ARUP Calculation sheet	Job No.		Rev.
	Member Location		
Job Title	Drg. ref.		
	Made By LY	Date 12-03-2021	Chd.

CSA S16-14 W-Section Element Design

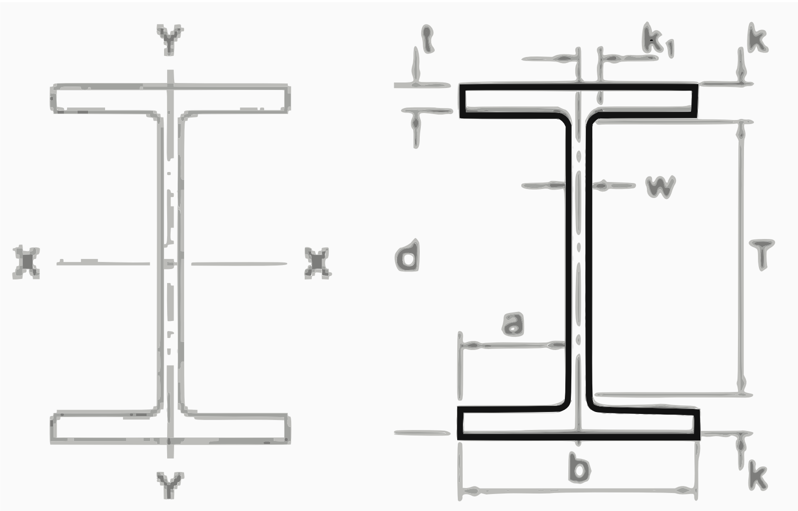
Process a comprehensive design check for a W-section Element in accordance with Canadian Code CSA S16-14.

Calculation ID: 1

Verification status: Work in progress

Assumptions:

- Calc is applicable for Class 1, 2 and 3 W sections only
- Tension resistance is checked based on yielding only
- Compression force is taken as a positive value
- Calculation does not check torsion
- Calculation for symmetric sections only



W-Beam Axis

Inputs

Compression force in member	$C_f = 50\,kN$
Tension force in member	$T_f = 0\,kN$
Bending moment on member about x-axis	$M_{fx} = 50\,kN$
Bending moment on member about y-axis	$M_{fy} = 20\,kN$
Shear force on member in x-axis direction	$V_{fx} = 50\,kN$
Shear force on member in y-axis direction	$V_{fy} = 20\,kN$
Overall depth of section	$d = 257\,mm$
Overall flange width	$b = 204\,mm$
Web thickness	$w = 8.9\,mm$

Flange thickness $t = 15.7\,mm$

Yield strength $F_y = 350\,MPa$

Tensile strength $F_u = 410\,MPa$

Effective length factor for buckling about x-axis $K_x = 1$

Unbraced length or span of member about principal x-axis direction $L_x = 2{\times}10^3\,mm$

Effective length factor for buckling about y-axis $K_y = 1$

Unbraced length or span of member about principal y-axis direction $L_y = 2{\times}10^3\,mm$

Unbraced length or span of member for torsional buckling $L_z = 2{\times}10^3\,mm$

Distance from centroid to shear center in principal x-axis direction $x_0 = 0\,mm$

Distance from centroid to shear center in principal y-axis direction $y_0 = 0\,mm$

Lateral support condition for a member $Condition = \text{Laterally\_Supported}$

Moment resistance coefficient accounting for moment gradient $\omega_2 = 1$

Coefficient to determine equivalent uniform bending effect in beam-columns for the principal x-axis $\omega_{1x} = 1$

Coefficient to determine equivalent uniform bending effect in beam-columns for the principal y-axis $\omega_{1y} = 1$

Whether member is in a braced or unbraced frame $Frame\ type = \text{Braced\_Frame}$

Calculation for section properties

Modulus of elasticity of steel $E = 2{\times}10^5\,MPa$

Shear modulus of steel $G = 7.7{\times}10^4\,MPa$

Full unreduced cross-sectional area of member

$$A = 2 \times b \times t + w \times (d - 2 \times t)$$
$$= 2 \times 204\,mm \times 15.7\,mm + 8.9\,mm \times (257\,mm - 2 \times 15.7\,mm)$$
$$= 8.41{\times}10^3\,mm^2$$

Moment of inertia major axis

$$I_x = \frac{(d - 2 \times t)^3 \times w}{12} + 2 \times \left(\frac{t^3 \times b}{12} + \frac{t \times b \times (d - t)^2}{4}\right)$$
$$= \frac{(257\,mm - 2 \times 15.7\,mm)^3 \times 8.9\,mm}{12} + 2 \times \left(\frac{(15.7\,mm)^3 \times 204\,mm}{12} + \frac{15.7\,mm \times 204\,mm \times (257\,mm - 15.7\,mm)^2}{4}\right)$$

$= 1.02{\times}10^{8}\,mm^{4}$

Moment of inertia minor axis

$$I_y = \frac{(d-2\times t)\times w}{12} + 2\times\frac{b^3\times t}{12}$$
$$= \frac{(257\,mm - 2\times 15.7\,mm)\times 8.9\,mm}{12} + 2\times\frac{(204\,mm)^3\times 15.7\,mm}{12}$$
$$= 2.22{\times}10^{7}\,mm^{4}$$

Radius of gyration about centroidal principal x axis

$$r_x = \left(\frac{I_x}{A}\right)^{0.5}$$
$$= \left(\frac{1.02{\times}10^{8}\,mm^{4}}{8.41{\times}10^{3}\,mm^{2}}\right)^{0.5}$$
$$= 110\,mm$$

Radius of gyration about centroidal principal y axis

$$r_y = \left(\frac{I_y}{A}\right)^{0.5}$$
$$= \left(\frac{2.22{\times}10^{7}\,mm^{4}}{8.41{\times}10^{3}\,mm^{2}}\right)^{0.5}$$
$$= 51.4\,mm$$

Elastic section modulus about x-axis

$$S_x = \frac{2\times I_x}{d}$$
$$= \frac{2\times 1.02{\times}10^{8}\,mm^{4}}{257\,mm}$$
$$= 7.93{\times}10^{5}\,mm^{3}$$

Elastic section modulus about y-axis

$$S_y = \frac{2\times I_y}{b}$$
$$= \frac{2\times 2.22{\times}10^{7}\,mm^{4}}{204\,mm}$$
$$= 2.18{\times}10^{5}\,mm^{3}$$

Plastic section modulus about x-axis

$$Z_x = b\times t\times(d-t) + \frac{w\times(d-2\times t)^2}{4}$$
$$= 204\,mm\times 15.7\,mm\times(257\,mm - 15.7\,mm) + \frac{8.9\,mm\times(257\,mm - 2\times 15.7\,mm)^2}{4}$$
$$= 8.86{\times}10^{5}\,mm^{3}$$

Plastic section modulus about y-axis

$$Z_y = \frac{t\times b^2}{2} + \frac{(d-2\times t)\times w^2}{4}$$
$$= \frac{15.7\,mm\times(204\,mm)^2}{2} + \frac{(257\,mm - 2\times 15.7\,mm)\times(8.9\,mm)^2}{4}$$
$$= 3.31{\times}10^{5}\,mm^{3}$$

Saint-Venant torsion constant of cross-section

$$J = \frac{2\times b\times t^3 + (d-2\times t)\times w^3}{3}$$
$$= \frac{2\times 204\,mm\times(15.7\,mm)^3 + (257\,mm - 2\times 15.7\,mm)\times(8.9\,mm)^3}{3}$$
$$= 5.79{\times}10^{5}\,mm^{4}$$

Torsional warping constant of cross-section

$$C_w = \frac{I_y\times(d-t)^2}{4}$$

$$= \frac{2.22\times10^{7}\,mm^{4} \times (257\,mm - 15.7\,mm)^{2}}{4}$$
$$= 3.23\times10^{11}\,mm^{6}$$

Classification of W section for axial compression

Width of stiffened or unstiffened compression elements

$$b_{el} = \frac{b}{2}$$
$$= \frac{204\,mm}{2}$$
$$= 102\,mm$$

S16-14 11.2 Table 2

Width to thickness ratio

$$\frac{b_{el}}{t} = \frac{b_{el}}{t}$$
$$= \frac{102\,mm}{15.7\,mm}$$
$$= 6.5$$

$$\frac{b_{el}}{t} = 6.5$$

S16-14 11.2 Table 1

Width to thickness limit for elements in axial compression

$$Limit = \frac{200}{\sqrt{F_y}}$$
$$= \frac{200}{\sqrt{350\,MPa}}$$
$$= 10.7$$

Check for maximum width to thickness ratio for flange

$$\frac{b_{el}}{t} \leqslant \frac{200}{\sqrt{F_y}}$$
$$6.5 \leqslant \frac{200}{\sqrt{350\,MPa}}$$
$$6.5 \leqslant 10.7$$

Flange does not exceed maximum permissible width to thickness ratio.

$$Check = \text{Flange is not Class 4}$$

Clear depth of web between flanges

$$h = d - 2 \times t$$
$$= 257\,mm - 2 \times 15.7\,mm$$
$$= 226\,mm$$

S16-14 11.3.2 b)

Width to thickness ratio

$$\frac{h}{w} = \frac{h}{w}$$
$$= \frac{226\,mm}{8.9\,mm}$$
$$= 25.3$$

$$\frac{h}{w} = 25.3$$

S16-14 11.2 Table 1

Maximum width to thickness ratio for webs supported on both edges

$$Limit = \frac{670}{\sqrt{F_y}}$$
$$= \frac{670}{\sqrt{350\,MPa}}$$
$$= 35.8$$

Check for maximum width to thickness ratio for web

$$\frac{h}{w} \leqslant \frac{670}{\sqrt{F_y}}$$
$$25.3 \leqslant \frac{670}{\sqrt{350\,MPa}}$$
$$25.3 \leqslant 35.8$$

Web does not exceed maximum permissible width to thickness ratio!

$$Check = \text{Web is not Class 4}$$

Classification of W section for flexural compression

Width of stiffened or unstiffened compression elements

$$b_{el} = \frac{b}{2}$$
$$= \frac{204\,mm}{2}$$
$$= 102\,mm$$

S16-14 11.2 Table 2

Width to thickness ratio

$$\frac{b_{el}}{t} = \frac{b_{el}}{t}$$
$$= \frac{102\,mm}{15.7\,mm}$$
$$= 6.5$$

$$\frac{b_{el}}{t} = 6.5$$

S16-14 11.2 Table 2

Section classification limit for Class 1 sections

$$Class\ 1\ Limit = \frac{145}{\sqrt{F_y}}$$
$$= \frac{145}{\sqrt{350\,MPa}}$$
$$= 7.75$$

S16-14 11.2 Table 2

Section classification limit for Class 2 sections

$$Class\ 2\ Limit = \frac{170}{\sqrt{F_y}}$$
$$= \frac{170}{\sqrt{350\,MPa}}$$
$$= 9.09$$

S16-14 11.2 Table 2

Section classification limit for Class 3 sections

$$Class\ 3\ Limit = \frac{200}{\sqrt{F_y}}$$

$$= \frac{200}{\sqrt{350\,MPa}}$$
$$= 10.7$$

$$Class = \text{Class\_1}$$

Clear depth of web between flanges

$$h = d - 2 \times t$$
$$= 257\,mm - 2 \times 15.7\,mm$$
$$= 226\,mm$$

S16-14 11.3.2 b)

Width to thickness ratio

$$\frac{h}{w} = \frac{h}{w}$$
$$= \frac{226\,mm}{8.9\,mm}$$
$$= 25.3$$

$$\frac{h}{w} = 25.3$$

Axial compressive load at yield stress

$$C_y = F_y \times A \times 10^{-3}$$
$$= 350\,MPa \times 8.41{\times}10^3\,mm^2 \times 10^{-3}$$
$$= 2.94{\times}10^3\,kN$$

S16-14 11.2 Table 2

Section classification limit for Class 1 sections

$$Class\ 1\ Limit = \frac{1.1{\times}10^3}{\sqrt{F_y}} \times \left(1 - 0.39 \times \frac{C_f}{\phi \times C_y}\right)$$
$$= \frac{1.1{\times}10^3}{\sqrt{350\,MPa}} \times \left(1 - 0.39 \times \frac{50\,kN}{0.9\ \times 2.94{\times}10^3\,kN}\right)$$
$$= 58.4$$

S16-14 11.2 Table 2

Section classification limit for Class 2 sections

$$Class\ 2\ Limit = \frac{1.7{\times}10^3}{\sqrt{F_y}} \times \left(1 - 0.61 \times \frac{C_f}{\phi \times C_y}\right)$$
$$= \frac{1.7{\times}10^3}{\sqrt{350\,MPa}} \times \left(1 - 0.61 \times \frac{50\,kN}{0.9\ \times 2.94{\times}10^3\,kN}\right)$$
$$= 89.8$$

S16-14 11.2 Table 2

Section classification limit for Class 3 sections

$$Class\ 3\ Limit = \frac{1.9{\times}10^3}{\sqrt{F_y}} \times \left(1 - 0.65 \times \frac{C_f}{\phi \times C_y}\right)$$
$$= \frac{1.9{\times}10^3}{\sqrt{350\,MPa}} \times \left(1 - 0.65 \times \frac{50\,kN}{0.9\ \times 2.94{\times}10^3\,kN}\right)$$
$$= 100$$

$$Class = \text{Class\_1}$$

Shear capacity

Shear in the y-axis direction, major axis

Shear area

$$A_w = d \times w$$

$= 257\,mm \times 8.9\,mm$

$= 2.29{\times}10^3\,mm^2$

$A_w = 2.29{\times}10^3\,mm^2$

Ultimate shear stress

$F_s = 0.66 \times F_y$

$= 0.66 \times 350\,MPa$

$= 231\,MPa$

$F_s = 231\,MPa$

S16-14 13.4.1.1 a) i)

Factored shear resistance of a member or component

$V_r = \phi \times A_w \times F_s \times 10^{-3}$

$= 0.9 \times 2.29{\times}10^3\,mm^2 \times 231\,MPa \times 10^{-3}$

$= 476\,kN$

$V_r = 476\,kN$

$\boxed{V_{ry} = 476\,kN}$

Shear in the x-axis direction, minor axis

Overall depth of section for weak axis shear (depth of 2 flanges)

$d = 2 \times b$

$= 2 \times 204\,mm$

$= 408\,mm$

Web thickness for weak axis shear (flange thickness)

$w = 15.7\,mm$

Shear area

$A_w = d \times w$

$= 408\,mm \times 15.7\,mm$

$= 6.41{\times}10^3\,mm^2$

$A_w = 6.41{\times}10^3\,mm^2$

Ultimate shear stress

$F_s = 0.66 \times F_y$

$= 0.66 \times 350\,MPa$

$= 231\,MPa$

$F_s = 231\,MPa$

S16-14 13.4.1.1 a) i)

Factored shear resistance of a member or component

$V_r = \phi \times A_w \times F_s \times 10^{-3}$

$= 0.9 \times 6.41{\times}10^3\,mm^2 \times 231\,MPa \times 10^{-3}$

$= 1.33{\times}10^3\,kN$

$V_r = 1.33{\times}10^3\,kN$

$V_{rx} = 1.33{\times}10^{3}\,kN$

Slenderness ratio check

Slenderness ratio about x-axis

$$\frac{K_x L_x}{r_x} = \frac{K_x \times L_x}{r_x} = \frac{1 \times 2{\times}10^{3}\,mm}{110\,mm} = 18.2$$

Slenderness ratio about y-axis

$$\frac{K_y L_y}{r_y} = \frac{K_y \times L_y}{r_y} = \frac{1 \times 2{\times}10^{3}\,mm}{51.4\,mm} = 38.9$$

S16-14 10.4.1 Slenderness ratio of member

$$\frac{KL}{r} = \max\left(\frac{K_x L_x}{r_x}, \frac{K_y L_y}{r_y}\right) = \max(18.2\,, 38.9\,) = 38.9$$

$\frac{KL}{r} = 38.9$

$$\frac{KL}{r} \leqslant 200$$
$$38.9 \leqslant 200$$
$$38.9 \leqslant 200$$

Slenderness ratio does not exceed maximum permissible slenderness ratio.

$Check =$ Slenderness ratio ok!

Axial compression capacity

Factored axial compressive resistance based on flexural buckling (about x-axis and y-axis)

S16-14 13.3.1 Euler buckling stress about x-axis

$$F_{ex} = \frac{\pi^2 \times E}{\left(\frac{K_x \times L_x}{r_x}\right)^2} = \frac{(\pi)^2 \times 2{\times}10^{5}\,MPa}{\left(\frac{1 \times 2{\times}10^{3}\,mm}{110\,mm}\right)^2} = 5.98{\times}10^{3}\,MPa$$

S16-14 13.3.1 Euler buckling stress about y-axis

$$F_{ey} = \frac{\pi^2 \times E}{\left(\frac{K_y \times L_y}{r_y}\right)^2}$$
$$= \frac{(\pi)^2 \times 2{\times}10^5\,MPa}{\left(\frac{1 \times 2{\times}10^3\,mm}{51.4\,mm}\right)^2}$$
$$= 1.3{\times}10^3\,MPa$$

Euler buckling stress

$$F_e = \min\left(F_{ex}, F_{ey}\right)$$
$$= \min\left(5.98{\times}10^3\,MPa, 1.3{\times}10^3\,MPa\right)$$
$$= 1.3{\times}10^3\,MPa$$

S16-14 13.3.1 Non-dimensional slenderness parameter

$$\lambda = \sqrt{\frac{F_y}{F_e}}$$
$$= \sqrt{\frac{350\,MPa}{1.3{\times}10^3\,MPa}}$$
$$= 0.518$$

$$\lambda = 0.518$$

S16-14 13.3.1 Factored compressive resistance of a member or component

$$C_r = \frac{\phi \times A \times F_y}{\left(1+\lambda^{2\times n}\right)^{\frac{1}{n}}} \times 10^{-3}$$
$$= \frac{0.9 \times 8.41{\times}10^3\,mm^2 \times 350\,MPa}{\left(1+0.518^{2\times 1.34}\right)^{\frac{1}{1.34}}} \times 10^{-3}$$
$$= 2.35{\times}10^3\,kN$$

$$C_r = 2.35{\times}10^3\,kN$$

Factored axial compressive resistance based on torsional buckling

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Effective length factor for torsional buckling

$$K_z = 1$$

S16-14 13.3.2 Polar radius of gyration about shear centre

$$\overline{r}_o{}^2 = x_0{}^2 + y_0{}^2 + r_x{}^2 + r_y{}^2$$
$$= (0\,mm)^2 + (0\,mm)^2 + (110\,mm)^2 + (51.4\,mm)^2$$
$$= 1.48{\times}10^4\,mm^2$$

S16-14 13.3.1 Euler buckling stress

$$F_e = \left(\frac{\pi^2 \times E \times C_w}{(K_z \times L)^2} + G \times J\right) \times \frac{1}{A \times \overline{r}_o{}^2}$$
$$= \left(\frac{(\pi)^2 \times 2{\times}10^5\,MPa \times 3.23{\times}10^{11}\,mm^6}{(1 \times 2{\times}10^3\,mm)^2} + 7.7{\times}10^4\,MPa \times 5.79{\times}10^5\,mm^4\right) \times \frac{1}{8.41{\times}10^3\,mm^2 \times 1.48{\times}10^4\,mm^2}$$
$$= 1.65{\times}10^3\,MPa$$

S16-14 13.3.1 Non-dimensional slenderness parameter

$$\lambda = \sqrt{\frac{F_y}{F_e}}$$

$$= \sqrt{\frac{350\,MPa}{1.65\times10^3\,MPa}}$$
$$= 0.461$$

$$\lambda = 0.461$$

Parameter for compressive resistance $n = 1.34$

S16-14 13.3.1 Factored compressive resistance of a member or component

$$C_r = \frac{\phi \times A \times F_y}{\left(1+\lambda^{2\times n}\right)^{\frac{1}{n}}} \times 10^{-3}$$
$$= \frac{0.9\ \times 8.41\times10^3\,mm^2 \times 350\,MPa}{\left(1+0.461^{\,2\times1.34}\right)^{\frac{1}{1.34}}} \times 10^{-3}$$
$$= 2.43\times10^3\,kN$$

$$C_r = 2.43\times10^3\,kN$$

Overall axial compressive resistance

Non-dimensional slenderness parameter $\lambda = 0.518$

$$\lambda = 0.518$$

Factored compressive resistance of member based on flexural buckling $C_{r,flexural} = 2.35\times10^3\,kN$

Factored compressive resistance of member based on torsional buckling $C_{r,torsional} = 2.43\times10^3\,kN$

S16-14 13.3 Factored compressive resistance of a member or component

$$C_r = \min\left(C_{r,flexural}, C_{r,torsional}\right)$$
$$= \min\left(2.35\times10^3\,kN, 2.43\times10^3\,kN\right)$$
$$= 2.35\times10^3\,kN$$

$$C_r = 2.35\times10^3\,kN$$

$$\boxed{C_r = 2.35\times10^3\,kN}$$

Moment capacity (laterally supported member)

Strong axis bending

S16-14 13.5 a) Factored moment resistance of a member or component

$$M_r = \phi \times F_y \times Z \times 10^{-6}$$
$$= 0.9\ \times 350\,MPa \times 8.86\times10^5\,mm^3 \times 10^{-6}$$
$$= 279\,kNm$$

$$M_r = 279\,kNm$$

$$\boxed{M_{rx} = 279\,kN}$$

Weak axis bending

S16-14 13.5 a) | Factored moment resistance of a member or component

$$M_r = \phi \times F_y \times Z \times 10^{-6}$$
$$= 0.9 \times 350\,MPa \times 3.31{\times}10^{5}\,mm^3 \times 10^{-6}$$
$$= 104\,kNm$$

$$M_r = 104\,kNm$$

$$\boxed{M_{ry} = 104\,kN}$$

Axial tension capacity

S16-14 13.2 a) i) | Factored tensile resistance of a member or component

$$T_r = \phi \times \frac{A_g \times F_y}{1{\times}10^3}$$
$$= 0.9 \times \frac{8.41{\times}10^3\,mm^2 \times 350\,MPa}{1{\times}10^3}$$
$$= 2.65{\times}10^3\,kN$$

$$T_r = 2.65{\times}10^3\,kN$$

$$\boxed{T_r = 2.65{\times}10^3\,kN}$$

Biaxial bending

S16-14 13.6 f) | Utilization

$$Util = \frac{M_{fx}}{M_{rx}} + \frac{M_{fy}}{M_{ry}}$$
$$= \frac{50\,kN}{279\,kN} + \frac{20\,kN}{104\,kN}$$
$$= 0.371$$

$$Util_{bending} = 0.371$$

$$\boxed{Util_{bending} = 0.371}$$

Combined axial compression and bending Calculation

Compression and bending cross sectional strength I shaped class1 & 2

S16-14 13.8.2 a) i) — Factored compressive resistance of a member or component

$$C_r = \phi \times F_y \times A \times 10^{-3}$$
$$= 0.9 \times 350\,MPa \times 8.41{\times}10^{3}\,mm^2 \times 10^{-3}$$
$$= 2.65{\times}10^{3}\,kN$$

S16-14 13.8.4 — Euler buckling strength about x-axis

$$C_{ex} = \frac{\pi^2 \times E \times I_x}{{L_x}^2} \times 10^{-3}$$
$$= \frac{(\pi)^2 \times 2{\times}10^{5}\,MPa \times 1.02{\times}10^{8}\,mm^4}{(2{\times}10^{3}\,mm)^2} \times 10^{-3}$$
$$= 5.03{\times}10^{4}\,kN$$

S16-14 13.8.4 — Euler buckling strength about y-axis

$$C_{ey} = \frac{\pi^2 \times E \times I_y}{{L_y}^2} \times 10^{-3}$$
$$= \frac{(\pi)^2 \times 2{\times}10^{5}\,MPa \times 2.22{\times}10^{7}\,mm^4}{(2{\times}10^{3}\,mm)^2} \times 10^{-3}$$
$$= 1.1{\times}10^{4}\,kN$$

S16-14 13.8.2 a) iii) and 13.8.4 — Factor to account for moment gradient and for second-order effects of axial fore acting on the deformed member for the x-axis

$$U_{1x} = \max\left(\frac{\omega_{1x}}{1 - \frac{C_f}{C_{ex}}}, 1\right)$$
$$= \max\left(\frac{1}{1 - \frac{50\,kN}{5.03{\times}10^{4}\,kN}}, 1\right)$$
$$= 1$$

S16-14 13.8.2 a) iii) and 13.8.4 — Factor to account for moment gradient and for second-order effects of axial fore acting on the deformed member for the y-axis

$$U_{1y} = \max\left(\frac{\omega_{1y}}{1 - \frac{C_f}{C_{ey}}}, 1\right)$$
$$= \max\left(\frac{1}{1 - \frac{50\,kN}{1.1{\times}10^{4}\,kN}}, 1\right)$$
$$= 1$$

Coefficient for weak axis bending in beam-columns

$$\beta = 0.6$$

S16-14 13.8.2 a) — Utilization

$$Util = \frac{C_f}{C_r} + \frac{0.85 \times U_{1x} \times M_{fx}}{M_{rx}} + \frac{\beta \times U_{1y} \times M_{fy}}{M_{ry}}$$
$$= \frac{50\,kN}{2.65{\times}10^{3}\,kN} + \frac{0.85 \times 1 \times 50\,kN}{279\,kN} + \frac{0.6 \times 1 \times 20\,kN}{104\,kN}$$
$$= 0.287$$

$$Util_{sect} = 0.287$$

Compression and bending overall member strength I shaped class1 & 2

Cr is as specified in Clause 13.3, with the value K = 1

For biaxial bending Cr is based on the lesser value of Cr due to bending about the x-axis and Cr due to bending about the y-axis

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S16-14 13.3.1 — Euler buckling stress about x-axis

$$F_{ex} = \frac{\pi^2 \times E}{\left(\frac{K_x \times L_x}{r_x}\right)^2} = \frac{(\pi)^2 \times 2{\times}10^5\,MPa}{\left(\frac{1\,\times 2{\times}10^3\,mm}{110\,mm}\right)^2} = 5.98{\times}10^3\,MPa$$

S16-14 13.3.1 — Euler buckling stress about y-axis

$$F_{ey} = \frac{\pi^2 \times E}{\left(\frac{K_y \times L_y}{r_y}\right)^2} = \frac{(\pi)^2 \times 2{\times}10^5\,MPa}{\left(\frac{1\,\times 2{\times}10^3\,mm}{51.4\,mm}\right)^2} = 1.3{\times}10^3\,MPa$$

Euler buckling stress

$$F_e = \min\left(F_{ex}, F_{ey}\right) = \min\left(5.98{\times}10^3\,MPa, 1.3{\times}10^3\,MPa\right) = 1.3{\times}10^3\,MPa$$

S16-14 13.3.1 — Non-dimensional slenderness parameter

$$\lambda = \sqrt{\frac{F_y}{F_e}} = \sqrt{\frac{350\,MPa}{1.3{\times}10^3\,MPa}} = 0.518$$

$$\lambda = 0.518$$

S16-14 13.3.1 — Factored compressive resistance of a member or component

$$C_r = \frac{\phi \times A \times F_y}{\left(1+\lambda^{2\times n}\right)^{\frac{1}{n}}} \times 10^{-3} = \frac{0.9\,\times 8.41{\times}10^3\,mm^2 \times 350\,MPa}{\left(1+0.518^{\,2\times 1.34}\right)^{\frac{1}{1.34}}} \times 10^{-3} = 2.35{\times}10^3\,kN$$

$$C_r = 2.35{\times}10^3\,kN$$

U1x and U1y are as specified in Clause 13.8.2 b) iv) for members in unbraced frames

S16-14 13.8.4 — Euler buckling strength about x-axis

$$C_{ex} = \frac{\pi^2 \times E \times I_x}{{L_x}^2} \times 10^{-3} = \frac{(\pi)^2 \times 2{\times}10^5\,MPa \times 1.02{\times}10^8\,mm^4}{\left(2{\times}10^3\,mm\right)^2} \times 10^{-3} = 5.03{\times}10^4\,kN$$

S16-14 13.8.4

Euler buckling strength about y-axis

$$C_{ey} = \frac{\pi^2 \times E \times I_y}{{L_y}^2} \times 10^{-3} = \frac{(\pi)^2 \times 2{\times}10^5\,MPa \times 2.22{\times}10^7\,mm^4}{(2{\times}10^3\,mm)^2} \times 10^{-3} = 1.1{\times}10^4\,kN$$

S16-14 13.8.4

Factor to account for moment gradient and for second-order effects of axial fore acting on the deformed member for the x-axis

$$U_{1x} = \frac{\omega_{1x}}{1 - \frac{C_f}{C_{ex}}} = \frac{1}{1 - \frac{50\,kN}{5.03{\times}10^4\,kN}} = 1$$

S16-14 13.8.4

Factor to account for moment gradient and for second-order effects of axial fore acting on the deformed member for the y-axis

$$U_{1y} = \frac{\omega_{1y}}{1 - \frac{C_f}{C_{ey}}} = \frac{1}{1 - \frac{50\,kN}{1.1{\times}10^4\,kN}} = 1$$

S16-14 13.8.2

Coefficient for weak axis bending in beam-columns

$$\beta = \min\left(0.6 + 0.4 \times \lambda, 0.85\right) = \min\left(0.6 + 0.4 \times 0.518\,, 0.85\right) = 0.807$$

S16-14 13.8.2 b)

Utilization

$$Util = \frac{C_f}{C_r} + \frac{0.85 \times U_{1x} \times M_{fx}}{M_{rx}} + \frac{\beta \times U_{1y} \times M_{fy}}{M_{ry}} = \frac{50\,kN}{2.35{\times}10^3\,kN} + \frac{0.85 \times 1 \times 50\,kN}{279\,kN} + \frac{0.807 \times 1 \times 20\,kN}{104\,kN} = 0.329$$

$$Util_{member} = 0.329$$

Compression and bending lateral torsional buckling strength I shaped class1 & 2

Cr is as specified in Clause 13.3 and based on weak-axis or torsional-flexural buckling per Clause 13.8.2 c) i)

Factored axial compressive resistance based on flexural buckling (about x-axis and y-axis)

S16-14 13.3.1

Euler buckling stress about x-axis

$$F_{ex} = \frac{\pi^2 \times E}{\left(\frac{K_x \times L_x}{r_x}\right)^2} = \frac{(\pi)^2 \times 2{\times}10^5\,MPa}{\left(\frac{1 \times 2{\times}10^3\,mm}{110\,mm}\right)^2} = 5.98{\times}10^3\,MPa$$

S16-14 13.3.1 — Euler buckling stress about y-axis

$$F_{ey} = \frac{\pi^2 \times E}{\left(\frac{K_y \times L_y}{r_y}\right)^2}$$
$$= \frac{(\pi)^2 \times 2{\times}10^5\,MPa}{\left(\frac{1\times 2{\times}10^3\,mm}{51.4\,mm}\right)^2}$$
$$= 1.3{\times}10^3\,MPa$$

Euler buckling stress

$$F_e = \min\left(F_{ex}, F_{ey}\right)$$
$$= \min\left(5.98{\times}10^3\,MPa, 1.3{\times}10^3\,MPa\right)$$
$$= 1.3{\times}10^3\,MPa$$

S16-14 13.3.1 — Non-dimensional slenderness parameter

$$\lambda = \sqrt{\frac{F_y}{F_e}}$$
$$= \sqrt{\frac{350\,MPa}{1.3{\times}10^3\,MPa}}$$
$$= 0.518$$

$$\lambda = 0.518$$

S16-14 13.3.1 — Factored compressive resistance of a member or component

$$C_r = \frac{\phi \times A \times F_y}{\left(1+\lambda^{2\times n}\right)^{\frac{1}{n}}} \times 10^{-3}$$
$$= \frac{0.9 \times 8.41{\times}10^3\,mm^2 \times 350\,MPa}{\left(1+0.518^{\,2\times 1.34}\right)^{\frac{1}{1.34}}} \times 10^{-3}$$
$$= 2.35{\times}10^3\,kN$$

$$C_r = 2.35{\times}10^3\,kN$$

Factored axial compressive resistance based on torsional buckling

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Effective length factor for torsional buckling

$$K_z = 1$$

S16-14 13.3.2 — Polar radius of gyration about shear centre

$$\overline{r}_o{}^2 = x_0{}^2 + y_0{}^2 + r_x{}^2 + r_y{}^2$$
$$= (0\,mm)^2 + (0\,mm)^2 + (110\,mm)^2 + (51.4\,mm)^2$$
$$= 1.48{\times}10^4\,mm^2$$

S16-14 13.3.1 — Euler buckling stress

$$F_e = \left(\frac{\pi^2 \times E \times C_w}{(K_z \times L)^2} + G \times J\right) \times \frac{1}{A \times \overline{r}_o{}^2}$$
$$= \left(\frac{(\pi)^2 \times 2{\times}10^5\,MPa \times 3.23{\times}10^{11}\,mm^6}{(1 \times 2{\times}10^3\,mm)^2} + 7.7{\times}10^4\,MPa \times 5.79{\times}10^5\,mm^4\right) \times \frac{1}{8.41{\times}10^3\,mm^2 \times 1.48{\times}10^4\,mm^2}$$
$$= 1.65{\times}10^3\,MPa$$

S16-14 13.3.1 — Non-dimensional slenderness parameter

$$\lambda = \sqrt{\frac{F_y}{F_e}}$$

$$= \sqrt{\frac{350\,MPa}{1.65\times10^{3}\,MPa}}$$
$$= 0.461$$

$$\lambda = 0.461$$

Parameter for compressive resistance $n = 1.34$

S16-14 13.3.1 Factored compressive resistance of a member or component

$$C_r = \frac{\phi \times A \times F_y}{\left(1+\lambda^{2\times n}\right)^{\frac{1}{n}}} \times 10^{-3}$$
$$= \frac{0.9 \times 8.41\times10^{3}\,mm^{2} \times 350\,MPa}{\left(1+0.461^{\,2\times1.34}\right)^{\frac{1}{1.34}}} \times 10^{-3}$$
$$= 2.43\times10^{3}\,kN$$

$$C_r = 2.43\times10^{3}\,kN$$

Overall axial compressive resistance

Non-dimensional slenderness parameter $\lambda = 0.518$

$$\lambda = 0.518$$

Factored compressive resistance of member based on flexural buckling $C_{r,flexural} = 2.35\times10^{3}\,kN$

Factored compressive resistance of member based on torsional buckling $C_{r,torsional} = 2.43\times10^{3}\,kN$

S16-14 13.3 Factored compressive resistance of a member or component

$$C_r = \min\left(C_{r,flexural}, C_{r,torsional}\right)$$
$$= \min\left(2.35\times10^{3}\,kN, 2.43\times10^{3}\,kN\right)$$
$$= 2.35\times10^{3}\,kN$$

$$C_r = 2.35\times10^{3}\,kN$$

U1x is as specified in Clause 13.8.2 c) v) for members in braced frames

S16-14 13.8.4 Euler buckling strength about x-axis

$$C_{ex} = \frac{\pi^{2} \times E \times I_x}{{L_x}^{2}} \times 10^{-3}$$
$$= \frac{(\pi)^{2} \times 2\times10^{5}\,MPa \times 1.02\times10^{8}\,mm^{4}}{\left(2\times10^{3}\,mm\right)^{2}} \times 10^{-3}$$
$$= 5.03\times10^{4}\,kN$$

S16-14 13.8.4 Factor to account for moment gradient and for second-order effects of axial fore acting on the deformed member for the x-axis

$$U_{1x} = \max\left(\frac{\omega_{1x}}{1-\frac{C_f}{C_{ex}}}, 1\right)$$
$$= \max\left(\frac{1}{1-\frac{50\,kN}{5.03\times10^{4}\,kN}}, 1\right)$$

$$= 1$$

U1y is as specified in Clause 13.8.2 c) vi) for members in braced frames

S16-14 13.8.4

Euler buckling strength about y-axis

$$C_{ey} = \frac{\pi^2 \times E \times I_y}{{L_y}^2} \times 10^{-3}$$
$$= \frac{(\pi)^2 \times 2{\times}10^5\ MPa \times 2.22{\times}10^7\ mm^4}{(2{\times}10^3\ mm)^2} \times 10^{-3}$$
$$= 1.1{\times}10^4\ kN$$

S16-14 13.8.4

Factor to account for moment gradient and for second-order effects of axial fore acting on the deformed member for the y-axis

$$U_{1y} = \frac{\omega_{1y}}{1 - \frac{C_f}{C_{ey}}}$$
$$= \frac{1}{1 - \frac{50\ kN}{1.1{\times}10^4\ kN}}$$
$$= 1$$

S16-14 13.8.2

Coefficient for weak axis bending in beam-columns

$$\beta = \min\left(0.6 + 0.4 \times \lambda, 0.85\right)$$
$$= \min\left(0.6 + 0.4 \times 0.518\ , 0.85\right)$$
$$= 0.807$$

S16-14 13.8.2 c)

Utilization

$$Util = \frac{C_f}{C_r} + \frac{0.85 \times U_{1x} \times M_{fx}}{M_{rx}} + \frac{\beta \times U_{1y} \times M_{fy}}{M_{ry}}$$
$$= \frac{50\ kN}{2.35{\times}10^3\ kN} + \frac{0.85 \times 1\ \times 50\ kN}{279\ kN} + \frac{0.807\ \times 1\ \times 20\ kN}{104\ kN}$$
$$= 0.329$$

$$Util_{LTB} = 0.329$$

$$\boxed{Util_{sect} = 0.287}$$

$$\boxed{Util_{member} = 0.329}$$

$$\boxed{Util_{LTB} = 0.329}$$

Capacity check summary

Summary table of demands, capacities and utilisation ratios for axial forces, moments and shear forces:

Summary	**Compression, Cf/Cr**	**Tension, Tf/Tr**	**Strong Axis Moment, Mfx/Mrx**	**Weak Axis Moment, Mfy/Mry**	**Shear in X-Axis Direction, Vfx/Vrx**	**Shear in Y-Axis Direction, Vfy/Vry**
Demand (kN)	50	0	50	20	50	20
Capacity (kN)	2354.506	2650.234	279.115	104.313	1331.724	475.53
Utilisation	0.021	0	0.179	0.192	0.038	0.042

Summary table of utilisation ratios for combined axial compression and bending, biaxial bending and combined axial tension and bending:

Cross Section Utilisation	**Overall Member Strength Utilisation**	**Lat Torsional Buckling Utilisation**	**Biaxial Bending Utilisation**	**Tension and Bending Utilisation**	**Max Utilisation**
0.287	0.329	0.329	0.371	0	0.371

Bibliography

S16-14 CSA S16 (2014) Canadian Standards Association: Design of steel structures. Canada.