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WEB CRIPPLING OF DECKS SUBJECTED TO TWO FLANGE LOADING

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

SUMMARY

This paper presents web crippling expressions for multi-web deck sections subjected to (1) interior two flange loading and (2) exterior two flange loading. In comparison with the test data for the range of parameters investigated, the expressions predicted the web crippling loads within the commonly accepted scatter range of ± 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 expressions. Also, the bearing length term of the interior two flange loading expression is substantially different from its counterpart in the 1980 AISI expression. Comparing the test data with the 1980 AISI web crippling expressions resulted in a considerably larger than ± 20% scatter, and in the case of exterior two flange loading, a consistent underestimation of the load carrying capacity by an average of 75% was experienced.

INTRODUCTION

Cold formed steel multi-web deck sections are used extensively in building construction, not only are they subjected to one flange loading but also to two flange loading. In practice, two flange loading will occur where a concentrated load is located directly over a supporting wall or beam. If the loading is at the interior of the cold formed section it is referred to as interior two flange loading, shown in Fig. 1a, and if at the exterior edge then it is referred to as exterior two flange loading, shown in Fig. 1b. The primary mode of failure of two flange loaded deck sections is web crippling, where the ultimate load carrying capacity is a function of a number of parameters, namely, the web slenderness ratio, the inside bend radius ratio, the bearing length ratio, the angle of web inclincation and the yield capacity of the steel. The present Standard for the design of cold formed steel structures in Canada (CSA S136-1974) [3] does not cover the two flange load case, while the 1980 edition of the AISI Specification [2] does specifically cover this loading condition. However, the AISI expressions, although presented for all shapes defined as having single webs (including decks), were developed primarily from data of channel-type sections.

OBJECTIVE AND SCOPE

The objective of this study was to determine the ultimate load carrying capacity of multi-web deck sections subjected to (1) interior two flange loading and (2) exterior two flange loading. See Fig. 1 for loading conditions. Due

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to the complexity of a purely theoretical analysis of the post-buckling capacity of web elements under concentrated crippling loads, as reported in detail in Reference [6], an experimental test program was initiated in an effort to carry out the above stated objective. Also, the test program was to provide experimental data so that the 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 present S136-1974 Standard [3] specifies 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 Fig. 2. The bearing length, n, is shown in Fig. 1. To be applicable to the majority of sections presently being manufactured, the specimens tested included R values up to 10 and H values up to 200.

TEST PROGRAM

The test program was designed to encompass the most important parameter variations that influence the web crippling capacity of multi-web deck sections subjected to two flange loading. Test specimens consisted of deck sections specifically fabricated for this study (break-formed) and commercially manufactured multi-web profiles, roll-formed by different Canadian manufacturers. The commercial deck sections were tested to insure that the design expressions would also be applicable to these products. 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 Two Flange Test Setup (ITF)

Two symmetrical bearing plates of the same width were positioned at mid-length of the specimen, as shown in Fig. 1a. The load was applied to the top bearing plate and the bottom bearing plate was supported by a rigid support. The ultimate test load was the largest load observed during the test. The specimens were of sufficient length, such that the localized region of failure did not extend over the entire length of the specimen. This ensured that the test load would not be a function of the length of the specimen.

Exterior Two Flange Test Setup (ETF)

The test setup for exterior two flange loading was similar to the setup of the interior two flange tests, however, the bearing plates were located at an exterior edge of the specimen, as shown in Fig. 1b. Again, the overall length of the specimen was such, that the localized region of failure did not extend over the entire length of the specimen.

TEST RESULTS

The ultimate test loads were first compared with the ultimate computed loads using the AISI-1980 Specification [2] equation times a factor of safety of 1.85. A new equation was then developed to predict the test loads. In evaluating the accuracy of the computed web crippling load, 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 variation were computed using only the tests within the limits of the governing equation. A mean value of close to 1.0 with a small coefficient of variation indicates a good prediction of the test loads.

Interior Two Flange Tests (ITF)

A total of 82 ITF tests were used in checking the existing web crippling expressions and in developing a new expression. All of the 82 tests analyzed were conducted at the University of Waterloo, 33 on profiles fabricated at the University of Waterloo identified by the letter W, 12 on specimens specifically made with large inside bend radius ratios, identified by the letters WR, and 37 on commercially manufactured decks from various Canadian manufacturers. The range of parameters for the interior two flange tests are listed in Table 1.

Fig. 3 shows a photograph of a commercial interior two flange test specimen and illustrates the failure mode for this loading arrangement.

Table 1 - Parameter Range for Interior Two Flange Tests

Parameter	Product Name			
	Waterloo (W)	Waterloo Radius (WR)	Commercial	All Tests
t (in.)	0.024-0.060	0.0247-0.0606	0.025-0.050	0.024-0.0606
$H = h/t$	31.3-215.0	53.9-167.2	22.5-95.3	31.3-215.0
$R = r/t$	1.57-3.92	3.61-10.12	1.34-10.0	1.34-10.12
$N = n/t$	16.7-125.0	33.0-81.0	30.0-125.0	16.7-125.0
F_y (ksi)	33.5-39.8	43.4-46.1	40.9-49.0	33.5-49.0
θ (degrees)	50°,70°,90°	70° or 90°	45°-87.5°	45° - 90°

Comparison of Test Results with AISI-1980 Specification [2]

The AISI-1980 Specification [2] is the only specification which specifically addresses interior two flange loading and was therefore the only method of computation with which the test data was compared. The AISI-1980 Specification [2] expression for web crippling subjected to interior two flange loading is given by Eq. 1,

$$P_{max} = t^2F_y/33\ C_1C_2C_\theta\ (417-1.22H)(1.0+0.0013N)\ , \tag{1}$$

where:

P_{max} = allowable concentrated load or reaction per web
t = web thickness
F_y = yield strength of steel
H = web slenderness ratio, h/t
N = bearing length to web thickness ratio, n/t
C_1 = $(1.22 - 0.22k)$
k = $F_y(ksi)/33$; $(F_y(N/mm^2)/228)$
C_2 = $(1.06-0.06R) \leq 1.0$
R = inside bend radius to web thickness ratio, r/t
C_θ = $(0.7 + 0.3\ (\theta/90)^2)$
θ = angle of web inclination, degrees.

The limits of Eq. 1 are $R \leq 6$ for beams, $R \leq 7$ for decks, $H \leq 200$, $N \leq 210$ and $N/H \leq 3.5$.

The terms C_1 and C_2 of Eq. 1 are the same as the terms used for interior one flange loading in the AISI-1968 Specification [1] and the present S136 Standard [3]. The test results were compared with the AISI-1980 expression, Eq. 1, multiplied by the factor of safety of 1.85, resulting in Eq. 2,

$$P_c = (1.85)t^2F_y/33\ C_1C_2C_\theta\ (417-1.22H)(1.0+0.0013N) \tag{2}$$

where:

P_c = computed ultimate concentrated load or reaction per web.

The mean value and the coefficient of variation of the test/computed load ratios, P_t/P_c, are 1.061 and 0.267, respectively, for the 70 tests within the specified limits. P_t was plotted against P_c, as defined by Eq. 2, in Fig. 4, and as can be seen there are numerous test points above and below the $\pm$ 20% scatter lines. This, and the rather large value of the coefficient of variation indicates that Eq. 2 is somewhat inconsistent in predicting the test loads.

The coefficient, 0.0013, of the bearing length term, $(1.0 + 0.0013N)$ of Eq. 2 is in the order of 1/7 of the coefficients of N for the AISI-1980 Specification [2] expressions for exterior one flange loading, $(1.0 + 0.01N)$, interior one flange loading, $(1.0 + 0.007N)$ and exterior two flange loading, $(1.0 + 0.01N)$. It is questionable at this point that the web crippling load would not be as sensitive to the bearing length ratio, N, for the interior two flange load case only. Eq. 2 was based on the work by Hetrakul and Yu [5], where 30 interior two flange tests were conducted, with the bearing length ratio, N, varying between 20 and 60. This is a somewhat small variation in the bearing length ratio, N, to conclusively determine the dependence of the web crippling load on the bearing length.

Fig. 5 is a plot of the load ratio, P_t/P_c versus the bearing length ratio, N, and shows that the load ratio P_t/P_c is generally increasing with increasing values of N, indicating that the computed load, using Eq. 2, is generally underestimating the test load for larger values of N.

The inside bend radius term, C_2, of Eq. 2 is the same as the term used for interior one flange loading in the AISI-1968 Specification [1] and S136 [3], which was based on research carried out at Cornell University [4]. The Cornell test specimens had inside bend radius ratios, $R = r/t$, of either 1 or 3 only. It is therefore possible that this term, C_2, is not completely valid for R values significantly larger than 3. Fig. 6 is a plot of the load ratios, P_t/P_c, versus R for the tests conducted at Waterloo, showing that the load ratio, P_t/P_c, increases with an increase in R, which indicates that the computed load, using Eq. 2 is underestimating the test load for R values larger than about 4.

Development of Expressions for Ultimate Web Crippling Load

Two expressions were developed for interior two 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 slightly better results and is given by Eq. 3,

$$P_{w4} = 18.0\ t^2 F_y (\text{sine}\ \Theta)(1.0 - 0.00139H)\ (1.0 + 0.00948N)$$
$$(1.0 - 0.0306\ \sqrt{R})\ (1.0 - 0.221k)\ , \qquad (3)$$

P_{w4} = computed ultimate interior two flange web crippling load per Waterloo Method, using $\sqrt{R}$ term,

other terms as previously defined.

A correction term for web inclination of sine θ was used because it was felt that this term had more engineering significance. For example, a gravity load of one unit per web on a hat section with 45° webs would result in a load of 1.414 units in the web. To account for this, the web crippling load can be multiplied by the sine of the web inclination (sine θ). The web inclination term, $(0.7 + 0.3\ (\theta/90)^2)$, of the AISI-1980 Specification [2] expression, Eq. 2, was plotted against the angle of web inclination in Fig. 7. The sine of the web inclination, sine θ, was also plotted against the angle of web inclination, θ, in Fig. 7. Sine θ and the term $(0.7 + 0.3\ (\theta/90)^2)$, differ by no more than 10% within the range of 45° and 90°, which is the range for sections commercially manufactured and commonly found in practice.

The mean value of the ratios P_t/P_{w4} using all 82 tests is 0.989 and the coefficient of variation is 0.113. The test load P_t was plotted against P_{w4} of Eq. 3, as shown in Fig. 8. Using the Waterloo expression, Eq. 3, produced a good correlation with the test data, illustrating that all of the points are within or near the ± 20% scatter lines.

The coefficient of the bearing length term of (1.0 + 0.00948N), is in the order of the coefficients for the AISI-1980 Specification [2] expressions for exterior one flange loading (1.0 + 0.01N), interior one flange loading (1.0 + 0.007N), and exterior two flange loading (1.0 + 0.01N). However, the expression for interior two flange loading, Eq. 2, as previously stated has a bearning length term of (1.0 + 0.0013N), the coefficient of which is in the order of 1/7 of that of the bearing length term of Eq. 3. The AISI-1980 Specification implies that the web crippling load for interior two flange loading is not sensitive to the bearing length, which does not seem to be the case based on the Waterloo results.

The load ratios, P_t/P_{w4} were plotted versus N and are shown in Fig. 9. This figure shows that the load ratio is evenly distributed about the 1.0 line and within or near the ± 20% scatter lines over the range of N values of the tests. This indicates that the bearing length term of Eq. 3 performs well over the range of N values of the 82 tests.

The load ratios, P_t/P_{w4}, were plotted versus $\sqrt{R}$ in Fig. 10 and again, the load ratios remain evenly distributed about the 1.0 line and within or near the ± 20% scatter lines over the range of R values of the tests. The R term of Eq. 3 as well as the R term of the AISI-1980 Specification [2] expression, Eq. 2, were plotted versus R in Fig. 11. Fig. 11 shows that the R term of Eq. 2 decreases much more rapidly with an increase in R than the R term of Eq. 3. This is why Eq. 2 consistently underestimates the web crippling capacity for specimens with larger R values.

Summary of Comparisons of Test Loads with Computed Loads

Table 2 summarizes the statistical information of the comparisons of the test loads with different methods of computing the ultimate interior two flange web crippling loads.

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

Method of Computation	Statistical Information		
	Mean of P_t/P_c*	Coefficient of Variation of P_t/P_c*	Number of Tests Within Limits/ Total Tests
AISI-1980 Specification [2], Eq. 2	1.061	0.267	70/82
Waterloo Method Eq. 3	0.989	0.113	82/82

*Note: for Waterloo Method: $P_c = P_{w4}$ of Eq. 3.

Exterior Two Flange (ETF)

The placement of bearing plates and general test setup is shown in Fig. 1b. There was no moment in the specimens during the test and failure was strictly of a web crippling type nature.

A total of 80 exterior two flange tests were conducted, 32 on Waterloo made profiles, 14 on specimens especially made with large inside bend radius values, and 34 on commercially manufactured decks. The range of parameters for the exterior two flange load tests are listed in Table 3.

Table 3 - Parameter Range for Exterior Two Flange Tests

Parameter	Product Name			
	Waterloo	Waterloo Radius	Commercial	All Tests
t (in.)	0.024-0.060	0.0247-0.0606	0.025-0.062	0.024-0.062
H = h/t	31.7-334.4	53.9-212	30.8-96.2	30.8-334.4
R = r/t	1.57-3.92	3.61-10.12	1.34-10.0	1.34-10.12
N = n/t	16.7-41.7	33.0-81.0	30.6-125	16.7-125
F_y = (ksi)	33.5-39.8	43.4-46.1	40.9-49.0	33.5-49.0
θ (degrees)	50°,70°,90°	50°,70°,90°	45.0°-87.5°	45°-90°

Fig. 12 shows a photograph of a typical exterior two flange test specimen and illustrates the failure mode for this loading case.

Comparison of Test Results with the AISI-1980 Specification [2]

The AISI-1980 Specification [2], is the only specification which specifically addresses exterior two flange loading and is therefore the only method of computation with which the test data was compared. The AISI-1980 Specification expression for exterior two flange web crippling is given by Eq. 4,

$$P_{max} = t^2 F_y / 33 \; C_3 C_4 C_\theta \; (132 - 0.31H) \; (1.0 + 0.01N) \;, \qquad (4)$$

where:

$C_3 = (1.33 - 0.33k)$

$C_4 = (1.15 - 0.15R) \leq 1.0$ but not less than 0.5

other terms as previously defined.

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

The yield strength term, C_3, and the inside bend radius term C_4, are the same as the terms used for exterior one flange loading in the S136-1974 Standard [3], and the AISI-1968 Specification [1]. The test results were compared with the AISI-1980 Specification [2] expression, Eq. 4, multiplied by a factor of safety of 1.85 to obtain the ultimate load as given by Eq. 5,

$$P_c = (1.85)\ t^2F_y/33\ C_3C_4C_\theta\ (132 - 0.31H)(1.0 + 0.01N)\ , \qquad (5)$$

where:

P_c = computed ultimate concentrated load or reaction per web.

The mean value and the coefficient of variation of the load ratio, P_t/P_c, are 1.751 and 0.265, respectively, for the 63 tests within the limits of Eq. 5. Fig. 13 is a plot of P_t versus P_c using Eq. 5.

The AISI-1980 Specification [2] places a limit of $R \leq 7$ for decks on the use of Eq. 5 which was based on the work by Hetrakul and Yu [5], in which 30 exterior two flange tests were conducted. The range of the inside bend radius ratio, $R = r/t$, for these 30 tests was only between 0.96 and 2.72. The range of R values for the tests conducted at the University of Waterloo was between 1.34 and 10.12 and only 28 of the 80 tests had R values less than 2.72.

The load ratio, P_t/P_c, where P_c was computed by Eq. 5, was plotted against the inside bend radius to web thickness ratio, R, in Fig. 14. The R term of Eq. 5, C_4, which is $(1.15 - 0.15R)$, is not to be less than 0.5, therefore for any value of R greater than 4.33, C_4 is equal to 0.5. Due to this, the values of the load ratio, P_t/P_c, do not continue to increase for $R \geq 4.33$, however it is evident from Fig. 14 that for values of R less than 4.33, the load ratio, P_t/P_c, increases with an increase in R. For R greater than 4.33, Fig. 14 shows that the P_t/P_c ratio is approximately 2, indicating that P_c, as computed by Eq. 5 is about one half that of the test load. The inside bend radius term of Eq. 5, $(1.15 - 0.15R)$, was plotted against the inside bend radius ratio, R, in Fig. 15. To make the inside bend radius term $(1.15 - 0.15R)$ equal to 1.0 when $R = 0$, the term was divided by 1.15 resulting in the term $(1.0 - 0.130R)$ as shown in Fig. 15. Fig. 15 demonstrates that the value of the inside bend radius term decreases rapidly for $R \leq 4.33$ then remains constant for any further increase in R.

Development of Expressions for Ultimate Web Crippling Load

Two expressions were developed, again using R as the inside bend radius term and the square root of R, $(\sqrt{R})$. The expression using $\sqrt{R}$ only is presented in this paper, since it gave slightly better results, and is given by Eq. 6.

$$P_{w6} = 10.9\ t^2F_y(\text{sine}\ \theta)(1.0 - 0.00206H)(1.0 + 0.00887N)$$
$$(1.0 - 0.111\ \sqrt{R})(1.0 - 0.0777\dot{k})\ , \qquad (6)$$

where:

P_{w6} = computed ultimate exterior two flange web crippling load per web as per Waterloo Method, using $\sqrt{R}$ term,

other terms as previously defined.

The only limit of Eq. 6 for the variation of the parameters of the specimens tested, as listed in Table 3, is $H \leq 250$. The mean and coefficient of variation of the load ratio P_t/P_{w6}, are 0.970 and 0.153, respectively. Fig. 16 is a plot of P_t versus P_{w6} and again, most of the tests are within the ± 20% scatter lines.

The inside bend radius term of Eq. 6 was plotted against the inside bend radius ratio in Fig. 15, which shows that the values of this term do not decrease as rapidly as the term of the AISI-1980 Specification [2], for increasing values of R. The load ratio P_t/P_{w6} was plotted against $\sqrt{R}$ in Fig. 17 for the 80 tests and the load ratios are evenly distributed about the 1.0 line and within or near the ± 20% scatter lines over the range of R values of the tests.

Summary of Comparisons of Test Loads with Computed Loads

Table 4 summarizes the comparisons of test loads with the different methods of computing the ultimate exterior two flange web crippling loads.

Table 4 - Summary of Comparison of Test Loads with Computed Loads for Exterior Two Flange Loading

Method of Calculation	Statistical Information		
	Mean of P_t/P_c*	Coefficient of Variation of P_t/P_c*	Number of Tests Within Limits/ Total Tests
AISI-1980 Specification [2] Eq. 5	1.751	0.265	63/80
Waterloo Method Eq. 6	0.970	0.153	77/80

*Note: for Waterloo Method $P_c = P_{w6}$ of Eq. 6.

CONCLUSIONS

Interior Two Flange Loading

Based on the comparisons of the results of 82 interior two flange multi-web tests with the AISI [2] and Waterloo Methods, the following conclusions are made:

(a) The AISI-1980 Specification [2] expression for interior two flange loading, Eq. 2, does not accurately predict the web crippling load for a number of the tests within the limits of the specification. The bearing length term of Eq. 2, does not properly account for the increase in capacity offered by larger bearing lengths. In addition, the value of the inside bend radius term of Eq. 2 decreases too rapidly for increasing R values, causing the the computed load to significantly underestimate the web crippling capacity for profiles with R values larger than about 4.

(b) The Waterloo expression, Eq. 3, resulted in a better estimation of the web crippling loads than the AISI-1980 expression, Eq. 2, and is applicable to all 82 tests.

Exterior Two Flange Loading

Based on the comparisons of the results of 80 exterior two flange multi-web tests and the AISI [2] and Waterloo Methods, the following conclusions are made:

(a) The AISI-1980 Specification [2] expression for exterior two flange loading, Eq. 5, consistently underestimates the web crippling loads. The value of the inside bend radius term of Eq. 5, decreases rapidly for increasing R values, causing the computed load to underestimate the web crippling capacity for profiles with larger R values. Even for the 63 tests within the stated limits of the Specification, the web crippling capacities were underestimated by an average of 75%.

(b) The Waterloo expression, Eq. 6, resulted in a good estimation of the web crippling loads for all 80 tests.

ACKNOWLEDGEMENT

This research was carried out at the University of Waterloo and was sponsored by the National Sciences and Engineering Research Council of Canada. The financial support of NSERC is gratefully acknowledged by the authors.

APPENDIX 1 - NOTATIONS

C_1 = $(1.22 - 0.22k)$

C_2 = $(1.06 - 0.06R) \leq 1.0$

C_3 = $(1.33 - 0.33k)$

C_4 = $(1.15 - 0.15R) \leq 1$ but not less than 0.5

C_θ = $(0.7 + 0.3\ (\theta/90)^2)$

ETF = exterior two flange

F_y = yield strength

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

H = web slenderness ratio, h/t

ITF = interior two flange

k = $F_y(\text{ksi})/33$; $(F_y(\text{N/mm}^2)/228)$

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_{w4} = computed ultimate interior two flange web crippling load per web as per Waterloo Method, using $\sqrt{R}$ term

P_{w6} = computed ultimate exterior two 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, $\leq 90°$

APPENDIX 2 - REFERENCES

[1] AMERICAN IRON AND STEEL INSTITUTE, *Specification for the Design of Cold-Formed Steel Structural Members*, 1968 Edition, including Addendum No. 1, 1970 and Addendum No. 2, 1977, Washington, D.C., 1968.

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[4] Cornell University, 65th and 66th Progress Reports on Light Gage Steel Beams of Cold-Formed Steel, September, 1952 and January, 1953, respectively, (unpublished).

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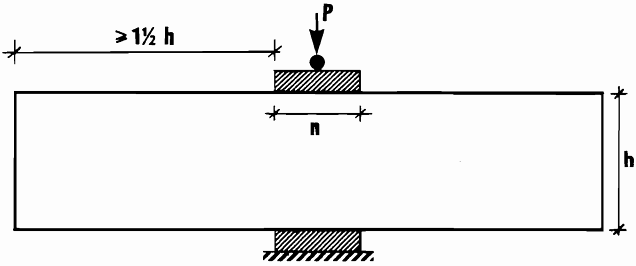
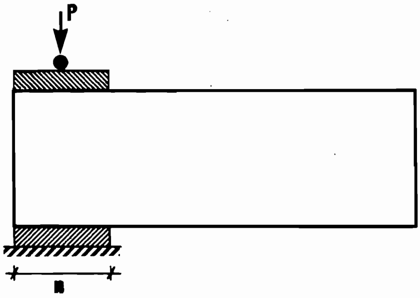


(a) Interior Two Flange Loading (ITF)



(b) Exterior Two Flange Loading (ETF)

Fig. 1 - Loading Conditions

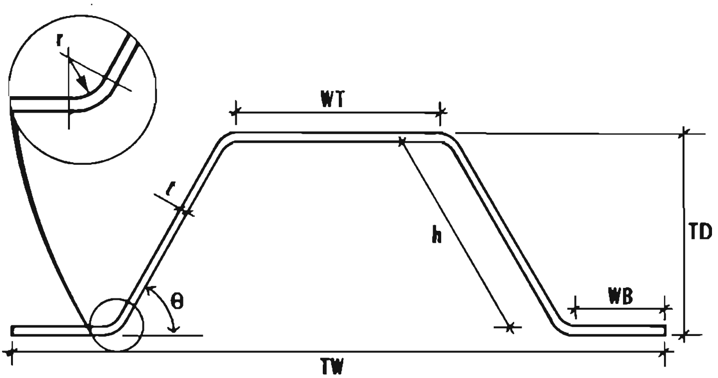


Fig. 2 - Designation of Symbols

Fig. 3 - Photograph of Interior Two Flange Test Specimen, Commercial Profile

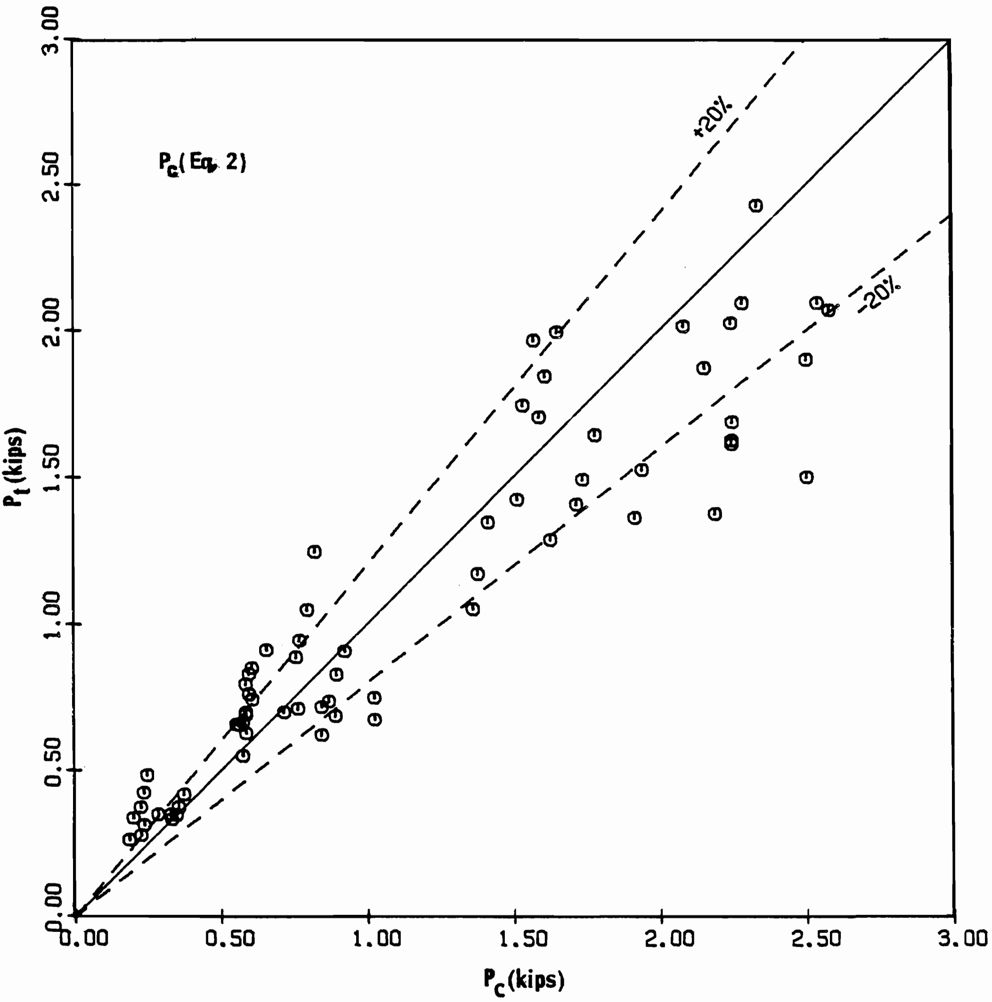


Fig. 4 - Test Load, P_t, vs. Computed Load, P_c, Using AISI-1980 Specification [2] for Interior Two Flange Tests

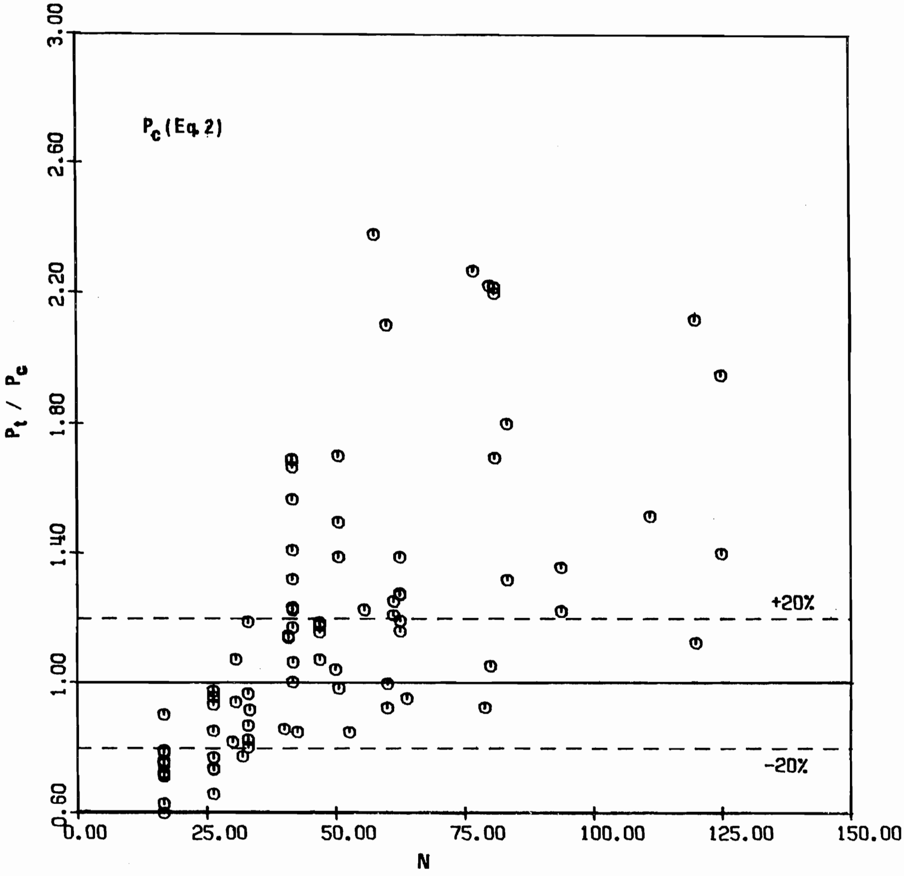


Fig. 5 - Load Ratio, P_t/P_c, Using AISI-1980 Specification [2] vs. Bearing Length Ratio, N = n/t, for Interior Two Flange Tests

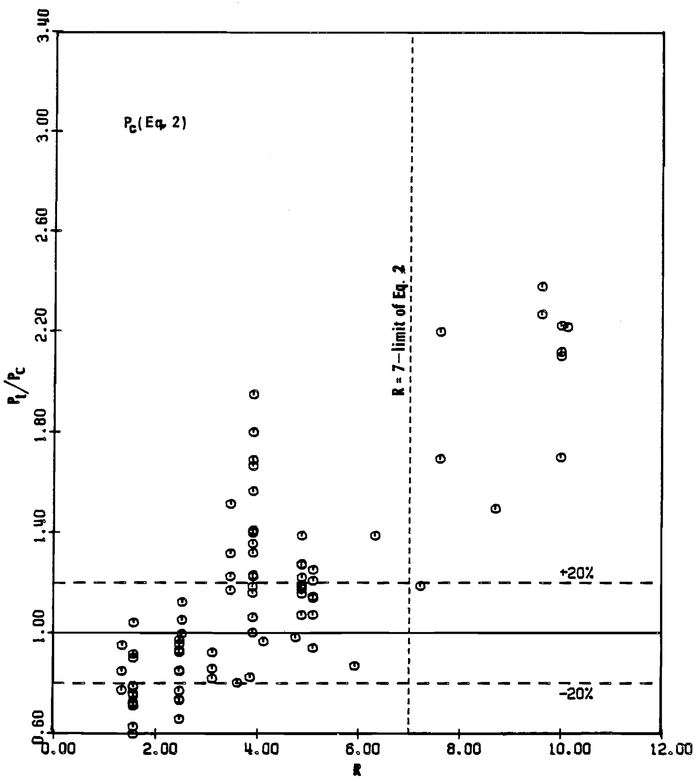


Fig. 6 - Load Ratio, P_t/P_c, Using AISI-1980 Specification [2] vs. Inside Bend Radius Ratio, R = r/t, for Interior Two Flange Tests

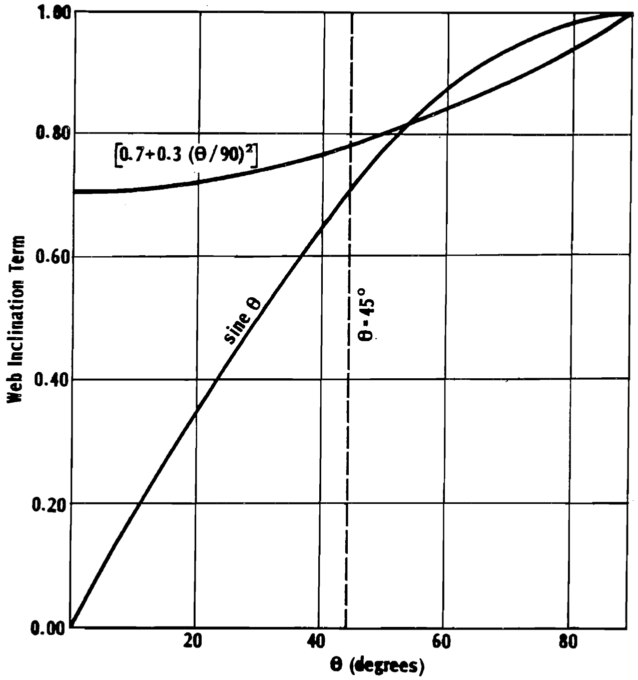


Fig. 7 - Web Inclination Term vs. θ

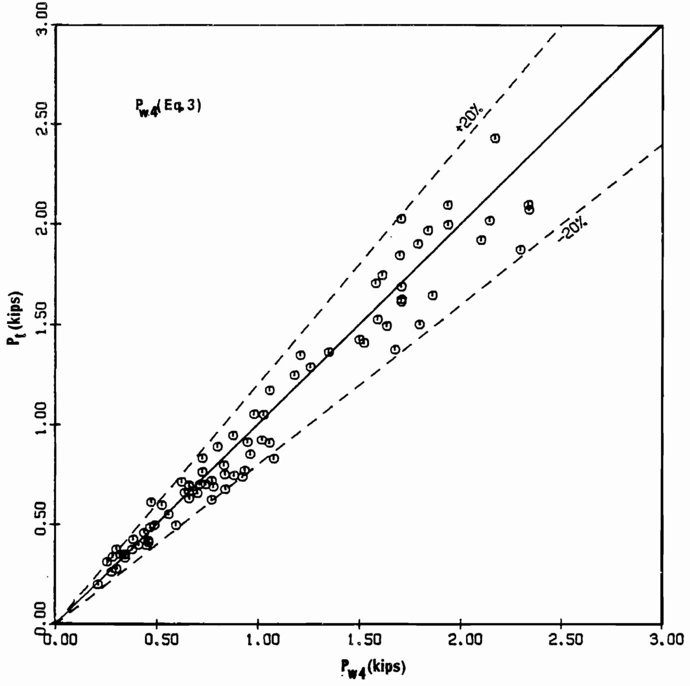


Fig. 8 - Test Load, P_t, vs. Computed Load, P_{w_4} Using Waterloo Method, Eq. 3, for Interior Two Flange Tests

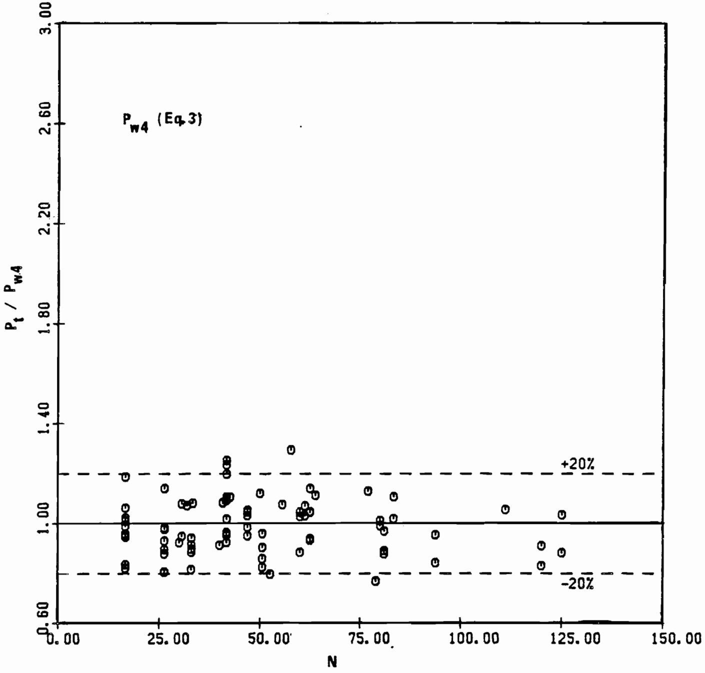


Fig. 9 - Load Ratio, P_t/P_{w_4}, Using Waterloo Method, Eq. 3, vs. Bearing Length Ratio, N = n/t, for Interior Two Flange Tests

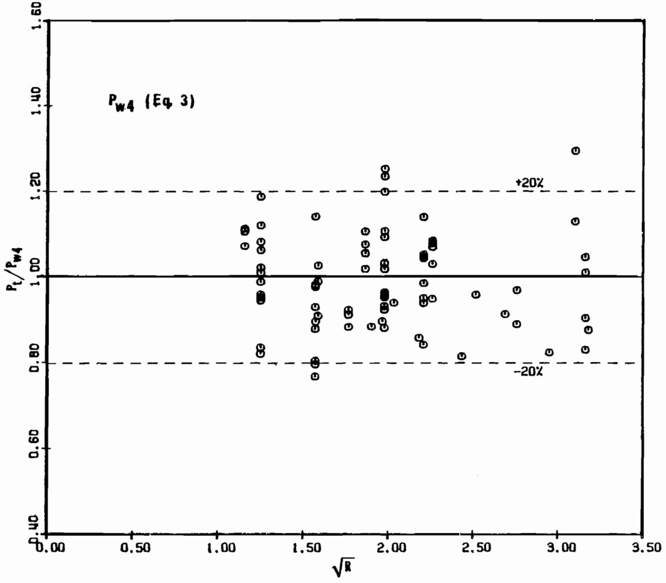


Fig. 10 - Load Ratio, P_t/P_{w_4}, Using Waterloo Method, Eq. 3 vs. Square Root of Inside Bend Radius Ratio, $\sqrt{R = r/t}$, for Interior Two Flange Tests

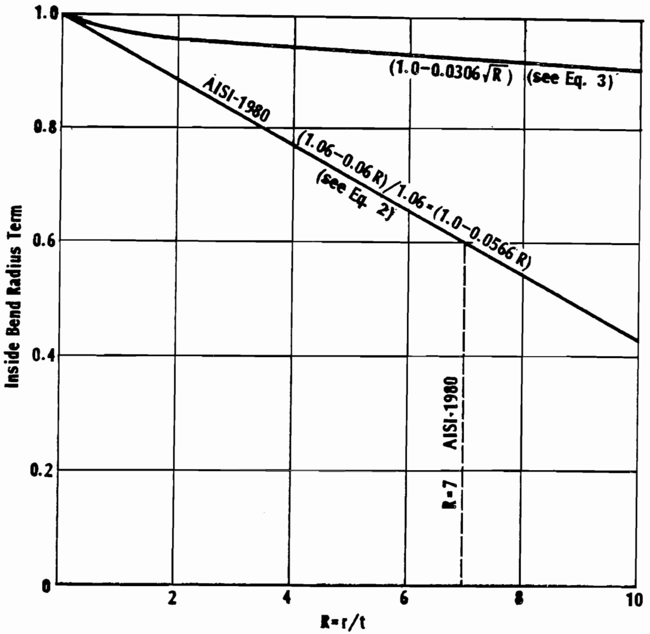


Fig. 11 - Inside Bend Radius Term vs. Inside Bend Radius Ratio, R = r/t, for Interior Two Flange Loading

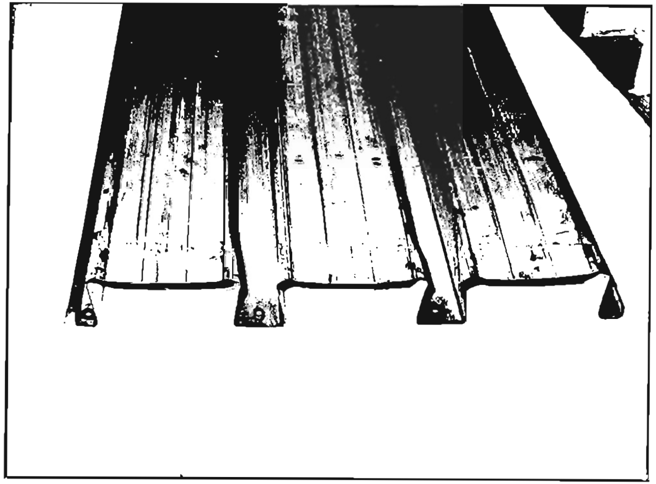


Fig. 12 - Photograph of Exterior Two Flange Test Specimen, Commercial Profile

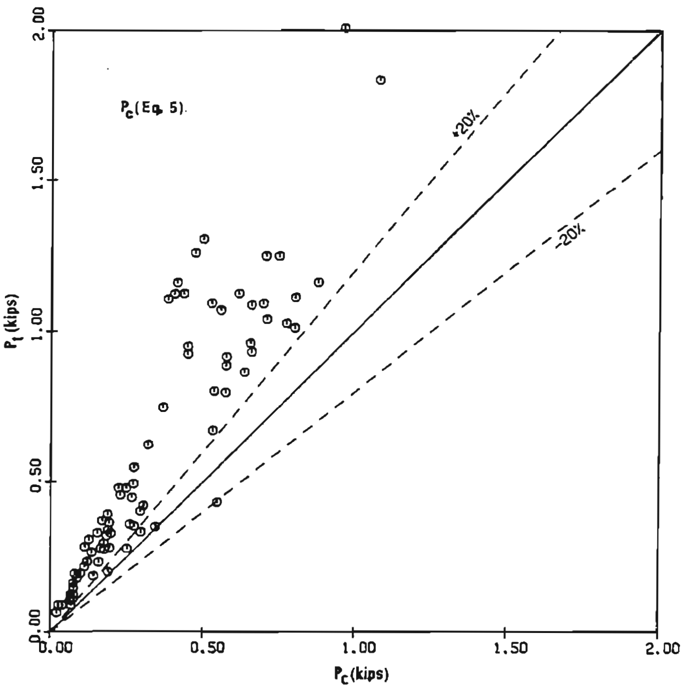


Fig. 13 - Test Load, P_t, vs. Computed Load, P_c, Using AISI-1980 Specification [2] for Exterior Two Flange Tests

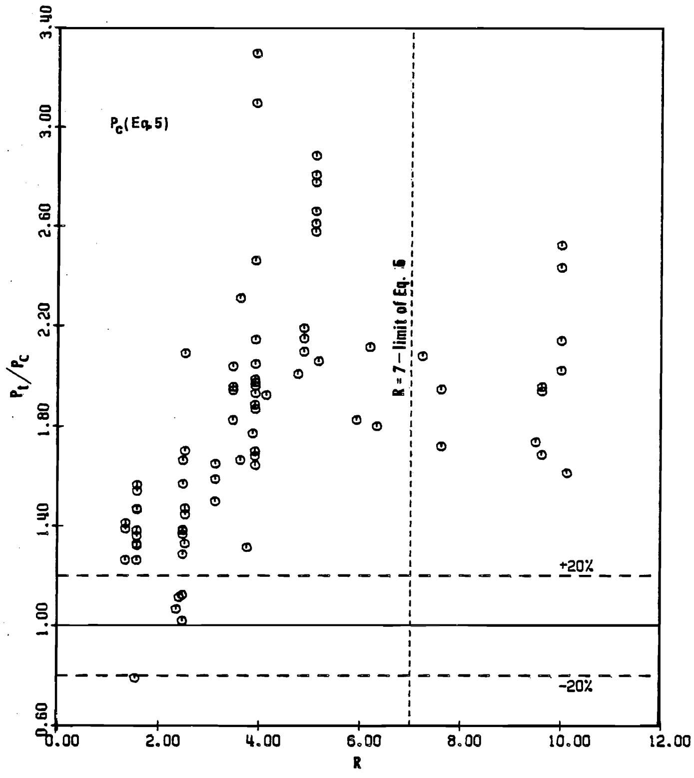


Fig. 14 - Load Ratio, P_t/P_c, Using AISI-Specification [2] vs. Inside Bend Radius Ratio, R = r/t for Exterior Two Flange Tests

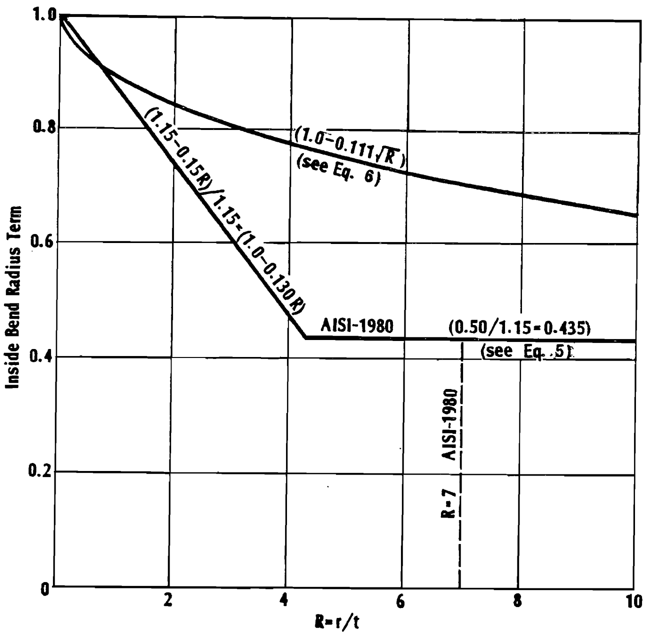


Fig. 15 - Inside Bend Radius Term vs. Inside Bend Radius Ratio, R = r/t, for Exterior Two Flange Loading

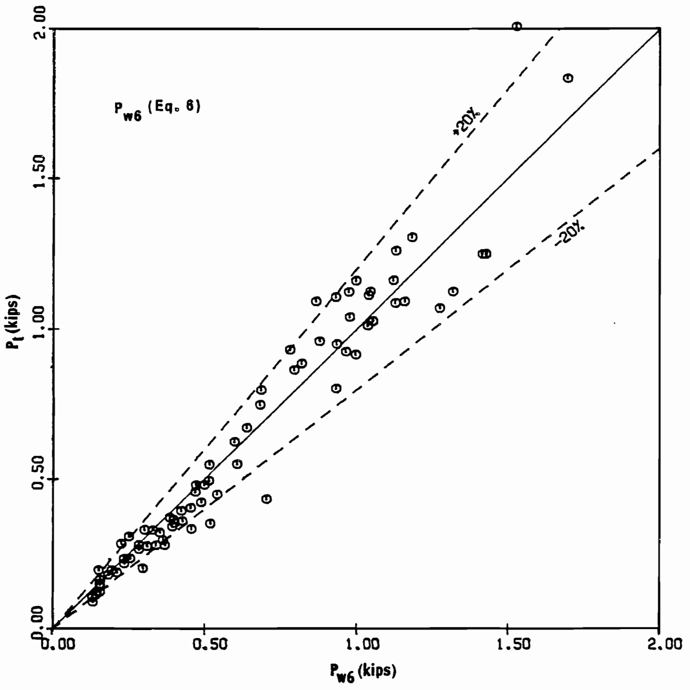


Fig. 16 - Test Load, P_t, vs. Computed Load, P_{w6} Using Waterloo Method, Eq. 6, for Exterior Two Flange Tests

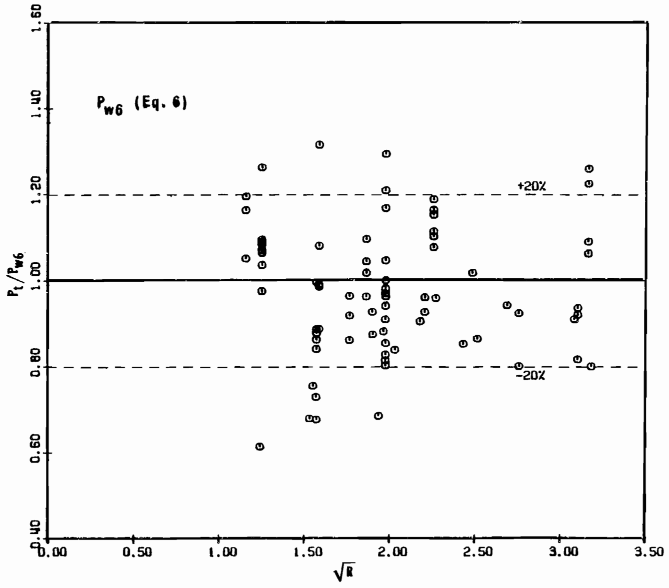


Fig. 17 - Load Ratio, P_t/P_{w6}, Using Waterloo Method, Eq. 6 vs. Square Root of Inside Bend Radius Ratio, $\sqrt{R} = r/t$, for Exterior Two Flange Tests