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Web Crippling of Cold Formed Steel C-and Z- Sections

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WEB CRIPPLING OF COLD FORMED STEEL C-and Z- SECTIONS

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ABSTRACT

An experimental investigation of cold formed steel stiffened C-and Z sections subjected to web crippling is presented in this paper. This study was devoted to two loading conditions according to the AISI Specification (1), namely End Two Flange (ETF) and Interior Two Flange (ITF) loading, with particular emphasis on large inside bend radius to thickness ratios, R, (up to 12) and the specimens being fastened to the support during testing. There is no experimental data available in the literature regarding the web crippling resistance of such members that are fastened to the support and have inside bend radius to thickness ratios greater than 2.7. A total of 72 tests were conducted on C-and Z sections at the University of Waterloo, Waterloo, Canada.

Although most of the parameters of the test specimens were beyond the limits specified by the current North American Cold Formed Steel Design Standards (AISI (1) and S136 (4)), the test results were compared to the calculated values of the AISI (1) and the S136 (4) web crippling design equations. This was done in an effort to determine the behavior of the current design equations for fastened to the support sections with large inside bend radius ratios. Using the same model of the web crippling design expression currently used in S136 (4), a nonlinear regression analysis was used to establish the new coefficients for the ETF and ITF loading conditions for both C and Z-sections. The new coefficients showed an excellent agreement with the test results. Furthermore, the S136 (4) design expression was calibrated for the safety requirements of both the S136-94) (4) Standard and the AISI (1) Specification.

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1- Introduction

Single web cold formed steel members are typically C-and Z sections that are fabricated from thin steel sheets through a series of bending/ forming operations. The thin sheet steel makes these sections prone to web buckling (or web crippling) when subjected to concentrated loads. The web crippling behavior of cold formed steel members is directly affected by the following factors:

1- Section geometry (I-section, C-section, Z-section, single hat section, multi-web section)
2- Section parameters (yield strength, web thickness, web height and inside bend radius)
3- Load conditions (end one flange (EOF), interior one flange (IOF), end two flanges (ETF), and interior two flanges (ITF)).
4- Bearing length (length over which the load is distributed).

Winter and Pian [11] first investigated the problem of web crippling of cold formed steel members in 1946 at Cornell University. They carried out over 100 tests on I-sections and single hat sections to develop expressions for computing the web crippling strength, considering the above four loading conditions. Since then, numerous experimental tests have been carried out relating to web crippling of cold formed steel sections.

2- Objective and Scope

The primary objective of this study was to check the validity of the current North American design expressions (AISI[1] and S136[4]) for predicting the ETF and ITF web crippling resistance of single web cold formed steel members fastened to the support and with large inside bend radius to thickness ratios, R, up to 12. An experimental investigation [2] was carried out at the University of Waterloo, where 72 stiffened C-and Z sections were tested as follows:

18 C-sections subjected to ETF	18 C-sections subjected to ITF
18 Z-sections subjected to ETF	18 Z-sections subjected to ITF

Comparisons were made between the test results and the calculated web crippling resistances, using the current North American design equations (AISI[1] and S136[4]). By conducting a nonlinear regression analysis, new web crippling coefficients were developed for each section type and load condition, using the same unified web crippling expression as specified in the current Canadian Standard, S136 [4]. Furthermore, the expression was calibrated for the safety requirements of both AISI [1] and S136 [4].

3- Current North American Web Crippling Provisions

The current web crippling design expressions for single web members in AISI [1] are mainly based on research up to 1978 (Heatrakul and Yu [6]). They are based on data of C-and single hat sections. The same design expressions apply to stiffened and unstiffened flanges of C- and Z-sections, as well as to single hat and multi-web sections. Furthermore, the data that was used was primarily based on specimens that were not fastened to the supports during testing, a situation that rarely exists in practice. It has been shown by Bhakta et al. [3] that there is an effect of flange restraint on the web crippling strength.

The current Canadian Standard, S136 [4] is based on available data up to 1993 (Prabakaran [8]), and is mainly based on data of specimens not fastened to the supports during testing (the same data as was used in AISI [1]). However, in the case of multi-web sections Wing's [10] data was used where the specimens were fastened to the support during testing. A unified web crippling expression with different web crippling coefficients for each section type and load case was introduced by the Canadian Standard, S136 [(4)] in 1994. The expression is totally non-dimensional and includes the major parameters that effect the web crippling resistance. In S136 [(4)], C-and Z-sections are considered as single web shapes and hat and deck sections as multi-web shapes.

4- Test Specimens

A preliminary study was carried out on eight specimens of C-sections fastened and unfastened to the supports and subjected to the ETF and ITF loading conditions. As well, the specimen lengths were also varied, i.e., 530 mm and 1210 mm in length. The results showed that the web crippling resistance is not only affected by whether or not the specimen is fastened to the support, but also by the length of the test specimen. This is especially the case for the ITF loading condition (see Table 1).

Based on the preliminary tests, an additional 72 specimens (36 C-sections and 36 Z-sections) were tested at the University of Waterloo for both loading conditions, ETF and ITF. The test program was designed to establish the effect that various parameters have on the web crippling strength and behavior. Two different grades of steel 323 MPa (46.8 ksi) and 448 MPa (65.0 ksi) were used in this study. All sections were stiffened flanges with inside bend radius to thickness ratios, $R = r/t$, ranging from 4.8 to 12.1 (the maximum R ratio used in pervious studies was 2.7). Since it was found in the preliminary study that the length of the test specimen affects the web crippling resistance, the length of the specimens was chosen to be approximately five times the depth of both C and Z-sections. Hetrakul et al. [(6)] used specimens with a length to depth ratio between two and three. Three different section depths were used in the test program, i.e., 120 mm (4.72 in.), 200 mm (7.87 in.) and 300 mm (11.81 in.). The steel thickness, t, was varied with the specimen depth and was between 1.16 mm (0.0457 in.) and 1.45 mm (0.057 in.). The bearing length, n, was also varied, using three different lengths, 30 mm (1.18 in.), 63.5 mm (2.5 in.) and 101 mm (3.98 in.). All specimens were fastened to the support bearing plates to simulate the actual situation found in practice and were duplicated to check the reproducibility of the test results.

5- Test Set-Up

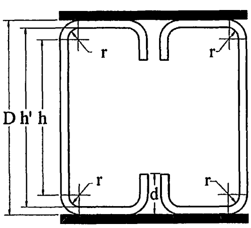
Since it is difficult to apply the load through the shear center of a single C-section and a single Z-section has an oblique axes condition, all test specimens were constructed of two equally sized sections facing each other in a box-type arrangement. This was done in effort to avoid any premature torsional buckling failure (see Figure 1). The box section was constructed of two identical sections (C or Z-sections) and six bearing plates (three at the top of the flanges and three at the bottom of the flanges). The bearing plates were bolted to the flanges, one at each end of the beam and one in the middle at both the top and the bottom flanges as shown in Figure 2. The end bearing plates were placed flush with the end of the specimen.

All test specimens were supported on rigid supports and were carefully positioned and aligned in the test frame prior to testing (see Figure 3). Since the length of the box specimen was approximately five times the depth of the section, two ETF tests were carried out from each box specimen, one at each end (see Figure 4a). The load was applied at one end until failure, which was then repeated at the other end of the specimen. No damage from the first end test was transferred to the other end. For the ITF loading condition, only one test was carried out for each box specimen by placing the specimen on a rigid support at mid span (see Figure 4b). For this loading condition, no other supports were provided at the ends to insure that only web

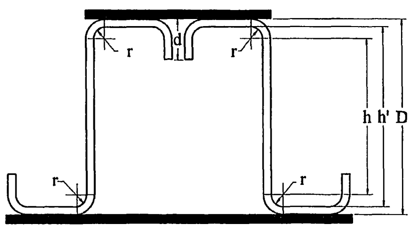
Table 1 - Test Results of Preliminary Study

No.	Specimen	t (mm)	F_y (MPa)	h' (mm)	h (mm)	r (mm)	n (mm)	Length (mm)	H h/t	R r/t	N n/t	P_t (kN)
1	C-L-F-ETF	1.2	300	198	194	1.8	101	1210	162	1.5	84.2	3.12
2	C-S-F-ETF	1.2	300	198	194	1.8	101	530	162	1.5	84.2	3.02
3	C-L-U-ETF	1.2	300	198	194	1.8	101	1210	162	1.5	84.2	2.18
4	C-S-U-ETF	1.2	300	198	194	1.8	101	530	162	1.5	84.2	2.22
5	C-L-F-ITF	1.2	300	198	194	1.8	101	1210	162	1.5	84.2	8.12
6	C-S-F-ITF	1.2	300	198	194	1.8	101	530	162	1.5	84.2	5.28
7	C-L-U-ITF	1.2	300	198	194	1.8	101	1210	162	1.5	84.2	6.71
8	C-S-U-ITF	1.2	300	198	194	1.8	101	530	162	1.5	84.2	3.98

- C = C-Section
- L = long specimen
- S = short specimen
- F = fastened to support
- U = unfastened to support
- ETF = end two flange loading
- ITF = interior two flange loading



C-Sections



Z-Sections

Figure 1 - Schematic of Typical Box Specimen Arrangement

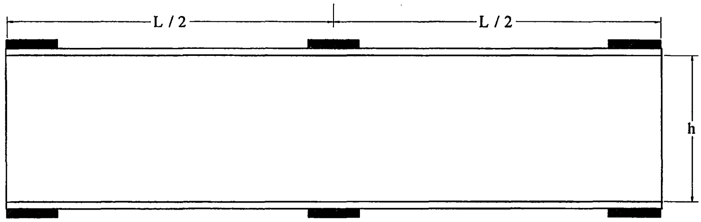


Figure 2 - Schematic of Bearing Plate Arrangement

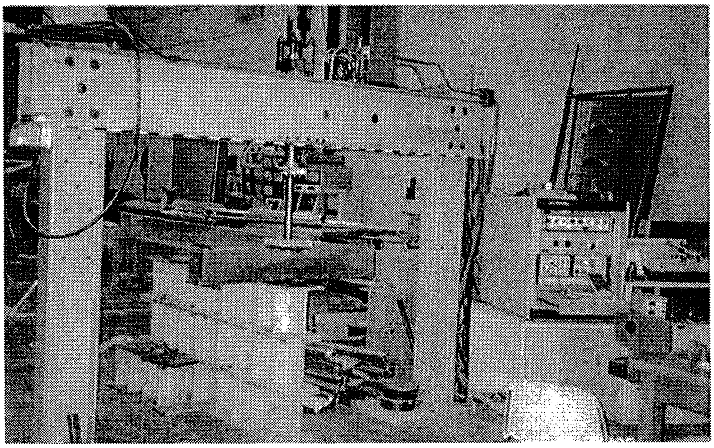
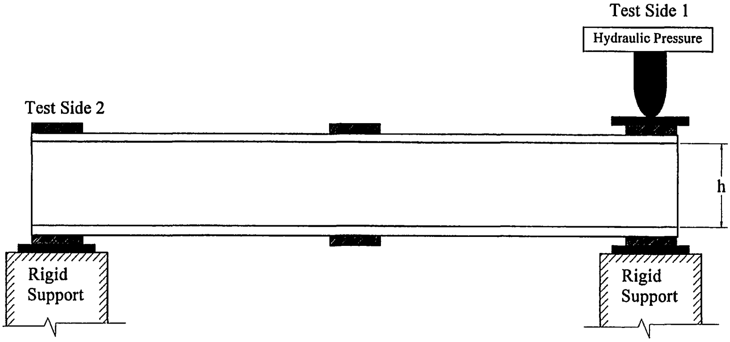


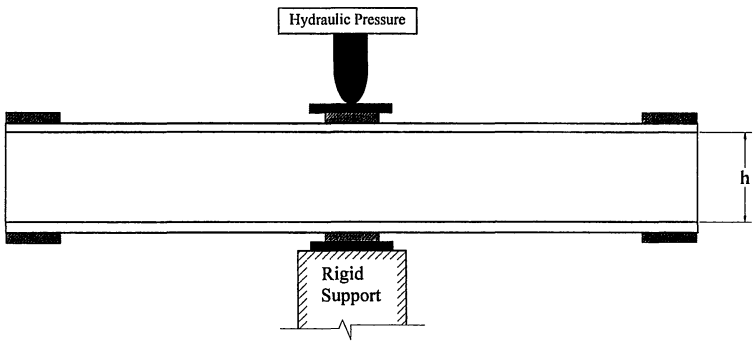
Figure 3 - Photograph of Test Frame

crippling failure occurred at mid span of the specimen. The length of specimen (approximately five times the depth of the section) was sufficient, such that the localized region of failure did not extend over the entire length of the specimen, which further proved that the test load was not a function of the length of the specimen.

The load was gradually applied by a stroke control hydraulic jack system. The speed of the hydraulic jack was constant throughout the test for all specimens at a rate of 1 mm/min to maintain consistency of loading among the test specimens.



(a) End Two Flange Loading Test, ETF (Two Tests per Specimen)



(b) Interior Two Flange Loading Test, ITF (One Test per Specimen)

Figure 4 - Schematic of Typical Test Set-up

6- Test Results

The test results are summarized in Tables 4 through 6. The failure load per web, P_t, was determined by dividing the total failure load by two. The web crippling failure of both C and Z-sections was due to a yield arc failure mechanism. This type of failure was also observed by Gerges [5], where the web deformation is a result of the formation of an arc (yield arc). The web moved out of plane and the line of maximum out-of-plane deformation took the shape of an arc. The large compressive in-plane load (larger than the elastic buckling capacity) caused the thin web plate to buckle out-of plane and initiated the failure. The length of the yield arc was approximately equal to the length of the bearing plate, n. It was also found that the deeper sections experienced larger out-of-plan deformations in comparison to the shallow sections (see Figures 5 to 8).

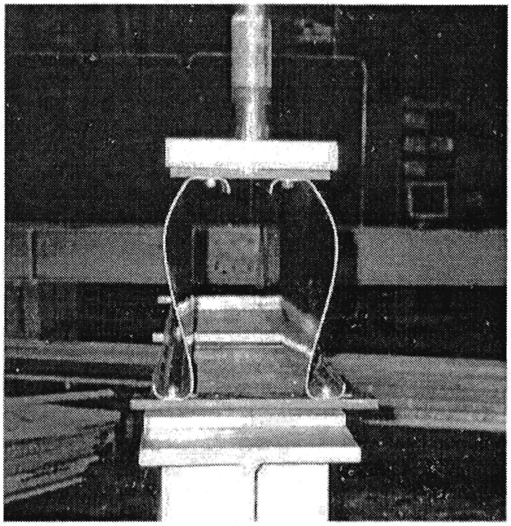


Figure 5 - End Two Flange Loading, ETF of Z-Sections

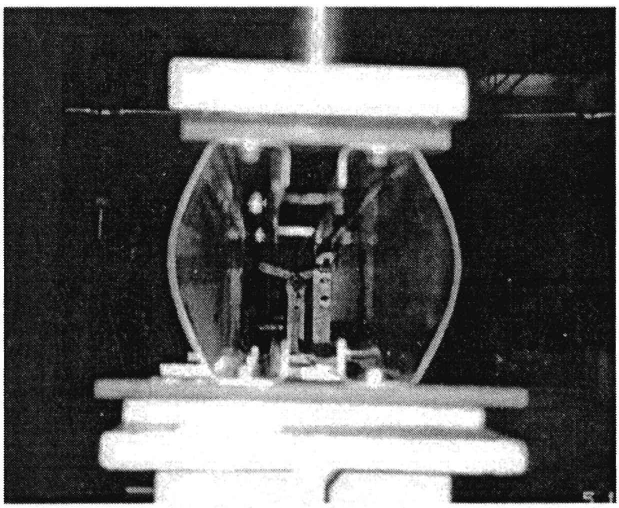


Figure 6 - End Two Flange Loading, ETF of C-Sections

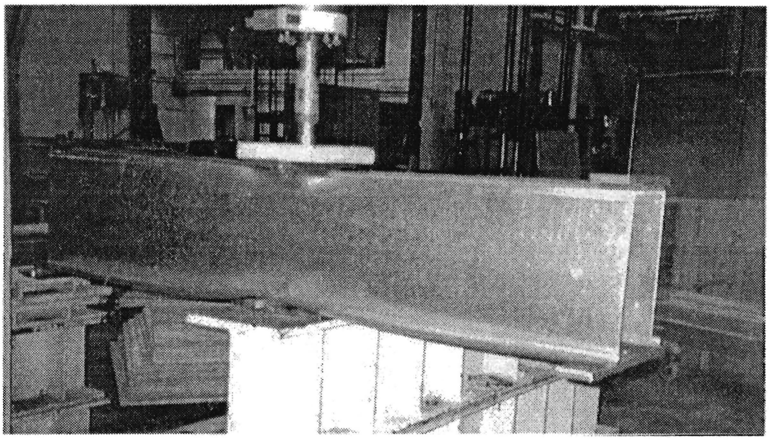


Figure 7 - Interior Two Flange Loading, ITF of Z-Sections

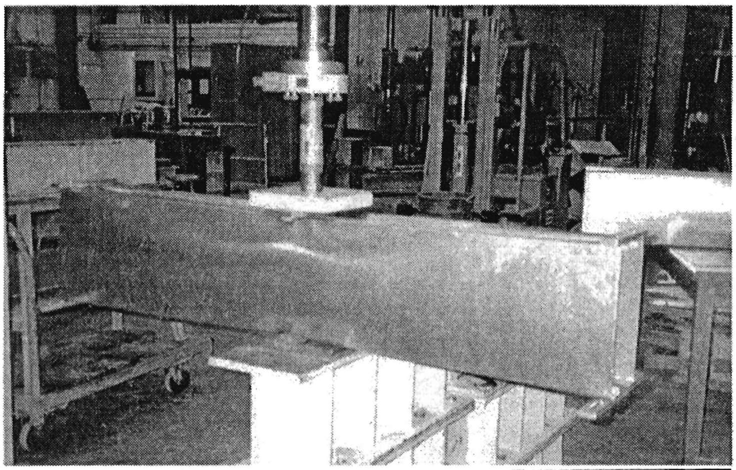


Figure 8 - Interior Two Flange Loading, ITF of C-Sections

The test results showed that Z-sections could carry a larger load than did the C-sections, by approximately 20 % for ETF and by about 10 to 20 % for ITF of the same section properties. Furthermore, the preliminary study showed that the long specimens (more than five times the section depth) experienced a larger failure load than the short specimens (two and half times the section depth), i.e., by more than 50 % for ITF and by about 5% for ETF. This can be explained by hypothesizing that better load distribution can be obtained under the load due to the extra material for the long specimens than the short specimens.

7- Evaluation of Current Design Expressions

Although most of the parameters of the test specimens were beyond the limits specified by the current North American Cold Formed Steel Design Standards (AISI [1] and S136 [4]), the test results were compared to the calculated values of the AISI [1] and the S136 [4] web crippling design equations. This was done in an effort to determine the behavior of the design equations for sections with large inside bend radius ratios and fastened to the support. The web crippling loads per web obtained from the tests were compared with the current web crippling design expressions (AISI-96 [1] and S136-94 [4]) of cold formed steel members subjected to end two flange loading, ETF, and interior two flange loading, ITF.

7.1- AISI-96 Expressions [1]

Since the web crippling expressions contained in AISI-96 [1] were based on specimens not fastened to the support (unfastened) (Winter, Pian [11], Heatrakul and Yu [6]) with inside bend radius to thickness ratios, $R \leq 6$, the AISI-96 [1] expression underestimate the web crippling resistance for the ETF load condition by about 67% for C-sections and by more than 100% for Z-sections. Furthermore, because the length of specimens of this study (longer specimens were tested than did Hetrakul and Yu [6]), the expression for the ITF loading condition underestimates the web crippling resistance by more than 100% for both C-and Z-sections. Tables 4 to 7 show the failure test values in comparison to the calculated values, P_t/P_c, according to the AISI-96 [1] expressions. Charts 1 to 4 show the relationship between P_t/P_c and the number of tested specimens.

7.2- S136-94 Expression [4]

In S136 [4] only one web crippling design expression exists with different coefficients for each section and loading condition. For shapes having single webs, the coefficients for the ETF and ITF loading conditions were mainly based on C-section data from specimens not fastened to the support during testing (unfastened) (Hetrakul and Yu [6]) with inside bend radius to thickness ratios, $R \leq 4$. Since the inside bend radius to thickness ratio for the tested specimens, $R > 4$, the expression for the ETF loading condition results in negative values in some cases and in other cases the web crippling resistance is underestimated for both C-and Z-sections. Furthermore, because the length of specimens of this study (longer specimens were tested than did Hetrakul and Yu [6]), the expression for the ITF loading condition underestimates the web crippling resistance by more than 90% for both C-and Z-sections. Tables 4 to 7 show the failure test values in comparison to the calculated values, P_t/P_c, according to the S136-94 [4] expressions. Charts 1 to 4 show the relationship between P_t/P_c and the number of tested specimens.

Based on the above discussion, the current North American design expressions for web crippling of single web sections subjected to ETF and ITF loading are not valid for sections fastened to the supports with large inside bend radius to thickness ratio ($R > 4$ for S136-94 [4] and $R > 6$ for AISI-96 [1]). Also, the expressions are not valid for sections having lengths greater than five times the depth (for ITF loading condition). The comparisons between tested and calculated web crippling values indicates that new design expressions are needed.

8- Design Formulation

As stated before, there are five major parameters that govern the web crippling resistance of cold formed steel members (Prabakaran 1993 [8], Hetrakul and Yu [6]), and they are: thickness of the web element, t, yield strength of steel, F_y, the web slenderness ratio, $H = h/t$, the inside bend radius ratio, $R = r/t$ and the bearing plate length to thickness ratio, $N = n/t$. Prabakaran and Schuster [8] introduced the following unified expression currently used in the Canadian Standard (S136-94) [4], which includes the above-mentioned parameters:

$$P_n = Ct^2 F_y \sin\theta \; (1 - C_R\sqrt{R}) \; (1 + C_N\sqrt{N}) \; (1 - C_H\sqrt{H}) \qquad \text{Eq. (1)}$$

Where P_n is the nominal calculated web crippling resistance, C, C_R, C_N and C_H are coefficients that depend on the section type and load condition. These coefficients can be determined by using test data in a regression analysis. Each term within the brackets of Eq. (1) can be thought of as a correction factor, i.e. the first term is the inside bend radius correction factor, the second term is the bearing width correction factor and the third term is the web slenderness correction factor. Similarly, the term $\sin\theta$ is the web inclination correction factor. Since the web crippling resistance increases with an increase in the bearing width ratio, N, a plus sign is used in the bearing plate correction factor. On the other hand, the web crippling resistance decreases with an increase in inside bend radius ratio, R, and web slenderness ratio, H; hence, minus signs are used in both cases for their correction factors. Equation (1) was used as a design model in the development of the new coefficients for C-and Z-sections for the ETF and ITF load conditions. It should be noted, Eq. (1) is totally non-dimensional and can be used with any consistent units of measurements.

9- Development of New Coefficients

Non-linear regression analysis procedures were performed using the Canadian Standard (S136-94)(4) expression as a model (Eq. (1)), in order to estimate the values of the new web crippling coefficients. The non-linear procedures were mainly based on the minimum of squared errors, SEE. Since there were no data in the literature for fastened C-or Z-sections subjected to the ETF or ITF loading condition, only the test results of this study were used in the regression analysis. The test results showed that the web crippling resistance of C-sections differ from Z-sections for each loading condition. Therefore, new different coefficients were developed for each individual section and loading condition. The regression analysis resulted in the coefficients and statistical parameters as summarized in Table 2.

Table 2 – Web Crippling Coefficients and Statistical Parameters

Section	Load Condition	C	C_R	C_N	C_H	Statistical Parameters for P_t/P_c				
						Mean	S.D.	C.O.V	Min.	Max.
C-section	ETF	7.5	0.08	0.12	0.048	1.03	0.12	0.12	0.88	1.21
	ITF	20	0.10	0.08	0.031	1.01	0.13	0.13	0.85	1.26
Z-section	ETF	9.0	0.05	0.16	0.052	1.00	0.12	0.12	0.86	1.23
	ITF	24	0.07	0.07	0.040	1.03	0.18	0.18	0.81	1.35

Note: The above coefficients apply when $H \leq 200$, $N \leq 210$, $n/h \leq 1.0$, $R \leq 12$ and $\theta = 90°$.

A comparison between the tested and the predicted failure loads, using the new coefficients indicates excellent agreement. Tables 4 to 7 show the failure test values in comparison to the calculated values, P_t/P_c, using the new coefficients. Charts 1 to 4 show the relationship between P_t/P_c and the number of test specimens used.

10- Calibration of the New Coefficients

Safety factors or load factors are provided against the uncertainties and variabilities which are inherent in the design process. The calibration results depend on the reliability index value, β, the dead load to the live load ratio, dead, and live load factors. The reliability index value, β, for a given structural material depends on two characteristics, i.e., the first is the load action type (e.g.

wind load, gravity load,...) and the second is the resistance type (e.g. web crippling, bending, shear,...). When two designs are compared, the one with the larger β is more reliable. Procedures for calculating both the resistance factor, ϕ, for the Load and Resistance Factored Design method, LRFD, and the factor of safety, Ω, for the Allowable Stress Design method, ASD, are well described by Hsiao [7], Supornsilaphachai [9] and Gerges [5].

For the AISI Specification [1], the ratio between dead and live load is D/L = 1/5 and the load factors for dead and live load are α_D = 1.20, and α_L = 1.60, respectively. The following two equations give the values of Ω and ϕ for any β value.

$$\Omega = \frac{e^{\beta\sqrt{0.0554+V_P^2}}}{(1.091P_m)}, \qquad \phi = \frac{1.673P_m}{e^{\beta\sqrt{0.0553+V_P^2}}} \qquad \text{Eq. (2,3)}$$

For the S136 Standard [4], the ratio between dead and live load is D/L = 1/3 and the load factors for dead and live load are α_D = 1.25, and α_L = 1.50, respectively. The following equation gives the value of ϕ for any β value.

$$\phi = \frac{1.562P_m}{e^{\beta\sqrt{0.0475+V_P^2}}} \qquad \text{Eq. (4)}$$

Where P_m and V_P are the mean value and the coefficient of variation of the prediction of the ultimate resistance, respectively. The recommended value for β is 2.5 for AISI-96 [1] and 3.0 for S136-94 [4]. By substituting the values of P_m, V_P and β into the above equations, the factor of safety and the resistance factor for each section and loading condition is obtained, as summarized in Table 3.

Table 3 – Factors of Safety and Resistance Factors

Section	Load Condition	AISI-96 [1]		S136-94 [4]
		Ω	ϕ	ϕ
C-section	ETF	1.71	0.89	0.77
	ITF	1.77	0.86	0.74
Z-section	ETF	1.76	0.86	0.74
	ITF	1.86	0.82	0.69

11- Conclusions

Presented in this paper are the results of an experimental study of the behavior of cold formed steel single web C-and Z-sections subjected to end two-flange loading, ETF, and interior two-flange loading, ITF. The main objective of this study was to investigate the conservative and unconservative aspects of the North American design expressions for predicting the web crippling resistance of single web cold formed steel members. Special consideration was given to whether or not the test specimens were fastened to the support during testing. As well, the inside bend radius to thickness ratio, R, was extended up to 12 and the specimen length was more than five times the depth of the section. The test program included 72 tests and was designed to determine the various parameters influencing the web crippling resistance (t, F_y, h, r, and n). Test specimens were made of two equal sized C-or Z-sections placed facing each other in a box beam arrangement. All specimens were fastened to the support bearing plates with bolts.

Based on the test results, the present design expressions, AISI-96 [1] and S136-94 [4] were found to underestimate the web crippling resistance for both C-and Z-sections. For some of the specimens tested, the degree of the underestimation was more than 100% and in other cases, unaccepted estimations were obtained (negative values). Since the current North American web crippling design expressions are being evaluated, new web crippling coefficients were developed to be considered for adoption by both the AISI Specification and the Canadian Standard for each section and load condition.

Finally, the proposed new web crippling coefficients were used in the calibration of the safety requirement in accordance with both the American Specification and the Canadian Standard.

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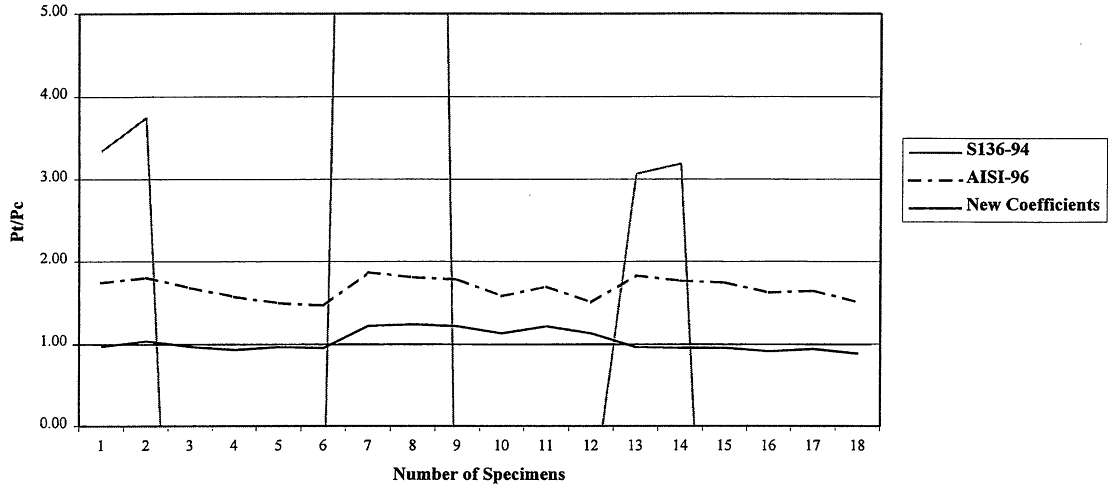
Table 4
Single Web C-Sections (Stiffened Flanges)
End Two Flange Loading (ETF) - Fastened to Support
Beshara - University of Waterloo, Canada – 1999 (2)

No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	Pt (kN)	S136-94 Pc (kN)	S136-94 Pt/Pc (ratio)	AISI-96 Pc (kN)	AISI-96 Pt/Pc (ratio)	New Coefficients Pc (kN)	New Coefficients Pt/Pc (ratio)
1	C-120-7-30-ETF	1.45	332	81.4	71.8	4.83	20.7	3.84	1.15	3.34	2.20	1.74	3.96	0.97
2	C-120-7-60-ETF	1.45	332	81.4	71.8	4.83	43.8	4.74	1.27	3.74	2.62	1.81	4.59	1.03
3	C-120-10-30-ETF	1.45	332	80.8	67.0	6.90	20.7	3.75	-0.49	-7.68	2.23	1.68	3.88	0.97
4	C-120-10-60-ETF	1.45	332	80.8	67.0	6.90	43.8	4.17	-0.54	-7.75	2.66	1.57	4.50	0.93
5	C-120-14-100-ETF A	1.45	332	79.4	60.1	9.66	69.7	4.77	-2.88	-1.66	3.20	1.49	4.94	0.97
6	C-120-14-100-ETF B	1.45	332	79.4	60.1	9.66	69.7	4.68	-2.88	-1.63	3.20	1.46	4.94	0.95
7	C-200-7-30-ETF	1.16	328	170	158	6.03	25.9	2.07	0.08	27.6	1.11	1.87	1.70	1.22
8	C-200-7-60-ETF	1.16	328	170	158	6.03	54.7	2.46	0.08	29.5	1.36	1.81	1.99	1.24
9	C-200-10-30-ETF	1.16	328	170	153	8.62	25.9	2.01	-0.77	-2.62	1.13	1.78	1.66	1.21
10	C-200-10-60-ETF	1.16	328	170	153	8.62	54.7	2.19	-0.85	-2.56	1.39	1.58	1.94	1.13
11	C-200-14-30-ETF	1.16	328	171	147	12.1	25.9	1.95	-1.76	-1.11	1.15	1.69	1.61	1.21
12	C-200-14-60-ETF	1.16	328	171	147	12.1	54.7	2.13	-1.96	-1.09	1.42	1.50	1.88	1.13
13	C-300-7-30-ETF	1.45	448	205	195	4.83	20.7	2.85	0.93	3.07	1.56	1.83	2.96	0.96
14	C-300-7-60-ETF	1.45	448	205	195	4.83	43.8	3.27	1.03	3.19	1.85	1.76	3.44	0.95
15	C-300-10-30-ETF	1.45	448	205	191	6.90	20.7	2.76	-0.39	-7.00	1.58	1.74	2.90	0.95
16	C-300-10-60-ETF	1.45	448	205	191	6.90	43.8	3.06	-0.43	-7.04	1.89	1.62	3.37	0.91
17	C-300-14-30-ETF	1.45	448	204	185	9.66	20.7	2.67	-1.95	-1.37	1.63	1.64	2.85	0.94
18	C-300-14-60-ETF	1.45	448	204	185	9.66	43.8	2.91	-2.15	-1.35	1.94	1.50	3.31	0.88
							Pt/Pc Mean value			1.53		1.67		1.03
							S.D.			10.2		0.13		0.12
							C.O.V.			6.66		0.08		0.12

Chart 1

Pt/Pc for Single Web C-Sections (Stiffened Flanges)
End Two Flange Loading (ETF) - Fastened to Support



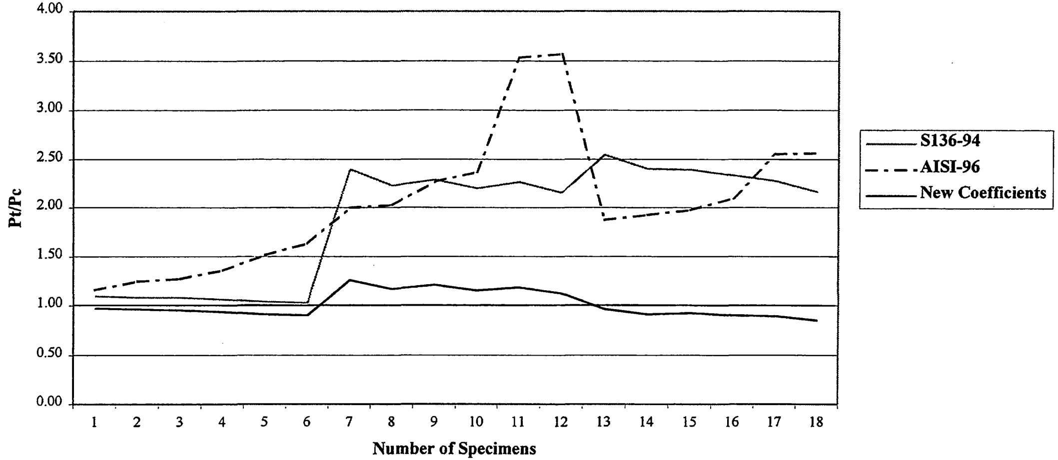
S136-94			AISI-96			New Coefficients		
Pt/Pc mean	=	1.53	Pt/Pc mean	=	1.67	Pt/Pc mean	=	1.03
S.D.	=	10.2	S.D.	=	0.13	S.D.	=	0.12
C.O.V.	=	6.66	C.O.V.	=	0.08	C.O.V.	=	0.12

Table 5
Single Web C-Sections (Stiffened Flanges)
Interior Two Flange Loading (ITF) - Fastened to Support
Beshara - University of Waterloo, Canada – 1999 (2)

No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	Pt (kN)	S136-94 Pc (kN)	S136-94 Pt/Pc (ratio)	AISI-96 Pc (kN)	AISI-96 Pt/Pc (ratio)	New Coefficients Pc (kN)	New Coefficients Pt/Pc (ratio)
1	C-120-7-30-ITF	1.45	332	81.4	71.8	4.83	20.7	10.7	9.71	1.10	9.17	1.16	11.0	0.97
2	C-120-7-60-ITF	1.45	332	81.4	71.8	4.83	43.8	11.8	10.9	1.08	9.45	1.25	12.3	0.96
3	C-120-10-30-ITF	1.45	332	81.4	67.7	6.90	20.7	9.96	9.18	1.09	7.82	1.27	10.5	0.95
4	C-120-10-60-ITF	1.45	332	81.4	67.7	6.90	43.8	11.0	10.3	1.06	8.05	1.36	11.7	0.93
5	C-120-14-30-ITF	1.45	332	79.4	60.1	9.66	20.7	9.06	8.72	1.04	5.98	1.52	9.97	0.91
6	C-120-14-60-ITF	1.45	332	79.4	60.1	9.66	43.8	10.1	9.78	1.03	6.15	1.63	11.2	0.90
7	C-200-7-30-ITF	1.16	328	170	158	6.03	25.9	7.20	3.00	2.40	3.61	2.00	5.71	1.26
8	C-200-7-60-ITF	1.16	328	170	158	6.03	54.7	7.56	3.39	2.23	3.74	2.02	6.47	1.17
9	C-200-10-30-ITF	1.16	328	170	152	8.62	25.9	6.57	2.87	2.29	2.90	2.27	5.42	1.21
10	C-200-10-60-ITF	1.16	328	170	153	8.62	54.7	7.08	3.22	2.20	2.99	2.37	6.12	1.16
11	C-200-14-60-ITF	1.16	328	171	147	12.1	51.7	6.72	2.96	2.27	1.90	3.53	5.66	1.19
12	C-200-14-100-ITF	1.16	328	171	147	12.1	87.1	7.08	3.29	2.15	1.98	3.57	6.28	1.13
13	C-300-7-30-ITF	1.45	448	205	195	4.83	20.7	11.0	4.31	2.55	5.87	1.87	11.4	0.97
14	C-300-7-60-ITF	1.45	448	205	195	4.83	43.8	11.6	4.83	2.40	6.04	1.92	12.7	0.91
15	C-300-10-30-ITF	1.45	448	205	191	6.90	20.7	9.99	4.17	2.39	5.06	1.97	10.8	0.92
16	C-300-10-60-ITF	1.45	448	205	191	6.90	43.8	10.9	4.68	2.33	5.21	2.10	12.1	0.90
17	C-300-14-60-ITF	1.45	448	205	186	9.66	43.8	10.3	4.51	2.28	4.02	2.55	11.5	0.89
18	C-300-14-100-ITF	1.45	448	205	186	9.66	69.7	10.6	4.91	2.16	4.15	2.56	12.5	0.85
							Pt/Pc Mean value			1.89		2.05		1.01
							S.D.			0.59		0.68		0.13
							C.O.V.			0.31		0.33		0.13

Chart 2

**Pt/Pc for Single Web C-Sections (Stiffened Flanges)
Interior Two Flange Loading (ITF) - Fastened to Support**



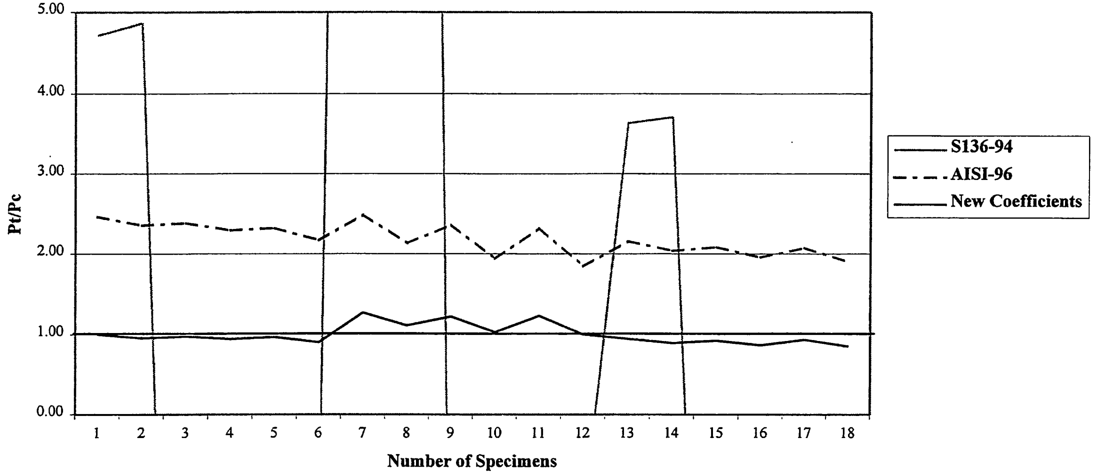
S136-94			AISI-96			New Coefficients		
Pt/Pc mean	=	1.89	Pt/Pc mean	=	2.05	Pt/Pc mean	=	1.01
S.D.	=	0.59	S.D.	=	0.68	S.D.	=	0.13
C.O.V.	=	0.31	C.O.V.	=	0.33	C.O.V.	=	0.13

Table 6
Single Web Z-Sections (Stiffened Flanges)
End Two Flange Loading (ETF) - Fastened to Support
Beshara - University of Waterloo, Canada – 1999 (2)

No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	Pt (kN)	S136-94 Pc (kN)	S136-94 Pt/Pc (ratio)	AISI-96 Pc (kN)	AISI-96 Pt/Pc (ratio)	New Coefficients Pc (kN)	New Coefficients Pt/Pc (ratio)
1	Z-120-7-30-ETF	1.45	332	80.8	71.1	4.83	20.7	5.43	1.15	4.72	2.21	2.46	5.42	1.00
2	Z-120-7-60-ETF	1.45	332	80.8	71.1	4.83	43.8	6.18	1.27	4.87	2.63	2.35	6.46	0.96
3	Z-120-10-30-ETF	1.45	332	80.8	67.0	6.90	20.7	5.31	-0.49	-10.9	2.23	2.38	5.42	0.98
4	Z-120-10-60-ETF	1.45	332	80.8	67.0	6.90	43.8	6.09	-0.54	-11.3	2.66	2.29	6.45	0.94
5	Z-120-14-30-ETF	1.45	332	80.8	61.4	9.66	20.7	5.25	-2.41	-2.18	2.27	2.32	5.43	0.97
6	Z-120-14-60-ETF	1.45	332	80.8	61.4	9.66	43.8	5.85	-2.66	-2.20	2.70	2.17	6.47	0.90
7	Z-200-7-30-ETF	1.16	323	170	158	6.03	25.9	2.73	0.07	37.0	1.10	2.48	2.15	1.27
8	Z-200-7-60-ETF	1.16	323	170	158	6.03	54.7	2.88	0.08	35.1	1.35	2.13	2.59	1.11
9	Z-200-10-30-ETF	1.16	323	170	153	8.62	25.9	2.64	-0.76	-3.49	1.12	2.36	2.16	1.22
10	Z-200-10-60-ETF	1.16	323	170	153	8.62	54.7	2.67	-0.84	-3.17	1.38	1.94	2.60	1.03
11	Z-200-14-30-ETF	1.16	323	173	149	12.1	25.9	2.64	-1.72	-1.53	1.14	2.32	2.14	1.23
12	Z-200-14-60-ETF	1.16	323	173	149	12.1	54.7	2.58	-1.91	-1.35	1.40	1.84	2.58	1.00
13	Z-300-7-30-ETF	1.45	446	205	195	4.83	20.7	3.36	0.93	3.63	1.56	2.16	3.55	0.95
14	Z-300-7-60-ETF	1.45	446	205	195	4.83	43.8	3.78	1.02	3.70	1.85	2.04	4.23	0.89
15	Z-300-10-30-ETF	1.45	446	205	191	6.90	20.7	3.30	-0.39	-8.41	1.58	2.08	3.56	0.93
16	Z-300-10-60-ETF	1.45	446	205	191	6.90	43.8	3.69	-0.43	-8.53	1.89	1.96	4.24	0.87
17	Z-300-14-30-ETF	1.45	446	205	186	9.66	20.7	3.36	-1.93	-1.74	1.62	2.07	3.59	0.94
18	Z-300-14-60-ETF	1.45	446	205	186	9.66	43.8	3.66	-2.13	-1.72	1.93	1.90	4.28	0.86
							Pt/Pc Mean value			1.80		2.18		1.00
							S.D.			13.0		0.19		0.12
							C.O.V.			7.21		0.09		0.12

Chart 3

Pt/Pc for Single Web Z-Sections (Stiffened Flanges)
End Two Flange Loading (ETF) - Fastened to Support



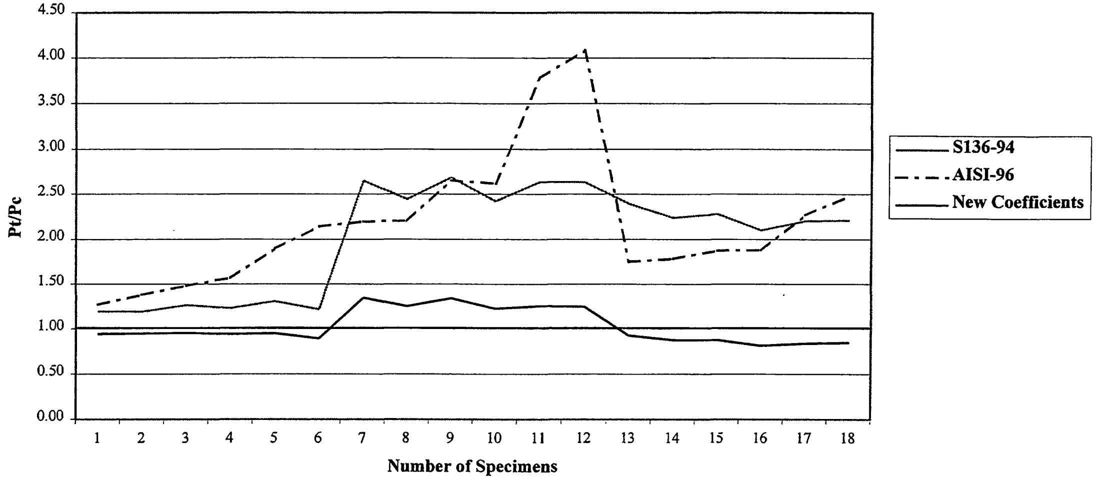
S136-94		AISI-96		New Coefficients	
Pt/Pc mean =	1.80	Pt/Pc mean =	2.18	Pt/Pc mean =	1.00
S.D. =	13.0	S.D. =	0.19	S.D. =	0.12
C.O.V. =	7.21	C.O.V. =	0.09	C.O.V. =	0.12

Table 7
Single Web Z-Sections (Stiffened Flanges)
Interior Two Flange Loading (ITF) - Fastened to Support
Beshara - University of Waterloo, Canada – 1999 (2)

No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	Pt (kN)	S136-94 Pc (kN)	S136-94 Pt/Pc (ratio)	AISI-96 Pc (kN)	AISI-96 Pt/Pc (ratio)	New Coefficients Pc (kN)	New Coefficients Pt/Pc (ratio)
1	Z-120-7-30-ITF	1.45	332	80.8	71.1	4.83	20.7	11.7	9.76	1.20	9.20	1.27	12.4	0.94
2	Z-120-7-60-ITF	1.45	332	80.8	71.1	4.83	43.8	13.1	10.9	1.19	9.47	1.38	13.8	0.95
3	Z-120-10-30-ITF	1.45	332	82.1	68.3	6.90	20.7	11.6	9.14	1.26	7.79	1.48	12.1	0.96
4	Z-120-10-60-ITF	1.45	332	82.8	69.0	6.90	43.8	12.6	10.2	1.23	8.00	1.57	13.4	0.94
5	Z-120-14-30-ITF	1.45	332	80.8	61.4	9.66	20.7	11.3	8.64	1.31	5.95	1.90	11.9	0.95
6	Z-120-14-60-ITF	1.45	426	80.8	61.4	9.66	43.8	15.1	12.4	1.22	7.06	2.14	16.9	0.90
7	Z-200-7-30-ITF	1.16	323	170	158	6.03	25.9	7.83	2.95	2.65	3.57	2.19	5.82	1.35
8	Z-200-7-60-ITF	1.16	323	170	158	6.03	54.7	8.16	3.34	2.44	3.70	2.21	6.51	1.25
9	Z-200-10-30-ITF	1.16	323	169	151	8.62	25.9	7.65	2.85	2.69	2.88	2.66	5.70	1.34
10	Z-200-10-60-ITF	1.16	323	168	151	8.62	54.7	7.86	3.25	2.42	3.00	2.62	6.41	1.23
11	Z-200-14-30-ITF	1.16	323	170	146	12.1	25.9	6.93	2.63	2.64	1.83	3.78	5.53	1.25
12	Z-200-14-60-ITF	1.16	323	173	149	12.1	54.7	7.65	2.90	2.63	1.87	4.09	6.13	1.25
13	Z-300-7-30-ITF	1.45	446	205	195	4.83	20.7	10.3	4.29	2.39	5.86	1.75	11.1	0.93
14	Z-300-7-60-ITF	1.45	446	205	195	4.83	43.8	10.8	4.81	2.24	6.03	1.79	12.3	0.88
15	Z-300-10-30-ITF	1.45	446	205	191	6.90	20.7	9.48	4.15	2.28	5.05	1.88	10.8	0.88
16	Z-300-10-60-ITF	1.45	446	205	191	6.90	43.8	9.78	4.66	2.10	5.20	1.88	12.0	0.81
17	Z-300-14-30-ITF	1.45	446	204	185	9.66	20.7	8.88	4.03	2.20	3.91	2.27	10.6	0.84
18	Z-300-14-60-ITF	1.45	446	204	185	9.66	43.8	9.99	4.52	2.21	4.03	2.48	11.8	0.85
							Pt/Pc Mean value			2.02		2.19		1.03
							S.D.			0.58		0.73		0.18
							C.O.V.			0.29		0.34		0.18

Chart 4

Pt/Pc for Single Web Z-Sections (Stiffened Flanges)
Interior Two Flange Loading (ITF) - Fastened to Support



S136-94		AISI-96		New Coefficients	
Pt/Pc mean =	2.02	Pt/Pc mean =	2.19	Pt/Pc mean =	1.03
S.D. =	0.58	S.D. =	0.73	S.D. =	0.18
C.O.V. =	0.29	C.O.V. =	0.34	C.O.V. =	0.18