APPENDIX 1

MODEL CALCULATION OF VARIOUS CODES

A1.1 DESIGN AS PER NORTH AMERICAN SPECIFICATION OF COLD FORMED STEEL (AISI S100: 2007)

1. Based on Initiation of Yielding:

   Effective yield moment, \( M_n = S_e \times F_y \)

   \( S_e \) = Elastic section modulus of effective section calculated relative to extreme compression or tension fiber at \( F_y \)

   \( F_y \) = Yield stress

2. Based on Lateral Torsional Buckling Strength:

   \( M_n = S_c \times F_c \)

   \( S_c \) = Elastic section modulus of effective section calculated relative to extreme compression fiber at \( F_c \)

   \( F_c \) shall be determined as follows:

   - \( F_c > 2.78F_y \), no lateral buckling at bending moments less than or equal to \( M_y \)
   - \( 2.78F_y > F_c > 0.56F_y \) \[ F_c = \frac{10}{9} F_y \left( 1 - \frac{10F_c}{36F_e} \right) \]
   - \( F_c < 0.56F_y \) \[ F_c = F_e \]

   where, \( F_e = \frac{C_d \pi F_y}{S(K_s l_y)} \)
C_b is conservatively taken as unity for all cases

d - Depth of section

I_{yc} - Moment of inertia of compression portion of section about centroidal axis of entire section parallel to web, using full unreduced section.

\( I_{yc} = \frac{I_{yc}}{2} \)

S_E - Elastic section modulus of full unreduced section relative to extreme compression fiber

K_y - Effective length factor for bending about y axis

L_y - Unbraced length of member for bending about y axis

\( F_e = \frac{GJ\Delta}{S_E \sqrt{\sigma_{yc} G_1}} \)

A = area of the full cross-section

\( r_o = \) polar radius of gyration of the cross section about the shear centre = \( \sqrt{\frac{I_{xc}}{\rho_x^2} + \frac{I_{yc}}{\rho_y^2}} \)

\( r_x, r_y = \) radii of gyration of the cross section about the x- and y-axes respectively

\( x_o = \) distance from shear centre to centroidal along principal x-axis taken as negative.

\( \sigma_{yc} = \frac{\pi^2 E}{(\rho_x \rho_y)^2} \)

\( \sigma_t = \frac{GJ}{M_{nS}^2} \left( 1 + \frac{\pi^2 C_w}{GJ (K_t + 4)} \right) \)

E = Modulus of elasticity of steel

G = Shear modulus

J = Saint-Venant torsion constant for a cross section

\( C_w = \) Torsional warping constant of cross section

Kt = Effective length factors for twisting
Lt = Unbraced length of member for twisting.

Ky = Effective length factors for bending about y-axis.

Ly = Unbraced length of member for bending about y-axis.

1. **Based on Distortional Buckling Strength:** Distortional Buckling Strength (moment of resistance) $M_n$ is given by,

For $\lambda_d \leq 0.673$ 

$$M_n = M_y$$

For $\lambda_d > 0.673$ 

$$M_n = \left(1 - 0.22 \left(\frac{M_{crd}}{M_y}\right)^{0.5}\right) \left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y$$

$$\lambda_d = \frac{M_y}{M_{crd}}$$

$M_y = S_{fy} x F_y$

Where, $S_{fy}$ = Elastic section modulus of full unreduced section relative to extreme fiber in first yield.

$M_{crd} = S_f \times F_d$

$S_d = $ Elastic section modulus of full unreduced section relative to extreme compression fiber.

$F_d$ = Elastic distortional buckling stress

$$F_d = \beta K_{d} \frac{\pi^2}{12(1+\mu^2)} \left(\frac{h_d}{t}\right)^2$$

$$K_d = 0.5 \leq 0.6 \left(\frac{b_0 D\sin \theta}{h_d}\right)^{0.7} \leq 8.0$$

$\beta$ = A value accounting for moment gradient, which is permitted to be conservatively taken as 1.0

$E$ = Modulus of elasticity

$t$ = Base steel thickness

$\mu$ = Poisson’s ratio

$b_0$ - Out-to-out flange width

$D$ - Out-to-out lip dimension
θ - Lip angle

h_o - Out-to-out web depth

A1.2 NUMERICAL EXAMPLE FOR SPECIMEN TCDW-2000-200-100-1 AS PER AISI S100: 2007

1. Based on Yield Strength

Effective yield moment, \( M_n = S_c \times F_y \)

Effective section modulus, \( S_c = 55877.2186 \text{mm}^3 \)

Yield stress, \( F_c = 247 \text{N/mm}^2 \)

\[ M_n = 55877.2186 \times 247 \]

\[ M_n = 13.80 \times 10^6 \text{N.mm} \]

2. Lateral - Torsional Buckling Strength

\[ M_n = S_c \times F_c \]

\[ S_c = 57146.53438 \text{mm}^3 \]

\[ F_e = \frac{C_h \pi d L c}{S(K_h K_c)} = \frac{1^{14}2.11^{10}62.00^{3}339894.582}{57146.53438(1^{14}2000)^2} \]

\[ F_e = 587.494 \text{N/mm}^2 \]

\[ F_c = \frac{C_h A}{S_f \sqrt{\sigma_y G_i}} = \frac{1^{4}98 \times 46^{5}59.998}{\sqrt{441.75^{5}507.98}} \]

\[ F_c = 620.08 \text{N/mm}^2 \]

\[ 2.78F_y > F_c > 0.56F_y F_c = \frac{10}{9} F_y \left(1 - \frac{10F_c}{36F_y}\right) \]

\[ = \frac{10}{9} \times 247 \left(1 - \frac{104247}{36 \times 620.08}\right) \]

\[ = 244.89 \text{N/mm}^2 \]

\[ M_n = S_c \times F_c \]

\[ = 55877.2186 \times 244.89 = 13.69 \times 10^6 \text{N.mm} \]
3. **Distortional Buckling Strength**

\[
F_d = \left[ K_d \frac{\pi^2 E}{12(1-\nu^2)} \left( \frac{t}{h_o} \right)^2 \right]
\]

\[
K_d = 0.5 \leq 0.6 \left( \frac{b_D \sin \theta}{b_0} \right)^{0.7} \leq 8.0
\]

\[
L_{cr} = 1.2 h_o \left( \frac{b_D \sin \theta}{b_0} \right)^{0.6} \leq 10 h_o
\]

\[
b_0 = 71.42 \text{ mm}
\]

\[
D = 15 \text{ mm}
\]

\[
\theta = 90^\circ
\]

\[
h_o = 200 \text{ mm}
\]

\[
K_d = \left( \frac{71.42 \times 15 \times \sin 90^\circ}{200 \times 1.2} \right)^{0.7}
\]

\[
= 1.709 \quad (0.5 < 1.315 < 8)
\]

\[
F_d = 1 \times 1.69 \times \frac{\pi^2 \times 2.11 \times 10^5}{12(1-0.32)} \left( \frac{2}{33.64} \right)^2
\]

\[
= 1081.423696 \text{ N/mm}^2
\]

\[
M_{crd} = S_e \times f_y
\]

\[
= 57146.53438 \times 1081.423696
\]

\[
= 61799616.42 \text{ N.mm}
\]

\[
M_y = S_y \times F_y
\]

\[
= 57146.53438 \times 247
\]

\[
= 14286633.6 \text{ N.mm}
\]

\[
\lambda_d = \frac{M_{crd}}{M_y}
\]

\[
= \sqrt{\frac{14286633.6}{61799616.42}} = 0.48080
\]
M_n = M_y

M_n = 14.28 \times 10^6 \text{ N.mm}

The least of the above will be the nominal moment capacity of the section. Hence the governing mode of failure is lateral torsional buckling and the moment capacity is Mn = 13.69 \times 10^6 \text{N.mm}

**A.1.3 DESIGN AS PER AUSTRALIAN/NEW ZEALAND STANDARD FOR COLD FORMED STEEL (AS/NZS 4600:2005)**

1. **Based on initiation of Yielding:**

   \[ M_s = Z_e f_y \]

   Z_e is the effective section modulus calculated with the extreme compression or tension fibre at f_y

   fy is the yield stress

2. **Based on Lateral Torsional Buckling:**

   \[ M_b = Z_c f_c \]

   Where \( Z_c = \) effective section modulus calculated at a stress \( f_c \) in the extreme

   \( f_c = \left( \frac{M}{Z_f} \right) \)

   \( M_c = \) critical moment

   \( Z_f = \) full unreduced section modulus for the extreme compression fibre

   The critical moment \( (M_c) \) shall be calculated as follows:

   For \( \lambda_b \leq 0.60 \):

   \( M_c = M_y \)
For $0.60 < \lambda_b < 1.336$ \[ M_c = 1.11 M_y \left[ 1 - \left( \frac{100 \lambda_b^2}{\lambda_0^3} \right) \right] \]

For $\lambda_b \geq 1.336$: \[ M_c = M_y \left( \frac{1}{\lambda_0^3} \right) \]

Where $\lambda_b = \text{non-dimensional slenderness ratio used to determine } M_c \text{ for}

members subjected to lateral buckling

$\lambda_b = \frac{M_c}{\sqrt{M_o}}$

$M_y = \text{moment causing initial yield at the extreme compression fibre of}

\text{the full section}

= Z_4 f_y$

$M_o = \text{elastic buckling moment}

\text{Where } M_o = C_b A r_{o1} \sqrt{f_{o y} l_{o y}}$

$r_{o1} = \text{polar radius of gyration of the cross section about the shear centre.}

= \sqrt{r_x^2 + r_y^2 + x_o^2 + y_o^2} \]

$C_b$ is permitted to be taken as unity for all cases.

$A = \text{area of the full cross-section}

r_{o1} = \text{polar radius of gyration of the cross section about the shear}

centre.\]

$= \sqrt{r_x^2 + r_y^2 + x_o^2 + y_o^2} \]

$r_x, r_y = \text{radii of gyration of the cross section about the x- and y- axes}

\text{respectively} \]

$x_o, y_o = \text{coordinates of the shear centre of the cross section}$

$f_{o y} = \text{elastic buckling stress in an axially loaded compression member for}

\text{the flexural buckling about the y- axis.}$
\[\frac{\pi 2E}{(l_{e y}/r_y)^2}\]

\[f_{oz} = \text{elastic buckling stress in an axially loaded compression member for torsional buckling}\]

\[= \frac{GJ}{A\Gamma_d} \left(1 + \frac{\pi 2Elw}{GJl_{ez}^2}\right)\]

\[l_{ex}, l_{ey}, l_{ez} = \text{effective length for buckling about the x-axis and y-axes, and for twisting, respectively}\]

\[G = \text{shear modulus of elasticity (80 × 10}^3\text{Mpa)}\]

\[J = \text{torsion constant for a cross section}\]

\[I_w = \text{warping constant for a cross section}\]

3. **Based on Distortional Buckling:**

The critical moment \(M_c\) shall be calculated as follows:

For \(\lambda_d < 0.59\):

\[M_c = M_y\]

For \(0.59 < \lambda_d \leq 1.70\):

\[M_c = M_y \left(\frac{0.59}{\lambda_d}\right)\]

For \(\lambda_d \geq 1.70\):

\[M_c = M_y \left(\frac{1}{\lambda_d}\right)\]

Where \(M_y = \text{moment causing initial yield at the extreme compression fibre of the full section}\)

\(\lambda_d = \text{non-dimensional slenderness used to determine } M_c \text{ for the member subjected to distortional buckling}\)

\[= \frac{M_c}{\sqrt{M_0}}\]

\(M_{od} = \text{elastic buckling moment in the distortional mode}\)

\[= Z_{d}f_{od}\]

Minimum of above moment is taken as Moment capacity of the section.
A1.4 NUMERICAL EXAMPLE FOR SPECIMEN TCDW-2000-200-100-1 AS PER AS/NZS 4600:2005

1. Based on initiation of Yielding:

\[ Z_e = 55877.219 \text{ mm}^3 \text{ (Calculated as per code)} \]

\[ f_y = 247 \text{ N/mm}^2 \text{ (Extreme flange material yield stress)} \]

\[ M_s = Z_f f_y = 55877.219 \times 247 = 13.801 \times 10^6 \text{ Nmm} \]

2. Based on Lateral buckling:

\[ Z_c = 55877.219 \text{ mm}^3 \]

\[ Z_f = 57146.534 \text{ mm}^3 \]

\[ f_c = \left( \frac{M_s}{Z_f} \right) \]

\[ M_y = Z_f f_y = 57146.534 \times 247 = 14.28 \times 10^6 \text{ Nmm} \]

\[ C_b = 1 \]

\[ A = 759.998 \text{ mm}^2 \]

\[ r_x = 87.577 \text{ mm} \]

\[ r_y = 29.908 \text{ mm} \]

\[ x_0 = 40 \text{ mm} \]

\[ y_0 = 100 \text{ mm} \]

\[ r_{ol} = \sqrt{r_x^2 + r_y^2 + x_0^2 + y_0^2} = \sqrt{87.577^2 + 59.908^2 + 40^2 + 100^2} = 94.058 \text{ mm} \]

\[ E = 2.11 \times 10^5 \text{ N/mm}^2 \]

\[ G = 76923.077 \text{ N/mm}^2 \]

\[ J = 808.530 \text{ mm}^4 \]
\[ l_{ez} = l = 2000 \text{ mm} \]

\[ I_w = 6400821135.242 \text{ mm}^6 \]

\[ f_{oz} = \frac{G_1}{\lambda r_{o2}} \left( 1 + \frac{\pi^2 E_{t_u}}{G_1 I_{ez}} \right) \]

\[
= \frac{76923.077 \times 808.530}{759.998 \times 94.058^2} \left( 1 + \frac{\pi^2 \times 2.11 \times 10^5 \times 6400821135.242}{76923.077 \times 808.530 \times 2000^2} \right) \\
= 215.678 \text{ N/mm}^2
\]

\[ f_{oy} = \frac{\pi^2 E}{(l_{ey}/r_Y)^2} \]

\[
= \frac{\pi^2 \times 2.11 \times 10^5}{(2000/29908)^2} \\
= 3787.886 \text{ N/mm}^2
\]

\[ M_o = C_b Ar_{o1} \sqrt{I_{o1}} f_{on} = 1 \times 759.998 \times 94.058 \sqrt{3787.886 \times 215.678} \\
= 3283664.012 \text{ N.mm}
\]

\[ \hat{\lambda}_b = \frac{\sqrt{M_k}}{M_0} \]

\[
= \frac{\sqrt{14.28 \times 10^6}}{\sqrt{32.88 \times 10^6}} = 0.659
\]

For \(0.60 < \lambda_b < 1.336\),

\[ M_c = 1.11 M_y \left[ 1 - \left( \frac{10\lambda_b^3}{36} \right) \right] \]

\[
= 1.11 \times 1.14286633.5 \left[ 1 - \left( \frac{10 \times 0.659^3}{36} \right) \right] \\
= 13945135.69 \text{ N.mm}
\]

\[ f_c = \left( \frac{13945135.69}{57146.534} \right) \]

\[ = 244.024 \text{ N/mm}^2 \]
\[ M_b = Z_c f_c \]
\[ = 55877.219 \times 244.024 \]
\[ = 13635382.49 \text{ N.mm} \]

3. **Based on Distortional Buckling:**

\[ f_{od} = \text{elastic distortional buckling stress calculated as per} \]
Appendix D of *AS/NZS 4600:2005*

\[ = \frac{E}{2A} \left( \alpha_1 + \alpha_2 \right) - \sqrt{\left( \alpha_1 + \alpha_2 \right)^2 - 4\alpha_3} \]
\[ = \frac{2.11 \times 10^5}{2759.998} \left( 290.580 + 66.635 \right) \]
\[ - \sqrt{(290.580 + 66.635)^2 - 4 \times 9239.081} \]
\[ = 7386.865 \text{ N/mm}^2 \]

\[ M_{od} = Z_f f_{od} \]
\[ = 57146.534 \times 7386.865 \]
\[ = 422133731.9 \text{ N.mm} \]

\[ M_y = Z_f f_y \]
\[ = 57146.534 \times 247 \]
\[ = 14.28 \times 10^6 \text{ N.mm} \]

\[ \lambda_{od} = \frac{M_y}{\sqrt{M_0}} = \frac{142866335}{422133731.9} \]
\[ = 0.184 < 0.59 \]

Hence \( M_c = M_y \)
\[ f_c = \left( \frac{M_n}{Y_f} \right) \]

\[ = \left( \frac{14.28 \times 10^6}{57146.534} \right) \]

\[ = 249.88 \text{N/mm}^2 \]

The nominal member capacity \( M_b = Z_c f_c \)

\[ = 55877.219 \times 249.88 \]

\[ = 13962599.48 \text{N/mm}^2 \]

The least of the above will be the nominal moment capacity of the section, Hence the governing mode of failure is lateral torsional buckling and the moment capacity is \( M_n = 13.63 \times 10^6 \text{N.mm} \)

A.1.5 DESIGN AS PER INDIAN STANDARD FOR COLD FORMED STEEL IS 801-1975

1. Based on Yielding

Nominal Moment = \( S \times F_y \)

\( F_y \) = Specified minimum yield point.

\( S \) = unreduced Elastic section modulus

2. Based on Lateral Torsional Buckling

When

\[ \frac{1.8 \pi^2 E C_b}{d_{yyc}} \geq \frac{0.36 \pi^2 E C_b}{d_{yyc}} \]

\[ F_b = \frac{2F_y}{3} = \frac{E \pi^2 E C_b}{5.4 \pi^2 E C_b \cdot d_{yyc}} \]

When

\[ \frac{1.8 \pi^2 E C_b}{d_{yyc}} \geq \frac{1.8 \pi^2 E C_b}{F_y} \]

\[ F_b = 0.6 \pi^2 E C_b \cdot \frac{d_{yyc}}{1.8 \pi^2 E C_b} \]
\[ \text{Mn} = F_B \times I_{yc} / Y_c \quad \text{N.mm} \]

\[ L = \text{the unbraced length of the member} \]

\[ I_{yc} = \text{the moment of inertia of the compression portion of a section about the gravity axis of the entire section parallel to the web} \]

\[ S_{xc} = \text{Compression section modulus of entire section about major axis, } I_x \text{ divided by distance to extreme compression fibre} \]

\[ E = \text{modulus of elasticity} \]

\[ d = \text{depth of section.} \]

\[ C_b = \text{bending coefficient which can conservatively be taken as unity.} \]

**Numerical example for specimen TCDW-2000-200-100-1 as per IS 801:1975**

1. **Based on Yielding**

   \[ F_y = 247 \text{ N/mm}^2 \]

   \[ S = 68502.02 \text{ mm}^3 \]

   Nominal Moment \[ M_n = S \times F_y = 68502.02 \times 247 \]

   \[ M_n = 16.92 \times 10^6 \text{ N.mm} \]

2. **Based on Lateral Torsional Buckling**

   \[ L = 2000 \text{ mm} \]

   \[ I_{yc} = 339894.582 \text{ mm}^4 \]

   \[ S_{xc} = 55877.2186 \text{ mm}^3 \]

   \[ E = 2.11 \times 10^5 \text{ N/mm}^2 \]
\[ d = 200 \text{ mm} \]

\[ C_b = 1 \]

When
\[
\frac{I_z S_{xc}}{d l_{yc}} > \frac{0.36 \pi^2 E C_b}{F_Y} \quad \& \quad \frac{I_z S_{xc}}{d l_{yc}} < \frac{1.8 \pi^2 E G_b}{F_Y}
\]

\[
\frac{I_z S_{xc}}{d l_{yc}} = \frac{2000^2 \times 64474.14}{200 \times 339894.582} = 3793.7727
\]

\[
\frac{0.36 \pi^2 E C_b}{F_Y} = \frac{0.36 \times 3.14^2 \times 3.14 \times 2 \times 11 \times 10^5 \times 1}{247} = 3032.126
\]

\[
\frac{1.8 \pi^2 E G_b}{F_Y} = \frac{1.8 \times 3.14^2 \times 2 \times 11 \times 10^5 \times 1}{247} = 14370.26
\]

\[
F_b = \frac{2F_Y}{3} - \frac{F_Y^2}{5.4 \pi^2 E C_b \frac{d l_{yc}}{l_{xc}}}
\]

When
\[
\frac{I_z S_{xc}}{d l_{yc}} \geq \frac{1.8 \pi^2 E G_b}{F_Y}
\]

\[
F_b = 0.6 \pi^2 E C_b \frac{d l_{yc}}{l_{xc}}
\]

\[
F_B = \frac{2 \times 247}{3} - \frac{247^2}{5.4 \times 3.14^2 \times 2 \times 11 \times 10^5 \times 1} \frac{2000^2 \times 55877.2186}{200 \times 339894.582} = 146.8043 \text{ N/mm}^2
\]

\[
Mn = F_b \times I_{yc} / Y_c \quad \text{N.mm}
\]

\[= 146.8043 \times 6242528 / 100 = 16118534 \text{ N.mm} \]

The least of the above will be the nominal moment capacity of the section,

Hence the governing mode of failure is lateral torsional buckling and the moment capacity is \( Mn = 16.11 \times 10^6 \text{N.mm} \)
APPENDIX 2

MODEL CALCULATION OF PROPOSED EQUATION

Specimen TCA-3600-400-150-6

A.2.1 CALCULATION OF UNREDUCED SECTION MODULUS

\[ I_{XX} = \frac{t_w h w^3}{12} + 2 \left[ \frac{b_f t_f^3}{12} + b_f t_f \left( \frac{D}{2} - \frac{t_f}{2} \right)^2 \right] \]

\[ + 4 \left[ \frac{t_f (b_t - t_f)}{12} + (b_t - t_f) \times t_f \left( \frac{D}{2} - \frac{(b_t - t_f)}{2} - \frac{t_f}{2} \right)^2 \right] \]

\[ = \frac{1.2 \times 396^3}{12} + 2 \left[ \frac{150 \times 2^3}{12} + 150 \times 2 \times \frac{400}{2} - \frac{2}{2} \right]^2 \]

\[ + 4 \left[ \frac{2(15 - 2)}{12} + (15 - 2) \times 2 \times \frac{400}{2} - \frac{(15 - 2)}{2} - 2 \right]^2 \]

\[ = 6209913.6 + 23760800 + 3815378.667 \]

\[ = 33786092.27 \text{ mm}^4 \]

\[ Z_f = I_{XX} / y \]

\[ = 33786092.27 / 200 \]

\[ = 168930.4614 \text{ mm}^3 \]

A.2.2 CALCULATION OF YIELDING MOMENT \( M_y \)

CONSIDERING FULL SECTION

\[ M_y = Z_f f_y = 168930.4614 \times 247 = 41.725 \times 10^6 \text{ Nmm} \]
A.2.3 CALCULATION OF ELASTIC BUCKLING MOMENT $M_o$

$C_b = 1$

$A = 119.998 \text{ mm}^2$

$r_x = 170.413 \text{ mm}$

$r_y = 39.596 \text{ mm}$

$x_0 = 40 \text{ mm}$

$y_0 = 100 \text{ mm}$

$r_{ol} = \sqrt{r_x^2 + r_y^2 + x_0^2 + y_0^2} = \sqrt{170.413^2 + 39.596^2 + 40^2 + 100^2}$

$= 175.091 \text{ mm}$

$E = 2.11 \times 10^5 \text{ N/mm}^2$

$G = 76923.077 \text{ N/mm}^2$

$J = 1190.380 \text{ mm}^4$

$l_{ex} = l = 3600 \text{ mm}$

$I_w = 1881449.290 \text{ mm}^6$

$f_{oz} = \frac{GJ}{Ar_{ol}} \left( 1 + \frac{\pi^2 E I_b}{GJ l_{ex}^2} \right)$

$= \frac{76923.077 \times 1190.380}{119.998 \times 175.091} \left( 1 + \frac{\pi^2 \times 2.11 \times 10^5}{76923.077 \times 1190.380 \times 3600^2} \right)$

$= 95.827 \text{ N/mm}^2$

$f_{oy} = \frac{\pi E}{(l_{ex}/r_y)^2}$

$= \frac{\pi^2 \times 2.11 \times 10^5}{(3600/39.596)^2}$

$= 238.801 \text{ N/mm}^2$

$M_o = C_b A r_{ol} \sqrt{l_{oz} I_{oz}} = 1 \times 1119.998 \times 175.091 \sqrt{95.827 \times 238.801}$

$= 49792199.279 \text{ N.mm}$
\[ \hat{\lambda}_b = \frac{M_c}{M_s} \]

\[ = \frac{41.725 \times 10^6}{49.79 \times 10^6} = 0.915 \]

\( \hat{\lambda}_b \) lies between 0.879 & 1.310, as per the proposed equation 6.1,

Critical moment \( M_c = M_y (1.378 - 0.489\hat{\lambda}_b^2) \)

\[ = 41.725 \times 10^6(1.378 - 0.489 \times 0.915^2) \]

\[ = 40414708.13 \text{ N.mm} \]

\[ f_c = \left( \frac{40798074.13}{1689304614} \right) \]

\[ = 239.239 \text{ N/mm}^2 \]

**A.2.4 CALCULATION OF EFFECTIVE SECTION MODULUS AS PER CODE**

For the first iteration, assume a compression stress \( F_y = 247 \text{ N/mm}^2 \) in the top fibre of the section and that the neutral axis is 200mm. Below the top fibre.

i. Calculation of effective width of flange:

\( w = b = 99.38 \text{ mm} \)

\( w/t = 99.38/2 = 49.69 < 60 \text{ OK} \)

\( S = 1.28 \sqrt{\frac{E}{f}} \)

\[ = 1.28 \sqrt{\frac{2.11 \times 10^5}{247}} = 37.41129319 \]

\( w/t \geq 0.328S \rightarrow \text{check effective width of flange} \)

Compute \( k \) of the flange based on stiffener lip properties
\[ I_a = 399 \cdot t^4 \left[ \frac{\nu + 1}{S} - 0.328 \right]^3 \leq (1)^4 \cdot \left[ \frac{115 + w}{S} + 5 \right] \]

\[ I_a = 399 \cdot 2^4 \left[ \frac{49.69}{37.411} - 0.328 \right]^3 \leq (2)^4 \cdot \left[ \frac{115 + 49.69}{37.411} + 5 \right] \]

\[ = 6388.194 \text{ mm}^4 \leq 2523.92291 \text{ mm}^4 \]

\[ I_a = 2523.922 \text{ mm}^4 \]

\[ R = \text{radius of corner} \]

\[ d = c = \text{lip depth} - \left( (R + \frac{t}{2}) + \left( \frac{t}{2} \right) \right) = 15 - \left( 2 + \frac{t}{2} + \frac{t}{2} \right) = 11 \text{ mm}. \]

\[ \theta = 90 \text{ degrees}. \]

\[ I_s = \frac{(d^3 \cdot \sin^2 \theta)}{12} \]

\[ = (11^3 \cdot 2 \cdot \sin^2 90^\circ)/12 \]

\[ = 221.833 \text{ mm}^4 \]

\[ R_l = \frac{t}{k} \leq 1 \]

\[ \frac{221.833}{2523.922} = 0.08789 < 1 \text{ Hence OK.} \]

\[ n = \left[ 0.582 - \frac{w}{4S} \right] \geq 1/3 \]

\[ = \left[ 0.582 - \frac{49.69}{4 \cdot 37.411} \right] \geq 1/3 \]

\[ n = 0.2499 < 1/3 \quad n = 0.333 \]

\[ D = \text{depth of lip} = 15 \text{ mm} \]

\[ D/ w = \frac{15}{9.38} = 0.1509 < 0.8 \text{ OK} \]

\[ K = \left( 4.82 - 5 \frac{D}{w} \right) R_l^n + 0.43 \leq 4 \]

\[ K = \left( 4.82 - 5 \cdot 0.1509 \right) (0.08789)^{0.1509} + 0.43 \leq 4 \]
\[ F_{cr} = k \frac{\pi^2 E}{12(1-\nu^2)} \left( \frac{t}{W} \right)^2 \]

\[ = 2.252 \times \frac{3.1415^2 \times 201 \times 10^6}{12(1-0.3^2)} \left( \frac{2}{99.38} \right)^2 = 173.75 \text{ N/mm}^2 \]

\[ \lambda = \frac{f}{\sqrt{F_{cr}}} \]

\[ = \frac{247}{\sqrt{17375}} = 1.199 > 0.673 \rightarrow \text{flange is subject to local buckling} \]

\[ \rho = \frac{1 - 0.22}{\lambda} / \lambda \]

\[ = \frac{1 - 0.22}{1.199} / 1.199 \]

\[ = 0.979 \]

\[ b = \rho w \]

\[ = 0.979 \times 99.38 = 97.29 \text{mm} \]

ii. Calculation of effective width of Stiffener lip:

\[ w/t = d/t = 11/2 = 5.5 \]

Maximum stress in lip (by similar triangles)

\[ f = f_1 = f_y \times \frac{(N.A - \frac{d}{2} - t)}{N.A} \]

\[ = 247 \times \frac{(200 - \frac{2}{2} - 3)}{200} = 242.06 \text{ N/mm}^2 \]

\[ f_2 = f_y \times \frac{(N.A - D)}{N.A} \]

\[ = 247 \times \frac{200 - 15}{200} = 228.475 \text{ N/mm}^2 \]

\[ \Psi = \frac{f_2}{f_1} \]

\[ = 228.475 / 242.06 = 0.94388 \]

\[ k = \frac{0.578}{\Psi + 0.34} = \frac{0.578}{0.94388 + 0.34} = 0.4502 \]
\[ F_{cr} = k \frac{\pi^2 E}{12(1-\nu^2)} \left( \frac{t}{w} \right)^2 \]

\[ = 0.4502 \times \frac{3 \times 4 \times 2 \times 11 \times 10}{12(1-0.5^2)} \left( \frac{1}{5.5} \right)^2 \]

\[ = 2838.17 \text{ N/mm}^2 \]

\[ \lambda_c = \sqrt{\frac{f}{F_{cr}}} \]

\[ = \sqrt{\frac{247}{2838.17}} = 0.29204 < 0.673 \rightarrow \text{lip is not subjected to local buckling} \]

\[ d_s = d = 11 \text{ mm.} \]

\[ d_s = d_s^* (R_1) \]

\[ = 11 \times 0.1509 = 1.66025 \text{ mm} \]

iii. Calculation of effective width of Web:

\[ \frac{w}{t} = 333.33 \]

\[ f = f_1 = f_y * \left( \frac{(N.A - \frac{b_w}{2} - r)}{N.A} \right) \]

\[ f_1 = 247 * \left( \frac{(200 - \frac{1}{2} - 3)}{200} \right) \]

\[ = 247.494 \text{ N/mm}^2 \]

\[ \Lambda' = \text{overall depth of section} = 400 + 2 + 2 = 404 \text{ mm} \]

\[ f_2 = f_y * \left( \Lambda' - N.A - \frac{b_w}{2} - r \right) / N.A \]

\[ = 247 * \left( 404 - 200 - \frac{1}{2} - 3 \right) / 200 = 247.494 \text{ N/mm}^2 \]

\[ \Psi = \left| \frac{f_2}{f_1} \right| = \frac{247.494}{242.554} = 1.020 \]

\[ K = 4 + 2(1 + \Psi^3) + 2(1 + \Psi) \]

\[ = 4 + 2(1 + 1.020)^3 + 2(1 + 1.020) \]

\[ = 24.5345 \]
\[ F_{cr} = k \frac{\pi^2 E}{12(1-\mu^2)} \left( \frac{t}{w} \right)^2 \]

\[ F_{cr} = 24.5345 \times \frac{3.14^4 \times 3.14 \times 2110000}{12(1-0.3^4 \times 0.3)} \times \left( \frac{2}{166.667} \right)^2 = 42.1095 \text{ N/mm}^2 \]

\[ \lambda = \sqrt{\frac{f}{F_{cr}}} \]

\[ = \sqrt{\frac{247}{42.1095}} = 2.40002 > 0.673 \rightarrow \text{web may be subjected to local buckling} \]

\[ \rho = (1 - 0.22/ \lambda_\lambda) \]

\[ = (1 - 0.22/ 2.40002)/2.40002 \]

\[ = 0.37847 \]

\[ a = \text{depth of web} = 400 \text{ mm} \]

\[ b_e = b = a \rho = 151.388 \text{ mm} \]

\[ h_o/b_o = 5.38667 < 4.0 \]

\[ b_1 = b_e (3+y) \quad (y = \Psi) \]

\[ = 151.388/ (3+1.020) = 37.6553 \text{ mm} \]

For \( \Psi > 0.236 \)

\[ B_2 = b_o/2 = 151.388/2 = 75.6939 \text{ mm} \]

\[ B_1 + b_2 \leq w/2 \]

\[ 37.6553 + 75.6939 = 113.349 < 196 \rightarrow \text{web is not fully effective for this iteration. Recomputing properties by parts. Considering the ineffective portion of the web as an element with a negative length} \]

\[ B_{neg} = -(196-113.349) = -7.368491 \text{ mm} \]

Its centroidal location below the top fibre:

\[ y = t/2 + r + b_1 + b_{neg}/2 \]

\[ = 1.2/2 + 3 + 37.6553 + 7.368/2 \]

\[ = 82.9806 \text{ mm} \]
\[
Y = \frac{\sum Ay}{\sum A} = \frac{227631.53}{1020.2} = 223.12 \text{ mm below top fibre}
\]

\[
I_x = \frac{\sum I_x + \sum Ay^2 - y^2 \sum A}{\sum A} = \frac{[4.028 \times 10^{11} + 7.46 \times 10^7 - (347.047)^2 \times (1020.2)]}{\sum A}
\]

\[
= 32917421.69 \text{ mm}^4
\]

The calculated neutral axis location (344.584mm) does not equal the assumed neutral axis location (200 mm); therefore, iteration is required. After further iterations, the solution converges to:

\[
I_x = 31516355.43 \text{ mm}^4
\]

\[
Y = 344.584 \text{ mm}
\]

Effective section modulus \( S_e = 135095.1838 \text{ mm}^3 \)

Predicted moment

\[
M_{Pr} = Z_e f_c
\]

\[
= 135095.1838 \times 239.238
\]

\[
= 32319999.99 \text{ N.mm}
\]