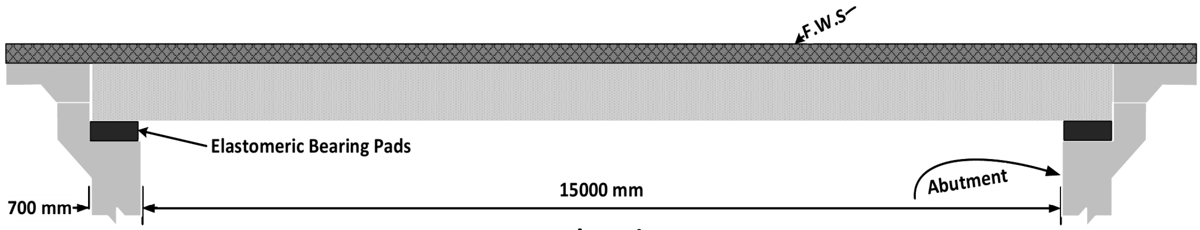
- Calculate factored moment (M_u) and shear (V_u) according to ($LRFD$) method
- Determine the required main reinforcement (A_s) details for flexure
- Check the shear reinforcement (A_v) requirements and design the stirrups when it is needed
- Check if skin reinforcement (A_{sk}) is required and design its details when it is needed
- Continue to design the deck

Ex. 1: Design the monolithic beam bridge shown below to carry standard HS-93 load on simple span with 15 m clear length and 8 m clear width. The compressive strength of concrete (f_c') = 28 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 = 15 kN/m^2

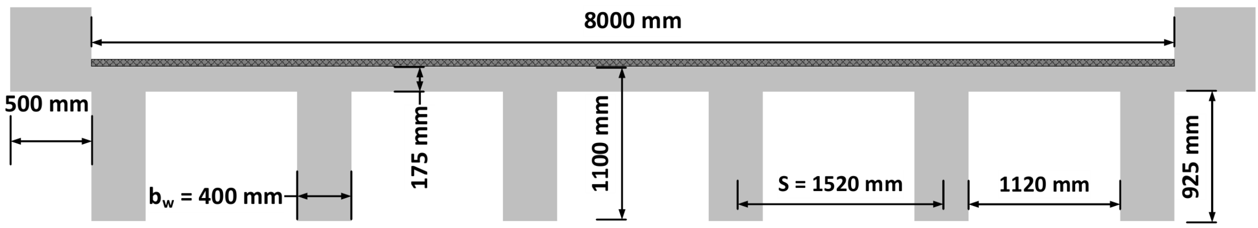


Elavation

Sol:

- **Preliminary Design**

Try 6 longitudinal beams (N_g) and each beam width (b_w) is 400 mm



Section

$S = (8000 - 400)/5 = 1520$ mm

$h_{d,min} = (S + 3000)/30 = (1520 + 3000)/30 = 150.67$ mm

use $h_d = 175$ mm (in order to match AASHTO specifications)

Note: you can use $S = 1120$ mm to check h_d because the section is monolithic

$L = 15700$ mm

$h_{min} = 0.07L = 0.07\ x\ 15700 = 1099$ mm

use $h = 1100$ mm $\rightarrow$ $h_w = 925$ mm

- **Design of Interior T-Beams**

Design for flexure:

Force effects from unfactored permanent loads:

$b_f = 1520$ mm

$A_g = A_f + A_w = 1520\ x\ 175 + 400\ x\ 925 = 636x10^3\ \text{mm}^2 = 0.636\ \text{m}^2$

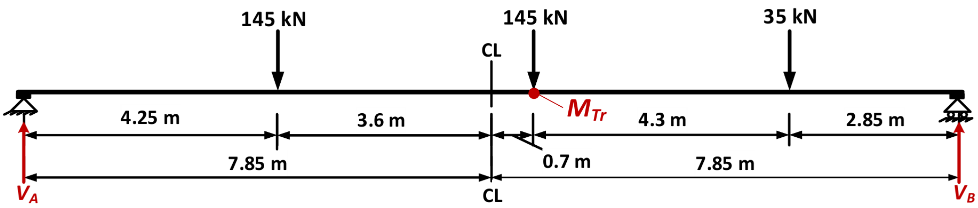
$w_{DC1} = A_g\ x\ \Upsilon_c = 0.636\ x\ 24 = 15.26$ kN/m

$w_{DC2} = w_{pa}/N_g = 15/6 = 2.5$ kN/m

$w_{DC} = w_{DC1} + w_{DC2} = 15.26 + 2.5 = 17.76$ kN/m
$\rightarrow M_{DC} = w_{DC}.L^2/8 = 17.76\ x\ 15.7^2/8 = 547.21$ kN.m
$w_{DW} = 3$ kN/m
$\rightarrow M_{DW} = w_{DW}.L^2/8 = 3\ x\ 15.7^2/8 = 92.44$ kN.m

Force effects from unfactored live load:

$w_{Ln} = 9.3$ kN/m
$\rightarrow M_{Ln} = w_{Ln}.L^2/8 = 9.3\ x\ 15.7^2/8 = 286.55$ kN.m
$\because L = 15.7\text{ m} > 12\text{ m} \rightarrow M_{Mo} = M_{Tr}$



$\Sigma M_B = 0$ ↷+
$V_A\ x\ 15.7 - 145\ x\ 11.45 - 145\ x\ 7.15 - 35\ x\ 2.85 = 0$
$\rightarrow V_A = 178.14$ kN , $V_B = 146.86$ kN
$M_{Tr} = 178.14\ x\ 8.55 - 145\ x\ 4.3 = 899.6$ kN.m

Live load distribution factors:

Check the applicability criteria:

$N_g \geq 4$	$N_g = 6\ \therefore$ OK
$6 \leq L \leq 73$	$L = 15.7$ m $\therefore$ OK
$1.1 \leq S \leq 4.9$	$S = 1.52$ m $\therefore$ OK
$110 \leq h_d \leq 300$	$h_d = 175$ mm $\therefore$ OK

$n = E_g/E_d = 1$ (because both the deck and web have the same f_c')
$I_g = I_w = 400\ x\ 925^3/12 = 26.382x10^9$ mm^4
$A_g = 636x10^3$ mm^2
$e_g = 925/2 + 175/2 = 550$ mm
$K_g = n(I_g + A_g.{e_g}^2) = 26.382x10^9 + 636x10^3\ x\ 550^2 = 218.772x10^9$ mm^4
$4x10^9 \leq K_g \leq 3x10^{12}$ $\quad K_g = 218.8x10^9$ mm^4 $\therefore$ OK

Thus, the trial cross section satisfies the design stipulations
$N_L = INT(w/3.6) = INT(8/3.6) = 2$
$\because N_L = 2 \rightarrow \therefore$ check both DF_s and DF_m

Live Load Distribution Factor for Moment:

$DFM_{si} = 0.06 + (S/4300)^{0.4}.(S/L)^{0.3}.\left(K_g/L.{h_d}^3\right)^{0.1}$
$= 0.06 + (1.52/4.3)^{0.4}.(1.52/15.7)^{0.3}.(0.2188/15.7x0.175^3)^{0.1} = 0.421$
$DFM_{mi} = 0.075 + (S/2900)^{0.6}.(S/L)^{0.2}.\left(K_g/L.{h_d}^3\right)^{0.1}$
$= 0.075 + (1.52/2.9)^{0.6}.(1.52/15.7)^{0.2}.(0.2188/15.7x0.175^3)^{0.1} = 0.544$
$\therefore DFM_{int} = 0.544$
$IM = 0.33$

$\rightarrow M_{LL+IM} = DFM_{int}[(1 + IM)M_{Tr} + M_{Ln}]$
$= 0.544[1.33\ x\ 899.6 + 286.55] = 806.76$ kN.m

Strength I limit State: Factored Moments:

$M_u = \eta_i[1.25M_{DC} + 1.50M_{DW} + 1.75M_{LL+IM}]$
$= 1.0[1.25\ x\ 547.21 + 1.50\ x\ 92.44 + 1.75\ x\ 806.76] = 2234.5$ kN.m

Calculate the amount of main reinforcements:

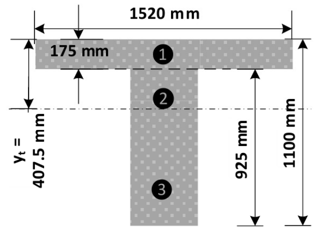
$Try\ c_b = 50$ mm, $\emptyset_v = 12$ mm and $\emptyset_b = 30$ mm
$d_s = h - c_b - \emptyset_v - \emptyset_b/2 = 1100 - 50 - 12 - 15 = 1023$ mm
$A_s = 1.25M_u/f_y.d_s = 1.25\ x\ 2234.5x10^6/(420\ x\ 1023) = 6500.79$ mm^2
$\emptyset_b = 30\ mm \rightarrow A_b = 706.85\ mm^2$
$N_b = A_s/A_b = 6500.79/706.85 = 9.2$ say 10 bars
$s_{min} = 1.5\emptyset_b = 45$ mm ← governs
$\geq 1.5d_{ag} = 1.5\ x\ 19 = 28.5$ mm
≥ 38 mm
$s = [b_w - 2(c_c + \emptyset_v) - N_b.\emptyset_b]/(N_b - 1)$
$= [400 - 2(50 + 12) - 10\ x\ 30]/9 = -2.6$ mm NOK

Arrange the bars in 3 layers of 4 bars at each layer
$s = [400 - 2(50 + 12) - 4\ x\ 30]/3 = 52$ mm ∴ OK

Spacing of layers:
$s_{min} = \emptyset_b = 30$ mm ← governs
≥ 25 mm
$s_{max} = 150$ mm
$d_s = h - c_b - \emptyset_v - 3\emptyset_b/2 - 30 = 1100 - 50 - 12 - 45 - 30 = 963$ mm
$A_s = 12\ x\ 706.85 = 8482.2$ mm^2
$f_c' = 28$ MPa $\rightarrow \beta_1 = 0.85$
$c = A_s.f_y/(0.85f_c'.\beta_1.b_f) = 8482.2\ x\ 420/(0.85\ x\ 28\ x\ 0.85\ x\ 1520) = 115.9$ mm
$d_t = 1023\ mm$
$\varepsilon_t = \varepsilon_{cu}[(d_t - c)/c] = 0.003[(1023 - 115.9)/115.9] = 0.0235 > 0.005$ ∴ OK
$a = \beta_1.c = 0.85\ x\ 115.9 = 98.5$ mm
$\because a = 98.5\ mm < h_d = 175$ mm ∴ the section behaves as a rectangular
$M_n = A_s.f_y(d_s - a/2) = 8482.2\ x\ 420(963 - 98.5/2) = 3255.26$ kN.m
$M_r = \phi M_n = 0.9\ x\ 3255.26 = 2929.73$ kN.m $> M_u = 2234.5$ kN.m ∴ OK

Check for minimum reinforcement:

$f_r = 0.63\sqrt{f_c'} = 0.63\ x\ \sqrt{28} = 3.33$ MPa
$A_f = 1520\ x\ 175 = 266x10^3$ mm^2
$A_w = 400\ x\ 925 = 370x10^3$ mm^2
$\bar{y} = (A_f\ x\ \bar{y}_f + A_w\ x\ \bar{y}_w)/A_g$
$= (266x10^3\ x\ 87.5 + 370x10^3\ x\ 637.5)/636x10^3 = 407.5$ mm



$I_g = 1520\ x\ 175^3/12 + 266x10^3\ x\ 320^2 + 400\ x\ 232.5^3/3 + 400\ x\ 692.5^3/3$
$= 73.87x10^9\ \text{mm}^4$

$S_{nc} = I_g/\bar{y} = 73.87x10^9/407.5 = 181.28x10^6\ \text{mm}^3$

$M_{cr} = f_r.S_{nc} = 3.33\ x\ 181.28x10^6\ \text{mm}^3 = 603.66\ \text{kN.m}$

$1.2M_{cr} = 1.2\ x\ 603.66 = 724.4\ \text{kN.m}$

$1.33M_u = 1.33\ x\ 2234.5 = 2971.89\ \text{kN.m} > 1.2M_{cr} = 724.4\ \text{kN.m}\ \therefore \text{OK}$

$M_r = 2929.73\ \text{kN.m} > 1.2M_{cr} = 724.4\ \text{kN.m}\ \therefore \text{OK}$

Check and design for shear:

Location of the Critical Section:

$\because A_{ps} = 0 \rightarrow d_e = d_s = 963\ \text{mm}$

$d_v = d_s - a/2 = 963 - 98.5/2 = 913.7\ \text{mm}$ ← governs

$\geq 0.9d_e = 0.9\ x\ 963 = 866.7\ \text{mm}$

$\geq 0.72h = 0.72\ x\ 1100 = 792\ \text{mm}$

$w_b = 300\ \text{mm}$ [typically assumed]

$x = d_v + w_b/2 = 913.7 + 150 = 1063.7\ \text{mm} \cong 1\ \text{m}$

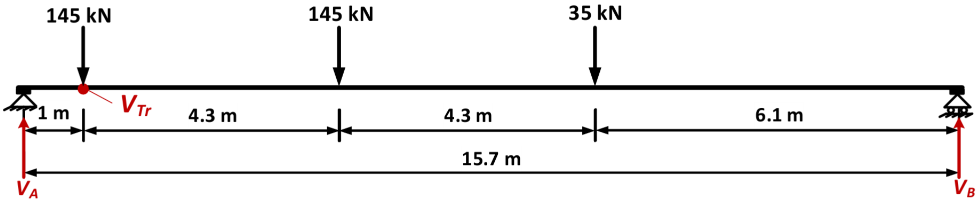
Calculation of Shear Force at the Critical Section:

$V_{DC} = w_{DC}(L/2 - x) = 17.76(15.7/2 - 1) = 121.66\ \text{kN}$

$V_{DW} = w_{DW}(L/2 - x) = 3(15.7/2 - 1) = 20.55\ \text{kN}$

$V_{Ln} = w_{Ln}(L/2 - x) = 9.3(15.7/2 - 1) = 63.71\ \text{kN}$

$\because L = 15.7\ \text{m} > 8.5\ \text{m} \rightarrow V_{Mo} = V_{Tr}$



$\Sigma M_B = 0$ ↷+

$V_A\ x\ 15.7 - 145\ x\ 14.7 - 145\ x\ 10.4 - 35\ x\ 6.1 = 0$

$\therefore V_B = 245.41\ \text{kN}$

$\rightarrow V_{Tr} = 245.41\ \text{kN}$

Live Load Distribution Factor for Shear:

$DFV_{si} = 0.36 + S/7600$
$= 0.36 + 1.52/7.6 = 0.560$

$DFV_{mi} = 0.2 + S/3600 - (S/10700)^2$
$= 0.2 + 1.52/3.6 - (1.52/10.7)^2 = 0.602$

$\therefore DFV_{int} = 0.602$