Ratio

$$(h/t)_{max} = 150 \tag{4}$$

II.1.2.3 Maximum Tensile Stress

The maximum stress in tension on the extreme fiber shall not exceed the yield strength, F_y.

II.1.2.4 Maximum Compressive Stress

The maximum stress in compression shall not exceed the yield strength, F_y, on the effective area of stiffened compression element.

II.1.2.5 Bending Stresses in Webs

The actual compressive stress, f_{bw}, in the flat web of a beam due to bending in its plane shall not exceed the yield strength, F_y, nor shall it exceed the following maximum stress:

$$F_{bwu} = 640000/(h/t)^2 \tag{5}$$

II.1.2.6 Shear Stresses in Webs

The actual average shear stress, f_v, on the gross area of a flat web shall not exceed the following maximum values according to the h/t ratio:

(a) For $h/t \leqslant 648/\sqrt{F_y}$:

$$F_{vu} = 219\sqrt{F_y}/(h/t) \leqslant 0.577F_y \tag{6}$$

(b) For $h/t > 648/\sqrt{F_y}$:

$$F_{vu} = 142000/(h/t)^2 \tag{7}$$

In Eqs. (3) through (7), h is a clear distance between flanges measured along the plane of the web, and t is the web thickness. For webs consist of two or more sheets, each sheet shall be considered as a seperate member carrying its share of the shear.

II.1.2.7 Combined Bending and Shear Stresses in Webs

For webs subjected to both bending and shear stresses, the member shall be so proportioned that such stresses do not exceed the values specified in Sections II.1.2.5 and II.1.2.6 and that

$$(f_{bw}/F_{bwu})^2 + (f_v/F_{vu})^2 \leqslant 1.0 \tag{8}$$

where f_{bw} = actual compression stress in the web, ksi

f_v = actual average shear stress in the web, ksi

F_{bwu} = maximum compression stress as specified in Section II.1.2.5, ksi

F_{vu} = maximum average shear stress as specified in Section II.1.2.6, ksi

II.1.2.8 Web Crippling Strength for Beams Under Concentrated Loads and Reactions

The ultimate strength for reactions of interior supports or for concentrated loads located on the span of beams having single unreinforced webs and R/t up to 4 can be determined as

$$P_c = 1.85t^2(1.06-0.06(R/t))(305+2.30(N/t)-0.009(N/t)(h/t)$$
$$-0.50(h/t))(1.22-0.22(F_y/33))(F_y/33) \qquad (9)$$

where F_y = yield strength of web, ksi

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

N = actual length of bearing or "h", whichever is smaller, in.

R = inside bend radius, in.

t = web thickness, in.

II.2 AISI 1980 Specification for the Design of Cold-Formed Steel Structural Members

II.2.1 Properties of Stiffened Compression Elements

Section 2.3.1.1 of the 1980 Specification states that stiffened compression elements are fully effective (b = w) up to

$$(w/t)_{lim} = 221/\sqrt{f} \qquad (10)$$

For stiffened compression elements with $w/t > (w/t)_{lim}$

$$\frac{b}{t} = \frac{326}{\sqrt{f}}\left[1 - \frac{71.3}{(w/t)\sqrt{f}}\right] \tag{11}$$

where b = effective design width, in.

w = flat width of the stiffened element, in.

t = thickness of the element, in.

f = actual stress in the compression element computed on the basis of the effective design width, ksi

II.2.2 Flexural Members

According to Sections 2.3.3, 2.3.4.1, 3.1, 3.4, and 3.5 of the 1980 Specification, the following requirements are included for the design of beams:

II.2.2.1 Maximum Allowable Flat-Width Ratio

$$(w/t)_{max} = 500 \tag{12}$$

II.2.2.2 Maximum Allowable Web-Depth Ratio

$$(h/t)_{max} = 200 \tag{13}$$

II.2.2.3 Maximum Tensile Stress

The maximum stress in tension on the extreme fiber shall not exceed the yield strength, F_y.

II.2.2.4 Maximum Compressive Stress

The maximum stress in compression shall not exceed the yield strength, F_y, on the effective area of stiffened compression element.

II.2.2.5 Bending Stresses in Webs

The actual compressive stress, f_{bw}, in the flat web of a beam due to bending in its plane shall not exceed the yield strength, F_y, nor shall it exceed the following maximum stress for beams having stiffened compression flanges:

$$F_{bwu} = (1.21 - 0.00034(h/t)\sqrt{F_y})F_y \leq F_y \qquad (14)$$

II.2.2.6 Shear Stresses in Webs

The actual average shear stress, f_v, on the gross area of a flat web shall not exceed the following maximum values according to the h/t ratio:

(a) For $h/t \leq 237\sqrt{k_v/F_y}$

$$F_{vu} = 110\sqrt{k_v F_y}/(h/t) \leq 0.577F_y \qquad (15)$$

(b) For $h/t > 237\sqrt{k_v/F_y}$

$$F_{vu} = 26660k_v/(h/t)^2 \qquad (16)$$

where k_v is the shear buckling coefficient, which has the value of 5.34 for unreinforced webs.

In Eqs. (12) through (16), h is a clear distance between flanges measured along the plane of the web, and t is the web thickness. For webs consisting of two or more sheets, each sheet shall be considered as a seperate member carrying its share of the shear.

II.2.2.7 Combined Bending and Shear Stresses in Webs

For unreinforced beam webs subjected to both bending and shear stresses, the member shall be so proportioned that such stresses do not exceed the values specified in Sections II.2.2.5 and II.2.2.6 and that

$$(f_{bw}/F_{bwu})^2 + (f_v/F_{vu})^2 \leq 1.0 \qquad (17)$$

where f_{bw} = actual compression stress in the web, ksi

f_v = actual average shear stress in the web, ksi

F_{bwu} = maximum compression stress as specified in Section II.2.2.5 without the limitation of F_y, ksi

F_{vu} = maximum average shear stress as specified in Section II.2.2.6 without the limitation of $0.577F_y$, ksi

II.2.2.8 Web Crippling Strength for Beams Under Concentrated Loads and Reactions

The ultimate strength for reactions of interior supports or for concentrated loads located on the span of beams having single unreinforced webs with R/t up to 6, N/t up to 210, and N/h up to 3.5 can be determined as

$$P_c = 1.85t^2(1.06-0.06(R/t))(1+0.007(N/t))(291-0.40(h/t))$$
$$(1.22-0.22(F_y/33))(F_y/33) \qquad (18)$$

where F_y = yield strength of web, ksi

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

N = actual length of bearing, in.

R = inside bend radius, in.

t = web thickness, in.

When $N/t > 60$, the factor $(1+0.007(N/t))$ may be increased to $(0.75+0.011(N/t))$.

II.2.2.9 Combined Bending and Web Crippling

Unreinforced flat webs of shapes subjected to a combination of bending and reaction or concentrated load shall be designed as

$$1.07(P/P_c) + (M/M_u) \leq 1.42 \qquad (19)$$

where P = concentrated load or reaction, kips

P_c = ultimate web crippling load in absence of bending moment, kips

M = applied bending moment at or immediately adjacent to the point of application of the concentrated load or reaction, kip-in.

M_u = ultimate bending moment if bending stress only exists, kip-in.

II.3 Inelastic Reserve Capacity of Flexural Members

According to Section 3.9 of the 1980 Specification, the inelastic flexural reserve capacity of hat sections may be used when the following conditions are met:

(a) The member is not subjected to twisting, lateral, torsional, or torsional flexural buckling

(b) The effect of cold-forming is not included in determining the yield point, F_y

(c) The ratio of the depth of the compressed part of the web to its thickness does not exceed $190/\sqrt{F_y}$

(d) The web to thickness ratio of the entire web does not exceed $640/\sqrt{F_y}$

(e) The shear force based on the maximum applied load does not exceed $0.5F_y$ times the web area

(f) The angle between any web and the vertical does not exceed 20 degrees.

The design moment shall not exceed M_u, which is the ultimate moment causing a maximum compression strain of $C_y e_y$ (no limit is placed on the maximum tensile strain), kip-in.

where e_y = yield strain = F_y/E

E = modulus of elasticity, ksi

C_y = a factor determined as follows:

For stiffened compression elements without intermediate stiffeners

$$C_y = 3 \text{ for } w/t \leqslant 190/\sqrt{F_y} \tag{20}$$

$$C_y = 3 - ((w/t)\sqrt{F_y} - 190)/15.5 \text{ for } w/t > 190/\sqrt{F_y} \text{ but } \leqslant 221/\sqrt{F_y} \tag{21}$$

$$C_y = 1 \text{ for } w/t > 221/\sqrt{F_y} \tag{22}$$

When applicable, effective design widths shall be used in calculating section properties, M_u shall be calculated considering equilibrium of stresses, assuming an ideally elastic plastic stress-strain curve, which is the same in tension as in compression, assuming small deformation and assuming that plane sections before bending remain plane during flexure.

III. EVALUATION OF EXPERIMENTAL DATA

A. General

During recent years, numerous beam tests of automotive components made of high strength sheet steels have been conducted by Inland Steel Company and Ford Motor Company. The experimental data reported by Errera[4], Levy[6], and Vecchio[7] have been used to compare the test results with the AISI design provisions outlined in Section II. This section presents the details of the available experimental data along with comparisons of the test results and the predicted failure loads, which are determined on the basis of the AISI 1981 Guide and the 1980 Specification.

B. Experimental Data

In this study, the experimental data for beam strength were obtained from the reports of Errera[4], Levy[6], and Vecchio[7]. The first group includes 68 tests conducted by Inland Steel Company and the second group includes 39 tests conducted by Ford Motor Company.

(a) Inland Tests - A total of 68 hat sections as shown in Fig. 1 were fabricated from six different types of sheet steels. The yield strengths for specimens No. 1 through 30 (Table 1) range from 35.3 to 73 ksi. For other 38 Inland tests, the yield strengths of materials vary from 169 to 189 ksi. The material properties and dimensions for all the Inland specimens are given in Tables 1 and 2 respectively. The actual yield stresses listed in Table 1 were obtained from the tests of tensile coupons taken from flat materials. Because all the specimens were press-braked, there was little or no cold working of materials except in the corners. All the specimens were tested as simply supported flexural members under third-point loading on a 36 in. span. See Fig. 2 for the loading arrangement.

(b) Ford Tests - A total of 39 composite sections (Fig. 3) were tested by Ford Motor Company. Each section consisted of a hat section and a 0.030 in. thick coverplate welded to the tension flange of the hat section. The yield strengths of the materials used for the hat sections range from 27.5 to 108.4 ksi. However, the yield strength of all the coverplates is 27.5 ksi.

All the specimens were tested as simply supported flexural members under third-point loading on an 18 in. span (Fig. 2). Each of the 13 test data used in this report is the average value of the data obtained from three tests of each specimen series. The yield strengths listed in Table 3 and the thicknesses given in Table 4 were obtained for the following two conditions:

1. As received properties and thicknesses were achieved from flat materials.
2. As formed properties and thicknesses were achieved from flanges and webs of formed hat sections. In Tables 3 and 4, the subscripts f and w represent flange and web respectively.

Other dimensions of composite sections are given in Table 4.

It should be noted that for the Ford test sections, which were fabricated by using a die forming process, a significant increase of yield strengths in the webs was observed as indicated in Table 3. In some cases, the yield strength increase is as high as 110 % over the virgin steel.

Because the current AISI design provision for the ultimate web crippling load is intended for the application of sections having flat flange surfaces contacted to bearing plates, the test data reported by Vecchio[7] for the remaining specimens with beaded top flanges were excluded from the present investigation.

C. Prediction of Failure Loads

Failure loads were predicted by using a computer program based on the AISI requirements included in the 1981 Guide and the 1980 Specification. The types of failure modes considered in this investigation were bending, shear, combined bending and shear, web crippling, and combined bending and web crippling.

In addition to the AISI design requirements reviewed in Section II, the following design approaches were used in predicting the failure loads.

1. In appling Eqs. (9) and (18) to determine the ultimate web crippling loads, a value of 0.7 was used for the factor $(1.06-0.06(R/t))$ for $R/t \geq 6$.
2. For failures caused by the combination of bending and web crippling, the following interaction equation stated in Addendum No. 2 of the 1968 Specification[2] was used to calculate the ultimate load whenever evaluation of the test data was based on the AISI 1981 Guide:

$$P/P_c + M/M_u \leq 1.3 \qquad (23)$$

where P = concentrated load or reaction, kips

P_c = ultimate web crippling load in the absence of bending moment, kips

M = applied bending moment at or immediately adjacent to the point of application of the concentrated load or reaction, kip-in.

M_u = ultimate bending moment if a bending moment only exists, kip-in.

For the Ford tests, four different types of calculations were performed on the basis of the material properties measured before and after forming the hat sections. The following considerations were used in the calculations of the moment capacity of the sections:

1. Use the virgin steel properties listed in Table 3 under the column of "As Received" and neglect the effect of the low yield strength in the coverplate.
2. Use the virgin steel properties of the hat sections and consider the effect of low yield strength in the coverplate.
3. Use the material properties of the hat sections listed in Table 3 under the column of "As Formed" and neglect the effect of low yield strength in the coverplate.
4. Use the as formed data for the hat sections and consider the effect of low yield strength in the coverplate.

In the application of "As Formed" data, the yield strengths of the flanges, F_{yf}, were used to calculate the bending moment capacities, whereas the yield strengths of the webs, F_{yw}, were used in determining shear capacities and web crippling loads.

The effect of lower yield strength in the coverplates rather than in the hat sections was considered by assuming that 1) the strain varies linearly from top to bottom of the section and 2) the coverplate has a perfect elastic-plastic stress-strain curve. The effective width of the top compression flange was calculated by using the yield strength of the flange of the hat section, F_{yf}. Figure 4 shows the strain and stress diagrams for a composite section with consideration being given to the effect of lower yield strength in the coverplate.

Based on the aforementioned design considerations, comparisons of the test results and predicted values are presented in Tables 5 and 6. The symbols used in these two tables for each type of failure load are defined as follows:

1) P_m is the ultimate load computed for the bending moment only, kips. It was calculated from the following equation:

$$P_m = 6M_u/L \tag{24}$$

where M_u is the ultimate the bending moment if the bending moment only exists, kip-in., and L is the span length, in. The bending moment was determined by using Eq. (25) as follows:

$$M_u = S_{eff}F_{yf} \tag{25}$$

where S_{eff} is the effective section modulus of the cross section. This is determined by using the effective design width of the compression flange established according to Eqs. (1), (2), (10), or (11). This computed bending moment was also checked against the bending capacity of the beam webs on the basis of Eq. (5) or Eq. (14), whichever was applicable. The symbol F_{yf} indicates the yield strength of the beam flanges.

2) P_{cw} is the computed ultimate web crippling load for the entire section in the absence of a bending moment , kips. It was calculated by using the following formula:

$$P_{cw} = 4P_c \tag{26}$$

where P_c is the web crippling load determined by Eqs. (9) and (18).

3) P_{mc} is the ultimate load computed for the combined bending moment and web crippling, kips. It was determined by employing Eqs. (19) and (23). That is,

(i) based on the 1981 Guide (Eq. (23)),

$$(P_{mc}/P_{cw}) + ((P_{mc}L/6)/(P_mL/6)) = 1.3 \tag{27}$$

$$P_{mc} = 1.3P_{cw}P_m/(P_{cw}+P_m) \tag{28}$$

(ii) based on the 1980 Specification (Eq. (19)),

$$1.07(P_{mc}/P_{cw}) + ((P_{mc}L/6)/(P_mL/6)) = 1.42 \tag{29}$$

$$P_{mc} = 1.42P_{cw}P_m/(P_{cw}+1.07P_m) \tag{30}$$

where P_{cw} is the ultimate web crippling load determined from Eq. (26), P_m the ultimate load for bending moment computed by using Eq. (24), and L the span length used for the test. (L = 36 in. for the Inland tests, and L = 18 in. for the Ford tests.)

4) P_s is the ultimate load computed only for shear in webs, kips. It was calculated by using the following formula:

$$P_s/2 = A_wF_{vu} = (2ht)F_{vu} \tag{31}$$

or

$$P_s = 4htF_{vu} \tag{32}$$

where A_w is the area of both webs, and F_{vu} the ultimate shear stress determined by Eqs. (6), (7), (15), and (16), whichever is applicable; h and t have already been defined.

5) P_{ms} is the ultimate load computed for the combined bending moment and shear in webs, kips. It was determined from Eq. (8) or Eq. (17). By using a force ratio instead of a stress ratio, Eqs. (8) and (17) can be rewritten as:

$$(P_{ms}/P_{mw})^2 + (P_{ms}/P_s)^2 = 1.0 \quad (33)$$

$$P_{ms} = (P_{mw}P_s)^2/(P_{mw}^2+P_s^2) \quad (34)$$

In the above formula, P_s is the ultimate load for shear in the web determined by Eq. (32), P_{mw} is the ultimate load for bending governed by the web strength, which is calculated as:

$$P_{mw} = 6F_{bwu}I_{eff}/(L(C_{eff}-t)) \quad (35)$$

where F_{bwu} is the ultimate bending stress in the web determined by Eqs. (5) or (14), I_{eff} the effective moment of inertia, and C_{eff} the distance from the extreme top compression fiber to the neutral axis calculated on the basis of the effective design width of the compression flange. L and t were defined previously.

6) P_{test} is the tested failure load obtained from Errera[4], Levy[6], and Vecchio[7].

7) P_{test}/P_{comp} is the ratio of the tested failure load to the smallest value of P_m, P_{cw}, P_{mc}, P_s, and P_{ms} discussed previously.

The corresponding predicted modes of failure are also indicated in Tables 5 and 6 for all specimens with yield strengths lower than 80 ksi. The symbols M and MC represent bending moment failure and the failure under combined bending moment and web crippling respectively.

It should be noted that the effect of shear lag on unusually short span was also considered in this evaluation. The provision for determining this effect is stated in Section 3.4.8 of the 1981 Guide and Section 2.3.5 of the 1980 Specification. This design consideration was included in the computer program as shown in Appendix II. It was found that the bending moment capacity for this group of specimens was not governed by the shear lag.

D. Discussion

Even though the design expressions included in the 1981 Guide are intended for the use of materials having yield strengths not greater than 80 ksi with a proportional limit not less than 70 % of the yield stress, these design equations have been used for comparison of all test results and predicted loads.

From Table 5 on Inland tests, it can be seen that the 1981 Guide and the 1980 Specification can provide reasonable estimates of the failure loads for sections with yield strengths less than 80 ksi. The mean value and standard deviation for using the 1981 Guide (Table 5a) are 1.072 and 0.187 respectively. For the use of the 1980 Specification, Table 5b gives a mean value of 1.024 with a standard deviation of 0.211. It should be noted that for some shallow sections for which the bending moment alone is the governing mode of failure, the 1981 Guide and the 1980 Specification usually underestimate the failure loads. This underestimation may be due to the following factors:

a) The cold-work effect of a large portion of shallow cross sections may cause a significant increase in yield strength.

b) The inelastic reserve capacity may result in a higher ultimate load for compact sections for which the local buckling of the compression flange and the compression portion of the web is prevented.

For all cross sections with very high yield strengths (specimens No. 31 through 68), the predicted loads for web crippling (P_{cw}) and for combined bending moment and web crippling (P_{mc}) are extremely small. As a result, the ratios of P_{test}/P_{comp} for these specimens are unreasonable.

An examination of the design formulas for web crippling indicated that Eqs. (9) and (18) can be rewritten as Eqs. (36) and (37) respectively. That is,

(i) based on the 1981 Guide,

$$P_c = f_1(t,R/t,N/t,h/t)f_3(F_y) \tag{36}$$

(ii) based on the 1980 Specification,

$$P_c = f_2(t,R/t,N/t,h/t)f_3(F_y) \tag{37}$$

In the above two equations, the function of F_y is defined by Eq. (38) as follows:

$$f_3(F_y) = (1.22-0.22(F_y/33))(F_y/33) \tag{38}$$

From Eq. (38), it was found that for a given section, the predicted web crippling load increases as the yield strength, F_y, increases up to a limiting value of 91.5 ksi, beyond which the ultimate web crippling load decreases as the yield strength increases as shown in Fig. 5. This phenomenon is not totally surprising because Eqs. (9) and (18) were developed empirically on the basis of the test data obtained from materials having yield strengths from 27.0 to 56.1 ksi.[8] Therefore these formulas are not necessarily applicable to those materials having very high yield strengths without modification. For this reason, Eqs. (9) and (18) considerably underestimate the ultimate web crippling loads for specimens No. 31 through 68.

For the Ford tests, the tested and predicted failure loads are compared in Table 6 on the basis of the 1981 Guide and the 1980

Specification. For each design document, four different comparisons were made as discussed on page 16. The following is a summary of the mean values and standard deviations obtained from this study.

(a) Based on the 1981 Guide

	Table No.	Mean Value	Standard Deviation
1. Use the as received data and neglect the effect of low F_y in coverplate	6a-1	1.113	0.184
2. Use the as received data and consider the effect of low F_y in coverplate	6a-2	1.193	0.191
3. Use the as formed data and neglect the effect of low F_y in coverplate	6a-3	1.105	0.136
4. Use the as formed data and consider the effect of low F_y in coverplate	6a-4	1.197	0.164

(b) Based on the 1980 Specification

	Table No.	Mean Value	Standard Deviation
1. Use the as received data and neglect the effect of low F_y in coverplate	6b-1	1.051	0.182
2. Use the as received data and consider the effect of	6b-2	1.126	0.189

	low F_y in coverplate			
3.	Use the as formed data and neglect the effect of low F_y in coverplate	6b-3	1.037	0.140
4.	Use the as formed data and consider the effect of low F_y in coverplate	6b-4	1.127	0.181

From Table 6, it can be seen that both the 1981 Guide and the 1980 Specification can provide reasonable predictions except for specimens No. 10 and 12 for which the predicted failure loads are considerably smaller than the tested values. This incident may be due to the following:

a) For specimen No. 10, which is a compact section, the ultimate bending moment can be increased by considering the inelastic reserve capacity.

b) For specimen No. 12, the ratio of tensile strength to yield strength, F_u/F_y, is very large. A substantial amount of cold-work may cause the average yield stress of the compression flange to be much higher than the yield stress of the middle of the flange, F_{yf}, and the yield stress of the virgin steel, F_y.

It was noted that for some specimens the load-carrying capacities had been affected by the large amount of cold work, and, therefore, this effect should be considered in the evaluation of the test data.

The above summary of the mean values and standard deviations seems to indicate that the 1980 Specification provides a somewhat better prediction than the 1981 Guide..

The design provisions for utilizing the inelastic reserve capacity of flexural members can improve the accuracy of prediction for the shallow compact sections. These provisions were reviewed in Section II, and their application for predicting bending moments are discussed in Section IV.

IV. PROPOSED MODIFICATIONS OF DESIGN PROVISIONS

As discussed in Section III, when the yield strength exceeds 91.5 ksi, the predicted ultimate web crippling load decreases as the yield strength increases. In order to modify the current design provisions for predicting the ultimate web crippling load, the results of 38 tests obtained from the Inland study of yield strengths ranging from 169 to 189 ksi were studied in detail.

According to the AISI 1980 Specification, the interacting relationship for a combination of bending moment and web crippling is given in Eq. (19) and subsequently used in Eq. (29). By considering the tested failure loads as the ultimate loads for combined bending moment and web crippling, Eq. (29) can be rewritten as:

$$1.07(P_{test}/P_{cw}) + (P_{test}/P_m) = 1.42 \qquad (39)$$

where P_{test} = tested failure load, kips

P_{cw} = computed ultimate web crippling load determined by Eq. (26), kips

P_m = ultimate load for bending moment only, calculated by using Eq. (24), kips

This interaction equation is shown graphically in Fig. 6. It was used to select the data for specimens having the failure mode of combined bending moment and web crippling. That is, whenever $0.35 < P_{test}/P_m < 1.0$, the test data were used for evaluation.

From Eq. (39), the ultimate web crippling load, P_{cw}, was computed by using the tested failure load as follows:

$$P_{cw} = 1.07P_{test}/(1.42-(P_{test}/P_m)) \qquad (40)$$

Consequently, the ultimate web crippling load for each web, P_c can be determined by employing Eq. (26).

The effect of yield strength, F_y, on the web crippling strength was obtained by employing Eq. (37) from which the function of F_y is

$$f_3(F_y) = P_c/f_2(t,R/t,N/t,h/t) \qquad (41)$$

The value of $f_3(F_y)$ was calculated for each specimen selected previously. These values were plotted against F_y and are shown in Fig. 7, which includes a comparison with Eq. (38).

By using a regression analysis of a selected group of test data, it was found that Eq. (41) may be represented by a constant value of 1.69, which is the tangent line to the maximum value of Eq. (38). For simplification, the value of 1.69 was used for the materials with yield strengths greater than 91.5 ksi. In other words, if the actual yield strength is greater than 91.5 ksi, the value of 91.5 ksi can be used in lieu of the actual value of F_y in Eq. (38).

By using this modified function of F_y, the predicted failure loads were computed and compared with the tested failure loads for Inland tests and Ford tests. Detailed data are given in Tables 7 and 8.

From Table 7 on Inland tests, it can be seen that a significant improvement was made in the prediction of failure loads as compared with the results presented in Table 5 for specimens having yield strengths ranging from 169 to 189 ksi. The mean value and standard deviation for using the 1981 Guide (Table 7a) are 1.315 and 0.468 respectively. For the use of the 1980 Specification, Table 7b gives a mean value of 1.046 with a standard deviation of 0.182. The above summary of the mean values and standard deviations for the ratios of tested failure loads to predicted failure loads indicates that the 1980 Specification gives better predictions than the 1981 Guide. It should be noted that for specimens No. 61 through 68, which have large h/t ratios, an underestimation of predicted failure loads was observed. This matter will be discussed later in this Section.

The following is a summary of the mean values and standard deviations for the Ford tests included in Table 8:

(a) Based on the 1981 Guide

	Table No.	Mean Value	Standard Deviation
1. Use the as received data and neglect the effect of low F_y in coverplate	8a-1	1.111	0.186
2. Use the as received data and consider the effect of low F_y in coverplate	8a-2	1.193	0.192
3. Use the as formed data and neglect the effect of low F_y in coverplate	8a-3	1.093	0.142
4. Use the as formed data and consider the effect of low F_y in coverplate	8a-4	1.186	0.163

(b) Based on the 1980 Specification

	Table No.	Mean Value	Standard Deviation
1. Use the as received data and neglect the effect of	8b-1	1.050	0.183

	low F_y in coverplate			
2.	Use the as received data and consider the effect of low F_y in coverplate	8b-2	1.124	0.191
3.	Use the as formed data and neglect the effect of low F_y in coverplate	8b-3	1.027	0.144
4.	Use the as formed data and consider the effect of low F_y in coverplate	8b-4	1.116	0.182

Table 8 shows only slight changes of the ratios of P_{test}/P_{comp} compared with Table 6 for specimens having yield strengths greater than 91.5 ksi. This is because the yield strengths of the materials exceeded the limiting value of 91.5 ksi by a small margin, which caused small changes in the function $f_3(F_y)$.

The relationships between the ratios of P_{test}/P_{comp} vs. F_y, h/t, R/t, and N/t for Inland tests, which are governed by a combined bending moment and web crippling, are shown in Figs. 8 through 11. It can be seen that in general good agreements were obtained for the tested and predicted loads, except for Fig. 9, which represents the effect of the h/t ratio on the predicted load.

A study of the effect of the h/t ratio on the ultimate web crippling load determined from Eq. (40) indicates that the web crippling load increases as the h/t ratio increases for the group of materials having yield strengths ranging from 169 to 189 ksi. However, the following function of the h/t ratio according to the 1980 Specification gives a lower value of predicted load with an increase in the h/t ratio:

$$f(h/t) = 291-0.40(h/t) \tag{42}$$

The above equation is shown graphically in Fig. 12. For simplification, a constant value of $f(h/t) = 291$ was used for materials with yield strengths ranging from 169 to 189 ksi.

It should be noted that there is an obvious discontinuity in the modified $f(h/t)$ function for very high strength steels. This subject should receive further study. It is hoped that this incident can be resolved by additional experimental data to be obtained from future research for specimens having yield strengths ranging from 75 to 165 ksi.

The predicted failure loads were calculated on the basis of the 1980 Specification with consideration being given to the modifications of both $f_3(F_y)$ and $f(h/t)$. These calculated values were compared with the tested failure loads of the Inland tests. Detailed data are given in Table 9. The relationships between the ratio of P_{test}/P_{comp} vs. F_y, h/t, R/t, and N/t for Inland tests, which are governed by a combined bending moment and web crippling, are shown in Figs. 13 through 16.

Table 9 shows the improvements achieved in the prediction of failure loads for specimens having yield strengths ranging from 169 to 189 ksi with large h/t ratios for specimens No. 61 through 68. The mean value and standard deviation for the ratios of P_{test}/P_{comp} were reduced to 1.011 and 0.169 respectively. The plots shown in Figs. 13 through 16 demonstrate the agreements between the predicted and tested failure loads.

The modified equation for predicting the ultimate web crippling loads for sections with single unreinforced webs under interior one-flange loading can be summarized as follows:

$$P_c = f'(t)f'(R/t)f'(N/t)f'(h/t)f'(F_y) \quad (43)$$

where $f'(t) = 1.85t^2$ (44)

$$f'(R/t) = 1.06 - 0.06(R/t) \text{ for } R/t \leq 6 \quad (45a)$$

$$= 0.7 \text{ for } R/t > 6 \quad (45b)$$

$$f'(N/t) = 1 + 0.007(N/t) \text{ for } N/t \leq 60 \quad (46a)$$

$$= 0.75 + 0.011(N/t) \text{ for } N/t > 60 \quad (46b)$$

$$f'(h/t) = 291 - 0.40(h/t) \text{ for } F_y \leq 169 \text{ ksi} \quad (47a)$$

$$= 291 \text{ for } F_y > 169 \text{ ksi} \quad (47b)$$

$$f'(F_y) = (1.22 - 0.22(F_y/33))(F_y/33) \text{ for } F_y \leq 91.5 \text{ ksi} \quad (48a)$$

$$= 1.69 \text{ for } F_y > 91.5 \text{ ksi} \quad (48b)$$

As discussed in Section III, the predictions of failure loads were underestimated for some specimens because of the effect of the inelastic reserve capacity of the flexural members. The calculation of the bending moment capacities was performed for Inland tests where applicable by employing the design provisions for the inelastic reserve capacity of the flexural members. The predicted failure loads based on the 1980 Specification with consideration being given to the modification of both $f_3(F_y)$ and $f(h/t)$ were computed and compared with the tested failure loads. The final results are presented in Table 10. The computer program, which was used in this calculation, is shown in Appendix II.

From Table 10, it is evident that for specimens with shallow compact sections the use of inelastic reserve capacity can considerably improve the prediction of failure loads. As a result, the mean value and standard deviation for the ratios of P_{test}/P_{comp} are reduced to 0.990 and 0.126 respectively. The asterisk indicates the specimens for which the inelastic reserve capacity was used in the moment calculation.

V. PROPOSED FUTURE STUDY

The possible modifications of the 1981 Guide Eq. (3.4.7a2) for predicting the ultimate web crippling load under interior loading for sections with single unreinforced webs fabricated from high strength sheet steels were discussed in Section IV. These modifications are based on a limited number of experimental data obtained from Inland tests with yield strengths ranging from 169 to 189 ksi. As pointed out in Section III, the design formulas for the prediction of the ultimate web crippling loads currently included in the AISI document are empirical expressions developed on the basis of the test data obtained from sections cold-formed from materials having yield strengths from 27.0 to 56.1 ksi. In order to develop some general criteria, additional experimental data for materials with yield strengths ranging from 56 to 169 ksi are needed to confirm the validity of the proposed modifications. Furthermore, these additional data can also be used for resolving the discontinuity of the f(h/t) function for different yield strengths of materials.

In addition to the proposed study of web crippling load for interior one-flange loading as discussed above, it should be noted that Section 3.4.7 of the 1981 Guide also includes other design provisions for determining ultimate web crippling loads of unreinforced beam webs for the following conditions:

- End one-flange loading for beams having single webs (Eq. 3.4.7a1)
- End one-flange loading for I-beams (Eq. 3.4.7b1)

. Interior one-flange loading for I-beams (Eq. 3.4.7b2)

All these design criteria were developed from the test results of sections having yield strengths not greater than about 56 ksi. For the use of any cold-formed steel sections made with very high strength materials, some modifications may also be needed.

In Phase I of the present research program, mechanical properties of six types of high strength sheet steels were studied in detail. The yield strengths of these sheet steels range from 55.8 to 141.1 ksi. Apparently, these materials are suitable for the future study of ultimate web crippling loads of cold-formed sections under interior one-flange loading and end one-flange loading.

The proposed specimens for the future study of sections with single unreinforced webs are hat sections as shown in Fig. 17. I-beams (Fig. 18) may be used for sections that provide a high degree of restraint against rotation of the webs. These specimens will be cold-formed from six different types of sheet steels used in Phase I of the research project. The material properties and thicknesses of these sheet steels are given in Table 11.

As proposed in Tables 12 and 13, different profiles of cross sections will be used for each type of material. The number of specimens and testing arrangement for each case of loading conditions are proposed as follows:

1) For the interior one-flange loading condition, 36 hat sections and 30 I-beams, as proposed in Tables 14 and 16, will be tested as simply supported beams. Two 4 in. bearing plates will be used at both ends, and a 2 in. bearing plate will be under a concentrated load applied at midspan. The clear

distance between the bearing plates will be equal to 1.5h. The testing arrangement is shown in Fig. 19(a).

2) For the end one-flange loading condition, the same number of specimens (Tables 15 and 17) will be used. The test setup (Fig. 19(b)) will be the same as that for the interior one-flange loading condition except that the bearing plates will be 4 in. at midspan under concentrated load and 2 in. at both ends. In addition, the webs will be stiffened at midspan length.

All the test data should be checked to ascertain that the actual bending moment is less than 30% of the maximum bending moment capacity of each section. This will eliminate the effect of bending moment on the ultimate web crippling load.

VI. CONCLUSIONS

Various types of high strength sheet steels with yield strengths greater than 80 ksi are now available for engineers to reduce car weight for the purpose of achieving fuel economy. Flexural tests of hat sections reported by Errera[4], Levy[6], and Vecchio[7] were used to verify the validity of the existing design criteria issued by the American Iron and Steel Institute. The yield strengths of materials used for these tests ranged from 27.5 to 189 ksi.

The available test data have been evaluated in this report according to the 1981 AISI Guide and the 1980 AISI Specification. It was found that reasonable estimates of failure loads can be obtained by using the 1981 Guide for sections with yield strengths not greater than 91.5 ksi. However, the AISI Guide underestimates the failure loads for sections fabricated from very high strength materials having yield strengths exceeding 91.5 ksi.

Based on a limited number of experimental data evaluated in this investigation, the 1981 Guide can be improved by considering the following revisions:

1. The design provisions for maximum shear stress, bending stress, and the combination of shear and bending stresses in the webs of flexural members should be revised on the basis of Section 3.4 of the 1980 Specification.
2. The expression for predicting the ultimate web crippling load for sections with single unreinforced webs under interior one-flange loading should be revised to accomodate the use of high strength materials. This may be done by using the

modified functions for F_y and h/t as discussed in Section IV.

3. The design provisions for considering the inelastic reserve capacity of flexural members that was added to the 1980 AISI Specification should be included in the Guide.

More experimental investigation is needed for future study in order to confirm the validity of the proposed modifications of the design formulas and to improve other design criteria. The required tests for determining the web crippling loads of hat sections and I-beams are proposed in Section V.

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TABLE 1

Material Properties For Inland Specimens

Specimen No.	Material Designation	F_y (ksi)	Source Specimen No. Used in Refs. 4 & 6
1	CRLC	35.3	Ref. 4: C1
2	CRLC	35.3	C2
3	CRLC	35.3	C3
4	CRLC	35.3	C4
5	CRLC	35.3	C5
6	CRLC	35.3	C6
7	40XK	39.8	H1
8	40XK	39.8	H2
9	40XK	39.8	H3
10	40XK	39.8	H4
11	40XK	39.8	H5
12	40XK	39.8	H6
13	60DF	47.4	D1
14	60DF	47.4	D2
15	60DF	47.4	D3
16	60DF	47.4	D4
17	60DF	47.4	D5
18	60DF	47.4	D6
19	80DF	56.6	E1
20	80DF	56.6	E2
21	80DF	56.6	E3
22	80DF	56.6	E4
23	80DF	56.6	E5
24	80DF	56.6	E6
25	60XK	73.0	G1
26	60XK	73.0	G2
27	60XK	73.0	G3
28	60XK	73.0	G4
29	60XK	73.0	G5
30	60XK	73.0	G6
31	M-190	189.0	Ref.6: 7-1
32	M-190	184.0	7-2
33	M-190	189.0	8-1
34	M-190	184.0	8-2
35	M-190	189.0	9-1
36	M-190	184.0	9-2
37	M-190	185.0	1-1
38	M-190	169.0	1-2
38	M-190	185.0	2-1
40	M-190	169.0	2-2

TABLE 1 (Cont'd)

Material Properties For Inland Specimens

Specimen No.	Material Designation	F_y (ksi)	Source Specimen No. Used in Refs. 4 & 6
41	M-190	185.0	3-1
42	M-190	169.0	3-2
43	M-190	189.0	10-1
44	M-190	184.0	10-2
45	M-190	176.0	18-1
46	M-190	180.0	18-2
47	M-190	189.0	11-1
48	M-190	184.0	11-2
49	M-190	176.0	16-1
50	M-190	180.0	16-2
51	M-190	185.0	4-1
52	M-190	169.0	4-2
53	M-190	176.0	19-1
54	M-190	180.0	19-2
55	M-190	189.0	12-1
56	M-190	184.0	12-2
57	M-190	189.0	20-1
58	M-190	184.0	20-2
59	M-190	185.0	5-1
60	M-190	169.0	5-2
61	M-190	189.0	13-1
62	M-190	184.0	13-2
63	M-190	189.0	14-1
64	M-190	184.0	14-2
65	M-190	189.0	15-1
66	M-190	184.0	15-2
67	M-190	185.0	6-1
68	M-190	169.0	6-2

TABLE 2

Dimensions For Inland Specimens

Specimen No.	t (in.)	B1 (in.)	B2 (in.)	D1 (in.)	D2 (in.)	R (in.)	N (in.)
1	0.0280	1.0	2.2	1.0	0.30	0.25	2.0
2	0.0280	1.5	3.2	1.5	0.31	0.25	2.0
3	0.0280	2.0	4.2	2.0	0.44	0.25	2.0
4	0.0280	2.5	5.2	2.5	0.38	0.25	2.0
5	0.0280	3.0	6.2	3.0	0.44	0.25	2.0
6	0.0280	4.0	8.2	4.0	0.44	0.25	2.0
7	0.0340	1.0	2.2	1.0	0.30	0.25	2.0
8	0.0340	1.5	3.2	1.5	0.31	0.25	2.0
9	0.0340	2.0	4.2	2.0	0.44	0.25	2.0
10	0.0340	2.5	5.2	2.5	0.38	0.25	2.0
11	0.0340	3.0	6.2	3.0	0.44	0.25	2.0
12	0.0340	4.0	8.2	4.0	0.44	0.25	2.0
13	0.0340	1.0	2.2	1.0	0.30	0.25	2.0
14	0.0340	1.5	3.2	1.5	0.31	0.25	2.0
15	0.0340	2.0	4.2	2.0	0.44	0.25	2.0
16	0.0340	2.5	5.2	2.5	0.38	0.25	2.0
17	0.0340	3.0	6.2	3.0	0.44	0.25	2.0
18	0.0340	4.0	8.2	4.0	0.44	0.25	2.0
19	0.0340	1.0	2.2	1.0	0.30	0.25	2.0
20	0.0340	1.5	3.2	1.5	0.31	0.25	2.0
21	0.0340	2.0	4.2	2.0	0.44	0.25	2.0
22	0.0340	2.5	5.2	2.5	0.38	0.25	2.0
23	0.0340	3.0	6.2	3.0	0.44	0.25	2.0
24	0.0340	4.0	8.2	4.0	0.44	0.25	2.0
25	0.0410	1.0	2.2	1.0	0.30	0.25	2.0
26	0.0410	1.5	3.2	1.5	0.31	0.25	2.0
27	0.0410	2.0	4.2	2.0	0.44	0.25	2.0
28	0.0410	2.5	5.2	2.5	0.38	0.25	2.0
29	0.0410	3.0	6.2	3.0	0.44	0.25	2.0
30	0.0410	4.0	8.2	4.0	0.44	0.25	2.0
31	0.0256	1.0	2.1	1.0	0.25	0.19	2.0
32	0.0344	1.0	2.2	1.0	0.41	0.19	2.0
33	0.0256	2.5	3.9	0.9	0.50	0.19	2.0
34	0.0344	2.5	3.9	0.9	0.50	0.19	2.0
35	0.0256	4.0	5.4	0.9	0.50	0.19	2.0
36	0.0344	4.0	5.4	0.9	0.50	0.19	2.0
37	0.0256	1.0	2.1	1.0	0.30	0.25	2.0
38	0.0334	1.0	2.1	1.0	0.30	0.25	2.0
39	0.0256	1.5	3.1	1.5	0.31	0.25	2.0
40	0.0334	1.5	3.1	1.5	0.31	0.25	2.0

TABLE 2 (Cont'd)

Dimensions For Inland Specimens

Specimen No.	t (in.)	B1 (in.)	B2 (in.)	D1 (in.)	D2 (in.)	R (in.)	N (in.)
41	0.0256	2.0	4.1	2.0	0.44	0.25	2.0
42	0.0334	2.0	4.1	2.0	0.44	0.25	2.0
43	0.0256	1.0	3.4	2.5	0.50	0.19	2.0
44	0.0344	1.0	3.4	2.5	0.50	0.19	2.0
45	0.0253	2.5	3.7	2.5	0.44	0.19	2.0
46	0.0346	2.5	3.7	2.5	0.44	0.19	2.0
47	0.0256	2.5	4.9	2.5	0.38	0.19	2.0
48	0.0344	2.5	4.9	2.5	0.50	0.19	2.0
49	0.0253	2.5	4.9	2.5	0.44	0.19	2.0
50	0.0346	2.5	4.9	2.5	0.44	0.19	2.0
51	0.0256	2.5	5.1	2.5	0.38	0.25	2.0
52	0.0344	2.5	5.1	2.5	0.38	0.25	2.0
53	0.0253	2.5	7.4	2.5	0.44	0.19	2.0
54	0.0346	2.5	7.4	2.5	0.44	0.19	2.0
55	0.0256	4.0	6.4	2.5	0.53	0.19	2.0
56	0.0344	4.0	6.4	2.5	0.53	0.19	2.0
57	0.0253	4.0	5.9	2.5	0.44	0.19	2.0
58	0.0334	4.0	5.9	2.5	0.44	0.19	2.0
59	0.0256	3.0	6.1	3.0	0.44	0.25	2.0
60	0.0334	3.0	6.1	3.0	0.44	0.25	2.0
61	0.0256	1.0	4.9	4.0	0.56	0.19	2.0
62	0.0344	1.0	4.9	4.0	0.56	0.19	2.0
63	0.0256	2.5	6.4	4.0	0.56	0.19	2.0
64	0.0344	2.5	6.4	4.0	0.56	0.19	2.0
65	0.0256	4.0	7.9	4.0	0.44	0.19	2.0
66	0.0344	4.0	7.9	4.0	0.44	0.19	2.0
67	0.0256	4.0	8.1	4.0	0.44	0.25	2.0
68	0.0334	4.0	8.1	4.0	0.44	0.25	2.0

Note: See Fig. 1 for definitions of symbols.

TABLE 3

Material Properties For Ford Specimens

Specimen No.	Material Designation	As Received	As Formed		Source Specimen Designation used in Ref.7
		F_y(ksi)	F_{yf}(ksi)	F_{yw}(ksi)	
1	MILD	27.5	31.0	49.7	U
2	HSLA-50	41.7	44.8	68.8	A
3	DPL-85T	67.0	69.6	94.0	T
4	DPA-90T	48.3	56.1	102.3	S
5	DPLB-85-T-M	58.8	56.9	101.7	W
6	DPLB-85-T	62.3	61.1	94.8	X
7	HSLA-80	108.4	-	-	R
8	DPL-85T	61.3	62.7	80.4	P
9	HSLA-80	71.3	75.9	97.0	O
10	MILD	35.7	39.8	59.8	L
11	HSLA-50	63.2	55.3	71.6	K
12	DPA-90T	58.5	55.9	92.8	M
13	HSLA-80	84.2	-	-	N

Note: All values are the average values of 3 identical tests.

TABLE 4

Dimensions For Ford Specimens

Specimen No.	t (in.)	t_f (in.)	t_w (in.)	B1 (in.)	B2 (in.)	D1 (in.)	R (in.)	N (in.)
1	0.0315	0.0330	0.0300	1.563	3.0	2.402	0.1	2.0
2	0.0350	0.0356	0.0340	1.570	3.0	2.405	0.1	2.0
3	0.0318	0.0323	0.0300	1.564	3.0	2.402	0.1	2.0
4	0.0343	0.0346	0.0290	1.569	3.0	2.404	0.1	2.0
5	0.0290	0.0300	0.0260	1.558	3.0	2.399	0.1	2.0
6	0.0290	0.0302	0.0260	1.558	3.0	2.399	0.1	2.0
7	0.0330	0.0330	0.0300	1.566	3.0	2.403	0.1	2.0
8	0.0380	0.0400	0.0380	1.576	3.0	2.408	0.1	2.0
9	0.0420	0.0440	0.0390	1.584	3.0	2.412	0.1	2.0
10	0.0590	0.0594	0.0540	1.618	3.0	1.959	0.1	2.0
11	0.0540	0.0594	0.0510	1.608	3.0	1.954	0.1	2.0
12	0.0530	0.0543	0.0520	1.606	3.0	1.953	0.1	2.0
13	0.0550	0.0550	0.0510	1.610	3.0	1.955	0.1	2.0

Notes: 1. All values are the average values of 3 identical tests.
2. See Fig. 3 for definitions of symbols.

TABLE 5a

Comparisons of Tested and Predicted Failure Loads for Inland Tests
Based on the AISI 1981 Guide

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	0.163	1.520	0.163	2.153	0.172	0.216	M	1.32
2	0.415	1.599	0.415	3.294	0.426	0.414	M	1.00
3	0.707	1.654	0.644	4.080	0.714	0.618	MC	0.96
4	1.026	1.581	0.809	4.080	1.014	0.762	MC	0.94
5	1.384	1.493	0.934	4.080	1.330	0.900	MC	0.96
6	2.053	1.319	1.044	3.161	1.722	0.975	MC	0.93
7	0.219	2.396	0.219	2.911	0.232	0.306	M	1.40
8	0.560	2.515	0.560	4.472	0.580	0.594	M	1.06
9	1.000	2.608	0.940	6.034	1.017	0.876	MC	0.93
10	1.461	2.528	1.203	6.389	1.458	1.090	MC	0.91
11	1.973	2.424	1.414	6.389	1.920	1.320	MC	0.93
12	3.161	2.215	1.693	5.678	2.792	1.610	MC	0.95
13	0.260	2.703	0.260	3.467	0.277	0.384	M	1.48
14	0.667	2.837	0.667	5.326	0.690	0.726	M	1.09
15	1.160	2.941	1.082	6.972	1.180	1.100	MC	1.02
16	1.690	2.851	1.379	6.972	1.681	1.380	MC	1.00
17	2.282	2.733	1.617	6.972	2.208	1.610	MC	1.00
18	3.662	2.498	1.930	5.678	3.109	1.960	MC	1.02
19	0.311	3.008	0.311	4.139	0.330	0.498	M	1.60
20	0.796	3.158	0.796	6.360	0.824	0.905	M	1.14
21	1.349	3.273	1.242	7.619	1.368	1.360	MC	1.10
22	1.960	3.173	1.575	7.619	1.942	1.640	MC	1.04
23	2.648	3.042	1.840	7.614	2.545	1.930	MC	1.05
24	3.651	2.780	2.052	5.678	3.071	2.340	MC	1.14
25	0.471	4.814	0.471	6.341	0.507	0.678	M	1.44
26	1.218	5.036	1.218	9.795	1.273	1.260	M	1.03
27	2.118	5.220	1.959	12.582	2.167	1.840	MC	0.94
28	3.089	5.111	2.503	12.582	3.085	2.370	MC	0.95
29	4.178	4.949	2.945	12.582	4.051	2.740	MC	0.93
30	6.562	4.626	3.527	9.992	5.485	3.190	MC	0.90
31	0.786	-0.279	-0.564	7.893	0.820	0.705		****
32	1.090	-0.083	-0.116	13.604	1.158	1.185		****
33	0.816	-0.277	-0.546	7.893	0.851	0.698		****
34	1.183	-0.082	-0.115	12.727	1.261	1.178		****
35	0.825	-0.277	-0.543	7.893	0.861	0.690		****
36	1.206	-0.082	-0.115	12.727	1.286	1.140		****
37	0.772	-0.091	-0.134	7.809	0.806	0.705		****
38	0.903	0.962	0.606	12.157	0.960	1.134		****
39	1.593	-0.096	-0.133	6.577	1.593	1.071		****
40	2.037	1.010	0.878	12.704	2.093	1.890		****

TABLE 5a (Cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests
Based on the AISI 1981 Guide

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
41	1.580	-0.099	-0.137	4.890	1.504	1.470		****
42	3.321	1.047	1.035	10.947	3.264	2.592		****
43	1.344	-0.287	-0.475	3.891	1.270	1.655		****
44	3.437	-0.087	-0.116	9.510	3.233	2.898		****
45	1.244	0.305	0.305	3.755	1.181	1.584		****
46	3.491	0.260	0.260	9.679	3.284	2.979		****
47	1.408	-0.287	-0.470	3.891	1.324	1.718		****
48	3.741	-0.087	-0.116	9.510	3.482	3.142		****
49	1.366	0.305	0.305	3.755	1.284	1.635		****
50	3.827	0.260	0.260	9.679	3.559	3.069		****
51	1.456	-0.094	-0.130	3.891	1.364	1.746		****
52	3.894	1.074	1.074	9.510	3.604	3.012		****
53	1.493	0.305	0.305	3.755	1.387	1.599		****
54	4.176	0.260	0.260	9.679	3.835	3.168		****
55	1.417	-0.287	-0.469	3.891	1.331	1.805		****
56	3.787	-0.087	-0.116	9.510	3.518	3.048		****
57	1.323	-0.281	-0.463	3.755	1.248	1.536		****
58	3.331	-0.081	-0.108	8.698	3.111	3.243		****
59	1.369	-0.088	-0.122	3.232	1.261	2.091		****
60	3.294	0.971	0.971	7.215	2.997	3.522		****
61	1.182	-0.233	-0.377	2.413	1.061	2.302		****
62	2.972	-0.077	-0.102	5.882	2.653	4.135		****
63	1.221	-0.233	-0.374	2.413	1.089	2.470		****
64	3.159	-0.077	-0.102	5.882	2.783	4.405		****
65	1.225	-0.233	-0.373	2.413	1.093	2.475		****
66	3.184	-0.077	-0.102	5.882	2.800	4.628		****
67	1.257	-0.076	-0.105	2.413	1.115	2.607		****
68	2.984	0.885	0.885	5.381	2.610	4.562		****
Mean Value*								1.072
Standard Deviation*								0.187

* The mean value and standard deviation are based on the ratios of P_{test}/P_{comp} for specimens No. 1 through No. 30, for which the yield strengths of sheet steels are lower than 91.5 ksi.

**** Eq. (9) does not apply.

TABLE 5b

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the AISI 1980 Specification

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	0.163	1.823	0.163	2.153	0.196	0.216	M	1.32
2	0.415	1.776	0.415	3.294	0.473	0.414	M	1.00
3	0.707	1.729	0.698	4.435	0.765	0.618	MC	0.89
4	1.026	1.682	0.882	4.736	1.055	0.762	MC	0.86
5	1.384	1.635	1.032	4.246	1.333	0.900	MC	0.87
6	2.080	1.541	1.208	3.170	1.739	0.975	MC	0.81
7	0.219	2.726	0.219	2.911	0.268	0.306	M	1.40
8	0.560	2.668	0.560	4.472	0.652	0.594	M	1.06
9	1.000	2.611	1.000	6.034	1.110	0.876	M	0.88
10	1.461	2.554	1.287	7.415	1.547	1.090	MC	0.85
11	1.973	2.497	1.518	7.415	1.988	1.320	MC	0.87
12	3.085	2.382	1.836	5.692	2.712	1.610	MC	0.88
13	0.260	3.074	0.260	3.467	0.318	0.384	M	1.48
14	0.667	3.009	0.667	5.326	0.770	0.726	M	1.09
15	1.160	2.945	1.159	7.186	1.273	1.100	MC	0.95
16	1.690	2.880	1.474	8.092	1.762	1.380	MC	0.94
17	2.282	2.816	1.736	7.634	2.243	1.610	MC	0.93
18	3.490	2.687	2.073	5.692	2.975	1.960	MC	0.95
19	0.311	3.422	0.311	4.139	0.377	0.498	M	1.60
20	0.796	3.350	0.796	6.360	0.912	0.905	M	1.14
21	1.349	3.278	1.330	8.581	1.460	1.360	MC	1.02
22	1.960	3.206	1.683	8.843	2.008	1.640	MC	0.97
23	2.648	3.134	1.975	7.634	2.522	1.930	MC	0.98
24	3.947	2.990	2.323	5.692	3.244	2.340	MC	1.01
25	0.471	5.344	0.471	6.341	0.582	0.678	M	1.44
26	1.218	5.252	1.218	9.795	1.417	1.260	M	1.03
27	2.118	5.160	2.090	13.249	2.332	1.840	MC	0.88
28	3.089	5.067	2.655	14.603	3.223	2.370	MC	0.89
29	4.178	4.975	3.125	13.450	4.090	2.740	MC	0.88
30	6.373	4.790	3.734	10.017	5.377	3.190	MC	0.85
31	0.786	-0.346	-0.779	9.161	0.851	0.705		****
32	1.090	-0.094	-0.136	13.604	1.257	1.185		****
33	0.816	-0.347	-0.764	9.161	0.893	0.698		****
34	1.183	-0.094	-0.135	12.727	1.380	1.178		****
35	0.825	-0.347	-0.758	9.161	0.903	0.690		****
36	1.206	-0.094	-0.135	12.727	1.408	1.140		****
37	0.772	-0.113	-0.173	9.063	0.838	0.705		****
38	0.903	1.097	0.682	12.157	1.043	1.134		****
39	1.557	-0.110	-0.156	6.594	1.516	1.071		****
40	2.037	1.073	0.954	14.805	2.142	1.890		****

TABLE 5b (Cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the AISI 1980 Specification

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
41	2.271	-0.106	-0.148	4.902	2.061	1.470		****
42	3.262	1.050	1.050	10.975	3.127	2.592		****
43	2.771	-0.316	-0.470	3.901	2.259	1.655		****
44	4.364	-0.088	-0.119	9.535	3.968	2.898		****
45	2.480	0.337	0.337	3.765	2.071	1.584		****
46	4.311	0.262	0.262	9.704	3.940	2.979		****
47	2.902	-0.316	-0.467	3.901	2.328	1.718		****
48	4.750	-0.088	-0.119	9.535	4.251	3.142		****
49	2.723	0.337	0.337	3.765	2.206	1.635		****
50	4.726	0.262	0.262	9.704	4.249	3.069		****
51	2.956	-0.103	-0.142	3.901	2.356	1.746		****
52	4.611	1.083	1.083	9.535	4.151	3.012		****
53	2.976	0.337	0.337	3.765	2.335	1.599		****
54	5.157	0.262	0.262	9.704	4.554	3.168		****
55	2.921	-0.316	-0.467	3.901	2.338	1.805		****
56	4.808	-0.088	-0.119	9.535	4.293	3.048		****
57	2.774	-0.310	-0.460	3.765	2.233	1.536		****
58	4.442	-0.082	-0.111	8.720	3.958	3.243		****
59	3.557	-0.100	-0.136	3.240	2.395	2.091		****
60	5.513	1.003	1.003	7.234	4.385	3.522		****
61	4.060	-0.287	-0.408	2.419	2.078	2.302		****
62	7.622	-0.082	-0.110	5.897	4.664	4.135		****
63	4.194	-0.287	-0.407	2.419	2.096	2.470		****
64	8.101	-0.082	-0.110	5.897	4.768	4.405		****
65	4.210	-0.287	-0.407	2.419	2.098	2.475		****
66	8.164	-0.082	-0.110	5.897	4.780	4.628		****
67	4.293	-0.094	-0.127	2.419	2.108	2.607		****
68	7.535	0.956	0.956	5.395	4.386	4.562		****
Mean Value*								1.024
Standard Deviation*								0.211

* The mean value and standard deviation are based on the ratios of P_{test}/P_{comp} for specimens No. 1 through No. 30, for which the yield strengths of sheet steels are lower than 91.5 ksi.

**** Eq. (18) does not apply.

TABLE 6a-1

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Received Data and Neglect the Effect of Low F_y in Coverplate
Based on the AISI 1981 Guide

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.049	1.249	4.558	1.711	1.616	MC	1.29
2	2.963	3.536	2.096	6.930	2.775	2.320	MC	1.11
3	3.990	3.801	2.530	7.251	3.547	2.377	MC	0.94
4	3.289	3.740	2.275	7.163	3.041	2.453	MC	1.08
5	3.193	2.923	1.984	5.649	2.816	1.948	MC	0.98
6	3.356	3.010	2.063	5.815	2.944	2.031	MC	0.98
7	6.315	4.282	3.317	8.734	5.184	2.995	MC	0.90
8	4.566	5.322	3.195	9.904	4.229	3.602	MC	1.13
9	5.858	6.993	4.144	13.048	5.465	4.195	MC	1.01
10	3.084	9.242	3.006	8.950	3.047	4.567	MC	1.52
11	5.034	11.150	4.509	14.540	4.949	4.858	MC	1.08
12	4.580	10.332	4.125	13.217	4.499	5.783	MC	1.40
13	6.821	12.709	5.770	19.720	6.712	6.065	MC	1.05
Mean Value								1.113
Standard Deviation								0.184

TABLE 6a-2

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Received data and Consider the Effect of Low F_y in Coverplate
Based on the AISI 1981 Guide

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.049	1.249	4.558	1.711	1.616	MC	1.29
2	2.963	3.536	2.096	6.930	2.775	2.320	MC	1.11
3	3.543	3.801	2.384	7.251	3.932	2.377	MC	1.00
4	3.289	3.740	2.275	7.163	3.041	2.453	MC	1.08
5	3.193	2.923	1.984	5.649	2.816	1.948	MC	0.98
6	3.356	3.010	2.063	5.815	2.944	2.031	MC	0.98
7	4.831	4.282	2.951	8.734	4.957	2.995	MC	1.01
8	3.590	5.322	2.787	9.904	3.375	3.602	MC	1.29
9	4.259	6.993	3.441	13.048	4.049	4.195	MC	1.22
10	3.084	9.242	3.006	8.950	3.047	4.567	MC	1.52
11	4.231	11.150	3.987	14.540	5.257	4.858	MC	1.22
12	3.966	10.332	3.726	13.217	4.839	5.783	MC	1.55
13	5.159	12.709	4.770	19.720	7.042	6.065	MC	1.27
Mean Value								1.193
Standard Deviation								0.191

TABLE 6a-3

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Formed Data and Neglect the Effect of Low F_y in Coverplate
Based on the AISI 1981 Guide

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	2.021	2.857	1.539	6.128	2.908	1.616	MC	1.05
2	3.155	4.381	2.384	8.771	4.216	2.320	MC	0.97
3	4.123	3.607	2.501	7.811	4.592	2.377	MC	0.95
4	3.745	3.306	2.283	9.815	5.685	2.453	MC	1.07
5	3.103	2.596	1.838	5.918	4.009	1.948	MC	1.06
6	3.300	2.625	1.901	5.918	3.910	2.031	MC	1.07
7	6.742	3.114	2.769	8.734	5.635	2.995	MC	1.08
8	4.656	5.886	3.379	11.342	5.382	3.602	MC	1.07
9	6.184	6.285	4.052	15.219	7.164	4.195	MC	1.04
10	3.438	10.846	3.394	14.991	5.104	4.567	MC	1.35
11	4.405	10.467	4.030	16.473	5.607	4.858	MC	1.21
12	4.377	11.427	4.114	20.967	7.137	5.783	MC	1.41
13	7.934	10.256	5.815	26.980	9.038	6.065	MC	1.04
Mean Value								1.105
Standard Deviation								0.136

TABLE 6a-4

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Formed data and Consider the Effect of Low F_y in Coverplate
Based on the AISI 1981 Guide

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.857	1.440	6.128	2.930	1.616	MC	1.12
2	2.963	4.381	2.298	8.771	4.245	2.320	MC	1.01
3	3.543	3.607	2.324	7.811	5.026	2.377	MC	1.02
4	3.289	3.306	2.143	9.815	5.761	2.453	MC	1.14
5	3.193	2.596	1.861	5.918	3.999	1.948	MC	1.05
6	3.356	2.625	1.915	5.918	3.904	2.031	MC	1.06
7	4.831	3.114	2.462	8.734	5.445	2.995	MC	1.22
8	3.964	5.886	3.079	11.342	4.348	3.602	MC	1.17
9	4.753	6.285	3.518	15.219	5.415	4.195	MC	1.19
10	3.084	10.846	3.084	14.991	5.104	4.567	MC	1.48
11	4.231	10.467	3.917	16.473	5.956	4.858	MC	1.24
12	3.966	11.427	3.827	20.967	7.676	5.783	MC	1.51
13	5.159	10.256	4.462	26.980	9.634	6.065	MC	1.36
Mean Value								1.197
Standard Deviation								0.164

TABLE 6b-1

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Received data and Neglect the Effect of Low F_y in Coverplate

Based on the AISI 1980 Specification

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.087	1.333	4.676	1.862	1.616	MC	1.21
2	2.963	3.548	2.222	7.866	2.990	2.320	MC	1.04
3	3.990	3.861	2.691	7.831	3.624	2.377	MC	0.88
4	3.289	3.762	2.413	8.314	3.245	2.453	MC	1.02
5	3.193	3.057	2.141	5.933	2.848	1.948	MC	0.91
6	3.356	3.148	2.226	5.933	2.944	2.031	MC	0.91
7	6.179	4.302	3.459	8.757	5.049	2.995	MC	0.87
8	4.566	5.297	3.373	11.495	4.503	3.602	MC	1.07
9	5.858	6.904	4.360	15.145	5.836	4.195	MC	0.96
10	3.084	9.037	3.084	8.950	3.659	4.567	M	1.48
11	5.034	10.937	4.790	14.540	5.707	4.858	M	1.01
12	4.580	10.142	4.385	13.217	5.202	5.783	MC	1.32
13	6.821	12.458	6.107	19.720	7.599	6.065	MC	0.99
Mean Value								1.051
Standard Deviation								0.182

TABLE 6b-2

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Received data and Consider the Effect of Low F_y in Coverplate
Based on the AISI 1980 Specification

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.087	1.333	4.676	1.862	1.616	MC	1.21
2	2.963	3.548	2.222	7.866	2.990	2.320	MC	1.04
3	3.543	3.861	2.539	7.831	4.033	2.377	MC	0.94
4	3.289	3.762	2.413	8.314	3.245	2.453	MC	1.02
5	3.193	3.057	2.141	5.933	2.848	1.948	MC	0.91
6	3.356	3.148	2.226	5.933	2.944	2.031	MC	0.91
7	4.831	4.302	3.116	8.757	4.821	2.995	MC	0.96
8	3.590	5.297	2.955	11.495	3.571	3.602	MC	1.22
9	4.259	6.904	3.643	15.145	4.292	4.195	MC	1.15
10	3.084	9.037	3.084	8.950	3.659	4.567	M	1.48
11	4.231	10.937	4.231	14.540	6.088	4.858	M	1.15
12	3.966	10.142	3.966	13.217	5.625	5.783	M	1.46
13	5.159	12.458	5.076	19.720	7.992	6.065	MC	1.19
Mean Value								1.126
Standard Deviation								0.189

TABLE 6b-3

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Formed data and Neglect the Effect of Low F_y in Coverplate
Based on the AISI 1980 Specification

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	2.021	2.955	1.657	7.113	3.075	1.616	MC	0.98
2	3.155	4.410	2.537	10.180	4.434	2.320	MC	0.91
3	4.123	3.731	2.683	7.831	4.496	2.377	MC	0.89
4	3.745	3.457	2.463	9.840	5.597	2.453	MC	1.00
5	3.103	2.820	2.024	5.933	3.938	1.948	MC	0.96
6	3.300	2.852	2.094	5.933	3.783	2.031	MC	0.97
7	6.742	3.221	2.955	8.757	5.437	2.995	MC	1.01
8	4.656	5.858	3.573	13.399	5.668	3.602	MC	1.01
9	6.184	6.240	4.262	17.665	7.525	4.195	MC	0.98
10	3.438	10.644	3.438	14.991	5.975	4.567	M	1.33
11	4.405	10.303	4.292	16.473	6.409	4.858	MC	1.13
12	4.377	11.230	4.377	20.967	7.961	5.783	M	1.32
13	7.934	10.087	6.118	26.980	9.948	6.065	MC	0.99
Mean Value								1.037
Standard Deviation								0.140

TABLE 6b-4

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Formed data and Consider the Effect of Low F_y in Coverplate
Based on the AISI 1980 Specification

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.955	1.553	7.113	3.099	1.616	MC	1.04
2	2.963	4.410	2.448	10.180	4.467	2.320	MC	0.95
3	3.543	3.731	2.496	7.831	4.934	2.377	MC	0.95
4	3.289	3.457	2.314	9.840	5.673	2.453	MC	1.06
5	3.193	2.820	2.050	5.933	3.928	1.948	MC	0.95
6	3.356	2.852	2.109	5.933	3.777	2.031	MC	0.96
7	4.831	3.221	2.634	8.757	5.244	2.995	MC	1.14
8	3.964	5.858	3.265	13.399	4.532	3.602	MC	1.10
9	4.753	6.240	3.719	17.665	5.626	4.195	MC	1.13
10	3.084	10.644	3.084	14.991	5.975	4.567	M	1.48
11	4.231	10.303	4.174	16.473	6.833	4.858	MC	1.16
12	3.966	11.230	3.966	20.967	8.588	5.783	M	1.46
13	5.159	10.087	4.735	26.980	10.621	6.065	MC	1.28
Mean Value								1.127
Standard Deviation								0.181

TABLE 7a

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the AISI 1981 Guide with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	0.163	1.520	0.163	2.153	0.172	0.216	M	1.32
2	0.415	1.599	0.415	3.294	0.426	0.414	M	1.00
3	0.707	1.654	0.644	4.080	0.714	0.618	MC	0.96
4	1.026	1.581	0.809	4.080	1.014	0.762	MC	0.94
5	1.384	1.493	0.934	4.080	1.330	0.900	MC	0.96
6	2.053	1.319	1.044	3.161	1.722	0.975	MC	0.93
7	0.219	2.396	0.219	2.911	0.232	0.306	M	1.40
8	0.560	2.515	0.560	4.472	0.580	0.594	M	1.06
9	1.000	2.608	0.940	6.034	1.017	0.876	MC	0.93
10	1.461	2.528	1.203	6.389	1.458	1.090	MC	0.91
11	1.973	2.424	1.414	6.389	1.920	1.320	MC	0.93
12	3.161	2.215	1.693	5.678	2.792	1.610	MC	0.95
13	0.260	2.703	0.260	3.467	0.277	0.384	M	1.48
14	0.667	2.837	0.667	5.326	0.690	0.726	M	1.09
15	1.160	2.941	1.082	6.972	1.180	1.100	MC	1.02
16	1.690	2.851	1.379	6.972	1.681	1.380	MC	1.00
17	2.282	2.733	1.617	6.972	2.208	1.610	MC	1.00
18	3.662	2.498	1.930	5.678	3.109	1.960	MC	1.02
19	0.311	3.008	0.311	4.139	0.330	0.498	M	1.60
20	0.796	3.158	0.796	6.360	0.824	0.905	M	1.14
21	1.349	3.273	1.242	7.619	1.368	1.360	MC	1.10
22	1.960	3.173	1.575	7.619	1.942	1.640	MC	1.04
23	2.648	3.042	1.840	7.614	2.545	1.930	MC	1.05
24	3.651	2.780	2.052	5.678	3.071	2.340	MC	1.14
25	0.471	4.814	0.471	6.341	0.507	0.678	M	1.44
26	1.218	5.036	1.218	9.795	1.273	1.260	M	1.03
27	2.118	5.220	1.959	12.582	2.167	1.840	MC	0.94
28	3.089	5.111	2.503	12.582	3.085	2.370	MC	0.95
29	4.178	4.949	2.945	12.582	4.051	2.740	MC	0.93
30	6.562	4.626	3.527	9.992	5.485	3.190	MC	0.90
31	0.786	2.063	0.740	7.893	0.820	0.705	MC	0.95
32	1.090	3.764	1.090	13.604	1.158	1.185	M	1.09
33	0.816	2.048	0.758	7.893	0.851	0.698	MC	0.92
34	1.183	3.739	1.169	12.727	1.261	1.178	MC	1.01
35	0.825	2.048	0.765	7.893	0.861	0.690	MC	0.90
36	1.206	3.739	1.186	12.727	1.286	1.140	MC	0.96
37	0.772	2.063	0.730	7.809	0.806	0.705	MC	0.97
38	0.903	3.404	0.903	12.157	0.960	1.134	M	1.26
39	1.593	2.171	1.195	6.577	1.593	1.071	MC	0.90
40	2.037	3.574	1.687	12.704	2.093	1.890	MC	1.12

TABLE 7a (Cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests
Based on the AISI 1981 Guide with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
41	1.580	2.239	1.204	4.890	1.504	1.470	MC	1.22
42	3.321	3.705	2.277	10.947	3.264	2.592	MC	1.14
43	1.344	2.122	1.070	3.891	1.270	1.655	MC	1.55
44	3.437	3.973	2.396	9.510	3.233	2.898	MC	1.21
45	1.244	2.072	1.011	3.755	1.181	1.584	MC	1.57
46	3.491	4.028	2.431	9.679	3.284	2.979	MC	1.23
47	1.408	2.122	1.100	3.891	1.324	1.718	MC	1.56
48	3.741	3.973	2.505	9.510	3.482	3.142	MC	1.25
49	1.366	2.072	1.070	3.755	1.284	1.635	MC	1.53
50	3.827	4.028	2.551	9.679	3.559	3.069	MC	1.20
51	1.456	2.122	1.123	3.891	1.364	1.746	MC	1.56
52	3.894	3.799	2.500	9.510	3.604	3.012	MC	1.20
53	1.493	2.072	1.128	3.755	1.387	1.599	MC	1.42
54	4.176	4.028	2.666	9.679	3.835	3.168	MC	1.19
55	1.417	2.122	1.105	3.891	1.331	1.805	MC	1.63
56	3.787	3.973	2.520	9.510	3.518	3.048	MC	1.21
57	1.323	2.072	1.050	3.755	1.248	1.536	MC	1.46
58	3.331	3.701	2.279	8.698	3.111	3.243	MC	1.42
59	1.369	1.987	1.054	3.232	1.261	2.091	MC	1.98
60	3.294	3.435	2.186	7.215	2.997	3.522	MC	1.61
61	1.182	1.717	0.910	2.413	1.061	2.302	MC	2.53
62	2.972	3.489	2.087	5.882	2.653	4.135	MC	1.98
63	1.221	1.717	0.928	2.413	1.089	2.470	MC	2.66
64	3.159	3.489	2.155	5.882	2.783	4.405	MC	2.04
65	1.225	1.717	0.930	2.413	1.093	2.475	MC	2.66
66	3.184	3.489	2.164	5.882	2.800	4.628	MC	2.14
67	1.257	1.717	0.943	2.413	1.115	2.607	MC	2.76
68	2.984	3.131	1.986	5.381	2.610	4.562	MC	2.30
Mean Value								1.315
Standard Deviation								0.468

TABLE 7b

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the AISI 1980 Specification with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	0.163	1.823	0.163	2.153	0.196	0.216	M	1.32
2	0.415	1.776	0.415	3.294	0.473	0.414	M	1.00
3	0.707	1.729	0.698	4.435	0.765	0.618	MC	0.89
4	1.026	1.682	0.882	4.736	1.055	0.762	MC	0.86
5	1.384	1.635	1.032	4.246	1.333	0.900	MC	0.87
6	2.080	1.541	1.208	3.170	1.739	0.975	MC	0.81
7	0.219	2.726	0.219	2.911	0.268	0.306	M	1.40
8	0.560	2.668	0.560	4.472	0.652	0.594	M	1.06
9	1.000	2.611	1.000	6.034	1.110	0.876	M	0.88
10	1.461	2.554	1.287	7.415	1.547	1.090	MC	0.85
11	1.973	2.497	1.518	7.415	1.988	1.320	MC	0.87
12	3.085	2.382	1.836	5.692	2.712	1.610	MC	0.88
13	0.260	3.074	0.260	3.467	0.318	0.384	M	1.48
14	0.667	3.009	0.667	5.326	0.770	0.726	M	1.09
15	1.160	2.945	1.159	7.186	1.273	1.100	MC	0.95
16	1.690	2.880	1.474	8.092	1.762	1.380	MC	0.94
17	2.282	2.816	1.736	7.634	2.243	1.610	MC	0.93
18	3.490	2.687	2.073	5.692	2.975	1.960	MC	0.95
19	0.311	3.422	0.311	4.139	0.377	0.498	M	1.60
20	0.796	3.350	0.796	6.360	0.912	0.905	M	1.14
21	1.349	3.278	1.330	8.581	1.460	1.360	MC	1.02
22	1.960	3.206	1.683	8.843	2.008	1.640	MC	0.97
23	2.648	3.134	1.975	7.634	2.522	1.930	MC	0.98
24	3.947	2.990	2.323	5.692	3.244	2.340	MC	1.01
25	0.471	5.344	0.471	6.341	0.582	0.678	M	1.44
26	1.218	5.252	1.218	9.795	1.417	1.260	M	1.03
27	2.118	5.160	2.090	13.249	2.332	1.840	MC	0.88
28	3.089	5.067	2.655	14.603	3.223	2.370	MC	0.89
29	4.178	4.975	3.125	13.450	4.090	2.740	MC	0.88
30	6.373	4.790	3.734	10.017	5.377	3.190	MC	0.85
31	0.786	2.552	0.786	9.161	0.851	0.705	M	0.90
32	1.090	4.274	1.090	13.604	1.257	1.185	M	1.09
33	0.816	2.561	0.816	9.161	0.893	0.698	M	0.86
34	1.183	4.285	1.183	12.727	1.380	1.178	M	1.00
35	0.825	2.561	0.825	9.161	0.903	0.690	M	0.84
36	1.206	4.285	1.206	12.727	1.408	1.140	M	0.95
37	0.772	2.552	0.772	9.063	0.838	0.705	M	0.91
38	0.903	3.881	0.903	12.157	1.043	1.134	M	1.26
39	1.557	2.480	1.323	6.594	1.516	1.071	MC	0.81
40	2.037	3.798	1.838	14.805	2.142	1.890	MC	1.03

TABLE 7b (Cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the AISI 1980 Specification with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
41	2.271	2.408	1.605	4.902	2.061	1.470	MC	0.92
42	3.262	3.715	2.388	10.975	3.127	2.592	MC	1.09
43	2.771	2.335	1.734	3.901	2.259	1.655	MC	0.95
44	4.364	4.008	2.862	9.535	3.968	2.898	MC	1.01
45	2.480	2.291	1.632	3.765	2.071	1.584	MC	0.97
46	4.311	4.061	2.866	9.704	3.940	2.979	MC	1.04
47	2.902	2.335	1.769	3.901	2.328	1.718	MC	0.97
48	4.750	4.008	2.974	9.535	4.251	3.142	MC	1.06
49	2.723	2.291	1.702	3.765	2.206	1.635	MC	0.96
50	4.726	4.061	2.989	9.704	4.249	3.069	MC	1.03
51	2.956	2.335	1.783	3.901	2.356	1.746	MC	0.98
52	4.611	3.832	2.862	9.535	4.151	3.012	MC	1.05
53	2.976	2.291	1.768	3.765	2.335	1.599	MC	0.90
54	5.157	4.061	3.105	9.704	4.554	3.168	MC	1.02
55	2.921	2.335	1.774	3.901	2.338	1.805	MC	1.02
56	4.808	4.008	2.990	9.535	4.293	3.048	MC	1.02
57	2.774	2.291	1.716	3.765	2.233	1.536	MC	0.90
58	4.442	3.748	2.781	8.720	3.958	3.243	MC	1.17
59	3.557	2.263	1.884	3.240	2.395	2.091	MC	1.11
60	5.513	3.549	2.941	7.234	4.385	3.522	MC	1.20
61	4.060	2.119	1.890	2.419	2.078	2.302	MC	1.22
62	7.622	3.742	3.404	5.897	4.664	4.135	MC	1.21
63	4.194	2.119	1.910	2.419	2.096	2.470	MC	1.29
64	8.101	3.742	3.469	5.897	4.768	4.405	MC	1.27
65	4.210	2.119	1.912	2.419	2.098	2.475	MC	1.29
66	8.164	3.742	3.477	5.897	4.780	4.628	MC	1.33
67	4.293	2.119	1.924	2.419	2.108	2.607	MC	1.35
68	7.535	3.383	3.163	5.395	4.386	4.562	MC	1.44
Mean Value								1.046
Standard Deviation								0.182

TABLE 8a-1

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Received Data and Neglect the Effect of Low F_y in Coverplate
Based on the AISI 1981 Guide with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.049	1.249	4.558	1.711	1.616	MC	1.29
2	2.963	3.536	2.096	6.930	2.775	2.320	MC	1.11
3	3.990	3.801	2.530	7.251	3.547	2.377	MC	0.94
4	3.289	3.740	2.275	7.163	3.041	2.453	MC	1.08
5	3.193	2.923	1.984	5.649	2.816	1.948	MC	0.98
6	3.356	3.010	2.063	5.815	2.944	2.031	MC	0.98
7	6.315	4.433	3.386	8.734	5.184	2.995	MC	0.88
8	4.566	5.322	3.195	9.904	4.229	3.602	MC	1.13
9	5.858	6.993	4.144	13.048	5.465	4.195	MC	1.01
10	3.084	9.242	3.006	8.950	3.047	4.567	MC	1.52
11	5.034	11.150	4.509	14.540	4.949	4.858	MC	1.08
12	4.580	10.332	4.125	13.217	4.499	5.783	MC	1.40
13	6.821	12.709	5.770	19.720	6.712	6.065	MC	1.05
Mean Value								1.111
Standard Deviation								0.186

TABLE 8a-2

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Received Data and Consider the Effect of Low F_y in Coverplate
Based on the AISI 1981 Guide with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.049	1.249	4.558	1.711	1.616	MC	1.29
2	2.963	3.536	2.096	6.930	2.775	2.320	MC	1.11
3	3.543	3.801	2.384	7.251	3.932	2.377	MC	1.00
4	3.289	3.740	2.275	7.163	3.041	2.453	MC	1.08
5	3.193	2.923	1.984	5.649	2.816	1.948	MC	0.98
6	3.356	3.010	2.063	5.815	2.944	2.031	MC	0.98
7	4.831	4.433	3.005	8.734	4.957	2.995	MC	1.00
8	3.590	5.322	2.787	9.904	3.375	3.602	MC	1.29
9	4.259	6.993	3.441	13.048	4.049	4.195	MC	1.22
10	3.084	9.242	3.006	8.950	3.047	4.567	MC	1.52
11	4.231	11.150	3.987	14.540	5.257	4.858	MC	1.22
12	3.966	10.332	3.726	13.217	4.839	5.783	MC	1.55
13	5.159	12.709	4.770	19.720	7.042	6.065	MC	1.27
Mean Value								1.193
Standard Deviation								0.192

TABLE 8a-3

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Formed Data and Neglect the Effect of Low F_y in Coverplate
Based on the AISI 1981 Guide with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	2.021	2.857	1.539	6.128	2.908	1.616	MC	1.05
2	3.155	4.381	2.384	8.771	4.216	2.320	MC	0.97
3	4.123	3.610	2.502	7.811	4.592	2.377	MC	0.95
4	3.745	3.353	2.300	9.815	5.685	2.453	MC	1.07
5	3.103	2.629	1.850	5.918	4.009	1.948	MC	1.05
6	3.300	2.629	1.902	5.918	3.910	2.031	MC	1.07
7	6.742	3.610	3.056	8.734	5.635	2.995	MC	0.98
8	4.656	5.886	3.379	11.342	5.382	3.602	MC	1.07
9	6.184	6.308	4.060	15.219	7.164	4.195	MC	1.03
10	3.438	10.846	3.394	14.991	5.104	4.567	MC	1.35
11	4.405	10.467	4.030	16.473	5.607	4.858	MC	1.21
12	4.377	11.430	4.114	20.967	7.137	5.783	MC	1.41
13	7.934	10.993	5.991	26.980	9.038	6.065	MC	1.01
Mean Value								1.093
Standard Deviation								0.142

TABLE 8a-4

Comparisons of Tested and Predicted Failure Loads for Ford Tests Use the As Formed Data and Consider the Effect of Low F_y in Coverplate Based on the AISI 1981 Guide with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
2	2.963	4.381	2.298	8.771	4.245	2.320	MC	1.01
3	3.543	3.610	2.325	7.811	5.026	2.377	MC	1.02
4	3.289	3.353	2.158	9.815	5.761	2.453	MC	1.14
5	3.193	2.629	1.874	5.918	3.999	1.948	MC	1.04
6	3.356	2.629	1.916	5.918	3.904	2.031	MC	1.06
7	4.831	3.610	2.686	8.734	5.445	2.995	MC	1.12
8	3.964	5.886	3.079	11.342	4.348	3.602	MC	1.17
9	4.753	6.308	3.524	15.219	5.415	4.195	MC	1.19
10	3.084	10.846	3.084	14.991	5.104	4.567	M	1.48
11	4.231	10.467	3.917	16.473	5.956	4.858	MC	1.24
12	3.966	11.430	3.828	20.967	7.676	5.783	MC	1.51
13	5.159	10.993	4.565	26.980	9.634	6.065	MC	1.33
Mean Value								1.186
Standard Deviation								0.163

TABLE 8b-1

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Received Data and Neglect the Effect of Low F_y in Coverplate
Based on the AISI 1980 Specification with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.087	1.333	4.676	1.862	1.616	MC	1.21
2	2.963	3.548	2.222	7.866	2.990	2.320	MC	1.04
3	3.990	3.861	2.691	7.831	3.624	2.377	MC	0.88
4	3.289	3.762	2.413	8.314	3.245	2.453	MC	1.02
5	3.193	3.057	2.141	5.933	2.848	1.948	MC	0.91
6	3.356	3.148	2.226	5.933	2.944	2.031	MC	0.91
7	6.179	4.454	3.532	8.757	5.049	2.995	MC	0.85
8	4.566	5.297	3.373	11.495	4.503	3.602	MC	1.07
9	5.858	6.904	4.360	15.145	5.836	4.195	MC	0.96
10	3.084	9.037	3.084	8.950	3.659	4.567	M	1.48
11	5.034	10.937	4.790	14.540	5.707	4.858	MC	1.01
12	4.580	10.142	4.385	13.217	5.202	5.783	MC	1.32
13	6.821	12.458	6.107	19.720	7.599	6.065	MC	0.99
Mean Value								1.050
Standard Deviation								0.183

TABLE 8b-2

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Received Data and Consider the Effect of Low F_y in Coverplate
Based on the AISI 1980 Specification with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.087	1.333	4.676	1.862	1.616	MC	1.21
2	2.963	3.548	2.222	7.866	2.990	2.320	MC	1.04
3	3.543	3.861	2.539	7.831	4.033	2.377	MC	0.94
4	3.289	3.762	2.413	8.314	3.245	2.453	MC	1.02
5	3.193	3.057	2.141	5.933	2.848	1.948	MC	0.91
6	3.356	3.148	2.226	5.933	2.944	2.031	MC	0.91
7	4.831	4.454	3.175	8.757	4.821	2.995	MC	0.94
8	3.590	5.297	2.955	11.495	3.571	3.602	MC	1.22
9	4.259	6.904	3.643	15.145	4.292	4.195	MC	1.15
10	3.084	9.037	3.084	8.950	3.659	4.567	M	1.48
11	4.231	10.937	4.231	14.540	6.088	4.858	M	1.15
12	3.966	10.142	3.966	13.217	5.625	5.783	M	1.46
13	5.159	12.458	5.076	19.720	7.992	6.065	MC	1.19
Mean Value								1.124
Standard Deviation								0.191

TABLE 8b-3

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Formed Data and Neglect the Effect of Low F_y in Coverplate
Based on the AISI 1980 Specification with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	2.021	2.955	1.657	7.113	3.075	1.616	MC	0.98
2	3.155	4.410	2.537	10.180	4.434	2.320	MC	0.91
3	4.123	3.734	2.684	7.831	4.496	2.377	MC	0.89
4	3.745	3.506	2.481	9.840	5.597	2.453	MC	0.99
5	3.103	2.856	2.038	5.933	3.938	1.948	MC	0.96
6	3.300	2.856	2.095	5.933	3.783	2.031	MC	0.97
7	6.742	3.734	3.265	8.757	5.437	2.995	MC	0.92
8	4.656	5.858	3.573	13.399	5.668	3.602	MC	1.01
9	6.184	6.263	4.270	17.665	7.525	4.195	MC	0.98
10	3.438	10.644	3.438	14.991	5.975	4.567	M	1.33
11	4.405	10.303	4.292	16.473	6.409	4.858	MC	1.13
12	4.377	11.232	4.377	20.967	7.961	5.783	M	1.32
13	7.934	10.812	6.311	26.980	9.948	6.065	MC	0.96
Mean Value								1.027
Standard Deviation								0.144

TABLE 8b-4

Comparisons of Tested and Predicted Failure Loads for Ford Tests
Use the As Formed Data and Consider the Effect of Low F_y in Coverplate
Based on the AISI 1980 Specification with Modified $f_3(F_y)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	1.810	2.955	1.553	7.113	3.099	1.616	MC	1.04
2	2.963	4.410	2.448	10.180	4.467	2.320	MC	0.95
3	3.543	3.734	2.496	7.831	4.934	2.377	MC	0.95
4	3.289	3.506	2.331	9.840	5.673	2.453	MC	1.05
5	3.193	2.856	2.064	5.933	3.928	1.948	MC	0.94
6	3.356	2.856	2.111	5.933	3.777	2.031	MC	0.96
7	4.831	3.734	2.877	8.757	5.244	2.995	MC	1.04
8	3.964	5.858	3.265	13.399	4.532	3.602	MC	1.10
9	4.753	6.263	3.725	17.665	5.626	4.195	MC	1.13
10	3.084	10.644	3.084	14.991	5.975	4.567	M	1.48
11	4.231	10.303	4.174	16.473	6.833	4.858	MC	1.16
12	3.966	11.232	3.966	20.967	8.588	5.783	M	1.46
13	5.159	10.812	4.850	26.980	10.621	6.065	MC	1.25
Mean Value								1.116
Standard Deviation								0.182

TABLE 9

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the AISI 1980 Specification with Modified $f_3(F_y)$ and $f(h/t)$

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	0.163	1.823	0.163	2.153	0.196	0.216	M	1.32
2	0.415	1.776	0.415	3.294	0.473	0.414	M	1.00
3	0.707	1.729	0.698	4.435	0.765	0.618	MC	0.89
4	1.026	1.682	0.882	4.736	1.055	0.762	MC	0.86
5	1.384	1.635	1.032	4.246	1.333	0.900	MC	0.87
6	2.080	1.541	1.208	3.170	1.739	0.975	MC	0.81
7	0.219	2.726	0.219	2.911	0.268	0.306	M	1.40
8	0.560	2.668	0.560	4.472	0.652	0.594	M	1.06
9	1.000	2.611	1.000	6.034	1.110	0.876	M	0.88
10	1.461	2.554	1.287	7.415	1.547	1.090	MC	0.85
11	1.973	2.497	1.518	7.415	1.988	1.320	MC	0.87
12	3.085	2.382	1.836	5.692	2.712	1.610	MC	0.88
13	0.260	3.074	0.260	3.467	0.318	0.384	M	1.48
14	0.667	3.009	0.667	5.326	0.770	0.726	M	1.09
15	1.160	2.945	1.159	7.186	1.273	1.100	MC	0.95
16	1.690	2.880	1.474	8.092	1.762	1.380	MC	0.94
17	2.282	2.816	1.736	7.634	2.243	1.610	MC	0.93
18	3.490	2.687	2.073	5.692	2.975	1.960	MC	0.95
19	0.311	3.422	0.311	4.139	0.377	0.498	M	1.60
20	0.796	3.350	0.796	6.360	0.912	0.905	M	1.14
21	1.349	3.278	1.330	8.581	1.460	1.360	MC	1.02
22	1.960	3.206	1.683	8.843	2.008	1.640	MC	0.97
23	2.648	3.134	1.975	7.634	2.522	1.930	MC	0.98
24	3.947	2.990	2.323	5.692	3.244	2.340	MC	1.01
25	0.471	5.344	0.471	6.341	0.582	0.678	M	1.44
26	1.218	5.252	1.218	9.795	1.417	1.260	M	1.03
27	2.118	5.160	2.090	13.249	2.332	1.840	MC	0.88
28	3.089	5.067	2.655	14.603	3.223	2.370	MC	0.89
29	4.178	4.975	3.125	13.450	4.090	2.740	MC	0.88
30	6.373	4.790	3.734	10.017	5.377	3.190	MC	0.85
31	0.786	2.689	0.786	9.161	0.851	0.705	M	0.90
32	1.090	4.439	1.090	13.604	1.257	1.185	M	1.09
33	0.816	2.689	0.816	9.161	0.893	0.698	M	0.86
34	1.183	4.439	1.183	12.727	1.380	1.178	M	1.00
35	0.825	2.689	0.825	9.161	0.903	0.690	M	0.84
36	1.206	4.439	1.206	12.727	1.408	1.140	M	0.95
37	0.772	2.689	0.772	9.063	0.838	0.705	M	0.91
38	0.903	4.036	0.903	12.157	1.043	1.134	M	1.26
39	1.557	2.689	1.365	6.594	1.516	1.071	MC	0.78
40	2.037	4.036	1.878	14.805	2.142	1.890	MC	1.01

TABLE 9 (Cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests
Based on the AISI 1980 Specification with Modified $f_3(F_y)$ and f(h/t)

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
41	2.271	2.689	1.694	4.902	2.061	1.470	MC	0.87
42	3.262	4.036	2.484	10.975	3.127	2.592	MC	1.04
43	2.771	2.689	1.871	3.901	2.259	1.655	MC	0.88
44	4.364	4.439	3.020	9.535	3.968	2.898	MC	0.96
45	2.480	2.643	1.757	3.765	2.071	1.584	MC	0.90
46	4.311	4.495	3.021	9.704	3.940	2.979	MC	0.99
47	2.902	2.689	1.912	3.901	2.328	1.718	MC	0.90
48	4.750	4.439	3.145	9.535	4.251	3.142	MC	1.00
49	2.723	2.643	1.839	3.765	2.206	1.635	MC	0.89
50	4.726	4.495	3.158	9.704	4.249	3.069	MC	0.97
51	2.956	2.689	1.929	3.901	2.356	1.746	MC	0.91
52	4.611	4.245	3.028	9.535	4.151	3.012	MC	0.99
53	2.976	2.643	1.917	3.765	2.335	1.599	MC	0.83
54	5.157	4.495	3.287	9.704	4.554	3.168	MC	0.96
55	2.921	2.689	1.918	3.901	2.338	1.805	MC	0.94
56	4.808	4.439	3.162	9.535	4.293	3.048	MC	0.96
57	2.774	2.643	1.855	3.765	2.233	1.536	MC	0.83
58	4.442	4.165	2.946	8.720	3.958	3.243	MC	1.10
59	3.557	2.689	2.091	3.240	2.395	2.091	MC	1.00
60	5.513	4.036	3.181	7.234	4.385	3.522	MC	1.11
61	4.060	2.689	2.204	2.419	2.078	2.302	MC	1.11
62	7.622	4.439	3.815	5.897	4.664	4.135	MC	1.08
63	4.194	2.689	2.232	2.419	2.096	2.470	MC	1.18
64	8.101	4.439	3.896	5.897	4.768	4.405	MC	1.13
65	4.210	2.689	2.235	2.419	2.098	2.475	MC	1.18
66	8.164	4.439	3.906	5.897	4.780	4.628	MC	1.18
67	4.293	2.689	2.251	2.419	2.108	2.607	MC	1.24
68	7.535	4.036	3.570	5.395	4.386	4.562	MC	1.28
Mean Value								1.011
Standard Deviation								0.169

TABLE 10

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the AISI 1980 Specification with Modified $f_3(F_y)$ and f(h/t) and Consider Inelastic Reserve Capacity

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
1	0.251*	1.823	0.251	2.153	0.196	0.216	M	1.10
2	0.415	1.776	0.415	3.294	0.473	0.414	M	1.00
3	0.707	1.729	0.698	4.435	0.765	0.618	MC	0.89
4	1.026	1.682	0.882	4.736	1.055	0.762	MC	0.86
5	1.384	1.635	1.032	4.246	1.333	0.900	MC	0.87
6	2.080	1.541	1.208	3.170	1.739	0.975	MC	0.81
7	0.350*	2.726	0.350	2.911	0.268	0.306	M	1.14
8	0.621*	2.668	0.621	4.472	0.652	0.594	M	0.96
9	1.000	2.611	1.000	6.034	1.110	0.876	M	0.88
10	1.461	2.554	1.287	7.415	1.547	1.090	MC	0.85
11	1.973	2.497	1.518	7.415	1.988	1.320	MC	0.87
12	3.085	2.382	1.836	5.692	2.712	1.610	MC	0.88
13	0.414*	3.074	0.414	3.467	0.318	0.384	M	1.21
14	0.667	3.009	0.667	5.326	0.770	0.726	M	1.09
15	1.160	2.945	1.159	7.186	1.273	1.100	MC	0.95
16	1.690	2.880	1.474	8.092	1.762	1.380	MC	0.94
17	2.282	2.816	1.736	7.634	2.243	1.610	MC	0.93
18	3.490	2.687	2.073	5.692	2.975	1.960	MC	0.95
19	0.462*	3.422	0.462	4.139	0.377	0.498	M	1.32
20	0.796	3.350	0.796	6.360	0.912	0.905	M	1.14
21	1.349	3.278	1.330	8.581	1.460	1.360	MC	1.02
22	1.960	3.206	1.683	8.843	2.008	1.640	MC	0.97
23	2.648	3.134	1.975	7.634	2.522	1.930	MC	0.98
24	3.947	2.990	2.323	5.692	3.244	2.340	MC	1.01
25	0.754*	5.344	0.754	6.341	0.582	0.678	M	1.16
26	1.218	5.252	1.218	9.795	1.417	1.260	M	1.03
27	2.118	5.160	2.090	13.249	2.332	1.840	MC	0.88
28	3.089	5.067	2.655	14.603	3.223	2.370	MC	0.89
29	4.178	4.975	3.125	13.450	4.090	2.740	MC	0.88
30	6.373	4.790	3.734	10.017	5.377	3.190	MC	0.85
31	0.786	2.689	0.786	9.161	0.851	0.705	M	0.90
32	1.090	4.439	1.090	13.604	1.257	1.185	M	1.09
33	0.816	2.689	0.816	9.161	0.893	0.698	M	0.86
34	1.183	4.439	1.183	12.727	1.380	1.178	M	1.00
35	0.825	2.689	0.825	9.161	0.903	0.690	M	0.84
36	1.206	4.439	1.206	12.727	1.408	1.140	M	0.95
37	0.772	2.689	0.772	9.063	0.838	0.705	M	0.91
38	0.903	4.036	0.903	12.157	1.043	1.134	M	1.26
39	1.557	2.689	1.365	6.594	1.516	1.071	MC	0.78
40	2.037	4.036	1.878	14.805	2.142	1.890	MC	1.01

TABLE 10 (Cont'd)

Comparisons of Tested and Predicted Failure Loads for Inland Tests Based on the AISI 1980 Specification with Modified $f_3(F_y)$ and $f(h/t)$ and Consider Inelastic Reserve Capacity

Specimen No.	P_m (kips)	P_{cw} (kips)	P_{mc} (kips)	P_s (kips)	P_{ms} (kips)	P_{test} (kips)	Failure Mode	P_{test}/P_{comp}
41	2.271	2.689	1.694	4.902	2.061	1.470	MC	0.87
42	3.262	4.036	2.484	10.975	3.127	2.592	MC	1.04
43	2.771	2.689	1.871	3.901	2.259	1.655	MC	0.88
44	4.364	4.439	3.020	9.535	3.968	2.898	MC	0.96
45	2.480	2.643	1.757	3.765	2.071	1.584	MC	0.90
46	4.311	4.495	3.021	9.704	3.940	2.979	MC	0.99
47	2.902	2.689	1.912	3.901	2.328	1.718	MC	0.90
48	4.750	4.439	3.145	9.535	4.251	3.142	MC	1.00
49	2.723	2.643	1.839	3.765	2.206	1.635	MC	0.89
50	4.726	4.495	3.158	9.704	4.249	3.069	MC	0.97
51	2.956	2.689	1.929	3.901	2.356	1.746	MC	0.91
52	4.611	4.245	3.028	9.535	4.151	3.012	MC	0.99
53	2.976	2.643	1.917	3.765	2.335	1.599	MC	0.83
54	5.157	4.495	3.287	9.704	4.554	3.168	MC	0.96
55	2.921	2.689	1.918	3.901	2.338	1.805	MC	0.94
56	4.808	4.439	3.162	9.535	4.293	3.048	MC	0.96
57	2.774	2.643	1.855	3.765	2.233	1.536	MC	0.83
58	4.442	4.165	2.946	8.720	3.958	3.243	MC	1.10
59	3.557	2.689	2.091	3.240	2.395	2.091	MC	1.00
60	5.513	4.036	3.181	7.234	4.385	3.522	MC	1.11
61	4.060	2.689	2.204	2.419	2.078	2.302	MC	1.11
62	7.622	4.439	3.815	5.897	4.664	4.135	MC	1.08
63	4.194	2.689	2.232	2.419	2.096	2.470	MC	1.18
64	8.101	4.439	3.896	5.897	4.768	4.405	MC	1.13
65	4.210	2.689	2.235	2.419	2.098	2.475	MC	1.18
66	8.164	4.439	3.906	5.897	4.780	4.628	MC	1.18
67	4.293	2.689	2.251	2.419	2.108	2.607	MC	1.24
68	7.535	4.036	3.570	5.395	4.386	4.562	MC	1.28
Mean Value								0.990
Standard Deviation								0.126

TABLE 11

Material Properties and Thicknesses of Six Sheet Steels to Be Used for Future Study[5]

Material Designation	F_y (ksi)	F_u (ksi)	t (in.)
80SK	82.2	88.8	0.061
80DF	55.8	88.8	0.114
80DK	58.2	87.6	0.048
80XF	88.3	98.7	0.082
100XF	113.1	113.1	0.062
140XF	141.2	141.2	0.043

TABLE 12

Nominal Dimensions of Hat Sections Proposed for Future Study

Profile No.	B1 (in.)	B2 (in.)	D1 (in.)	R (in.)
1	3.0	6.0	3.0	0.25
2	4.0	8.0	4.0	0.25
3	5.0	10.0	5.0	0.25

Note: See Fig.17 for definitions of symbols.

TABLE 13

Nominal Dimensions of I-Sections Proposed for Future Study

Profile No.	B1 (in.)	D1 (in.)	R (in.)
1	3.0	3.0	0.25
2	4.0	4.0	0.25
3	5.0	5.0	0.25

Note: See Fig.18 for definitions of symbols.

TABLE 14

Proposed Number of Web Crippling Tests on Hat Sections Subject to Interior One-Flange Loading

Profile No.	Material Designation						Total
	80SK	80DF	80DK	80XF	100XF	140XF	
1	2	2	2	2	2	2	12
2	2	2	2	2	2	2	12
3	2	2	2	2	2	2	12
Total	6	6	6	6	6	6	36

Notes: See Fig 19(a) for loading condition
Types of profiles are given in Table 12.

TABLE 15

Proposed Number of Web Crippling Tests on Hat Sections Subject to End One-Flange Loading

Profile No.	Material Designation						Total
	80SK	80DF	80DK	80XF	100XF	140XF	
1	2	2	2	2	2	2	12
2	2	2	2	2	2	2	12
3	2	2	2	2	2	2	12
Total	6	6	6	6	6	6	36

Notes: See Fig 19(b) for loading condition
Types of profiles are given in Table 12.

TABLE 16

Proposed Number of Web Crippling Tests on I-Sections Subject to Interior One-Flange Loading

Profile No.	Material Designation						Total
	80SK	80DF	80DK	80XF	100XF	140XF	
1	2	2	2	2	2	-	10
2	2	2	2	2	2	-	10
3	2	2	2	2	2	-	10
Total	6	6	6	6	6	-	30

Notes: See Fig 19(a) for loading condition
Types of profiles are given in Table 13.

TABLE 17

Proposed Number of Web Crippling Tests on I-Sections Subject to End One-Flange Loading

Profile No.	Material Designation						Total
	80SK	80DF	80DK	80XF	100XF	140XF	
1	2	2	2	2	2	-	10
2	2	2	2	2	2	-	10
3	2	2	2	2	2	-	10
Total	6	6	6	6	6	-	30

Notes: See Fig 19(b) for loading condition
Types of profiles are given in Table 13.

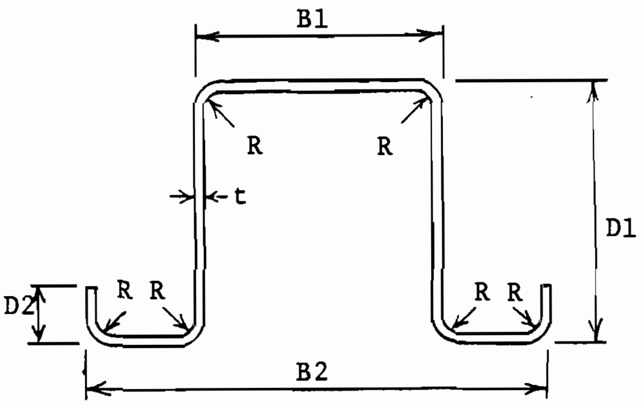


Fig. 1 Hat Sections Used for Indland Tests[4,6]

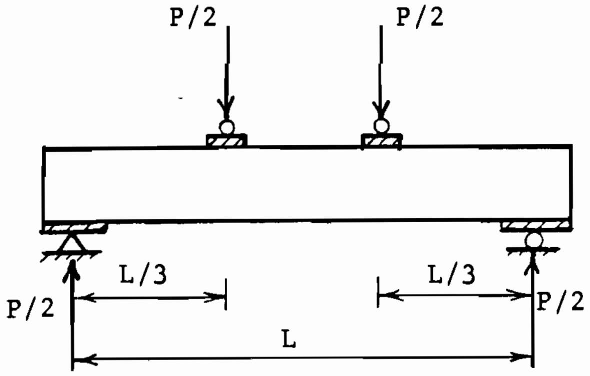


Fig. 2 Loading Arrangement for Inland Tests and Ford Tests[4,6,7]

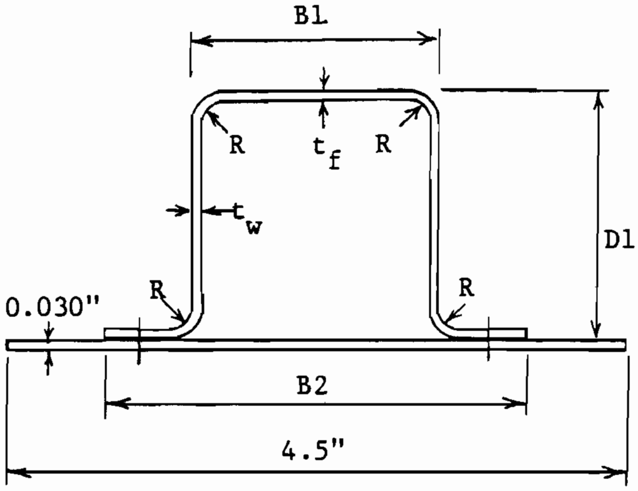
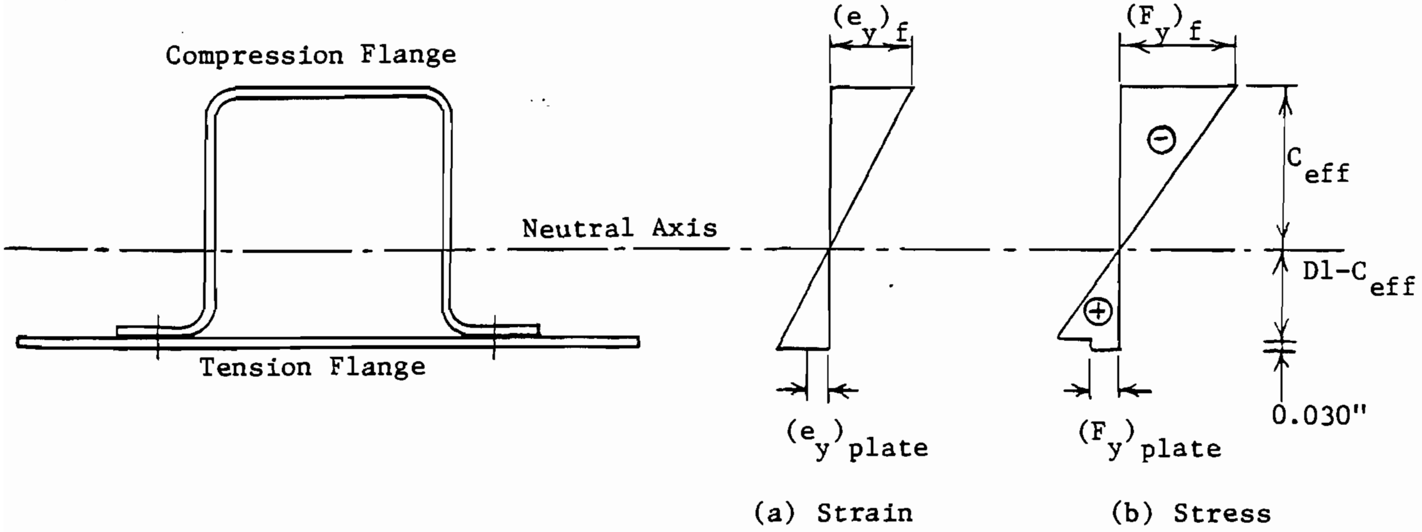


Fig. 3 Composite Sections Used for Ford Tests



(a) Strain (b) Stress

Fig. 4 Strain and Stress Diagrams for Composite Sections

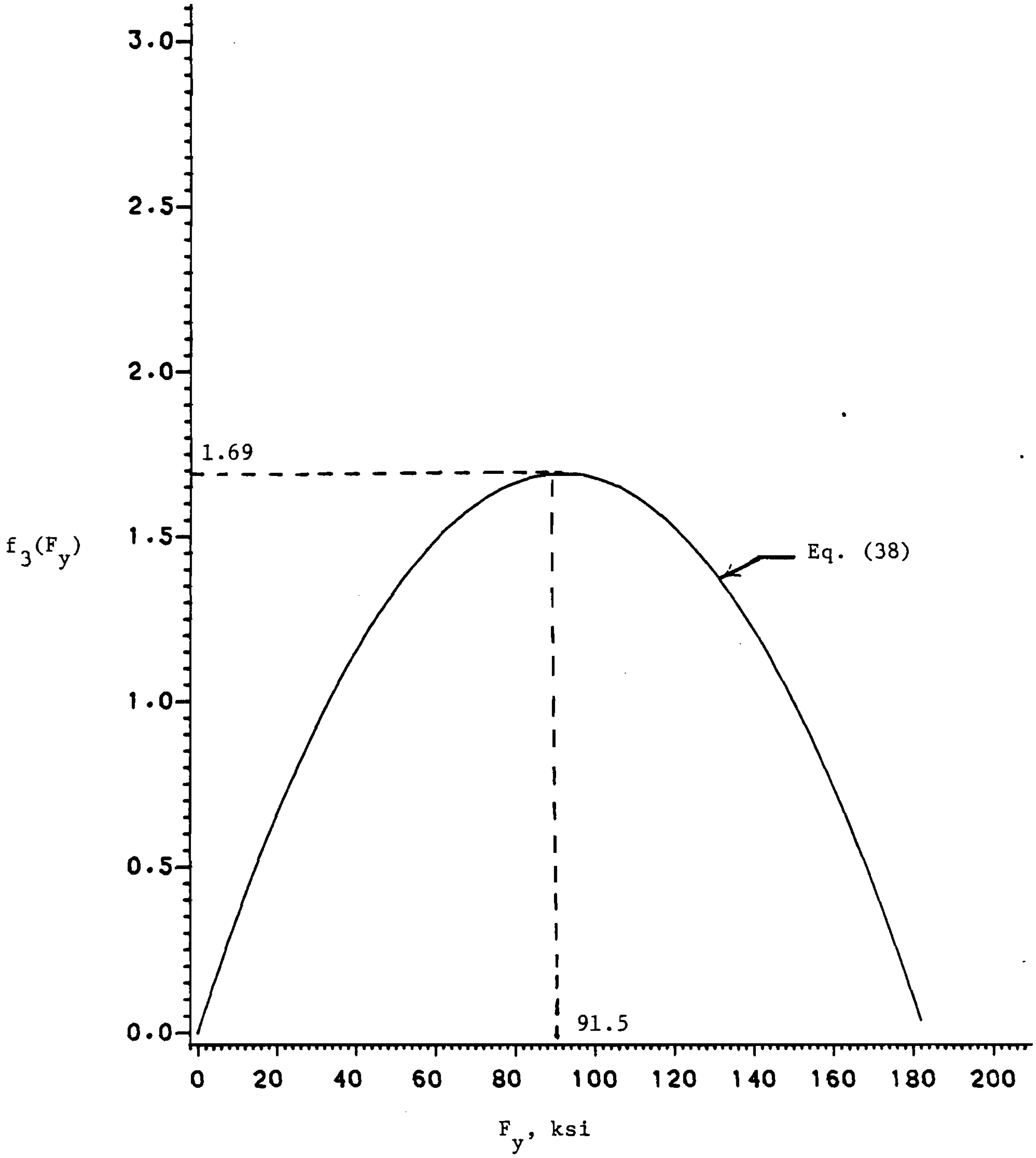


Fig. 5 Effect of F_y on Eq. (38)

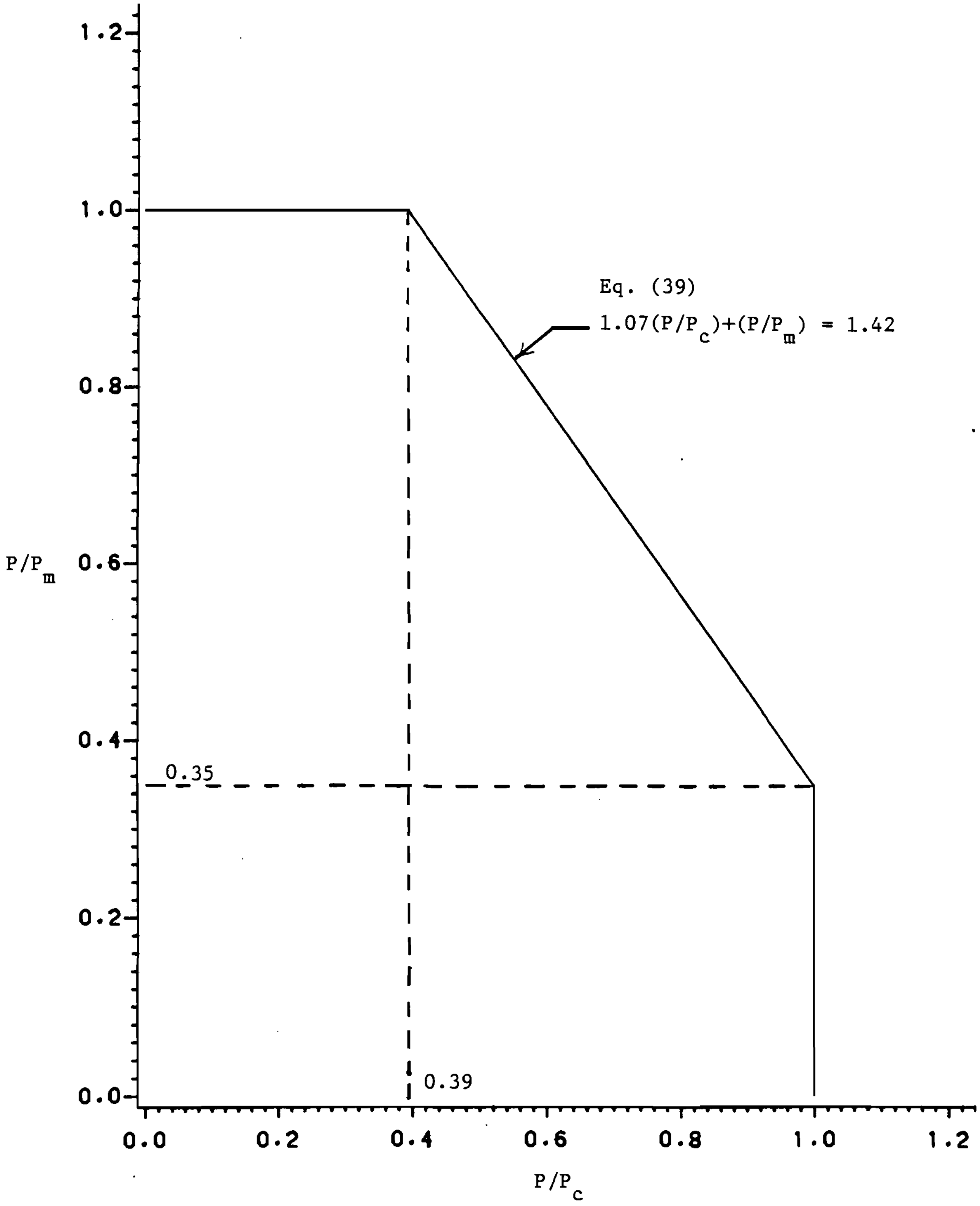


Fig. 6 Interaction of Bending Moment and Web Crippling Load for Single Unreinforced Webs

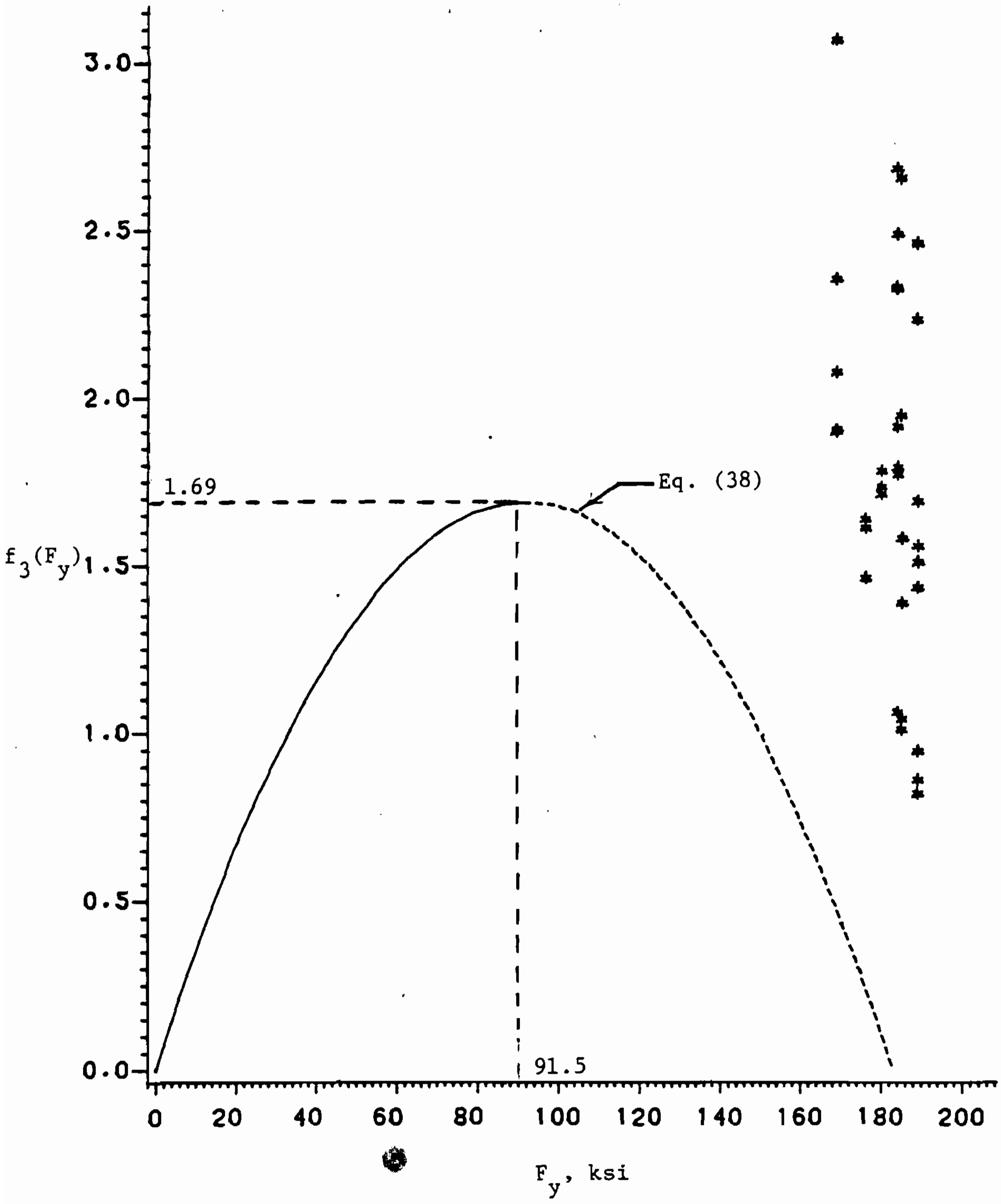


Fig. 7 Correlation Between $f_3(F_y)$ and the Test Data

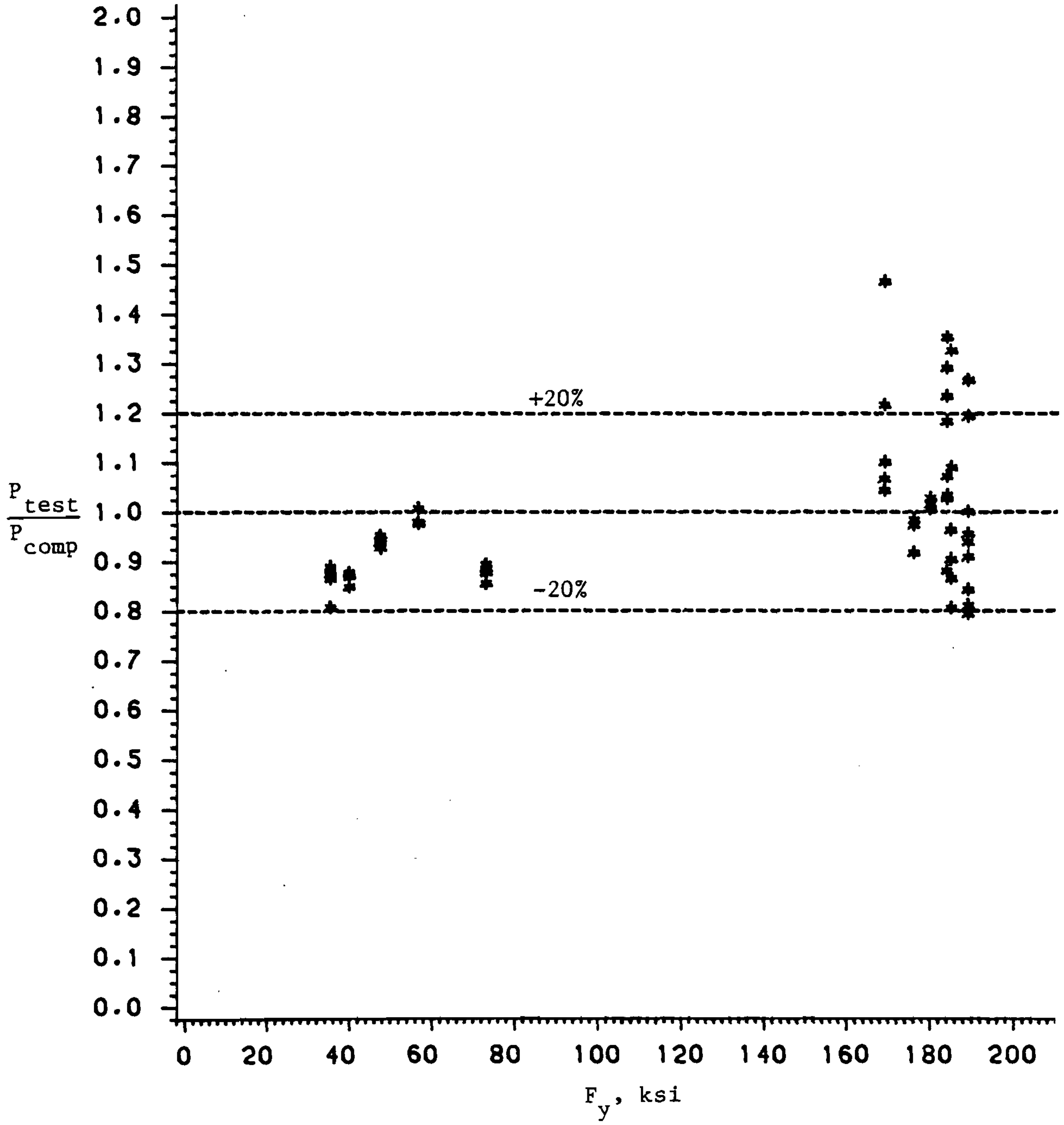


Fig. 8 Effect of F_y on the Ratios of P_{test}/P_{comp}

Using Eq. (48)

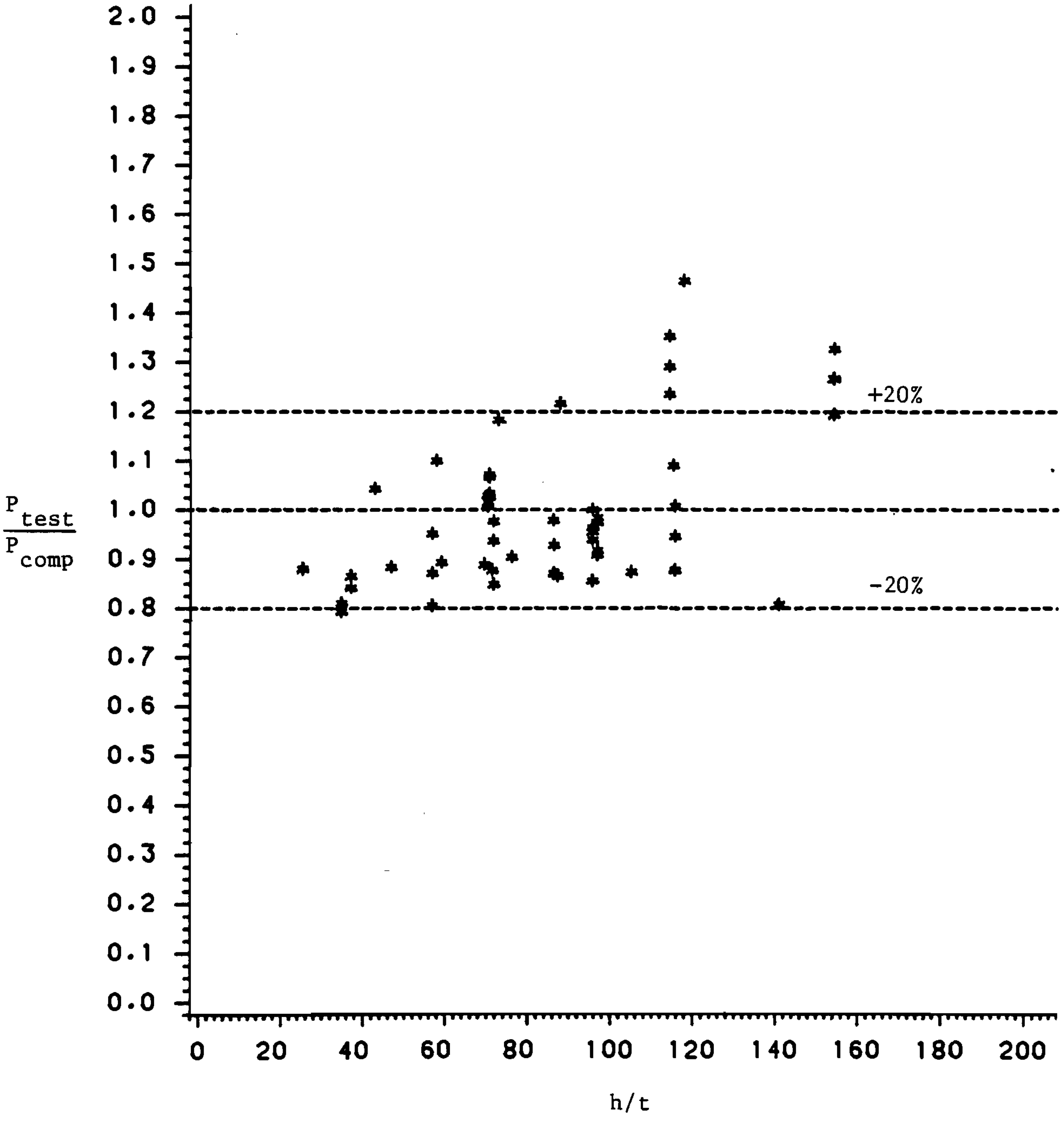


Fig. 9 Effect of h/t on the Ratios of P_{test}/P_{comp} Using Eq. (48)

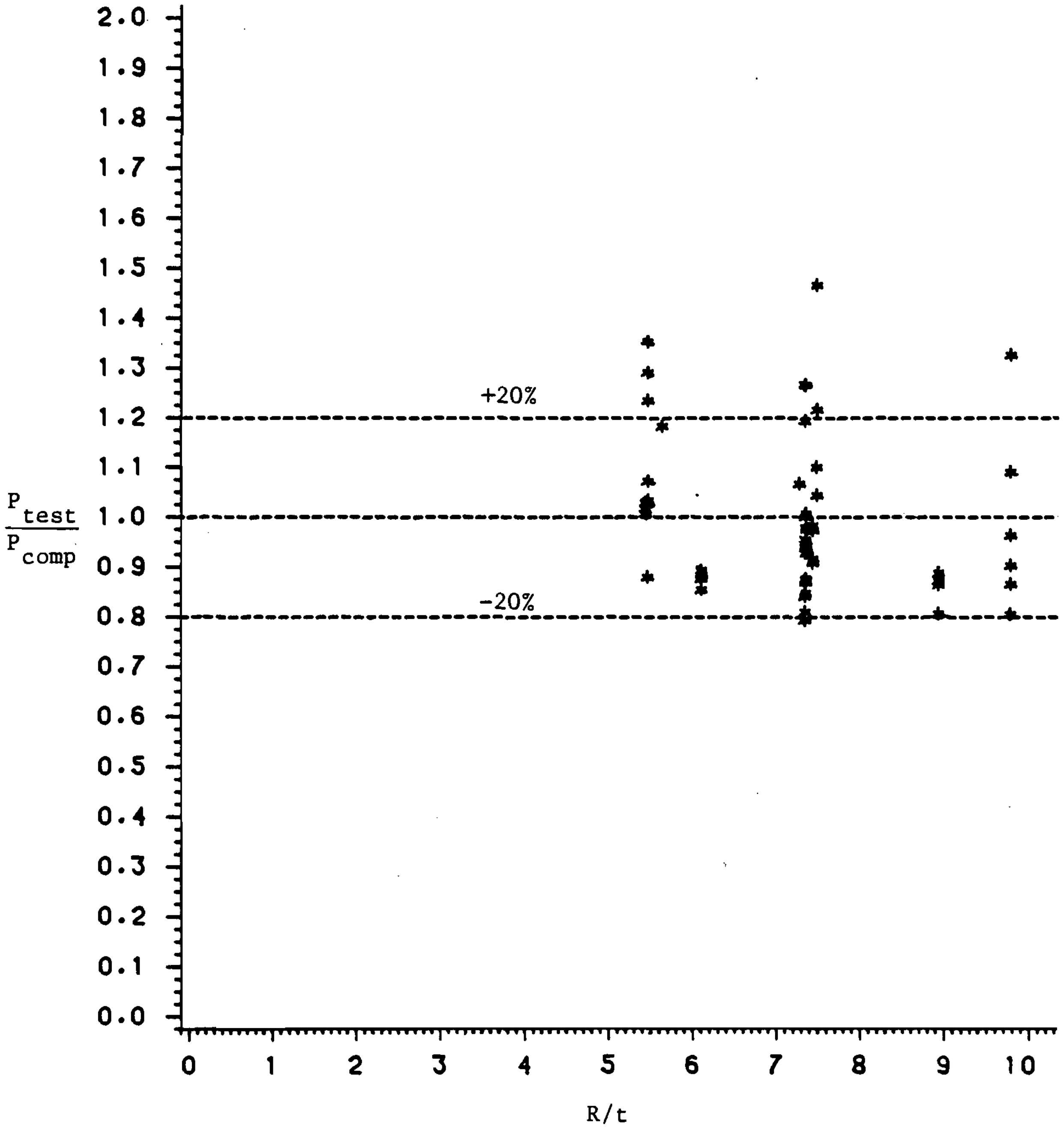


Fig. 10 Effect of R/t on the Ratios of P_{test}/P_{comp} Using Eq. (48)

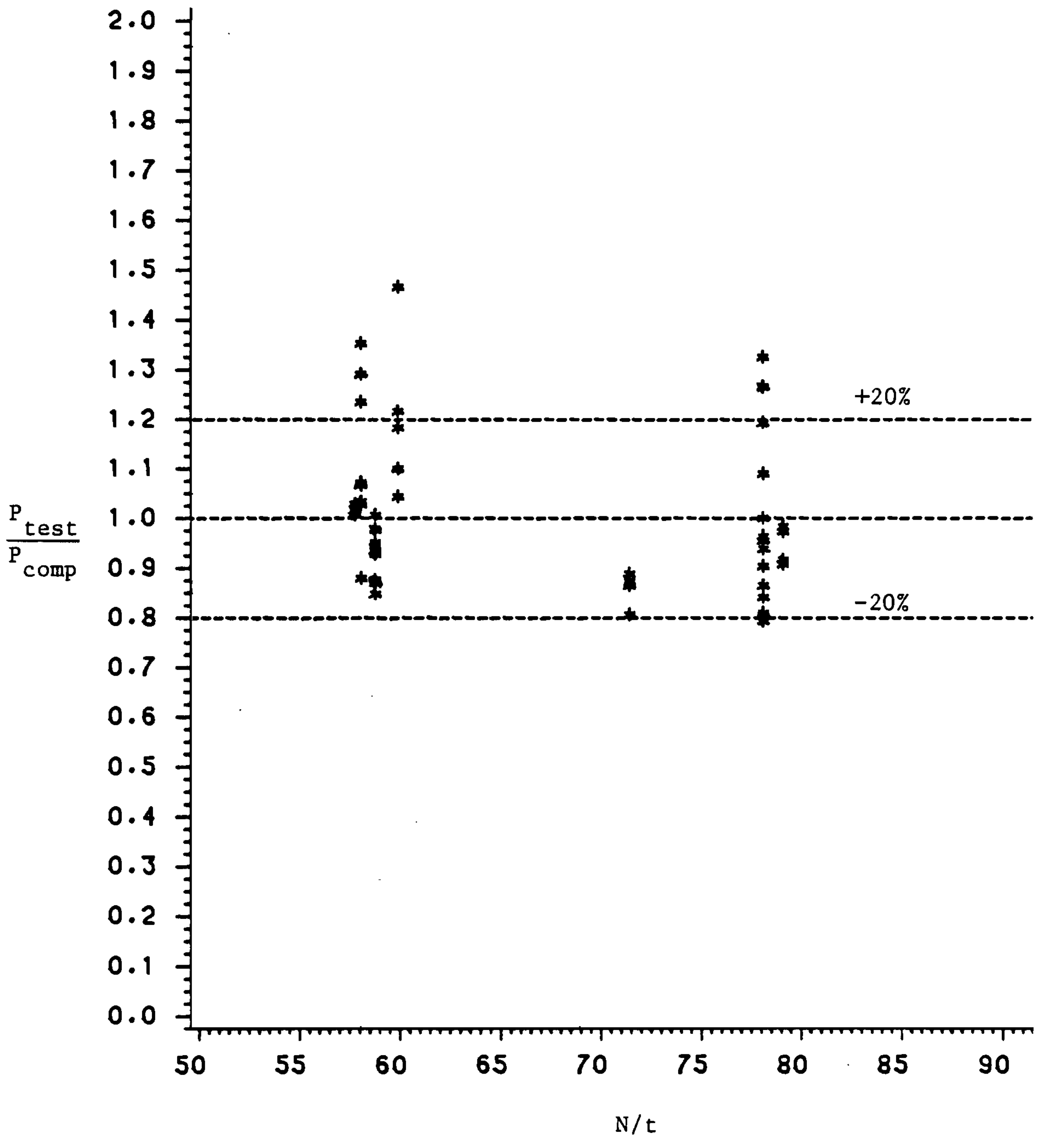


Fig. 11 Effect of N/t on the Ratios of P_{test}/P_{comp} Using Eq. (48)

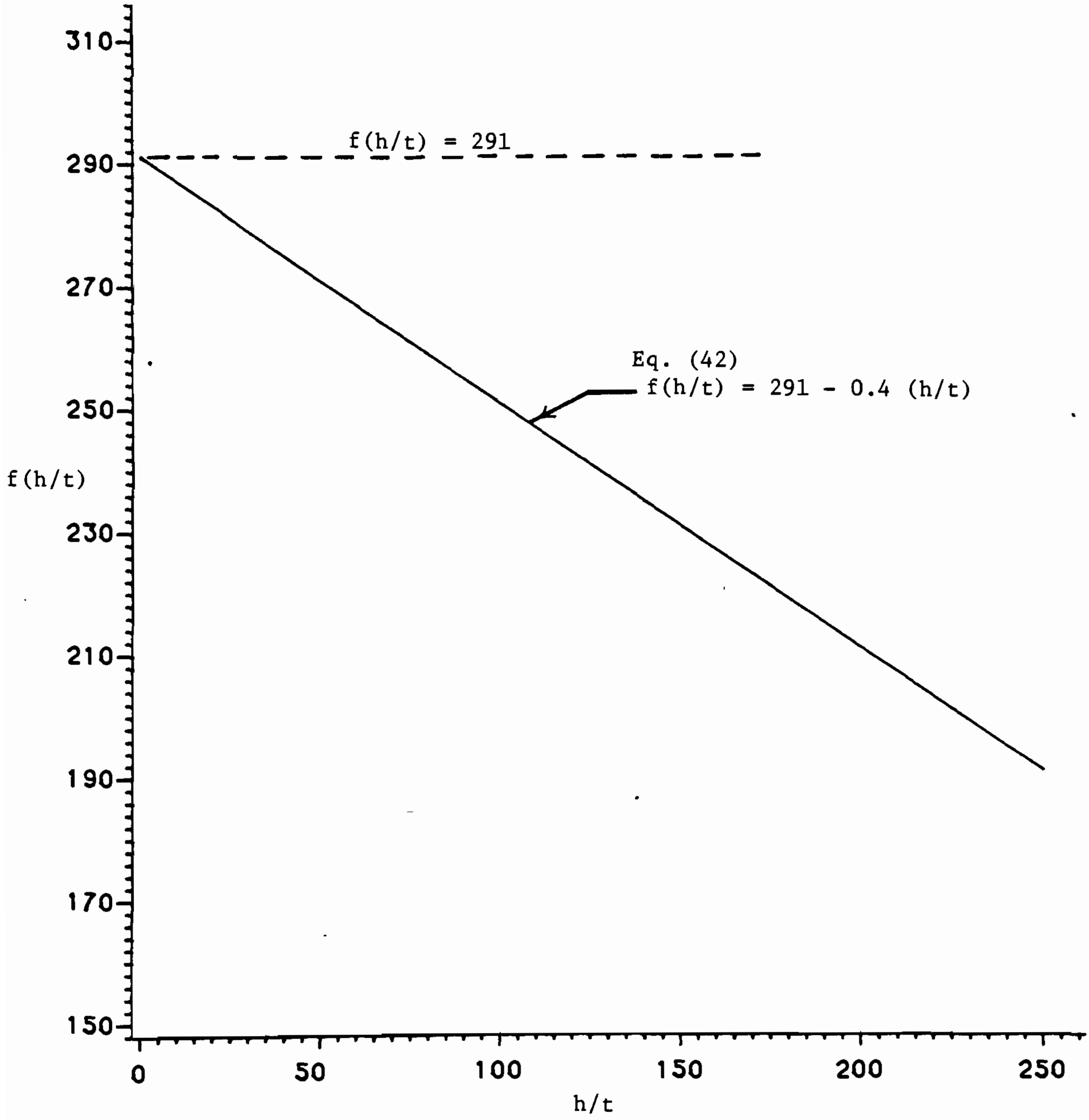


Fig. 12 Effect of h/t on Eq. (42)

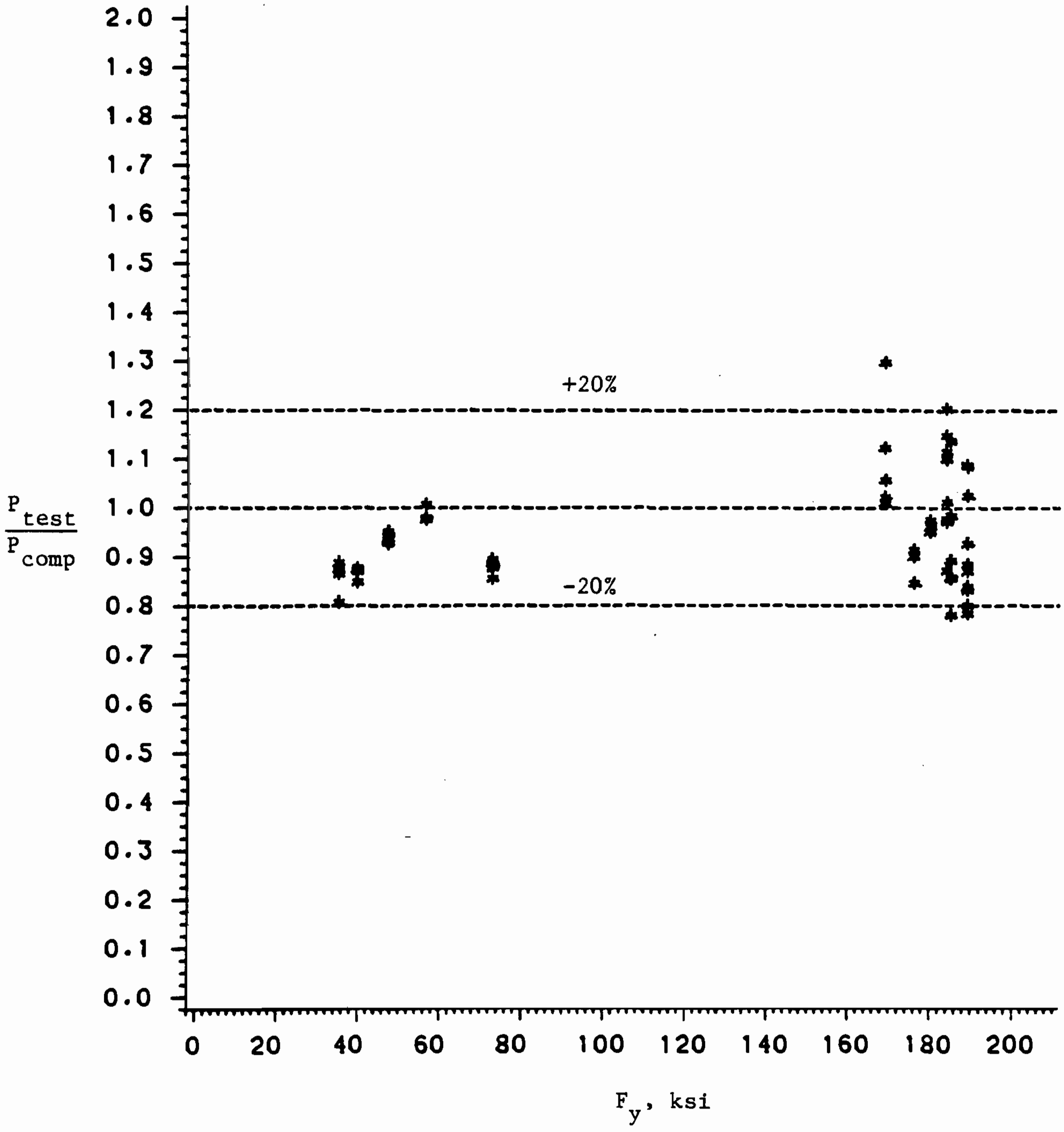


Fig. 13 Effect of F_y on the Ratios of P_{test}/P_{comp} Using Eqs. (47) and (48)

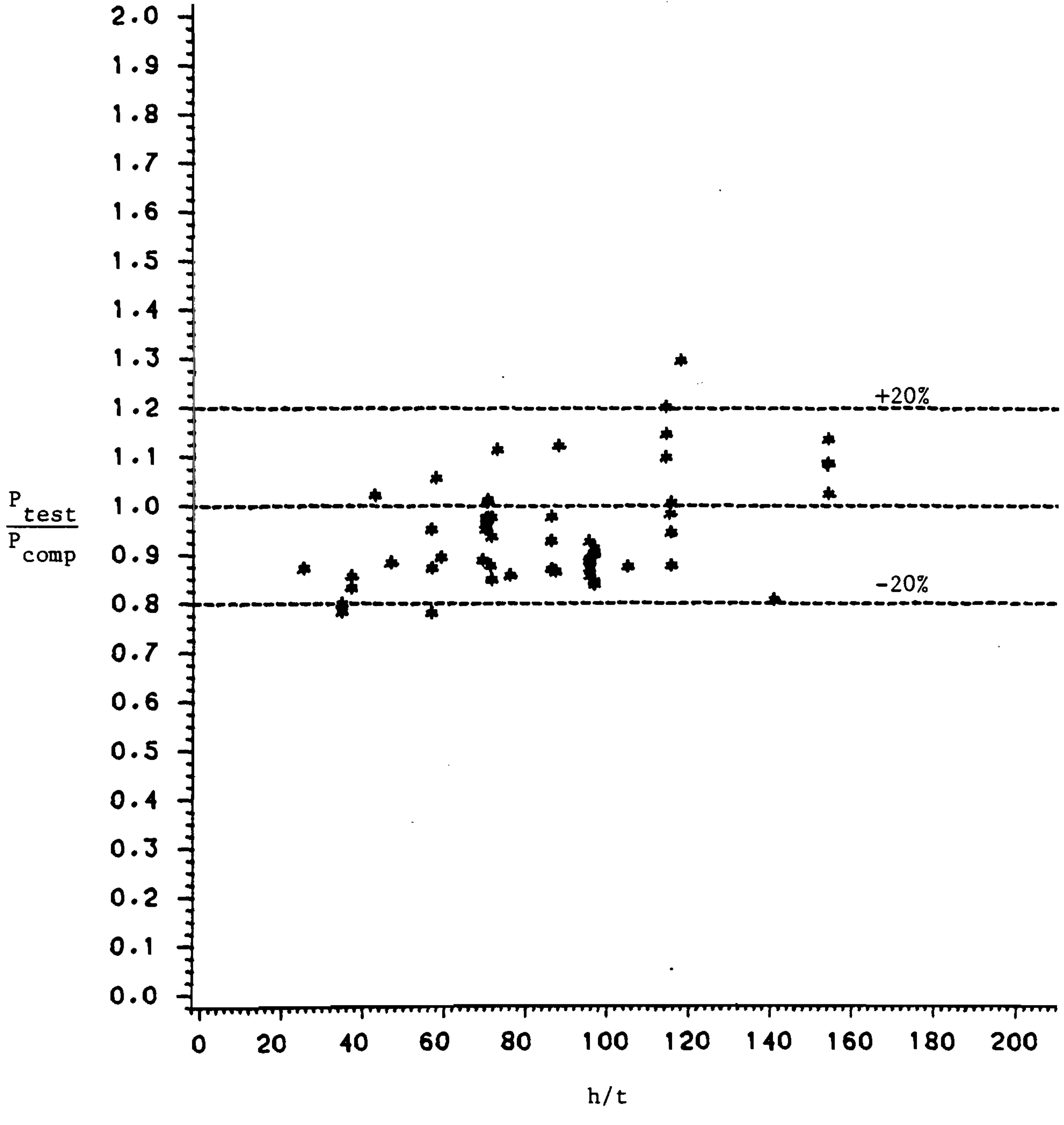


Fig. 14 Effect of h/t on the Ratios of P_{test}/P_{comp} Using Eqs. (47) and (48)

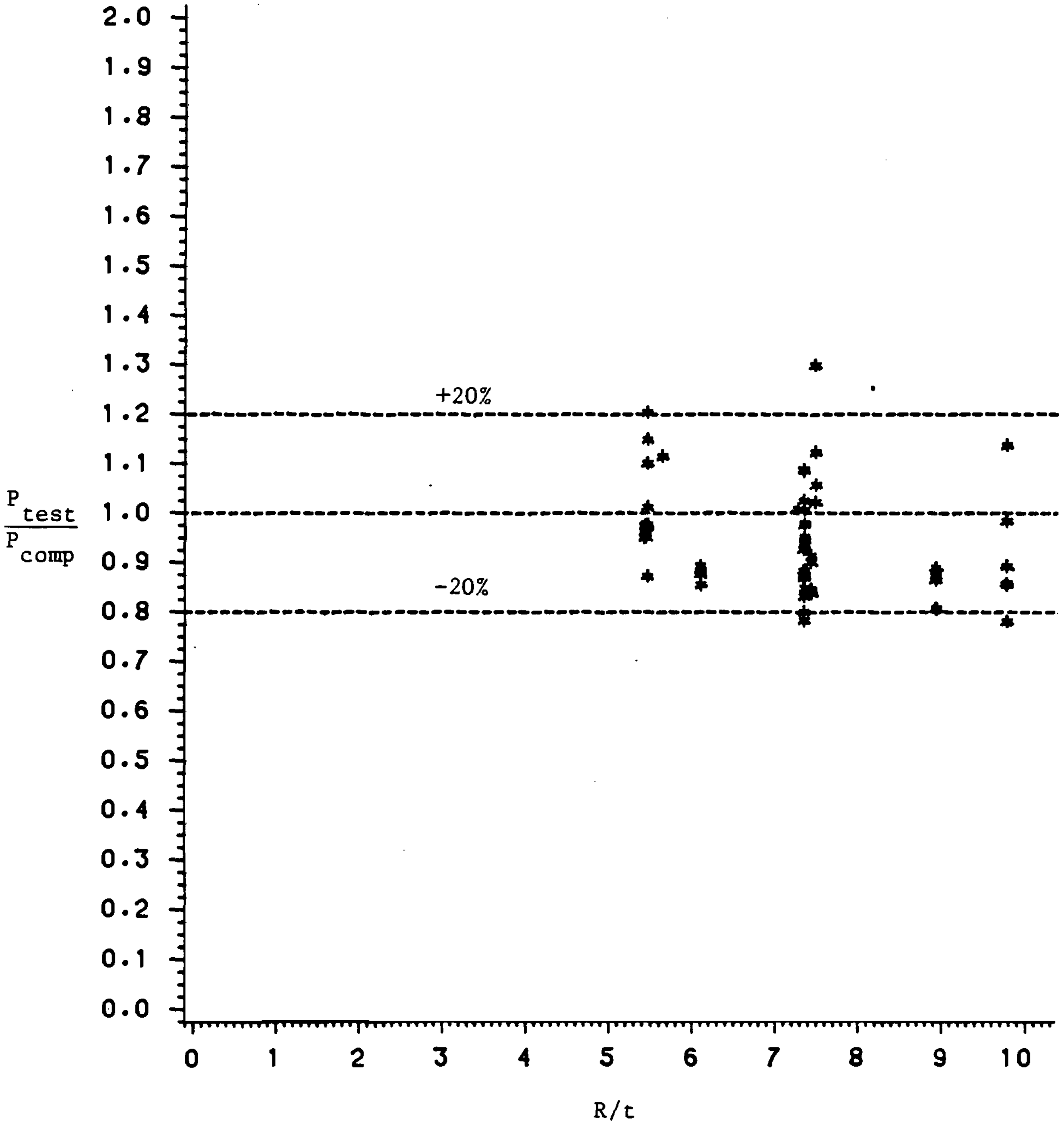


Fig. 15 Effect of R/t on the Ratios of P_{test}/P_{comp} Using Eqs. (47) and (48)

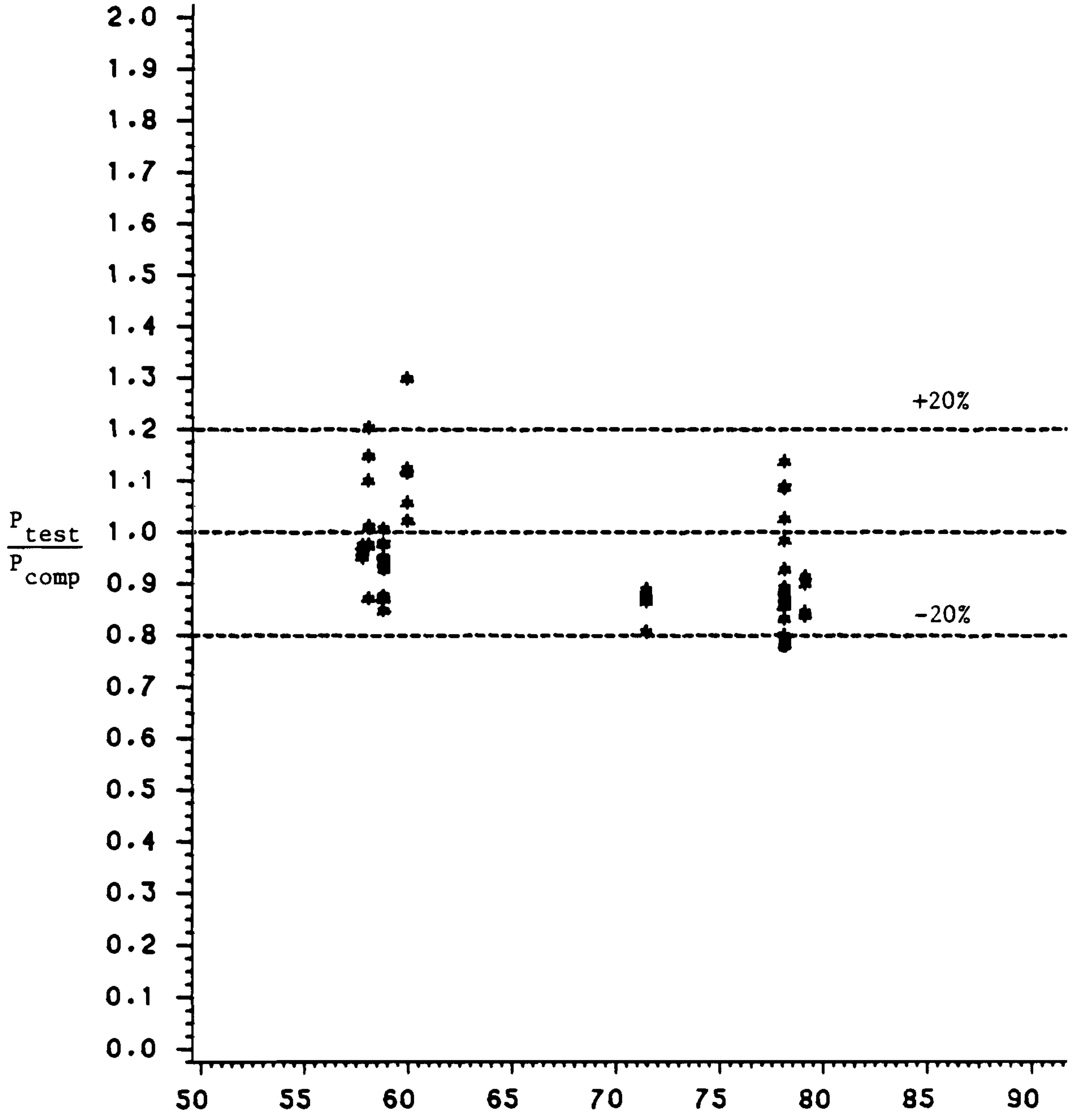


Fig. 16 Effect of N/t on the Ratios of P_{test}/P_{comp} Using Eqs. (47) and (48)

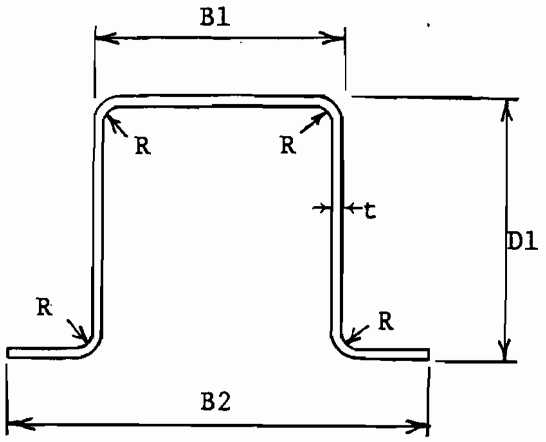


Fig. 17 Proposed Hat Sections for Future Study

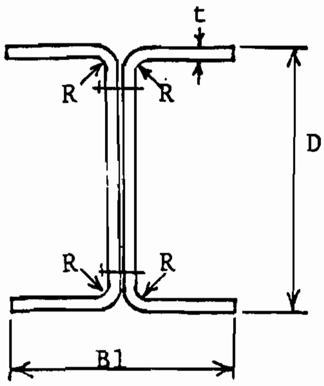
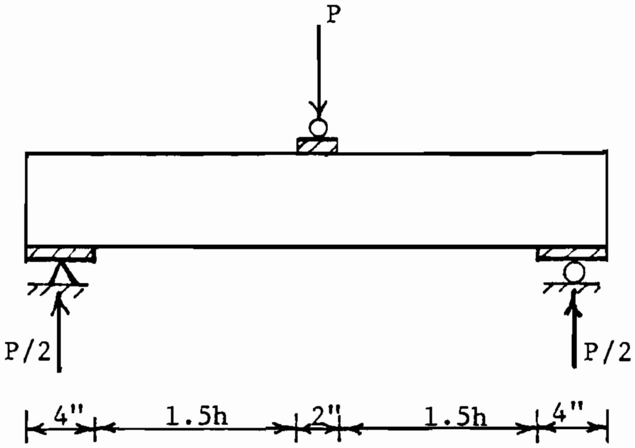
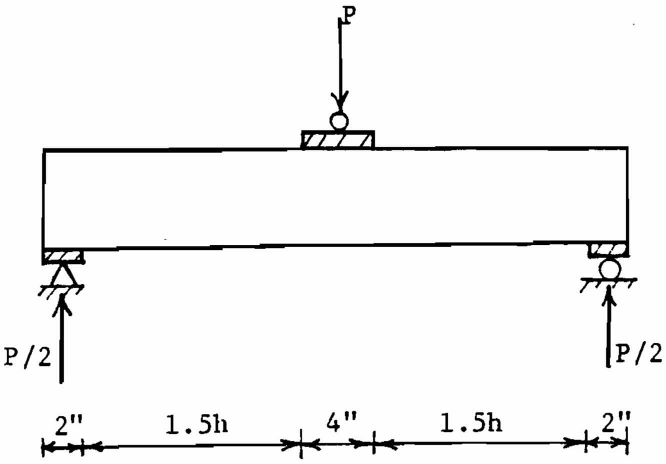


Fig. 18 Proposed I-Sections for Future Study



(a) Interior One-Flange Loading



(b) End One-Flange Loading

Fig. 19 Test Setup for Web Crippling

APPENDIX I

NOTATION

Symbol	Definition
A_w	Area of web for the entire section, $in.^2$
b	Effective design width, in.
C_{eff}	Distance from extreme top fiber to the neutral axis calculated on the basis of the effective design width of the compression flange, in.
f	Actual stress in the compression element computed on the basis of the effective design width, ksi
f_{bw}	Actual compression stress at junction of flange and web, ksi
F_{bwu}	Maximum compression stress in the flat web of a beam due to bending, ksi
F_u	Tensile strength, ksi
f_v	Actual average shear stress, ksi
F_{vu}	Maximum average shear stress on the gross area of a flat web, ksi
F_y	Yield strength, ksi
F_{yf}	Yield strength of compression flange, ksi
F_{yw}	Yield strength of web, ksi
h	Clear distance between flanges measured along the plane of the web, in.
I_{eff}	Effective moment of inertia calculated on the basis of the effective design width of the compression flange, $in.^4$
k_v	Shear buckling coefficient
L	Span length, in.
M	Applied bending moment, at or immediately adjacent to the point of application of the concentrated load or reaction, kip-in.
M_u	Ultimate bending moment if bending stress only exists, kip-in.
N	Actual length of bearing, in.
P	Concentrated load or reaction, kips

Symbol	Definition
P_c	Computed ultimate web crippling load per web in the absence of bending moment, kips
P_{com}	Computed failure load, kips
P_{cw}	Computed ultimate web crippling load for the entire section in the absence of bending moment, kips
P_m	Computed ultimate load for moment only, kips
P_{mc}	Computed load for combined moment and web crippling, kips
P_{ms}	Computed load for combined moment and shear in web, kips
P_{mw}	Computed ultimate load for bending moment governed by web strength, kips
P_s	Computed ultimate load for shear in web only, kips
P_{test}	Tested failure load, kips
R	Inside bend radius, in.
S_{eff}	Effective section modulus computed on the basis of the effective design width of the compression flange, $in.^3$
t	Base steel thickness, in.
w	Flat width of stiffened element, in.

APPENDIX II

COMPUTER PROGRAM

```
C*****************************************************************************
C
C                             PROGRAM
C                               FOR
C                  PREDICTION OF FAILURE LOAD BY
C                     1) MOMENT
C                     2) SHEAR
C                     3) WEB CRIPPLING
C                     4) MOMENT & SHEAR
C                     5) MOMENT & WEB CRIPPLING
C
C  --- DATA FOR SPECIMEN NO. 1-30 OBTAINED FROM S.J. ERRERA'S PAPER
C  --- DATA FOR SPECIMEN NO. 31-68 OBTAINED FROM B.S. LEVY'S PAPER
C
C  --- INELASTIC RESERVE CAPACITY IS CONSIDERED IN MOMENT CALCULATION
C      FOR THE 1980 SPEC.
C
C  --- FOR COMBINED MOMENT & SHEAR IN WEBS
C          - NO LIMITATION ON FVU & FBWU FOR THE 1980 SPEC.
C          - USE LIMITATION ON FVU & FBWU FOR THE 1981 GUIDE
C
C  --- FOR WEB CRIPPLING
C          - FOR R/T > 6 USE R/T = 6 IN (1.06-.06*R/T)
C          - FOR FY > 91.5 USE FY = 91.5 IN (1.22-.22*FY/33)*FY/33
C          - FOR FY > 91.5 USE (291-.4*H/T) = 291 FOR THE 1980 SPEC.
C
C  --- NOTATION
C          - PM = MAX. LOAD FOR MOMENT ONLY
C          - PC = MAX. LOAD FOR WEB CRIPPLING ONLY
C          - PMC = COMBINED WEB CRIPPLING & BENDING
C          - PS = MAX. LOAD FOR SHEAR ONLY
C          - PMS = COMBINED MOMENT & SHEAR IN WEBS
C          - PTEST = TESTED FAILURE LOAD
C          - PCOM = PREDICTED FAILURE LOAD WHICH IS
C                   THE SMALLEST VALUE OF PMC,PS & PMS
C          - * DENOTES SECTIONS WITH INELASTIC RESERVE CAPACITY
C
C
C*****************************************************************************
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT,FAC,FACT
      DIMENSION PC(100),PM(100),PMC(100),PTEST(100),RATIO(100),PC1(100),
     /RATIO1(100),PMS(100),PMC1(100),PMS1(100),PS(100),PS1(100),PBW1(100
     /),PBW(100),PM1(100),MF(100)
      WRITE(6,1001)
      READ(5,*)NN
      DO 60 I=1,NN
      READ(5,*)NTYPE,B1,B2,D1,D2,R,T,BRG,FY,FU,SPAN,PTEST(I)
```

```
      H=D1-2.*T
      TH=H/T
      TR=R/T
      TN=BRG/T
      HN=BRG/H
C CONSIDER SHEAR LAG EFFECT
      CALL SLAG(SPAN,B1,B2,D2,T,FAC,FACT)
      GO TO (10,20),NTYPE
C CALCULATE INELASTIC RESERVE CAPACITY
   10 CALL MU1
C CALCULATE FLEXURAL YIELD MOMENT
      CALL MY1
      GO TO 30
   20 CALL MU2
      CALL MY2
   30 CALL WEB(SPAN,SMP,SMP1,SP,SP1,BWP,BWP1)
      PS(I)=SP
      PS1(I)=SP1
      PBW(I)=BWP
      PBW1(I)=BWP1
      PMS(I)=SMP
      PMS1(I)=SMP1
      FF=FY/33.*(1.22-.22*FY/33.)
      IF (FY.GT.91.5) FF=91.5/33.*(1.22-.22*91.5/33.)
      FR=1.06-.06*TR
      IF (TR.GT.6.0) FR=1.06-.06*6.0
      FH=291.-.40*TH
      IF (FY.GT.91.5) FH=291.
      FN=1+.007*TN
      IF (TN.GT.60.) FN=.75+.011*TN
C 1.85=SAFETY FACTOR,  4=NO. OF WEBS USED IN CALCULATION
      PC(I)=4.*1.85*T**2.*FF*FH*FR*FN
C FOR RAM LOAD - MOMENT=1/6*(P*L)
      PM(I)=6.*XM/SPAN
C COMPARE FLEXURAL MOMENT TO MOMENT IN WEB
      IF (PM(I).GT.PBW(I)) PM(I)=PBW(I)
      IF (LIMIT.EQ.1) PM(I)=6.*UM/SPAN
      MF(I)=LIMIT
C COMBINED MOMENT AND WEB CRIPPLING
      PMC(I)=1.42*PM(I)*PC(I)/(PC(I)+1.07*PM(I))
      IF (PMC(I).GT.PM(I)) PMC(I)=PM(I)
      IF (PMC(I).GT.PC(I)) PMC(I)=PC(I)
      AA=PS(I)
      BB=PMC(I)
      CC=PMS(I)
C SELECT SMALLEST FAILURE LOAD
      CALL SELECT(AA,BB,CC,NF)
      GO TO (101,102,103),NF
  101 RATIO(I)=PS(I)/PTEST(I)
      GO TO 105
  102 RATIO(I)=PMC(I)/PTEST(I)
      GO TO 105
  103 RATIO(I)=PMS(I)/PTEST(I)
```

```
      GO TO 105
  105 FF=FY/33.*(1.22-.22*FY/33.)
      IF (FY.GT.91.5) FF=91.5/33.*(1.22-.22*91.5/33.)
      FR=1.06-.06*TR
      IF (TR.GT.6.0) FR=1.06-.06*6.0
      IF (TN.GT.TH)TN=TH
      FHN=305+2.30*TN-.009*TN*TH-.5*TH
      PC1(I)=T**2.*FF*FR*FHN*4.*1.85
      PM1(I)=6.*XM/SPAN
      IF (PM1(I).GT.PBW1(I)) PM1(I)=PBW1(I)
      PMC1(I)=1.3*PM1(I)*PC1(I)/(PC1(I)+PM1(I))
      IF (PMC1(I).GT.PM1(I)) PMC1(I)=PM1(I)
      IF (PMC1(I).GT.PC1(I)) PMC1(I)=PC1(I)
      XX=PS1(I)
      YY=PMC1(I)
      ZZ=PMS1(I)
      CALL SELECT(XX,YY,ZZ,NF)
      GO TO (201,202,203),NF
  201 RATIO1(I)=PS1(I)/PTEST(I)
      GO TO 205
  202 RATIO1(I)=PMC1(I)/PTEST(I)
      GO TO 205
  203 RATIO1(I)=PMS1(I)/PTEST(I)
      GO TO 205
  205 TN=BRG/T
      WRITE(6,1002)I,T,H,R,BRG,FY,TH,TR,TN,HN
      RATIO(I)=1./RATIO(I)
      RATIO1(I)=1./RATIO1(I)
   60 CONTINUE
      WRITE(6,1005)
      WRITE(6,1003)
      DO 70 I=1,NN
      IF (MF(I).EQ.2) GO TO 65
      WRITE(6,1007)I,PM(I),PC(I),PMC(I),PS(I),PMS(I),PTEST(I),RATIO(I)
      GO TO 70
   65 WRITE(6,1004)I,PM(I),PC(I),PMC(I),PS(I),PMS(I),PTEST(I),RATIO(I)
   70 CONTINUE
      WRITE(6,1006)
      WRITE(6,1003)
      DO 80 I=1,NN
   80 WRITE(6,1004)I,PM1(I),PC1(I),PMC1(I),PS1(I),PMS1(I),PTEST(I),RATIO
     /1(I)
 1001 FORMAT('1',1X,'OBS',5X,'T',7X,'H',7X,'R',7X,'N',7X,'FY',6X,'H/T',5
     /X,'R/T',5X,'N/T',5X,'N/H'/)
 1002 FORMAT(3X,I2,4(2X,F6.3),2X,F6.1,3X,F6.1,2X,F6.3,2X,F6.1,2X,F6.2)
 1003 FORMAT('0',1X,'OBS',4X,'PM',7X,'PC',6X,'PMC',5X,'PS',6X,'PMS',4X,'
     /PTEST',5X,'PTEST/PCOM'/)
 1004 FORMAT(3X,I2,2X,F6.3,3X,F6.3,2X,F6.3,2X,F6.3,2X,F6.3,2X,F6.3,5X,F6
     /.2)
 1005 FORMAT('1','BASED ON 1980 SPECIFICATION')
 1006 FORMAT('1','BASED ON 1981 GUIDE')
 1007 FORMAT(3X,I2,2X,F6.3,'*',5(2XF6.3),5X,F6.2)
      STOP
```

```
      END
C
C
C
      SUBROUTINE MY1
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT,FAC,FACT
      DIMENSION H(5),Y(5)
      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
      H(1)=2.*D4
      H(2)=4.*U1
      H(3)=2.*W1
      H(4)=2.*D3
      H(5)=2.*U1
      Y(1)=D1-R-T-D4/2.
      Y(2)=D1-R-T+C1
      Y(3)=D1-T/2.
      Y(4)=D1/2.
      Y(5)=R+T-C1
      HL=0.0
      HYL=0.0
      HYYL=0.0
      DO 10 I=1,5
      HL=HL+H(I)
      HYL=HYL+H(I)*Y(I)
      HYYL=HYYL+H(I)*Y(I)*Y(I)
   10 CONTINUE
      HHC=W*FAC
      HHT=2.*W1*FACT
      HLS=HL-H(3)+HHC+HHT
      HYLS=HYL-(H(3)-HHT)*Y(3)+HHC*T/2.
      HYYLS=HYYL-(H(3)-HHT)*Y(3)*Y(3)+HHC*T/2.*T/2.
      XI0=2.*(D3**3.+D4**3.)/12.+6.*.149*R1**3.
      YCGSL=HYLS/HLS
      XISL=(HYYLS+XI0-HLS*YCGSL**2.)*T
      CC=YCGSL
      IF(YCGSL.LT.D1/2.)CC=D1-YCGSL
      SLM=FY*XISL/CC
      CALL TRIAL(W,D1,T,FY,WT,HL,HYL,HYYL,XI0,XI,XM,XS,ASSUMF,YCG,FAC)
      IF(XM.GT.SLM)XM=SLM
      RETURN
      END
C
C
C
      SUBROUTINE MY2
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      END
C
C
C
      SUBROUTINE MY1
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT,FAC,FACT
      DIMENSION H(5),Y(5)
      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
      H(1)=2.*D4
      H(2)=4.*U1
      H(3)=2.*W1
      H(4)=2.*D3
      H(5)=2.*U1
      Y(1)=D1-R-T-D4/2.
      Y(2)=D1-R-T+C1
      Y(3)=D1-T/2.
      Y(4)=D1/2.
      Y(5)=R+T-C1
      HL=0.0
      HYL=0.0
      HYYL=0.0
      DO 10 I=1,5
      HL=HL+H(I)
      HYL=HYL+H(I)*Y(I)
      HYYL=HYYL+H(I)*Y(I)*Y(I)
   10 CONTINUE
      HHC=W*FAC
      HHT=2.*W1*FACT
      HLS=HL-H(3)+HHC+HHT
      HYLS=HYL-(H(3)-HHT)*Y(3)+HHC*T/2.
      HYYLS=HYYL-(H(3)-HHT)*Y(3)*Y(3)+HHC*T/2.*T/2.
      XI0=2.*(D3**3.+D4**3.)/12.+6.*.149*R1**3.
      YCGSL=HYLS/HLS
      XISL=(HYYLS+XI0-HLS*YCGSL**2.)*T
      CC=YCGSL
      IF(YCGSL.LT.D1/2.)CC=D1-YCGSL
      SLM=FY*XISL/CC
      CALL TRIAL(W,D1,T,FY,WT,HL,HYL,HYYL,XI0,XI,XM,XS,ASSUMF,YCG,FAC)
      IF(XM.GT.SLM)XM=SLM
      RETURN
      END
C
C
C
      SUBROUTINE MY2
```

```
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT,FAC,FACT
      W=B1-2.*(R+T)
      W1=(B2-B1)/2.-R
      D3=D1-2.*(R+T)
      R1=R+T/2.
      U1=1.57*R1
      C1=0.637*R1
      WT=W/T
      H1=2.*W1*FACT
      H2=2.*U1
      H3=2.*D3
      H4=2.*U1
      HL=H1+H2+H3+H4
      Y1=D1-T/2.
      Y2=D1-R-T+C1
      Y3=D1/2.
      Y4=R+T-C1
      HY1=H1*Y1
      HY2=H2*Y2
      HY3=H3*Y3
      HY4=H4*Y4
      HYL=HY1+HY2+HY3+HY4
      HYY1=HY1*Y1
      HYY2=HY2*Y2
      HYY3=HY3*Y3
      HYY4=HY4*Y4
      HYYL=HYY1+HYY2+HYY3+HYY4
      XIO=2.*(D3**3.)/12.
      CALL TRIAL(W,D1,T,FY,WT,HL,HYL,HYYL,XIO,XI,XM,XS,ASSUMF,YCG,FAC)
      RETURN
      END
C
C
C
      SUBROUTINE TRIAL(W,D1,T,FY,WT,HL,HYL,HYYL,XIO,XI,XM,XS,ASSUMF,YCG,
     /FAC)
      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,FAC,FACT
      H=D1-2.*T
      HT=H/T
      SF=SQRT(FY)
C BENDING IN WEB
      FBWU1=640000./(HT)**2.
      IF (FBWU1.GT.FY) FBWU1=FY
      FBWU=(1.21-.00034*HT*SF)*FY
      CFBWU=FBWU
      IF (FBWU.GT.FY) FBWU=FY
C SHEAR IN WEB
      SFY=.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 SHEAR IN WEB
   40 PS=4.*H*T*FVU
      PS1=4.*H*T*FVU1
C BENDING IN WEB
      PBW=FBWU*XI*6./(YCG-T)/SPAN
      PBW1=FBWU1*XI*6./(YCG-T)/SPAN
C COMBINE BENDING AND SHEAR
      BWEB=(SPAN*(YCG-T)/6./XI/CFBWU)**2.
      BWEB1=(SPAN*(YCG-T)/6./XI/FBWU1)**2.
      SWEB=(.25/H/T/CFVU)**2.
      SWEB1=(.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
C
C
C
      SUBROUTINE MU1
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT,FAC,FACT
      D=D1-T
      W=B1-T
      BT=(B2-B1)
      DT=D2-T/2.
      SF=SQRT(FY)
      WTLIM=221./SF
      WT=W/T
      IF(WT.GT.WTLIM) GO TO 100
      BC=W
      GO TO 110
  100 BC=326./SF*(1.-71.3/WT/SF)*T
  110 YC=.25*(BT-BC+2.*D+2.*DT)
      CALL ULIMIT(YC,D,T,SF,LIMIT)
      IF(LIMIT.GT.1) GO TO 200
      WTLIM1=190./SF
      WTLIM2=221./SF
      IF(WT.GT.WTLIM1) GO TO 120
      CY=3.
      GO TO 140
  120 IF(WT.GT.WTLIM2) GO TO 130
      CY=3.-(WT*SF-190.)/15.5
      GO TO 140
  130 CY=1.
  140 YP=YC/CY
      YCP=YC-YP
      YTP=D-YC-YP
      YT=D-YC
      UM=FY*T*(BC*YC+2.*YCP*(YP+YCP/2.)+4./3.*YP**2.+2.*YTP*(YP+YTP/2.)+
     /BT*YT+DT*(YT-DT/2.))
  200 RETURN
```

```
      END
C
C
      SUBROUTINE MU2
      COMMON/DIMEN/B1,B2,D1,D2,R,T,FY,FU
      COMMON/VALUE/XM,XI,XS,ASSUMF,YCG,UM,LIMIT,FAC,FACT
      D=D1-T
      W=B1-T
      BT=(B2-B1+T)*FACT
      SF=SQRT(FY)
      WTLIM=221./SF
      WT=W/T
      IF(WT.GT.WTLIM) GO TO 100
      BC=W
      GO TO 110
  100 BC=326./SF*(1.-71.3/WT/SF)*T
  110 BC=BC*FAC
      YC=.25*(BT-BC+2.*D+2.*DT)
      CALL ULIMIT(YC,D,T,SF,LIMIT)
      IF(LIMIT.GT.1) GO TO 200
      WTLIM1=190./SF
      WTLIM2=221./SF
      IF(WT.GT.WTLIM1) GO TO 120
      CY=3.
      GO TO 140
  120 IF(WT.GT.WTLIM2) GO TO 130
      CY=3.-(WT*SF-190.)/15.5
      GO TO 140
  130 CY=1.
  140 YP=YC/CY
      YCP=YC-YP
      YTP=D-YC-YP
      YT=D-YC
      UM=FY*T*(BC*YC+2.*YCP*(YP+YCP/2.)+4./3.*YP**2.+2.*YTP*(YP+YTP/2.)+
     /BT*YT)
  200 RETURN
      END
C
C
      SUBROUTINE ULIMIT(YC,D,T,SF,LIMIT)
      WTLIM1=190./SF
      WTLIM2=640./SF
      YCT=YC/T
      DT=D/T
      IF(YCT.GT.WTLIM1) GO TO 100
      IF(DT.GT.WTLIM2) GO TO 100
      LIMIT=1
      GO TO 110
  100 LIMIT=2
  110 RETURN
      END
C
C
C
```

```
      SUBROUTINE SLAG(SPAN,B1,B2,D2,T,FAC,FACT)
      LWF=SPAN/((B1-2.*T)/2.)
      CALL INTP(LWF,FAC)
      LWFT=SPAN/((B2-B1)/2.+D2)
      CALL INTP(LWFT,FACT)
      RETURN
      END
C
C
C
      SUBROUTINE INTP(LWF,FAC)
      IF(LWF.GE.30.) FAC=1.0
      IF(LWF.LT.30..AND.LWF.GE.25.) FAC=1.0-0.04*(30.-LWF)/5.
      IF(LWF.LT.25..AND.LWF.GE.20.) FAC=.96-0.05*(25.-LWF)/5.
      IF(LWF.LT.20..AND.LWF.GE.18.) FAC=.91-0.02*(20.-LWF)/2.
      IF(LWF.LT.18..AND.LWF.GE.16.) FAC=.89-0.03*(18.-LWF)/2.
      IF(LWF.LT.16..AND.LWF.GE.14.) FAC=.86-0.04*(16.-LWF)/2.
      IF(LWF.LT.14..AND.LWF.GE.12.) FAC=.82-0.04*(14.-LWF)/2.
      IF(LWF.LT.12..AND.LWF.GE.10.) FAC=.78-0.05*(12.-LWF)/2.
      IF(LWF.LT.10..AND.LWF.GE.8.) FAC=.73-0.06*(10.-LWF)/2.
      IF(LWF.LT.8..AND.LWF.GE.6.) FAC=.67-0.12*(8.-LWF)/2.
      RETURN
      END
```