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
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.

Super structure: Structural parts of the bridge which provides the horizontal span.

Sub structure: Structural parts of the bridge which supports the horizontal span.
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).

- 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.
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.

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   Arch

      Axial force  Axial force
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- **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).

• Main Structure Above Deck line

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

• Main Structure Above Deck line

Through Bridges

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.

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.
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.

- **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

Girder Bridge Under Construction

Box Girder Bridge

Types of Bridges

- Main Structure Coinciding with Deck line

T-Beam

Prestressed Girder

Slab

Box Girder
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
    - $\gamma_{\text{bitumen}} = 140 \text{ lb/ft}^3$
    - $\gamma_{\text{concrete}} = 150 \text{ lb/ft}^3$
  - Load factors for Pavement Dead Loads
    - The maximum load factor for DC = 1.25
    - The maximum load factor for DW = 1.5

- **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.

HL-93 Truck Load
 Loads for Bridge Design

• Vehicular Design Loads
  • Design Tandem

Design Tandem

24 kips 24 kips

4 ft

• Vehicular Design Loads
  • Design Lane Load

The AASHTO design lane loading is like a caravan of trucks.

- It is 0.064 kip/ft² and is assumed to occupy a region of 10 ft.
  - It is applied as 0.064 kip/ft² (64 lb/ft²) of pressure to a width of 10 ft over the entire length of bridge for FEM.

Bridge

(0.64 kip/ ft)
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

- **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

- 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.

- 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.

- Design lane widths can be calculated using equations given as follows.
• Design Lane Width
  - For single lane loaded:
    \[ E \text{ (inches)} = 10.0 + 5.0 \sqrt{L_1 W_1} \]  \hspace{1cm} (1)
    \[ L_1 = \text{Modified span length} = \text{Minimum of (S) and 60 ft} \]
    \[ W_1 = \text{Modified edge to edge width} = \text{Minimum of (Overall width of bridge, } W_1) \text{ or 30 ft} \]
  - For multilane loaded:
    \[ E \text{ (inches)} = 84 + 1.44 \sqrt{L_1 W_1} \leq \frac{W_1}{N_L} \]  \hspace{1cm} (2)
    \[ L_1 = \text{Same as single lane loaded case} = \text{Minimum of (S) and 60 ft} \]
    \[ W_1 = \text{Minimum of (overall width of bridge, } W_1) \text{ or 60 ft} \]
    \[ N_L = \text{No. of design lanes} = \text{INT} (W/12) \]
  - 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) = \( 1.2(S + 10)/30 \)
  - \( (S = \text{span of bridge}) \)

- \( \phi Mn \geq Mu \)
  - \( M_u = 1.05 \left[ 1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+IM} \right] \) (per foot)

- Dead Loads
  - \( M_{DC} = W_{DC}S^2/8 \) (ft-kip/ft) \( (W_{DC} = h_{\text{concrete}}) \)
  - \( M_{DW} = W_{DW}S^2/8 \) (ft-kip/ft) \( (W_{DW} = h_{\text{wearing surface}}) \)
  - \( M_{LL+IM} = 1.33(M_{\text{Tandem}} \text{ OR } M_{\text{Truck}}) + M_{\text{lane}} \) (ft-kip)

- Live Load
  - Convert \( M_{LL+IM} \) to ft-kip/ft, Divide \( M_{LL+IM} \) by \( E \), design lane width.

- Slab moments due to live loads:
  1. Moment due to HL-93 Truck load, \( M_{\text{Truck}} \)

(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, \( M_{\text{Tandem}} \)
      (Max. moment due to tandem load can be obtained by placing the two loads at a distance of 2 ft from the mid span)

\[
\text{Moment due Tandem Load, } M_{\text{Tandem}} = 0.64 \frac{S^2}{8}
\]

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, \( M_{\text{Lane}} \)
      - \( M_{\text{Lane}} = 0.64 \frac{S^2}{8} \)}
Analysis and Design of Simply Supported RC Slab Bridges

- Design of RC Slab Bridge
  a) Distribution reinforcement (bottom transverse reinforcement) (A5.14.4.1):
     - \( A_{\text{transverse}} = (100/\sqrt{S} \text{ or } 50 \%) \) of \( A_s \) (whichever is less, But It should not be less than \( A_s(\text{Shrinkage}) \))
     - \( A_s(\text{shrinkage}) = 0.0018A_g \)
  b) Shrinkage and temperature reinforcement in top face of slab (long and transverse both): For grade 60 steel,
     - \( A_s = 0.0018A_g \)

Analysis and Design of Simply Supported RC Slab Bridges

- Reinforcement Detail in Slab Bridge:

As per shrinkage and temperature reinforcement requirements

\[ A_s \text{ Main reinforcement (to be designed)} \]
\[ A_s(\text{shrinkage}) \text{ (least of } 100/\sqrt{S} \text{ % or } 50 \text{ %) of } A_s \]
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.
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 (W₁) = 44 + (2 × 15/12) = 46.5 ft
- Minimum thickness of bridge slab is given by formula:
  \[ h_{\text{min}} = \frac{1.2(S + 10)}{30} = \frac{1.2(35 + 10)}{30} = 1.8 \text{ ft} = 21.6'' \approx 22'' \]

Solution:

Step No 2: Loads.

- Slab load (\( w_{\text{DC}} \)) = \( h_{\text{concrete}} \y \)
  \[ = \frac{22}{12} \times 0.15 = 0.275 \text{ ksf} \]
- Wearing surface load (\( w_{\text{DW}} \)) = \( h_{\text{wearing surface}} \y \)
  \[ = \frac{3}{12} \times 0.14 = 0.035 \text{ ksf} \]
Example

- Solution:
- Step No 3: Analysis.
  - Dead load moments:
    Slab moments \( M_{DC} = \frac{w_{DC}S^2}{8} \)
    \[ = 0.275 \times \frac{(35^2)}{8} = 42 \text{ ft-kip/ft} \]
    Wearing surface moment \( M_{DW} = \frac{w_{DW}S^2}{8} \)
    \[ = 0.035 \times \frac{35^2}{8} = 5.3 \text{ ft-kip/ft} \]

- Live load moments:
  - Truck Load moments:
    \[ M_{\text{Truck}} = 350 \text{ ft-kip} \]
Example

Solution:

Step No 3: Analysis.

Live load moments:

- Tandem moment:
  \[ M_{\text{tandem}} = 372 \text{ ft-kip} \]

- Lane moment:
  \[ M_{\text{lane}} = 640 \times \frac{35^2}{8} = 98000 \text{ ft-lb} = 98 \text{ ft-kip} \]

\[ M_{\text{LL+IM}} = 1.33M_{\text{tandem}} + M_{\text{lane}} = 1.33 \times 372 + 98 = 593 \text{ ft-kip} \]

To convert \( M_{\text{LL+IM}} \) to moment/ft, Divide \( M_{\text{LL+IM}} \) 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_1 W_1)}
    
    L_1 = \text{Modified span length} = \text{Minimum of (S = 35 ft and 60 ft = 35 ft)}
    
    W_1 = \text{Modified edge to edge width} = \text{Minimum of (W_1 = 46.5 ft or 30 ft = 30 ft)}
  
  Therefore, E = 10.00 + 5.0 \sqrt{(35 \times 30.00)} = 172 \text{ in} = 14.3 \text{ ft}

Example

• Solution:

• Step No 3: Analysis.
  
  • Design Lane width "E" :
  
  For multilane loaded:

  - E (inches) = 84 + 1.44 \sqrt{(L_1 W_1)} \leq W_1/N_L
    
    L_1 = 35 \text{ ft}
    
    W_1 = \text{Minimum of (W_1 = 46.5 ft) or 60 ft = 46.5 ft}
    
    N_L = \text{No. of design lanes} = \text{INT (W/12) = INT (44/12) = 3}
  
  Therefore, E = 84 + 1.44 \sqrt{(35 \times 46.5)} \leq 46.5/3
  
    = 142 \text{ inch or 11.84 ft} \leq 15.5
  
  Therefore, E = 11.84 \text{ 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,
      - \( M_u = 1.05 \times [1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+IM} \text{ (per foot)}] \)
      - \( M_u = 1.05 \times (1.25 \times 42 + 1.5 \times 5.33 + 1.75 \times 50) \)
      - \( M_u = 155.3 \text{ ft-kip/ft} = 1863.6 \text{ in-kip/ft} \)

Example

- **Solution:**
- **Step No 4: Design.**
  - (a) Design:
    - **Moment** \( (M_u) = 155.3 \text{ ft-kip/ft} = 1863.6 \text{ in-kip/ft} \)
    - **Effective depth of bridge slab** (d) = h – cover – \( \frac{1}{2} \times \text{Dia of bar used} \)
    - Using #8 bar, effective depth is bottom cover for slab is taken equal to \( 1^{\prime} \).
    - d = 22 – 1 – \( \frac{1}{2} \times 1 = 20.5 \text{ inch} \)
    - \( A_{min} = 0.0018 \times 12 \times 22 = 0.47 \text{ in}^2 \)
    - \( A_s = M_u/\Phi f_y (d - a/2) \)
    - After trials, \( A_s = 1.80 \text{ in}^2, (#8 @ 5 \text{ inches c/c}) \)
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:
    - \( A_{\text{transverse}} = \left( \frac{100}{\sqrt{S}} \text{ or } 50 \% \right) \) of \( A_s \) (whichever is less)
    - \( \frac{100}{\sqrt{L}} = \frac{100}{\sqrt{35}} = 16.9 \% < 50 \% \)
    - Therefore, \( A_{\text{transverse}} = 0.169 \times 1.80 = 0.304 \text{ in}^2 \)
    - \( A_{\text{trim}} \) (shrinkage)= \( 0.0018A_3 = 0.0018 \times 12 \times 22 = 0.47 \text{ in}^2 \) (#5 @ 8 inches c/c)
Example

Solution:

Step No 4: Design.

(e) Shrinkage and temperature reinforcement in top face of slab (long and transverse both): For grade 60 steel,

- $A_{st} = 0.0018A_g = 0.0018 \times 12 \times 22 = 0.47 \text{ in}^2$ (#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

(Main reinforcement)

(Bottom transverse reinforcement)

(Shrinkage reinforcement)
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
THE END