Third Edition
First Printing, December 2015
Errata No. 1, March 2016

ISBN 978-0-88811-192-0

PRINTED IN CANADA

6) Calculate Elastic Section Properties x-x (for the built-up section)

Material	A (mm^2)	y_b (mm)	Ay_b (10^3 mm^3)	Ay_b^2 (10^6 mm^4)	I_0 (10^6 mm^4)
W	27 800	314	8 730	2 740	1 910
Plate	4 839	634.4	3 070	1 948	0.065
Σ	32 639		11 800	4 688	1 910

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$$y_B = \frac{\sum Ay_b}{\sum A} = \frac{11\,800 \times 10^3}{32\,639} = 361.5 \text{ mm} \text{ and } y_T = 640.7 - 361.5 = 279.2 \text{ mm}$$

$$I_{xx} = \sum I_0 + \sum Ay_b^2 - y_B^2 \sum A$$

$$= 1910 \times 10^6 + 4688 \times 10^6 - 32\,639(361.5)^2 = 2\,332 \times 10^6 \text{ mm}^4$$

$$S_B = \frac{I_{xx}}{y_B} = \frac{2\,332 \times 10^6}{361.5} = 6\,451 \times 10^3 \text{ mm}^3$$

$$S_T = \frac{I_{xx}}{y_T} = \frac{2\,332 \times 10^6}{279.2} = 8\,352 \times 10^3 \text{ mm}^3$$

7) Calculate Elastic Section Properties y-y

I_{yy} *top flange* $= \left(27.7 \times \frac{328^3}{12}\right) + \left(12.7 \times \frac{381^3}{12}\right)$

$= 81.46 \times 10^6 + 58.53 \times 10^6 = 140 \times 10^6 \text{ mm}^4$

I_{yy} *web* $= 572.6 \times \frac{16.5^3}{12} = 0.2143 \times 10^6 \text{ mm}^4$

I_{yy} *bottom flange* $= 81.46 \times 10^6 \text{ mm}^4$

$\sum I_{yy}$ $221.7 \times 10^6 \text{ mm}^4$

S_{yy} *top flange* $= \frac{140 \times 10^6}{190.5} = 0.7349 \times 10^6 \text{ mm}^3$

S_{yy} *bottom flange* $= \frac{81.46 \times 10^6}{164} = 0.4967 \times 10^6 \text{ mm}^3$

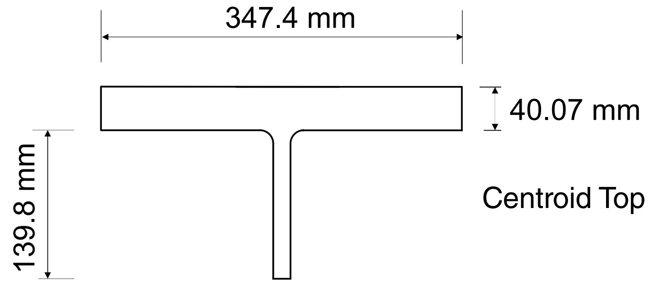
8) Calculate "Equivalent" top flange

$$A = (27.7 \times 328) + (12.7 \times 381) = 13.92 \times 10^3 \text{ mm}^2$$

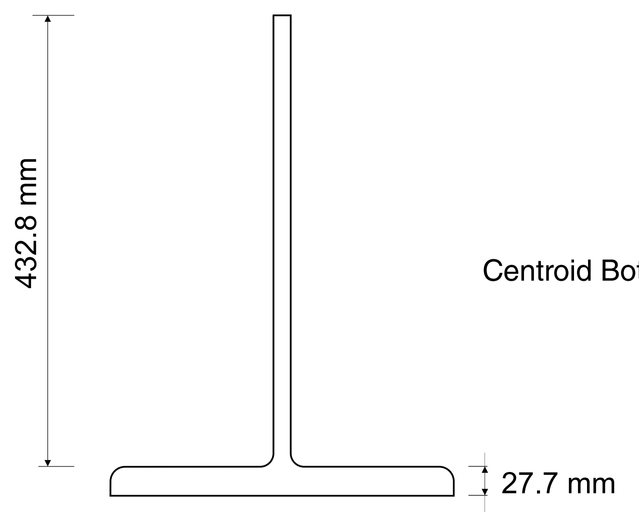
$$I = 140 \times 10^6 \text{ mm}^4$$

$$\frac{t\,w^3}{12} = 140 \times 10^6 \text{ mm}^4$$

Note: Two parallel plates must be continuously welded and the projecting element must be relatively small. For more information, refer to Tremblay and Legault (1996).



$$\text{Centroid Top} = \frac{\dfrac{16.5 \times 139.8^2}{2} + 13\,920 \times 159.8}{16\,227} = 147.0\ \text{mm}$$



$$\text{Centroid Bottom} = \frac{\dfrac{16.5 \times 432.8^2}{2} + 9\,086 \times 446.7}{16\,227} = 345.4\ \text{mm}$$

Figure A9
Centroid of Top and Bottom Flange

12) Calculate Section Properties for Mono-Symmetric Analysis

Refer to Galambos (1998), or visit http://www.cisc-icca.ca/resources/tech/updates/torsionprop

$$\alpha = \frac{1}{1 + \left[\left(\dfrac{347.4}{328}\right)^3 \times \left(\dfrac{40.07}{27.7}\right)\right]} = 0.367\,8$$

$$d' = 640.7 - \frac{(40.07 + 27.7)}{2} = 606.8\ \text{mm}$$

$$J = \frac{(347.4 \times 40.07^3) + (328 \times 27.7^3) + (606.8 \times 16.5^3)}{3} = 10.69 \times 10^6\ \text{mm}^4$$

$$C_w = \frac{606.8^2 \times 347.4^3 \times 40.07 \times 0.367\,8}{12} = 19.0 \times 10^{12}\ \text{mm}^6$$

Shear Centre Location

$$y_0 = 279.2 - \frac{40.07}{2} - (0.367\,8 \times 606.8) = +\ 35.98\ \text{mm}$$, therefore above the centroid

$$r_t = \frac{347.4}{\sqrt{12\left(1+\dfrac{239.1\times 16.5}{3\times 347.4\times 40.07}\right)}} = 95.86 \text{ mm}$$

$$L_u = \frac{490\times 95.86}{\sqrt{350}} = 2\,511 \text{ mm}$$

17) Since $M_u > M_{yr}$, calculate M_r

$$M_r = \phi\left[M_p - \left(M_p - M_{yr}\right)\left(\frac{L-L_u}{L_{yr}-L_u}\right)\right] \le \phi M_p$$

L_{yr} = length L obtained by setting $M_u = M_{yr}$

To find L_{yr}, M_u can be expressed as follows

$$M_u = \frac{1.851\times 10^{14}}{L_{yr}^2}\left[142.3+\sqrt{20\,249+4\left(1.881\times 10^{-3}L_{yr}^2+85\,701\right)}\right]$$

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L_{yr}, *mm*	M_u, *kN·m*
12 000	*1 729 < 1 570*
13 000	*1 556 < 1570, but close enough, can be refined if necessary*

18) Calculate M_r

From step 11, M_p = 2 797 kN·m, ϕM_p = 0.9 × 2 797 = 2 517 kN·m

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$$\begin{aligned} M_r &= 0.9\left[2\,797-\left(2\,797-1\,570\right)\left(\frac{10670-2\,511}{13000-2\,511}\right)\right] \\ &= 0.9\times 1843 \\ &= 1658 \text{ kN}\cdot\text{m} < 2\,517 \text{ kN}\cdot\text{m} \;\; \text{OK} \end{aligned}$$

19) Calculate the strength in bending for the load combination of side thrust, no impact.

$$M_u = \frac{1.851\times\pi^2 \;\; 200000 \text{ x } 221.7 \text{ x } 10^6}{2 \text{ x } 10670^2}\left[142.3+\sqrt{142.3^2+4\left(\frac{77000 \text{ x } 10.69 \text{ x } 10^6 \text{x } 10670^2}{\pi^2 \text{x } 220000 \text{ x } 221.7 \text{ x } 10^6}+\frac{19 \text{ x } 10^{12}}{221.7 \text{ x } 10^6}\right)}\right]$$

$$= 2.839 \text{ x } 10^9 \text{ N.mm} = 2839 \text{ kN.m}$$

20) Calculate M_{yr}

Refer to step 15

M_{yr} = 1570 kNm

21) Calculate L_u

Refer to step 16

$L_u = 2511\text{mm}$

22) Since $M_u > M_{yr}$, calculate M_r

$$M_r = \phi\left[M_p - \left(M_p - M_{yr}\right)\left(\frac{L - L_u}{L_{yr} - L_u}\right)\right] \leq \phi M_p$$

L_{yr} = length L obtained by setting $M_u = M_{yr}$

To find L_{yr}, M_u can be expressed as follows

$$M_u = \frac{2.593 \times 10^{14}}{L_{yr}^2}\left[142.3 + \sqrt{20\,249 + 4\left(1.881 \times 10^{-3} L_{yr}^2 + 85\,701\right)}\right]$$

L_{yr}, mm	*M_u, kN·m*
14 000	*1793 > 1570*
15 000	*1816 > 1570*
16 000	*1533 < 1570, but close enough*

23) Calculate M_r

From step 11, M_p = 2 797 kN·m, ϕM_p = 0.9 × 2 797 = 2 517 kN·m

$$M_r = 0.9\left[2\,797 - \left(2\,797 - 1\,570\right)\left(\frac{10670 - 2\,511}{10500 - 2\,511}\right)\right]$$
$$= 0.9 \times 2054$$
$$= 1849 \text{ kN}\cdot\text{m} < 2\,517 \text{ kN}\cdot\text{m OK}$$

24) Calculate distribution of the side thrust C*s* by flexural analogy

See figures A10 and A11.

Moment at Shear Centre

$$= C_s(243 + 89) = 332C_s$$

Couple, applied to each flange

$$= \frac{332C_s}{223 + 384} = 0.5470C_s$$

Note: This dimension should be to the centroid of the top flange, Close enough in this case.

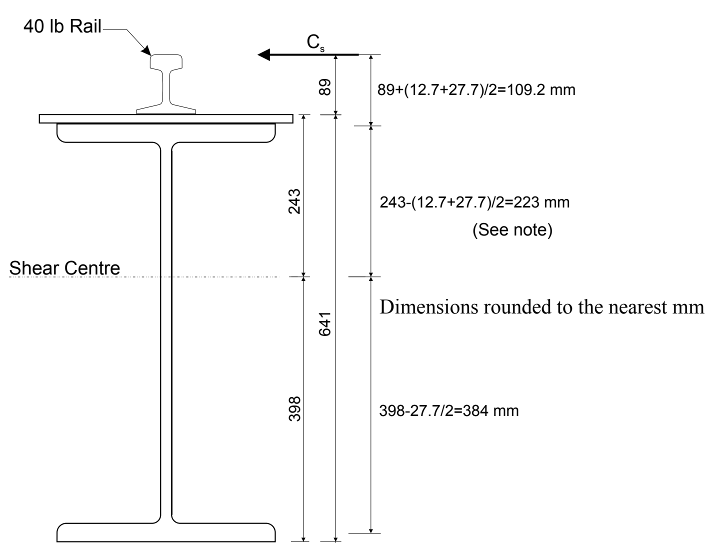

Figure A10
Distribution of Side Thrust

Distribution of horizontal load applied at shear centre, as a simple beam analogy

- to top flange $\dfrac{C_s \times 384}{(223 + 384)} = 0.6326\,C_s$

- to bottom flange $= 0.3674\,C_s$

M_{fyt} (top flange) $= 1.18 \times 73.19 = 86.36$ kN·m

M_{fyb} (bottom flange) $= 0.1796 \times 73.19 = 13.15$ kN·m

$M_{fx} = 1\,289$ kN·m

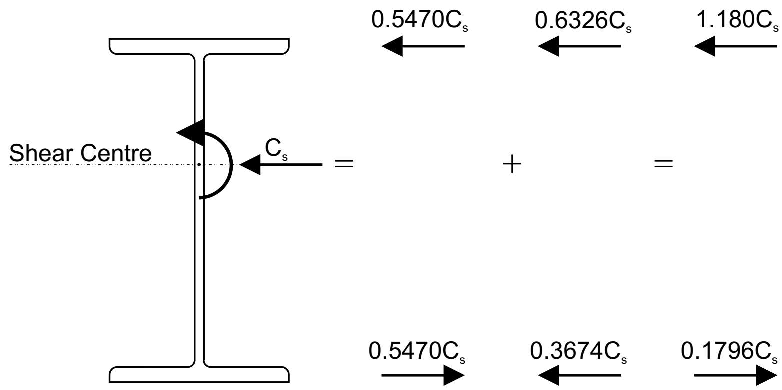

Figure A11

Moments about Shear Centre

25) Check overall member strength with impact, no side thrust

$$\frac{M_{fx}}{M_{rx}} + \frac{M_{fy}}{M_{ry}} \leq 1.0$$

$$\frac{1\,289}{0.9 \times 2797} + \frac{0.0}{0.9 \times 422} = 0.511 + 0.0 = 0.511 < 1.0 \text{ OK}$$

26) Check stability (lateral-torsional buckling) with impact, no side thrust

$$\frac{1\,289}{0.9 \times 1843} + \frac{0.0}{0.9 \times 422} = 0.777 + 0.0 = 0.777 < 1.0 \text{ OK}$$

27) Check overall member strength with side thrust, no impact.

Because side thrust produces calculated M_y, we are entitled to use the flexure analogy as in step 24.

$$\frac{1\,040}{0.9 \times 2797} + \frac{86.36}{0.9 \times 422} = 0.413 + 0.227 = 0.640 < 1.0 \text{ OK}$$

28) Check stability with side thrust, no impact

$$\frac{1\,040}{0.9 \times 2054} + \frac{86.36}{0.9 \times 422} = 0.563 + 0.227 = 0.790 < 1.0 \text{ OK}$$

No further checks are required (see Section 5.10)

Conclusion: Section is adequate in bending