$V_{LL+IM} = DFV_{int}[(1 + IM)V_{Tr} + V_{Ln}]$
$= 0.602[1.33\ x\ 245.41 + 63.71] = 234.84$ kN

Strength I limit State: Factored Shear:

$V_u = \eta_i[1.25V_{DC} + 1.50V_{DW} + 1.75V_{LL+IM}]$
$= 1.0[1.25\ x\ 121.66 + 1.50\ x\ 20.55 + 1.75\ x\ 234.84] = 593.87$ kN

Check the adequacy of the section for shear resistance:

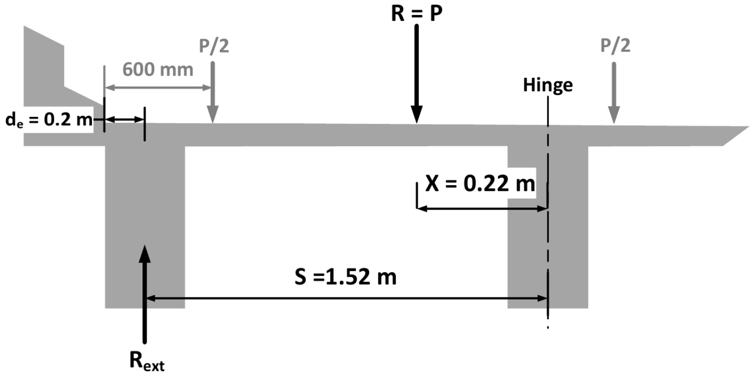
$\because V_p = 0 \rightarrow V_n = 0.25f_c'.b_v.d_v$
$V_n = 0.25f_c'.b_v.d_v = 0.25\ x\ 28\ x\ 400\ x\ 913.75 = 2558.5$ kN
$\phi V_n = 0.9\ x\ 2558.5 = 2302.6$ kN $> V_u = 954.4$ kN → the section is adequate
$V_c = 0.166\sqrt{f_c'}.b_v.d_v = 0.166\ x\ \sqrt{28}\ x\ 400\ x\ 913.75 = 321051.4$ N $= 321.05$ kN
$\phi V_c = 0.9\ x\ 321.05 = 288.95$ kN $< V_u \rightarrow A_v$ is required
$V_s = (V_u - \phi V_c)/\phi = (593.97 - 288.95)/0.9 = 338.91$ kN

Details of shear reinforcement:

$v_u = V_u/\phi b_v.d_v = 594.4x10^3/(0.9\ x\ 400\ x\ 913.75) = 1.8$ MPa
$0.125f_c' = 0.125\ x\ 28 = 3.5$ MPa $> v_u = 1.8$ MPa
$s_{max} = 0.8d_v = 0.8\ x\ 913.75 = 731$ mm
≤ 600 mm ← governs
$\emptyset_v = 12$ mm $\rightarrow A_v = 226.19$ mm^2
$s = A_v.f_y.d_v/V_s = 226.19\ x\ 420\ x\ 913.75/(338.91x10^3) = 256.13$ mm
$\leq A_v.f_y/(0.083\sqrt{f_c'}.b_v) = 226\ x\ 420/(0.083\ x\ \sqrt{28}\ x\ 400) = 540$ mm
use Ø12 @ 250 mm o.c. stirrups

- **Design of Exterior T-Beams**

$b_f = S/2 + w_o$
$= 1.52/2 + 0.7 = 1.46$ m $< b_{f,int} = 1.52$ m
→ DC and DW effects on exterior T-beam are less than that on interior T-beam
Check the applicability criteria:
$-0.3 \leq d_e \leq 1.7$ $\quad d_e = 0.2$ m ∴ OK



$R_{ext} = X/S = 0.22/1.52 = 0.144$
$DFM_{se} = DFV_{se} = m.R_{ext} = 1.2\ x\ 0.144 = 0.174$
$DFM_{se} < DFM_{si} = 0.421$

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

$e_M = 0.77 + d_e/2800$

$= 0.77 + 200/2800 = 0.842 < 1 \rightarrow DFM_{me} < DFM_{mi}$

$DFV_{se} < DFV_{si} = 0.560$

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

$e_V = 0.60 + d_e/3000$

$= 0.60 + 200/3000 = 0.667 < 1 \rightarrow DFV_{me} < DFV_{mi}$

$\rightarrow LL + IM$ effects on exterior T-beam are less than that on interior T-beam

$\therefore$ Provide the same main and transverse reinforcement of interior T-beams

- **Design of Deck Slab**

$S = 1520$ mm

$h_d = 175$ mm

Force effects from unfactored permanent loads per unit width:

$w_{DC} = h_d \; x \; \Upsilon_c = 0.175 \; x \; 24 = 4.2$ kN/m^2

$\rightarrow M_{DC} = w_{DC} . L^2/24 = 4.2 \; x \; 1.52^2/24 = 0.4$ kN.m

$\rightarrow M_{DC}{}^- = w_{DC} . L^2/12 = 4.2 \; x \; 1.52^2/12 = 0.8$ kN.m

$w_{DW} = 3$ kN/m^2

$\rightarrow M_{DW} = w_{DW} . L^2/24 = 3 \; x \; 1.52^2/24 = 0.3$ kN.m

$\rightarrow M_{DW}{}^- = w_{DW} . L^2/12 = 3 \; x \; 1.52^2/12 = 0.6$ kN.m

Force effects from unfactored live load:

$S = 1.5$ m : $M = 21.05$ kN.m

$S = 1.6$ m : $M = 21.19$ kN.m

$\therefore S = 1.52$ m : $M = 21.078$ kN.m

$\rightarrow M_{LL+IM} = 21.1$ kN.m

$S = 1.5$ m : $h_d = 0.175$ m : $M = 11.14$ kN.m

$S = 1.6$ m : $h_d = 0.175$ m : $M = 12.45$ kN.m

$\therefore S = 1.52$ m : $M = 11.4$ kN.m

$\rightarrow M_{LL+IM}{}^- = 11.4$ kN.m

Strength I limit State (Factored Moments):

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

$= 1.0[1.25 \; x \; 0.4 + 1.50 \; x \; 0.3 + 1.75 \; x \; 21.1] = 42.4$ kN.m

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

$= 1.0[1.25 \; x \; 0.8 + 1.50 \; x \; 0.6 + 1.75 \; x \; 11.4] = 21.9$ kN.m

Calculate the amount of main reinforcements:

$Try \; c_b = 25$ mm , $c_t = 50$ mm and $\emptyset_b = 16$ mm

$d_s = h_d - c_b - \emptyset_b/2 = 175 - 25 - 8 = 142$ mm $\cong 140$ mm

$A_s = 1.25M_u/f_y . d_s = 1.25 \; x \; 42.4x10^6/(420 \; x \; 140) = 901.4$ mm^2/m

$f_c' = 28$ MPa $\rightarrow \beta_1 = 0.85$

$c = A_s . f_y/(0.85f_c' . \beta_1 . b) = 901.4 \; x \; 420/(0.85 \; x \; 28 \; x \; 0.85 \; x \; 1000) = 18.8$ mm

$\varepsilon_t = \varepsilon_{cu}[(d_t - c)/c] = 0.003[(140 - 18.8)/18.8] = 0.0194 > 0.005 \quad \therefore \text{OK}$

$a = \beta_1.c = 0.85\ x\ 18.8 = 16$ mm

$M_n = A_s.f_y(d_s - a/2) = 901.4\ x\ 420(140 - 8) = 50$ kN.m

$M_r = \phi M_n = 0.9\ x\ 50 = 45$ kN.m $> M_u = 42.4$ kN.m $\therefore$ OK

$d_s^- = h_d - c_t - \emptyset_b/2 = 175 - 50 - 8 = 117$ mm $\cong 110$ mm

$A_s^- = 1.25M_u/f_y.d_s = 1.25\ x\ 21.9x10^6/(420\ x\ 110) = 592.6$ mm^2/m

$c = A_s^-.f_y/(0.85f_c'.\beta_1.b) = 592.6\ x\ 420/(0.85\ x\ 28\ x\ 0.85\ x\ 1000) = 12.3$ mm

$\varepsilon_t = \varepsilon_{cu}[(d_t^- - c)/c] = 0.003[(110 - 12.3)/12.3] = 0.0234 > 0.005 \quad \therefore \text{OK}$

$a = \beta_1.c = 0.85\ x\ 12.3 = 10.5$ mm

$M_n^- = A_s^-.f_y(d_s^- - a/2) = 592.6\ x\ 420(110 - 10.5/2) = 26$ kN.m

$M_r^- = \phi M_n^- = 0.9\ x\ 26 = 23.4$ kN.m $> M_u^- = 21.9$ kN.m $\therefore$ OK

Check for minimum reinforcement:

$f_r = 0.63\sqrt{f_c'} = 0.63\ x\ \sqrt{28} = 3.33$ MPa

$\bar{y} = h_d/2 = 175/2 = 87.5$ mm

$I_g = bh_d^3/12 = 1000\ x\ 175^3/12 = 446.62x10^6$ mm^4

$S_{nc} = I_g/\bar{y} = 446.62x10^6/87.5 = 5.1x10^6$ mm^3

$M_{cr} = f_r.S_{nc} = 3.33\ x\ 5.1x10^6 = 17$ kN.m

$1.2M_{cr} = 1.2\ x\ 17 = 20.4$ kN.m

$1.33M_u = 1.33\ x\ 42.4 = 56.4$ kN.m $> 1.2M_{cr} = 20.4$ kN.m $\therefore$ OK

$M_r = 45$ kN.m $> 1.2M_{cr} = 20.4$ kN.m $\therefore$ OK

$1.33M_u^- = 1.33\ x\ 21.9 = 29.1$ kN.m $> 1.2M_{cr}$ $\therefore$ OK

$M_r^- = 23.4$ kN.m $> 1.2M_{cr}$ $\therefore$ OK

Details of main reinforcement:

$s_{min} = 1.5\emptyset_b = 24$ mm

$\geq 1.5d_{ag} = 1.5\ x\ 19 = 28.5$ mm

≥ 38 mm ← governs

$s_{max} = 1.5h_d = 262.5$ mm ← governs for flexural reinforcements

$= 3h_d = 525$ mm (for $A_{s,S+T}$)

≤ 450 mm ← govern for shrinkage and temperature reinforcement

$\emptyset_b = 16$ mm $\rightarrow A_b = 201$ mm^2

$s = 1000A_b/A_s = 201x10^3/901.4 = 223$ mm

use Ø16 @ 200 mm o.c. perpendicular to traffic at bottom of the deck

$s^- = 1000A_b/A_s^- = 201x10^3/592.6 = 339$ mm

use Ø16 @ 300 mm o.c. perpendicular to traffic at top of the deck

Determine the size and spacing of lateral (distribution) reinforcements:

$\% = 38.4/\sqrt{S} = 38.4/\sqrt{1520} = 0.99 > 0.67 \quad \therefore \text{NOK}$

$A_{s,D} = \%A_s = 0.67\ x\ 901.4 = 604$ mm^2/m

$s = 1000A_b/A_s = 201x10^3/604 = 332$ mm use Ø16 @ 300 mm o.c. parallel to traffic at bottom of the deck

Shrinkage and temperature reinforcement:

$A_{s,S+T} = 750b.h/[2f_y(b+h)] = 750\ x\ 10^3\ x\ 175/[840(1175)] = 133\ \text{mm}^2/\text{m}$

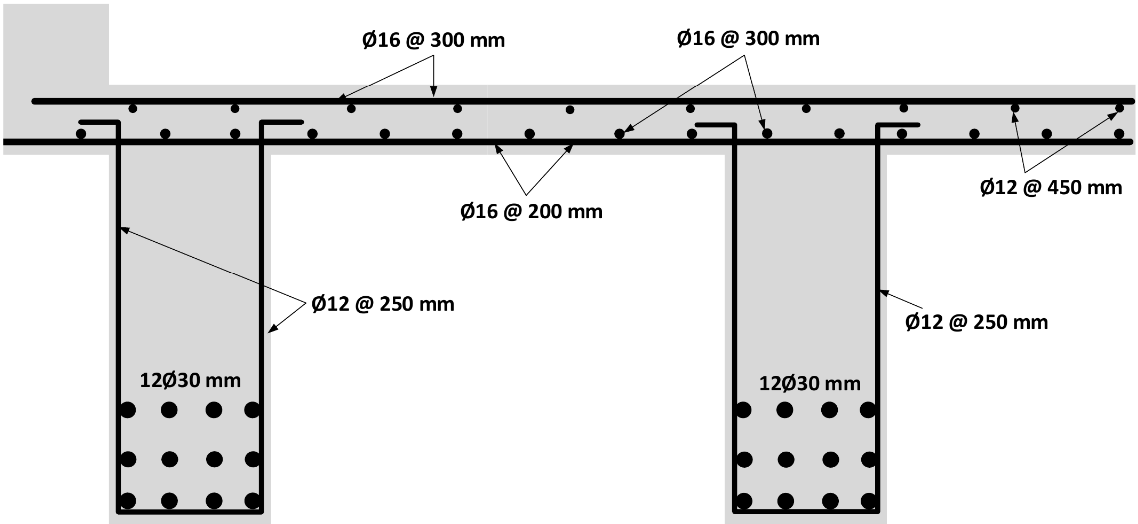
$233 \leq A_{s,S+T} \leq 1270\ \text{mm}^2/\text{m}\ \therefore \text{NOK}$

$A_{s,S+T} = 233\ \text{mm}^2/\text{m}$

$\emptyset_b = 12\ \text{mm} \rightarrow A_b = 113.1\ \text{mm}^2$

$s = 1000A_b/A_s = 113.1x10^3/233 = 485\ \text{mm}$

use Ø12 @ 450 mm o.c. parallel to traffic at top of the deck



Ex. 2: Design the monolithic beam bridge shown below to carry standard HS-93 load on simple span with 20 m effective length and 13.4 m clear width. The compressive strength of concrete (f_c') = 42 MPa and the yield stress of steel (f_y) = 420 MPa. The distributed weight of the future wearing surface = 3 kN/m^2 with total Traffic barriers = 16 kN/m^2