

# Example

Slab bridge design

## **Assumptions**

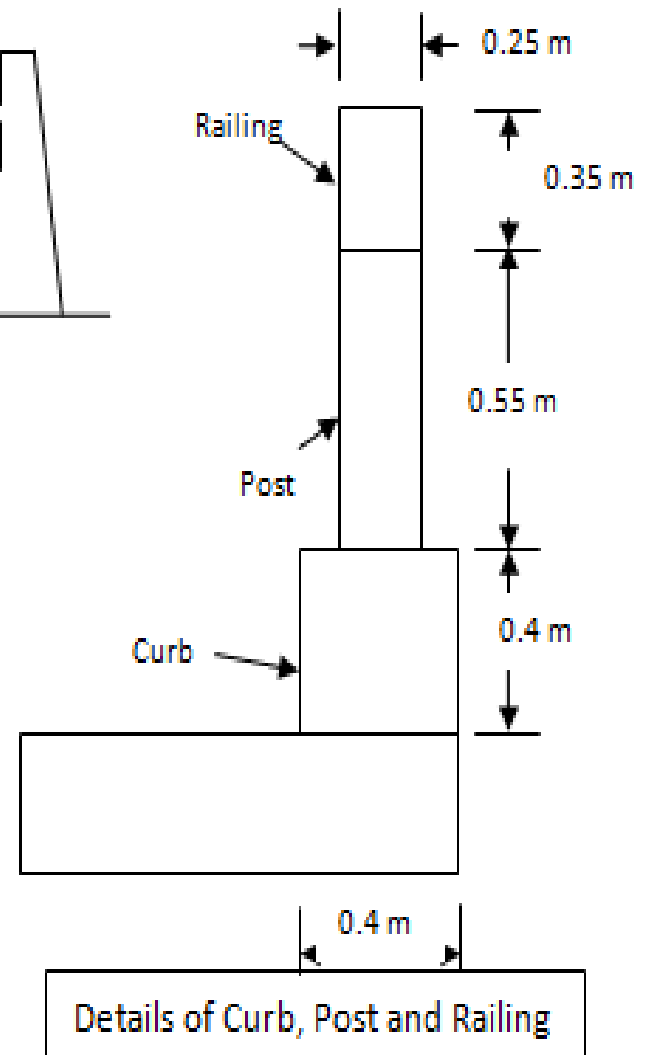
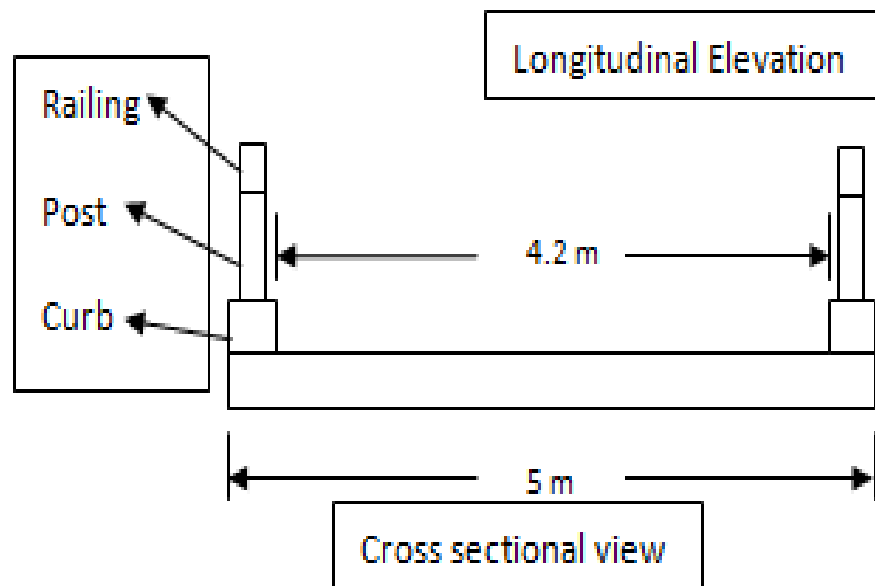
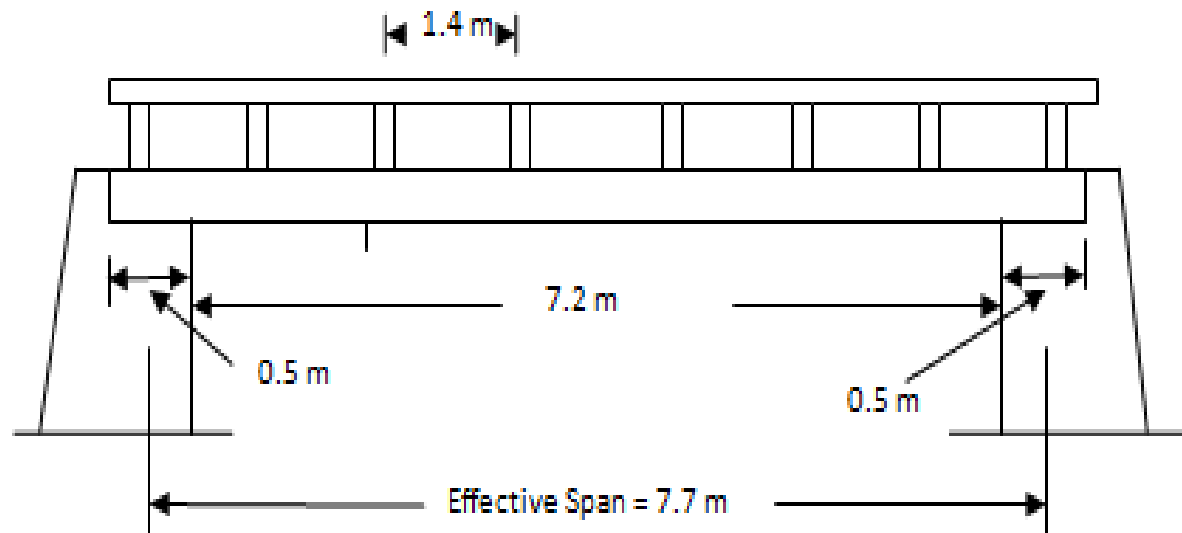
- Main reinforcements are placed parallel to the center line of road way
- The bottom of the slab is assumed level
- Center to center support is assumed perpendicular to the supports
- Additional amount of concrete thickness for cross fall is not considered for flexural design

# Conti....

## Preliminary dimensions:

- Clear span = 7.2 m
- Width of abutment shelf = 0.5 m
- Clear width of super structure = 4.2 m
- Total width of super structure = 5 m
- No. of lane = 1
- Total length of super structure =  $7.2 + 0.5 + 0.5 = 8.2$  m
- Skewness angle =  $0^{\circ} 00' 00''$
- Railing depth = 0.35 m
- Railing width = 0.25 m
- Post cross section =  $0.25 \text{ m} * 0.25 \text{ m}$
- Post height = 0.55 m
- Average post spacing = 1.4 m

# Conti.....



# Conti...

- **Materials:**

Concrete:  $f'_c = 30 \text{ MPa}$

- Unit weight of concrete =  $24 \text{ kN/m}^3$
- Steel: For bar size  $> 20 \text{ mm}$  diameter, Grade:60:  $f_{yk} = 420 \text{ MPa}$
- For bar size  $\leq 20 \text{ mm}$  diameter, Grade:40:  $f_{yk} = 300 \text{ MPa}$
- $E_s = 2 \cdot 10^5 \text{ MPa}$ ;  $E_c = 24000 \text{ MPa}$ ;
- Modulus of rupture =  $3.45 \text{ MPa}$

Conti....

### Preliminary thickness of slab:

- Depth of slab = 6% of the span length =  $(6/100) * 7700 = 462$  mm (Normally the slab is made with a uniform depth over the whole bridge. **The required design depth is usually 5.5 - 6 % of the span length**, due to the width of the cracks. If **stressed reinforced** concrete is used, the design depth shall be reduced to **4.5 % of the span length.**)  
Consider overall depth of slab = 470 mm

## **Live loads:**

- Equivalent width of longitudinal strips per lane for both shear and moment with one lane =

$$E_1 = 250 + 0.42 \sqrt{L_1 W_1} \quad L_1 = 7700 \text{ mm} \quad W_1 = 5000 \text{ mm}$$

$$E_1 = 250 + 0.42 \sqrt{7700 * 5000} = 2856 \text{ mm} = 2.86 \text{ m}$$

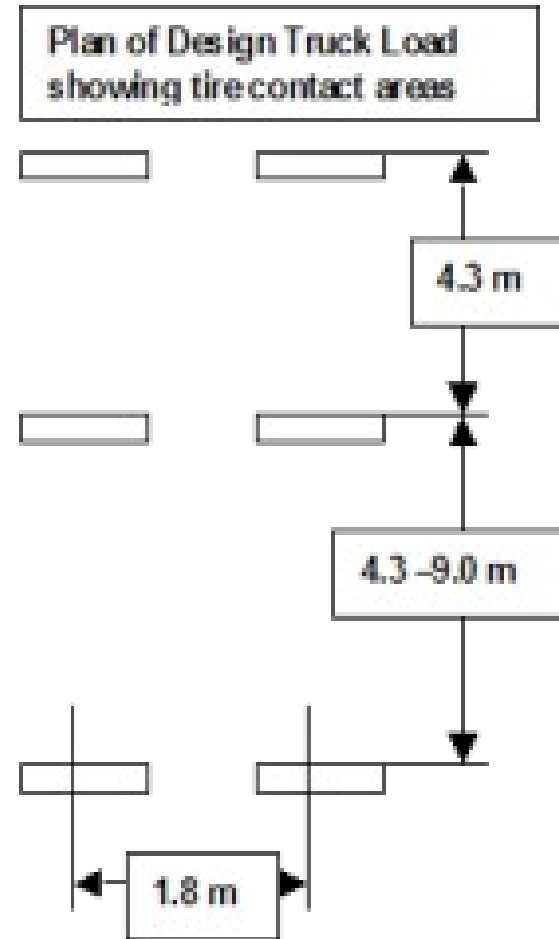
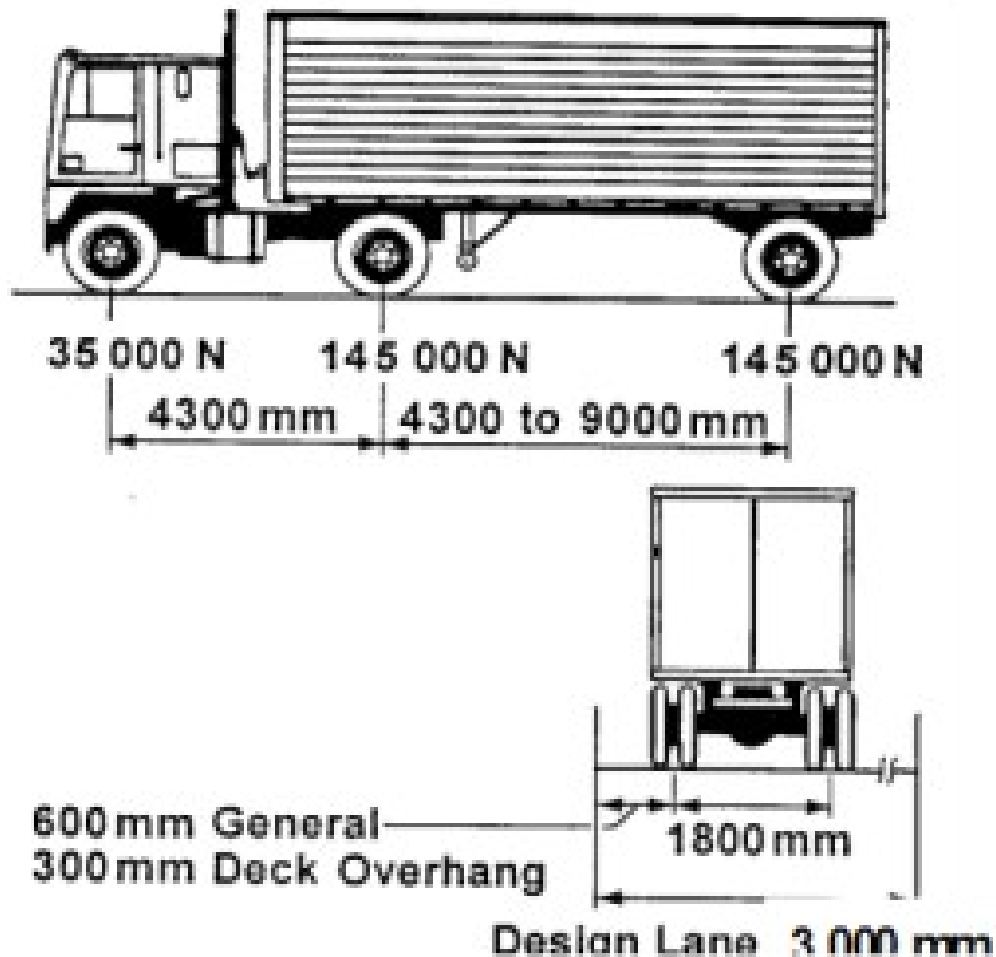
***(Equivalent strip widths for slab bridge:*** The equivalent width of longitudinal strips per lane for both shear and moment with one lane, i.e., two lines of wheels, loaded shall be determine

- Impact factor (Dynamic load allowance):  $(1 + \text{IM}/100) = (1 + 33/100) = 1.33$
- (The factor to be applied to the static load shall be taken as:  **$(1 + \text{IM}/100)$** . The dynamic load allowance shall not be applied to pedestrian loads or to the design lane load.)

| Component                        | IM  |
|----------------------------------|-----|
| Deck Joints – All Limit States   | 75% |
| All Other Components             | 1   |
| Fatigue and Fracture Limit State | 15% |
| All Other Limit States           | 33% |

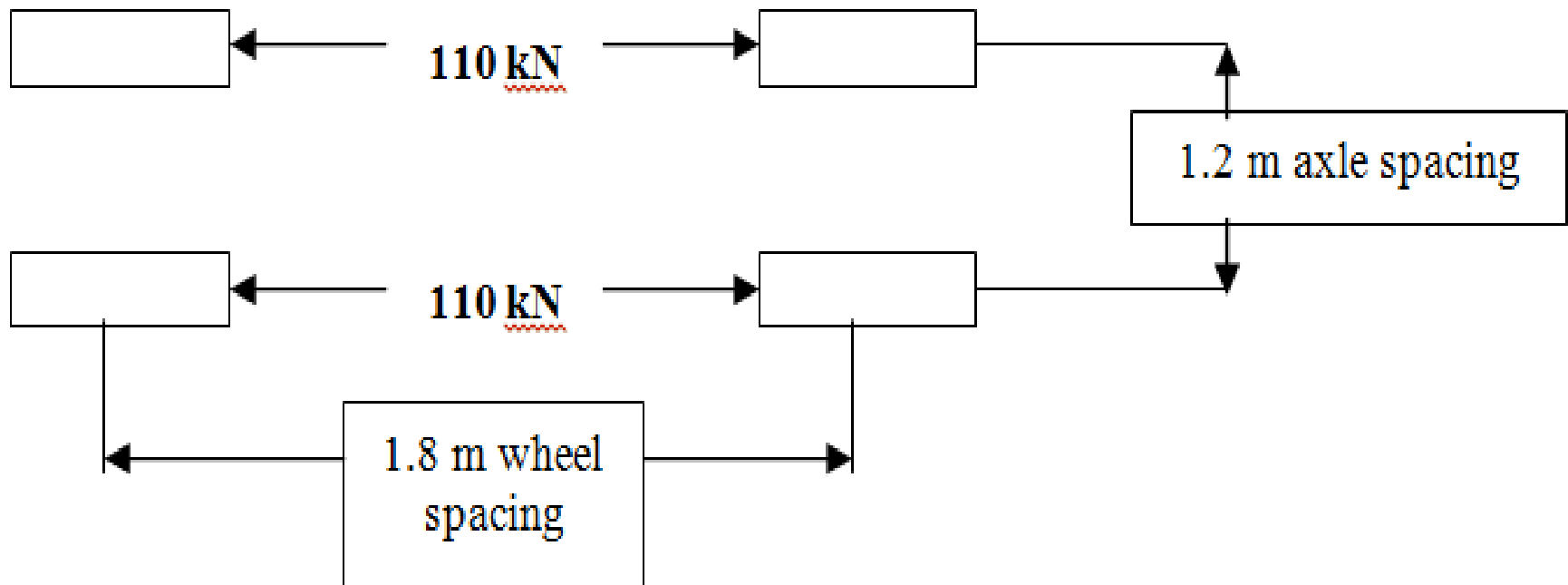
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## Design truck load:



# Conti.....

The **design tandem** used for Strategic Bridges (see *Chapter 2: General Requirements*) shall consist of a pair of **110 kN** axles spaced **1.2 m apart**. The transverse spacing of wheels shall be taken as **1.8 m**. A dynamic load allowance shall be considered as specified in a following subchapter



## Conti.....

### Load dispersion

#### For truck load

- Front axle load =  $\frac{35}{2.86}$  kN; Load dispersed per m in transverse direction = 12.24 kN/m
- Other axle loads =  $\frac{145}{2.86}$  kN Load dispersed per m in transverse direction = 50.7 kN/m

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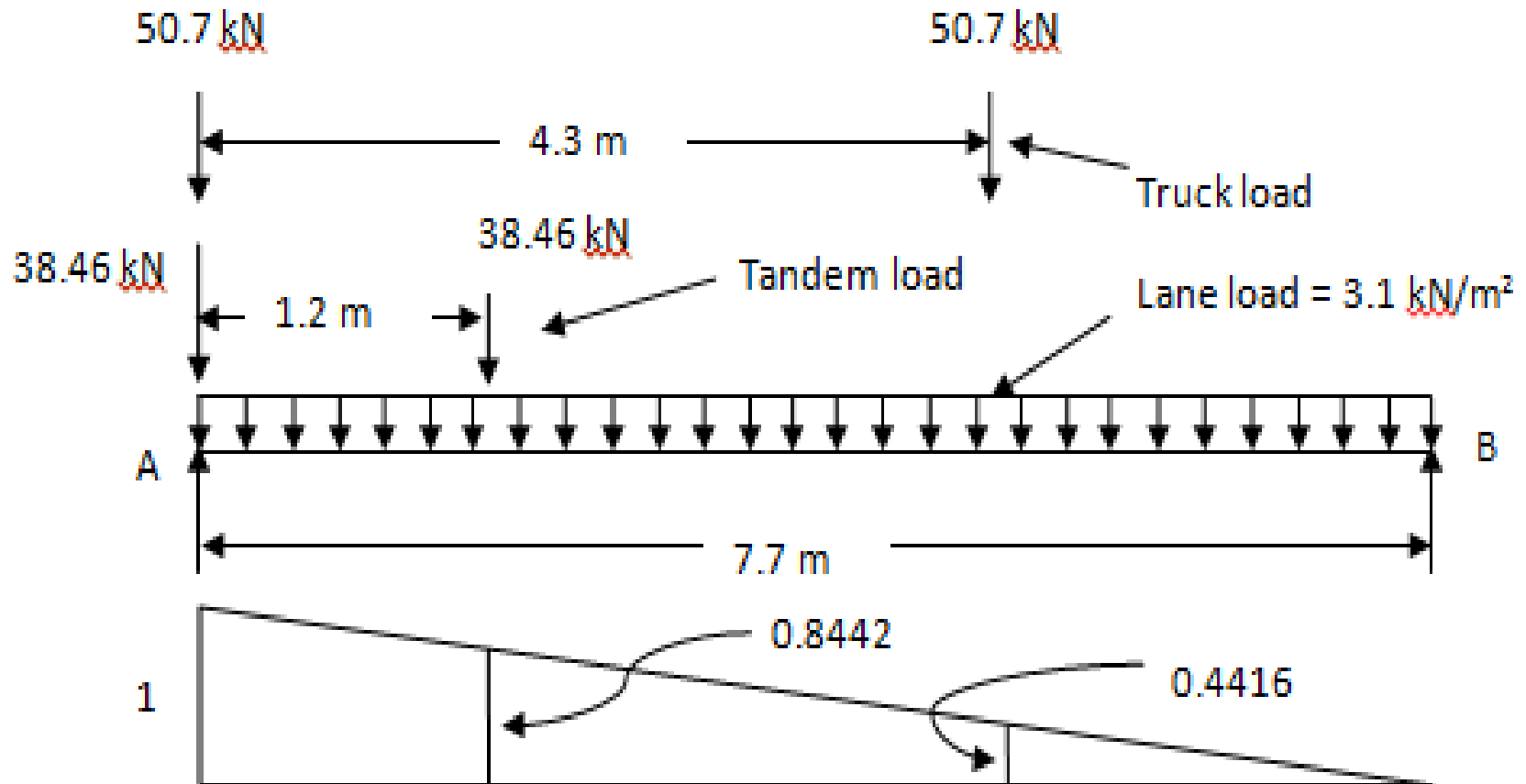
**Design tandem load:** Axle load = 110 kN; Load dispersed per m in transverse direction =  $110/2.86\text{m} = 38.46\text{kN/m}$

**Lane load:**

- Load = 9.3 kN/m; Load dispersed per m in transverse direction =  $3.1\text{ kN/m}^2$

# Shear force calculation:

## Loads on span



Conti....

### IL for maximum reaction at A

- Maximum shear at A due to truck loads =  $50.7 * 1 + 50.7 * 0.4416 = 73.09 \text{ kN}$
- Maximum shear at A due to tandem loads =  $38.46 * 1 + 38.46 * 0.8442 = 70.93 \text{ kN}$
- Maximum shear at A due to lane load =  $3.1 [1/2 * 7.7 * 1] = 11.94 \text{ kN}$

**Design truck load governs.**

- with dynamic load allowance =  $(73.09 * 1.33) + 11.94 = 109.15 \text{ kN}$

### **APPLICATION OF DESIGN VEHICULAR LIVE LOADS**

- The effects of **an axle sequence and the lane load are superimposed** in order to obtain extreme values. Unless otherwise specified, the extreme force effect shall be taken as the larger of the following:

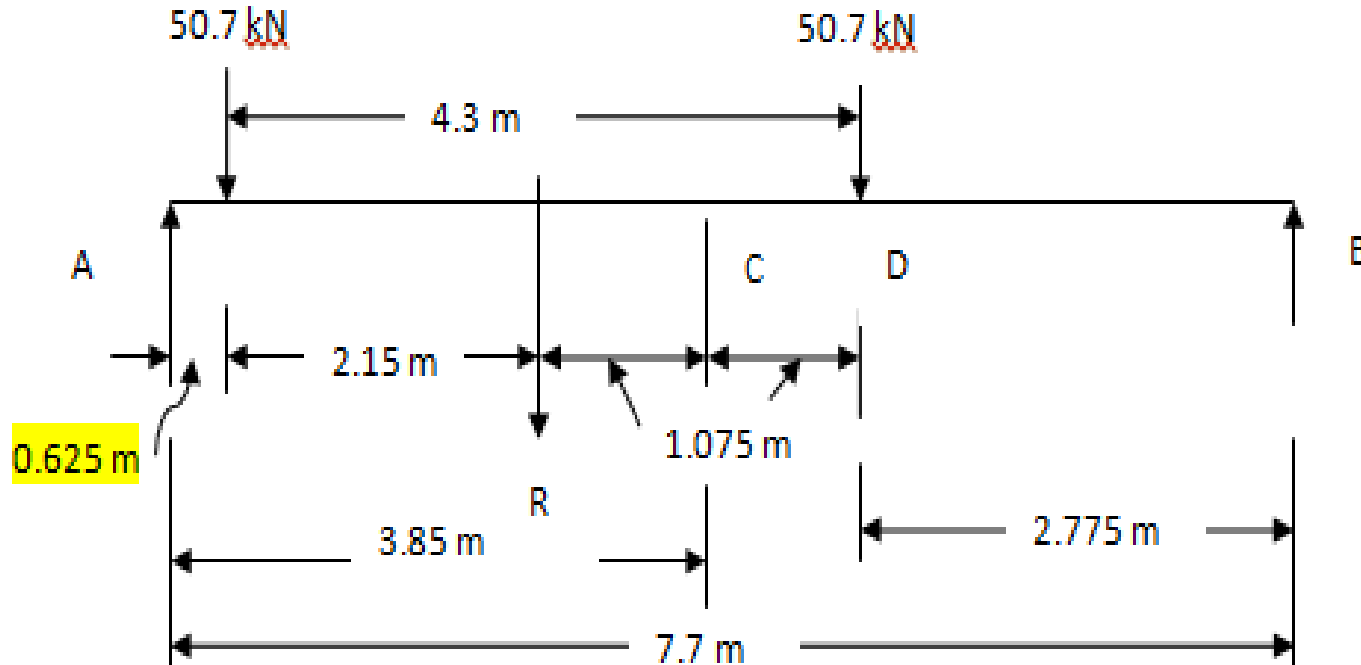
- The effect of the design tandem combined with the effect of the design lane load, or The effect of one design truck with the variable axle spacing specified in the subchapter *Multiple Presence of Live Load* above, combined with the effect of the design lane load, and
- For both negative and positive moment between points of contra flexure under a uniform load on all spans, and reaction at interior piers only, 90% of the effect of two design trucks spaced a minimum of 15.0 m between the lead axle of one truck and the rear axle of the other truck, combined with 90% of the effect of the design lane load. The distance between the 145 kN axles of each truck shall be taken as 4.3 m.
- The design truck or tandem shall be positioned transversely such that the center of any wheel load is not

Conti....

## Bending moment calculation:

- Absolute maximum bending moment due to moving loads is found by placing one of the axle loads and the resultant of the system at equidistant from the center.

for design truck load:



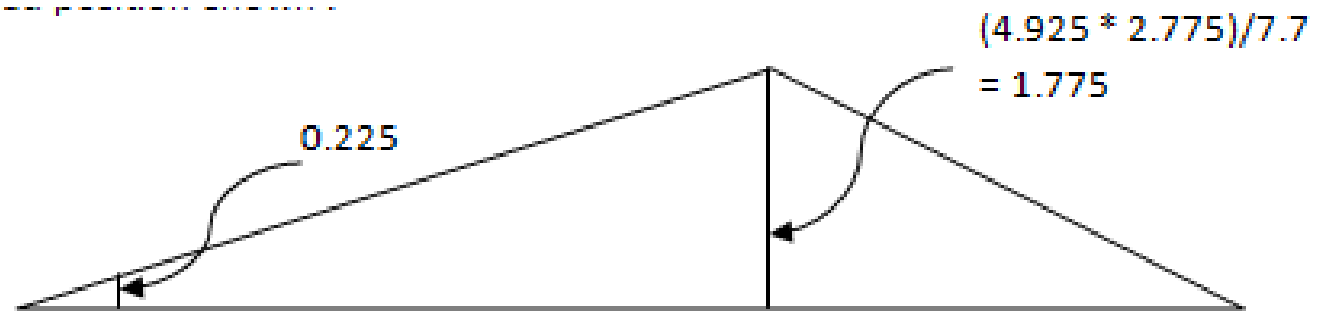
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## **TIRE CONTACT AREA**

- The tire contact area of a wheel consisting of one or two tires shall be assumed to be a single rectangle, whose **width is 50 mm** and length 500mm
- The design truck or tandem shall be positioned transversely such that the center of any wheel load is not closer .
- For the design of the deck **overhang - 300 mm** from the face of the curb or railing, and
- For the design of all **other components - 600 mm** from the edge of the design lane

Conti.....

- For this moving load of design truck, absolute maximum bending moment occurs at section D, for the load position shown



ILD for bending moment at D

$$\text{BM at D} = 50.7 (1.775 + 0.225) = 101.4 \text{ kN m}$$

For Design Tandem Load:

Load position for absolute maximum BM to occur at D, a section 0.3 m from mid span section is shown below.\_\_\_\_\_

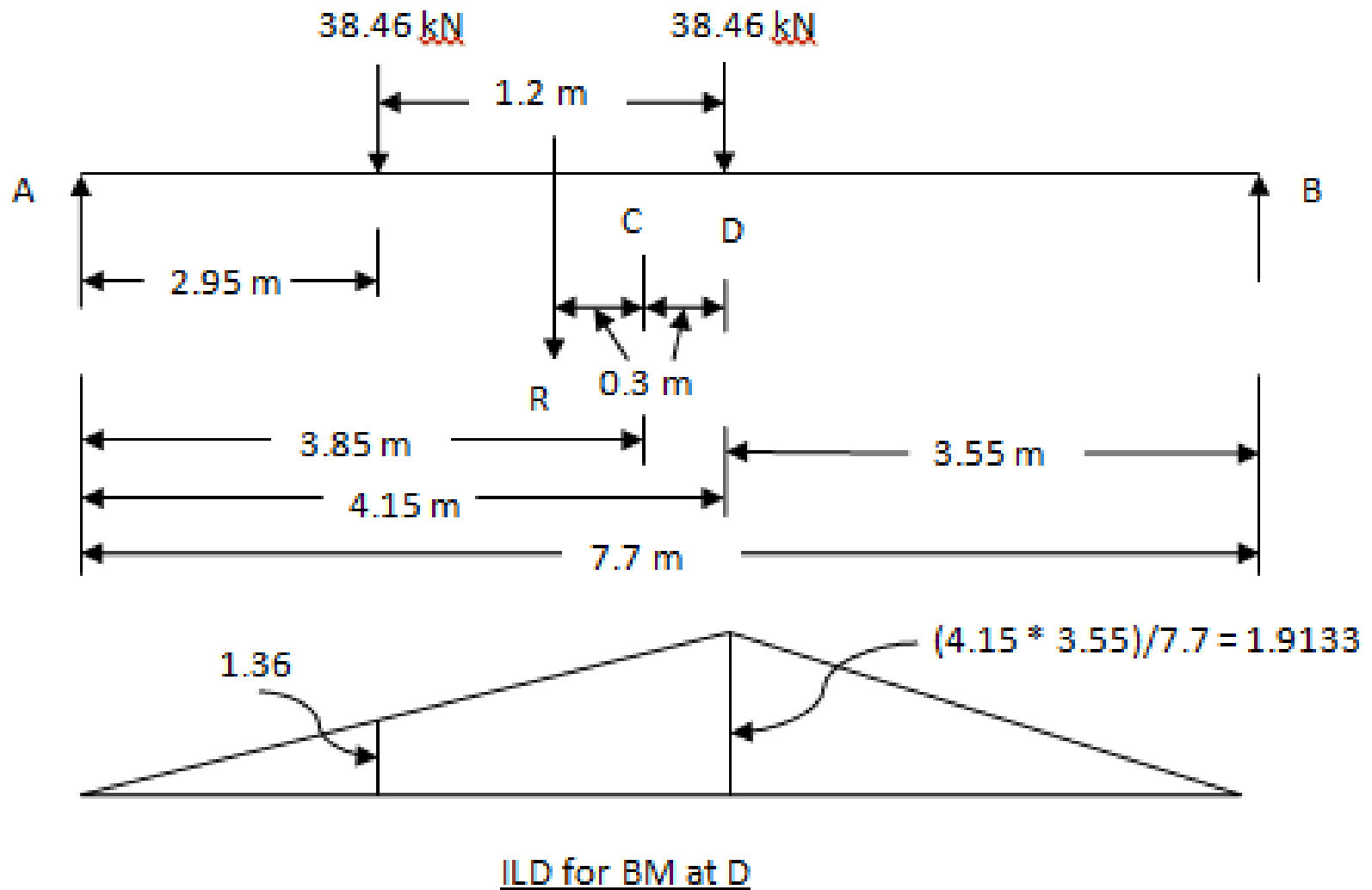
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$$\text{Maximum BM at D} = 38.46 * (1.9133 + 1.36) = 125.89 \text{ kN m}$$

Hence the BM is governed by design tandem load

Conti.....

- Load position



### For Design Lane Load:\_\_\_

- Lane load BM is determined at the section of maximum BM, section D, of design tandem loading

$$\text{Lane load BM at D} = 3.1 * (7.7 * 1.9133) / 2 = 22.84 \text{ kN m}$$

### **Total maximum BM**

- Total maximum BM with IM =  $(125.89 * 1.33) + 22.84 = 190.27 \text{ kN m}$

### **Dead Loads**

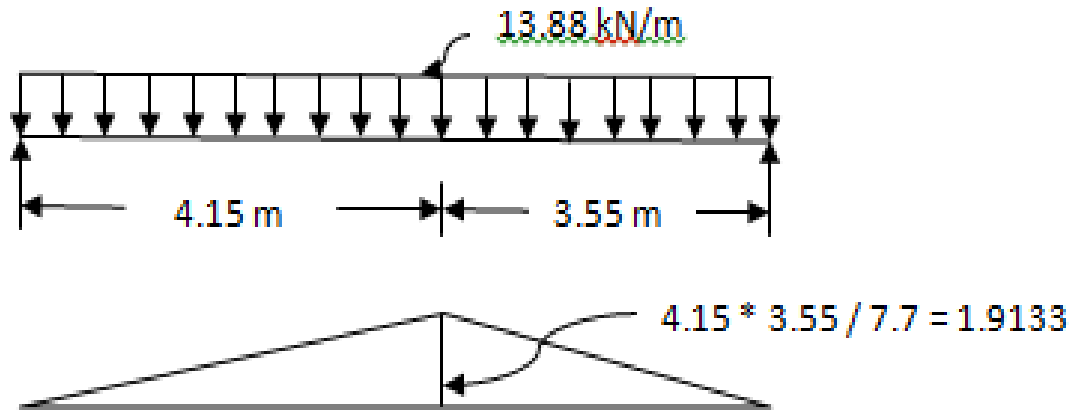
- Assume depth of wearing surface = 0.075 m
- Weight of wearing surface =  $0.075 * 22.5 = 1.6875 \text{ kN/m}^2$
- Weight of deck slab =  $0.47 * 24 = 11.28 \text{ kN/m}^2$
- Weight of railing, post and curb
- $= [ \{ (0.35 * 0.25 * 24) + 0.7143 * (0.25 * 0.25 * 0.55 * 24) + (0.4 * 0.4 * 24) \} * 2 ] \div 5$
- $= 2.6 \text{ kN/m}^2$  \_\_

## Conti.....

Total weight of components

DC = wt of deck + wt of railing =  $11.28 + 2.6 = 13.88 \text{ kN/m}^2$ \_\_

- Maximum shear due to DC =  $V_{DC} = 13.88 [\frac{1}{2} * 7.7 * 1] = 53.44 \text{ kN/m width}$
- Maximum Shear due to DW =  $V_{DW} = 1.6875 [\frac{1}{2} * 7.7 * 1] = 6.5 \text{ kN/m width}$
- Maximum bending moment due to DC at the section of maximum **LL BM**



- ✓ BM at the section D due to the load DC =  $13.88 [\frac{1}{2} * 7.7 * 1.9133] = 102.24 \text{ kNm}$
- ✓ Maximum BM due to DW at the section of maximum LL BM =  $1.6875 [\frac{1}{2} * 7.7 * 1.9133] = 12.43 \text{ kNm}$



**Table 3.4.1-2: Load Factors for Permanent Loads,  $\gamma_p$**

| Type of Load, Foundation Type, and Method Used to Calculate Downdrag               |                                                 | Load Factor |         |
|------------------------------------------------------------------------------------|-------------------------------------------------|-------------|---------|
|                                                                                    |                                                 | Maximum     | Minimum |
| <i>DC</i> : Component and Attachments                                              |                                                 | 1.25        | 0.90    |
| <i>DC</i> : Strength IV only                                                       |                                                 | 1.50        | 0.90    |
| <i>DC</i> : Downdrag                                                               | Piles, $\alpha$ Tomlinson Method                | 1.4         | 0.25    |
|                                                                                    | Piles, $\lambda$ Method                         | 1.05        | 0.30    |
|                                                                                    | Drilled shafts, O'Neill and Reese (1999) Method | 1.25        | 0.35    |
| <i>DW</i> : Wearing Surfaces and Utilities                                         |                                                 | 1.50        | 0.65    |
| <i>EH</i> : Horizontal Earth Pressure                                              |                                                 |             |         |
| • Active                                                                           |                                                 | 1.50        | 0.90    |
| • At-Rest                                                                          |                                                 | 1.35        | 0.90    |
| • <i>AEP</i> for anchored walls                                                    |                                                 | 1.35        | N/A     |
| <i>EL</i> : Locked-in Construction Stresses                                        |                                                 | 1.00        | 1.00    |
| <i>EV</i> : Vertical Earth Pressure                                                |                                                 |             |         |
| • Overall Stability                                                                |                                                 | 1.00        | N/A     |
| • Retaining Walls and Abutments                                                    |                                                 | 1.35        | 1.00    |
| • Rigid Buried Structure                                                           |                                                 | 1.30        | 0.90    |
| • Rigid Frames                                                                     |                                                 | 1.35        | 0.90    |
| • Flexible Buried Structures other than Metal Box Culverts                         |                                                 | 1.95        | 0.90    |
| • Flexible Metal Box Culverts and Structural Plate Culverts with Deep Corrugations |                                                 | 1.50        | 0.90    |
| <i>ES</i> : Earth Surcharge                                                        |                                                 | 1.50        | 0.75    |

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## **Design load combination for strength I limit state**

$$Q = \sum \eta_i \gamma_i Q_i$$

Consider the design to be of conventional one, non-redundant and typical bridge, for these assumptions,

$$\eta_D = 1.00 \quad \eta_R = 1.05 \quad \eta_I = 1.00$$

$$\text{Factored resistant moment } M_u = 1.05[1.25 M_{DC} + 1.5M_{DW} + 1.75M_{LL+IM}]$$

$$= 1.05[1.25 (102.24 ) + 1.5(12.43 ) + 1.75(190.27)] = 479.4 \text{ kNm}$$

# LOAD FACTORS AND COMBINATIONS

## *GENERAL*

- The total factored force effect:  $Q = \sum \eta_i \sum \lambda_i Q_i$   
 $\eta_i$  = load modifier (a factor relating to ductility, redundancy and operational importance)  
 $Q_i$  = force effects from loads specified herein  
 $\lambda_i$  = load factors

As per ERA bridge design manual LRFD design procedure, factored resistant moment  $M_u = \phi M_n$

Where,  $M_n$  = Nominal resistant moment,

$\Phi$  = Resistance factor

- $M_n = M_u / \phi$ , has to be used in the equation for steel ratio  $\rho$
- Steel ratio  $\rho$  can be written as,

Conti....

$$\rho = \left[ 1 - \sqrt{1 - \frac{2M_u}{\phi b d^2 f'_c}} \right] \frac{f'_c}{f_y} = \left[ 1 - \sqrt{1 - \frac{2 \times 479.4 \times 10^6}{0.9 \times 1000 \times 433^2 \times 30}} \right] \frac{30}{420} = 0.00712$$

- $\rho_{\min} = 0.03 * (30/420) = 0.00241 < 0.00712 = 0.03 f_{ck}/f_{yk}$

$$A_s = \rho * b * d = 0.00712 * 1000 * 433 = 3082.96 \text{ mm}^2$$

Where  $d = D - \text{cover} - \text{diameter of bar}/2 = 470 - 25 - 24/2 = 433 \text{ mm}$

Spacing of 24 mm diameter rods = 146.74 mm

Provide 24 mm diameter rods at 140 mm c/c as main flexural reinforcement along the span.

As provided =

$$\frac{\pi * (12)^2 * 1000}{140} = 3231 \text{ mm}^2$$

## **Distribution of main reinforcement to resist against cracking:**

- Concrete is considered cracked if tensile stress in concrete  $\geq 80\%$  of the modulus of rupture
- $f_r$  = Modulus of rupture = 3.45 MPa (as determined in the earlier steps)
- Service load moment  $M_u = \gamma_{EI} (\gamma_{Li} M_{DC} + \gamma_{Li} M_{DW} + \gamma_{Li} M_{LL+IM})$   
where  $\gamma_{Li} = 1$  for serviceability limit state I

$$1.05[1.00(102.24) + 1.00(12.43) + 1.00(190.27)] = 320.187 \text{ kNm}$$

- $f_{ct}$  = tensile stress in concrete =  $M^*C/I_g$  where  $C=d/2$  and  $I_g=bd^3/12 = m/(bd^3/3)$   
= 8.69 MPa

Conti.....

$0.8f_r = 0.8 * 3.45 = 2.76$ ;  $f_{ct} > 0.8f_r$  Therefore the section has to be taken as a cracked section.

Steel stress: To find the steel stress, for cracked section, consider the equivalent transformed section of concrete.

- Modular ratio  $= m = E_s/E_c = 2 * 10^5/24000 = 8.33$   $mA_s = 8.33 * 3231 = 26914.23 \text{ mm}^2$
- X can be determined by taking moments of areas above and below NA

$$1000 * x * x/2 = 26914.23 (433 - x) \text{ where } D_{\text{Slab-dc}} = 470 - 25 + \text{diameter}/2$$

It can be reduced to a quadratic equation

$$x^2 + 53.8x - 23307.7 = 0 \quad X = 128.12 \text{ mm}$$

$$\text{Moment of inertia } I = 1/3(1000 * 128.12^3) + 26914.23 (433 - 128.12)^2 = 3.2 * 10^9 \text{ mm}^4$$

Conti.....

$$f_s/m = My/I = 30.5; \text{that is } f_s/m = 30$$

$$\text{then } f_s = 8.33 * 30.5 = 254.11 \text{ MPa}$$

Allowable tensile stress in the reinforcement =  $f_{sa}$  =      Where  $Z$  =  
30,000 for moderate exposure;

$$d_c = \text{concrete cover} + \text{bar diameter}/2 = 25 + 24/2 = 37 \text{ mm}$$

$$A = 2d_c S = 2 * 37 * 140/1 = 10360 \text{ mm}^2 \text{ where } s = \text{bar spacing}$$

$$f_{sa} = 412.98 \text{ MPa} \quad \text{But } f_{sa} = \tau_{||}$$

$$0.6 f_y ; \quad 0.6(420) = 252 \text{ MPa}$$

$f_s > f_{sa}$  Hence the provision of spacing of main reinforcement is **not safe** against cracking.

The spacing of reinforcement shall be adjusted to satisfy the above criterion

## Distributor reinforcement

- For primary reinforcement parallel to traffic, % of main reinforcement as distributor reinforcement

$$1750 / \sqrt{S} \leq 50\%$$

- Where S = Span length = 7.7m = 7700 mm

$$1750 / \sqrt{7700} = 20\%$$

20% of main reinforcement =  $20 * A_s / 100 = (20/100) * 3231$   
 = 646.2 mm<sup>2</sup>

- Spacing of 16 mm dia rods = 311.15 mm
- Provide 16 mm diameter rods at 300 mm c/c as distribution reinforcement

Conti.....

## **Temperature and shrinkage reinforcement**

Temperature and shrinkage reinforcement  $A_s \leq 0.75 A_g / f_y$

Where  $A_g = b * D$  of concrete section

$A_s = 0.75 * 1000 * 470 / 420 = 839.3 \text{ mm}^2$  for both direction

For top layer alone:  $A_s = 839.3 / 2 = 419.6 \text{ mm}^2$

Spacing of 12 mm dia rods = = 269.5 mm

Provide 12 mm dia rods at 260 mm C/C in both directions at the top as temperature and shrinkage reinforcements.

**This is all about .....**

**Thank you**