research report

# Web Crippling and Bending Interaction of Cold-Formed Steel Members

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for the Design of Cold-Formed
Steel Structural Members

American Iron and Steel Institute

# WEB CRIPPLING AND BENDING INTERACTION
# OF
# COLD-FORMED STEEL MEMBERS

**FINAL REPORT**

**AN**

**AISI SPONSORED PROJECT**

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## ABSTRACT

A new web crippling design approach has recently been adopted by the American Iron and Steel Institute and the *North American Specification for the Design of Cold-Formed Steel Structural Members, November 9, 2001 Draft Edition* (NAS, 2001). The current web crippling and bending interaction equations for single-web sections in the Specification (NAS, 2001) are based on the previous web crippling methods. As well, the moment component of the interaction equations was based on the previous reduced web strength method instead of the stress gradient approach that is now contained in the Specification (NAS, 2001).

Based the available data found in the literature, regression analyses were carried out using the new web crippling equations and the stress gradient method to substantiate the current web crippling and bending interaction equations in the Specification (NAS, 2001).

Based on the results of this investigation, new web crippling and bending interaction equations have been developed.

## ACKNOWLDGEMENT

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# INTRODUCTION

With the recent adoption of the new web crippling design approach, the web crippling and bending interaction equations contained in the *North American Specification for the Design of Cold-Formed Steel Structural Members, November 9, 2001 Draft Edition* (NAS 2001) need to be re-evaluated. The *Specification* contains interaction equations for single web geometry, I-beam geometry, and two nested Z-shapes.

Changes in the moment strength calculation (effective web method) were introduced since the interaction equations were initially developed (Hetrakul and Yu, 1987) and hence, may also influence the combined web crippling and bending evaluation. Because of the changes in the web crippling and the bending strength calculations, the validity of the interaction equations must be investigated.

Two different formats for applying the phi and omega factors for the web crippling and bending interaction equations currently exist in the Specification (NAS, 2001). One format uses multiple phi and omega values for web crippling and bending, respectively, whereas the other format uses only one phi and one omega value on the combined behaviour. The application of phi and omega needs to be clarified by the Committee on Specification, and therefore is not discussed herein.

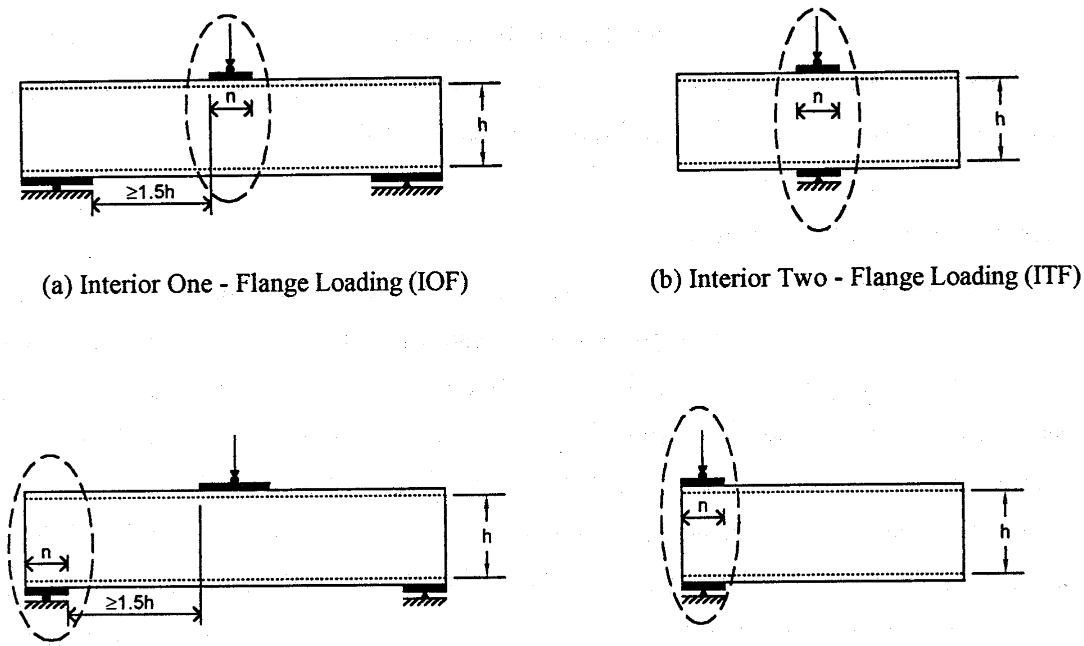
# SCOPE OF STUDY

The scope of this project was to review the available data and determine the validity of the present interaction equations for the geometric section types. The current interaction equations were evaluated using the appropriate available interaction web crippling data found in the literature for single-web sections, built-up sections and nested Z-sections. Multi-web deck sections were not considered in this study.  Based on the results of this study, new web crippling and bending interaction equations are proposed for adoption by theAISI Committee on Specification for the Specification (NAS, 2001).

# LITERATURE REVIEW

## *Web Crippling Only*

Four different load categories for web crippling are addressed by the Specification (NAS, 2001). These categories, illustrated in Figure 1, are: Interior One Flange (IOF) loading, Interior Two Flange (ITF) loading, End One Flange (EOF) loading, and End Two Flange (ETF) loading. In the case of IOF loading there is generally an interaction of web crippling and bending possible. Currently in the Specification (NAS, 2001), if the moment ratio, $M/M_n$, is $\leq 0.3$ for single web members and 0.4 for I-sections, the web crippling and bending interaction need not be considered.




(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: Load Categories for Web Crippling**

The nominal web crippling strength of unreinforced webs is determined by the following equation:

$$P_n = Ct^2F_y \sin(\theta)\left\{1 - C_R\sqrt{\frac{R}{t}}\right\}\left\{1 + C_N\sqrt{\frac{N}{t}}\right\}\left\{1 - C_h\sqrt{\frac{h}{t}}\right\} \qquad \text{Eq. C3.4.1-1 (NAS 2001)}$$

Where:

$C$ = Overall web crippling coefficient
$t$ = Web thickness
$F_y$ = Yield stress of steel
$\theta$ = Angle between plane of web and plane of bearing surface $45° \leq \theta \leq 90°$
$C_R$ = Inside bend radius coefficient
$R$ = Inside bend radius
$C_N$ = Inside bearing length coefficient
$N$ = Bearing length [3/4 in. (19 mm) minimum]
$C_h$ = Web slenderness coefficient
$h$ = Flat dimension of web measured in plane of web

The web crippling coefficients C, $C_R$, $C_N$ and $C_h$ are summarized by Tables C3.4.1-1 to C3.4.1-4 which were taken from the Specification (NAS 2001).

**TABLE C3.4.1-1**
**BUILT-UP SECTIONS**

| **Support and Flange Conditions** | | **Load Cases** | | **C** | $C_R$ | $C_N$ | $C_h$ | $\Omega_w$ | $\phi_w$ | Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| **FASTENED TO SUPPORT** | **Stiffened or Partially Stiffened flanges** | One - Flange Loading or Reaction | End | 10 | 0.14 | 0.28 | 0.001 | 2.00 | 0.75 | $R/t \leq 5$ |
| | | | Interior | 20 | 0.15 | 0.05 | 0.003 | 1.65 | 0.90 | $R/t \leq 5$ |
| **UNFASTENED** | **Stiffened or Partially Stiffened Flanges** | One - Flange Loading or Reaction | End | 10 | 0.14 | 0.28 | 0.001 | 2.00 | 0.75 | $R/t \leq 5$ |
| | | | Interior | 20.5 | 0.17 | 0.11 | 0.001 | 1.75 | 0.85 | $R/t \leq 3$ |
| | | Two - Flange Loading or Reaction | End | 15.5 | 0.09 | 0.08 | 0.04 | 2.00 | 0.75 | $R/t \leq 3$ |
| | | | Interior | 36 | 0.14 | 0.08 | 0.04 | 2.00 | 0.75 | |
| | **Unstiffened Flanges** | One - Flange Loading or Reaction | End | 10 | 0.14 | 0.28 | 0.001 | 2.00 | 0.75 | $R/t \leq 5$ |
| | | | Interior | 20.5 | 0.17 | 0.11 | 0.001 | 1.75 | 0.85 | $R/t \leq 3$ |

Notes:
(1) This Table applies to I-beams made from two channels connected back to back. See Section C3.4 of Commentary for explanation.
(2) The above coefficients apply when $h/t \leq 200$, $N/t \leq 210$, $N/h \leq 1.0$ and $\theta = 90°$.

## TABLE C3.4.1-2
## SINGLE WEB CHANNEL AND C-SECTIONS

| Support and Flange Conditions | | Load Cases | | C | $C_R$ | $C_N$ | $C_h$ | $\Omega_w$ | $\phi_w$ | Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| **FASTENED TO SUPPORT** | **Stiffened or Partially Stiffened Flanges** | One - Flange Loading or Reaction | End | 4 | 0.14 | 0.35 | 0.02 | 1.75 | 0.85 | $R/t \le 9$ |
| | | | Interior | 13 | 0.23 | 0.14 | 0.01 | 1.65 | 0.90 | $R/t \le 5$ |
| | | Two - Flange Loading or Reaction | End | 7.5 | 0.08 | 0.12 | 0.048 | 1.75 | 0.85 | $R/t \le 12$ |
| | | | Interior | 20 | 0.10 | 0.08 | 0.031 | 1.75 | 0.85 | $R/t \le 12$ |
| **UNFASTENED** | **Stiffened or Partially Stiffened Flanges** | One - Flange Loading or Reaction | End | 4 | 0.14 | 0.35 | 0.02 | 1.85 | 0.80 | $R/t \le 5$ |
| | | | Interior | 13 | 0.23 | 0.14 | 0.01 | 1.65 | 0.90 | |
| | | Two - Flange Loading or Reaction | End | 13 | 0.32 | 0.05 | 0.04 | 1.65 | 0.90 | $R/t \le 3$ |
| | | | Interior | 24 | 0.52 | 0.15 | 0.001 | 1.90 | 0.80 | |
| | **Unstiffened Flanges** | One - Flange Loading or Reaction | End | 4 | 0.40 | 0.60 | 0.03 | 1.80 | 0.85 | $R/t \le 2$ |
| | | | Interior | 13 | 0.32 | 0.10 | 0.01 | 1.80 | 0.85 | $R/t \le 1$ |
| | | Two - Flange Loading or Reaction | End | 2 | 0.11 | 0.37 | 0.01 | 2.00 | 0.75 | $R/t \le 1$ |
| | | | Interior | 13 | 0.47 | 0.25 | 0.04 | 1.90 | 0.80 | |

Notes:

(1) The above coefficients apply when $h/t \le 200$, $N/t \le 210$, $N/h \le 2.0$ and $\theta = 90°$.

(2) For interior two-flange loading or reaction of members having flanges fastened to the support, the distance from the edge of bearing to the end of the member shall be extended at least 2.5h. For the unfastened case, the distance from the edge of bearing to the end of the member shall be extended at least 1.5h.

## TABLE C3.4.1-3
## SINGLE WEB Z-SECTIONS

| Support and Flange Conditions | | Load Cases | | C | $C_R$ | $C_N$ | $C_h$ | $\Omega_w$ | $\phi_w$ | Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| **FASTENED TO SUPPORT** | **Stiffened or Partially Stiffened Flanges** | One - Flange Loading or Reaction | End | 4 | 0.14 | 0.35 | 0.02 | 1.75 | 0.85 | $R/t \le 9$ |
| | | | Interior | 13 | 0.23 | 0.14 | 0.01 | 1.65 | 0.90 | $R/t \le 5$ |
| | | Two - Flange Loading or Reaction | End | 9 | 0.05 | 0.16 | 0.052 | 1.75 | 0.85 | $R/t \le 12$ |
| | | | Interior | 24 | 0.07 | 0.07 | 0.04 | 1.85 | 0.80 | $R/t \le 12$ |
| **UNFASTENED** | **Stiffened or Partially Stiffened Flanges** | One - Flange Loading or Reaction | End | 5 | 0.09 | 0.02 | 0.001 | 1.80 | 0.85 | $R/t \le 5$ |
| | | | Interior | 13 | 0.23 | 0.14 | 0.01 | 1.65 | 0.90 | |
| | | Two - Flange Loading or Reaction | End | 13 | 0.32 | 0.05 | 0.04 | 1.65 | 0.90 | $R/t \le 3$ |
| | | | Interior | 24 | 0.52 | 0.15 | 0.001 | 1.90 | 0.80 | |
| | **Unstiffened Flanges** | One - Flange Loading or Reaction | End | 4 | 0.40 | 0.60 | 0.03 | 1.80 | 0.85 | $R/t \le 2$ |
| | | | Interior | 13 | 0.32 | 0.10 | 0.01 | 1.80 | 0.85 | $R/t \le 1$ |
| | | Two - Flange Loading or Reaction | End | 2 | 0.11 | 0.37 | 0.01 | 2.00 | 0.75 | $R/t \le 1$ |
| | | | Interior | 13 | 0.47 | 0.25 | 0.04 | 1.90 | 0.80 | |

Notes:

(1) The above coefficients apply when $h/t \le 200$, $N/t \le 210$, $N/h \le 2.0$ and $\theta = 90°$.

**(2)** For interior two-flange loading or reaction of members having flanges fastened to the support, the distance from the edge of bearing to the end of the member shall be extended at least 2.5h. For the unfastened case, the distance from the edge of bearing to the end of the member shall be extended at least 1.5h.

**TABLE C3.4.1-4**
**SINGLE HAT SECTIONS**

| Support Conditions | Load Cases | | C | $C_R$ | $C_N$ | $C_h$ | $\Omega_w$ | $\phi_w$ | Limits |
|---|---|---|---|---|---|---|---|---|---|
| **FASTENED TO SUPPORT** | **One - Flange Loading or Reaction** | End | 4 | 0.25 | 0.68 | 0.04 | 2.00 | 0.75 | R/t ≤ 4 |
| | | Interior | 17 | 0.13 | 0.13 | 0.04 | 1.90 | 0.80 | R/t ≤ 10 |
| | **Two - Flange Loading or Reaction** | End | 9 | 0.10 | 0.07 | 0.03 | 1.75 | 0.85 | R/t ≤ 10 |
| | | Interior | 10 | 0.14 | 0.22 | 0.02 | 1.80 | 0.85 | |
| **UNFASTENED** | **One - Flange Loading or Reaction** | End | 4 | 0.25 | 0.68 | 0.04 | 2.00 | 0.75 | R/t ≤ 4 |
| | | Interior | 17 | 0.13 | 0.13 | 0.04 | 1.70 | 0.90 | R/t ≤ 4 |

Note:

The above coefficients apply when h/t ≤ 200, N/t ≤ 200, N/h ≤ 2 and θ = 90°.

### *Bending Only*

The nominal moment strength, $M_{nxo}$, of a cold-formed steel member is determined using the following expression:

$$M_{nxo} = S_e F_y \,, \qquad \text{Eq. C3.1.1-1 (NAS 2001)}$$

where $F_y$ is the yield stress of the material and $S_e$ is the effective section modulus computed at a stress of $f = F_y$.

### *Combined Web Crippling and Bending*

The interaction of web crippling and bending is evaluated by Eqs. 1, 2 and 3. These nominal equations serve as the basis for the design equations contained in the Specification (NAS, 2001).

For shapes having single unreinforced webs

$$1.07\left(\frac{P_t}{P_n}\right) + \left(\frac{M_t}{M_n}\right) \le 1.42 \qquad \text{Eq. 1}$$

For I-sections such as two C-sections back-to-back

$$0.82\left(\frac{P_t}{P_n}\right) + \left(\frac{M_t}{M_n}\right) \le 1.32 \qquad \text{Eq. 2}$$

For two nested Z-shapes

$$0.85\left(\frac{P_t}{P_n}\right) + \left(\frac{M_t}{M_n}\right) \le 1.65 \qquad \text{Eq. 3}$$

## REVIEW OF DATA

The focus was on three geometric shapes, or cross sections:

(1) Shapes having single unreinforced webs

(2) Built-Up Sections such as I-sections

(3) Two nested Z-shapes

The cross-section type and dimensional notations for each test specimen type are shown in Figures A1 through A6 of Appendix A. Figure A1 shows the various I-sections and Figure A2 the types of hat sections tested by Winter and Pian (1946). Figure A3 shows the channel C-section and Figure A4 the stiffened and unstiffened I-sections tested by Hetrakul and Yu (1978). Figure A5 shows the nested Z- sections tested by LaBoube, Nunnery and Hodges (1994) and Figure A6 the unstiffened channel C-sections tested by Young and Hancock (2000).

The cross-sectional dimensions of the test specimens are summarized in Tables B1 through B7 of Appendix B. More specifically, Table B1 contains the data of the channel C-sections as shown in Figure A3, Table B2 the data of the hat sections as shown in Figure A2, Table B3 the data of the channel C- sections tested by Ratliff (1975), Table B4 the data of the unstiffened flange channel C-sections tested by Young and Hancock (2000), Table B5 the data of the stiffened flange I-sections as shown in Figure A4, Table B6 the data of the stiffened flange I-sections as shown in Figure A1 and Table B7 the data of the unstiffened flange I-sections as shown in Figure A4. No detailed dimensional data was given for the nested Z-section tests.

## REVIEW AND DEVELOPMENT OF INTERACTION EQUATIONS

The accuracy of Equations 1, 2, and 3 was determined by using the ratio of the following relationships:

$$[A/1.42]; \quad \text{where } \mathbf{A} = 1.07\left(\frac{P_t}{P_n}\right) + \left(\frac{M_t}{M_n}\right) \qquad \text{Eq. 4}$$

$$[B/1.32]; \quad \text{where } \mathbf{B} = 0.82\left(\frac{P_t}{P_n}\right) + \left(\frac{M_t}{M_n}\right) \qquad \text{Eq. 5}$$

$$[C/1.65]; \quad \text{where } \mathbf{C} = 0.85\left(\frac{P_t}{P_n}\right) + \left(\frac{M_t}{M_n}\right) \qquad \text{Eq. 6}$$

### *Proposed Interaction Equations:*

Based on a review of the test data, the following interaction equations were developed:

(1) For shapes having single unreinforced webs

C-sections using the data from Hetrakul & Yu (1978), Ratliff (1975), and Young (2000),

$$0.89\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)\leq 1.32 \qquad \text{Eq. 7}$$

For C-sections and hat sections using the data from Hetrakul & Yu (1978), Ratliff (1975), Young (200), and Cornell (1953),

$$0.91\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)\leq 1.33 \qquad \text{Eq. 8}$$

(2) For I-sections such as two C-sections back-to-back

*Using the data from Hetrakul and Yu (1978),*

$$0.88\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)\leq 1.46 \qquad \text{Eq. 9}$$

The Hetrakul & Yu (1978) data was based on double web I-sections (see Figure A4 of Appendix A).

*Using the data from Hetrakul & Yu (1978) and Winter & Pian (1946),*

$$0.64\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)\leq 1.29 \qquad \text{Eq. 10}$$

The Winter & Pian (1946) data was based on single and double web I-sections (see Figure A1 of Appendix A).

(3) For two nested Z-shapes

Using the data from LaBoube, Nunnery and Hodges (1994)

$$0.86\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)\leq 1.65 \qquad \text{Eq. 11}$$

A graphical presentation of the above equations is shown in Appendix C.

The accuracy of Equations 7, 9 and 11 was determined by the following ratios:

[A’/1.32]; where **A’** = $0.89\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)$ Eq. 12

[B’/1.46]; where **B’** = $0.88\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)$ Eq. 13

$$[C'/1.65]; \quad \text{where } \mathbf{C'} = 0.86\left(\frac{P_t}{P_n}\right) + \left(\frac{M_t}{M_n}\right) \qquad \text{Eq. 14}$$

The statistical accuracy of equations 8 and 10 was also determined by using ratios similar to Equations 12 and 13.

## CALIBRATIONS

Resistance factors, $\phi$, are used with the LRFD design method in the US and Mexico and with the LSD design method in Canada (NAS, 2001). The resistance factors are determined in conformance with each country's respective load factors and dead to live load ratios to provide a target reliability index, $\beta$, value of 2.5 for the US and Mexico and 3.0 for Canada (NAS, 2001). A satisfactory design can be obtained by equating the factored resistance to the factored loads, as follows:

$$\phi R_n = c(\alpha_D D_n + \alpha_L L_n) \qquad \text{Eq. 15}$$

Where $R_n$ is the nominal resistance and $\alpha_D$ and $\alpha_L$ are the dead and live load factors, respectively, such that the load combinations are 1.2D + 1.6L for the US and Mexico and 1.25D + 1.5L for Canada (NAS, 2001). The dead to live load ratios, D/L, are 1/5 for the US and Mexico and 1/3 for Canada (NAS, 2001).

Considering Equation 15, it can be shown that the resistance factors, $\phi$, can be determined as follows.

For AISI $$\phi = \frac{1.521(P_m M_m F_m)}{e^{\beta\sqrt{V_R^2+V_Q^2}}} \qquad \text{Eq. 16}$$

For S136 $$\phi = \frac{1.420(P_m M_m F_m)}{e^{\beta\sqrt{V_R^2+V_Q^2}}} \qquad \text{Eq. 17}$$

Where:

$$V_R = \sqrt{V_P^2 + V_M^2 + V_F^2} \qquad \text{Eq. 18}$$

$$V_Q = \frac{\sqrt{(D_m V_D)^2 + (L_m V_L)^2}}{D_m + L_m} \qquad \text{Eq. 19}$$

$P_m$ = mean ratio of experimental to calculated results
$M_m$ = mean ration of actual yield point to minimum specified value
$F_m$ = mean ratio of actual to specified section modulus
$D_m$ = mean dead load intensity (= 1.05 $D_n$*)
$L_m$ = mean live load intensity (= $L_n$*)

* Values recommended by Hsiao et al. (1998)

$D_n$ = nominal dead load intensity
$L_n$ = nominal live load intensity
$V_P$ = Factor of variation of experimental to calculated results
$V_M$ = Factor of variation reflecting material properties' uncertainties
$V_F$ = Factor of variation reflecting geometric uncertainties
$V_D$ = Factor of variation of the dead load intensities
$V_L$ = Factor of variation of the live load intensities

The values of $M_m = 1.10$, $V_M = 0.08$, $F_m = 1.00$, and $V_F = 0.05$ were taken from Table F1 – Statistical Data for the Determination of Resistance Factor in (NAS, 2001).

By knowing the resistance factor, $\phi$, the corresponding factor of safety, $\Omega$, can be computed as follows:

For the US and Mexico
$$\Omega = \frac{1.2\,D/L + 1.6}{\phi(D/L + 1)} = 1.533/\phi \qquad \text{Eq. 20}$$

Summarised in Tables 1 to 3 are the statistical values and corresponding factors of safety, $\Omega$, and resistance factors, $\phi$, calculated for the given test data.

## DISCUSSION OF RESULTS

Experimental and calculated results are summarized in Tables B8 through B13 of Appendix B and the respective interaction diagrams are shown in Figures C1 through C5 of Appendix C. The statistical data for the interaction equations are summarized in the Tables 1 to 3. More specifically, shown in Table 1 are the results of single-unreinforced web sections, in Table 2 the results of I-sections such as two channel C-sections back to back and in Table 3 the results of nested Z-sections. The statistical results in these tables are self-explanatory.

**Table 1 - Shapes having Single-Unreinforced Webs**

| Equation | Data Source | Mean | COV | U.S. & Mexico | | Canada $\phi$ |
|---|---|---|---|---|---|---|
| | | | | $\Omega$ | $\phi$ | |
| Eq. 1 (Current) | Hetrakul (1978) Ratliff (1975) Young (2000) | 1.025 | 0.097 | 1.69 | 0.907 | 0.782 |
| Eq. 1 (Current) | Hetrakul (1978) Ratliff (1975) Young (2000) Cornell (1953) | 1.021 | 0.097 | 1.70 | 0.903 | 0.779 |
| Eq. 7 (Proposed) | Hetrakul (1978) Ratliff (1975) Young (2000) | 1.004 | 0.101 | 1.73 | 0.885 | 0.762 |
| Eq. 8 (Proposed) | Hetrakul (1978) Ratliff (1975) Young (2000) Cornell (1953) | 0.999 | 0.101 | 1.74 | 0.880 | 0.759 |

**Table 2 - Stiffened Flange I-Sections**

| Equation | Data Source | Mean | COV | U.S. & Mexico | | Canada |
|---|---|---|---|---|---|---|
| | | | | $\Omega$ | $\phi$ | $\phi$ |
| Eq. 2 (Current) | Hetrakul (1978) | 1.071 | 0.094 | 1.61 | 0.950 | 0.820 |
| Eq. 2 (Current) | Hetrakul (1978)<br>Winter (1946) | 1.097 | 0.104 | 1.59 | 0.964 | 0.830 |
| Eq. 9 (Proposed) | Hetrakul (1978) | 1.001 | 0.091 | 1.72 | 0.891 | 0.769 |
| Eq. 10 (Proposed) | Hetrakul (1978)<br>Winter (1946) | 0.997 | 0.110 | 1.76 | 0.871 | 0.748 |

**Table 3 - Nested Z-Sections**

| Equation | Data Source | Mean | COV | U.S. & Mexico | | Canada |
|---|---|---|---|---|---|---|
| | | | | $\Omega$ | $\phi$ | $\phi$ |
| Eq. 3 (Current) | LaBoube (1994) | 0.991 | 0.034 | 1.68 | 0.914 | 0.798 |
| Eq. 11 (Proposed) | LaBoube (1994) | 0.998 | 0.033 | 1.66 | 0.921 | 0.804 |

In the case of I-sections such as two channel C-sections, the Hetrakul & Yu (1978) data was considered separately because the specimens were all double web I-sections made up of two channel C-sections, resulting in Eq. 9. The data from Winter & Pian (1946) on the other hand was made up of single and double web specimens. By considering both data sets, Eq. 10 was developed. By comparing Eq. 9 with Eq. 10, one can conclude that there is a considerable difference in interaction coefficients. Since most of the I-sections used in practice today are double web sections, it would be logical to use Eq. 9 instead of Eq. 10.

Figures C1 to C5 show that the new interaction equations yield an increase in computed strength and the statistical data in Tables 1 to 3 indicates that the new interaction equations provide an improved assessment of the interaction of web crippling and bending capacity when compared to the current interaction equations. As can be concluded from Table B13, insufficient data exists to draw final conclusions for I-sections having unstiffened flanges.

## CONCLUSIONS AND RECOMMENDATIONS

The current web crippling and bending interaction equations in the Specification (NAS, 2001) have been evaluated using the available data found in the literature. The objective of this study was to evaluate the current interaction equations in light of the recent changes in both the pure web crippling equations and the bending strength determination.

Based on this study, new web crippling and bending interaction equations have been developed. In each case, the typical statistical parameters have been established to substantiate the best data-fit interaction equations. Shown in Table 4 are the recommended interaction equations with their respective factors of safety and resistance factors rounded off to the nearest 0.05.

**Table 4 – Recommended Interaction Equations**

| Equation | Mean | COV | U.S. & Mexico | | Canada $\phi$ |
|---|---|---|---|---|---|
| | | | $\Omega$ | $\phi$ | |
| **C- and Hat Sections** $0.91\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)\leq 1.33$ | 0.999 | 0.101 | 1.70 | 0.90 | 0.75 |
| **I-Sections** $0.88\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)\leq 1.46$ | 1.001 | 0.091 | 1.70 | 0.90 | 0.75 |
| **Nested Z-Sections** $0.86\left(\frac{P_t}{P_n}\right)+\left(\frac{M_t}{M_n}\right)\leq 1.65$ | 0.998 | 0.033 | 1.70 | 0.90 | 0.80 |

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Ratliff, G.D. (1975), "Interaction of Concentrated Loads and Bending in C-shaped Beams," Proceedings of the Third Specialty Conference on Cold-Formed Steel Structures, University of Missouri-Rolla.

Winter, G. and Pian, R. H. J. (1946), "Crushing Strength of Thin Steel Webs," Engineering Experiment Station, Bulletin No. 35, Part 1, Cornell University, April.

Young, B, Hancock, G.J. (2000),"Experimental Investigation of Cold-Formed Channels Subjected to Combined Bending and Web Crippling," Proceedings of the 15th International Specialty Conference on Cold-Formed Steel Structures, University of Missouri-Rolla.

## APPENDIX A - GEOMETRIC SECTIONS INVESTIGATED

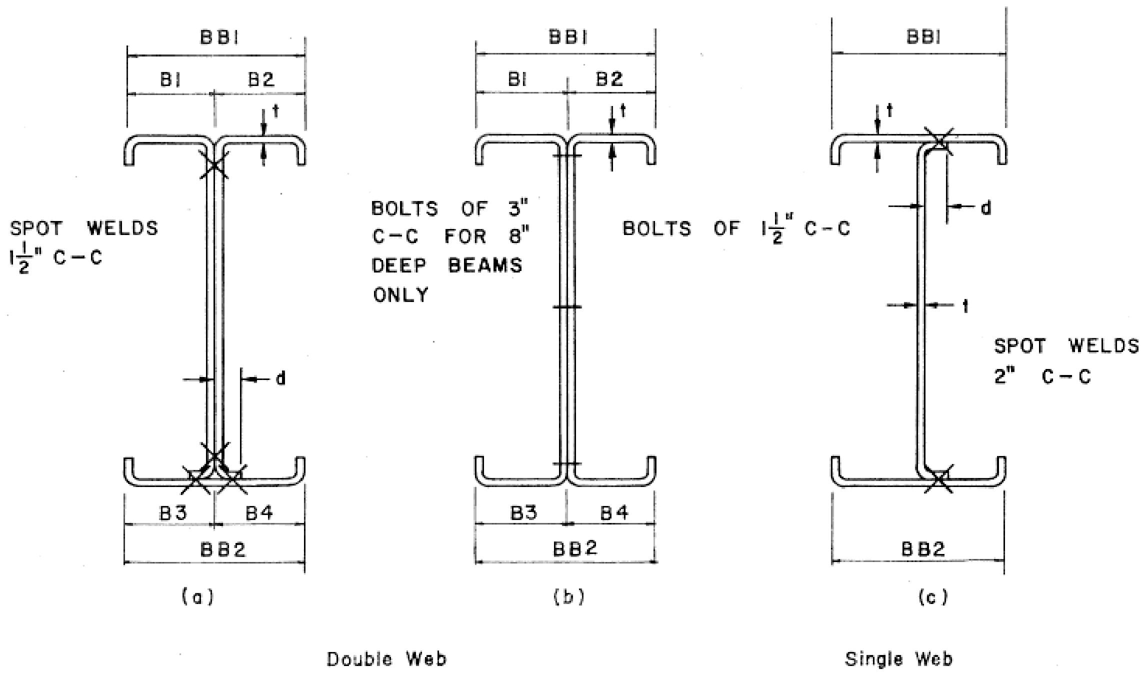



**Figure A1: I-sections Tested by Winter and Pian (1946)**

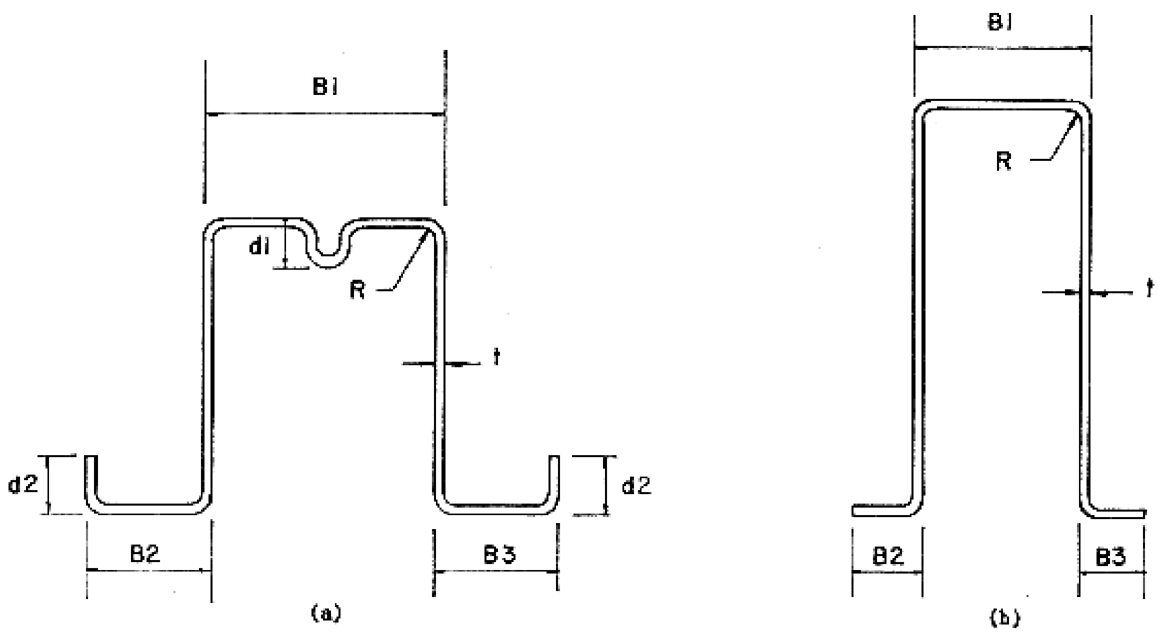



**Figure A2: Hat Sections Tested at Cornell (1953)**

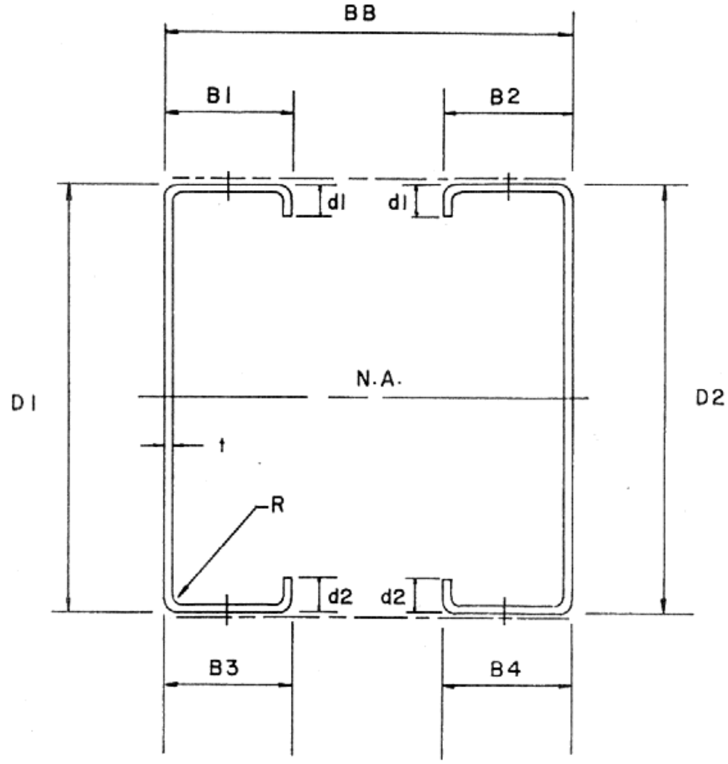
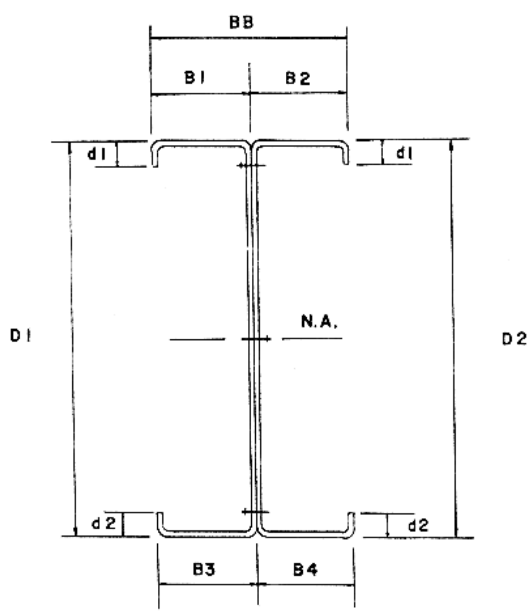



**Figure A3: Channel C-sections Tested by Hetrakul and Yu (1978)**



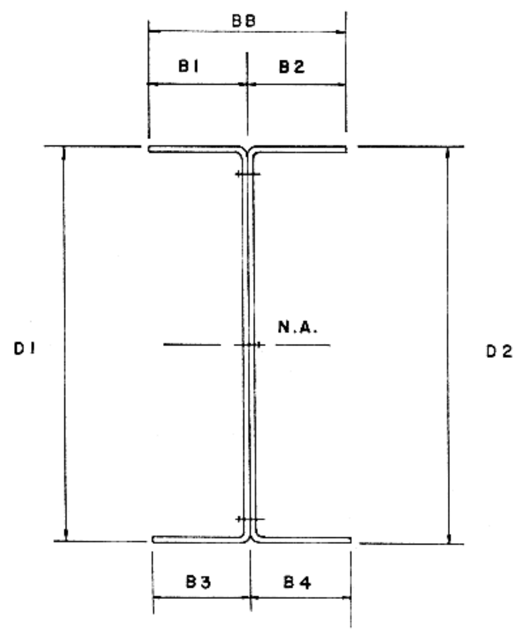




**Figure A4: Stiffened and Unstiffened I-sections Tested by Hetrakul and Yu (1978)**

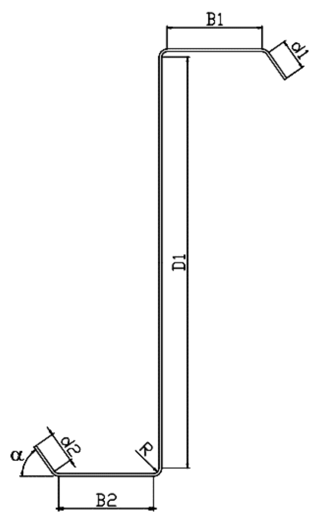



**Figure A5: Z-sections Tested by LaBoube, Nunnery and Hodges (1994)**

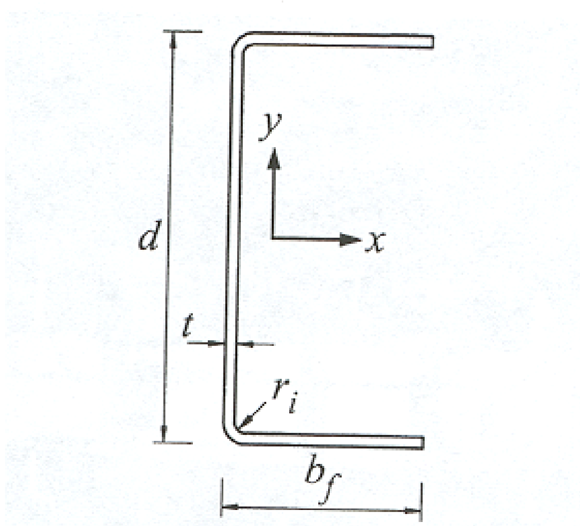



**Figure A6: Unstiffened C-sections Tested by Young and Hancock (2000)**

# APPENDIX B - DATA AND COMPARISONS

**Table B1: Dimensions of Channel C-sections - Hetrakul & Yu (1978)**

| Specimen | t (in.) | R (in.) | N (in.) | B1 (in.) | B2 (in.) | B3 (in.) | B4 (in.) | d1 (in.) | d2 (in.) | D1 (in.) | D2 (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SU-BC-1-1 | 0.0460 | 0.0625 | 3 | 1.934 | 1.983 | 1.930 | 1.886 | 0.585 | 0.607 | 4.838 | 4.709 |
| SU-BC-1-2 | 0.0460 | 0.0625 | 3 | 1.934 | 1.926 | 1.900 | 1.925 | 0.590 | 0.582 | 4.773 | 4.788 |
| SU-BC-1-3 | 0.0460 | 0.0625 | 3 | 1.894 | 1.975 | 1.957 | 1.914 | 0.601 | 0.613 | 4.784 | 4.669 |
| SU-BC-1-4 | 0.0465 | 0.0625 | 3 | 1.895 | 1.957 | 1.969 | 1.938 | 0.639 | 0.632 | 4.700 | 4.678 |
| SU-BC-1-5 | 0.0470 | 0.0625 | 3 | 1.903 | 1.956 | 1.964 | 1.900 | 0.637 | 0.633 | 4.718 | 4.728 |
| SU-BC-1-6 | 0.0460 | 0.0625 | 3 | 1.898 | 1.980 | 1.952 | 1.905 | 0.640 | 0.629 | 4.717 | 4.680 |
| SU-BC-3-1 | 0.0494 | 0.0470 | 3 | 1.625 | 1.658 | 1.665 | 1.632 | 0.617 | 0.639 | 9.815 | 9.800 |
| SU-BC-3-2 | 0.0494 | 0.0470 | 3 | 1.635 | 1.641 | 1.640 | 1.637 | 0.617 | 0.641 | 9.780 | 9.781 |
| SU-BC-3-3 | 0.0494 | 0.0470 | 3 | 1.643 | 1.644 | 1.648 | 1.638 | 0.620 | 0.635 | 9.768 | 9.788 |
| SU-BC-3-4 | 0.0494 | 0.0470 | 3 | 1.637 | 1.639 | 1.639 | 1.631 | 0.632 | 0.639 | 9.813 | 9.811 |
| SU-BC-3-5 | 0.0484 | 0.0470 | 3 | 1.636 | 1.635 | 1.632 | 1.634 | 0.638 | 0.625 | 9.785 | 9.775 |
| SU-BC-3-6 | 0.0494 | 0.0470 | 3 | 1.635 | 1.654 | 1.655 | 1.622 | 0.632 | 0.628 | 9.809 | 9.804 |
| SU-BC-15-1 | 0.0500 | 0.0781 | 3 | 3.150 | 3.132 | 3.140 | 3.180 | 0.584 | 0.620 | 7.460 | 7.396 |
| SU-BC-15-2 | 0.0510 | 0.0781 | 3 | 3.100 | 3.159 | 3.155 | 3.176 | 0.625 | 0.603 | 7.457 | 7.428 |
| SU-BC-15-3 | 0.0510 | 0.0781 | 3 | 3.175 | 3.132 | 3.132 | 3.157 | 0.615 | 0.605 | 7.408 | 7.437 |
| SU-BC-15-4 | 0.0500 | 0.0781 | 3 | 3.140 | 3.107 | 3.143 | 3.167 | 0.620 | 0.581 | 7.436 | 7.425 |
| SU-BC-15-5 | 0.0510 | 0.0781 | 3 | 3.186 | 3.124 | 3.131 | 3.181 | 0.612 | 0.615 | 7.428 | 7.383 |
| SU-BC-15-6 | 0.0520 | 0.0781 | 3 | 3.175 | 3.130 | 3.134 | 3.174 | 0.613 | 0.611 | 7.443 | 7.380 |
| SU-4-IOF-1 | 0.0494 | 0.0781 | 1 | 2.158 | 2.157 | 2.161 | 2.151 | 0.585 | 0.596 | 4.952 | 4.967 |
| SU-4-IOF-2 | 0.0498 | 0.0781 | 1 | 2.160 | 2.149 | 2.154 | 2.152 | 0.610 | 0.593 | 4.930 | 4.940 |
| SU-4-IOF-3 | 0.0502 | 0.0938 | 2 | 2.175 | 2.163 | 2.171 | 2.174 | 0.610 | 0.587 | 4.955 | 4.926 |
| SU-4-IOF-4 | 0.0500 | 0.0859 | 2 | 2.178 | 2.160 | 2.152 | 2.127 | 0.588 | 0.624 | 4.943 | 4.918 |
| SU-4-IOF-5 | 0.0500 | 0.0781 | 3 | 2.183 | 2.175 | 2.139 | 2.137 | 0.608 | 0.604 | 4.912 | 4.957 |
| SU-4-IOF-6 | 0.0500 | 0.0781 | 3 | 2.173 | 2.173 | 2.164 | 2.133 | 0.609 | 0.600 | 4.895 | 4.923 |
| M-SU-4-IOF-1 | 0.0500 | 0.0938 | 1 | 2.150 | 2.162 | 2.156 | 2.168 | 0.619 | 0.591 | 4.974 | 4.971 |
| M-SU-4-IOF-2 | 0.0505 | 0.0977 | 1 | 2.172 | 2.176 | 2.157 | 2.146 | 0.623 | 0.607 | 4.910 | 4.906 |
| M-SU-4-IOF-5 | 0.0510 | 0.0938 | 3 | 2.167 | 2.167 | 2.132 | 2.142 | 0.608 | 0.603 | 4.936 | 4.925 |
| M-SU-4-IOF-6 | 0.0503 | 0.0898 | 3 | 2.173 | 2.157 | 2.164 | 2.159 | 0.600 | 0.615 | 4.922 | 4.950 |
| SU-BC-6-1 | 0.0497 | 0.0781 | 3 | 1.625 | 1.641 | 1.632 | 1.622 | 0.628 | 0.637 | 2.562 | 2.560 |
| SU-BC-6-2 | 0.0497 | 0.0781 | 3 | 1.628 | 1.648 | 1.645 | 1.617 | 0.611 | 0.643 | 2.570 | 2.572 |
| SU-BC-6-3 | 0.0507 | 0.0781 | 3 | 1.635 | 1.634 | 1.618 | 1.644 | 0.609 | 0.645 | 2.560 | 2.559 |
| SU-BC-6-4 | 0.0497 | 0.0781 | 3 | 1.599 | 1.617 | 1.620 | 1.622 | 0.635 | 0.635 | 2.550 | 2.539 |
| SU-BC-16-1 | 0.0510 | 0.0625 | 3 | 1.503 | 1.500 | 1.500 | 1.501 | 0.616 | 0.603 | 4.000 | 4.032 |
| SU-BC-16-2 | 0.0500 | 0.0625 | 3 | 1.485 | 1.490 | 1.475 | 1.498 | 0.613 | 0.601 | 4.022 | 4.043 |
| SU-BC-16-3 | 0.0510 | 0.0625 | 3 | 1.479 | 1.487 | 1.500 | 1.482 | 0.619 | 0.598 | 4.050 | 4.062 |
| SU-BC-16-4 | 0.0510 | 0.0625 | 3 | 1.811 | 1.804 | 1.785 | 1.821 | 0.607 | 0.608 | 4.050 | 4.044 |
| SU-BC-7-1 | 0.0470 | 0.0625 | 3 | 2.500 | 2.495 | 2.465 | 2.507 | 0.581 | 0.598 | 4.775 | 4.797 |
| SU-BC-7-2 | 0.0460 | 0.0625 | 3 | 2.497 | 2.477 | 2.503 | 2.502 | 0.589 | 0.615 | 4.773 | 4.800 |
| SU-BC-7-3 | 0.0460 | 0.0625 | 3 | 2.500 | 2.494 | 2.520 | 2.500 | 0.598 | 0.614 | 4.729 | 4.736 |
| SU-BC-7-4 | 0.0460 | 0.0625 | 3 | 2.500 | 2.496 | 2.512 | 2.504 | 0.590 | 0.623 | 4.759 | 4.747 |
| SU-BC-8-1 | 0.0500 | 0.0781 | 3 | 3.059 | 3.024 | 3.000 | 3.000 | 0.607 | 0.606 | 6.125 | 6.175 |
| SU-BC-8-2 | 0.0500 | 0.0781 | 3 | 2.995 | 2.970 | 2.972 | 2.989 | 0.626 | 0.602 | 6.190 | 6.200 |
| SU-BC-8-3 | 0.0500 | 0.0781 | 3 | 2.990 | 3.000 | 3.005 | 3.004 | 0.602 | 0.616 | 6.211 | 6.168 |
| SU-BC-8-4 | 0.0500 | 0.0781 | 3 | 2.991 | 3.000 | 3.000 | 2.984 | 0.611 | 0.618 | 6.205 | 6.179 |
| SU-BC-8'-1 | 0.0760 | 0.0938 | 3 | 2.268 | 2.250 | 2.248 | 2.275 | 0.732 | 0.729 | 4.033 | 4.009 |
| SU-BC-8'-2 | 0.0755 | 0.0938 | 3 | 2.247 | 2.252 | 2.254 | 2.230 | 0.722 | 0.713 | 4.077 | 4.072 |
| SU-BC-8'-3 | 0.0760 | 0.0938 | 3 | 2.262 | 2.256 | 2.258 | 2.267 | 0.691 | 0.716 | 4.104 | 4.160 |
| SU-BC-8'-4 | 0.0760 | 0.0938 | 3 | 2.263 | 2.258 | 2.245 | 2.283 | 0.727 | 0.709 | 4.155 | 4.085 |

**Table B1: – (Continued )**

| Specimen | t (in.) | R (in.) | N (in.) | B1 (in.) | B2 (in.) | B3 (in.) | B4 (in.) | d1 (in.) | d2 (in.) | D1 (in.) | D2 (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SU-13-IOF-1 | 0.0510 | 0.0625 | 4 | 1.800 | 1.817 | 1.790 | 1.798 | 0.603 | 0.612 | 4.062 | 4.071 |
| SU-13-IOF-2 | 0.0510 | 0.0625 | 4 | 1.825 | 1.785 | 1.821 | 1.823 | 0.603 | 0.592 | 4.069 | 4.075 |
| SU-13-IOF-3 | 0.0500 | 0.0625 | 7 | 1.822 | 1.800 | 1.782 | 1.792 | 0.610 | 0.618 | 4.038 | 4.027 |
| SU-13-IOF-4 | 0.0500 | 0.0625 | 7 | 1.806 | 1.786 | 1.796 | 1.822 | 0.603 | 0.603 | 4.057 | 4.012 |
| SU-13-IOF-5 | 0.0490 | 0.0625 | 3 | 1.818 | 1.807 | 1.795 | 1.799 | 0.600 | 0.607 | 4.017 | 4.032 |
| SU-13-IOF-6 | 0.0500 | 0.0625 | 3 | 1.781 | 1.802 | 1.800 | 1.815 | 0.606 | 0.598 | 4.020 | 4.012 |
| SU-13-IOF-7 | 0.0500 | 0.0625 | 3 | 1.818 | 1.789 | 1.781 | 1.815 | 0.615 | 0.603 | 4.021 | 4.009 |
| SU-13-IOF-8 | 0.0510 | 0.0625 | 3 | 1.779 | 1.775 | 1.810 | 1.812 | 0.618 | 0.604 | 4.030 | 4.030 |
| SU-4-IOF-1 | 0.0460 | 0.0625 | 4 | 2.037 | 2.070 | 2.086 | 2.100 | 0.598 | 0.604 | 4.775 | 4.769 |
| SU-4-IOF-2 | 0.0470 | 0.0625 | 4 | 2.098 | 2.056 | 2.070 | 2.060 | 0.591 | 0.589 | 4.764 | 4.777 |
| SU-4-IOF-3 | 0.0470 | 0.0625 | 7 | 2.092 | 2.066 | 2.069 | 2.066 | 0.606 | 0.580 | 4.740 | 4.739 |
| SU-4-IOF-4 | 0.0470 | 0.0625 | 7 | 2.052 | 2.044 | 2.075 | 2.070 | 0.624 | 0.635 | 4.653 | 4.725 |
| SU-2-IOF-1 | 0.0490 | 0.0625 | 6 | 1.972 | 1.965 | 1.987 | 1.986 | 0.588 | 0.622 | 6.220 | 6.250 |
| SU-2-IOF-2 | 0.0500 | 0.0625 | 6 | 1.964 | 1.965 | 1.981 | 1.985 | 0.580 | 0.626 | 6.235 | 6.243 |
| SU-2'-IOF-1 | 0.0497 | 0.0938 | 7 | 1.670 | 1.663 | 1.617 | 1.620 | 0.595 | 0.660 | 7.372 | 7.375 |
| SU-2'-IOF-2 | 0.0487 | 0.0938 | 7 | 1.656 | 1.652 | 1.617 | 1.618 | 0.618 | 0.633 | 7.367 | 7.370 |
| SU-2'-IOF-3 | 0.0497 | 0.0938 | 3 | 1.635 | 1.660 | 1.636 | 1.625 | 0.628 | 0.611 | 7.327 | 7.329 |
| SU-2'-IOF-4 | 0.0507 | 0.0938 | 3 | 1.637 | 1.624 | 1.635 | 1.632 | 0.621 | 0.633 | 7.330 | 7.368 |
| SU-2'-IOF-5 | 0.0507 | 0.0938 | 3 | 1.643 | 1.631 | 1.630 | 1.653 | 0.622 | 0.632 | 7.364 | 7.341 |
| SU-2'-IOF-6 | 0.0507 | 0.0938 | 3 | 1.622 | 1.632 | 1.626 | 1.675 | 0.623 | 0.647 | 7.361 | 7.381 |
| SU-3-IOF-1 | 0.0497 | 0.0938 | 6 | 1.655 | 1.657 | 1.625 | 1.631 | 0.639 | 0.627 | 9.769 | 9.790 |
| SU-3-IOF-2 | 0.0497 | 0.0938 | 6 | 1.642 | 1.625 | 1.634 | 1.656 | 0.636 | 0.631 | 9.804 | 9.795 |

**Table B2: Dimensions of Hat Sections - Cornell (1953)**

| Specimen | t (in.) | R (in.) | N (in.) | B1 (in.) | B2 (in.) | B3 (in.) | d1 (in.) | d2 (in.) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0614 | 0.0614 | 0.75 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 2 | 0.0622 | 0.0622 | 1.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 3 | 0.0619 | 0.0619 | 2.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 4 | 0.0603 | 0.1810 | 0.75 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 5 | 0.0610 | 0.1830 | 1.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 6 | 0.0603 | 0.1810 | 2.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 7 | 0.0642 | 0.0642 | 0.75 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 8 | 0.0646 | 0.0646 | 1.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 9 | 0.0646 | 0.0646 | 2.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 10 | 0.0652 | 0.1956 | 0.75 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 11 | 0.0640 | 0.1920 | 1.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 12 | 0.0639 | 0.1917 | 2.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 15 | 0.0606 | 0.0606 | 2.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 21 | 0.0648 | 0.0648 | 2.50 | 4.0 | 2.0 | 2.0 | 1.0 | 1.0 |
| 27 | 0.0598 | 0.0598 | 2.50 | 3.0 | 1.5 | 1.5 | 0.0 | 0.0 |
| 32 | 0.0646 | 0.0646 | 1.50 | 3.0 | 1.5 | 1.5 | 0.0 | 0.0 |
| 33 | 0.0650 | 0.0650 | 2.50 | 3.0 | 1.5 | 1.5 | 0.0 | 0.0 |
| 45 | 0.0681 | 0.0681 | 2.50 | 3.0 | 1.5 | 1.5 | 0.0 | 0.0 |

**Table B3: Dimensions of Channel C-sections – Ratliff (1975)**

| Specimen | t(in.) | R (in.) | N (in.) | B1 (in.) | B2 (in.) | d1 (in.) | d2 (in.) | D (in.) |
|---|---|---|---|---|---|---|---|---|
| CJ-18 | 0.050 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |
| CJ-19 | 0.050 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |
| CJ-20 | 0.050 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |
| CJ-21 | 0.062 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |
| CJ-22 | 0.062 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |
| CJ-23 | 0.062 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |
| CJ-24 | 0.076 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |
| CJ-25 | 0.076 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |
| CJ-26 | 0.076 | 0.09 | 3.5 | 1.83 | 1.83 | 0.55 | 0.55 | 7.25 |

**Table B4: Dimensions of Channel C-Sections – Young & Hancock (2000)**

| Specimen | t (mm) | R (mm) | N (mm) | B1 (mm) | B2 (mm) | D (mm) |
|---|---|---|---|---|---|---|
| C100K0.7N50-a | 3.83 | 4.1 | 50 | 50.4 | 50.4 | 99.4 |
| C100K0.7N50-b | 3.84 | 4.1 | 50 | 50.5 | 50.5 | 99.4 |
| C100K1.0N50-a | 3.82 | 4.1 | 50 | 50.4 | 50.4 | 99.4 |
| C100K1.0N50-b | 3.83 | 4.1 | 50 | 50.5 | 50.5 | 99.7 |
| C100K1.5N50-a | 3.83 | 4.1 | 50 | 50.5 | 50.5 | 99.3 |
| C100K1.5N50-b | 3.83 | 4.1 | 50 | 50.5 | 50.5 | 99.6 |
| C100K0.7N25-a | 3.83 | 4.1 | 25 | 50.5 | 50.5 | 99.4 |
| C100K0.7N25-b | 3.85 | 4.1 | 25 | 50.5 | 50.5 | 99.4 |
| C100K1.0N25-a | 3.83 | 4.1 | 25 | 50.4 | 50.4 | 99.4 |
| C100K1.0N25-b | 3.83 | 4.1 | 25 | 50.4 | 50.4 | 99.6 |
| C100K1.5N25-a | 3.84 | 4.1 | 25 | 50.4 | 50.4 | 99.4 |
| C100K1.5N25-b | 3.84 | 4.1 | 25 | 50.4 | 50.4 | 99.5 |
| C200K0.7N75-a | 4.72 | 4.2 | 75 | 35.8 | 35.8 | 198.4 |
| C200K0.7N75-b | 4.72 | 4.2 | 75 | 35.8 | 35.8 | 198.9 |
| C200K1.0N75-a | 4.71 | 4.2 | 75 | 75.8 | 75.8 | 198.8 |
| C200K1.0N75-b | 4.71 | 4.2 | 75 | 75.9 | 75.9 | 198.8 |
| C200K1.5N75-a | 4.72 | 4.2 | 75 | 75.9 | 75.9 | 198.7 |
| C200K1.5N75-b | 4.74 | 4.2 | 75 | 75.9 | 75.9 | 198.6 |
| C200K0.7N37-a | 4.70 | 4.2 | 37.5 | 75.8 | 75.8 | 198.5 |
| C200K0.7N37-b | 4.72 | 4.2 | 37.5 | 75.8 | 75.8 | 198.2 |
| C200K1.0N37-a | 4.72 | 4.2 | 37.5 | 75.6 | 75.6 | 198.5 |
| C200K1.0N37-b | 4.68 | 4.2 | 37.5 | 75.8 | 75.8 | 198.5 |
| C200K1.5N37-a | 4.73 | 4.2 | 37.5 | 75.7 | 75.7 | 198.6 |
| C200K1.5N37-b | 4.71 | 4.2 | 37.5 | 75.6 | 75.6 | 198.5 |
| C300K0.5N90-a | 6.00 | 8.4 | 90 | 91.2 | 91.2 | 298.5 |
| C300K0.5N90-b | 6.02 | 8.4 | 90 | 91.2 | 91.2 | 298.5 |
| C300K1.0N90-a | 6.01 | 8.4 | 90 | 91.1 | 91.1 | 298.4 |
| C300K1.0N90-b | 6.01 | 8.4 | 90 | 91.3 | 91.3 | 298.6 |
| C300K0.5N45-a | 6.00 | 8.4 | 45 | 91.5 | 91.5 | 298 |
| C300K0.5N45-b | 6.00 | 8.4 | 45 | 91.2 | 91.2 | 298.2 |
| C300K1.0N45-a | 6.00 | 8.4 | 45 | 91.2 | 91.2 | 298.1 |
| C300K1.0N45-b | 6.01 | 8.4 | 45 | 91.4 | 91.4 | 298.3 |

1 in. = 25.4 mm

**Table B5: Dimensions of I-sections (Stiffened Flanges) - Hetrakul and Yu (1978)**

| Specimen | t (in.) | R (in.) | N (in.) | B1 (in.) | B2 (in.) | B3 (in.) | B4 (in.) | d1 (in.) | d2 (in.) | D1 (in.) | D2 (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I-BC-4-1 | 0.0460 | 0.0938 | 3.0 | 2.075 | 2.080 | 2.064 | 2.056 | 0.573 | 0.581 | 4.750 | 4.814 |
| I-BC-4-2 | 0.0465 | 0.0938 | 3.0 | 2.083 | 2.068 | 2.066 | 2.071 | 0.607 | 0.595 | 4.694 | 4.790 |
| I-BC-4-3 | 0.0470 | 0.0938 | 3.0 | 2.072 | 2.069 | 2.067 | 2.078 | 0.609 | 0.582 | 4.783 | 4.692 |
| I-BC-4-4 | 0.0460 | 0.0938 | 3.0 | 2.053 | 2.058 | 2.075 | 2.086 | 0.617 | 0.581 | 4.775 | 4.684 |
| I-BC-4-5 | 0.0460 | 0.0938 | 3.0 | 2.047 | 2.089 | 2.075 | 2.105 | 0.571 | 0.609 | 4.736 | 4.767 |
| I-BC-4-6 | 0.0460 | 0.0938 | 3.0 | 2.056 | 2.087 | 2.095 | 2.070 | 0.590 | 0.609 | 4.721 | 4.738 |
| I-BC-5-1 | 0.0494 | 0.0938 | 3.0 | 4.507 | 4.509 | 4.529 | 4.508 | 0.685 | 0.666 | 9.898 | 9.815 |
| I-BC-5-2 | 0.0489 | 0.0938 | 3.0 | 4.545 | 4.500 | 4.525 | 4.529 | 0.678 | 0.664 | 9.856 | 9.871 |
| I-BC-5-3 | 0.0499 | 0.0938 | 3.0 | 4.514 | 4.492 | 4.520 | 4.498 | 0.698 | 0.694 | 9.854 | 9.861 |
| I-BC-5-4 | 0.0500 | 0.0938 | 3.0 | 4.530 | 4.494 | 4.534 | 4.571 | 0.679 | 0.697 | 9.850 | 9.832 |
| I-BC-5-5 | 0.0494 | 0.0938 | 3.0 | 4.525 | 4.506 | 4.505 | 4.507 | 0.664 | 0.688 | 9.941 | 9.814 |
| I-BC-5-6 | 0.0494 | 0.0938 | 3.0 | 4.518 | 4.510 | 4.500 | 4.535 | 0.681 | 0.675 | 9.884 | 9.948 |
| I-BC-6-1 | 0.0504 | 0.0938 | 3.0 | 1.635 | 1.645 | 1.650 | 1.635 | 0.573 | 0.682 | 2.514 | 2.535 |
| I-BC-6-2 | 0.0494 | 0.0938 | 3.0 | 1.640 | 1.630 | 1.628 | 1.645 | 0.601 | 0.645 | 2.532 | 2.528 |
| I-BC-6-3 | 0.0494 | 0.0938 | 3.0 | 1.638 | 1.677 | 1.645 | 1.607 | 0.617 | 0.673 | 2.480 | 2.504 |
| I-BC-6-4 | 0.0494 | 0.0938 | 3.0 | 1.646 | 1.678 | 1.642 | 1.617 | 0.648 | 0.624 | 2.497 | 2.493 |
| I-BC-6-5 | 0.0494 | 0.0938 | 3.0 | 1.654 | 1.654 | 1.621 | 1.627 | 0.611 | 0.659 | 2.566 | 2.555 |
| I-BC-6-6 | 0.0494 | 0.0938 | 3.0 | 1.653 | 1.662 | 1.648 | 1.617 | 0.595 | 0.651 | 2.502 | 2.559 |
| I-BC-8-1 | 0.0760 | 0.1250 | 3.0 | 2.284 | 2.245 | 2.253 | 2.253 | 0.717 | 0.745 | 4.082 | 4.082 |
| I-BC-8-2 | 0.0760 | 0.1250 | 3.0 | 2.258 | 2.269 | 2.281 | 2.281 | 0.729 | 0.731 | 4.072 | 4.096 |
| I-BC-8-3 | 0.0760 | 0.1250 | 3.0 | 2.273 | 2.284 | 2.281 | 2.281 | 0.737 | 0.690 | 4.097 | 4.104 |
| I-BC-8-4 | 0.0760 | 0.1250 | 3.0 | 2.236 | 2.272 | 2.277 | 2.277 | 0.703 | 0.742 | 4.000 | 4.088 |
| I-BC-8-5 | 0.0750 | 0.1250 | 3.0 | 2.251 | 2.234 | 2.260 | 2.260 | 0.747 | 0.709 | 4.086 | 4.050 |
| I-BC-8-6 | 0.0760 | 0.1250 | 3.0 | 2.227 | 2.257 | 2.245 | 2.245 | 0.740 | 0.729 | 4.075 | 4.057 |
| I-BC-9-1 | 0.0760 | 0.1250 | 3.0 | 2.287 | 2.274 | 2.268 | 2.269 | 0.718 | 0.722 | 7.830 | 7.750 |
| I-BC-9-2 | 0.0760 | 0.1250 | 3.0 | 2.249 | 2.266 | 2.277 | 2.256 | 0.732 | 0.722 | 7.780 | 7.810 |
| I-BC-9-3 | 0.0760 | 0.1250 | 3.0 | 2.261 | 2.277 | 2.254 | 2.248 | 0.712 | 0.738 | 7.796 | 7.796 |
| I-BC-9-4 | 0.0760 | 0.1250 | 3.0 | 2.257 | 2.274 | 2.279 | 2.270 | 0.731 | 0.722 | 7.784 | 7.804 |
| I-BC-9-5 | 0.0750 | 0.1250 | 3.0 | 2.271 | 2.259 | 2.273 | 2.284 | 0.716 | 0.723 | 7.750 | 7.744 |
| I-BC-9-6 | 0.0750 | 0.1250 | 3.0 | 2.292 | 2.265 | 2.263 | 2.269 | 0.726 | 0.712 | 7.750 | 7.792 |
| I-BC-9'-1 | 0.0500 | 0.0781 | 3.0 | 3.476 | 3.524 | 3.494 | 3.529 | 0.611 | 0.626 | 7.384 | 7.325 |
| I-BC-9'-2 | 0.0510 | 0.0781 | 3.0 | 3.490 | 3.535 | 3.504 | 3.525 | 0.624 | 0.618 | 7.396 | 7.317 |
| I-BC-9'-3 | 0.0500 | 0.0781 | 3.0 | 3.527 | 3.477 | 3.508 | 3.495 | 0.625 | 0.611 | 7.319 | 7.386 |
| I-BC-9'-4 | 0.0510 | 0.0781 | 3.0 | 3.501 | 3.514 | 3.519 | 3.500 | 0.610 | 0.606 | 7.340 | 7.312 |
| I-BC-9'-5 | 0.0500 | 0.0781 | 3.0 | 3.500 | 3.517 | 3.511 | 3.504 | 0.616 | 0.608 | 7.375 | 7.380 |
| I-BC-9'-6 | 0.0510 | 0.0781 | 3.0 | 3.501 | 3.514 | 3.519 | 3.500 | 0.610 | 0.606 | 7.340 | 7.312 |
| I-BC-10-1 | 0.1070 | 0.1094 | 3.0 | 2.350 | 2.350 | 2.325 | 2.337 | 0.858 | 0.865 | 5.500 | 5.480 |
| I-BC-10-2 | 0.1070 | 0.1094 | 3.0 | 2.338 | 2.350 | 2.330 | 2.343 | 0.858 | 0.867 | 5.498 | 5.477 |
| I-BC-10-3 | 0.1060 | 0.1094 | 3.0 | 2.328 | 2.342 | 2.334 | 2.335 | 0.870 | 0.856 | 5.471 | 5.495 |
| I-BC-10-4 | 0.1070 | 0.1094 | 3.0 | 2.344 | 2.338 | 2.320 | 2.345 | 0.863 | 0.861 | 5.462 | 5.507 |
| I-BC-10-5 | 0.1070 | 0.1094 | 3.0 | 2.341 | 2.339 | 2.354 | 2.332 | 0.854 | 0.855 | 5.493 | 5.500 |
| I-BC-10-6 | 0.1065 | 0.1094 | 3.0 | 2.335 | 2.324 | 2.337 | 2.357 | 0.879 | 0.867 | 5.481 | 5.428 |
| I-BC-13-1 | 0.1090 | 0.1250 | 3.0 | 4.984 | 4.931 | 4.979 | 4.975 | 1.063 | 1.068 | 10.65 | 10.63 |
| I-BC-13-2 | 0.1070 | 0.1250 | 3.0 | 4.950 | 5.000 | 4.985 | 4.989 | 1.035 | 1.034 | 10.68 | 10.74 |
| I-BC-13-3 | 0.1065 | 0.1250 | 3.0 | 4.975 | 4.964 | 4.984 | 4.969 | 1.047 | 1.050 | 10.71 | 10.68 |
| I-BC-13-4 | 0.1080 | 0.1250 | 3.0 | 4.982 | 4.993 | 4.991 | 4.979 | 1.051 | 1.039 | 10.66 | 10.75 |
| I-BC-13-5 | 0.1090 | 0.1250 | 3.0 | 4.987 | 5.007 | 5.004 | 4.996 | 1.056 | 1.045 | 10.67 | 10.72 |
| I-BC-13-6 | 0.1070 | 0.1250 | 3.0 | 4.975 | 4.990 | 4.994 | 4.978 | 1.038 | 1.057 | 10.68 | 10.74 |
| I-3-IOF-5 | 0.0490 | 0.0938 | 3.0 | 2.006 | 1.977 | 1.990 | 1.979 | 0.624 | 0.599 | 7.355 | 7.367 |
| I-3-IOF-6 | 0.0490 | 0.0938 | 3.0 | 2.001 | 1.977 | 1.971 | 1.975 | 0.619 | 0.614 | 7.358 | 7.367 |

**Table B5: (Continued)**

| Specimen | t (in.) | R (in.) | N (in.) | B1 (in.) | B2 (in.) | B3 (in.) | B4 (in.) | d1 (in.) | d2 (in.) | D1 (in.) | D2 (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I-3'-IOF-1 | 0.0460 | 0.0938 | 1.0 | 1.931 | 1.959 | 1.938 | 1.931 | 0.600 | 0.643 | 7.075 | 7.102 |
| I-3'-IOF-2 | 0.0460 | 0.0938 | 1.0 | 1.937 | 1.935 | 1.927 | 1.973 | 0.608 | 0.607 | 7.112 | 7.065 |
| I-3'-IOF-5 | 0.0460 | 0.0938 | 3.0 | 1.916 | 1.933 | 1.959 | 1.928 | 0.602 | 0.601 | 7.172 | 7.116 |
| I-3'-IOF-6 | 0.0450 | 0.0938 | 3.0 | 1.924 | 1.952 | 1.922 | 1.928 | 0.605 | 0.590 | 7.106 | 7.108 |
| I-5'-IOF-5 | 0.0600 | 0.0938 | 3.0 | 1.739 | 1.749 | 1.885 | 1.917 | 0.540 | 0.513 | 7.277 | 7.313 |
| I-5'-IOF-6 | 0.0590 | 0.0938 | 3.0 | 1.735 | 1.745 | 1.880 | 1.895 | 0.528 | 0.520 | 7.292 | 7.337 |
| I-6-IOF-1 | 0.0752 | 0.1016 | 1.0 | 1.750 | 1.751 | 1.931 | 1.936 | 0.509 | 0.544 | 7.286 | 7.321 |
| I-6-IOF-2 | 0.0752 | 0.0938 | 1.0 | 1.750 | 1.750 | 1.928 | 1.934 | 0.509 | 0.522 | 7.287 | 7.325 |
| I-6-IOF-5 | 0.0752 | 0.0938 | 3.0 | 1.789 | 1.783 | 1.929 | 1.931 | 0.493 | 0.529 | 7.398 | 7.399 |
| I-6-IOF-6 | 0.0751 | 0.0938 | 3.0 | 1.768 | 1.772 | 1.930 | 1.934 | 0.496 | 0.517 | 7.381 | 7.420 |
| I-6-IOF-7 | 0.0755 | 0.0859 | 3.0 | 1.768 | 1.762 | 1.930 | 1.927 | 0.497 | 0.521 | 7.417 | 7.391 |
| I-6-IOF-8 | 0.0750 | 0.0938 | 3.0 | 1.767 | 1.770 | 1.929 | 1.933 | 0.502 | 0.515 | 7.390 | 7.430 |
| I-6"-IOF-5 | 0.0460 | 0.0938 | 3.0 | 2.986 | 3.032 | 2.981 | 3.009 | 0.644 | 0.623 | 7.079 | 7.116 |
| I-6"-IOF-6 | 0.0460 | 0.0938 | 3.0 | 2.938 | 2.940 | 2.951 | 2.946 | 0.683 | 0.673 | 6.931 | 6.974 |
| I-12-IOF-6 | 0.0510 | 0.0938 | 3.0 | 1.497 | 1.481 | 1.513 | 1.522 | 0.589 | 0.617 | 7.444 | 7.491 |
| I-12'-IOF-5 | 0.1080 | 0.1094 | 3.0 | 3.977 | 3.973 | 3.955 | 3.968 | 1.036 | 1.040 | 5.550 | 5.550 |
| I-12'-IOF-6 | 0.1070 | 0.1094 | 3.0 | 3.935 | 3.991 | 3.963 | 3.975 | 1.038 | 1.038 | 5.492 | 5.507 |
| I-16-IOF-1 | 0.0505 | 0.0938 | 1.0 | 2.516 | 2.524 | 2.536 | 2.513 | 0.565 | 0.582 | 4.056 | 4.031 |
| I-16-IOF-2 | 0.0505 | 0.0938 | 1.0 | 2.519 | 2.516 | 2.534 | 2.524 | 0.617 | 0.556 | 4.029 | 4.041 |
| I-16-IOF-5 | 0.0500 | 0.0938 | 3.0 | 2.493 | 2.513 | 2.509 | 2.499 | 0.611 | 0.556 | 3.978 | 4.006 |
| I-16-IOF-6 | 0.0510 | 0.0938 | 3.0 | 2.524 | 2.502 | 2.535 | 2.508 | 0.616 | 0.600 | 3.980 | 3.974 |
| I-13-IOF-1 | 0.0500 | 0.0625 | 4.0 | 1.792 | 1.807 | 1.832 | 1.793 | 0.610 | 0.614 | 4.007 | 4.020 |
| I-13-IOF-2 | 0.0510 | 0.0625 | 4.0 | 1.789 | 1.770 | 1.803 | 1.788 | 0.590 | 0.624 | 4.007 | 4.023 |
| I-4'-IOF-1 | 0.0497 | 0.0625 | 4.2 | 1.632 | 1.643 | 1.622 | 1.644 | 0.623 | 0.605 | 4.906 | 4.890 |
| I-4'-IOF-2 | 0.0497 | 0.0625 | 4.2 | 1.620 | 1.629 | 1.631 | 1.639 | 0.602 | 0.636 | 4.889 | 4.898 |
| I-2'-IOF-1 | 0.0497 | 0.0938 | 5.0 | 1.642 | 1.655 | 1.625 | 1.628 | 0.608 | 0.643 | 7.370 | 7.363 |
| I-2'-IOF-2 | 0.0497 | 0.0938 | 5.0 | 1.648 | 1.657 | 1.625 | 1.622 | 0.612 | 0.660 | 7.347 | 7.350 |
| I-3-IOF-1 | 0.0487 | 0.0938 | 6.0 | 1.625 | 1.636 | 1.633 | 1.633 | 0.652 | 0.609 | 9.806 | 9.828 |
| I-3-IOF-1 | 0.0487 | 0.0938 | 6.0 | 1.662 | 1.630 | 1.629 | 1.647 | 0.625 | 0.619 | 9.788 | 9.826 |

**Table B6: Dimensions of I-sections (Stiffened Flanges) – Winter & Pian (1946)**

| Specimen | t (in.) | R (in.) | N (in.) | B1 (in.) | B2 (in.) | B3 (in.) | B4 (in.) | d1 (in.) | d2 (in.) | D1 (in.) | D2 (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1b-1-IOF | 0.0460 | 0.0460 | 2.50 | 2.550 | 2.550 | 3.210 | 3.210 | 0.61 | 0.90 | 7.92 | 7.92 |
| 1c-1-IOF | 0.0460 | 0.0460 | 3.50 | 2.550 | 2.550 | 3.210 | 3.210 | 0.61 | 0.90 | 7.92 | 7.92 |
| 2a-1-IOF | 0.0603 | 0.0603 | 1.00 | 2.555 | 2.555 | 2.545 | 2.545 | 0.74 | 0.78 | 3.98 | 3.98 |
| 2b-1-IOF | 0.0603 | 0.0603 | 1.00 | 2.555 | 2.555 | 2.545 | 2.545 | 0.74 | 0.78 | 3.98 | 3.98 |
| 2b-2-IOF | 0.0603 | 0.0603 | 1.50 | 2.555 | 2.555 | 2.545 | 2.545 | 0.74 | 0.78 | 3.98 | 3.98 |
| 3-1-IOF | 0.0599 | 0.0599 | 3.00 | 1.975 | 1.975 | 1.965 | 1.965 | 0.56 | 0.53 | 3.97 | 3.97 |
| 3-2-IOF | 0.0599 | 0.0599 | 2.50 | 1.975 | 1.975 | 1.965 | 1.965 | 0.56 | 0.53 | 3.97 | 3.97 |
| 4b-1-IOF | 0.0609 | 0.0609 | 3.00 | 2.980 | 2.980 | 2.995 | 2.995 | 0.79 | 0.80 | 6.10 | 6.10 |
| 5a-1-IOF | 0.0616 | 0.0616 | 1.25 | 3.300 | 3.300 | 3.975 | 3.975 | 0.72 | 1.02 | 8.00 | 8.00 |
| 5b-1-IOF | 0.0616 | 0.0616 | 2.50 | 3.300 | 3.300 | 3.975 | 3.975 | 0.72 | 1.02 | 8.00 | 8.00 |
| 5c-1-IOF | 0.0616 | 0.0616 | 3.50 | 3.300 | 3.300 | 3.975 | 3.975 | 0.72 | 1.02 | 8.00 | 8.00 |
| 7a-1-IOF | 0.0752 | 0.0752 | 1.25 | 3.000 | 3.000 | 3.700 | 3.700 | 0.84 | 1.00 | 7.95 | 7.95 |
| 7b-1-IOF | 0.0752 | 0.0752 | 3.50 | 3.000 | 3.000 | 3.700 | 3.700 | 0.84 | 1.00 | 7.95 | 7.95 |
| 8-1-IOF | 0.0755 | 0.0755 | 2.50 | 4.035 | 4.035 | 4.975 | 4.975 | 0.89 | 0.96 | 8.00 | 8.00 |
| 9b-1-IOF | 0.1070 | 0.1070 | 0.80 | 2.485 | 2.485 | 2.485 | 2.485 | 0.75 | 0.74 | 3.94 | 3.94 |
| 10a-1-IOF | 0.1082 | 0.1082 | 1.00 | 3.015 | 3.015 | 3.000 | 3.000 | 0.80 | 0.77 | 5.92 | 5.92 |
| 10a-2-IOF | 0.1082 | 0.1082 | 1.50 | 3.015 | 3.015 | 3.000 | 3.000 | 0.80 | 0.77 | 5.92 | 5.92 |
| 10b-1-IOF | 0.1082 | 0.1082 | 3.00 | 3.015 | 3.015 | 3.000 | 3.000 | 0.80 | 0.77 | 5.92 | 5.92 |
| 12-1-IOF | 0.1109 | 0.1109 | 2.50 | 3.975 | 3.975 | 4.005 | 4.005 | 0.79 | 0.77 | 7.95 | 7.95 |
| 13a-1-IOF | 0.1342 | 0.1342 | 1.00 | 2.445 | 2.445 | 2.460 | 2.460 | 0.72 | 0.71 | 3.96 | 3.96 |
| 13b-1-IOF | 0.1342 | 0.1342 | 1.50 | 2.445 | 2.445 | 2.460 | 2.460 | 0.72 | 0.71 | 3.96 | 3.96 |
| 14a-1-IOF | 0.1478 | 0.1478 | 1.00 | 3.005 | 3.005 | 3.000 | 3.000 | 0.68 | 0.68 | 5.95 | 5.95 |
| 14a-2-IOF | 0.1478 | 0.1478 | 1.50 | 3.005 | 3.005 | 3.000 | 3.000 | 0.68 | 0.68 | 5.95 | 5.95 |
| 14b-1-IOF | 0.1478 | 0.1478 | 2.50 | 3.005 | 3.005 | 3.000 | 3.000 | 0.68 | 0.68 | 5.95 | 5.95 |
| 15a-1-IOF | 0.1473 | 0.1473 | 1.00 | 3.025 | 3.025 | 3.005 | 3.005 | 0.66 | 0.65 | 7.97 | 7.97 |
| 15a-2-IOF | 0.1473 | 0.1473 | 1.50 | 3.025 | 3.025 | 3.005 | 3.005 | 0.66 | 0.65 | 7.97 | 7.97 |
| 15b-1-IOF | 0.1473 | 0.1473 | 2.50 | 3.025 | 3.025 | 3.005 | 3.005 | 0.66 | 0.65 | 7.97 | 7.97 |
| 16a-1-IOF | 0.0460 | 0.0460 | 1.50 | 1.200 | 1.200 | 1.510 | 1.510 | 0.64 | 1.02 | 8.02 | 8.02 |
| 16b-1-IOF | 0.0460 | 0.0460 | 2.50 | 1.200 | 1.200 | 1.510 | 1.510 | 0.64 | 1.02 | 8.02 | 8.02 |
| 16c-1-IOF | 0.0460 | 0.0460 | 3.50 | 1.200 | 1.200 | 1.510 | 1.510 | 0.64 | 1.02 | 8.02 | 8.02 |
| 17a-1-IOF | 0.0755 | 0.0755 | 1.25 | 1.450 | 1.450 | 1.990 | 1.990 | 0.84 | 1.00 | 7.98 | 7.98 |
| 17b-1-IOF | 0.0755 | 0.0755 | 2.50 | 1.450 | 1.450 | 1.990 | 1.990 | 0.84 | 1.00 | 7.98 | 7.98 |
| 17c-1-IOF | 0.0755 | 0.0755 | 3.50 | 1.450 | 1.450 | 1.990 | 1.990 | 0.84 | 1.00 | 7.98 | 7.98 |

**Table B7: Dimensions of I-sections (Unstiffened Flanges) - Hetrakul and Yu (1978)**

| Specimen | t (in.) | R (in.) | N (in.) | B1 (in.) | B2 (in.) | B3 (in.) | B4 (in.) | d1 (in.) | d2 (in.) | D1 (in.) | D2 (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I-U-17-IOF-5 | 0.049 | 0.047 | 3 | 1.486 | 1.357 | 1.387 | 1.500 | - | - | 4.910 | 4.912 |
| I-U-17-IOF-6 | 0.049 | 0.047 | 3 | 1.375 | 1.386 | 1.425 | 1.380 | - | - | 4.960 | 4.925 |

**Table B8: Experimental and Calculated Results of Channel C-sections - Hetrakul & Yu (1978), Ratliff (1975), Young & Hancock (2000)**

| Specimen | Fy (ksi) | Pt (kip) | Pc (kip) | Mt (in-kip) | Mc (in-kip) | Pt/Pc | Mt/Mc | A/1.42 Eq.4 | A'/1.32 Eq. 12 |
|---|---|---|---|---|---|---|---|---|---|
| SU-BC-1-1 | 33.5 | 1.14 | 1.29 | 11.4 | 21.1 | 0.883 | 0.541 | 1.047 | 1.006 |
| SU-BC-1-2 | 33.5 | 1.18 | 1.29 | 11.3 | 21.2 | 0.914 | 0.532 | 1.064 | 1.020 |
| SU-BC-1-3 | 33.5 | 0.86 | 1.29 | 15.9 | 21.2 | 0.666 | 0.752 | 1.031 | 1.018 |
| SU-BC-1-4 | 33.5 | 0.89 | 1.32 | 16.5 | 21.5 | 0.674 | 0.764 | 1.046 | 1.033 |
| SU-BC-1-5 | 33.5 | 0.61 | 1.35 | 21.1 | 22.0 | 0.453 | 0.957 | 1.015 | 1.030 |
| SU-BC-1-6 | 33.5 | 0.53 | 1.29 | 18.3 | 21.3 | 0.410 | 0.859 | 0.914 | 0.927 |
| SU-BC-3-1 | 36.9 | 1.20 | 1.63 | 19.8 | 53.9 | 0.735 | 0.367 | 0.813 | 0.774 |
| SU-BC-3-2 | 36.9 | 1.34 | 1.63 | 22.0 | 53.7 | 0.818 | 0.410 | 0.905 | 0.862 |
| SU-BC-3-3 | 36.9 | 1.11 | 1.63 | 26.0 | 53.8 | 0.677 | 0.483 | 0.850 | 0.822 |
| SU-BC-3-4 | 36.9 | 1.17 | 1.63 | 27.5 | 54.1 | 0.717 | 0.509 | 0.898 | 0.869 |
| SU-BC-3-5 | 36.9 | 0.93 | 1.57 | 29.6 | 52.6 | 0.590 | 0.563 | 0.841 | 0.824 |
| SU-BC-3-6 | 36.9 | 1.02 | 1.63 | 32.6 | 54.1 | 0.625 | 0.603 | 0.896 | 0.878 |
| SU-BC-15-1 | 53.8 | 2.09 | 2.28 | 24.0 | 56.0 | 0.916 | 0.429 | 0.992 | 0.942 |
| SU-BC-15-2 | 53.8 | 2.08 | 2.37 | 23.9 | 59.6 | 0.874 | 0.400 | 0.940 | 0.892 |
| SU-BC-15-3 | 53.8 | 1.84 | 2.37 | 39.6 | 59.0 | 0.775 | 0.671 | 1.056 | 1.031 |
| SU-BC-15-4 | 53.8 | 1.80 | 2.28 | 38.7 | 57.6 | 0.789 | 0.671 | 1.067 | 1.040 |
| SU-BC-15-5 | 53.8 | 1.50 | 2.38 | 51.8 | 58.7 | 0.631 | 0.882 | 1.097 | 1.094 |
| SU-BC-15-6 | 53.8 | 1.50 | 2.47 | 51.8 | 60.4 | 0.607 | 0.856 | 1.061 | 1.058 |
| SU-4-IOF-1 | 47.1 | 1.53 | 1.56 | 9.53 | 31.1 | 0.978 | 0.307 | 0.953 | 0.892 |
| SU-4-IOF-2 | 47.1 | 1.53 | 1.59 | 9.53 | 31.7 | 0.961 | 0.300 | 0.936 | 0.875 |
| SU-4-IOF-3 | 47.1 | 1.77 | 1.80 | 11.1 | 32.0 | 0.985 | 0.345 | 0.985 | 0.925 |
| SU-4-IOF-4 | 47.1 | 1.78 | 1.82 | 11.1 | 31.3 | 0.976 | 0.354 | 0.985 | 0.926 |
| SU-4-IOF-5 | 47.1 | 2.09 | 2.05 | 13.0 | 31.9 | 1.017 | 0.409 | 1.054 | 0.995 |
| SU-4-IOF-6 | 47.1 | 1.99 | 2.05 | 12.4 | 31.7 | 0.968 | 0.391 | 1.005 | 0.949 |
| M-SU-4-IOF-1 | 47.1 | 1.61 | 1.54 | 10.0 | 32.3 | 1.044 | 0.311 | 1.006 | 0.939 |
| M-SU-4-IOF-2 | 47.1 | 1.63 | 1.56 | 10.2 | 32.3 | 1.048 | 0.316 | 1.012 | 0.946 |
| M-SU-4-IOF-5 | 47.1 | 2.20 | 2.05 | 13.8 | 32.5 | 1.072 | 0.423 | 1.106 | 1.043 |
| M-SU-4-IOF-6 | 47.1 | 2.08 | 2.02 | 13.0 | 31.9 | 1.030 | 0.407 | 1.063 | 1.003 |
| SU-BC-6-1 | 36.9 | 0.88 | 1.64 | 11.1 | 10.2 | 0.538 | 1.086 | 1.170 | 1.186 |
| SU-BC-6-2 | 36.9 | 0.84 | 1.64 | 10.6 | 10.3 | 0.514 | 1.031 | 1.113 | 1.128 |
| SU-BC-6-3 | 36.9 | 0.57 | 1.70 | 11.1 | 10.4 | 0.332 | 1.065 | 1.000 | 1.031 |
| SU-BC-6-4 | 36.9 | 0.65 | 1.64 | 12.8 | 10.1 | 0.397 | 1.266 | 1.191 | 1.227 |
| SU-BC-16-1 | 53.8 | 1.44 | 2.57 | 23.2 | 26.4 | 0.561 | 0.878 | 1.042 | 1.044 |
| SU-BC-16-2 | 53.8 | 1.35 | 2.47 | 21.8 | 25.9 | 0.547 | 0.839 | 1.004 | 1.005 |
| SU-BC-16-3 | 53.8 | 1.01 | 2.56 | 26.3 | 26.6 | 0.392 | 0.986 | 0.990 | 1.011 |
| SU-BC-16-4 | 53.8 | 1.11 | 2.56 | 28.9 | 27.4 | 0.431 | 1.052 | 1.066 | 1.088 |
| SU-BC-7-1 | 33.5 | 1.00 | 1.35 | 19.1 | 22.8 | 0.743 | 0.838 | 1.150 | 1.136 |
| SU-BC-7-2 | 33.5 | 0.94 | 1.29 | 18.0 | 22.4 | 0.729 | 0.803 | 1.115 | 1.100 |
| SU-BC-7-3 | 33.5 | 0.70 | 1.29 | 19.0 | 22.3 | 0.542 | 0.853 | 1.009 | 1.012 |
| SU-BC-7-4 | 33.5 | 0.76 | 1.29 | 20.5 | 22.2 | 0.585 | 0.922 | 1.090 | 1.093 |
| SU-BC-8-1 | 47.1 | 1.54 | 2.02 | 33.2 | 42.7 | 0.758 | 0.777 | 1.119 | 1.100 |
| SU-BC-8-2 | 47.1 | 1.47 | 2.02 | 31.8 | 43.7 | 0.727 | 0.728 | 1.060 | 1.041 |
| SU-BC-8-3 | 47.1 | 1.31 | 2.02 | 38.8 | 42.8 | 0.647 | 0.906 | 1.126 | 1.123 |
| SU-BC-8-4 | 47.1 | 1.30 | 2.02 | 38.5 | 43.1 | 0.642 | 0.893 | 1.113 | 1.109 |
| SU-BC-8'-1 | 43.6 | 2.21 | 4.25 | 38.9 | 41.0 | 0.518 | 0.947 | 1.058 | 1.067 |
| SU-BC-8'-2 | 43.6 | 2.37 | 4.20 | 41.7 | 41.3 | 0.564 | 1.010 | 1.136 | 1.145 |
| SU-BC-8'-3 | 43.6 | 1.59 | 4.25 | 42.3 | 41.9 | 0.374 | 1.009 | 0.993 | 1.017 |
| SU-BC-8'-4 | 43.6 | 1.70 | 4.25 | 45.3 | 42.3 | 0.400 | 1.070 | 1.055 | 1.080 |

**Table B8: (Continued)**

| Specimen | Fy (ksi) | Pt (kip) | Pc (kip) | Mt (in-kip) | Mc (in-kip) | Pt/Pc | Mt/Mc | A/1.42 Eq.4 | A'/1.32 Eq. 12 |
|---|---|---|---|---|---|---|---|---|---|
| SU-13-IOF-1 | 53.8 | 2.63 | 2.77 | 11.8 | 27.5 | 0.948 | 0.429 | 1.017 | 0.964 |
| SU-13-IOF-2 | 53.8 | 2.66 | 2.77 | 12.0 | 27.6 | 0.961 | 0.433 | 1.029 | 0.976 |
| SU-13-IOF-3 | 53.8 | 3.00 | 3.14 | 13.1 | 26.7 | 0.954 | 0.491 | 1.065 | 1.015 |
| SU-13-IOF-4 | 53.8 | 3.18 | 3.14 | 13.9 | 26.6 | 1.012 | 0.523 | 1.130 | 1.078 |
| SU-13-IOF-5 | 53.8 | 2.31 | 2.37 | 8.36 | 25.8 | 0.972 | 0.324 | 0.960 | 0.901 |
| SU-13-IOF-6 | 58.8 | 2.45 | 2.70 | 8.88 | 28.2 | 0.909 | 0.315 | 0.907 | 0.852 |
| SU-13-IOF-7 | 53.8 | 2.63 | 2.47 | 8.22 | 26.8 | 1.066 | 0.307 | 1.019 | 0.951 |
| SU-13-IOF-8 | 53.8 | 2.58 | 2.56 | 8.05 | 27.4 | 1.004 | 0.293 | - | - |
| SU-4-IOF-1 | 33.5 | 1.69 | 1.40 | 8.45 | 21.6 | 1.210 | 0.392 | 1.188 | 1.113 |
| SU-4-IOF-2 | 33.5 | 1.62 | 1.46 | 8.10 | 22.0 | 1.112 | 0.369 | 1.098 | 1.029 |
| SU-4-IOF-3 | 33.5 | 2.01 | 1.72 | 9.77 | 22.1 | 1.164 | 0.442 | 1.189 | 1.120 |
| SU-4-IOF-4 | 33.5 | 1.92 | 1.72 | 9.36 | 22.1 | 1.114 | 0.424 | 1.138 | 1.073 |
| SU-2-IOF-1 | 47.1 | 2.90 | 2.46 | 16.7 | 39.4 | 1.177 | 0.423 | 1.185 | 1.114 |
| SU-2-IOF-2 | 47.1 | 2.90 | 2.56 | 16.7 | 40.1 | 1.130 | 0.415 | 1.143 | 1.076 |
| SU-2'-IOF-1 | 36.9 | 2.31 | 1.90 | 16.5 | 39.4 | 1.219 | 0.418 | 1.213 | 1.139 |
| SU-2'-IOF-2 | 36.9 | 2.35 | 1.82 | 16.7 | 38.4 | 1.291 | 0.435 | 1.280 | 1.200 |
| SU-2'-IOF-3 | 36.9 | 1.75 | 1.49 | 11.6 | 39.1 | 1.177 | 0.296 | - | - |
| SU-2'-IOF-4 | 36.9 | 1.71 | 1.55 | 11.3 | 40.0 | 1.104 | 0.283 | - | - |
| SU-2'-IOF-5 | 36.9 | 1.58 | 1.55 | 8.10 | 40.1 | 1.020 | 0.202 | - | - |
| SU-2'-IOF-6 | 36.9 | 1.54 | 1.55 | 7.89 | 40.1 | 0.995 | 0.197 | - | - |
| SU-3-IOF-1 | 36.9 | 2.15 | 1.77 | 20.4 | 54.4 | 1.215 | 0.375 | 1.180 | 1.104 |
| SU-3-IOF-2 | 36.9 | 2.29 | 1.77 | 21.8 | 54.2 | 1.295 | 0.402 | 1.258 | 1.177 |
| CJ-18 | 42.2 | 1.16 | 1.82 | 33.6 | 42.8 | 0.639 | 0.786 | 1.035 | 1.027 |
| CJ-19 | 42.2 | 1.38 | 1.82 | 26.9 | 42.8 | 0.760 | 0.629 | 1.016 | 0.989 |
| CJ-20 | 42.2 | 1.74 | 1.82 | 8.57 | 42.8 | 0.958 | 0.200 | - | - |
| CJ-21 | 43.2 | 1.96 | 2.86 | 50.0 | 58.9 | 0.685 | 0.848 | 1.113 | 1.104 |
| CJ-22 | 43.2 | 2.62 | 2.86 | 33.3 | 58.9 | 0.915 | 0.564 | 1.087 | 1.045 |
| CJ-23 | 43.2 | 2.94 | 2.86 | 19.0 | 58.9 | 1.027 | 0.322 | 1.000 | 0.936 |
| CJ-24 | 41.9 | 2.88 | 4.16 | 55.6 | 73.0 | 0.692 | 0.761 | 1.058 | 1.043 |
| CJ-25 | 41.9 | 3.28 | 4.16 | 42.5 | 73.0 | 0.788 | 0.582 | 1.004 | 0.972 |
| CJ-26 | 41.9 | 3.82 | 4.16 | 27.7 | 73.0 | 0.918 | 0.379 | 0.959 | 0.906 |
| C100K0.7N50-a* | 440 | 54.2 | 91.8 | 7.62 | 8.92 | 0.591 | 0.854 | 1.047 | 1.045 |
| C100K0.7N50-b* | 440 | 54.2 | 92.3 | 7.64 | 8.92 | 0.587 | 0.856 | 1.046 | 1.045 |
| C100K1.0N50-a* | 440 | 44.0 | 91.3 | 8.83 | 8.92 | 0.482 | 0.990 | 1.060 | 1.075 |
| C100K1.0N50-b* | 440 | 44.0 | 91.8 | 8.84 | 8.92 | 0.479 | 0.991 | 1.059 | 1.074 |
| C100K1.5N50-a* | 440 | 34.6 | 91.8 | 10.4 | 8.92 | 0.377 | 1.171 | 1.109 | 1.142 |
| C100K1.5N50-b* | 440 | 34.6 | 91.8 | 10.4 | 8.92 | 0.377 | 1.169 | 1.108 | 1.140 |
| C100K0.7N25-a* | 440 | 48.9 | 82.8 | 7.07 | 8.92 | 0.591 | 0.793 | 1.004 | 0.999 |
| C100K0.7N25-b* | 440 | 48.9 | 83.6 | 7.08 | 8.92 | 0.585 | 0.793 | 0.999 | 0.995 |
| C100K1.0N25-a* | 440 | 40.7 | 82.8 | 8.37 | 8.92 | 0.492 | 0.938 | 1.031 | 1.042 |
| C100K1.0N25-b* | 440 | 40.7 | 82.7 | 8.41 | 8.92 | 0.492 | 0.943 | 1.035 | 1.046 |
| C100K1.5N25-a* | 440 | 31.6 | 83.2 | 9.81 | 8.92 | 0.380 | 1.100 | 1.061 | 1.089 |
| C100K1.5N25-b* | 440 | 31.6 | 83.2 | 9.81 | 8.92 | 0.380 | 1.100 | 1.061 | 1.089 |
| C200K0.7N75-a* | 415 | 91.8 | 138 | 19.7 | 33.3 | 0.667 | 0.590 | 0.918 | 0.897 |
| C200K0.7N75-b* | 415 | 91.8 | 138 | 19.7 | 33.3 | 0.667 | 0.590 | 0.919 | 0.897 |
| C200K1.0N75-a* | 415 | 68.5 | 137 | 29.4 | 33.3 | 0.500 | 0.881 | 0.997 | 1.005 |
| C200K1.0N75-b* | 415 | 68.5 | 137 | 29.4 | 33.3 | 0.500 | 0.881 | 0.998 | 1.005 |
| C200K1.5N75-a* | 415 | 53.0 | 138 | 34.1 | 33.3 | 0.385 | 1.023 | 1.011 | 1.035 |
| C200K1.5N75-b* | 415 | 53.0 | 139 | 34.1 | 33.3 | 0.382 | 1.023 | 1.008 | 1.032 |
| C200K0.7N37-a* | 415 | 82.9 | 122 | 18.4 | 33.3 | 0.679 | 0.552 | 0.901 | 0.876 |
| C200K0.7N37-b* | 415 | 82.9 | 123 | 18.4 | 33.3 | 0.673 | 0.552 | 0.896 | 0.872 |

**Table B8: (Continued)**

| Specimen | Fy (ksi) | Pt (kip) | Pc (kip) | Mt (in-kip) | Mc (in-kip) | Pt/Pc | Mt/Mc | A/1.42 Eq.4 | A'/1.32 Eq. 12 |
|---|---|---|---|---|---|---|---|---|---|
| C200K1.0N37-a* | 415 | 61.4 | 123 | 27.3 | 33.3 | 0.499 | 0.818 | 0.952 | 0.956 |
| C200K1.0N37-b* | 415 | 61.4 | 121 | 27.3 | 33.3 | 0.507 | 0.818 | 0.959 | 0.962 |
| C200K1.5N37-a* | 415 | 49.1 | 124 | 31.5 | 33.3 | 0.397 | 0.944 | 0.964 | 0.983 |
| C200K1.5N37-b* | 415 | 49.1 | 123 | 31.5 | 33.3 | 0.400 | 0.945 | 0.967 | 0.986 |
| C300K0.5N90-a* | 435 | 138.4 | 213 | 44.8 | 90.2 | 0.649 | 0.497 | 0.839 | 0.814 |
| C300K0.5N90-b* | 435 | 138.4 | 215 | 44.8 | 90.2 | 0.645 | 0.497 | 0.836 | 0.811 |
| C300K1.0N90-a* | 435 | 107.6 | 214 | 69.6 | 90.2 | 0.503 | 0.772 | 0.923 | 0.924 |
| C300K1.0N90-b* | 435 | 107.6 | 214 | 69.7 | 90.2 | 0.503 | 0.772 | 0.923 | 0.924 |
| C300K0.5N45-a* | 435 | 124.2 | 191 | 42.9 | 90.2 | 0.649 | 0.475 | 0.824 | 0.798 |
| C300K0.5N45-b* | 435 | 124.2 | 191 | 42.8 | 90.2 | 0.649 | 0.475 | 0.824 | 0.798 |
| C300K1.0N45-a* | 435 | 90.2 | 191 | 62.2 | 90.2 | 0.472 | 0.690 | 0.841 | 0.841 |
| C300K1.0N45-b* | 435 | 90.2 | 192 | 62.2 | 90.2 | 0.470 | 0.689 | 0.840 | 0.839 |
| *Values for these sections are given in S.I. Units (MPa, kN, kN m). | | | | | | | Average: | 1.025 | 1.004 |
| | | | | | | | Standard Deviation: | 0.099 | 0.101 |
| | | | | | | | Coefficient of Variation: | 0.097 | 0.101 |

$M_t/M_c \geq 0.3$

**Table B9: Experimental and Calculated Results of Hat Sections – Cornell (1953)**

| Specimen | Fy (ksi) | Pt (kip) | Pc (kip) | Mt (in-kip) | Mc (in-kip) | Pt/Pc | Mt/Mc |
|---|---|---|---|---|---|---|---|
| 1 | 33.6 | 1.93 | 1.98 | 5.79 | 17.0 | 0.976 | 0.341 |
| 2 | 34.5 | 2.26 | 2.35 | 6.78 | 17.6 | 0.960 | 0.386 |
| 3 | 30.8 | 2.62 | 2.32 | 7.86 | 15.6 | 1.130 | 0.504 |
| 4 | 35.2 | 1.67 | 1.78 | 5.00 | 18.1 | 0.936 | 0.276 |
| 5 | 32.4 | 1.87 | 1.89 | 5.60 | 16.9 | 0.985 | 0.331 |
| 6 | 33.8 | 2.02 | 2.15 | 6.06 | 17.4 | 0.939 | 0.348 |
| 7 | 54.9 | 2.85 | 3.54 | 8.55 | 28.9 | 0.805 | 0.296 |
| 8 | 55.2 | 3.34 | 4.06 | 10.0 | 29.2 | 0.822 | 0.343 |
| 9 | 54.0 | 4.10 | 4.42 | 12.0 | 28.6 | 0.927 | 0.421 |
| 10 | 52.0 | 2.79 | 3.08 | 8.37 | 29.0 | 0.905 | 0.289 |
| 11 | 54.7 | 3.10 | 3.52 | 9.30 | 29.9 | 0.881 | 0.311 |
| 12 | 54.8 | 3.54 | 3.91 | 10.6 | 29.9 | 0.905 | 0.355 |
| 15 | 31.1 | 2.21 | 1.88 | 13.3 | 39.3 | 1.177 | 0.338 |
| 21 | 53.8 | 3.75 | 3.74 | 22.5 | 70.3 | 1.003 | 0.320 |
| 27 | 31.8 | 1.78 | 1.59 | 16.0 | 42.0 | 1.119 | 0.381 |
| 32 | 53.3 | 2.66 | 2.84 | 24.0 | 66.5 | 0.937 | 0.360 |
| 33 | 52.4 | 2.88 | 3.15 | 25.9 | 66.5 | 0.912 | 0.389 |
| 45 | 55.0 | 3.07 | 3.18 | 36.8 | 102 | 0.963 | 0.359 |

**Table B10: Experimental and Calculated Results of I-sections (Stiffened Flanges) Hetrakul and Yu (1978)**

| Specimen | Fy (ksi) | Pt (kip) | Mt (in-kip) | Pc (kip) | Mc (in-kip) | Pt/Pc | Mt/Mc | B/1.32 Eq. 5 | B'/1.46 Eq. 13 |
|---|---|---|---|---|---|---|---|---|---|
| I-BC-4-1 | 33.5 | 2.03 | 14.7 | 2.05 | 20.9 | 0.986 | 0.702 | 1.144 | 1.075 |
| I-BC-4-2 | 33.5 | 1.94 | 14.1 | 2.10 | 21.5 | 0.925 | 0.654 | 1.070 | 1.005 |
| I-BC-4-3 | 33.5 | 1.53 | 20.7 | 2.14 | 21.6 | 0.714 | 0.955 | 1.167 | 1.084 |
| I-BC-4-4 | 33.5 | 1.45 | 19.3 | 2.05 | 21.3 | 0.703 | 0.905 | 1.122 | 1.044 |
| I-BC-4-5 | 33.5 | 0.83 | 23.2 | 2.05 | 20.7 | 0.404 | 1.121 | 1.100 | 1.011 |
| I-BC-4-6 | 33.5 | 0.88 | 24.5 | 2.05 | 20.9 | 0.426 | 1.171 | 1.152 | 1.059 |
| I-BC-5-1 | 36.9 | 2.59 | 22.0 | 2.59 | 64.3 | 1.001 | 0.342 | - | - |
| I-BC-5-2 | 36.9 | 2.52 | 21.4 | 2.54 | 63.1 | 0.991 | 0.339 | - | - |
| I-BC-5-3 | 36.9 | 2.51 | 41.3 | 2.64 | 65.9 | 0.950 | 0.627 | 1.065 | 1.002 |
| I-BC-5-4 | 36.9 | 2.47 | 40.8 | 2.65 | 65.1 | 0.933 | 0.626 | 1.054 | 0.991 |
| I-BC-5-5 | 36.9 | 1.79 | 55.3 | 2.59 | 63.5 | 0.690 | 0.872 | 1.089 | 1.013 |
| I-BC-5-6 | 36.9 | 1.64 | 50.8 | 2.59 | 64.5 | 0.634 | 0.788 | 0.991 | 0.922 |
| I-BC-6-1 | 36.9 | 1.89 | 9.45 | 2.71 | 10.1 | 0.698 | 0.938 | 1.144 | 1.063 |
| I-BC-6-2 | 36.9 | 1.87 | 9.35 | 2.61 | 9.94 | 0.718 | 0.940 | 1.158 | 1.077 |
| I-BC-6-3 | 36.9 | 1.41 | 9.84 | 2.61 | 9.78 | 0.539 | 1.006 | 1.097 | 1.014 |
| I-BC-6-4 | 36.9 | 1.43 | 9.98 | 2.61 | 9.79 | 0.547 | 1.019 | 1.112 | 1.027 |
| I-BC-6-5 | 36.9 | 1.02 | 10.7 | 2.61 | 10.2 | 0.390 | 1.049 | 1.037 | 0.954 |
| I-BC-6-6 | 36.9 | 1.04 | 10.9 | 2.61 | 9.99 | 0.397 | 1.088 | 1.071 | 0.985 |
| I-BC-8-1 | 43.6 | 6.76 | 37.2 | 6.78 | 41.4 | 0.997 | 0.897 | 1.299 | 1.215 |
| I-BC-8-2 | 43.6 | 6.53 | 35.9 | 6.78 | 41.7 | 0.963 | 0.861 | 1.251 | 1.170 |
| I-BC-8-3 | 43.6 | 5.01 | 45.1 | 6.78 | 41.8 | 0.738 | 1.077 | 1.274 | 1.183 |
| I-BC-8-4 | 43.6 | 4.75 | 42.8 | 6.78 | 40.7 | 0.701 | 1.050 | 1.231 | 1.142 |
| I-BC-8-5 | 43.6 | 2.55 | 48.4 | 6.61 | 40.7 | 0.385 | 1.188 | 1.139 | 1.046 |
| I-BC-8-6 | 43.6 | 2.59 | 49.1 | 6.78 | 41.1 | 0.381 | 1.195 | 1.143 | 1.049 |
| I-BC-9-1 | 43.6 | 5.81 | 66.8 | 6.76 | 96.6 | 0.860 | 0.692 | 1.058 | 0.992 |
| I-BC-9-2 | 43.6 | 5.79 | 66.5 | 6.76 | 96.8 | 0.856 | 0.687 | 1.052 | 0.987 |
| I-BC-9-3 | 43.6 | 4.04 | 86.9 | 6.76 | 96.3 | 0.598 | 0.902 | 1.055 | 0.978 |
| I-BC-9-4 | 43.6 | 4.20 | 90.3 | 6.76 | 97.0 | 0.621 | 0.931 | 1.092 | 1.012 |
| I-BC-9-5 | 43.6 | 2.68 | 92.3 | 6.59 | 94.2 | 0.406 | 0.979 | 0.994 | 0.916 |
| I-BC-9-6 | 43.6 | 2.49 | 85.9 | 6.59 | 95.1 | 0.378 | 0.903 | 0.919 | 0.847 |
| I-BC-9'-1 | 47.1 | 3.32 | 26.5 | 3.48 | 52.3 | 0.953 | 0.507 | 0.976 | 0.921 |
| I-BC-9'-2 | 47.1 | 2.96 | 23.6 | 3.61 | 54.4 | 0.818 | 0.435 | 0.837 | 0.791 |
| I-BC-9'-3 | 47.1 | 2.59 | 40.2 | 3.48 | 52.9 | 0.744 | 0.759 | 1.038 | 0.969 |
| I-BC-9'-4 | 47.1 | 2.70 | 41.8 | 3.61 | 53.6 | 0.746 | 0.780 | 1.054 | 0.983 |
| I-BC-9'-5 | 47.1 | 1.63 | 56.2 | 3.48 | 52.7 | 0.468 | 1.067 | 1.099 | 1.013 |
| I-BC-9'-6 | 47.1 | 1.60 | 55.2 | 3.61 | 53.6 | 0.443 | 1.030 | 1.056 | 0.973 |
| I-BC-10-1 | 45.7 | 11.5 | 74.8 | 14.0 | 92.2 | 0.824 | 0.810 | 1.126 | 1.052 |
| I-BC-10-2 | 45.7 | 12.1 | 78.5 | 14.0 | 92.3 | 0.865 | 0.850 | 1.182 | 1.104 |
| I-BC-10-3 | 45.7 | 9.65 | 106.1 | 13.7 | 91.2 | 0.704 | 1.163 | 1.319 | 1.221 |
| I-BC-10-4 | 45.7 | 8.65 | 94.7 | 14.0 | 92.0 | 0.620 | 1.029 | 1.164 | 1.078 |
| I-BC-10-5 | 45.7 | 5.07 | 111 | 14.0 | 92.4 | 0.363 | 1.206 | 1.139 | 1.045 |
| I-BC-10-6 | 45.7 | 4.90 | 108 | 13.8 | 91.1 | 0.354 | 1.182 | 1.115 | 1.023 |
| I-BC-13-1 | 45.7 | 13.9 | 187 | 14.2 | 298 | 0.976 | 0.628 | 1.082 | 1.019 |
| I-BC-13-2 | 45.7 | 13.0 | 176 | 13.7 | 290 | 0.949 | 0.606 | 1.048 | 0.987 |
| I-BC-13-3 | 45.7 | 12.4 | 229 | 13.6 | 289 | 0.912 | 0.794 | 1.168 | 1.093 |
| I-BC-13-4 | 45.7 | 11.6 | 215 | 14.0 | 295 | 0.832 | 0.728 | 1.069 | 1.001 |
| I-BC-13-5 | 45.7 | 10.5 | 267 | 14.2 | 299 | 0.738 | 0.894 | 1.136 | 1.057 |
| I-BC-13-6 | 45.7 | 10.5 | 268 | 13.7 | 290 | 0.766 | 0.923 | 1.175 | 1.093 |
| I-3-IOF-5 | 47.1 | 3.03 | 21.9 | 3.26 | 48.3 | 0.928 | 0.454 | 0.920 | 0.870 |
| I-3-IOF-6 | 47.1 | 3.01 | 21.8 | 3.26 | 48.1 | 0.922 | 0.453 | 0.915 | 0.866 |

**Table B10: (Continued)**

| Specimen | Fy (ksi) | Pt (kip) | Mt (in-kip) | Pc (kip) | Mc (in-kip) | Pt/Pc | Mt/Mc | B/1.32 Eq. 5 | B'/1.46 Eq. 13 |
|---|---|---|---|---|---|---|---|---|---|
| I-3'-IOF-1 | 33.5 | 1.81 | 11.8 | 1.64 | 33.7 | 1.102 | 0.349 | - | - |
| I-3'-IOF-2 | 33.5 | 1.85 | 12.0 | 1.64 | 34.1 | 1.126 | 0.353 | - | - |
| I-3'-IOF-5 | 33.5 | 2.10 | 13.7 | 2.05 | 34.2 | 1.025 | 0.399 | - | - |
| I-3'-IOF-6 | 33.5 | 2.32 | 15.1 | 1.96 | 32.8 | 1.178 | 0.459 | 1.080 | 1.025 |
| I-5'-IOF-5 | 47.1 | 4.16 | 31.2 | 4.82 | 60.2 | 0.863 | 0.518 | 0.928 | 0.875 |
| I-5'-IOF-6 | 47.1 | 4.00 | 30.0 | 4.66 | 58.5 | 0.858 | 0.513 | 0.921 | 0.868 |
| I-6-IOF-1 | 42.9 | 5.54 | 40.1 | 5.53 | 72.8 | 1.001 | 0.551 | 1.039 | 0.981 |
| I-6-IOF-2 | 42.9 | 5.40 | 39.2 | 5.58 | 72.9 | 0.967 | 0.537 | 1.008 | 0.951 |
| I-6-IOF-5 | 42.9 | 6.00 | 43.5 | 6.76 | 74.5 | 0.888 | 0.584 | 0.994 | 0.935 |
| I-6-IOF-6 | 42.9 | 6.49 | 38.2 | 6.74 | 74.1 | 0.962 | 0.516 | 0.989 | 0.934 |
| I-6-IOF-7 | 42.9 | 7.00 | 47.3 | 6.88 | 74.6 | 1.018 | 0.633 | 1.112 | 1.047 |
| I-6-IOF-8 | 42.9 | 6.98 | 47.1 | 6.72 | 74.2 | 1.038 | 0.635 | 1.126 | 1.060 |
| I-6"-IOF-5 | 33.5 | 2.16 | 14.0 | 2.05 | 37.0 | 1.051 | 0.379 | - | - |
| I-6"-IOF-6 | 33.5 | 2.32 | 15.1 | 2.05 | 37.4 | 1.129 | 0.403 | 1.007 | 0.957 |
| I-12-IOF-6 | 53.8 | 3.37 | 24.4 | 4.02 | 54.2 | 0.838 | 0.451 | 0.862 | 0.814 |
| I-12'-IOF-5 | 45.7 | 12.1 | 72.4 | 14.2 | 122 | 0.850 | 0.592 | 0.976 | 0.918 |
| I-12'-IOF-6 | 45.7 | 12.8 | 76.5 | 14.0 | 120 | 0.914 | 0.639 | 1.052 | 0.989 |
| I-16-IOF-1 | 53.8 | 2.73 | 13.0 | 3.19 | 28.4 | 0.856 | 0.457 | 0.878 | 0.829 |
| I-16-IOF-2 | 53.8 | 2.84 | 13.5 | 3.19 | 29.2 | 0.890 | 0.461 | 0.902 | 0.852 |
| I-16-IOF-5 | 53.8 | 3.53 | 16.8 | 3.88 | 28.3 | 0.909 | 0.592 | 1.014 | 0.954 |
| I-16-IOF-6 | 53.8 | 3.90 | 15.4 | 4.03 | 28.9 | 0.967 | 0.533 | 1.004 | 0.948 |
| I-13-IOF-1 | 53.8 | 3.62 | 14.5 | 4.39 | 26.7 | 0.823 | 0.542 | 0.922 | 0.868 |
| I-13-IOF-2 | 53.8 | 3.75 | 15.0 | 4.56 | 26.8 | 0.823 | 0.561 | 0.936 | 0.880 |
| I-4'-IOF-1 | 36.9 | 2.92 | 17.4 | 3.00 | 24.4 | 0.971 | 0.715 | 1.145 | 1.075 |
| I-4'-IOF-2 | 36.9 | 3.06 | 18.3 | 3.00 | 24.2 | 1.020 | 0.757 | 1.207 | 1.133 |
| I-2'-IOF-1 | 36.9 | 3.10 | 24.4 | 2.97 | 39.2 | 1.042 | 0.622 | 1.119 | 1.054 |
| I-2'-IOF-2 | 36.9 | 3.00 | 23.6 | 2.97 | 39.2 | 1.009 | 0.603 | 1.083 | 1.021 |
| I-3-IOF-1 | 36.9 | 3.37 | 29.5 | 3.00 | 53.1 | 1.123 | 0.556 | 1.119 | 1.058 |
| I-3-IOF-1 | 36.9 | 3.20 | 28.0 | 3.00 | 52.9 | 1.067 | 0.529 | 1.064 | 1.005 |
| | | | | | | | Average: | 1.071 | 1.001 |
| | | | | | | | Standard Deviation: | 0.101 | 0.091 |
| | | | | | | | Coefficient of Variation: | 0.094 | 0.091 |

$M_t/M_c \geq 0.4$

**Table B11: Experimental and Calculated Results of Stiffened I-sections (Winter & Pian (1946)**

| Specimen | Fy (ksi) | Pt (kip) | Pc (kip) | Mt (in-kip) | Mc (in-kip) | Pt/Pc | Mt/Mc |
|---|---|---|---|---|---|---|---|
| 1b-1-IOF | 32.2 | 2.325 | 2.07 | 20.9 | 39.9 | 1.12 | 0.525 |
| 1c-1-IOF | 32.2 | 2.60 | 2.24 | 23.4 | 39.9 | 1.16 | 0.587 |
| 2a-1-IOF | 30.2 | 2.70 | 2.68 | 16.2 | 24.7 | 1.01 | 0.656 |
| 2b-1-IOF | 30.2 | 3.25 | 2.68 | 8.13 | 24.7 | 1.21 | 0.329 |
| 2b-2-IOF | 30.2 | 3.90 | 2.87 | 9.75 | 24.7 | 1.36 | 0.395 |
| 3-1-IOF | 30.2 | 4.85 | 3.25 | 12.1 | 20.0 | 1.49 | 0.608 |
| 3-2-IOF | 30.2 | 4.80 | 3.13 | 12.0 | 20.0 | 1.53 | 0.601 |
| 4b-1-IOF | 30.2 | 4.35 | 3.34 | 17.4 | 45.8 | 1.30 | 0.380 |
| 5a-1-IOF | 37.9 | 3.725 | 3.62 | 33.5 | 72.7 | 1.03 | 0.461 |
| 5b-1-IOF | 37.9 | 4.10 | 4.11 | 36.9 | 72.7 | 0.996 | 0.508 |
| 5c-1-IOF | 37.9 | 4.65 | 4.43 | 41.9 | 72.7 | 1.05 | 0.576 |
| 7a-1-IOF | 35.8 | 5.70 | 4.94 | 51.3 | 93.7 | 1.15 | 0.547 |
| 7b-1-IOF | 35.8 | 7.80 | 5.97 | 70.2 | 93.7 | 1.31 | 0.749 |
| 8-1-IOF | 35.8 | 6.75 | 5.61 | 60.8 | 103 | 1.20 | 0.588 |
| 9b-1-IOF | 35.1 | 10.3 | 8.84 | 25.8 | 46.9 | 1.16 | 0.549 |
| 10a-1-IOF | 35.1 | 9.60 | 9.26 | 38.4 | 92.7 | 1.04 | 0.414 |
| 10a-2-IOF | 35.1 | 12.0 | 9.78 | 48.0 | 92.7 | 1.23 | 0.518 |
| 10b-1-IOF | 35.1 | 15.2 | 11.0 | 60.8 | 92.7 | 1.39 | 0.656 |
| 12-1-IOF | 36.2 | 15.7 | 11.4 | 62.8 | 154 | 1.37 | 0.408 |
| 13a-1-IOF | 35.7 | 15.3 | 14.1 | 38.3 | 57.2 | 1.08 | 0.669 |
| 13b-1-IOF | 35.7 | 15.1 | 14.9 | 37.8 | 57.2 | 1.01 | 0.660 |
| 14a-1-IOF | 33.1 | 16.5 | 15.7 | 66.0 | 114 | 1.05 | 0.579 |
| 14a-2-IOF | 33.1 | 18.2 | 16.5 | 72.6 | 114 | 1.10 | 0.637 |
| 14b-1-IOF | 33.1 | 21.2 | 17.8 | 84.6 | 114 | 1.19 | 0.743 |
| 15a-1-IOF | 33.1 | 17.4 | 15.6 | 69.4 | 167 | 1.11 | 0.415 |
| 15a-2-IOF | 33.1 | 20.3 | 16.4 | 81.0 | 167 | 1.24 | 0.484 |
| 15b-1-IOF | 33.1 | 21.2 | 17.6 | 86.6 | 167 | 1.20 | 0.517 |
| 16a-1-IOF* | 32.2 | 2.25 | 1.86 | 18.5 | 55.1 | 1.21 | 0.336 |
| 16b-1-IOF* | 32.2 | 2.80 | 2.07 | 23.1 | 55.1 | 1.35 | 0.419 |
| 16c-1-IOF* | 32.2 | 3.25 | 2.24 | 26.8 | 55.1 | 1.45 | 0.486 |
| 17a-1-IOF* | 35.8 | 5.83 | 4.98 | 52.5 | 128 | 1.17 | 0.411 |
| 17b-1-IOF* | 35.8 | 7.63 | 5.61 | 68.7 | 128 | 1.36 | 0.538 |
| 17c-1-IOF* | 35.8 | 7.24 | 6.01 | 65.2 | 128 | 1.20 | 0.511 |

* Denotes single web sections

**Table B12: Experimental and Calculated Results of Nested Z-sections LaBoube, Nunnery and Hodges (1994)**

| Specimen | t (in.) | h (in.) | R (in.) | N (in.) | Fy (ksi) | Pt (kip) | Mt (in-kip) | Pc (kip) | Mc (in-kip) | Pt/Pc | Mt/Mc | C/1.65 Eq. 6 | C'/1.65 Eq. 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 0.058 | 7.830 | 0.250 | 4.99 | 50.9 | 2.39 | 84.1 | 2.36 | 98.2 | 1.010 | 0.856 | 1.039 | 1.045 |
| 4 | 0.058 | 7.830 | 0.250 | 4.99 | 50.9 | 2.37 | 83.4 | 2.36 | 98.2 | 1.001 | 0.849 | 1.030 | 1.036 |
| 5 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 2.91 | 85.0 | 2.65 | 108 | 1.096 | 0.787 | 1.041 | 1.048 |
| 6 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 2.70 | 78.8 | 2.65 | 108 | 1.016 | 0.730 | 0.966 | 0.972 |
| 7 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 3.36 | 58.0 | 2.65 | 108 | 1.267 | 0.537 | 0.978 | 0.986 |
| 8 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 3.36 | 58.0 | 2.65 | 108 | 1.267 | 0.537 | 0.978 | 0.986 |
| 9 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 2.37 | 97.6 | 2.65 | 108 | 0.892 | 0.904 | 1.007 | 1.013 |
| 10 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 2.35 | 96.7 | 2.65 | 108 | 0.884 | 0.896 | 0.999 | 1.004 |
| 11* | 0.071 | 7.739 | 0.312 | 4.97 | 52.4 | 3.24 | 75.3 | 3.10 | 115 | 1.045 | 0.655 | 0.935 | 0.942 |
| 13* | 0.071 | 7.739 | 0.312 | 4.97 | 52.4 | 2.75 | 96.9 | 3.10 | 115 | 0.886 | 0.842 | 0.967 | 0.972 |
| 14* | 0.071 | 7.739 | 0.312 | 4.97 | 52.4 | 2.82 | 99.4 | 3.10 | 115 | 0.909 | 0.864 | 0.992 | 0.997 |
| 28 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 3.03 | 70.5 | 2.65 | 108 | 1.143 | 0.653 | 0.984 | 0.991 |
| 29 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 2.84 | 83.1 | 2.65 | 108 | 1.071 | 0.769 | 1.018 | 1.025 |
| 30 | 0.061 | 7.747 | 0.312 | 5.00 | 56.8 | 2.41 | 84.8 | 2.65 | 108 | 0.907 | 0.785 | 0.943 | 0.949 |
| | | | | | | | | | | | Average: | 0.991 | 0.998 |
| | | | | | | | | | | | Standard Deviation: | 0.033 | 0.033 |
| | | | | | | | | | | | Coeffient of Variation: | 0.034 | 0.033 |

* These sections were composed of nested Z-sections of two different thicknesses, 0.061 in. and 0.071 in.

**Table B13: Experimental and Calculated Results of I-sections (Unstiffened Flanges) Hetrakul and Yu (1978)**

| Specimen | Fy (ksi) | Pt (kip) | Mt (in-kip) | Pc (kip) | Mc (in-kip) | Pt/Pc | Mt/Mc |
|---|---|---|---|---|---|---|---|
| I-U-17-IOF-5 | 36.3 | 2.57 | 14.1 | 2.74 | 13.8 | 0.936 | 1.025 |
| I-U-17-IOF-6 | 36.3 | 2.50 | 13.8 | 2.74 | 13.8 | 0.912 | 0.994 |

# APPENDIX C - INTERACTION DIAGRAMS

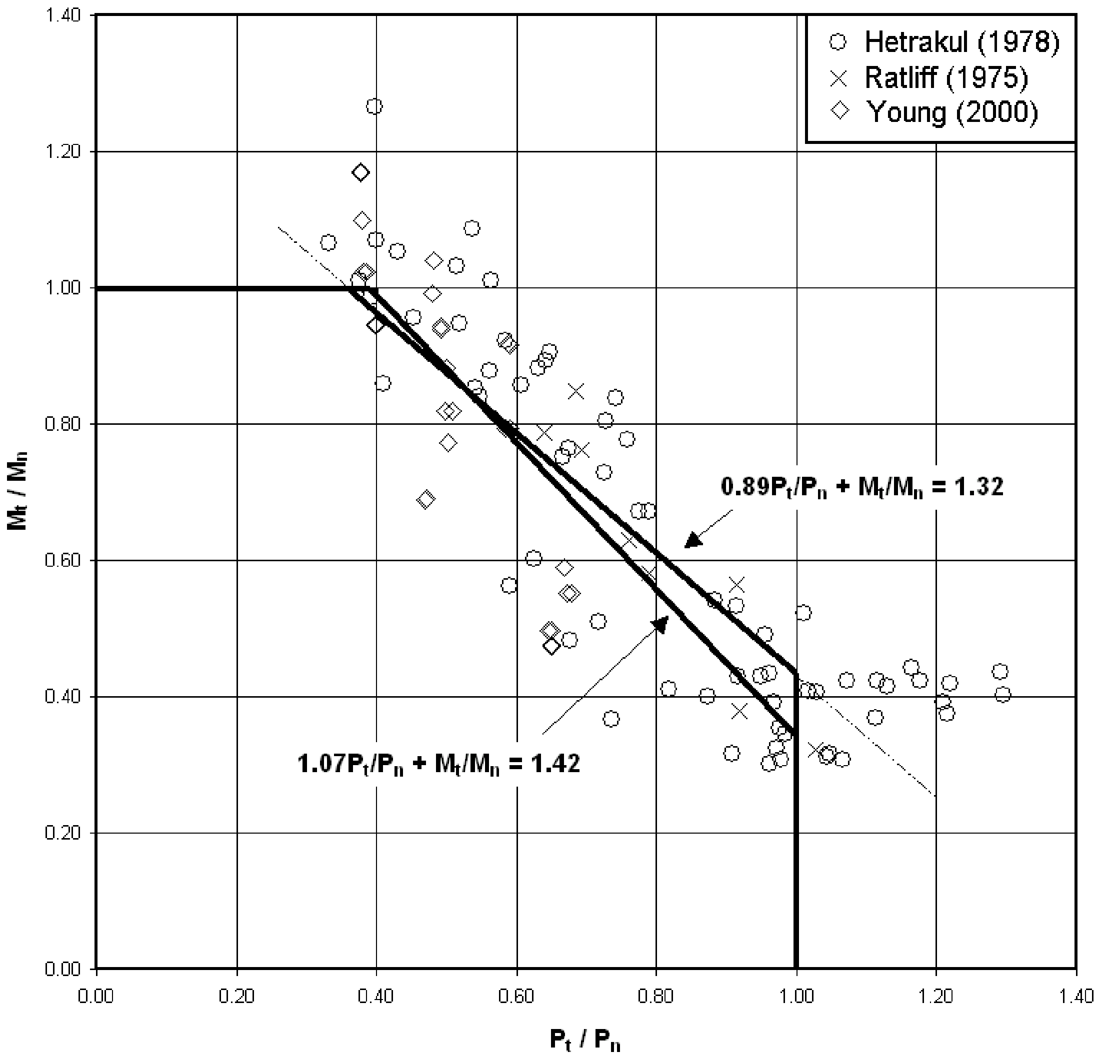



**Figure C1: Interaction Diagram of Channel C-sections**

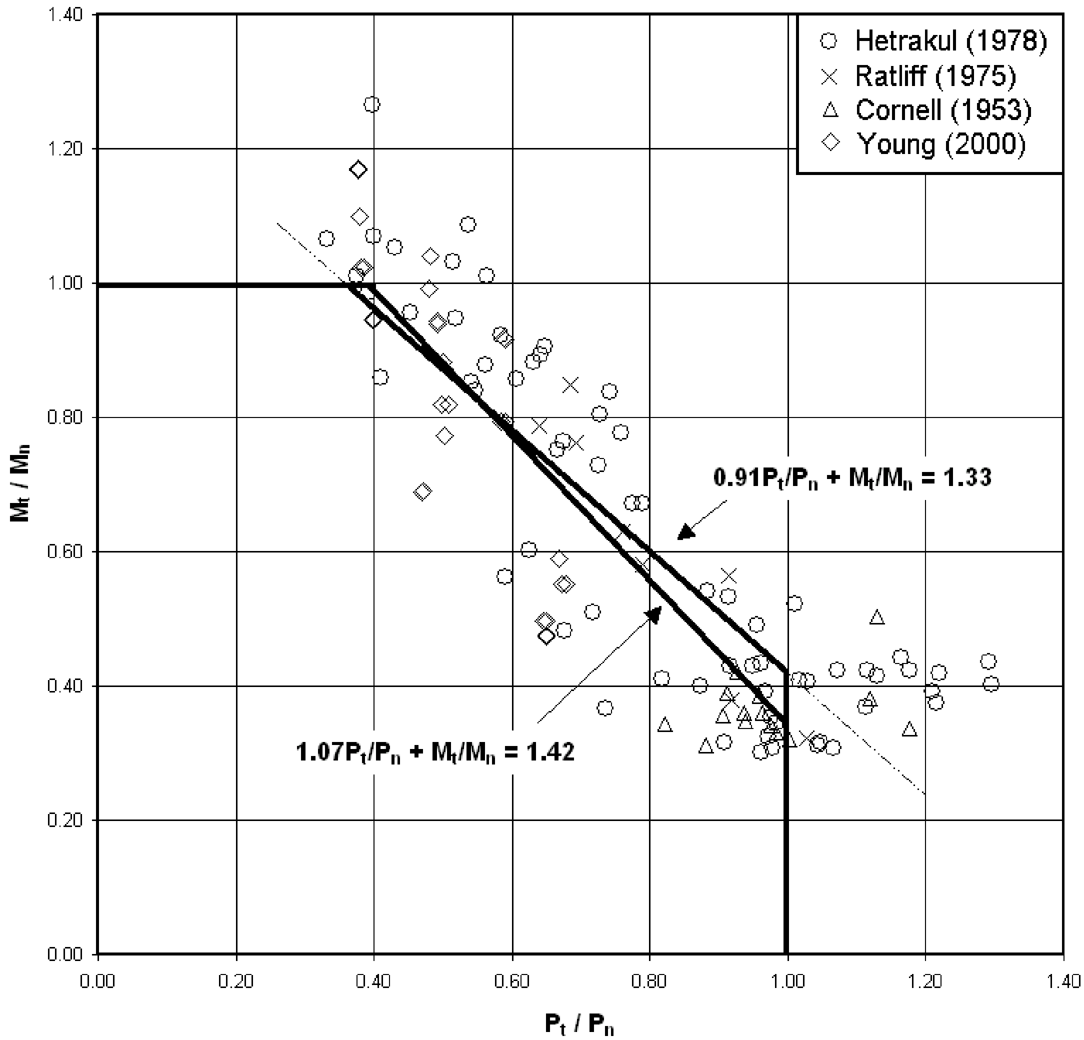



**Figure C2: Interaction Diagram of C- and Hat Sections**

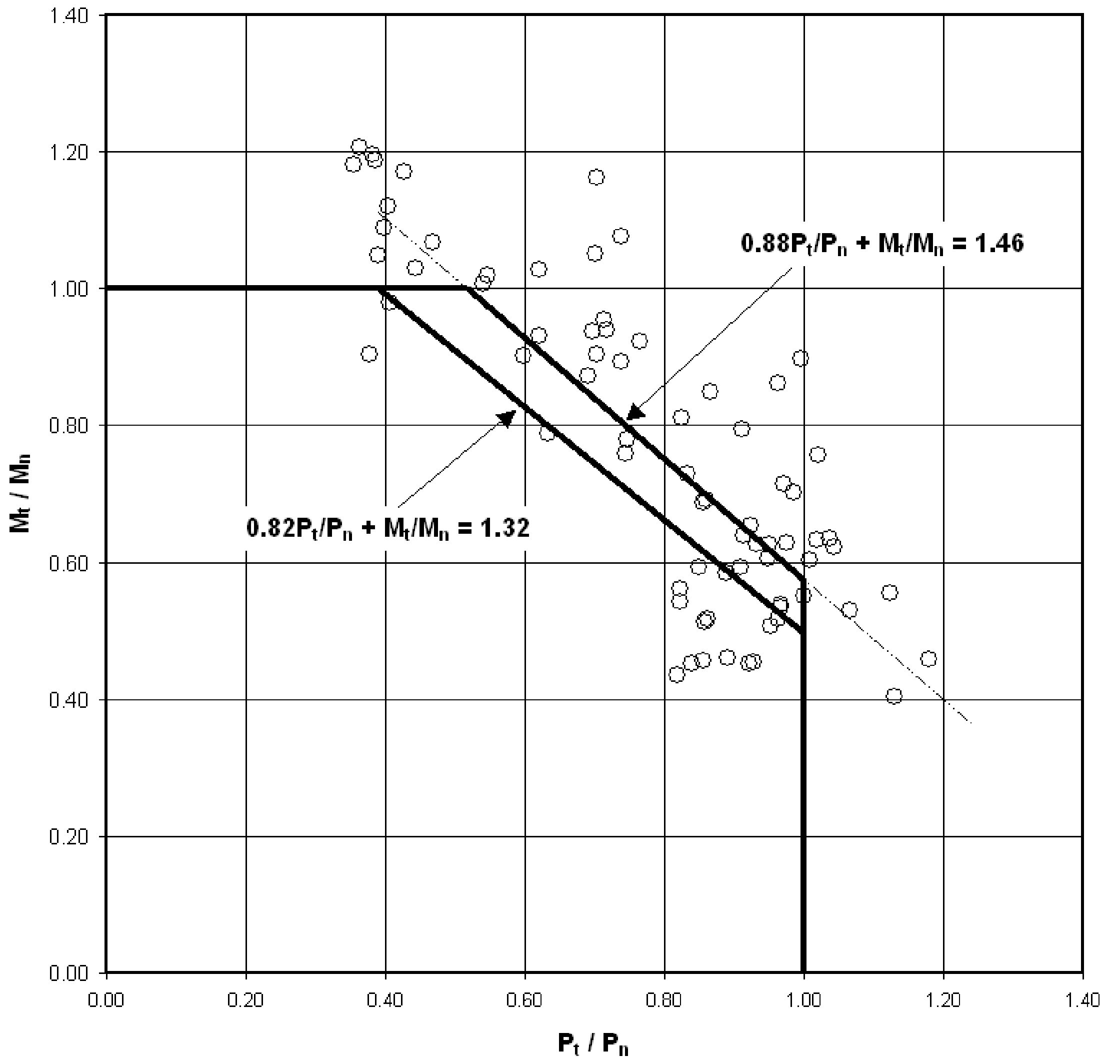



**Figure C3: Interaction Diagram of I-sections (Hetrakul 1978)**

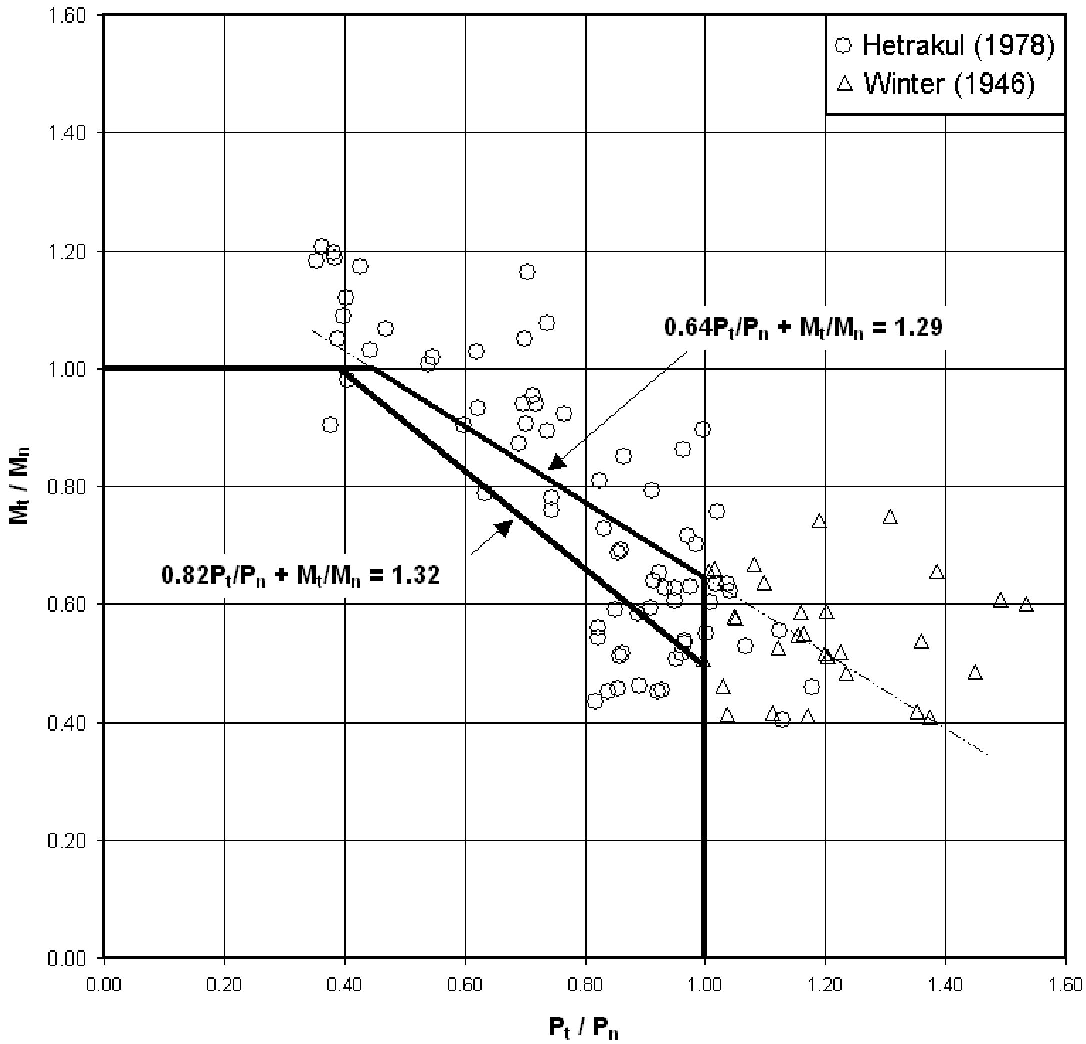



**Figure C4: Interaction Diagram of I-sections**

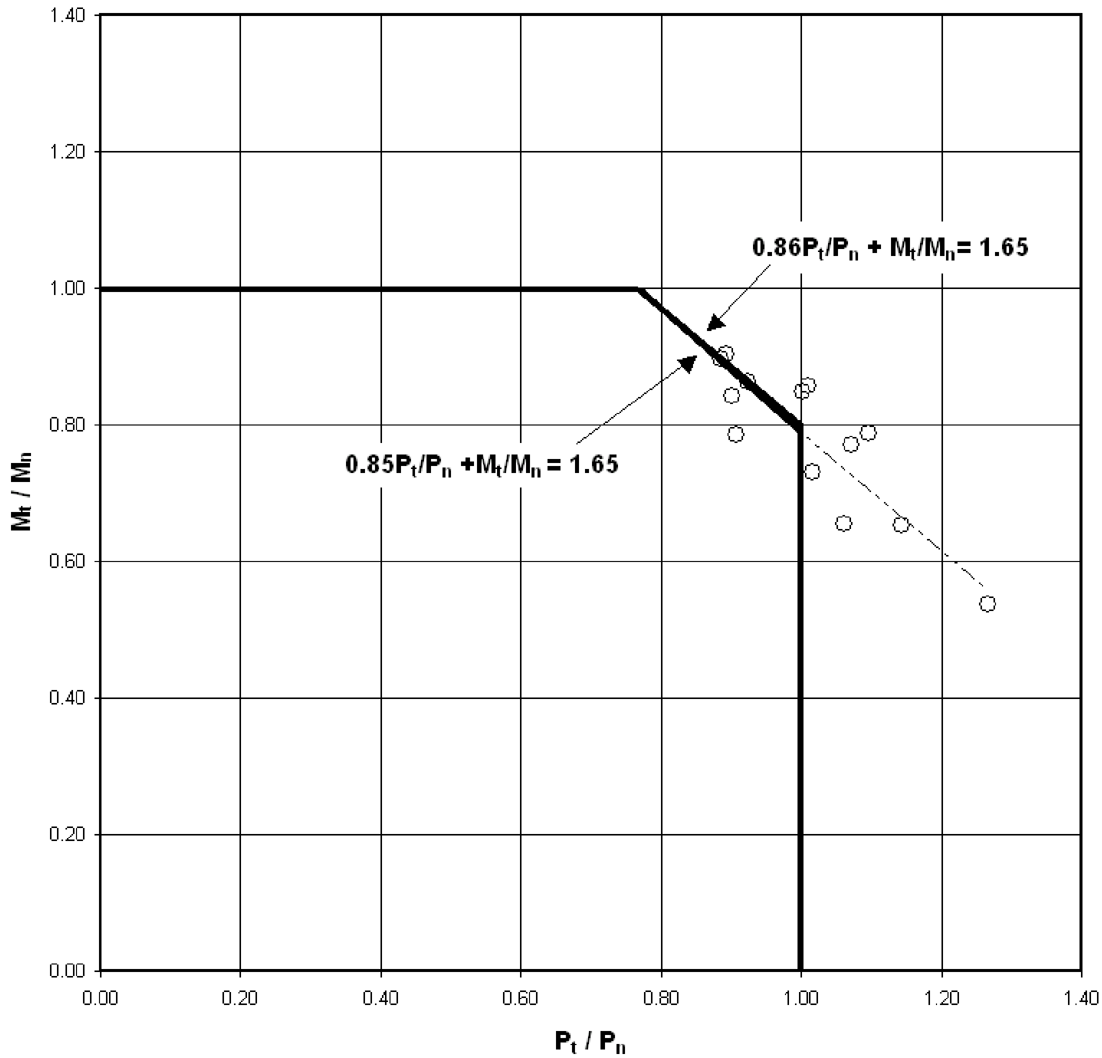



**Figure C5: Interaction Diagram of Nested Z-sections (LaBoube 1994)**

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