Deck Slab Design

1-Deck Slab Thickness

According to AASHTO, the minimum depths for constant depth members can be calculated from the following Table:-

Super structure type	Minimum Depth (ft)	
	Simple Span	Continuous Span
Bridge Slab with Main Reinforcement Parallel to Traffic(1)	1.2(***S***+10)/30	(***S***+10)/30≥0.542
T-Girders (Monolithic)	0.07***S***	0.065***S***
Box-Girders	0.06***S***	0.055***S***
Pedestrian Structure Girders	0.033***S***	0.033***S***

(1) May be used for Reinforcement Perpendicular to Traffic
S=Effective Span (ft).

The Effective Span (S) is the Least of:-

1-Clear Span (l_n) + Effective Depth (d)

2- c/c of Bearing.

Note: Traffic=Direction of Vehicle Movement

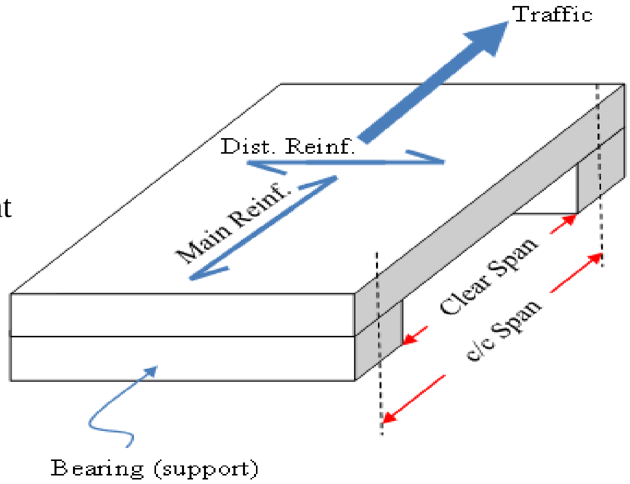

Figure (1) Main Reinforcement // Traffic

2-Deck Slab Reinforcement

2-1-Main Reinforcement ⊥ Traffic

2-1-1- Main Reinforcement $(As)_{main}$

Live load moment can be calculated by using the following formula:-

$$M_{LL} = \frac{3.28\,\boldsymbol{S} + 2}{32} * P$$

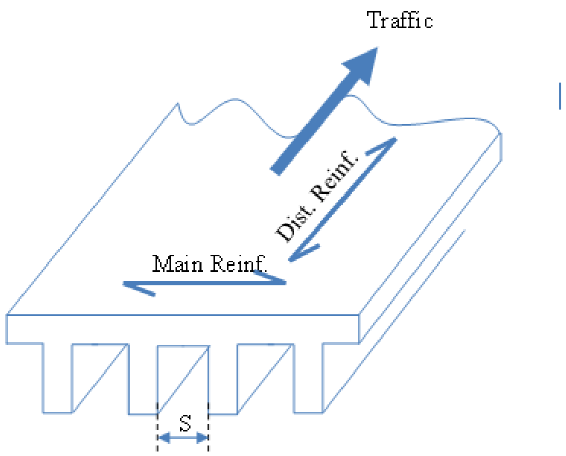

Figure (2) Main Reinforcement ⊥ Traffic

Where

$M_{L.L}$=Live Load Moment (kN. m/m)

S=Span (m) (0.6m≤ S≤7.3m)

P=Wheel Load (kN)

= 72 kN For (HS-20) AASHTO

= 90.74 kN For (Military) Iraqi Specification

Note:

In slabs continuous over three or more supports, a continuity factor of (**0.8**) shall be applied to the above formula for both ($\mathbf{M^+}$) and ($\mathbf{M^-}$).

Dead load moment can be calculated by using the following formula:-

$$M_{DL} = \frac{1}{10} * w_d * S^2$$

<u>Where</u>

$M_{D.L}$= Dead Load Moment (kN. m/m)

W_d= Service (un-factored) Dead Load

Total applied moment is:-

$$M_{Total} = M_{DL} + M_{LL} + M_I)$$

Check the slab thickness for strength requirements by using the following formula:-

$$d_{min} = \sqrt{\frac{2M_{Total}}{f_c . K . J . b}}$$

<u>Where</u>

d_{min}= Minimum effective depth (slab thickness) for strength requirements

f_c= Allowable Compressive Strength of Concrete= $0.4f_c'$ (MPa)

k= Neutral axis depth coefficient ≈ 3/8

j= Internal resisting moment arm coefficient ≈ 7/8

b= Strip width=1000mm

Note: f'_c =0.85f_{cu} (Relationship between cylinder and cube compressive strength)

The main reinforcement $(As)_{main}$ can be calculated by using the following formula:-

$$As_{main} = M_{total}/(f_s * J * d)$$

<u>Where</u>

f_s= Allowable Tensile Strength of Steel Reinforcement

f_s= 140MPa if fy <350 MPa

f_s= 170MPa if fy ≥350 MPa

2-1-2-Distribution Reinforcement (Secondary Reinforcement) $(A_S)_{Dist.}$

According AASHTO specifications, the distribution reinforcement, $(A_S)_{Dist.}$, can be calculated (for M^+) by using the formula:-

$$As_{Dist.} = \frac{2.2\ (As)Main}{\sqrt{3.28\ S}} \leq 0.67\ (As)Main$$

2-2-Min Reinforcement // Traffic

2-2-1-Min Reinforcement

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 (4.6m) spans *which primarily in the direction parallel to traffic.* The equivalent width of longitudinal strips per lane for both shear and moment with one lane (E) of **wheels** or two lanes (2E) for **lane loaded** may be determined as:-

$$\mathbf{E} = 1.22 + 0.06\,\mathbf{S} \leq 2.14\text{m}$$

Where

E=Effective Width (m)

S=Span (m)

= min. (c/c Span, Clear span+t)

t= Effective Depth

Use elastic analysis to calculate (M_{LL} and M_{DL}) and the Impact effect must be included

Check the slab thickness for strength requirements by using the following formula:-

$$d_{min} = \sqrt{\frac{2M_{Total}}{f_c . K . J . b}}$$

The main reinforcement $(As)_{main}$ can be calculated by using the following formula:-

$$As_{main} = M_{total}/(f_s * J * d)$$

2-2-2-Distribution reinforcement (Secondary reinforcement)

The distribution reinforcement $(As)_{Dist.}$ can be calculated by using the following formula:-

$$As_{Dist.} = \frac{(As)\text{Main}}{\sqrt{3.28\ S}} \leq 0.5\ (As)\text{Main}$$

Note:

1-For cantilever parts (such as sidewalk), use elastic analysis.

2-Lane load (UDL+KEL) are distributed over a width of (2E).

3-Single wheel load are distributed over a width of (E).

3-Slab Bridge

The slab bridges can be divided in to two types:-

Simply Supported Slab Bridge: The simplest form of bridge is the single-span slab bridge which is simply supported at its ends. This form is widely used when the bridge crosses a minor road or small river. In such cases, the span is relatively small and multiple spans are infeasible and/or unnecessary. The simply supported bridge is relatively simple to analyze and to construct but is disadvantaged by having bearings and joints at both ends. The cross-section is often solid rectangular but can be made with voided slab section.

Continuous Slab Bridge: continuous slab construction has significant advantages over simply supported spans in that there are fewer joints and bearings and the applied bending moments are less. For bridges of moderate total length, the concrete can be poured in-situ in one pour. This completely removes the need for any joints. However, as the total bridge length becomes large, the amount of concrete that needs to be cast in one pour can become excessive. This tends to increase cost as the construction becomes more of a batch process than a continuous one.

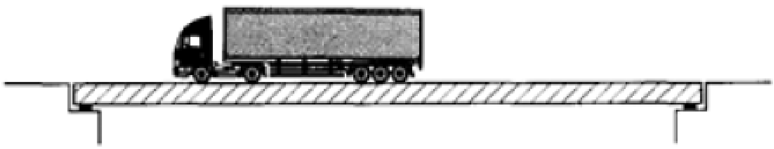

Figure (3) Simply supported Slab Bridge

Figure (4) Series of simply supported Slab Bridge

Figure (5) Continuous Slab Bridge

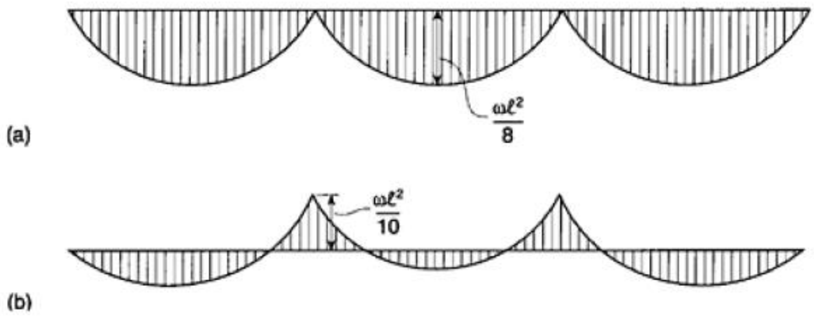

Figure (6) Bending moment diagrams due to uniform loading of intensity (w)
(a) Three simply supported spans of length (*l*); (b) Three-span continuous beam with span lengths (*l*).

4-Design of Slab Bridge (AASHTO)

The slab bridge is short-span **Bridge** consisting of a reinforced-concrete **Slab** resting on piers or abutments (supports). It is a simple type of bridges in which the main reinforcement parallel to traffic (because the bridge is rest on two opposite supports).

1- Distribution of wheel load HS20 (truck) over on effective width (E).

$$\mathbf{E} = 1.22 + 0.06\,\mathbf{S} \le 2.14\text{m}$$

2-Lane load (UDL+KEL) are distributed over a width of (2E).
3- When the span of bridge is smaller than the truck length, use single wheel load distributed over a width of (E).

Figure (7) Simply Supported Slab Bridge

Example-1

For the cross-section of Slab Bridge shown in Figure (8), compute the required reinforcement.

Effective span = S = 10m;
Surfacing = 5cm
f'_c = 25.5MPa, f_y = 350 MPa
γ_c=24kN/m^3, $\gamma_{Asphalt}$=22kN/m^3
Use HS-20 loading

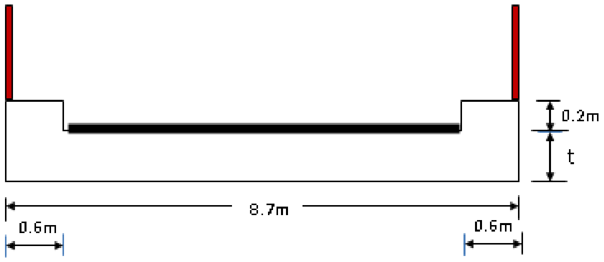

Figure (8) Slab Bridge Cross-section

Solution

t_{min} =1.2(S+10)/30=1.2 (10x3.28+10)/30=1.71ft= 52cm → use $t = 55cm$
E=1.22+0.06xS =1.22+0.06x10=1.82m ≤ 2.14m…..ok

Live load

1-Lane Loading (UDL+KEL)

According to AASHTO specifications, the lane loading (UDL+KEL) is distributed over a width of (2E).
2E=2x1.82=3.64m
UDL=9.3 kN/m-lane → UDL/m=9.3/3.64=2.55 kN/m
$M_{(UDL)}$ =1/8x2.55x(10)^2=31.88 kN.m/m
KEL=80 kN/lane → KEL /m=80/3.64=21.98 kN
$M_{(KEL)}$ =1/4x21.98x(10)=54.95 kN.m/m
$M_{(UDL+KEL)}$ =86.83 kN.m/m
Impact Factor=I=15.24/(S+38.1)= $\frac{15.24}{10+38.1} = 0.317 > 0.3$→use I=0.3
$M_{(UDL+KEL+I)}$ =86.83X1.3=112.88 kN.m/m

2-Wheel Loading

According to AASHTO specifications, the distribution of wheel load HS20 (truck) should be over on an effective width (E). Arrangement of wheel load for maximum moment is shown in Figure (9).

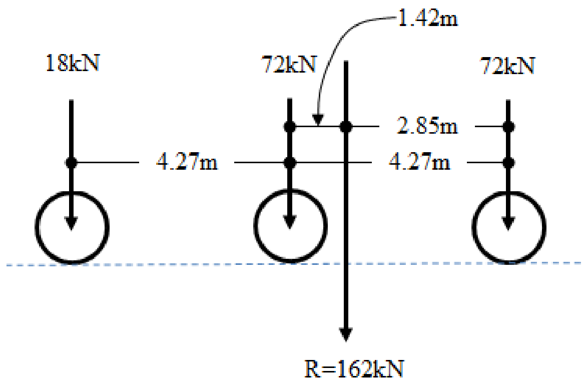

Figure (9) Arrangement of Wheel Load for Maximum Moment

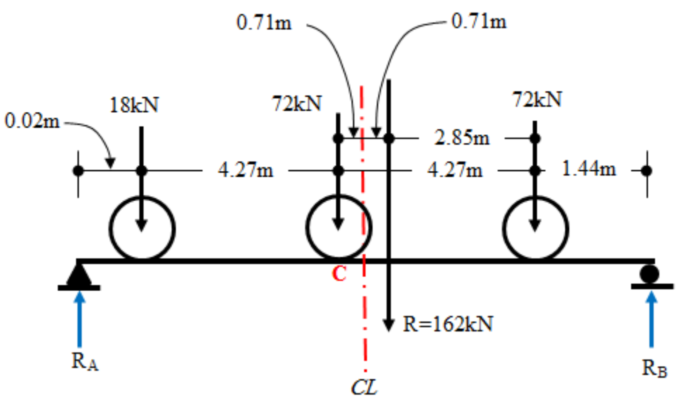

Figure (10) Arrangement of Wheel Load on Slab Bridge

Arrangement of wheel load on Slab Bridge is shown in Figure (10). The next step is drawing of SFD and BMD, and then the maximum bending moment is located at point (C) (under the middle wheel).

$$R_A = 162 \text{ x } \frac{(2.85 + 1.44)}{10} = 69.5 \text{ kN}$$

Since the maximum bending moment is located at point (C); then:-

M_c =69.5x (0.02+4.27)-18x4.27= 221.3kN.m

E=1.82m (as before)

Moment/m= M_c/E=221.3/1.82=121.6 kN.m

Impact Factor=I=0.3(as before)

$M_{(LL+I)}$= 121.6x1.3= 158.1 kN.m/m > $M_{(UDL+KEL+I)}$= 112.88 kN.m/m

Use $M_{(LL+I)}$ =158.1 kN.m/m for design………..ok

Dead load

$$\text{Slab weight} = 0.55 \times 24 = 13.2 \text{ kN/m}^2$$

$$\text{Surfacing} = 0.05 \times 22 = 1.10 \text{ kN/m}^2$$

$$M_{(DL)} = \frac{1}{8}(14.3) \times (10)^2 = 178.75 \text{ kN.m/m}$$

$$\text{Total Moment} = M_{(L.L+D.L+I)} = 178.75 + 158.1 = 336.85 \text{ kN.m}$$

$$d_{min} = \sqrt{\frac{2M}{f_c * k * J * b}} = \sqrt{\frac{2 \times 336.85 \times 10^6}{10.2 \times \frac{3}{8} \times \frac{7}{8} \times 10^3}} = 449mm$$

Assume bar diameter (ϕ) =16mm and concrete cover=50mm

$$d_{provided} = t - cover - \frac{\emptyset}{2} = 550 - 50 - \frac{16}{2} = 692 \text{ mm}$$

$d_{provided}$ =692mm > d_{min}=449mm…..ok

$$As = \frac{M}{f_s \, j \, d} = \frac{336.85 \times 10^6}{170 \times \frac{7}{8} \times 492} = 4630 \text{ mm}^2/\text{m}$$

use $\emptyset$ 32 @ 150(As = 5360mm^2/m)

Distribution Reinforcement

Since the main reinforcement // traffic, the distribution reinforcement can be calculated by:-

$$As_{Dist.} = \frac{As_{main}}{\sqrt{3.28xS}} \leq 0.5 \, As_{main}$$

$$= \frac{4630}{\sqrt{3.28 \times 10}} = 808 \text{ mm}^2/\text{m} \quad < 0.5 \times 4630 = 2315 \text{ mm}^2/\text{m}$$

Use $As_{Dist.} = 808 \text{ mm}^2/\text{m}$

$$As_{Temp.} = 0.002 * b * t = 0.002 \times 10^3 \times 550 = 1100\text{mm}^2/\text{m}$$

Use $\emptyset$16mm @ 175mm (As = 1149mm^2/m)

Shear and Bond

According to AASHTO specification, slabs designed for bending moment may be considered *satisfactory for shear*, but let's try it:-

Live load shear (V_{LL})

1-Lane Loading (UDL+KEL)

V_{LL}=KEL+UDLxL/2=21.98+2.55x (10/2) =34.73 kN

2-Wheel Loading

V_{LL}=72/1.82+72/1.82x (10-4.27)/10+18/1.82x (10-2x4.27)/10=63.7kN

Use V_{LL}=63.7kN

Dead load shear (V_{DL})

V_{DL}= (14.3)x10/2=71.5 kN

Impact Factor=I=0.3(as before)

V_{Total}=71.5+1.3x63.7=154.31 kN

Shear stress (v) = V/ (bxd) =154.31x1000/ (1000x692) =0.22MPa

According to AASHTO specification the allowable shear stress is $v_{all} = 0.03f'_c$

v_{all} =0.03*25.5=0.765MPa> Shear stress (v) =0.22MPa→The section ***safe*** against shear

Design of Edge Beam

Edge beam shall be provided for all slab bridge having main reinforcement parallel to traffic. The beam may consist of a slab section additionally reinforced, a beam integral with and deeper than slab, or an integral reinforced section of slab and curb.

It shall be designed to resist a live load moment of:-

$$M_{(LL)}=0.1 \text{x} P \text{x} S$$

Where

P=Wheel load (kN) → For HS-20, P=72kN

S=Span Length (m)

$$M_{L.L} = 0.1 \times 72 \times 10 = 72 \text{kN.m}$$

$$D.L = 0.6 \times 0.75 \times 25 = 11.25 \text{kN.m}$$

$$M_{D.L} = \frac{1}{8} \times 11.25 \times 10^2 = 140.63 \text{kN.m}$$

Total moment = $M_{(L.L+D.L+I)}$

$$= 72 \times 1.3 + 140.63$$

$$= 234.23 \text{kN.m}$$

$$d_{min} = \sqrt{\frac{2 \times 234.23 \times 10^6}{10.2 \times \frac{3}{8} \times \frac{7}{8} \times 600}} = 483\text{mm} < 684\text{mm} \ldots\ldots\ldots \text{ok}$$

$$\therefore As = \frac{234.23 \times 10^6}{170 \times \frac{7}{8} \times 684} = 2316 mm^2$$

Use 3 Ø 32 mm in the edge beam @ bottom

$(As)_{provided}=2413mm^2$……..ok

Note

$f_c = 0.4 f_c'$ and $fs = 170\ MPa \quad for\ f_y \geq 350\ MPa$

$fs = 140 MPa \quad for\ f_y < 350\ MPa$

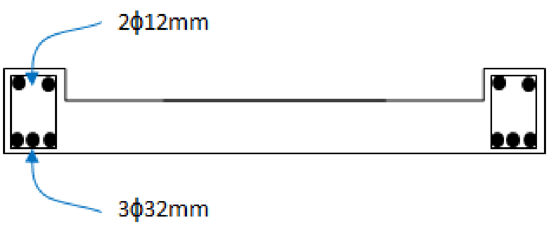

Figure (11) Reinforcement Details

Example-2-

Design a one way slab bridge which having a clear span of (5m), a width of (18m), asphalt paving weight of (1.4kN/m^2), seat width of (400mm), f'_c=30MPa, f_y=300MPa, γ_c=24kN/m^3, weight of hand rail=0.4kN/m, curb width=600mm, use (HS-20) truck and assume ($t_{min}=l_n/20$), (where l_n=clear span).

Solution

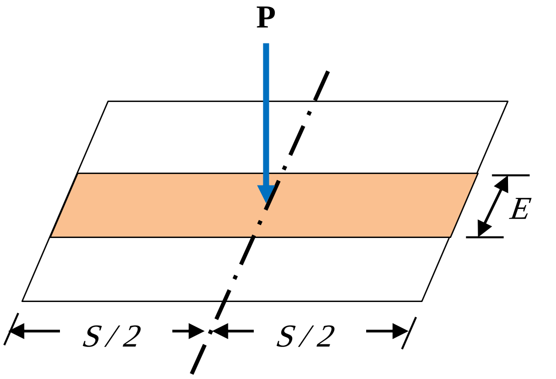

Figure (12) Slab Bridge Effective Width

$t_{min} = \frac{5000}{20} = 250\text{mm}$

use t = 300mm

$d \approx 300 - 50 - \frac{25}{2} \approx 238\text{mm}$

$s_{\min} = \min(\text{c/c spon}, \text{clear spon} + d)$

$= \min(5.4, 5.238)$

Use Smin = 5.4m

$E = 1.22 + 0.06S \leq 2.14m$

$= 1.22 + 0.06 \times 5.24 = 1.534m < 2.14m$

$M_{L.L} = \frac{\frac{P}{E}xL}{4} = \frac{\frac{72}{1.534} \times 5.24}{4}$

$= 61.47 \text{ kN.m}$

$I = \frac{15.24}{S + 38.1} = \frac{15.24}{5.24 + 38.1} = 0.352 > 0.3 \Rightarrow \text{use } I = 0.3$

$\therefore M_{(L.L+I)} = 61.47 \times 1.3 = 80\text{kN.m}$

$D.L = t * \gamma_C + \text{weight of asphalt}$

$= 0.3 \times 24 + 1.4 = 8.6kN/m^2$

$M_{D.L} = \frac{1}{8}(8.6)(5.24)^2 = 30\text{kN.m/m}$

$M_{Total} = 80 + 30 = 110\text{kN.m/m}$

$d_{min} = \sqrt{\frac{2M}{f_c Kjb}} = \sqrt{\frac{2 \times 110 \times 10^6}{12 \times \frac{3}{8} \times \frac{7}{8} \times 10^3}}$

$f_c = 0.4 \times 30 = 12MPa$

$f_s = 140\ MPa$

$= 236\text{mm} < d_{provided} = 238\text{mm}$

$As = \frac{M}{f_s jd} = \frac{110 \times 10^6}{140 \times \frac{7}{8} \times 238} = 3773\text{mm}^2/\text{m}$

For (Ø25mm), $A_b = 490\text{mm}^2$

$\text{Spacing} = \frac{A_b \times 10^3}{As} = \frac{490 \times 10^3}{3773} = 130\text{mm}$

Use Ø 25 @125mm (Main Reinfrocement)

Distribution Reinforcement

$Asd = \frac{As}{\sqrt{3.28\,S}} \leq 0.5\,As$

$\therefore As_{Dist.} = \frac{3773}{\sqrt{3.28 \times 5.24}} = 910\text{mm}^2 < 0.5 \times 3773 = 1887\text{mm}^2$

$As_{Temp.} = 0.002 \times t \times b = 0.002 \times 300 \times 1000 = 600mm^2/m$

For $(\emptyset 16mm), A_b = 201mm^2$, Spacing $= \dfrac{201 \times 10^3}{910} = 221mm$

Use $(\emptyset 16mm)$@ 200mm

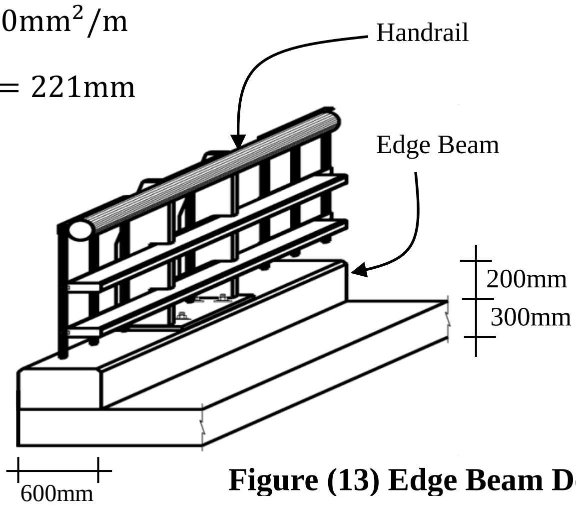

Figure (13) Edge Beam Details

Design of Edge beam

$D.L = (0.3 + 0.2) \times 0.6 \times 24 + 0.4 = 7.6kN.m$

$M_{D.L} = \dfrac{1}{8}(7.6)(5.24)^2 = 27.5kN.m$

$M_{L.L} = 0.1 \times 72 \times 5.24 = 35.84kN.m$

$I = 0.3\ (os\ before)$

$M_{Total} = 35.84 \times 1.3 + 27.5 = 74kN.m$

$$d_{min} = \sqrt{\frac{2 \times 74 \times 10^6}{12 \times \frac{3}{8} \times \frac{7}{8} \times 600}} = 250.3mm < d_{provided} = 500 - 50 - \frac{25}{2} \approx 438mm$$

$$A_S = \frac{M}{f_s jd} = \frac{74 \times 10^6}{140 \times \frac{7}{8} \times 438} = 1379mm^2$$

Use $(3\emptyset 25mm)$in the edge beam at the Bottom

$(As)_{provided} = 1473mm^2$

Example-3-

For the composite prestressed-concrete bridge shown in Figure (14), if the span length= 20m c/c of bearing, f'_c = 20 MPa , f_y = 410 MPa, total slab thickness =t=200mm, effective depth=d=140mm ,top flange width =400mm; Determine the main and distribution reinforcement. Use AASHTO (HS-20) loading.

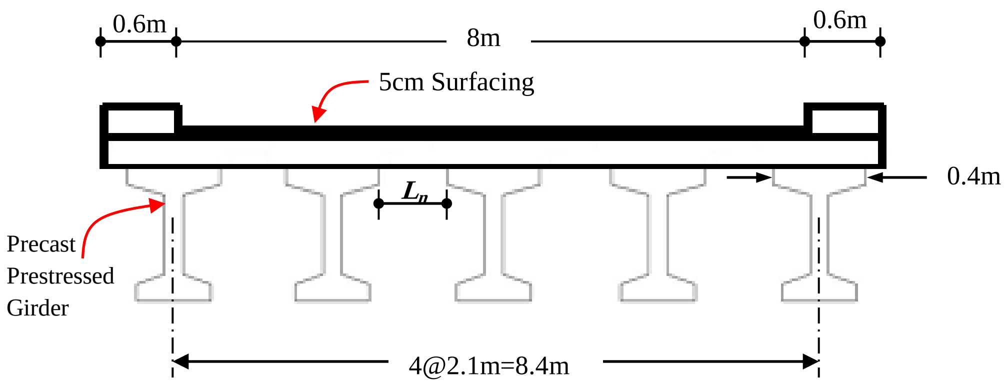

Figure (14) Composite Prestressed-Concrete Bridge

Solution

$S = \min(c/c\ spon\ , Clear\ spon + Effective\ depth)$

$= \min(2.1m\ , 2.1 - 0.4 + 0.14)$

$= \min(2.1m\ , 1.84m)$

$S = 1.84\ m \approx 6ft$

$$t_{min} = \frac{1.2(S + 10)}{30} = \frac{1.2(6 + 10)}{30} = 0.64\ ft \approx 19.5cm < 20cm$$

Dead Load Moment (M_{DL})

$$\left.\begin{aligned} Wd_{slab} &= 0.2 \times 24 = 4.8\ kN/m^2 \\ Wd_{surfacing} &= 0.05 \times 22 = 1.1 kN/m^2 \end{aligned}\right\} = 5.9 kN/m^2$$

$$\therefore M_{DL} = \frac{1}{10} wd \times S^2 = \frac{1}{10} x5.9x(1.84)^2 = 2kN.m/m$$

Live Load Moment (M_{LL})

$$M_{LL} = 0.8x \frac{3.28S + 2}{32} x\, P = 0.8\ \frac{3.28x1.84 + 2}{32} x72 = 14.46\ kN.m/m$$

$$I = \frac{15.24}{S + 38.1} = \frac{15.24}{1.84 + 38.1} = 0.38 > 0.3 \Rightarrow \text{Use } I = 0.3$$

$$MI = 0.3 \times 14.46 = 4.34 kN.m/m$$

$$M_{Total} = 2 + 14.46 + 4.34 = 20.8\ kN.m/m$$

$$d_{min} = \sqrt{\frac{2M}{f_c K\, j\, b}} = \sqrt{\frac{2 \times 20.8 \times 10^6}{8 \times \frac{3}{8} \times \frac{7}{8} \times 10^3}} = 126mm$$

$$d_{provided} = 140mm > d_{min} = 126mm \text{ ......ok}$$

$$As = \frac{M}{f_s\, j\, d} = \frac{20.8 \times 10^6}{170 \times \frac{7}{8} \times 140} = 999mm^2/m \Rightarrow \text{Use} \emptyset 16@180mm$$

($As=1117mm^2/m$), Top and Bottom in Transverse Direction.

Distribution Reinforcement (Longitudinal Reinforcement)

An AASHTO specification requires an amount as the percentage of the main reinforcement for (M^+): For main Reinforcement $\perp$ traffic;

$$As_{Dist.} = \frac{2.2As}{\sqrt{3.28S}} = \frac{2.2 \times 999}{\sqrt{3.28 \times 1.84}} = 895mm^2/m > 0.67As = 669mm^2/m$$

$\therefore$ Use $As = 669mm^2/m \Rightarrow$ Use $\emptyset 16mm@250(As = 804mm^2/m)$ →Bottom Longitudinal

$$As_{Temp.} = 0.002x\, b\, x\, t = 0.002x10^3 x200 = 400mm^2/m$$

Use $\emptyset$ $12mm@250(As = 452mm^2/m)$ ↔ Top Longitudinal

Shear and Bond

The AASHTO specification says that designed for moment will be says that slabs designed for moment will be considered safe in shear and bond (i.e. No need to check shear and bond).

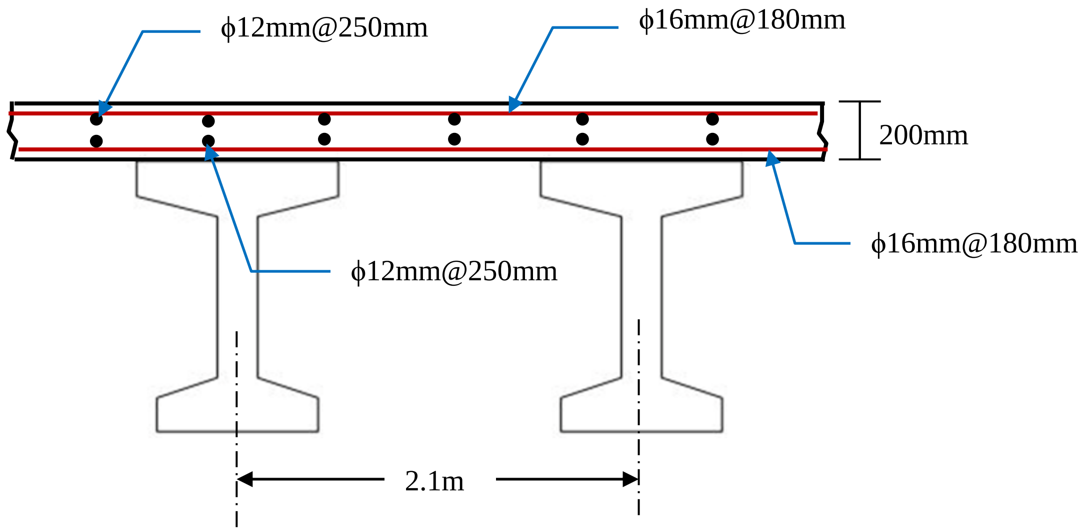

Figure (15) Deck Slab Reinforcement Details