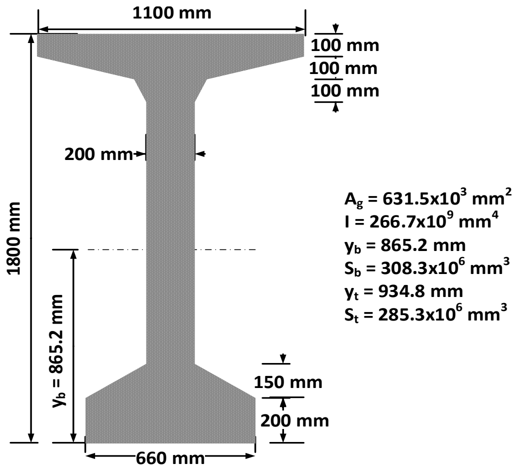
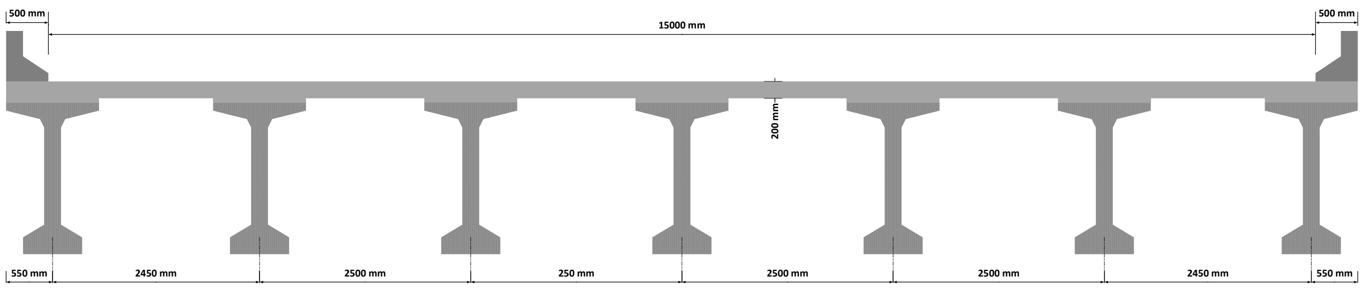
Ex. 3: Design the prestressed girders for a bridge of simply supported span (L) = 30 m to carry standard HL-93 load on total width of 16 m. The distributed weights are overlay (FWS) of 50 mm thickness, nonstructural concrete layer of 20 mm thickness, New Jersey-type barriers of 5 kN/m/side, haunch of 5 cm at top of each flange and intermediate diaphragms of 0.3 m thickness with 1 m depth at 1/3 points. The beams must be pretensioned precast concrete supporting CIP deck slab. The design data are: for beams; concrete strength at prestress transfer (f'_{ci}) = 38 MPa and at service (f'_c) = 42 MPa, for slab; concrete strength (f'_c) = 28 MPa, for reinforcing steel; yield strength of (f_y) = 420 MPa. Also, the prestressing steel is low-relaxation strands of yield strength of (f_{py}) = 1674 MPa, ultimate strength (f_{pu}) = 1860 MPa and 25% losses expected. Use 7 girders, 15 clear roadway width and 200 mm concrete deck thickness.



Sol:



Section

- **Design of Interior T-Girders**

Determination of Composite Section Properties:

$$b_f = S = 2500\ mm$$

$$E_c = 0.043 K_1 \Upsilon_c^{1.5}\sqrt{f'_c}$$

$$n = E_{c,d}/E_{c,g} = \sqrt{28/42} = 0.8165$$

$$b_e = n.b_f = 0.8165\ x\ 2500 = 2041.25\ mm$$

$$A_{d,tr} = b_e.h_d = 2041.25\ x\ 200 = 408.25x10^3\ mm^2$$

$$I_{d,tr} = b_e.h^3/12 = 2041.25\ x\ 200^3/12 = 1.361x10^9\ mm^4$$

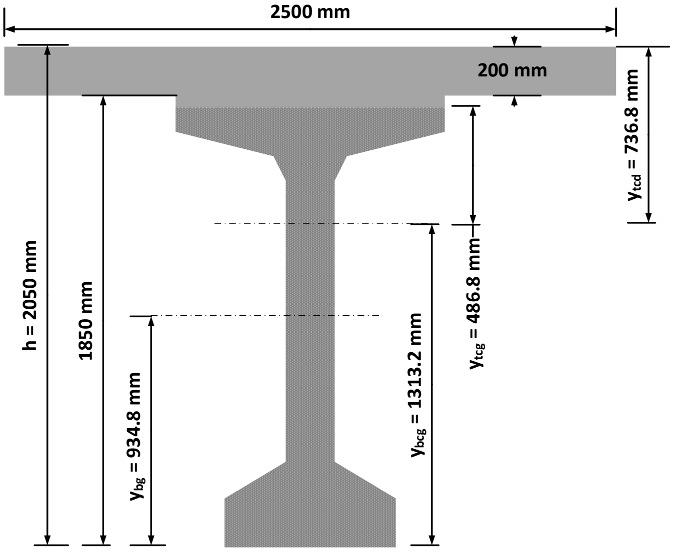
$$h = h_d + h_h + h_g = 200 + 50 + 1800 = 2050\ mm$$

Component	A mm^2	y_t mm	$A.y_t$ mm^3	y_{tc} mm	$I_\circ$ mm^4	$d=(y_t - y_{tc})$ mm	$A.d^2$ mm^4	$I_\circ + A.d^2$ mm^4
Deck	$408.25x10^3$	100	$40.83x10^6$	736.8	$1.361x10^9$	⍰ 636.8	$165.551x10^9$	$166.912x10^9$
Girder	$631.5x10^3$	1148.8	$725.47x10^6$		$266.7x10^9$	412	$107.193x10^9$	$373.893x10^9$
$\sum$	$1.04x10^6$		$766.3x10^6$					$540.805x10^9$

$y_{tcd} = \sum(A.y_t)/\sum A = 766.31x10^6/1.04x10^6 = 736.8\ mm$

$y_{tcg} = y_{tcd} - h_d - h_h = 736.8 - 200 - 50 = 486.8\ mm$

$y_{bcg} = h - y_{tcd} = 2050 - 736.8 = 1313.2\ mm$



$I_c = \sum(I_\circ + A.d^2) = 540.805x10^9\ mm^4$

$S_{tcd} = I_c/(n.y_{tcd}) = 540.805x10^9/(0.8165\ x\ 736.8) = 898.95x10^6\ mm^3$

$S_{tcg} = I_c/y_{tcg} = 540.805x10^9/486.8 = 1110.94x10^6\ mm^3$

$S_{bcg} = I_c/y_{bcg} = 540.805x10^9/1313.2 = 411.82x10^6\ mm^3$

Determination of Live load distribution factors:

$N_g \geq 4$ $\qquad N_g = 7\ \therefore OK$

$6 \leq L \leq 73$ $\qquad L = 30\ m\ \therefore OK$

$1.1 \leq S \leq 4.9$ $\qquad S = 2.5\ m\ \therefore OK$

$110 \leq h_d \leq 300$ $\qquad h_d = 200\ mm\ \therefore OK$

$n = E_{c,g}/E_{c,d} = \sqrt{42/28} = 1.225$

$e_g = y_{tg} + h_h + h_d/2 = 934.8 + 50 + 200/2 = 1084.8\ mm$

$K_g = n(I_g + A_g.e_g{}^2) = 1.225(266.7x10^9 + 631.5x10^3\ x\ 1048.8^2)$

$= 1.237x10^{12}\ mm^4$

$4x10^9 \leq K_g \leq 3x10^{12}$ $\qquad K_g = 1.237x10^{12}\ mm^4\ \therefore OK$

Live Load Distribution Factor for Moment:

$w = 16 - 2(0.5) = 15\ m\ \rightarrow N_L = 4$

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

$= 0.06 + (2.5/4.3)^{0.4}.(2.5/30)^{0.3}.(1.237/30x0.2^3)^{0.1} = 0.51$

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

$= 0.075 + (2.5/2.9)^{0.6}.(2.5/30)^{0.2}.(1.237/30x0.2^3)^{0.1} = 0.731$

$\rightarrow DFM_{int} = 0.731$

Live Load Distribution Factor for Shear:

$DFV_{si} = 0.36 + S/7600$

$= 0.36 + 2.5/7.6 = 0.689$

$DFV_{mi} = 0.2 + S/3600 - (S/10700)^2$

$= 0.2 + 2.5/3.6 - (2.5/10.7)^2 = 0.84$

$\rightarrow DFV_{int} = 0.84$

Determination of Unfactored Loads:

Force effects from unfactored composite (dead) loads:

$w_d = h_d\ x\ b_f\ x\ \Upsilon_c = 0.2\ x\ 2.5\ x\ 24 = 12\ kN/m$

$w_{iws} = h_{iws}\ x\ b_f\ x\ \Upsilon_c = 0.02\ x\ 2.4\ x\ 24 = 1.2\ kN/m$

$w_h = h_h\ x\ b_h\ x\ \Upsilon_c = 0.05\ x\ 1.1\ x\ 24 = 1.32\ kN/m$

$w_g = A_g\ x\ \Upsilon_c = 0.6315\ x\ 24 = 15.16\ kN/m$

$b_{dia} = S - b_w = 2.5 - 0.2 = 2.3\ m$

$DL_{dia} = (b\ x\ d\ x\ t)_{dia}\ x\ \Upsilon_c = 2.3\ x\ 1\ x\ 0.3\ x\ 24 = 16.56\ kN$

$w_{dia} = N_{dia} x\ DL_{dia}/L = 2\ x\ 16.56/30 = 1.1\ kN/m$

$w_{DC1} = w_{D,nc} = 12 + 1.2 + 1.32 + 15.16 + 1.1 = 30.78\ kN/m$

$M_{DC1} = w_{DC1} L^2/8 = 30.78\ x\ 30^2/8 = 3462.75\ kN.m$

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

$w_{DC2} = w_{D,c} = 2w_{ba}/N_g = 2\ x\ 5/7 = 1.43\ kN/m$

$M_{DC2} = w_{DC2}.L^2/8 = 1.43\ x\ 30^2/8 = 160.88\ kN.m$

$w_{DW} = h_{iws}\ x\ w\ x\ \Upsilon_{as}/N_g = 0.05\ x\ 15\ x\ 22.5/7 = 2.41\ kN/m$

$M_{DW} = w_{DW}.L^2/8 = 2.41\ x\ 30^2/8 = 271.13\ kN.m$

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

$M_{Ln} = w_{Ln}.L^2/8 = 9.3\ x\ 30^2/8 = 1046.25\ kN.m$

$M_{Tr} = 2056.23\ kN.m$

$IM = 0.33$

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

$= 0.731[1.33\ x\ 2056.23 + 1046.25] = 2763.94\ kN.m$

Determination of Required Effective Prestress Load

$$f_{bot} = \frac{M_{DC1}}{S_{bg}} + \frac{M_{DC2} + M_{DW} + 0.8M_{(LL+IM)}}{S_{bcg}}$$

$$= \frac{3462.75x10^6}{308.3x10^6} + \frac{(160.88 + 271.13 + 0.8\ x\ 2763.94)x10^6}{411.82x10^6} = 17.65\ MPa$$

$f_t = 0.50\sqrt{f_c'} = 0.5\ x\ \sqrt{42} = 3.24\ MPa$

$\because f_t = 2.95\ MPa < f_{bot} = 17.65\ MPa$ $\therefore$ prestress is required

$f_{c,pe} = f_{bot} - f_t = 17.65 - 3.24 = 14.41\ MPa$

Take $y_{bp} = 150\ mm$

$e_c = y_{bg} - y_{bp} = 865.2 - 150 \cong 715\ mm$

$$f_{c,pe} = \frac{P_e}{A_g} + \frac{P_e . e_c}{S_{bg}}$$

$$14.41 = \frac{P_e}{631.5x10^3} + \frac{P_e\ x\ 715}{308.3x10^6} \rightarrow P_e = 3692.31\ kN$$

Determination of Required Number of Strands

$f_{pi} = 0.75 f_{pu} = 0.75\ x\ 1860 = 1395\ MPa$

Try $\emptyset_p = 12.7\ mm \ \rightarrow\ A_p = 98.7\ mm^2$

$P_{i,p} = A_p . f_{pi} = 98.7\ x\ 1395 = 137.68\ kN$

$R = 1 - losses = 1 - 0.25 = 0.75$

$P_{e,p} = R . P_{i,p} = 0.75\ x\ 137.86 = 103.4\ kN$

$N_p = P_e / P_{e,p} = 3692.31/103.4 \cong 36$ strands

Distribution of Strands

Try to layout the strands with $s = 50\ mm$

$\bar{y} = 81.94\ mm$ fron the bottom layer cenetr

$c_b = 50\ mm$

$y_{bp} = 50 + 12 + 12.7/2 + 81.94 = 150.29\ mm$

$\rightarrow e_c = 865.2 - 150.29 \cong 715\ mm\ \therefore OK$

$c_s = (660 - 9x12.7 - 8x50)/2 = 72.85\ mm > 50\ mm\ \ \therefore OK$