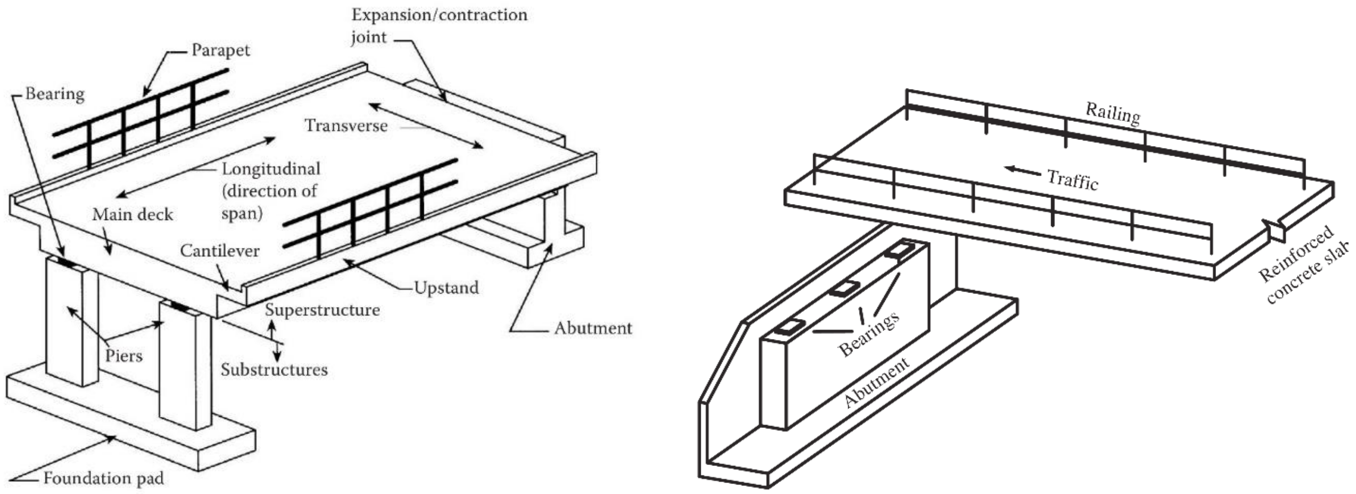
Slab Bridges

It is the simplest system of superstructure and used for short bridges where the span length is about 15 m or less. Generally, the slab (deck) carries the traffic and other design loads of the bridge into abutments (exterior supports) or/and piers (interior supports). Also, the slab behaves as simply supported, continuous or cantilever span depending on the number and position of supports. The span length (S) and thus the main reinforcement of the slabs shall be taken parallel to traffic direction. The slab edges shall either be strengthened or integrated with supporting edge beams. The edge beams are to carry the curbs, parapets and barriers but not to carry the slab.



Slab Bridge Components

Strip Method for Decks Analysis

An approximate analysis method in which the deck is subdivided into strips perpendicular to the supporting components. This method shall be considered acceptable for slab bridges and concrete slabs having more than 4600 mm spans which primarily in the direction parallel to traffic.

Equivalent Interior Strip Widths

This Article shall be applied to the CIP solid or voided concrete slab bridges. The equivalent width of longitudinal strips per lane for both shear and moment with one lane (E_{single}), or two lines of wheels, loaded may be determined as:

$$E_{single} = 250 + 0.42\sqrt{L_1 W_1}$$

Whereas, the equivalent width of longitudinal strips per lane for both shear and moment with more than one lane (E_{multi}) loaded may be determined as:

$$E_{multi} = 2100 + 0.12\sqrt{L_1 W_1}$$
$$\leq W/N_L$$

where:

E: equivalent width (mm)

L_1: modified span length (mm)
W_1: modified edge to edge width of bridge (mm)
W: physical edge to edge width of bridge (mm)
N_L: number of design lanes

- $L_1 = S$
  $\leq 18000\ mm$
- $W_1 = W$
  $\leq 18000\ mm$ [multilane loading]
  $\leq 9000\ mm$ [single-lane loading]

Equivalent Edge Strip Width

Unless otherwise specified, the edge of the deck shall either be strengthened or be supported by a beam or other line component. The beam or component shall be integrated in or made composite with the deck. The edge beams may be designed as beams support one line of wheels and whose width may be taken as the equivalent width of longitudinal edge strip per lane (E_{edge}) loaded. The edge beam equivalent strip width may be determined as:

$$E_{edge} = W_e + 300 + E_{int}/4$$
$$\leq E_{int}/2$$
$$\leq 1800\ mm$$

where:
W_e: distance between the edge of the deck and the inside face of the barrier (mm)
E_{int}: equivalent width of interior strip for deck (mm)

Where the primary direction of the deck is transverse, and/or the deck is composite with a structurally continuous concrete barrier, no additional edge beam need be provided.

Slabs designed using the equivalent strip width method may be assumed to be adequate in shear, but edge beams on slab bridges require shear analysis.

Main Reinforcement

The amount of main reinforcement that required for flexural resistance can be estimated ($A_{s,est}$) to provide the primary reinforcement for positive moment:

$$A_{s,est} = 1.25 M_u / f_y . d_s$$

After estimation for required amount of steel, the ductile failure ($f_s \geq f_y$) and resistance factor (ϕ) must be checked.

$$\varepsilon_s = \varepsilon_{cu}[(d_s - c)/c]$$

If ($\varepsilon_s \geq 0.005$) $\rightarrow$ *tension failure is controlled*, then:

- $f_s = f_y$
- $\phi_f = 0.9$ [reinforced concrete section]
  $= 1.0$ [prestressed concrete section]

Limits for Main Reinforcement

- Maximum reinforcement:
  - $No\ provisions\ for\ maximum\ reinforcemen$
- Minimum reinforcement:
  - $M_r \geq 1.20M_{cr}$
  - $1.20M_{cr} \leq 1.33M_u$

$$M_{cr} = S_{nc}.f_r$$

where:

M_{cr}: cracking moment (N.mm)

S_{nc}: section modulus of non-cracked section (mm^3)

f_r: modulus of rupture (MPa)

Distribution Reinforcement

It is reinforcement shall be placed in the secondary direction in the bottom of slabs as a percentage of the primary reinforcement for positive moment as follows:

$$A_{s,Dist} = \%A_s$$

- $\% = 17.5/\sqrt{S} \leq 0.50$ [primary reinforcement parallel to traffic]

  $= 38.4/\sqrt{S} \leq 0.67$ [primary reinforcement perpendicular to traffic]

where:

S: effective span length (mm)

Shrinkage and Temperature Reinforcement

Reinforcement for shrinkage and temperature stresses shall be provided near surfaces of concrete exposed to daily temperature changes and in structural mass concrete.

Reinforcement for shrinkage and temperature may be in the form of bars, welded wire fabric or prestressing tendons and shall satisfy:

- $A_{s,S+T} \geq 0.75b.h/2(b+h)f_y$
- $0.233 \leq A_{s,S+T} \leq 1.27$

where:

A_s: area of reinforcement in each direction and each face (mm^2/mm)

b: least width of component section (mm)

h: least thickness of component section (mm)

f_y: specified yield strength of reinforcing bars (MPa)

Transverse Reinforcement

For edge beams, transverse reinforcement (A_v) shall be provided where:

$$V_u > \phi_v(V_c + V_p)/2$$

- $V_c = 0.166\sqrt{f_c'}.b_v.d_v$
- $V_s = [V_u - \phi_v(V_c + V_p)]/\phi_v$
- $A_v = V_s.s/d_v.f_y$

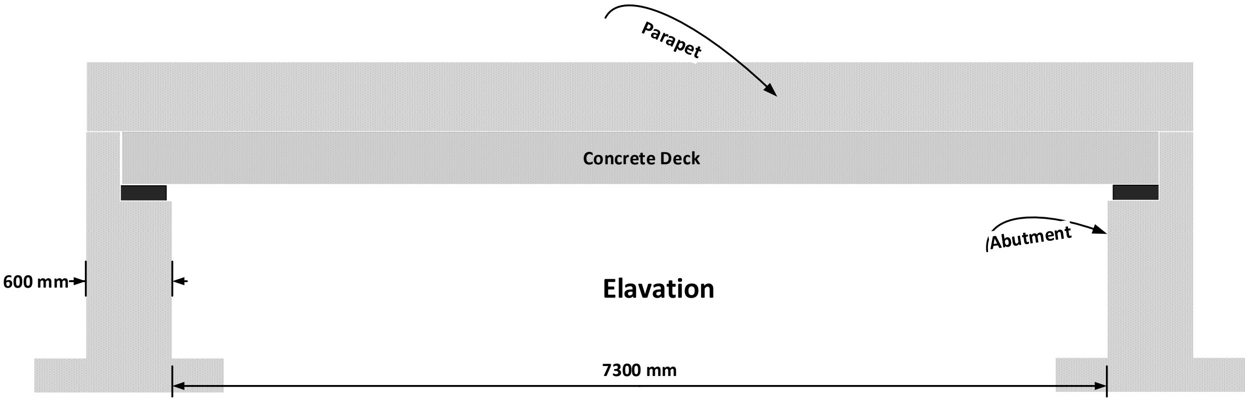
Minimum Transverse Reinforcement

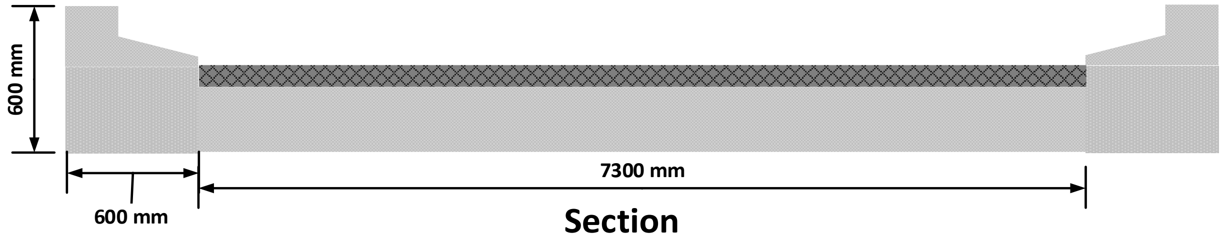
- $A_v \geq 0.083\sqrt{f_c'}.b_v.s/f_y$

Design Procedure

- Determine the effective slab span length (S)
- From AASHTO Tables, find minimum slab thickness (h_{min}) and then use ($h_d \geq h_{min}$)
    - $h_{min} \geq 175\ mm$
      $\geq S/20$ [cracking control]
- Calculate the unfactored dead load force effects per unit width
- Calculate the live load force effects
- Determine the equivalent width of the interior strip for live load
- Calculate the unfactored live load force effects per unit width of the equivalent strip
- Calculate ultimate moment (M_u) and shear (V_u) according to ($LRFD$) method
- Determine the required main reinforcement details for flexure as well all other distributed, shrinkage and temperature reinforcements
- No need to check shear and bond stresses when the deck is designed as a slab
- No need for thermal expansion when the span length (S) is less than 12200 mm
- Design of longitudinal edge beams (if exist) by the same steps of slab design, except:
    - Use equivalent edge strip for live load
    - No distribution reinforcement. However, stirrups are required to resist shear stresses.

Ex. 1: Slab bridge shown below, is designed to carry standard HS-93 vehicular load with concrete compressive strength (f_c') = 28 MPa and steel yield stress of (f_y) = 420 MPa. The thickness of nonstructural overlay is 70 mm and the expected future wearing surface is 50 mm. Determine the details of reinforcements required for the deck slab. Take the area of concrete parapet = 0.3 m^2.





Sol:

- **Design of Deck Slab**

$S = 7500\ mm$

Find minimum slab thickness (h_{min}) for the deck to control deflection:

$h_{min} = 0.04(S + 3000) = 0.04(7500 + 3000) = 420\ mm$

$use\ h_d = 450\ mm$

Calculate the unfactored dead load force effects per unit width:

$w_{DC} = h_d\ x\ \Upsilon_c = 0.45\ x\ 24 = 10.8\ kN/m^2$

$\rightarrow M_{DC} = w_{DC}.L^2/8 = 10.8\ x\ 7.5^2/8 = 75.94\ kN.m$

$w_{DW1} = t_{as}\ x\ \Upsilon_{as} = 0.07\ x\ 22.5 = 1.575\ kN/m^2$

$w_{DW2} = t_{fws}\ x\ \Upsilon_{as} = 0.05\ x\ 22.5 = 1.125\ kN/m^2$

$w_{DW} = 1.575 + 1.125 = 2.7\ kN/m^2$

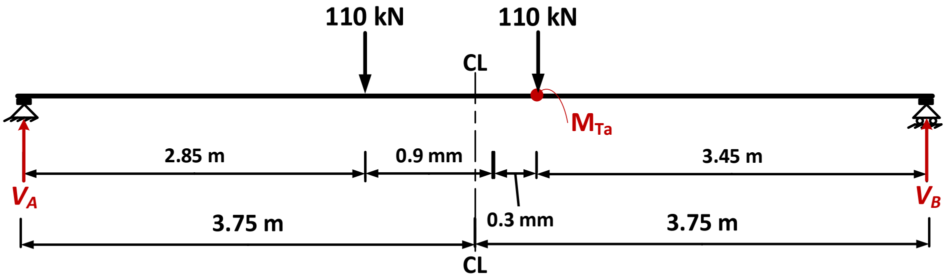
$\rightarrow M_{DW} = w_{DW}.L^2/8 = 2.7\ x\ 7.5^2/8 = 18.99\ kN.m$

Calculate the live load force effects:

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

$\rightarrow M_{Ln} = w_{Ln}.L^2/8 = 9.3\ x\ 7.5^2/8 = 65.39\ kN.m$

$Since\ L = 7.5\ m < 12\ m\ \rightarrow M_{Ta} > M_{Tr}$



$\Sigma M_B = 0\ \curvearrowleft^+$

$V_A \, x \, 7.5 - 110(3.45 + 4.65) = 0$

$\therefore V_A = 118.8 \, kN \quad , \quad V_B = 101.2 \, kN$

$\rightarrow M_{Ta} = 118.8 \, x \, 4.05 - 110 \, x \, 1.2 = 349.14 \, kN.m$

$IM = 0.33$

$\rightarrow M_{LL+IM} = (1 + IM)M_{Ta} + M_{Ln}$

$= 1.33 \, x \, 349.14 + 65.39 = 529.75 \cong 530 \, kN.m$

Determine the equivalent width of the interior strip for live load:

$N_L = INT(w/3.6) = INT(7.3/3.6) = 2$

$\because N_L = 2 \rightarrow \therefore check \ both \ E_{single} \ and \ E_{multi}$

$L_1 = S = 7.5 \, m \qquad \leftarrow governs$

$\leq 18 \, m$

$W_1 = W = 8.5 \, m \qquad \leftarrow governs$

$\leq 18 \, m$

$E_{single} = 250 + 0.42\sqrt{L_1 W_1} = 250 + 0.42\sqrt{7.5 \, x \, 8.5x10^6} \cong 3.6 \, m$

$E_{multi} = 2100 + 0.12\sqrt{L_1 W_1} = 2100 + 0.12\sqrt{7.5 \, x \, 8.5x10^6} \cong 3 \, m$

$\leq W/N_L = 8.5/2 = 4.25 \, m$

$\rightarrow E_{int} = 3 \, m$

Calculate the unfactored live load force effects per unit width of the equivalent strip:

$\rightarrow M_{LL+IM} = 530/E_{int} = 530/3 = 176.67 \, kN.m$

Strength I limit State: Factored Moments and Shear:

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

$= 1.0[1.25 \, x \, 75.94 + 1.50 \, x \, 18.99 + 1.75 \, x \, 176.67] = 432.6 \, kN.m$

Calculate the amount of main reinforcements:

$Try \ c_b = 25 \, mm \ and \ \emptyset_b = 30 \, mm$

$d_s = h_d - c_b - \emptyset_b/2 = 450 - 25 - 15 = 410 \, mm$

$A_s = 1.25M_u/f_y.d_s = 1.25 \, x \, 432.6x10^6/(420 \, x \, 410) = 3140.25 \, mm^2/m$

$c = A_s.f_y/(0.85f'_c.\beta_1.b) = 3140.25 \, x \, 420/(0.85 \, x \, 28 \, x \, 0.85 \, x \, 1000) = 65.2 \, mm$

$\varepsilon_s = \varepsilon_{cu}[(d_s - c)/c] = 0.003[(410 - 65.2)/65.2] = 0.0159 \geq 0.005 \quad \therefore OK$

$a = \beta_1.c = 0.85 \, x \, 65.2 = 55.42 \, mm$

$M_n = A_s.f_y(d_s - 0.5a) = 3140.25 \, x \, 420(410 - 0.5 \, x \, 55.42) = 504.2 \, kN.m$

$M_r = \phi_f.M_n = 0.9 \, x \, 504.2 = 453.78 \, kN.m > M_u = 432.6 \, kN.m \quad \therefore OK$

Check for minimum reinforcement:

$\bar{y} = h_d/2 = 450/2 = 225 \, mm$

$I_g = bh_d{}^3/12 = 1000 \, x \, 450^3/12 = 7.59x10^9 \, mm^4$

$S_{nc} = I_g/\bar{y} = 7.59x10^9/225 = 33.75x10^6 \, mm^3$

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

$M_{cr} = f_r.S_{nc} = 3.33 \, x \, 33.75x10^6 = 112.39 \, kN.m$

$1.2M_{cr} = 1.2 \, x \, 112.39 = 134.87 \, kN.m$

$1.33M_u = 1.33\ x\ 432.6 = 575.36\ kN.m > 1.2M_{cr} = 134.87\ kN.m \quad \therefore OK$

$M_r = 453.78\ kN.m > 1.2M_{cr} = 134.87\ kN.m \quad \therefore OK$

Details of main reinforcement:

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

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

$\geq 38\ mm$

$s_{max} = 1.5h_d = 675\ mm$

$= 3h_d = 1350\ mm \quad (shrinkage\ and\ temperature\ reinforcement\ )$

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

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

$s = 1000A_b/A_s = 706.85x10^3/3140.25 = 225\ mm$

$use\ \emptyset 30\ mm\ @\ 200\ mm$ o.c. parallel to traffic

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

$\% = 17.5/\sqrt{S} = 17.5/\sqrt{7500} = 0.202 \leq 0.5 \quad \therefore OK$

$A_{s,Dist} = \%A_s = 0.202\ x\ 3140.25 = 634.33\ mm^2/m$

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

$s_{Dist} = 1000A_b/A_s = 201.06x10^3/634.33 = 316.96\ mm$

$use\ \emptyset 16\ mm\ @\ 300\ mm$ o.c. parallel to traffic

Shrinkage and temperature reinforcement:

$A_{s,S+T} = 0.75b.h/2(b+h)f_y = 0.75\ x\ 1000\ x\ 450/2(1000+450)420 = 0.277$

$0.233 \leq A_{s,S+T} \leq 1.27 \quad \therefore OK$

$A_{s,S+T} = 277\ mm^2/m$

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

$s = 1000A_b/A_s = 113.1x10^3/277 = 408\ mm$

$use\ \emptyset 12\ mm\ @\ 400\ mm$ o.c. on each side and each direction at the top face

Check for Shear:

Slab and slab bridges designed for moment using equivalent strips method are considered safe in shear. Therefore, calculations are not required for shear.

- **Design of Edge Beams**

Determine the equivalent width of the edge strip:

$W_e = 600\ mm$

$E_{edge} = W_e + 300 + E_{int}/4 = 600 + 300 + 3000/4 = 1.65\ m$

$\leq E_{int}/2 = 1.5\ m$

$\leq 1.8\ m$

$\rightarrow E_{edge} = 1.5\ m$

$E_{beam} = E_{edge} = 1.5\ m$

Calculate the unfactored dead load force effects per unit width:

$w_{DC1} = 10.8\ kN/m^2$

$w_{DC2} = A_{pa}\ x\ \Upsilon_c = 0.3\ x\ 24 = 7.2\ kN/m$

$= 7.2/E_{edge} = 7.2/1.5 = 4.8\ kN/m^2$

$w_{DC} = w_{DC1} + w_{DC2} = 10.8 + 4.8 = 15.6\ kN/m^2$

$\rightarrow M_{DC} = w_{DC}.L^2/8 = 15.6\ x\ 7.5^2/8 = 109.69\ kN.m$

$w_{DW} = 2.7\ x\ (E_{edge} - W_{tb})/E_{edge} = 2.7(1.5 - 0.6)/1.5 = 1.62\ kN/m^2$

$\rightarrow M_{DW} = w_{DW}.L^2/8 = 1.62\ x\ 7.5^2/8 = 11.39\ kN.m$

Calculate the unfactored live load force effects per unit width:

$w_{Ln} = 9.3\ x\ (E_{edge} - W_{tb})/E_{edge} = 9.3(1.5 - 0.6)/1.5 = 5.58\ kN/m^2$

$\rightarrow M_{Ln} = w_{Ln}.L^2/8 = 5.58\ x\ 7.5^2/8 = 39.24\ kN.m$

$\rightarrow M_{Ta} = 0.5\ x\ 349.24/E_{edge} = 0.5\ x\ 349.24/1.5 = 116.41\ kN.m$

$\rightarrow M_{LL+IM} = (1 + IM)M_{Ta} + M_{Ln} = 1.33\ x\ 116.41 + 39.24 = 194.07\ kN.m$

Strength I limit State: Factored Moments and Shear:

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

$= 1.0[1.25\ x\ 109.67 + 1.50\ x\ 11.39 + 1.75\ x\ 194.07] = 493.8\ kN.m$

Calculate the amount of main reinforcements:

$M_r = 453.78\ kN.m < M_u = 493.8\ kN.m \quad \therefore NOK \rightarrow strengthening\ is\ required$

$Using\ c_c = 25\ mm, \emptyset_b = 30\ mm\ and\ d_s = 410\ mm$

$A_s = 1.25M_u/f_y.d_s = 1.25\ x\ 493.8x10^6/(420\ x\ 410) = 3584.5\ mm^2/m$

$c = A_s.f_y/(0.85f'_c.\beta_1.b) = 3584.5\ x\ 420/(0.85\ x\ 28\ x\ 0.85\ x\ 1000) = 74.42\ mm$

$\varepsilon_s = \varepsilon_{cu}[(d_s - c)/c] = 0.003[(410 - 74.42)/74.42] = 0.0135 \geq 0.005 \quad \therefore OK$

$a = \beta_1.c = 0.85\ x\ 74.42 \cong 63.26\ mm$

$M_n = A_s.f_y(d_s - 0.5a) = 3584.5\ x\ 420(410 - 0.5\ x\ 63.26) = 569.63\ kN.m$

$M_r = \phi_f.M_n = 0.9\ x\ 569.63 = 512.66\ kN.m > M_u = 493.8\ kN.m \quad \therefore OK$

Check for minimum reinforcement:

$M_r = 512.66\ kN.m > 1.2M_{cr} = 134.87\ kN.m \quad \therefore OK$

Details of reinforcement:

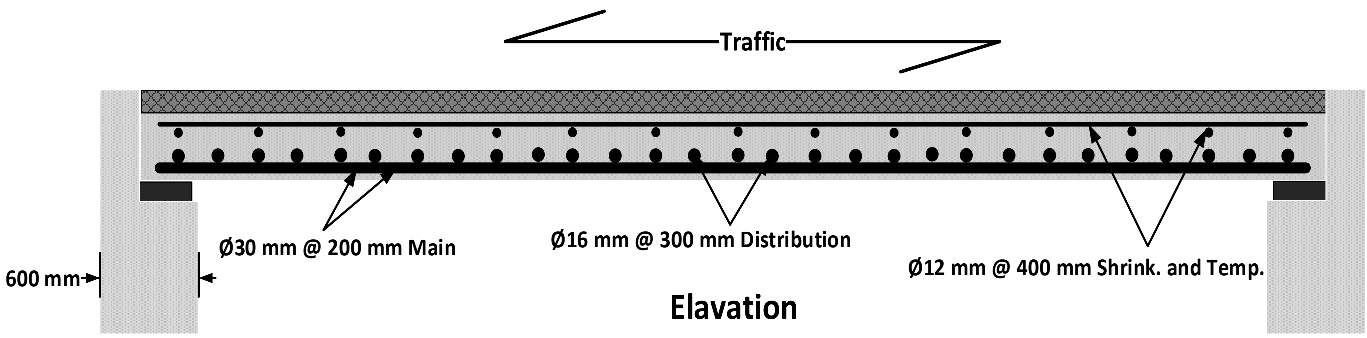
$s = 1000A_b/A_s = 706.85x10^3/3584.5 \approx 200\ mm$

∴Amount of reinforcement in interior strip is enough for edge strip

$use\ \emptyset30\ mm\ @\ 200\ mm$ o. c. parallel to traffic at the bottom face

$use\ \emptyset16\ mm\ @\ 300\ mm$ o. c. perpendicular to traffic at the bottom face

$use\ \emptyset12\ mm\ @\ 400\ mm$ o. c. on each side and each direction at the top face



Elevation