

Fundamentals of Bridge Design

Chapter 4: Super Structure Design of Bridge

- ☐ Concrete Deck Design
- ☐ T-Girder Design
- ☐ Box Girder Design

5.1-Slab Design

- **Deck/Slab bridges** are most commonly used to short spans up to 12m. The load carrying mechanism is by plate action, i.e., by bending and twisting .
- According to **AASHTO 4.6.2** slab bridge can be analyzed by
 - ❑ 1-Approximate Strip method
 - ❑ 2-empirical method
 - ❑ 3-Refined method

Conti...

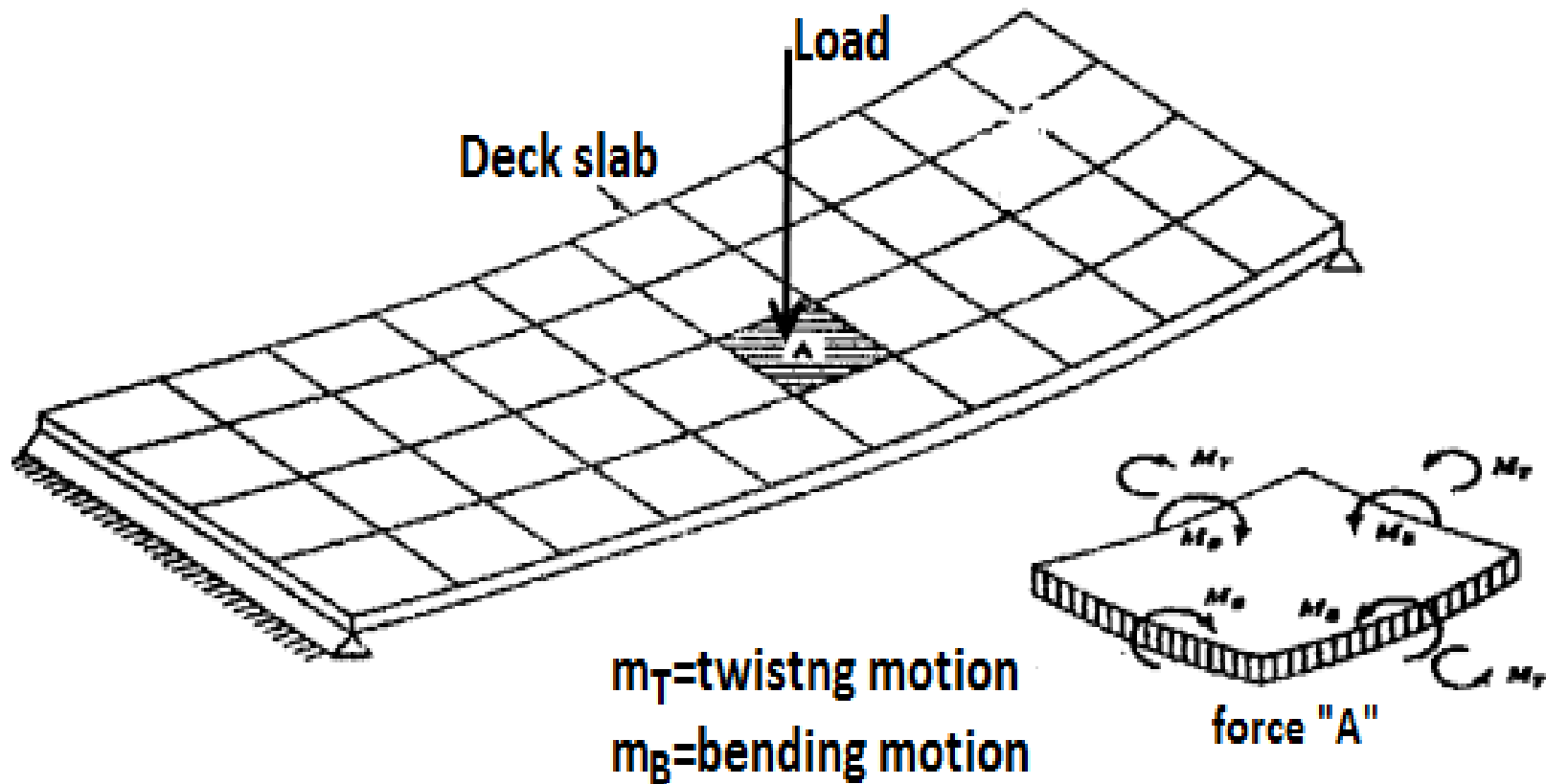


Fig:-Load carrying mechanism of slab bridge treated as a plate

1-Approximate equivalent strip method

- **AASHTO specifications allow** ,To simplify the design, concrete deck is assumed to be divided into edge and interior strip perpendicular to supporting abutment.



- **Empirical Design** is a method of deck slab design based on Laboratory test data on the concept of internal arching action(not flexure and shear) within concrete slabs.
- **refined(finite element) analysis** method would be better suited for a more complex deck slab structure.

Thickness of Slab

- The deck slab may be designed as **One-Way Slab** with main reinforcement parallel to the traffic .
- **Depth Determination:**
- According to **AASHTO, Table 2.5.2.6.3.1**, minimum recommended depth for the purpose of deflection control slab with main reinforcement **parallel to the traffic**.

$$t = \frac{1.2(S + 3000)}{30}$$

- **According to ERA Bridge Design Manual 2013, article 5.4.1.1**, the depth of a concrete deck, excluding any provision for grinding, grooving, and sacrificial surface, should not be less than **185 mm**.

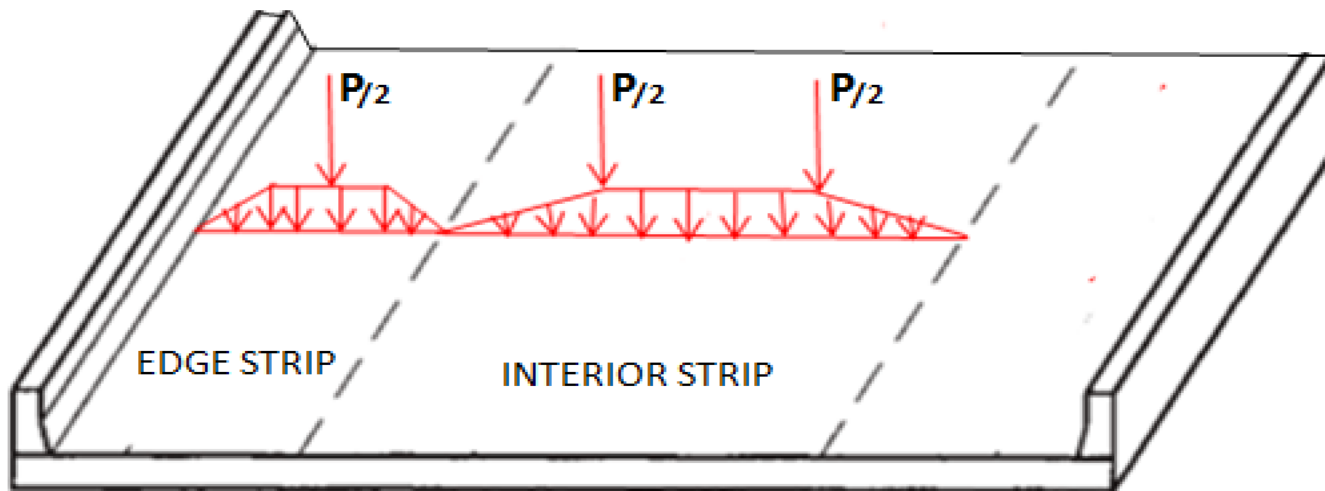
Conti...

Table 2.5.2.6.3.1- Traditional minimum depth of superstructure

Superstructure		Minimum Depth (Including Deck)	
		When variable depth members are used, values may be adjusted to account for changes in relative stiffness of positive and negative moment sections	
Material	Type	Simple Spans	Continuous Spans
Reinforced Concrete	Slabs with main reinforcement parallel to traffic	$\frac{1.2 (S + 3000)}{30}$	$\frac{S + 3000}{30} \geq 165 \text{ mm}$
	T-Beams	$0.070L$	$0.065L$
	Box Beams	$0.060L$	$0.055L$
	Pedestrian Structure Beams	$0.035L$	$0.033L$
Prestressed Concrete	Slabs	$0.030L \geq 165 \text{ mm}$	$0.027L \geq 165 \text{ mm}$
	CIP Box Beams	$0.045L$	$0.040L$
	Precast I-Beams	$0.045L$	$0.040L$
	Pedestrian Structure Beams	$0.033L$	$0.030L$
	Adjacent Box Beams	$0.030L$	$0.025L$
Steel	Overall Depth of Composite I-Beam	$0.040L$	$0.032L$
	Depth of I-Beam Portion of Composite I-Beam	$0.033L$	$0.027L$
	Trusses	$0.100L$	$0.100L$

Live Load distribution Strip width

- in **Approximate method of Analysis** Slab width divided in to edge and interior strip perpendicular direction to abutment.
- **According to AASHTO sec. 4.6.2.3**, the equivalent width (E) of longitudinal strips per lane for both shear and moment with one lane, i.e., two lines of wheels, loaded shall be determined as



Conti...

⇒ Equivalent strip width shall be determine for

⇒ Interior Strip Width -multiple presence factor is included

i. Single lane loaded:

- The equivalent width of longitudinal strips per lane for both shear and moment with one lane, i.e., two lines of wheels, loaded shall be determined as:

$$E = 250 + 0.42\sqrt{L_1 W_1}$$

ii. Multi lane loaded

- The equivalent width of longitudinal strips per lane for both shear and moment with more than one lane loaded shall be determined as

$$E = 2100 + 0.12\sqrt{L_1 W_1} \leq \frac{W}{N_l}$$

Cont...

Where:

E = Equivalent strip width (mm)

L_1 = modified span length taken equal to the lesser of the actual span or 18000 (mm)

W_L = modified edge- to-edge width of bridge taken equal to the lesser of the actual width or 18000 mm for multi -lane loading, or 9000 mm for single lane loading (mm)

W = physical edge-to-edge width of bridge (mm)

N_L = number of loaded lanes

Conti...

- **Edge strip** is limited to half lane width; use multiple presence factors 1.2 and half design lane load (for a two lane bridge, because the possibility of occurrence of two trucks at a time is less). AASHTO[Art. 4.6.2.1.4]

➔ Thus, live loads due to truck and tandem are divided by 2 as the width of the edge strip is less than 2.1m (wheel are placed 300mm from curb edge and wheel spacing of 1800mm) plus curb width. Thus the effect of the live load is reduced by half.

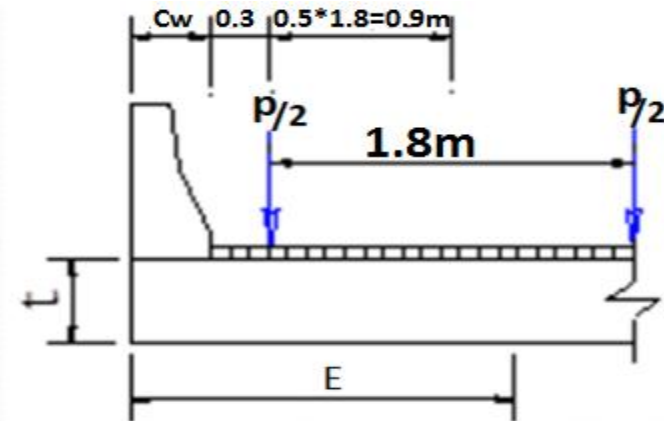
$$E_e = \min \left\{ \left(C_w + 300 + \frac{E_i}{2} \right) \right. \\ \left. 1800 (mm) \right\}$$

Where:

E_e : Edge strip width

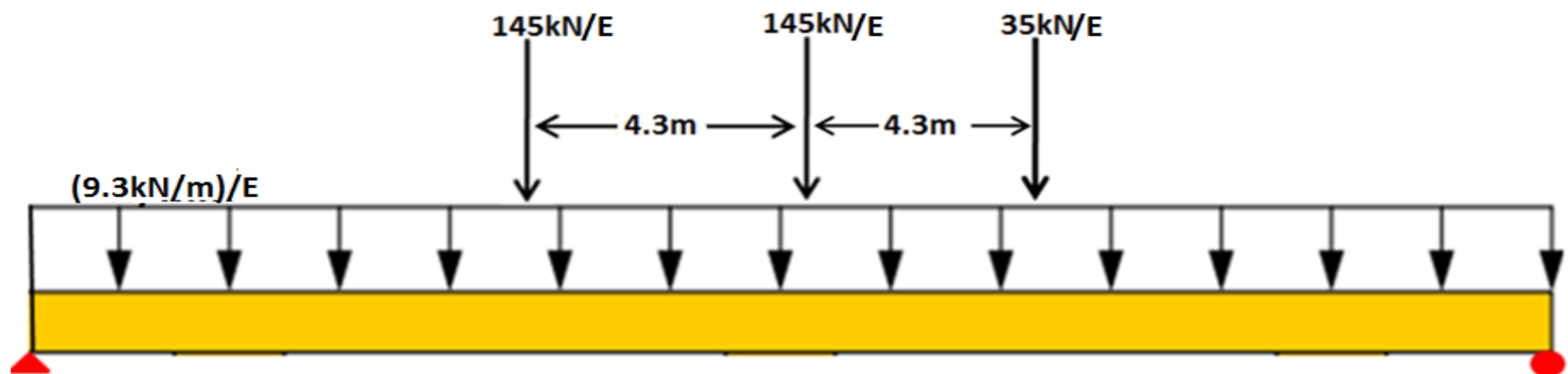
C_w : Curb width

E_i : interior strip width



Equivalent Concentrated and Distributed Loads

The equivalent concentrated and distributed loads per meter width of both interior and edge strips are obtained by **dividing the design loads** to the corresponding **strip width and applying a dynamic impact factor**. For the calculation of live load force effects, influence line is used and the maximum effect will be selected for the design.



Design Moment

- The **design moment** is computed by combining the effects of **dead loads** and **live loads** and applying the corresponding load combinations and load factors specified in **AASHTO, Table 3.4.1.1**.
- For deck design only **strength I** load combinations needs to be investigated:

$$\Phi M_n \geq \eta \sum \gamma_i Q_i$$

$$M_{UR} = \eta [1.25 M_{DC} + 1.5 M_{DW} + 1.75 (M_{(LL + IM)} + ML_a)]$$

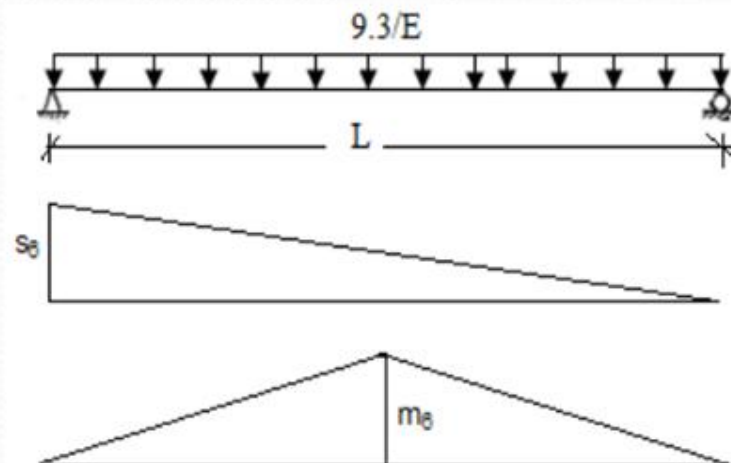
Resistance factors for strength limit state Φ : **0.90** for flexure and tension of reinforced concrete.

Live load moment

- The maximum Live Load Moments for both **interior and edge strips** can be computed using influence line concepts and the **influence line coefficients (maximum ordinates)**

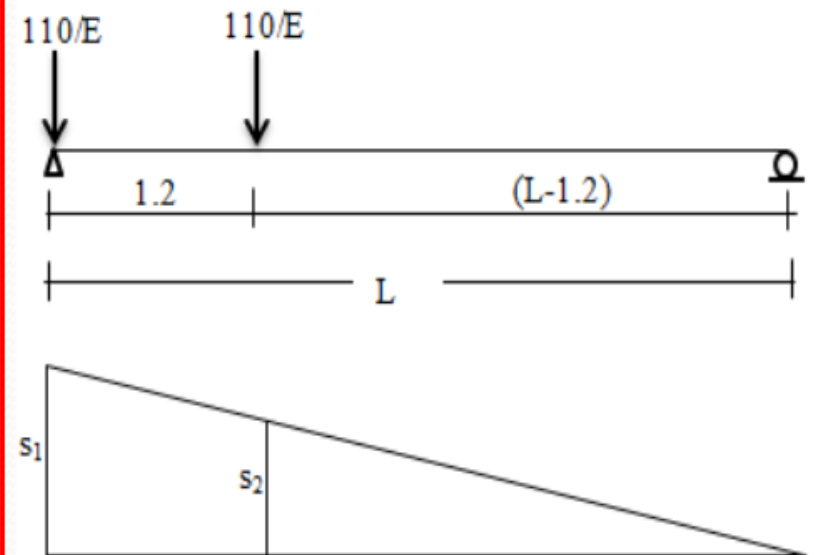
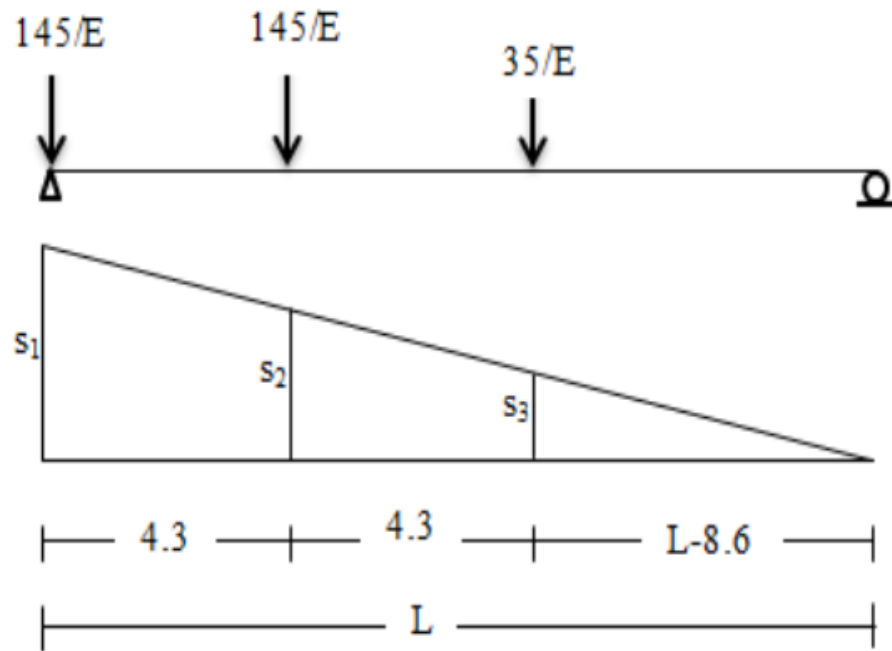
⇒ Lane Load:

The design lane load shall consist of a load of 9.3kN/m uniformly distributed in the longitudinal direction.



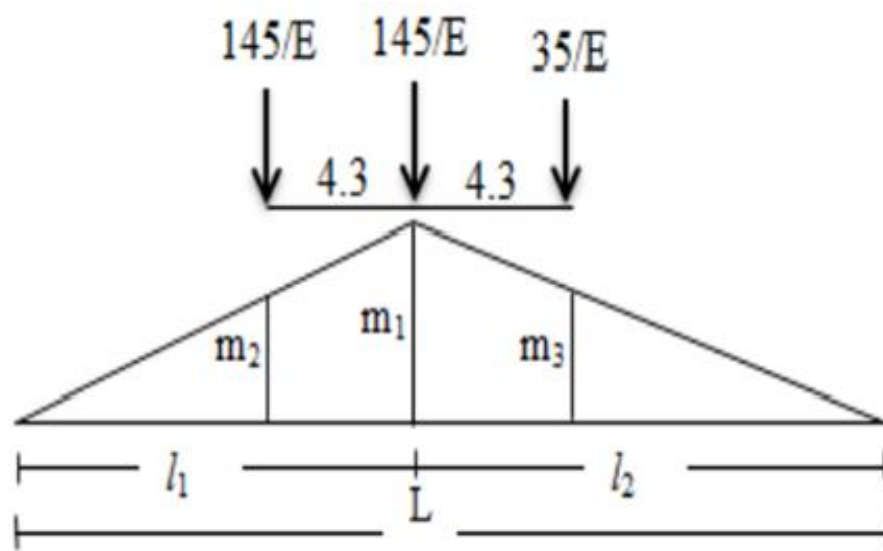
IL for maximum moment and shear due to lane load

Conti...



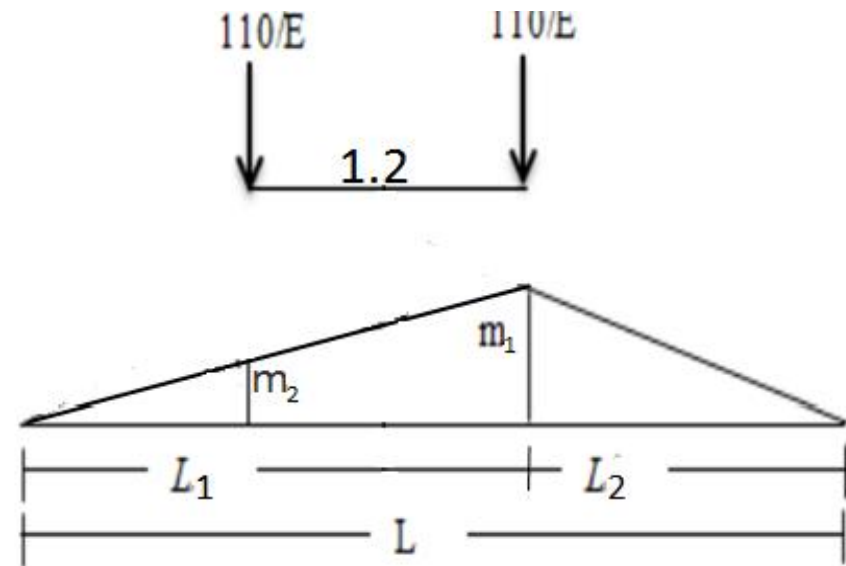
IL for maximum shear force due to truck and tandem loads

Conti....



$$m_1 = \frac{l_1 l_2}{L} \quad m_2 = \frac{l_2 \langle l_1 - 4.3 \rangle}{L}$$

$$m_3 = \frac{l_1 \langle l_2 - 4.3 \rangle}{L}$$



$$m_1 = \frac{l_1 l_2}{L} \quad m_2 = \frac{l_2 \langle l_1 - 1.2 \rangle}{L}$$

Fig. IL for maximum bending moment due to truck and tandem loads

Conti....

- The maximum Live Load Moments for both **interior and edge strips** can be computed using influence line concepts and the influence line coefficients (**maximum ordinates**).

-Interior Strip

$$M_{tr} = \frac{145}{E} (m_1 + m_2) + \frac{35}{E} m_3$$

$$M_{tan} = \frac{110}{E} (m_1 + m_2)$$

$$M_{ln} = \frac{9.3}{E} \frac{(L^2)}{8}$$

$$(M_{LL+IM})_{int} = 1.33 \max (M_{tr}, M_{tan}) + M_{ln}$$

where E : interior strip width

Conti...

- the exterior design moment is taking by considering the maximum effects due to live and dead load moments.

-Edge Strip

$$M_{tr} = \frac{m}{2} \left(\frac{145}{E_e} (m_1 + m_2) + \frac{35}{E_e} m_3 \right)$$

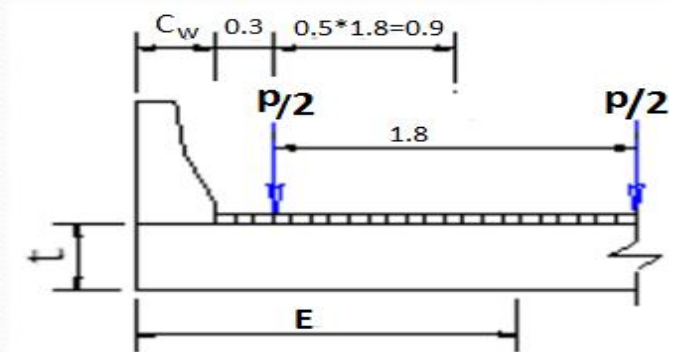
$$M_{tan} = \frac{m}{2} \left(\frac{110}{E_e} (m_1 + m_2) \right)$$

$$M_{ln} = \frac{m}{2} \left(\frac{9.3}{E_e} \frac{(L^2)}{8} \right)$$

$$(M_{LL+IM})_{edge} = 1.33 \max (M_{tr}, M_{tan}) + M_{ln}$$

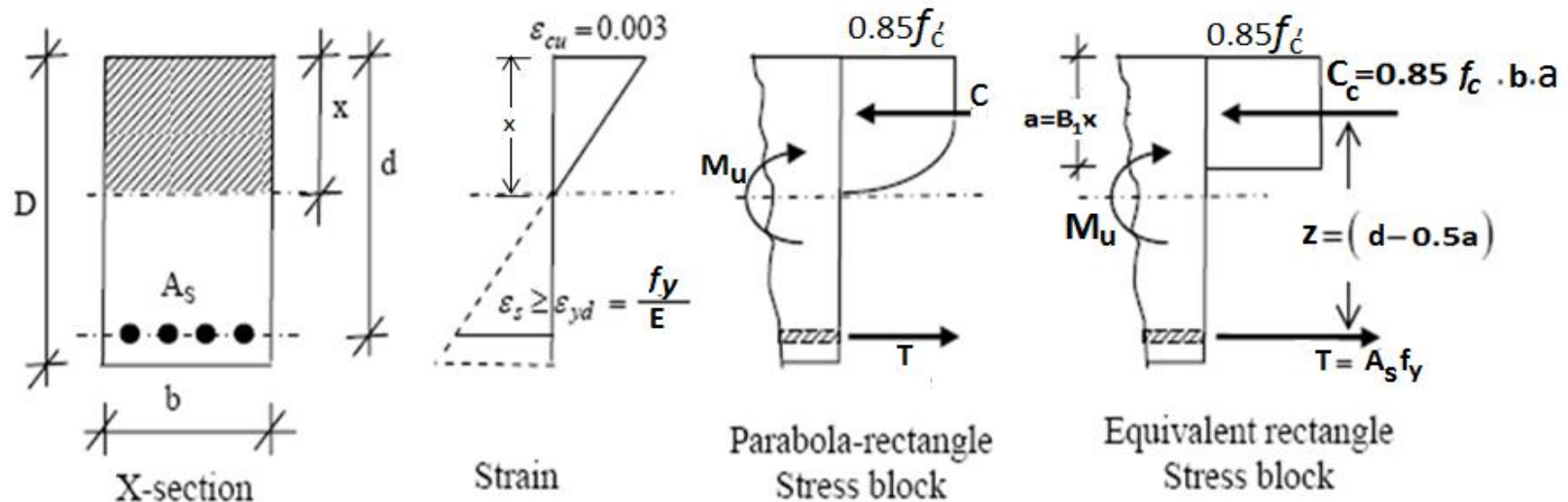
where E_e : edge strip width

m : multiple presence factor (=1.2)



Flexural design

- Limits for reinforcement** [Art 5.7.3.3] Maximum reinforcement is such that, $x/d \leq 0.42$, if $x > 0.42d$ section will be over reinforced.



$$\Rightarrow \beta_1 = \begin{cases} 0.85 & \text{for } f'_c \leq 28 \text{ MPa} \\ 0.85 - 0.05 \left(\frac{f'_c - 28}{7} \right) & \text{for } 28 \text{ MPa} \leq f'_c \leq 56 \text{ MPa} \\ 0.65 & \text{for } f'_c \geq 56 \text{ MPa} \end{cases}$$

Cont...

- Horizontal force equilibrium, $C=T$

$$0.85f'_c \beta_1 x b = A_s f_y$$

$$0.85f'_c a b = A_s f_y$$

$$a = A_s f_y / 0.85f'_c b$$

$$a = \rho f_y d / 0.85f'_c \text{---for Single reinforced section}$$

Moment resistance

$$M_n = T(d-a/2) = A_s f_y (d-a/2)$$

$$M_R = \phi M_n$$

$$M_R = \phi [A_s f_y (d-a/2)] \text{ then substitute "a"}$$

$$M_R = \phi M_n = \phi A_s f_y d (1 - 0.588 \rho f_y / f'_c) \text{ then equate with } M_u \rightarrow$$

- We get Required Steel ratio

$$\rho = \left[1 - \sqrt{1 - \frac{2.352 M_u}{\phi b d^2 f'_c}} \right] \frac{f'_c}{1.176 f_y} \quad \text{Minimum: } \rho_{min} \geq \frac{0.03 f'_c}{f_y} \quad d = \sqrt{\frac{M_u}{0.2492 b f'_c}}$$

Conti...

- **Shear Resistance** of Deck/Slab section According (AASHTO Article 5.1 4.4.1) V_n

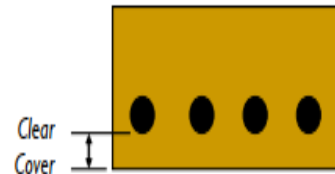
➔ Nominal Shear resistance, V_n

$$V_n = \min \left\{ \begin{array}{l} V_c + V_s \\ 0.25 f_c b v d v \end{array} \right.$$

$$V_c = 0.083 \beta b v \sqrt{f_c} \quad , \beta = 2 \text{ for } D < 400 \text{ mm}$$

V_s -no need to provide shear reinforcement

- **Minimum Concrete Cover**
- According to **AASHTO 5.1 2.3.1** Minimum cover is specified so that there is enough concrete to cover the steel and prevent the steel from corrosion.



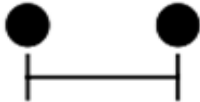
Conti....

Table 5.12.3.1- concrete cover

SITUATION	COVER (mm)
Direct exposure to salt water	100
Cast against earth	75
Coastal	75
Exposure to deicing salts	60
Deck surfaces subject to tire stud or chain wear	60
Exterior other than above	50
Interior other than above	
• Up to No. 36 bar	40
• No. 43 and No. 57 bars	50
Bottom of cast-in-place slabs	
• Up to No. 36 bar	25
• No. 43 and No. 57 bars	50
Precast soffit form panels	20
Precast reinforced piles	
• Noncorrosive environments	50
• Corrosive environments	75
Precast prestressed piles	50
Cast-in-place piles	
• Noncorrosive environments	50
• Corrosive environments	
- General	75
- Protected	75
• Shells	50
• Auger-cast, tremie concrete, or slurry construction	75

Spacing b/n bars

Table-Minimum spacing bars for CIP AASHTO 5.10.3

Bar Size (mm)	Minimum Spacing			
				
13	51	51	63	63
16	54	56	70	70
19	57	68	76	83
22	60	78	82	96
25	64	90	90	110
29	72	101	101	124
32	81	114	114	140
36	90	127	127	155
43	108	152	152	
57	143	203	203	

- 1.5 times the nominal diameter of the bars,
- 1.5 times the maximum size of the coarse aggregate, or
- 38 mm.

Shrinkage & Temperature Reinforcement

- As indicated in AASHTO, section 5.10.8.2, reinforcement for shrinkage and temperature reinforcement shall be provided near surfaces of concrete exposed to daily temperature changes. The specified amount of the steel should be distributed equally on both sides at top parallel and transverse to traffic direction:- A_s

$$A_s \geq 0.75 A_g / f_y$$

where:

A_g = gross area of section (mm²)

f_y = specified yield strength of reinforcing bars (MPa)

Distribution Reinforcement

- According to AASHTO, article 5.14.4.1, the amount of **bottom transverse reinforcement** may be taken as a percentage of the main reinforcement required for positive moment.

⇒ For primary reinforcement parallel to traffic:

$$1750 / \sqrt{S} \leq 50 \text{ percent}$$

⇒ For primary reinforcement perpendicular to traffic:

$$3840 / \sqrt{S} \leq 67 \text{ percent}$$

where:

S = the effective span length taken as equal to the effective length specified in Article 9.7.2.3 (mm)

Limit state

- During Bridge Design **all limit state should verify in LRFD**

1.Service Limit States : concrete crack can be controlled by

- distributing steel reinforcements and by limiting allowable
- Deflection on member.

I-Limiting of Deflections (AASHTO 2.5.2.6.2)

- Vehicular load, general.....L/800
- Vehicular and/or pedestrian load.....L/1000
- Vehicular load on cantilever arm L/300

II-Control of Cracking (AASHTO 9.14)

- -The tensile stress in the reinforcement (f_s) at the service load doesn't exceed f_{sa} .

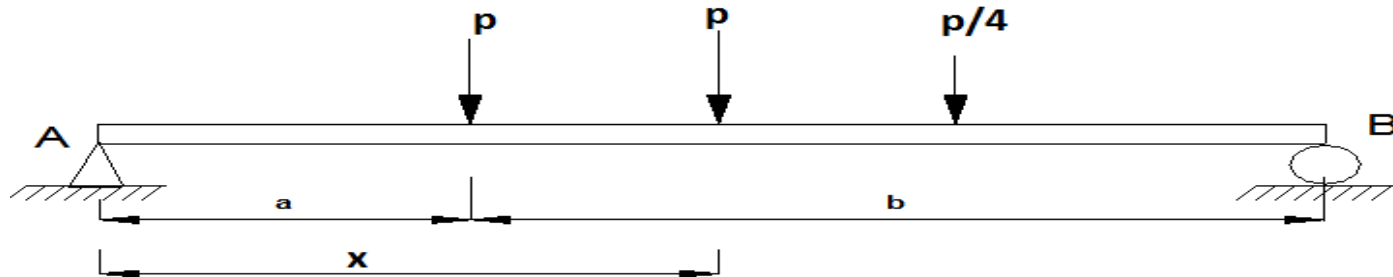
$$f_s \leq f_{sa}$$

$$f_{sa} = \frac{Z}{(d_c A)^{1/3}} \leq 0.6 f_y$$

$$Z = \begin{cases} 30,000 & \text{moderate exposure conditions} \\ 23,000 & \text{severe exposure conditions} \\ 17,500 & \text{buried structures} \end{cases}$$

Live Load Deflection

- **design Truck –consider IM , m and number of vehicle**



$$\text{For } x > a, \text{ ---} \Delta = \frac{pa(L-x)}{6EIL} (x^2 + a^2 - 2Lx)$$

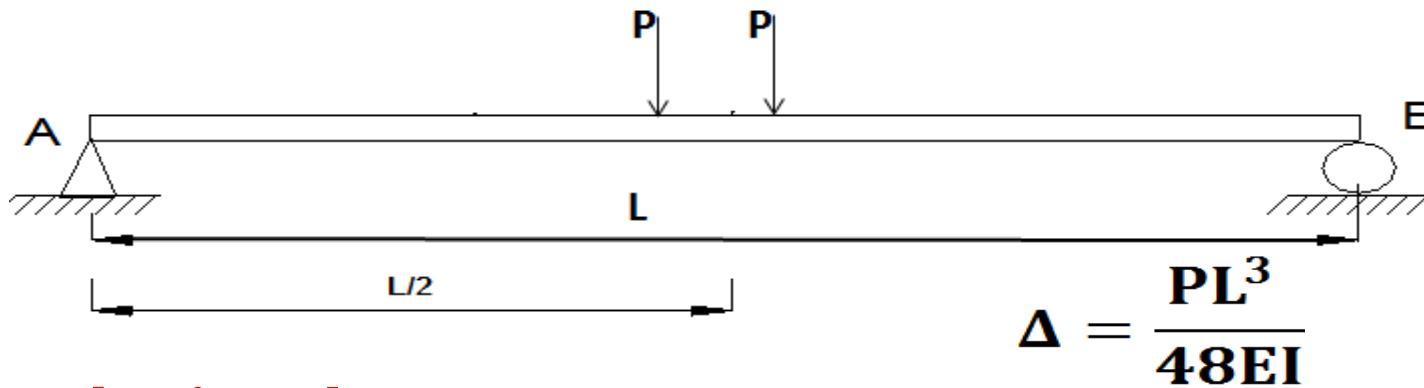
$$\text{For } x < a, \text{ ---} \Delta = \frac{pb}{6EIL} (x^3 + xb^2 - L^2x)$$

$$\text{Total deflection } \Delta_t @x = \Delta_{1x} + \Delta_{2x} + \Delta_{3x}$$

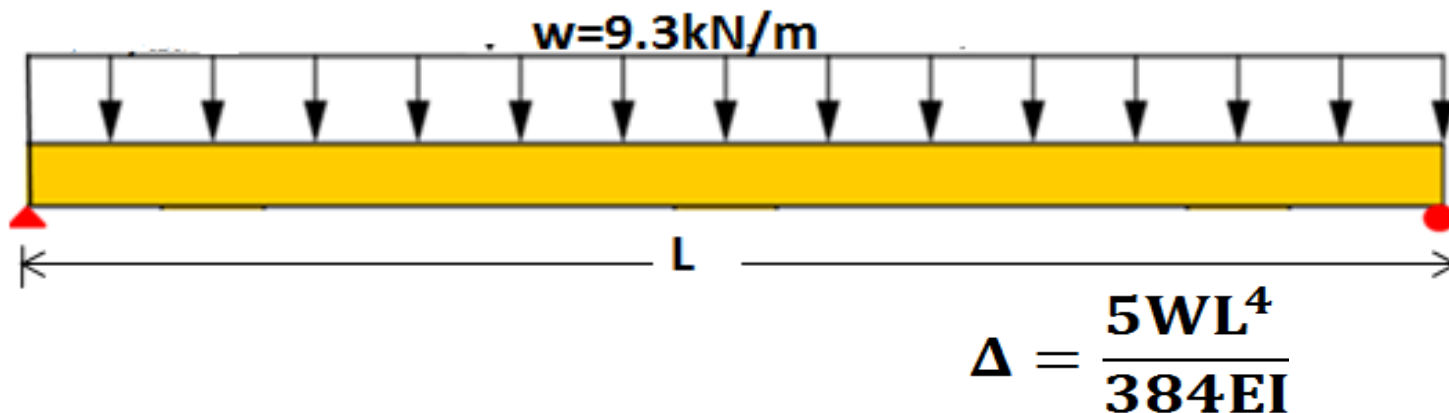
- live load deflection should be taken as the larger of :
 - ✓ 25 percent of the design truck plus the design lane load
 - ✓ 100% design truck alone

Conti...

□ design Tandem--- $p=220\text{kN}$



□ design lane



Conti....

- **2.Strength Limit States:-**This state shall be taken to ensure that **strength and stability**, are provided to resist the Design load combinations that a bridge is expected to experience in its design life. Moment ,shear ,torsion and axial force resistance should be checked.

$$\Phi R_n \geq \eta \sum \gamma_i Q_i$$

- **3.Extreme Event Limit States**
- Intended to ensure structural survival of a bridge during an earthquake, vehicle collision, ice flow, or foundation scour.

Conti...

- **4-fatigue limit states:-** are used to limit stress in steel reinforcements to control concrete crack growth under repetitive truck loading and need **not be investigated for concrete decks in multi-girder** and **fatigue stress** in straight reinforcement is limited to:-
- $$f_f = 145 - 0.33 f_{min} + 55 \left(\frac{r}{h} \right) \geq f_s = \frac{M_s}{A_s * j d}$$

⇒ where:

f_f = stress range (MPa)

f_{min} = algebraic minimum stress level, tension positive, compression negative (MPa)

r/h = ratio of base radius to height of rolled-on transverse deformations; if the actual value is not known, 0.3 may be used

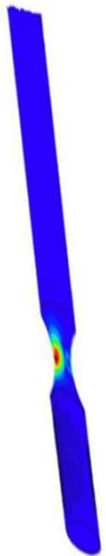
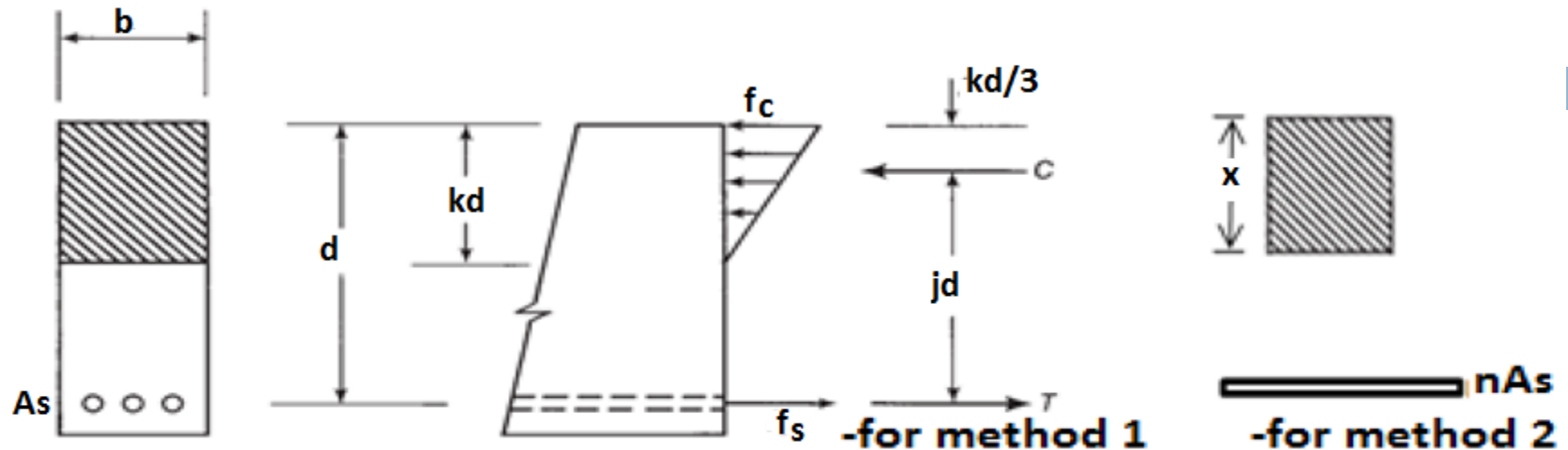


Fig:-rebar necking by Fatigue

Conti....

➤ Service-Load and fatigue Stresses “ f_s ”



-method -1

$$\frac{b(kd)^2}{2} - nAs(d - kd) = 0$$

$$k^2 + 2pnk - 2pn = 0$$

$$k = \sqrt{2pn + (pn)^2} - pn$$

$$jd = d - \frac{kd}{3} = d(1 - \frac{k}{3})$$

$$f_s = \frac{Ms}{As \cdot jd}$$

-Using method 2

$$\frac{b(x)^2}{2} - nAs(d - x) = 0$$

$$x^2 + \frac{2nAs}{b} - \frac{2nAsd}{Asb} = 0$$

$$I_{cr} = \frac{bx^3}{3} + nAs(d - x)^2 = 0$$

$$f_s = \frac{nMs(d - x)}{I_{cr}}, \quad n = \frac{E_s}{E_c}$$

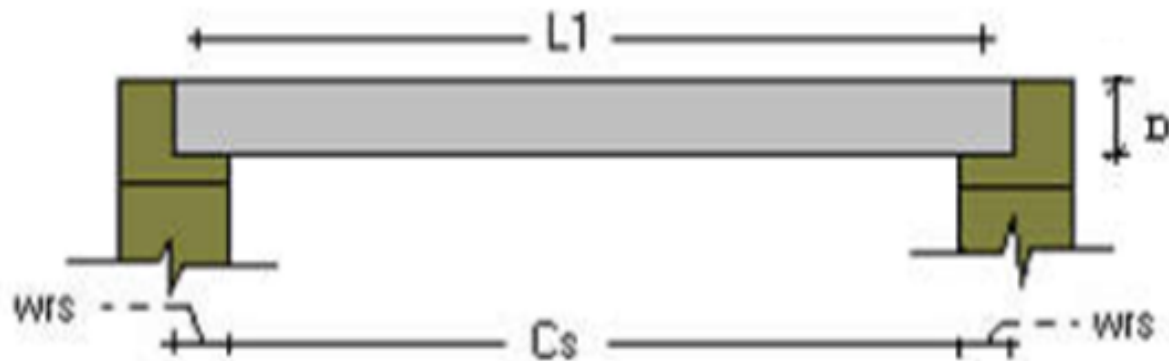
Design example of slab bridge

➤ Design the superstructure of slab bridge on rural area using the following **Preliminary dimension**

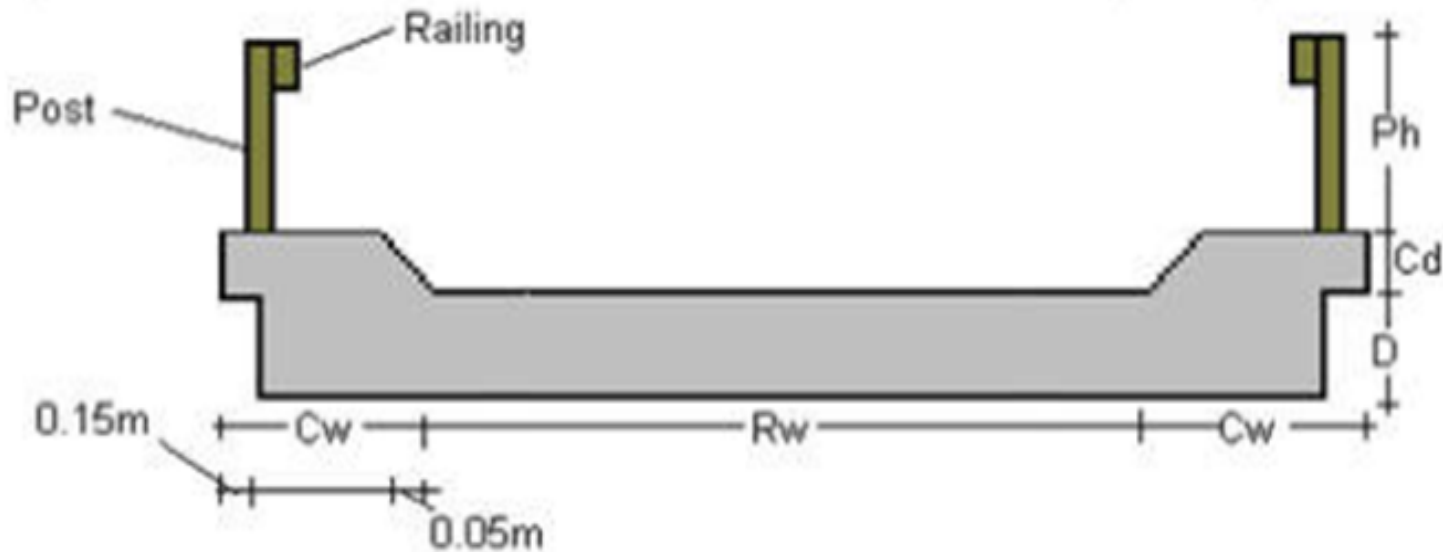
➤ Use Design Specification AASHTO code 2007 & HL-93 load

- ✓ Clear span of the bridge (C_s)- 11m
- ✓ Road way width (R_w) – 7.3m
- ✓ Additional curb width (C_w) – 0.8m
- ✓ Curb Depth (C_d) – 0.25m
- ✓ Abutment width (W_{rs}) - 0.5m
- ✓ Concrete railing depth (R_d) – 0.3m
- ✓ Railing width (R_{ww}) – 0.3m
- ✓ Concrete post depth (P_d)- 0.3m
- ✓ Concrete post width (P_w) – 0.3m
- ✓ Concrete post height (P_h) – 0.8m
- ✓ Concrete post spacing (P_s) – 1.2m
- ✓ Thickness of asphalt layers -75mm

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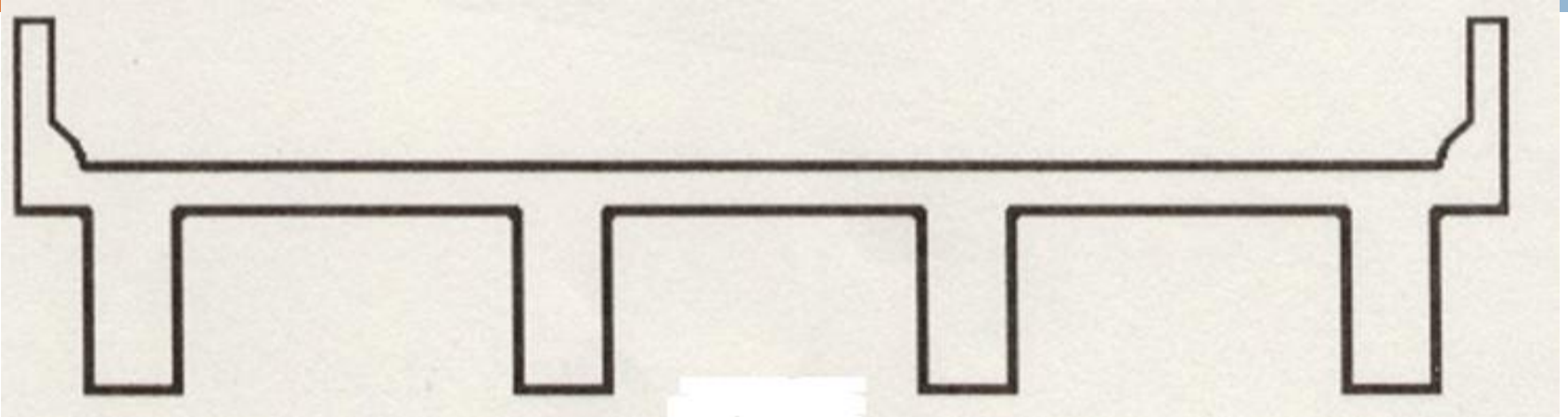
Longitudinal Section of Slab Bridge



Cross-Section of Slab Bridge

Fundamental of Bridge Design

5.2-T-BEAM DESIGN



T-beam design

- ❑ IN T-BEAM/GIRDER BRIDGE design follow the following
- ❑ 1.develop the typical section design sections
 - a)Top flange thickness
 - ❖ Minimum depth of concrete deck is 175mm
 - b)Bottom flange thickness
 - ❖ Not applicable for T-bridge
 - c)web thickness
 - ❖ Minimum 200mm
 - ❖ Minimum concrete cover for main reinforcement extension 50mm.

Conti...

- d) *Structure Depth* (Table 2.1) [Table A2.5.2.6.3-1] According to AASHITO
- Minimum depth continuous spans = $0.065L$

Conti....

e) Reinforcement Limits

- Deck overhang: at least $\frac{1}{3}$ of bottom layer of transverse reinforcement [A5.14.1.3.2a]
- Minimum reinforcement: the lesser of $\phi M_n > 1.2M_{cr}$ or $\phi M_n \geq 1.33$ times the factored moment required for the Strength I limit state. [A5.7.3.3.2]

$$\rho_{\min} \geq 0.03 \frac{f'_c}{f_y}$$

- Crack control: $f_s \leq f_{sa} = \frac{Z}{(d_c A)^{1/3}} \leq 0.6f_y$ [A5.7.3.4]
- Flanges in tension: tension reinforcement shall be distributed over the lesser of the effective flange width or a width equal to 1/10 of the average of the adjacent spans [A4.6.2.6, A5.7.3.4]
- Longitudinal skin reinforcement required if web depth > 900 mm [A5.7.3.4]
- Shrinkage and temperature reinforcement [A5.10.8]

$$A_s \geq 0.75 \frac{A_g}{f_y}$$

Conti..

f) *Effective Flange Widths* [A4.6.2.6.1]

- Effective span length for continuous spans

= distance between points of permanent load inflections

- Interior beams

$$b_i \leq \begin{cases} \frac{1}{4} \text{ effective span} \\ 12t_s + b_w \\ \text{average spacing of adjacent beams} \end{cases}$$

Conti....

- Exterior beams

$$b_e - \frac{1}{2}b_t \leq \begin{cases} \frac{1}{8}\text{effective spans} \\ 6t_s + \frac{1}{2}b_w \\ \text{width of overhanging} \end{cases}$$

Conti..

2. develop conventional reinforced concrete deck

-put the design sketch

3. Select the resistance factor ϕ

1. *Strength Limit State*

Flexure and tension 0.9

Shear and torsion 0.9

Axial compression 0.75

Bearing 0.7

2. *Nonstrength Limit States* 1.0 [A 1.3.2.1]

Conti...

4. Select Load Modifiers [A1.3.2.1]

	Strength	Service	fatigue	
Ductility, η_D	0.95	1.0	1.0	[A1.3.3]
Redundancy, η_R	0.95	1.0	1.0	[A1.3.4]
Importance, η_I	1.05	N/A	N/A	[A1.3.5]
$\eta = \eta_D \eta_R \eta_I$	0.95	1.0	1.0	

5. Select Applicable Load Combinations

a. Strength I Limit State

Conti...

$$U = \eta[1.25DC + 1.50DW + 1.75(LL + IM) + 1.0(WA + FR) + \dots]$$

b. Service I Limit State

$$U = 1.0(DC + DW) + 1.0(LL + IM) + 1.0WA + 0.3(W_S + W_L) + \dots$$

c. Fatigue Limit State

$$U = 0.75(LL + IM)$$

Conti...

7. Calculate Live Load Force Effects

7.1. Select Number of Lanes [A3.6.1.1.1]

$$N_L = \text{INT}\left(\frac{w}{3600}\right)$$

7.2. Multiple Presence (Table 4.6) [A3.6.1.1.2]

No. of Loaded Lanes	m
1	1.20
2	1.00
3	0.85

7.3. Dynamic Load Allowance (Table 4.7) [A3.6.2.1] Not applied to the design lane load.

Component	IM (%)
Deck joints	75
Fatigue	15
All other	33

Conti...

8. Define distribution factors for moments and shear

A. For moments

a. Interior beams with concrete decks

One Design Lane Loaded:

$$mg_M^{sl} = 0.06 + \left(\frac{S}{4300} \right)^{0.4} \left(\frac{S}{L} \right)^{0.3} \left(\frac{K_g}{L t_s^3} \right)^{0.1}$$

mg = girder distribution factor with multiple presence factor

Conti...

SI = single lane loaded, interior *M*=moment

Two or More Design Lanes Loaded

$$mg_M^{MI} = 0.075 + \left(\frac{S}{2900}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{Kg}{Lts^3}\right)^{0.1}$$

MI = multiple lanes loaded, interior *M*=moment

For interior girders, distribution factors are governed by multiple lanes loaded.

Conti...

b. Exterior beams (Table 6.5) [A4.6.2.2.2d and Table A4.6.2.2.2d-1]

One Design Lane Loaded—Lever Rule, $m = 1.2$ (Fig. E7.3-4)

$$R = 0.5P \left(\frac{Y_d}{S} + X - \right) = {}^{DF} P$$

$$g_M^{SE} = {}^{DF} \quad SE = \text{single lane, exterior}$$

$$mg_M^{SE} = 1.2 \text{ DF Governs} \quad \begin{array}{l} X\text{-distance b/n assumed hinge and} \\ Y_d\text{-distance b/n rare axles} \end{array}$$

Two or More Design Lanes Loaded,

$$mg_M^{ME} = e mg_M^{MI} \quad ME = \text{multiple lanes loaded, exterior}$$

$$\text{where } e = 0.77 + \frac{d_e}{2800} > 1$$

Conti....

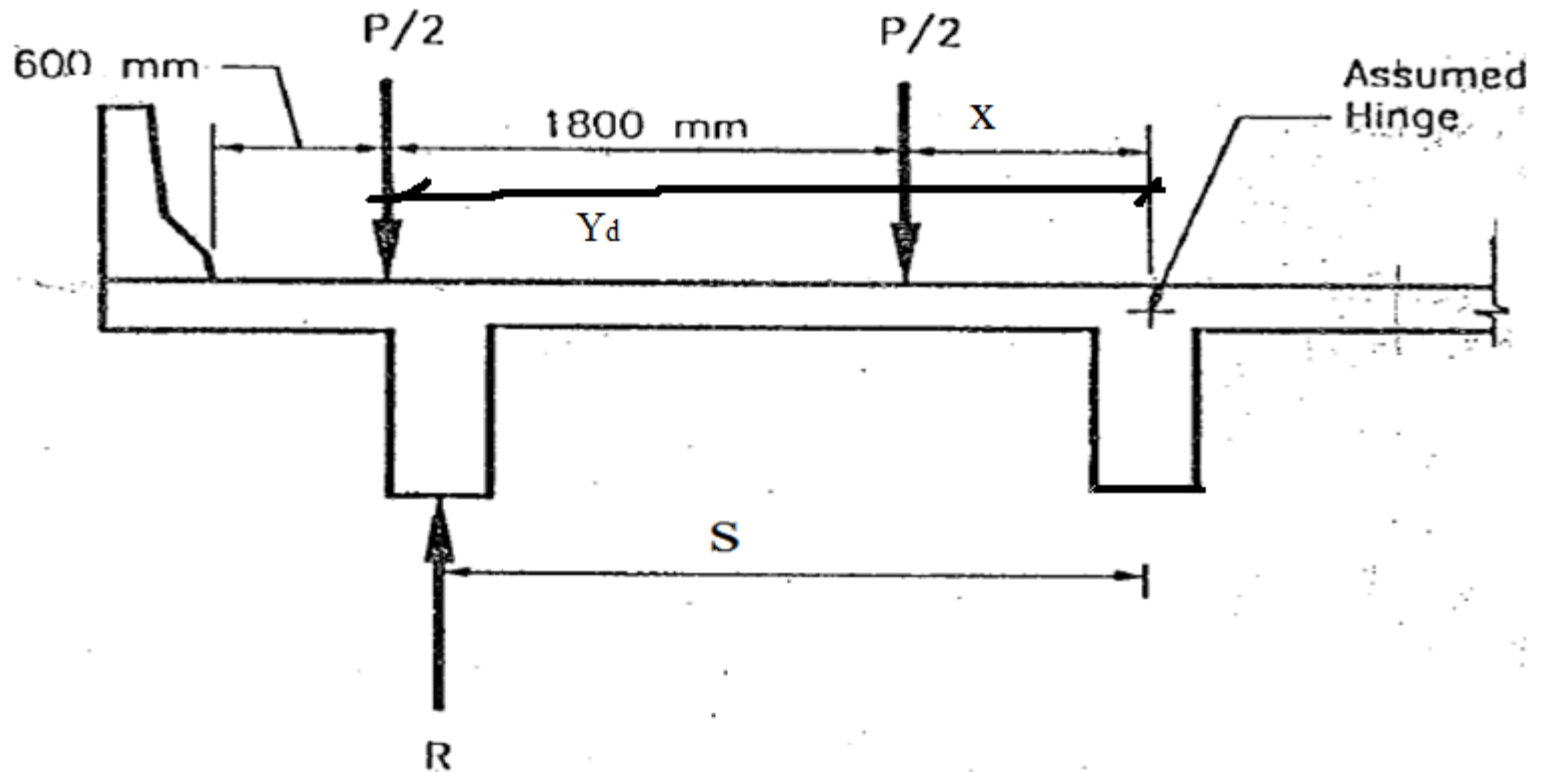


Fig. E7.3-4 Definition of level rule.

Conti...

➤ Distributed live load moment

$$M_{II+IM} = mgr[M_{tr}, M_{ta}](1 + IM/100) + M_{lan}]$$

B) Distribution factor for shear

a. Interior beams (Table 6.5)

$$mg_V^{SI} = 0.36 + \frac{S}{7600}$$

$$mg_V^{MI} = 0.2 + \frac{S}{3600} - \left(\frac{S}{10700}\right)^2$$

$V = \text{shear}$

Conti....

b. Exterior beams

Lever Rule: mg_V^{SE}

$$mg_V^{ME} = e mg_V^{MI}, \text{ where } e = 0.6 + \frac{d_e}{3000}$$

i.e. distribution factor of
ext.girder=e*interior girder

Distributed live load shears

$$V_{LL+IM} = mgr[(V_{Tr} \text{ or } V_{Tn})1.33 + V_{Ln}]$$















