Lecture - 08

Introduction to Bridge Engineering

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Topics

- Introduction
- Bridge Components
- Types of Bridges
- Loads for Bridge Design
- Analysis & Design of Simply Supported RC Slab Bridges
- Example
- Famous Bridges in the World

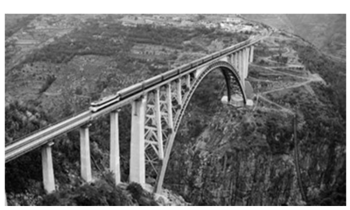
Objectives

At the end of this lecture, students will be able to

- Differentiate between bridge and culvert
- Explain how different type of bridges resist loads
- Analyze & Design Simply Supported RC Slab Bridges

Introduction

- Bridge is a structure having an opening not less than 6000 mm that forms part of a highway or over, or under which the highway passes.
- Structures < 6000 mm generally called culverts.

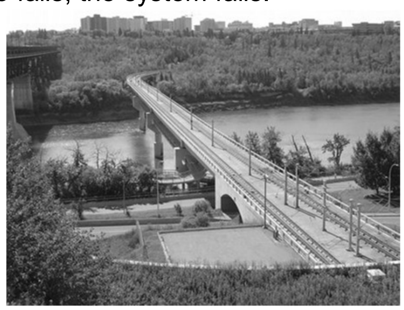


Bridge

Culvert

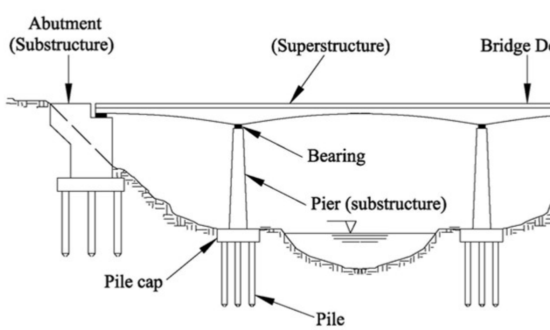
Introduction

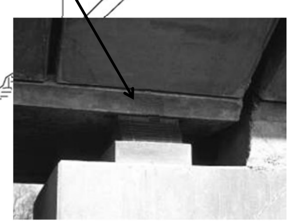
- Bridge is the key element in a Transportation System:
  - It controls the capacity of the system.
  - It is the highest cost per mile of the system.
  - If the bridge fails, the system fails.



Bridge Components

- A bridge consists of super structure and sub structure.

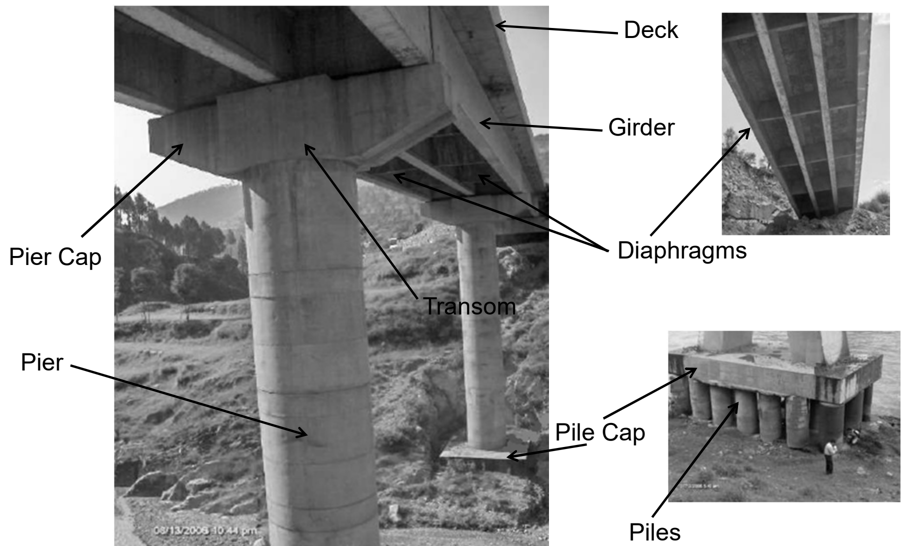




<u>Super structure:</u> Structural parts of the bridge which provides the horizontal span.

<u>Sub structure:</u> Structural parts of the bridge which supports the horizontal span.

Bridge Components



Types of Bridges

- **Bridges can be classified according to:**
  - Materials (concrete, steel or wood etc),
  - Usage (pedestrian, highway, or railroad),
  - Span (short, medium, or long),
  - Structural form (slabs, girder, truss, arch, suspension, or cable-stayed).

Types of Bridges

- It is however, suitable to classify bridges according to the location of the main structural elements relative to the surface on which the user travels:
  - Main structure Below the deck line,
  - Main structure Above the deck line, or
  - Main structure Coinciding with the deck line.

Types of Bridges

- **Main Structure Below Deck line**
  - Arched, Truss-Arched Bridges, Masonry Arch, Concrete Arch, the Steel-Truss Arch, and the Steel Deck Truss.

Masonry Arch

Masonry Arch

Steel Deck Truss Bridge

Types of Bridges

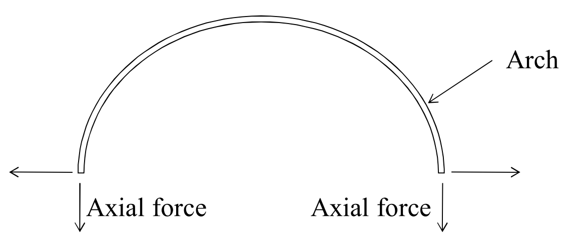
- **Main Structure Below Deck line**

Concrete Arch

Steel Truss Arch

Types of Bridges

- **Main Structure Below Deck line**
  - With arch shape, gravity loads are transmitted to the supports primarily by axial compressive forces.
  - At the supports, both vertical and horizontal reactions must be resisted.

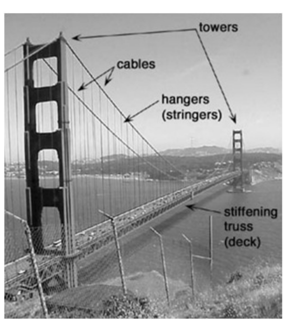


Types of Bridges

- **Main Structure Below Deck line**
  - Salient features of Arch Type Bridge
    - The arch form is intended to reduce bending moments in the superstructure.
    - The most suitable site for this form of structure is a valley, with the arch foundation located on dry rock slopes.
    - The conventional curved arch rib may have high fabrication and erection costs, although these may be controlled by skilled labor.
    - The classic arch form tends to favor concrete as a construction material.

Types of Bridges

- **Main Structure Above Deck line**
  - Suspension, Cable Stayed, and Through-Truss bridges are included in this category.



Suspension: Deck is supported by two main cables through secondary cables (hangers).

Types of Bridges

- **Main Structure Above Deck line**

Cable-stayed: Deck is supported by tower directly through cables.

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Types of Bridges

- **Main Structure Above Deck line**

Through Bridges

Types of Bridges

- **Main Structure Above Deck line**
  - Salient features of Suspension Bridges
    - The flexible cables of a suspension bridge are shaped and supported to transfer major loads to the towers and anchorages by direct tension.
    - The deck is hung from the cable by hangers constructed of high strength wire ropes in tension.
    - This use of high strength steel in tension leads to an economical structure.

Types of Bridges

- **Main Structure Above Deck line**
  - Salient features of Suspension Bridges
    - The main cable is stiffened either by a pair of stiffening trusses or by a system of girders at deck level.
    - This stiffening system serves to:
      - a) Control aerodynamic movements,
      - b) Limit local angle changes in the deck.

Stiffening trusses

Types of Bridges

- **Main Structure Above Deck line**
  - Salient features of Cable Stayed bridges
    - As compared with suspension bridges, the cables are straight rather than curved. As a result, the stiffness is greater.
    - Aerodynamics instability has not been found to be a problem in such structures.

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Types of Bridges

- **Main Structure Above Deck line**
  - Salient features of Through Bridges
    - A bridge truss has two main structural advantages:
      1. The primary member forces are axial loads;
      2. The open web system permits the use of a greater overall depth (due to lesser dead load) than for an equivalent solid web girder.
    - Both these factors lead to economy in material and a reduced dead weight.
    - The increased depth also leads to reduced deflection.
    - Economical for medium spans.
    - Aesthetically pleasing.

Types of Bridges

- **Main Structure Coinciding with Deck line**
  - Girder bridges of all types are included in this category. Examples are:
    - Slab (solid and voided),
    - T-beam,
    - I-beam,
    - Wide-flange beam,
    - Concrete box girder,
    - Steel box,
    - Steel plate girder.

Concrete Box Girder Bridge

Types of Bridges

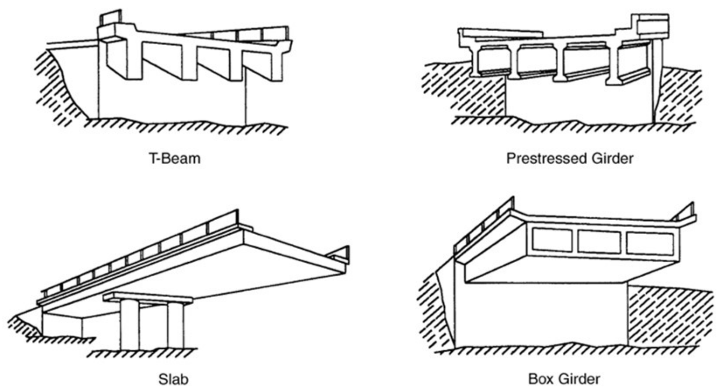
- **Main Structure Coinciding with Deck line**

Box Girder Bridge

Girder Bridge Under Construction

Types of Bridges

- **Main Structure Coinciding with Deck line**



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Loads for Bridge Design

- Loads to be considered in bridge design can be divided into two broad categories:
  - Permanent loads,
  - Transient loads.

Loads for Bridge Design

- **Permanent Loads**
  - Self weight of girders and deck, wearing surface, curbs and parapets and railings, utilities and luminaries and pressures from earth retainments.
  - Two important dead loads are:
    - DC: Dead load of structural components and non structural attachments.
    - DW: Dead load of wearing surface.

Loads for Bridge Design

- **Permanent Loads**
  - Material Properties for Pavement
    - $\gamma_{bitumen}$ = 140 lb/ cft
    - $\gamma_{concrete}$ = 150 lb/ cft
  - Load factors for Pavement Dead Loads
    - The maximum load factor for DC = 1.25
    - The maximum load factor for DW = 1.5

Loads for Bridge Design

- **Transient Loads**
  - Gravity (Live) loads due to vehicular, railway and pedestrian traffic.
  - The automobile is one of the most common vehicular live load on most bridges; it is the truck that causes the critical load effects.
  - Lateral loads due to water, wind, earthquake and ship collisions etc.

Loads for Bridge Design

- **Transient Loads**
  - Following effects caused by Live load are also very important and must be considered in the design of a bridge.
    - Impact (dynamic effects),
    - Braking forces,
    - Centrifugal forces (if present) and
    - The effects of other trucks simultaneously present.

Loads for Bridge Design

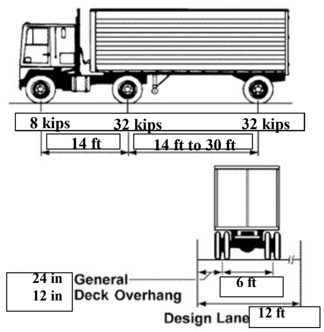
- **Vehicular Design Loads**
  - The AASHTO design loads model consists of three distinctly different loads:
    - Design Truck,
    - Design Tandem,
    - Design Lane.

Loads for Bridge Design

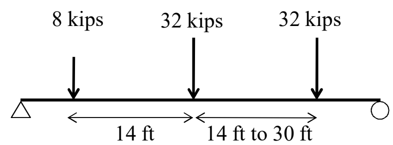
- **Vehicular Design Loads**
  - The vehicle combination as described in AASHTO (1994) LRFD Bridge specifications are designated as HL-93 for Highway Loading accepted in 1993.

Loads for Bridge Design

- **Vehicular Design Loads**
  - Design Truck



HL-93 Truck Load



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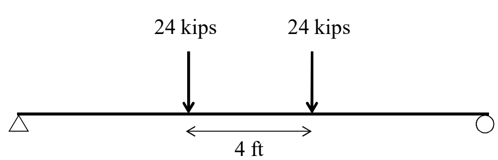
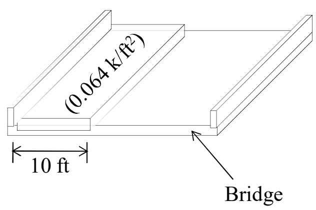
Loads for Bridge Design

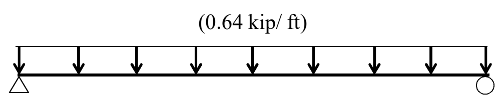
- **Vehicular Design Loads**
  - Design Tandem



Loads for Bridge Design

- **Vehicular Design Loads**
  - Design Lane Load
    - The AASHTO design lane loading is like a caravan of trucks.
    - It is 0.064 k/ft^2 and is assumed to occupy a region of 10 ft.
      - It is applied as 0.064 k/ft^2 (64 lb/ft^2) of pressure to a width of 10 ft over the entire length of bridge for FEM.





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Loads for Bridge Design

- **Vehicular Design Loads**
  - In summary three design loads should be considered:

    the design truck, design tandem, and the design lane.
  - These loads are superimposed by two ways to yield the live load effects, which are combined with the other load effects.
  - The two ways of superposition are:
    - Truck + lane
    - Tandem + lane

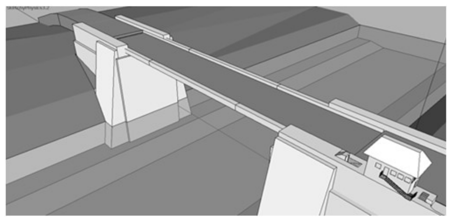
Loads for Bridge Design

- **Load Modifier**
  - A factor accounting for ductility, redundancy and the operational importance of the bridge.
  - It is taken as 1.05 for simply supported bridges and is applied on already factored values of bending moments.

Analysis and Design of Simply Supported RC Slab Bridges

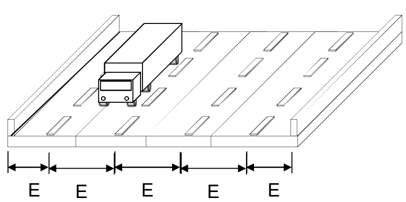
Analysis and Design of Simply Supported RC Slab Bridges

- **Simply Supported RC Slab Bridge**
  - This type of bridge consist of only a slab (without any other supporting member such as girders).
  - A slab bridge is widely used when the bridge crosses a minor road or small river.



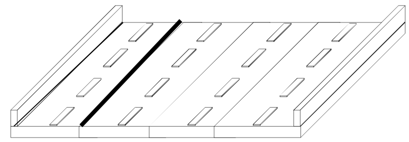
Analysis and Design of Simply Supported RC Slab Bridges

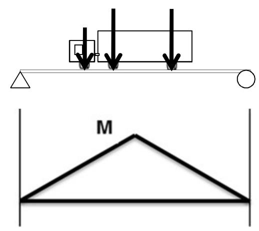
- **Design lane**
  - Slab bridges can be analyzed as 3D, 2D and 1D models.
  - If it is to be analyzed as 1D model (line analysis), the bridge width will be divided into various strips.
  - These strips with a strip width of "E" are called design lanes.



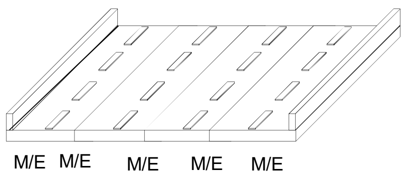
Analysis and Design of Simply Supported RC Slab Bridges

- **Design lane**
  - The design lanes are then transformed to line elements (1D model) for line analysis. The moment are calculated from line analysis.
  - These moments (M) are then divided by the design lane width (E) to get moment per foot (M/E) for the slab.





Moment Obtained from 1D analysis



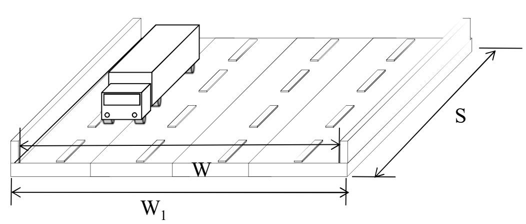
- Design lane widths can be calculated using equations given as follows.

Analysis and Design of Simply Supported RC Slab Bridges

- **Design Lane Width**
  - **<u>For single lane loaded</u>**:
  - E (inches) = $10.0 + 5.0 \sqrt{(L_1 W_1)}$ …….. **(1)**

    L_1 = Modified span length = Minimum of (S) and 60 ft

    W_1 = Modified edge to edge width = Minimum of (Overall width of bridge, W_1) or 30 ft



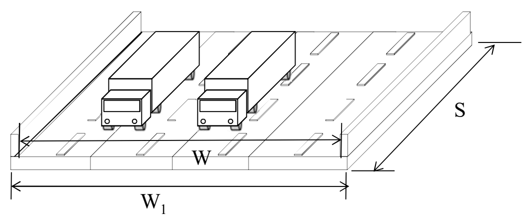
Analysis and Design of Simply Supported RC Slab Bridges

- **Design Lane Width**
  - **For multilane loaded:**
  - E (inches) = $84 + 1.44\sqrt{(L_1W_1)} \leq W_1/N_L$ ……… **(2)**

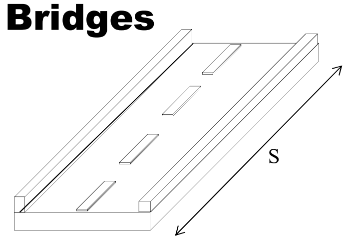
    L_1 = Same as single lane loaded case = Minimum of (S) and 60 ft

    W_1 = Minimum of (overall width of bridge, W_1) or 60 ft

    N_L = No. of design lanes= INT (W/12)
- Design Lane Width **E**, is the smallest value of (1) & (2)



Analysis and Design of Simply Supported RC Slab Bridges



- **Design of RC Slab Bridge**
  - Depth, h (ft) = 1.2(S + 10)/30

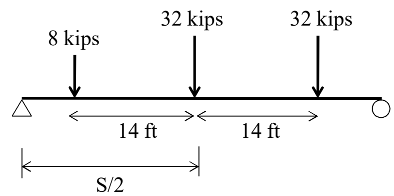
    (S = span of bridge)
- **ØMn ≥ Mu**
  - $M_u = 1.05\,[1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+IM}]$ (per foot)
    - $M_{DC} = W_{DC}S^2/8$ (ft-kip/ft) ($W_{DC} = h\gamma_{concrete}$) } **Dead Loads**
    - $M_{DW} = W_{DW}S^2/8$ (ft-kip/ft) ($W_{DW} = h\gamma_{wearing\ surface}$) } **Dead Loads**
    - $M_{LL+IM} = 1.33(M_{Tandem}$ OR $M_{Truck}) + M_{lane}$ (ft-kip) } **Live Load**
      - Convert M_{LL+IM} to ft-kip/ft, Divide M_{LL+IM} by "E", design lane width.

Analysis and Design of Simply Supported RC Slab Bridges

- **Design of RC Slab Bridge**
  - Slab moments due to live loads:

1. Moment due to HL-93 Truck load, M_{Truck}

(Max. moment due to truck load can be obtained by placing the middle axle at mid span of the bridge and rear axle load at a distance of 14 ft from the middle axle load)



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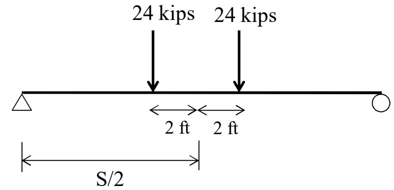
Analysis and Design of Simply Supported RC Slab Bridges

- **Design of RC Slab Bridge**
  - Slab moments due to live loads:

2. Moment due Tandem Load, M_{Tandem}

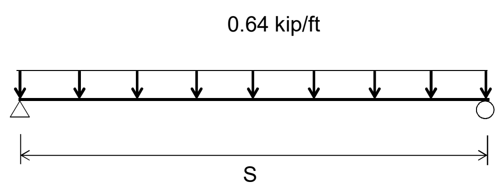
(Max. moment due to tandem load can be obtained by placing the two loads at a distance of 2 ft from the mid span)



Analysis and Design of Simply Supported RC Slab Bridges

- **Design of RC Slab Bridge**
  - Slab moments due to live loads:

  3. Moment due design lane load, M_{Lane}
     - $M_{Lane} = 0.64\ S^2/8$



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Analysis and Design of Simply Supported RC Slab Bridges

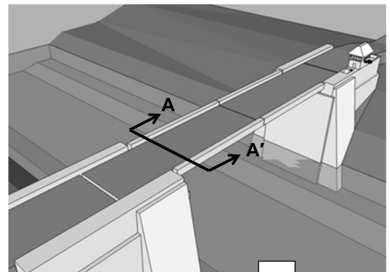
- **Design of RC Slab Bridge**

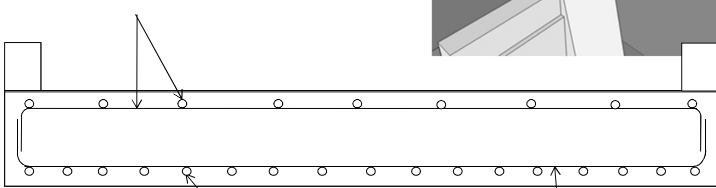
  a) Distribution reinforcement (bottom transverse reinforcement) {A5.14.4.1}:
     - $A_{transverse} = (100/\sqrt{S}$ or 50 %) of A_s (whichever is less, But It should not be less than A_s(Shrinkage)
     - A_{stmin} (shrinkage)= $0.0018A_g$

  b) Shrinkage and temperature reinforcement in top face of slab (long and transverse both): For grade 60 steel,
     - $A_{st} = 0.0018A_g$

Analysis and Design of Simply Supported RC Slab Bridges

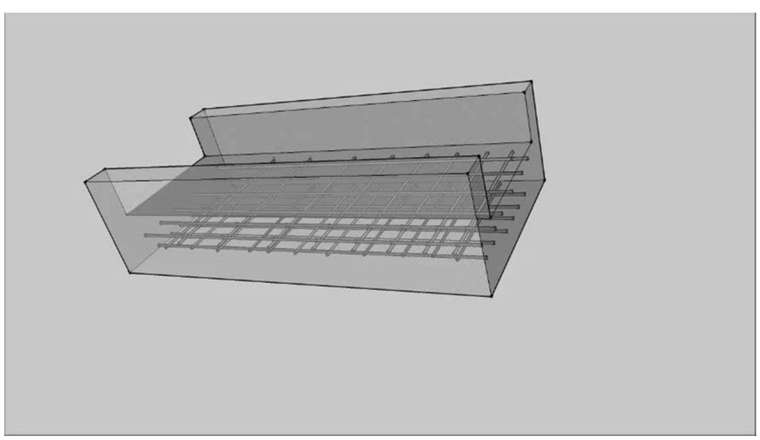
- **Reinforcement Detail in Slab Bridge:**





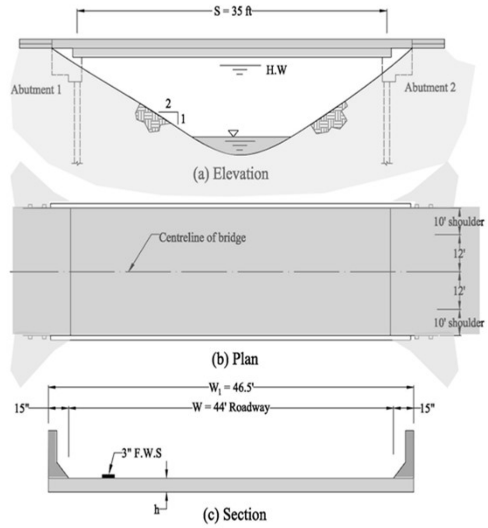
Analysis and Design of Simply Supported RC Slab Bridges

- **Reinforcement Detail in Slab Bridge:**
  - Bridge Reinforcement Animation



Example

- **Design Problem:** Design of simply supported slab bridge for HL-93 live load.
  - Span length of 35 ft centre to centre of bearings.
  - Roadway width is 44 ft curb to curb.
  - Allow for a future wearing surface of 3 inch thick bituminous overlay.
  - Use f_c' = 4000 psi and f_y = 60 ksi.



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Example

- **Solution:**
- **Step No 1: Sizes.**
  - Span length of bridge (S) = 35 ft c/c
  - Clear roadway width (W) = 44 ft (curb to curb)
  - For a curb width of 15 inches, total width of the bridge (W_1) = 44 + (2 × 15/12) = 46.5 ft
  - Minimum thickness of bridge slab is given by formula:

    h_{min} = 1.2(S + 10)/30 = 1.2 (35 + 10)/30 = 1.8 ft = 21.6″ ≈ 22″

Example

- **Solution:**
- **Step No 2: Loads.**
  - Slab load (w_{DC}) = $h\gamma_{conc}$

    = (22/12) × 0.15 = 0.275 ksf
  - Wearing surface load (w_{DW}) = $h\gamma_{wearing\ surface}$

    = (3/12) × 0.14 = 0.035 ksf

Example

- **Solution:**
- **Step No 3: Analysis.**
  - Dead load moments:

    Slab moments (M_{DC}) = $w_{DC}S^2/8$

    = 0.275 × (35^2)/8 = 42 ft-kip/ft

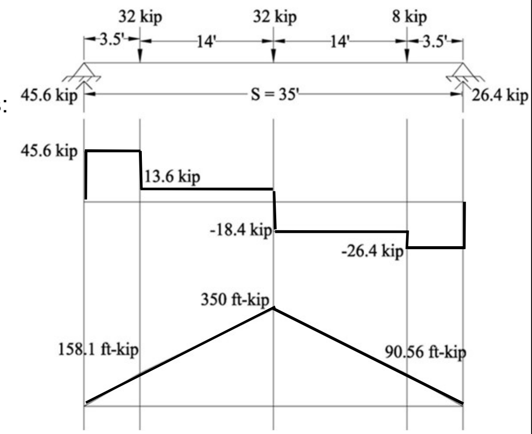
    Wearing surface moment (M_{DW}) = $w_{DW}S^2/8$

    = 0.035 × 35^2/8 = 5.3 ft-kip/ft

Example

- **Solution:**
- **Step No 3: Analysis.**
  - Live load moments:
    - Truck Load moments:

      M_{Truck} = 350 ft-kip



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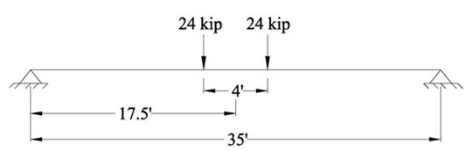
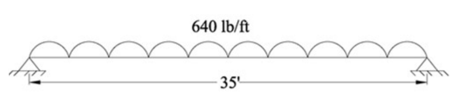
Example

- **Solution:**
- **Step No 3: Analysis.**
  - Live load moments:
    - Tandem moment:

      M_{tandem} = 372 ft-kip





    - Lane moment:

      $M_{lane} = 0.64 \times 35^2/8 = 98$ ft-kip

Example

- **Solution:**
- **Step No 3: Analysis.**
  - Live load moments:
    - $M_{tandem} > M_{truck}$, therefore we will use M_{tandem}
    - M_{LL+IM} (Including impact) = $1.33M_{tandem} + M_{lane}$

      = 1.33 × 372 + 98 = 593 ft-kip
    - To convert M_{LL+IM} to moment/ft, Divide M_{LL+IM} by "E" design lane width.

Example

- **Solution:**
- **Step No 3: Analysis.**
  - Design Lane width "E" :
  - For single lane loaded:
    - E (inches) = $10.0 + 5.0 \sqrt{(L_1W_1)}$

      L_1 = Modified span length = Minimum of (S = 35 ft) and 60 ft = 35 ft

      W_1 = Modified edge to edge width = Minimum of (W_1 = 46.5 ft) or 30 ft = 30 ft
    - Therefore, E = $10.00 + 5.0\sqrt{(35 \times 30.00)}$ = 172 in = 14.3 ft

Example

- **Solution:**
- **Step No 3: Analysis.**
  - Design Lane width "E" :
  - For multilane loaded:
    - E (inches) = 84 + 1.44√ (L_1W_1) ≤ W_1/N_L

      L_1 = 35 ft

      W_1 = Minimum of (W_1 = 46.5 ft) or 60 ft = 46.5 ft

      N_L = No. of design lanes.= INT (W/12) =INT (44/12) = 3
    - E = 84 + 1.44 √ (35 × 46.5) ≤ 46.5/3

      = 142 inch or 11.84 ft ≤ 15.5
    - Therefore, E = 11.84 ft (Least of all)

Example

- **Solution:**
- **Step No 3: Analysis.**
  - Moment (per foot)
    - M_{LL+IM} per foot = 593/11.84 = 50 ft-kip/ft

      Now,
    - M_u = 1.05 [1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+IM} (per foot)]
    - M_u = 1.05 (1.25 × 42 + 1.5 × 5.33 + 1.75 × 50)
    - M_u = 155.3 ft-kip/ft = 1863.6 in-kip/ft

Example

- **Solution:**
- **Step No 4: Design.**
  - (a) Design :
    - Moment (M_u) = 155.3 ft-kip/ft = 1863.6 in-kip/ft
    - Effective depth of bridge slab (d) = h – cover – ½ × Dia of bar used
    - Using #8 bar, effective depth is bottom cover for slab is taken equal to 1″.
    - d = 22 – 1 – ½ × 1 = 20.5 inch
    - A_{smin} = 0.0018 × 12 × 22 = 0.47 in^2
    - $A_s = M_u/\{\Phi f_y (d - a/2)\}$
    - After trials, A_s = 1.80 in^2,(#8 @ 4 inches c/c)

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Example

- **Solution:**
- **Step No 4: Design.**
  - (b) Distribution reinforcement (bottom transverse reinforcement) {A5.14.4.1}:
    - The amount of bottom transverse reinforcement may be taken as a percentage of the main reinforcement required for positive moment as follows but not less than Shrinkage reinforcement:
    - $A_{transverse}$ = (100/√S or 50 %) of A_s (whichever is less)

      100/√L = 100/√35 = 16.9 % < 50 %
    - Therefore, $A_{transverse}$ = 0.169 × 1.80 = 0.304 in^2
    - A_{stmim} (shrinkage)= 0.0018A_g = 0.0018 × 12 × 22 = 0.47 in^2 (#5 @ 8 inches c/c)

Example

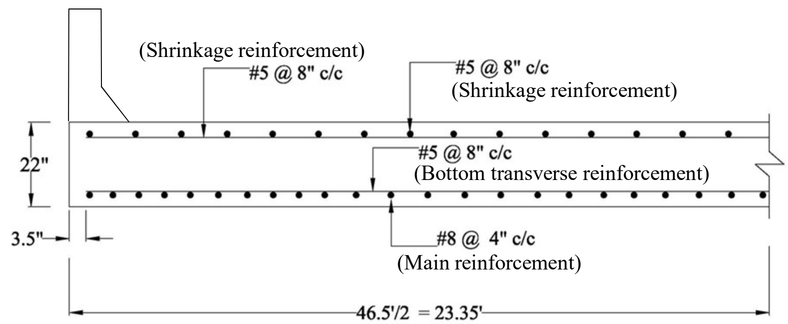
- **Solution:**
- **Step No 4: Design.**
  - (b) Distribution reinforcement (bottom transverse reinforcement) {A5.14.4.1}:
    - Maximum spacing for temperature steel reinforcement in one way slab according to ACI 7.7.6.2.1 is minimum of:
      - $5h_f = 5 \times 22 = 110''$
      - 18″
    - Therefore #5 @ 8 inches c/c is OK.

Example

- **Solution:**
- **Step No 4: Design.**
  - (e) Shrinkage and temperature reinforcement in top face of slab (long and transverse both): For grade 60 steel,
    - $A_{st} = 0.0018A_g = 0.0018 \times 12 \times 22 = 0.47$ in^2 (#5 @ 8 inches c/c)
    - Finally use #5 @ 8 inches c/c.
  - **Final Recommendation:**
    - Main steel (bottom) = #8 @ 4″ c/c.
    - Transverse bottom reinforcement = #5 @ 8″ c/c throughout.
    - Top steel (long and transverse) = #5 @ 8″ c/c.

Example

- **Solution:**
- **Step No 5: Drafting**

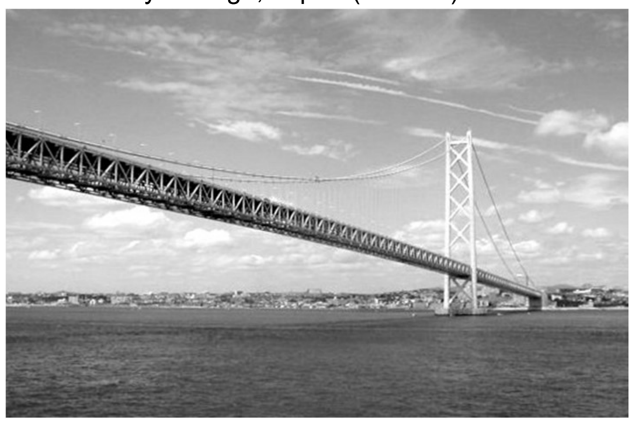


Some Famous Bridges

- **Longest Bridge**
  - Danyang–Kunshan Grand Bridge in China (164800 m)

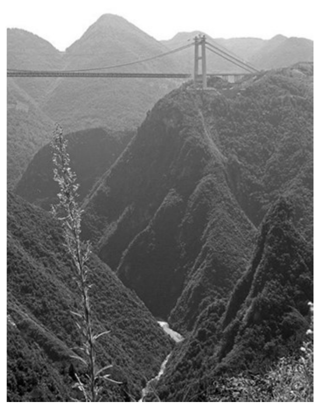
Some Famous Bridges

- **Longest Span**
  - Akashi Kaikyō Bridge, Japan (1991 m)



Some Famous Bridges

- **Highest Bridge**
  - Si Du River Bridge (472 m high)



Bridges in Pakistan

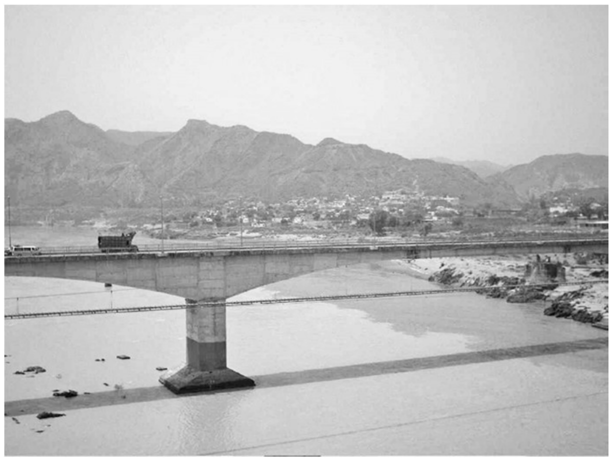
- **Lansdowne Bridge, Sukkur**

Bridges in Pakistan

- **Jamshoro Bridge, Jamshoro**

Bridges in Pakistan

- **Attock Bridge, Attock**



Bridges in Pakistan

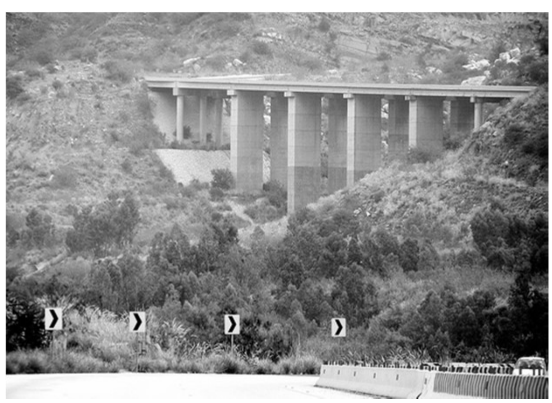
- **Malir Bridge, Karachi**
  - Longest Bridge in Pakistan (5000 m)

Bridges in Pakistan

- **Chiniot Railway Bridge**
  - Constructed in 1877.

Bridges in Pakistan

- **Bridge on M2 Motorway**
  - One of the highest in Asia.



References

- Design of Highway Bridges by Richard M. Barker.
- ACI 318-14

THE END