research report

Web Crippling Data and Calibrations of Cold Formed Steel Members

RESEARCH REPORT RP00-2

OCTOBER 2000
REVISION 2006

Committee on Specifications
for the Design of Cold-Formed
Steel Structural Members

American Iron and Steel Institute

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WEB CRIPPLING DATA AND CALIBRATIONS OF COLD FORMED STEEL MEMBERS

FINAL REPORT

A Project Partially Sponsored by the

American Iron and Steel Institute
1101 17th Street, NW
Washington, DC 20036-4700

By

Baher Beshara
Research Assistant

Professor R. M. Schuster
Project Director

Canadian Cold Formed Steel Research Group
Department of Civil Engineering
University of Waterloo
Waterloo, Ontario, Canada

October 2000

REFACE

This research report is based on a thesis by Mr. Baher Beshara, presented to the Graduate School of the Faculty of Engineering of the University of Waterloo in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

Attached at the end of this research report are the test results of a number of two-flange loading cases where self-drilling screws were used instead of bolts to fasten the bearing plates to the web crippling test specimens. This was done in effort to establish the web crippling integrity of screw-fastened specimens in comparison to the common bolt-fastened specimens. Also attached at the end of this report is a small report of the "Cold Formed Steel Web Crippling Data" project

ACKNOWLEDGEMENTS

The authors wish to thank the American Iron and Steel Institute for their financial contribution in support of the "Cold Formed Steel Web Crippling Data" project. We wish to also thank Mr. Kenneth M. de Souza of Dofasco Inc. for having supplied the steel for the test specimens and Bridgeport Steel Inc. of Kitchener for having fabricating the test specimens..

A great big thank you goes to Professor Roger LaBoube for his valuable guidance, encouragement and support during the course of the research and to Mr. Steve Fox, Manager of the Canadian Sheet Steel Building Institute (CSSBI) for his help and words of wisdom.

ABSTRACT

The structural behaviour of cold formed steel members subjected to web crippling was investigated. The objective of the work was to develop improved coefficients for predicting the web crippling strength expression currently used in the Canadian Standard. An extensive statistical analysis was performed using test data from Canada, the United States and Australia. Four different load cases were considered: (1) End One Flange Loading (EOF), (2) Interior One Flange Loading (IOF), (3) End Two Flange Loading (ETF) and (4) Interior Two Flange Loading (ITF) were investigated. The work was carried out for different types of sections, as follows: I-sections, channel sections, Z-sections, single hat sections and multi-web sections (decks). The new coefficients were developed based on two different support conditions, i.e., test specimens fastened to the bearing plate/support and test specimens not fastened to the bearing plate/support.

An experimental investigation was also conducted on single web members (C-and Z sections) subjected to end and interior two flange loading (ETF and ITF) fastened to the bearing plate/support, and with particular emphasis on large inside bend radius to thickness ratios, R, (up to 10). There were no experimental data available in the literature regarding the web crippling resistance of such members that were fastened to the bearing plate/support and with R values greater than five.

The proposed coefficients show excellent agreement with the test results for a wide range of cross section dimensions, yield strengths, bearing lengths and the angle between the plane of the web and the plane of the bearing surface (θ).

The web crippling data of approximately 1200 data points has been organized and documented using ***<u>Microsoft Access Database.</u>*** A common 3.5" HD diskette contains all of this information.

Additional ETF and ITF web crippling tests fastened to the bearing plate/support with screw fasteners were carried out to substantiate the web crippling coefficients that were developed from data where the test specimens were fastened to the bearing plate/support with bolts. In no case did the screws fail, i.e., the full web crippling strength was obtained in each case within the established scatter limits.

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LIST OF NOTATIONS

AISI	American Iron and Steel Institute, "Specification for the Design of Cold-Formed Steel Structural Members", 1996 Edition, Washington, DC, U.S.A., 1996 [1]
ASTM	American Standard of Testing and Martial A370-92, "Standard Method and Definitions for Mechanical testing of Steel Products", 1992 [2]
C	Coefficient
C_H	Web slenderness coefficient
C_N	Bearing length coefficient
C_R	Inside bend radius coefficient
C.O.V.	Coefficient of variation
D	Flexural rigidity, $Et^3/\{12(1-\nu^2)\}$
E	Young's modulus of steel
EOF	End one flange loading
ETF	End two flange loading
F_u	Tensile strength of steel
F_y	Yield strength of steel
h	Flat dimension of web measured in the plane of the web
H	Web slenderness ratio, r/t
IOF	Interior one flange loading
ITF	Interior two flange laoding
k	894 F_y/E
k	Buckling coefficient of a plate subjected to edge forces
ℓ	Length of plate
L	Length of span
n	Bearing length of load
N	Bearing length to thickness ratio, n/t
P	Applied load per web

P_c Computed ultimate web crippling load per web

P_{cr} Elastic critical buckling load per web

P_n Nominal computed ultimate web crippling load or reaction per web using Prabakaran expression [16]

P_r Factored web crippling resistance per web

P_t Test ultimate web crippling load per web

P_{ult} Computed ultimate web crippling load per web

P_w Computed ultimate web crippling load per web using Wing's expression [21]

r Inside bend radius

R Inside bend radius to thickness ratio, r/t

R_a Allowable design strength

R_n Nominal strength

R_u Required strength, $\Sigma\gamma_i Q_i$

S136 CSA S136-94 "Cold Formed Steel Structural Members, Canadian Standards Association, Rexdale, Toronro, Canada, 1994 [8]

S.D. Standard deviation

S.S. Simply supported

t Web thickness

Ω Factor of Safety

β Reliability index

ϕ Resistance factor

γ_i Load factors

θ Angle between plane of web and plane of bearing surface in degrees

ν Poisson's ratio

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CHAPTER 1

INTRODUCTION

1.1 General

There are two main types of steel structural materials; hot rolled and cold formed. Cold formed steel is less familiar to structural designers compared to hot rolled steel. Hot rolled members have been the traditional choice for steel structures, but the use of cold formed steel in similar applications has been growing steadily since the early 1950's. It was initially used as a cladding and decking material for roofs, floors and walls, but over time, the use of cold formed steel has extended into the commercial industrial market as an alternative to traditional structural elements (i.e. timber and hot rolled steel). Cold formed C-sections are now also being used in residential construction as alternatives to timber members such as studs, joists and rafters. The development of heavier gauge manufacturing processes has facilitated the use of cold formed steel as secondary structural members such as purlins and girts, and more recently, advances in assembly techniques have allowed the use of cold formed steel in the construction of roof trusses and pre-fabricated wall assemblies.

The choice of cold formed steel over other products has been driven by the ease of fabrication, versatility in application and high strength to weight ratio. These advantages of cold formed steel translate directly into a reduction in the cost of material and labour required to erect the structure. As well, these savings allow the owner the freedom to address other important issues of occupancy with little extra cost.

Cold formed steel sections are typically members that are fabricated from thin steel sheets through a series of bending/forming operations. Fabrication of cold formed steel sections can be divided into two basic processes; roll forming and press breaking. The roll forming process allows the fabrication of large quantities directly from coils of sheet steel, while the press braking of flat sheets allows the fabrication of individual members as required. Industry standard thicknesses typically range from 0.5 mm to 7 mm for both fabrication methods. Cold formed steel is primarily derived from high strength to weight ratio, and relatively large width to thickness ratios of the plate elements individual members generally consist of sections that are relatively thin and wide. The geometry of these thin sections essentially produce shell type sections from plates and play a major role in contributing to a member's strength. The thin elements that comprise a cold formed steel section have an inherent tendency to buckle locally when subjected to compressive loads. This local buckling generally occurs at stress levels below the yield point of the material and, therefore, becomes one of the major design considerations. It is well known that elements will continue to carry load after the onset of local elastic buckling, reaching loads that can be up to seven times the value at which elastic local buckling first occurs (Yu, 1991) [28]. This increase in capacity beyond elastic buckling arises from the redistribution of stresses within the compression element. The post-buckling capacity of thin plate elements is a characteristic which makes cold formed steel design unique, in that the strength beyond the initial elastic buckling stress is included in determining the capacity of a section.

Web crippling is one of the most important failure modes that must be considered in the design of cold formed steel members. It is defined as a localized failure of structural members caused by a concentrated load or reaction applied on a short length of the member.

Different design expressions are used to predict the web crippling resistance, which started in 1939 at Cornell University under the direction of Dr. George Winter. Research and development in this area resulted in the first design specification (AISI Specification, 1940) published in 1940 by the American Iron and Steel Institute. Specifications in other countries followed, including the first Canadian design standard (CSA, 1963) in 1963. Subsequent research at various institutions throughout the world has led to the present day design standards in both Canada (S136-94) [8] and the United States (AISI, 1996) [1].

In the current American Specification (AISI, 1996) [1], different design expressions are used to predict the web crippling resistance. Each one of these expressions is only applicable to a certain type of cross section geometry and particular load case. In the current Canadian Standard (S136-94) [8], a unified approach with one design expression is being used, where, different coefficients for different types of section geometries and load cases are used.

1.2 Factors Affecting the Web Crippling Resistance

There are many factors that affect the web crippling resistance, such as section geometry, section parameters, load cases and bearing length.

1.2.1 Section Geometry

Since web crippling is affected by the degree of restraint of the web against rotation, each section has different behavior characteristics. There are many geometric shapes in the market place, with the following being the most common in the construction building industry: (See Figure 1.1)

- I –Sections
- C-Sections
- Z-Sections
- Single Hat Sections
- Multi-Web Sections (decks)

Web crippling failure is primarily experienced in the web element of a member and the web-flange interaction affects the resistance of this mode of failure. Stiffened and unstiffened flanges (See Figure1.1) play an important role in the web crippling resistance. Both the Canadian and American Design Standards [CSA 1994, AISI 1996], separate the sections into stiffened sections and unstiffened sections for some geometric shapes.

1.2.2 Section Parameters

The web crippling behaviour of cold formed steel members is directly affected by the following section parameters, which are considered proportional factors to the web crippling resistance: (See Figure 1.1)

- Yield strength of steel (F_y).
- Web thickness (t).
- Inside bend radius (r).
- Web height (h).
- Angle between the plane of the web and the plane of the bearing surface (θ).

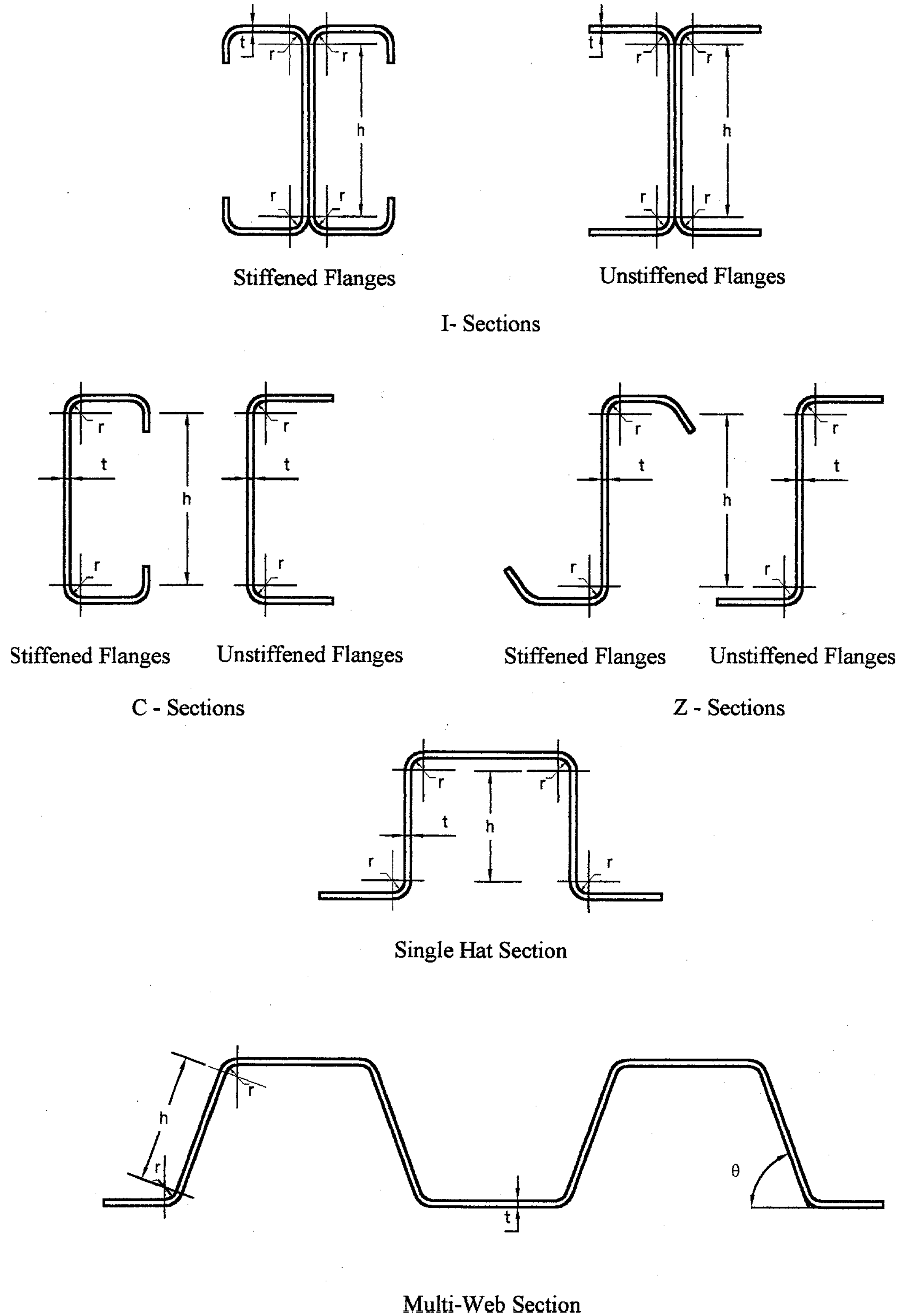
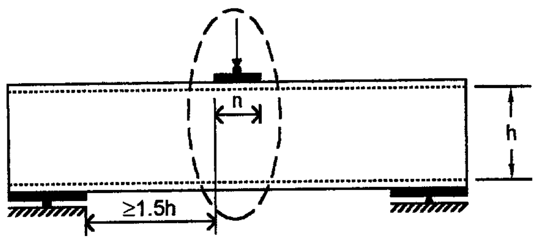
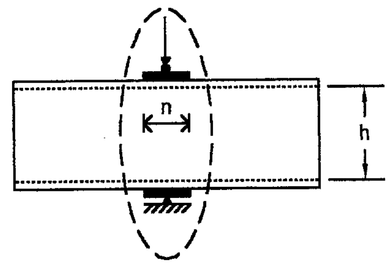


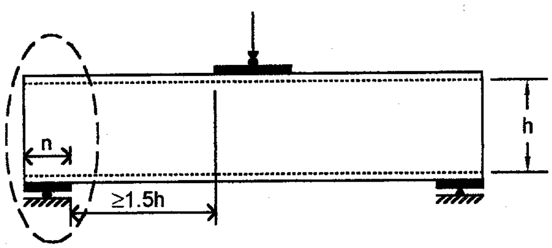
Figure 1.1 Cold Formed Steel Section Types



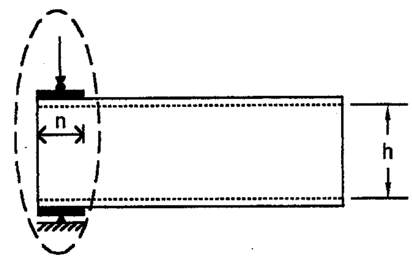
(a) Interior One - Flange Loading (IOF)



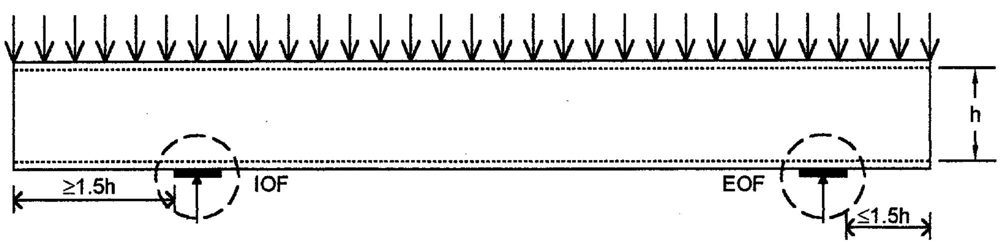
(b) Interior Two - Flange Loading (ITF)



(c) End One - Flange Loading (EOF)



(d) End Two - Flange Loading (ETF)



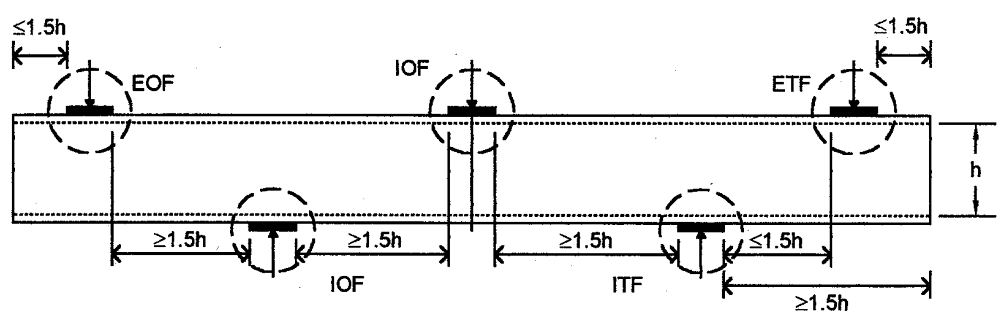


Figure 1.2 Classification of Load Cases for Web Crippling

1.2.3 Load Cases

There are four different load cases in both the American Specification (AISI 1996) [1] and the Canadian Standard (CSA S136-94) [8]. These are based on whether or not the concentrated load is acting on both flanges (Two Flange Loading) or through one flange only (One Flange Loading). Also, it depends on the load position, i.e., if it is end loading, the concentrated load is applied at the end of the member or in the case of interior loading, the concentrate load is applied somewhere in the middle of the member span. These four different loading cases can be summarized as follows. (See Figure 1.2):

One Flange Loading	**Two Flange Loading**
End One Flange Loading (EOF)	End Two Flange Loading (ETF)
Interior One Flange Loading (IOF)	Interior Two Flange Loading (ITF)

1.2.4 Bearing Length (n)

The length over which the load is distributed also has an influence on the web crippling resistance i.e. the longer the bearing plate width, the larger the web crippling resistance (See Figure 1.2).

1.3 Objective of Investigation

The preliminary objective of this study was to check the validity of the current design expressions in both the Canadian Standard [8] and the American Specification [1] for predicting web crippling resistances. Using the available data of all the current sections tested (I, C, Z, single hat and multi-web) for the four different load cases (EOF, IOF, ETF, ITF). Also, carrying out tests for sections that have never been tested before under certain load cases i.e. C- and Z-sections subjected to ITF and ETF loading cases.

Since it was found that the current expressions in both the Canadian Standard [8] and the American Specification [1] are underestimating in some cases and overestimating in others, the main objective became to develop new web crippling coefficients to be valid with all tested sections and all load cases.

Furthermore, the proposed design expressions were calibrated for safety requirements in both the Canadian Standard [8] and the American Specification [1] for Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD).

1.4 Scope of Investigation

As the first step of the investigation, experimental test data were collected from all available sources and technical publications regarding web crippling to date and was organized according to section geometry and load case. Also, analytical studies of plate elements subjected to in-plane edge loading and the current North American web crippling expressions were reviewed. A literature review is presented in Chapter 2.

An experimental program was carried out, which involved testing some sections that have never been tested before, such as stiffened C-and Z- sections under end two flange loading (ETF) and interior two flange loading (ITF). This was necessary in order to establish the behavior and to quantify the web crippling resistance. Detailed descriptions of test specimens, test set up, test procedures and test results are presented in Chapter 3.

Described in Chapter 4 are the comparisons between the experimental and calculated web crippling resistances based on the current design expressions in North America.

Calibrations for safety requirements using the new coefficients in both the Canadian Standard [8] and the American Specifications [1] for Load Resistance Factor Design (LRFD) and Allowable Stress Design (ASD) are presented in Chapter 5.

Finally, a summary of the study with concluding remarks and design recommendations is presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The purpose of this chapter is to provide the reader with the necessary background about the existing analytical and experimental studies of the strength of web plates subjected primarily to web crippling load. Numerous publications and research reports were carefully reviewed in the initial phase of this study. A brief review of the history of analytical and experimental studies is presented in the next section, as well as the present North American design criteria for determining the web crippling strength.

2.2 Theoretical Approaches

The theoretical background of web crippling was reviewed in this section. Webs of cold formed steel members can be idealized as simply supported rectangular thin plates along the edges, subjected to locally distributed in-plane edge compressive forces. The critical elastic buckling load can be computed by relatively simple rational analytical formulae presented later in this section. However, some stiffened compression elements will not fail when the elastic buckling load is reached but will develop post-buckling strength by means of redistribution of stresses. The computation of the post-buckling strength is rather complex. In addition, the interaction between the flange and web elements further complicates the computations. Reviewed in the next section is the elastic buckling behavior of idealized thin plates.

2.2.1 Euler [19]

The elastic critical buckling load of thin plates are analogous to Euler ’s [19] Equation:

$$P_{cr} = \frac{k \pi^2 D}{h} \tag{2.1}$$

Where:

D = flexural rigidity $\left(\dfrac{E\ t^3}{12\ (1\ -\ \nu^2)}\right)$

E = Young's modulus of elasticity
h = depth of plate
k = buckling coefficient of plate subjected to edge loading
P_{cr} = elastic critical buckling load
t = plate thickness
ν = Poisson's ratio

Equation (2.1) applies to simply supported rectangular plates subjected to uniform loading (See Figure 2.1a). For a square plate, when h = ℓ, the plate buckling coefficient, k, is equal to 4 and for a long plate, the plate buckling coefficient approaches 1, as shown in Figure 2.1b.

2.2.2 Timoshenko [19]

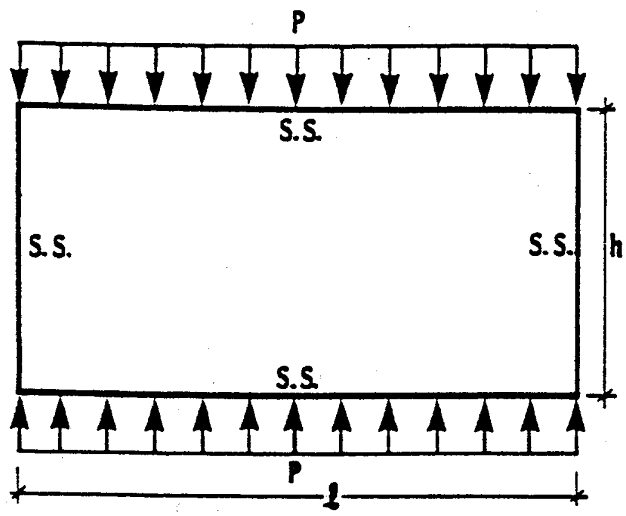
The elastic critical buckling load of a rectangular simply supported plate subjected to two equal and opposite concentrated loads was derived by Timoshenko [19] as follows:

$$P_{cr} = \frac{k\pi^2 D}{h} \tag{2.2}$$

Where:

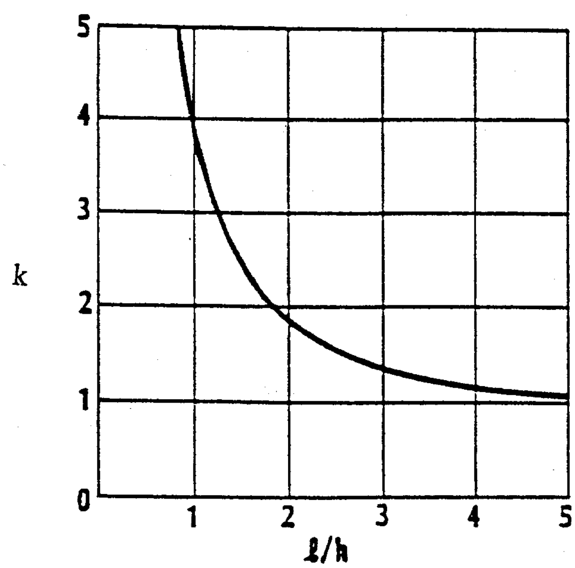
D = flexural rigidity $\left(\dfrac{E\ t^3}{12\ (1-\ \nu^2\ )}\right)$

E = Young's modulus of elasticity
h = depth of plate
k = buckling coefficient of plate subjected to edge loading
P_{cr} = elastic critical buckling load
t = plate thickness
ν = Poisson's ratio



S.S. = simply supported

(a) Plate under loading



(b) Plate Buckling Coefficient, k vs ℓ/h

Figure 2.1 Rectangular Plate Subjected to In-Plane Uniformly Distributed Loading [19]

The plate buckling coefficient, k, was presented by Yamaki [25] who studied the elastic buckling of rectangular plates subjected to concentrated loads and locally distributed forces applied on the opposite edges with different boundary conditions. Shown in Figure 2.2a and Figure 2.2b is the concentrated load case and the variation of the plate buckling coefficient, k, with l/h, respectively.

2.2.3 Walker [20]

The elastic buckling load of` a simply supported rectangular plate under compression due to two equal and opposite partially distributed forces, as shown in Figure 2.3a, was investigated by Walker [20] who developed the following equation to compute the elastic buckling load:

$$P_{cr} = \frac{k\,\pi^2\,E\,t^3}{12\,(1-\nu^2)\,h} \tag{2.3}$$

Where:

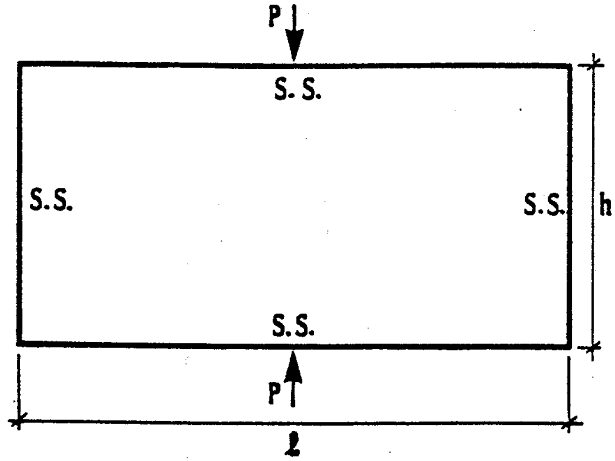
E = Young's modulus of elasticity
h = depth of plate
k = buckling coefficient of plate subjected to edge loading
P_{cr} = elastic critical buckling load
t = plate thickness
ν = Poisson's ratio

The bearing plate length, n, is contained in the plate buckling coefficient, k (See Figure 2.3b). Buckling of plates subjected to localized edge loading was also investigated by Khan [13].

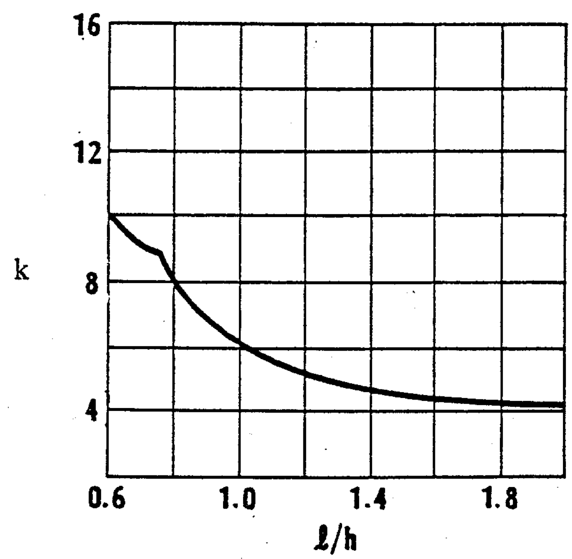
2.2.4 Zetlin [29]

Zetlin developed the following equation to compute the elastic critical buckling load for simply supported plate under partial edge loading as shown in Figure 2.4a:

$$P_{cr} = \frac{k\,\pi^2\,E\,t^3}{12\,(1-\nu^2)\,l^2} \tag{2.4}$$

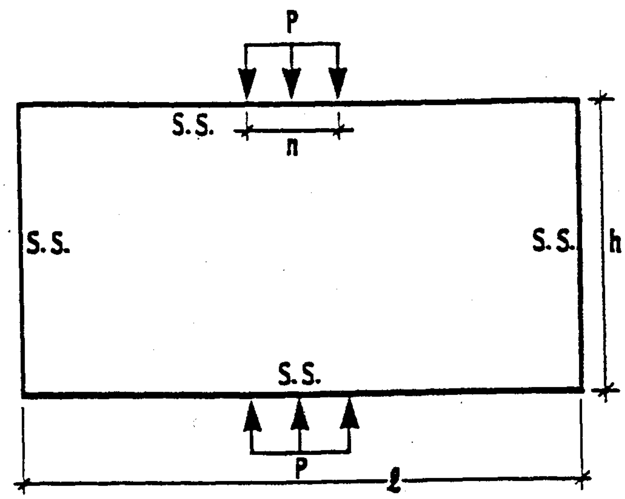


(a) Plate Loading



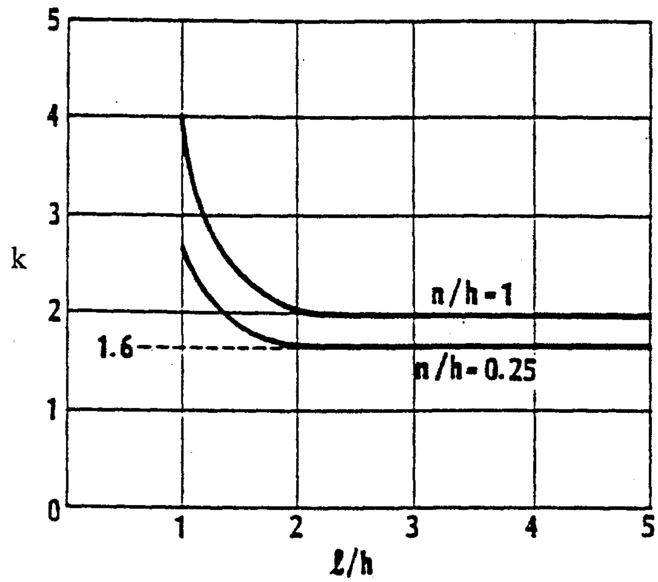
(b) Plate Buckling Coefficient, k

Figure 2.2 Simply Supported Plate Subjected to Two Opposite Concentrated Loads [19]



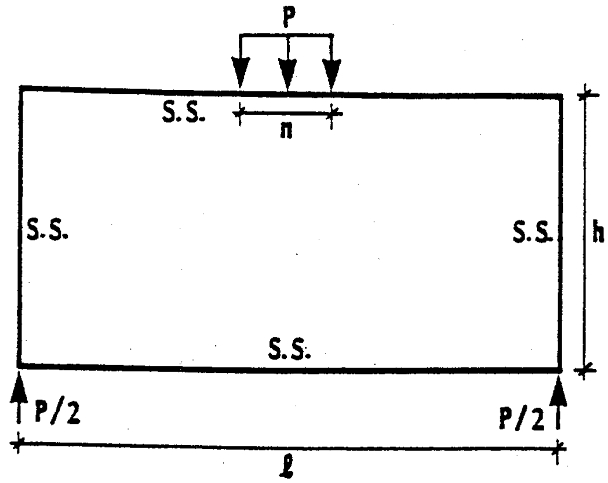
S.S. = simply supported

(a) Plate Under Loading

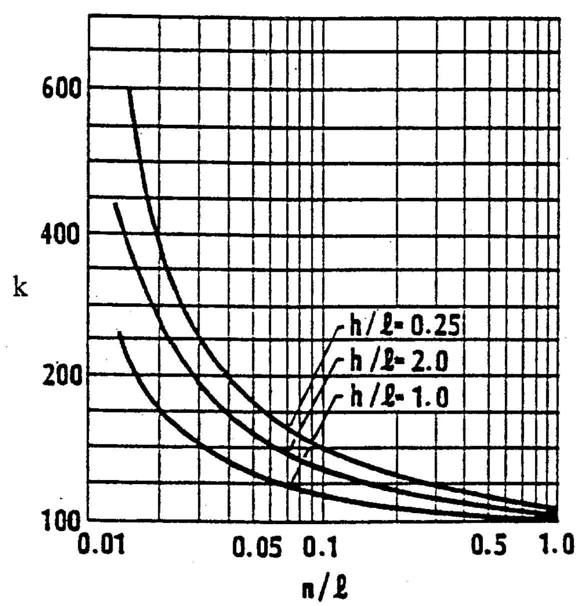


(b) Plate Buckling Coefficient, k vs ℓ/h

Figure 2.3 Rectangular Plate Subjected to In-Plane Partially Distributed Loading [20]



(a) Plate Under Loading



(b) Plate Buckling Coefficient k vs n/ℓ

Figure 2.4 Rectangular Plate Subjected to Partial Edge Loading [29]

Where:

E = Young's modulus of elasticity
ℓ = length of plate
k = buckling coefficient of plate subjected to edge loa ding
P_{cr} = elastic critical buckling load
t = plate thickness
ν = Poisson's ratio

The plate buckling coefficient, k, range is between 100 to 400 as a function of n/h and ℓ/h (See Figure 2.4b).

2.2.5 Summary of Theoretical Approaches

The literature reveals different approaches regarding the theoretical elastic analysis of web crippling for cold formed steel members subjected to different load conditions. It should be noted that the web element of a cold formed steel member is not identical to a four sided simply supported rectangular plate. The idealized boundary conditions of the rectangular plate (simply supported at its four sides) is not totally accurate as the web connected to the flanges is not purely simply supported nor an ideally clamped condition.

Also, the critical elastic buckling load, P_{cr} does not necessarily imply failure of the plate but distinguishes a load carrying region where the load carrying mechanism of the web changes from one to another. The additional load carrying capacity developed in the plate beyond P_{cr} is called the "Post buckling capacity". Due to the difficulty associated with the theoretical analysis, most of the studies rely on experimental data in developing web crippling expressions for design.

2.3 Experimental Approaches

The theoretical analysis of web crippling for cold formed steel members is extremely complicated as stated before, therefore, carrying out laboratory tests on real specimens is the most reliable approach for studying the true behavior of cold formed steel members. The usefulness of this approach is much appreciated in studying the post buckling behaviour of thin walled structures where mathematical difficulties arise.

It also introduces non-quantifiable parameters that affect the behavior such as initial imperfections and cold work of forming. A literature review of experimental approaches is presented in the following section:

2.3.1 Winter [23]

In the 1940's at Cornell University, Winter and Pian [23] investigated the web crippling problem with cold formed steel sections. The investigators considered four different load cases (shown in Figure 1.2). Steel plates not fastened to the specimen flange were used to transmit the loads from a standard testing machine to the webs and the ultimate loads only at which the specimens failed were recorded. They carried out 136 tests on I-sections (shown in Figure 2.5) to develop expressions for computing the web crippling capacity of cold formed steel I-sections. For I-sections and other sections, which provide a high degree of restraint against rotation of web, the web crippling capacity can be computed by the following expressions:

(a) For End one flange loading (EOF)

$$P_{ult} = F_y t^2 (10 + 1.25\sqrt{N}) \qquad (2.5)$$

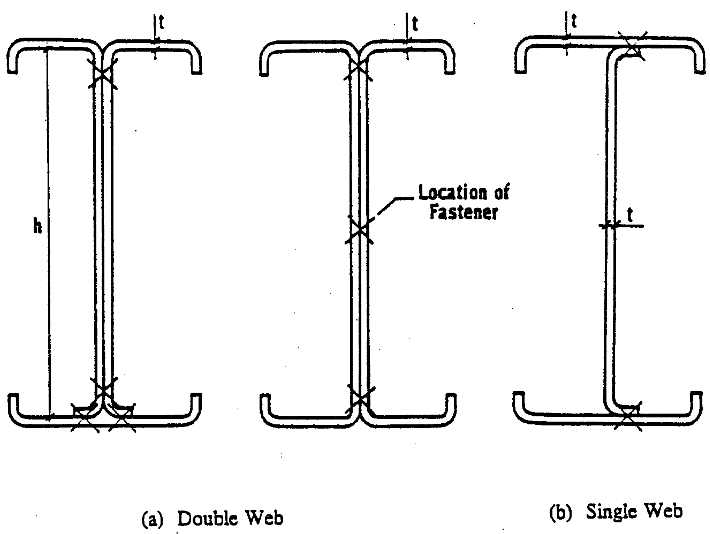
(b) For interior one flange loading (IOF)

$$P_{ult} = F_y t^2 (15 + 3.25\sqrt{N}) \qquad (2.6)$$

Where

P_{ult} = ultimate web crippling load per web
F_y = yield strength of steel
h = clear distance between flanges measured in the plane of the web
n = bearing length of load
N = bearing length to thickness ratio, n/t
t = thickness of web

The range of parameters of these tests was, 30 < h/t < 175, 7 < n/t < 77 and 30 < F_y < 39 ksi.



Parameter Range

$30 < h/t < 175$

$7 < n/t < 77$

$30 < F_y < 39$ ksi

Figure 2.5 Typical Cross-Sections Used by Winter and Pian [23]

For cold formed steel members having single unreinforced webs, such as hat sections, channels and Z-sections, experimental investigations were also conducted at Cornell University by Winter [7]. A total of 128 hat sections and 26 U-sections were tested. Figure 2.6 shows the cross sections of those tested specimens. None of the specimens tested had inclined webs, i.e. the webs were perpendicular to the flanges for all tests.

Based on the test results, it was found that the web crippling strength of single unreinforced webs depends primarily on n/t, h/t, r/t and F_y. The following expressions were derived from the test data for use in the design of cold formed steel sections having unreinforced webs:

1- For end reactions or for concentrated loads on outer ends of cantilevers:

(a) R ≤ 1

$$P_{ult} = \frac{t^2 F_y}{10^3}(1.33 - 0.33k)(5450 + 235N - 1.2NH - 0.6H) \quad (2.7)$$

(b) 1 < R ≤ 4

$$(P_{ult})_1 = [1.15 - .015R](P_{ult}) \quad (2.7.a)$$

2- For reactions at interior supports or for concentrated loads:

(a) R ≤ 1

$$P_{ult} = \frac{t^2 F_y}{10^3}(1.22 - 0.22k)(17000 + 125N - 0.5NH - 30H) \quad (2.8)$$

(b) 1 < R ≤ 4

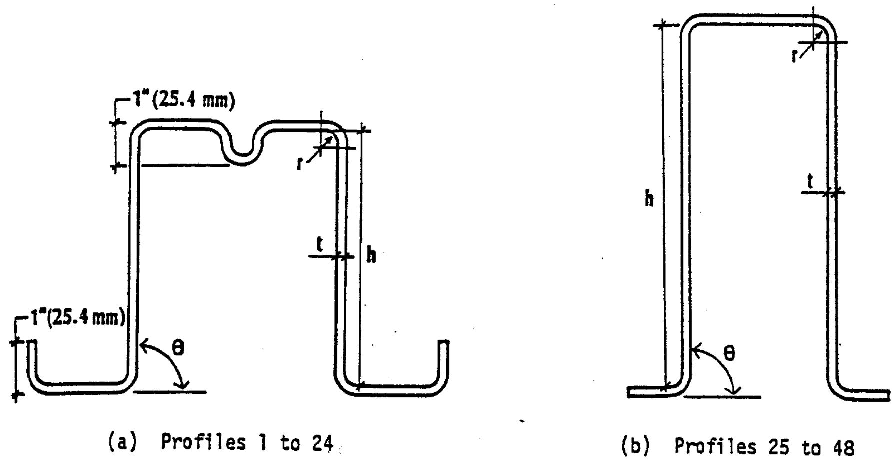
$$(P_{ult})_1 = [1.06 - .06R](P_{ult}) \quad (2.8.a)$$

Where:

P_{ult} = ultimate computed web crippling load per web
t = web thickness
F_y = yield strength
k = F_y (ksi)/33 ; (F_y (N/mm^2)/228)
n = bearing length of load
N = bearing length to thickness ratio, n/t
h = clear distance between flanges measured in the plane of the web
H = web slenderness ratio, h/t
r = inside bend radius
R = inside bend radius to web thickness ratio, r/t

2.3.2 Baehre [3]

Baehre investigated web crippling of single unreinforced multi-web sections (hat type, shown in Figure 2.7) subjected to interior one flange loading. The ultimate web crippling capacity for the reactions of interior supports or concentrated loads located anywhere on the



Parameter Range

30 < h/t < 175

7 < n/t < 77

30 < F_y < 39 ksi

Figure 2.6 Typical Unreinforced Hat Sections Used in Cornell University Study [7]

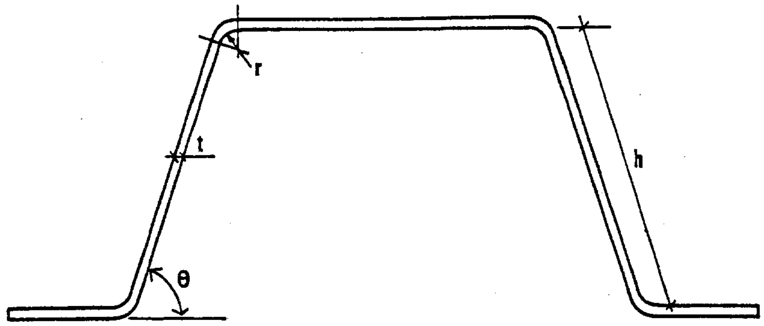
span can be computed by the following expression:

$$P_{ult} = 1.8 F_y t^2 (2.8 - 0.8k)(1 - 0.1\sqrt{R})(1 + 0.01N)(2.4 + q/90)^2 \quad (2.9)$$

Where:

P_{ult} = computed ultimate web crippling load per web
F_y = yield strength of steel
h = clear distance between flanges measured in the plane of the web
H = web slenderness ratio, h/t
k = F_y (ksi)/49.3
n = bearing length of load
N = bearing length to thickness ratio, n/t
r = inside bend radius
R = inside bend radius to thickness ratio, r/t
t = web thickness
θ = angle between plane of web and plane of bearing surface

The above expression has the following limitations: h/t $\leq$ 170, r/t $\leq$ 10 and $50^\circ \leq \theta \leq 90^\circ$. For end reactions, it was recommended to use one half of the computed load from Eq. (2.9) as the ultimate web crippling load, although no tests were carried out.



Parameter Range

50°≤ q ≤ 90°

4 £ r/t £ 10

40 £ h/t £ 170

Figure 2.7 Typical Unreinforced Multi-Web Sections Used by Baehre [3]

2.3.3 Hetrakul [11]

Hetrakul and Yu in 1978 at the University of Missouri-Rolla researched web crippling of cold formed steel sections having single unreinforced webs. They developed new expressions based on 140 tests carried out at the University of Missouri-Rolla (most of them not fastened to the support) and 96 tests from Cornell University [7] (hat-type sections). These expressions were developed on the basis of minimizing the sum of the squares of the residuals between the test and the computed capacities. The expressions are as follows:

(i) Interior one flange loading, IOF (for stiffened and unstiffened flanges)

$$P_{ult} = \frac{F_y t^2}{10^3} C_1 C_2 (16317 - 22.52H)(1 + 0.0069N) \qquad (2.10)$$

If N > 60 then (1 + 0.0069N) may be increased to (0.748 + 0.0111N)

(ii) End one flange loading, EOF

(a) For stiffened flanges

$$P_{ult} = \frac{F_y t^2}{10^3} C_3 C_4 (10018 - 18.24H)(1 + 0.0102N) \qquad (2.11)$$

If N > 60 then (1 + 0.0102N) may be increased to (0.922 + 0.0115N)

(b) For unstiffened flanges

$$P_{ult} = \frac{F_y t^2}{10^3} C_3 C_4 (6570 - 8.51H)(1 + 0.0099N) \qquad (2.12)$$

If N > 60 then (1 + 0.0099N) may be increased to (0.706 + 0.0148N)

(iii) Interior two flange loading, ITF (for stiffened and unstiffened flanges)

$$P_{ult} = \frac{F_y t^2}{10^3} C_1 C_2 (23356 - 68.64H)(1 + 0.0013N) \qquad (2.13)$$

(iv) End two flange loading, ETF (for stiffened and unstiffened flanges)

$$P_{ult} = \frac{F_y t^2}{10^3} C_3 C_4 (7411 - 17.28H)(1 + 0.0099N) \qquad (2.14)$$

Where:

P_{ult} = computed ultimate web crippling load per web
C_1 = (1.22 - 0.22k)
C_2 = (1.06 - 0.06R)
C_3 = (1.33 - 0.33k)
C_4 = (1.15 - 0.15k)
F_y = yield strength of steel
h = clear distance between flanges measured in the plane of the web
k = F_y (ksi)/33
n = bearing length of load
N = bearing length to thickness ratio, n/t
r = inside bend radius
R = inside bend radius to thickness ratio, r/t
t = web thickness

The parameter range for all tests was 45 < h/t < 258, 11 < n/t < 140, 1 < r/t < 3 and 33 < F_y < 54 ksi with a web inclination, θ, of 90° for all tests.

2.3.4 Wing [21], [22]

Wing in 1981 at the University of Waterloo investigated web crippling and the interaction of bending and web crippling of multi-web cold formed steel sections. He carried out an extensive experimental study to develop new web crippling expressions for all load cases, except for the end one flange loading case. He also fastened all of the specimens to the reaction supports. The following expressions were developed by Wing [21] to compute the ultimate web crippling capacities of multi-web cold formed steel sections:

(i) Interior one flange loading (IOF)

$$P_w = 16.6t^2 F_y (\sin q)(1 - 0.000985H)(1 + 0.00526N)(1 - 0.074\sqrt{R})(1 - 0.107k) \qquad (2.15)$$

(ii) Interior two flange loading (ITF)

$$P_w = 18t^2 F_y (\sin q)(1 - 0.00139H)(1 + 0.00948N)(1 - 0.0306\sqrt{R})(1 - 0.22k) \qquad (2.16)$$

(iii) End two flange loading (ETF)

$$P_w = 10.9t^2 F_y (\sin q)(1 - 0.00206H)(1 + 0.00887N)(1 - 0.111\sqrt{R})(1 - 0.0777k) \qquad (2.17)$$

Where:

P_w = computed ultimate web crippling load per web using Wing's expressions
F_y = yield strength of steel
h = clear distance between flanges measured in the plane of the web
k = F_y (ksi)/33
n = bearing length of load
N = bearing length to thickness ratio, n/t
r = inside bend radius
R = inside bend radius to thickness ratio, r/t
t = web thickness
θ = angle between plane of web and plane of bearing surface

Expressions 2.15 to 2.17 have the following limitations: H $\leq$ 200 and R $\leq$ 10.

2.3.5 Bhakta [5]

Bhakta, LaBoube and Yu in 1992 at the University of Missouri-Rolla experimentally investigated the influence of the flange restraint on the web crippling capacity of beam web elements. Bhakta [5] performed 52 different tests subjected to end one flange loading and interior one flange loading on channels, I-sections, Z-sections, long span roof decks and floor decks. The conclusions of the study were:

- Channels and I-sections subjected to either end one flange loading (EOF) or interior one flange loading (IOF) have marginal increase in strength when the flanges are fastened to the support beams.
- For end one flange loading (EOF), Z-sections experienced an average increase in strength of 30% with the flanges being fastened to the supports, while for interior one flange loading (IOF), only a 3 % increase in strength was experienced.
- For long span roof decks with end one flange loading (EOF), an average increase of over 37% was experienced when the flanges were fastened to the support, while only a 20% increase for floor decks under the same loading condition was experienced.

Figure 2.8 shows a typical bolt pattern for I-section specimens tested by Bhakta [5].

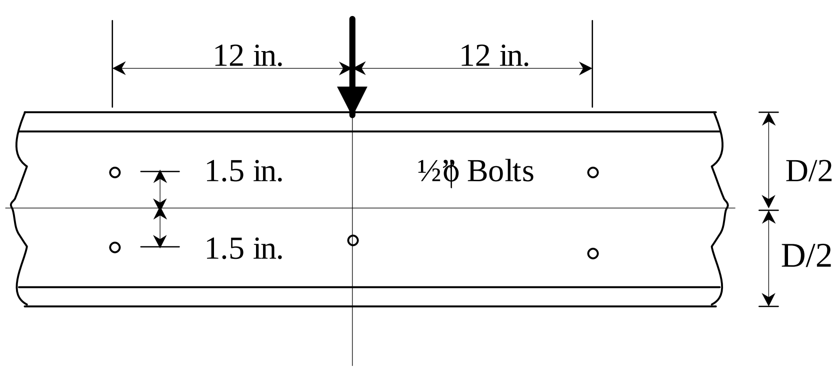


Figure 2.8 Typical Bolt Pattern for I-Section Specimens Tested by Bhakta [5]

2.3.6 Prabakaran [15], [16]

Prabakaran in 1993 at the University of Waterloo completed an extensive statistical analysis of the web crippling capacity of cold formed steel sections by using the available experimental data found in the literature. The object of his study was to develop one simplified expression to calculate the web crippling capacity of cold formed steel sections. Based on the results of his research, Prabakaran recommended the following unified expression with different coefficients for design of I-sections, single web sections and multi-web sections (decks):

$$P_n = C\, t^2 F_y \sin q\ (1 - C_R\sqrt{R})(1 + C_N\sqrt{N})(1 - C_H\sqrt{H}) \qquad (2.18)$$

Where:

P_n = nominal computed ultimate web crippling load or reaction per web using new expression
C = coefficient
C_H = web slenderness coefficient
C_N = bearing length coefficient
C_R = inside bend radius coefficient
F_y = yield strength of steel
h = flat dimension of web measured in plane of web
n = bearing length of load
N = bearing length to thickness ratio, n/t
r = inside bend radius
R = inside bend radius to thickness ratio, r/t
t = web thickness
θ = angle between plane of web and plane of bearing surface

The parameter limits for I-sections and shapes having single webs are $H \leq 200$, $N \leq 200$, $n/h \leq 1$ and $R \leq 4$, for multi-web sections (decks) $H \leq 200$, $N \leq 200$, $n/h \leq 2$ and $R \leq 10$. Expression (2.18) is currently being used in the Canadian Standard CSA 1994 [8].

2.3.7 Cain [6]

Cain, LaBoube and Yu in 1995 at the University of Missouri-Rolla experimentally investigated the conservative and unconservative aspects of the AISI design provisions for web crippling of Z-sections subjected to end one flange loading (EOF) and I-sections subjected to interior one flange loading (IOF). Cain [6] performed 28 tests on Z-sections and 14 tests on I-sections. In his report, he recommended that the American Specification (AISI-86) expressions are conservative predictors for the web crippling strength of unfastened Z-sections subjected to EOF loading and for fastened or unfastened I-sections subjected to IOF loading. Also, he recommend that a modification be applied to the expressions for fastened Z-sections subjected to EOF loading.

2.3.8 Gerges [9], [10]

Gerges investigated in 1997 at the University of Waterloo the conservative and unconservative aspects of the North American design expressions for predicting the web crippling resistance of single web cold formed steel members with large inside bend radius to thickness ratios, R, ($R \leq 10$) subjected to end one flange loading (EOF). Also he developed new parameter coefficients for Prabakaran's expression (2.18) based on 72 tests performed on C-sections fastened to the support. The new parameter coefficients are $C = 4.70$, $C_R = 0.0521$, $C_N = 0.165$, $C_H = 0.0221$ [9].

2.3.9 Young [26]

An experimental investigation was carried out by Young and Hancock [26] in 1998 at the University of Sydney to investigated the conservative and unconservative aspects of the American Specification (AISI-96) [1] in cold formed unlipped channels subjected to web crippling. A series of tests were carried out for the four loading conditions (EOF, IOF, ETF, ITF). Based on the results of his research, the design web crippling strength predictions given by AISI-96 [1] were found to be unconservative for the unlipped channel sections tested. In the paper, a simple plastic mechanism expression for web crippling strength of unlipped channels is proposed.

2.4 Current North American Design Expressions

The following section is a review and a discussion of the web crippling design expressions used for predicting the web crippling strength of cold formed steel members in the North American Specifications [1], [8].

2.4.1 American Specification (AISI) [1]

The first edition of the American Iron and Steel Institute Specification was in 1946 (AISI, 1946), it was primarily based on the research work at Cornell University since 1939 and it was revised subsequently by AISI Committee in 1956, 1960, 1962, 1980 and 1986 to reflect the technical developments and the results of continuing research.

In 1991, AISI published the first edition of the Load and Resistance Factor Design Specification for Cold Formed Steel Members (AISI ,1991). Both allowable stress design (ASD) and load and resistance factor design (LRFD) specifications were combined into one single document in 1996.

The design provisions of the current specification (AISI, 1996) [1] for web crippling are mainly based on the extensive experimental investigations conducted at Cornell University by Winter and Pian (1946), [23], and Zetlin (1955a) [29] in the 1940s and 1950s, and at the University of Missouri-Rolla by Hetrakul and Yu (1978) [11]. In these experimental investigations, the web crippling tests have been carried out under the following four loading conditions for beams having single unreinforced webs and I-beams:

1- End One Flange loading (EOF)
2- Interior One Flange loading (IOF)
3- End Two Flange loading (ETF)
4- Interior Two Flange loading (ITF)

The nominal web crippling strength, P_n in the current (AISI-96) Specification [1] shall be determined from Table (2.1).

Table 2.1 Equation Numbers for Nominal Strength of Webs, P_n, kips (N)

		Shapes Having Single Webs		I-Sections or Similar Sections
		Stiffened or Partially Stiffened Flanges	Unstiffened Flanges	Stiffened, Partially Stiffened and Unstiffened Flanges
Opposing Loads Spaced > 1.5h	End Reaction	*Eq.* (2.19)	*Eq.* (2.20)	*Eq.* (2.21)
	Interior Reaction	*Eq.* (2.22)	*Eq.* (2.22)	*Eq.* (2.23)
Opposing Loads Spaced ≤ 1.5h	End Reaction	*Eq.* (2.24)	*Eq.* (2.24)	*Eq.* (2.25)
	Interior Reaction	*Eq.* (2.26)	*Eq.* (2.26)	*Eq.* (2.27)

Equations for Table 2.1:

$$t^2 \, kC_3C_4C_9C_\theta[331 - 0.61(h/t)]\,[1 + 0.01(N/t)] \qquad (2.19)$$

$$t^2 \, kC_3C_4C_9C_\theta[217 - 0.28(h/t)]\,[1 + 0.01(N/t)] \qquad (2.20)$$

When N/t > 60, the factor [1 + 0.01(N/t)] may be increased to [0.71 + 0.015(N/t)]

$$t^2F_yC_6\left(10.0 + 1.25\sqrt{N/t}\right) \qquad (2.21)$$

$$t^2 \, kC_1C_2C_9C_\theta[538 - 0.74(h/t)]\,[1 + 0.007(N/t)] \qquad (2.22)$$

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

$$t^2F_yC_5(0.88 + 0.12m)\left(15.0 + 3.25\sqrt{N/t}\right) \qquad (2.23)$$

$$t^2 \, kC_3C_4C_9C_\theta[244 - 0.57(h/t)]\,[1 + 0.01(N/t)] \qquad (2.24)$$

$$t^2F_yC_8(0.64 + 0.31m)\left(10.0 + 1.25\sqrt{N/t}\right) \qquad (2.25)$$

$$t^2 \, kC_1C_2C_9C_\theta[771 - 2.26(h/t)]\,[1 + 0.0013(N/t)] \qquad (2.26)$$

$$t^2F_yC_7(0.82 + 0.15m)\left(15.0 + 3.25\sqrt{N/t}\right) \qquad (2.27)$$

In the above-referenced equations:

P_n = Nominal strength for concentrated load or reaction per web, kips (N)

$$C_1 = 1.22 - 0.22k \qquad (2.28)$$

$$C_2 = 1.06 - 0.06R/t \leq 1.0 \qquad (2.29)$$

$C_3 = 1.33 - 0.33k$ (2.30)

$C_4 = 1.15 - 0.15R/t \leq 1.0$ but not less than 0.50 (2.31)

$C_5 = 1.49 - 0.53k \geq 0.6$ (2.32)

$C_6 = 1 + \left(\frac{h/t}{750}\right)$ when $h/t \leq 150$ (2.33)

$= 1.20$, when $h/t > 150$ (2.34)

$C_7 = 1/k$, when $h/t \leq 66.5$ (2.35)

$= \left[1.10 - \frac{h/t}{665}\right]\frac{1}{k}$, when $h/t > 66.5$ (2.36)

$C_8 = \left[0.98 - \frac{h/t}{865}\right]\frac{1}{k}$ (2.37)

$C_9 = 1.0$ for U.S. customary units, kips and in.

$= 6.9$ for metric units, N and mm

$C_\theta = 0.7 + 0.3\,(\theta / 90)^2$ (2.38)

F_y = Design yield stress of the web, see Section A7.1, ksi (MPa)

h = Depth of the flat portion of the web measured along the plane of the web, in. (mm)

$k = 894\,F_y/E$ (2.39)

$m = t/0.075$, when t is in inches (2.40)

$m = t/1.91$, when t is in mm (2.41)

t = Web thickness, in. (mm)

N = Actual length of bearing, in. (mm). For the case of two equal and opposite concentrated loads distributed over unequal bearing lengths, the smaller value of N shall be taken

R = Inside bend radius

θ = Angle between the plane of the web and the plane of the bearing surface $\geq 45°$ but not more than 90°

The equations in Table 2.1 apply to beams when $R/t \leq 6$ and to decks when $R/t \leq 7$, $N/t \leq 210$ and $N/h \leq 3.5$. For Z-sections having their flange bolted to the support member, Equation (2.19) may be multiplied by 1.3 (based on Bhakta [5] report in 1992) this is valid for sections meeting the following limitations:

(1) $h/t \leq 150$

(2) $R/t \leq 4$

(4) Cross-section base metal thickness $\geq$ 0.060 inches (1.52mm)

(5) Support member thickness $\geq$ 3/16 inches (4.76 mm)

In the 1996 edition of the AISI Specification [1], the maximum yield strength of any steel is 80 ksi (552 MPa). The AISI provisions for web crippling strength were previously developed on the basis of the experimental data of Cornell University [7, 23] and of Hetrakul and Yu, 1978 [11]. The term kC_3 in Eqs. (2.19), (2.20) and (2.24) was decreasing in magnitude when F_y was equal to or greater than 66.5 ksi (459 MPa), which is illustrated in Figure 2.9. Since the web crippling strength increases with an increase in yield strength, a footnote was included in the 1996 Edition of the Specification to provide conservative design values, i.e., [* When $F_y \geq 66.5$ ksi (459 MPa), the value of kC_3 shall be taken as 1.34]. This was based on the research by (Hetrakul and Yu, 1978) [11] where the maximum yield strength of the specimens tested was 55 ksi (379 MPa). The latest changes are contained in Supplement No. 1 (effective July 30, 1999), where the term C_3 was replaced in Eqs. (2.19), (2.20) and (2.24) by the term C_1, as graphically illustrated in Figure 2.9. The use of the term kC_1 results in an increase in web crippling strength up to the maximum yield strength of 92 ksi (634 MPa), which is larger than the maximum yield strength limited by the Specification.

It is also observed that a discontinuity results with the factor F_yC_5 of Eq. (2.23), as shown in Figure 2.10. This discontinuity is a consequence of the imposed minimum value of 0.6 for the factor C_5. The minimum restriction value is in effect for yield strengths greater than 55.5 ksi (383 MPa) and results in web crippling strength gains directly proportional to increasing values of F_y.

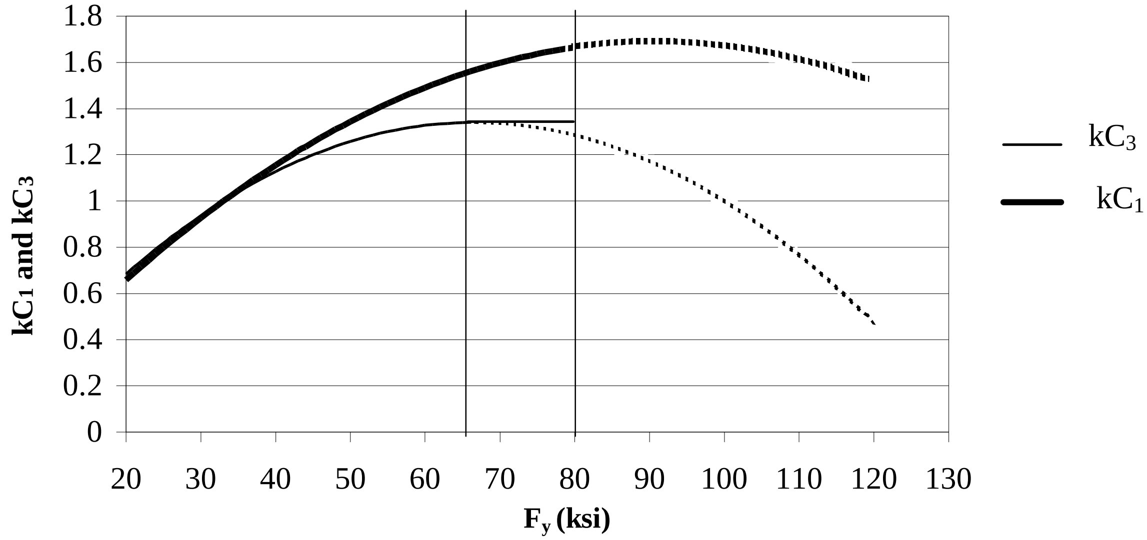


Figure 2.9 kC_1 and kC_3 According to AISI-96 Expressions

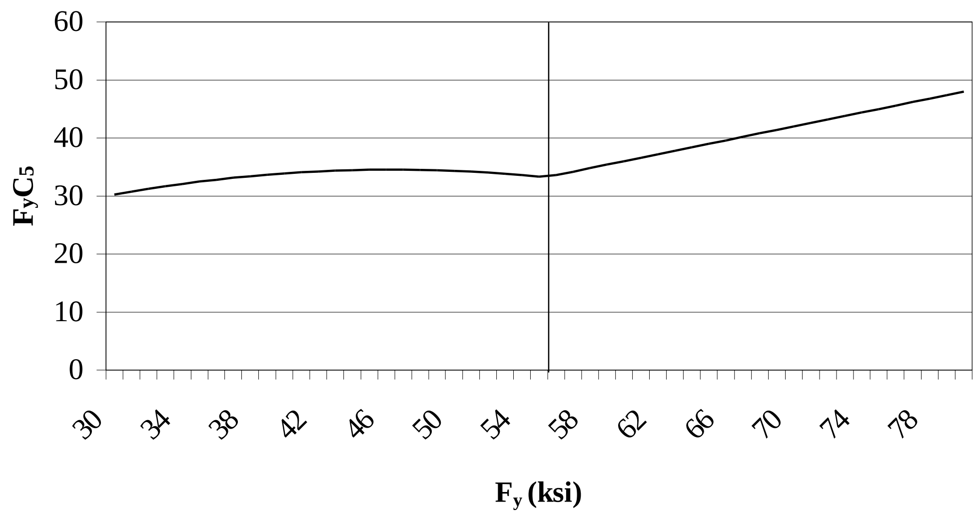


Figure 2.10 F_yC_5 According to AISI-96 Expressions

2.4.2 Canadian Standard (CSA S136-94) [8]

The first edition of the CSA standard S 136 was published in 1963 under the title "Design of Light Gauge Steel Structural Members". In 1974, the second edition was published under a new title, " Cold Formed Steel Structural Members" which is retained in the third (1984), fourth (1989) and fifth (1994) editions.

In the pervious editions to 1994, the web crippling expressions were almost the same as the American Specification (AISI). Many changes have been incorporated into the 1994 edition of the standard, including a new approach for calculating the web crippling resistance based on one unified expression with variable coefficients for different section types and load cases. The expression is based on Prabakaran's [15] research in 1993 at the University of Waterloo. The expression is totally nondimensional and is based on the new definition of the web slenderness ratio, H, where H = h/t (see Figure1.1).

The factored web crippling resistance, P_r, of an unreinforced web of a member in bending shall be determined as follows:

$$P_r = f_s C\, t^2 F_y \sin q \;\; (1 - C_R \sqrt{R})(1 + C_N \sqrt{N})(1 - C_H \sqrt{H}) \qquad (2.42)$$

Where:

P_r = factored web crippling resistance
C = web crippling coefficient from Table, 2.2, 2.3, 2.4
C_H = web slenderness coefficient from Table, 2.2, 2.3, 2.4
C_N = bearing length coefficient from Table, 2.2, 2.3, 2.4
C_R = inside bend radius coefficient from Table, 2.2, 2.3, 2.4
F_y = yield strength of steel
h = flat dimension of web measured in plane of web
n = bearing length of load
N = bearing length to thickness ratio, n/t
r = inside bend radius
R = inside bend radius to thickness ratio, r/t
t = web thickness
θ = angle between plane of web and plane of bearing surface

The parameter limits for I-sections and shapes having single webs are $H \le 200$, $N \le 200$, $n/h \le 1$ and $R \le 4$, for multi-web sections (decks) $H \le 200$, $N \le 200$, $n/h \le 2$ and $R \le 10$.

Table 2.2

S136-94 Coefficients for Built-up Sections

		f_s	**C**	C_R	C_N	C_H
One-flange Loading or reaction	End	0.67	9.85	0.185	0.315	0.001
	Interior	0.67	18.0	0.001	0.075	0.001
Two-flange Loading or reaction	End	0.67	15.0	0.001	0.100	0.050
	Interior	0.67	28.0	0.001	0.035	0.025

Table 2.3

S136-94 Coefficients for Shapes Having Single Webs

		f_s	**C**	C_R	C_N	C_H
One-flange Loading or reaction	End, Stiffened flanges	0.80	4.00	0.230	0.650	0.035
	End, Unstiffened flanges	0.80	7.20	0.250	0.120	0.030
	Interior	0.80	17.0	0.130	0.130	0.040
Two-flange Loading or reaction	End	0.80	17.0	0.400	0.064	0.045
	Interior	0.80	29.5	0.135	0.080	0.060

Table 2.4

S136-94 Coefficients for Deck Sections (Multi-webs)

		f_s	**C**	$\mathbf{C_R}$	$\mathbf{C_N}$	$\mathbf{C_H}$
One-flange Loading or reaction	End	0.80	4.00	0.070	0.200	0.001
	Interior	0.80	21.0	0.120	0.065	0.040
Two-flange Loading or reaction	End	0.80	9.00	0.180	0.200	0.044
	Interior	0.80	10.0	0.140	0.210	0.020

2.5 Summary of Experimental Approaches

Due to the complexity of calculating the web crippling resistance using a theoret ical approach as stated in Section 2, the experimental approach is considered the only way for developing reliable expressions for evaluating the web crippling resistance of cold formed steel members.

The current American Specification (AISI, 1996) [1] is mainly based on pervious research up to 1978, and it is based on unfastened test specimens. The AISI-96 [1] introduced the design expressions under two different section types, I-sections and shapes having single web, which include C-and Z-sections, hat sections and multi-web (deck) sections.

The current Canadian standard (S136, 1994) [8] is based on pervious research done up to 1993, and it is based on a unified expression with different parameter factors for each section and load case. Most of these parameters are based on unfastened test specimens.

CHAPTER 3

EXPERIMENTAL INVESTIGATION

3.1 General

The current web crippling design criteria (CSA 1994, AISI 1996) for cold formed steel members with single unreinforced webs subjected to end two flange loading, ETF, or interior two flange loading, ITF, is primarily based on test results where the flanges were not fastened to the support reactions. Usual field practice is to bolt or screw-fasten the flanges of the cold formed steel members to their supporting members. Due to the restraining effect of the fasteners, the cold formed steel members will experience additional web crippling capacity (Bhakta, 1992) [5], which is not reflected in the current design expressions (S136-94 [8], AISI-96 [1]).

A preliminary study as a part of this work was based on eight test specimens (C-sections unstiffened flanges) carried out at the University of Waterloo under the ETF and ITF loading conditions (Fastened and Unfastened). The results showed that the web crippling resistance is also affected by the length of the test specimen, especially for ITF loading (See Table 3.1). In order to verify the adequacy of the current design expressions or to possibly develop new coefficients, additional tests had to be carried out.

A total of 72 specimens (36 C-sections and 36 Z-sections) were tested in the Structures Laboratory at University of Waterloo for both loading cases, ETF and ITF. The test program was designed to enable the determination of the influences of various parameters on the web crippling behaviour.

Table 3.1 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	1.20	300	198	194	1.8	101	1210	162	1.5	84.2	3.12
2	C-S-F-ETF	1.20	300	198	194	1.8	101	530	162	1.5	84.2	3.02
3	C-L-U-ETF	1.20	300	198	194	1.8	101	1210	162	1.5	84.2	2.18
4	C-S-U-ETF	1.20	300	198	194	1.8	101	530	162	1.5	84.2	2.22
5	C-L-F-ITF	1.20	300	198	194	1.8	101	1210	162	1.5	84.2	8.12
6	C-S-F-ITF	1.20	300	198	194	1.8	101	530	162	1.5	84.2	5.28
7	C-L-U-ITF	1.20	300	198	194	1.8	101	1210	162	1.5	84.2	6.71
8	C-S-U-ITF	1.20	300	198	194	1.8	101	530	162	1.5	84.2	3.98

Where:

- 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

3.2 Test Specimens

Two different steel grades were obtained from Dofasco for the test specimens. C-and Z-sections were fabricated by Bridgeport Steel Inc. of Kitchener, Ontario with single unreinforced webs and stiffened flanges with inside bend radius to thickness ratios, R = r/t, up to 12 (Maximum R ratio used in pervious studies was 2.7). The length of the specimens was chosen to be more than five times the depth for both sections. Hetrakul [11] used specimens with a length to depth ratio of two to three times. In practice, such specimens have a considerable length to depth ratio (up to 20 or more for joists).

In the current AISI Specification (AISI 1996) [1] the same design expressions are used for C, Z, hat and multi-web (deck) sections, while in the Canadian Standard (CSA 1994) [8], C-and Z-sections are considered as shapes having single webs but hat and deck sections as multi-web shapes. The test program performed for the two different loading cases, ETF and ITF were as follow:

- 18 C-Section specimens subjected to ETF loading
- 18 C-section specimens subjected to ITF loading
- 18 Z-section specimens subjected to ETF loading
- 18 Z-section specimens subjected to ITF loading

All of the test specimens were made from cold formed steel sections and were bolted (fastened) to the reaction supports, which were made from hot-rolled steel.

3.2.1 Mechanical Properties of Test Specimens

Since the test program included three different section depths, three coupon specimens were cut from each depth for C-and Z-Sections to determine the mechanical properties of the steel according to the American Standard of Testing and Materials (ASTM A370, 1992) [2]. The coupon specimens were cut from the webs of the tested C-and Z-sections, away from the web crippling failure zone. The galvanizing was removed from the specimens using a hydrochloric acid solution and the base steel thickness was measured for each coupon specimen prior to testing.

Summarized in Table 3.2 are the average yield and ultimate strengths, thickness and the elongation percent based on a 50 mm gauge length.

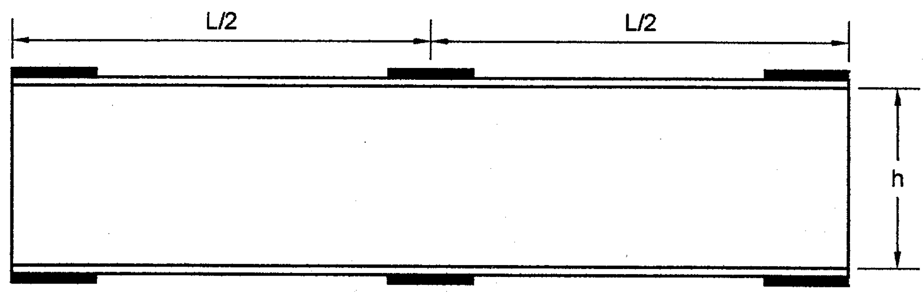
3.2.2 Overview of Test Program

There are five major parameters that control the web crippling resistance in cold formed steel members, as stated in pervious investigations (Prabakaran 1993 [15], Hetrakul and Yu 1978 [11]). These five parameters are: thickness of the web, t; yield strength, F_y; the web slenderness ratio, H = h/t; the inside bend radius to thickness ratio, R = r/t; and the bearing plate length to thickness ratio, N = n/t. For this test program, specimens were chosen with a variation in these parameters to obtain a better evaluation of the web crippling resistance. Three different overall section depths, D (See Figure 3.1) were used in the test

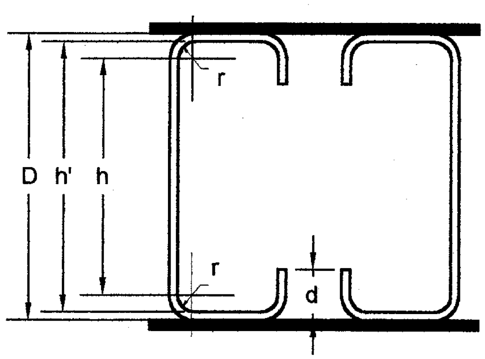
Table 3.2 Material Properties of Test Specimens

Section Type	Specimen	t (mm)	F_y (MPa)	F_u (MPa)	% Elongation*
C-Sections	1C-120	1.45	336	463	32.0
	2C-120	1.45	329	463	30.0
	3C-120	1.45	332	465	32.0
	Average		**332**	**464**	**31.3**
	1C-200	1.16	327	428	30.0
	2C-200	1.16	327	427	30.0
	3C-200	1.16	331	427	30.0
	Average		**328**	**427**	**30.0**
	1C-300	1.45	439	527	30.0
	2C-300	1.45	461	532	28.0
	3C300	1.45	443	518	28.0
	Average		**448**	**526**	**28.7**
Z-Sections	1Z-120	1.45	336	463	32.0
	2Z-120	1.45	329	465	20.0
	3Z-120	1.45	332	463	32.0
	Average		**332**	**464**	**31.3**
	1Z-200	1.17	321	422	32.0
	2Z-200	1.17	320	421	32.0
	3Z-200	1.17	329	427	32.0
	Average		**323**	**423**	**32.0**
	1Z-300	1.45	449	519	30.0
	2Z-300	1.45	446	518	28.0
	2Z-300	1.45	444	515	30.0
	Average		**446**	**517**	**29.3**
Preliminary Tests		**1.20**	**300**	**425**	**32.1**

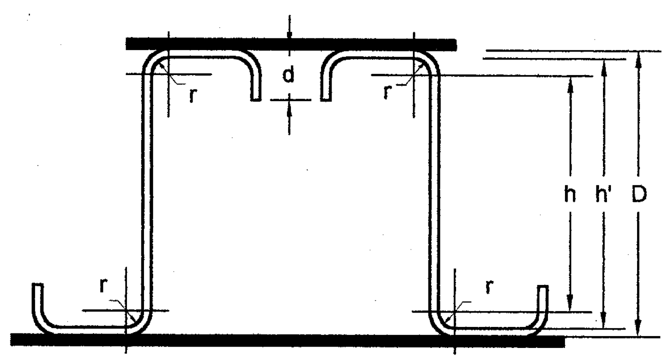
* Based on 50 mm gauge length



(a) View of Bearing Plate Elevation



(b) C - Sections



(c) Z - Sections

Figure 3.1 Schematic of Typical Test Specimen Arrangement

program for both section types (C-and Z-sections), 120 mm, 200 mm and 300 mm. Three different inside bend radius, r, values were used, 7 mm, 10 mm and 14 mm and two different thicknesses, t, were used, 1.45 mm for sections having depths of 120 mm and 300 mm and 1.16 mm for sections having a depth of 200 mm. The yield strength of steel, F_y, varied according to the coupon tests (Table 3.2). Two different bearing plate lengths were used i.e. 30 mm and 63.5 mm for all tests. For verification purposes, another bearing plate length 101 mm was used in some tests. The test specimens parameter ranges are shown in Table 3.3.

Table 3.3 Test Specimens Parameter Ranges

Parameter	Minimum Value	Maximum Value
Thickness (t), mm	1.16	1.45
Slenderness ratio (h/t)	60	195
Inside bend radius ratio (r/t)	4.83	12
Bearing plate length ratio (n/t)	20.7	87
Yield Strength (F_y), MPa	323	448

Test specimens were characterized by the following code: **T-D-r-n**

Where, **T** = section type (C for C-section and Z for Z-section)

D = nominal value of overall depth of section

r = inside bend radius of the conjunction between web and flange (same as between lip and flange)

n = length of the bearing plate

Tables A.1 to A.4 of Appendix A give a full listing of the measured dimensions of the test specimens.

3.3 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, all test specimens were constructed of two equally sized sections facing each other in a box beam arrangement (See Figure 3.1) to avoid any premature torsional failure.

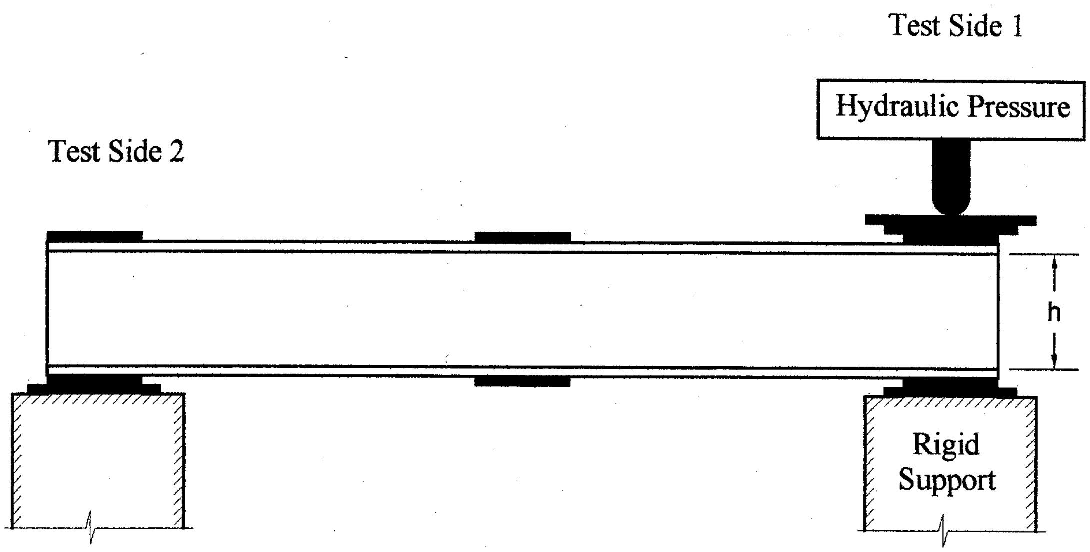
The box section was constructed from two identical sections (C-or Z-sections) and six bearing plates (three at the top of the flange and three at the bottom of the flange). The bearing plates were bolted to the flanges, one at each end of the beam and one in the middle at both the top and bottom flanges as shown in Figure 3.1a. The end bearing plates were placed flush with the end of the specimen.

All test specimens were supported as shown in Figure 3.2 and were carefully positioned and aligned in the test frame prior to testing, as shown in Figure 3.3. Since the length of the box beam specimen was more than 5 times the depth for the ETF load case, two tests were carried out from each box beam specimen (one at each end) by applying the load at one end until failure and then applying the load at the other test end (See Figure 3.2). There were no collapse effects of the first end failure transferred to the other end. For ITF loading, only one test was carried out for each box specimen by placing the mid span of the specimen over a rigid support. No other supports were provided at the ends to make sure that the only web crippling failure occurred at the mid span of the specimen, as shown in Figure 3.2. The specimen length (five times the depth) was sufficient, such that the localized region of failure did not extended over the entire length of the specimen, which ensured that the test load was not a function of the length of specimen.

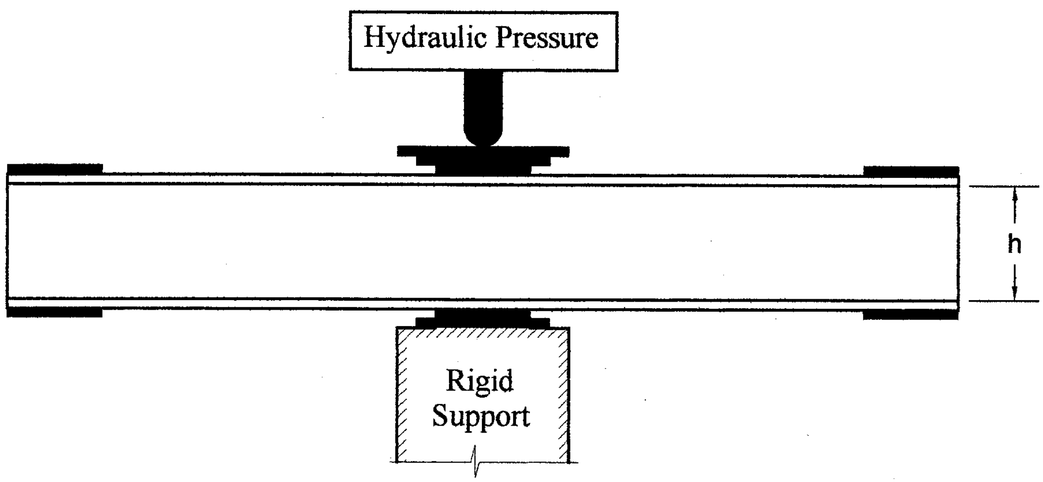
The load was gradually applied by a stroke control hydraulic jack system, so that the descending branch of the load-deformation behavior could be determined. The speed of movement of the hydraulic jack was constant throughout the test for all specimens at 1 mm/min to maintain consistency among the test results. Some of the specimens were loaded to failure, while others experienced excessive deformations prior to failure, after which the test was terminated.

3.4 Test Results

The failure load per web is denoted by P_t and was determined by dividing the total failure load by two. The web crippling failure for shallow C- and Z-sections (120 mm) occurred due to a yield arc failure mechanism. This type of failure was also experienced by



(a) End Two Flange Loading Test, ETF (two tests per specimen)



(b) Interior Two Flange Loading Test, ITF (one test per specimen)

Figure 3.2 Schematic of Typical Test Set-Up

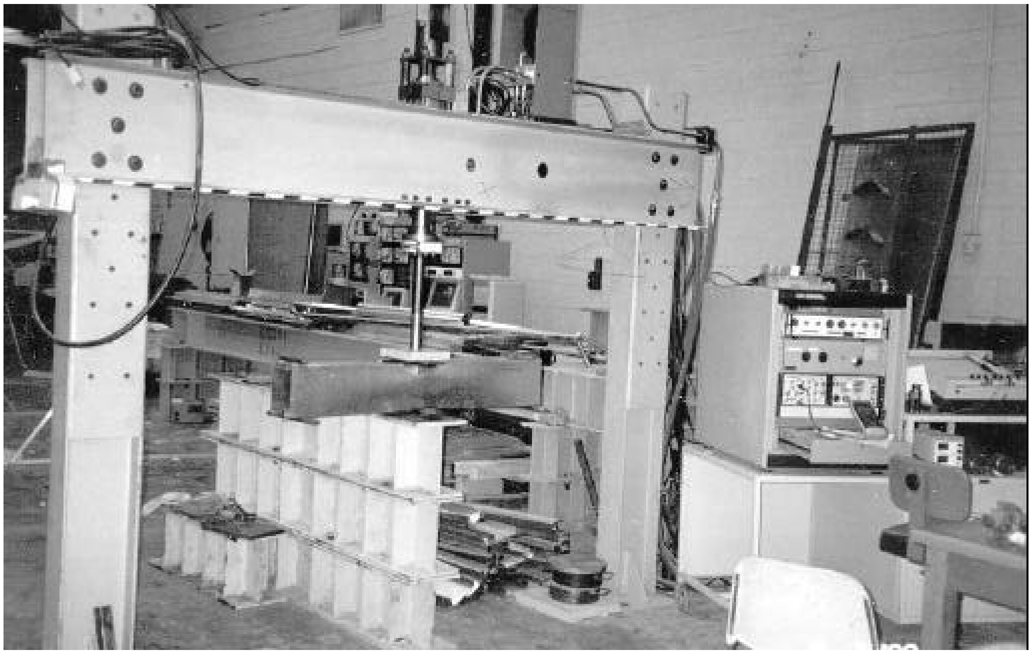


Figure 3.3 Testing Frame at the University of Waterloo

Gerges [9], where the web deformation is enabled by the formation of an arc (yield arc). The length of the yield arc was approximately equal to the length of the bearing plate, n (see Figure 3.4 and 3.6). Its depth was dependent on the length of the bearing plate, n, the height of the web, h, and the inside bend radius. For deep C-and Z-sections (200mm and 300 mm), the failure occurred due to an excessive overall buckling as shown in Figure 3.5, 3.8, 3.9, 3.10 and 3.11.

Based on the preliminary and final test results, the long specimens (more than five times the depth) experienced a higher load at failure than expected, more than 50% for interior two flange loading, ITF, and about 5% for end two flange loading, ETF. Also, the test results showed that Z-sections could carry a higher load than C-sections (more than 20% for ETF, and about 10 to 20% for ITF) with the same properties and under the same load cases.

Tables A.5 to A.8 of Appendix A present the failure load values for ETF and ITF load cases, respectively.

3.5 Evaluation of Existing Design Expressions

The web crippling loads per web obtained from the tests are compared in this section with the current web crippling design expressions (AISI-1996 [1], S136-94 [8]) of cold formed steel members subjected to end two flange loading condition, ETF, and interior two flange loading condition, ITF.

3.5.1 AISI-96 Expressions [1]

The AISI-96 [1] expressions for single web shapes are valid only for inside bend radius to thickness ratios, R, of less than or equal to 6, hence, only four data points are applicable. Because the web crippling expressions contained in AISI-96 [1] were based on specimens not fastened to the support during testing (Winter, Pian [23], Hetrakul and Yu [11]), the expression underestimates the web crippling resistance for the ETF load case by about 61% for C-sections and by more than 100 % for Z-sections. On the other hand, the AISI-96 [1] expression for the ITF load case underestimates the web crippling resistance by about 55% for both C-and Z-sections.

Tables A.5 to A.8 of Appendix A show the failure test values in comparison to the calculated values, P_t/P_c, according to the AISI-96 expressions.

3.5.2 S136-94 Expression [8]

The S136-94 [8] expression for single web shapes is valid only for inside bend radius to thickness ratios, R, of less than or equal to 4. Thus, the expression could not be applied to the tested data of this study.

3.5.3 Conclusions

The present design expressions for web crippling of single web sections subjected to end two flange loading, ETF, and interior two flange loading, ITF, are not valid for sections fastened to the support, with inside bend radius to thickness ratios, R, greater than 4 and specimen lengths greater than 5 times the depth. Comparisons between test and calculated web crippling resistance values, using the present AISI-96 [1] design expressions indicate that new web crippling coefficients are needed.

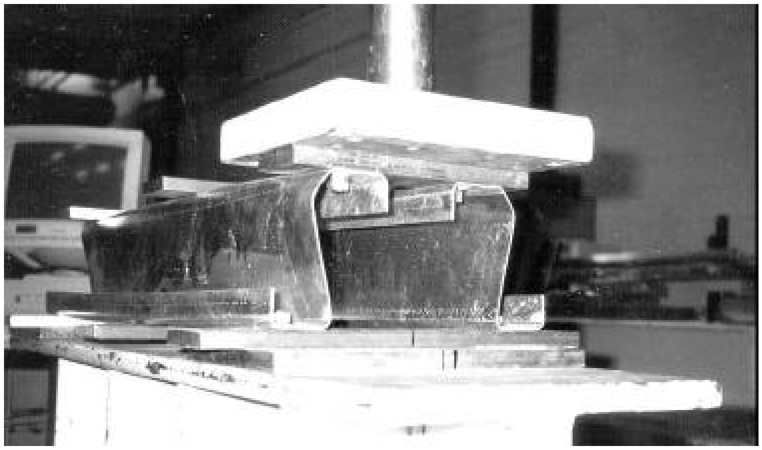


Figure 3.4 End Two Flange Loading, ETF, of Z-Sections

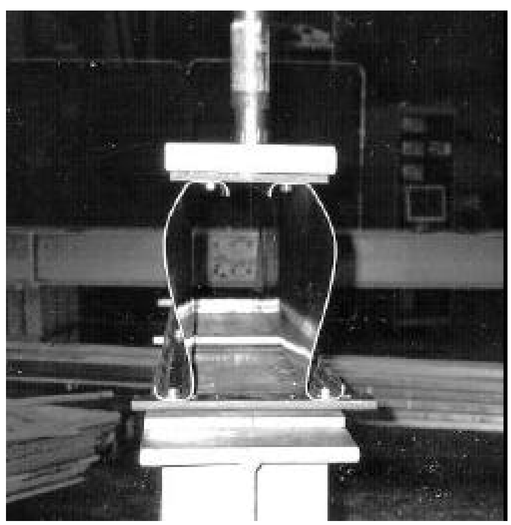


Figure 3.5 End Two Flange Loading, ETF, of Z-Sections

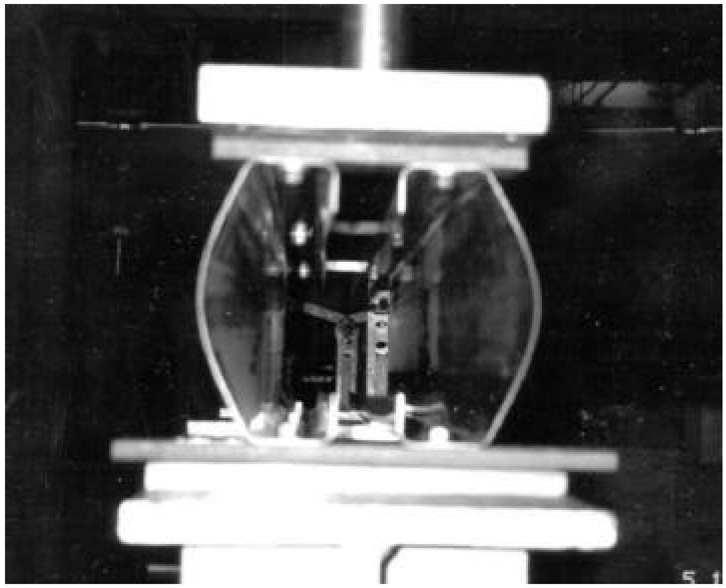


Figure 3.6 End Two Flange Loading, ETF, of C-Sections

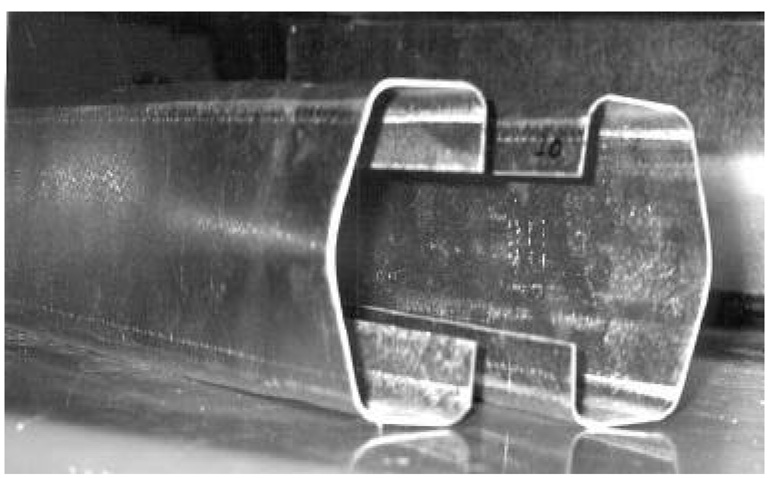


Figure 3.7 End Two Flange Loading, ETF, of C-Sections

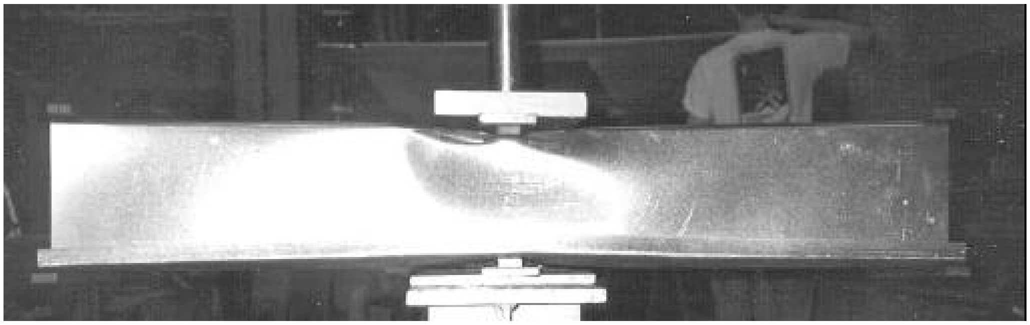


Figure 3.8 Interior Two Flange Loading, ITF, of Z-Sections

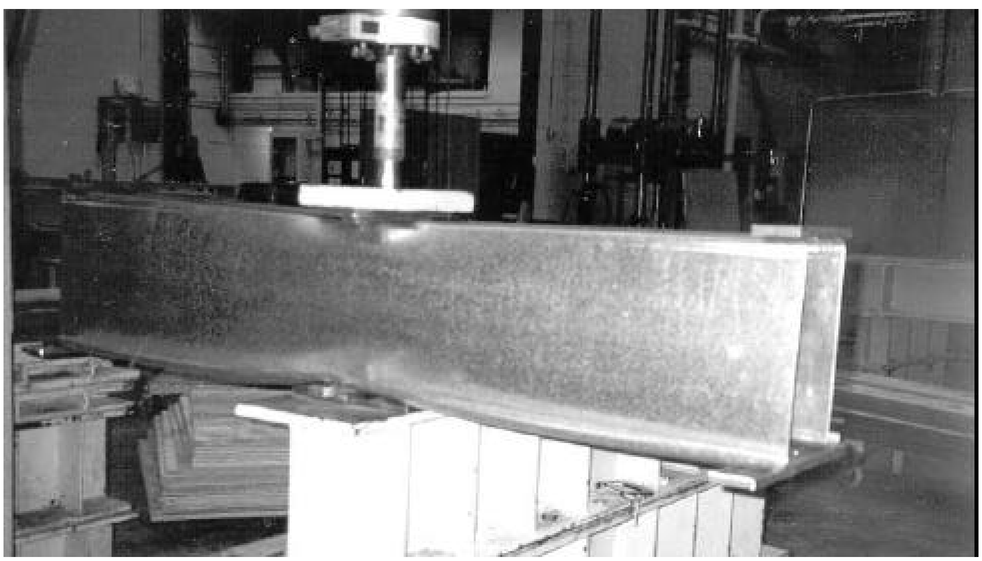


Figure 3.9 Interior Two Flange Loading, ITF, of Z-Sections

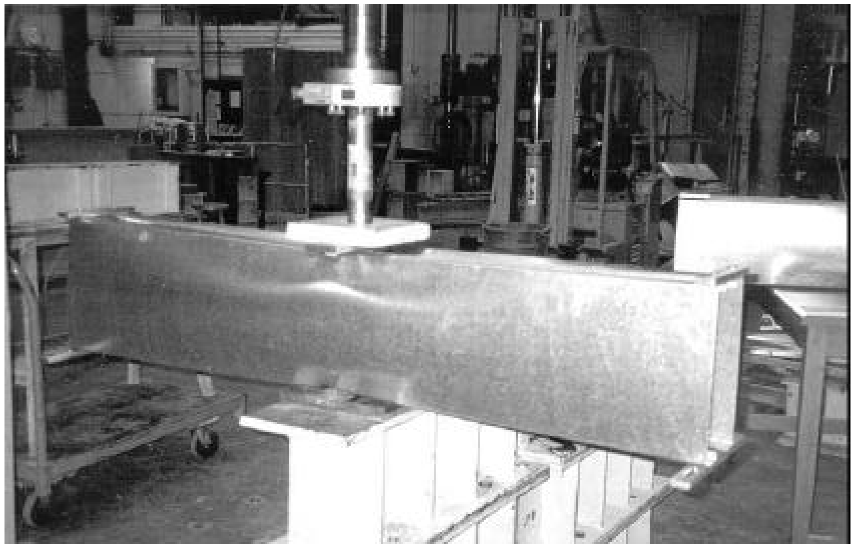


Figure 3.10 Interior Two Flange Loading, ITF, of C-Sections

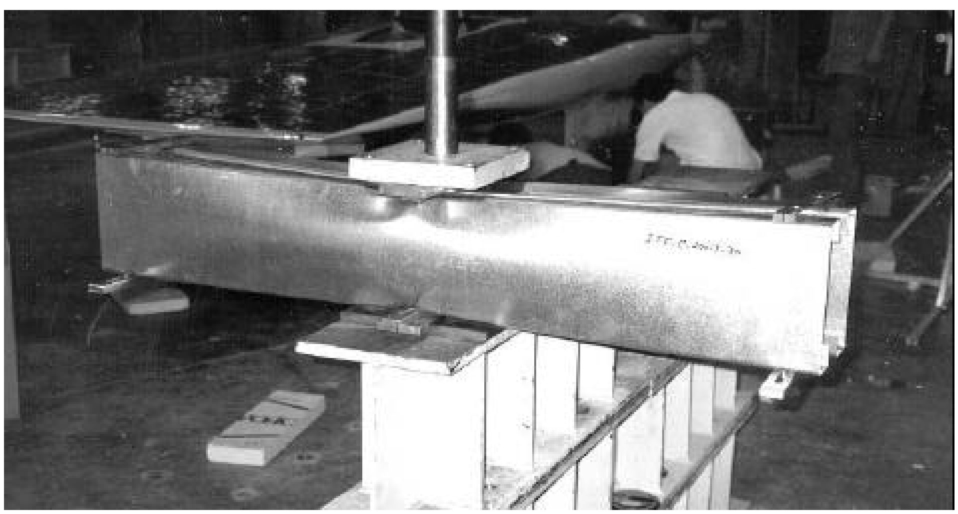


Figure 3.11 Interior Two Flange Loading, ITF, of C-Sections

CHAPTER 4

DEVELOPMENT OF NEW COEFFICIENTS

4.1 General

As discussed in Chapter 3, the current North American design criteria (CSA 1994, AISI 1996) regarding web crippling for cold formed steel members are not suitable for the following sections:

- Sections fastened to the support.
- Sections with inside bend radius to thickness ratios greater than 4 for S136-94 [8] and 6 for AISI-96 [1].
- Sections subjected to ITF loading condition with the length to depth ratio greater than five times.

New research and tests have been carried out recently on web crippling for cold formed steel members that are not included in the current North American design expressions [1], [8]. Comparisons between new tests and calculated web crippling values indicate that further improvements of the current design expressions are desirable.

Described in this chapter is the development process of the new design coefficients to predict the ultimate web crippling resistance for I, C, Z, single hat and multi-web sections subjected to the four different load cases (EOF, IOF, ETF and ITF). The data used in regression analysis and the design range parameters are also presented in this chapter.

4.2 Design Formulation

As discussed in the previous chapter, there are five major parameters that govern the web crippling resistance in cold formed steel members (Prabakaran 1993 [15], Hetrakul and Yu 1978 [11]), these five parameters are: thickness of the web, t, yield strength, F_y, the web slenderness ratio, H = h/t, the inside bend radius to thickness ratio, R = r/t and the bearing plate length to thickness ratio, N = n/t. The Canadian Standard (S136-94) [8] introduced the

$$P_C = C\ t^2 F_y \sin q\ \ (1 - C_R\sqrt{R})(1 + C_N\sqrt{N})(1 - C_H\sqrt{H}) \qquad (4.1)$$

Where P_c 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 case and can be determined by using a regression analysis. Each term within the brackets of Eq. (4.1) 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 bearing width ratio, N, a plus sign is used in the bearing plate correction factor term. On the other hand, the resistance decreases with an increase in inside bend radius to thickness ratio, R, and web slenderness ratio, H, hence, minus signs are used in both cases for their correction factors. The web inclination correcting factor, $\sin\theta$, represents the actual behavior of the web crippling resistance (maximum at 90° and it decreases as the angle is below or above 90°). Comparisons between C_θ in the current AISI-96 [1] and $\sin\theta$ are shown in Figure 4.1. Expression 4.1 is dimensionally correct and as shown, it includes correction factors for each parameter affecting the web crippling resistance.

Based on the above discussion, Eq. 4.1, was used in the development of the new coefficients for each section type and load case. Comparisons between the current AISI-96 [1] expressions and the S136-94 expression [8] are shown in Table 4.1. It can be observed from

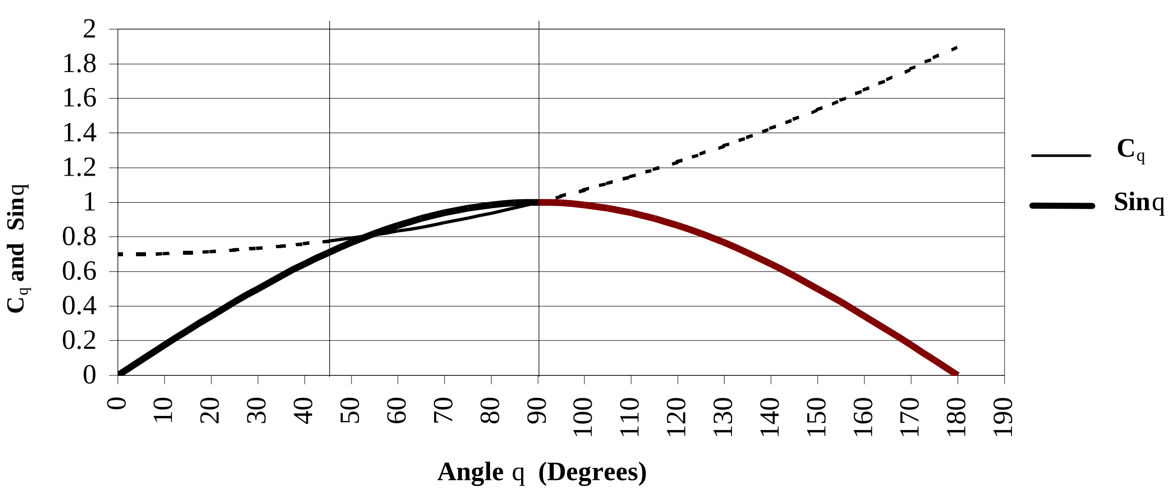


Figure 4.1 C_q According to Current AISI-96 and Sinq

Fig 4.1 that within the limits of θ specified by AISI [$\geq 45° < 90°$], the two approaches yield about the same results.

Table 4.1 Comparison Between AISI-96 and S136-94

AISI-96 Expressions	S136-94 Expression
23 Expressions	One Expression and 5 tables
Some expressions are dimensionally dependent	Dimensionally independent
m = t/0.075 for inch, m = t/1.91 for mm	
F_yC_5 problem (see Section 2.4.1)	C
Same expressions for single web used for C, Z, single hat and multi-web	Different coefficients for each section

4.3 Computer Program used in Developing the New Coefficients

In developing the new coefficients, a computer program was written using the Visual Basic 6.0 programming language. The program was created on a database that includes all test data available in the literature to date. These data were organized according to section type, fasten status (fastened or unfastened to the support), loading condition, researcher's name, University and year of study. The program has the following features:

- Evaluate and compare the current North America design expressions (AISI-96 and S136-94) with the new coefficients.
- Calculate calibration factors for S136-94 [8] and AISI-96 [1] based on Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD).
- Analyze major parameters that effect the web crippling resistance.
- Add new coefficients and compare them with current design criteria.
- Add new test data to the database.

Some of the program's interfaces are shown in Appendix B. The program was used in conjunction with the statistical software package known as Statistical Analysis System (SAS). SAS is a well-known software package, where the model can be specified and the coefficients that minimize the sum of the squares of the residuals are computed.

4.4 Test Data used in Developing the New Coefficients

The current American specification (AISI-96) [1] has introduced the web crippling expressions under two different section types, I-sections and shapes having single webs, which include C-and Z-sections, hat sections and multi-web (deck) sections. Knowing that the rotational restraint of the web (boundary condition of the web plate) is a major factor that affects it's in-plane load carrying capacity, one can conclude that the web crippling behavior of each section mentioned in the single web category is different. Treating all of these sections as single web elements does not reflect the actual web crippling behavior, as will be discussed later in this chapter.

On other hand, the current Canadian Standard (S136-94) [8] considers C and Z-sections as shapes having single webs but hat and deck sections as multi-web shapes, which is considered closer to the actual web crippling behavior, as will be shown later in this chapter.

Based on the above discussion, a separation and reorganization of the test data was necessary in order to obtain an accurate evaluation of the true web crippling behavior. More than a thousand test data points were collected from ten different sources, (as shown in Table 4.2) in addition to the results from this experimental study. The data was organized into the following categories:

1- I-sections
2- Single web sections (C-and Z-sections)
3- Single hat sections
4- Multi-web sections

Additional separations were made based on whether or not the section was stiffened or unstiffened, fastened or unfastened, and the load case type (EOF, IOF, ETF, ITF).

4.4.1 Development of New Coefficients for I-Sections

Bhakta [5] showed in his research that fastened I-sections subjected to either EOF or IOF loading have marginal increase in the web crippling resistance in comparison to unfastened I-sections. Also, he mentioned that the web crippling resistance for I-sections depends on the number and location of the web fasteners, which forms a built-up I-section. Based on this study, new and different coefficients were produced for fastened and unfastened I-sections.

Table 4.2 Selected Data Information

Name, Year	University	Country	No. Of Points
1- Winter, 1953 [7]	Cornell	U.S.A.	193
2- Hetrakul, 1978 [11]	Missouri-Rolla	U.S.A.	283
3- Yu 1981 [27]	Missouri-Rolla	U.S.A.	18
4- Wing, 1981 [21]	Waterloo	Canada	219
5- Bhakta, 1992 [5]	Missouri-Rolla	U.S.A.	44
6- Langan, 1994 [14]	Missouri-Rolla	U.S.A.	31
7- Cain, 1995 [6]	Missouri-Rolla	U.S.A.	40
8- Gerges, 1997 [9]	Waterloo	Canada	67
9- Wu, 1997 [24]	Missouri-Rolla	U.S.A.	51
10- Young, 1998 [26]	Sydney	Australia	56
11- Beshara, 1999 (this study)	Waterloo	Canada	72
Total			**1074**

a) Fastened I-Sections

Test data was available only for the IOF loading case. No data was available for the EOF loading case.

i) <u>Interior One Flange Loading (IOF)</u>

Six stiffened section data points from Bhakta [5] and 12 stiffened section data points from Cain [6] were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.1 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.1 of Appendix C.

As discussed before, the web crippling resistance depends on the location of web fasteners (Bhakta [5]), i.e., the closer the web fasteners to the flanges the larger the web crippling resistance. The Bhakta [5] and Cain [6] data were based on the same built-up

I-section pattern where the location of the web fasteners were close to the center of gravity of the C-sections (1.5 inch or 39 mm above and below the section center line, as shown in Figure 2.8). Their built-up I-sections experienced rather low web crippling resistances than the expected by AISI-96 expressions (which were based on unfastened I-sections with web fasteners close to the flanges) as shown in Table C.1. The new coefficients represent the statistical regression of the test data and they are considered conservative for fastened I-sections with web fasteners closer to the flanges.

b) Unfastened I-Sections

Test data was available for all load cases (EOF, IOF, ETF, and ITF) from previous researchers, hence, new coefficients were produced for each load case based on this data.

i) End One Flange Loading (EOF):

86 stiffened section data points were used in the statistical regression analysis as follows:

30 data points from Cornell [7], 50 from Hetrakul [11] and 6 from Bhakta [5] were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.2 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.2 of Appendix C.

ii) Interior One Flange Loading (IOF):

29 stiffened section data points were used in the statistical regression analysis as follows:

10 test data points from Cornell [7] and 19 from Hetrakul [11] were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.3 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.3 of Appendix C.

iii) <u>End Two Flange Loading (ETF):</u>

57 stiffened section data points were used in the statistical regression analysis as follows:

27 test data points from Cornell [7] and 30 from Hetrakul [11] were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.4 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.4 of Appendix C.

iv) <u>Interior Two Flange Loading (ITF):</u>

66 stiffened section data points were used in the statistical regressions analysis as follows:

36 test data points from Cornell [7] and 30 from Hetrakul [11] were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.5 of Appendix C.

A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.5 of Appendix C.

Since the web crippling resistance depends on the number and location of the web fasteners (Bhakta) [5], which varies from researcher to researchers, resulting in a considerable scatter in the load ratio, P_t/P_c as can be observed from the Charts. The current AISI-96 method results in a better estimation of the web crippling resistance for the unfastened ETF and ITF load cases, while the new coefficients result in better estimation for other cases.

For unstiffened-unfastened sections, there were only four test data points for EOF and two for IOF from Hetrakul [11]. The new coefficients results in good estimation values for these tests, which implies that there is no major difference in the web crippling resistance between stiffened and unstiffened I-sections. Parameters and test data of the specimens for unstiffened-unfastened sections, EOF and IOF, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values are given in Tables C.6 and C.7 of Appendix C.

The new coefficients (C, C_R, C_N, C_H) are summarized in Table 4.3 for all the above-mentioned cases. Number of test data for each researcher used to develop the design expressions for AISI-96, S136-94 and the new coefficients are listed in Table 4.4. Parameter ranges for test data are shown in Table 4.5.

Table 4.3 New Coefficients for I-Sections

Support and Flange Conditions		Load Cases		C	C_R	C_N	C_H
FASTENED TO SUPPORT	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	10	0.14	0.28	0.001
			Interior	20	0.15	0.05	0.003
UNFASTENED	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	10	0.14	0.28	0.001
			Interior	20.5	0.17	0.11	0.001
		Two - Flange Loading or Reaction	End	15.5	0.09	0.08	0.04
			Interior	36	0.14	0.08	0.04
	Unstiffened Flanges	One - Flange Loading or Reaction	End	10	0.14	0.28	0.001
			Interior	20.5	0.17	0.11	0.001

Table 4.4 Number of the Test Data Used to Develop Design Expressions for I - Sections

Section			S136-94 [8]	AISI-96 [1]	New Coefficients
i) Stiffened	a) Fastened	IOF	No Coefficients	No Expression	6 Bhakta,UMR,1992 [5] 12 Cain,UMR,1995 [6]
	b) Unfastened	1) EOF	30 Cornell,1953 [7] 42 (38 Stiff.+ 4 Unstiff.)Hetrakul,UMR,1978 [11] 72 Total	30 Cornell,1953 [7] 46 (42 Stiff.+ 4 Unstiff.)Hetrakul,UMR,1978 [11] 76 Total	30 Cornell,1953 [7] 50 Hetrakul,UMR,1978 [11] 6 Bhakta,UMR,1992 [5] 86 Total
		2) IOF	10 Cornell,1953 [7] 17 (15 Stiff.+ 2 Unstiff.)Hetrakul,UMR,1978 [11] 27 Total	10 Cornell,1953 [7] 21 (19 Stiff.+ 2 Unstiff.)Hetrakul,UMR,1978 [11] 31 Total	10 Cornell,1953 [7] 19 Hetrakul,UMR,1978 [11] 29 Total
		3) ETF	27 Cornell,1953 [7] 26 Hetrakul,UMR,1978 [11] 53 Total	27 Cornell,1953 [7] 30 Hetrakul,UMR,1978 [11] 57 Total	27 Cornell,1953 [7] 30 Hetrakul,UMR,1978 [11] 57 Total
		4) ITF	36 Cornell,1953 [7] 26 Hetrakul,UMR,1978 [11] 62 Total	36 Cornell,1953 [7] 30 Hetrakul,UMR,1978 [11] 66 Total	36 Cornell,1953 [7] 30 Hetrakul,UMR,1978 [11] 66 Total
ii) Unstiffened	Unfastened	1) EOF	Same expression for Stiffened	Same expression for Stiffened	4 Hetrakul,UMR,1978 [11] (Same Coeff. for stiff. Unfast.)
		2) IOF	Same expression for Stiffened	Same expression for Stiffened	2 Hetrakul,UMR,1978 [11] (Same Coeff. for stiff. Unfast.)

Table 4.5 I – Section Data Prameter Ranges

Section			Researcher's Name	No. of Points	t min to t max (mm)	F_y min to F_y max (MPa)	h/t min to h/t max (ratio)	r/t min to r/t max (ratio)	n/t min to n/t max (ratio)
i) Stiffened	a) Fastened	IOF	Bhakta, UMR, 1992 [5]	6	1.600 to 2.769	390.8 to 431.8	68.2 to 134.0	1.4 to 5.0	48.2 to 83.3
			Cain, UMR, 1995 [6]	12	1.702 to 2.159	421.6 to 436.3	88.3 to 112.0	1.8 to 2.3	61.8 to 78.4
	b) Unfastened	1) EOF	Cornell, 1953 [7]	30	1.168 to 3.754	208.0 to 259.0	25.5 to 170.4	1.0 to 1.0	6.8 to 54.4
			Hetrakul, UMR, 1978 [11]	50	1.168 to 2.743	230.5 to 370.5	46.9 to 249.8	1.0 to 2.7	13.3 to 123.2
			Bhakta, UMR, 1992 [5]	6	1.600 to 2.769	390.8 to 431.8	68.2 to 131.2	1.4 to 5.0	48.2 to 83.3
		2) IOF	Cornell, 1953 [7]	10	1.168 to 3.124	208.0 to 259.0	61.9 to 168.2	1.0 to 1.0	8.1 to 38.6
			Hetrakul, UMR, 1978 [11]	19	1.156 to 1.308	230.5 to 370.5	139.0 to 247.0	1.8 to 2.6	19.4 to 65.9
		3) ETF	Cornell, 1953 [7]	27	1.168 to 3.754	208.0 to 259.0	25.5 to 170.4	1.0 to 1.0	6.8 to 54.4
			Hetrakul, UMR, 1978 [11]	30	1.168 to 2.743	230.5 to 324.6	47.0 to 260.7	1.0 to 2.7	13.3 to 65.2
		4) ITF	Cornell, 1953 [7]	36	1.168 to 3.754	208.0 to 259.0	25.5 to 170.4	1.0 to 1.0	6.8 to 54.4
			Hetrakul, UMR, 1978 [11]	30	1.168 to 2.743	230.5 to 324.6	46.9 to 254.7	1.0 to 2.7	13.3 to 65.2
ii) Unstiffened	Unfastened	1) EOF	Hetrakul, UMR, 1978 [11]	4	1.232 to 1.245	249.8 to 249.8	95.7 to 195.1	1.0 to 1.0	61.2 to 61.9
		2) IOF	Hetrakul, UMR, 1978 [11]	2	1.245 to 1.245	249.8 to 249.8	192.7 to 193.1	1.0 to 1.0	61.2 to 61.2

4.4.2 Development of New Coefficients for Single Web Sections

A preliminary study showed that unfastened Z-sections have a considerable lower web crippling resistance than fastened Z-sections, unfastened C-sections and fastened C-sections. Also, it was shown that there is a difference in web crippling resistance between stiffened and unstiffened flanges. Bhakta [5] reported a 30% increase in the web crippling resistance for Z-section subjected to EOF loading if the specimen is fastened to the bearing plate. In this study, new coefficients were produced for stiffened and unstiffened, fastened and unfastened C-and Z-sections subjected to the four load cases (EOF, IOF, ETF, ITF).

1- Stiffened Flange Sections:

New coefficients were developed for stiffened flanges based on the available test data as follows:

a) Fastened

Test data was available for C- and Z-sections subjected to EOF load, in addition to the tests, which were carried out in this study for both C-and Z-sections under ETF and ITF load cases.

i) <u>End One Flange Loading (EOF):</u>

As mentioned above, there is no difference in the web crippling resistance for fastened C-and Z-sections. 81 test data points for C-sections and 18 test data points for Z-sections were used in the statistical regression analysis as follows:

Eight test data points from Hetrakul [11], 10 Bhakta [5], 14 from Cain [6] and 67 from Gerges [9], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.8 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.6 of Appendix C.

ii) <u>End Two Flange Loading (ETF):</u>

C-sections:

18 test data points from the experimental investigation of this study, were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.9 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.7 of Appendix C.

Z-sections:

18 test data points form the experimental investigation of this study, were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.10 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.8 of Appendix C.

iii) Interior Two Flange Loading (ITF):

C-sections:

18 test data points form the experimental investigation of this study, were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.11 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.9 of Appendix C.

Z-sections:

18 test data points form the experimental investigation of this study, were used in the statistical regression to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.12 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.10 of Appendix C.

b) Unfastened

Test data for C-sections was available for all load cases (EOF, IOF, ETF and ITF), and for Z-sections only for EOF loading case. New coefficients were produced for each load case.

i) End One Flange Loading (EOF):

Because there is a difference in the web crippling resistance between unfastened C-and Z-sections, new coefficients were developed for each section separately.

Z-sections:

18 test data points were used in the statistical regression analysis as follows: Four test data points from Bhakta [5], and 14 from Cain [6], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.13 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.11 of Appendix C.

C-sections:

63 test data points were used in the statistical regression analysis as follows: 34 test data points from Hetrakul [11], six from Bhakta [5] and 23 from Langan [14], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94

and the new coefficients compared with the tested values, are given in Table C.14 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.12 of Appendix C.

ii) Interior One Flange Loading (IOF):

32 test data points were used in the statistical regressions analysis as follows: 24 test data points from Hetrakul [11] and eight from Langan [14], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.15 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.13 of Appendix C.

iii) End Two Flange Loading (ETF):

26 test data points taken from Hetrakul [11], were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.16 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.14 of Appendix C.

iv) Interior Two Flange Loading (ITF):

26 test data points taken from Hetrakul [11], were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.17 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.15 of Appendix C.

2- Unstiffened Flange Sections

Test data was available only for unfastened C-sections for the four load cases (EOF, IOF, ETF and ITF). New coefficients are produced for each loading case.

i) <u>End One Flange Loading (EOF):</u>

32 test data points were used in the statistical regression analysis as follows:

18 test data points from Hetrakul [11] and 14 from Young [26], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.18 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.16 of Appendix C.

ii) <u>Interior One Flange Loading (IOF):</u>

20 test data points were used in the statistical regression analysis as follows:

Four test data points from Hetrakul [11] and 16 from Young [26], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.19 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.17 of Appendix C.

iii) <u>End Two Flange Loading (ETF):</u>

16 test data points were used in the statistical regression analysis as follows:

Four test data points from Hetrakul [11] and 12 Young [26], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.20 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.18 of Appendix C.

iv) Interior Two Flange Loading (ITF):

18 test data points were used in the statistical regression analysis as follows: Four test data points from Hetrakul [11] and 14 from Young [26], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.21 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.19 of Appendix C.

Since there was no test data for fastened C-sections subjected to IOF loading, the new coefficients for unfastened C-sections subjected to IOF loading can be used for that case as a conservative solution. Summarized in Table 4.6 are the new coefficients (C, C_R, C_N, C_H) for the above-mentioned cases. Number of test data for each researcher used to develop the design expressions for AISI-96, S136-94 and the new coefficients are listed in Table 4.7. Parameter ranges for the selected test data are shown in Table 4.8.

Table 4.6 New Coefficients for Single Web Sections

Support and Flange Conditions		**Load Cases**		**Section Type**	**C**	**C_R**	**C_N**	**C_H**
FASTENED TO SUPPORT	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	C & Z	4	0.14	0.35	0.02
			Interior	C	13	0.23	0.14	0.01
		Two - Flange Loading or Reaction	End	C	7.5	0.08	0.12	0.048
				Z	9	0.05	0.16	0.052
			Interior	C	20	0.10	0.08	0.031
				Z	24	0.07	0.07	0.04
UNFASTENED	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	C	4	0.14	0.35	0.02
				Z	5	0.09	0.02	0.001
			Interior	C	13	0.23	0.14	0.01
		Two - Flange Loading or Reaction	End	C	13	0.32	0.05	0.04
			Interior	C	24	0.52	0.15	0.001
	Unstiffened Flanges	One - Flange Loading or Reaction	End	C	4	0.40	0.60	0.03
			Interior	C	13	0.32	0.10	0.01
		Two - Flange Loading or Reaction	End	C	2	0.11	0.37	0.01
			Interior	C	13	0.47	0.25	0.04

Table 4.7 Number of the Test Data Used to Develop Design Expressions for Single Web Sections

Section			S136-94 [8]	AISI-96 [1]	New Coefficients
i) Stiffened	a) Fastened	1) EOF	No Coefficients	No Expression	For C: 8 Hetrakul,UMR,1978 [11] 6 Bhakta,UMR,1992 [5] 67 Gerges,UW,1997 [9] 81 Total For Z: 4 Bhakta,UMR,1992 [5] 14 Cain,UMR,1995 [6] 18 Total (99 test points used in regression)
		2) ETF	No Coefficients	No Expression	For C: 18 Beshara,UW,1999* For Z: 18 Beshara,UW,1999*
		2) ITF	No Coefficients	No Expression	For C: 18 Beshara,UW,1999* For Z: 18 Beshara,UW,1999*
	b) Unfastened	1) EOF	22 C (Stiff.-Unfast.)Hetrakul,UMR,1978 [11] 8 C (Stiff.-Fast.)Hetrakul,UMR,1978 [11] 38 Single Hat-Cornell,1953 [7] 68 Total	26 C (Stiff.-Unfast.)Hetrakul,UMR,1978 [11] 8 C (Stiff.-Fast.)Hetrakul,UMR,1978 [11] 8 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 36 Single Hat-Cornell,1953 [7] 78 Total	For C: 34 Hetrakul,UMR,1978 [11] 6 Bhakta,UMR,1992 [5] 23 Langan,UMR,1994 [14] 63 Total For Z: 4 Bhakta,UMR,1992 [5] 14 Cain,UMR,1995 [6] 18 Total
		2) IOF	16 C (Stiff.-Unfast.)Hetrakul,UMR,1978 [11] 4 C (Stiff.-Fast.)Hetrakul,UMR,1978 [11] 4 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 30 Single Hat-Cornell,1953 [7] 54 Total	20 C (Stiff.-Unfast.)-Hetrakul,UMR,1978 [11] 4 C (Stiff.-Fast.)Hetrakul,UMR,1978 [11] 4 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 30 Single Hat-Cornell,1953 [7] 58 Total	For C: 24 Hetrakul,UMR,1978 [11] 8 Lnagan,UMR,1994 [14] 32 Total
		3) ETF	22 C (Stiff.-Unfast.)Hetrakul,UMR,1978 [11] 4 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 26 Total	26 C (Stiff.-Unfast.)Hetrakul,UMR,1978 [11] 4 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 30 Total	For C: 26 Hetrakul,UMR,1978 [11]
		4) ITF	22 C (Stiff.-Unfast.)Hetrakul,UMR,1978 [11] 4 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 26 Total	26 C (Stiff.-Unfast.)Hetrakul,UMR,1978 [11] 4 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 30 Total	For C: 26 Hetrakul,UMR,1978 [11]

* Experimental work of this study

Table 4.7 Continued - Number of the Test Data Used to Develop Design Expressions for Single Web Sections

Section			S136-94 [8]	AISI-96 [1]	New Coefficients
i) Unstiffened	Unfastened	1) EOF	8 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 22 Single Hat-Cornell,1953 [7] 30 Total	8 C (Unstiff.-Unfast.)Hetrakul,UMR,1978 [11] 24 Single Hat-Cornell,1953 [7] 32 Total	For C: 18 Hetrakul,UMR,1978 [11] 14 Young,Sydney,1998 [26] 32 Total
		2) IOF	Same Stiffened Coefficients	Same Stiffened Expression	For C: 4 Hetrakul,UMR,1978 [11] 16 Young,Sydney,1998 [26] 20 Total
		3) ETF	Same Stiffened Coefficients	Same Stiffened Expression	For C: 4 Hetrakul,UMR,1978 [11] 12 Young,Sydney,1998 [26] 16 Total
		4) ITF	Same Stiffened Coefficients	Same Stiffened Expression	For C: 4 Hetrakul,UMR,1978 [11] 14 Young,Sydney,1998 [26] 18 Total

Table 4.8 Single Web Data Parameter Ranges

Section			Researcher's Name	No. of Points	t min to t max (mm)	F_y min to F_y max (MPa)	h/t min to h/t max (ratio)	r/t min to r/t max (ratio)	n/t min to n/t max (ratio)
i) Stiffened	a) Fastened	1) EOF	Hetrakul, UMR, 1978 [11]	8	1.270 to 1.295	324.6 to 324.6	91.7 to 141.6	1.7 to 1.9	19.7 to 60.0
			Bhakta, UMR, 1992 [5]	10	1.600 to 2.769	390.8 to 447.0	68.3 to 132.7	1.4 to 5.0	24.1 to 41.7
			Gerges, UW, 1997 [9]	67	1.280 to 1.280	321.0 to 321.0	96.1 to 222.7	5.0 to 9.3	23.4 to 78.9
			Cain, UMR, 1995 [6]	14	1.499 to 2.108	391.9 to 508.2	69.9 to 150.5	3.0 to 4.2	31.6 to 44.5
		2) ETF	Beshara, UW, 1999*	36	1.160 to 1.450	323.0 to 448.0	60.1 to 195.2	4.8 to 12.1	20.7 to 69.7
		3) ITF	Beshara, UW, 1999*	36	1.160 to 1.450	323.0 to 448.0	60.1 to 195.2	4.8 to 12.1	20.7 to 87.1
	b) Unfastened	1) EOF	Hetrakul, UMR, 1978 [11]	34	1.194 to 1.321	254.0 to 370.5	73.1 to 253.2	1.2 to 2.8	19.6 to 140.9
			Bhakta, UMR, 1992 [5]	10	1.600 to 2.769	390.8 to 447.0	68.8 to 132.6	1.4 to 5.0	24.1 to 41.7
			Langan, UMR, 1994 [14]	23	0.838 to 1.956	234.2 to 640.6	33.6 to 192.3	2.0 to 4.7	13.0 to 30.3
			Cain, UMR, 1995 [6]	14	1.499 to 2.108	391.9 to 508.2	69.9 to 150.5	3.0 to 4.2	31.6 to 44.5
		2) IOF	Hetrakul, UMR, 1978 [11]	24	1.207 to 1.283	301.8 to 324.6	116.7 to 249.2	1.7 to 2.8	19.9 to 62.5
			Langan, UMR, 1994 [14]	8	0.838 to 1.143	365.1 to 495.9	72.4 to 167.6	3.5 to 4.7	66.7 to 121.2
		3) ETF	Hetrakul, UMR, 1978 [11]	26	1.168 to 1.308	301.8 to 324.6	90.0 to 255.1	1.8 to 2.7	19.4 to 63.8
		4) ITF	Hetrakul, UMR, 1978 [11]	26	1.194 to 1.326	301.8 to 324.6	88.7 to 252.6	1.7 to 2.7	19.3 to 63.8
ii) Unstiffened	Unfastened	1) EOF	Hetrakul, UMR, 1978 [11]	18	1.232 to 1.295	249.8 to 283.7	94.4 to 193.1	0.9 to 1.6	20.4 to 140.0
			Young,Sydney,1998 [26]	14	3.820 to 4.740	275.0 to 415.0	16.9 to 38.3	0.9 to 1.1	7.9 to 19.4
		2) IOF	Hetrakul, UMR, 1978 [11]	4	1.245 to 1.245	249.8 to 249.8	96.1 to 192.2	1.0 to 1.0	61.2 to 61.2
			Young,Sydney,1998	16	3.810 to 4.740	275.0 to 415.0	16.9 to 38.4	0.9 to 1.1	7.9 to 19.5
		3) ETF	Hetrakul, UMR, 1978 [11]	4	1.232 to 1.245	249.8 to 249.8	96.7 to 192.9	1.0 to 1.0	61.2 to 61.9
			Young,Sydney,1998 [26]	12	1.470 to 4.830	275.0 to 550.0	16.2 to 62.7	0.6 to 1.2	7.9 to 51.0
		4) ITF	Hetrakul, UMR, 1978 [11]	4	1.245 to 1.257	249.8 to 249.8	94.2 to 193.9	1.0 to 1.0	60.6 to 61.2
			Young,Sydney,1998 [26]	14	1.460 to 4.820	275.0 to 550.0	16.2 to 62.7	0.6 to 1.2	7.9 to 51.0

*** Experimental work of this study**

4.4.3 Development of New Coefficients for Single Hat Sections

Test data was available for fastened EOF, IOF, ETF and ITF loading and for unfastened EOF and IOF loading , hence, new coefficients were produced for each loading case.

i) End One Flange Loading (EOF):

62 unfastened test data points were used in the statistical regression analysis as follows:

60 unfastened test data points from Cornell [7] and two from Bhakta [5], were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.22 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.20 of Appendix C

Because there was not enough fastened data, only five fastened data points were available, two from Bhakta [5] and three from Wu [24]. The new unfastened coefficients can be used as a conservative solution for the fastened case. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values are given in Table C.23 of Appendix C.

ii) Interior One Flange Loading (IOF):

A preliminary study showed that there is no difference in the web crippling resistance between fastened and unfastened sections for the IOF loading case. Based on this study, the new coefficients were developed based on both the fastened and unfastened data. 55 test data points were used in the statistical regression analysis as follows:

25 fastened test data points from Wing [21] and 30 unfastened test data points from Cornell [7], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given

in Table C.24 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.21 of Appendix C

iii) <u>End Two Flange Loading (ETF):</u>

17 fastened test data points from Wing [21], were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.25 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.22 of Appendix C.

iv) <u>Interior Two Flange Loading (ITF):</u>

23 fastened test data points from Wing [21] were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.26 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.23 of Appendix C.

The new coefficients (C, C_R, C_N, C_H) are summarized in Table 4.9 for all above-mentioned cases. Number of test data for each researcher used to develop the design expressions for AISI-96, S136-94 and the new coefficients are listed in Table 4.10. Parameter ranges for the selected test data are shown in Table 4.11

Table 4.9 New Coefficients for Single Hat Sections

Support Conditions	**Load Cases**		**C**	**C_R**	**C_N**	**C_H**
FASTENED TO SUPPORT	One - Flange Loading or Reaction	End	4	0.25	0.68	0.04
		Interior	17	0.13	0.13	0.04
	Two - Flange Loading or Reaction	End	9	0.10	0.07	0.03
		Interior	10	0.14	0.22	0.02
UNFASTENED	One - Flange Loading or Reaction	End	4	0.25	0.68	0.04
		Interior	17	0.13	0.13	0.04

Table 4.10 Number of the Test Data Used to Develop Design Expressions for Single Hat Sections

Section		S136-94 [8]	AISI-96 [1]	New Coefficients
a) Fastened	1) EOF	No Coefficients	No Expression	2 Bhakta,UMR,1992 [5] 3 Wu,UMR,1997 [24] 5 Total (Same Coeff. For Unfastened)
	2) IOF	No Coefficients	No Expression	25 Wing,UW,1981 [21] (used with the unfastened data in regression)
	3) ETF	No Coefficients	No Expression	17 Wing,UW,1981 [21]
	4) ITF	No Coefficients	No Expression	23 Wing,UW,1981 [21]
b) Unfastened	1) EOF	Included in Single Web Expression	Included in Single Web Expression	60 Cornell,1953 [7] 2 Bhakta,UMR,1992 [5] 62 Total
	2) IOF	Included in Single Web Expression	Included in Single Web Expression	30 Cornell,1953 [7] (used with the fastened data in regression)

Table 4.11 Single Hat Data Parameter Ranges

Section		Researcher's Name	No. of Points	t min to t max (mm)	F_y min to F_y max (MPa)	h/t min to h/t max (ratio)	r/t min to r/t max (ratio)	n/t min to n/t max (ratio)
a) Fastened	1) EOF	Bhakta, UMR, 1992 [5]	2	1.245 to 1.245	301.8 to 301.8	145.4 to 145.5	4.1 to 4.1	53.6 to 53.6
		WU, UMR, 1997 [24]	3	0.737 to 0.737	715.7 to 715.7	51.0 to 155.3	4.3 to 4.3	34.5 to 34.5
	2) IOF	Wing, UW, 1981 [21]	25	0.549 to 1.524	230.8 to 317.5	62.0 to 204.0	1.6 to 17.4	16.7 to 208.3
	3) ETF	Wing, UW, 1981 [21]	17	0.610 to 1.539	230.8 to 317.5	28.5 to 323.9	1.6 to 9.1	16.7 to 81.0
	4) ITF	Wing, UW, 1981 [21]	23	0.610 to 1.539	230.8 to 317.5	28.2 to 157.2	1.6 to 10.1	16.7 to 125.0
b) Unfastened	1) EOF	Cornell, 1953 [7]	60	1.130 to 1.839	186.0 to 413.3	37.1 to 193.1	1.0 to 3.0	10.9 to 56.2
		Bhakta, UMR, 1992 [5]	2	1.245 to 1.245	301.8 to 301.8	145.3 to 145.4	4.1 to 4.1	53.6 to 53.6
	2) IOF	Cornell, 1953 [7]	30	1.491 to 1.699	212.8 to 384.4	83.0 to 195.0	1.0 to 3.0	11.3 to 42.6

4.4.4 Development of New Coefficients for Multi-Web Sections

Test data was available for fastened and unfastened EOF, IOF, ETF and ITF loading, hence, new coefficients were produced for each load case.

a) Fastened and Unfastened

i) <u>End One Flange Loading (EOF):</u>

36 unfastened test data points were used in the statistical regression analysis as follows:

18 unfastened test points from Yu [27], two from Bhakta [5] and 16 from Wu [24], were used to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.27 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.24 of Appendix C.

Since only two fastened test data points from Bhakta [5] were available, it was not possible to establish web crippling coefficients for that case. However, the new unfastened coefficients can be used as a conservative solution for the fastened case. Parameters and test data of the specimens for the Bhakta fastened data, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.28 of Appendix C.

ii) <u>Interior One Flange Loading (IOF):</u>

As in single hat sections, a preliminary study showed that there is no difference in web crippling resistance between fastened and unfastened sections for IOF loading. Based on this study, the new coefficients were developed using both the fastened and the unfastened data together. 38 test data points were used in the statistical regression analysis as follows:

34 fastened test data points from Wing [21], two fastened test data points from Bhakta [5] and two unfastened test data points from Bhakta [5], were used to develop

the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.29 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.25 of Appendix C.

b) Fastened

i) <u>End Two Flange Loading (ETF):</u>

A total of 63 fastened test data points from Wing [21], were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.30 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.26 of Appendix C.

ii) <u>Interior Two Flange Loading (ITF):</u>

57 fastened test data points from Wing [21], were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.31 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.27 of Appendix C.

c) Unfastened

i) <u>End Two Flange Loading (ETF):</u>

16 unfastened test data points from Wu [24], were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in

Table C.32 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.28 of Appendix C.

ii) Interior Two Flange Loading (ITF):

16 unfastened test data points from Wu [24], were used in the statistical regression analysis to develop the new coefficients. Parameters and test data of the specimens, as well as the computed values of the web crippling resistance using AISI-96, S136-94 and the new coefficients compared with the tested values, are given in Table C.33 of Appendix C. A comparison between S136-94, AISI-96 and the new coefficients based on P_t/P_c is shown in Chart C.29 of Appendix C.

The new coefficients (C, C_R, C_N, C_H) are summarized in Table 4.12 for the above-mentioned cases. Number of test data for each researcher used to develop the design expressions for AISI-96, S136-94 and the new coefficients are listed in Table 4.13. Parameter ranges for the selected test data are shown in Table 4.14

Table 4.12 New Coefficients for Multi-Web Sections

Support Conditions	Load Cases		C	C_R	C_N	C_H
FASTENED TO SUPPORT	One - Flange Loading or Reaction	End	3	0.08	0.70	0.055
		Interior	8	0.10	0.17	0.004
	Two - Flange Loading or Reaction	End	9	0.12	0.14	0.040
		Interior	10	0.11	0.21	0.020
UNFASTENED	One - Flange Loading or Reaction	End	3	0.08	0.70	0.055
		Interior	8	0.10	0.17	0.004
	Two - Flange Loading or Reaction	End	6	0.16	0.15	0.050
		Interior	17	0.10	0.10	0.046

Table 4.13 Number of the Test Data Used to Develop Design Expressions for Multi-Web Sections

Section		S136-94 [8]	AISI-96 [1]	New Coefficients
a) Fastened	1) EOF	2 (fastened single hat)Bhakta, UMR,1992 [5] 2 (fastened multi-web)Bhakta, UMR,1992 [5] 4 Total	No Expression	2 Bhakta,UMR,1992 [5] (Same coefficients for unfastened)
	2) IOF	31 (unfastened single hat)Cornell,1953 [7] 26 (fastened single hat)Wing,UW,1981 [21] 33 (fastened multi-web) Wing,UW,1981[21] 90 Total	No Expression	34 Wing,UW,1981 [21] 2 Bhakta,UMR,1992 [5] 36 Total (used with the unfasened data in regression)
	3) ETF	17 (fastened single hat)Wing,UW,1981 [21] 63 (fastened multi-web) Wing,UW,1981 [21] 80 Total	No Expression	63 Wing,UW,1981 [21]
	4) ITF	25 (fastened single hat)Wing,UW,1981 [21] 57 (fastened multi-web)Wing,UW,1981 [21] 82 Total	No Expression	57 Wing,UW,1981 [21]
b) Unfastened	1) EOF	No Coefficients	Included in Single Web Expression	18 Yu, UMR,1981 [27] 2 Bhakta,UMR,1992 [5] 16 Wu,UMR,1997 [24] 36 Total
	2) IOF	No Coefficients	Included in Single Web Expression	2 Bhakta,UMR,1992 [5] 2 Total (used with the fasened data in regression)
	3) ETF	No Coefficients	Included in Single Web Expression	16 Wu,UMR,1997 [24]
	4) ITF	No Coefficients	Included in Single Web Expression	16 Wu,UMR,1997 [24]

Table 4.14 Multi-Web Data Parameter Ranges

Section		Researcher's Name	No. of Points	t min to t max (mm)	F_y min to F_y max (MPa)	h/t min to h/t max (ratio)	r/t min to r/t max (ratio)	n/t min to n/t max (ratio)
a) Fastened	1) EOF	Bhakta, UMR, 1992 [5]	2	0.660 to 0.660	396.0 to 396.0	102.8 to 102.9	6.6 to 6.6	101.0 to 101.0
	2) IOF	Wing, UW, 1981 [21]	34	0.508 to 1.549	230.8 to 317.5	72.3 to 207.2	1.5 to 13.0	16.4 to 161.9
		Bhakta, UMR, 1992 [5]	2	0.660 to 0.660	396.0 to 396.0	102.8 to 102.9	6.6 to 6.6	201.9 to 201.9
	3) ETF	Wing, UW, 1981 [21]	63	0.610 to 1.575	230.8 to 337.5	20.6 to 324.3	1.3 to 10.1	16.4 to 125.0
	4) ITF	Wing, UW, 1981 [21]	57	0.610 to 1.539	230.8 to 337.5	20.6 to 207.2	1.3 to 10.0	16.7 to 125.0
b) Unfastened	1) EOF	Yu, UMR, 1981 27]	18	0.721 to 1.240	270.7 to 343.7	38.0 to 99.3	3.1 to 7.1	61.1 to 208.1
		Bhakta, UMR, 1992 [5]	2	0.660 to 0.660	396.0 to 396.0	102.7 to 102.9	6.6 to 6.6	101.0 to 101.0
		WU, UMR, 1997 [24]	16	0.432 to 0.737	715.7 to 774.9	25.9 to 208.3	2.2 to 5.5	34.5 to 58.8
	2) IOF	Bhakta, UMR, 1993 [5]	2	0.660 to 0.660	396.0 to 396.0	102.8 to 103.0	6.6 to 6.6	201.9 to 201.9
	3) ETF	WU, UMR, 1997 [24]	16	0.432 to 0.737	715.7 to 774.9	25.9 to 208.3	2.2 to 5.5	34.5 to 58.8
	4) ITF	WU, UMR, 1997 [24]	16	0.432 to 0.737	715.7 to 774.9	25.9 to 208.3	2.2 to 5.5	34.5 to 58.8

4.5 Summary

New coefficients were developed using a regression analysis for separated and reorganized web crippling test data available in the literature to date. Based on the results of this chapter, the expressions in the current AISI-96 [1] Specification results in reasonable web crippling resistance values for unfastened I-and C-sections with inside bend radius to thickness ratios, R, of less than 6 and yield strengths less than 66.5 ksi (459MPa). However, the expressions underestimate the web crippling resistance for fastened I-and C-sections, and results in random values for single hat and multi-web sections. The current S136-94 [8] Standard results in reasonable values for I-and C-sections, however, it underestimates the web crippling resistance for single hat and multi-web sections in some cases and it yields unacceptable values in other cases.

The new coefficients result in better estimation values of the web crippling resistance for all standard sections and all loading cases than AISI-96 [1] and S136-94 [8]. In some fastened cases there was no test data available in the literature, hence, the unfastened coefficients were used as a conservative solution. Section parameter limits for the test data are shown in Table 4.3, 4.6, 4.9 and 4.12.

CHAPTER 5

CALIBRATION OF THE NEW COEFFICIENTS

5.1 General

There are two different design methods for cold formed steel structures, Allowable Stress Design (ASD) and Limit State Design (LSD), each method is required to achieve efficient and economic designs under a uniform degree of structural safety. Based on a probabilistic concept, the structural safety can be measured in terms of a reliability index, β. To achieve the most conservative and accurate analysis, both of the American Specification and the Canadian Standard introduced a range of β values based on the load action (e.g. gravity load, wind load,…) and the resistance type (e.g. web crippling, shear, connections,…). Presented in this chapter, are the calculations of the calibration factors of the new coefficients for both design methods (ASD, LSD) using the current American and Canadian Specifications [8], [1].

5.2 Allowable Stress Design (ASD)

In the allowable stress design approach, the computed strengths (web crippling, bending moments, shear forces…) are based on the specified nominal or working loads for all applicable load combinations. The allowable design strength is determined by dividing the nominal strength by a factor of safety as follows:

$$R_a = R_n/\Omega \qquad (5.1)$$

Where

R_a = allowable design strength
R_n = nominal strength
Ω = factor of safety

The fundamental nature of the factor of safety is to compensate for uncertainties inherent in the design, fabrication, or erection of building components, as well as uncertainties in the estimation of the applied loads (AISI-96)[1].

The disadvantage of the ASD method is using only one factor of safety for a certain mode of failure, regardless of the combination of applied loads. The use of multiple load factors provides a refinement in the design, which accounts for the different degrees of uncertainties and variabilities in loads. Such a design method is called “Limit States Design” (LSD). Both allowable stress design (ASD) and load and resistance factored design (LRFD) are combined in the current AISI-96 [1] Specification.

5.3 Limit States Design (LSD)

In LSD (as known in Canada), the design performance is checked against various limiting conditions at appropriate load levels; in general, these limits are the ultimate strength limit state and serviceability limit state. Serviceability limit state design checks the structural behavior for excessive deflections or excessive permanent deformations under specified loads. For the strength limit state, the general format of load and resistance factored design, LRFD (as known in United States), the structure is checked for exceedance of the load carrying capacity and can be expressed by the following equation:

$$\sum \gamma_i Q_i \leq \phi R_n \tag{5.2}$$

or

$$R_u \leq \phi R_n \tag{5.3}$$

Where

$R_u = \sum \gamma_i Q_i$ = required strength
R_n = nominal resistance
ϕ = resistance factor
γ_i = load factors
Q_i = load effects
ϕR_n = design strength

The nominal resistance is the strength of the element or member for a given limit state, computed for nominal section properties and for minimum material properties according to the analytical model which defines the strength. For the ultimate strength limit state resistance, the structural member must retain its full capacity up to the factored load levels. This is insured by introducing the resistance factor, ϕ, which is a reduction factor applied to the nominal resistance.

The resistance factor, ϕ, accounts for uncertainties and variabilities inherent in the nominal resistance, R_n, and is usually less than unity. On the other hand, the load effect, Q_i, is the force on the cross section (i.e. axial force, shear force or bending moment) determined from the specified nominal loads by structural analysis while the load factors, γ_i, are corresponding load factors which account for uncertainties and variabilities of the loads.

The advantage of strength limit state design is that the uncertainties and variabilities of varies types of loads are different (e.g. dead load is less variable than wind load), and so these differences can be accounted for by the use of multiple factors, which leads to a more consistent reliability in design [AISI-96].

5.4 Calibration of New Coefficients

Procedures for calculating both the resistance factor, ϕ, for load and resistance factored design (LRFD), and the factor of safety, Ω, for allowable stress design (ASD), are well described by Hsiao [12], Supornsilaphachai [18] and Gerges [9]. The calibration results depend on the dead to the live load factor ratio and the reliability index value, β. The reliability index is a calculated logarithmic type measure of the reliability. When two designs are compared, the one with the larger β is more reliable.

The reliability index, β, for a given structural material (e.g. steel, reinforced concrete, cold formed steel, …) depends on two main factors, the load action type (e.g. wind load, gravity load,…) and the resistance type (e.g. web crippling, bending, shear,…). The target β value for AISI-96 [1] is equal to 2.5, which is recommended as a lower bound value for members. For S136-94 [8], β ranges between 3.0 and 4.0. The general equation for β is as follows:

$$\beta = \frac{\ln\left(R_m/Q_m\right)}{\sqrt{V_R^2 + V_Q^2}} \tag{5.4}$$

Where R_m and Q_m are the mean values of resistance and load effect, respectively. V_R and V_Q are the corresponding coefficients of variation and the R_m value can be determined from the following equation:

$$R_m = R_n M_m F_m P_m \tag{5.5}$$

Where R_n is the nominal resistance, M_m, F_m and P_m are the mean values of the dimensionless random variables reflecting the uncertainties in the material properties, the geometry of the cross section and the prediction of the ultimate resistance, respectively. The mean value for the load effect can be calculated from the following equation:

$$Q_m = C\,(D_m + L_m) \tag{5.6}$$

Where C is a deterministic influence coefficient, which transforms the dead and live load intensities to load effects and D_m and L_m are the mean values of the dead load and the live load intensities, respectively.

$$V_R = \sqrt{V_M^2 + V_F^2 + V_P^2} \tag{5.7}$$

Where V_M, V_F, V_P are coefficients of variation of the dimensionless random variables reflecting the uncertainties in the material properties, the geometry of the cross section, and the prediction of the ultimate resistance, respectively.

$$V_Q = \frac{\sqrt{D_m^2 V_D^2 + L_m^2 V_L^2}}{D_m + L_m} \tag{5.8}$$

or

$$V_Q = \frac{\sqrt{(D_m/L_m)^2 V_D^2 + V_L^2}}{(D_m/L_m) + 1.0} \tag{5.9}$$

Where V_D and V_L are the coefficients of variation of the dead load and the live load intensities, respectively. On the basis of the statistical analysis of the data on yield strength values obtained from tests and cross sectional dimensions from numerous measurements, it is recommended by Hsiao [12] to use the following values:

$$M_m = 1.10,\ F_m = 1.00,\ V_m = 0.10,\ V_F = 0.05 \tag{5.10}$$

Substituting the values of Eq. (5.10) into Eq. (5.5),

$$R_m = (1.10)\,(1.00)\,P_m\,R_n = 1.10\,P_m\,R_n \tag{5.11}$$

Substituting the values of Eq. (5.10) into Eq. (5.7)

$$V_R = \sqrt{(0.10)^2 + (0.05)^2 + V_P^2} = \sqrt{(0.0125) + V_P^2} \tag{5.12}$$

The following values for the mean and coefficients of variation of the dead load and the live load intensities, are recommended by Hsiao [12].

$$D_m = 1.05\,D_n, \quad L_m = L_n \tag{5.13}$$

$$V_D = 0.10, \qquad V_L = 0.25 \tag{5.14}$$

Where D_n and L_n are the nominal values of the dead and live load intensities, respectively. By substituting the values of Eqs. (5.13) & (5.14) into Eq.(5.9)

$$V_Q = \frac{\sqrt{(1.05\,D_n/L_n)^2 (0.10)^2 + (0.25)^2}}{(1.05\,D_n/L_n) + 1.0} \tag{5.15}$$

The dead to live load ratio, D_n / L_n, in the S136-94 Standard is 1/3, while in the AISI-96 Specification is 1/5. Substituting these two values into Eq. (5.15)

For S136-94 $\qquad V_Q = 0.187$ (5.16)

For AISI-96 $\qquad V_Q = 0.207$ (5.17)

5.5 Determination of Factors of Safety, W

The factor of safety for the ASD method can be evaluated by equating the nominal resistance to the effect of service loads multiplied by a certain factor of safety as follows:

$$R_n = \Omega\,C\,(D_n + L_n) \tag{5.18}$$

By substituting the values of Eqs (5.5), (5.6) and (5.18) into Eq. (5.4) we obtain a general equation for the factor of safety.

$$O = \frac{e^{ß\sqrt{V_R^2 + V_Q^2}}}{(M_m F_m P_m)} [1.05 D_n / L_n + 1] / [D_n / L_n + 1] \quad (5.19)$$

Now, substituting the values of Eqs (5.10), (5.12) and (5.16) or (5.17) into Eq. (5.19),

For S136-94 $$O = \frac{e^{ß\sqrt{0.0475 + V_P^2}}}{(1.086 P_m)} \quad (5.20)$$

For AISI-96 $$O = \frac{e^{ß\sqrt{0.0554 + V_P^2}}}{(1.091 P_m)} \quad (5.21)$$

5.6 Determination of Resistance Factors, f

In the LSD and LRFD design methods, the nominal resistance is reduced by a resistance factor ϕ. A satisfactory design from a safety point of view can be obtained by equating the factored resistance to the effect of the factored loads as follows:

$$\phi R_n = C (\alpha_D D_n + \alpha_L L_n)$$

or $$\phi R_n = (\alpha_D D_n / L_n + \alpha_L) C L_n \quad (5.22)$$

By substituting the values of D_n/L_n , α_D and α_L into Eq. (5.22),

For S136-94 $D_n/L_n = 1/3$, $\alpha_D = 1.25$, $\alpha_L = 1.5$

Which gives, $C L_n = \phi R_n/1.917$ (5.23)

For AISI-96 $D_n/L_n = 1/5$, $\alpha_D = 1.2$, $\alpha_L = 1.6$

Which gives, $C L_n = \phi R_n/1.840$ (5.24)

Substituting values of D_m and L_m from Eq. (5.13) into Eq. (5.6)

$$Q_m = (1.05 D_n / L_n + 1.0) C L_n \quad (5.25)$$

Now substituting values of D_n/L_n and CL_n from Eq. (5.23) and (5.24) into Eq. (5.25)

For S136-94 $Q_m = \phi R_n/1.420$ (5.26)

For AISI-96 $Q_m = \phi R_n/1.521$ (5.27)

Substituting in Eq. (5.4) for the value of Q_m from Eq. (5.26) or (5.27) and the value of R_m from Eq. (5.5).

For S136-94
$$\phi = \frac{1.420\,(M_m F_m P_m)}{e^{\beta\sqrt{V_R^2 + V_Q^2}}} \qquad (5.28)$$

For AISI-96
$$\phi = \frac{1.521\,(M_m F_m P_m)}{e^{\beta\sqrt{V_R^2 + V_Q^2}}} \qquad (5.29)$$

Substituting for values of M_m and F_m from Eq. (5.10) and the values of V_R and V_Q from Eqs. (5.12) & (5.16) or (5.17), respectively.

For S136-94
$$\phi = \frac{1.562\,P_m}{e^{\beta\sqrt{0.0475 + V_P^2}}} \qquad (5.30)$$

For AISI-96
$$\phi = \frac{1.673\,P_m}{e^{\beta\sqrt{0.0553 + V_P^2}}} \qquad (5.31)$$

5.7 Recommended Resistance Factors, ϕ, and Factors of Safety, Ω

Based on the available tests in the literature and the predicted web crippling resistances using the new coefficients, the professional factors were determined by using the ratio of P_t/P_c. A new resistance factor, ϕ, and factor of safety, Ω were calculated for each section and loading case individually by using β equal to 2.5 for the American Specification (AISI-96)[1], which is recommended as a lower bound value for members and 3.0 for the Canadian Standard (S136-94) [8]. The increase in resistance factor and the decrease in the factor of safety is due to the improved accuracy of the new web crippling coefficients. The confidence gained with the new coefficients can be observed by comparing the mean and the coefficient of variation for each expression. The new coefficient's mean values and coefficients of variation of the professional factors as well as the recommended resistance factors and the factors of safety for each section and loading case are summarized in Tables 5.1 to 5.

Table 5.1 Resistance Factors and Factors of Safety for I-Sections

Support and Flange Conditions		Load Cases		Tests No.	Mean Value	C.O.V.	S136		AISI	
							W	f	W	f
FASTENED TO SUPPORT	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	Interior	18	1.01	0.06	1.80	0.80	1.67	0.92
UNFASTENED	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	86	1.00	0.21	2.30	0.62	2.03	0.75
			Interior	29	1.01	0.13	1.91	0.75	1.74	0.88
		Two - Flange Loading or Reaction	End	57	1.01	0.21	2.28	0.63	2.01	0.76
			Interior	66	1.00	0.19	2.23	0.65	1.98	0.77

Table 5.2 Resistance Factors and Factors of Safety for Single Web Sections

Support and Flange Conditions		Load Cases		Tests No.	Section Type	Mean Value	C.O.V.	S136		AISI	
								W	f	W	f
FASTENED TO SUPPORT	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	99	C &Z	1.00	0.11	1.91	0.75	1.75	0.88
		Two - Flange Loading or Reaction	End	18	C	1.03	0.12	1.88	0.77	1.72	0.89
				18	Z	1.00	0.12	1.95	0.74	1.78	0.86
			Interior	18	C	1.01	0.13	1.96	0.74	1.78	0.86
				18	Z	1.03	0.18	2.09	0.69	1.88	0.82
UNFASTENED	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	63	C	1.00	0.16	2.06	0.70	1.86	0.83
				18	Z	1.01	0.13	1.96	0.74	1.78	0.86
			Interior	32	C	1.02	0.07	1.79	0.80	1.66	0.92
		Two - Flange Loading or Reaction	End	26	C	1.01	0.06	1.80	0.80	1.67	0.92
			Interior	26	C	1.02	0.19	2.14	0.67	1.92	0.80
	Unstiffened Flanges	One - Flange Loading or Reaction	End	32	C	1.01	0.14	1.99	0.72	1.80	0.85
			Interior	20	C	1.01	0.15	2.01	0.71	1.82	0.84
		Two - Flange Loading or Reaction	End	16	C	1.01	0.20	2.21	0.65	1.96	0.78
			Interior	18	C	1.00	0.19	2.18	0.66	1.94	0.79

Table 5.3 Resistance Factors and Factors of Safety for Single Hat Sections

Support Conditions	Load Cases		Tests No.	Mean Value	C.O.V.	S136		AISI	
						W	f	W	f
FASTENED TO SUPPORT	One - Flange Loading or Reaction	Interior	25	1.01	0.17	2.11	0.68	1.89	0.81
	Two - Flange Loading or Reaction	End	17	1.02	0.11	1.89	0.76	1.73	0.89
		Interior	23	1.0	0.12	1.96	0.73	1.79	0.86
UNFASTENED	One - Flange Loading or Reaction	End	62	1.01	0.21	2.26	0.64	2.00	0.77
		Interior	30	1.05	0.14	1.88	0.76	1.71	0.90

Table 5.4 Resistance Factors and Factors of Safety for Multi-Web Sections

Support Conditions	Load Cases		Tests No.	Mean Value	C.O.V.	S136		AISI	
						W	f	W	f
FASTENED TO SUPPORT	One - Flange Loading or Reaction	Interior	36	1.02	0.12	1.92	0.75	1.76	0.87
	Two - Flange Loading or Reaction	End	63	1.00	0.14	2.02	0.71	1.83	0.84
		Interior	57	1.01	0.11	1.91	0.76	1.75	0.88
UNFASTENED	One - Flange Loading or Reaction	End	36	1.00	0.28	2.68	0.53	2.29	0.67
	Two - Flange Loading or Reaction	End	16	1.01	0.05	1.78	0.81	1.65	0.93
		Interior	16	1.01	0.05	1.78	0.81	1.65	0.93

CHAPTER 6

CONCLUSIONS

6.1 Summary

The objective of this research was to study the structural behaviour of cold formed steel single web C and Z-sections subjected to web crippling, and 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 or not. As well, the inside bend radius to thickness ratios, R, was extended up to 12 and the specimen length was more than five times the depth. All test specimens were subjected to end two flange loading, ETF, and interior two flange loading, ITF. Since the accuracy of the current North American cold formed steel web crippling design expressions is being considered, the development of new web crippling design coefficients became the main objective of this study.

A theoretical background of web crippling and the current North American design expressions was carried out and presented in Chapter 2 on literature review. Due to the mathematical complexities involved in the theoretical analysis of the post bucking behavior of thin plate elements subjected to in-plane patch loading and the modeling of the web-flange interaction, it is apparent that experimental testing is the most suitable and reliable approach to establish the web crippling resistance of cold formed steel members.

An experimental study was carried out for the purpose of obtaining the web crippling resistance for C and Z-sections subjected to end two flange loading, ETF, and interior two flange loading, ITF, that were fastened to the support. A total of 72 tests were carried out as follows:

- 18 tests of fastened C-sections subjected to ETF
- 18 tests of fastened Z-sections subjected to ETF
- 18 tests of fastened C-sections subjected to ITF
- 18 tests of fastened Z-sections subjected to ITF

The test program was designed in order to determine the influences of various parameters (t, F_y, h, r, n) on web crippling. Test specimens were assembled 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 data found in the literature and on this experimental investigation, the present design expressions, S136-94 [8] and AISI-96 [1], were found to underestimate the web crippling resistances for most tested sections. For some tested specimens, the degree of underestimation was more than 100%.

An extensive Statistical analysis of web crippling for cold formed steel sections was carried out using the available experimental data, which was taken from ten sources cited in the literature, in addition to the experimental work of this study. The objective of this analysis was to develop new coefficients for the current Canadian Standard (S136-94) [8] web crippling expressions. This was done because the expression includes all of the major parameters and can fit the common section types, as well as, the four load cases, which makes it one of the most reliable unified web crippling expression available. A software program was developed using Visual Basic that was built on a database, which includes all of the available test data. The data was separated and reorganized according to section type (I-sections, single-web sections, hat sections and multi-web sections), fasten status (fastened to support and unfastened to support) and loading condition (EOF, IOF, ETF, ITF).

Finally, the proposed new web crippling coefficients were used in the calibration of the safety requirements in accordance with both the Canadian Standard [8] and the American Specification [1]. The calibration results showed an increase in the resistance factor and a decrease in the factor of safety due to the improved accuracy of the new web crippling prediction coefficients.

6.2 Design Recommendations

Based on the conclusions of this study, it is recommended that the results summarized in Table 6.1 be used for the design of built-up members (I-sections), Table 6.2 is recommended for the design of single web sections (C and Z-sections), Table 6.3 is recommended for the design of single hat sections and Table 6.4 is recommended for the design of multi-web (deck) sections. Since there are not enough test data for some fastened cases, i.e., C-sections subjected to IOF, single hat subjected to EOF and multi-web sections subjected to EOF, it is recommended that the unfastened coefficients be used as a conservative approach (Bhakta [5]). Section parameter limits are based on the test data were used in statistical regression and are summarized in each table.

6.3 Recommendations for Future Work

Based on the experimental work carried out in this study, it was found that the length of the specimen played an important role in the web crippling resistance, especially for the ITF load case. Also, it was found that the length of the edge stiffener (lip) and the flange width have an effect on the web crippling resistance, which is not included in the current design expression. The author recommends that these additional factors be incorporated into the web crippling expression. Since fastened sections represent actual field practice and because of the shortage of fastened test data, the author also recommends that additional tests to be carried out for the following sections and load cases:

- I-sections subjected to ETF loading
- I-sections subjected to ITF loading
- C-and Z sections subjected to IOF loading
- Single hat sections subjected to EOF loading
- Multi-web sections subjected to EOF loading

The reason for the above recommendations for additional testing is to verify the current expressions and to possibly develop new coefficients that will reflect actual practice more accurately.

Table 6.1 Recommended New Coefficients for I-Sections

Support and Flange Conditions		Load Cases		C	C_R	C_N	C_H	S136 [8]		AISI [1]		Parameter Limits
								W	f	W	f	
FASTENED TO SUPPORT	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	10	0.14	0.28	0.001	2.30	0.62	2.03	0.75	H ≤ 249, R ≤ 5.0, N ≤ 123
			Interior	20	0.15	0.05	0.003	1.80	0.80	1.67	0.92	H ≤ 112, R≤ 2.0, N ≤ 83.0
UNFASTENED	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	10	0.14	0.28	0.001	2.30	0.62	2.03	0.75	H ≤ 249, R ≤ 5.0, N ≤ 123
			Interior	20.5	0.17	0.11	0.001	1.91	0.75	1.74	0.88	H ≤ 247, R ≤ 2.6, N ≤ 66.0
		Two - Flange Loading or Reaction	End	15.5	0.09	0.08	0.04	2.28	0.63	2.01	0.76	H ≤ 260, R ≤ 2.7, N ≤ 65.0
			Interior	36	0.14	0.08	0.04	2.23	0.65	1.98	0.77	H ≤ 255 R≤ 2.7, N ≤ 65.0
	Unstiffened Flanges	One - Flange Loading or Reaction	End	10	0.14	0.28	0.001	2.30	0.62	2.03	0.75	H ≤ 249, R ≤ 5.0, N ≤ 123
			Interior	20.5	0.17	0.11	0.001	1.91	0.75	1.74	0.88	H ≤ 247, R ≤ 2.6, N ≤ 78.0

Table 6.2 Recommended New Coefficients for Single Web Sections

Support and Flange Conditions		Load Cases		Section Type	C	C_R	C_N	C_H	S136 [8]		AISI [1]		Parameter Limits
									W	f	W	f	
FASTENED TO SUPPORT	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	C & Z	4	0.14	0.35	0.02	1.91	0.75	1.75	0.88	H ≤ 222, R ≤ 9.0, N ≤ 78.0
			Interior	C	13	0.23	0.14	0.01	1.77	0.80	1.65	0.92	H ≤ 249, R ≤ 5.0, N ≤ 121
		Two - Flange Loading or Reaction	End	C	7.5	0.08	0.12	0.048	1.88	0.77	1.72	0.89	H ≤ 195, R ≤ 12.0, N ≤ 70.0
				Z	9	0.05	0.16	0.052	1.95	0.74	1.78	0.86	H ≤ 195, R ≤ 12.0, N ≤ 70.0
			Interior	C	20	0.10	0.08	0.031	1.96	0.74	1.78	0.86	H ≤ 195, R ≤ 12.0, N ≤ 87.0
				Z	24	0.07	0.07	0.04	2.09	0.69	1.88	0.82	H ≤ 195, R ≤ 12.0, N ≤ 87.0
UNFASTENED	**Stiffened or Partially Stiffened Flanges**	One - Flange Loading or Reaction	End	C	4	0.14	0.35	0.02	2.06	0.70	1.86	0.83	H ≤ 253, R ≤ 5.0, N ≤ 141
				Z	5	0.09	0.02	0.001	1.96	0.74	1.78	0.86	H ≤ 150, R ≤ 5.0, N ≤ 44.0
			Interior	C	13	0.23	0.14	0.01	1.79	0.80	1.66	0.92	H ≤ 249, R ≤ 5.0, N ≤ 121
		Two - Flange Loading or Reaction	End	C	13	0.32	0.05	0.04	1.80	0.80	1.67	0.92	H ≤ 255, R ≤ 3.0, N ≤ 64.0
			Interior	C	24	0.52	0.15	0.001	2.14	0.67	1.92	0.80	H ≤ 253, R ≤ 3.0, N ≤ 64.0
	Unstiffened Flanges	One - Flange Loading or Reaction	End	C	4	0.40	0.60	0.03	1.99	0.72	1.80	0.85	H ≤ 193, R ≤ 2.0, N ≤ 140
			Interior	C	13	0.32	0.10	0.01	2.01	0.71	1.82	0.84	H ≤ 192, R ≤ 1.0, N ≤ 61.0
		Two - Flange Loading or Reaction	End	C	2	0.11	0.37	0.01	2.21	0.65	1.96	0.78	H ≤ 193, R ≤ 1.0, N ≤ 62.0
			Interior	C	13	0.47	0.25	0.04	2.18	0.66	1.94	0.79	H ≤ 194, R ≤ 1.0, N ≤ 61.0

Table 6.3 Recommended New Coefficients for Single Hat Sections

Support Conditions	Load Cases		C	C_R	C_N	C_H	S136 [8]		AISI [1]		Parameter Limits
							W	f	W	f	
FASTENED TO SUPPORT	One - Flange Loading or Reaction	End	4	0.25	0.68	0.04	2.26	0.64	2.00	0.77	H ≤ 155, R ≤ 5.0 N ≤ 54.0
		Interior	17	0.13	0.13	0.04	2.11	0.68	1.89	0.81	H ≤ 204, R ≤ 17.0, N ≤ 208
	Two - Flange Loading or Reaction	End	9	0.10	0.07	0.03	1.89	0.76	1.73	0.89	H ≤ 324, R ≤ 9.0, N ≤ 81.0
		Interior	10	0.14	0.22	0.02	1.96	0.73	1.79	0.86	H ≤ 157, R ≤ 10.0, N ≤ 125
UNFASTENED	One - Flange Loading or Reaction	End	4	0.25	0.68	0.04	2.26	0.64	2.00	0.77	H ≤ 193, R ≤ 4.0, N ≤ 56.0
		Interior	17	0.13	0.13	0.04	1.88	0.76	1.71	0.90	H ≤ 195, R ≤ 3.0, N ≤ 43.0

Table 6.4 Recommended New Coefficients for Multi-Web Sections

Support Conditions	Load Cases		C	C_R	C_N	C_H	S136 [8]		AISI [1]		Parameter Limits
							W	f	W	f	
FASTENED TO SUPPORT	One - Flange Loading or Reaction	End	3	0.08	0.70	0.055	2.68	0.53	2.29	0.67	H ≤ 103, R ≤ 7.0, N ≤ 101
		Interior	8	0.10	0.17	0.004	1.92	0.75	1.76	0.87	H ≤ 207 R ≤ 13.0, N ≤ 202
	Two - Flange Loading or Reaction	End	9	0.12	0.14	0.040	2.02	0.71	1.83	0.84	H ≤ 324 R ≤ 10.0, N ≤ 125
		Interior	10	0.11	0.21	0.020	1.91	0.76	1.75	0.88	H ≤ 207 R ≤ 10.0, N ≤ 125
UNFASTENED	One - Flange Loading or Reaction	End	3	0.08	0.70	0.055	2.68	0.53	2.29	0.67	H ≤ 208, R ≤ 7.0, N ≤ 101
		Interior	8	0.10	0.17	0.004	1.92	0.75	1.76	0.87	H ≤ 103, R ≤ 7.0, N ≤ 202
	Two - Flange Loading or Reaction	End	6	0.16	0.15	0.050	1.78	0.81	1.65	0.93	H ≤ 208, R ≤ 6.0, N ≤ 59.0
		Interior	17	0.10	0.10	0.046	1.78	0.81	1.65	0.93	H ≤208, R ≤ 6.0, N ≤ 59.0

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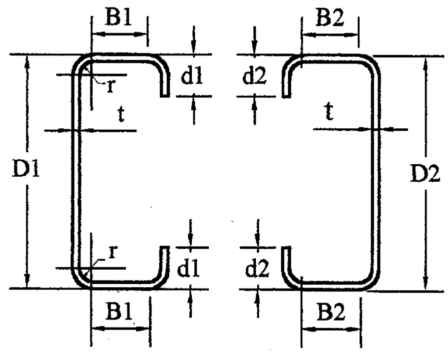
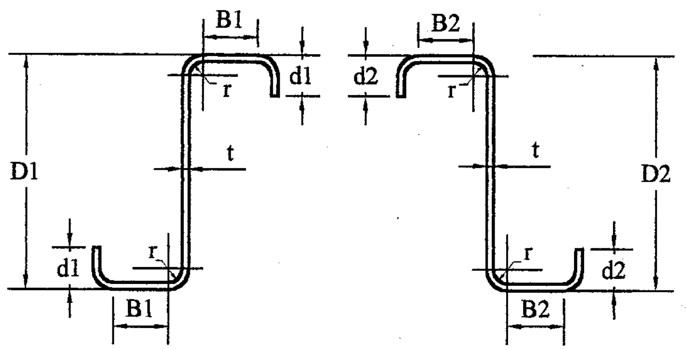
APPENDIX "A"

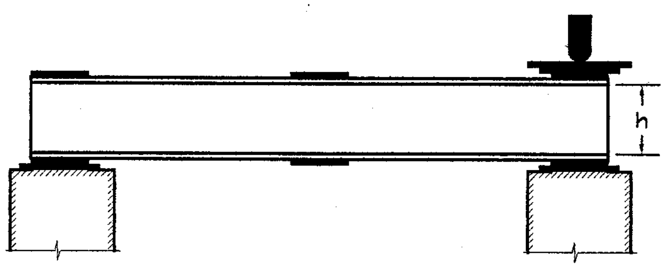
WATERLOO WEB CRIPPLING TEST DATA



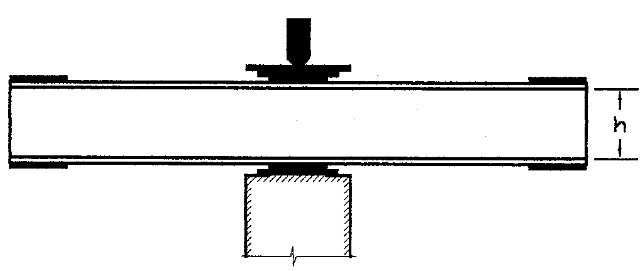
(a) C - Sections



(b) Z - Sections



(c) End Two Flange Loading Test, ETF



(d) Interior Two Flange Loading Test, ITF

Figure A.1 Test Specimen Dimensions

Table A.1

Measured Test Specimen Dimensions, Yield Strengths and Test Loads for C-Sections (ETF)

No.	Specimen	t (mm)	D1 (mm)	D2 (mm)	r (mm)	B1 (mm)	B2 (mm)	d1 (mm)	d2 (mm)	L (mm)	n (mm)	F_y (MPa)	P_t (kN)
1	C-120-7-30-ETF	1.45	121	121	7	45.8	46.0	27.3	27.5	610	30.0	332	3.84
2	C-120-7-60-ETF	1.45	121	121	7	45.8	46.0	27.3	27.5	610	63.5	332	4.74
3	C-120-10-30-ETF	1.45	120	120	10	45.6	45.3	29.0	29.3	610	30.0	332	3.75
4	C-120-10-60-ETF	1.45	120	120	10	45.6	45.3	29.0	29.3	610	63.5	332	4.17
5	C-120-14-100-ETF A	1.45	118	118	14	51.3	51.4	28.2	28.0	610	101	332	4.77
6	C-120-14-100-ETF B	1.45	118	118	14	51.3	51.4	28.2	28.0	610	101	332	4.68
7	C-200-7-30-ETF	1.16	200	200	7	51.9	51.4	32.4	33.0	1220	30.0	328	2.07
8	C-200-7-60-ETF	1.16	200	200	7	51.9	51.4	32.4	33.0	1220	63.5	328	2.46
9	C-200-10-30-ETF	1.16	200	200	10	56.1	56.7	31.6	31.4	1220	30.0	328	2.01
10	C-200-10-60-ETF	1.16	200	200	10	56.1	56.7	31.6	31.4	1220	63.5	328	2.19
11	C-200-14-30-ETF	1.16	200	200	14	61.0	61.1	27.9	28.3	1220	30.0	328	1.95
12	C-200-14-60-ETF	1.16	200	200	14	61.0	61.1	27.9	28.3	1220	63.5	328	2.13
13	C-300-7-30-ETF	1.45	300	300	7	46.8	46.7	16.3	17.0	1500	30.0	448	2.85
14	C-300-7-60-ETF	1.45	300	300	7	46.8	46.7	16.3	17.0	1500	63.5	448	3.27
15	C-300-10-30-ETF	1.45	300	300	10	45.7	47.0	20.5	19.9	1500	30.0	448	2.76
16	C-300-10-60-ETF	1.45	300	300	10	45.7	47.0	20.5	19.9	1500	63.5	448	3.06
17	C-300-14-30-ETF	1.45	299	298	14	51.5	51.9	18.6	19.3	1500	30.0	448	2.67
18	C-300-14-60-ETF	1.45	299	298	14	51.5	51.9	18.6	19.3	1500	63.5	448	2.91

Table A.2

Measured Test Specimen Dimensions, Yield Strengths and Test Loads for Z-Sections (ETF)

No.	Specimen	t (mm)	D1 (mm)	D2 (mm)	r (mm)	B1 (mm)	B2 (mm)	d1 (mm)	d2 (mm)	L (mm)	n (mm)	F_y (MPa)	P_t (kN)
1	Z-120-7-30-ETF	1.45	120	120	7	45.8	45.8	28.0	27.4	610	30.0	332	5.43
2	Z-120-7-60-ETF	1.45	120	120	7	45.8	45.8	28.0	27.4	610	63.5	332	6.18
3	Z-120-10-30-ETF	1.45	120	120	10	45.4	45.9	30.1	29.2	610	30.0	332	5.31
4	Z-120-10-60-ETF	1.45	120	120	10	45.4	45.9	30.1	29.2	610	63.5	332	6.09
5	Z-120-14-30-ETF	1.45	120	120	14	51.4	51.0	29.5	28.3	610	30.0	332	5.25
6	Z-120-14-30-ETF	1.45	120	120	14	51.4	51.0	29.5	28.3	610	63.5	332	5.85
7	Z-200-7-30-ETF	1.16	200	200	7	50.7	50.2	32.6	32.7	1220	30.0	323	2.73
8	Z-200-7-60-ETF	1.16	200	200	7	50.7	50.2	32.6	32.7	1220	63.5	323	2.88
9	Z-200-10-30-ETF	1.16	200	200	10	56.5	56.2	31.3	30.2	1220	30.0	323	2.64
10	Z-200-10-60-ETF	1.16	200	200	10	56.5	56.2	31.3	30.2	1220	63.5	323	2.67
11	Z-200-14-30-ETF	1.16	203	203	14	60.7	60.8	28.1	29.6	1220	30.0	323	2.64
12	Z-200-14-60-ETF	1.16	203	203	14	60.7	60.8	28.1	29.6	1220	30.0	323	2.58
13	Z-300-7-30-ETF	1.45	300	300	7	44.8	45.2	16.5	16.8	1500	30.0	446	3.36
14	Z-300-7-60-ETF	1.45	300	300	7	44.8	45.2	16.5	16.8	1500	63.5	446	3.78
15	Z-300-10-30-ETF	1.45	300	300	10	46.7	46.5	19.3	19.4	1500	30.0	446	3.30
16	Z-300-10-60-ETF	1.45	300	300	10	46.7	46.5	19.3	19.4	1500	63.5	446	3.69
17	Z-300-14-30-ETF	1.45	300	300	14	50.1	50.1	18.8	18.6	1500	30.0	446	3.36
18	Z-300-14-60-ETF	1.45	300	300	14	50.1	50.1	18.8	18.6	1500	635	446	3.66

Table A.3

Measured Test Specimen Dimensions, Yield Strengths and Test Loads for C-Sections (ITF)

No.	Specimen	t (mm)	D1 (mm)	D2 (mm)	r (mm)	B1 (mm)	B2 (mm)	d1 (mm)	d2 (mm)	L (mm)	n (mm)	F_y (MPa)	P_t (kN)
1	C-120-7-30-ITF	1.45	121	121	7	45.9	45.8	27.6	27.3	610	30.0	332	10.7
2	C-120-7-60-ITF	1.45	121	121	7	45.8	46.0	27.5	27.4	610	63.5	332	11.8
3	C-120-10-30-ITF	1.45	121	121	10	45.2	45.6	30.4	29.0	610	30.0	332	9.96
4	C-120-10-60-ITF	1.45	121	121	10	45.1	45.1	30.1	30.1	610	63.5	332	11.0
5	C-120-14-30-ITF	1.45	118	118	14	51.2	51.6	28.2	28.2	610	30.0	332	9.06
6	C-120-14-60-ITF	1.45	118	118	14	51.4	51.3	28.4	28.3	610	63.5	332	10.1
7	C-200-7-30-ITF	1.16	200	200	7	51.0	50.6	32.4	32.2	1220	30.0	328	7.20
8	C-200-7-60-ITF	1.16	200	200	7	50.4	50.9	32.2	32.4	1220	63.5	328	7.56
9	C-200-10-30-ITF	1.16	199	199	10	56.3	56.2	31.3	32.0	1220	30.0	328	6.57
10	C-200-10-60-ITF	1.16	200	200	10	56.6	56.7	31.0	31.3	1220	63.5	328	7.08
11	C-200-14-60-ITF	1.16	201	201	14	61.0	61.1	27.9	28.4	1220	63.5	328	6.72
12	C-200-14-100-ITF	1.16	201	201	14	60.2	60.6	27.8	28.3	1220	101	328	7.08
13	C-300-7-30-ITF	1.45	300	300	7	45.3	46.1	16.3	17.0	1500	30.0	448	11.0
14	C-300-7-60-ITF	1.45	300	300	7	46.8	46.8	15.9	15.8	1500	63.5	448	11.6
15	C-300-10-30-ITF	1.45	299	300	10	45.4	46.7	17.4	18.6	1500	30.0	448	9.99
16	C-300-10-60-ITF	1.45	300	300	10	48.7	48.6	19.4	19.1	1500	63.5	448	10.9
17	C-300-14-60-ITF	1.45	300	300	14	51.7	51.8	18.5	18.6	1500	63.5	448	11.3
18	C-300-14-100-ITF	1.45	300	300	14	50.9	50.8	19.6	18.9	1500	101	448	10.6

Table A.4

Measured Test Specimen Dimensions, Yield Strengths and Test Loads for Z-Sections (ITF)

No.	Specimen	t (mm)	D1 (mm)	D2 (mm)	r (mm)	B1 (mm)	B2 (mm)	d1 (mm)	d2 (mm)	L (mm)	n (mm)	F_y (MPa)	P_t (kN)
1	Z-120-7-30-ITF	1.45	120	120	7	45.5	44.4	28.0	27.5	610	30.0	332	11.7
2	Z-120-7-60-ITF	1.45	120	120	7	45.3	45.0	27.5	28.2	610	63.5	332	13.1
3	Z-120-10-30-ITF	1.45	122	122	10	45.5	44.4	31.3	30.7	610	30.0	332	11.6
4	Z-120-10-60-ITF	1.45	123	123	10	44.7	44.7	31.5	30.9	610	63.5	332	12.6
5	Z-120-14-30-ITF	1.45	120	120	14	51.0	51.2	28.1	29.1	610	30.0	332	11.3
6	Z-120-14-60-ITF	1.45	120	120	14	52.2	52.1	28.5	28.2	610	63.5	426	15.1
7	Z-200-7-30-ITF	1.16	200	200	7	50.5	50.0	32.9	32.3	1220	30.0	323	7.83
8	Z-200-7-60-ITF	1.16	200	200	7	50.5	50.5	33.2	32.7	1220	63.5	323	8.16
9	Z-200-10-30-ITF	1.16	198	198	10	54.5	55.0	31.6	30.5	1220	30.0	323	7.65
10	Z-200-10-60-ITF	1.16	197	197	10	55.1	55.2	30.9	31.3	1220	63.5	323	7.86
11	Z-200-14-30-ITF	1.16	200	200	14	59.2	60.0	29.8	28.4	1220	30.0	323	6.93
12	Z-200-14-60-ITF	1.16	203	203	14	60.3	60.1	29.8	29.1	1220	63.5	323	7.65
13	Z-300-7-30-ITF	1.45	300	300	7	45.3	45.4	17.3	17.3	1500	30.0	448	10.3
14	Z-300-7-60-ITF	1.45	300	300	7	44.4	44.7	16.5	16.6	1500	63.5	448	10.8
15	Z-300-10-30-ITF	1.45	300	300	10	46.0	46.1	19.2	19.7	1500	30.0	448	9.48
16	Z-300-10-60-ITF	1.45	300	300	10	46.5	46.1	19.4	19.4	1500	63.5	448	9.78
17	Z-300-14-30-ITF	1.45	300	300	14	49.9	49.6	19.4	18.7	1500	30.0	448	8.88
18	Z-300-14-60-ITF	1.45	300	300	14	50.1	50.1	18.8	18.6	1500	63.5	448	9.99

Table A.5

Single Web C-Sections (Stiffened Flanges)
Fastened - End Two Flange Loading (ETF)

Beshara - University of Waterloo, Canada - 1999*

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)
1	C-120-7-30	1.45	332	81.4	71.8	4.83	20.7	3.84	----	----	2.34	1.64
2	C-120-7-60	1.45	332	81.4	71.8	4.83	43.8	4.74	----	----	2.78	1.70
3	C-120-10-30	1.45	332	80.8	67.0	6.90	20.7	3.75	----	----	----	----
4	C-120-10-60	1.45	332	80.8	67.0	6.90	43.8	4.17	----	----	----	----
5	C-120-14-100A	1.45	332	79.4	60.1	9.66	69.7	4.77	----	----	----	----
6	C-120-14-100B	1.45	332	79.4	60.1	9.66	69.7	4.68	----	----	----	----
7	C-200-7-30	1.16	328	170	158	6.03	25.9	2.07	----	----	----	----
8	C-200-7-60	1.16	328	170	158	6.03	54.7	2.46	----	----	----	----
9	C-200-10-30	1.16	328	170	153	8.62	25.9	2.01	----	----	----	----
10	C-200-10-60	1.16	328	170	153	8.62	54.7	2.19	----	----	----	----
11	C-200-14-30	1.16	328	171	147	12.1	25.9	1.95	----	----	----	----
12	C-200-14-60	1.16	328	171	147	12.1	54.7	2.13	----	----	----	----
13	C-300-7-30	1.45	448	205	195	4.83	20.7	2.85	----	----	1.80	1.58
14	C-300-7-60	1.45	448	205	195	4.83	43.8	3.27	----	----	2.15	1.52
15	C-300-10-30	1.45	448	205	191	6.90	20.7	2.76	----	----	----	----
16	C-300-10-60	1.45	448	205	191	6.90	43.8	3.06	----	----	----	----
17	C-300-14-30	1.45	448	204	185	9.66	20.7	2.67	----	----	----	----
18	C-300-14-60	1.45	448	204	185	9.66	43.8	2.91	----	----	----	----

*** Experimental work of this study**

	S136-94 P_t/P_c	AISI-96 P_t/P_c
P_t/P_c Mean value	----	1.61
S.D.	----	0.08
C.O.V.	----	0.05

Table A.6

Single Web Z-Sections (Stiffened Flanges)
Fastened - End Two Flange Loading (ETF)

Beshara - University of Waterloo, Canada - 1999*

				H'	H	R	N		S136-94		AISI-96	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
1	Z-120-7-30	1.45	332	80.8	71.1	4.83	20.7	5.43	----	----	2.34	2.32
2	Z-120-7-60	1.45	332	80.8	71.1	4.83	43.8	6.18	----	----	2.79	2.22
3	Z-120-10-30	1.45	332	80.8	67.0	6.90	20.7	5.31	----	----	----	----
4	Z-120-10-60	1.45	332	80.8	67.0	6.90	43.8	6.09	----	----	----	----
5	Z-120-14-30	1.45	332	80.8	61.4	9.66	20.7	5.25	----	----	----	----
6	Z-120-14-60	1.45	332	80.8	61.4	9.66	43.8	5.85	----	----	----	----
7	Z-200-7-30	1.16	323	170	158	6.03	25.9	2.73	----	----	----	----
8	Z-200-7-60	1.16	323	170	158	6.03	54.7	2.88	----	----	----	----
9	Z-200-10-30	1.16	323	170	153	8.62	25.9	2.64	----	----	----	----
10	Z-200-10-60	1.16	323	170	153	8.62	54.7	2.67	----	----	----	----
11	Z-200-14-30	1.16	323	173	149	12.1	25.9	2.64	----	----	----	----
12	Z-200-14-60	1.16	323	173	149	12.1	54.7	2.58	----	----	----	----
13	Z-300-7-30	1.45	446	205	195	4.83	20.7	3.36	----	----	1.80	1.87
14	Z-300-7-60	1.45	446	205	195	4.83	43.8	3.78	----	----	2.14	1.76
15	Z-300-10-30	1.45	446	205	191	6.90	20.7	3.30	----	----	----	----
16	Z-300-10-60	1.45	446	205	191	6.90	43.8	3.69	----	----	----	----
17	Z-300-14-30	1.45	446	205	186	9.66	20.7	3.36	----	----	----	----
18	Z-300-14-60	1.45	446	205	186	9.66	43.8	3.66	----	----	----	----
								P_t/P_c Mean value		----		2.04
								S.D.		----		0.27
								C.O.V.		----		0.13

*** Experimental work of this study**

Table A.7

Single Web C-Sections (Stiffened Flanges)
Fastened - Interior Two Flange Loading (ITF)

Beshara - University of Waterloo, Canada - 1999*

No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)
1	C-120-7-30	1.45	332	81.4	71.8	4.83	20.7	10.7	----	----	9.17	1.16
2	C-120-7-60	1.45	332	81.4	71.8	4.83	43.8	11.8	----	----	9.45	1.25
3	C-120-10-30	1.45	332	81.4	67.7	6.90	20.7	9.96	----	----	----	----
4	C-120-10-60	1.45	332	81.4	67.7	6.90	43.8	11.0	----	----	----	----
5	C-120-14-30	1.45	332	79.4	60.1	9.66	20.7	9.06	----	----	----	----
6	C-120-14-60	1.45	332	79.4	60.1	9.66	43.8	10.1	----	----	----	----
7	C-200-7-30	1.16	328	170	158	6.03	25.9	7.20	----	----	----	----
8	C-200-7-60	1.16	328	170	158	6.03	54.7	7.56	----	----	----	----
9	C-200-10-30	1.16	328	170	152	8.62	25.9	6.57	----	----	----	----
10	C-200-10-60	1.16	328	170	153	8.62	54.7	7.08	----	----	----	----
11	C-200-14-60	1.16	328	171	147	12.1	51.7	6.72	----	----	----	----
12	C-200-14-100	1.16	328	171	147	12.1	87.1	7.08	----	----	----	----
13	C-300-7-30	1.45	448	205	195	4.83	20.7	11.0	----	----	5.87	1.87
14	C-300-7-60	1.45	448	205	195	4.83	43.8	11.6	----	----	6.04	1.92
15	C-300-10-30	1.45	448	205	191	6.90	20.7	9.99	----	----	----	----
16	C-300-10-60	1.45	448	205	191	6.90	43.8	10.9	----	----	----	----
17	C-300-14-60	1.45	448	205	186	9.66	43.8	10.3	----	----	----	----
18	C-300-14-100	1.45	448	205	186	9.66	69.7	10.6	----	----	----	----
	P_t/P_c Mean value									----		1.55
	S.D.									----		0.40
	C.O.V.									----		0.26

*** Experimental work of this study**

Table A.8

Single Web Z-Sections (Stiffened Flanges)
Fastened - Interior Two Flange Loading (ITF)

Beshara - University of Waterloo, Canada - 1999*

				H'	H	R	N		S136-94		AISI-96	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
1	Z-120-7-30	1.45	332	80.8	71.1	4.83	20.7	11.7	----	----	9.20	1.27
2	Z-120-7-60	1.45	332	80.8	71.1	4.83	43.8	13.1	----	----	9.47	1.38
3	Z-120-10-30	1.45	332	82.1	68.3	6.90	20.7	11.6	----	----	----	----
4	Z-120-10-60	1.45	332	82.8	69.0	6.90	43.8	12.6	----	----	----	----
5	Z-120-14-30	1.45	332	80.8	61.4	9.66	20.7	11.3	----	----	----	----
6	Z-120-14-60	1.45	426	80.8	61.4	9.66	43.8	15.1	----	----	----	----
7	Z-200-7-30	1.16	323	170	158	6.03	25.9	7.83	----	----	----	----
8	Z-200-7-60	1.16	323	170	158	6.03	54.7	8.16	----	----	----	----
9	Z-200-10-30	1.16	323	169	151	8.62	25.9	7.65	----	----	----	----
10	Z-200-10-60	1.16	323	168	151	8.62	54.7	7.86	----	----	----	----
11	Z-200-14-30	1.16	323	170	146	12.1	25.9	6.93	----	----	----	----
12	Z-200-14-60	1.16	323	173	149	12.1	54.7	7.65	----	----	----	----
13	Z-300-7-30	1.45	446	205	195	4.83	20.7	10.3	----	----	5.86	1.75
14	Z-300-7-60	1.45	446	205	195	4.83	43.8	10.8	----	----	6.03	1.79
15	Z-300-10-30	1.45	446	205	191	6.90	20.7	9.48	----	----	----	----
16	Z-300-10-60	1.45	446	205	191	6.90	43.8	9.78	----	----	----	----
17	Z-300-14-30	1.45	446	204	185	9.66	20.7	8.88	----	----	----	----
18	Z-300-14-60	1.45	446	204	185	9.66	43.8	9.99	----	----	----	----

	S136-94	AISI-96
P_t/P_c Mean value	----	1.55
S.D.	----	0.26
C.O.V.	----	0.17

*** Experimental work of this study**

APPENDIX "B"

COMPUTER PROGRAM USED TO ANALYZE TEST DATA

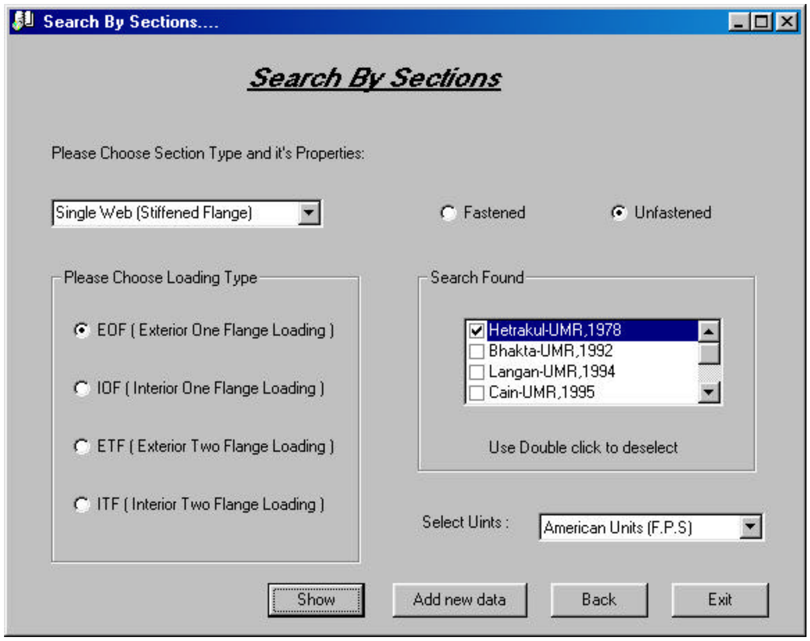


Figure B.1 Program Main Window

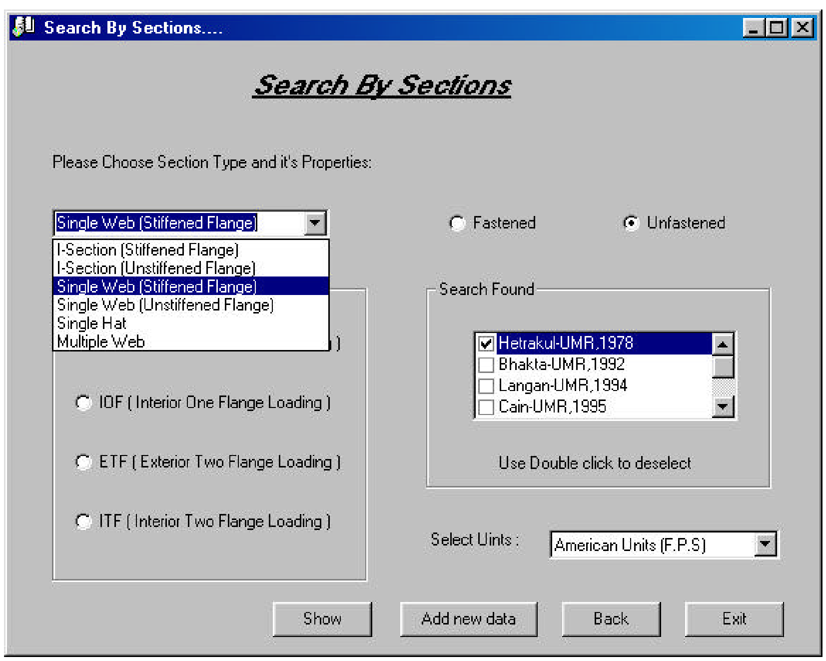


Figure B.2 Choosing Section Type, Fasten Status and Loading Case

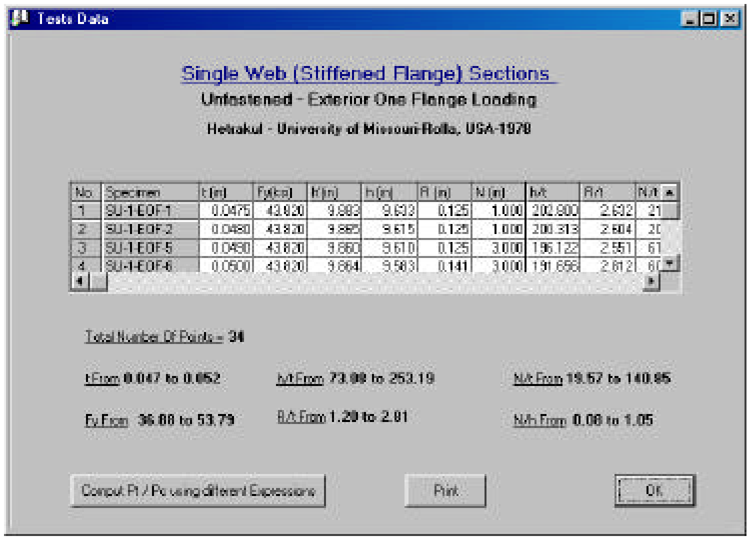


Figure B.3 Viewing Tests Data

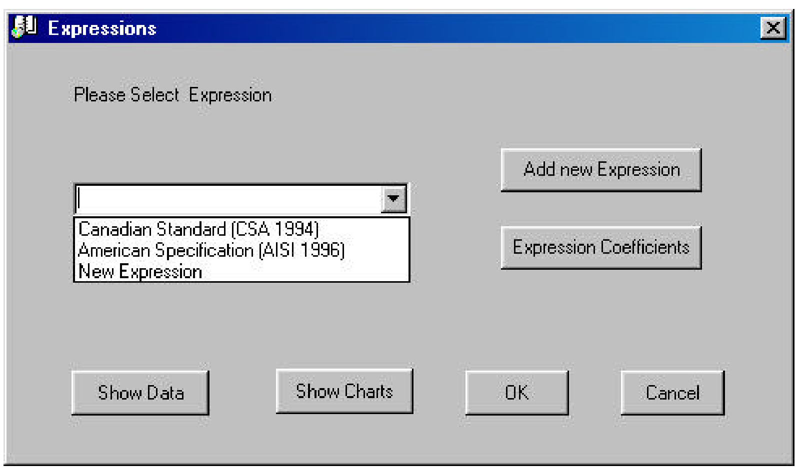


Figure B.4 Calculating Web Crippling

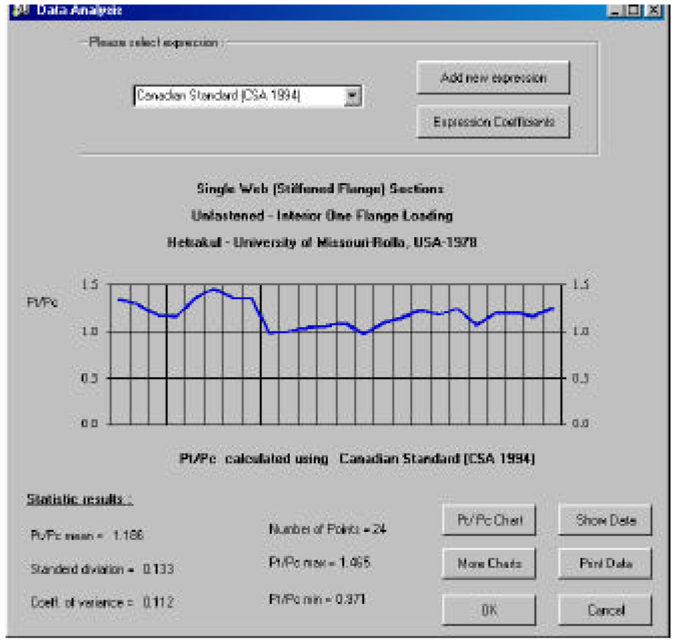


Figure B.5 Analyzing Test Data Based on P_t/P_c

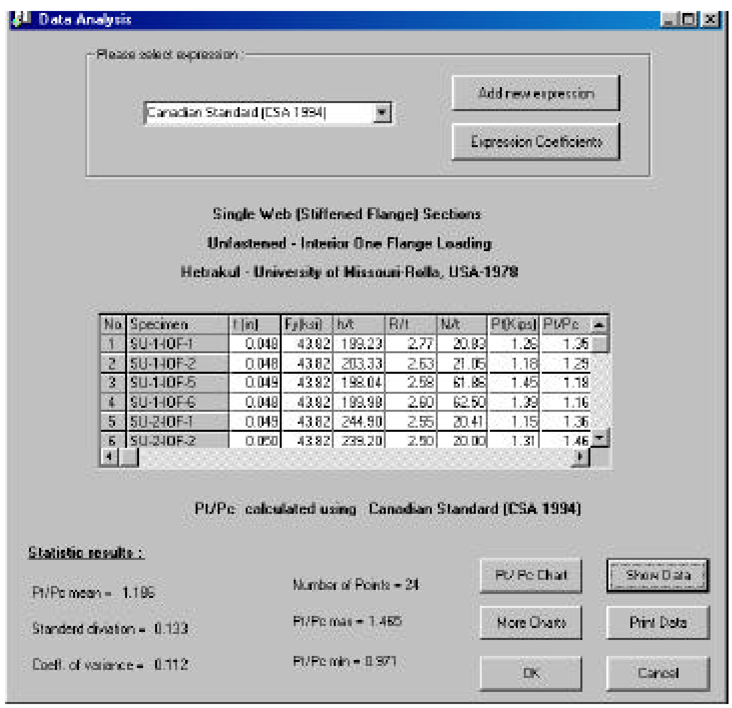


Figure B.6 Viewing Tests Data Parameters with Calculated P_t/P_c

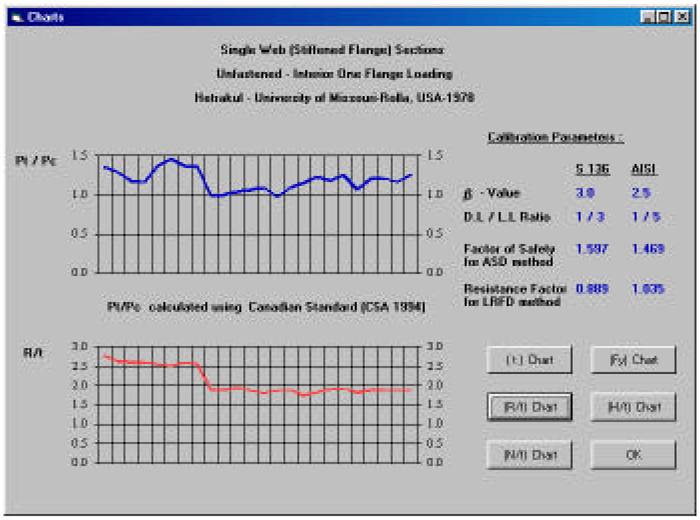


Figure B.7 Analyzing Major Parameters

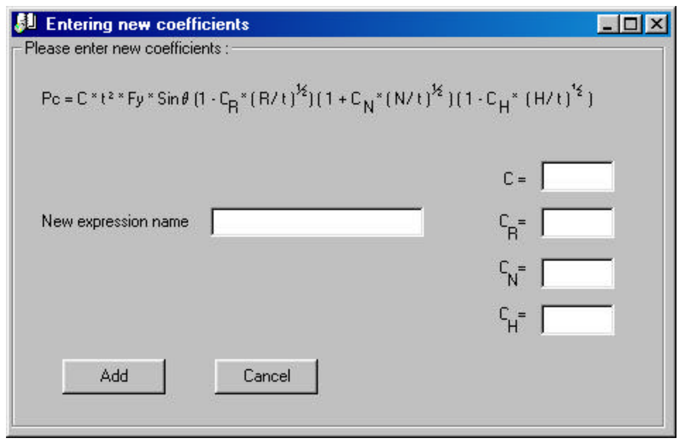


Figure B.8 Adding New Coefficients

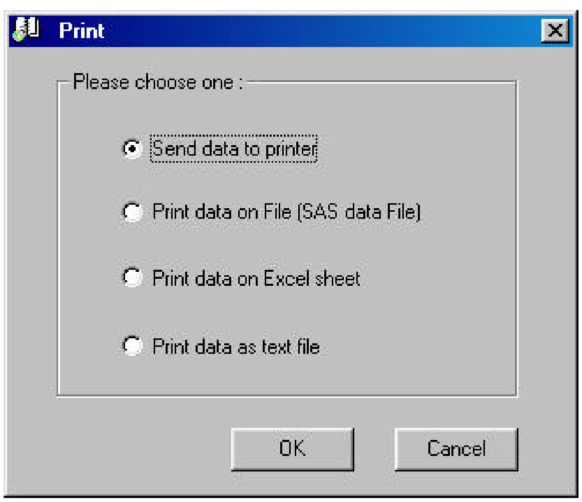


Figure B.9 Printing Tests Data

APPENDIX “C”

WEB CRIPPLING TEST DATA

USED TO DEVELOP THE NEW COEFFICIENTS

Table C.1

I-Sections (Stiffened Flanges)
Fastened - Interior One Flange Loading (IOF)

Bhakta - University of Missouri-Rolla, USA-1992 [5]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
1	I1-F	2.769	391	71.1	68.3	1.43	48.2	58.7	81.3	0.72	71.3	0.82	64.6	0.91
2	I2-F	2.769	391	71.1	68.2	1.43	48.2	60.5	81.2	0.75	71.3	0.85	64.6	0.94
3	I5-F	1.626	413	121	116	2.44	82.0	20.5	32.6	0.63	28.6	0.72	23.5	0.87
4	I6-F	1.626	413	121	116	2.44	82.0	21.4	32.6	0.66	28.6	0.75	23.5	0.91
5	I9-F	1.600	432	144	134	4.97	83.3	21.2	----	----	27.9	0.73	20.7	1.02
6	I10-F	1.600	432	141	131	4.97	83.3	21.5	----	----	27.9	0.74	20.7	1.04

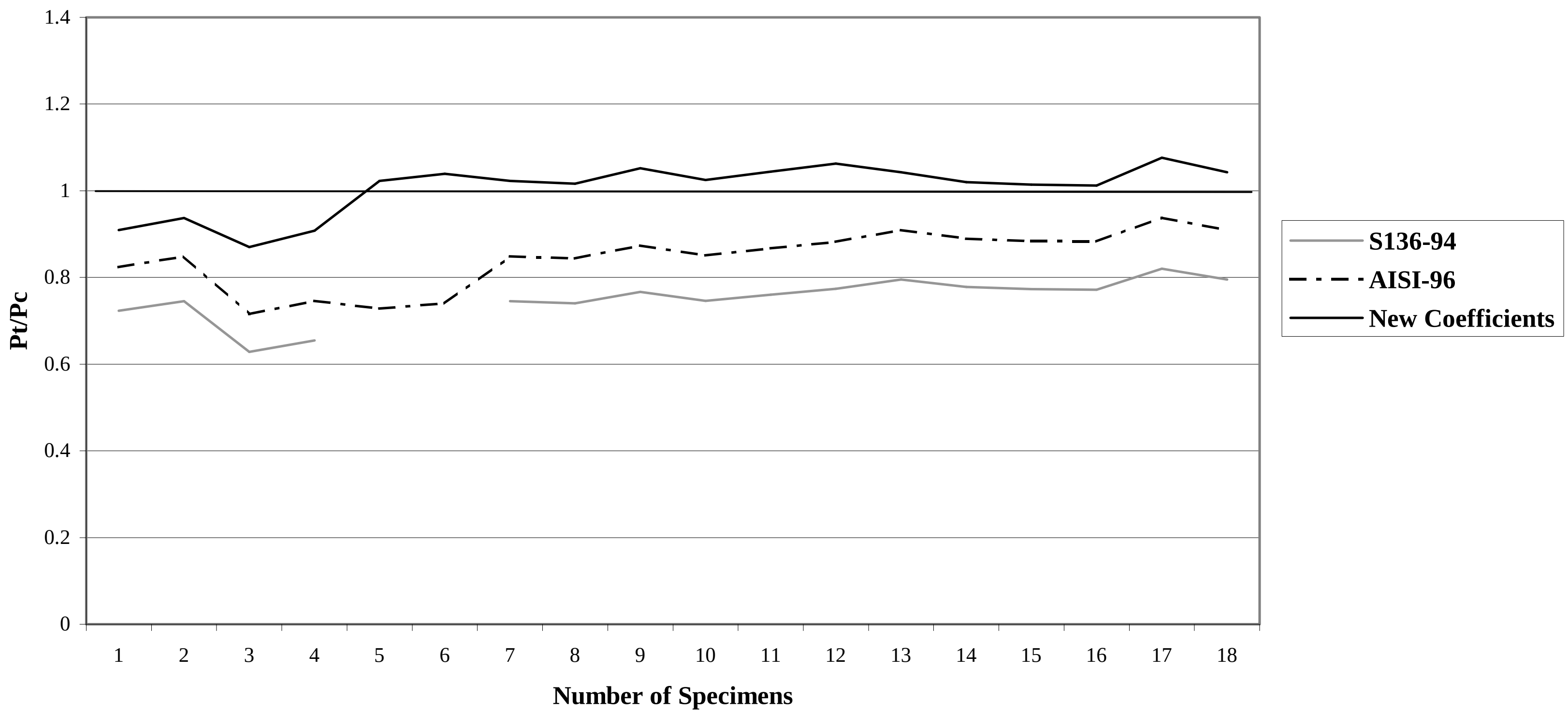
Cain - University of Missouri-Rolla, USA-1995 [6]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
7	I1-F	1.702	422	117	112	2.33	78.4	26.9	36.1	0.75	31.7	0.85	26.3	1.02
8	I2-F	1.702	422	116	112	2.33	78.4	26.7	36.1	0.74	31.7	0.84	26.3	1.02
9	I3-F	1.702	422	116	112	2.33	78.4	27.7	36.1	0.77	31.7	0.87	26.3	1.05
10	I4-F	1.702	422	116	112	2.33	78.4	27.0	36.1	0.75	31.7	0.85	26.3	1.03
11	I5-F	1.702	422	116	112	2.33	78.4	27.5	36.1	0.76	31.7	0.87	26.3	1.04
12	I6-F	1.702	422	117	112	2.33	78.4	28.0	36.1	0.77	31.7	0.88	26.3	1.06
13	I7-F	2.159	436	92.9	89.2	1.84	61.8	45.8	57.6	0.80	50.4	0.91	43.9	1.04
14	I8-F	2.159	436	92.1	88.4	1.84	61.8	44.8	57.6	0.78	50.4	0.89	43.9	1.02
15	I9-F	2.159	436	91.9	88.3	1.84	61.8	44.5	57.6	0.77	50.3	0.88	43.9	1.01
16	I10-F	2.159	436	92.1	88.4	1.84	61.8	44.4	57.6	0.77	50.3	0.88	43.9	1.01
17	I11-F	2.159	436	91.9	88.3	1.84	61.8	47.2	57.6	0.82	50.3	0.94	43.9	1.08
18	I12-F	2.159	436	92.9	89.2	1.84	61.8	45.8	57.6	0.80	50.4	0.91	43.9	1.04
							P_t/P_c Mean value			0.75		0.84		1.01
							S.D.			0.05		0.07		0.06
							C.O.V.			0.07		0.08		0.06

---- Exceeds AISI-96 or S136-94 Limit

Chart C.1

Pt/Pc for I - Sections (Stiffened Flanges)
Fastened - Interior One Flange Loading (IOF)



S136-94	AISI-96	New Coefficients
Pt/Pc mean = 0.75	Pt/Pc mean = 0.84	Pt/Pc mean = 1.01
S.D. = 0.05	S.D. = 0.07	S.D. = 0.06
C.O.V. = 0.07	C.O.V. = 0.08	C.O.V. = 0.06

Table C.2

I-Sections (Stiffened Flange)
Unfastened - End One Flange Loading (EOF)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	2a-2-EOF	1.532	208	64.0	62.0	1.00	16.6	7.88	8.87	0.89	7.98	0.99	8.91	0.88
2	2a-3-EOF	1.532	208	64.0	62.0	1.00	41.5	8.46	11.8	0.72	9.55	0.89	11.7	0.73
3	2b-3-EOF	1.532	208	64.0	62.0	1.00	16.6	8.68	8.87	0.98	7.98	1.09	8.91	0.97
4	2b-4-EOF	1.532	208	64.0	62.0	1.00	24.9	9.39	10.0	0.94	8.63	1.09	10.02	0.94
5	4a-3-EOF	1.547	208	98.2	96.2	1.00	16.4	8.32	9.01	0.92	8.48	0.98	9.05	0.92
6	4b-2-EOF	1.547	208	98.2	96.2	1.00	24.6	10.0	10.1	0.99	9.11	1.10	10.1	0.99
7	6a-3-EOF	1.643	257	121	119	1.00	15.5	8.23	12.3	0.67	12.0	0.69	12.4	0.66
8	6b-2-EOF	1.643	257	121	119	1.00	23.2	9.70	13.9	0.70	12.9	0.75	13.9	0.70
9	6b-3-EOF	1.643	257	121	119	1.00	38.6	10.6	16.3	0.65	14.3	0.74	16.2	0.66
10	9b-2-EOF	2.718	242	34.8	32.8	1.00	7.48	25.37	26.5	0.96	25.0	1.01	27.0	0.94
11	10a-3-EOF	2.748	242	52.7	50.7	1.00	9.24	27.5	28.5	0.96	26.9	1.02	28.9	0.95
12	10b-2-EOF	2.748	242	52.7	50.7	1.00	13.9	32.7	31.6	1.03	28.6	1.14	31.9	1.03
13	10b-3-EOF	2.748	242	52.7	50.7	1.00	27.7	37.8	38.7	0.98	32.4	1.17	38.6	0.98
14	11-3-EOF	2.774	249	70.7	68.7	1.00	9.16	24.9	29.8	0.84	28.9	0.86	30.2	0.83
15	12-2-EOF	2.817	249	69.7	67.7	1.00	13.5	29.5	34.0	0.87	31.5	0.93	34.3	0.86
16	12-3-EOF	2.817	249	69.7	67.7	1.00	22.5	26.7	39.3	0.68	34.4	0.78	39.3	0.68
17	13a-2-EOF	3.409	246	27.5	25.5	1.00	7.45	35.3	42.4	0.83	39.7	0.89	43.1	0.82
18	13b-2-EOF	3.409	246	27.5	25.5	1.00	11.2	37.3	46.9	0.80	42.0	0.89	47.3	0.79
19	14a-3-EOF	3.754	228	38.3	36.3	1.00	6.77	41.6	46.7	0.89	44.7	0.93	47.5	0.88
20	14b-2-EOF	3.754	228	38.3	36.3	1.00	10.1	47.7	51.4	0.93	47.2	1.01	52.0	0.92
21	14b-3-EOF	3.754	228	38.3	36.3	1.00	16.9	56.1	58.8	0.95	51.1	1.10	59.1	0.95

Table C.2 (Continued)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
22	15a-3-EOF	3.741	228	52.1	50.1	1.00	6.79	41.8	46.3	0.90	45.2	0.93	47.1	0.89
23	15b-2-EOF	3.741	228	52.1	50.1	1.00	10.2	51.0	51.0	1.00	47.7	1.07	51.6	0.99
24	15b-3-EOF	3.741	228	52.1	50.1	1.00	17.0	53.9	58.5	0.92	51.7	1.04	58.7	0.92
25	16e-1-EOF	1.168	222	172	170	1.00	21.7	4.95	5.93	0.84	5.76	0.86	5.93	0.84
26	16f-1-EOF	1.168	222	172	170	1.00	54.3	5.68	7.97	0.71	6.99	0.81	7.87	0.72
27	17e-1-EOF	1.918	247	104	102	1.00	13.2	16.0	15.5	1.04	15.0	1.07	15.6	1.03
28	17f-1-EOF	1.918	247	104	102	1.00	33.1	18.1	20.3	0.90	17.7	1.02	20.2	0.90
29	18b-1-EOF	3.124	259	63.9	61.9	1.00	8.13	31.7	38.2	0.83	37.2	0.85	38.8	0.82
30	18b-2-EOF	3.124	259	63.9	61.9	1.00	20.3	45.9	48.7	0.94	42.8	1.07	48.8	0.94

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
31	I-1-EOF-1	1.207	302	207	202	2.63	21.1	8.19	----	----	----	----	7.65	1.07
32	I-1-EOF-2	1.194	302	209	203	2.66	21.3	7.88	----	----	----	----	7.50	1.05
33	I-1-EOF-5	1.194	302	210	204	2.66	63.8	9.68	----	----	----	----	10.6	0.91
34	I-1-EOF-6	1.168	302	214	209	2.72	65.2	9.84	----	----	----	----	10.2	0.97
35	I-2-EOF-1	1.232	302	252	247	2.58	20.6	7.70	----	----	----	----	7.94	0.97
36	I-2-EOF-2	1.219	302	255	250	2.60	20.8	7.34	----	----	----	----	7.79	0.94
37	I-2-EOF-5	1.245	302	250	245	2.55	61.2	10.3	----	----	----	----	11.4	0.90
38	I-2-EOF-6	1.270	302	245	240	2.50	60.0	10.6	----	----	----	----	11.8	0.89
39	I-2'-EOF-1	1.262	254	146	142	1.89	101	10.7	12.2	0.87	10.9	0.98	12.3	0.87
40	I-2'-EOF-2	1.237	254	149	145	1.93	103	11.4	11.8	0.97	10.5	1.08	11.9	0.96
41	I-3-EOF-1	1.245	325	148	144	1.91	20.4	10.5	8.82	1.19	9.39	1.12	9.07	1.16

---- Exceeds AISI-96 or S136-94 Limit

Table C.2 (Continued)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
42	I-3-EOF-2	1.270	325	145	141	1.88	20.0	11.0	9.16	1.20	9.71	1.13	9.42	1.17
43	I-3-EOF-5	1.257	325	147	143	1.90	60.6	13.3	12.8	1.04	12.1	1.10	13.0	1.02
44	I-3-EOF-6	1.245	325	148	145	1.91	61.2	12.2	12.6	0.97	11.9	1.03	12.8	0.96
45	I-3'-EOF-1	1.168	230	150	146	2.04	21.7	8.41	5.56	1.51	5.96	1.41	5.73	1.47
46	I-3'-EOF-2	1.168	230	151	146	2.04	21.7	7.52	5.56	1.35	5.96	1.26	5.73	1.31
47	I-3'-EOF-5	1.168	230	152	148	2.04	65.2	10.6	7.99	1.33	7.58	1.40	8.11	1.31
48	I-3'-EOF-6	1.168	230	151	147	2.04	65.2	10.9	7.99	1.36	7.57	1.43	8.11	1.34
49	I-4'-EOF-1	1.237	254	98	96	1.29	85.2	12.9	11.7	1.10	9.46	1.37	11.6	1.11
50	I-4'-EOF-2	1.262	254	97	94	1.26	83.5	12.1	12.1	1.00	9.77	1.24	12.0	1.01
51	I-5'-EOF-5	1.524	325	120	117	1.56	50.0	18.3	18.2	1.01	16.4	1.12	18.3	1.00
52	I-5'-EOF-6	1.524	325	120	116	1.56	50.0	19.9	18.2	1.09	16.4	1.21	18.3	1.09
53	I-6"-EOF-1	1.194	230	150	146	2.00	21.3	7.9	5.79	1.37	6.19	1.28	5.97	1.33
54	I-6"-EOF-2	1.168	230	149	144	2.04	21.7	8.5	5.56	1.54	5.95	1.44	5.73	1.49
55	I-6"-EOF-5	1.168	230	150	146	2.04	65.2	11.3	7.98	1.42	7.56	1.50	8.11	1.39
56	I-6"-EOF-6	1.168	230	152	148	2.04	65.2	10.5	7.98	1.31	7.58	1.38	8.11	1.29
57	I-6-EOF-1	1.905	295	96.7	94.2	1.25	13.3	23.1	17.8	1.30	17.6	1.32	18.1	1.28
58	I-6-EOF-2	1.910	295	96.4	93.9	1.25	13.3	24.0	17.9	1.34	17.7	1.36	18.2	1.32
59	I-6-EOF-5	1.905	295	96.8	94.3	1.25	40.0	25.1	24.8	1.01	21.6	1.16	24.8	1.01
60	I-6-EOF-6	1.910	295	96.2	93.7	1.25	39.9	23.7	24.9	0.95	21.7	1.09	24.9	0.95
61	I-6-EOF-7	1.969	295	92.5	90.1	1.21	38.7	25.1	26.3	0.95	22.8	1.10	26.3	0.95
62	I-6-EOF-8	1.930	295	95.1	92.6	1.23	39.5	30.0	25.4	1.18	22.1	1.36	25.4	1.18
63	I-9-EOF-1	1.168	230	148	144	2.04	21.7	9.24	5.56	1.66	5.95	1.55	5.73	1.61
64	I-9-EOF-2	1.168	230	150	146	2.04	21.7	8.12	5.56	1.46	5.96	1.36	5.73	1.42
65	I-9-EOF-5	1.168	230	150	146	2.04	65.2	11.2	7.98	1.40	7.56	1.48	8.11	1.38
66	I-9-EOF-6	1.168	230	149	145	2.04	65.2	11.4	7.98	1.43	7.56	1.51	8.11	1.41

Table C.2 (Continued)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

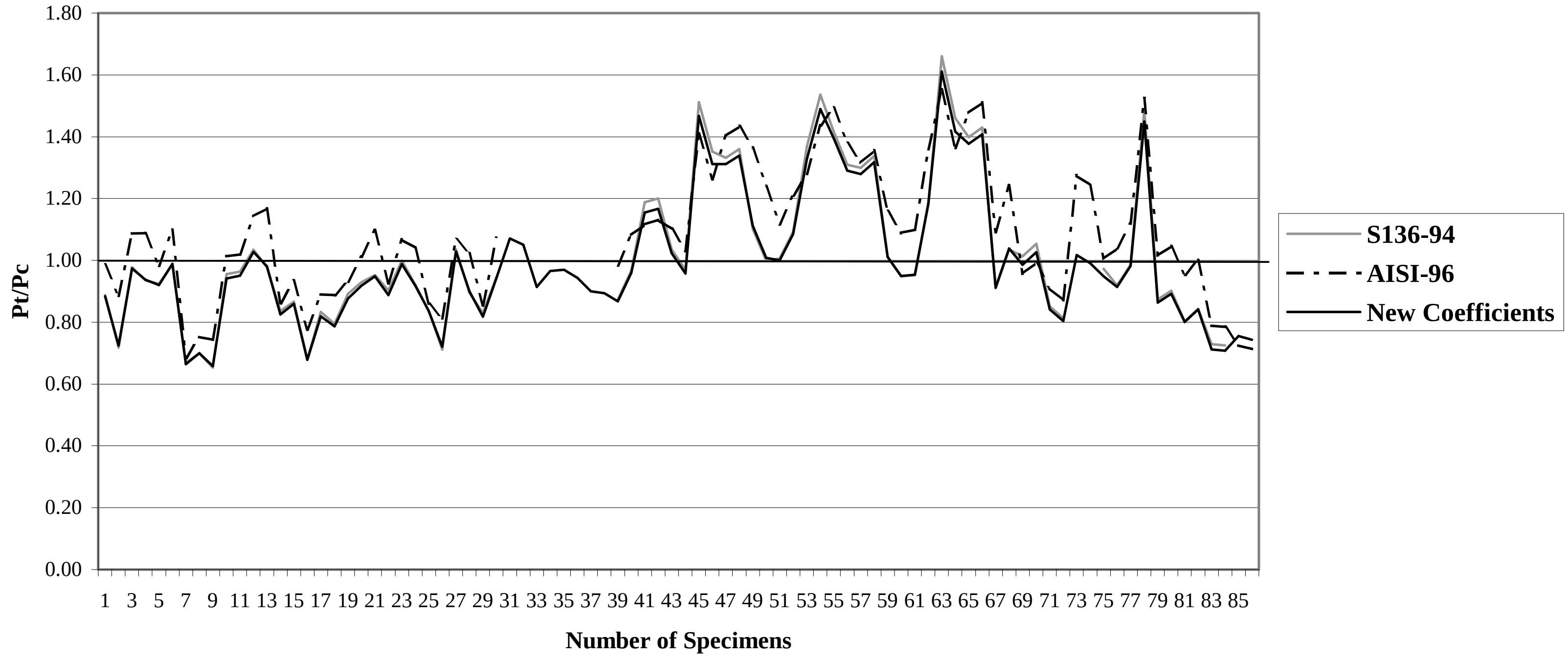
No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
67	I-12'-EOF-5	2.743	315	49.0	46.9	1.01	27.8	45.6	50.1	0.91	41.8	1.09	50.0	0.91
68	I-12'-EOF-6	2.731	315	49.4	47.4	1.02	27.9	51.5	49.7	1.04	41.5	1.24	49.6	1.04
69	I-12-EOF-1	1.295	371	144	140	1.84	19.6	11.0	10.9	1.01	11.5	0.96	11.1	0.99
70	I-12-EOF-2	1.278	371	146	142	1.87	19.9	11.1	10.6	1.05	11.2	0.99	10.9	1.03
71	I-12-EOF-5	1.295	371	144	140	1.84	58.8	13.2	15.5	0.85	14.5	0.91	15.7	0.84
72	I-12-EOF-6	1.295	371	143	140	1.84	58.8	12.6	15.5	0.81	14.5	0.87	15.7	0.80
73	I-13-EOF-1	1.270	371	78.5	76.0	1.25	80.0	17.8	----	----	14.0	1.28	17.5	1.02
74	I-13-EOF-2	1.270	371	78.3	75.8	1.25	80.0	17.4	----	----	14.0	1.24	17.5	0.99
75	I-16-EOF-1	1.346	371	73.1	69.5	1.77	18.9	11.4	11.7	0.97	11.3	1.01	12.0	0.95
76	I-3-EOF-1	1.237	254	199	195	1.93	123.2	11.6	12.6	0.92	11.1	1.04	12.7	0.91
77	I-3-EOF-2	1.262	254	195	191	1.89	120.7	12.9	13.1	0.99	11.5	1.12	13.1	0.98
78	I-16-EOF-2	1.283	371	77.1	73.4	1.86	19.8	15.9	10.7	1.49	10.4	1.53	11.0	1.45
79	I-16-EOF-5	1.295	371	76.3	72.6	1.84	58.8	13.6	15.5	0.87	13.4	1.02	15.7	0.86
80	I-16-EOF-6	1.295	371	77.2	73.5	1.84	58.8	14.0	15.5	0.90	13.4	1.05	15.7	0.89

Bhakta - University of Missouri-Rolla, USA-1992 [5]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
81	I3	2.769	391	71.1	68.2	1.43	48.2	58.3	72.6	0.80	61.1	0.95	72.8	0.80
82	I4	2.769	391	71.1	68.3	1.43	48.2	61.2	72.6	0.84	61.1	1.00	72.8	0.84
83	I7	1.626	413	121	116	2.44	82.0	21.3	29.2	0.73	26.9	0.79	29.8	0.71
84	I8	1.626	413	121	116	2.44	82.0	21.1	29.2	0.73	26.9	0.79	29.9	0.71
85	I11	1.600	432	141	131	4.97	83.3	20.2	----	----	27.9	0.73	26.8	0.76
86	I12	1.600	432	141	131	4.97	83.3	19.9	----	----	27.9	0.71	26.7	0.74
	---- Exceeds AISI-96 or S136-94 Limit						**P_t/P_c Mean value**			1.02		1.09		1.00
							S.D.			0.23		0.22		0.21
							C.O.V.			0.23		0.20		0.21

Chart C.2

Pt/Pc for I - Sections (Stiffened Flanges)
Unfastened - End One Flange Loading (EOF)



S136-94	**AISI-96**	**New Coefficients**
Pt/Pc mean = 1.02	Pt/Pc mean = 1.09	Pt/Pc mean = 1.00
S.D. = 0.23	S.D. = 0.22	S.D. = 0.21
C.O.V. = 0.23	C.O.V. = 0.20	C.O.V. = 0.21

Table C.3

I-Sections (Stiffened Flanges)
Unfastened - Interior One Flange Loading (IOF)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	1a-1-IOF	1.168	222	170	168	1.00	27.2	8.12	7.47	1.09	8.99	0.90	8.00	1.02
2	4a-1-IOF	1.547	208	98.2	96.2	1.00	16.4	16.7	11.6	1.44	13.8	1.21	12.1	1.38
3	4a-2-IOF	1.547	208	98.2	96.2	1.00	24.6	17.1	12.2	1.41	15.2	1.12	13.0	1.32
4	6a-1-IOF	1.643	257	121	119	1.00	15.5	17.8	16.0	1.11	16.9	1.05	16.7	1.06
5	6a-2-IOF	1.643	257	121	119	1.00	23.2	19.6	16.8	1.17	18.7	1.05	17.9	1.10
6	6b-1-IOF	1.643	257	121	119	1.00	38.6	19.1	18.1	1.06	21.4	0.89	19.7	0.97
7	11-1-IOF	2.774	249	70.7	68.7	1.00	9.16	49.0	42.0	1.17	45.7	1.07	43.1	1.14
8	11-2-IOF	2.774	249	70.7	68.7	1.00	13.7	55.2	43.7	1.26	49.8	1.11	45.6	1.21
9	18c-1-IOF	3.124	259	63.9	61.9	1.00	8.13	46.7	54.7	0.85	58.6	0.80	56.0	0.83
10	18c-2-IOF	3.124	259	63.9	61.9	1.00	20.3	57.4	60.4	0.95	71.6	0.80	63.9	0.90

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
11	I-1-IOF-1	1.219	302	206	201	2.60	20.8	10.6	----	----	----	----	9.88	1.07
12	I-1-IOF-2	1.219	302	207	202	2.60	20.8	11.1	----	----	----	----	9.89	1.12
13	I-1-IOF-5	1.232	302	206	201	2.58	61.9	13.0	----	----	----	----	12.6	1.03
14	I-1-IOF-6	1.219	302	207	202	2.60	62.5	12.7	----	----	----	----	12.3	1.03
15	I-2-IOF-1	1.245	302	250	245	2.55	20.4	10.8	----	----	----	----	10.4	1.03
16	I-2-IOF-2	1.270	302	245	240	2.50	20.0	11.0	----	----	----	----	10.6	1.03
17	I-2-IOF-5	1.232	302	252	247	2.58	61.9	12.7	----	----	----	----	12.3	1.03
18	I-2-IOF-6	1.270	302	245	240	2.50	60.0	13.1	----	----	----	----	13.8	0.95
19	I-3-IOF-1	1.245	325	149	145	1.91	20.4	11.1	11.1	1.00	10.5	1.07	10.1	1.10

---- Exceeds AISI-96 or S136-94 Limit

Table C.3 (Continued)

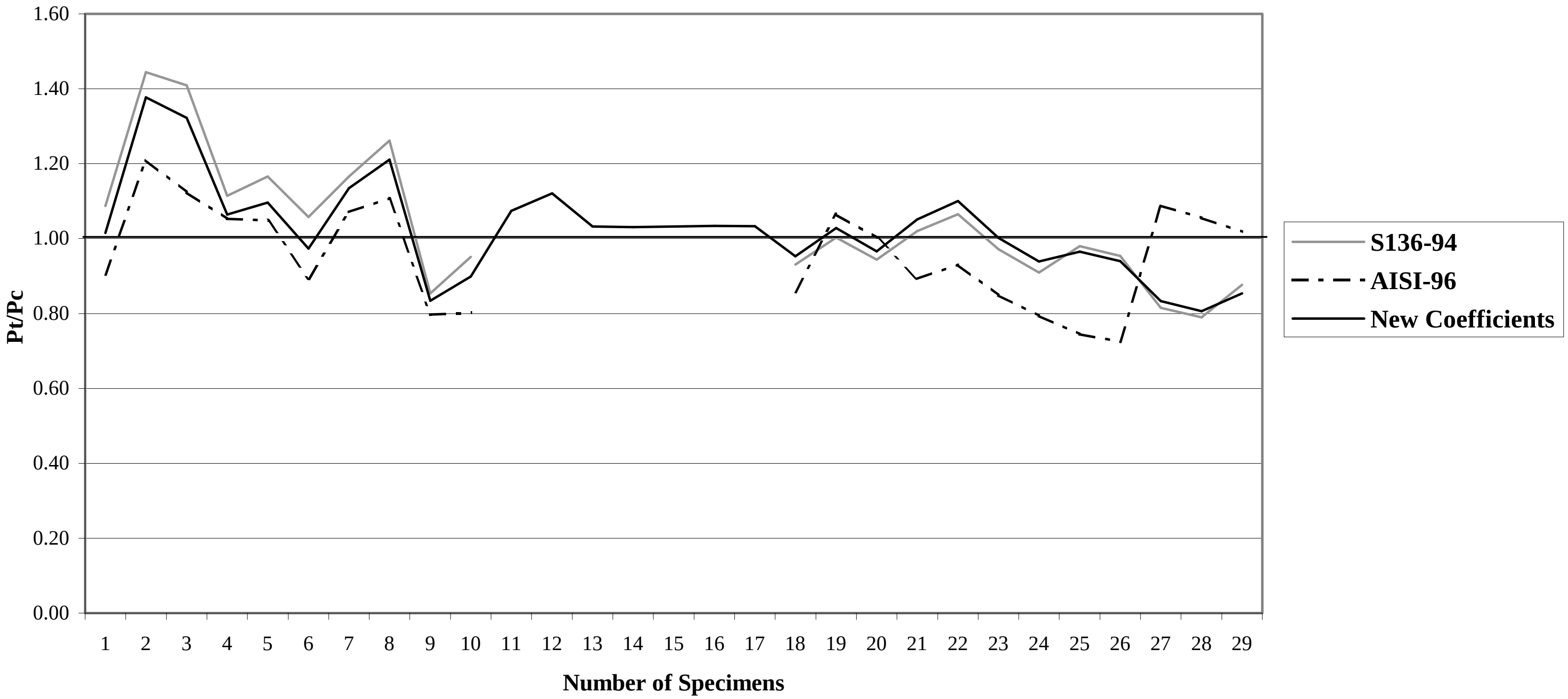
Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
20	I-3-IOF-2	1.270	325	146	142	1.88	20.0	10.9	11.6	0.94	10.9	1.00	10.5	1.04
21	I-6"-IOF-1	1.194	230	149	145	2.00	21.3	8.01	7.85	1.02	8.98	0.89	7.62	1.05
22	I-6"-IOF-2	1.168	230	149	145	2.04	21.7	8.03	7.54	1.07	8.63	0.93	7.30	1.10
23	I-9-IOF-1	1.181	230	148	144	2.02	21.5	7.48	7.69	0.97	8.81	0.85	7.46	1.00
24	I-9-IOF-2	1.168	230	150	146	2.04	21.7	6.85	7.54	0.91	8.63	0.79	7.30	0.94
25	I-9-IOF-5	1.168	230	149	145	2.04	65.2	8.79	8.97	0.98	11.8	0.75	9.11	0.97
26	I-9-IOF-6	1.156	230	151	147	2.06	65.9	8.39	8.79	0.95	11.6	0.72	8.93	0.94
27	I-12-IOF-1	1.283	371	145	141	1.86	19.8	11.8	14.4	0.82	10.8	1.09	14.1	0.83
28	I-12-IOF-2	1.308	371	143	139	1.82	19.4	11.8	15.0	0.79	11.2	1.06	14.7	0.81
29	I-12-IOF-5	1.283	371	146	142	1.86	59.4	15.0	17.1	0.88	14.7	1.02	17.5	0.85

	S136-94 P_t/P_c	AISI-96 P_t/P_c	New Coeff. P_t/P_c
P_t/P_c Mean value	1.04	0.96	1.02
S.D.	0.15	0.13	0.13
C.O.V.	0.15	0.14	0.13

Chart C.3

P_t/P_c for I - Sections (Stiffened Flanges)
Unfastened -Interior One Flange Loading (IOF)



S136-94	**AISI-96**	**New Coefficients**
Pt/Pc mean = 1.04	Pt/Pc mean = 0.96	Pt/Pc mean = 1.02
S.D. = 0.15	S.D. = 0.13	S.D. = 0.13
C.O.V. = 0.15	C.O.V. = 0.14	C.O.V. = 0.13

Table C.4

I-Sections (Stiffened Flanges)
Unfastened - End Two Flange Loading (ETF)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	2b-6-ETF	1.532	208	64.0	62.0	1.00	24.9	8.32	6.64	1.25	7.00	1.19	6.60	1.26
2	3-4-ETF	1.521	208	64.3	62.3	1.00	41.7	8.01	7.19	1.11	7.67	1.04	7.05	1.14
3	4a-6-ETF	1.547	208	98.2	96.2	1.00	16.4	7.12	5.34	1.33	6.36	1.12	5.65	1.26
4	4a-7-ETF	1.547	208	98.2	96.2	1.00	24.6	7.57	5.69	1.33	6.83	1.11	5.96	1.27
5	4b-4-ETF	1.547	208	98.2	96.2	1.00	41.1	8.46	6.24	1.36	7.60	1.11	6.45	1.31
6	6a-5-ETF	1.643	257	121	119	1.00	15.5	8.23	6.57	1.25	7.01	1.18	7.24	1.14
7	6a-6-ETF	1.643	257	121	119	1.00	23.2	8.55	6.99	1.22	7.52	1.14	7.63	1.12
8	6b-5-ETF	1.643	257	121	119	1.00	38.6	10.0	7.65	1.31	8.35	1.20	8.25	1.21
9	9a-3-ETF	2.718	242	34.8	32.8	1.00	9.35	22.7	24.9	0.91	23.7	0.96	24.2	0.94
10	9b-6-ETF	2.718	242	34.8	32.8	1.00	9.35	23.8	24.9	0.96	23.7	1.01	24.2	0.99
11	9b-7-ETF	2.718	242	34.8	32.8	1.00	14.0	26.5	26.2	1.01	25.2	1.05	25.2	1.05
12	9b-8-ETF	2.718	242	34.8	32.8	1.00	23.4	30.5	28.3	1.08	27.5	1.11	26.9	1.13
13	10a-6-ETF	2.748	242	52.7	50.7	1.00	9.24	26.3	23.0	1.14	23.8	1.11	22.9	1.15
14	10a-7-ETF	2.748	242	52.7	50.7	1.00	13.9	26.5	24.2	1.10	25.2	1.05	23.9	1.11
15	10b-5-ETF	2.748	242	52.7	50.7	1.00	23.1	34.5	26.1	1.32	27.6	1.25	25.5	1.35
16	13a-5-ETF	3.409	246	27.5	25.5	1.00	7.45	30.0	40.8	0.74	40.3	0.75	39.2	0.77
17	13a-6-ETF	3.409	246	27.5	25.5	1.00	11.2	37.8	42.7	0.89	42.6	0.89	40.8	0.93
18	13b-4-ETF	3.409	246	27.5	25.5	1.00	18.6	57.0	45.8	1.24	46.2	1.23	43.3	1.32
19	14a-6-ETF	3.754	228	38.3	36.3	1.00	6.77	39.6	42.4	0.93	49.9	0.79	41.6	0.95
20	14a-7-ETF	3.754	228	38.3	36.3	1.00	10.1	49.6	44.4	1.12	52.6	0.94	43.2	1.15
21	14b-5-ETF	3.754	228	38.3	36.3	1.00	16.9	54.7	47.5	1.15	57.0	0.96	45.7	1.20

Table C.4 (Continued)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
22	16d-3-ETF	1.168	222	172	170	1.00	21.7	3.92	2.31	1.70	3.20	1.23	2.80	1.40
23	16d-4-ETF	1.168	222	172	170	1.00	54.3	4.10	2.74	1.50	3.88	1.06	3.24	1.26
24	17d-3-ETF	1.918	247	104	102	1.00	13.2	10.9	9.19	1.19	10.0	1.09	9.85	1.11
25	17d-4-ETF	1.918	247	104	102	1.00	33.1	13.6	10.6	1.28	11.8	1.15	11.1	1.22
26	18a-3-ETF	3.124	259	63.9	61.9	1.00	8.13	30.3	29.5	1.03	31.4	0.96	30.0	1.01
27	18a-4-ETF	3.124	259	63.9	61.9	1.00	20.3	33.4	33.3	1.00	36.2	0.92	33.2	1.00

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
28	I-1-ETF-1	1.219	302	212	206	2.69	21.5	3.14	----	----	----	----	3.25	0.97
29	I-1-ETF-2	1.245	302	201	196	2.55	20.4	3.07	3.04	1.01	3.50	0.88	3.71	0.83
30	I-1-ETF-5	1.245	302	200	195	2.55	61.2	3.96	3.76	1.05	4.43	0.89	4.45	0.89
31	I-1-ETF-6	1.245	302	201	196	2.55	61.2	4.16	3.74	1.11	4.43	0.94	4.44	0.94
32	I-2-ETF-1	1.194	302	261	255	2.66	21.3	2.87	----	----	----	----	2.81	1.02
33	I-2-ETF-2	1.168	302	266	261	2.72	21.7	2.96	----	----	----	----	2.65	1.12
34	I-2-ETF-5	1.207	302	258	253	2.63	63.2	3.43	----	----	----	----	3.46	0.99
35	I-2-ETF-6	1.168	302	265	260	2.72	65.2	3.07	----	----	----	----	3.18	0.97
36	I-3-ETF-1	1.270	325	145	141	1.88	20.0	3.58	4.60	0.78	3.96	0.91	5.07	0.71
37	I-3-ETF-2	1.257	325	145	141	1.88	20.0	3.78	4.60	0.82	3.96	0.96	5.06	0.75
38	I-3-ETF-5	1.270	325	146	142	1.88	60.0	4.99	5.63	0.89	4.99	1.00	6.04	0.83
39	I-3-ETF-6	1.245	325	149	145	1.91	61.2	4.61	5.35	0.86	4.78	0.96	5.76	0.80
40	I-3-ETF-1*	1.270	325	148	144	1.91	20.4	3.65	4.37	0.84	3.78	0.97	4.83	0.76
41	I-3-ETF-2*	1.270	325	145	142	1.88	20.0	3.61	4.59	0.79	3.96	0.91	5.06	0.71
42	I-3-ETF-5*	1.245	325	147	143	1.90	60.6	4.47	5.49	0.82	4.88	0.92	5.89	0.76
43	I-3-ETF-6*	1.270	325	148	144	1.91	61.2	4.27	5.35	0.80	4.78	0.89	5.76	0.74

---- Exceeds AISI-96 or S136-94 Limit

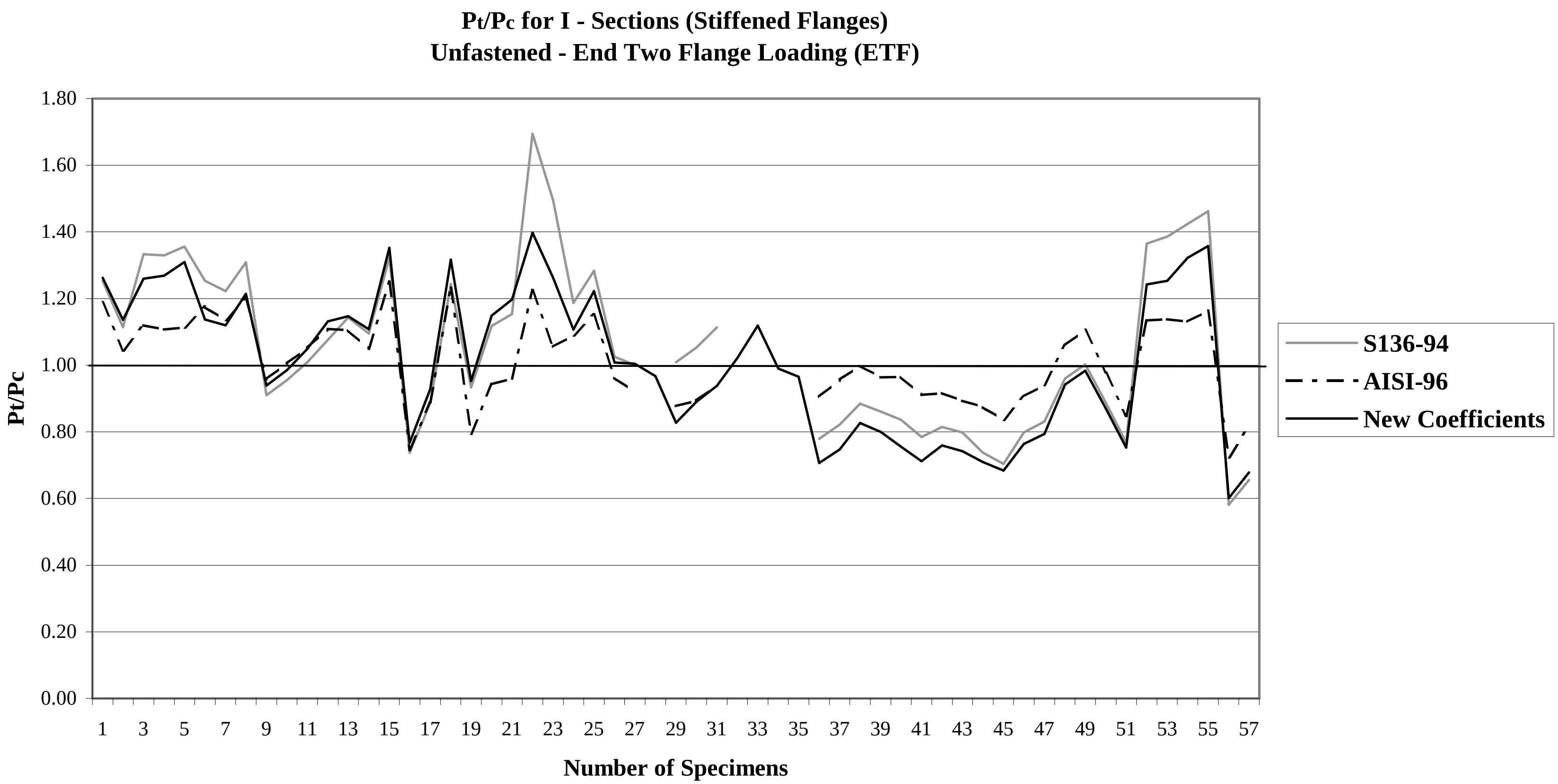
Table C.4 (Continued)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
44	I-5'-ETF-5	1.524	325	120	116	1.56	50.0	6.54	8.88	0.74	7.48	0.88	9.23	0.71
45	I-5'-ETF-6	1.524	325	120	116	1.82	50.0	6.25	8.88	0.70	7.48	0.84	9.14	0.68
46	I-6-ETF-1	1.908	295	96.1	93.6	1.25	13.3	9.06	11.3	0.80	10.0	0.91	11.9	0.76
47	I-6-ETF-2	1.905	295	96.7	94.2	1.25	13.3	9.37	11.3	0.83	9.96	0.94	11.8	0.79
48	I-6-ETF-5	1.910	295	95.9	93.4	1.25	39.9	13.1	13.6	0.96	12.3	1.06	13.9	0.94
49	I-6-ETF-6	1.910	295	96.4	93.9	1.25	39.9	13.6	13.6	1.00	12.3	1.11	13.8	0.98
50	I-6-ETF-7	1.905	295	96.5	94.0	1.25	40.0	12.0	13.5	0.89	12.2	0.98	13.8	0.87
51	I-6-ETF-8	1.930	295	95.2	92.8	1.23	39.5	10.7	13.9	0.77	12.6	0.85	14.2	0.75
52	I-6"-ETF-1	1.194	230	147	143	2.00	21.3	3.94	2.89	1.37	3.47	1.13	3.17	1.24
53	I-6"-ETF-2	1.168	230	152	148	2.04	21.7	3.76	2.71	1.39	3.30	1.14	3.00	1.25
54	I-6"-ETF-5	1.168	230	153	149	2.04	65.2	4.74	3.33	1.42	4.19	1.13	3.59	1.32
55	I-6"-ETF-6	1.168	230	152	148	2.04	65.2	4.87	3.33	1.46	4.19	1.16	3.59	1.36
56	I-12'-ETF-5	2.743	315	49.0	47.0	1.01	27.8	20.7	35.6	0.58	28.6	0.72	34.4	0.60
57	I-12'-ETF-6	2.743	315	49.0	47.0	1.01	27.8	23.3	35.6	0.66	28.6	0.82	34.4	0.68

	S136-94 P_t/P_c	AISI-96 P_t/P_c	New Coeff. P_t/P_c
P_t/P_c Mean value	1.05	1.01	1.01
S.D.	0.25	0.13	0.21
C.O.V.	0.24	0.13	0.21

Chart C.4



S136-94			AISI-96			New Coefficients		
Pt/Pc mean	=	1.05	Pt/Pc mean	=	1.01	Pt/Pc mean	=	1.01
S.D.	=	0.25	S.D.	=	0.13	S.D.	=	0.21
C.O.V.	=	0.24	C.O.V.	=	0.13	C.O.V.	=	0.21

Table C.5

I-Sections (Stiffened Flanges)
Unfastened - Interior Two Flange Loading (ITF)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	2a-4-ITF	1.532	208	64.0	62.0	1.00	16.6	15.9	12.5	1.27	14.2	1.12	13.7	1.16
2	2b-5-ITF	1.532	208	64.0	62.0	1.00	24.9	17.4	12.9	1.36	15.7	1.11	14.5	1.21
3	3-3-ITF	1.521	208	64.3	62.3	1.00	41.7	21.6	13.3	1.63	17.8	1.21	15.5	1.40
4	4a-4-ITF	1.547	208	98.2	96.2	1.00	16.4	15.6	12.0	1.30	13.8	1.13	12.4	1.26
5	4a-5-ITF	1.547	208	98.2	96.2	1.00	24.6	16.9	12.3	1.37	15.3	1.11	13.1	1.29
6	4b-3-ITF	1.547	208	98.2	96.2	1.00	41.1	21.1	12.9	1.64	17.6	1.20	14.2	1.49
7	6a-4-ITF	1.643	257	121	119	1.00	23.2	16.2	16.5	0.98	16.5	0.98	16.8	0.97
8	6b-4-ITF	1.643	257	121	119	1.00	38.6	18.9	17.2	1.10	18.9	1.00	18.1	1.04
9	9a-1-ITF	2.718	242	34.8	32.8	1.00	9.35	47.2	47.4	1.00	43.4	1.09	53.1	0.89
10	9a-2-ITF	2.718	242	34.8	32.8	1.00	14.0	57.4	48.4	1.19	47.3	1.22	55.4	1.04
11	9b-3-ITF	2.718	242	34.8	32.8	1.00	9.35	43.6	47.4	0.92	43.4	1.01	53.1	0.82
12	9b-4-ITF	2.718	242	34.8	32.8	1.00	14.0	48.3	48.4	1.00	47.3	1.02	55.4	0.87
13	9b-5-ITF	2.718	242	34.8	32.8	1.00	23.4	57.4	50.1	1.15	53.4	1.08	59.1	0.97
14	10a-4-ITF	2.748	242	52.7	50.7	1.00	9.24	46.1	46.4	0.99	44.3	1.04	50.3	0.92
15	10a-5-ITF	2.748	242	52.7	50.7	1.00	13.9	51.4	47.5	1.08	48.3	1.06	52.5	0.98
16	10b-4-ITF	2.748	242	52.7	50.7	1.00	23.1	55.9	49.0	1.14	54.5	1.02	56.0	1.00
17	11-4-ITF	2.774	249	70.7	68.7	1.00	9.16	51.6	47.1	1.10	45.0	1.15	49.3	1.05
18	11-5-ITF	2.774	249	70.7	68.7	1.00	13.7	49.4	48.1	1.03	49.0	1.01	51.5	0.96
19	12-4-ITF	2.817	249	69.7	67.7	1.00	22.5	57.0	51.3	1.11	57.0	1.00	57.0	1.00
20	12-5-ITF	2.817	249	69.7	67.7	1.00	27.1	64.1	52.0	1.23	59.9	1.07	58.3	1.10
21	13a-3-ITF	3.409	246	27.5	25.5	1.00	7.45	70.1	76.5	0.92	68.7	1.02	85.5	0.82
22	13a-4-ITF	3.409	246	27.5	25.5	1.00	11.2	77.2	78.0	0.99	74.5	1.04	89.5	0.86

Table C.5 (Continued)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
23	13b-3-ITF	3.409	246	27.5	25.5	1.00	18.6	80.3	80.4	1.00	83.6	0.96	95.0	0.85
24	14a-4-ITF	3.754	228	38.3	36.3	1.00	6.77	74.1	83.3	0.89	83.9	0.88	91.3	0.81
25	14a-5-ITF	3.754	228	38.3	36.3	1.00	10.1	90.3	84.8	1.07	90.7	1.00	94.8	0.95
26	14b-4-ITF	3.754	228	38.3	36.3	1.00	16.9	97.7	87.3	1.12	102	0.96	101	0.97
27	15a-4-ITF	3.741	228	52.1	50.1	1.00	6.79	79.9	80.2	1.00	83.4	0.96	85.6	0.93
28	15a-5-ITF	3.741	228	52.1	50.1	1.00	10.2	87.9	81.7	1.08	90.2	0.98	88.9	0.99
29	15a-6-ITF	3.741	228	52.1	50.1	1.00	17.0	106	84.1	1.27	101	1.06	94.2	1.13
30	15b-4-ITF	3.741	228	52.1	50.1	1.00	20.4	89.5	85.1	1.05	105	0.85	96.4	0.93
31	16d-1-ITF	1.168	222	172	170	1.00	21.7	7.12	6.64	1.07	7.21	0.99	6.15	1.16
32	16d-2-ITF	1.168	222	172	170	1.00	54.3	7.38	6.08	1.22	7.89	0.94	7.10	1.04
33	17d-1-ITF	1.918	247	104	102	1.00	13.2	27.6	21.2	1.30	20.4	1.35	21.4	1.29
34	17d-2-ITF	1.918	247	104	102	1.00	33.1	30.0	22.8	1.32	25.9	1.16	24.5	1.23
35	18a-1-ITF	3.124	259	63.9	61.9	1.00	8.13	57.4	62.5	0.92	57.5	1.00	65.9	0.87
36	18a-2-ITF	3.124	259	63.9	61.9	1.00	20.3	65.0	65.8	0.99	70.2	0.93	73.0	0.89

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
37	I-1-ITF-1	1.181	302	212	207	2.69	21.5	7.23	----	----	----	----	6.81	1.06
38	I-1-ITF-2	1.219	302	206	201	2.60	20.8	7.41	----	----	----	----	7.40	1.00
39	I-1-ITF-5	1.168	302	214	209	2.72	65.2	8.35	----	----	----	----	7.93	1.05
40	I-1-ITF-6	1.194	302	209	204	2.66	63.8	8.55	----	----	----	----	8.39	1.02
41	I-2-ITF-1	1.219	302	254	249	2.60	20.8	6.63	----	----	----	----	6.30	1.05
42	I-2-ITF-2	1.207	302	257	251	2.63	21.1	6.77	----	----	----	----	6.11	1.11
43	I-2-ITF-5	1.194	302	260	255	2.66	63.8	7.63	----	----	----	----	7.09	1.08
44	I-2-ITF-6	1.219	302	255	249	2.60	62.5	7.52	----	----	----	----	7.51	1.00

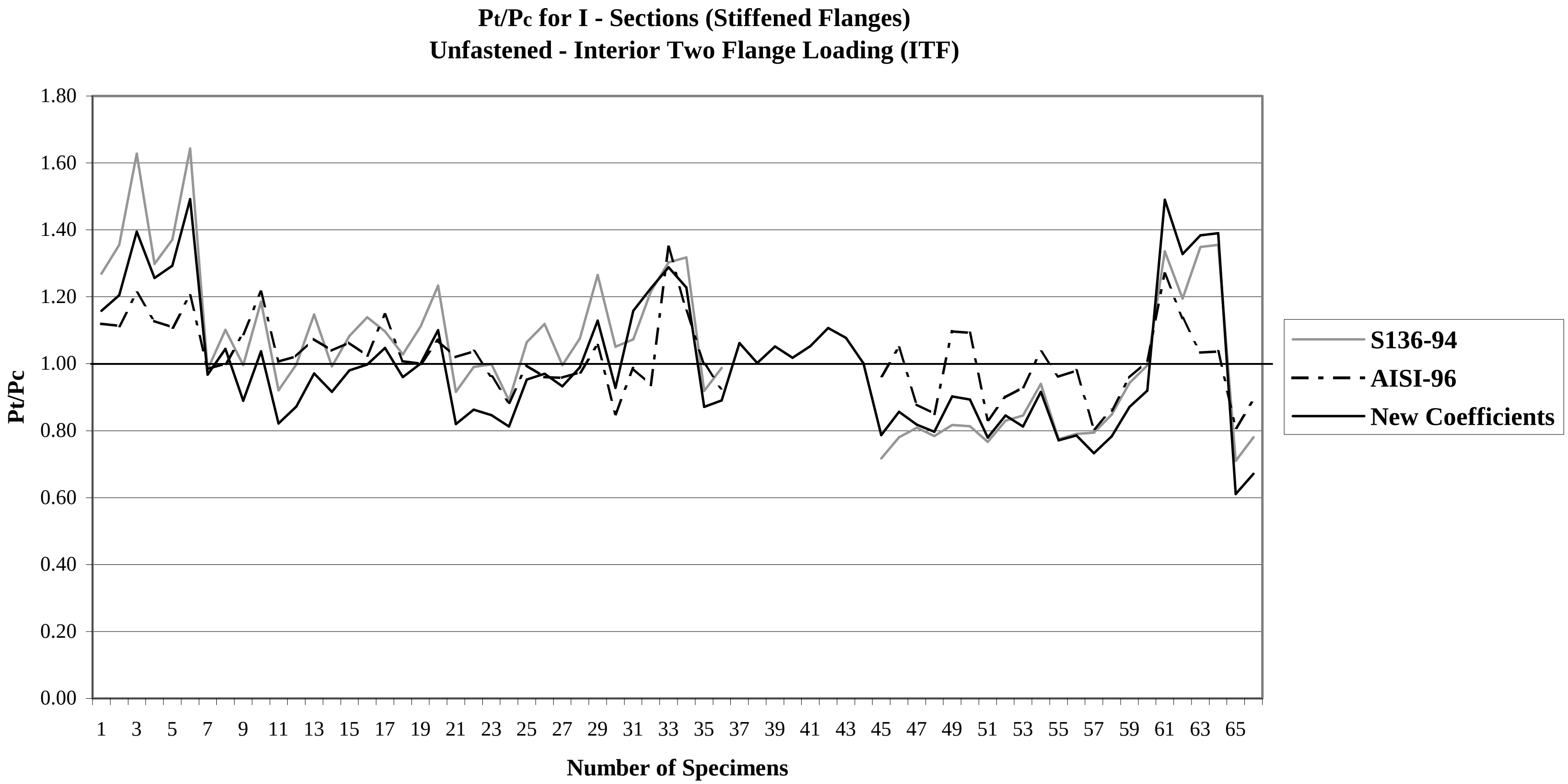
---- Exceeds AISI-96 or S136-94 Limit

Table C.5 (Continued)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**H'** **h'/t** (ratio)	**H** **h/t** (ratio)	**R** **r/t** (ratio)	**N** **n/t** (ratio)	**P_t** (kN)	**S136-94** **P_c** (kN)	**P_t/P_c** (ratio)	**AISI-96** **P_c** (kN)	**P_t/P_c** (ratio)	**New Coeff.** **P_c** (kN)	**P_t/P_c** (ratio)
45	I-3-ITF-1	1.270	325	146	142	1.80	20.0	8.52	11.89	0.72	8.84	0.96	10.83	0.79
46	I-3-ITF-2	1.270	325	146	142	1.88	20.0	9.27	11.88	0.78	8.84	1.05	10.82	0.86
47	I-3-ITF-5	1.270	325	145	142	1.80	60.0	10.6	13.1	0.81	12.0	0.88	12.9	0.82
48	I-3-ITF-6	1.245	325	149	145	1.91	61.2	9.81	12.5	0.78	11.5	0.85	12.3	0.80
49	I-3-ITF-1*	1.245	325	148	145	1.91	20.4	9.30	11.4	0.82	8.48	1.10	10.3	0.90
50	I-3-ITF-2*	1.270	325	146	142	1.88	20.0	9.66	11.9	0.81	8.84	1.09	10.8	0.89
51	I-3-ITF-5*	1.257	325	147	143	1.90	60.6	9.81	12.8	0.77	11.8	0.83	12.6	0.78
52	I-3-ITF-6*	1.245	325	149	145	1.91	61.2	10.4	12.5	0.83	11.5	0.90	12.3	0.85
53	I-5'-ITF-5	1.549	325	118	115	1.54	49.2	16.8	19.9	0.85	18.0	0.93	20.7	0.81
54	I-5'-ITF-6	1.562	325	117	113	1.78	48.8	19.0	20.2	0.94	18.4	1.04	20.7	0.92
55	I-6-ITF-1	1.905	295	96.5	94.0	1.25	13.3	19.9	25.7	0.78	20.7	0.96	25.9	0.77
56	I-6-ITF-2	1.908	295	96.5	94.0	1.25	13.3	20.3	25.7	0.79	20.8	0.98	25.9	0.79
57	I-6-ITF-5	1.908	295	95.9	93.4	1.25	39.9	22.1	27.9	0.79	27.5	0.81	30.2	0.73
58	I-6-ITF-6	1.905	295	96.0	93.5	1.25	39.9	23.6	27.8	0.85	27.4	0.86	30.1	0.78
59	I-6-ITF-7	1.930	295	95.9	93.4	1.24	39.7	26.5	28.1	0.94	27.7	0.96	30.4	0.87
60	I-6-ITF-8	1.930	295	96.8	94.3	1.25	40.0	27.6	27.7	1.00	27.3	1.01	30.0	0.92
61	I-6"-ITF-1	1.168	230	152	148	2.04	21.7	9.52	7.12	1.34	7.50	1.27	6.39	1.49
62	I-6"-ITF-2	1.181	230	150	146	2.02	21.5	8.71	7.29	1.20	7.67	1.14	6.56	1.33
63	I-6"-ITF-5	1.168	230	152	148	2.04	65.2	10.6	7.85	1.35	10.3	1.03	7.65	1.38
64	I-6"-ITF-6	1.168	230	152	148	2.04	65.2	10.6	7.85	1.36	10.3	1.04	7.65	1.39
65	I-12'-ITF-5	2.743	315	49.1	47.0	1.01	27.8	46.2	65.01	0.71	57.05	0.81	75.54	0.61
66	I-12'-ITF-6	2.743	315	48.9	46.9	1.01	27.8	50.7	64.99	0.78	57.02	0.89	75.55	0.67
							P_t/P_c Mean value			1.05		1.02		1.00
							S.D.			0.22		0.11		0.19
							C.O.V.			0.21		0.11		0.19

Chart C.5



S136-94	**AISI-96**	**New Coefficients**
Pt/Pc mean = 1.05	Pt/Pc mean = 1.02	Pt/Pc mean = 1.00
S.D. = 0.22	S.D. = 0.11	S.D. = 0.19
C.O.V. = 0.21	C.O.V. = 0.11	C.O.V. = 0.19

Table C.6

I-Sections (Unstiffened Flanges)
Unfastened - End One Flange Loading (EOF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	I-U-17-EOF-5	1.245	250	99.0	97.1	0.96	61.2	11.4	10.7	1.06	8.65	1.31	10.5	1.08
2	I-U-17-EOF-6	1.245	250	97.6	95.7	0.96	61.2	9.93	10.7	0.93	8.65	1.15	10.5	0.94
3	I-U-18-EOF-5	1.232	250	197	195	0.97	61.9	9.08	10.5	0.87	9.03	1.01	10.3	0.88
4	I-U-18-EOF-6	1.245	250	195	193	0.96	61.2	10.2	10.7	0.95	9.20	1.11	10.5	0.97
							P_t/P_c Mean value			0.95		1.14		0.97
							S.D.			0.07		0.11		0.07
							C.O.V.			0.07		0.10		0.07

Table C.7

I-Sections (Unstiffened Flange)
Unfastened - Interior One Flange Loading (IOF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	I-U-18-IOF-5	1.245	250	195	193	0.96	61.2	12.2	10.9	1.12	13.6	0.89	12.1	1.00
2	I-U-18-IOF-6	1.245	250	195	193	0.96	61.2	11.4	10.9	1.05	13.6	0.84	12.1	0.94
							P_t/P_c Mean value			1.08		0.87		0.97
							S.D.			0.03		0.02		0.03
							C.O.V.			0.03		0.03		0.03

Table C.8

Single Web Sections (Stiffened Flanges)
Fastened - End One Flange Loading (EOF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t**	**F_y**	**h'/t**	**h/t**	**r/t**	**n/t**	**P_t**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**
		(mm)	(MPa)	(ratio)	(ratio)	(ratio)	(ratio)	(kN)	(kN)	(ratio)	(kN)	(ratio)	(kN)	(ratio)
1	M-SU-4-EOF-1	1.270	325	96.0	92.4	1.80	20.0	3.89	3.76	1.04	4.18	0.93	3.52	1.11
2	M-SU-4-EOF-2	1.288	325	95.4	91.7	1.85	19.7	3.89	3.82	1.02	4.25	0.91	3.60	1.08
3	M-SU-4-EOF-5	1.270	325	95.9	92.5	1.72	60.0	6.60	5.86	1.13	5.64	1.17	5.12	1.29
4	M-SU-4-EOF-6	1.270	325	96.4	92.6	1.88	60.0	6.26	5.74	1.09	5.49	1.14	5.07	1.23
5	M-SU-6'-EOF-1	1.273	325	145	141	1.87	20.0	3.78	3.28	1.15	3.69	1.03	3.32	1.14
6	M-SU-6'-EOF-2	1.283	325	144	140	1.86	19.8	3.87	3.34	1.16	3.76	1.03	3.37	1.15
7	M-SU-6'-EOF-5	1.270	325	145	142	1.88	60.0	5.23	5.05	1.04	4.89	1.07	4.78	1.09
8	M-SU-6'-EOF-6	1.295	325	143	139	1.84	58.8	5.25	5.27	1.00	5.12	1.03	4.97	1.06

Bhakta - University of Missouri-Rolla, USA-1992 [5]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t**	**F_y**	**h'/t**	**h/t**	**r/t**	**n/t**	**P_t**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**
		(mm)	(MPa)	(ratio)	(ratio)	(ratio)	(ratio)	(kN)	(kN)	(ratio)	(kN)	(ratio)	(kN)	(ratio)
9	C1-F	2.769	391	71.1	68.3	1.43	24.1	20.4	25.9	0.79	25.7	0.79	22.6	0.90
10	C2-F	2.769	391	72.2	69.3	1.43	24.1	20.9	25.8	0.81	25.6	0.82	22.6	0.93
11	C5-F	1.626	413	121	116	2.44	41.0	8.29	9.00	0.92	7.8	1.06	8.68	0.96
12	C6-F	1.626	413	121	116	2.44	41.0	7.40	9.00	0.82	7.8	0.95	8.68	0.85
13	C9-F	1.600	432	141	131	4.97	41.7	6.65	----	----	4.8	1.39	7.64	0.87
14	C10-F	1.600	432	141	132	4.97	41.7	6.62	----	----	4.8	1.39	7.64	0.87
15	Z3-F	1.778	421	142	133	4.76	37.5	8.43	----	----	5.6	1.49	8.95	0.94
16	Z4-F	1.778	421	142	133	4.76	37.5	8.15	----	----	5.6	1.44	8.95	0.91
17	Z7-F	2.540	447	78.6	72.0	3.33	26.3	18.3	20.4	0.90	16.3	1.13	19.9	0.92
18	Z8-F	2.540	447	78.5	71.9	3.33	26.3	17.6	20.4	0.86	16.2	1.08	19.9	0.88

---- Exceeds AISI-96 or S136-94 Limit

Table C.8 (Continued)

Cain - University of Missouri-Rolla, USA-1995 [6]

				H'	**H**	**R**	**N**		**S136-94**		**AISI-96**		**New Coeff.**	
No.	**Specimen**	**t**	**F_y**	**h'/t**	**h/t**	**r/t**	**n/t**	**P_t**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**
		(mm)	(MPa)	(ratio)	(ratio)	(ratio)	(ratio)	(kN)	(kN)	(ratio)	(kN)	(ratio)	(kN)	(ratio)
19	Z1.3-F	1.549	425	104	95.9	4.10	43.0	7.01	----	----	5.23	1.34	7.75	0.90
20	Z1.4-F	1.549	425	104	95.6	4.10	43.0	6.99	----	----	5.23	1.34	7.76	0.90
21	Z2.3-F	2.108	449	76	69.9	3.01	31.6	13.8	15.8	0.87	12.61	1.09	14.9	0.92
22	Z2.4-F	2.108	449	76	69.9	3.01	31.6	13.8	15.8	0.87	12.61	1.09	14.9	0.92
23	Z3.3-F	1.549	427	137	129	4.10	43.0	7.58	----	----	4.85	1.56	7.49	1.01
24	Z3.4-F	1.549	427	137	129	4.10	43.0	7.77	----	----	4.85	1.60	7.49	1.04
25	Z4.3-F	2.108	434	100	94.4	3.01	31.6	12.3	14.2	0.86	11.77	1.05	14.0	0.88
26	Z4.4-F	2.108	434	100	94.4	3.01	31.6	12.1	14.3	0.85	11.77	1.03	14.0	0.87
27	Z5.3-F	1.499	504	159	151	4.24	44.5	6.19	----	----	4.49	1.38	8.10	0.76
28	Z5.4-F	1.499	504	159	150	4.24	44.5	6.56	----	----	4.46	1.47	8.10	0.81
29	Z6.3-F	1.905	508	124	118	3.33	35.0	11.0	12.9	0.86	9.23	1.19	13.2	0.83
30	Z6.4-F	1.905	508	125	118	3.33	35.0	11.2	12.9	0.87	9.26	1.21	13.2	0.85
31	Z7.3-F	1.905	392	152	143	4.17	35.0	9.01	----	----	6.26	1.44	9.48	0.95
32	Z7.4-F	1.905	392	151	143	4.17	35.0	9.12	----	----	6.26	1.46	9.48	0.96

Gerges - University of Waterloo, Canada-1997 [9]

				H'	**H**	**R**	**N**		**S136-94**		**AISI-96**		**New Coeff.**	
No.	**Specimen**	**t**	**F_y**	**h'/t**	**h/t**	**r/t**	**n/t**	**P_t**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**
		(mm)	(MPa)	(ratio)	(ratio)	(ratio)	(ratio)	(kN)	(kN)	(ratio)	(kN)	(ratio)	(kN)	(ratio)
33	150-7-30-B	1.280	321	118	108	4.96	23.4	3.47	----	----	2.38	1.46	3.09	1.12
34	150-7-60-A	1.280	321	116	106	4.96	49.6	3.81	----	----	2.89	1.32	3.98	0.96
35	150-7-100-A	1.280	321	116	106	4.96	78.9	4.94	----	----	3.66	1.35	4.72	1.05
36	150-7-100-B	1.280	321	116	106	4.96	78.9	4.94	----	----	3.66	1.35	4.72	1.05
37	150-10-30-A	1.280	321	115	100	7.45	23.4	3.37	----	----	----	----	2.80	1.20
38	150-10-30-B	1.280	321	115	100	7.45	23.4	3.32	----	----	----	----	2.80	1.19

---- Exceeds AISI-96 or S136-94 Limit

Table C.8 (Continued)

Gerges - University of Waterloo, Canada-1997 [9]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
39	150-10-60-A	1.280	321	115	100	7.45	49.6	3.67	----	----	----	----	3.61	1.02
40	150-10-60-B	1.280	321	116	101	7.45	49.6	3.70	----	----	----	----	3.60	1.03
41	150-10-100-A	1.280	321	114	99.2	7.45	78.9	4.05	----	----	----	----	4.28	0.95
42	150-10-100-B	1.280	321	117	102	7.45	78.9	4.11	----	----	----	----	4.26	0.97
43	150-12-30-A	1.280	321	115	96.9	9.30	23.4	3.17	----	----	----	----	2.61	1.22
44	150-12-30-B	1.280	321	115	96.9	9.30	23.4	3.16	----	----	----	----	2.61	1.21
45	150-12-60-A	1.280	321	115	96.9	9.30	49.6	3.40	----	----	----	----	3.36	1.01
46	150-12-100-A	1.280	321	115	96.9	9.30	78.9	4.03	----	----	----	----	3.98	1.01
47	150-12-100-B	1.280	321	115	96.1	9.30	78.9	4.01	----	----	----	----	3.98	1.01
48	200-7-30-A	1.280	321	155	145	4.96	23.4	3.38	----	----	2.17	1.56	2.96	1.14
49	200-7-60-A	1.280	321	154	144	4.96	49.6	3.65	----	----	2.64	1.38	3.81	0.96
50	200-7-60-B	1.280	321	155	145	4.96	49.6	3.63	----	----	2.63	1.38	3.81	0.95
51	200-7-100-A	1.280	321	154	144	4.96	78.9	4.41	----	----	3.35	1.32	4.52	0.98
52	200-7-100-B	1.280	321	154	144	4.96	78.9	4.43	----	----	3.35	1.32	4.52	0.98
53	200-10-30-A	1.280	321	155	140	7.45	23.4	3.10	----	----	----	----	2.67	1.16
54	200-10-30-B	1.280	321	154	139	7.45	23.4	3.12	----	----	----	----	2.68	1.17
55	200-10-60-A	1.280	321	155	140	7.45	49.6	3.41	----	----	----	----	3.44	0.99
56	200-10-60-B	1.280	321	154	139	7.45	49.6	3.41	----	----	----	----	3.44	0.99
57	200-10-100-A	1.280	321	155	140	7.45	78.9	3.67	----	----	----	----	4.08	0.90
58	200-10-100-B	1.280	321	154	139	7.45	78.9	3.67	----	----	----	----	4.08	0.90
59	200-12-30-A	1.280	321	155	136	9.30	23.4	2.82	----	----	----	----	2.49	1.13
60	200-12-30-B	1.280	321	155	136	9.30	23.4	2.92	----	----	----	----	2.49	1.17
61	200-12-60-A	1.280	321	155	136	9.30	49.6	3.33	----	----	----	----	3.21	1.04
62	200-12-60-B	1.280	321	155	136	9.30	49.6	3.33	----	----	----	----	3.21	1.04
63	200-12-100-A	1.280	321	155	137	9.30	78.9	3.53	----	----	----	----	3.80	0.93

---- Exceeds AISI-96 or S136-94 Limit

Table C.8 (Continued)

Gerges - University of Waterloo, Canada-1997 [9]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
64	200-12-100-B	1.280	321	155	136	9.30	78.9	3.60	----	----	----	----	3.80	0.95
65	250-7-30-A	1.280	321	194	184	4.96	23.4	3.17	----	----	1.96	1.62	2.84	1.12
66	250-7-30-B	1.280	321	194	184	4.96	23.4	3.26	----	----	1.96	1.66	2.84	1.15
67	250-7-60-A	1.280	321	194	184	4.96	49.6	3.53	----	----	2.38	1.49	3.65	0.97
68	250-7-60-B	1.280	321	194	184	4.96	49.6	3.51	----	----	2.37	1.48	3.65	0.96
69	250-7-100-A	1.280	321	194	184	4.96	78.9	4.04	----	----	3.01	1.34	4.33	0.93
70	250-7-100-B	1.280	321	194	184	4.96	78.9	4.06	----	----	3.01	1.35	4.33	0.94
71	250-10-30-A	1.280	321	194	179	7.45	23.4	3.00	----	----	----	----	2.57	1.17
72	250-10-30-B	1.280	321	193	178	7.45	23.4	2.94	----	----	----	----	2.57	1.15
73	250-10-60-A	1.280	321	193	178	7.45	49.6	3.21	----	----	----	----	3.30	0.97
74	250-10-60-B	1.280	321	192	177	7.45	49.6	3.19	----	----	----	----	3.31	0.97
75	250-10-100-A	1.280	321	194	179	7.45	78.9	3.64	----	----	----	----	3.91	0.93
76	250-10-100-B	1.280	321	193	178	7.45	78.9	3.52	----	----	----	----	3.92	0.90
77	250-12-30-A	1.280	321	194	176	9.30	23.4	2.90	----	----	----	----	2.39	1.22
78	250-12-30-B	1.280	321	194	175	9.30	23.4	2.96	----	----	----	----	2.39	1.24
79	250-12-60-A	1.280	321	194	175	9.30	49.6	3.17	----	----	----	----	3.07	1.03
80	250-12-60-B	1.280	321	193	174	9.30	49.6	3.15	----	----	----	----	3.08	1.02
81	250-12-100-A	1.280	321	193	174	9.30	78.9	3.48	----	----	----	----	3.65	0.95
82	250-12-100-B	1.280	321	191	173	9.30	78.9	3.48	----	----	----	----	3.65	0.95
83	300-7-30-A	1.280	321	231	221	4.96	23.4	3.00	----	----	----	----	2.74	1.10
84	300-7-30-B	1.280	321	232	222	4.96	23.4	3.10	----	----	----	----	2.74	1.13
85	300-7-60-A	1.280	321	233	223	4.96	49.6	3.37	----	----	----	----	3.52	0.96
86	300-7-60-B	1.280	321	233	223	4.96	49.6	3.33	----	----	----	----	3.52	0.95
87	300-7-100-A	1.280	321	233	223	4.96	78.9	3.73	----	----	----	----	4.17	0.89
88	300-7-100-B	1.280	321	233	223	4.96	78.9	3.77	----	----	----	----	4.17	0.90

---- Exceeds AISI-96 or S136-94 Limit

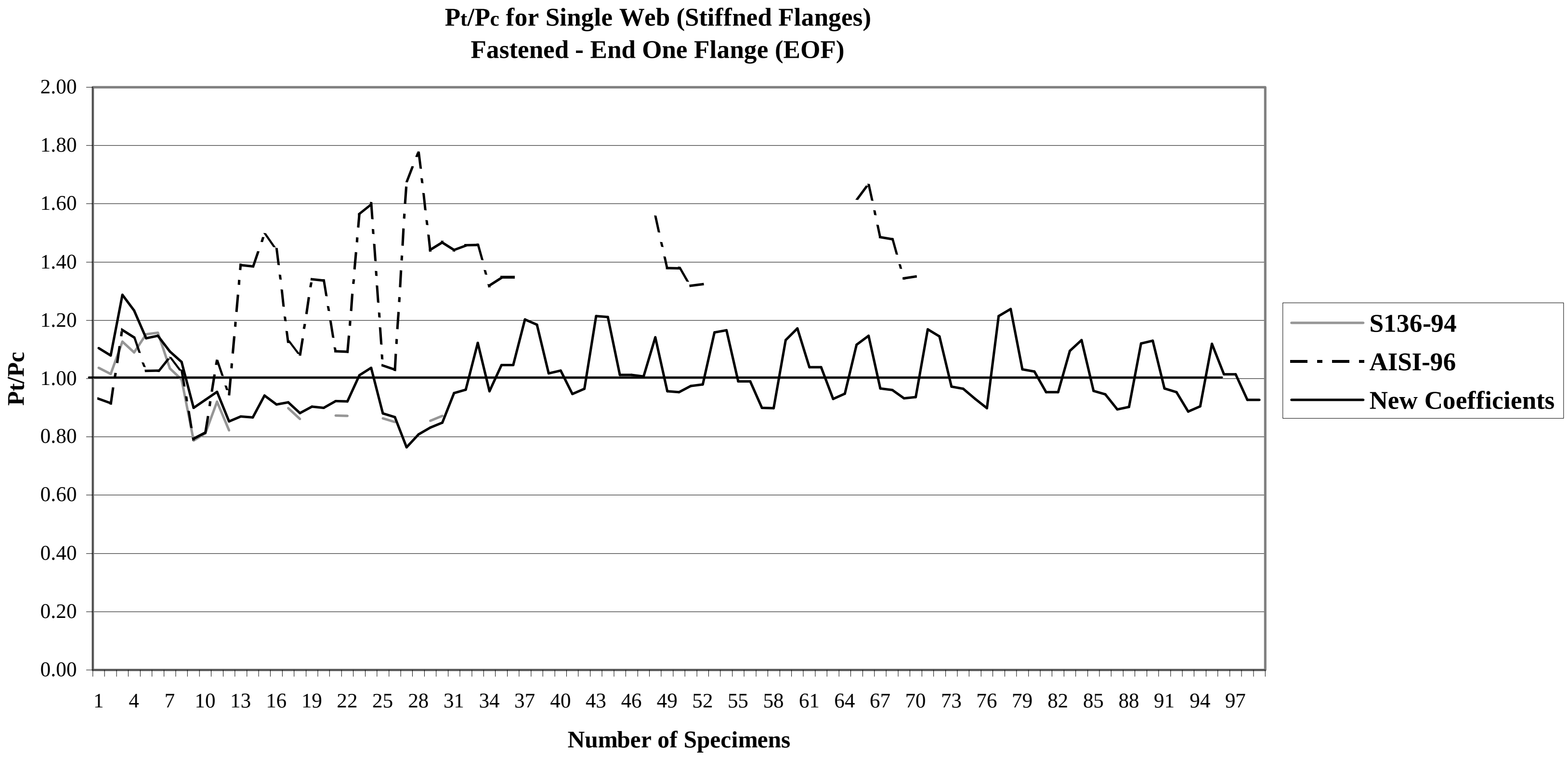
Table C.8 (Continued)

Gerges - University of Waterloo, Canada-1997 [9]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
89	300-10-30-A	1.280	321	232	217	7.45	23.4	2.77	----	----	----	----	2.47	1.12
90	300-10-30-B	1.280	321	233	218	7.45	23.4	2.79	----	----	----	----	2.47	1.13
91	300-10-60-A	1.280	321	232	217	7.45	49.6	3.07	----	----	----	----	3.18	0.97
92	300-10-60-B	1.280	321	232	217	7.45	49.6	3.03	----	----	----	----	3.18	0.95
93	300-10-100-A	1.280	321	232	217	7.45	78.9	3.34	----	----	----	----	3.77	0.89
94	300-10-100-B	1.280	321	232	217	7.45	78.9	3.41	----	----	----	----	3.77	0.91
95	300-12-30-A	1.280	321	233	215	9.30	23.4	2.57	----	----	----	----	2.30	1.12
96	300-12-60-A	1.280	321	233	214	9.30	49.6	3.00	----	----	----	----	2.96	1.02
97	300-12-60-B	1.280	321	233	214	9.30	49.6	3.00	----	----	----	----	2.96	1.02
98	300-12-100-A	1.280	321	232	213	9.30	78.9	3.25	----	----	----	----	3.51	0.93
99	300-12-100-B	1.280	321	232	213	9.30	78.9	3.25	----	----	----	----	3.51	0.93
							P_t/P_c Mean value			0.95		1.29		1.01
							S.D.			0.12		0.24		0.11
							C.O.V.			0.13		0.19		0.11

---- Exceeds AISI-96 or S136-94 Limit

Chart C.6



S136-94	**AISI-96**	**New Coefficients**
Pt/Pc mean = 0.95	Pt/Pc mean = 1.29	Pt/Pc mean = 1.01
S.D. = 0.12	S.D. = 0.24	S.D. = 0.11
C.O.V. = 0.13	C.O.V. = 0.19	C.O.V. = 0.11

Table C.9

Single Web C-Sections (Stiffened Flanges)
Fastened - End Two Flange Loading (ETF)

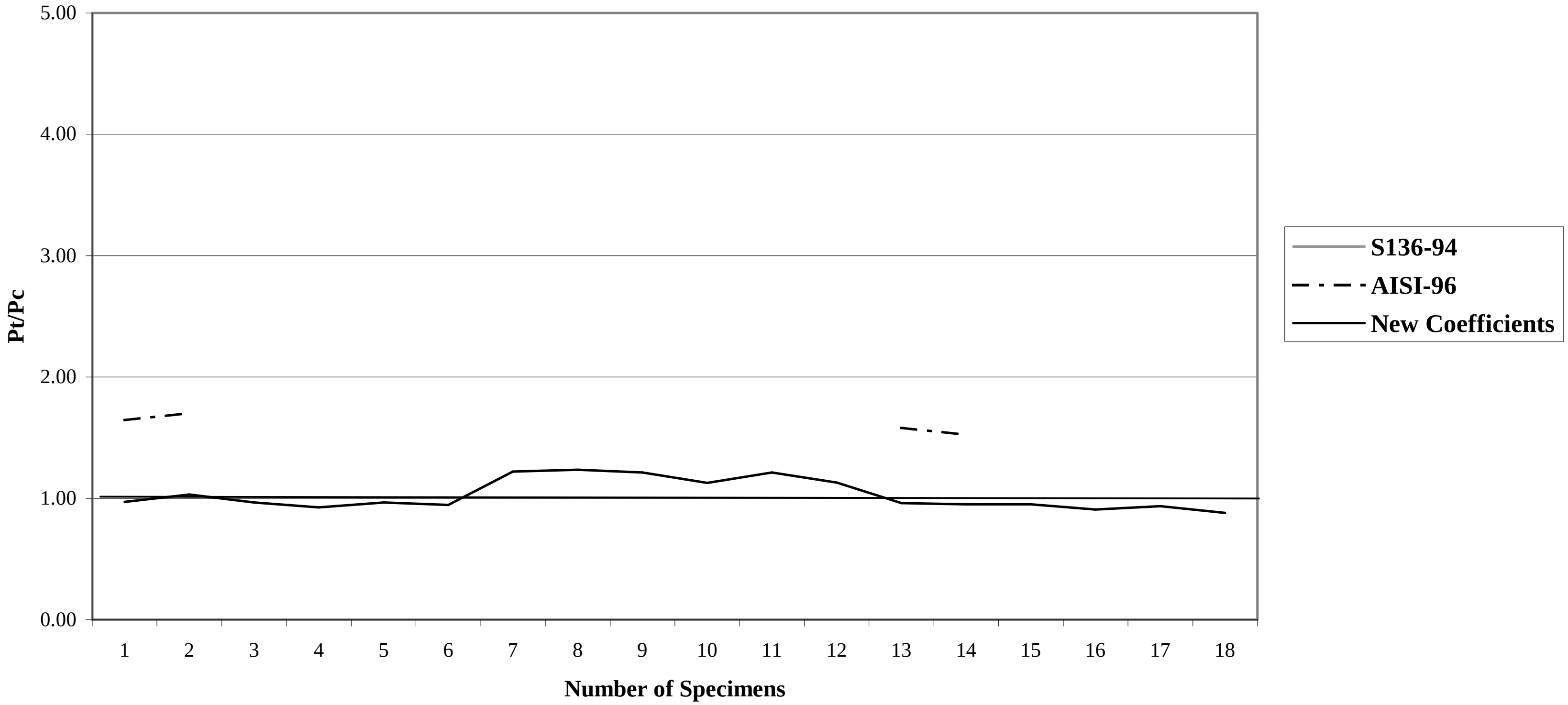
Beshara - University of Waterloo, Canada - 1999*

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	C-120-7-30	1.450	332	81.4	71.8	4.83	20.7	3.84	----	----	2.34	1.64	3.96	0.97
2	C-120-7-60	1.450	332	81.4	71.8	4.83	43.8	4.74	----	----	2.78	1.70	4.59	1.03
3	C-120-10-30	1.450	332	80.8	67.0	6.90	20.7	3.75	----	----	----	----	3.88	0.97
4	C-120-10-60	1.450	332	80.8	67.0	6.90	43.8	4.17	----	----	----	----	4.50	0.93
5	C-120-14-100A	1.450	332	79.4	60.1	9.66	69.7	4.77	----	----	----	----	4.94	0.97
6	C-120-14-100B	1.450	332	79.4	60.1	9.66	69.7	4.68	----	----	----	----	4.94	0.95
7	C-200-7-30	1.160	328	170	158	6.03	25.9	2.07	----	----	----	----	1.70	1.22
8	C-200-7-60	1.160	328	170	158	6.03	54.7	2.46	----	----	----	----	1.99	1.24
9	C-200-10-30	1.160	328	170	153	8.62	25.9	2.01	----	----	----	----	1.66	1.21
10	C-200-10-60	1.160	328	170	153	8.62	54.7	2.19	----	----	----	----	1.94	1.13
11	C-200-14-30	1.160	328	171	147	12.1	25.9	1.95	----	----	----	----	1.61	1.21
12	C-200-14-60	1.160	328	171	147	12.1	54.7	2.13	----	----	----	----	1.88	1.13
13	C-300-7-30	1.450	448	205	195	4.83	20.7	2.85	----	----	1.80	1.58	2.96	0.96
14	C-300-7-60	1.450	448	205	195	4.83	43.8	3.27	----	----	2.15	1.52	3.44	0.95
15	C-300-10-30	1.450	448	205	191	6.90	20.7	2.76	----	----	----	----	2.90	0.95
16	C-300-10-60	1.450	448	205	191	6.90	43.8	3.06	----	----	----	----	3.37	0.91
17	C-300-14-30	1.450	448	204	185	9.66	20.7	2.67	----	----	----	----	2.85	0.94
18	C-300-14-60	1.450	448	204	185	9.66	43.8	2.91	----	----	----	----	3.31	0.88
								P_t/P_c Mean value		----		1.61		1.03
								S.D.		----		0.08		0.12
								C.O.V.		----		0.05		0.12

* Experimental work of this study
---- Exceeds AISI-96 or S136-94 Limit

Chart C.7

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



S136-94	AISI-96	New Coefficients
Pt/Pc mean = ----	Pt/Pc mean = 1.61	Pt/Pc mean = 1.03
S.D. = ----	S.D. = 0.08	SD = 0.12
C.O.V. = ----	C.O.V. = 0.05	C.O.V. = 0.12

Table C.10

Single Web Z-Sections (Stiffened Flanges)
Fastened - End Two Flange Loading (ETF)

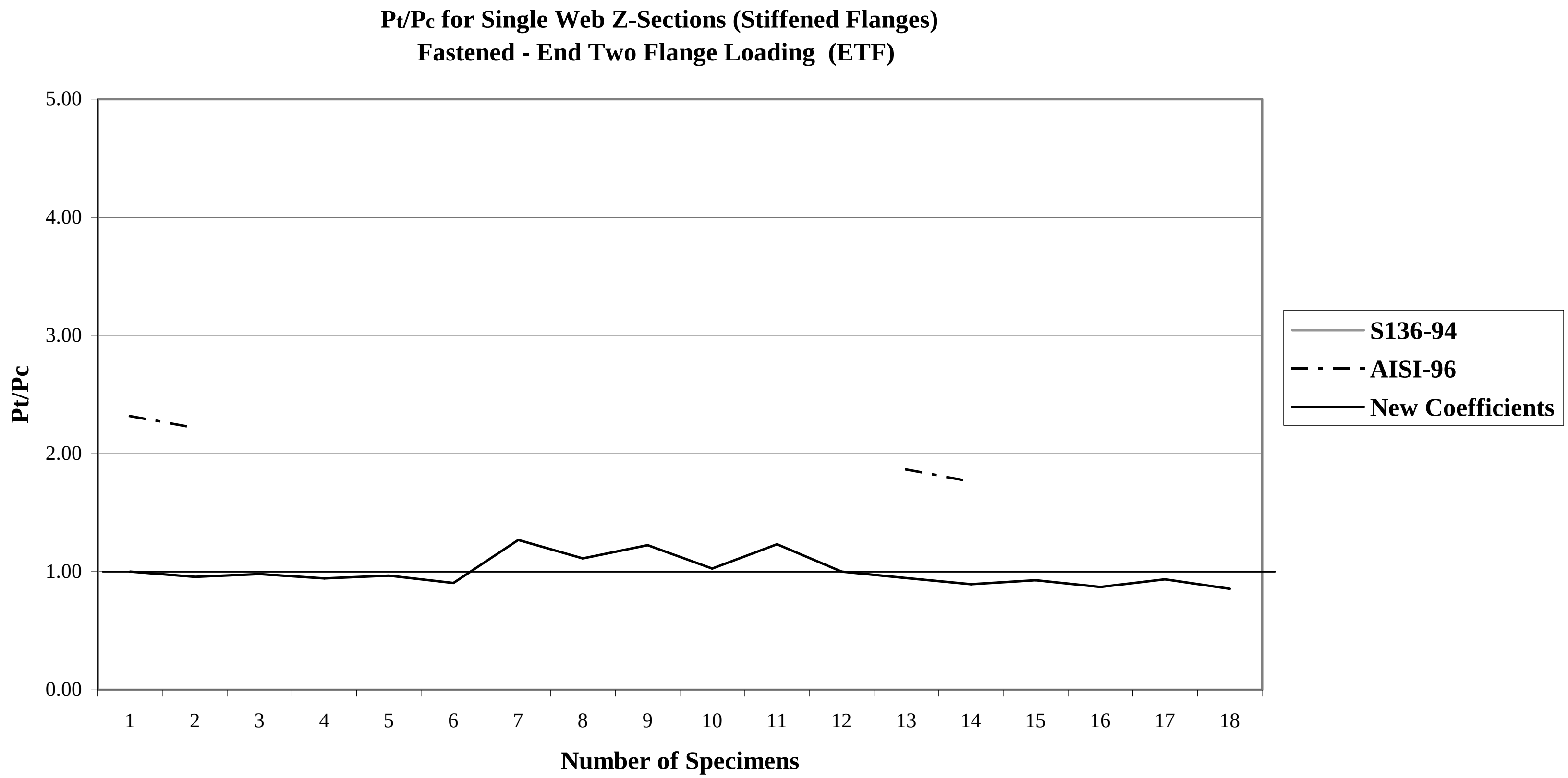
Beshara - University of Waterloo, Canada - 1999*

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t**	**F_y**	**h'/t**	**h/t**	**r/t**	**n/t**	**P_t**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**
		(mm)	(MPa)	(ratio)	(ratio)	(ratio)	(ratio)	(kN)	(kN)	(ratio)	(kN)	(ratio)	(kN)	(ratio)
1	Z-120-7-30	1.450	332	80.8	71.1	4.83	20.7	5.43	----	----	2.34	2.32	5.42	1.00
2	Z-120-7-60	1.450	332	80.8	71.1	4.83	43.8	6.18	----	----	2.79	2.22	6.46	0.96
3	Z-120-10-30	1.450	332	80.8	67.0	6.90	20.7	5.31	----	----	----	----	5.42	0.98
4	Z-120-10-60	1.450	332	80.8	67.0	6.90	43.8	6.09	----	----	----	----	6.45	0.94
5	Z-120-14-30	1.450	332	80.8	61.4	9.66	20.7	5.25	----	----	----	----	5.43	0.97
6	Z-120-14-60	1.450	332	80.8	61.4	9.66	43.8	5.85	----	----	----	----	6.47	0.90
7	Z-200-7-30	1.160	323	170	158	6.03	25.9	2.73	----	----	----	----	2.15	1.27
8	Z-200-7-60	1.160	323	170	158	6.03	54.7	2.88	----	----	----	----	2.59	1.11
9	Z-200-10-30	1.160	323	170	153	8.62	25.9	2.64	----	----	----	----	2.16	1.22
10	Z-200-10-60	1.160	323	170	153	8.62	54.7	2.67	----	----	----	----	2.60	1.03
11	Z-200-14-30	1.160	323	173	149	12.1	25.9	2.64	----	----	----	----	2.14	1.23
12	Z-200-14-60	1.160	323	173	149	12.1	54.7	2.58	----	----	----	----	2.58	1.00
13	Z-300-7-30	1.450	446	205	195	4.83	20.7	3.36	----	----	1.80	1.87	3.55	0.95
14	Z-300-7-60	1.450	446	205	195	4.83	43.8	3.78	----	----	2.14	1.76	4.23	0.89
15	Z-300-10-30	1.450	446	205	191	6.90	20.7	3.30	----	----	----	----	3.56	0.93
16	Z-300-10-60	1.450	446	205	191	6.90	43.8	3.69	----	----	----	----	4.24	0.87
17	Z-300-14-30	1.450	446	205	186	9.66	20.7	3.36	----	----	----	----	3.59	0.94
18	Z-300-14-60	1.450	446	205	186	9.66	43.8	3.66	----	----	----	----	4.28	0.86
						P_t/P_c Mean value				----		2.04		1.00
						S.D.				----		0.27		0.12
						C.O.V.				----		0.13		0.12

* Experimental work of this study

---- Exceeds AISI-96 or S136-94 Limit

Chart C.8



S136-94			AISI-96			New Coefficients		
Pt/Pc mean	=	----	Pt/Pc mean	=	2.04	Pt/Pc mean	=	1.00
S.D.	=	----	S.D.	=	0.27	S.D.	=	0.12
C.O.V.	=	----	C.O.V.	=	0.13	C.O.V.	=	0.12

Table C.11

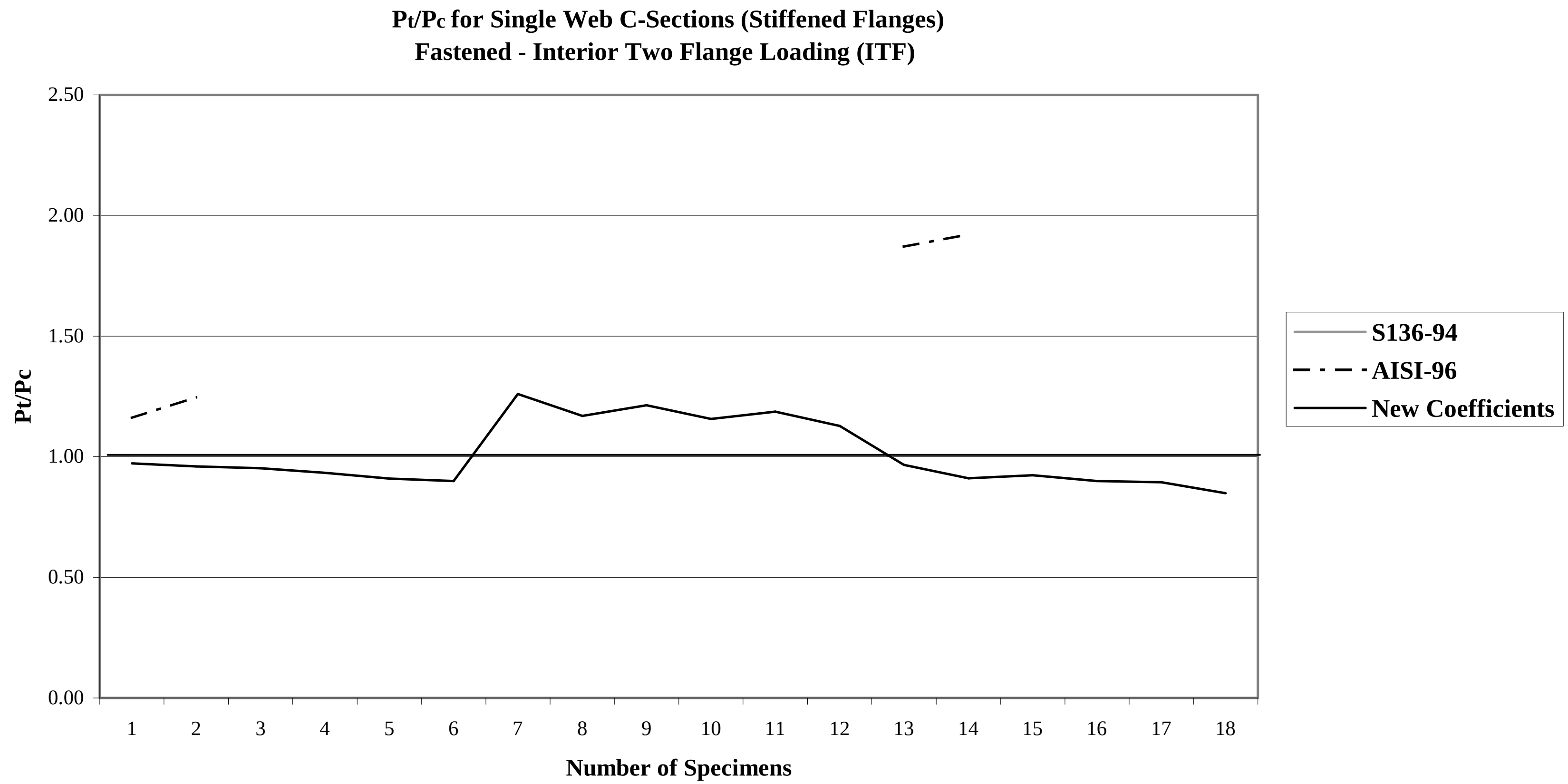
Single Web C-Sections (Stiffened Flanges)
Fastened - Interior Two Flange Loading (ITF)

Beshara - University of Waterloo, Canada - 1999*

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	C-120-7-30	1.450	332	81.4	71.8	4.83	20.7	10.7	----	----	9.17	1.16	11.0	0.97
2	C-120-7-60	1.450	332	81.4	71.8	4.83	43.8	11.8	----	----	9.45	1.25	12.3	0.96
3	C-120-10-30	1.450	332	81.4	67.7	6.90	20.7	9.96	----	----	----	----	10.5	0.95
4	C-120-10-60	1.450	332	81.4	67.7	6.90	43.8	11.0	----	----	----	----	11.7	0.93
5	C-120-14-30	1.450	332	79.4	60.1	9.66	20.7	9.06	----	----	----	----	9.97	0.91
6	C-120-14-60	1.450	332	79.4	60.1	9.66	43.8	10.1	----	----	----	----	11.2	0.90
7	C-200-7-30	1.160	328	170	158	6.03	25.9	7.20	----	----	----	----	5.71	1.26
8	C-200-7-60	1.160	328	170	158	6.03	54.7	7.56	----	----	----	----	6.47	1.17
9	C-200-10-30	1.160	328	170	152	8.62	25.9	6.57	----	----	----	----	5.42	1.21
10	C-200-10-60	1.160	328	170	153	8.62	54.7	7.08	----	----	----	----	6.12	1.16
11	C-200-14-60	1.160	328	171	147	12.1	51.7	6.72	----	----	----	----	5.66	1.19
12	C-200-14-100	1.160	328	171	147	12.1	87.1	7.08	----	----	----	----	6.28	1.13
13	C-300-7-30	1.450	448	205	195	4.83	20.7	11.0	----	----	5.87	1.87	11.4	0.97
14	C-300-7-60	1.450	448	205	195	4.83	43.8	11.6	----	----	6.04	1.92	12.7	0.91
15	C-300-10-30	1.450	448	205	191	6.90	20.7	9.99	----	----	----	----	10.8	0.92
16	C-300-10-60	1.450	448	205	191	6.90	43.8	10.9	----	----	----	----	12.1	0.90
17	C-300-14-60	1.450	448	205	186	9.66	43.8	10.3	----	----	----	----	11.5	0.89
18	C-300-14-100	1.450	448	205	186	9.66	69.7	10.6	----	----	----	----	12.5	0.85
	P_t/P_c Mean value									----		1.55		1.01
	S.D.									----		0.40		0.13
	C.O.V.									----		0.26		0.13

* Experimental work of this study
---- Exceeds AISI-96 or S136-94 Limit

Chart C.9



S136-94		AISI-96		New Coefficients	
Pt/Pc mean =	----	Pt/Pc mean =	1.55	Pt/Pc mean =	1.01
S.D. =	----	S.D. =	0.40	S.D. =	0.13
C.O.V. =	----	C.O.V. =	0.26	C.O.V. =	0.13

Table C.12

Single Web Z-Sections (Stiffened Flanges)
Fastened - Interior Two Flange Loading (ITF)

Beshara - University of Waterloo, Canada - 1999*

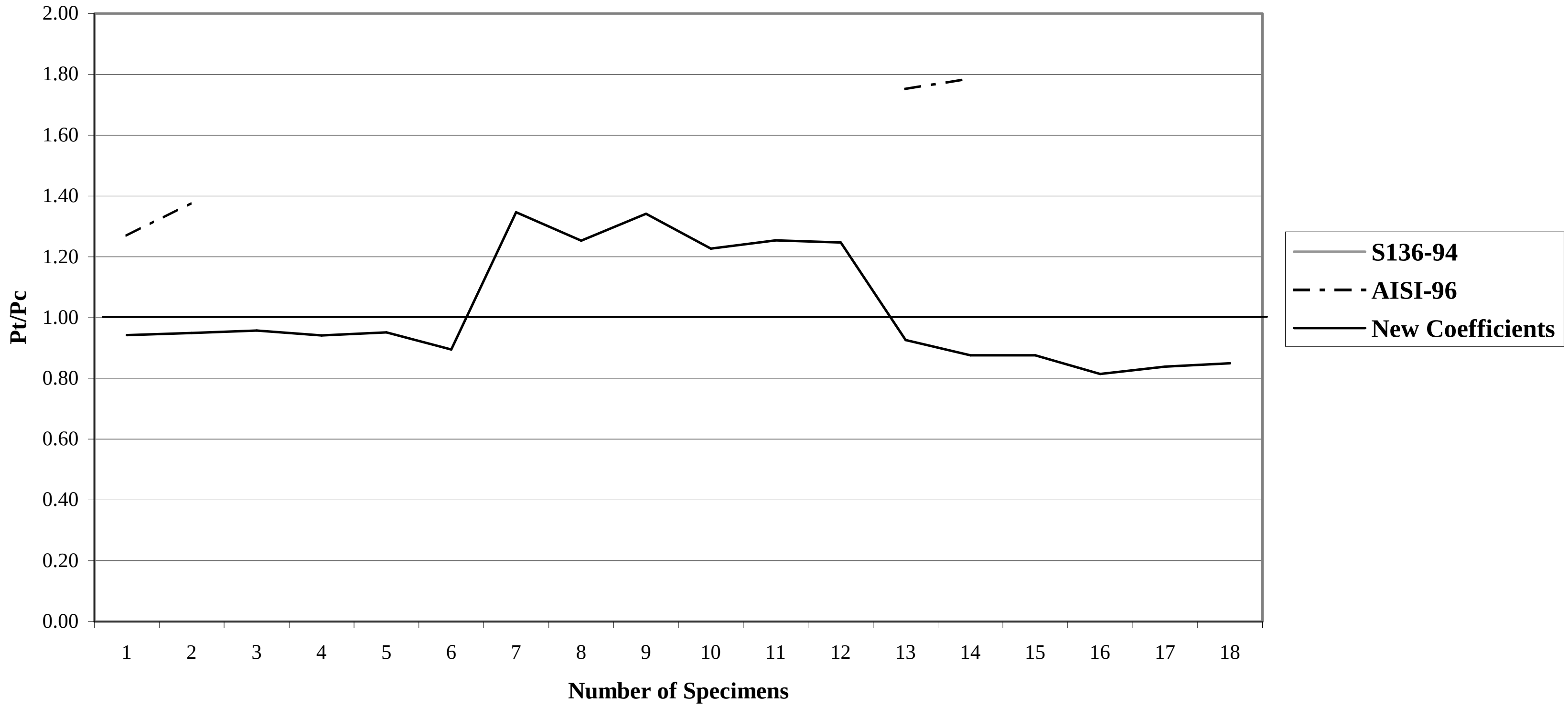
				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
1	Z-120-7-30	1.450	332	80.8	71.1	4.83	20.7	11.7	----	----	9.20	1.27	12.4	0.94
2	Z-120-7-60	1.450	332	80.8	71.1	4.83	43.8	13.1	----	----	9.47	1.38	13.8	0.95
3	Z-120-10-30	1.450	332	82.1	68.3	6.90	20.7	11.6	----	----	----	----	12.1	0.96
4	Z-120-10-60	1.450	332	82.8	69.0	6.90	43.8	12.6	----	----	----	----	13.4	0.94
5	Z-120-14-30	1.450	332	80.8	61.4	9.66	20.7	11.3	----	----	----	----	11.9	0.95
6	Z-120-14-60	1.450	426	80.8	61.4	9.66	43.8	15.1	----	----	----	----	16.9	0.90
7	Z-200-7-30	1.160	323	170	158	6.03	25.9	7.83	----	----	----	----	5.82	1.35
8	Z-200-7-60	1.160	323	170	158	6.03	54.7	8.16	----	----	----	----	6.51	1.25
9	Z-200-10-30	1.160	323	169	151	8.62	25.9	7.65	----	----	----	----	5.70	1.34
10	Z-200-10-60	1.160	323	168	151	8.62	54.7	7.86	----	----	----	----	6.41	1.23
11	Z-200-14-30	1.160	323	170	146	12.1	25.9	6.93	----	----	----	----	5.53	1.25
12	Z-200-14-60	1.160	323	173	149	12.1	54.7	7.65	----	----	----	----	6.13	1.25
13	Z-300-7-30	1.450	446	205	195	4.83	20.7	10.3	----	----	5.86	1.75	11.1	0.93
14	Z-300-7-60	1.450	446	205	195	4.83	43.8	10.8	----	----	6.03	1.79	12.3	0.88
15	Z-300-10-30	1.450	446	205	191	6.90	20.7	9.48	----	----	----	----	10.8	0.88
16	Z-300-10-60	1.450	446	205	191	6.90	43.8	9.78	----	----	----	----	12.0	0.81
17	Z-300-14-30	1.450	446	204	185	9.66	20.7	8.88	----	----	----	----	10.6	0.84
18	Z-300-14-60	1.450	446	204	185	9.66	43.8	9.99	----	----	----	----	11.8	0.85

	S136-94 P_t/P_c	AISI-96 P_t/P_c	New Coeff. P_t/P_c
P_t/P_c Mean value	----	1.55	1.03
S.D.	----	0.26	0.18
C.O.V.	----	0.17	0.18

* Experimental work of this study
---- Exceeds AISI-96 or S136-94 Limit

Chart C.10

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



S136-94	**AISI-96**	**New Coefficients**
Pt/Pc mean = ----	Pt/Pc mean = 1.55	Pt/Pc mean = 1.03
S.D. = ----	S.D. = 0.26	S.D. = 0.18
C.O.V. = ----	C.O.V. = 0.17	C.O.V. = 0.18

Table C.13

Single Web Z-Sections (Stiffened Flanges)
Unfastened - End One Flange Loading (EOF)

Bhakta - University of Missouri-Rolla, USA-1992 [5]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	Z1	1.778	421	142	133	4.76	37.5	6.20	----	----	5.65	1.10	5.94	1.05
2	Z2	1.778	421	142	132	4.76	37.5	6.18	----	----	5.65	1.09	5.93	1.04
3	Z5	2.540	447	78.8	72.1	3.33	26.3	13.9	20.4	0.68	16.25	0.86	13.2	1.06
4	Z6	2.540	447	78.7	72.1	3.33	26.3	14.3	20.4	0.70	16.26	0.88	13.2	1.09

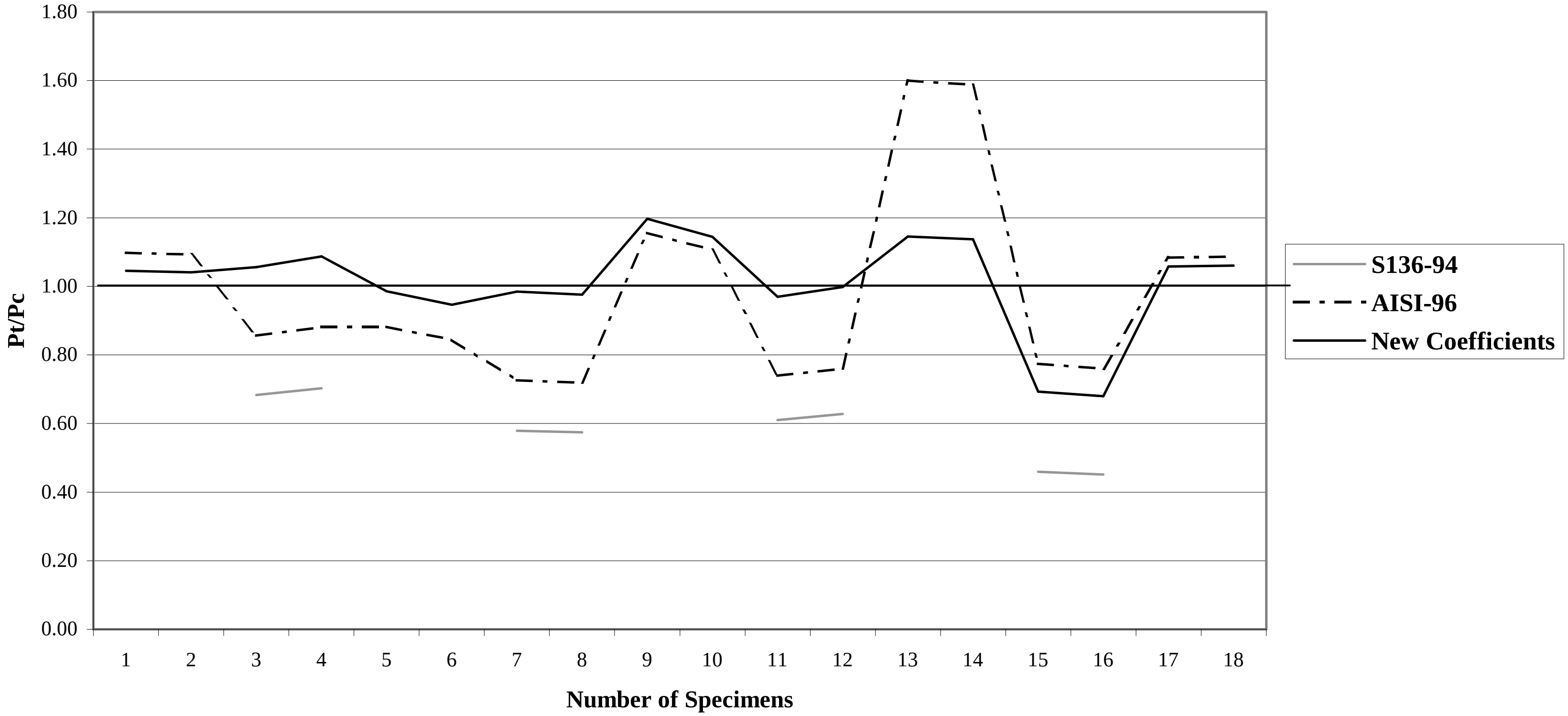
Cain - University of Missouri-Rolla, USA-1995 [6]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
5	Z1.1	1.549	425	104	95.9	4.10	43.0	4.61	----	----	5.23	0.88	4.68	0.99
6	Z1.2	1.549	425	104	95.6	4.10	43.0	4.42	----	----	5.23	0.85	4.67	0.95
7	Z2.1	2.108	449	75.9	69.9	3.01	31.6	9.15	15.8	0.58	12.60	0.73	9.29	0.99
8	Z2.2	2.108	449	75.9	69.9	3.01	31.6	9.06	15.8	0.57	12.60	0.72	9.28	0.98
9	Z3.1	1.549	427	137	129	4.10	43.0	5.61	----	----	4.85	1.16	4.69	1.20
10	Z3.2	1.549	427	137	129	4.10	43.0	5.36	----	----	4.85	1.11	4.69	1.14
11	Z4.1	2.108	434	100	94.2	3.01	31.6	8.70	14.3	0.61	11.77	0.74	8.97	0.97
12	Z4.2	2.108	434	100	94.2	3.01	31.6	8.95	14.3	0.63	11.78	0.76	8.97	1.00
13	Z5.1	1.499	504	159	151	4.24	44.5	5.91	----	----	4.48	1.32	5.16	1.15
14	Z5.2	1.499	504	159	150	4.24	44.5	5.87	----	----	4.48	1.31	5.16	1.14
15	Z6.1	1.905	508	124	118	3.33	35.0	5.91	12.9	0.46	9.23	0.64	8.52	0.69
16	Z6.2	1.905	508	125	118	3.33	35.0	5.80	12.9	0.45	9.20	0.63	8.53	0.68
17	Z7.1	1.905	392	152	143	4.17	35.0	6.78	----	----	6.26	1.08	6.41	1.06
18	Z7.2	1.905	392	151	143	4.17	35.0	6.81	----	----	6.26	1.09	6.41	1.06
	P_t/P_c Mean value									0.59		1.09		1.01
	S.D.									0.09		0.25		0.13
	C.O.V.									0.16		0.23		0.13

---- Exceeds AISI-96 or S136-94 Limit

Chart C.11

Pt/Pc for Single Web Z-Sections (Stiffened Flanges)
Unfastened - End One Flange Loading (EOF)



S136-94	AISI-96	New Coefficients
Pt/Pc mean = 0.59	Pt/Pc mean = 1.09	Pt/Pc mean = 1.01
S.D. = 0.09	S.D. = 0.25	S.D. = 0.13
C.O.V. = 0.16	C.O.V. = 0.23	C.O.V. = 0.13

Table C.14

Single Web C-Sections (Stiffened Flanges)
Unfastened - End One Flange Loading (EOF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	SU-1-EOF-1	1.207	302	208	203	2.63	21.1	2.56	----	----	----	----	2.53	1.01
2	SU-1-EOF-2	1.219	302	206	200	2.60	20.8	2.25	----	----	----	----	2.59	0.87
3	SU-1-EOF-5	1.245	302	201	196	2.55	61.2	2.89	3.67	0.79	3.48	0.83	3.91	0.74
4	SU-1-EOF-6	1.270	302	197	192	2.81	60.0	2.76	3.72	0.74	3.42	0.81	4.00	0.69
5	SU-2-EOF-1	1.232	302	250	245	2.58	20.6	2.20	----	----	----	----	2.53	0.87
6	SU-2-EOF-2	1.219	302	253	247	2.60	20.8	2.25	----	----	----	----	2.47	0.91
7	SU-2-EOF-5	1.219	302	254	249	2.60	62.5	2.49	----	----	----	----	3.58	0.70
8	SU-2-EOF-6	1.194	302	259	253	2.66	63.8	2.49	----	----	----	----	3.44	0.73
9	SU-2'-EOF-1	1.262	254	145	142	1.89	121	6.34	5.26	1.21	6.40	0.99	4.83	1.31
10	SU-2'-EOF-2	1.262	254	146	143	1.89	121	6.42	5.25	1.22	6.38	1.01	4.82	1.33
11	SU-3-EOF-1	1.262	254	195	191	1.89	141	5.34	4.98	1.07	6.28	0.85	4.88	1.10
12	SU-3-EOF-2	1.262	254	195	191	1.89	141	5.52	4.98	1.11	6.28	0.88	4.88	1.13
13	SU-4-EOF-1	1.270	325	96.5	93.0	1.74	20.0	4.00	3.77	1.06	4.22	0.95	3.53	1.13
14	SU-4-EOF-2	1.270	325	96.6	93.5	1.56	20.0	4.03	3.86	1.04	4.34	0.93	3.57	1.13
15	SU-4-EOF-3	1.260	325	97.2	93.8	1.73	40.3	4.62	4.87	0.95	4.85	0.95	4.37	1.06
16	SU-4-EOF-4	1.258	325	97.9	94.3	1.77	40.4	4.45	4.83	0.92	4.80	0.93	4.34	1.03
17	SU-4-EOF-5	1.270	325	96.8	93.4	1.69	60.0	5.01	5.86	0.85	5.66	0.89	5.12	0.98
18	SU-4-EOF-6	1.245	325	99.1	95.6	1.75	61.2	4.92	5.60	0.88	5.45	0.90	4.93	1.00
19	SU-4'-EOF-1	1.262	254	96.8	94.3	1.26	85.5	6.21	5.56	1.12	6.27	0.99	4.66	1.33
20	SU-4'-EOF-2	1.288	254	94.8	92.4	1.23	83.8	6.84	5.79	1.18	6.50	1.05	4.83	1.42
21	SU-5-EOF-1	1.270	325	122	118	1.88	20.0	3.92	3.47	1.13	3.89	1.01	3.40	1.15
22	SU-5-EOF-2	1.298	325	118	115	1.76	19.6	3.73	3.68	1.01	4.16	0.90	3.57	1.05
23	SU-5-EOF-3	1.295	325	120	116	1.84	39.2	4.41	4.74	0.93	4.74	0.93	4.42	1.00

---- Exceeds AISI-96 or S136-94 Limit

Table C.14 (Continued)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
24	SU-5-EOF-4	1.283	325	121	117	2.01	39.6	4.32	4.55	0.95	4.52	0.96	4.30	1.01
25	SU-5-EOF-5	1.285	325	120	117	1.85	59.3	4.48	5.50	0.81	5.32	0.84	5.03	0.89
26	SU-5-EOF-6	1.273	325	122	118	1.87	59.9	4.75	5.39	0.88	5.21	0.91	4.94	0.96
27	SU-6'-EOF-1	1.265	325	146	143	1.73	20.1	3.95	3.30	1.20	3.73	1.06	3.31	1.19
28	SU-6'-EOF-2	1.257	325	147	144	1.89	20.2	3.89	3.19	1.22	3.58	1.09	3.24	1.20
29	SU-6'-EOF-3	1.252	325	148	144	1.74	40.6	4.02	4.22	0.95	4.25	0.95	4.07	0.99
30	SU-6'-EOF-4	1.245	325	149	145	1.99	40.8	4.16	4.05	1.03	4.02	1.03	3.96	1.05
31	SU-6'-EOF-5	1.270	325	146	142	1.88	60.0	4.65	5.04	0.92	4.89	0.95	4.78	0.97
32	SU-6'-EOF-6	1.270	325	146	142	1.88	60.0	4.98	5.04	0.99	4.89	1.02	4.78	1.04
33	SU-13-EOF-1	1.321	371	75	73.1	1.20	76.9	8.93	----	----	8.75	1.02	7.38	1.21
34	SU-13-EOF-2	1.295	371	77	74.6	1.23	78.4	9.18	----	----	8.46	1.09	7.13	1.29

Bhakta - University of Missouri-Rolla, USA-1992 [5]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
35	C3	2.769	391	71.9	69.0	1.43	24.1	19.0	25.8	0.74	25.7	0.74	22.6	0.84
36	C4	2.769	391	71.6	68.8	1.43	24.1	18.9	25.8	0.73	25.7	0.74	22.6	0.84
37	C7	1.626	413	121	116	2.44	41.0	6.79	9.01	0.75	7.8	0.87	8.68	0.78
38	C8	1.626	413	121	116	2.44	41.0	6.90	9.01	0.77	7.8	0.88	8.68	0.80
39	C11	1.600	432	141	131	4.97	41.7	6.65	----	----	4.8	1.39	7.64	0.87
40	C12	1.600	432	141	131	4.97	41.7	6.73	----	----	4.8	1.41	7.64	0.88

---- Exceeds S136-94 Limit

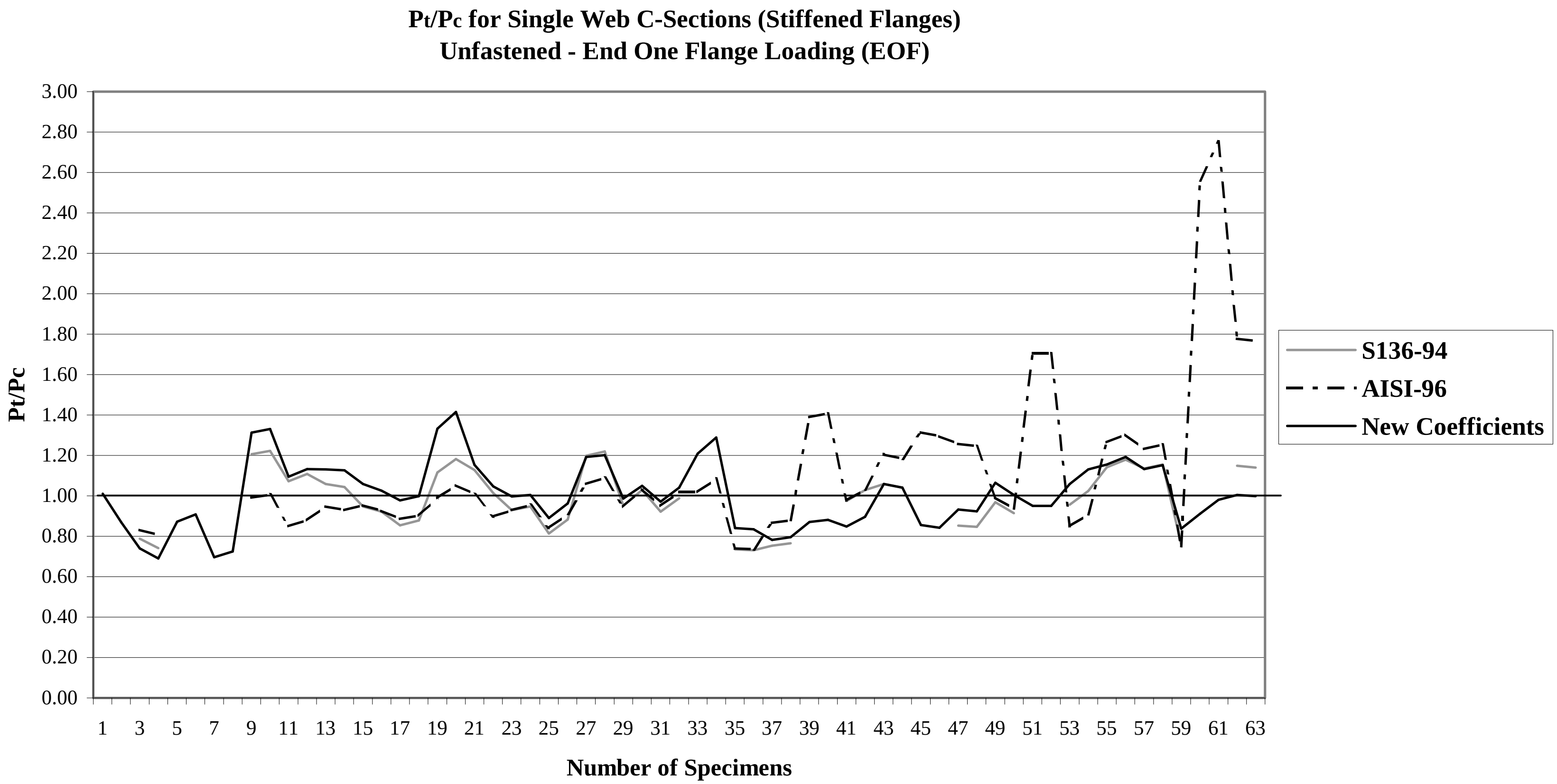
Table C.14 (Continued)

Langan - University of Missouri-Rolla, USA-1994 [14]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
41	EOF-SU-1-1-1	1.524	413	198	192	2.60	16.7	4.42	4.54	0.97	4.53	0.98	5.22	0.85
42	EOF-SU-1-1-2	1.524	413	198	192	2.60	16.7	4.67	4.54	1.03	4.53	1.03	5.22	0.90
43	EOF-SU-2-1-1	1.118	365	80.3	73.2	3.55	22.7	3.14	2.97	1.06	2.61	1.20	2.97	1.06
44	EOF-SU-2-1-2	1.118	365	80.3	73.2	3.55	22.7	3.09	2.97	1.04	2.61	1.18	2.97	1.04
45	EOF-SU-3-1-1	0.914	441	98.1	89.4	4.33	27.8	2.06	----	----	1.57	1.32	2.41	0.86
46	EOF-SU-3-1-2	0.914	441	98.1	89.4	4.33	27.8	2.03	----	----	1.57	1.30	2.41	0.84
47	EOF-SU-4-1-1	1.803	558	49.2	44.8	2.20	14.1	10.7	12.6	0.85	10.63	1.01	11.5	0.93
48	EOF-SU-4-1-2	1.803	558	49.2	44.8	2.20	14.1	10.7	12.6	0.85	10.66	1.00	11.5	0.92
49	EOF-SU-5-1-1	1.499	372	39.7	34.4	2.64	16.9	5.92	6.11	0.97	5.97	0.99	5.56	1.07
50	EOF-SU-5-1-2	1.499	372	39.7	34.4	2.64	16.9	5.59	6.11	0.92	5.97	0.94	5.56	1.01
51	EOF-SU-6-1-1	0.838	462	71.6	62.1	4.73	30.3	2.11	----	----	1.46	1.45	2.23	0.95
52	EOF-SU-6-1-2	0.838	462	71.6	62.1	4.73	30.3	2.11	----	----	1.46	1.45	2.23	0.95
53	EOF-SU-7-1-1	1.575	255	38.6	33.5	2.52	16.1	4.42	4.62	0.96	5.21	0.85	4.18	1.06
54	EOF-SU-7-1-2	1.575	255	38.6	33.5	2.52	16.1	4.73	4.62	1.02	5.21	0.91	4.18	1.13
55	EOF-SU-8-1-1	0.991	234	62.1	54.1	4.00	25.6	1.81	1.58	1.14	1.43	1.26	1.56	1.16
56	EOF-SU-8-1-2	0.991	234	62.1	54.1	4.00	25.6	1.87	1.58	1.18	1.43	1.30	1.56	1.19
57	EOF-SU-9-1-1	1.118	324	81.4	74.3	3.55	22.7	2.98	2.62	1.14	2.42	1.23	2.63	1.13
58	EOF-SU-9-1-2	1.118	324	81.4	74.3	3.55	22.7	3.03	2.62	1.16	2.42	1.25	2.63	1.15
59	EOF-SU-10-1-1	1.956	441	46.1	42.1	2.03	13.0	8.90	11.7	0.76	11.87	0.75	10.6	0.84
60	EOF-SU-12-1-1	0.838	641	177	168	4.73	30.3	2.48	----	----	1.22	2.03	2.72	0.91
61	EOF-SU-12-1-2	0.838	641	177	168	4.73	30.3	2.66	----	----	1.22	2.18	2.72	0.98
62	EOF-SU-13-1-1	1.143	496	174	168	3.47	22.2	3.78	3.29	1.15	2.56	1.48	3.76	1.01
63	EOF-SU-13-1-2	1.143	496	174	168	3.47	22.2	3.76	3.29	1.14	2.56	1.47	3.76	1.00
								P_t/P_c Mean value		0.99		1.12		1.01
								S.D.		0.15		0.39		0.16
								C.O.V.		0.15		0.34		0.16

---- Exceeds S136-94 Limit

Chart C.12



S136-94			**AISI-96**			**New Coefficients**		
Pt/Pc mean	=	0.99	Pt/Pc mean	=	1.12	Pt/Pc mean	=	1.01
S.D.	=	0.15	S.D .	=	0.39	S.D.	=	0.16
C.O.V.	=	0.15	C.O.V.	=	0.34	C.O.V.	=	0.16

Table C.15

Single Web Sections (Stiffened Flanges)
Unfastened - Interior One Flange Loading (IOF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	Specimen	t (mm)	F_y (MPa)	h'/t (ratio)	h/t (ratio)	r/t (ratio)	n/t (ratio)	P_t (kN)	P_c (kN)	P_t/P_c (ratio)	P_c (kN)	P_t/P_c (ratio)	P_c (kN)	P_t/P_c (ratio)
1	SU-1-IOF-1	1.219	302	205	199	2.77	20.8	5.61	4.15	1.35	5.05	1.11	5.07	1.11
2	SU-1-IOF-2	1.207	302	209	203	2.63	21.1	5.23	----	----	----	----	5.04	1.04
3	SU-1-IOF-5	1.232	302	203	198	2.58	61.9	6.45	5.45	1.19	6.54	0.99	6.78	0.95
4	SU-1-IOF-6	1.219	302	205	200	2.60	62.5	6.16	5.31	1.16	6.40	0.96	6.64	0.93
5	SU-2-IOF-1	1.245	302	250	245	2.55	20.4	5.10	----	----	----	----	5.30	0.96
6	SU-2-IOF-2	1.270	302	244	239	2.50	20.0	5.81	----	----	----	----	5.54	1.05
7	SU-2-IOF-5	1.219	302	254	249	2.60	62.5	6.16	----	----	----	----	6.51	0.95
8	SU-2-IOF-6	1.245	302	250	245	2.55	61.2	6.48	----	----	----	----	6.80	0.95
9	SU-5-IOF-1	1.257	325	123	119	1.90	20.2	6.24	6.39	0.98	6.85	0.91	6.61	0.94
10	SU-5-IOF-2	1.275	325	121	117	1.87	19.9	6.59	6.61	1.00	7.07	0.93	6.81	0.97
11	SU-5-IOF-3	1.270	325	122	118	1.95	40.0	7.79	7.50	1.04	7.83	1.00	7.76	1.00
12	SU-5-IOF-4	1.283	325	120	117	1.86	39.6	8.15	7.71	1.06	8.03	1.01	8.00	1.02
13	SU-5-IOF-5	1.280	325	121	117	1.78	59.5	9.26	8.48	1.09	8.91	1.04	8.89	1.04
14	SU-5-IOF-6	1.278	325	121	117	1.87	59.6	8.17	8.41	0.97	8.83	0.93	8.76	0.93
15	SU-6'-IOF-1	1.270	325	145	142	1.88	20.0	6.59	6.06	1.09	6.74	0.98	6.68	0.99
16	SU-6'-IOF-2	1.270	325	146	143	1.72	20.0	7.03	6.09	1.15	6.79	1.04	6.81	1.03
17	SU-6'-IOF-3	1.257	325	147	143	1.81	40.4	8.41	6.84	1.23	7.43	1.13	7.66	1.10
18	SU-6'-IOF-4	1.262	325	148	144	1.89	40.2	8.08	6.86	1.18	7.45	1.09	7.64	1.06
19	SU-6'-IOF-5	1.250	325	148	145	1.91	61.0	9.28	7.39	1.26	8.07	1.15	8.28	1.12
20	SU-6'-IOF-6	1.278	325	145	141	1.79	59.6	8.41	7.83	1.08	8.53	0.99	8.75	0.96
21	M-SU-6'-IOF-1	1.275	325	145	142	1.87	19.9	7.34	6.11	1.20	6.79	1.08	6.73	1.09
22	M-SU-6'-IOF-2	1.270	325	146	142	1.88	20.0	7.31	6.05	1.21	6.73	1.09	6.68	1.10
23	M-SU-6'-IOF-5	1.283	325	144	141	1.86	59.4	9.10	7.86	1.16	8.55	1.06	8.74	1.04
24	M-SU-6'-IOF-6	1.265	325	146	142	1.88	60.2	9.52	7.63	1.25	8.27	1.15	8.49	1.12

---- Exceeds AISI-96 or S136-94 Limit

Table C.15 (Continued)

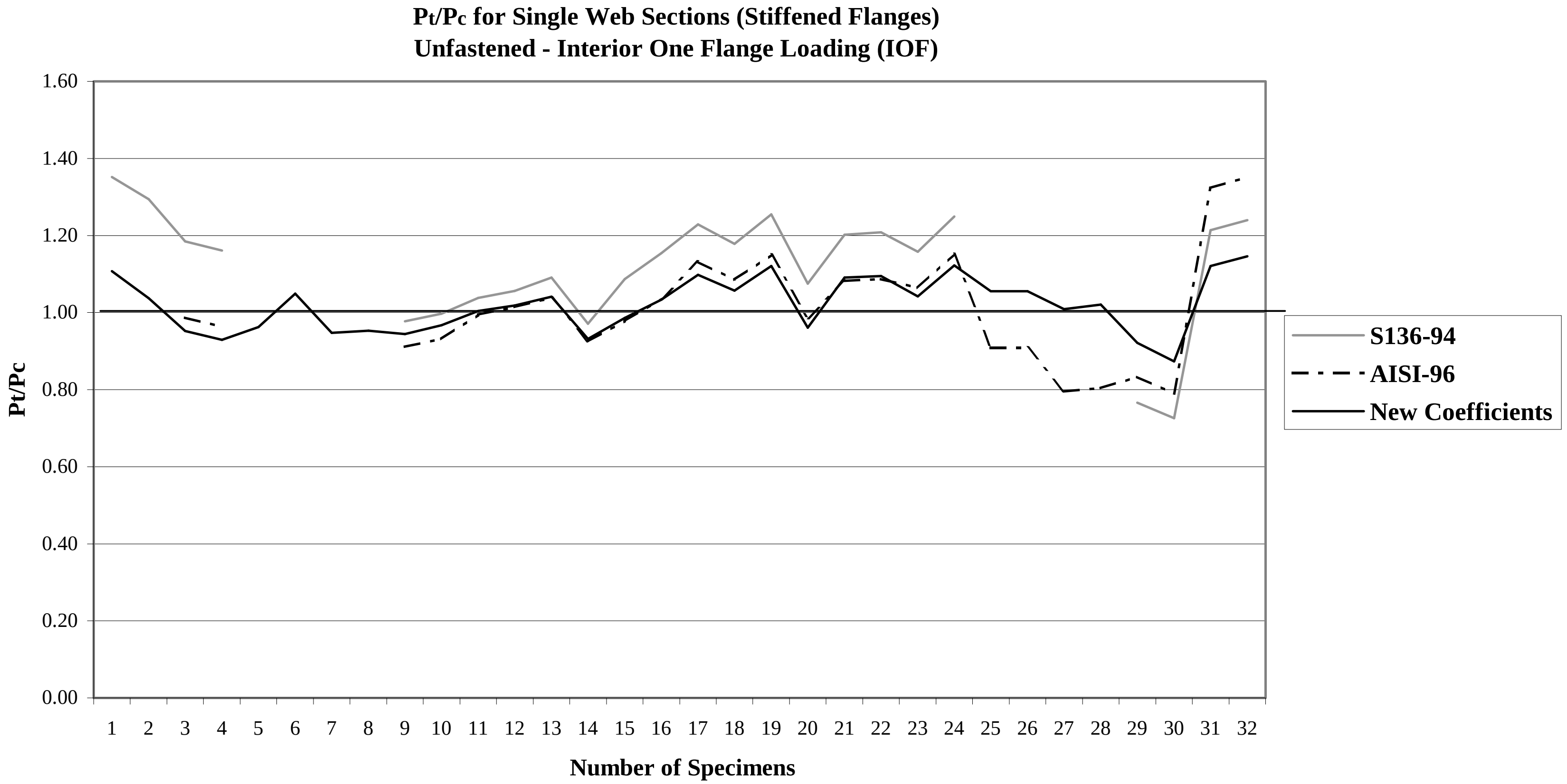
Langan - University of Missouri-Rolla, USA-1994 [14]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
25	IOF-SU-5-1-1	0.838	406	107	97.9	4.73	90.9	4.12	----	----	4.53	0.91	3.90	1.06
26	IOF-SU-5-1-2	0.838	406	107	97.9	4.73	90.9	4.12	----	----	4.53	0.91	3.90	1.06
27	IOF-SU-5-8-1	0.838	406	107	97.9	4.73	121	4.29	----	----	5.39	0.80	4.25	1.01
28	IOF-SU-5-8-2	0.838	406	107	97.9	4.73	121	4.34	----	----	5.40	0.80	4.25	1.02
29	IOF-SU-6-1-1	1.143	365	79	72.4	3.47	66.7	6.40	8.36	0.77	7.68	0.83	6.95	0.92
30	IOF-SU-6-1-2	1.143	365	79	72.4	3.47	66.7	6.07	8.36	0.73	7.68	0.79	6.95	0.87
31	IOF-SU-10-1-1	1.143	496	174	168	3.47	66.7	10.1	8.30	1.21	7.61	1.32	8.98	1.12
32	IOF-SU-10-1-2	1.143	496	174	168	3.47	66.7	10.3	8.30	1.24	7.61	1.35	8.98	1.15

---- Exceeds S136-94 Limit

	S136-94 P_t/P_c	AISI-96 P_t/P_c	New Coeff. P_t/P_c
P_t/P_c Mean value	1.12	1.01	1.02
S.D.	0.15	0.14	0.07
C.O.V.	0.14	0.14	0.07

Chart C.13



S136-94	**AISI-96**	**New Coefficients**
Pt/Pc mean = 1.12	Pt/Pc mean = 1.01	Pt/Pc mean = 1.02
S.D. = 0.15	S.D. = 0.14	S.D. = 0.07
C.O.V. = 0.14	C.O.V. = 0.14	C.O.V. = 0.07

Table C.16

Single Web Sections (Stiffened Flanges)
Unfastened - End Two Flange Loading (ETF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	SU-1-ETF-1	1.168	302	214	208	2.72	21.7	1.42	----	----	----	----	1.32	1.08
2	SU-1-ETF-2	1.194	302	209	204	2.66	21.3	1.38	----	----	----	----	1.41	0.98
3	SU-1-ETF-5	1.207	302	207	202	2.63	63.2	1.69	----	----	----	----	1.66	1.02
4	SU-1-ETF-6	1.219	302	205	200	2.60	62.5	1.58	----	----	----	----	1.71	0.93
5	SU-2-ETF-1	1.194	302	260	254	2.66	21.3	1.25	----	----	----	----	1.19	1.05
6	SU-2-ETF-2	1.245	302	249	244	2.55	20.4	1.25	----	----	----	----	1.37	0.91
7	SU-2-ETF-5	1.194	302	260	255	2.66	63.8	1.40	----	----	----	----	1.35	1.04
8	SU-2-ETF-6	1.245	302	249	244	2.55	61.2	1.29	----	----	----	----	1.55	0.83
9	SU-4-ETF-1	1.270	325	97.3	93.53	1.88	20.0	3.05	2.92	1.04	2.86	1.07	2.87	1.06
10	SU-4-ETF-2	1.308	325	93.9	90.0	1.97	19.4	2.97	3.04	0.98	3.00	0.99	3.01	0.99
11	SU-4-ETF-3	1.295	325	95.1	91.4	1.84	39.2	3.32	3.38	0.98	3.50	0.95	3.25	1.02
12	SU-4-ETF-4	1.295	325	94.6	90.9	1.84	39.2	3.34	3.39	0.99	3.50	0.95	3.26	1.03
13	SU-4-ETF-5	1.270	325	96.8	93.1	1.88	60.0	3.41	3.41	1.00	3.82	0.89	3.26	1.05
14	SU-4-ETF-6	1.270	325	96.7	92.9	1.88	60.0	3.45	3.41	1.01	3.82	0.90	3.26	1.06
15	SU-5-ETF-1	1.283	325	120	117	1.78	19.8	2.67	2.80	0.95	2.76	0.97	2.76	0.97
16	SU-5-ETF-2	1.290	325	120	116	1.77	19.7	2.74	2.84	0.96	2.80	0.98	2.80	0.98
17	SU-5-ETF-3	1.288	325	120	117	1.85	39.4	2.74	3.00	0.91	3.19	0.86	2.95	0.93
18	SU-5-ETF-4	1.273	325	121	117	2.03	39.9	2.78	2.77	1.01	3.03	0.92	2.77	1.00
19	SU-5-ETF-5	1.293	325	119	116	1.84	58.9	3.05	3.24	0.94	3.69	0.83	3.15	0.97
20	SU-5-ETF-6	1.278	325	121	117	1.87	59.6	3.00	3.13	0.96	3.58	0.84	3.05	0.99
21	SU-6'-ETF-1	1.245	325	149	145	1.91	20.4	2.60	2.26	1.15	2.32	1.12	2.32	1.12
22	SU-6'-ETF-2	1.270	325	145	142	1.88	20.0	2.43	2.40	1.01	2.45	0.99	2.45	0.99
23	SU-6'-ETF-3	1.247	325	148	144	1.99	40.7	2.71	2.42	1.12	2.69	1.01	2.47	1.10
24	SU-6'-ETF-4	1.260	325	147	143	1.89	40.3	2.65	2.56	1.04	2.80	0.95	2.58	1.03

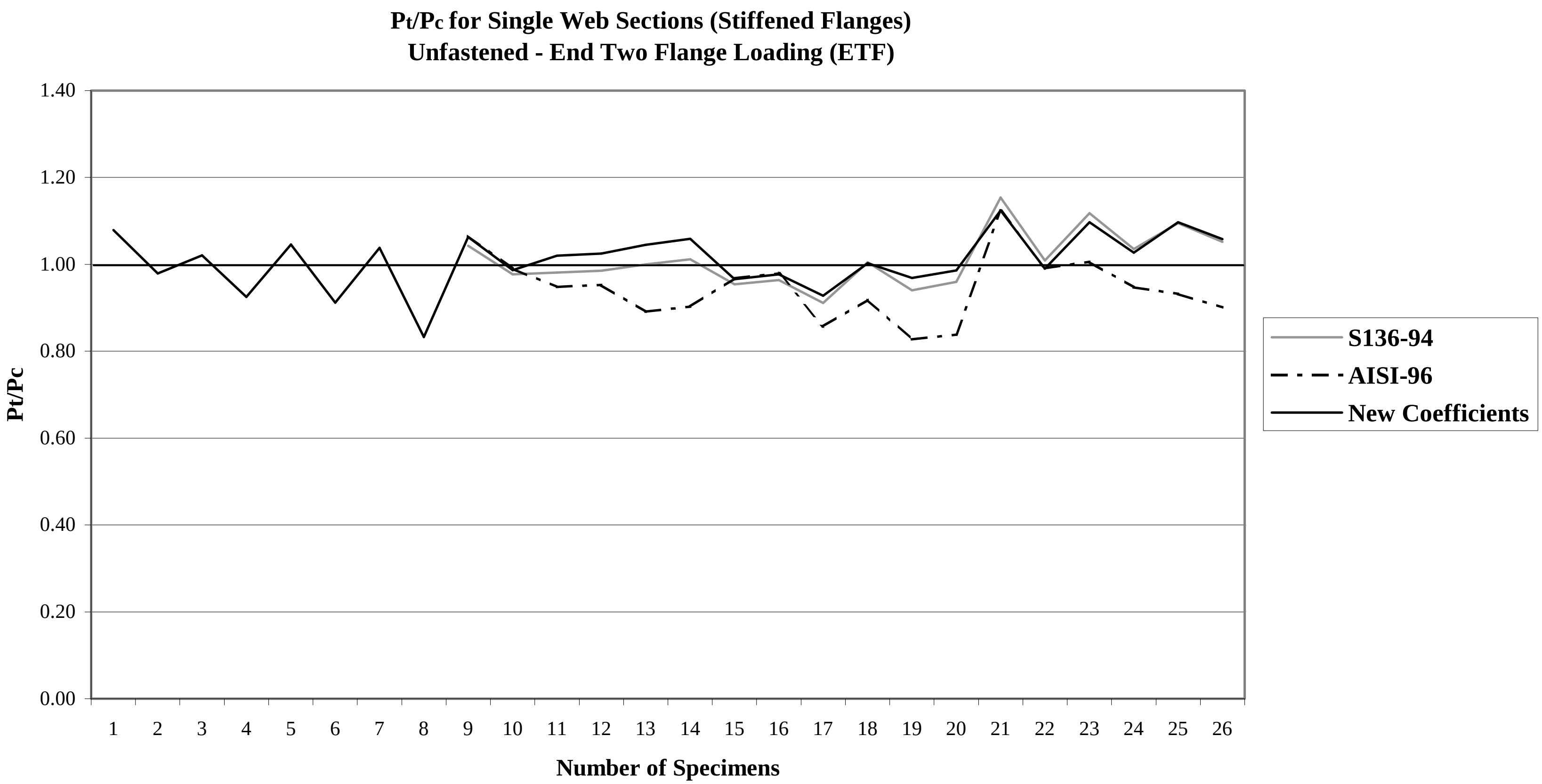
---- Exceeds AISI-96 or S136-94 Limit

Table C.16 (Continued)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
25	SU-6'-ETF-5	1.257	325	148	144	1.90	60.6	2.96	2.70	1.10	3.18	0.93	2.70	1.10
26	SU-6'-ETF-6	1.270	325	146	142	1.88	60.0	2.94	2.79	1.05	3.26	0.90	2.78	1.06
							P_t/P_c Mean value			1.01		0.95		1.01
							S.D.			0.06		0.08		0.06
							C.O.V.			0.06		0.08		0.06

Chart C.14



S136-94	**AISI-96**	**New Coefficients**
Pt/Pc mean = 1.01	Pt/Pc mean = 0.95	Pt/Pc mean = 1.01
S.D. = 0.06	S.D. = 0.08	S.D. = 0.06
C.O.V. = 0.06	C.O.V. = 0.08	C.O.V. = 0.06

Table C.17

Single Web Sections (Stiffened Flanges)
Unfastened - Interior Two Flange Loading (ITF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	SU-1-ITF-1	1.219	302	205	200	2.60	20.8	3.43	2.14	1.61	3.74	0.92	2.88	1.19
2	SU-1-ITF-2	1.207	302	207	202	2.63	21.1	3.49	----	----	----	----	2.74	1.27
									----	----				
3	SU-1-ITF-5	1.219	302	205	200	2.60	62.5	3.54	2.55	1.39	3.93	0.90	3.73	0.95
4	SU-1-ITF-6	1.194	302	210	205	2.66	63.8	3.65	----	----	----	----	3.40	1.07
5	SU-2-ITF-1	1.219	302	255	250	2.60	20.8	2.72	----	----	----	----	2.87	0.95
6	SU-2-ITF-2	1.207	302	257	252	2.63	21.1	2.72	----	----	----	----	2.74	0.99
7	SU-2-ITF-5	1.219	302	253	248	2.60	62.5	2.80	----	----	----	----	3.73	0.75
8	SU-2-ITF-6	1.194	302	258	253	2.66	63.8	2.65	----	----	----	----	3.39	0.78
9	SU-4-ITF-1	1.313	325	93.6	90.0	1.81	19.3	7.63	7.87	0.97	8.52	0.90	6.61	1.15
10	SU-4-ITF-2	1.318	325	93.6	90.0	1.81	19.3	7.68	7.93	0.97	8.59	0.89	6.69	1.15
11	SU-4-ITF-3	1.270	325	96.8	93.1	1.88	40.0	8.52	7.98	1.07	8.04	1.06	6.97	1.22
12	SU-4-ITF-4	1.285	325	96.0	92.3	1.86	39.5	8.81	8.22	1.07	8.27	1.07	7.21	1.22
13	SU-4-ITF-5	1.326	325	92.8	88.7	2.02	57.5	9.84	9.50	1.04	9.03	1.09	7.57	1.30
14	SU-4-ITF-6	1.295	325	94.6	90.7	1.99	58.8	10.3	8.99	1.14	8.58	1.20	7.42	1.39
15	SU-5-ITF-1	1.270	325	122	118	1.88	20.0	6.71	5.96	1.13	7.07	0.95	5.98	1.12
16	SU-5-ITF-2	1.278	325	121	117	1.87	19.9	6.81	6.07	1.12	7.18	0.95	6.09	1.12
17	SU-5-ITF-3	1.283	325	121	117	1.86	39.6	6.90	6.79	1.02	7.42	0.93	7.18	0.96
18	SU-5-ITF-4	1.273	325	121	117	1.87	39.9	7.61	6.65	1.14	7.28	1.05	7.01	1.09
19	SU-5-ITF-5	1.270	325	121	118	1.80	60.0	7.21	7.16	1.01	7.46	0.97	8.15	0.89
20	SU-5-ITF-6	1.278	325	121	117	1.79	59.6	7.17	7.26	0.99	7.57	0.95	8.28	0.87
21	SU-6'-ITF-1	1.257	325	147	143	1.90	20.2	6.52	4.74	1.38	6.14	1.06	5.79	1.13
22	SU-6'-ITF-2	1.260	325	147	143	1.73	20.2	5.49	4.79	1.15	6.22	0.88	6.46	0.85
23	SU-6'-ITF-3	1.270	325	145	142	1.72	40.0	5.45	5.47	1.00	6.53	0.84	7.70	0.71
24	SU-6'-ITF-4	1.257	325	147	143	1.90	40.4	5.70	5.24	1.09	6.28	0.91	6.76	0.84

---- Exceeds AISI-96 or S136-94 Limit

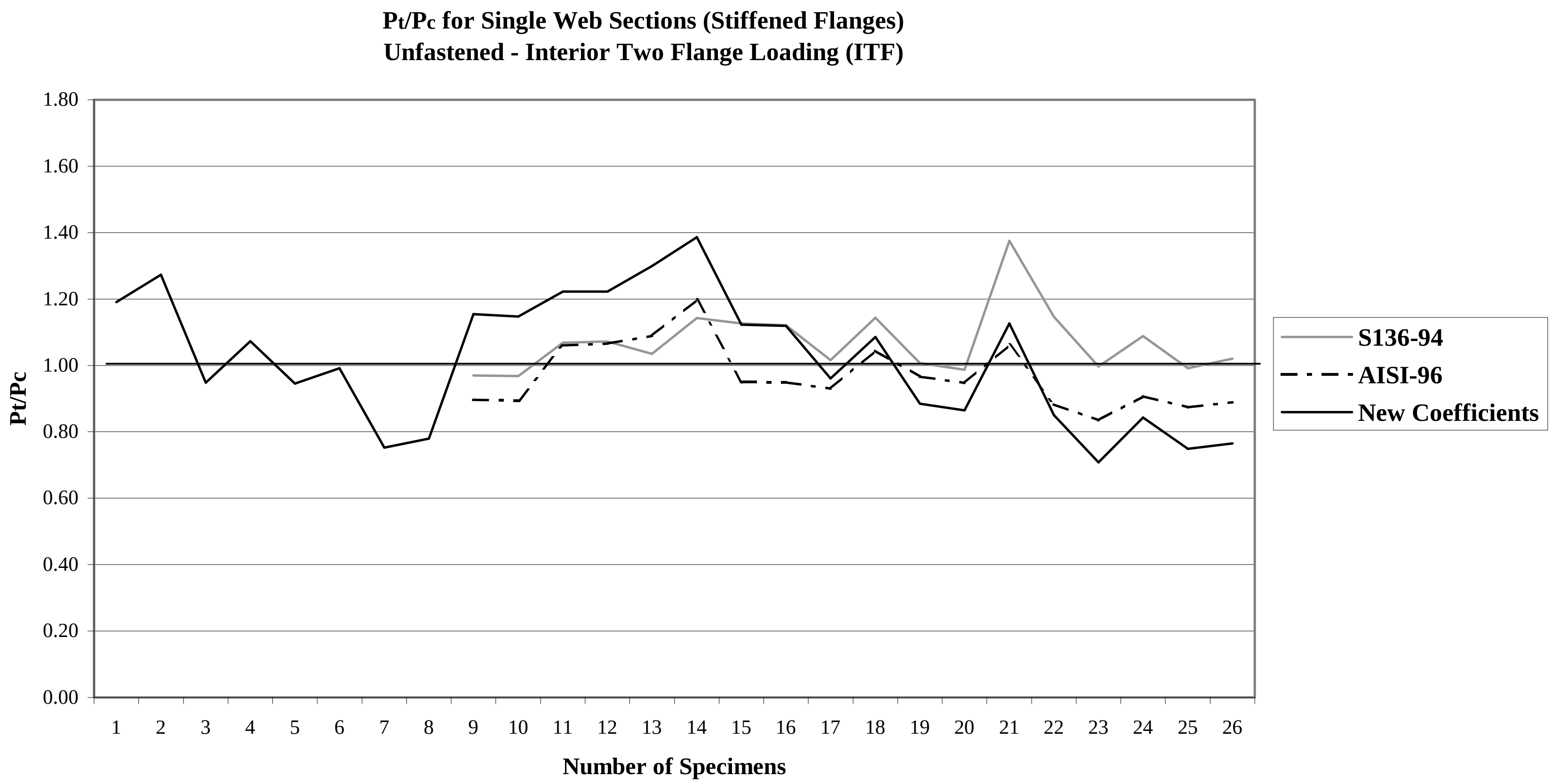
Table C.17 (Continued)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
25	SU-6'-ITF-5	1.280	325	144	141	1.86	59.5	5.92	5.97	0.99	6.77	0.87	7.90	0.75
26	SU-6'-ITF-6	1.245	325	149	145	1.91	61.2	5.56	5.45	1.02	6.26	0.89	7.27	0.77

	S136-94 P_t/P_c	AISI-96 P_t/P_c	New Coeff. P_t/P_c
P_t/P_c Mean value	1.11	0.96	1.02
S.D.	0.16	0.09	0.19
C.O.V.	0.15	0.10	0.19

Chart C.15



S136-94			AISI-96			New Coefficients		
Pt/Pc mean	=	1.11	Pt/Pc mean	=	0.96	Pt/Pc mean	=	1.02
S.D.	=	0.16	S.D.	=	0.09	S.D.	=	0.19
C.O.V.	=	0.15	C.O.V.	=	0.10	C.O.V.	=	0.19

Table C.18

Single Web Sections (Unstiffened Flanges)
Unfastened - End One Flange Loading (EOF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
1	U-SU-3-EOF-1	1.270	250	191	188	1.25	140	3.82	2.97	1.28	5.32	0.72	4.24	0.90
2	U-SU-3-EOF-2	1.270	250	191	188	1.25	140	4.79	2.98	1.61	5.32	0.90	4.25	1.13
3	U-SU-4-EOF-1	1.270	250	96.3	94.4	0.94	85.0	5.47	3.28	1.67	4.53	1.21	4.57	1.20
4	U-SU-4-EOF-2	1.245	250	98.6	96.6	0.96	86.7	4.87	3.14	1.55	4.39	1.11	4.37	1.12
5	U-SU-5-EOF-1	1.232	250	148	146	1.29	108	4.43	2.80	1.58	4.43	1.00	3.82	1.16
6	U-SU-5-EOF-2	1.245	250	147	144	1.28	107	4.60	2.87	1.61	4.51	1.02	3.91	1.18
7	U-SU-9-EOF-1	1.283	284	142	139	1.55	119	5.61	3.46	1.62	5.47	1.03	4.57	1.23
8	U-SU-9-EOF-2	1.295	284	140	137	1.53	118	5.76	3.53	1.63	5.55	1.04	4.68	1.23
9	U-SU-10-EOF-1	1.295	284	184	181	1.53	137	4.91	3.39	1.45	5.78	0.85	4.60	1.07
10	U-SU-10-EOF-2	1.295	284	184	181	1.53	137	4.72	3.40	1.39	5.79	0.82	4.60	1.03
11	U-SU-17-EOF-1	1.245	250	99.2	97.3	0.96	20.4	2.80	2.28	1.22	2.63	1.06	2.46	1.14
12	U-SU-17-EOF-2	1.245	250	98.1	96.2	0.96	20.4	2.66	2.29	1.16	2.63	1.01	2.46	1.08
13	U-SU-17-EOF-5	1.245	250	97.8	95.9	0.96	61.2	4.00	2.88	1.39	3.56	1.12	3.79	1.06
14	U-SU-17-EOF-6	1.232	250	99.4	97.5	0.97	61.9	3.72	2.82	1.32	3.50	1.06	3.70	1.01
15	U-SU-18-EOF-1	1.232	250	195	193	0.97	20.6	2.10	1.85	1.13	2.21	0.95	2.00	1.05
16	U-SU-18-EOF-2	1.245	250	195	193	0.96	20.4	1.91	1.89	1.01	2.26	0.84	2.04	0.94
17	U-SU-18-EOF-5	1.270	250	191	189	0.94	60.0	2.53	2.49	1.01	3.14	0.80	3.27	0.77
18	U-SU-18-EOF-6	1.245	250	195	193	0.96	61.2	2.43	2.38	1.02	3.06	0.79	3.13	0.78

Young & Hancock - University of Sydney, Austrlia-1998 [26]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
19	S1EOF125N65-a	3.850	405	30.5	28.5	1.01	16.9	35.3	40.6	0.87	36.8	0.96	41.8	0.85
20	S1EOF125N65-b	3.840	405	30.5	28.5	1.02	16.9	35.3	40.3	0.88	36.6	0.96	41.5	0.85

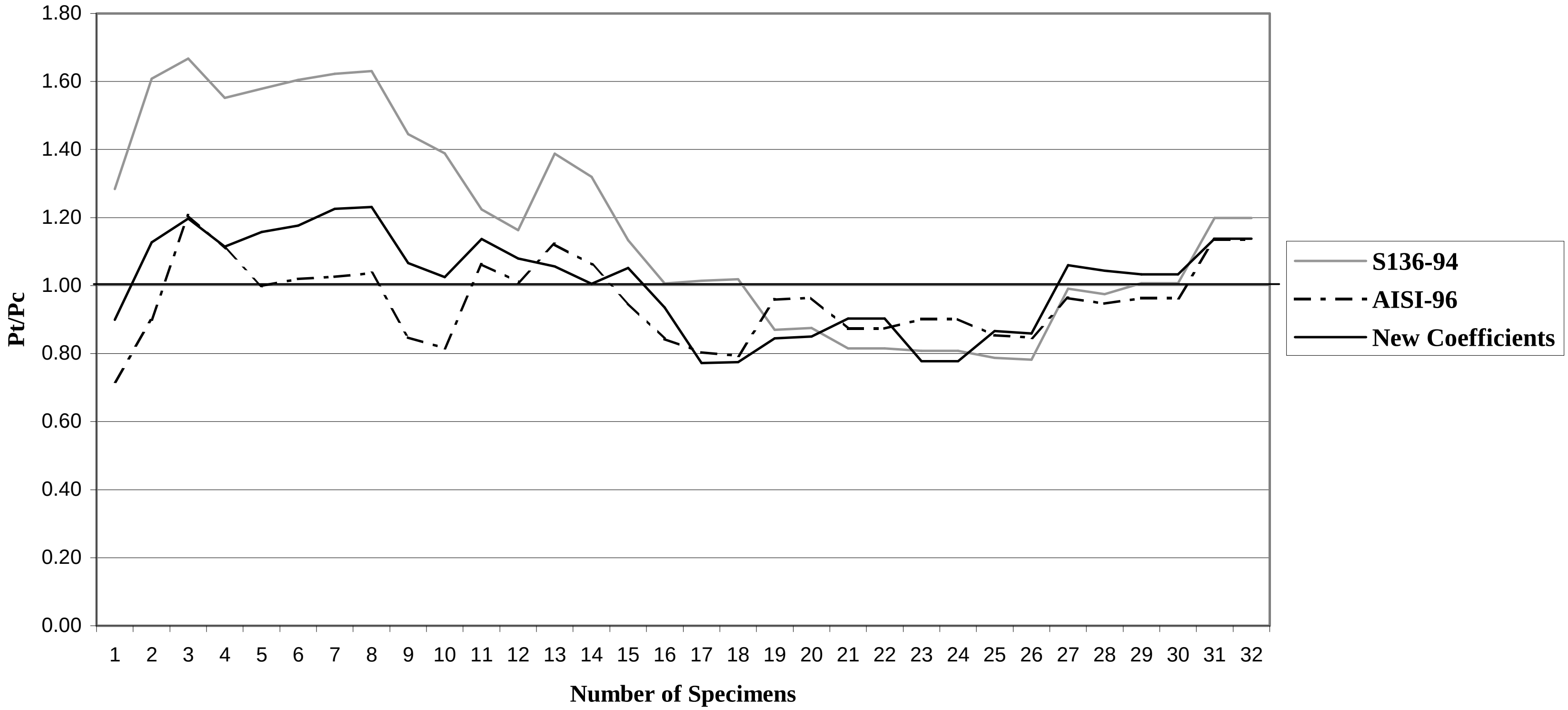
Table C.18 (Continued)

Young & Hancock - University of Sydney, Austrlia-1998 [26]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
21	S1EOF125N32.5-a	3.840	405	30.5	28.5	1.02	8.46	29.7	36.4	0.82	34.0	0.87	32.9	0.90
22	S1EOF125N32.5-b	3.840	405	30.5	28.5	1.02	8.46	29.7	36.4	0.82	34.0	0.87	32.9	0.90
23	S1EOF200N75-a	4.710	415	40.1	38.3	0.89	15.9	49.3	61.0	0.81	54.7	0.90	63.4	0.78
24	S1EOF200N75-b	4.710	415	40.1	38.3	0.89	15.9	49.3	61.0	0.81	54.7	0.90	63.4	0.78
25	S1EOF200N37.5-a	4.720	415	40.1	38.3	0.89	7.95	43.7	55.5	0.79	51.2	0.85	50.5	0.87
26	S1EOF200N37.5-b	4.740	415	40.1	38.3	0.89	7.91	43.7	55.9	0.78	51.6	0.85	50.9	0.86
27	S2EOF80N40-a	3.820	280	19.0	16.9	1.05	10.5	26.4	26.6	0.99	27.4	0.96	24.9	1.06
28	S2EOF80N40-b	3.850	280	19.0	16.9	1.04	10.4	26.4	27.1	0.98	27.9	0.95	25.3	1.04
29	S2EOF140N50-a	3.870	290	34.1	32.0	1.03	12.9	27.9	27.7	1.01	29.0	0.96	27.0	1.03
30	S2EOF140N50-b	3.870	290	34.1	32.0	1.03	12.9	27.9	27.7	1.01	29.0	0.96	27.0	1.03
31	S2EOF150N75-a	3.860	275	36.7	34.6	1.04	19.4	33.2	27.7	1.20	29.2	1.14	29.2	1.14
32	S2EOF150N75-b	3.860	275	36.7	34.6	1.04	19.4	33.2	27.7	1.20	29.2	1.14	29.2	1.14
							P_t/P_c Mean value			1.18		1.00		1.00
							S.D.			0.29		0.11		0.14
							C.O.V.			0.25		0.11		0.14

Chart C.16

Pt/Pc for Single Web Sections (Unstiffened Flanges)
Unfastened - End One Flange Loading (EOF)



S136-94	AISI-96	New Coefficient
Pt/Pc mean = 1.18	Pt/Pc mean = 1.00	Pt/Pc mean = 1.00
S.D. = 0.29	S.D. = 0.11	S.D. = 0.14
C.O.V. = 0.25	C.O.V. = 0.11	C.O.V. = 0.14

Table C.19

Single Web Sections (Unstiffened Flanges)
Unfastened - Interior One Flange Loading (IOF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	U-SU-17-IOF-5	1.245	250	98.2	96.2	0.96	61.2	6.68	7.03	0.95	7.63	0.88	5.55	1.20
2	U-SU-17-IOF-6	1.245	250	98.0	96.1	0.96	61.2	6.79	7.04	0.96	7.63	0.89	5.55	1.22
3	U-SU-18-IOF-5	1.245	250	193	191	0.96	61.2	7.52	5.18	1.45	6.49	1.16	5.30	1.42
4	U-SU-18-IOF-6	1.245	250	194	192	0.96	61.2	6.52	5.16	1.26	6.47	1.01	5.30	1.23

Young & Hancock - University of Sydney, Austrlia-1998 [26]

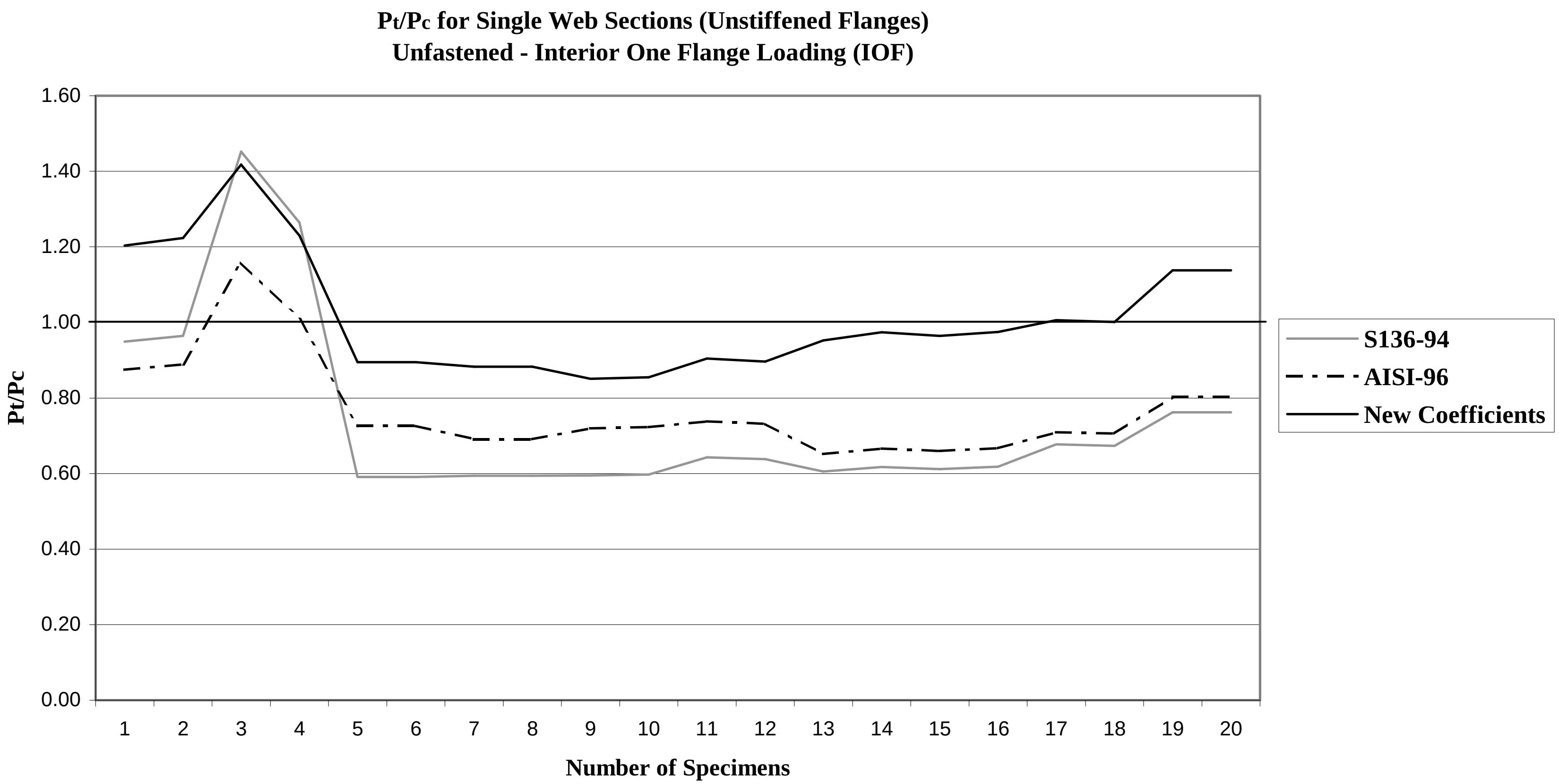
No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
5	S1IOF125N65-a	3.860	405	30.5	28.5	1.01	16.8	63.6	108	0.59	87.6	0.73	71.1	0.90
6	S1IOF125N65-b	3.860	405	30.5	28.5	1.01	16.8	63.6	108	0.59	87.6	0.73	71.1	0.90
7	S1IOF125N32.5-a	3.860	405	30.5	28.5	1.01	8.42	57.4	96.6	0.59	83.1	0.69	65.0	0.88
8	S1IOF125N32.5-b	3.860	405	30.5	28.5	1.01	8.42	57.4	96.6	0.59	83.1	0.69	65.0	0.88
9	S1IOF200N75-a	4.740	415	40.1	38.3	0.89	15.8	94.5	159	0.60	131	0.72	111	0.85
10	S1IOF200N75-b	4.730	415	40.1	38.3	0.89	15.9	94.5	158	0.60	131	0.72	111	0.86
11	S1IOF200N37.5-a	4.720	415	40.1	38.3	0.89	7.95	91.2	142	0.64	124	0.74	101	0.90
12	S1IOF200N37.5-b	4.740	415	40.1	38.3	0.89	7.91	91.2	143	0.64	125	0.73	102	0.90
13	S2IOF80N40-a(1)	3.850	280	19.0	16.9	1.04	10.4	43.9	72.6	0.61	67.3	0.65	46.1	0.95
14	S2IOF80N40-b(1)	3.810	280	19.0	16.9	1.05	10.5	43.9	71.2	0.62	65.9	0.67	45.1	0.97
15	S2IOF80N40-a(2)	3.840	280	19.0	16.9	1.04	10.4	44.2	72.2	0.61	67.0	0.66	45.9	0.96
16	S2IOF80N40-b(2)	3.820	280	19.0	16.9	1.05	10.5	44.2	71.5	0.62	66.3	0.67	45.3	0.98
17	S2IOF140N50-a	3.890	290	34.1	32.0	1.03	12.9	49.7	73.4	0.68	70.1	0.71	49.4	1.01
18	S2IOF140N50-b	3.900	290	34.1	32.0	1.03	12.8	49.7	73.8	0.67	70.4	0.71	49.7	1.00

Table C.19 (Continued)

Young & Hancock - University of Sydney, Austrlia-1998 [26]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
19	S2IOF150N75-a	3.850	275	36.7	34.6	1.04	19.5	55.1	72.3	0.76	68.6	0.80	48.4	1.14
20	S2IOF150N75-b	3.850	275	36.7	34.6	1.04	19.5	55.1	72.3	0.76	68.6	0.80	48.4	1.14
							P_t/P_c Mean value			0.74		0.77		1.01
							S.D.			0.23		0.13		0.15
							C.O.V.			0.32		0.16		0.15

Chart C.17



S136-94	AISI-96	New Coefficient
Pt/Pc mean = 0.74	Pt/Pc mean = 0.77	Pt/Pc mean = 1.01
S.D. = 0.23	S.D. = 0.13	S.D. = 0.15
C.O.V. = 0.32	C.O.V. = 0.16	C.O.V. = 0.15

Table C.20

Single Web Sections (Unstiffened Flanges)
Unfastened - End Two Flange Loading (ETF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

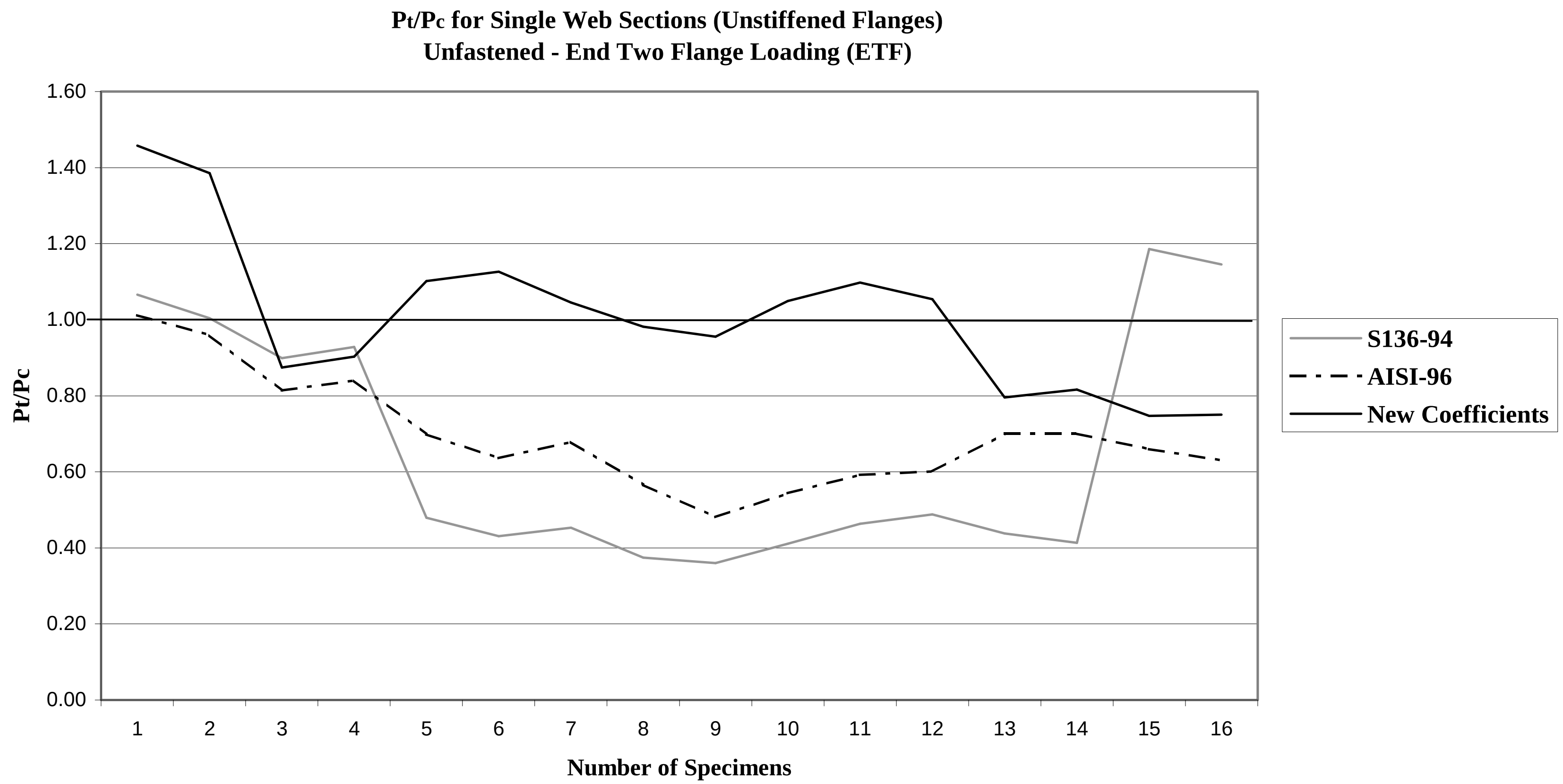
No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	U-SU-17-ETF-5	1.232	250	100	98.1	0.97	61.9	3.47	3.26	1.07	3.43	1.01	2.38	1.46
2	U-SU-17-ETF-6	1.245	250	98.6	96.7	0.96	61.2	3.36	3.35	1.00	3.50	0.96	2.42	1.39
3	U-SU-19-ETF-5	1.245	250	195	193	0.96	61.2	2.03	2.25	0.90	2.49	0.81	2.33	0.87
4	U-SU-19-ETF-6	1.245	250	194	193	0.96	61.2	2.09	2.25	0.93	2.49	0.84	2.32	0.90

Young & Hancock - University of Sydney, Austrlia-1998 [26]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
5	S1ETF125N65	3.860	405	30.5	28.5	1.01	16.8	28.2	58.9	0.48	40.3	0.70	25.6	1.10
6	S1ETF125N32.5	3.830	405	30.5	28.5	1.02	8.49	23.4	54.3	0.43	36.8	0.64	20.7	1.13
7	S1ETF200N75	4.720	415	40.0	38.2	0.89	15.9	40.2	88.7	0.45	59.2	0.68	38.3	1.05
8	S1ETF200N37.5	4.720	415	40.0	38.2	0.89	7.95	31.2	83.4	0.37	55.1	0.57	31.8	0.98
9	S2ETF80N40	3.850	280	19.0	16.9	1.04	10.4	14.8	41.1	0.36	30.8	0.48	15.4	0.96
10	S2ETF100N50	4.830	295	18.6	16.2	1.20	10.4	26.7	65.0	0.41	49.1	0.54	25.4	1.05
11	S2ETF140N50	3.880	290	34.1	32.0	1.03	12.9	18.7	40.4	0.46	31.6	0.59	17.0	1.10
12	S2ETF150N75	3.860	275	36.7	34.6	1.04	19.4	19.0	38.9	0.49	31.6	0.60	18.1	1.05
13	S3ETF96N75	1.470	510	62.0	60.9	0.58	51.0	5.40	12.3	0.44	7.7	0.70	6.8	0.80
14	S3ETF96N50	1.470	510	62.0	60.9	0.58	34.0	4.80	11.6	0.41	6.9	0.70	5.9	0.82
15	S3ETF96N37.5	1.470	550	63.9	62.7	0.58	25.5	4.3	3.6	1.19	6.5	0.66	5.7	0.75
16	S3ETF96N25	1.470	550	63.9	62.7	0.58	17.0	3.8	3.3	1.15	6.0	0.63	5.07	0.75

	S136-94 P_t/P_c	AISI-96 P_t/P_c	New Coeff. P_t/P_c
P_t/P_c Mean value	0.56	0.76	1.01
S.D.	0.25	0.14	0.20
C.O.V.	0.44	0.19	0.20

Chart C.18



S136-94	**AISI-96**	**New Coefficient**
Pt/Pc mean = 0.56	Pt/Pc mean = 0.76	Pt/Pc mean = 1.01
S.D. = 0.25	S.D. = 0.14	S.D. = 0.20
C.O.V. = 0.44	C.O.V. = 0.19	C.O.V. = 0.20

Table C.21

Single Web Sections (Unstiffened Flanges)
Unfastened - Interior Two Flange Loading (ITF)

Hetrakul - University of Missouri-Rolla, USA-1978 [11]

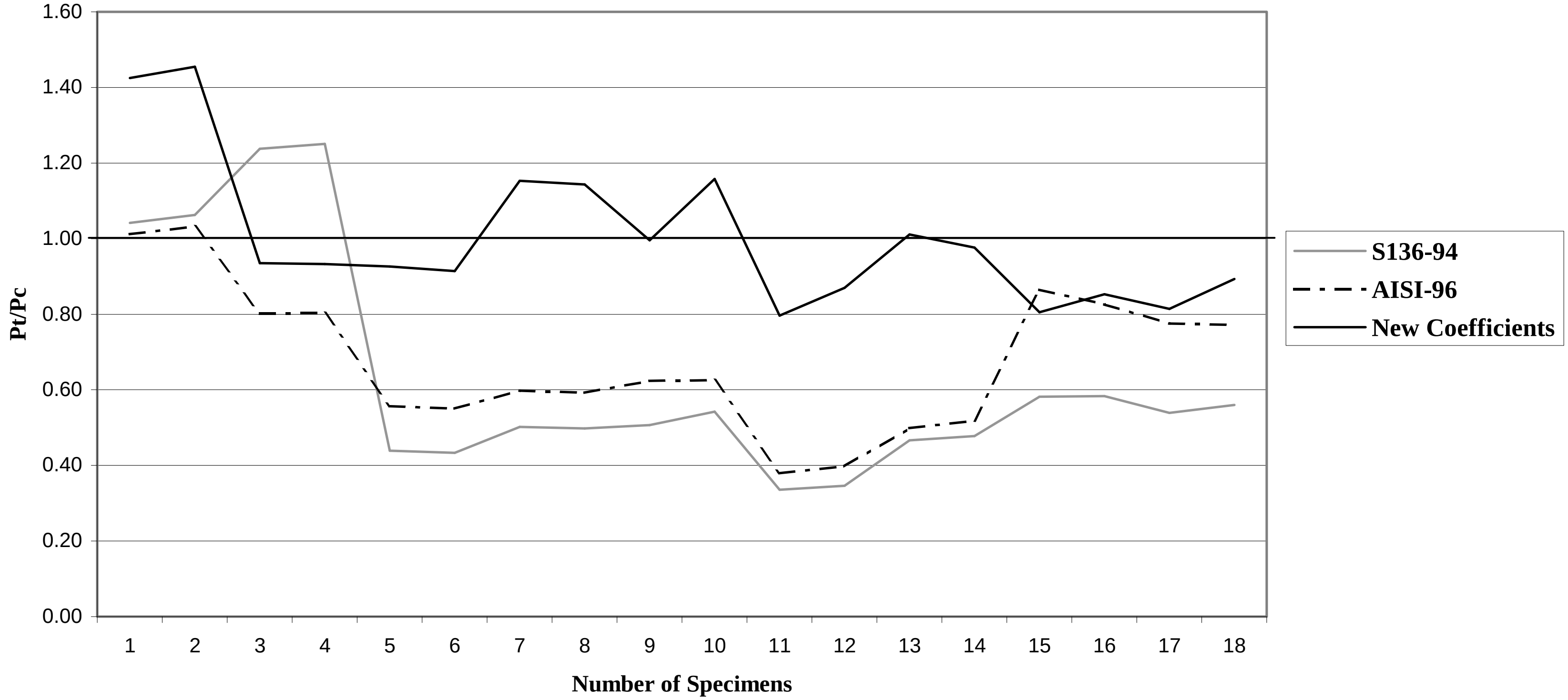
				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
1	U-SU-17-ITF-5	1.257	250	96.1	94.2	0.95	60.6	7.14	6.86	1.04	7.06	1.01	5.01	1.43
2	U-SU-17-ITF-6	1.245	250	96.2	94.3	0.96	61.2	7.14	6.72	1.06	6.92	1.03	4.91	1.46
3	U-SU-19-ITF-5	1.245	250	194	193	0.96	61.2	3.34	2.70	1.24	4.16	0.80	3.57	0.94
4	U-SU-19-ITF-6	1.245	250	196	194	0.96	61.2	3.32	2.65	1.25	4.13	0.80	3.55	0.93

Young & Hancock - University of Sydney, Austrlia-1998 [26]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
5	S1ITF125N65(1)	3.840	405	30.5	28.5	1.02	16.9	60.4	138	0.44	108	0.56	65.2	0.93
6	S1ITF125N65(2)	3.840	405	30.5	28.5	1.02	16.9	59.6	138	0.43	108	0.55	65.2	0.91
7	S1ITF125N32.5(1)	3.850	405	30.5	28.5	1.01	8.44	64.4	128	0.50	108	0.60	55.9	1.15
8	S1ITF125N32.5(2)	3.850	405	30.5	28.5	1.01	8.44	63.8	128	0.50	108	0.59	55.8	1.14
9	S1ITF200N75	4.720	415	40.1	38.3	0.89	15.9	100	197	0.51	160	0.62	101	1.00
10	S1ITF200N37.5	4.730	415	40.1	38.3	0.89	7.93	99.8	184	0.54	160	0.63	86.2	1.16
11	S2ITF80N40	3.780	280	19.0	16.9	1.06	10.6	32.4	96.4	0.34	85.5	0.38	40.7	0.80
12	S2ITF100N50	4.820	295	18.6	16.2	1.20	10.4	56.9	164	0.35	143	0.40	65.4	0.87
13	S2ITF140N50	3.890	290	34.1	32.0	1.03	12.9	44.3	95.1	0.47	88.8	0.50	43.8	1.01
14	S2ITF150N75	3.860	275	36.7	34.6	1.04	19.4	43.6	91.2	0.48	84.2	0.52	44.7	0.98
15	S3ITF96N75	1.470	510	62.0	60.9	0.58	51.0	14.2	24.4	0.58	16.4	0.87	17.6	0.81
16	S3ITF96N50	1.460	510	62.1	60.9	0.58	34.2	13.1	22.5	0.58	15.9	0.83	15.4	0.85
17	S3ITF96N37.5	1.470	550	63.9	62.7	0.58	25.5	12.5	23.2	0.54	16.1	0.78	15.4	0.81
18	S3ITF96N25	1.470	550	63.9	62.7	0.58	17.0	12.3	22.0	0.56	16.0	0.77	13.8	0.89
							P_t/P_c Mean value			0.63		0.68		1.00
							S.D.			0.29		0.19		0.19
							C.O.V.			0.45		0.27		0.19

Chart C.19

Pt/Pc for Single Web Sections (Unstiffened Flanges)
Unfastened - Interior Two Flange Loading (ITF)



S136-94	AISI-96	New Coefficients
Pt/Pc mean = 0.63	Pt/Pc mean = 0.68	Pt/Pc mean = 1.00
S.D. = 0.29	S.D. = 0.19	S.D. = 0.19
C.O.V. = 0.45	C.O.V. = 0.27	C.O.V. = 0.19

Table C.22

Single Hat Sections
Unfastened - End One Flange Loading (EOF)

Cornell University, USA-1953 [7]

				H'	H	R	N		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
1	50	1.552	231	47.1	45.1	1.00	24.6	6.42	4.10	1.57	6.37	1.01	5.35	1.20
2	51	1.565	227	46.7	44.7	1.00	40.6	7.97	4.68	1.70	7.21	1.11	6.53	1.22
3	53	1.519	225	48.2	42.2	3.00	25.1	3.84	3.62	1.06	4.22	0.91	3.84	1.00
4	54	1.527	200	47.9	41.9	3.00	41.6	4.95	3.74	1.33	4.40	1.13	4.23	1.17
5	55	1.684	373	43.2	41.3	0.95	11.3	7.99	6.56	1.22	9.39	0.85	7.83	1.02
6	56	1.664	370	43.8	41.8	1.00	22.9	9.23	7.41	1.25	10.06	0.92	9.7	0.95
7	57	1.608	375	45.4	43.4	1.00	39.5	11.1	8.10	1.37	10.72	1.04	11.3	0.98
8	58	1.643	361	44.4	38.4	3.00	11.6	4.25	5.72	0.74	6.19	0.69	5.52	0.77
9	59	1.633	382	44.7	38.7	3.00	23.3	7.43	6.99	1.06	6.97	1.07	7.43	1.00
10	60	1.613	380	45.2	39.2	3.00	39.4	9.35	7.79	1.20	7.66	1.22	8.8	1.06
11	61	1.544	226	96.7	94.7	1.00	12.3	3.92	3.38	1.16	5.03	0.78	3.35	1.17
12	62	1.511	210	98.8	96.8	1.00	25.2	4.47	3.54	1.26	5.04	0.89	3.86	1.16
13	63	1.521	267	98.2	96.2	1.00	41.7	5.29	5.21	1.02	6.96	0.76	6.08	0.87
14	64	1.527	234	97.8	91.8	3.00	12.5	2.56	3.24	0.79	3.55	0.72	2.58	0.99
15	65	1.534	223	97.3	91.3	3.00	24.8	4.10	3.65	1.12	3.85	1.06	3.22	1.27
16	66	1.527	216	97.8	91.8	3.00	41.6	4.34	4.01	1.08	4.20	1.03	3.77	1.15
17	67	1.707	375	87.3	85.3	1.00	11.2	7.14	6.73	1.06	8.82	0.81	6.74	1.06
18	68	1.697	362	87.8	85.8	1.00	22.5	7.79	7.48	1.04	9.38	0.83	8.29	0.94
19	69	1.687	362	88.4	86.4	1.00	37.7	8.74	8.47	1.03	10.41	0.84	10.0	0.87
20	70	1.702	371	87.6	81.6	3.00	11.2	5.34	6.24	0.86	6.14	0.87	5.09	1.05
21	71	1.740	362	85.6	79.6	3.00	21.9	7.46	7.38	1.01	6.97	1.07	6.66	1.12
22	72	1.750	369	85.1	79.1	3.00	36.3	8.77	8.68	1.01	7.99	1.10	8.43	1.04
23	73	1.529	220	148	146	1.00	12.5	3.12	3.22	0.97	4.28	0.73	2.71	1.15
24	74	1.534	218	147	145	1.00	24.8	3.52	3.77	0.93	4.76	0.74	3.52	1.00

Table C.22 (Continued)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
25	75	1.516	214	149	147	1.00	41.9	3.81	4.14	0.92	5.17	0.74	4.09	0.93
26	76	1.524	238	148	142	3.00	12.5	1.83	3.27	0.56	3.19	0.57	2.23	0.82
27	77	1.519	220	148	142	3.00	25.1	2.00	3.53	0.57	3.32	0.60	2.67	0.75
28	78	1.521	413	148	142	3.00	41.7	2.34	7.61	0.31	5.77	0.41	6.15	0.38
29	79	1.638	354	138	136	1.00	11.6	4.52	5.87	0.77	7.01	0.64	5.08	0.89
30	80	1.621	372	139	137	1.00	23.5	4.06	7.08	0.57	7.78	0.52	6.66	0.61
31	81	1.615	355	140	138	1.00	39.3	4.78	7.68	0.62	8.48	0.56	7.83	0.61
32	82	1.621	377	139	133	3.00	11.8	3.33	5.80	0.57	5.02	0.66	4.01	0.83
33	83	1.628	377	138	132	3.00	23.4	3.60	6.82	0.53	5.60	0.64	5.21	0.69
34	84	1.610	377	140	134	3.00	39.4	4.09	7.67	0.53	6.18	0.66	6.29	0.65
35	85	1.552	219	194	192	1.00	12.3	3.36	3.29	1.02	3.87	0.87	2.38	1.41
36	86	1.547	222	195	193	1.00	24.6	2.78	3.88	0.72	4.31	0.65	3.09	0.90
37	88	1.524	216	198	192	3.00	12.5	1.86	2.97	0.63	2.59	0.72	1.72	1.08
38	89	1.521	214	198	192	3.00	25.0	3.34	3.44	0.97	2.85	1.17	2.20	1.52
39	91	1.755	386	172	170	1.00	10.9	5.21	7.25	0.72	7.71	0.68	5.54	0.94
40	92	1.750	378	172	170	1.00	21.8	5.47	8.22	0.67	8.31	0.66	6.92	0.79
41	93	1.730	371	174	172	1.00	36.7	5.72	9.02	0.63	8.96	0.64	8.05	0.71
42	94	1.697	372	178	172	3.00	11.2	4.52	6.20	0.73	4.93	0.92	3.80	1.19
43	95	1.671	368	180	174	3.00	22.8	4.33	6.96	0.62	5.21	0.83	4.66	0.93
44	96	1.692	371	178	175	1.80	37.5	4.23	8.44	0.50	7.54	0.56	6.82	0.62
45	18-F2	1.130	226	167	163	1.93	56.2	2.45	2.57	0.95	2.73	0.90	2.25	1.09
46	18-F3	1.130	226	167	163	1.93	56.2	2.58	2.57	1.00	2.73	0.95	2.24	1.15
47	18-C1	1.130	226	65.4	61.6	1.93	56.2	3.41	2.58	1.32	3.46	0.99	3.15	1.08
48	18-C4	1.130	226	65.4	61.6	1.93	56.2	3.23	2.58	1.25	3.46	0.93	3.16	1.02

Table C.22 (Continued)

Cornell University, USA-1953 [7]

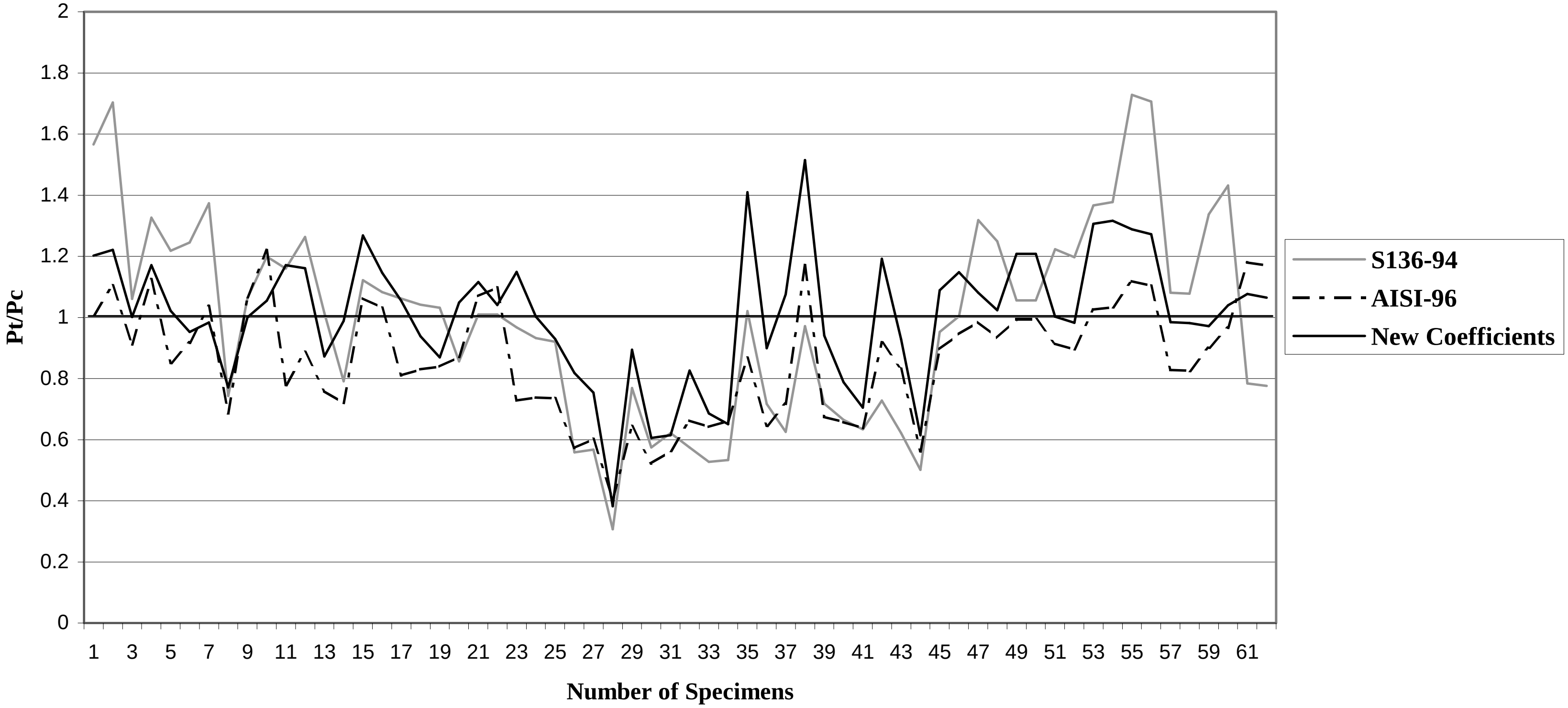
No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
49	18-H5	1.130	226	167	163	1.93	56.2	2.72	2.57	1.06	2.73	0.99	2.24	1.21
50	18-H5	1.130	226	167	163	1.93	56.2	2.72	2.57	1.06	2.73	0.99	2.24	1.21
51	18-G1	1.130	226	65.4	61.6	1.93	56.2	3.16	2.58	1.22	3.46	0.91	3.16	1.00
52	18-G3	1.130	226	65.4	61.6	1.93	56.2	3.09	2.58	1.20	3.46	0.90	3.16	0.98
53	16-E1	1.615	186	116	113	1.35	39.3	5.43	3.98	1.37	5.29	1.03	4.15	1.31
54	16-E4	1.615	186	116	113	1.35	39.3	5.47	3.98	1.38	5.29	1.03	4.15	1.32
55	16-B2	1.615	186	45.2	42.5	1.35	39.3	6.90	3.99	1.73	6.17	1.12	5.35	1.29
56	16-B4	1.615	186	45.2	42.5	1.35	39.3	6.81	3.99	1.71	6.17	1.10	5.36	1.27
57	14-D4	1.839	260	102	99.2	1.19	34.5	7.57	7.00	1.08	9.14	0.83	7.72	0.98
58	14-D6	1.839	260	102	99.2	1.19	34.5	7.54	7.00	1.08	9.14	0.83	7.70	0.98
59	14-A1	1.839	260	39.4	37.1	1.19	34.5	9.39	7.02	1.34	10.42	0.90	9.7	0.97
60	14-A6	1.839	260	39.4	37.1	1.19	34.5	10.1	7.02	1.43	10.42	0.97	9.7	1.04

Bhakta - University of Missouri-Rolla, USA-1992 [5]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
61	RD1	1.245	302	154	145	4.14	53.6	3.06	3.91	0.78	2.59	1.18	2.84	1.08
62	RD2	1.245	302	154	145	4.14	53.6	3.03	3.91	0.78	2.59	1.17	2.83	1.07
							P_t/P_c Mean value			1.00		0.89		1.01
							S.D.			0.32		0.19		0.21
							C.O.V.			0.32		0.21		0.21

Chart C.20

Pt/Pc for Single Hat Sections
Unfastened - End One Flange Loading (EOF)



S136-94	AISI-96	New Expression
Pt/Pc mean = 1.00	Pt/Pc mean = 0.89	Pt/Pc mean = 1.01
S.D. = 0.32	S.D. = 0.19	S.D. = 0.21
C.O.V. = 0.32	C.O.V. = 0.21	C.O.V. = 0.21

Table C.23

Single Hat Sections
Fastened - End One Flange Loading (EOF)

Bhakta - University of Missouri-Rolla, USA-1992 [5]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	RD3-F	1.245	302	154	145	4.14	53.6	4.14	3.91	1.06	2.59	1.60	2.84	1.46
2	RD4-F	1.245	302	154	145	4.14	53.6	4.23	3.91	1.08	2.59	1.63	2.84	1.49

Wu - University of Missouri-Rolla, USA-1997 [24]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
3	t22h1.5R1/8ANGLE90	0.737	716	59.6	51.0	4.31	34.5	3.71	1.44*	2.57	1.14**	3.27	2.67	1.39
4	t22h3R1/8ANGLE90	0.737	716	112	104	4.31	34.5	2.78	1.44*	1.93	1.01**	2.74	2.22	1.25
5	t22h4.5R1/8ANGLE90	0.737	716	164	155	4.31	34.5	2.21	1.44*	1.54	0.90**	2.47	1.87	1.18

	S136-94	AISI-96	New Coeff.
Pt/Pc Mean value	1.64	2.34	1.35
S.D.	0.63	0.72	0.12
C.O.V.	0.39	0.31	0.09

* Based on F_y = 360 MPa
** Based on F_y = 60 ksi or 413.7 MPa

Table C.24

Single Hat Sections
Fastened - Interior One Flange Loading (IOF)

Wing - University of Waterloo, Canada-1981 [21]

				H'	**H**	**R**	**N**		**S136-94**		**AISI-96**		**New Coeff.**	
No.	**Specimen**	**t**	**F_y**	**h'/t**	**h/t**	**r/t**	**n/t**	**P_t**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**	**P_c**	**P_t/P_c**
		(mm)	(MPa)	(ratio)	(ratio)	(ratio)	(ratio)	(kN)	(kN)	(ratio)	(kN)	(ratio)	(kN)	(ratio)
1	5W-IOF	0.965	274	104	98.7	2.47	26.3	2.70	3.50	0.77	3.72	0.73	3.47	0.78
2	6W-IOF	0.610	265	165	158	3.91	41.7	1.26	1.12	1.13	1.30	0.97	1.14	1.10
3	7W-IOF	1.524	231	131	128	1.56	16.7	6.90	6.63	1.04	7.76	0.89	6.40	1.08
4	8W-IOF	0.965	274	209	204	2.47	26.3	3.15	----	----	----	----	2.47	1.28
5	34W-IOF	0.610	265	165	157	3.91	41.7	1.39	1.12	1.25	1.30	1.07	1.14	1.22
6	35W-IOF	0.610	265	164	156	3.91	83.3	1.73	1.26	1.37	1.68	1.03	1.36	1.27
7	36W-IOF	0.610	265	164	156	3.91	125	2.00	1.36	1.47	2.14	0.94	1.53	1.31
8	57W-IOF	1.524	231	65.2	62.0	1.56	16.7	6.51	8.29	0.79	8.61	0.76	8.00	0.81
9	60W-IOF	1.143	253	86.9	82.7	2.08	22.2	4.40	4.76	0.92	5.04	0.87	4.68	0.94
10	61W-IOF	1.143	253	86.9	82.7	2.08	44.4	5.27	5.23	1.01	5.71	0.92	5.41	0.97
11	62W-IOF	1.143	253	87.3	83.2	2.08	66.7	5.73	5.58	1.03	6.46	0.89	5.97	0.96
12	69W-IOF	0.965	274	104	99.0	2.47	78.9	4.23	4.13	1.02	5.08	0.83	4.48	0.94
13	124W-IOF	0.610	265	166	158	3.91	208	1.78	----	----	3.04	0.59	1.78	1.00
14	125W-IOF	0.610	265	166	158	3.91	167	1.78	1.44	1.23	2.59	0.69	1.66	1.07
15	128W-IOF	0.610	265	165	157	3.91	167	1.87	1.45	1.29	2.59	0.72	1.66	1.12
16	134W-IOF	0.965	274	104	99.5	2.47	105	4.95	4.36	1.13	5.98	0.83	4.84	1.02
17	135W-IOF	0.965	274	105	100	2.47	132	5.43	4.56	1.19	6.88	0.79	5.16	1.05
18	136W-IOF	0.965	274	104	99.5	2.47	26.3	3.32	3.49	0.95	3.71	0.89	3.46	0.96
19	137W-IOF	0.965	274	104	99.0	2.47	52.6	3.92	3.86	1.02	4.29	0.91	4.04	0.97
20	3WR-IOF	0.627	318	136	120	7.59	81.0	1.35	1.56	0.87	-----	-----	1.66	0.82
21	12WR-IOF	0.627	318	139	119	10.1	81.0	1.37	-----	-----	-----	-----	1.52	0.90
22	15WR-IOF	0.848	284	99.1	84.1	7.49	59.9	2.11	2.74	0.77	-----	-----	2.84	0.74
23	21WR-IOF	0.549	278	154	119	17.4	92.6	1.09	-----	-----	-----	-----	0.83	1.32
24	24WR-IOF	1.003	299	85.6	67.4	9.10	50.6	2.72	3.96	0.69	-----	-----	4.02	0.68
25	131WR-IOF	0.627	318	139	119	10.1	162	1.65	-----	-----	-----	-----	1.87	0.88

---- Exceeds AISI-96 or S136-94 Limit

Table C.24 (Continued)

Single Hat Sections
Unfastened - Interior One Flange Loading (IOF)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
26	13	1.537	234	97.2	95.2	1.00	12.4	9.04	7.66	1.18	8.48	1.07	7.27	1.24
27	14	1.516	254	98.5	96.5	1.00	25.1	8.37	8.69	0.96	9.48	0.88	8.67	0.97
28	16	1.516	255	98.5	92.5	3.00	12.6	7.66	7.38	1.04	7.78	0.98	6.94	1.10
29	17	1.534	225	97.3	91.3	3.00	24.8	8.81	7.19	1.23	7.81	1.13	7.08	1.24
30	18	1.537	225	97.2	91.2	3.00	41.3	8.50	7.76	1.10	8.64	0.98	7.95	1.07
31	19	1.641	372	90.9	88.9	1.00	11.6	15.6	14.1	1.11	13.3	1.17	13.3	1.17
32	20	1.661	369	89.7	87.7	1.00	22.9	15.1	15.4	0.98	14.6	1.03	15.3	0.99
33	22	1.641	372	90.9	84.9	3.00	11.6	13.8	12.9	1.08	11.8	1.17	12.0	1.15
34	23	1.648	365	90.4	84.4	3.00	23.1	14.0	13.7	1.02	12.7	1.10	13.4	1.04
35	24	1.674	366	89.0	83.0	3.00	37.9	14.9	15.2	0.98	14.3	1.04	15.5	0.96
36	25	1.527	260	148	146	1.00	12.5	6.90	7.11	0.97	8.32	0.83	6.75	1.02
37	26	1.511	247	149	147	1.00	25.2	6.85	7.10	0.96	8.47	0.81	7.09	0.97
38	28	1.527	287	148	142	3.00	12.5	5.79	7.17	0.81	7.93	0.73	6.74	0.86
39	29	1.511	227	149	143	3.00	25.2	6.28	5.97	1.05	7.05	0.89	5.89	1.07
40	30	1.491	222	151	145	3.00	42.6	6.79	6.07	1.12	7.42	0.92	6.23	1.09
41	31	1.651	375	135	133	1.00	11.5	10.7	12.4	0.86	12.6	0.85	11.7	0.91
42	34	1.618	377	139	133	3.00	11.8	10.7	10.8	0.99	12.6	0.85	10.1	1.06
43	35	1.626	373	139	133	3.00	23.4	10.5	11.6	0.90	11.6	0.91	11.4	0.92
44	36	1.608	373	140	134	3.00	39.5	10.7	12.1	0.89	12.4	0.87	12.4	0.87
45	37	1.532	221	197	195	1.00	12.4	6.45	5.2	1.24	6.78	0.95	4.94	1.31
46	38	1.565	229	193	191	1.00	24.4	6.90	6.12	1.13	7.88	0.88	6.08	1.13
47	39	1.554	263	194	192	1.00	40.9	7.57	7.41	1.02	9.48	0.80	7.67	0.99
48	40	1.504	213	201	195	3.00	12.7	6.12	4.36	1.41	5.59	1.10	4.10	1.49
49	41	1.542	224	196	190	3.00	24.7	6.23	5.26	1.18	6.65	0.94	5.18	1.20

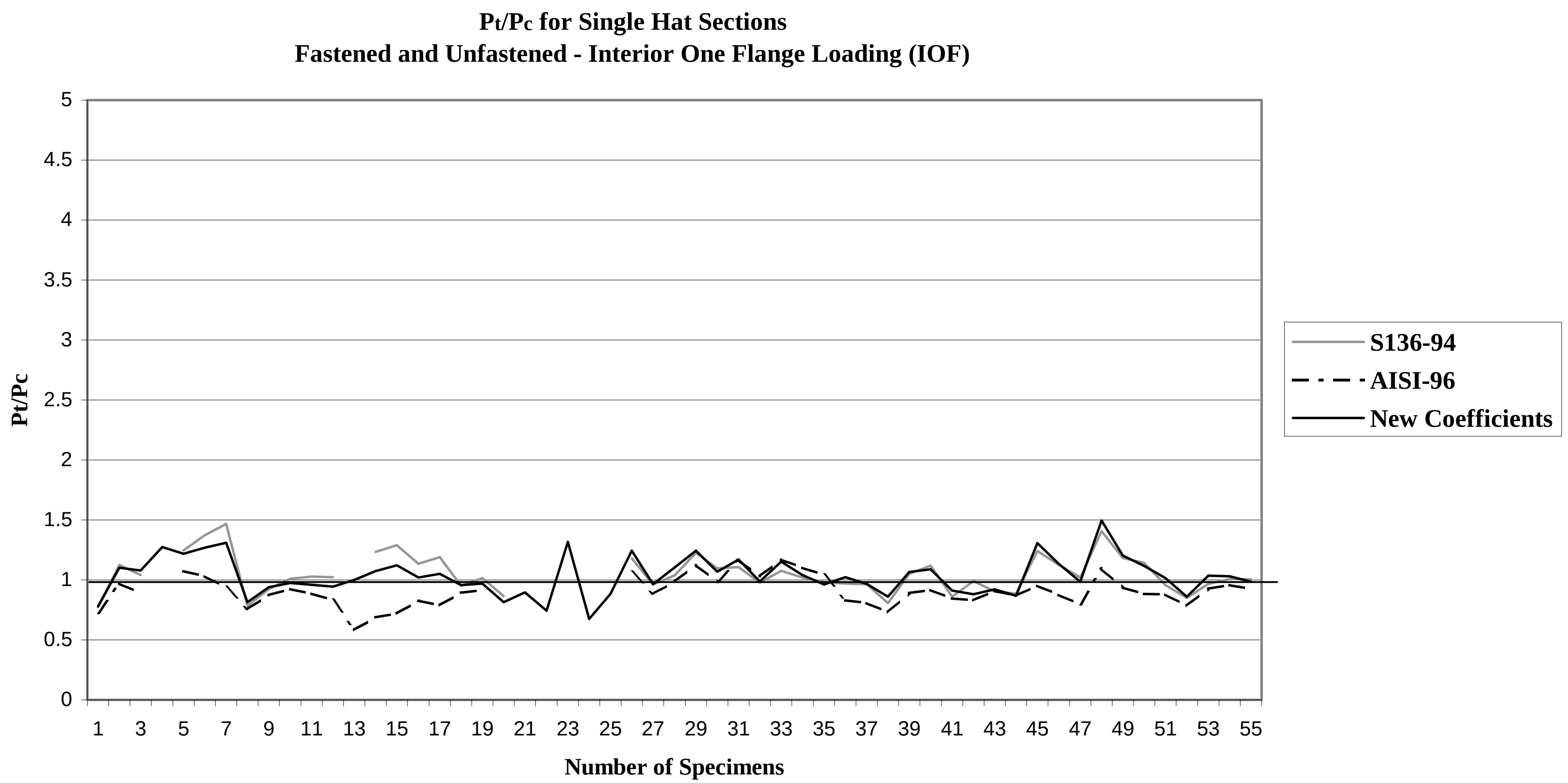
Table C.24 (Continued)

Single Hat Sections
Unfastened - Interior One Flange Loading (IOF)

Cornell University, USA-1953 [7]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
50	42	1.547	222	195	189	3.00	41.1	6.45	5.65	1.14	7.32	0.88	5.78	1.12
51	43	1.687	371	179	177	1.00	11.3	10.6	11.1	0.96	12.1	0.88	10.5	1.01
52	44	1.687	373	179	177	1.00	22.6	10.2	12.0	0.85	13.1	0.78	11.9	0.86
53	46	1.676	384	180	174	3.00	11.4	10.0	10.4	0.97	10.8	0.93	9.68	1.04
54	47	1.699	373	177	171	3.00	22.4	11.2	11.2	1.01	11.7	0.96	10.9	1.03
55	48	1.679	368	180	174	3.00	37.8	11.5	11.4	1.00	12.4	0.93	11.6	0.99
							P_t/P_c Mean value			1.04		0.94		1.03
							S.D.			0.17		0.12		0.16
							C.O.V.			0.16		0.13		0.15

Chart C.21



S136-94	AISI-96	New Expression
Pt/Pc mean = 1.04	Pt/Pc mean = 0.94	Pt/Pc mean = 1.03
S.D. = 0.17	S.D. = 0.12	S.D. = 0.16
C.O.V. = 0.16	C.O.V. = 0.13	C.O.V. = 0.15

Table C.25

Single Hat Sections
Fastened - End Two Flange Loading (ETF)

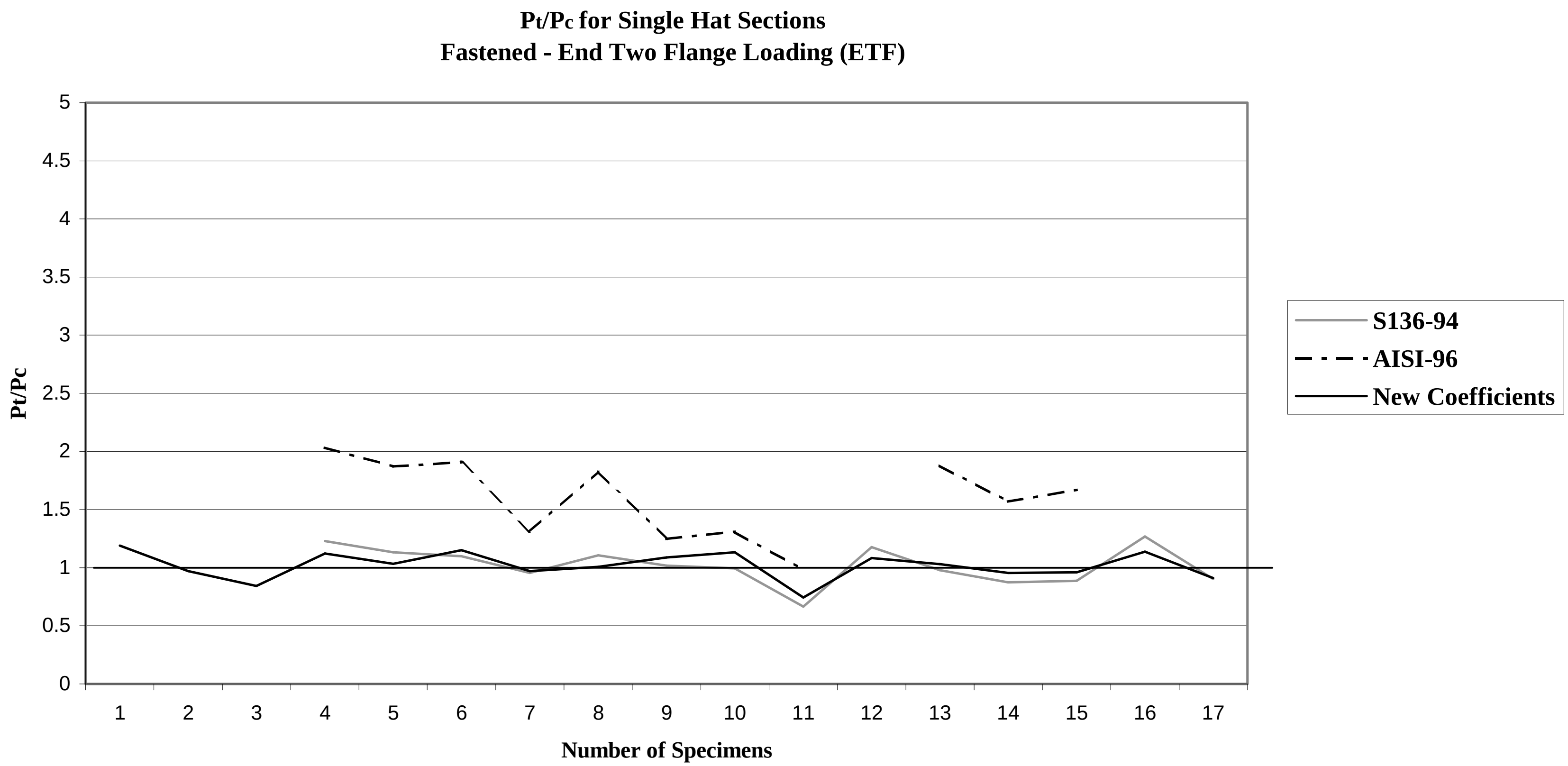
Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	5W-ETF	1.524	231	131	128	1.56	16.7	4.26	3.41	1.25	2.97	1.44	3.59	1.19
2	6W-ETF	0.965	274	209	204	2.47	26.3	1.46	----	----	----	----	1.51	0.97
3	7W-ETF	0.610	265	332	324	3.91	41.7	0.40	----	----	----	----	0.48	0.84
4	26W-ETF	0.610	265	164	156	3.91	41.7	0.73	0.59	1.23	0.36	2.03	0.65	1.12
5	27W-ETF	0.610	265	164	156	3.91	41.7	0.67	0.59	1.13	0.36	1.87	0.65	1.03
6	28W-ETF	0.610	265	89.2	81.4	3.91	41.7	0.87	0.79	1.10	0.45	1.91	0.75	1.15
7	29W-ETF	0.965	274	104	99.5	2.47	26.3	1.79	1.88	0.95	1.36	1.31	1.84	0.97
8	30W-ETF	0.610	265	165	157	3.91	41.7	0.65	0.59	1.11	0.36	1.83	0.64	1.01
9	31W-ETF	1.524	231	66.2	63.0	1.56	16.7	4.50	4.41	1.02	3.60	1.25	4.14	1.09
10	32W-ETF	1.524	231	31.7	28.5	1.56	16.7	5.16	5.22	0.99	3.94	1.31	4.56	1.13
11	33W-ETF	0.965	274	51.1	46.1	2.47	26.3	1.56	2.33	0.67	1.59	0.98	2.10	0.74
12	1WR-ETF	0.627	318	136	120	7.59	81.0	0.97	0.82	1.18	----	----	0.89	1.08
13	2WR-ETF	1.003	299	82.0	72.5	4.75	50.6	2.44	2.49	0.98	1.30	1.88	2.36	1.03
14	3WR-ETF	1.539	302	54.5	47.2	3.61	33.0	5.55	6.37	0.87	3.54	1.57	5.80	0.96
15	4WR-ETF	1.539	302	54.0	46.2	3.87	33.0	5.55	6.23	0.89	3.32	1.67	5.77	0.96
16	5WR-ETF	1.003	299	85.6	67.4	9.10	50.6	2.43	1.91	1.27	----	----	2.14	1.14
17	6WR-ETF	1.539	302	55.0	43.1	5.93	33.0	4.99	5.55	0.90	2.94	1.70	5.48	0.91

---- Exceeds AISI-96 or S136-94 Limit

	S136-94 P_t/P_c	AISI-96 P_t/P_c	New Coeff. P_t/P_c
P_t/P_c Mean value	1.04	1.60	1.02
S.D.	0.17	0.32	0.12
C.O.V.	0.16	0.20	0.11

Chart C.22



S136-94	AISI-96	New Coefficient
Pt/Pc mean = 1.04	Pt/Pc mean = 1.60	Pt/Pc mean = 1.02
S.D. = 0.17	S.D. = 0.32	S.D. = 0.12
C.O.V. = 0.16	C.O.V. = 0.20	C.O.V. = 0.11

Table C.26

Single Hat Sections
Fastened - Interior Two Flange Loading (ITF)

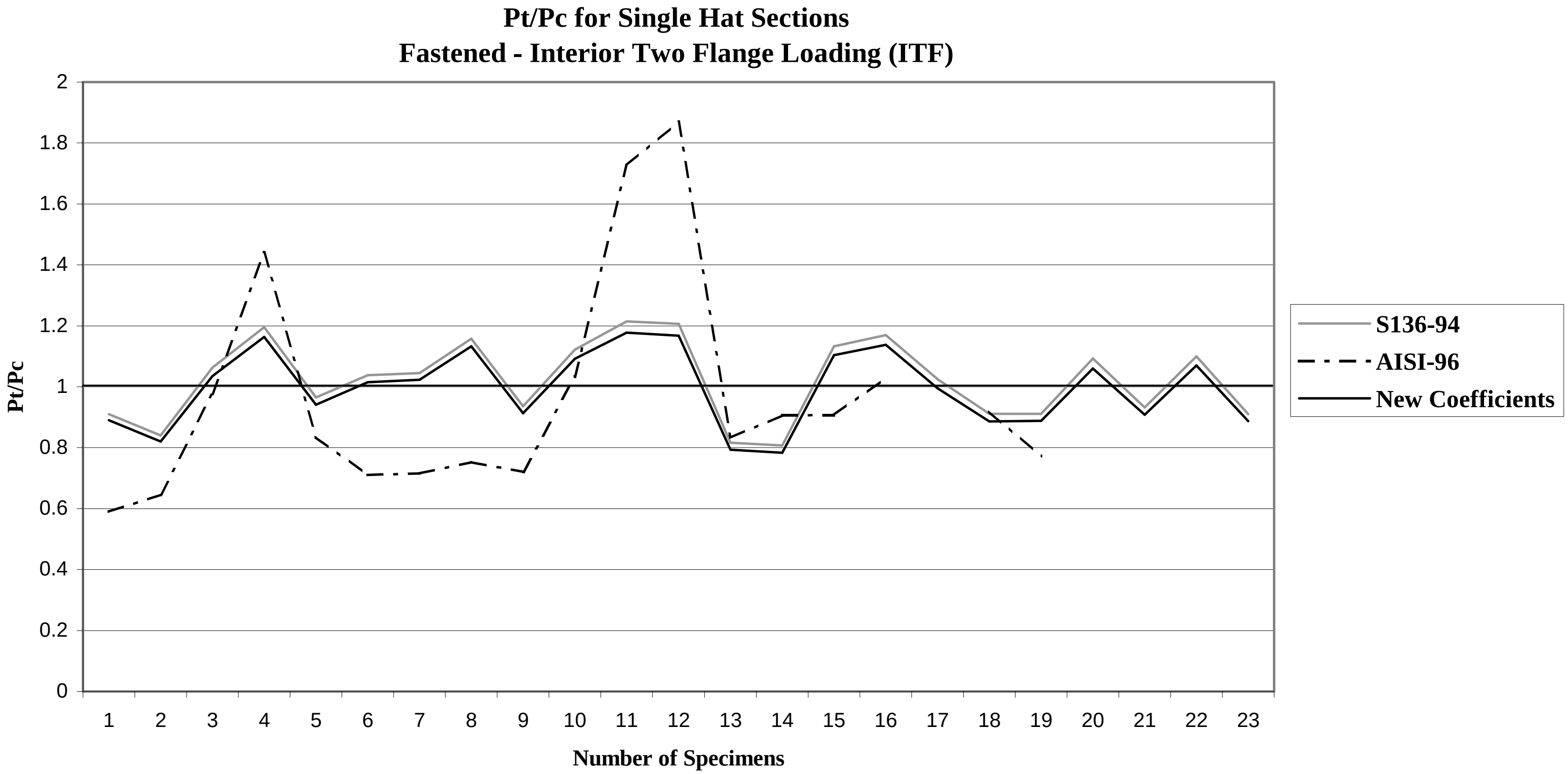
Wing-UW, 1981-Except one point [21]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	1W-ITF	1.524	231	31.3	28.2	1.57	16.7	6.68	7.34	0.91	11.3	0.59	7.50	0.89
2	2W-ITF	0.965	274	51.1	46.1	2.47	26.3	3.00	3.58	0.84	4.65	0.65	3.66	0.82
3	3W-ITF	0.610	265	81.7	73.8	3.92	41.7	1.48	1.39	1.06	1.51	0.98	1.43	1.04
4	4W-ITF	0.610	265	165	157	3.92	41.7	1.50	1.26	1.20	1.04	1.44	1.29	1.16
5	7W-ITF	0.965	274	103	98.2	2.47	26.3	3.20	3.32	0.97	3.83	0.84	3.40	0.94
6	8W-ITF	1.524	231	65.0	61.9	1.57	16.7	7.18	6.92	1.04	10.1	0.71	7.07	1.02
7	9W-ITF	1.524	231	65.0	61.9	1.57	16.7	7.23	6.92	1.05	10.1	0.72	7.07	1.02
8	22W-ITF	1.524	231	33.5	30.4	1.57	16.7	8.46	7.30	1.16	11.2	0.75	7.46	1.13
9	23W-ITF	0.965	274	52.4	47.4	2.47	26.3	3.34	3.57	0.94	4.63	0.72	3.66	0.91
10	24W-ITF	0.610	265	82.5	74.7	3.92	41.7	1.56	1.39	1.12	1.51	1.03	1.43	1.09
11	25W-ITF	0.610	265	165	157	3.92	83.3	1.89	1.56	1.22	1.10	1.73	1.61	1.18
12	26W-ITF	0.610	265	164	156	3.92	125	2.16	1.79	1.21	1.15	1.87	1.85	1.17
13	27W-ITF	0.965	274	104	98.7	2.47	52.6	3.29	4.03	0.82	3.95	0.83	4.14	0.79
14	28W-ITF	0.965	274	104	99.0	2.47	78.9	3.69	4.57	0.81	4.07	0.91	4.71	0.78
15	29W-ITF	1.524	231	66.2	63.0	1.57	33.3	9.32	8.23	1.13	10.3	0.91	8.44	1.10
16	30W-ITF	1.524	231	65.8	62.7	1.57	50.0	10.8	9.24	1.17	10.5	1.03	9.50	1.14
17	1WR-ITF	0.635	318	134	119	7.52	80.0	1.82	1.78	1.03	----	----	1.83	1.00
18	2WR-ITF	1.016	299	81.0	71.6	4.70	50.0	4.04	4.44	0.91	4.40	0.92	4.56	0.89
19	3WR-ITF	1.549	302	54.1	46.9	3.59	32.8	9.21	10.1	0.91	11.9	0.77	10.4	0.89
20	4WR-ITF	0.635	318	138	118	10.0	80.0	1.76	1.61	1.09	----	----	1.66	1.06
21	6WR-ITF	1.549	302	53.6	45.9	3.84	32.8	9.32	10.0	0.93	11.8	0.79	10.3	0.91
22	8WR-ITF	1.016	299	84.5	66.6	8.98	50.0	4.10	3.73	1.10	----	----	3.83	1.07
23	9WR-ITF	1.549	302	54.6	42.8	5.89	32.8	8.33	9.15	0.91	10.1	0.82	9.39	0.89

---- Exceeds AISI-96 Limit

	S136-94	AISI-96	New Coeff.
P_t/P_c Mean value	1.02	0.95	1.00
S.D.	0.13	0.34	0.12
C.O.V.	0.12	0.36	0.12

Chart C.23



S136-94	**AISI-96**	**New Coefficient**
Pt/Pc mean = 1.02	Pt/Pc mean = 0.95	Pt/Pc mean = 1.00
S.D. = 0.13	S.D. = 0.34	S.D. = 0.12
C.O.V. = 0.12	C.O.V. = 0.36	C.O.V. = 0.12

Table C.27

Multi-Web Sections
Unfastened - End One Flange Loading (EOF)

Yu - University of Missouri-Rolla, USA-1981 [27]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	EOF-1A	0.742	298	76.4	62.7	6.85	102	62.4	4	2.12	1.43	1.49	1.28	1.65	1.58	1.35
2	EOF-1B	0.744	298	75.8	62.1	6.83	102	61.6	4	2.14	1.42	1.51	1.29	1.66	1.58	1.36
3	EOF-2A	0.765	298	73.4	59.5	6.98	197	62.1	4	2.62	----	----	2.24	1.17	2.28	1.15
4	EOF-2B	0.752	298	75.3	61.1	7.10	200	62.7	4	2.57	----	----	----	----	2.20	1.17
5	EOF-3A	1.123	296	49.3	40.3	4.53	67.4	63.7	4	5.29	2.99	1.77	2.37	2.23	3.66	1.45
6	EOF-3B	1.135	296	48.8	39.8	4.47	66.7	63.0	4	5.35	3.02	1.77	2.40	2.23	3.71	1.44
7	EOF-4A	1.199	296	47.0	38.1	4.45	126	64.4	4	5.54	----	----	4.10	1.35	5.59	0.99
8	EOF-4B	1.196	296	46.9	38.0	4.46	126	64.5	4	5.45	----	----	4.10	1.33	5.58	0.98
9	EOF-5A	0.790	331	102	88.7	6.43	95.8	69.5	4	1.77	1.87	0.95	1.48	1.20	1.76	1.01
10	EOF-5B	0.805	331	100	87.4	6.31	94.0	70.0	4	1.82	1.94	0.94	1.53	1.19	1.83	0.99
11	EOF-6A	0.744	331	106	92.2	6.83	202	70.5	4	2.7	----	----	2.27	1.18	2.13	1.26
12	EOF-6B	0.747	331	107	93.5	6.80	202	70.0	4	2.70	----	----	2.27	1.19	2.12	1.28
13	EOF-7A	1.240	284	63.5	55.7	3.89	61.1	71.3	4	4.46	3.62	1.23	3.04	1.47	3.99	1.12
14	EOF-7B	1.217	284	65.1	57.2	3.97	62.2	72.2	4	4.46	3.52	1.27	2.90	1.54	3.85	1.16
15	EOF-8A	1.168	284	67.2	58.0	4.57	129	71.3	4	6.38	----	----	3.87	1.65	4.75	1.34
16	EOF-8B	1.219	284	63.5	54.8	4.38	124	71.3	4	6.26	----	----	4.09	1.53	5.20	1.20
17	EOF-19A	0.732	284	67.4	57.6	4.86	103	75.9	10	1.46	1.50	0.98	1.33	1.10	1.73	0.85
18	EOF-19B	0.729	284	66.2	56.4	4.88	104	75.1	10	1.35	1.49	0.91	1.32	1.02	1.72	0.78

---- Exceeds AISI-96 or S136-94 Limit

Bhakta - University of Missouri-Rolla, USA-1992 [5]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
19	FD1	0.660	396	116	103	6.62	101	71.0	6	1.51	1.60	0.95	1.16	1.30	1.38	1.09
20	FD2	0.660	396	116	103	6.62	101	71.0	6	1.48	1.60	0.93	1.16	1.28	1.38	1.07

Table C.27 (Continued)

Wu - University of Missouri-Rolla, USA-1997 [24]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
21	t26h0.75R3/32ANGLE60	0.432	775	56.2	45.3	5.47	58.8	61.0	4	0.73	0.49*	1.48	0.39**	1.88	1.24	0.59
22	t26h0.75R3/64ANGLE60	0.432	775	50.8	45.3	2.77	58.8	61.0	4	0.76	0.52*	1.44	0.57**	1.32	1.32	0.57
23	t26h1.5R3/32ANGLE60	0.432	775	101	90.0	5.47	58.8	61.0	4	0.49	0.49*	0.99	0.35**	1.39	0.94	0.52
24	t26h1.5R3/64ANGLE60	0.432	775	94.4	88.8	2.77	58.8	60.1	4	0.54	0.52*	1.05	0.52**	1.05	1.00	0.54
25	t22h0.75R5/64ANGLE60	0.737	716	33.3	27.9	2.69	34.5	60.4	4	2.08	1.30*	1.60	1.47**	1.41	3.20	0.65
26	t22h0.75R1/16ANGLE60	0.737	716	30.2	25.9	2.17	34.5	60.6	4	2.16	1.32*	1.64	1.64**	1.32	3.31	0.65
27	t22h1.5R5/64ANGLE60	0.737	716	58.8	53.4	2.69	34.5	59.8	4	1.83	1.29*	1.42	1.40**	1.31	2.68	0.68
28	t22h1.5R1/16ANGLE60	0.737	716	56.4	52.1	2.17	34.5	60.0	4	2.07	1.31*	1.58	1.55**	1.33	2.75	0.75
29	t22h2R5/64ANGLE60	0.737	716	76.1	70.7	2.69	34.5	61.0	4	1.40	1.31*	1.07	1.35**	1.03	2.44	0.57
30	t22h2R1/16ANGLE60	0.737	716	73.3	69.0	2.17	34.5	59.9	4	1.45	1.31*	1.11	1.49	0.97	2.47	0.59
31	t22h3R5/64ANGLE60	0.737	716	111	106	2.69	34.5	60.4	2	1.92	1.30*	1.48	1.25**	1.54	1.96	0.98
32	t22h3R1/16ANGLE60	0.737	716	108	103	2.17	34.5	60.5	2	2.07	1.31*	1.57	1.39**	1.48	2.02	1.02
33	t22h4.5R5/64ANGLE60	0.737	716	162	157	2.69	34.5	61.6	2	1.50	1.31*	1.15	1.11**	1.35	1.42	1.06
34	t22h4.5R1/16ANGLE60	0.737	716	160	156	2.17	34.5	61.0	2	1.64	1.32*	1.24	1.23**	1.33	1.45	1.13
35	t22h6R5/64ANGLE60	0.737	716	214	208	2.69	34.5	62.8	2	1.23	1.32*	0.93	0.97**	1.27	0.95	1.30
36	t22h6R1/16ANGLE60	0.737	716	211	207	2.17	34.5	61.0	2	1.33	1.32*	1.01	1.07**	1.25	0.96	1.38
								P_t/P_c Mean value				1.27		1.38		1.00
								S.D.				0.29		0.29		0.28
								C.O.V.				0.23		0.21		0.28

* Based on F_y = 360 MPa
** Based on F_y = 60 ksi or 413.7 MPa

Table C.28

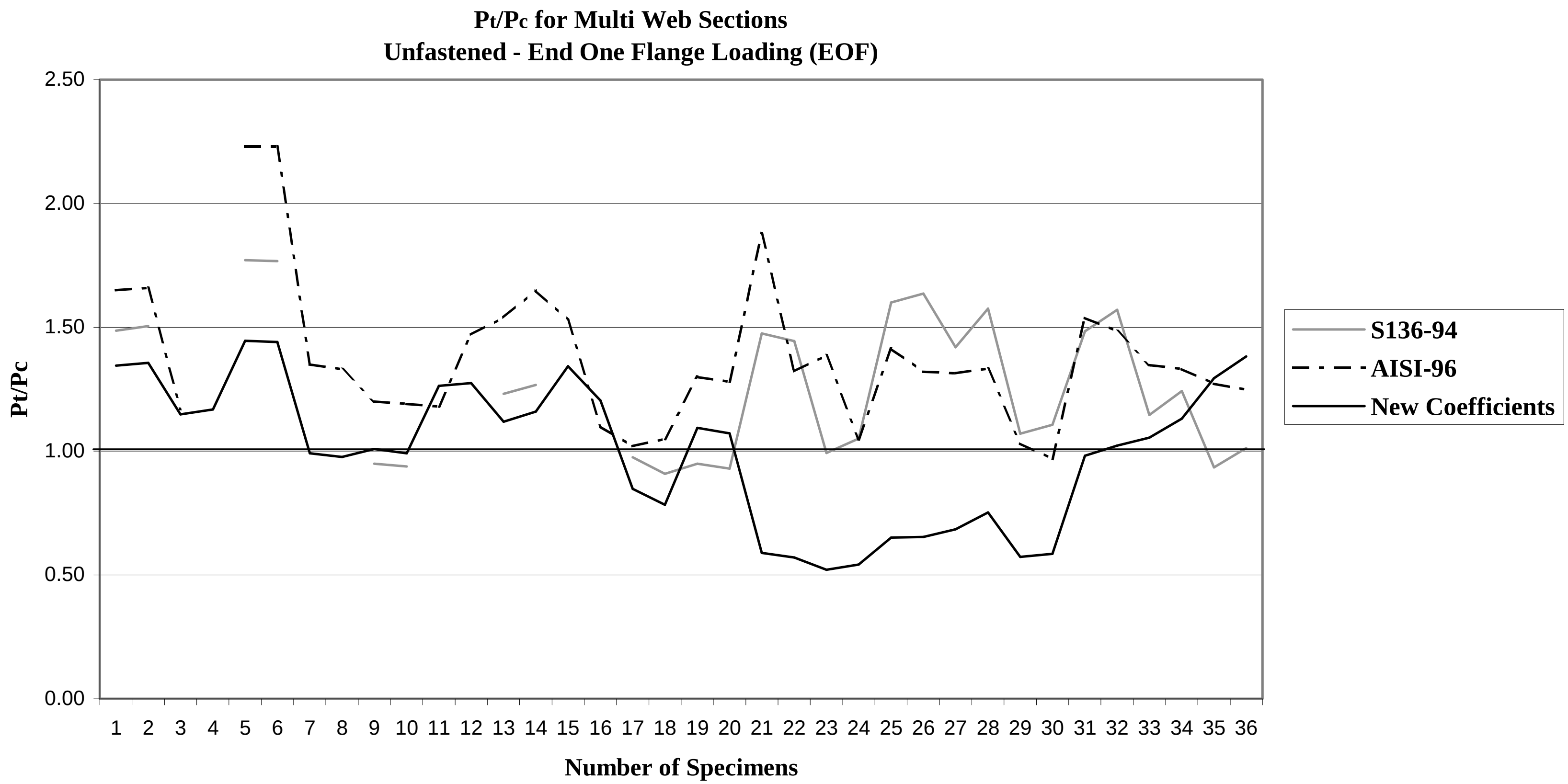
Multi-Web Sections
Fastened - End One Flange Loading (EOF)

Bhakta - University of Missouri-Rolla, USA-1992

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	Webs #	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	FD3-F	0.660	396	116	103	6.62	101	71.0	6	1.79	1.60	1.12	1.16	1.54	1.93	0.93
2	FD4-F	0.660	396	116	103	6.62	101	71.0	6	1.85	1.59	1.16	1.16	1.59	1.93	0.96

	S136-94	AISI-96	New Coeff.
P_t/P_c Mean value	1.14	1.74	0.94
S.D.	0.02	0.03	0.02
C.O.V.	0.02	0.02	0.02

Chart C.24



S136-94	AISI-96	New Coefficient
Pt/Pc mean = 1.27	Pt/Pc mean = 1.38	Pt/Pc mean = 1.00
S.D. = 0.29	S.D. = 0.29	S.D. = 0.28
C.O.V. = 0.23	C.O.V. = 0.21	C.O.V. = 0.28

Table C.29

Multi-Web Sections
Fastened - Interior One Flange Loading (IOF)

Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	Pt (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	14W-IOF	0.965	274	103	98	2.47	26.3	70.0	2	2.51	3.29	0.76	3.28	0.77	2.91	0.86
2	15W-IOF	0.610	265	166	158	3.91	41.7	70.0	2	0.92	1.05	0.88	1.14	0.81	1.18	0.78
3	16W-IOF	1.524	231	132	129	1.56	16.7	70.0	2	6.40	6.22	1.03	6.83	0.94	5.70	1.12
4	17W-IOF	0.965	274	209	204	2.47	26.3	70.0	2	2.81	----	----	----	----	2.86	0.99
5	23W-IOF	0.991	274	102	97	2.41	25.6	50.0	2	2.11	2.84	0.74	3.11	0.68	2.49	0.85
6	24W-IOF	0.635	265	161	153	3.75	40.0	50.0	2	0.98	0.94	1.04	1.12	0.87	1.04	0.94
7	25W-IOF	1.549	231	129	126	1.54	16.4	50.0	2	5.34	5.28	1.01	6.37	0.84	4.79	1.11
8	26W-IOF	1.016	274	199	194	2.35	25.0	50.0	2	2.00	2.18	0.92	2.77	0.72	2.56	0.78
9	51W-IOF	0.914	274	114	108	2.61	27.8	70.0	2	2.38	2.86	0.83	2.89	0.82	2.63	0.91
10	52W-IOF	0.610	265	173	165	3.91	41.7	70.0	2	1.15	1.02	1.13	1.13	1.02	1.18	0.98
11	54W-IOF	0.914	274	141	135	2.61	27.8	50.0	2	1.88	2.13	0.88	2.49	0.76	2.13	0.88
12	55W-IOF	0.965	274	133	128	2.47	26.3	50.0	2	1.95	2.44	0.80	2.81	0.69	2.36	0.83
13	56W-IOF	0.914	274	141	136	2.61	27.8	50.0	2	1.89	2.13	0.89	2.49	0.76	2.13	0.89
14	89W-IOF	0.610	265	175	168	3.91	41.7	70.0	2	1.11	1.02	1.10	1.12	0.99	1.18	0.94
15	91W-IOF	0.965	274	112	107	2.47	26.3	70.0	2	2.56	3.20	0.80	3.24	0.79	2.90	0.88
16	101W-IOF	0.610	265	215	207	3.91	41.7	50.0	2	0.84	----	----	----	----	0.96	0.87
17	103W-IOF	0.965	274	137	132	2.47	26.3	50.0	2	2.34	2.40	0.97	2.79	0.84	2.36	0.99
18	139W-IOF	0.508	265	198	189	4.50	50.0	90.0	4	1.07	0.70	1.52	0.85	1.26	0.90	1.19
19	30WR-IOF	0.627	318	168	152	7.59	81.0	70.0	2	1.47	1.32	1.11	----	----	1.64	0.90
20	33WR-IOF	0.848	284	121	110	5.61	59.9	70.0	2	2.25	2.52	0.89	2.42	0.93	2.60	0.87
21	39WR-IOF	0.627	318	168	148	10.10	81.0	70.0	2	1.58	----	----	----	----	1.54	1.03
22	42WR-IOF	1.003	299	104	91.1	6.33	50.6	70.0	2	3.21	3.75	0.86	3.25	0.99	3.60	0.89
23	48WR-IOF	0.549	278	192	166	13.0	92.6	70.0	2	1.18	----	----	----	----	1.01	1.17
24	51WR-IOF	1.003	299	106	88.2	8.71	50.6	70.0	2	3.11	3.50	0.89	----	----	3.39	0.92

---- Exceeds AISI-96 or S136-94 Limit

Table C.29 (Continued)

Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	Pt (kN)	S136-94 Pc (kN)	S136-94 Pt/Pc (ratio)	AISI-96 Pc (kN)	AISI-96 Pt/Pc (ratio)	New Coeff. Pc (kN)	New Coeff. Pt/Pc (ratio)
25	57WR-IOF	0.627	318	206	191	7.59	81.0	50.0	2	1.46	0.95	1.54	----	----	1.33	1.10
26	60WR-IOF	0.848	284	147	130	8.42	59.9	50.0	2	2.11	1.75	1.21	----	----	1.96	1.08
27	66WR-IOF	0.627	318	212	192	10.1	81.0	50.0	2	1.33	----	----	----	----	1.25	1.07
28	69WR-IOF	1.003	299	126	113	6.33	50.6	50.0	2	3.08	2.84	1.08	2.82	1.09	2.92	1.05
29	75WR-IOF	0.549	278	226	200	13.0	92.6	50.0	2	1.00	----	----	----	----	0.82	1.23
30	78WR-IOF	1.003	299	133	114	9.49	50.6	50.0	2	2.98	2.56	1.17	----	----	2.70	1.11
31	81WR-IOF	1.539	302	84.7	72.3	6.19	33.0	50.0	2	6.61	7.31	0.90	6.56	1.01	6.28	1.05
32	137WR-IOF	0.627	318	168	152	7.59	162	70.0	2	1.91	1.53	1.25	----	----	2.05	0.94
33	140WR-IOF	0.627	318	168	148	10.1	162	70.0	2	1.91	----	----	----	----	1.93	0.99
34	144WR-IOF	1.003	299	106	88.2	8.71	101	70.0	2	3.78	3.96	0.96	----	----	4.16	0.91

Bhakta - University of Missouri-Rolla, USA-1992 [5]

No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	Pt (kN)	S136-94 Pc (kN)	S136-94 Pt/Pc (ratio)	AISI-96 Pc (kN)	AISI-96 Pt/Pc (ratio)	New Coeff. Pc (kN)	New Coeff. Pt/Pc (ratio)
35	FD7-F	0.660	396	116	103	6.62	202	71.0	6	3.51	----	----	3.54	0.99	3.19	1.10
36	FD8-F	0.660	396	116	103	6.62	202	71.0	6	3.47	----	----	3.54	0.98	3.18	1.09

Multi-Web Sections
Unfastened - Interior One Flange Loading (IOF)

Bhakta - University of Missouri-Rolla, USA-1992 [5]

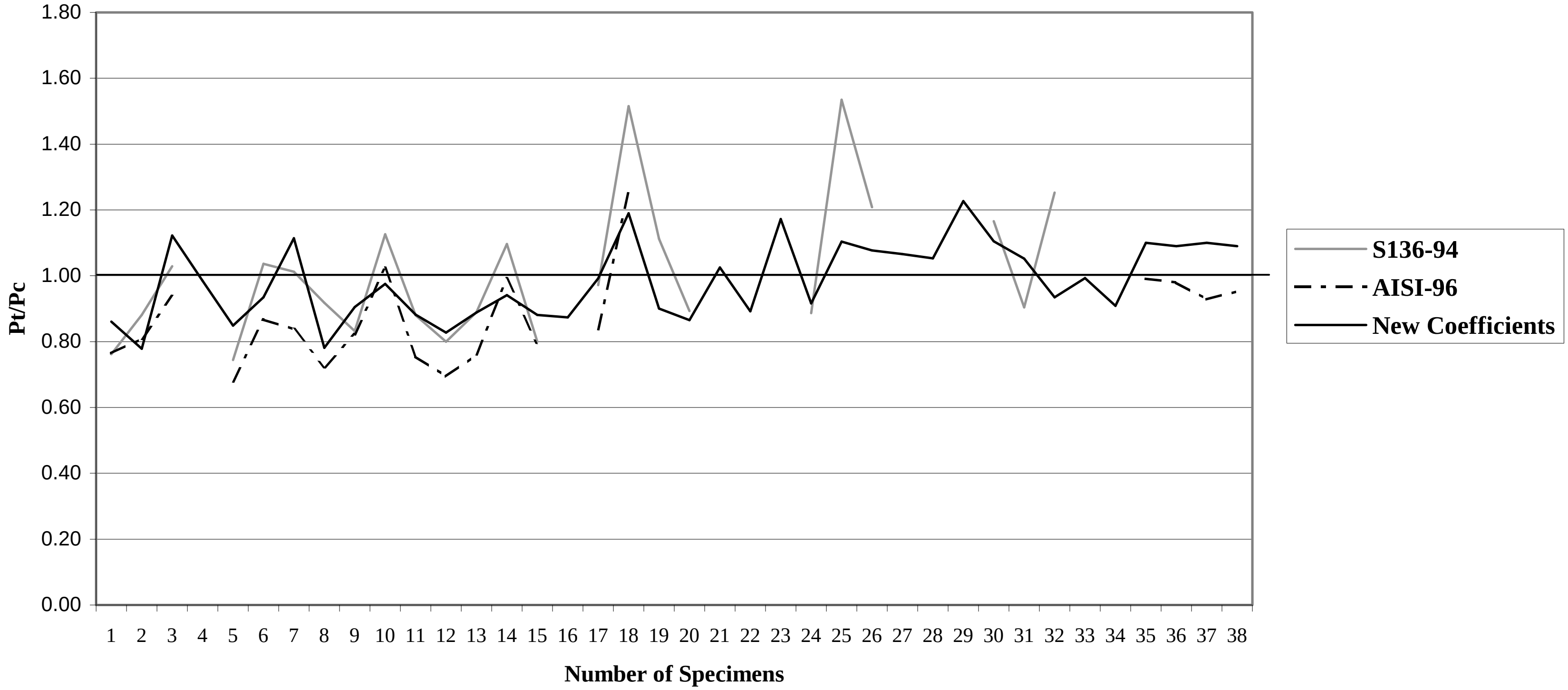
No.	Specimen	t (mm)	Fy (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	Pt (kN)	S136-94 Pc (kN)	S136-94 Pt/Pc (ratio)	AISI-96 Pc (kN)	AISI-96 Pt/Pc (ratio)	New Coeff. Pc (kN)	New Coeff. Pt/Pc (ratio)
37	FD5	0.660	396	116	103	6.62	202	71.0	6	3.29	----	----	3.55	0.93	2.99	1.10
38	FD6	0.660	396	116	103	6.62	202	71.0	6	3.37	----	----	3.54	0.95	3.09	1.09

---- Exceeds AISI-96 or S136-94 Limit

	S136-94 Pt/Pc	AISI-96 Pt/Pc	New Coeff. Pt/Pc
Pt/Pc Mean value	1.01	0.89	1.02
S.D.	0.20	0.14	0.13
C.O.V.	0.20	0.16	0.12

Chart C.25

Pt/Pc for Multi Web Sections
Fastened and Unfastened - Interior One Flange Loading (IOF)



S136-94			**AISI-96**			**New Coefficient**		
Pt/Pc mean	=	1.01	Pt/Pc mean	=	0.89	Pt/Pc mean	=	1.02
S.D.	=	0.20	S.D.	=	0.14	S.D.	=	0.13
C.O.V.	=	0.20	C.O.V.	=	0.16	C.O.V.	=	0.12

Table C.30

Multi-Web Sections
Fastened - End Two Flange Loading (ETF)

Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	8W-ETF	1.524	231	32.2	29.0	1.56	16.7	70.0	2	4.56	4.87	0.94	3.47	1.31	4.75	0.96
2	9W-ETF	0.965	274	50.3	45.3	2.47	26.3	70.0	2	1.87	2.21	0.85	1.40	1.33	2.20	0.85
3	10W-ETF	0.610	265	82.1	74.3	3.91	41.7	70.0	2	0.80	0.76	1.05	0.41	1.96	0.79	1.01
4	11W-ETF	1.524	231	64.8	61.7	1.56	16.7	70.0	2	4.62	4.17	1.11	3.19	1.45	4.15	1.11
5	12W-ETF	0.965	274	103	98.5	2.47	26.3	69.5	2	1.59	1.76	0.90	1.20	1.32	1.81	0.88
6	13W-ETF	0.610	265	166	158	3.91	41.7	70.0	2	0.55	0.55	1.01	0.31	1.77	0.60	0.92
7	14W-ETF	1.524	231	132	129	1.56	16.7	69.5	2	3.94	3.19	1.24	2.60	1.52	3.30	1.19
8	15W-ETF	0.965	274	209	204	2.47	26.3	70.0	2	1.22	----	----	----	----	1.29	0.95
9	16W-ETF	0.660	265	307	300	3.61	38.5	71.0	2	0.40	----	----	----	----	0.44	0.91
10	17W-ETF	1.524	231	32.2	29.0	1.56	16.7	50.5	2	4.85	4.00	1.21	3.13	1.55	3.90	1.24
11	18W-ETF	0.965	274	50.5	45.6	2.47	26.3	50.5	2	1.56	1.81	0.86	1.26	1.24	1.81	0.87
12	19W-ETF	0.610	265	82.9	75.1	3.91	41.7	50.5	2	0.87	0.62	1.39	0.37	2.36	0.65	1.34
13	20W-ETF	1.524	231	66.2	63.0	1.56	16.7	50.0	2	3.84	3.38	1.14	2.86	1.35	3.37	1.14
14	21W-ETF	0.991	274	102	96.7	2.41	25.6	50.0	2	1.24	1.53	0.81	1.16	1.07	1.56	0.79
15	22W-ETF	0.635	265	161	153	3.75	40.0	50.5	2	0.40	0.50	0.80	0.32	1.25	0.54	0.74
16	23W-ETF	1.549	231	129	126	1.54	16.4	50.5	2	1.92	2.74	0.70	2.45	0.78	2.82	0.68
17	24W-ETF	1.016	274	199	194	2.35	25.0	51.0	2	0.90	1.11	0.81	0.87	1.03	1.22	0.74
18	25W-ETF	0.610	265	332	324	3.91	41.7	49.5	2	0.29	----	----	----	----	0.27	1.06
19	34W-ETF	0.610	265	164	156	3.91	41.7	90.0	4	0.56	0.59	0.94	0.36	1.56	0.64	0.86
20	35W-ETF	0.965	274	103	98.0	2.47	26.3	90.0	4	1.48	1.89	0.78	1.37	1.08	1.94	0.76
21	36W-ETF	1.524	231	65.2	62.0	1.56	16.7	90.0	4	4.94	4.43	1.11	3.61	1.37	4.41	1.12
22	7WR-ETF	1.539	302	68.8	57.5	5.68	33.0	70.0	2	4.75	4.95	0.96	2.49	1.91	5.43	0.88
23	8WR-ETF	1.539	302	67.0	52.5	7.23	33.0	70.0	2	4.85	4.57	1.06	----	----	5.24	0.93
24	9WR-ETF	0.627	318	206	191	7.59	81.0	50.0	2	0.51	0.48	1.07	----	----	0.58	0.88

---- Exceeds AISI-96 or S136-94 Limit

Table C.30 (Continued)

Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
25	10WR-ETF	0.627	318	212	192	10.1	81.0	50.0	2	0.47	----	----	----	----	0.54	0.87
26	11WR-ETF	1.003	299	126	113	6.33	50.6	50.0	2	1.51	1.46	1.03	0.91	1.66	1.66	0.91
27	12WR-ETF	1.539	302	84.7	74.3	5.16	33.0	50.0	2	4.11	3.89	1.06	2.14	1.92	4.24	0.97
28	13WR-ETF	1.003	299	133	114	9.49	50.6	50.0	2	1.42	1.19	1.20	----	----	1.50	0.95
29	14WR-ETF	1.539	302	84.7	72.3	6.19	33.0	50.0	2	4.22	3.66	1.15	2.15	1.96	4.12	1.03
30	1E-ETF	1.575	293	46.6	41.6	2.52	32.3	85.0	8	8.92	7.12	1.25	4.50	1.99	7.02	1.27
31	2E-ETF	1.575	293	46.6	41.6	2.52	48.4	85.0	8	8.15	7.97	1.02	5.04	1.62	7.72	1.06
32	1C-ETF	0.914	286	83.3	76.4	3.47	41.7	81.5	6	2.13	1.99	1.07	1.16	1.84	2.05	1.04
33	2C-ETF	0.914	286	83.3	76.4	3.47	55.6	81.5	6	2.19	2.17	1.01	1.27	1.73	2.20	1.00
34	3C-ETF	0.914	286	83.3	76.4	3.47	83.3	81.5	6	2.77	2.46	1.13	1.50	1.85	2.45	1.13
35	4C-ETF	0.914	286	83.3	76.4	3.47	111	81.5	6	3.33	2.71	1.23	1.72	1.93	2.66	1.25
36	5C-ETF	0.813	282	93.8	85.9	3.91	46.9	81.5	6	1.31	1.50	0.88	0.82	1.61	1.56	0.84
37	6C-ETF	0.813	282	93.8	85.9	3.91	62.5	81.5	6	1.61	1.63	0.99	0.91	1.78	1.67	0.96
38	7C-ETF	0.813	282	93.8	85.9	3.91	93.8	81.5	6	2.03	1.86	1.09	1.08	1.88	1.87	1.08
39	8C-ETF	0.813	282	93.8	85.9	3.91	125	81.5	6	1.99	2.04	0.97	1.25	1.59	2.04	0.98
40	1R-ETF	1.245	333	33.5	23.3	5.10	30.6	77.5	8	4.99	4.47	1.12	1.95	2.55	4.74	1.05
41	2R-ETF	1.245	333	33.5	23.3	5.10	40.8	77.5	8	4.99	4.83	1.03	2.11	2.37	5.06	0.99
42	3R-ETF	1.245	333	33.5	23.3	5.10	61.2	77.5	8	5.79	----	----	2.41	2.40	5.59	1.04
43	4R-ETF	0.635	304	69.2	49.2	10.0	60.0	77.5	8	1.26	0.82	1.54	----	----	1.00	1.26
44	5R-ETF	0.635	304	69.2	49.2	10.0	80.0	77.5	8	1.37	0.90	1.53	----	----	1.08	1.26
45	6R-ETF	0.635	304	69.2	49.2	10.0	120	77.5	8	1.47	----	----	----	----	1.22	1.20
46	7R-ETF	1.245	338	31	20.6	5.10	30.6	66.5	10	4.91	4.32	1.14	1.86	2.65	4.57	1.08
47	8R-ETF	1.245	338	31	20.6	5.10	40.8	66.5	10	5.15	4.67	1.10	2.00	2.57	4.88	1.06
48	9R-ETF	1.245	338	30.8	20.6	5.10	61.2	66.5	10	5.59	----	----	2.29	2.44	5.40	1.04
49	10R-ETF	0.660	335	58.1	38.8	9.62	57.7	66.5	10	1.04	0.97	1.07	----	----	1.17	0.89
50	11R-ETF	0.660	335	58.1	38.8	9.62	76.9	66.5	10	1.18	1.07	1.11	----	----	1.27	0.93

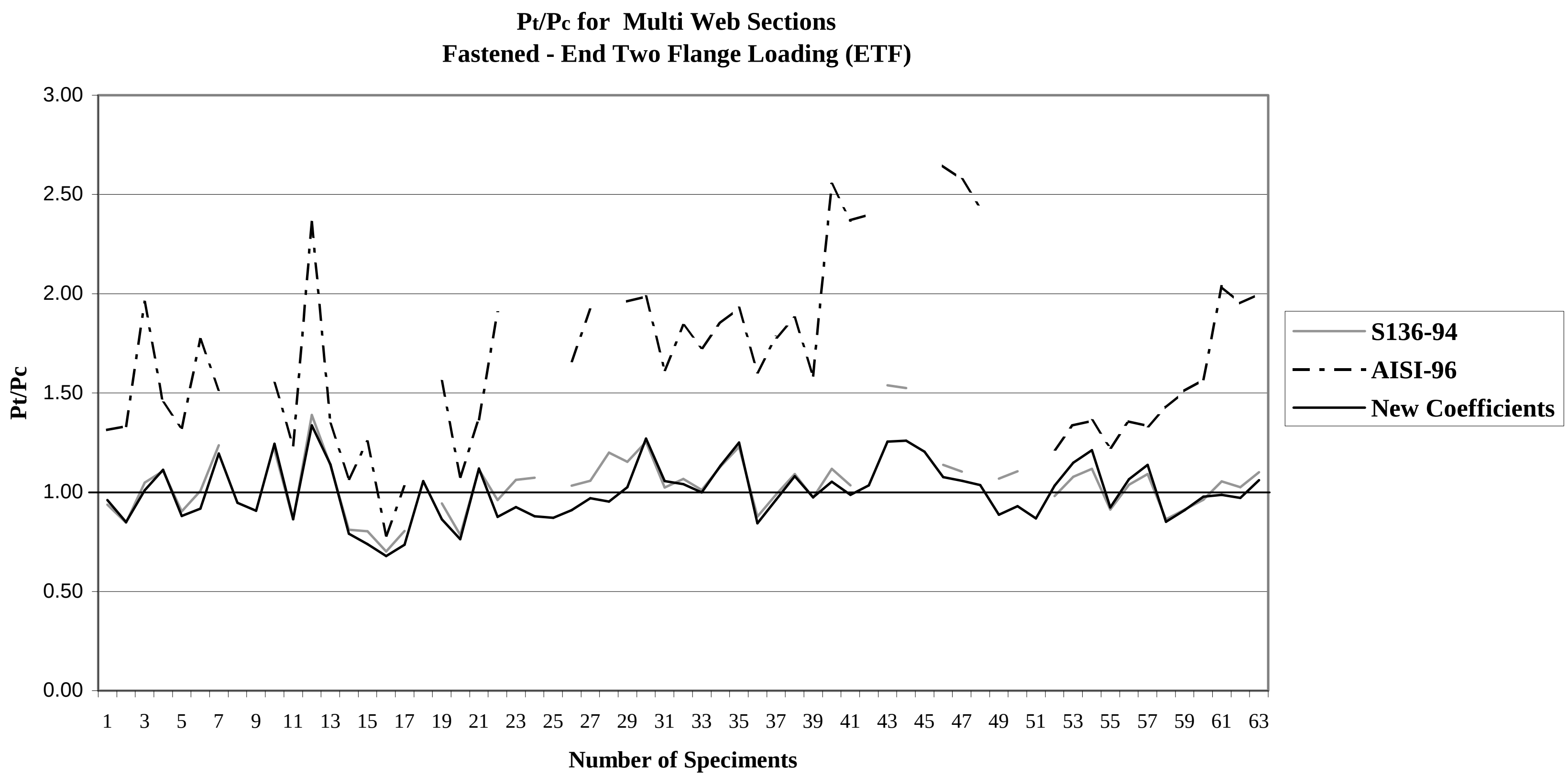
---- Exceeds AISI-96 or S136-94 Limit

Table C.30 (Continued)

Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
51	12R-ETF	0.660	335	58.1	38.8	9.62	115	66.5	10	1.24	----	----	----	----	1.43	0.87
52	13R-ETF	1.194	284	49.8	47.1	1.33	31.9	45.0	12	2.98	3.04	0.98	2.45	1.22	2.89	1.03
53	14R-ETF	1.194	284	49.8	47.1	1.33	42.6	45.0	12	3.54	3.29	1.08	2.65	1.34	3.09	1.15
54	15R-ETF	1.194	284	49.8	47.1	1.33	63.8	45.0	12	4.14	3.71	1.12	3.05	1.36	3.42	1.21
55	16R-ETF	0.635	336	96.0	91.0	2.50	60.0	45.0	12	0.83	0.91	0.91	0.68	1.23	0.90	0.92
56	17R-ETF	0.635	336	96.0	91.0	2.50	80.0	45.0	12	1.04	1.00	1.04	0.76	1.36	0.97	1.07
57	18R-ETF	0.635	336	96.0	91.0	2.50	120	45.0	12	1.25	1.14	1.09	0.93	1.33	1.09	1.14
58	25R-ETF	1.270	291	58.0	51.7	3.13	30.0	87.5	6	3.57	4.13	0.86	2.50	1.43	4.19	0.85
59	26R-ETF	1.270	291	58.0	51.7	3.13	40.0	87.5	6	4.07	4.46	0.91	2.69	1.51	4.47	0.91
60	27R-ETF	1.270	291	58.0	51.7	3.13	60.0	87.5	6	4.83	5.02	0.96	3.08	1.57	4.94	0.98
61	28R-ETF	0.813	307	91.9	82.1	4.88	46.9	87.5	6	1.65	1.56	1.05	0.81	2.04	1.67	0.99
62	29R-ETF	0.813	307	91.9	82.1	4.88	62.5	87.5	6	1.75	1.70	1.03	0.89	1.95	1.80	0.97
63	30R-ETF	0.813	307	91.9	82.1	4.88	93.8	87.5	6	2.13	1.94	1.10	1.07	2.00	2.01	1.06
	---- Exceeds AISI-96 or S136-94 Limit							**P_t/P_c Mean value**				1.05		1.68		1.00
								S.D.				0.16		0.44		0.14
								C.O.V.				0.16		0.26		0.14

Chart C.26



S136-94		AISI-96		New Coefficient	
Pt/Pc mean	= 1.05	Pt/Pc mean	= 1.68	Pt/Pc mean	= 1.00
S.D.	= 0.16	S.D.	= 0.44	S.D.	= 0.14
C.O.V.	= 0.16	C.O.V.	= 0.26	C.O.V.	= 0.14

Table C.31

Multi-Web Sections
Fastened - Interior Two Flange Loading (ITF)

Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	10W-ITF	0.610	265	87.9	80.1	3.91	41.7	70.0	2	1.56	1.30	1.20	1.30	1.20	1.40	1.11
2	11W-ITF	0.965	274	55.0	50.1	2.47	26.3	70.0	2	3.07	3.34	0.92	4.05	0.76	3.54	0.87
3	12W-ITF	1.524	231	35.7	32.5	1.56	16.7	70.0	2	6.14	6.84	0.90	9.84	0.62	7.15	0.86
4	13W-ITF	0.610	265	175	168	3.91	41.7	70.0	2	1.16	1.17	0.99	0.87	1.34	1.26	0.92
5	14W-ITF	0.965	274	112	107	2.47	26.3	70.0	2	3.12	3.08	1.01	3.26	0.96	3.27	0.95
6	15W-ITF	1.524	231	70.3	67.2	1.56	16.7	70.0	2	6.81	6.45	1.06	8.73	0.78	6.74	1.01
7	16W-ITF	0.610	265	106	98.4	3.91	41.7	50.0	2	1.38	1.03	1.34	1.09	1.27	1.12	1.24
8	17W-ITF	0.965	274	69.2	64.3	2.47	26.3	50.0	2	3.16	2.66	1.19	3.46	0.91	2.82	1.12
9	18W-ITF	1.524	231	43.7	40.5	1.56	16.7	50.0	2	6.05	5.49	1.10	8.62	0.70	5.74	1.06
10	19W-ITF	0.610	265	215	207	3.91	41.7	50.0	2	0.89	----	----	----	----	0.99	0.90
11	20W-ITF	0.965	274	137	132	2.47	26.3	50.0	2	2.45	2.44	1.00	2.62	0.94	2.59	0.95
12	21W-ITF	1.524	231	88.5	85.4	1.56	16.7	50.0	2	5.74	5.13	1.12	7.33	0.78	5.36	1.07
13	31W-ITF	0.610	265	164	156	3.91	41.7	90.0	4	1.25	1.26	0.99	1.05	1.19	1.36	0.91
14	32W-ITF	0.965	274	103	98.0	2.47	26.3	90.0	4	2.76	3.32	0.83	3.84	0.72	3.52	0.78
15	33W-ITF	1.524	231	65.2	62.0	1.56	16.7	90.0	4	9.21	6.92	1.33	10.1	0.91	7.23	1.27
16	10WR-ITF	0.627	318	168	152	7.59	81.0	70.0	2	1.78	1.57	1.13	----	----	1.78	1.00
17	14WR-ITF	1.003	299	104	91.1	6.33	50.6	70.0	2	4.05	3.70	1.10	3.07	1.32	4.13	0.98
18	15WR-ITF	1.539	302	68.5	60.2	4.13	33.0	70.0	2	8.99	8.96	1.00	9.54	0.94	9.72	0.93
19	17WR-ITF	1.003	299	106	88.2	8.71	50.6	70.0	2	3.43	3.36	1.02	----	----	3.87	0.89
20	18WR-ITF	1.539	302	67.0	52.5	7.23	33.0	70.0	2	8.55	7.90	1.08	----	----	8.92	0.96
21	3U-ITF	0.813	291	48.8	39.0	4.88	46.9	70.0	12	2.80	2.67	1.05	2.69	1.04	2.92	0.96
22	4U-ITF	0.813	291	48.8	39.0	4.88	62.5	70.0	12	3.38	2.91	1.16	2.74	1.24	3.19	1.06
23	5U-ITF	0.813	291	48.8	39.0	4.88	46.9	70.0	2	3.07	2.67	1.15	2.69	1.14	2.92	1.05
24	6U-ITF	0.813	291	48.8	39.0	4.88	62.5	70.0	2	3.69	2.91	1.27	2.74	1.35	3.19	1.16

---- Exceeds AISI-96 or S136-94 Limit

Table C.31 (Continued)

Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
25	9U-ITF	0.813	291	48.8	39.0	4.88	46.9	70.0	4	3.12	2.66	1.17	2.69	1.16	2.92	1.07
26	10U-ITF	0.813	291	48.8	39.0	4.88	62.5	70.0	4	3.38	2.91	1.16	2.74	1.24	3.19	1.06
27	1C-ITF	0.914	286	83.3	76.4	3.47	41.7	81.5	6	3.96	3.40	1.17	3.48	1.14	3.65	1.08
28	2C-ITF	0.914	286	83.3	76.4	3.47	55.6	81.5	6	4.23	3.70	1.14	3.54	1.20	3.98	1.06
29	3C-ITF	0.914	286	83.3	76.4	3.47	83.3	81.5	6	4.67	4.21	1.11	3.66	1.28	4.52	1.03
30	4C-ITF	0.914	286	83.3	76.4	3.47	111	81.5	6	5.56	4.63	1.20	3.77	1.47	4.98	1.12
31	5C-ITF	0.813	282	93.8	85.9	3.91	46.9	81.5	6	2.94	2.64	1.11	2.56	1.15	2.86	1.03
32	6C-ITF	0.813	282	93.8	85.9	3.91	62.5	81.5	6	2.94	2.89	1.02	2.61	1.13	3.12	0.94
33	7C-ITF	0.813	282	93.8	85.9	3.91	93.8	81.5	6	3.56	3.29	1.08	2.70	1.32	3.56	1.00
34	8C-ITF	0.813	282	93.8	85.9	3.91	125	81.5	6	3.78	3.63	1.04	2.80	1.35	3.93	0.96
35	1R-ITF	1.245	333	33.5	23.3	5.10	30.6	77.5	8	7.61	6.74	1.13	7.30	1.04	7.40	1.03
36	2R-ITF	1.245	333	33.5	23.3	5.10	40.8	77.5	8	8.19	7.29	1.12	7.40	1.11	8.01	1.02
37	3R-ITF	1.245	333	33.5	23.3	5.10	61.2	77.5	8	8.90	----	----	7.59	1.17	9.05	0.98
38	4R-ITF	0.635	304	69.2	49.2	10.0	60.0	77.5	8	2.05	1.51	1.36	----	----	1.76	1.16
39	5R-ITF	0.635	304	69.2	49.2	10.0	80.0	77.5	8	2.23	1.65	1.35	----	----	1.93	1.15
40	6R-ITF	0.635	304	69.2	49.2	10.0	120	77.5	8	2.23	----	----	----	----	2.22	1.00
41	7R-ITF	1.245	338	30.8	20.6	5.10	30.6	66.5	10	6.32	6.44	0.98	6.95	0.91	7.09	0.89
42	8R-ITF	1.245	338	30.8	20.6	5.10	40.8	66.5	10	7.79	6.98	1.12	7.04	1.11	7.67	1.02
43	9R-ITF	1.245	338	30.8	20.6	5.10	61.2	66.5	10	8.77	----	----	7.22	1.22	8.66	1.01
44	10R-ITF	0.660	335	58.1	38.8	9.62	57.7	66.5	10	2.72	1.72	1.57	----	----	2.01	1.35
45	11R-ITF	0.660	335	58.1	38.8	9.62	76.9	66.5	10	2.67	1.89	1.41	----	----	2.20	1.21
46	13R-ITF	1.194	284	49.8	47.1	1.33	31.9	45.0	12	4.67	4.53	1.03	6.11	0.77	4.72	0.99
47	14R-ITF	1.194	284	49.8	47.1	1.33	42.6	45.0	12	5.21	4.92	1.06	6.19	0.84	5.11	1.02
48	15R-ITF	1.194	284	49.8	47.1	1.33	63.8	45.0	12	6.01	5.55	1.08	6.35	0.95	5.78	1.04
49	16R-ITF	0.635	336	96.0	91.0	2.50	60.0	45.0	12	1.56	1.59	0.98	1.58	0.99	1.68	0.93
50	17R-ITF	0.635	336	96.0	91.0	2.50	80.0	45.0	12	1.69	1.74	0.97	1.62	1.04	1.84	0.92

---- Exceeds AISI-96 or S136-94 Limit

Table C.31 (Continued)

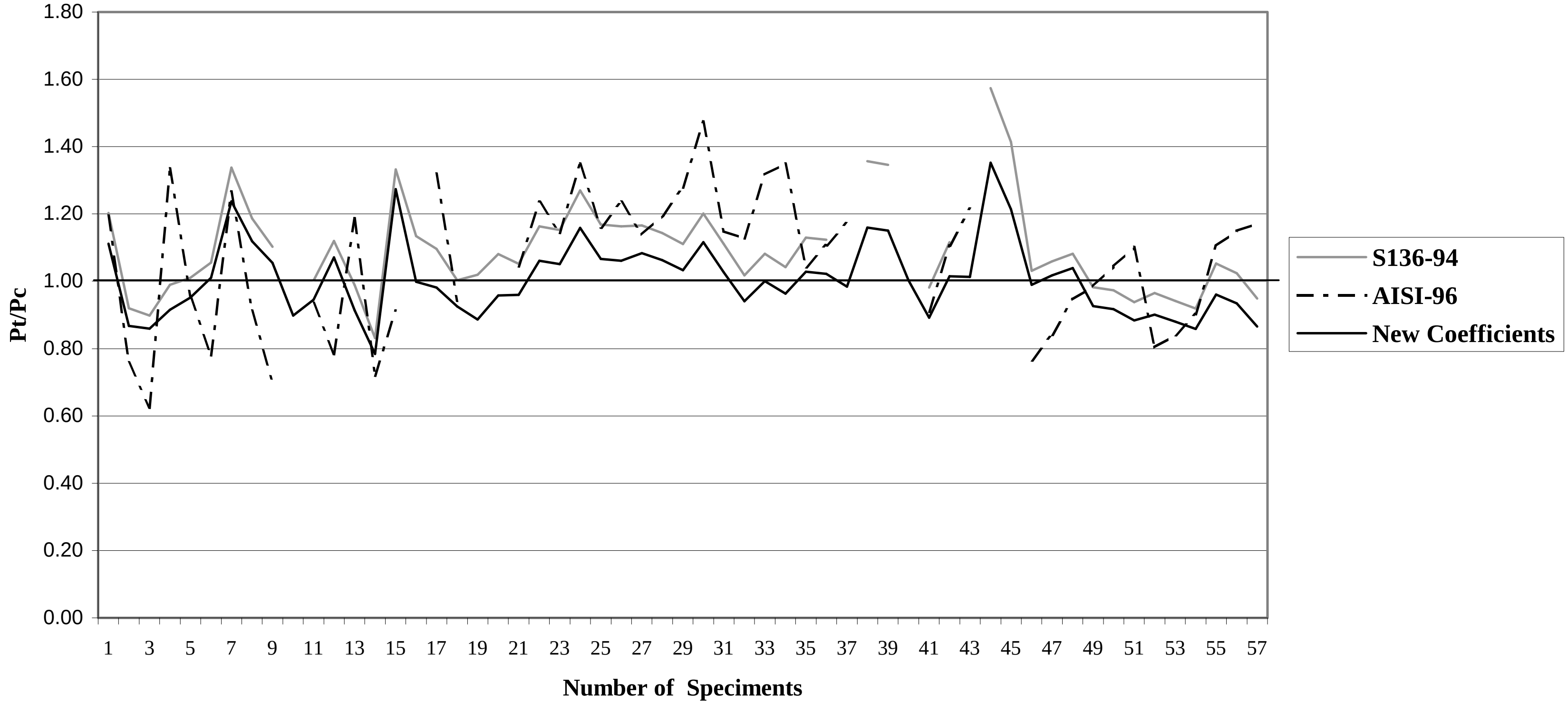
Wing - University of Waterloo, Canada-1981 [21]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
51	18R-ITF	0.635	336	96.0	91.0	2.50	120	45.0	12	1.87	1.99	0.94	1.70	1.10	2.11	0.88
52	25R-ITF	1.270	291	58.0	51.7	3.13	30.0	87.5	6	6.28	6.50	0.97	7.80	0.80	6.96	0.90
53	26R-ITF	1.270	291	58.0	51.7	3.13	40.0	87.5	6	6.63	7.04	0.94	7.90	0.84	7.54	0.88
54	27R-ITF	1.270	291	58.0	51.7	3.13	60.0	87.5	6	7.30	7.94	0.92	8.09	0.90	8.51	0.86
55	28R-ITF	0.813	307	91.9	82.1	4.88	46.9	87.5	6	2.94	2.79	1.05	2.66	1.11	3.06	0.96
56	29R-ITF	0.813	307	91.9	82.1	4.88	62.5	87.5	6	3.12	3.04	1.02	2.71	1.15	3.34	0.93
57	30R-ITF	0.813	307	91.9	82.1	4.88	93.8	87.5	6	3.29	3.47	0.95	2.81	1.17	3.80	0.87

	S136-94	AISI-96	New Coeff.
P_t/P_c Mean value	1.10	1.06	1.01
S.D.	0.14	0.20	0.11
C.O.V.	0.13	0.19	0.11

Chart C.27

Pt/Pc for Multi Web Sections
Fastened - Interior Two Flange Loading (ITF)



S136-94	**AISI-96**	**New Coefficient**
Pt/Pc mean = 1.10	Pt/Pc mean = 1.06	Pt/Pc mean = 1.01
S.D. = 0.14	S.D. = 0.20	S.D. = 0.11
C.O.V. = 0.13	C.O.V. = 0.19	C.O.V. = 0.11

Table C.32

Multi-Web Sections
Unfastened - End Two Flange Loading (ETF)

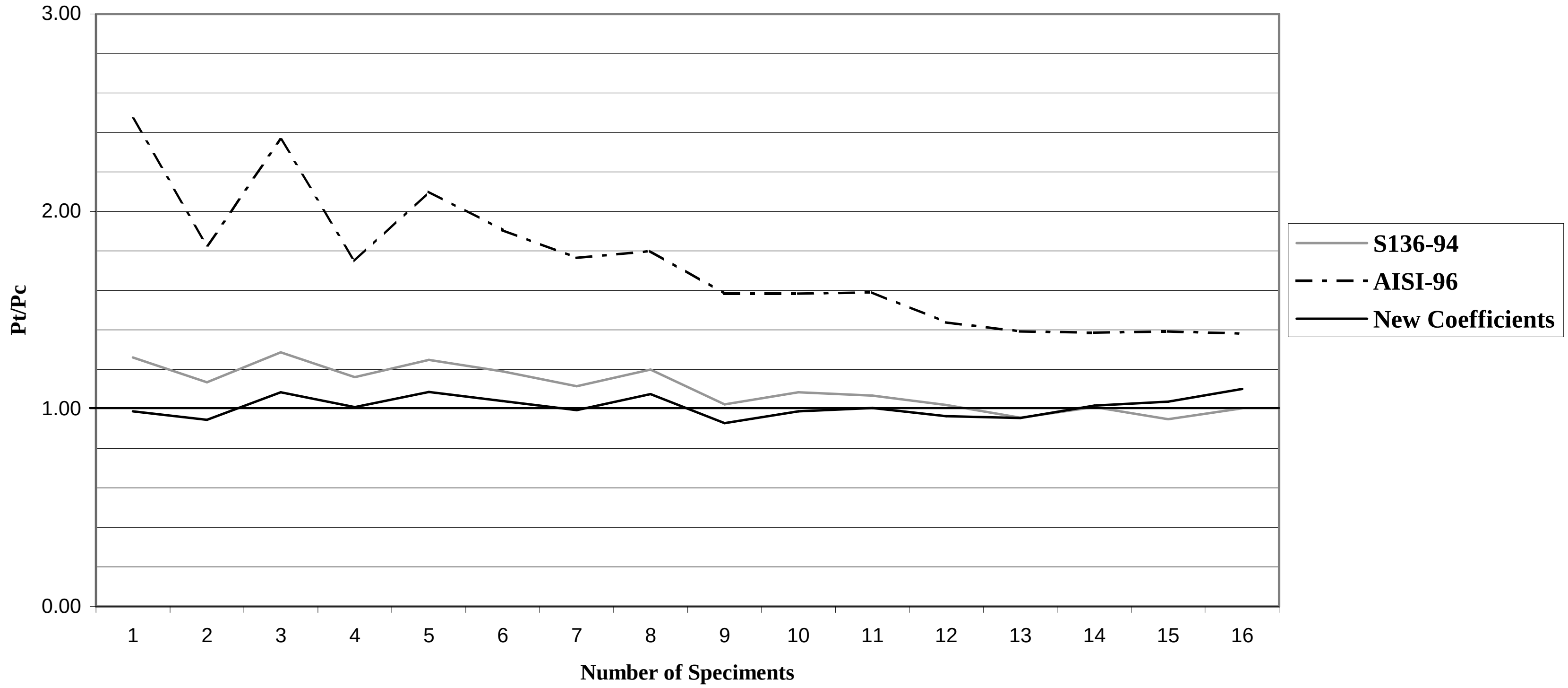
Wu - University of Missouri-Rolla, USA-1997 [24]

No.	Specimen	t (mm)	F_y (MPa)	H' h'/t (ratio)	H h/t (ratio)	R r/t (ratio)	N n/t (ratio)	q	No. of Webs	P_t (kN)	S136-94 P_c (kN)	S136-94 P_t/P_c (ratio)	AISI-96 P_c (kN)	AISI-96 P_t/P_c (ratio)	New Coeff. P_c (kN)	New Coeff. P_t/P_c (ratio)
1	t26h0.75R3/32ANGLE60	0.432	775	56.2	45.3	5.47	58.8	61.0	4	0.67	0.53*	1.26	0.27**	2.47	0.68	0.99
2	t26h0.75R3/64ANGLE60	0.432	775	50.8	45.3	2.77	58.8	61.0	4	0.75	0.66*	1.14	0.41**	1.83	0.79	0.95
3	t26h1.5R3/32ANGLE60	0.432	775	101	90.0	5.47	58.8	61.0	4	0.58	0.45*	1.29	0.25**	2.36	0.54	1.09
4	t26h1.5R3/64ANGLE60	0.432	775	94.4	88.8	2.77	58.8	60.1	4	0.63	0.54*	1.16	0.36**	1.75	0.63	1.01
5	t22h0.75R5/64ANGLE60	0.737	716	33.3	27.9	2.69	34.5	60.4	4	2.25	1.80*	1.25	1.07**	2.10	2.07	1.09
6	t22h0.75R1/16ANGLE60	0.737	716	30.2	25.9	2.17	34.5	60.6	4	2.27	1.90*	1.19	1.19**	1.91	2.18	1.04
7	t22h1.5R5/64ANGLE60	0.737	716	58.8	53.4	2.69	34.5	59.8	4	1.76	1.58*	1.12	1.00**	1.77	1.77	0.99
8	t22h1.5R1/16ANGLE60	0.737	716	56.4	52.1	2.17	34.5	60.0	4	1.99	1.66*	1.20	1.11**	1.80	1.85	1.08
9	t22h2R5/64ANGLE60	0.737	716	76.1	70.7	2.69	34.5	61.0	4	1.52	1.49*	1.02	0.96**	1.59	1.64	0.93
10	t22h2R1/16ANGLE60	0.737	716	73.3	69.0	2.17	34.5	59.9	4	1.68	1.54*	1.09	1.06**	1.59	1.69	0.99
11	t22h3R5/64ANGLE60	0.737	716	111	106	2.69	34.5	60.4	2	1.37	1.28*	1.07	0.86**	1.59	1.36	1.01
12	t22h3R1/16ANGLE60	0.737	716	108	103	2.17	34.5	60.5	2	1.38	1.35*	1.02	0.96**	1.44	1.43	0.96
13	t22h4.5R5/64ANGLE60	0.737	716	162	157	2.69	34.5	61.6	2	1.02	1.06*	0.96	0.73**	1.39	1.06	0.96
14	t22h4.5R1/16ANGLE60	0.737	716	160	156	2.17	34.5	61.0	2	1.12	1.11*	1.01	0.81**	1.39	1.10	1.02
15	t22h6R5/64ANGLE60	0.737	716	214	208	2.69	34.5	62.8	2	0.83	0.88*	0.95	0.60**	1.39	0.80	1.04
16	t22h6R1/16ANGLE60	0.737	716	211	207	2.17	34.5	61.0	2	0.91	0.90*	1.00	0.66**	1.38	0.82	1.10
									P_t/P_c Mean value			1.11		1.73		1.01
									S.D.			0.11		0.34		0.05
									C.O.V.			0.10		0.20		0.05

* Based on F_y = 360 MPa
** Based on F_y = 60 ksi or 413.7 MPa

Chart C.28

Pt/Pc for Multi Web Sections
Unfastened - End Two Flange Loading (ETF)



S136-94			**AISI-96**			**New Coefficient**		
Pt/Pc mean	=	1.11	Pt/Pc mean	=	1.73	Pt/Pc mean	=	1.01
S.D.	=	0.11	S.D.	=	0.34	S.D.	=	0.05
C.O.V.	=	0.10	C.O.V.	=	0.20	C.O.V.	=	0.05

Table C.33

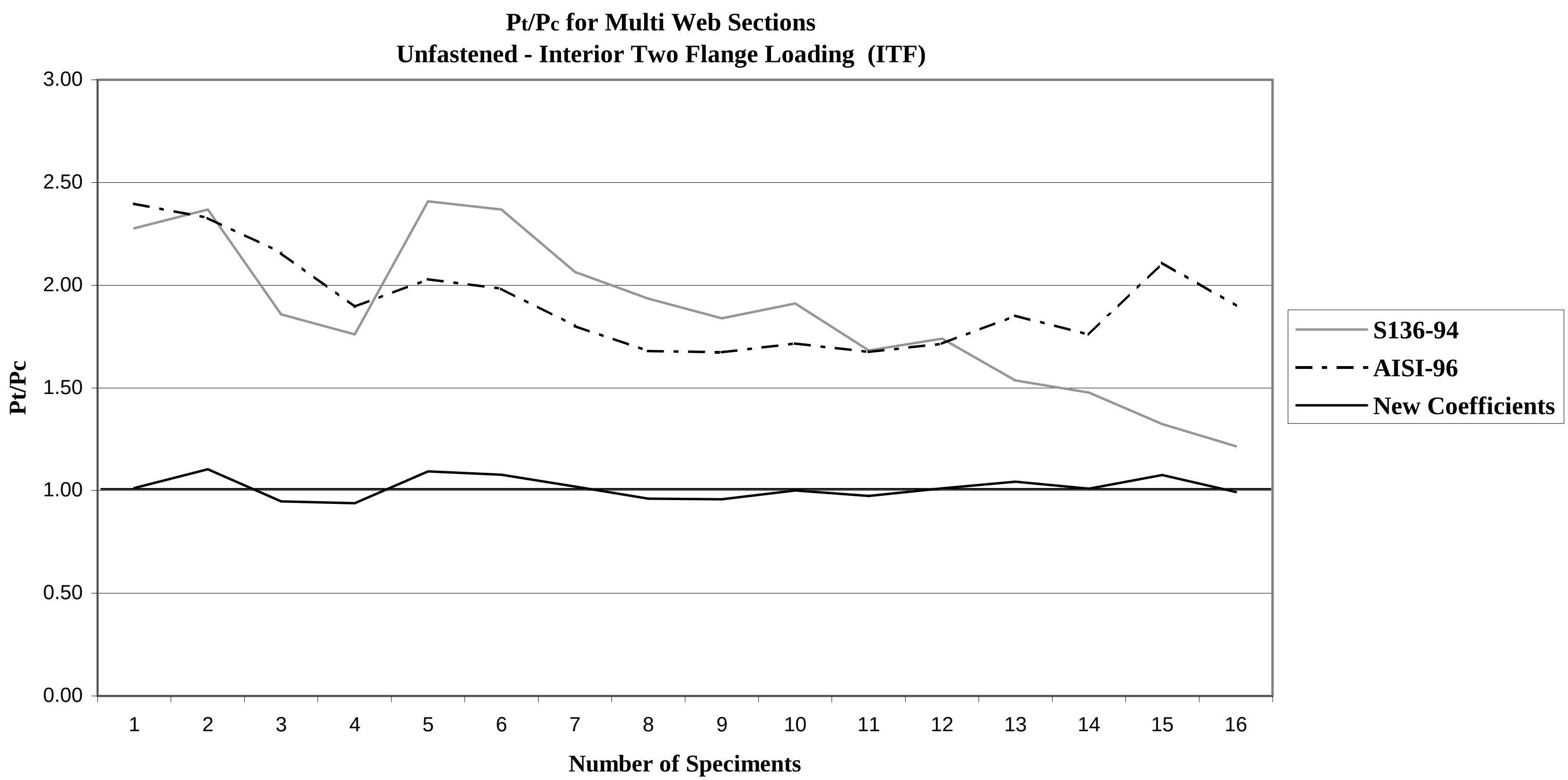
Multi-Web Sections
Unfastened - Interior Two Flange Loading (ITF)

Wu - University of Missouri-Rolla, USA-1997 [24]

				H'	H	R	N		No. of		S136-94		AISI-96		New Coeff.	
No.	**Specimen**	**t** (mm)	**F_y** (MPa)	**h'/t** (ratio)	**h/t** (ratio)	**r/t** (ratio)	**n/t** (ratio)	q	**Webs**	**P_t** (kN)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)	**P_c** (kN)	**P_t/P_c** (ratio)
1	t26h0.75R3/32ANGLE60	0.432	775	56.2	45.3	5.47	58.8	61.0	4	2.03	0.89*	2.28	0.85**	2.40	2.01	1.01
2	t26h0.75R3/64ANGLE60	0.432	775	50.8	45.3	2.77	58.8	61.0	4	2.41	1.02*	2.37	1.04**	2.33	2.18	1.10
3	t26h1.5R3/32ANGLE60	0.432	775	101	90	5.47	58.8	61.0	4	1.55	0.84*	1.858	0.72**	2.157	1.64	0.95
4	t26h1.5R3/64ANGLE60	0.432	775	94.4	88.8	2.77	58.8	60.1	4	1.67	0.95*	1.76	0.88**	1.90	1.78	0.94
5	t22h0.75R5/64ANGLE60	0.737	716	33.3	27.9	2.69	34.5	60.4	4	6.30	2.62*	2.41	3.10**	2.03	5.76	1.09
6	t22h0.75R1/16ANGLE60	0.737	716	30.2	25.9	2.17	34.5	60.6	4	6.42	2.71*	2.368	3.24**	1.984	5.96	1.08
7	t22h1.5R5/64ANGLE60	0.737	716	58.8	53.4	2.69	34.5	59.8	4	5.12	2.48*	2.06	2.84**	1.80	5.02	1.02
8	t22h1.5R1/16ANGLE60	0.737	716	56.4	52.1	2.17	34.5	60.0	4	4.97	2.57*	1.93	2.96**	1.68	5.17	0.96
9	t22h2R5/64ANGLE60	0.737	716	76.1	70.7	2.69	34.5	61.0	4	4.50	2.45*	1.838	2.69**	1.673	4.70	0.96
10	t22h2R1/16ANGLE60	0.737	716	73.3	69.0	2.17	34.5	59.9	4	4.78	2.50*	1.91	2.79**	1.72	4.78	1.00
11	t22h3R5/64ANGLE60	0.737	716	111	106	2.69	34.5	60.4	2	3.91	2.32*	1.68	2.33**	1.68	4.01	0.97
12	t22h3R1/16ANGLE60	0.737	716	108	103	2.17	34.5	60.5	2	4.18	2.40*	1.74	2.44**	1.714	4.14	1.01
13	t22h4.5R5/64ANGLE60	0.737	716	162	157	2.69	34.5	61.6	2	3.41	2.22*	1.54	1.84**	1.85	3.27	1.04
14	t22h4.5R1/16ANGLE60	0.737	716	160	156	2.17	34.5	61.0	2	3.36	2.27*	1.48	1.91**	1.76	3.33	1.01
15	t22h6R5/64ANGLE60	0.737	716	214	208	2.69	34.5	62.8	2	2.82	2.13*	1.324	1.34**	2.11	2.62	1.08
16	t22h6R1/16ANGLE60	0.737	716	211	207	2.17	34.5	61.0	2	2.63	2.16*	1.22	1.38**	1.90	2.64	0.99
										P_t/P_c Mean value		1.86		1.92		1.01
										S.D.		0.37		0.23		0.05
										C.O.V.		0.20		0.12		0.05

* Based on F_y = 360 MPa
** Based on F_y = 60 ksi or 413.7 MPa

Chart C.29



<u>**S136-94**</u>	<u>**AISI-96**</u>	<u>**New Coefficient**</u>
Pt/Pc mean = 1.86	Pt/Pc mean = 1.92	Pt/Pc mean = 1.01
S.D. = 0.37	S.D. = 0.23	S.D. = 0.05
C.O.V. = 0.20	C.O.V. = 0.12	C.O.V. = 0.05

COLD FORMED STEEL WEB CRIPPLING DATA

A Project Sponsored by

American Iron and Steel Institute
1101 17th Street, NW
Washington, DC 20036-4700

Prepared for

AISI Committee on Specifications for the
Design of Cold-Formed Steel Structural Members

By

Professor R. M. Schuster
Project Director

Kevin Xu
Computer Consultant

Baher Beshara
Research Assistant

Canadian Cold Formed Steel Research Group
Department of Civil Engineering
University of Waterloo
Waterloo, Ontario, Canada

April 1999
(Updated November 1999)

COLD FORMED STEELWEB CRIPPLING DATA

Introduction

The primary objective of this project was to assimilate the web crippling data available in the literature to date, using ***Microsoft Access Database***. With over 1000 available data values, it is extremely important to have this data properly organized and documented. This will be of great help to researchers that are working in this area by not having to reproduce the data each time. A common 3.5" HD diskette contains all of the information. ***Microsoft Access Database*** is required to open the data file. Once this is done, the data can be exported to ***Microsoft Excel*** for future use and manipulation. Every effort was made to reproduce the data as reported in the reference documents. The user of this data is encouraged to check the data contained herein with the actual data as reported in the reference documents. See Appendix for reference listings.
Anyone making use of the data contained on the diskette assumes any and all liability from such use.

The web crippling data contained herein was compiled by Mr. Kevin Xu under the supervision of Prof. R. Schuster and Baher Beshara at the University of Waterloo. This effort was financially supported by the American Iron and Steel Institute. The authors of this report wish to thank Prof. R. LaBoube for his valuable guidance and help during the course of this project.

Web Crippling

Whenever a cold formed steel member is supported, either by a beam, masonry wall or by any other means, a concentrated load is induced into the web of the member by way of a reaction at the support. In addition, concentrated loads in the form of heavy equipment may also act on the member. These loads can cause localized crushing or crippling of the relatively thin webs of cold formed steel members

Web crippling is one of the most important failure modes that must be considered in the design of cold formed steel structural members. It is defined as a localized failure of structural members caused by a concentrated load or reaction applied on a short length of the member. There are many factors that affect the web crippling strength, which can be summarized as follow:

1- Section Geometry

Since web crippling is affected by the degree of restraint of the web against rotation, each section has different behavior characteristics from another. There are many geometric shapes in the market place, the most common sections of which are (See Fig.1):

- I-Sections
- C-Sections
- Z-Sections
- Single Hat Sections
- Multi-Web Sections

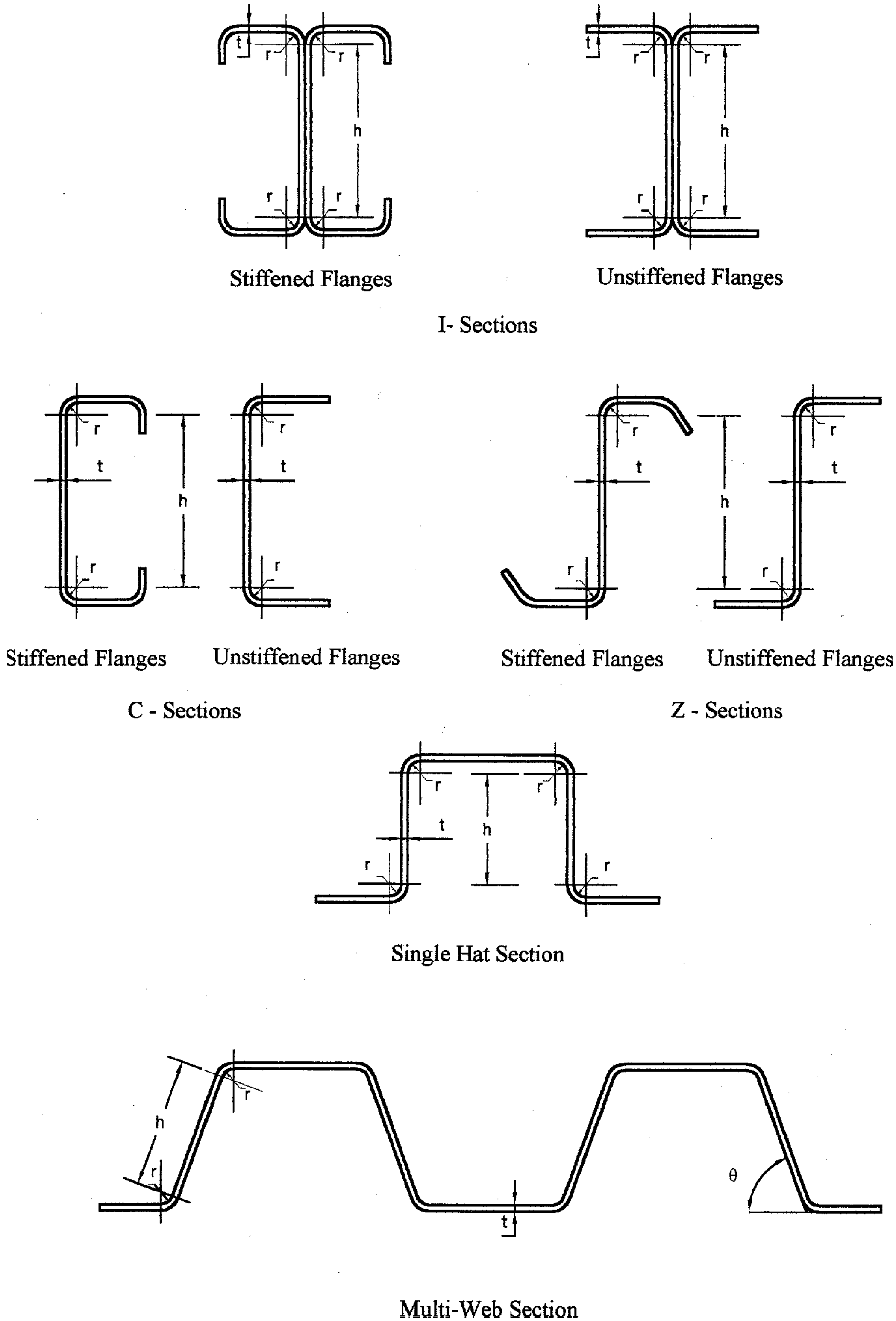


Figure 1: Cold Formed Steel Section Types

Despite the fact that web crippling failure is mainly taking place in the web element of the structural member, the web-flange interaction affects the resistance of this mode of failure. Stiffened and unstiffened flanges (See Fig. 1) play an important role in the web crippling resistance.

2- Loading Cases

A distinction is made between cases of loading, which is based on whether the concentrated load is applied to both flanges (two flange loading) or through one flange only (one flange loading). Furthermore, a distinction is made between end loading, in which the concentrated load is applied near the end of the member and interior loading, where the concentrated load is applied somewhere in the middle of the member span. This results in four different loading cases, as follows. (See Figure 2):

- Interior One Flange loading (IOF).
- Interior Two Flange loading (ITF).
- End One Flange loading (EOF).
- End Two Flange loading (ETF).

In both the American Specification [AISI 1996] and the Canadian Standard [CSA S136-94], similar classifications for load cases are given.

3- Section Parameters

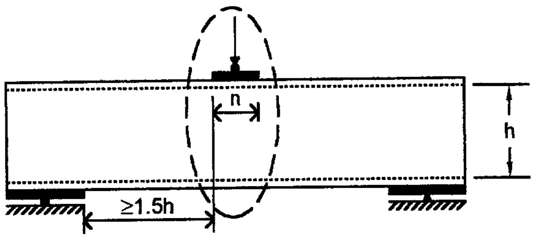
The following important section parameters are considered to be influencing factors that affect the web crippling resistance:

- Yield strength of steel (F_y).
- Web thickness (t).
- Inside bend radius (r).
- Web height (h).
- Angle between the plane of the web and the plane of the bearing surface (θ).

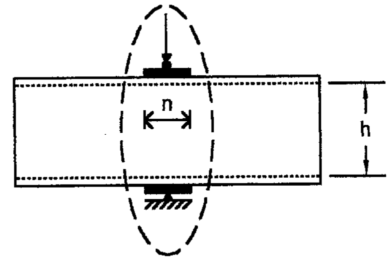
See Figure 1 for details.

4- Bearing Length (n)

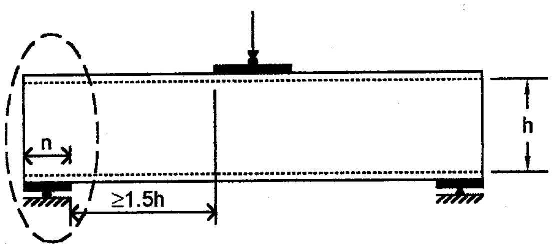
The length over which the load is distributed also has an aff ect on the web crippling resistance, i.e. the longer the bearing plate length, the larger the web crippling resistance (See Figure 2).



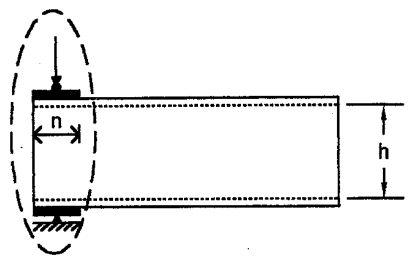
(a) Interior One - Flange Loading (IOF)



(b) Interior Two - Flange Loading (ITF)



(c) End One - Flange Loading (EOF)



(d) End Two - Flange Loading (ETF)

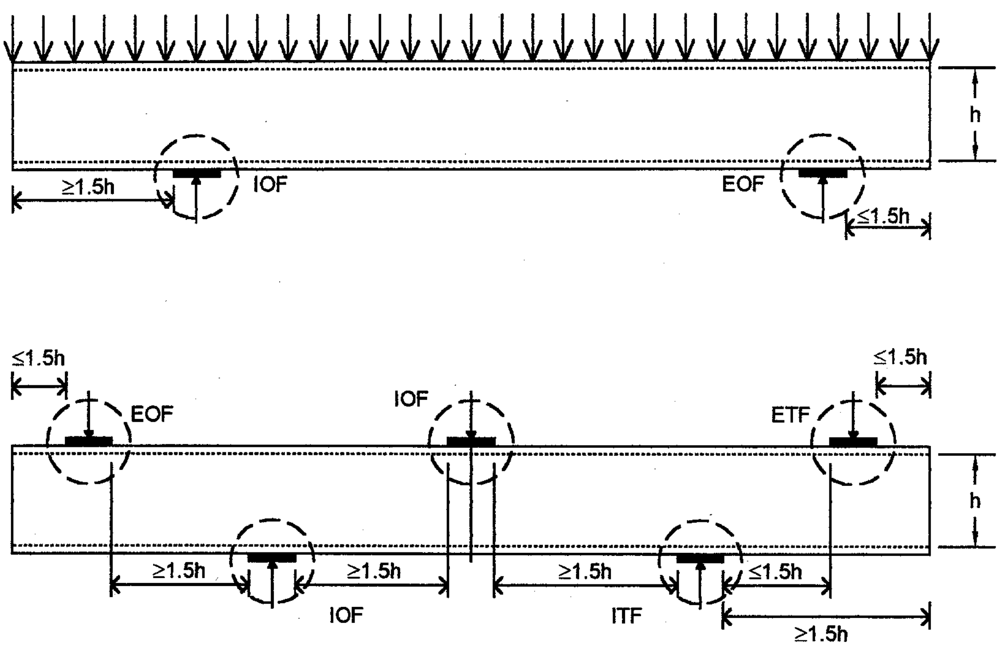


Figure 2: Classification of Load Cases

Data Organization

The primary objective of the data organization was to create a database file using Access97, to include the data from all available previous research studies and technical publications related to web crippling.
The database file will help in the future to check the validity of the current design expressions for predicting web crippling resistance, as well as, to create new expressions for some cases not included in the current expressions.

Data was collected from all the available sources and is organized into four levels, as follows.

- First level according to section geometry i.e. ***I-Sections***, ***Single-Web Sections***, ***Single-Hat Sections*** and ***Multi-Web Sections*** [See Figure 3].

- Second level according to fasten status i.e. ***Fastened*** (specimens fastened to support during testing) or ***Unfastened*** (specimens not fastened to support during testing) [See Figure 4].

- Third level according to load case i.e. End One Flange loading ***(EOF),*** Interior One Flange Loading ***(IOF),*** End Two Flange loading ***(ETF)*** and Interior Two Flange loading ***(ITF)*** [See Figure 5].

- Forth level according to the ***Researcher's name***, ***University*** and ***year of study*** [See Figure 6].

Data was input into the database tables with the same units as presented in the original sources, i.e., Imperial units or Metric units.

Also, the data was selected for the Interior One Flange loading case (IOF) with the condition that $M_t/M_{comp} \leq 0.4$. This was done so that the moment influence is kept to a minimum for this loading case.

Figure 7 shows a typical data table example, such as for an I-Section (Stiffened flanges), IOF loading and Fastened to the support. Note, the important parameter ranges are indicated at the bottom of each table.

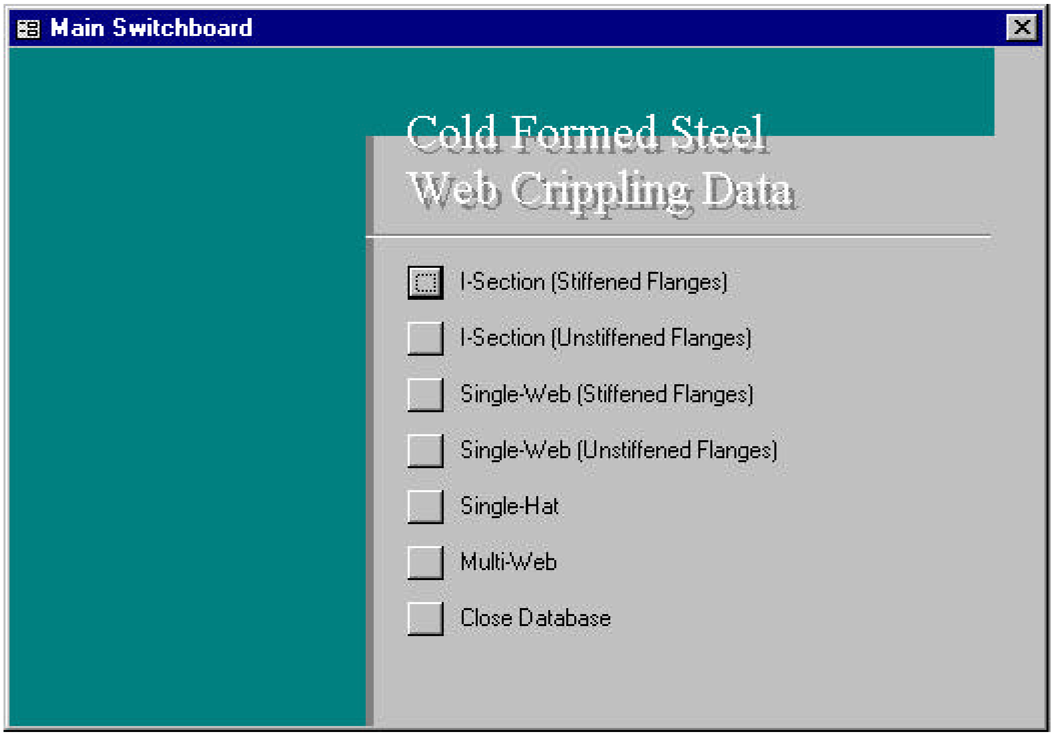


Figure 3: Organization of Data According to Section Geometry

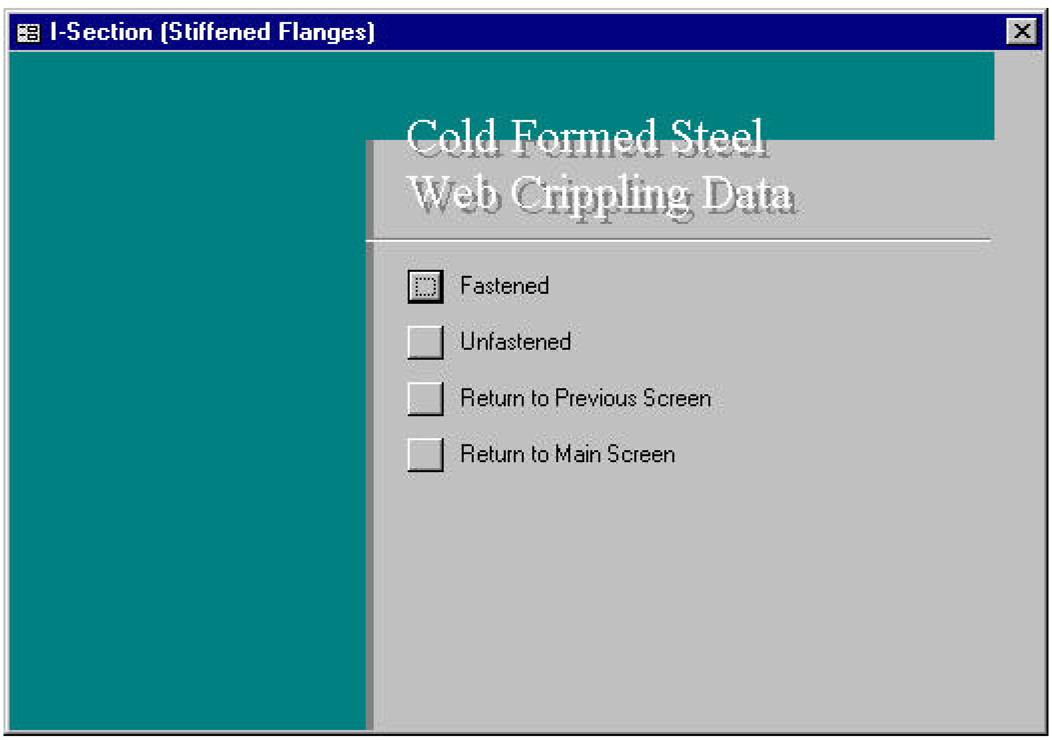


Figure 4: Organization of Data According to Fastened or Unfastened Status

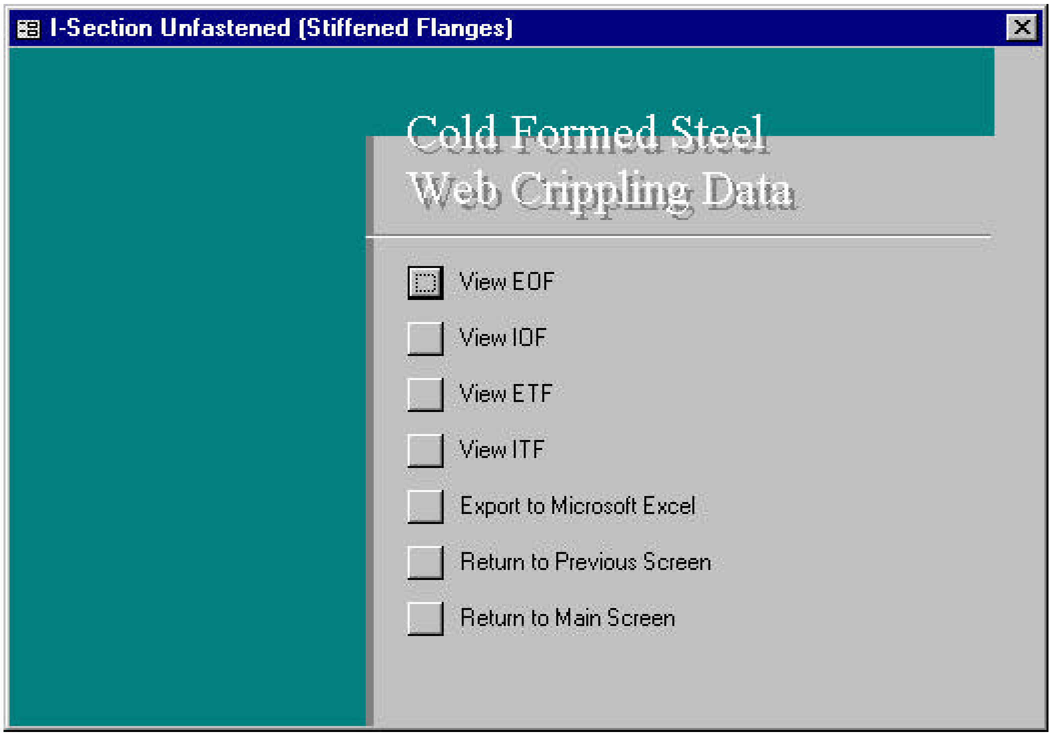


Figure 5: Organization of Data According to Load Case

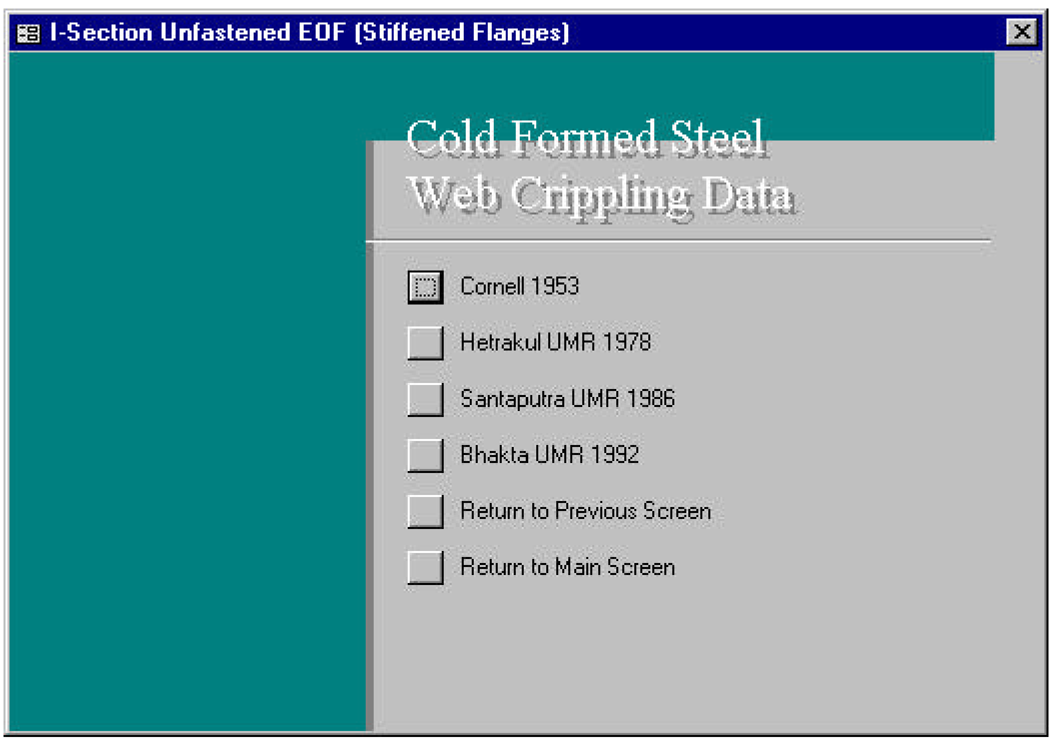


Figure 6: Organization of Data According to Researcher's Name, University and Year

I-Section (Stiffened Flanges) IOF Fastened

Cain, UMR, 1995

Specimen	t (in)	Fy (ksi)	h (in)	R (in)	N (in)	Pt (kips)	h / t	R / t	N / t	N / h
I1-F	0.067	61.200	7.507	0.156	5.250	6.048	112.045	2.328	78.358	0.699
I2-F	0.067	61.200	7.475	0.156	5.250	6.010	111.567	2.328	78.358	0.702
I3-F	0.067	61.200	7.492	0.156	5.250	6.223	111.821	2.328	78.358	0.701
I4-F	0.067	61.200	7.475	0.156	5.250	6.060	111.567	2.328	78.358	0.702
I5-F	0.067	61.200	7.492	0.156	5.250	6.173	111.821	2.328	78.358	0.701
I6-F	0.067	61.200	7.507	0.156	5.250	6.285	112.045	2.328	78.358	0.699
I7-F	0.085	63.340	7.581	0.156	5.250	10.285	89.188	1.835	61.765	0.693
I8-F	0.085	63.340	7.518	0.156	5.250	10.060	88.447	1.835	61.765	0.698
I9-F	0.085	63.340	7.502	0.156	5.250	9.998	88.259	1.835	61.765	0.700
I10-F	0.085	63.340	7.518	0.156	5.250	9.985	88.447	1.835	61.765	0.698
I11-F	0.085	63.340	7.502	0.156	5.250	10.610	88.259	1.835	61.765	0.700
I12-F	0.085	63.340	7.581	0.156	5.250	10.285	89.188	1.835	61.765	0.693

t (in) = **0.067** to **0.085**
Fy (ksi) = **61.200** to **63.340**
h / t = **88.259** to **112.045**
R / t = **1.835** to **2.328**
N / t = **61.765** to **78.358**
N / h = **0.693** to **0.702**

Mt / Mcomp ≤ 0.4 — 12 Data Points

Record: 1 of 12

Figure 7: Example of Data Table for Fastened IOF I –Sections (Stiffened Flanges)

APPENDIX

References

The following references were used in the assimilation of the data contained on the diskette.

1) ***Bhakta***, B.H., LaBoube, R.A. and Yu, W.W., "The Effect of Flange Restraint on Web Crippling Strength," Civil Engineering Study 92-1, Cold-Formed Steel Series, Final Report, University of Missouri- Rolla, Rolla, Missouri, USA, March 1992.

2) ***Cain***, D.E., LaBoube, R.A. and Yu, W.W., "The Effect of Flange Restraint on Web Crippling Strength of Cold-Formed Steel Z- and I- Sections," Civil Engineering Study 95-2, Cold-Formed Steel Series, Final Report, University of Missouri- Rolla, Rolla, Missouri, USA, May 1995.

3) ***Cornell***, 1953. This data can be obtained from Reference 5) by Hetrakul and Yu.

4) ***Gerges***, R.R., "Web Crippling of Single Web Cold Formed Steel Members Subjected to End One-Flange Loading," M.A.Sc. Thesis, University of Waterloo, Canada, 1997.

5) ***Hetrakul***, N. and Yu. W.W., "Structural Behavior of Beam Webs Subjected to Web Crippling and a Combination of Web Crippling and Bending," Civil Engineering Study 78-4, Cold-Formed Steel Series, Final Report, University of Missouri- Rolla, Rolla, Missouri, USA, June 1978.

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7) ***Santaputra,*** C., "Web Crippling of High Strength of Cold-Formed Steel Beams," Ph.D. Thesis, University of Missouri- Rolla, Rolla, Missouri, USA, 1986.

8) ***Wing,*** B.A., "Web Crippling and the Interaction of Bending and Web Crippling of Unreinforced Multi-Web Cold Formed Steel Sections," M.A.Sc. Thesis, University of Waterloo, Canada, 1981.

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SCREW-FASTENED WEB CRIPPLING TESTS

General

The question was raised at the 1999 AISI Cleveland Subcommittee 24 meeting regarding what constitutes a "Fastened to Support" condition, especially since the existing test data is only based on bolted specimens. More specifically, since self-drilling screws are used extensively in the field, will the proposed web crippling coefficients also apply to sections fastened to the supports with self-drilling screws. Based on this, a number of tests were carried out by Prof. Schuster at the University of Waterloo in November of 1999, in an effort to supply an answer to this question. Only two flange loading tests were carried out because it was assumed that this loading case would be more sever in comparison to one flange loading. The screws must be able to keep the flanges from rotating, without failure, so that the full web crippling strength can be achieved in comparison to bolted fasteners.

Testing

Six self-drilling screw-fastened web crippling specimens were tested, three of which were subjected to end two flange loading (ETF) and three to interior two flange loading (ITF). The cold formed steel sections tested were common light weight steel framing C-sections – (8 x 15/8 x 0.5 x 0.048) in. [203 mm x 41.3 mm x 12.7 mm x 1.18 mm]. The available length of each specimen was 36 in. [914 mm], or 4.5 times the overall depth of the section. The bearing plate width for each specimen was 63.5 mm [2.5 in.]. Also, all self-drilling screws were # 10 x 11/4 Hex Head type. See Figure 1 for view of typical test specimen.

The average mechanical properties were obtained from three tensile coupon specimens, as follows.

F_y = 336 MPa [48.7 ksi] ;	F_u = 431 MPa [62.5 ksi];	29.6 % elongation in 2 in. [50 mm]
The base steel thickness was 1.18 mm [0.0465 in.].		

Summarized below are the test results.

ITF Loading	**r/t**	**h/t**	**n/t**	**P_t (kN)[kip]**	**P_n(kN)[kip]**	**P_t/P_n**
Test # 1	2	166	53.8	7.20 [1.62]	7.66 [1.72]	0.942
Test # 2	2	166	53.8	7.10 [1.60]	7.66 [1.72]	0.930
Test # 3	2	166	53.8	7.30 [1.64]	7.66 [1.72]	0.953
Average …………………………………				7.20 [1.62]	7.66 [1.72]	**0.942**
ETF Loading						
Test # 1	2	166	53.8	2.46 [0.553]	2.24 [0.504]	1.10
Test # 2	2	166	53.8	2.49 [0.560]	2.24 [0.504]	1.11
Test # 3	2	166	53.8	2.43 [0.546]	2.24 [0.504]	1.08
Average …………………………………				2.45 [0.553]	2.24 [0.504]	**1.10**

Where P_t is the ultimate test load per specimen web and P_n is the nominal calculated load per specimen web based on the recommended coefficients in Ballot 51.

Figure 1 Screw-fastened Specimen in Test Frame

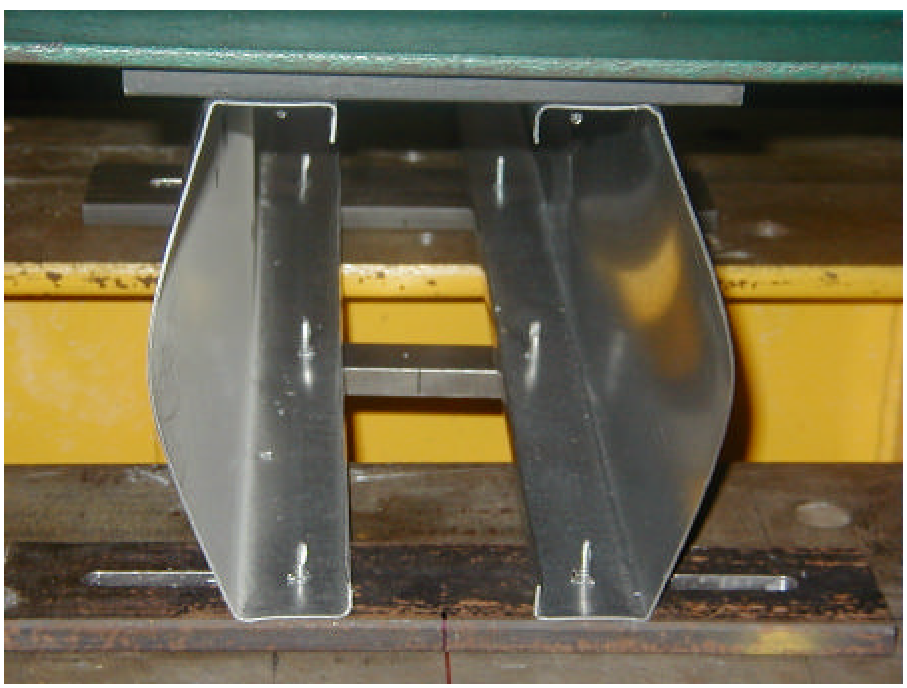

Figure 2 Failed Screw-fastened ETF Specimen

Test Results and Conclusions

The test results above clearly demonstrate that the web crippling capacities for both the ITF and the ETF load case, when compared to the recommended coefficients, are within the usual scatter limits associated with web crippling tests. As well, in no case did the self-drilling screws fail during or at ultimate load of the six specimens tested . Further, it can be observed from Figure 2 that the flanges did not rotate with respect to the bearing plates and the screws remained tight within the C-section flanges after completion of testing.

Based on these results, one can conclude that self-drilling screws perform as well as bolts when comparing the web crippling strength of the ITF and ETF load case.

American Iron and Steel Institute

1140 Connecticut Avenue, NW
Suite 705
Washington, DC 20036

www.steel.org

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Research Report RP-00-2