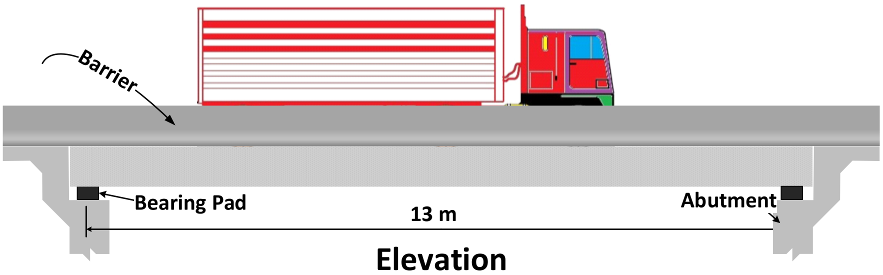
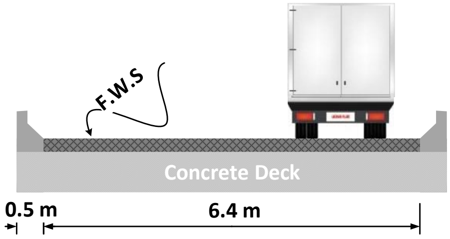
**Ex. 2:** Design the slab bridge deck with data: compressive strength of concrete $(f_c')$ = 35 MPa, the yield stress of steel $(f_y)$ = 420 MPa and standard HS-93 vehicular load. Take the distributed weight of future wearing surface plus nonstructural overlay = 2.8 kN/m$^2$ and total concrete barriers = 14 kN/m$^2$.




Elevation




Section

**Sol:**

$$S = 13\ m$$

Find minimum slab thickness $(h_{min})$:

$$h_{min} = 0.04(S + 3000) = 0.04(13 + 3) = 0.64\ m$$
$$use\ h_d = 650\ mm$$

Determine the equivalent width of the strips for live load:

$$\because w = 6.4\ m \rightarrow N_L = 2\ with\ 3.2\ m \text{ for each lane}$$
$$\because N_L = 2 \rightarrow \therefore check\ both\ E_{single}\ and\ E_{multi}$$
$$L_1 = S = 13\ m \qquad \leftarrow governs$$
$$\leq 18\ m$$
$$W_1 = W = 7.4\ m \qquad \leftarrow governs$$
$$\leq 18\ m$$
$$E_{single} = 250 + 0.42\sqrt{L_1 W_1} = 250 + 0.42\sqrt{13\ x\ 7.4x10^6} \cong 4.3\ m$$
$$E_{multi} = 2100 + 0.12\sqrt{L_1 W_1} = 2100 + 0.12\sqrt{13\ x\ 7.4x10^6} \cong 3.2\ m$$
$$\leq W/N_L = 7.4/2 = 3.7\ m$$
$$\rightarrow E_{int} = 3.2\ m$$
$$W_e = 500\ mm$$
$$E_{edge} = W_e + 300 + 0.25E_{int} = 0.5 + 0.3 + 0.25\ x\ 3.2 = 1.6\ m$$
$$\leq 0.5E_{int} = 1.6\ m$$
$$\leq 1.8\ m$$
$$\rightarrow E_{edge} = 1.6\ m$$

- **Design of Interior Strips**

Calculate the unfactored dead load force effects per unit width:

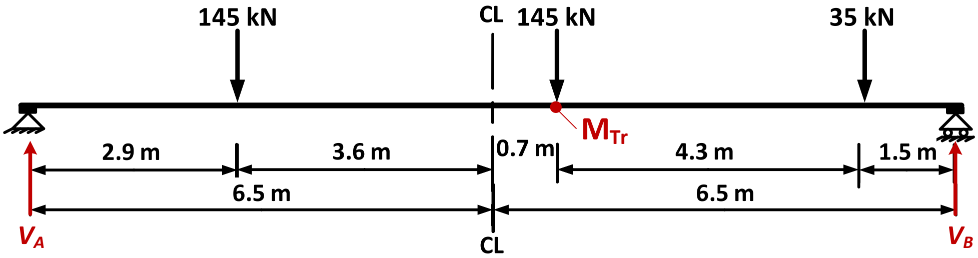
$$w_{DC} = h_d\ x\ \Upsilon_c = 0.65\ x\ 24 = 15.6\ kN/m^2$$
$$\rightarrow M_{DC} = w_{DC}.L^2/8 = 15.6\ x\ 13^2/8 = 329.55\ kN.m$$
$$w_{DW} = 2.8\ kN/m^2$$
$$\rightarrow M_{DW} = w_{DW}.L^2/8 = 2.8\ x\ 13^2/8 = 59.15\ kN.m$$

Calculate the live load force effects per unit width:

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

$\rightarrow M_{Ln} = w_{Ln}.L^2/8 = 9.3\ x\ 13^2/8 = 196.47\ kN.m$

$Since\ L = 13\ m > 12\ m\ \rightarrow M_{Tr} > M_{Ta}$




$\Sigma M_B = 0\ \curvearrowright^{+}$

$V_A\ x\ 13 - 145\ x\ 10.1 - 145\ x\ 5.8 - 35\ x\ 1.5 = 0$

$\therefore V_A = 181.39 kN\ , V_B = 143.61\ kN$

$\rightarrow M_{Tr} = 181.39\ x\ 7.2 - 145\ x\ 4.3 = 682.51\ kN.m$

$IM = 0.33$

$\rightarrow M_{LL+IM} = [(1 + IM)M_{Tr} + M_{Ln}]/E_{int}$

$= [1.33\ x\ 682.51 + 196.47]/3.2 = 345.07\ kN.m$

Strength I limit State: Factored Moments:

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

$= 1.0[1.25\ x\ 329.55 + 1.50\ x\ 59.15 + 1.75\ x\ 345.07] = 1104.54\ kN.m$

Limits of reinforcement:

$Try\ c_b = 25\ mm\ , c_t = 50\ mmand\ \emptyset_b = 30\ mm$

$d_s = h_d - c_b - \emptyset_b/2 = 650 - 25 - 15 = 610\ mm$

$A_s = 1.25M_u/f_y.d_s = 1.25\ x\ 1104.54x10^6/(420\ x\ 610) = 5389.06\ mm^2/m$

$\beta_1 = 0.85 - 0.05(f_c' - 28)/7 = 0.85 - 0.05(35 - 28)/7 = 0.8$

$c = A_s.f_y/(0.85f_c'.\beta_1.b) = 5389.06\ x\ 420/(0.85\ x\ 35\ x\ 0.80\ x\ 1000) = 95.1\ mm$

$\varepsilon_s = \varepsilon_{cu}[(d_s - c)/c] = 0.003[(610 - 95.1)/95.1] = 0.0162 \geq 0.005\quad \therefore OK$

$a = \beta_1.c = 0.8\ x\ 95.1 = 76.08\ mm$

$M_n = A_s.f_y(d_s - 0.5a) = 5389.06\ x\ 420(610 - 0.5\ x\ 76.08) = 1294.58\ kN.m$

$M_r = \phi_f.M_n = 0.9\ x\ 1294.58 = 1165.11\ kN.m > M_u = 1104.54\ kN.m\quad \therefore OK$

Check for minimum reinforcement:

$\bar{y} = h_d/2 = 650/2 = 325\ mm$

$I_g = bh_d{}^3/12 = 1000\ x\ 650^3/12 = 22.885x10^9\ mm^4$

$S_{nc} = I_g/\bar{y} = 22.885x10^9/325 = 70.42x10^6\ mm^3$

$f_r = 0.63\sqrt{f_c'} = 0.63\ x\ \sqrt{35} = 3.73\ MPa$

$M_{cr} = f_r.S_{nc} = 3.73\ x\ 70.42x10^6 = 262.67\ kN.m$

$1.2M_{cr} = 1.2\ x\ 262.67 = 315.2\ kN.m$

$1.33M_u = 1.33\ x\ 1104.52 = 1469.04\ kN.m > 1.2M_{cr} = 315.2\ kN.m\quad \therefore OK$

$M_r = 1165.11\ kN.m > 1.2M_{cr} = 315.2\ kN.m\quad \therefore OK$

Details of main reinforcement:

$s_{min} = 1.5\emptyset_b = 45\ mm \quad \leftarrow governs$

$\geq 1.5d_{ag} = 1.5\ x\ 19 = 28\ mm$

$\geq 38\ mm$

$s_{max} = 1.5h_d = 975\ mm$

$= 3h_d = 1950\ mm$ (shrinkage and temperature reinforcement )

$\leq 450\ mm \quad \leftarrow governs$

$\emptyset_b = 30\ mm \rightarrow A_b = 706.85\ mm^2$

$s = 1000A_b/A_s = 706.85x10^3/5389.06 = 131.16\ mm$

$use\ \emptyset 30\ mm$ @ $100\ mm$ o.c. parallel to traffic

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

$\% = 17.5/\sqrt{S} = 17.5/\sqrt{13000} = 0.154 \leq 0.5 \quad \therefore OK$

$A_{s,Dist} = \%A_s = 0.154\ x\ 5389.06 = 829.92\ mm^2/m$

$\emptyset_b = 16\ mm \rightarrow A_b = 201.06\ mm^2$

$s_{Dist} = 1000A_b/A_s = 201.06x10^3/829.92 = 242.26\ mm$

$use\ \emptyset 16\ mm$ @ $200\ mm$ o.c. perpendicular to traffic

Shrinkage and temperature reinforcement:

$A_{s,S+T} = 750b.h/2(b+h)f_y = 750\ x\ 10^3\ x\ 650/2(1650)420 = 351.73$

$233 \leq A_{s,S+T} \leq 1270 \quad \therefore OK$

$A_{s,S+T} = 351.73\ mm^2/m$

$\emptyset_b = 12\ mm \rightarrow A_b = 113.1\ mm^2$

$s = 1000A_b/A_s = 113.1x10^3/351.73 = 321.55\ mm$

$use\ \emptyset 12\ mm$ @ $300\ mm$ o.c. on each side and each direction at the top face

- **Design of Exterior Strips**

Calculate the unfactored dead load force effects per unit width:

$w_{DC1} = 15.6\ kN/m^2$

$w_{DC2} = 7/E_{edge} = 7/1.6 = 4.38\ kN/m$

$w_{DC} = w_{DC1} + w_{DC2} = 15.6 + 4.38 = 19.98\ kN/m^2$

$\rightarrow M_{DC} = w_{DC}.L^2/8 = 19.98\ x\ 13^2/8 = 422.08\ kN.m$

$w_{DW} = 2.8\ x\ (E_{edge} - W_e)/E_{edge} = 2.8(1.6 - 0.5)/1.6 = 2\ kN/m^2$

$\rightarrow M_{DW} = w_{DW}.L^2/8 = 2\ x\ 13^2/8 = 42.25\ kN.m$

Calculate the unfactored live load force effects per unit width:

$w_{Ln} = 9.3\ x\ (E_{edge} - W_e)/E_{edge} = 9.3\ x\ 1.1/1.6 = 6.39\ kN/m^2$

$\rightarrow M_{Ln} = w_{Ln}.L^2/8 = 6.39\ x\ 13^2/8 = 135.07\ kN.m$

$\rightarrow M_{Tr} = 0.5\ x\ 682.51/E_{edge} = 0.5\ x\ 682.51/1.6 = 213.28\ kN.m$

$\rightarrow M_{LL+IM} = (1 + IM)M_{Tr} + M_{Ln} = 1.33\ x\ 213.28 + 135.07 = 418.73\ kN.m$

Strength I limit State: Factored Moments:

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

$= 1.0[1.25\ x\ 422.08 + 1.50\ x\ 42.25 + 1.75\ x\ 418.73] = 1323.75\ kN.m$

Calculate the amount and details of reinforcements:

$A_{s,Pro} = 1000A_b/s = 706.85x10^3/100 = 7086.5\ mm^2/m$

$c = A_s.f_y/(0.85f'_c.\beta_1.b) = 7086.5\ x\ 420/(0.85\ x\ 35\ x\ 0.80\ x\ 1000) = 125\ mm$

$\varepsilon_s = \varepsilon_{cu}[(d_s - c)/c] = 0.003[(610 - 125)/125] = 0.0116 \geq 0.005 \quad \therefore OK$

$a = \beta_1.c = 0.8\ x\ 125 = 100\ mm$

$M_n = A_s.f_y(d_s - a/2) = 7086.5\ \ x\ 420(610 - 50) = 1666.7\ kN.m$

$M_r = \phi_f.M_n = 0.9\ x\ 1666.7 = 1500\ kN.m > M_u = 1323.75\ kN.m \quad \therefore OK$

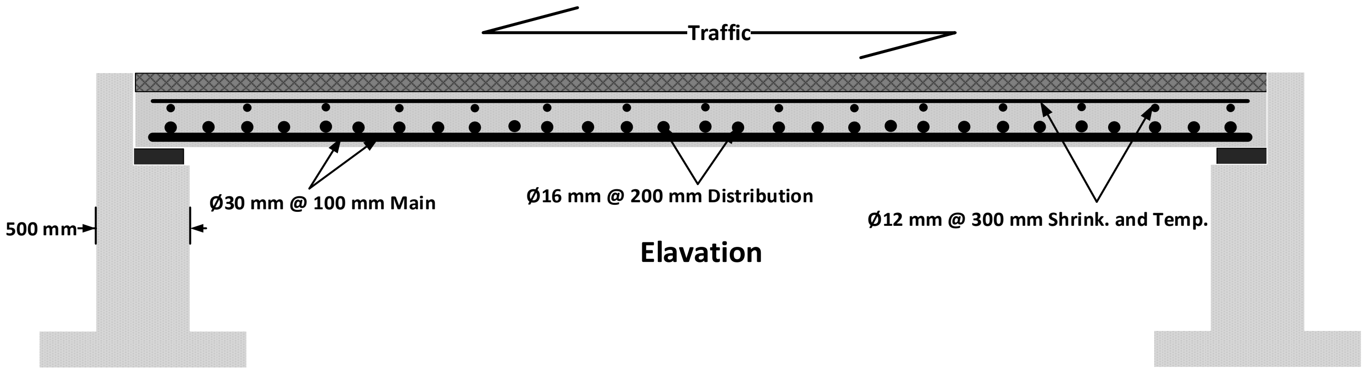
$> 1.2M_{cr} = 315.2\ kN.m \quad \therefore OK$

Details of reinforcement:

$use$ Ø30 $mm$ @ 100 $mm\ c/c$ parallel to traffic at the bottom face

$use$ Ø16 $mm$ @ 200 $mm\ c/c$ perpendicular to traffic at the bottom face

$use$ Ø12 $mm$ @ 300 $mm\ c/c$ on each side and each direction at the top face




Elavation