# Lecture 07

# Introduction to Bridge Engineering

By:
Prof. Dr. Qaisar Ali
Civil Engineering Department
UET Peshawar

drqaisarali@uetpeshawar.edu.pk
www.drqaisarali.com

# Lecture Contents

- General
- Design of Bridges
- Design of Simply Supported RC Slab Bridges
- Example 7.1
- Famous Bridges in the World
- References

# Learning Outcomes

- **At the end of this lecture, students will be able to;**
  - ***Differentiate*** among different type of bridges.
  - ***Learn*** AASHTO design loads for bridge design
  - ***Analyze & Design*** Simply Supported RC Slab Bridges

# General

## ❑ 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.

# General

## ❑ Introduction

- Structures having span less than 6000mm are generally called culverts.
- Culvert is a tunnel structure constructed under roadways or railways to provide cross drainage.

# General

## ❑ 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.

# General

## ❑ Components of Bridge

- A bridge consists of super structure and sub structure.

1. **Super structure**

   Structural parts of the bridge which provides the horizontal span

   e.g., girder and deck.

2. **Sub structure**

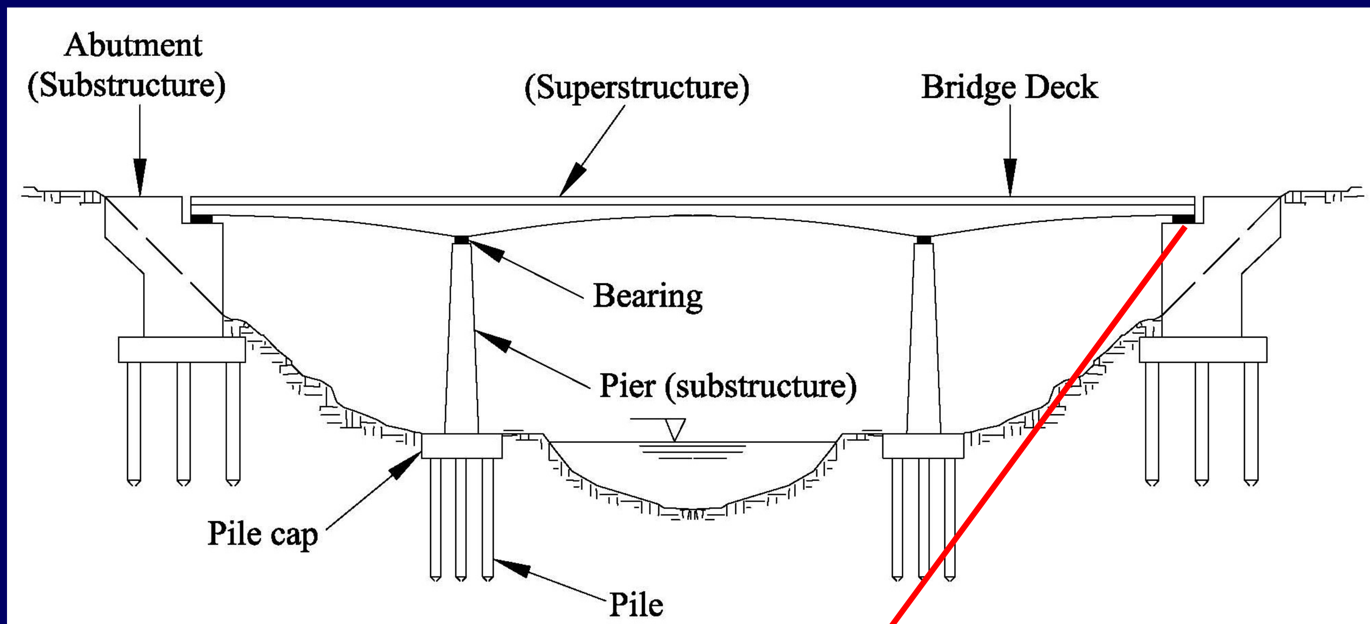
   Structural parts of the bridge which supports the horizontal span.

   e.g., pier cap, pier pile cap etc.

- These components are shown in figure on the next slide.

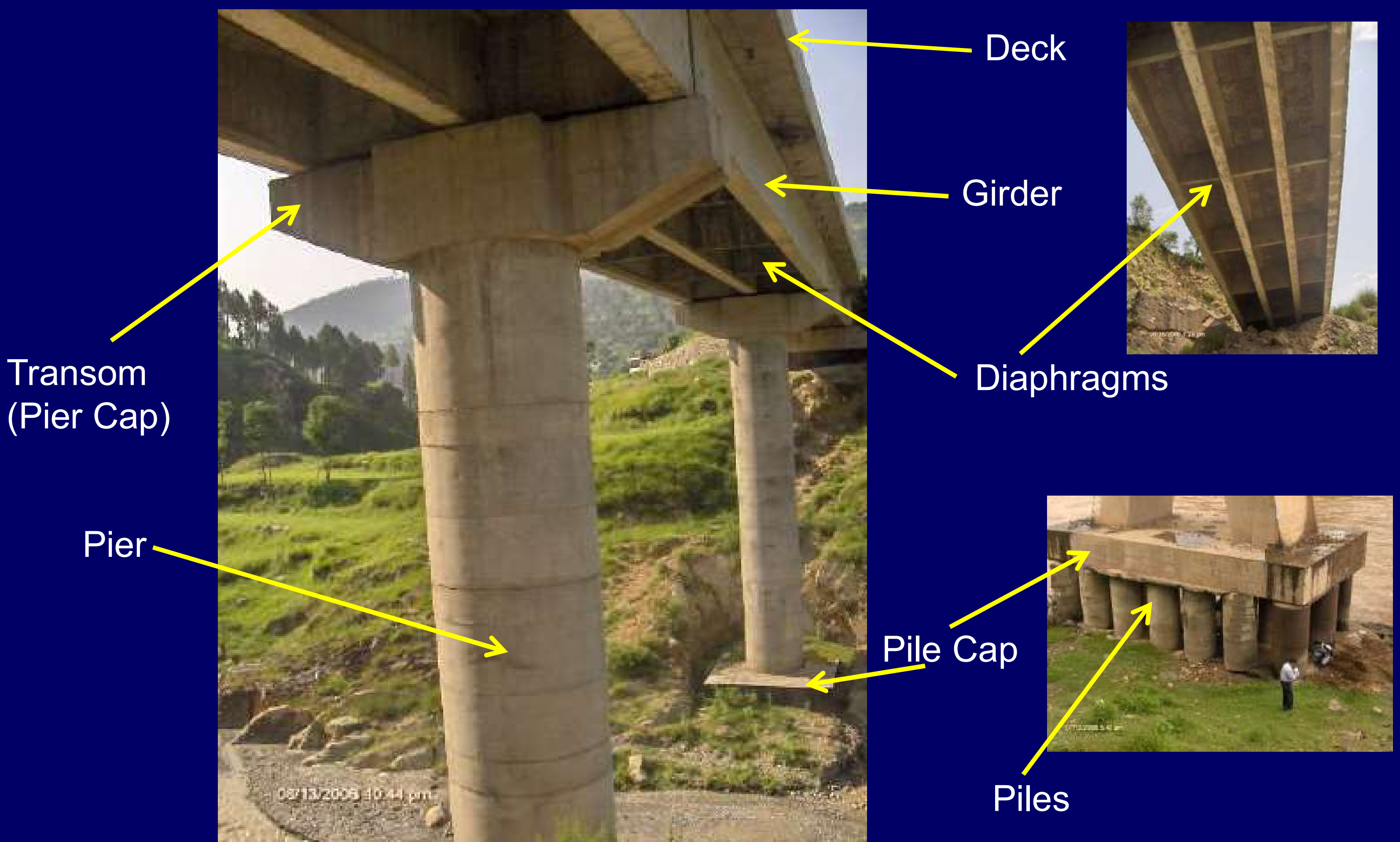
# General

## ❑ Components of Bridge




# General

## ❑ Components of Bridge



# General

## ❑ Classification 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).

# General

## ❑ Classification 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

1. Main structure Below the deck line,
2. Main structure Above the deck line, or
3. Main structure Coinciding with the deck line.

# General

## ❑ Classification of Bridges

### 1. Main structure Below the 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

# General

## ❑ Classification of Bridges

1. **Main structure Below the deck line**

Concrete Arch

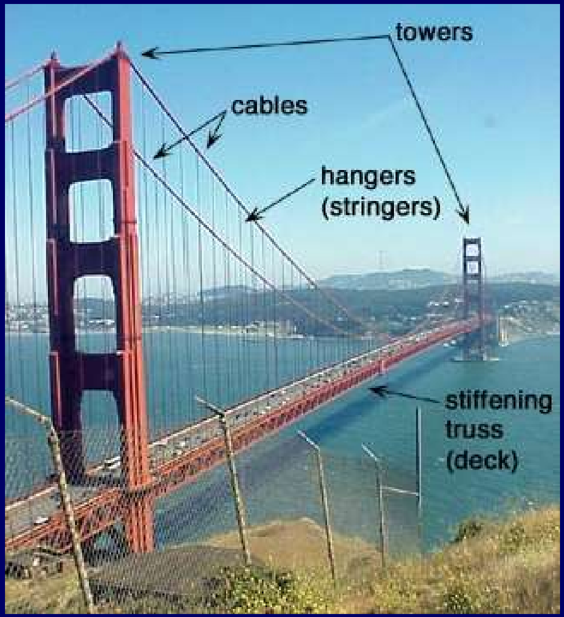
Steel Truss Arch

# General

## ❑ Classification of Bridges

### 2. Main structure Above the 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).

# General

## ❑ Classification of Bridges

### 2. Main structure Above the deck line

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

# General

## ❑ Classification of Bridges

### 2. Main structure Above the deck line

Through Bridges

# General

## ❑ Classification of Bridges

### 3. Main structure Coinciding with the deck line

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


Concrete Box Girder Bridge

# General

## ❑ Classification of Bridges

3. **Main structure Coinciding with the deck line**

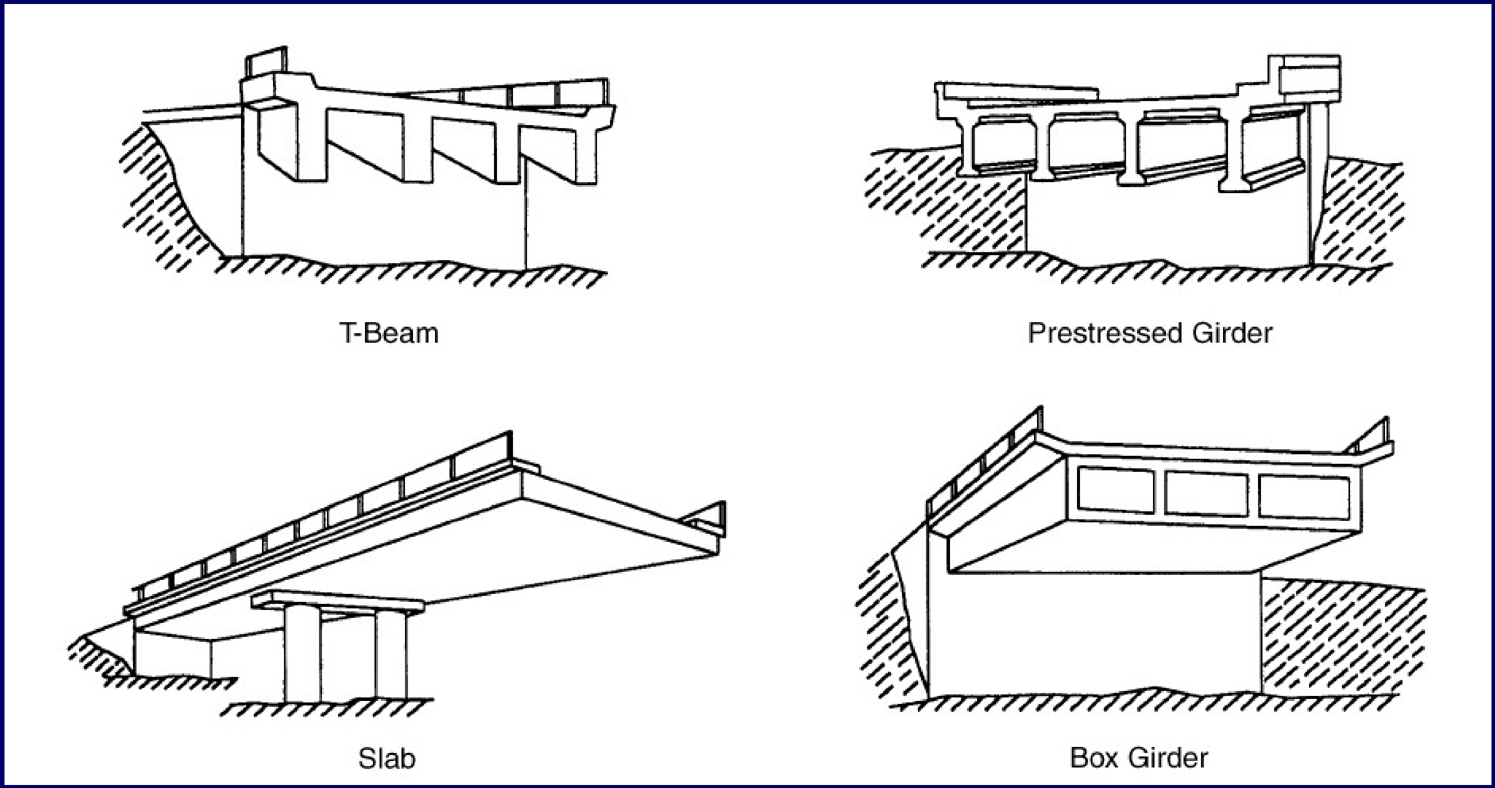

Box Girder Bridge

Girder Bridge Under Construction

# General

## Classification of Bridges

3. **Main structure Coinciding with the deck line**



# Design of Bridges

## ❑ Loads for Bridge Design

- Loads to be considered in bridge design can be divided into two broad categories:

  1. **Permanent loads**
  2. **Transient loads.**

# Design of Bridges

## ❑ Loads for Bridge Design

### 1. Permanent Loads

- Self weight of girders and deck, wearing surface, curbs and parapets and railings, utilities and luminaries and pressures from earth retainment.
- Two important dead loads are:

  i. DC: Dead load of structural components and nonstructural attachments.

  ii. DW: Dead load of wearing surface.

# Design of Bridges

## Loads for Bridge Design

### 1. Permanent Loads

- Material Properties for Pavement
  - Unit weight of Bitumen, $\gamma_B = 140lb/cft$
  - Unit weight of Concrete, $\gamma_c = 150lb/cft$

- Load factors for Pavement Dead Loads
  - The maximum load factor for DC = 1.25
  - The maximum load factor for DW = 1.5

# Design of Bridges

## ❑ Loads for Bridge Design

### 2. 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.

# Design of Bridges

## ❑ Loads for Bridge Design

### 2. 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.

# Design of Bridges

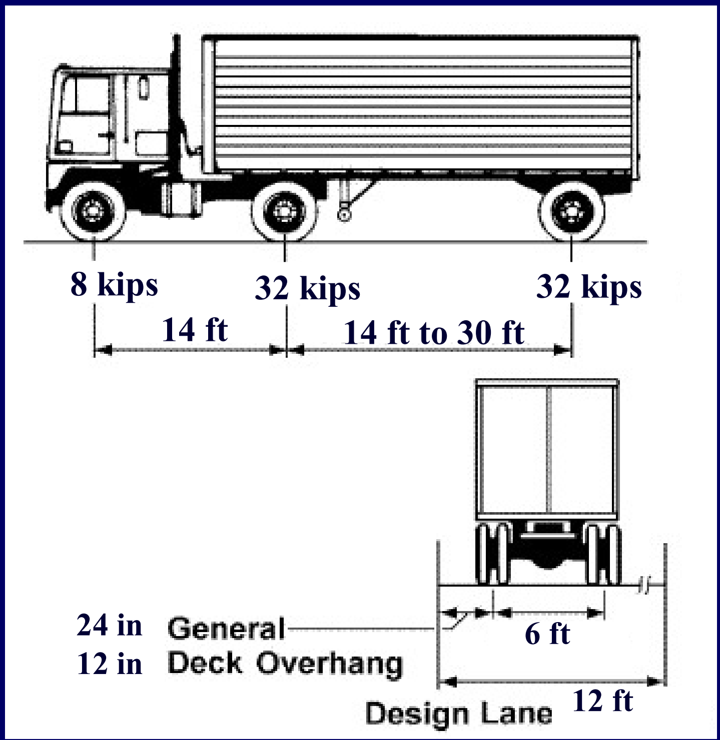
## ❑ Vehicular Design Loads

- The vehicle combination as described in AASHTO (1994) LRFD Bridge specifications are designated as HL-93 for Highway Loading accepted in 1993.
- The AASHTO design loads model consists of three distinctly different loads
  1. Design Truck,
  2. Design Tandem,
  3. Design Lane.

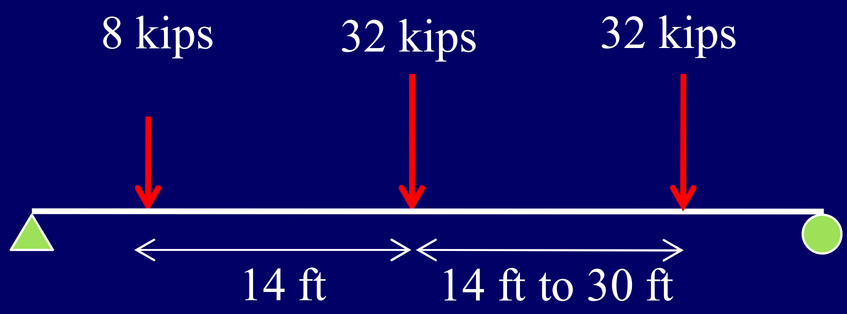
# Design of Bridges

## ❑ Vehicular Design Loads

- **Design Truck**

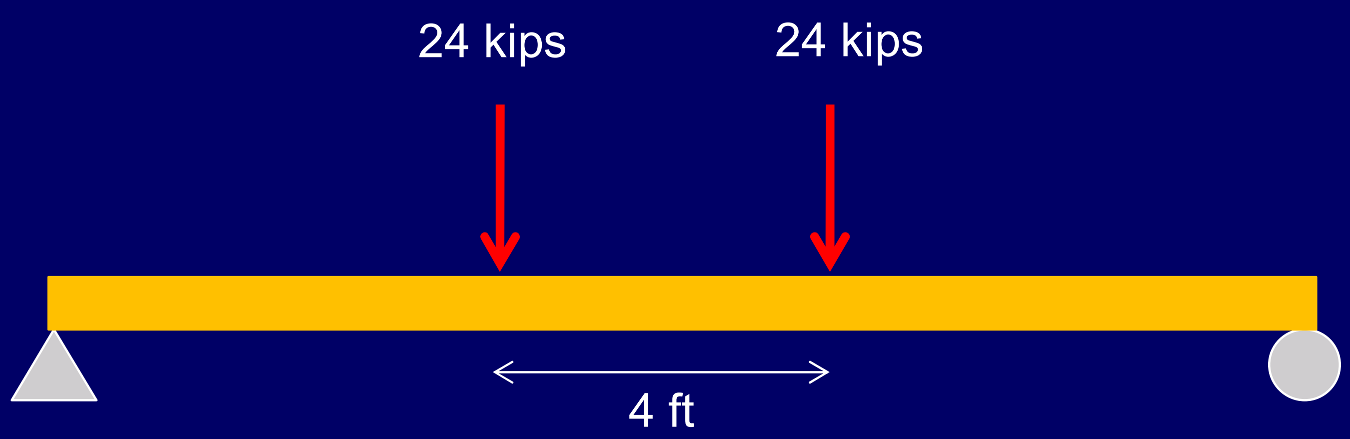



HL-93 Truck Load



# Design of Bridges

- Vehicular Design Loads
  - Design Tandem

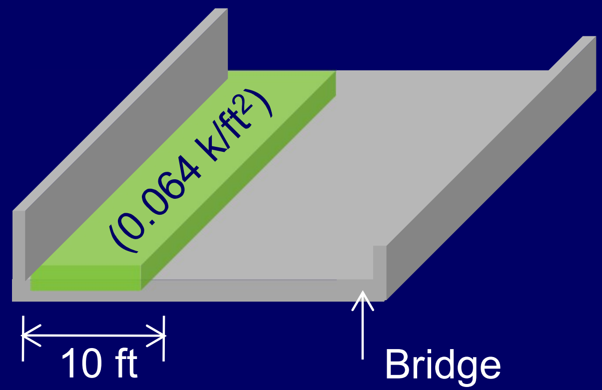


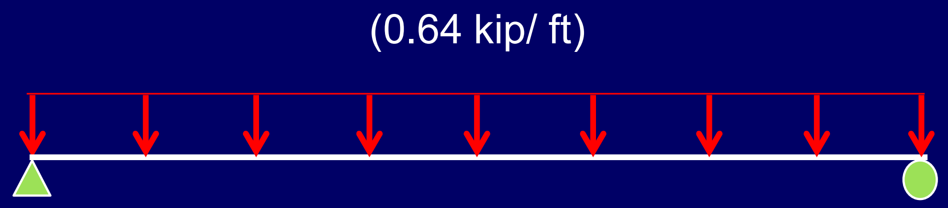
# Design of Bridges

## ❑ Vehicular Design Loads

### ❖ Design Lane load

- The AASHTO design lane loading is like a caravan of trucks.
- It is 0.064 k/ft² and is assumed to occupy a region of 10 ft.
- It is applied as 0.064 k/ft² (64 lb/ft²) of pressure to a width of 10 ft over the entire length of bridge for FEM.



# Design of Bridges

## ❑ Vehicular Design Loads

### ❖ Summary

- In summary three design loads should be considered;

  (i) Design truck (ii) Design tandem and (iii) 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

# Design of Bridges

## ❑ Load Modifier

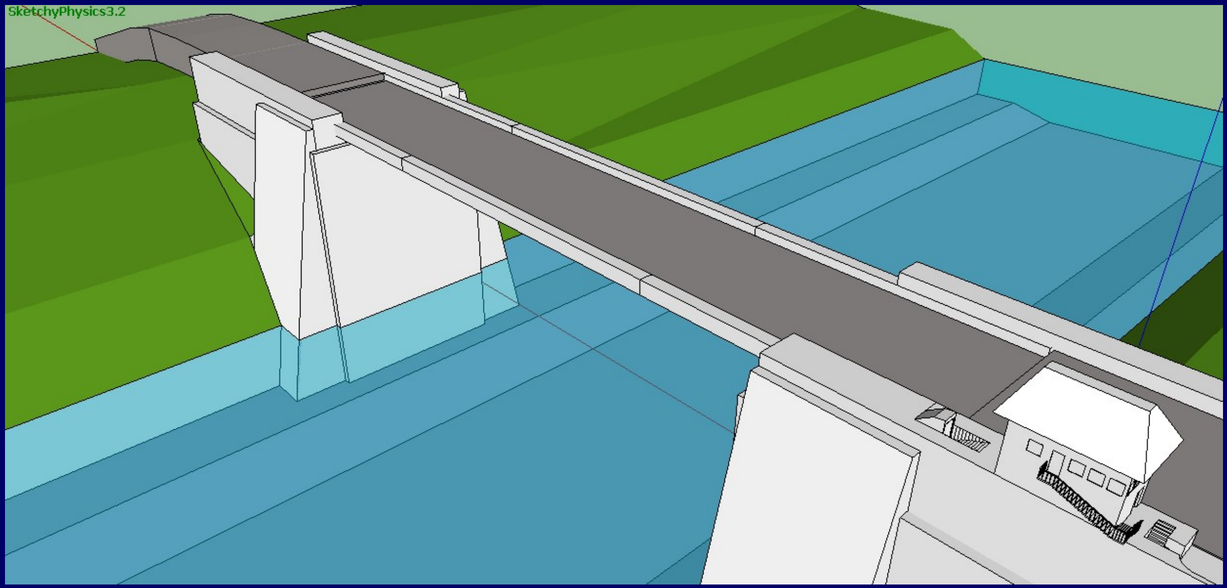
- A factor accounting for ductility, redundancy and the operational importance of the bridge.
- It is taken as 1.05 for simply supported bridges and is applied on already factored values of bending moments.

# 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 design as ID model, then it is called Line Analysis.
- Line Analysis is the simplest of all methods, which has been described in subsequent slides.

# Analysis and Design of Simply Supported RC Slab Bridges

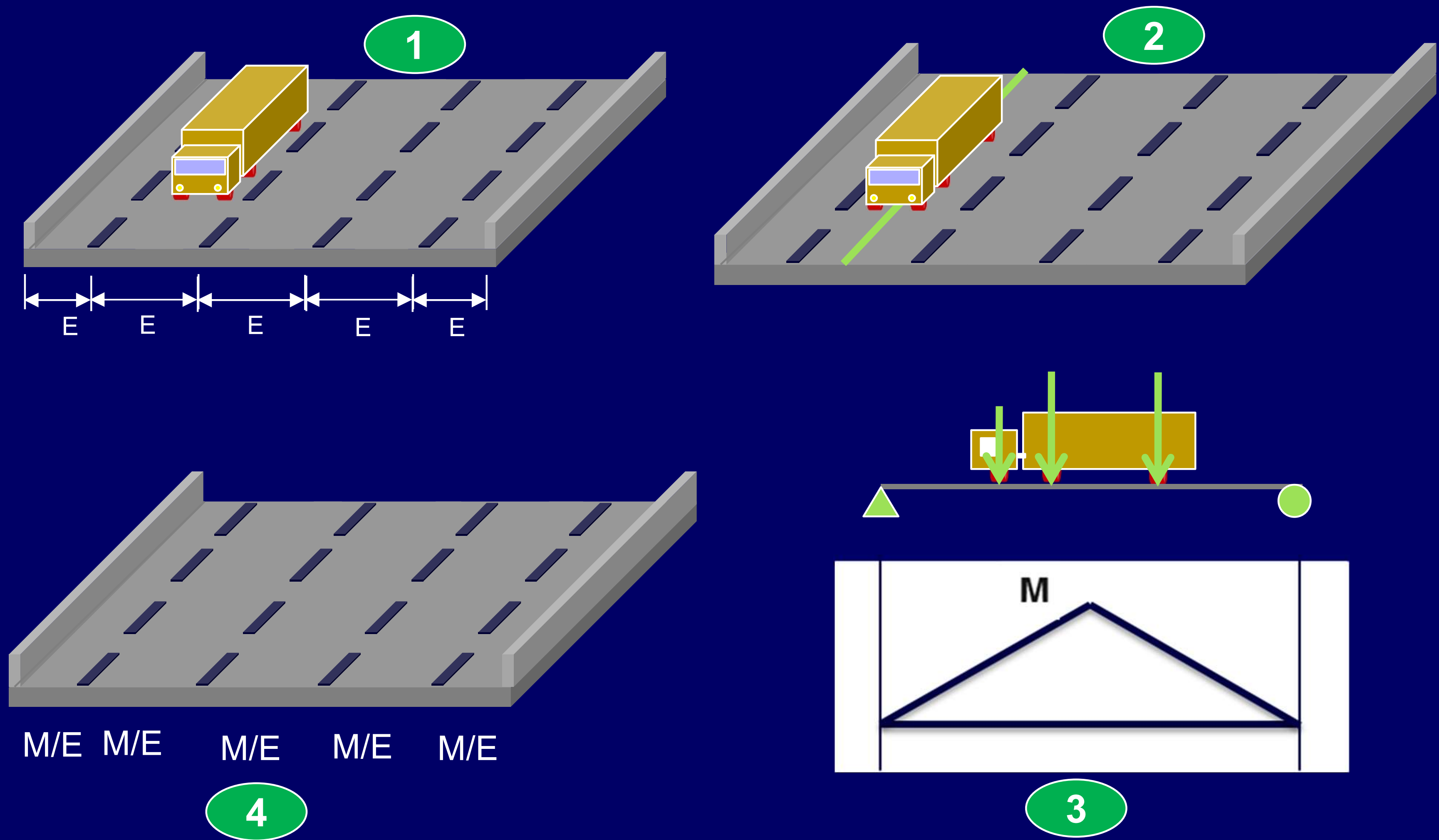
## Design Lane

### Steps in Line Analysis

1. The bridge deck is divided into various strips having width “E” called design lanes
2. These design lanes are then transformed to line elements (1D model) for line analysis.
3. The moment are calculated from line analysis.
4. These moments (M) are then divided by the design lane width (E) to get moment per foot (M/E) for the slab.

# Analysis and Design of Simply Supported RC Slab Bridges

- Design Lane (Line analysis)



# Analysis and Design of Simply Supported RC Slab Bridges

## Design Lane

### Calculation of Design Lane Width

- Design lane widths can be calculated as;

$$E = Smaller\ of\ E_s\ and\ E_m$$

Where;

$E_s =$ lane width for Single lane loaded

$E_m =$ lane width for multi lane loaded

- The procedure of determing $E_s$ and $E_m$ is described in next slides

# Analysis and Design of Simply Supported RC Slab Bridges

## ❑ Design Lane

### ❖ Calculation of Design Lane Width

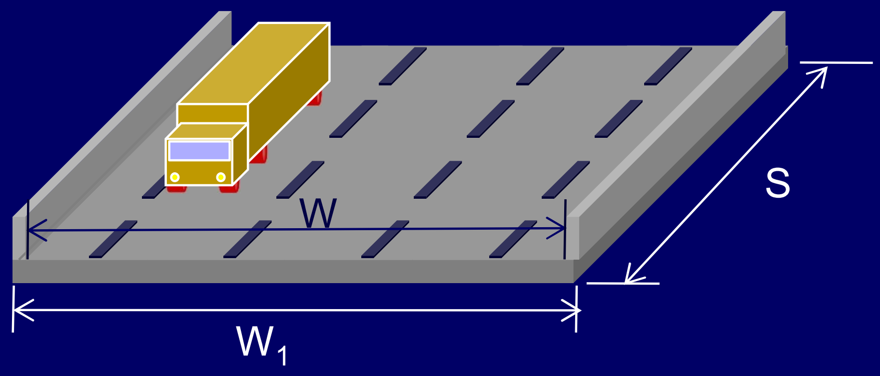
- **For single lane loaded**

$$E_s = 10 + 5\sqrt{L_1 W_1{}'}\ (in) - (i)$$

Where;

- $L_1$ = Modified span length = Minimum of span length "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

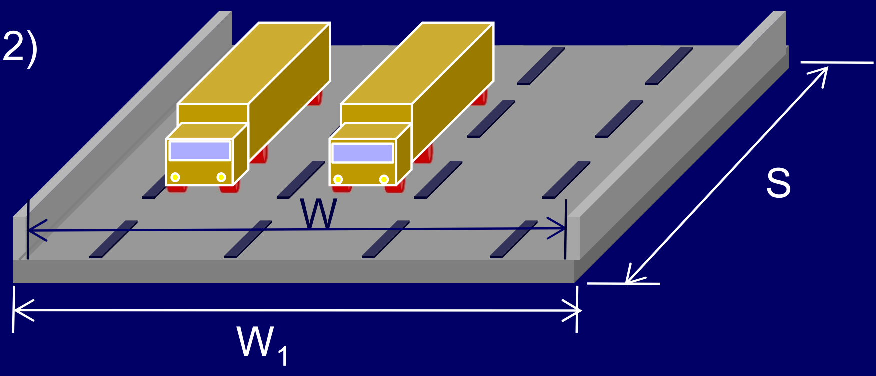
### Calculation of Design Lane Width

- **For multi lane loaded**

$$E_m = 84 + 1.44\sqrt{L_1 W_m} \leq \frac{W_m}{N_L} \quad (in) \quad ------ (ii)$$

Where;

- $L_1$ = Same as single lane loaded case = Minimum of (S) and 60 ft
- $W_m$ = Minimum of (overall width of bridge, $W_1$) or 60 ft
- $N_L$ = No. of design lanes = INT(W/12)



# Analysis and Design of Simply Supported RC Slab Bridges

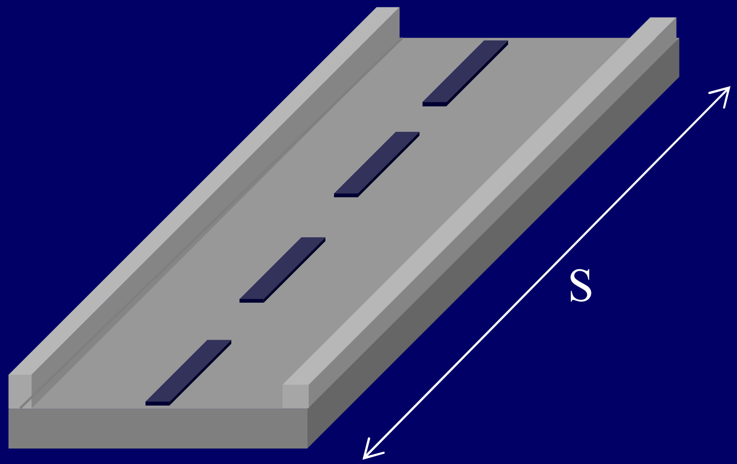
## ❑ Thickness of Bridge Slab

Minimum thickness of bridge slab is given by;

$$h_{min} = \frac{1.2(S + 10)}{30} \quad (ft)$$

where;

$S$ = span of bridge (ft)



# Analysis and Design of Simply Supported RC Slab Bridges

## ❑ Flexural Analysis

- Maximum factored bending moment per unit feet is given by;

$$M_u = 1.05\,(1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+IM})$$

Where;

- $M_{DC} = W_{DC}S^2/8$ (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

## ❑ Flexural Analysis

### ❖ Slab Moments due to Live Loads

#### a) Moment due to HL-93 Truck load, $M_{truck}$

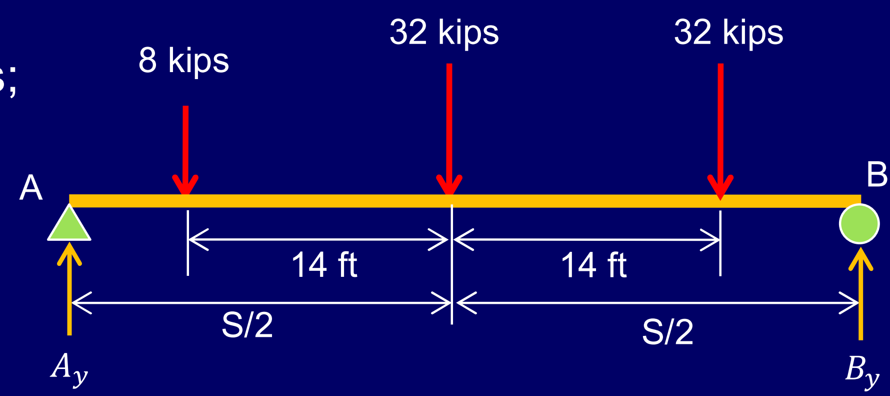
- Max. moment due to truck load can be obtained by placing the middle axle at mid span of the bridge and rear axle load at a distance of 14 ft from the middle axle load.

- Analyzing the given system gives;

$$A_y = 72 - \frac{36S - 336}{S}$$

And

$$M_{truck} = M_{mid} = A_y\left(\frac{S-28}{2} + 14\right) - 448$$



# Analysis and Design of Simply Supported RC Slab Bridges

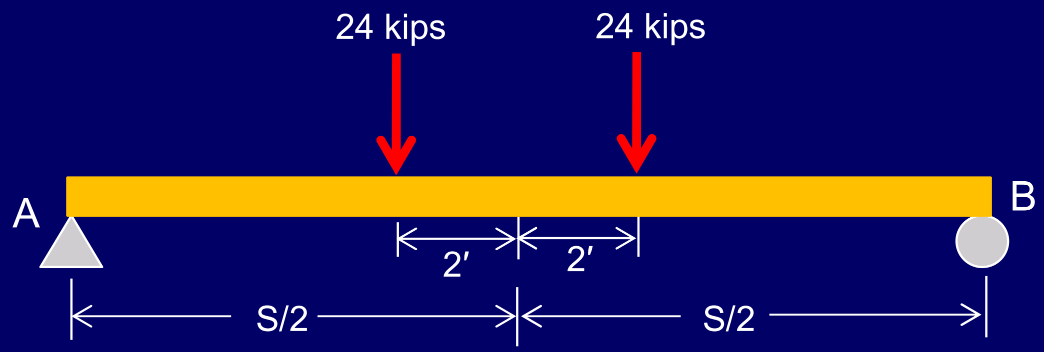
## ❑ Flexural Analysis

### ❖ Slab Moments due to Live Loads

#### b) Moment due to Tandem load, $M_{tandem}$

- Maximum moment due to tandem load can be obtained by placing the two loads at 2 ft from the mid span.
- Solving the given system gives

$$M_{tandem} = 12S - 48$$



# Analysis and Design of Simply Supported RC Slab Bridges

## ❑ Flexural Analysis

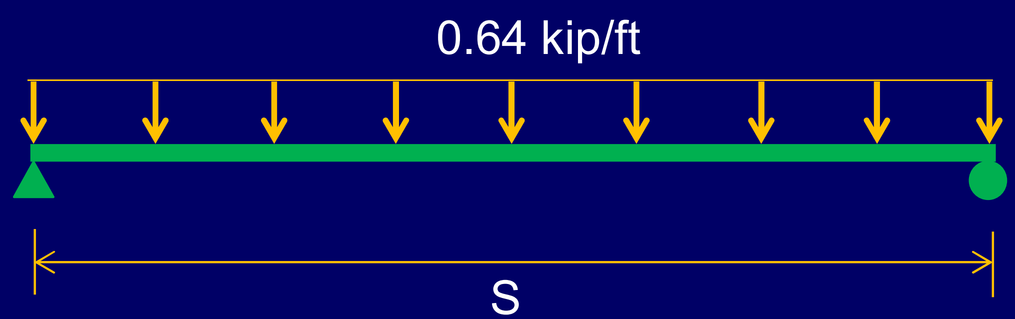
### ❖ Slab Moments due to Live Loads

#### b) Moment due to Design lane load, $M_{Lane}$

- The maximum bending moment due to design lane load is given by

$$M_{Lane} = \frac{WS^2}{8}$$

Putting W = 0.64 gives




$$M_{Lane} = \frac{0.64S^2}{8}$$

# Analysis and Design of Simply Supported RC Slab Bridges

## ❑ Determination of Reinforcement

### 1. Bottom longitudinal reinforcement

$$a = d - \sqrt{d^2 - \frac{2.614M_u}{f_c{}'b_w}} \qquad and \qquad A_s = \frac{M_u}{\emptyset f_y\left(d - \frac{a}{2}\right)}$$

$$S_{max} = lesser\ of\ 3h\ or\ 18''$$

### 2. Bottom Transverse reinforcement (A5.14.4.1)

$$A_{tr} = Smaller\ of\ \left(\frac{A_s}{\sqrt{S}}, \frac{A_s}{2}\right) \qquad but\ not\ less\ than\ A_{S+T}$$

Where;

$$A_{S+T} = 0.0018A_g$$

# Analysis and Design of Simply Supported RC Slab Bridges

- **Determination of Reinforcement**

3. **Top longitudinal reinforcement**

$$A_{S+T} = 0.0018A_g$$

$$S_{max} = lesser\ of\ 5h\ or\ 18''$$

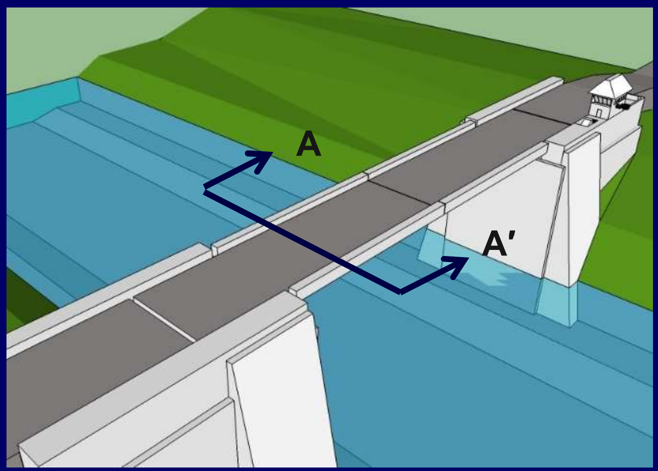
4. **Top Transverse reinforcement (distribution reinforcement)**

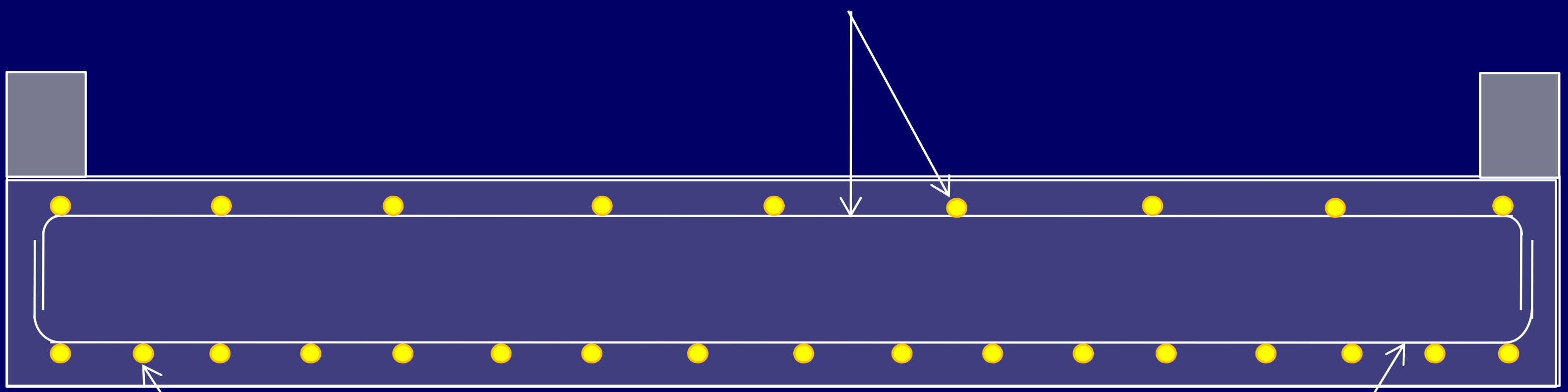
$$A_{S+T} = 0.0018A_g$$

$$S_{max} = lesser\ of\ 5h\ or\ 18''$$

# Analysis and Design of Simply Supported RC Slab Bridges

## ❑ Reinforcement Detailing



# Example 7.1

## ❑ Problem Statement

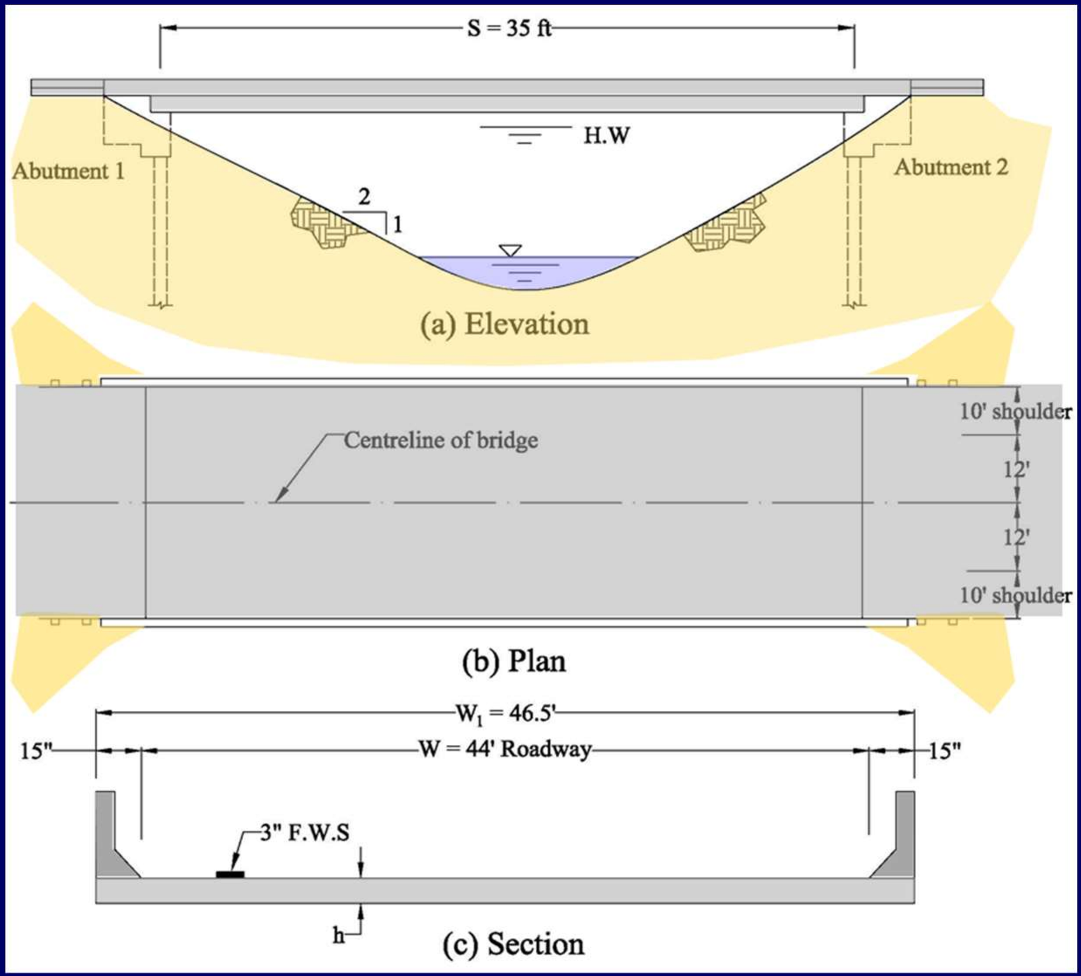
- A simply supported RC slab bridge shown in Figure on the next slide, with span length of 35′ center to center of bearings. The Roadway width is 44 ft curb to curb. Allow for a future wearing surface of 3″ thick bituminous overlay. The material strengths are $f_c' = 4$ ksi and $f_y = 60$ ksi

a) ***Analyze*** the RC slab using HL-93 live load model for live loads.

b) ***Design*** the bridge slab using #8 bar only.

# Example 7.1

## ❑ Problem Statement



# Example 7.1

## ❑ Solution

- **Given Data**

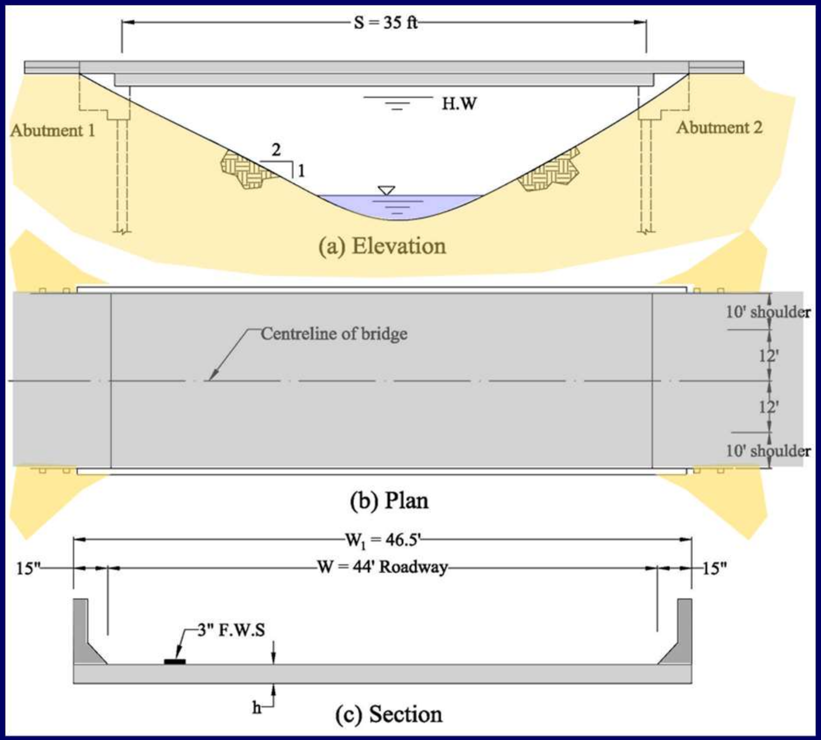
  $Span, S = 35'$

  $W = 44'$

  $W_1 = 46.5'$

  Wearing surface, $h_{WS} = 3"$

  $f_c' = 4ksi$ and $f_y = 60ksi$.




- **Required Data**

  *a)* ***Analyze*** the RC slab using HL-93 live load model for live loads.

  *b)* ***Design*** the bridge slab using #8 bar only.

# Example 7.1

## ❑ Solution

### ➢ Step 1: Selection of sizes

Minimum thickness of bridge slab is given by formula

$$h_{min} = \frac{1.2(10 + S)}{30}$$

Substituting value of S , gives

$$h_{min} = \frac{1.2(10 + 35)}{30} = 1.8' \;\; or\; 21.6''$$

Take $h = 22"$

# Example 7.1

## ❑ Solution

### ➢ Step 2: Calculation of loads

Self weight of slab and wearing surface is calculated as follows;

$$W_{DC} = \gamma_c h = 0.150 \times \left(\frac{22}{12}\right) = 0.275ksf$$

And

$$W_{DW} = \gamma_W h = 0.140 \times \left(\frac{3}{12}\right) = 0.035ksf$$

# Example 7.1

## Solution

### Step 3: Analysis

#### b) Dead load Moments

$$M_{DC} = \frac{W_{DC}S^2}{8} = \frac{0.275 \times 35^2}{8} = 42kip.ft$$

And

$$M_{DW} = \frac{W_{DC}S^2}{8} = \frac{0.035 \times 35^2}{8} = 5.33kip.ft$$

# Example 7.1

## ❑ Solution

### ➢ Step 3: Analysis

#### b) Live load Moments (HL-93 Live load model)

I. Truck Moment

$$A_y = 72 - \frac{36S - 336}{S} = 72 - \frac{36(35) - 336}{35} = 45.6kip$$

And

$$M_{truck} = A_y\left(\frac{S - 28}{2} + 14\right) - 448 = 45.6\left(\frac{35 - 28}{2} + 14\right) - 448$$

$$M_{truck} = 350kip.ft$$

# Example 7.1

## ❑ Solution

### ➢ Step 3: Analysis

#### b) Live load Moments (HL-93 Live load model)

II. Tandem moment

Moment due to tandem load is given by

$$M_{tandem} = 12S - 48$$

By putting value of S, we get

$$M_{tandem} = 12(35) - 48$$

$$M_{tandem} = 372 kip.ft$$

# Example 7.1

## ❑ Solution

### ➢ Step 3: Analysis

#### b) Live load Moments (HL-93 Live load model)

III. Lane load moment

Moment due to Lane load is given by

$$M_{Lane} = \frac{0.64S^2}{8} = \frac{0.64(35)^2}{8}$$

$$M_{Lane} = \frac{0.64S^2}{8} = 98kip.ft$$

# Example 7.1

## ❑ Solution

### ➢ Step 3: Analysis

#### b) Live load Moments (HL-93 Live load model)

Now,

$M_{LL+IM} = 1.33[larger\ of\ M_{tandem}\ or\ M_{truck}] + M_{Lane}$

Since $M_{tandem} > M_{truck}$ , therefore we will use $M_{tandem}$

$M_{LL+IM} = 1.33[372] + 98$

$M_{LL+IM} = 592.76 kip.ft$

To convert $M_{LL+IM}$ to moment/ft, Divide MLL+IM by "E" design lane width.

# Example 7.1

## ❑ Solution

### ➢ Step 3: Analysis

#### b) Live load Moments (HL-93 Live load model)

- Calculation of Design Lane width “E”

$$E_s = 10 + 5\sqrt{L_1 W_s} \ (in)$$

$$E_s = 10 + 5\sqrt{35 \times 30} = 172"$$

And

$$E_m = 84 + 1.44\sqrt{L_1 W_m} \ \leq \frac{W_m}{N_L} \quad (in)$$

$$E_m = 142'' \ \leq 186''$$

Now,

$$E = min. of\ E_s\ and\ E_m = 142''\ or\ 11.84'$$

$L_1$ = Min. of S = 35′ and 60′ = 35′

$W_s$ = Min. of $W_1$ = 46.5′ or 30′ = 30′

$W_m$ = Min. of $W_1$ = 46.5′ or 60′ = 46.5′

and

$N_L$ = INT (W/12) =INT (44/12) = 3

# Example 7.1

## ❑ Solution

### ➢ Step 3: Analysis

#### b) Live load Moments (HL-93 Live load model)

Hence the $M_{LL+IM}$ per foot is determined as;

$$M_{LL+IM}(per\ foot) = \frac{M_{LL+}}{E} = \frac{592.76}{11.84} = 50 kip.ft$$

- **Total Factored Moment**

$$M_u = 1.05\,(1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+I}\quad)$$

$$= 1.05\,(1.25 \times 42 + 1.5 \times 5.33 + 1.75 \times 50\,)$$

$$M_u = 155.39 kip.ft\ or\ 1864.8 in.kip$$

# Example 7.1

## ❑ Solution

### ➢ Step 4: Determination of reinforcement

1. **Bottom Longitudinal Reinforcement**

$$a = d - \sqrt{d^2 - \frac{2.614 M_u}{f_c{}' b_w}} = 20.5 - \sqrt{20.5^2 - \frac{2.614 \times 1864.8}{4 \times 12}} = 2.64''$$

Now,

$$A_s = \frac{M_u}{\emptyset f_y \left(d - \frac{a}{2}\right)} = \frac{1864.8}{0.9 \times 60 \left(20.5 - \frac{2.64}{2}\right)} = 1.8 in^2/ft$$

Provide #8@4″ c/c

$$S_{max} = 3h \; or \; 18'' = 18'' > provided \; spacing \rightarrow OK!$$

# Example 7.1

## ❑ Solution

➢ **Step 4: Determination of reinforcement**

2. **Bottom Transverse Reinforcement**

$$A_{tr} = Smaller\ of\ \left(\frac{A_s}{\sqrt{S}}, \frac{A_s}{2}\right) \quad but\ not\ less\ than\ A_{s,min}$$

By putting values, we get

$$A_{tr} = Smaller\ of\ \left(\frac{1.8}{\sqrt{35}}, \frac{1.8}{2}\right) = 0.30in^2/ft$$

$$A_{s,min} = 0.0018A_g = 0.0018 \times 12 \times 22 = 0.476in^2/ft > A_{tr}$$

Take $A_{tr} = 0.476in^2/ft$ (Provide #5 @ 7.5″ c/c)

# Example 7.1

## Solution

### Step 4: Determination of reinforcement

3. **Top longitudinal reinforcement**

$A_{S+T} = 0.0018A_g = 0.476in^2/ft$

Provide #5 @ 7.5″ c/c

$S_{max} = 5h \ or \ 18'' = 18'' > provided \ spacing \rightarrow OK!$

4. **Top Transverse reinforcement (distribution reinforcement)**

$A_{S+T} = 0.0018A_g = 0.476in^2/ft$

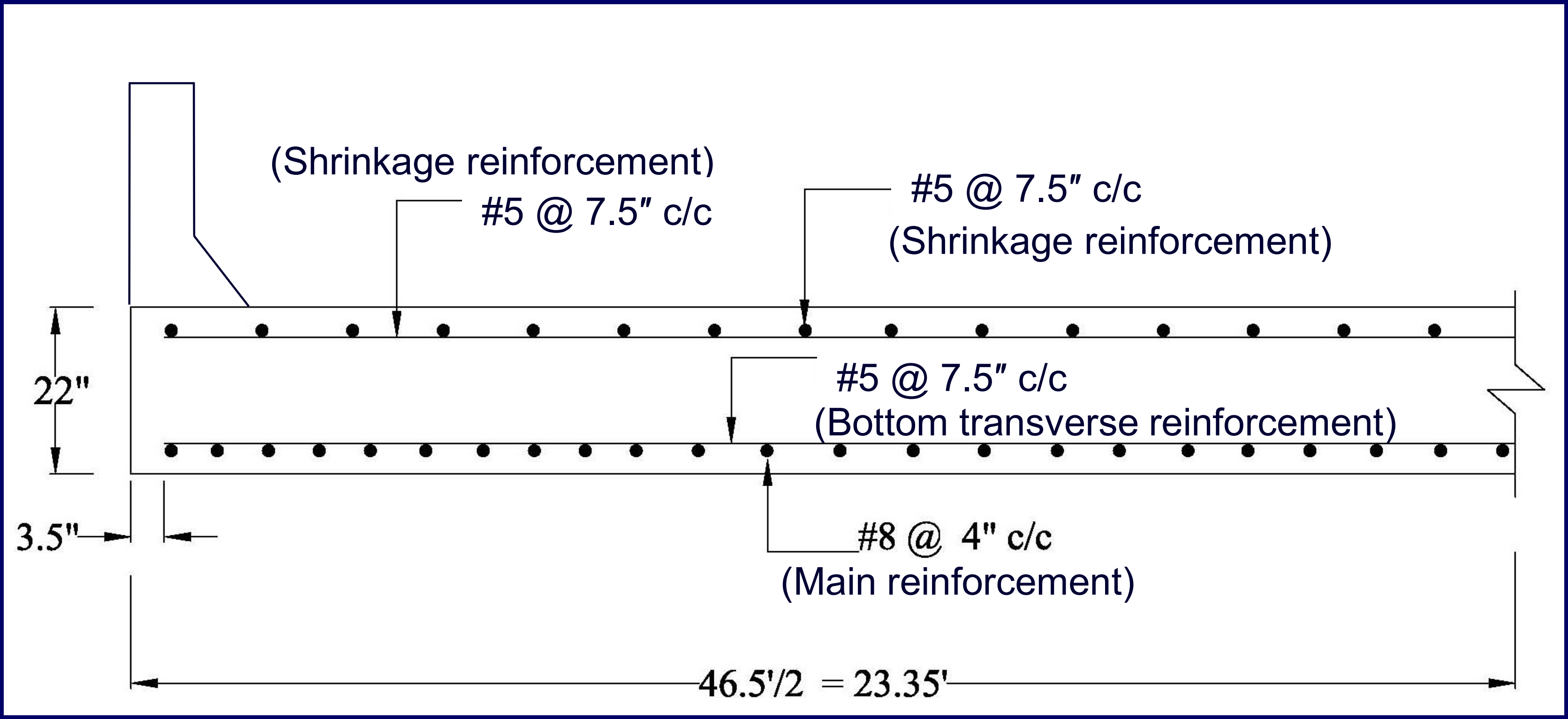
Provide #5 @ 7.5″ c/c

$S_{max} = 5h \ or \ 18'' = 18'' > provided \ spacing \ \rightarrow OK!$

# Example 7.1

## ❑ Solution

### ➢ Step 5: Drafting



# Some Famous Bridges in The World

# Some Famous Bridges in the World

- **Longest Bridge**

Danyang–Kunshan Grand Bridge in China (164800 m)

# Some Famous Bridges in the World

- Longest Span

Akashi Kaikyō Bridge, Japan (1991 m)

# Some Famous Bridges in the World

- Highest Bridge

Si Du River Bridge (472 m high)

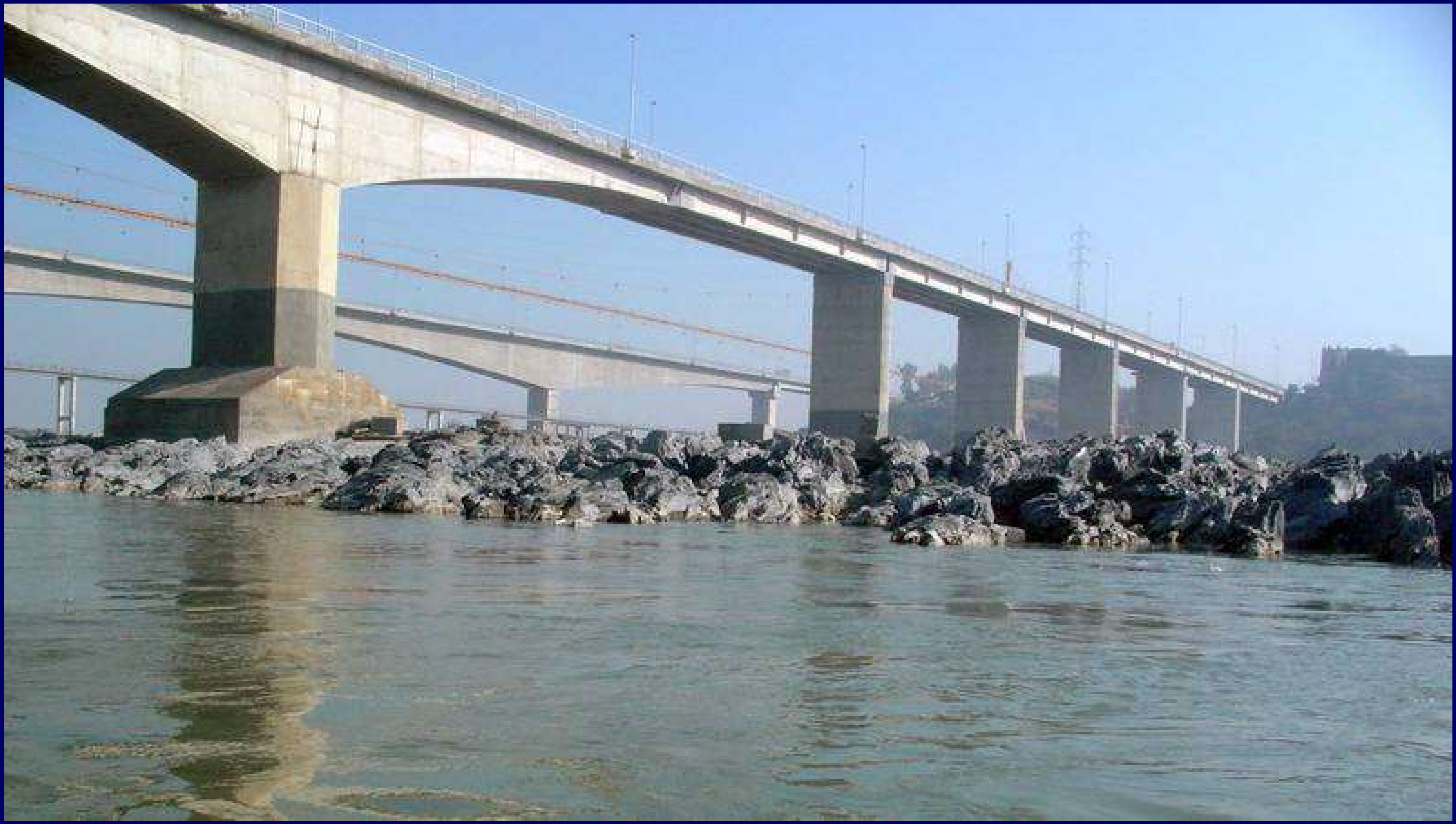
# Some Famous Bridges in the World

- **Bridges in Pakistan**

Jamshoro Bridge, Jamshoro

# Some Famous Bridges in the World

- Bridges in Pakistan



Attock Bridge, Attock

# Some Famous Bridges in the World

- Bridges in Pakistan

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

# Some Famous Bridges in the World

- Bridges in Pakistan

Chiniot Railway Bridge (1877)

# Some Famous Bridges in the World

- Bridges in Pakistan

Bridge at Kallar Kahar, M2 Motorway

# References

- Design of Highway Bridges by Richard M. Barker.
- Building Code Requirements for Structural Concrete (ACI 318-19)