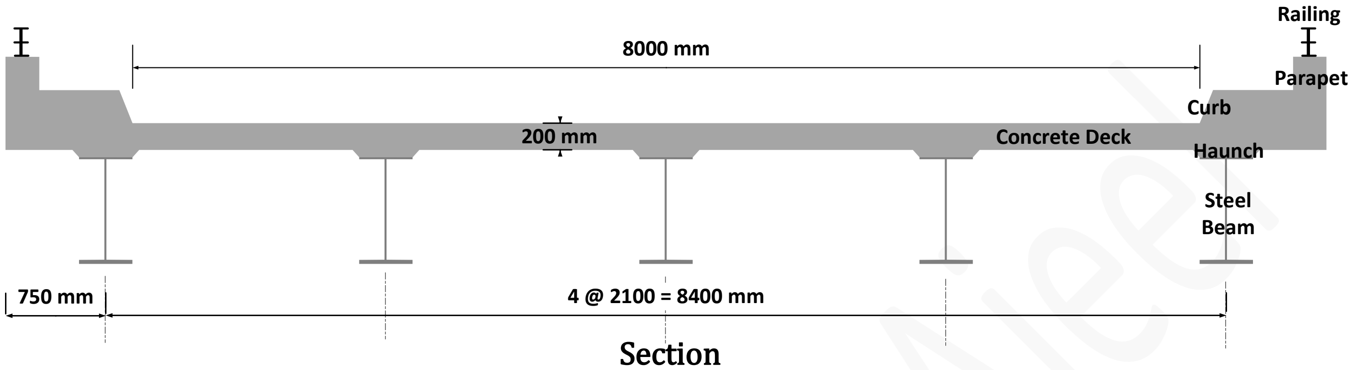
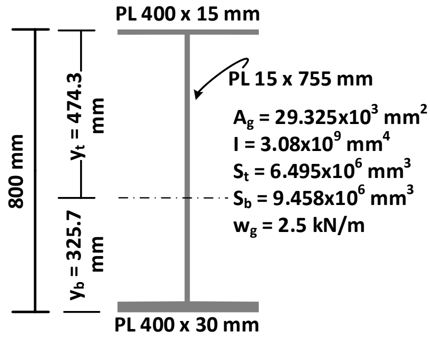
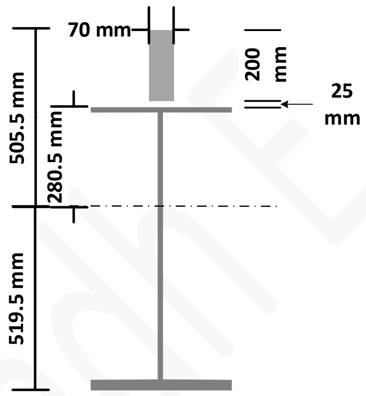
Design of Composite Bridges

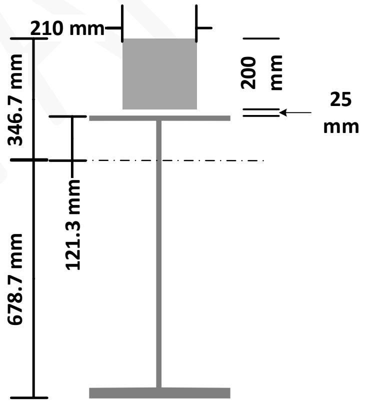
Ex. 1: Design the interior beams shown below for a single span bridge of (L) = 20 m to carry standard HL-93 load and overlay layer of 50 mm thickness (h_{fws}), curb, parapet with railing 0.4 kN/m each side on roadway width of 8 m. The compressive strength (f_c') = 30 MPa for all concrete sections. For steel section (A242); service stress (f_s) = 162 MPa and yield strength (f_y) = 295 MPa.



Section







Sol:

Determination of Composite Section Properties

$$b_f = S = 2100 \text{ mm}$$

$$n_A = E_d/3E_g = 0.033 \qquad \text{[long-time loading]}$$

$$n_B = E_d/E_g = 0.1 \qquad \text{[short-time loading]}$$

Long-Time Loading

$$b_e = n_A . b_f = 0.033 \; x \; 2100 = 70 \text{ mm}$$

$$A_{d,tr} = b_e . h_d = 70 \; x \; 200 = 14x10^3 \text{ mm}^2$$

$$I_{d,tr} = b_e . h^3/12 = 70 \; x \; 200^3/12 = 46.67x10^6 \text{ mm}^4$$

$$h = h_d + h_h + h_g = 200 + 25 + 800 = 1025 \text{ mm}$$

Component	A mm^2	y_t mm	$A.y_t$ mm^3	y_{tc} mm	$I_\circ$ mm^4	d mm	$A.d^2$ mm^4	$I_\circ + A.d^2$ mm^4
Deck	$14x10^3$	100	$1.4x10^6$	505.5	$0.05x10^9$	-405.5	$2.3x10^9$	$2.35x10^9$
Girder	$29.325x10^3$	699.3	$20.5x10^6$		$3.08x10^9$	193.8	$1.1x10^9$	$4.18x10^9$
$\sum$	$43.325x10^3$		$21.9x10^6$					$6.53x10^9$

$$y_{tcd} = \sum(A.y_t)/\sum A = 21.9x10^6/43.325x10^3 = 505.5 \text{ mm}$$

$y_{tcg} = y_{tcd} - h_d - h_h = 505.5 - 200 - 25 = 280.5\ mm$

$y_{bcg} = h - y_{tcd} = 1025 - 505.5 = 519.5$ mm

$I_c = \sum(I_\circ + A.d^2) = 6.53x10^9$ mm^4

$S_{tcdA} = I_c/(n_A.y_{tcd}) = 6.53x10^9/(0.033\ x\ 505.5) = 391.45x10^6$ mm^3

$S_{tcgA} = I_c/y_{tcg} = 6.53x10^9/280.5 = 23.28x10^6$ mm^3

$S_{bcgA} = 6.53x10^9/519.5 = 12.57x10^6$ mm^3

Short-Time Loading

$b_e = n_B.b_f = 0.1\ x\ 2100 = 210$ mm

$A_{d,tr} = b_e.h_d = 210\ x\ 200 = 42x10^3$ mm^2

$I_{d,tr} = b_e.h^3/12 = 210\ x\ 200^3/12 = 140x10^6$ mm^4

$h = 1025\ mm$

Component	A mm^2	y_t mm	$A.y_t$ mm^3	y_{tc} mm	$I_\circ$ mm^4	d mm	$A.d^2$ mm^4	$I_\circ + A.d^2$ mm^4
Deck	$42x10^3$	100	$4.2x10^6$	346.3	$0.14x10^9$	-246.3	$2.55x10^9$	$2.69x10^9$
Girder	$29.33x10^3$	699.3	$20.5x10^6$		$3.08x10^9$	353	$3.65x10^9$	$6.73x10^9$
$\sum$	$71.33x10^3$		$24.7x10^6$					$9.42x10^9$

$y_{tcd} = \sum(A.y_t)/\sum A = 24.7x10^6/71.325x10^3 = 346.3$ mm

$y_{tcg} = 346.3 - 225 = 121.3$ mm

$y_{bcg} = h - y_{tcd} = 1025 - 346.3 = 678.7$ mm

$I_c = \sum(I_\circ + A.d^2) = 9.42x10^9$ mm^4

$S_{tcdB} = I_c/(n_B.y_{tcd}) = 9.42x10^9/(0.1\ x\ 346.3) = 272.02x10^6$ mm^3

$S_{tcgB} = I_c/y_{tcg} = 9.42x10^9/121.3 = 77.66x10^6$ mm^3

$S_{bcgB} = 9.42x10^9/678.7 = 13.88x10^6$ mm^3

Determination of Unfactored Loads

Force effects from unfactored composite (dead) loads:

$w_d = h_d\ x\ b_f\ x\ \Upsilon_c = 0.2\ x\ 2.1\ x\ 24 = 10.08$ kN/m

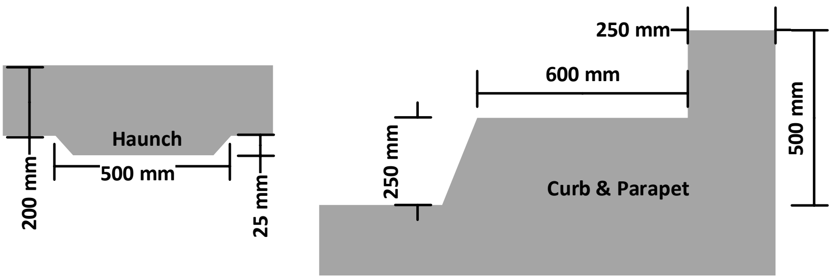
$w_h = h_h\ x\ b_h\ x\ \Upsilon_c = 0.025\ x\ 0.45\ x\ 24 = 0.27$ kN/m

$w_g = 2.5$ kN/m [with diaphragms]

$w_{DC1} = w_{D,nc} = 10.08 + 0.27 + 2.5 = 12.85$ kN/m

$M_{DC1} = w_{DC1}L^2/8 = 12.85\ x\ 20^2/8 = 642.5$ kN.m

Force effects from unfactored composite (dead and live) loads:



$w_{cu} = h_{cu}\ x\ b_{cu}\ x\ \Upsilon_c\ x\ N_{cu}/N_g = 0.25\ x\ 0.6\ x\ 24\ x\ 2/5 = 1.44$ kN/m

$w_{pa} = h_{pa}\ x\ b_{pa}\ x\ \Upsilon_c\ x\ N_{pa}/N_g = 0.50\ x\ 0.25\ x\ 24\ x\ 2/5 = 1.2\ \text{kN/m}$

$w_{ra} = w_{ra}\ x\ N_{ra}/N_g = 0.4\ x\ 2/5 = 0.16\ \text{kN/m}$

$w_{DC2} = w_{D,c} = 1.44 + 1.2 + 0.16 = 2.8\ \text{kN/m}$

$M_{DC2} = w_{DC2}L^2/8 = 2.8\ x\ 20^2/8 = 140\ \text{kN.m}$

$w_{fws} = h_{fws}\ x\ w\ x\ \Upsilon_{as}/N_g = 0.05\ x\ 8\ x\ 22.5/5 = 1.8\ \text{kN/m}$

$M_{DW} = w_{DW}L^2/8 = 1.8\ x\ 20^2/8 = 90\ \text{kN.m}$

$w_{Ln} = 9.3\ \text{kN/m}$

$M_{Ln} = w_{Ln}.L^2/8 = 9.3\ x\ 20^2/8 = 465\ \text{kN.m}$

$M_{Tr} = 1246.6\ \text{kN.m}$

Live load distribution factors:

$N_g \geq 4$ $\quad N_g = 5\ \therefore \text{OK}$

$6 \leq L \leq 73$ $\quad L = 20\ \text{m}\ \therefore \text{OK}$

$1.1 \leq S \leq 4.9$ $\quad S = 2.1\ \text{m}\ \therefore \text{OK}$

$110 \leq h_d \leq 300$ $\quad h_d = 200\ \text{mm}\ \therefore \text{OK}$

$n_B = 10$

$I_g = 3.08x10^9\ \text{mm}^4$

$A_g = 29.325x10^3\ \text{mm}^2$

$e_g = y_{tg} + h_h + h_d/2 = 474.3 + 25 + 100 = 599.3\ \text{mm}$

$K_g = n(I_g + A_g.{e_g}^2) = 10(3.08x10^9 + 29.325x10^3\ x\ 599.3^2)$

$= 136.124x10^9\ \text{mm}^4$

$4x10^9 \leq K_g \leq 3x10^{12}$ $\quad K_g = 136.124x10^9\ \text{mm}^4\ \therefore \text{OK}$

Thus, the cross section satisfies the design stipulations

$w = 8\ \text{m} \rightarrow N_L = 2$

$\therefore$ check both DF_{si} and DF_{mi}

Live load distribution factor for moment:

$DFM_{si} = 0.06 + (S/4300)^{0.4}.(S/L)^{0.3}.\left(K_g/L.{h_d}^3\right)^{0.1}$

$= 0.06 + (2.1/4.3)^{0.4}.(2.1/20)^{0.3}.(0.136124/20x0.2^3)^{0.1} = 0.436$

$DFM_{mi} = 0.075 + (S/2900)^{0.6}.(S/L)^{0.2}.\left(K_g/L.{h_d}^3\right)^{0.1}$

$= 0.075 + (2.1/2.9)^{0.6}.(2.1/20)^{0.2}.(0.136124/20x0.2^3)^{0.1} = 0.592$

$\rightarrow DFM_{int} = 0.592$

$IM = 0.33$

$M_{LL+IM} = DFM_{int}[(1 + IM)M_{Tr} + M_{Ln}]$

$= 0.592[1.33\ x\ 1246.6 + 465] = 1256.8\ \text{kN.m}$

Check Stresses on Steel Girder

$f_s = 162\ \text{MPa}$

At midspan

$$f_{top} = \frac{M_{DC1}}{S_{tg}} + \frac{M_{DC2} + M_{DW}}{S_{tcgA}} + \frac{M_{(LL+IM)}}{S_{tcgB}}$$

$$= \frac{642.5x10^6}{6.5x10^6} + \frac{(140+90)x10^6}{23.28x10^6} + \frac{1256.8x10^6}{77.66x10^6}$$

$$= 98.85 + 9.88 + 16.18 = 124.91 \text{ MPa} < f_s = 162 \text{ MPa} \therefore \text{OK}$$

$$f_{bot} = \frac{M_{DC1}}{S_{bg}} + \frac{M_{DC2} + M_{DW}}{S_{bcgA}} + \frac{M_{(LL+IM)}}{S_{bcgB}}$$

$$= \frac{642.5x10^6}{9.46x10^6} + \frac{(140+90)x10^6}{12.57x10^6} + \frac{1256.8x10^6}{13.88x10^6}$$

$$= 67.92 + 18.3 + 90.55 = 176.77 \text{ MPa} > f_s = 162 \text{ MPa} \therefore \text{NOK}$$

Check Stresses on Concrete Deck

$$f_c = 0.45 f_c' = 0.45 \ x \ 30 = 13.5 \text{ MPa}$$

$$f_{top} = \frac{M_{DC2} + M_{DW}}{S_{tcdA}} + \frac{M_{(LL+IM)}}{S_{tcdB}}$$

$$= \frac{(140+90)x10^6}{391.45x10^6} + \frac{1256.8x10^6}{272.02x10^6}$$

$$= 0.59 + 4.62 = 5.21 \text{ MPa} < f_c = 13.5 \text{ MPa} \therefore \text{OK}$$

If Dimensions of Steel Beam Are Not Designed

$h_g = L/25$

$t_w = h_g/170 \geq 15$ mm [to avoid needing to stiffeners]

$t_{f,upper} = t_w$

$A_{f,upper} = M_{DC1}/(150 h_g)$

$b_{f,upper} = A_{f,upper}/t_{f,upper}$

$b_{f,lower} = b_{f,upper}$

$t_{f,lower} = 2 t_{f,upper}$

$h_w = h_g - (t_{f,lower} + t_{f,upper})$