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## **CSA S16-14 W-Section Element Design**

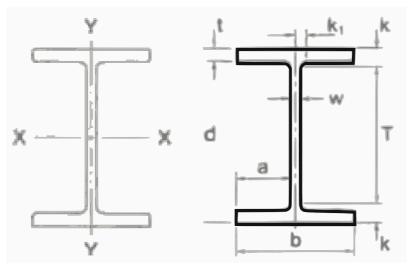
Process a comprehensive design check for a W-section Element in accordance with Canadian Code CSA S16-14.

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

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Flange thickness

 $t = 15.7 \, mm$ 

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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  $L_x=2{ imes}10^3\,mm$ 

direction

Effective length factor for buckling about y-axis

 $K_v = 1$ 

Unbraced length or span of

 $L_y = 2 \times 10^3 \, mm$ 

member about principal y-axis direction

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

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

 $Condition = Laterally\_Supported$ 

Moment resistance coefficient

 $\omega_2 = 1$ 

accounting for moment gradient

 $\omega_{1x} = 1$ 

 $\omega_{1y}=1$ 

Coefficient to determine equivalent uniform bending effect in beam-columns for the principal

Coefficient to determine equivalent uniform bending effect in beam-columns for the principal

Whether member is in a braced or  $Frame \ type = Braced\_Frame$ 

#### 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

A=2 imes b imes t+w imes (d-2 imes t)

area of member

 $=2 imes 204\,mm imes 15.7\,mm + 8.9\,mm imes (257\,mm - 2 imes 15.7\,mm)$ 

 $= 8.41 \times 10^3 \, mm^2$ 

Moment of inertia major axis

$$I_x = rac{\left(d-2 imes t
ight)^3 imes w}{12} + 2 imes \left(rac{t^3 imes b}{12} + rac{t imes b imes (d-t)^2}{4}
ight)$$

$$=rac{{{{\left( {257\,mm - 2 imes 15.7\,mm} 
ight)}^3 imes 8.9\,mm}}}{{12}} + 2 imes }{{\left( {rac{{{{\left( {15.7\,mm} 
ight)}^3 imes 204\,mm}}}{{12}} + rac{{15.7\,mm imes 204\,mm imes {{\left( {257\,mm - 15.7\,mm} 
ight)}^2}} 
ight)}}$$

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 $=1.02\times10^{8} \, mm^{2}$ 

$$egin{aligned} I_y &= rac{(d-2 imes t) imes w}{12} + 2 imes rac{b^3 imes t}{12} \ &= rac{(257\,mm - 2 imes 15.7\,mm) imes 8.9\,mm}{12} + 2 imes rac{(204\,mm)^3 imes 15.7\,mm}{12} \ &= 2.22 imes 10^7\,mm^4 \end{aligned}$$

## Radius of gyration about centroidal principal x axis

$$egin{split} r_x &= \left(rac{I_x}{A}
ight)^{0.5} \ &= \left(rac{1.02{ imes}10^8\ mm^4}{8.41{ imes}10^3\ mm^2}
ight)^{0.5} \end{split}$$

## Radius of gyration about centroidal principal y axis

$$egin{align} r_y &= \left(rac{I_y}{A}
ight)^{0.5} \ &= \left(rac{2.22{ imes}10^7\ mm^4}{8.41{ imes}10^3\ mm^2}
ight)^{0.5} \end{array}$$

## Elastic section modulus about x-axis

$$egin{aligned} S_x &= rac{2 imes I_x}{d} \ &= rac{2 imes 1.02 imes 10^8 \, mm^4}{257 \, mm} \ &= 7.93 imes 10^5 \, mm^3 \end{aligned}$$

## Elastic section modulus about y-axis

$$egin{aligned} S_y &= rac{2 imes I_y}{b} \ &= rac{2 imes 2.22 imes 10^7 \, mm^4}{204 \, mm} \ &= 2.18 imes 10^5 \, mm^3 \end{aligned}$$

## Plastic section modulus about x-axis

$$egin{aligned} Z_x &= b imes t imes (d-t) + rac{w imes (d-2 imes t)^2}{4} \ &= 204 \, mm imes 15.7 \, mm imes (257 \, mm - 15.7 \, mm) + \ &= rac{8.9 \, mm imes (257 \, mm - 2 imes 15.7 \, mm)^2}{4} \ &= 8.86 { imes} 10^5 \, mm^3 \end{aligned}$$

Plastic section modulus about y-axis

$$egin{align*} Z_y &= rac{t imes b^2}{2} + rac{(d-2 imes t) imes w^2}{4} \ &= rac{15.7 \, mm imes (204 \, mm)^2}{2} + rac{(257 \, mm - 2 imes 15.7 \, mm) imes (8.9 \, mm)^2}{4} \ &= 3.31 imes 10^5 \, mm^3 \end{gathered}$$

Saint-Venant torsion constant of cross-section

cross-section

$$egin{aligned} J &= rac{2 imes b imes t^3 + (d - 2 imes t) imes w^3}{3} \ &= rac{2 imes 204 \, mm imes \left(15.7 \, mm
ight)^3 + \left(257 \, mm - 2 imes 15.7 \, mm
ight) imes \left(8.9 \, mm
ight)^3}{3} \ &= 5.79 imes 10^5 \, mm^4 \end{aligned}$$

Torsional warping constant of

$$C_{w}=rac{I_{y} imes\left(d-t
ight)^{2}}{4}$$

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$$\frac{2.22{\times}10^7\,mm^4\times\left(257\,mm-15.7\,mm\right)^2}{4}$$

$$= 3.23{\times}10^{11}\,mm^6$$

#### Classification of W section for axial compression

Width of stiffened or unstiffened compression elements

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

 $=102\,mm$ 

S16-14 11.2 Table 2

Width to thickness ratio

$$egin{aligned} rac{b_{el}}{t} &= rac{b_{el}}{t} \\ &= rac{102\,mm}{15.7\,mm} \\ &= 6.5 \end{aligned}$$

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

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

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

Flange does not exceed maximum permissible width to thickness ratio.

Check = Flange is not Class 4

Clear depth of web between flanges

$$h=d-2 imes t$$
 $=257\,mm-2 imes15.7\,mm$ 

 $=226\,mm$ 

S16-14 11.3.2 b) Width to thickness ratio

$$\begin{aligned} \frac{h}{w} &= \frac{h}{w} \\ &= \frac{226\,mm}{8.9\,mm} \\ &= 25.3 \end{aligned}$$

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

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S16-14 11.2 Table 1

Maximum width to thickness ratio for webs supported on both

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

 $\begin{aligned} \frac{b_{el}}{t} &= \frac{b_{el}}{t} \\ &= \frac{102 \, mm}{15.7 \, mm} \\ &= 6.5 \end{aligned}$ 

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

S16-14 11.2 Table 2

Section classification limit for Class 1 sections

 $Class~1~Limit = rac{145}{\sqrt{F_y}} \ = rac{145}{\sqrt{350~MPa}} \ = 7.75$ 

S16-14 11.2 Table 2

Section classification limit for Class 2 sections

 $Class~2~Limit = rac{170}{\sqrt{F_y}} \ = rac{170}{\sqrt{350~MPa}} \ = 9.09$ 

S16-14 11.2 Table 2

Section classification limit for Class 3 sections

 $Class~3~Limit = rac{200}{\sqrt{F_y}}$ 

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		=	$\frac{200}{\sqrt{350  MPa}}$		
			10.7		
					$Class =  ext{Class\_1}$
	Clear depth of web between flanges		d-2 imes t		
	Ü		257mm-2 imes15.7mm $226mm$	)	
<i>S16-14</i> 11.3.2 b)	Width to thickness ratio	$\frac{h}{}$ _	<u>h</u>		
,	w		$\frac{\overline{w}}{226  mm}$ $8.9  mm$		
			8.9mm $25.3$		
					$\frac{h}{w}=25.3$
					w
	Axial compressive load at yield stress	v	$egin{aligned} F_y  imes A  imes 10^{-3} \ 350MPa  imes 8.41  imes 10^3m \end{aligned}$	$nm^2  imes 10^{-3}$	
		=	$2.94{ imes}10^3~kN$		
<i>S16-14</i> 11.2 Table 2	Section classification limit for Class 1 sections	Class 1 Lir	$nit = rac{1.1 imes 10^3}{\sqrt{F_y}} imes igg(1-6)$	$0.39  imes rac{C_f}{\phi  imes C_u} igg)$	
			$39  imes rac{50kN}{0.9 imes 2.94{ imes}10^3kN}$	)	
			$\sqrt{350} MPa$ \ $58.4$	0.9 × 2.94×10° kN	/
<i>S16-14</i> 11.2 Table 2	Section classification limit for Class 2 sections	Class 2 Lin	$mit = rac{1.7 imes 10^3}{\sqrt{F_n}} imes \left(1-6 ight)$	$0.61  imes rac{C_f}{\phi  imes C_u} igg)$	
	Glass 2 sections		v g	$51 imesrac{50kN}{0.9 imes2.94 imes10^3kN}$	)
			89.8		,
S16-14 11.2 Table 2	Section classification limit for Class 3 sections	Class 3 Lir	$mit = rac{1.9  imes 10^3}{\sqrt{F_y}}  imes igg(1 - 0)$	$0.65 imesrac{C_f}{\phi imes C_y} igg)$	
		=	$\frac{1.9 \times 10^3}{\sqrt{350  MPa}} \times \left(1 - 0.6\right)$	$55 imesrac{50kN}{0.9 imes2.94{ imes}10^3kN}$	)
		=	100		

 $Class = {\it Class\_1}$ 

### Shear capacity

Shear in the y-axis direction, major axis

Shear area

 $A_w = d imes w$ 

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			257mm  imes			
		=2	$2.29 \times 10^{3}  n$	$nm^2$		
						$A_w=2.29{ imes}10^3mm^2$
U	Iltimate shear stress	$F_s = 0$	$0.66  imes F_y$			
			0.66  imes 350	MPa		
		=2	231MPa			
						$F_s=231MPa$
	actored shear resistanc	te of a $V_r=q$	$\phi  imes A_w  imes A_w$	$F_s  imes 10^{-3}$		
n	nember or component	= (	$0.9 \times 2.29$	$ imes 10^3mm^2 imes 2$	$31MPa  imes 10^{-3}$	
		=4	476kN			
						$V_r = 476kN$
						$V_{ry}=476kN$
S	hear in the x-axis di	rection minor axis				

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

d=2 imes b

 $=2 imes204\,mm$ 

 $=408\,mm$ 

Web thickness for weak axis shear (flange thickness)

 $w=15.7\,mm$ 

Shear area

 $A_w = d imes w$ 

 $=408\,mm imes 15.7\,mm$ 

 $=6.41\times10^{3} \, mm^{2}$ 

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

 $F_s = 0.66 imes F_y$ Ultimate shear stress

 $= 0.66 \times 350 \, MPa$ 

 $=231\,MPa$ 

 $F_s = 231 \, MPa$ 

S16-14 13.4.1.1 a) i) Factored shear resistance of a member or component

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

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

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

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

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

#### Slenderness ratio check

Slenderness ratio about x-axis

$$egin{aligned} rac{K_x L_x}{r_x} &= rac{K_x imes L_x}{r_x} \ &= rac{1 imes 2 imes 10^3 \, mm}{110 \, mm} \ &= 18.2 \end{aligned}$$

Slenderness ratio about y-axis

$$\begin{split} \frac{K_y \, L_y}{r_y} &= \frac{K_y \times L_y}{r_y} \\ &= \frac{1 \, \times 2 \! \times \! 10^3 \, mm}{51.4 \, mm} \\ &= 38.9 \end{split}$$

S16-14 10.4.1

Slenderness ratio of member

$$egin{aligned} rac{KL}{r} &= \max\left(rac{K_x L_x}{r_x}, rac{K_y L_y}{r_y}
ight) \ &= \max\left(18.2\,,38.9\,
ight) \ &= 38.9 \end{aligned}$$

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

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

Slenderness ratio does not exceed maximum permissible slenderness ratio.

 $Check = {\bf Slenderness\ ratio\ ok!}$ 

#### **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

$$egin{aligned} F_{ex} &= rac{\pi^2 imes E}{\left(rac{K_{x} imes L_{x}}{r_{x}}
ight)^2} \ &= rac{\left(\pi
ight)^2 imes 2 imes 10^5 \, MPa}{\left(rac{1 imes 2 imes 10^3 \, mm}{110 \, mm}
ight)^2} \ &= 5.98 imes 10^3 \, MPa \end{aligned}$$

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S16-14 13.3.1	Euler buckling stress about y-axis	$egin{align}  ext{s} & F_{ey} = rac{\pi^2  imes E}{\left(rac{K_y  imes L_y}{r_y} ight)^2} \ & = rac{\left(\pi ight)^2  imes 2  imes 10^5  MPa}{\left(rac{1  imes 2  imes 10^3  mm}{51.4  mm} ight)^2} \ & = 1.3  imes 10^3  MPa \ \end{aligned}$	
	Euler buckling stress	$egin{aligned} F_e &= \min\left(F_{ex}, F_{ey} ight) \ &= \min\left(5.98{ imes}10^3MPa, 1.3{ imes}10^3MPa ight) \ &= 1.3{ imes}10^3MPa \end{aligned}$	
S16-14 13.3.1	Non-dimensional slendemess parameter	$egin{aligned} \lambda &= \sqrt{rac{F_y}{F_e}} \ &= \sqrt{rac{350MPa}{1.3{ imes}10^3MPa}} \ &= 0.518 \end{aligned}$	
			$\lambda=0.518$
S16-14 13.3.1	Factored compressive resistance of a member or component	of $C_r = rac{\phi  imes A  imes F_y}{\left(1 + \lambda^{2  imes n} ight)^{rac{1}{n}}}  imes 10^{-3} \ = rac{0.9  imes 8.41  imes 10^3 \ mm^2  imes 350 \ MPa}{\left(1 + 0.518^{\ 2  imes 1.34} ight)^{rac{1}{1.34}}}  imes 10^{-3} \ = 2.35  imes 10^3 \ kN$	
			$C_r=2.35{ imes}10^3kN$
	Factored axial compressive resi	istance based on torsional buckling	
	Effective length factor for torsional buckling	$K_z=1$	
S16-14 13.3.2	Polar radius of gyration about shear centre	$egin{aligned} \overline{r}_{o}^{\; 2} &= {x_{0}}^{2} + {y_{0}}^{2} + {r_{x}}^{2} + {r_{y}}^{2} \ &= (0mm)^{2} + (0mm)^{2} + (110mm)^{2} + (51.4m)^{2} \end{aligned}$	$m)^2$

	Effective length factor for torsional buckling	$K_z=1$
S16-14 13.3.2	Polar radius of gyration about shear centre	$egin{aligned} \overline{r}_o{}^2 &= {x_0}^2 + {y_0}^2 + {r_x}^2 + {r_y}^2 \ &= (0mm)^2 + (0mm)^2 + (110mm)^2 + (51.4mm)^2 \ &= 1.48{ imes}10^4mm^2 \end{aligned}$
S16-14 13.3.1	Euler buckling stress	$F_e = \left(rac{\pi^2  imes E  imes C_w}{\left(K_z  imes L ight)^2} + G  imes J ight)  imes rac{1}{A  imes \overline{r}_o{}^2}$
		$= \left(rac{\left(\pi ight)^2  imes 2  imes 10^5  MPa  imes 3.23  imes 10^{11}  mm^6}{\left(1   imes 2  imes 10^3  mm ight)^2} + 7.7  imes 10^4  MPa  imes 5.79  imes 10^5  mm^4 ight)  imes 10^5  mm^4}$
		$egin{array}{l} 8.41{ imes}10^3mm^2 imes1.48{ imes}10^4mm^2 \ &= 1.65{ imes}10^3MPa \end{array}$
S16-14 13.3.1	Non-dimensional slenderness parameter	$\lambda = \sqrt{rac{F_y}{F_e}}$

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		$= \sqrt{\frac{1}{1}}$ $= 0.46$	$350MPa \over 65  imes 10^3MPa$		
					$\lambda=0.461$
S16-14 13.3.1	Parameter for compressive resistance  Factored compressive resistance of a member or component	$=\frac{0.9}{}$	$rac{A  imes F_y}{-\lambda^{2 imes n})^{rac{1}{n}}}  imes 10^{-3} \  imes 8.41  imes 10^3  mm^2  imes \ (1 + 0.461^{2 imes 1.34})$	$ imes rac{350MPa}{1.34}  imes 10^{-3}$	
		= 2.43	$ imes 10^3~kN$		$C_r=2.43{ imes}10^3kN$
	Overall axial compressive resistance	ce			
	Non-dimensional slenderness parameter	$\lambda=0.51$	8		
					$\lambda=0.518$
	Factored compressive resistance of ${\cal C}$ member based on flexural buckling	$T_{r,flexural}=2.35$	$5{ imes}10^3kN$		
	Factored compressive resistance of ${\cal C}$ member based on torsional buckling	$T_{r,torsional}=2.4$	$3{ imes}10^3kN$		
S16-14 13.3	Factored compressive resistance of a member or component	$= \min$	$(C_{r,flexural}, C_{r,torsio})$ $(2.35{ imes}10^3~kN, 2.45)$ ${ imes}10^3~kN$		
					$C_r=2.35{ imes}10^3kN$

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

### Moment capacity (laterally supported member)

Strong axis bending

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

 $egin{aligned} M_r &= \phi imes F_y imes Z imes 10^{-6} \ &= 0.9 imes 350 \, MPa imes 8.86 imes 10^5 \, mm^3 imes 10^{-6} \ &= 279 \, kNm \end{aligned}$ 

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 $M_r = 279 \, kNm$ 

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 $M_{rx}=279\,kN$ 

#### Weak axis bending

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

$$egin{aligned} M_r &= \phi imes F_y imes Z imes 10^{-6} \ &= 0.9 imes 350 \, MPa imes 3.31 imes 10^5 \, mm^3 imes 10^{-6} \ &= 104 \, kNm \end{aligned}$$

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 $M_r = 104 \, kNm$ 

 $M_{ry}=104\,kN$ 

#### **Axial tension capacity**

S16-14 13.2 a) i)

Factored tensile resistance of a member or component

$$egin{aligned} T_r &= \phi imes rac{A_g imes F_y}{1 imes 10^3} \ &= 0.9 imes rac{8.41 imes 10^3 \, mm^2 imes 350 \, MPa}{1 imes 10^3} \ &= 2.65 imes 10^3 \, kN \end{aligned}$$

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

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

#### **Biaxial bending**

S16-14 13.6 f)

Utilization

$$egin{aligned} Util &= rac{M_{fx}}{M_{rx}} + rac{M_{fy}}{M_{ry}} \ &= rac{50\,kN}{279\,kN} + rac{20\,kN}{104\,kN} \ &= 0.371 \end{aligned}$$

 $Util_{bending} = 0.371\,$ 

 $Util_{bending} = 0.371$ 

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#### **Combined axial compression and bending Calculation**

## Compression and bending cross sectional strength I shaped class 1 &~2

S16-14 13.8.2 a) i)	Factored compressive resistance of a member or component	$egin{aligned} C_r &= \phi  imes F_y  imes A  imes 10^{-3} \ &= 0.9  imes 350  MPa  imes 8.41  imes 10^3  mm^2  imes 10^{-3} \ &= 2.65  imes 10^3  kN \end{aligned}$
S16-14 13.8.4	Euler buckling strength about x-axis	$egin{aligned} C_{ex} &= rac{\pi^2  imes E  imes I_x}{{L_x}^2}  imes 10^{-3} \ &= rac{\left(\pi ight)^2  imes 2  imes 10^5  MPa  imes 1.02  imes 10^8  mm^4}{\left(2  imes 10^3  mm ight)^2}  imes 10^{-3} \end{aligned}$
S16-14 13.8.4	Euler buckling strength about y-axis	$egin{align} &=5.03{ imes}10^4kN \ &C_{ey} = rac{\pi^2  imes E  imes I_y}{L_y{}^2}  imes 10^{-3} \ &= rac{\left(\pi ight)^2  imes 2{ imes}10^5MPa  imes 2.22{ imes}10^7mm^4}{\left(2{ imes}10^3mm ight)^2}  imes 10^{-3} \ &= 1.1{ imes}10^4kN \ \end{array}$
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	$egin{align} &=1.1 imes 10^{-} kIV \ &U_{1x}=\max\left(rac{\omega_{1x}}{1-rac{C_f}{C_{ex}}},1 ight) \ &=\max\left(rac{1}{1-rac{50kN}{5.03 imes 10^4kN}},1 ight) \ &=1 \ \end{array}$
\$16-14 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	$egin{align} U_{1y} &= \max \left( rac{\omega_{1y}}{1 - rac{C_f}{C_{ey}}}, 1  ight) \ &= \max \left( rac{1}{1 - rac{50kN}{1.1  imes 10^4kN}}, 1  ight) \ &= 1 \end{split}$
	Coefficient for weak axis bending in beam-columns	eta=0.6
S16-14 13.8.2 a)	Utilization	$egin{aligned} Util &= rac{C_f}{C_r} + rac{0.85  imes U_{1x}  imes M_{fx}}{M_{rx}} + rac{eta  imes U_{1y}  imes M_{fy}}{M_{ry}} \ &= rac{50  kN}{2.65  imes 10^3  kN} + rac{0.85  imes 1  imes 50  kN}{279  kN} + rac{0.6  imes 1  imes 20  kN}{104  kN} \ &= 0.287 \end{aligned}$

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

## Compression and bending overall member strength I shaped class 1 $\&\ 2$

Job No.	Rev.

Member Location

LY

Job Title

Drg. ref.

Made By

Date 12-03-2021

Chd.

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

S16-14 13.3.1

Euler buckling stress about x-axis

$$egin{align} F_{ex} &= rac{\pi^2 imes E}{\left(rac{K_x imes L_x}{r_x}
ight)^2} \ &= rac{\left(\pi
ight)^2 imes 2 imes 10^5 \, MPa}{\left(rac{1 imes 2 imes 10^3 \, MPa}{110 \, mm}
ight)^2} \ \end{array}$$

S16-14 13.3.1

Euler buckling stress about y-axis

$$egin{align} F_{ey} &= rac{\pi^2 imes E}{\left(rac{K_y imes L_y}{r_y}
ight)^2} \ &= rac{\left(\pi
ight)^2 imes 2 imes 10^5 MPa}{\left(rac{1 imes 2 imes 10^3 MPa}{51.4 \, mm}
ight)^2} \ &= 1.3 imes 10^3 MPa \end{array}$$

Euler buckling stress

$$egin{aligned} F_e &= \min \left( F_{ex}, F_{ey} 
ight) \ &= \min \left( 5.98{ imes}10^3\,MPa, 1.3{ imes}10^3\,MPa 
ight) \ &= 1.3{ imes}10^3\,MPa \end{aligned}$$

S16-14 13.3.1

Non-dimensional slenderness parameter

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

$$= \sqrt{rac{350\,MPa}{1.3{ imes}10^3\,MPa}}$$

$$= 0.518$$

 $\lambda = 0.518$ 

S16-14 13.3.1

Factored compressive resistance of a member or component

$$egin{aligned} C_r &= rac{\phi imes A imes F_y}{\left(1 + \lambda^{2 imes n}
ight)^{rac{1}{n}}} imes 10^{-3} \ &= rac{0.9 imes 8.41 imes 10^3 \, mm^2 imes 350 \, MPa}{\left(1 + 0.518^{\, 2 imes 1.34}\,
ight)^{rac{1}{1.34}}} imes 10^{-3} \ &= 2.35 imes 10^3 \, kN \end{aligned}$$

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

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-

$$egin{aligned} C_{ex} &= rac{\pi^2 imes E imes I_x}{L_x^{\ 2}} imes 10^{-3} \ &= rac{(\pi)^2 imes 2 imes 10^5 \, MPa imes 1.02 imes 10^8 \, mm^4}{(2 imes 10^3 \, mm)^2} imes 10^{-3} \ &= 5.03 imes 10^4 \, kN \end{aligned}$$

			Job No.
ARI	ID	Calculat	tion
AIV	Jľ	sheet	
			Member Location
Job Title			Drg. ref.
			Made By  LY  Date  12-03-2021  Chd.
S16-14 13.8.4	Euler buckling axis	g strength about y-	$C_{ey} = rac{\pi^2  imes E  imes I_y}{{L_y}^2}  imes 10^{-3}$
			$=rac{{{{\left( \pi  ight)}^2}  imes 2 imes 10^5MPa imes 2.22 imes 10^7mm^4}}{{{{\left( 2 imes 10^3mm  ight)}^2}}}  imes 10^{-3}$
			$= 1.1{\times}10^4~kN$
S16-14 13.8.4	gradient and for effects of axial	unt for moment or second-order I fore acting on the other for the x-axis	$egin{align} U_{1x} &= rac{\omega_{1x}}{1 - rac{C_f}{C_{ex}}} \ &= rac{1}{1 - rac{50kN}{5.03  imes 10^4kN}} \ \end{gathered}$
			$=1$ $\omega_{1n}$
S16-14 13.8.4	gradient and for effects of axial	unt for moment or second-order fore acting on the other for the y-axis	$egin{align} U_{1y} &= rac{\omega_{1y}}{1 - rac{C_f}{C_{ey}}} \ &= rac{1}{1 - rac{50kN}{1.1  imes 10^4kN}} \ &= 1 \ \end{pmatrix}$
S16-14 13.8.2	Coefficient for	weak axis bending	$eta=\min\left(0.6+0.4 imes\lambda,0.85 ight)$
	in beam-colun	nns	$= \min \left(0.6 + 0.4  imes 0.518 , 0.85 ight) \ = 0.807$
S16-14 13.8.2 b)	Utilization		$Util = rac{C_f}{C_r} + rac{0.85  imes U_{1x}  imes M_{fx}}{M_{rx}} + rac{eta  imes U_{1y}  imes M_{fy}}{M_{ry}}$
			$=rac{50kN}{2.35{ imes}10^3kN}+rac{0.85{ imes}1{ imes}50kN}{279kN}+rac{0.807{ imes}1{ imes}20kN}{104kN}$
			= 0.329

 $Util_{\it member} = 0.329$ 

## Compression and bending lateral torsional buckling strength I shaped class 1 & 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

$$egin{aligned} F_{ex} &= rac{\pi^2 imes E}{\left(rac{K_x imes L_x}{r_x}
ight)^2} \ &= rac{\left(\pi
ight)^2 imes 2 imes 10^5 \, MPa}{\left(rac{1 imes 2 imes 10^3 \, mm}{110 \, mm}
ight)^2} \ &= 5.98 imes 10^3 \, MPa \end{aligned}$$

		Job No.	Rev.
AR	Calcula sheet	ntion	
		Member Location	
Job Title		Drg. ref.	
		Made By LY Date 12-03-2021	Chd.
S16-14 13.3.1	Euler buckling stress about y-axis	$egin{aligned} F_{ey} &= rac{\pi^2  imes E}{\left(rac{K_y  imes L_y}{r_y} ight)^2} \ &= rac{(\pi)^2  imes 2  imes 10^5  MPa}{\left(rac{1  imes 2  imes 10^3  mm}{51.4  mm} ight)^2} \ &= 1.3  imes 10^3  MPa \end{aligned}$	, ,
	Euler buckling stress	$egin{aligned} F_e &= \min \left( F_{ex}, F_{ey}  ight) \ &= \min \left( 5.98{ imes}10^3MPa, 1.3{ imes}10^3MPa  ight) \ &= 1.3{ imes}10^3MPa \end{aligned}$	
S16-14 13.3.1	Non-dimensional slendemess parameter	$egin{aligned} \lambda &= \sqrt{rac{F_y}{F_e}} \ &= \sqrt{rac{350MPa}{1.3 imes10^3MPa}} \ &= 0.518 \end{aligned}$	
			$\lambda=0.518$
S16-14 13.3.1	Factored compressive resistance of a member or component	$egin{align} C_r &= rac{\phi  imes A  imes F_y}{\left(1 + \lambda^{2  imes n} ight)^{rac{1}{n}}}  imes 10^{-3} \ &= rac{0.9  imes 8.41  imes 10^3 \ mm^2  imes 350 \ MPa}{\left(1 + 0.518^{2  imes 1.34} ight)^{rac{1}{1.34}}}  imes 10^{-3} \ &= 2.35  imes 10^3 \ kN \end{split}$	
			$C_r=2.35{ imes}10^3kN$
	Factored axial compressive resista	nce based on torsional buckling	
	Effective length factor for torsional buckling	$K_z=1$	
S16-14 13.3.2	Polar radius of gyration about shear centre	$egin{aligned} \overline{r}_{o}^{\;\;2} &= x_{0}^{\;\;2} + y_{0}^{\;\;2} + r_{x}^{\;\;2} + r_{y}^{\;\;2} \ &= \left(0mm ight)^{2} + \left(0mm ight)^{2} + \left(110mm ight)^{2} + \left(51.4m ight)^{2} \end{aligned}$	$m)^2$

	Effective length factor for torsional buckling	$K_z = 1$
S16-14 13.3.2	Polar radius of gyration about shear centre	$egin{aligned} \overline{r}_o{}^2 &= {x_0}^2 + {y_0}^2 + {r_x}^2 + {r_y}^2 \ &= (0mm)^2 + (0mm)^2 + (110mm)^2 + (51.4mm)^2 \ &= 1.48{ imes}10^4mm^2 \end{aligned}$
S16-14 13.3.1	Euler buckling stress	$F_e = \left(rac{\pi^2  imes E  imes C_w}{\left(K_z  imes L ight)^2} + G  imes J ight)  imes rac{1}{A  imes \overline{r}_o{}^2}$
		$=\left(rac{\left(\pi ight)^{2} imes2 imes10^{5}MPa imes3.23 imes10^{11}mm^{6}}{\left(1 imes2 imes10^{3}mm ight)^{2}}+7.7 imes10^{4}MPa imes5.79 imes10^{5}mm^{4} ight) imesrac{1}{0.41110^{3}m^{2}}+1.0010^{4}m^{2}$
		$egin{aligned} 8.41{ imes}10^3mm^2 { imes}1.48{ imes}10^4mm^2 \ &= 1.65{ imes}10^3MPa \end{aligned}$
S16-14 13.3.1	Non-dimensional slendemess parameter	$\lambda = \sqrt{rac{F_y}{F_e}}$

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ARUP	Calculation sheet	Job No.  Member Location	
Job Title		Drg. ref.  Made By  LY	Date 12-03-2021
	=	$\sqrt{350MPa}$	1 00 200

 $\lambda = 0.461$ 

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Parameter for compressive resistance

n = 1.34

S16-14 13.3.1

Factored compressive resistance of a member or component

$$egin{aligned} C_r &= rac{\phi imes A imes F_y}{\left(1 + \lambda^{2 imes n}
ight)^{rac{1}{n}}} imes 10^{-3} \ &= rac{0.9 imes 8.41 imes 10^3 \, mm^2 imes 350 \, MPa}{\left(1 + 0.461^{\, 2 imes 1.34}
ight)^{rac{1}{1.34}}} imes 10^{-3} \ &= 2.43 imes 10^3 \, kN \end{aligned}$$

 $C_r=2.43{ imes}10^3\,kN$ 

#### Overall axial compressive resistance

Non-dimensional slenderness parameter

$$\lambda = 0.518$$

 $\lambda = 0.518$ 

Factored compressive resistance of  $C_{r,flexural}=2.35{ imes}10^3~kN$  member based on flexural buckling

Factored compressive resistance of  $C_{r,torsional}=2.43{ imes}10^3~kN$  member based on torsional buckling

S16-14 13.3

Factored compressive resistance of a member or component

$$C_r = \min \left( C_{r,flexural}, C_{r,torsional} \right)$$
  
=  $\min \left( 2.35 \times 10^3 \ kN, 2.43 \times 10^3 \ kN \right)$   
=  $2.35 \times 10^3 \ kN$ 

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

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

$$egin{aligned} C_{ex} &= rac{\pi^2 imes E imes I_x}{{L_x}^2} imes 10^{-3} \ &= rac{{{(\pi )}^2 imes 2 imes 10^5 \,MPa imes 1.02 imes 10^8 \,mm^4 }}{{{(2 imes 10^3 \,mm)}^2 }} imes 10^{-3} \ &= 5.03 imes 10^4 \,kN \end{aligned}$$

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

$$egin{align} U_{1x} &= \max \left( rac{\omega_{1x}}{1 - rac{C_f}{C_{ex}}}, 1 
ight) \ &= \max \left( rac{1}{1 - rac{50 \, kN}{5.03 imes 10^4 \, kN}}, 1 
ight) 
onumber \end{align}$$

		Job No.		Rev.	
ARUP	Calculation sheet				
		Member Location			
ob Title		Drg. ref.			
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=1

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

S16-14 13.8.4 E

Euler buckling strength about y-

$$egin{align} C_{ey} &= rac{\pi^2 imes E imes I_y}{{L_y}^2} imes 10^{-3} \ &= rac{(\pi)^2 imes 2 imes 10^5 \, MPa imes 2.22 imes 10^7 \, mm^4}{(2 imes 10^3 \, mm)^2} imes 10^{-3} \ &= 1.1 imes 10^4 \, kN \ \end{align}$$

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

$$egin{align} U_{1y} &= rac{\omega_{1y}}{1 - rac{C_f}{C_{ey}}} \ &= rac{1}{1 - rac{50\,kN}{1.1 imes 10^4\,kN}} \ \end{array}$$

S16-14 13.8.2

Coefficient for weak axis bending in beam-columns

$$eta = \min \left( 0.6 + 0.4 \times \lambda, 0.85 \right)$$

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

$$= 0.807$$

S16-14 13.8.2 c)

Utilization

$$egin{aligned} Util &= rac{C_f}{C_r} + rac{0.85 imes U_{1x} imes M_{fx}}{M_{rx}} + rac{eta imes U_{1y} imes M_{fy}}{M_{ry}} \ &= rac{50 \, kN}{2.35 imes 10^3 \, kN} + rac{0.85 imes 1 imes 50 \, kN}{279 \, kN} + rac{0.807 imes 1 imes 20 \, kN}{104 \, kN} \ &= 0.329 \end{aligned}$$

 $Util_{LTB} = 0.329$ 

 $Util_{sect} = 0.287$ 

 $Util_{member} = 0.329$ 

 $oxed{Util_{LTB}=0.329}$ 

#### 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

		Job No.	Rev.	
ARUP	Calculation sheet			
		Member Location		
Job Title		Drg. ref.		
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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.

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