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B. A. Wing

R. M. Schuster

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WEB CRIPPLING OF MULTI-WEB DECK SECTIONS SUBJECTED TO INTERIOR ONE FLANGE LOADING

by

B.A. Wing[1] and R.M. Schuster[2]

SUMMARY

This paper presents a web crippling expression for multi-web deck sections subjected to interior one flange loading. In comparison with the test data for the range of parameters investigated, the expression predicts the web crippling loads within the commonly accepted scatter range of $\pm$ 20%. Based on a parameter investigation of the test data, it can be concluded that the inside bend radius term is significantly different in comparison with the bend radius term contained in the 1980 AISI expression. Comparing the test data with the S136-1974 Standard, the 1980 AISI web crippling expression results in a considerably larger than $\pm$ 20% scatter. The developed expression has since been adopted for use in the Canadian Standard CAN3-S136-M84.

INTRODUCTION

Cold formed steel multi-web deck sections are used extensively in building construction. Where these sections are continuous over an interior support, or are subjected to a concentrated load at some point on the span, failure of the deck can occur by web crippling. Bending stress is of course also present, but for some combinations of loading and deck profiles the contribution of the bending stress is small and may not contribute significantly to failure. When the bending stress is small, less than 0.3 of ultimate, the primary mode of failure can be considered to be web crippling, where the ultimate load carrying capacity is a functin of a number of parameters, namely, the web slenderness ratio, the inside bend radius ratio, the bearing length ratio, the angle of web inclination and the yield strength of the steel.

OBJECTIVE AND SCOPE

The objective of this study was to determine the load resistance of multi-web deck sections subjected to interior one flange loading, as shown in Figure 1. Due to the complexity of a purely theoretical analysis of the post-buckling resistance of web elements under concentrated crippling loads, as reported in detail in Reference [10]. An experimental test program was initi-

[1]Civil Engineer, The Algoma Steel Corporation, Limited, Mississauga, Ontario, Canada. Formerly Graduate Student, University of Waterloo.

[2]Associate Professor, School of Architecture and Department of Civil Engineering, University of Waterloo, Waterloo, Ontario, Canada.

ated in an effort to carry out the above-stated objective. Also, the test program was to provide experimental data so that existing methods of computation could be compared and evaluated.

More specifically, the study addressed the following important parameters:

1) inside bend radius to web thickness ratio,
2) bearing length to web thickness ratio,
3) angle of web inclination.

The S136-1974 Standard [4] and the AISI-1968 Specification [1] specify limits of $R \leq 4$, $H \leq 150$, and $N \leq H$ for the governing web crippling equations, where $R = r/t$, $H = h/t$ and r, h and t are shown in Figure 2. The bearing length, n, is shown in Figure 1. The AISI-1980 Specification [2] extended these limits to $R \leq 7$ (for decks), $H \leq 200$, $N/H \leq 35$ and $N \leq 210$.

TEST PROGRAM

The test program was designed to encompass the most important parameter variations that influence the web crippling resistance of multi-web deck sections subjected to interior one flange loading. Test specimens consisted of deck sections specifically fabricated for this study (break-formed), as well as deck sections obtained from various Canadian manufacturers.

All of the specimens tested had unreinforced webs and the rate of load application was uniform up to the failure load. Spreading of webs was prevented by bolting the lower flanges to the bottom bearing plate.

Interior One Flange Test Setup (IOF)

The specimens were simply supported at the ends and the load was applied at the centre, as shown in Figure 1. Relatively large end bearing plates were used for these tests to insure that failure would occur at the interior load position. The distance from the edge of the interior bearing plate to the interior edge of the exterior bearing plate was 1-1/2 h or larger, as shown in Figure 1 (where h = clear distance between flanges measured in the plane of the web). This restriction is the result of tests conducted by Winter in the 1940s and insures that there is a one flange load, not a two flange load condition. The AISI-1980 Specification [2] uses a distance between bearing plates of 1-1/2 h to define one and two flange loading.

Due to the geometry of loading, shown in Figure 1, it is impossible to produce a web crippling load test setup without at least some influence of bending moment. The moment ratio, test moment/computed ultimate moment, M_t/M_c, was chosen to be less than 0.3 for the tests to be considered interior one flange tests. Research reported by Baehre [3] has shown that there is negligible interaction for $M_t/M_c \leq 0.3$ and Hetrakul and Yu [7] also adopted this method in their work.

Tests with moment ratios M_t/M_c larger than 0.3 were considered as combined bending and web crippling tests. Ratliff [9] demonstrated that there is an interaction between bending and web crippling and Baehre [3] established that the web crippling load decreases in the presence of M_t/M_c ratios greater than 0.3.

The test load P_t was taken as the largest load the specimen was able to sustain, after which a sudden decrease in load was experienced. The test moment M_t was computed from the test load, span and bearing length by Eq. 1:

$$M_t = P_t(L - n)/4 \qquad (1)$$

where M_t = test moment per web
P_t = test load per web
L = span length (Figure 1)
n = bearing length (Figure 1)

This method of computing the test moment was used since the bearing plate under the load was rigid in comparison to the specimen being tested. The applied load was therefore acting on the specimen as two point loads, each equal to one half of the total applied load and separated by the bearing length n. The resulting load and moment diagrams are shown in Figure 1.

TEST RESULTS

The ultimate test loads were first compared with the ultimate computed loads using the S136-1974 Standard [4] and the AISI-1980 Specification [2]. A new equation was then developed to predict the test loads. In evaluating the accuracy of the computed web crippling loads, the test load P_t was divided by the computed load P_c, giving the load ratio P_t/P_c, and the mean value of the load ratios and the coefficient of variations were computed using only the tests within the limits of the equation. A mean value of close to 1.0 with a small coefficient of variation indicates a good predicton of the test loads.

Interior One Flange Tests (IOF)

The IOF tests, as previously described, are combined bending and web crippling tests where the moment ratio M_t/M_c is less than 0.3. For moment ratios less than 0.3, it was assumed that the bending influence on the web crippling capacity was negligible.

Figure 3 is a photograph of a typical interior one flange test specimen and also shows the failure mode.

For determination of the moment ratio M_t/M_c, the AISI-1980 Specification [2] was used to compute the ultimate moment capacity of the specimens. The determination of the moment ratio M_t/M_c requires that some method of moment computation be used and the AISI-1980 method was chosen since it was the most recent method, and is the result of extensive research on web bending by LaBoube and Yu [8] in which nine different methods were evaluated and compared.

A total of 90 IOF tests were used in checking the existing web crippling expressions and in the development of a new expression. These 90 tests included 37 Waterloo specimens, identified by the letter W, and 22 specimens fabricated to include large inside bend radius ratios R, identified by the letters WR for Waterloo Radius. Also included were 31 specimens tested at Cornell University in the late 1940s [6] which were used in the development of the interior one flange expressions in the AISI-1968 Specification [1] and were also used in the S136-1974 Standard [4]. The range of parameters of these tests are summarized in Table 1.

Table 1 Parameter Range for Interior One Flange Tests

Parameter	Waterloo Type (W)	Waterloo Type (WR)	Cornell	All
t (in.)	0.024-0.061	0.022-0.061	0.069-0.067	0.022-0.067
H = h/t	65.2-215	84.6-226	89.0-201	65.2-226
R = r/t	1.54-3.92	5.63-17.4	1.0 or 3.0	1.0-17.4
N = n/t	16.7-208	33.0-162	11.3-42.6	11.3-208
F_y (ksi)	33.5-39.8	40.4-46.1	30.9-55.8	30.9-55.8
θ (degrees)	50°,70°,90°	50°,70°,90°	90° (only)	50°,70°,90°

Comparison of Test Results with Existing Methods of Computation

The test results were compared with the ultimate computed interior one flange web crippling loads using the S136-1974 Standard [4] and the AISI-1980 Specification [2]. The web crippling equations in S136-1974 Standard are the same as those used in the AISI-1968 Specification [1].

S136-1974 Standard (Including Amendments, May 1979)

The expression for interior one flange loading in the CSA S136-1974 Standard [4] is given by Eq. 2.

To avoid crippling of unreinforced beam webs having a web slenderness ratio H(h/t) equal to or less than 150, concentrated loads and reactions in the plane of the web shall not exceed the value of P_{max} given by Eq. 2. For reactions at interior supports or for concentrated loads located anywhere on the span: For corner radii up to 4t,

$$P_{max} = 0.01t^2\ Fy(305 + 2.30N - 0.009NH - 0.5H)(1.06 - 0.06R)(3.67 - 0.67k) \quad (2)$$

where P_{max} = allowable concentrated load or reaction in plane of web per web
t = web thickness
F_y = tensile yield strength
N = ratio of actual length of bearing to web thickness n/t, but not to exceed H
n = bearing length
H = web slenderness ratio h/t
h = clear distance between flanges in the plane of the web
R = inside bend radius to thickness ratio, r/t
r = inside bend radius
k = $F_y(ksi)/33$; $(F_y(N/mm^2)/228)$

For corner radii larger than 4t, tests shall be made in accordance with Clause 8.

The limits for the use of Eq. 2 are $R \leq 4$, $H \leq 150$ and N not to exceed H.

In applying Eq. 2 the S136-1974 Standard [4] states, "the concentrated loads and reactions in the plane of the web shall not exceed the values P_{max}." For specimens with inclined webs the load in the web will exceed the actual applied load or reaction. For example, a load of one unit per web on a hat section with 45° webs, as shown in Figure 4, would result in a load of 1.414 units in the web. To account for this, Eq. 2 can be multiplied by the sine of the web inclination (sine θ). The computed load in this case will be the actual concentrated load or reaction, not the concentrated load or reaction in the plane of the web.

Multiplying Eq. 2 by 1.85, the factor of safety used in the S136-1974 Standard [4], as well as by sine θ, Eq. 2 then becomes an expression for the ultimate web crippling load perpendicular to the flange. This allows for direct comparison with the test loads.

$$P_c = (1.85)\ 0.01t^2F_y(305 + 2.30N - 0.009NH - 0.5H)$$
$$(1.06 - 0.06R)(3.67 - 0.67k)(\text{sine}\ \theta) \qquad (3)$$

where P_c = computed ultimate concentrated load or reaction per web
Other symbols are the same as defined in Eq. 2.

The limits for Eq. 3 are $R \leq 4$, $H \leq 150$ and H is not to exceed H.

The test loads P_t were compared with the computed loads P_c using Eq. 3. Using only the 40 tests that are within the limits of Eq. 3, the mean of P_t/P_c was 0.950 with a coefficient of variation of 0.131. The computed loads P_c are plotted against the test loads P_t in Figure 5. The solid line in Figure 5 represents perfect correlation (P_t=P_c); the dashed lines are $\pm 20\%$ limits which are acceptable scatter limits for tests of this type, based on previous research.

Using Eq. 3, but removing the limit of $H \leq 150$, 68 tests were within the limits of $R \leq 4$ (including H values of up to 225) with the mean and the coefficient of variation being 1.007 and 1.045, respectively. Figure 6 is a plot of P_c, using Eq. 3 vs. P_t with no limit on H. When the limit of $R \leq 4$ was not imposed, but the limit of $H \leq 150$ was, the mean and the coefficient of variation are 1.024 and 0.204, respectively, using 53 tests with R values ranging up to 10.11. The test load P_c using Eq. 3 with no R limit vs. P_t was plotted in Figure 7. If no limits are imposed, the mean and coefficient of variation are 1.647 and 2.696, respectively. The large coefficient of variation is due largely to test 21 WR-IOF which has a P_t/P_c ratio of 42.9. P_c, using Eq. 3 with no limits on R or H, vs. P_t was plotted in Figure 8 for all 90 tests.

Figures 5 to 8 show the relationship between the test load P_t and P_c using the S136-1974 Standard [4] method of computation, with and without the limits on R and H. Specimens with relatively large R values, $R > 7$, generally also have large web slenderness ratios, $H > 150$. Therefore, tests with large R values were not plotted until both the R and h limits were dropped, as in Figure 8.

It is evident that Eq. 3, performs reasonably well within the stated limits and for H values up to 215. However, for larger R values (7-17) the expression consistently underestimates the load, as shown by the large number of tests below the minus 20% line in Figure 8. The load ratio P_t/P_c (where P_c is computed by Eq. 3) vs. R is plotted in Figure 9 and shows that the load ratio increases rapidly for $R > 7$. This increase in P_t/P_c is caused by an underestimation of the load when R is greater than about 7. The R reduction term $(1.06 - 0.06R)$ of Eqs. 2 and 3 is plotted against R in Figure 19 and will be discussed later, after other methods of computng the interior one flange load have been examined.

Figure 10 shows a comparison of the load ratio P_t/P_c (where P_c is computed by Eq. 3) versus the web slenderness ratio, H. The extreme values, greater than +20%, are mostly tests where the R values are larger than 7. Ignoring these values, Figure 10 indicates that the P_t/P_c ratio does not vary appreciably with H for values of H up to approximately 200.

Only three of the tests had bearing length to web thickness ratios, $N = n/t$, larger than the web slenderness ratio, $H = h/t$, with N only slightly larger than H. Therefore, no meaningful examination could be conducted on the effects of limiting $N \leq H$ when using Eq. 3.

AISI-1980 Specification [2]

The test results were compared with the AISI-1980 Specification [2] method for interior one flange loading multiplied by 1.85, given by Eq. 4.

$$P_{max} = (1.85)t^2F_y/33\ C_1C_2C_\theta(291 - 0.4H)(1 + 0.007N)\ ** \quad (4)$$

where
P_{max} = allowable concentrated load or reaction per web
t = web thickness
F_y = yield strength of web
H = web slenderness ratio h/t
h = clear distance between flanges measured in the plane of the web
N = bearing length to web thickness ratio n/t
n = bearing length

C_1 = (1.22 - 0.22k)
k = F_y(ksi)/33; (F_y(N/mm^2)/228)
C_2 = (1.06 - 0.06R) $\leq$ 1.0 (bend radius factor)
R = inside bend radius to thickness ratio
C_θ = 0.7 + 0.3 $(\theta/90)^2$ (web inclination factor)
θ = inclination of the web, 45° $\leq \theta \leq$ 90°

**When N > 60, the bearing width factor (1 + 0.007N) may be increased to (0.75 + 0.011N).

The limits for Eq. 4 are H $\leq$ 200, R $\leq$ 6 for beams, R $\leq$ 7 for decks, N $\leq$ 210 and n/H $\leq$ 3.5.

Eq. 4 is the result of a study on webs carried out at the University of Missouri-Rolla [7]. The factors C_1 and C_2 are the same as those used in the S136-1974 Standard [4] and AISI-1968 Specification [2] expressions. The University of Missouri-Rolla study assumed these factors to be adequate.

The web inclination factor C_θ did not appear in the University of Missouri-Rolla study [7] and has been subsequently added by AISI to account for the angle of web inclination, θ. This factor, C_θ, is plotted vs. θ in Figure 11 and is remarkably close to the sine term over the range of θ between 45° and 90°.

A comparison of the computed loads using Eq. 4 with the test loads are shown graphically in Figure 12. The mean value of the load ratio P_t/P_c is 0.904 with a coefficient of variation of 0.138, based on 68 of the 90 tests within the limits of H $\leq$ 200, R $\leq$ 7, N $\leq$ 210 and N/H $\leq$ 3.5.

If H is not limited to less than 200, the mean value and the coefficient of variation of the load ratio P_t/P_c for the 72 tests within the limits of Eq. 4 are 0.910 and 0.138, respectively, which is shown in Figure 13.

If the inside bend radius ratio R restriction of 7 is removed, 83 tests are within the remaining limits of Eq. 4 and the mean and coefficient of variation of the load ratio P_t/P_c are 1.355 and 2.584, respectively. The large value of the mean and the coefficient of variation are due mainly to test 21WR-IOF which has a P_t/P_c ratio of 32.8. Figure 14 illustrates this behaviour with no R limits.

If neither of the limits of H $\leq$ 200 and R $\leq$ 7 are imposed, then all 90 tests can be used, since none of the specimens tested had N > 210 nor H/H > 3.5, which are the remaining limits of Eq. 4. Using Eq. 4 for the 90 tests, the mean and the coefficient of variation of P_t/P_c are 1.361 and 2.472, respectively. Again, test 21WR-IOF is largely responsible for the large coefficient of variation, although two other tests also have load ratios P_t/P_c of greater than 2.0. Figure 15 is a plot of P_t using Eq. 4 vs. P_c, with no limits.

The load ratio P_t/P_c, using Eq. 4, is compared with R in Figure 16 for all 90 tests. As with the S136-1974 Standard [4] expression, Eq. 3, the values of P_t/P_c become very large for values of R greater than 7. This is to be expected since the inside bend radius factor (1.06 - 0.06R) is the same for both equations. The Pt/P_c ratio of 32.8 is very large for the extreme value, which indicates that the computed load is grossly underestimating the test load for specimens with large inside bend radius ratios. Clearly, this expression should not be used for R values larger than its limit of 7.

The web slenderness ratio H was plotted against P_t/P_c, using Eq. 4, in Figure 17 for all 90 tests. Disregarding the tests with R > 7 in Figure 17, there is no apparent relationship between P_t/P_c and H.

Development of Expressions for Ultimate Web Crippling Load [10]

Two expressions were developed for interior one flange loading using a statistical program, in one case using R, and in the other using the square root of R ($\sqrt{R}$). The expression using $\sqrt{R}$ only is presented in this paper since it gave better results, and is given in Eq. 5:

$$P_{w2} = 16.6\ t^2F_y(\text{sine}\ \theta)(1 - 0.000985H)(1 + 0.00526N)(1 - 0.0740\ \sqrt{R})(1 - 0.107k) \quad (5)$$

where P_{w2} = computed ultimate interior one flange web crippling load per web using $\sqrt{R}$ term.

All other terms are the same as defined in Eq. 2. The mean and coefficient of variation of P_t/P_{w2} are 0.980 and 0.134, respectively and P_t is plotted against P_{w2} in Figure 18.

The inside bend radius term $(1 - 0.0740\ \sqrt{R})$ of Eq. 5 is plotted against R in Figure 19. Also shown in Figure 19 are the inside bend radius terms from the S136-1974 Standard [4], Eq. 3, (1.06 - 0.06R) and the AISI-1980 Specification [2], Eq. 4, (1.06 - 0.06R). The term (1.06 - 0.06R) was divided by 1.06, resulting in (1 - 0.0566R) to equal 1 for R = 0 as shown in Figure 19. Up to R = 4, which is the limit for the S136-1974 Standard [4] web crippling expression, Eq. 3, the values of the terms plotted in Figure 19 are relatively similar. For values of R greater than 4 the values of the term (1.06 - 0.06R) from the S136-1974 Standard [4] and the AISI-1980 Specification [2] decrease at a much greater rate than the values of the other terms, at least over the range of R used in the testing, which included R values up to 17.4. For test specimens with large inside bend radius to thickness ratios, R > 7, the use of the S136-1974 Standard [4] and the AISI-1980 Specification [2] expressions for web crippling, Eqs. 3 and 4, respectively, lead to large underestimations of the load, thus indicating that the value of the inside bend radius term (1.06 - 0.06R) decreases too rapidly for larger R values.

The load ratios P_t/P_{w2} were plotted against R and H in Figures 20 and 21, showing that the values remain evenly distributed about the 1.0 line and within or near the $\pm 20\%$ limits over the full range of the parameters. This indicates that the inside bend radius term and the web slenderness term perform well over the range of R and H of these 90 tests.

Summary of Comparisons of Test Loads and Computed Loads for Interior One Flange Loading

The statistical measures of comparisons of the different methods of computing the ultimate interior one flange web crippling loads with the test loads are summarized in Table 2.

The S136-1974 Standard [4], Eq. 3, predicts the test loads reasonably accurately for specimens which are within the limits, i.e., $R \leq 4$ and $H \leq 150$, as well as for H values up to 215. For values of R greater than about 7, Eq. 3 grossly underestimates the web crippling capacity of the test specimens.

The AISI-1980 Specification [2], Eq. 4, overestimates the web crippling capacity by approximately 10% and is reasonably consistent for specimens which are within the limits of $R \leq 7$ and $H \leq 200$. However, for values of R greater than 7, Eq. 4 grossly underestimates the web crippling capacity of the test specimens.

Using the Waterloo expression, Eq. 5, results in a good prediction of the test load as indicated by the values of the mean and coefficnet of variation of P_t/P_c in Table 2. Eq. 5 has been adopted by CSA S136 in their 1984 edition [5].

CONCLUSIONS

Interior One Flange Loading

Based on the comparisons of the results of 90 interior one flange tests with different methods of computation, the following conclusions were made:

a) The S136-1974 Standard [4], Eq. 3, predicted the web crippling capacities reasonably well for the 40 tests which were within its limits of $R \leq 4$ and $H \leq 150$, but for specimens with R values larger than 4 the use of this method resulted in an average underestimation of the web crippling load by approximately 60%. When R was restricted to equal to or less than 4, Eq. 3 was found to predict the web crippling loads reasonably accurately for H values up to 215.

b) Using Eq. 4, which is the AISI 1980 Specification [2] web crippling expression, results in an overestimation of the test loads by approximately 10% for the 68 tests within the limits of $R < 7$ and $H < 200$. The use of Eq. 4 for specimens with $R > 7$ results in gross underestimation of the web crippling load by an average of 36% when all 90 tests were evaluated. When the limit of $R < 7$ was imposed, Eq. 4 was found to predict the web crippling loads reasonably accurately for H values up to 215. The value of the C_θ term of Eq. 4 is not significantly different than the value of sine θ over the range of 45° to 90°.

c) The use of the Waterloo expression, Eq. 5, resulted in a better prediction of the web crippling capacities than any of the existing methods; as well, the Waterloo expression is applicable to all 90 specimens tested as there were no limits applied for the tested range of parameters.

d) Of the methods of computation used, the Waterloo Method, given by Eq. 5, best predicted the test loads.

Table 2 Summary of Comparisons of Test Loads with Computed Loads for Interior One Flange Loading

Method of Computation	Equation	Mean of P_t/P_c	Coefficient of Variation of P_t/P_c	Number of Tests Within Limits /Total Tests
S136-1974 Standard [4]	Eq. 3	0.950	0.131	40/90
	Eq. 3 No limit on H	1.007	0.145	68/90
	Eq. 3 No limit on R	1.024	0.204	53/90
	Eq. 3 No limit on H or R	1.647	2.696	90/90
AISI-1980 Specification [2]	Eq. 4	0.904	0.138	68/90
	Eq. 4 No limit on H	0.910	0.138	72/90
	Eq. 4 No limit on R	1.355	2.584	83/90
	Eq. 4 No limits on H or R	1.361	2.472	90/90
Waterloo Method [5],[10]	Eq. 5	0.980	0.134	90/90

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NOTATIONS

C_1 = (1.22 - (0.22k)
C_2 = (1.06 - 0.06R) $\leq$ 1.0
C_θ = $(0.7 + 0.3(\theta/90)^2)$
F_y = yield strength
h = clear distance between flanges measured in the plane of the web
H = web slenderness ratio, h/t
IOF = interior one flange
k = F_y(ksi)/33; (F_y(N/mm^2)/228)
n = bearing length
N = bearing length to web thickness ratio, n/t
P = applied load
P_c = computed ultimate web crippling load per web
P_t = test web crippling load per web
P_{max} = computed allowable concentrated load or reaction per web
P_{w2} = computed ultimate interior one flange web crippling load per web as per Waterloo Method, using $\sqrt{R}$ term
r = inside bend radius
R = inside bend radius to web thickness ratio, r/t
t = web thickness
θ = angle of web inclination, $\leq 90°$

FIGURES

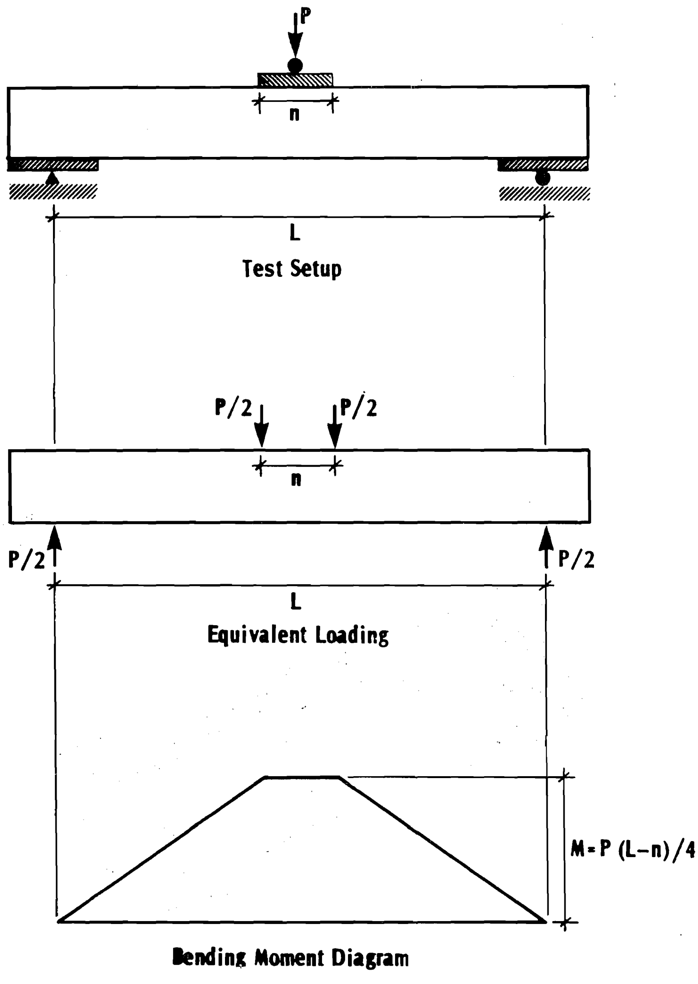

Figure 1 Interior One Flange Test Setup and Test Moment Diagram

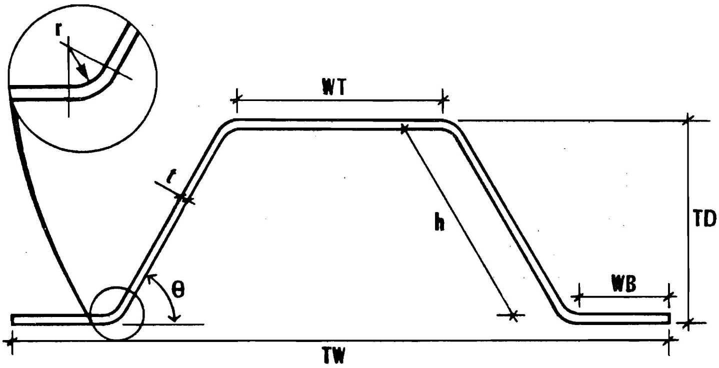

Figure 2 Designation of Symbols

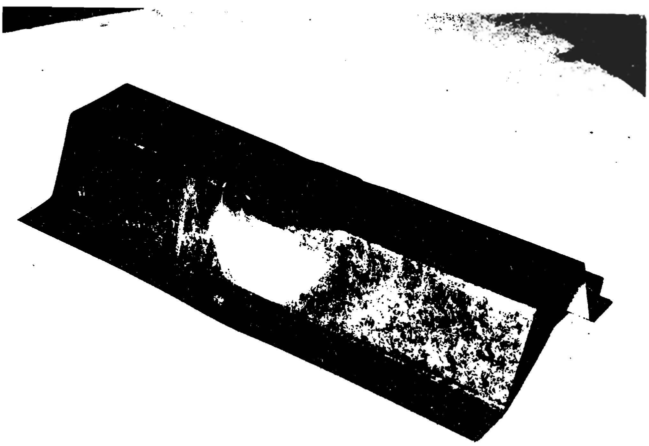

Figure 3 Photograph of Interior One Flange Test Specimen, Waterloo Radius Profile

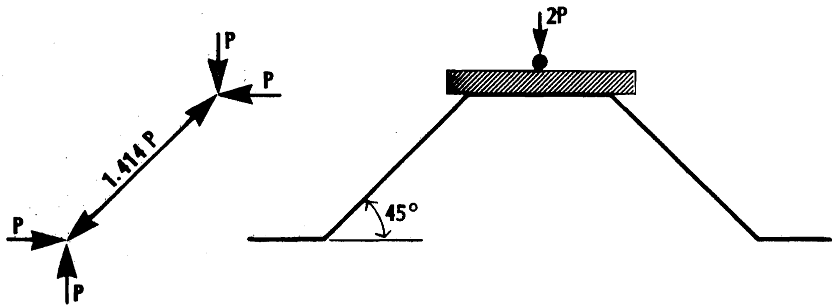

Figure 4 Web Crippling Load for Section with Inclined Webs

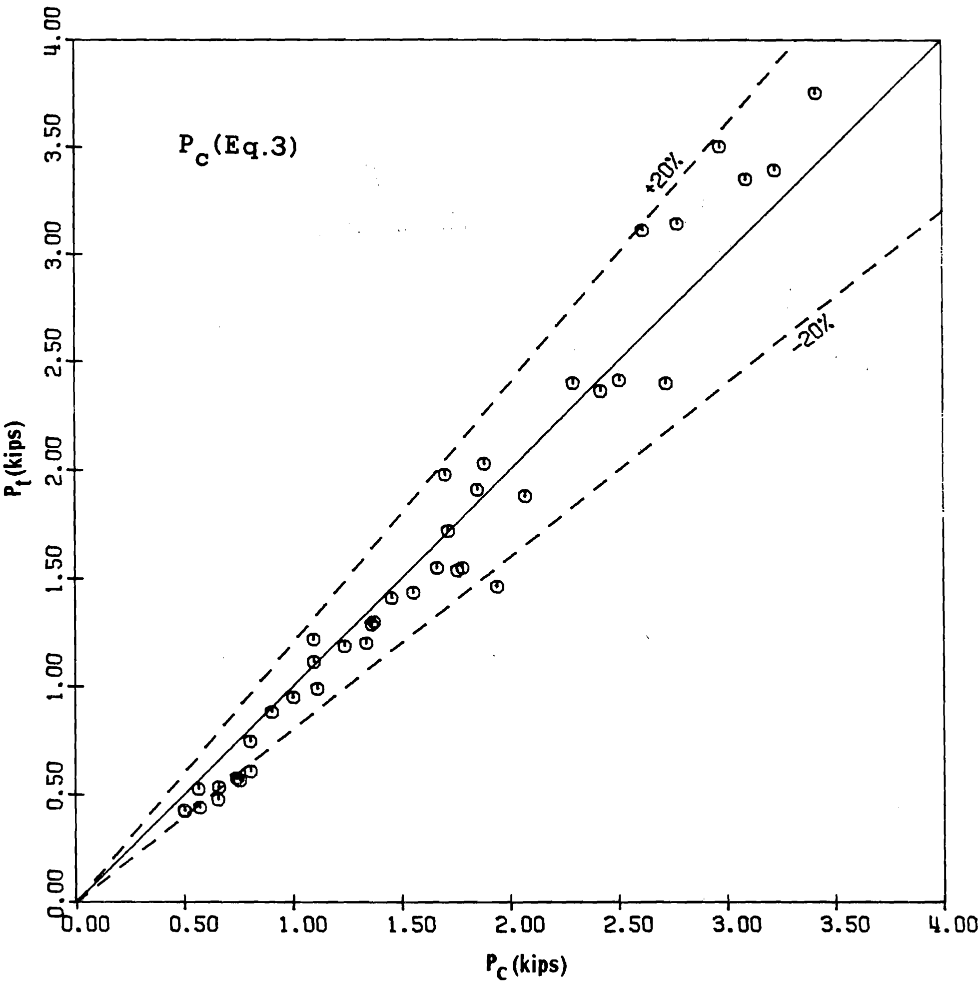

Figure 5 Test Load, P_t, vs. Computed Load, P_c, Using S136-1974 Standard [4] For Interior One Flange Tests

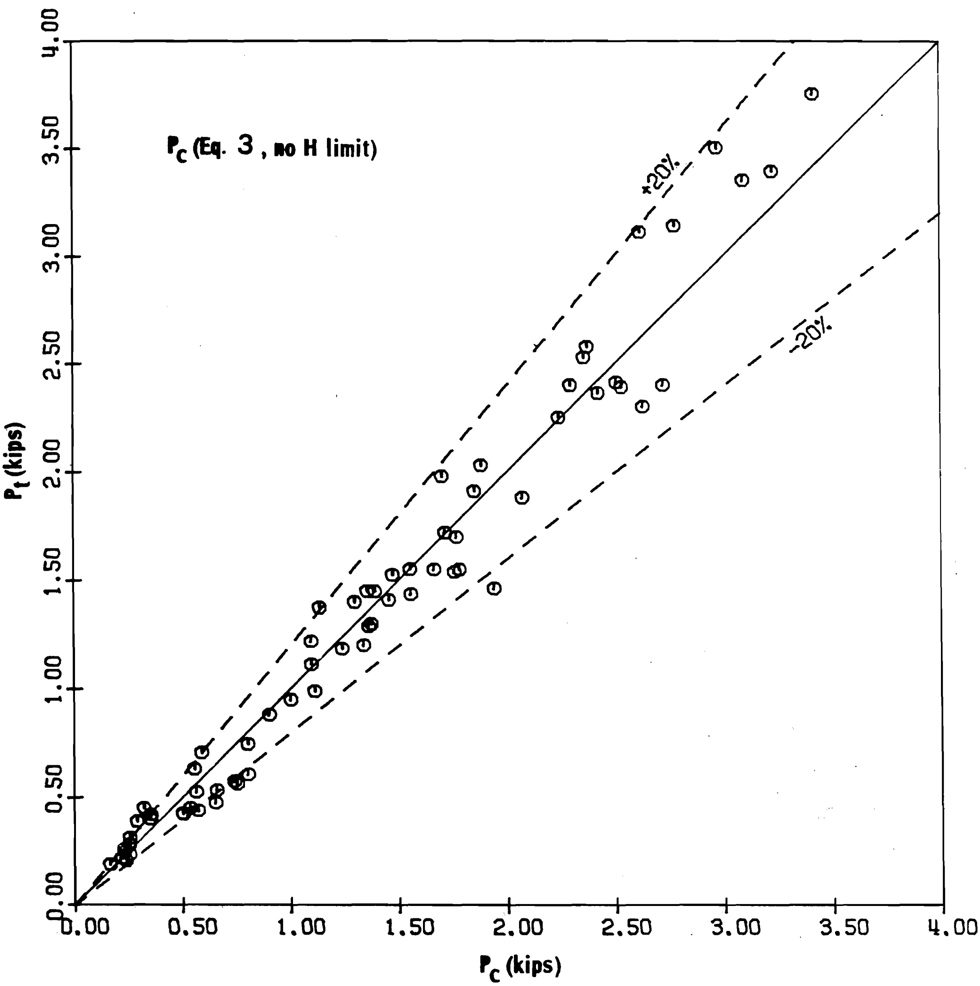

Figure 6 Test Load, P_t, vs. Computed Load, P_c, Using S136-1974 Standard [4] For Interior One Flange Tests, No Limit on H Ratio

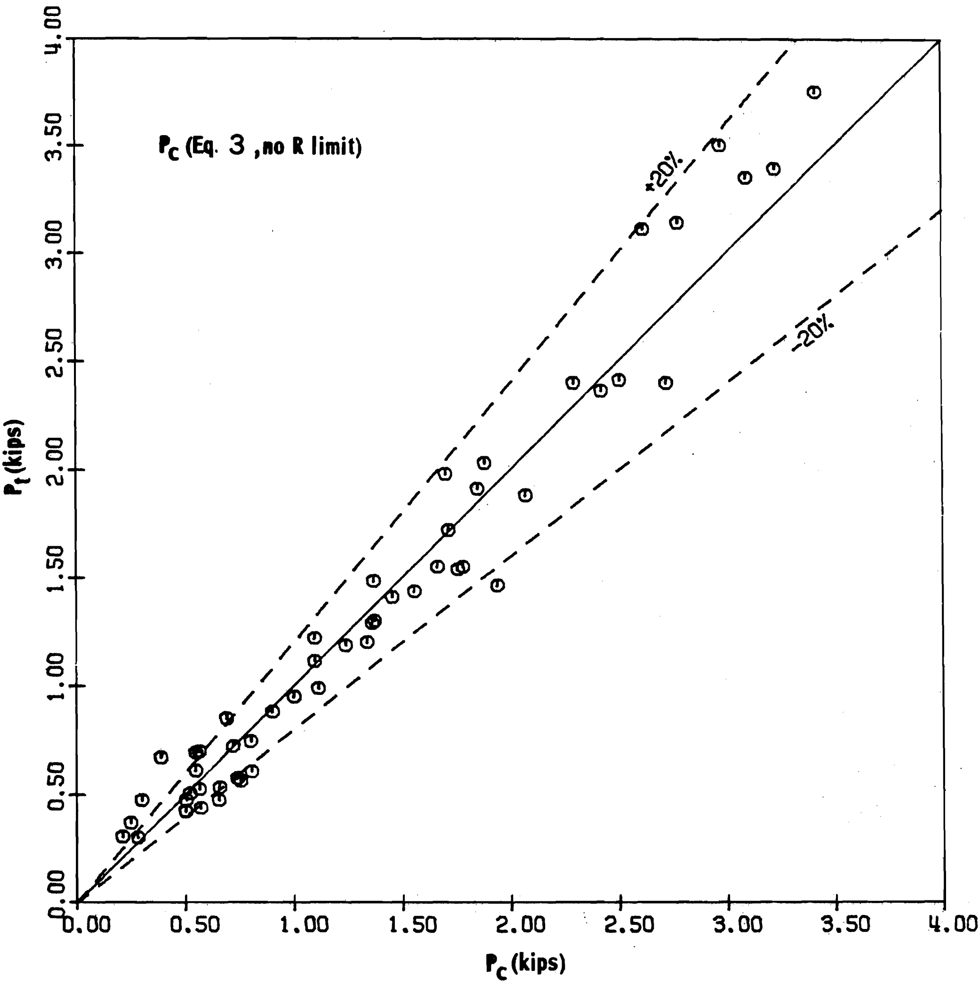

Figure 7 Test Load, P_t, vs. Computed Load, P_c, Using S136-1974 Standard [4] For Interior One Flange Tests, No Limit on R Ratio

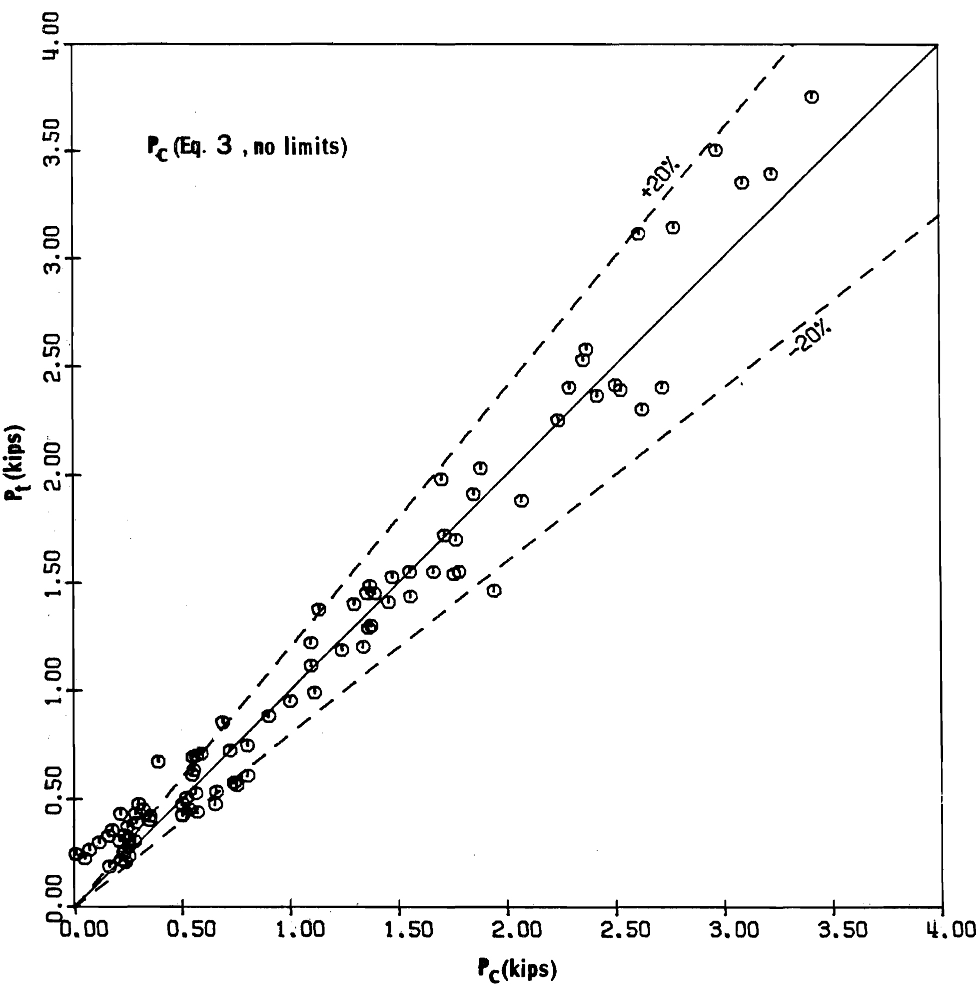

Figure 8 Test Load, P_t, vs. Computed Load, P_c, Using S136-1974 Standard [4] For Interior One Flange Tests, No Limit on H and R Ratios

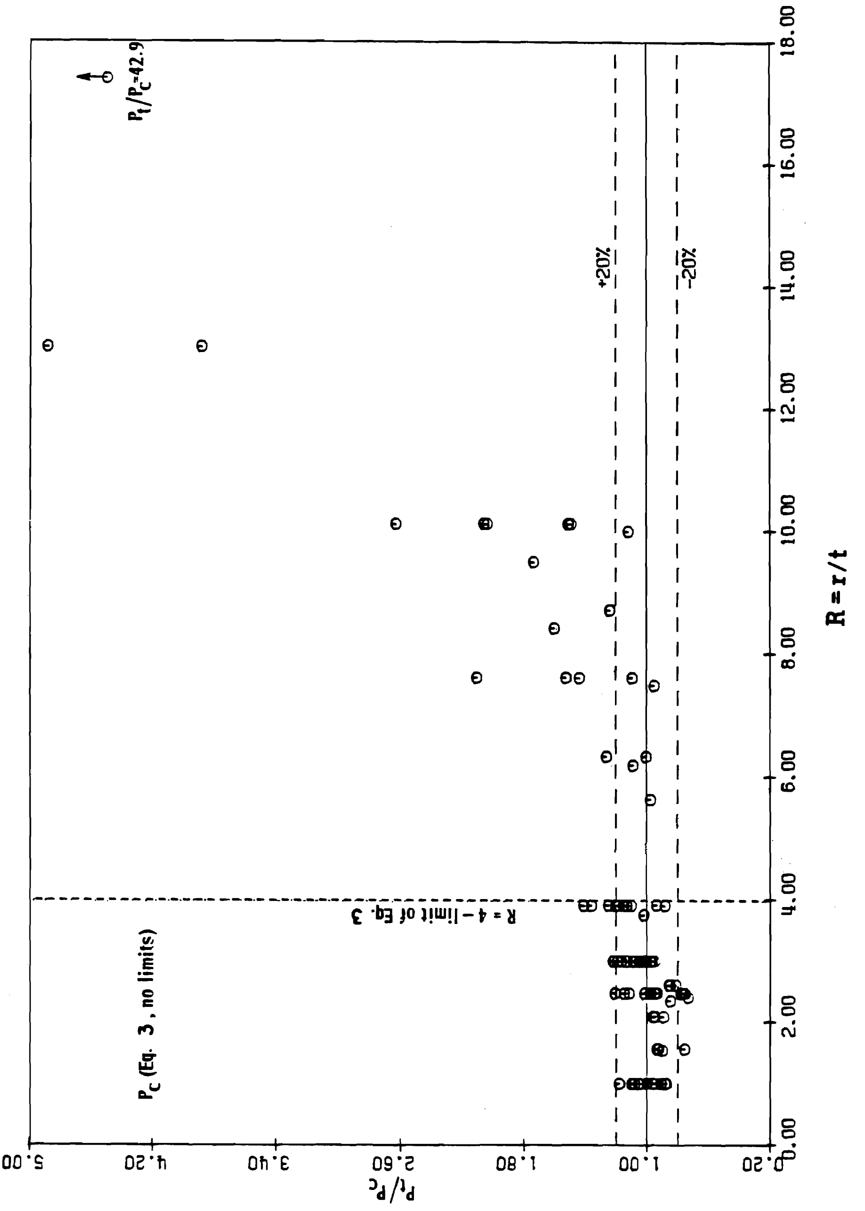

Figure 9 Load Ratio, P_t/P_c, Using S136-1974 Standard [4] vs. Inside Bend Radius Ratio For Interior One Flange Tests

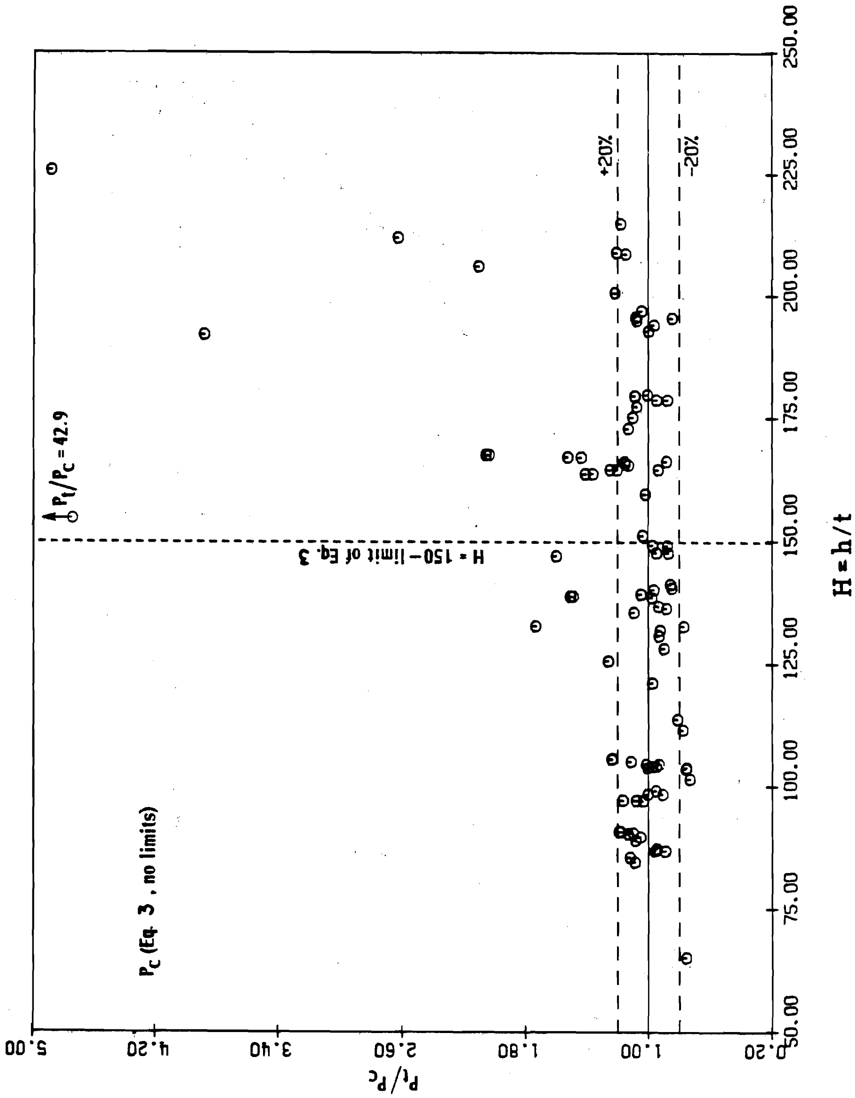

Figure 10 Load Ratio, P_t/P_c, Using S136-1974 Standard [4] vs. Web Slenderness Ratio For Interior One Flange Tests

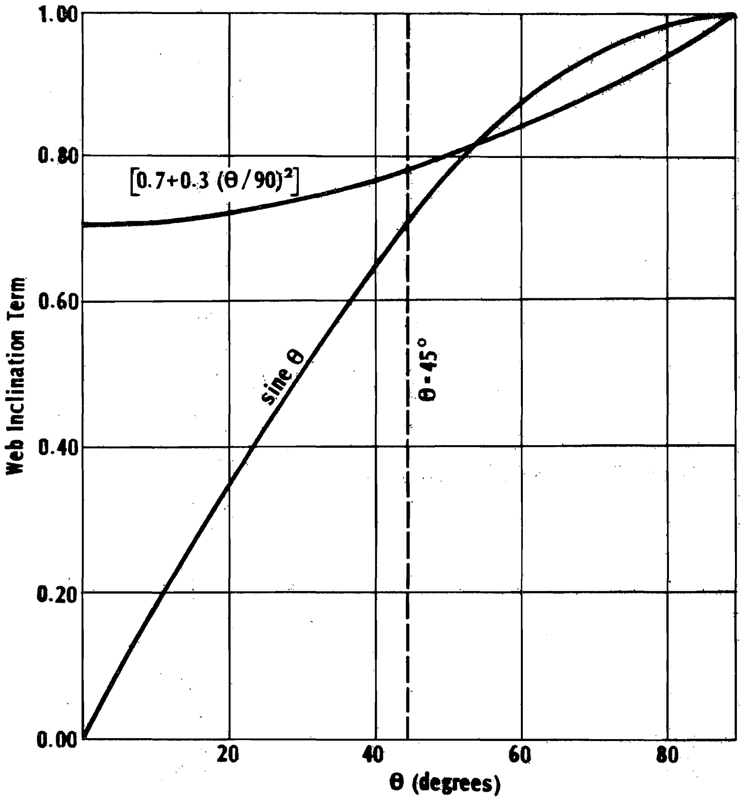

Figure 11 Web Inclination Term vs. θ

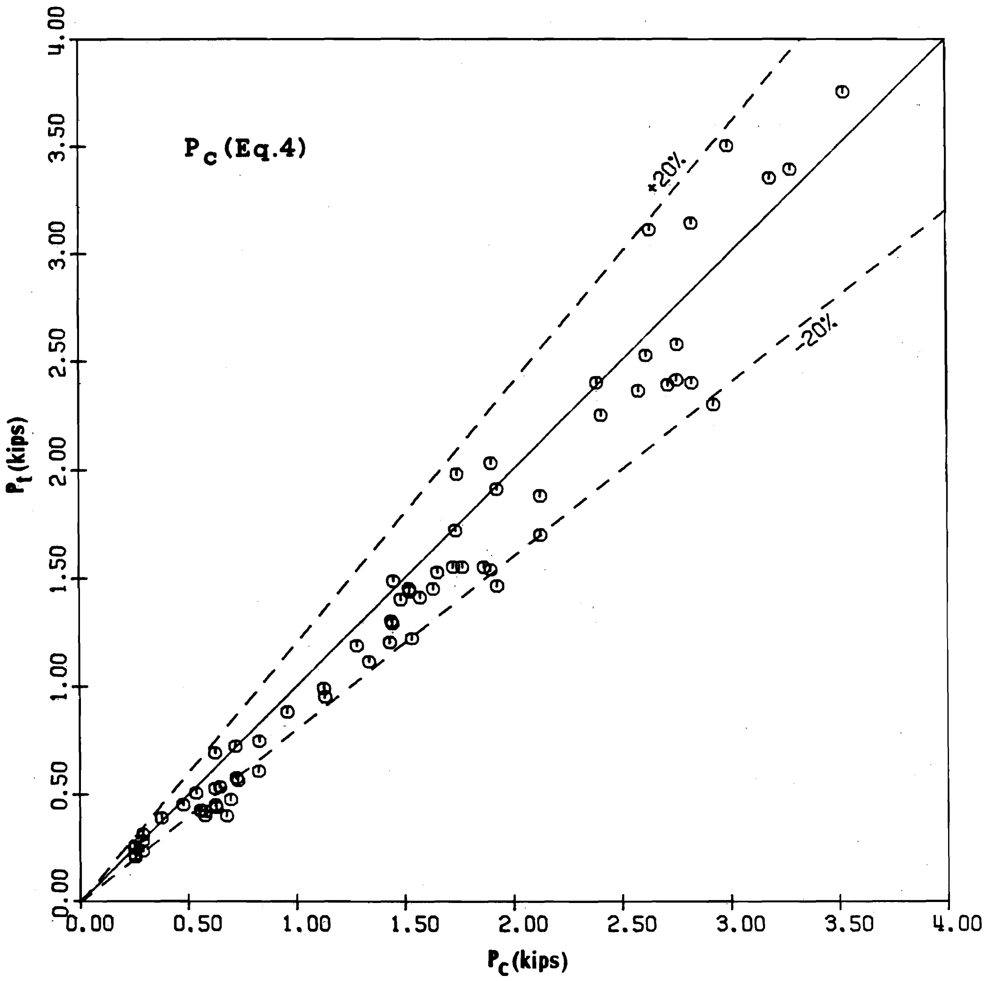

Figure 12 Test Load, P_t, vs. Computed Load, P_c, Using AISI-1980 Specification [2] For Interior One Flange Tests

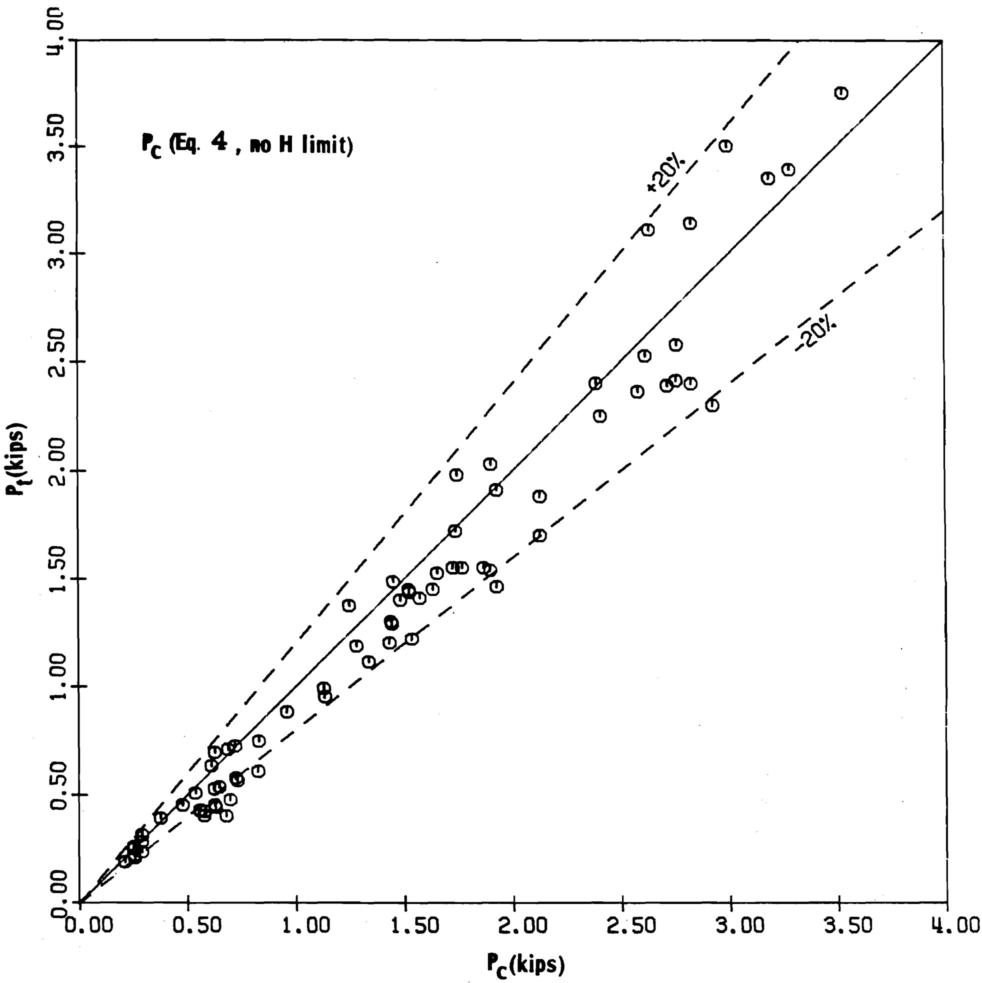

Figure 13 Test Load, P_t, vs. Computed Load, P_c, Using AISI-1980 Specification [2] For Interior One Flange Tests, No Limit on H Ratio

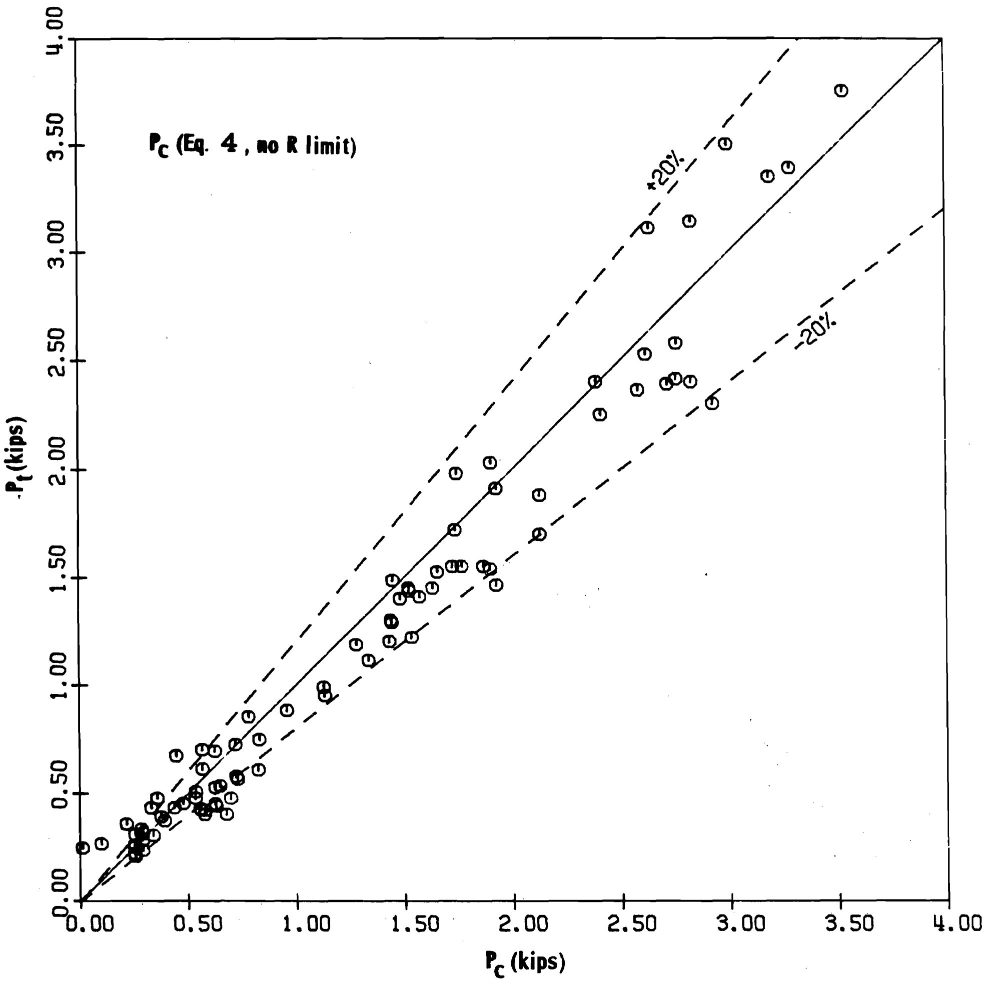

Figure 14 Test Load, P_t, vs. Computed Load, P_c, Using AISI-1980 Specification [2] For Interior One Flange Tests, No Limit on R Ratio

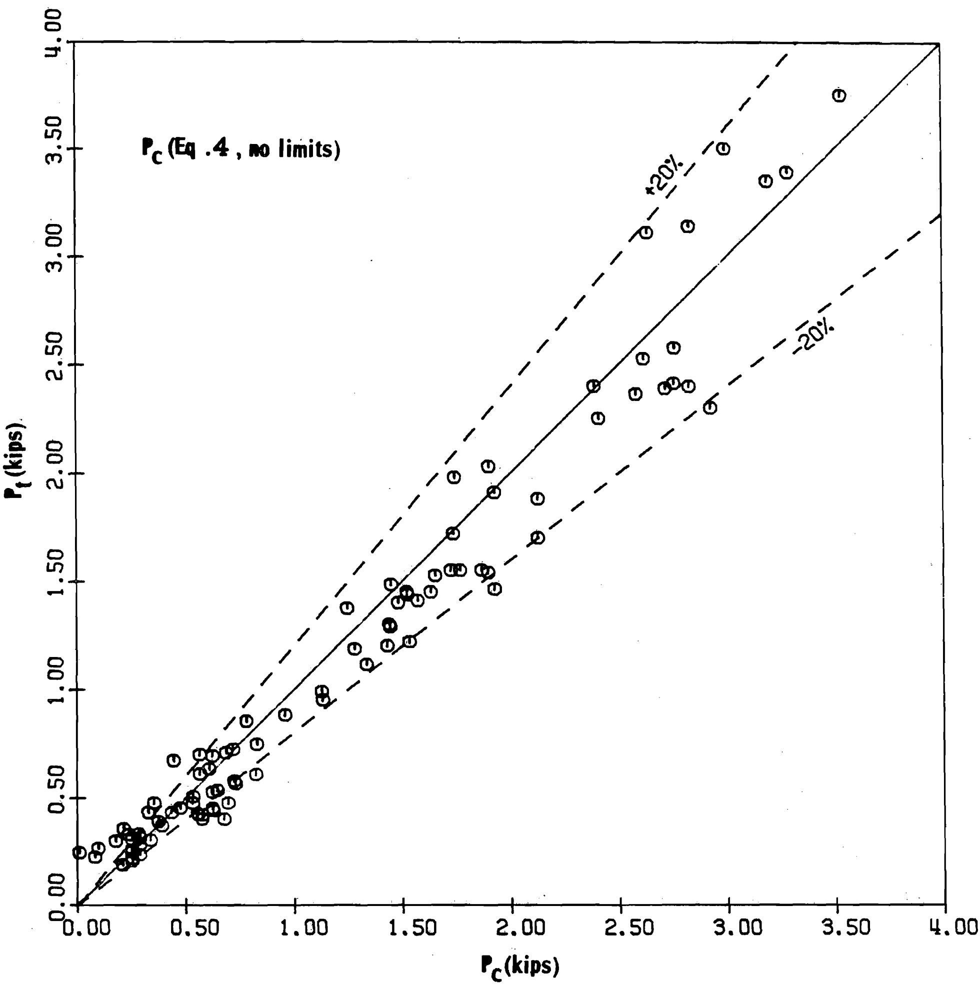

Figure 15 Test Load, P_t, vs. Computed Load, P_c, Using AISI-1980 Specification [2] For Interior One Flange Tests, No Limits on H and R Ratios

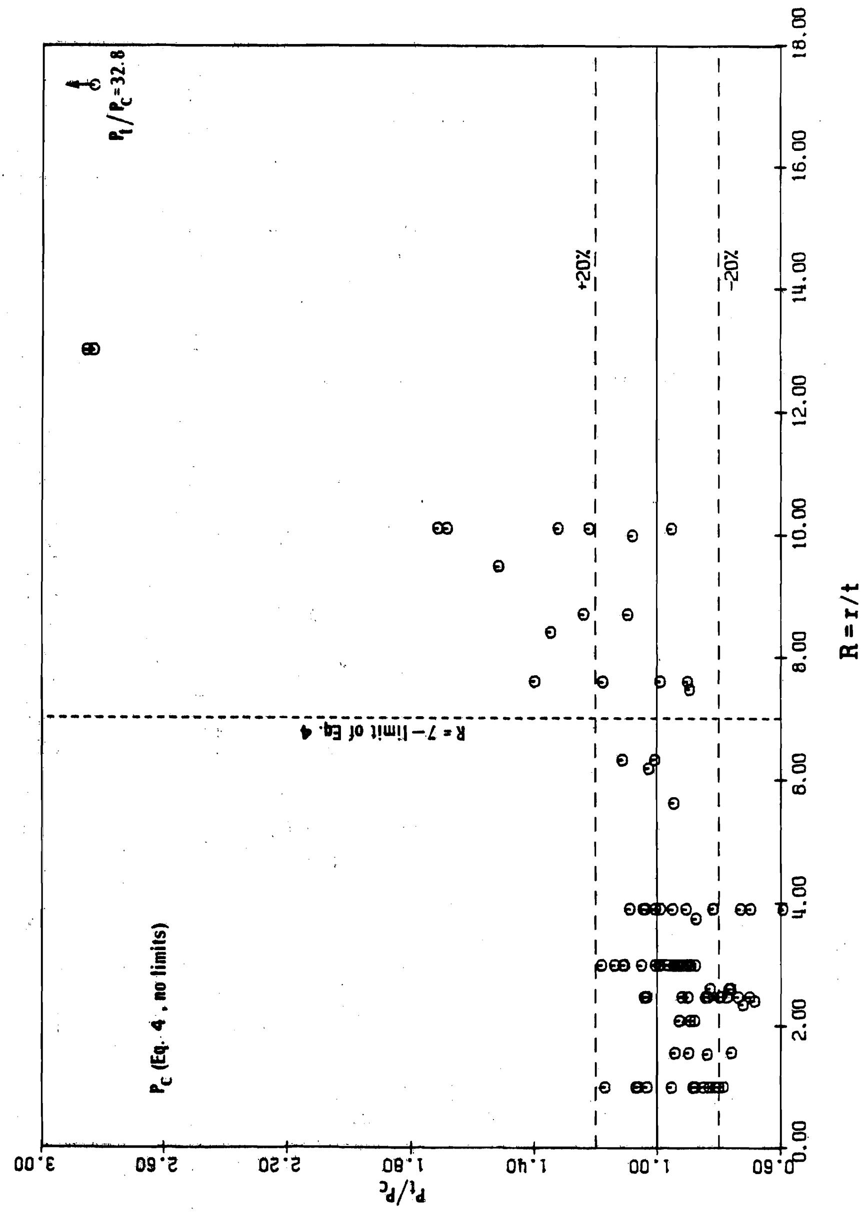

Figure 16 Load Ratio, P_t/P_c, Using AISI-1980 Specification [2] vs. Inside Bend Radius Ratio For Interior One Flange Tests

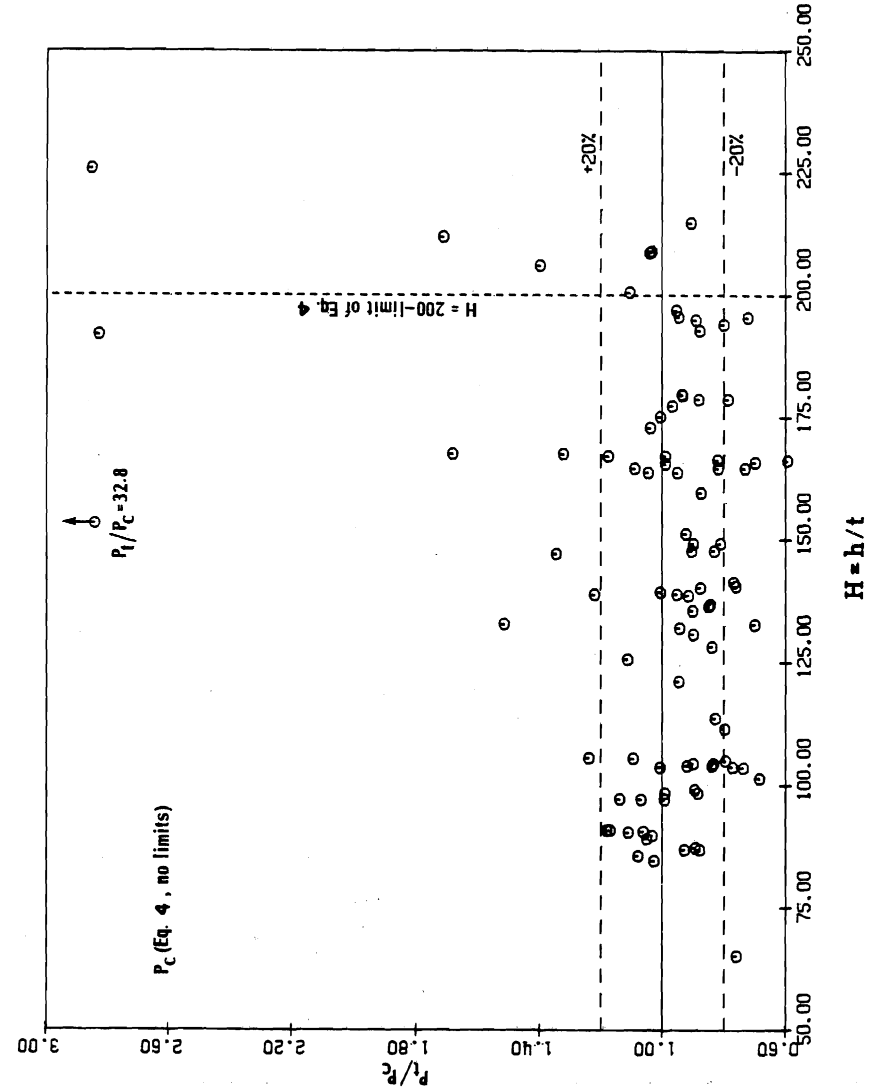

Figure 17 Load Ratio, P_t/P_c, Using AISI-1980 Specification [2] vs. Web Slenderness Ratio For Interior One Flange Tests

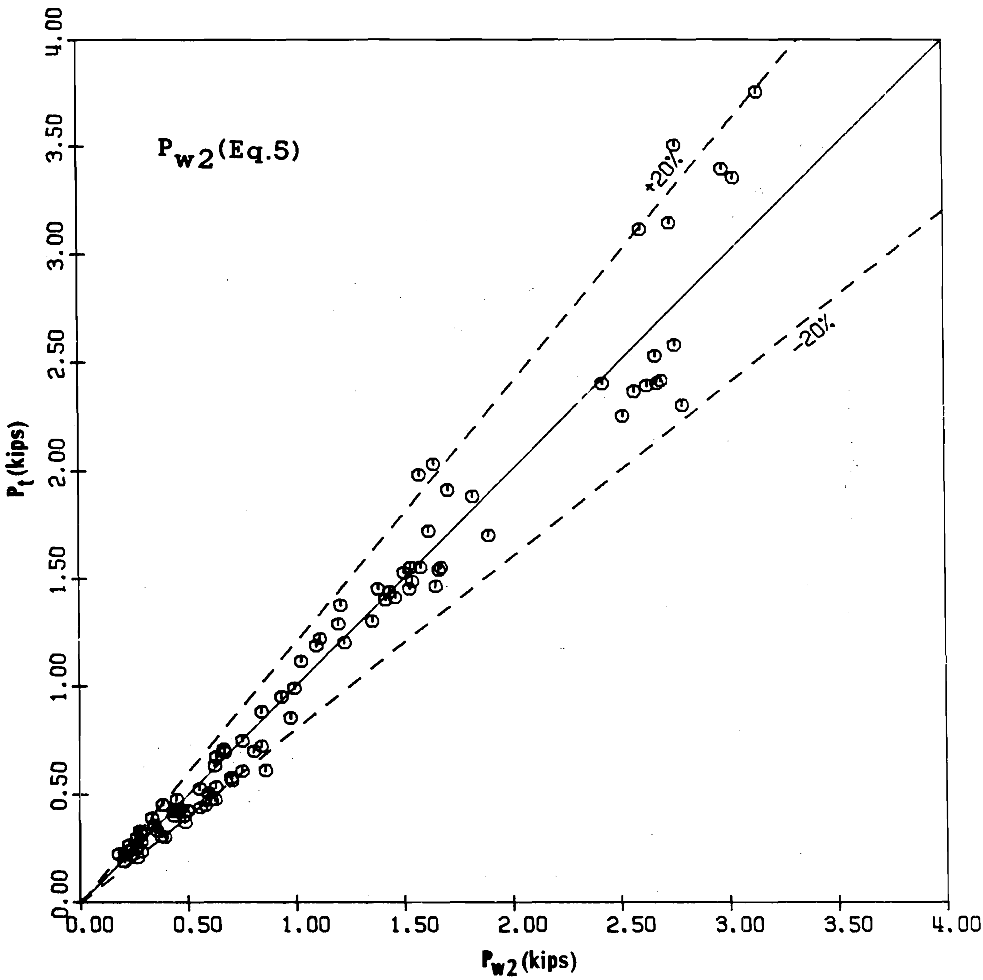

Figure 18 Test Load, P_t, vs. Computed Load, P_{w2}, Using Waterloo Method, Eq. 5, For Interior One Flange Tests

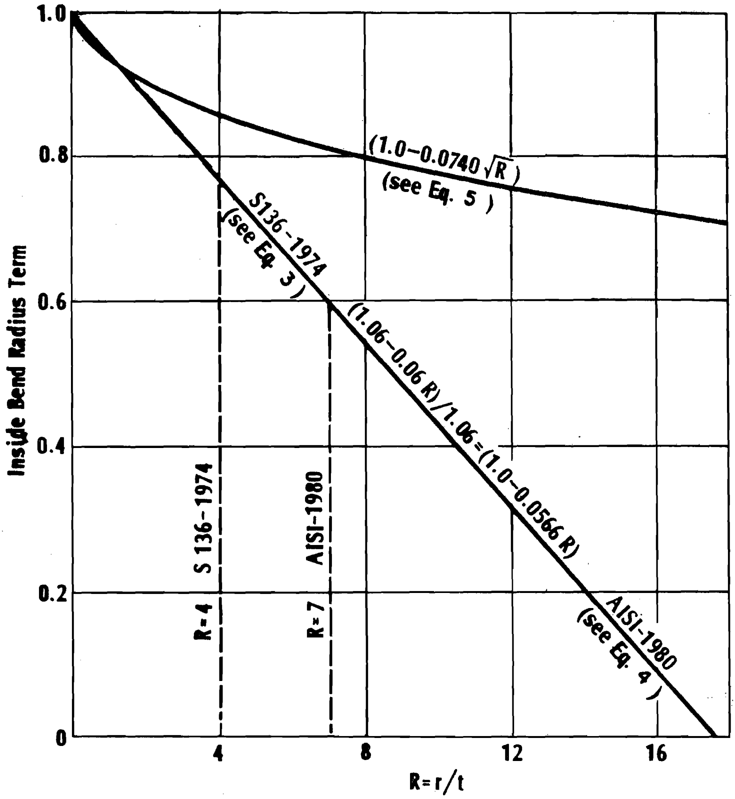

Figure 19 Inside Bend Radius Term vs. Inside Bend Radius Ratio For Interior One Flange Loading

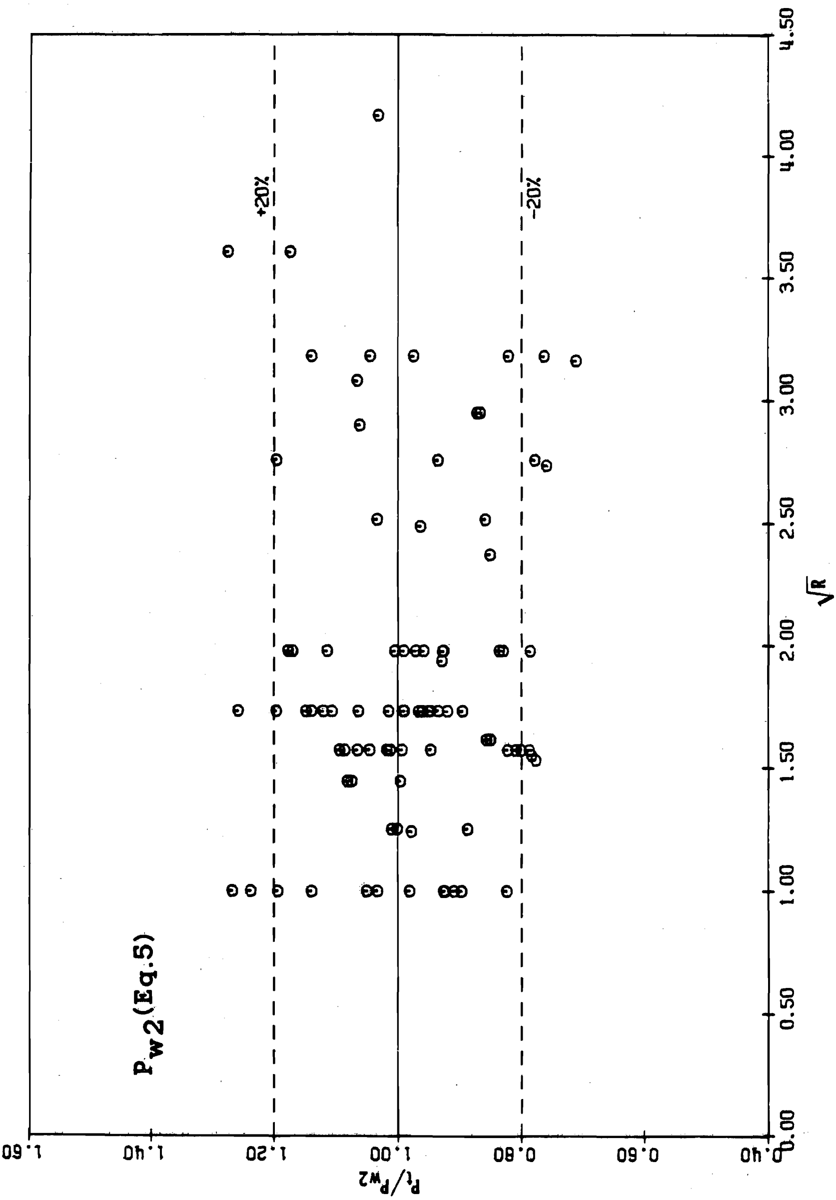

Figure 20 Load Ratio, P_t/P_{w2}, Using Eq. 5 vs. Square Root of Inside Bend Radius Ratio For Interior One Flange Tests

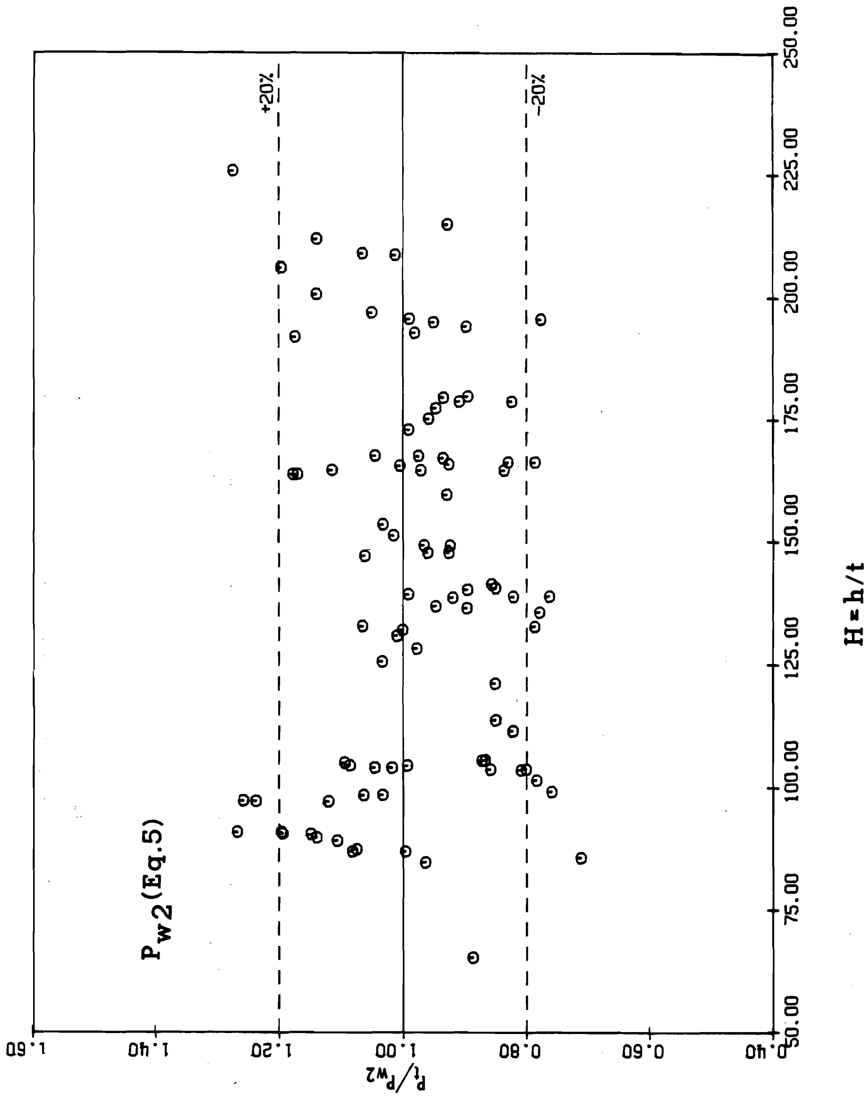

Figure 21 Load Ratio, P_t/P_{w2}, Using Eq. 5 vs. Web Slenderness Ratio For Interior One Flange Tests