Check of Concrete Stresses

At-Release Stage

$$f_{ti} = 0.63\sqrt{f'_{ci}} = 0.63\ x\ \sqrt{38} = 3.88\ MPa$$
$$f_{ci} = 0.6 f'_{ci} = 0.6\ x\ 38 = 22.8\ MPa$$

At midspan P_i and M_g.

$$P_i = N_p P_{i,p} = 36\ x\ 137.68 = 4956.48\ kN$$
$$M_g = w_g L^2/8 = 15.16\ x\ 30^2/8 = 1705.5\ kN.m$$
$$f_{i,top} = -\frac{P_i}{A_g} + \frac{P_i.e}{S_{tg}} - \frac{M_g}{S_{tg}} = -\frac{4956.48x10^3}{631.5x10^3} + \frac{4956.48x10^3\ x\ 715}{285.3x10^6} - \frac{1705.5x10^6}{285.3x10^6}$$
$$= -7.85 + 12.42 - 5.98 = -1.41\ MPa < 22.8\ MPa\quad \therefore OK$$
$$f_{i,bot} = -\frac{P_i}{A_g} - \frac{P_i.e}{S_{bg}} + \frac{M_g}{S_{bg}} = -7.85 - \frac{4956.48x10^3\ x\ 715}{308.3x10^6} + \frac{1705.5x10^6}{308.3x10^6}$$
$$= -7.85 - 11.5 + 5.53 = -13.82\ MPa < 22.8\ MPa\quad \therefore OK$$

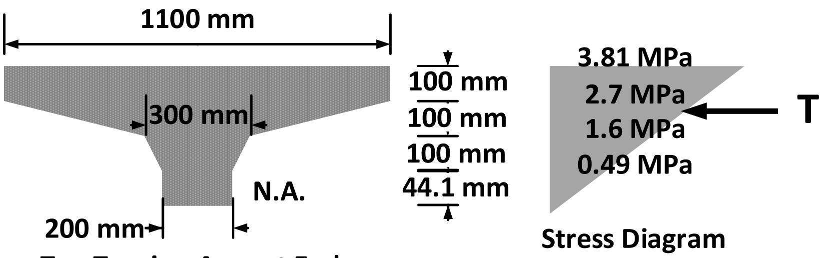
At ends P_i load only.

$$f_{i,top} = -\frac{P_i}{A_g} + \frac{P_i.e}{S_{tg}} = -7.85 + 12.42 = 4.57\ MPa > 3.88\ MPa\quad \therefore \rightarrow N_{dp}$$
$$N_{dp} = \frac{(f_{i,top} - f_{ti})}{f_{i,top}}.N_p = \frac{(4.57 - 3.88)}{4.57} x\ 36 \cong 6 \text{ strands}$$
$$\rightarrow P_{i,eff.} = \frac{(N_p - N_{dp})}{N_p}.P_i = \frac{30}{36}\ x\ 4956.48 = 4130.4\ kN$$
$$f_{i,top} = -\frac{P_{i,eff.}}{A_g} + \frac{P_{i,eff.}.e}{S_{tg}} = -\frac{4130.4x10^3}{631.5x10^3} + \frac{4130.4x10^3\ x\ 715}{285.3x10^6}$$
$$= -6.54 + 10.35 = 3.81\ MPa < 3.88\ MPa\quad \therefore OK$$
$$f_{i,bot} = -\frac{P_{i,eff.}}{A_g} - \frac{P_{i,eff.}.e}{S_{bg}} = -6.54 + \frac{4130.4x10^3\ x\ 715}{308.3x10^6}$$
$$= -6.54 - 9.58 = -16.12\ MPa < 22.8\ MPa\quad \therefore OK$$

Check if tensile reinforcement is needed at top of beam

$$f_{ti} = 0.25\sqrt{f'_{ci}} = 0.25\ x\ \sqrt{38} = 1.54\ MPa \rightarrow \text{use } f_{ti} = 1.38\ MPa$$
$$f_{i,top} = 3.81\ MPa > 1.38\ MPa\quad \therefore NOK$$

$y_t = 344.1\ mm$ from trigonometric on stress diagram at beam end



Top Tension Area at Ends

Stress Diagram

$$T = 200x44.1\ x\ 0.25 + 250x100\ x\ 1.05 + 700x100\ x\ 2.15 + 1100x100\ x\ 3.26$$
$$= 537555\ N$$

$f_y = 420\ MPa\ \rightarrow f_s = 170\ MPa$

$A_s = T/f_s = 537555/170 = 3162.1\ mm^2$

$\emptyset_b = 25\ mm\ \rightarrow\ A_b = 490.87\ mm^2$

$N_b = A_s/A_b = 3162.1/490.87 \cong 7$ bars

In-Service Stage

$f_c = 0.45 f_c' = 0.45\ x\ 42 = 18.9\ MPa$

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

At midspan P_e, $M_{D,nc}$, $M_{D,c}$, M_{DW} and $M_{(LL+IM)}$.

$P_e = R.P_i = 0.75\ x\ 4956.48 = 3717.36\ kN$

$$f_{top} = -\frac{P_e}{A_g} + \frac{P_e.e}{S_{tg}} - \frac{M_{DC1}}{S_{tg}} - \frac{M_{DC2} + M_{DW} + 0.8M_{(LL+IM)}}{S_{tcg}}$$

$$= -\frac{3717.36}{631.5} + \frac{3717.36x0.715}{285.3} - \frac{3462.75}{285.3} - \frac{160.88 + 271.13 + 0.8x2763.94}{1110.94}$$

$$= -5.89 + 9.32 - 12.14 - 2.38 = -11.09\ MPa < 18.9\ MPa\quad \therefore OK$$

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

$$= -5.89 - \frac{3717.36x0.715}{308.3} + \frac{3462.75}{308.3} + \frac{160.88 + 271.13 + 0.8x2763.94}{411.82}$$

$$= -5.89 - 8.62 + 11.23 + 6.42 = 3.14\ MPa < 3.24\ MPa\quad \therefore OK$$

At ends P_e load only.

$\because P_e < P_i\ \rightarrow P_{e,eff.} < P_{i,eff.}\quad \therefore$ no need to check

Check of Flexural Strength

Strength I limit State (Factored Moments):

$M_{DC} = M_{DC1} + M_{DC2} = 3462.75 + 160.88 = 3623.63\ kN.m$

$M_u = \eta_i[1.25M_{DC} + 1.50M_{DW} + 1.75M_{LL+IM}]$

$= 1.0[1.25\ x\ 3623.63 + 1.50\ x\ 271.13 + 1.75\ x\ 2763.94] \cong 9773.13\ kN.m$

$A_{ps} = N_p.A_p = 36\ x\ 98.7 = 3553.2\ mm^2$

$0.5f_{pu} = 0.5\ x\ 1860 = 930\ MPa$

$f_{pe} = R.f_{pi} = 0.75\ x\ 1395 = 1046.25\ MPa > 0.5f_{pu}\ \therefore OK$

$d_{ps} = h - y_{bp} = 2050 - 150 = 1900\ mm$

$\beta_1 = 0.85 - 0.05(f_c' - 28)/7 = 0.85 - 0.05(42 - 28)/7 = 0.75$

$k = 2(1.04 - f_{py}/f_{pu}) = 2(1.04 - 0.9) = 0.28$

$$c = \frac{A_{ps}.f_{pu}}{0.85f_c'.\beta_1.b_e + k.A_{ps}.f_{pu}/d_{ps}}$$

$$c = \frac{3553.2\ x\ 1860}{0.85\ x\ 42\ x\ 0.75\ x\ 2041.25 + 0.28\ x\ 3553.2\ x\ 1860/1900} = 118.8\ mm$$

$a = \beta_1.c = 0.75\ x\ 118.8 = 89.1\ mm\ < 100\ mm \rightarrow$ rectangular section

$f_{ps} = f_{pu}(1 - k.c/d_{ps}) = 1860(1 - 0.28\ x\ 118.8/1900) = 1827.44\ MPa$

$M_n = A_{ps}.f_{ps}(d_{ps} - a/2) = 3553.2\ x\ 1827.44(1900 - 89.1/2) = 12047.92\ kN.m$

$\phi = 1.0 \rightarrow M_r = 12047.92\ kN.m > M_u = 9773.13\ kN.m\quad \therefore OK$

Check of Minimum Reinforcement

$f_r = 0.63\sqrt{f_c'} = 0.63\ x\ \sqrt{42} = 4.08\ MPa$

$$f_{c,pe} = \frac{P_e}{A_g} + \frac{P_e.e_c}{S_{bg}} = 5.89 + 8.62 = 14.51\ MPa$$

$M_{cr} = (f_r + f_{c,pe} - M_{D,nc}/S_{bg})S_{bcg}$

$= (4.08 + 14.51 - 3462.75/308.3)\ x\ 411.82x10^6 = 3030.27\ kN.m$

$M_{cr} \geq f_r.S_{bcg} = 4.08\ x\ 411.82x10^6 = 1680.23\ kN.m\ \therefore OK$

$1.2M_{cr} = 1.2\ x\ 3030.27 = 3636.32\ kN/m$

$1.33M_u = 1.33\ x\ 9773.13 = 12998.26\ kN.m > 1.2M_{cr}\ \therefore OK$

$M_r = 12047.92\ kN.m > 1.2M_{cr}\quad \therefore OK$

Design of Shear

$\because A_s = 0 \rightarrow d_e = d_{ps} = 1900\ mm$

$d_v = d_{ps} - a/2 = 1900 - 89.1/2 = 1855.45\ mm\qquad \leftarrow$ governs

$\geq 0.9d_e = 0.9\ x\ 1900 = 1710\ mm$

$\geq 0.72h = 0.72\ x\ 2050 = 1476\ mm$

$x = d_v + 0.5w_b = 1855.45 + 150 = 2005.45\ mm \cong 2\ m$

$w_{DC} = w_{DC1} + w_{DC2} = 30.78 + 1.43 = 32.21\ kN/m$

$V_{DC} = w_{DC}(0.5L - x) = 32.21(0.5\ x\ 30 - 2) = 418.73\ kN$

$V_{DW} = w_{DW}(0.5L - x) = 2.41(13) = 31.33\ kN$

$V_{Ln} = w_{Ln}(0.5L - x) = 9.3(13) = 120.9\ kN$

$V_{Tr} = 272.52\ kN$

$V_{LL+IM} = DFV_{int}[(1 + IM)V_{Tr} + V_{Ln}]$

$= 0.84[1.33\ x\ 272.52 + 120.9] = 406.02\ kN$

Strength I limit State (Factored Shear):

$V_u = \eta_i[1.25V_{DC} + 1.50V_{DW} + 1.75V_{LL+IM}]$

$= 1.0[1.25\ x\ 418.73 + 1.5\ x\ 31.33 + 1.75\ x\ 406.02] = 1280.94\ kN$

Check the adequacy of the section for shear resistance:

$V_n = 0.25f_c'.b_v.d_v = 0.25\ x\ 42\ x\ 200\ x\ 1855.45 = 3896.45\ kN$

$\phi V_n = 0.9\ x\ 3896.45 = 3506.8\ kN > V_u$ $\therefore$ the section is adequate

$V_c = 0.166\sqrt{f_c'}.b_v.d_v = 0.166\ x\ \sqrt{42}\ x\ 200\ x\ 1855.45 = 399.22\ kN$

$\phi V_c = 0.9\ x\ 399.22 = 359.3\ kN < V_u \rightarrow A_v$ is required

$V_s = (V_u - \phi V_c)/\phi = (1280.94 - 359.3)/0.9 = 1024.04\ kN$

Details of shear reinforcement:

$v_u = V_u/\emptyset b_v.d_v = 1280.94x10^3/(0.9\ x\ 200\ x\ 1855.45) = 3.835\ MPa$

$0.125f_c' = 0.125\ x\ 42 = 5.25\ MPa > v_u$

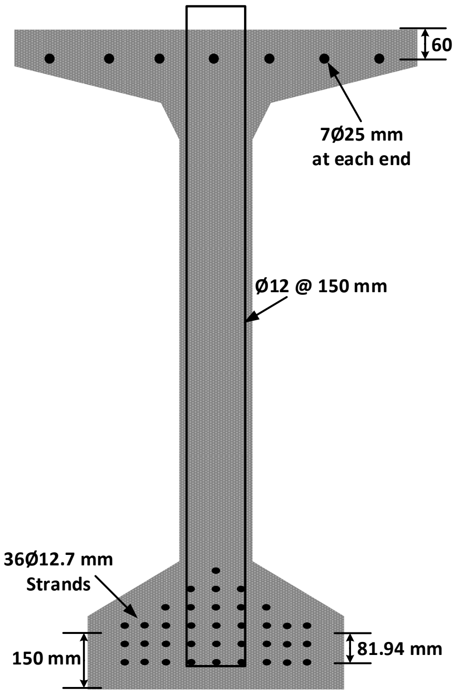
$s_{max} = 0.8d_v = 0.8\ x\ 1855.45 = 1484.36\ mm$

$\leq 600\ mm$ $\leftarrow$ governs

$\emptyset_v = 12\ mm \rightarrow A_v = 226\ mm^2$

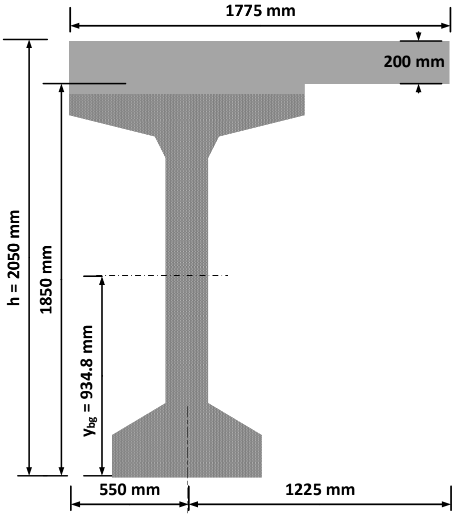
$s = A_v.f_y.d_v/V_s = 226\ x\ 420\ x\ 1855.45/(1024.04x10^3) = 171.98\ mm$

use $\emptyset 12$ @ $150\ mm$ o.c. stirrups



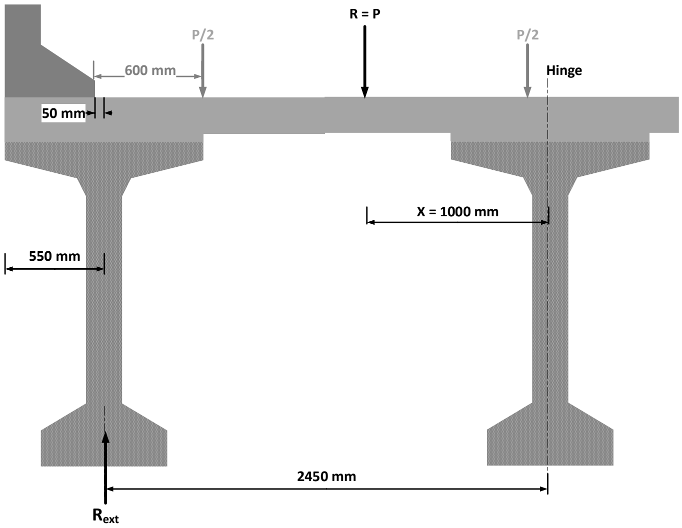
- **Design of Exterior T-Girders**

$$b_f = w_o + S/2 = 550 + 2450/2 = 1775\ mm < b_{f,int} = 2500\ mm$$



$\rightarrow M_{DC1,ext} < M_{DC1,int}$

$-0.3 \leq d_e \leq 1.7 \qquad d_e = 0.05\ m \ \therefore OK$



$R_{ext} = X/S = 1000/2450 = 0.4082$

$DFM_{se} = DFV_{se} = m.R_{ext} = 1.2\ x\ 0.4082 = 0.49$

$DFM_{se} < DFM_{si} = 0.51$

$DFM_{me} = e_M.DFM_{mi}$

$e_M = 0.77 + d_e/2800$

$= 0.77 + 50/2800 = 0.7879 < 1 \rightarrow DFM_{me} < DFM_{mi}$

$DFV_{se} < DFV_{si} = 0.689$

$DFV_{me} = e_V.DFV_{mi}$

$e_V = 0.60 + d_e/3000$

$= 0.60 + 50/3000 = 0.6167 < 1 \rightarrow DFV_{me} < DFV_{mi}$

$\rightarrow M_{LL+IM,ext} < M_{LL+IM,int}$

Thus $M_{u,ext} < M_{u,int}$

$\therefore$ Reinforcement of the interior T-girders is adequate for the exterior T-girders