

## MODULE1

### 1.0 Introduction

#### 1.1 Types of bridges

#### 1.2 Computation of discharge

#### 1.3 Afflux

#### 1.4 Scour depth

#### 1.5 Loads

#### 1.6 Assignment Questions

#### 1.7 Further study

### Bridge Engineering

The first bridges were made by nature — as simple as a log fallen across a stream. The first bridges made by humans were probably spans of wooden logs or planks and eventually stones, using a simple support and crossbeam arrangement. Most of these early bridges could not support heavy weights or withstand strong currents. It was these inadequacies which led to the development of better bridges. The oldest surviving stone bridge in China is the Zhaozhou Bridge, built from 595 to 605 AD during the Sui Dynasty. This bridge is also historically significant as it is the world's oldest open-spandrel stone segmental arch bridge. The first book on bridge engineering was written by Hubert Gautier in 1716. With the Industrial Revolution in the 19th century, truss systems of wrought iron were developed for larger bridges, but iron did not have the tensile strength to support large loads. With the advent of steel, which has a high tensile strength, much larger bridges were built, many using the ideas of Gustave Eiffel.

Bridges are classified on the basis that how the four forces namely shear, compression, tension, and moment are distributed in the bridge structure.

Generally speaking, bridges can be divided into two categories: standard overpass bridges or unique-design bridges over rivers, chasms, or estuaries. This article describes features common to both types, but it concentrates on the unique bridges because of their greater technical, economic, and aesthetic interest.

### Definition

A structure built to span and provide passage over a river, chasm, road, or any other physical hurdle. The function required from the bridge and the area where it is constructed decides the design of the bridge.

### 1.2 Types of bridges

Bridges can be categorized in several different ways. Common categories include the type of structural elements used, by what they carry, whether they are fixed or movable, and by the materials used.

#### Structure type

## Design Of Bridges

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Bridges may be classified by how the forces of tension, compression, bending, torsion and shear are distributed through their structure. Most bridges will employ all of the principal forces to some degree, but only a few will predominate. The separation of forces may be quite clear. In a suspension or cable-stayed span, the elements in tension are distinct in shape and placement. In other cases the forces may be distributed among a large number of members, as in a truss.

**Beam bridges:** are horizontal beams supported at each end by substructure units and can be either simply supported when the beams only connect across a single span, or continuous when the beams are connected across two or more spans. When there are multiple spans, the intermediate supports are known as piers. The earliest beam bridges were simple logs that sat across streams and similar simple structures. In modern times, beam bridges can range from small, wooden beams to large, steel boxes. The vertical force on the bridge becomes a shear and flexural load on the beam which is transferred down its length to the substructures on either side. They are typically made of steel, concrete or wood. Girder bridges and Plate girder bridges, usually made from steel, are types of Beam bridges. Box girder bridges, made from steel, concrete, or both are also beam bridges. Beam bridge spans rarely exceed 250 feet (76 m) long, as the flexural stresses increase proportional to the square of the length (and deflection increases proportional to the 4th power of the length)

**A truss bridge:** is a bridge whose load-bearing superstructure is composed of a truss. This truss is a structure of connected elements forming triangular units. The connected elements (typically straight) may be stressed from tension, compression, or sometimes both in response to dynamic loads. Truss bridges are one of the oldest types of modern bridges. The basic types of truss bridges shown in this article have simple designs which could be easily analyzed by nineteenth and early twentieth century engineers. A truss bridge is economical to construct owing to its efficient use of materials.

**Cantilever bridges:** are built using cantilevers—horizontal beams supported on only one end. Most cantilever bridges use a pair of continuous spans that extend from opposite sides of the supporting piers to meet at the center of the obstacle the bridge crosses. Cantilever bridges are constructed using much the same materials & techniques as beam bridges. The difference comes in the action of the forces through the bridge

**Arch bridges:** have abutments at each end. The weight of the bridge is thrust into the abutments at either side. The earliest known arch bridges were built by the Greeks, and include the Bridge. With the span of 220 metres (720 ft), the Solkan Bridge over the Soča River at Solkan in Slovenia is the second largest stone bridge in the world and the longest railroad stone bridge. It was completed in 1905. Its arch, which was constructed from over 5,000 tonnes (4,900 long tons; 5,500 short tons) of stone

**Tied arch :bridges** have an arch-shaped superstructure, but differ from conventional arch bridges. Instead of transferring the weight of the bridge and traffic loads into thrust forces into the abutments, the ends of the arches are restrained by tension in the bottom chord of the structure. They are also called bowstring arches.

**Suspension bridges:** are suspended from cables. The earliest suspension bridges were made of ropes or vines covered with pieces of bamboo. In modern bridges, the cables hang from towers that are attached to caissons or cofferdams. The caissons or cofferdams are implanted deep into the bed of the lake, river or sea. Sub-types include the simple suspension bridge, the stressed ribbon bridge, the under spanned suspension bridge, the suspended-deck suspension bridge, and the self-anchored suspension bridge. There is also what is sometimes called a "semi-suspension" bridge, of which the Ferry Bridge in Burton-upon-Trent is the only one of its kind in Europe

**Cable-stayed bridges:** like suspension bridges, are held up by cables. However, in a cable-stayed bridge, less cable is required and the towers holding the cables are proportionately higher

### 1.3 Computation of discharge

Hydraulics is the essential feature of bridge design. Fair assessment of flood levels, maximum flood discharge expected to occur at bridge site during design life of bridge, and maximum scour levels are essential aspects of bridge hydraulics.

Faulty determination of these parameters may lead to failure of structures. While doing hydraulic calculations attention should be paid to the following:

1. The river cross section should be truly representative. The cross section should not be vitiated by artificial cuts etc.

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2. If the bridge site is along the existing natural crossing, the cross section for hydraulics should be across the nearby natural undisturbed channel. The cross section within 100 m U/S or D/S may be quite useful.

3. Spill channels should be properly located, marked and catered for.

4. Appropriate coefficient of rigidity should be used. The same rigidity coefficient should not be used for bed and banks, as the nature of stream changes according to properties of material and vegetation growth etc.

5. The reasonableness of computed velocity should be judged in relation to bed material for e.g existence of boulders in the stream and low velocity of flow do not generally go together.

6. In tidal creeks the possibility of high tides and floods coinciding should be kept in view. In such cases discharge by usual ways i.e. by Manning's formula should be carefully worked out and tallied with Inglis discharge.

7. The adoption of either the observed H.F.L. obtained by local enquiry or the computed H.F.L. as design level should be done judiciously. The observed H.F.L. may be effected by obstructions like rice fields, bunds, blocking of spill channels etc. Higher of the two values be adopted as design H.F.L.

8. Details of various levels is explained as below.

- HFL (observed) Highest flood levels ever recorded. (50 years record)
- HFL(Inglis) Flood level giving Manning's discharge equal to Inglis discharge.
- HFL(Modified Inglis) Flood level giving Manning's discharge equal to Modified Inglis discharge.
- O.F.L. Ordinary flood level. This is level of flood when cleared by bridge (without submergence of bridge) that will not give more than permissible interruption to traffic during floods.

9. Maximum permissible interruptions for various standards of roads are as follows- National Highways – No interruptions.

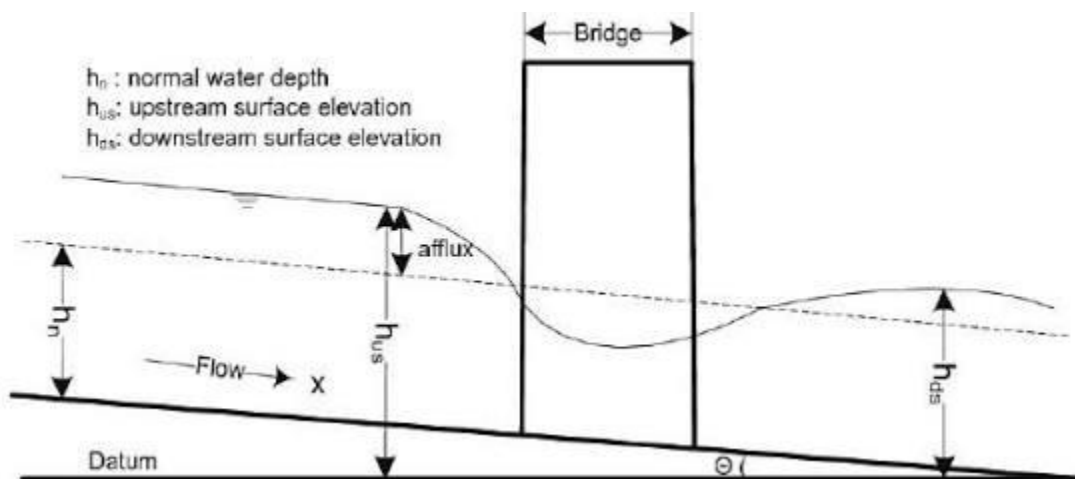
## 1.4 Afflux

Bridges are built across a waterway and the structure may be of single span or multiple spans. In a multiple span bridge piers need to be constructed in the river bed. These piers obstruct the natural flow. If the obstruction is considerable, the level of water on the upstream rises slightly compared to that at the downstream.

This rise in level is called afflux. Designer's calculate the afflux and incorporate the same in the design of sub structure so as to keep the superstructure clear of flood water.

**Afflux is defined as heading up of water when they hit any obstruction. In bridges the water hit at u/s side. When hiring the water rises.**

In design the height of bridge the afflux is taken into consideration with HFL. Hope u will understand. This picture helps u for understanding



Afflux can be estimated by using several empirical equations e.g. IRC:89 (1985) Nagler (1918), Rhebock (1921), Yarnel (1934), Rao (1997) etc.

IRC-SP 13 recommends use of **wier /orifice formula** for computing flow with known afflux or vice versa. For shallow channels with wide flood planes (as observed in most of the rivers across

the bridges on this roadway a rough first approximation of finding afflux can be obtained from the following expression, (Bradley 1970).

$$h^*1 = 3(1 - M) V_{n2}^2 / 2g$$

where  $M = Q_b / Q$

where

$Q_b$  = is that portion of the total discharge  $Q$  in the approach channel within a width equal to the projected length of the bridge

$$V_{n2} = Q / A_{n2}$$

$A_{n2}$  = is the gross area of waterway under the bridge opening below normal stream depth corresponding to design flood discharge.

IRC:5 and 89 recommend use of **Molesworth's equation** for computing approximate afflux given below:

$$h = \{V^2/17.88 + 0.01524\} \times \{(A/a)^2 - 1\}$$

For **minor and medium bridges**, weir and orifice formula given in IRC:SP-13 can be used for computing afflux depending on whether the flow under the bridge is choked or free.

For **choked weir type flow**:  $Q = C_d L_{eff} (D_u + u^2 / 2g)^{3/2}$  if  $h1 * D_d > 0.25$

For **orifice flow** :  $Q = C_d L_{eff} D_d \sqrt{2g \cdot h1^*}$  if  $h1^* / D_d < 0.25$

Where  $C_d$  &  $C_o$  are the coefficients of discharges for weir and orifice type flows respectively.  $C_d$  and  $C_o$  values are given in the IRC code, [notes4free.in](http://notes4free.in)

$$h^*1 = \text{afflux} = (D_u - D_d).$$

$D_u$  and  $D_d$  are the upstream and downstream depths measured from the lowest bed level under the bridge taken as datum.

### 1.5 Scour depth

Scouring can be defined as a process due to which the particles of the soil or rock around the periphery of the abutment or pier of the highway bridge spanning over a water body, gets eroded and removed over a certain depth called scour depth. Scouring usually occurs when the velocity of the flowing water increases or crosses the limiting value that the soil particles can easily handle

Scouring can be easily observed during the flood being passed through that water body. Scouring is initiated at the nose of the piers or at the sharp bends. Estimation of scour depth is very important for the design of foundation for abutment or pier. Scouring compromises the structural integrity and thus causes failure of the structure. It has been estimated that over 60 % of the highway bridges are being collapsed due to scouring.

When the discharge within the water body passes the allowed discharge; which is usually the case when flood is there; the scour is initiated; the scour depth can easily be obtained after the flood by finding the depth of the scour in reference with the surroundings or existing structures. If this is not possible the mean depth of scour may be easily obtained by a mathematical formula for natural streams in the alluvial depth

$$Y_{gs} = Y_{max} [(0.0685 V_m^{0.8}) / (Y_h^{0.4} S_e^{0.3}) - 1]$$

Where  $Y_{gs}$  = general scour depth (ft),  $Y_{max}$  is maximum depth of flow,  $V_m$  is the average velocity of flow(ft/sec),  $Y_h$  is hydraulic depth of flow (ft) and  $S_e$  is the energy slope (or bed slope for uniform flow),(ft) From actual field measuring scour depth charts to estimate scour depth, This method is applicable only for coarser sands where the bed slope ranges from 0.004 ft to 0.008 ft. Other empirical methods are also there like Neil, Blench and Lacey for estimation of the scour depth

### 1.6 Types of Loads for Design of Bridge Structures

Various design loads to be considered in the design of bridges are:

1. Dead load
2. Live load
3. Impact load
4. Wind load
5. Longitudinal forces
6. Centrifugal forces
7. Buoyancy effect
8. Effect of water current
9. Thermal effects
10. Deformation and horizontal effects
11. Erection stresses
12. Seismic loads

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#### **1. Dead Load**

The dead load is nothing but a self-weight of the bridge elements. The different elements of bridge are deck slab, wearing coat, railings, parapet, stiffeners and other utilities. It is the first design load to be calculated in the design of bridge.

## 2. Live Load

The live load on the bridge, is moving load on the bridge throughout its length. The moving loads are vehicles, Pedestrians etc. but it is difficult to select one vehicle or a group of vehicles to design a safe bridge.

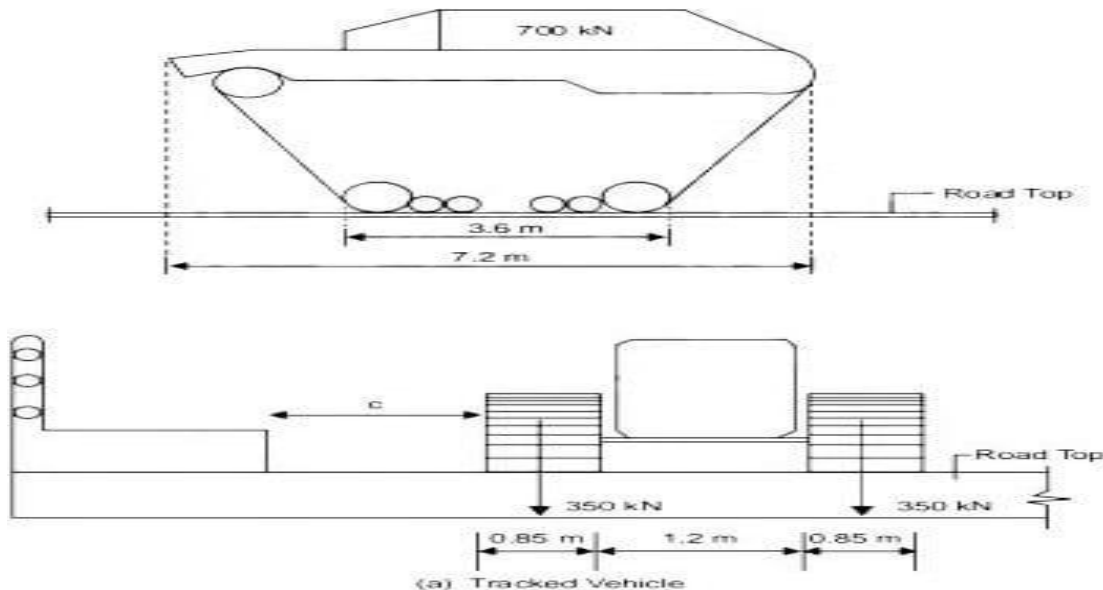
So, IRC recommended some imaginary vehicles as live loads which will give safe results against the any type of vehicle moving on the bridge. The vehicle loadings are categorized in to three types and they are

- IRC class AA loading
- IRC class A loading
- IRC class B loading
- **IRC Class AA Loading**

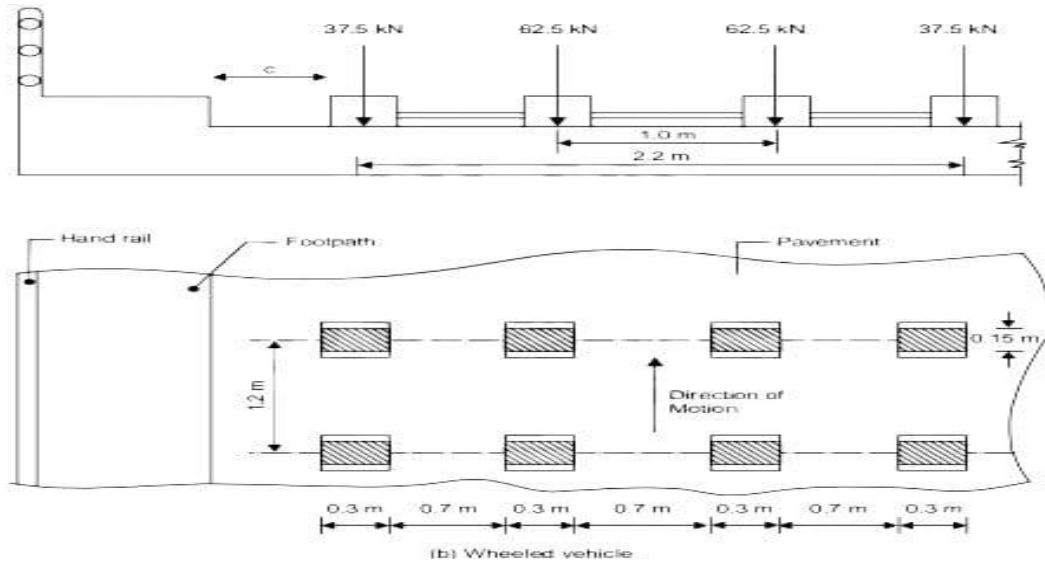
This type of loading is considered for the design of new bridge especially heavy loading bridges like bridges on highways, in cities, industrial areas etc. In class AA loading generally two types of vehicles considered, and they are

- Tracked type
- Wheeled type

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# Design Of Bridges



## IRC Class A Loading

This type of loading is used in the design of all permanent bridges. It is considered as standard live load of bridge. When we design a bridge using class AA type loading, then it must be checked for class A loading also.

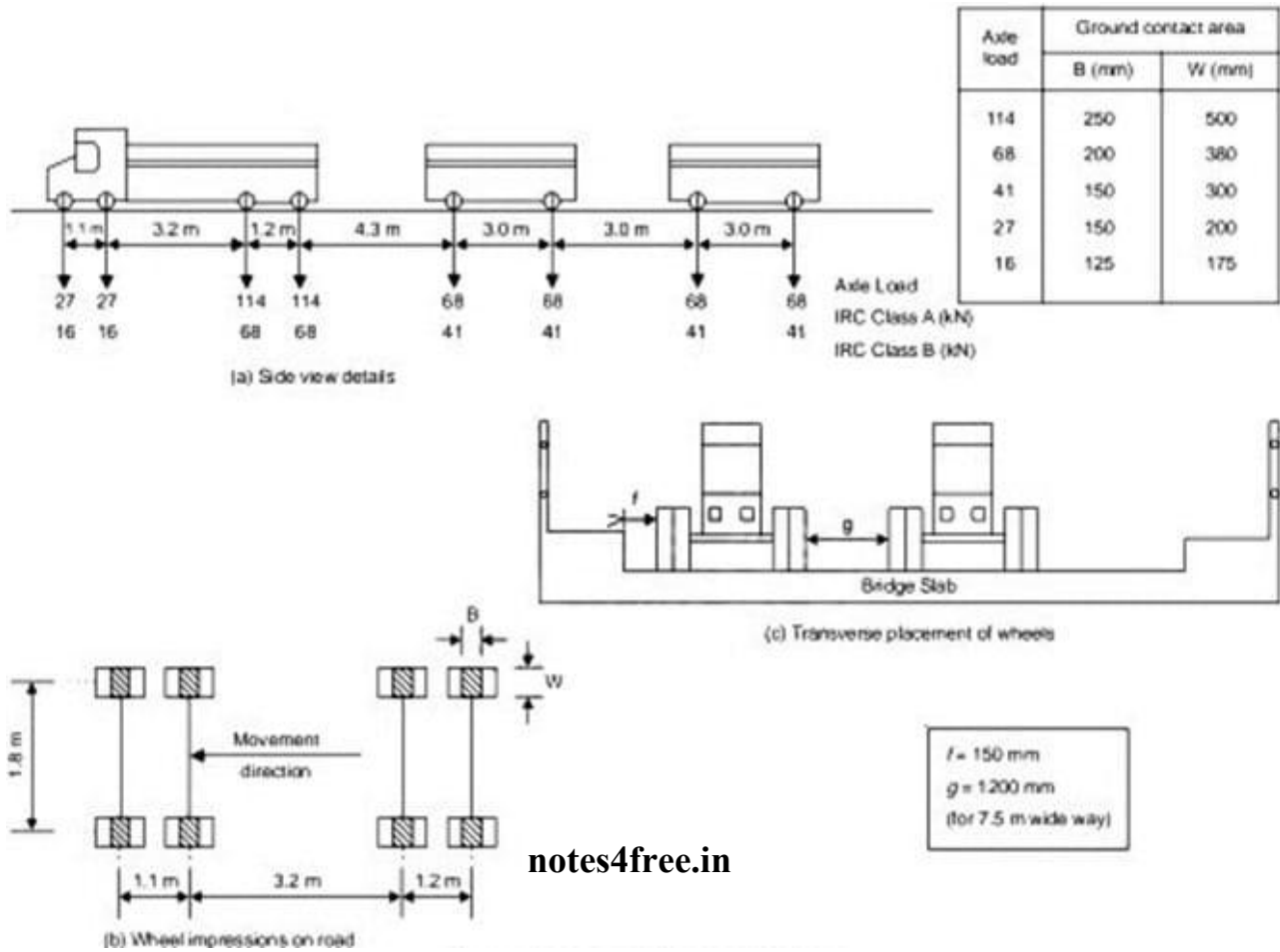
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## IRC Class B Loading

This type of loading is used to design temporary bridges like Timber Bridge etc. It is considered as light loading. Both IRC class A and Class B are shown in below figure.



# Design Of Bridges



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### 3. Impact Loads

The Impact load on bridge is due to sudden loads which are caused when the vehicle is moving on the bridge. When the wheel is in movement, the live load will change periodically from one wheel to another which results the impact load on bridge.

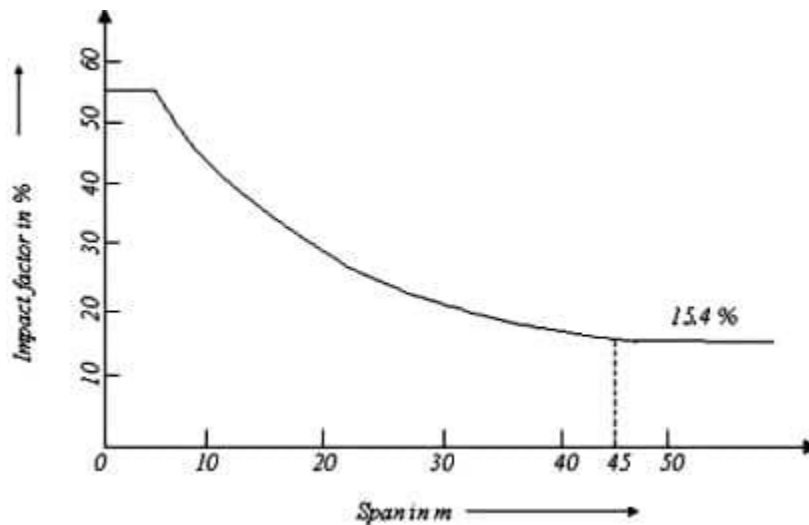
To consider impact loads on bridges, an impact factor is used. Impact factor is a multiplying factor which depends upon many factors such as weight of vehicle, span of bridge, velocity of vehicle etc. The impact factors for different IRC loadings are given below.

#### For IRC Class AA Loading and 70R Loading

## Design Of Bridges

Span	Vehicle type	Impact factor
Less than 9 meters	Tracked vehicle	25% up to 5m and linearly reducing to 10% from 5 m to 9 m.
	Wheeled vehicle	25% up to 9 m
Greater than 9 meters	Tracked vehicle (RCC bridge)	10% up to 40 m
	Wheeled vehicle (RCC bridge)	25% up to 12m
	Tracked vehicle (steel bridge)	10% for all spans
	Wheeled vehicle (steel bridge)	25% up to 23 m

If the length exceeds in any of the above limits, the impact factor should be considered from the graph given by IRC which is shown below.



**For IRC class A and class B loadings**

Bridge type	A	B
RCC	4.5	6.0
Steel	9.0	13.50

**Impact factor  $I_f = A/(B+L)$**

Where L = span in meters

A and B are constants

Apart from the super structure impact factor is also considered for substructures

- For bed blocks,  $I_f = 0.5$
- For substructure up to the depth of 3 meters  $I_f = 0.5$  to 0
- For substructure greater than 3 m depth  $I_f = 0$

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#### 4. Wind Loads

Wind load also an important factor in the bridge design. For short span bridges, wind load can be negligible. But for medium span bridges, wind load should be considered for substructure design. **For long span bridges, wind load is considered in the design of super structure.**

#### 5. Longitudinal Forces

The longitudinal forces are caused by braking or accelerating of vehicle on the bridge. When the vehicle stops suddenly or accelerates suddenly it induces longitudinal forces on the bridge structure especially on the substructure. So, IRC recommends 20% of live load should be considered as longitudinal force on the bridges.

## 6. Centrifugal Forces

If bridge is to be built on horizontal curves, then the movement of vehicle along curves will cause centrifugal force on to the super structure. Hence, in this case design should be done for centrifugal forces also.

Centrifugal force can be calculated by  $C \text{ (kN/m)} = (WV^2)/(12.7R)$

### Where

W = live load (kN)

V = Design speed (kmph)

R = Radius of curve (m)

## 7. Buoyancy Effect

Buoyancy effect is considered for substructures of large bridges submerged under deep water bodies. If the depth of submergence is less it can be negligible.

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## 8. Forces by Water Current

When the bridge is to be constructed across a river, some part of the substructure is under submergence of water. The water current induces horizontal forces on submerged portion. The forces caused by water currents are maximum at the top of water level and zero at the bottom water level or at the bed level.

The pressure by water current is  $P = KW [V^2/2g]$

Where P = pressure (kN/m<sup>2</sup>)

K = constant (value depending upon shape of pier)

W = unit weight of water

V = water current velocity (m/s)

G = acceleration due to gravity (m/s<sup>2</sup>)

## 9. Thermal Stresses

Thermal stresses are caused due to temperature. When the temperature is very high or very low they induce stresses in the bridge elements especially at bearings and deck joints. These stresses are tensile in nature so, concrete cannot withstand against this and cracks are formed.

To resist this, additional steel reinforcement perpendicular to main reinforcement should be provided. Expansion joints are also provided.

## 10. Seismic Loads

When the bridge is to be built in seismic zone or earthquake zone, earthquake loads must be considered. They induce both vertical and horizontal forces during earthquake. The amount of forces exerted is mainly depends on the self-weight of the structure. If weight of structure is more, larger forces will be exerted.

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## 11. Deformation and Horizontal Effects

Deformation stresses are occurred due to change in material properties either internally or externally. The change may be creep, shrinkage of concrete etc. similarly horizontal forces will develop due to temperature changes, braking of vehicles, earthquakes etc. Hence, these are also be considered as design loads in bridge design.

## 12. Erection Stresses

Erection stress is induced by the construction equipment during the bridge construction. These can be resisted by providing suitable supports for the members.

### 1.7 Assignment Questions?

1. Explain different types of bridges
2. Explain different types of load on bridges?

3. Explain IRC loading on Bridges?

### **1.8 Further study**

**1. [Steel.fsv.cvut.cz/suscos/PP/1C03-12-Footbridges.pdf](http://Steel.fsv.cvut.cz/suscos/PP/1C03-12-Footbridges.pdf)**

**2. <https://www.scribd.com/document/337010258/Bridge-Engineering-Lecture-Note-pdf>**

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## Module 2

### 2.0 Introduction

### 2.1 Skew Bridge

### 2.2 Slab Bridge

### 2.3 Assignment Questions

### 2.4 Further Reading

Bridges in the area are typically composed of short spans with span lengths of approximately 15 m. Bridges are simple spans with expansion joints at each pier and supported on elastomeric bearings with no continuity of the superstructure or any fixity at the intermediate diaphragms. L shaped abutments are typical for all newer concrete and older masonry bridges. The substructure of most bridges is wall piers supported on shallow foundations with no consideration for ductility. Use of deep foundations is not prevalent, even though liquefaction and lateral spreading is to be expected in the region in a seismic event. Both existing bridges and those under

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### 2.1 SKEW BRIDGE

The behaviour of skew bridges differs widely from that of normal bridges and therefore, the design of skew bridges needs special attention. In normal bridges, the deck slab is perpendicular to the supports and as such the load placed on the deck slab is transferred to the supports which are placed normal to the slab.

Load transference from a skew slab bridge, on the other-hand, is a complicated problem because there remains always a doubt as to the direction in which the slab will span and the manner in which the load will be transferred to the support.

It is believed that the load travels to the support in proportion to the rigidity of the various paths and since the thickness of the slab is the same everywhere, the rigidity will be maximum along shortest span i.e. along the span normal to the faces of the piers or abutments.

Though the span of the deck is the length BC or DE, the slab will span along AB or CD being the shortest distance between the supports. Therefore, the plane of maximum stresses in a skew slab are not parallel to the centre line of roadway and the deflection of such slab produces a warped surface.

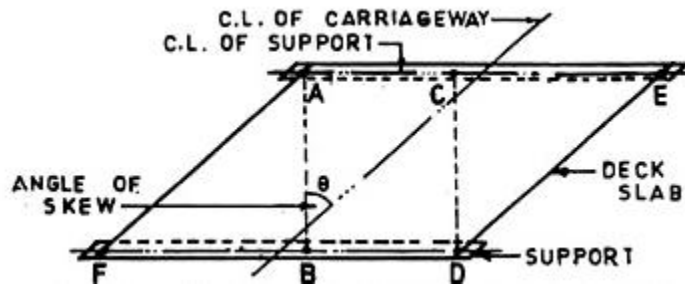


Figure showing plan of skew bridge

The effect of skew in deck slabs having skew angles up to 20 degrees is not so significant and in designing such bridges, the length parallel to the centre line of the roadway is taken as the span. The thickness of the slab and the reinforcement are calculated with this span lengths and the reinforcement are placed parallel to the centre line of the roadway.

such cases, the slab thickness is determined with shortest span but the reinforcement worked out on the basis of shortest span are multiplied by  $\sec. \theta$  ( $\theta$  being the skew angle) and are placed parallel to the roadway as shown in Fig. 1, the distribution bars being placed parallel to the supports as usual.

It is also a common practice to place the reinforcement perpendicular to the support when the skew angle lies between 20 degrees to 50 degrees.

## 2.2 Slab bridge

A short-span bridge consisting of a reinforced-concrete slab resting on abutments



## Slab Bridge



Main load bearing member in super structure of bridge is slab

Span coverage of slab bridge

*Solid Slab - up to 10m*

*Voided Slab - up to 15m*

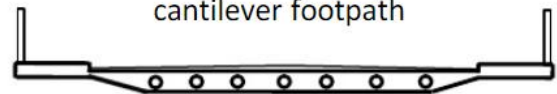
### Cross Section of Slab



Solid slab bridge



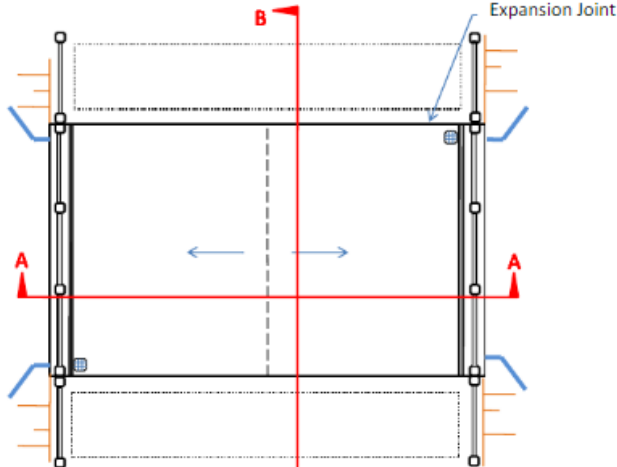
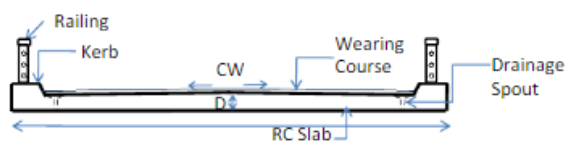
Solid slab bridge with cantilever footpath



Voided slab bridge with cantilever footpath

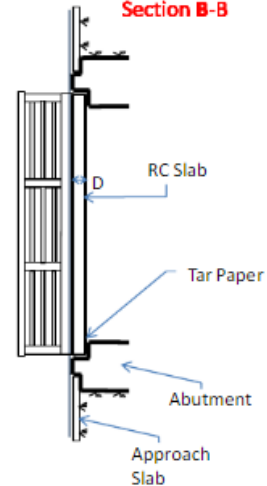
### General Arrangement of Deck of Solid Slab Bridge

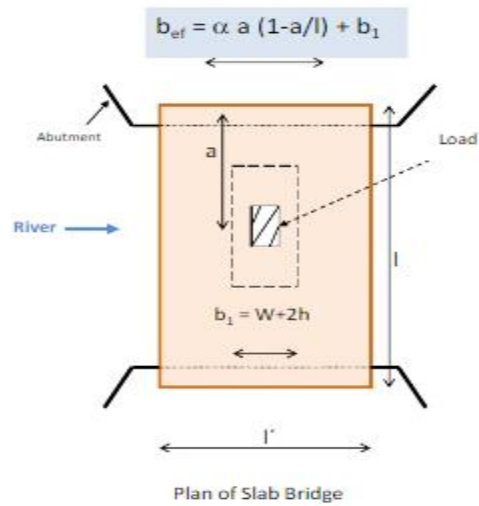
#### Section A-A



Plan of Slab Bridge

#### Section B-B





### 2.3 Assignment questions?

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1. Design a solid slab skew bridge having a clear span of 7.5 m along the roadway without any footpath and a skew angle of 25 degrees with IRC loading for N.H. Standard. M20 grade concrete and S415 grade steel will be used.

### 2.4 Further reading

1. <https://nptel.ac.in/courses/105105165/13>
2. <https://www.scribd.com/document/345712603/Design-of-Slab-Bridge>

# Design of bridges

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## MODULE 3

- 3.1 Introduction
- 3.2 Design of t-bridges
- 3.3 Problems
- 3.4 Course outcomes
- 3.5 Further reading

### 3.1 introduction

T-beam Bridge is composite concrete structure which is composed of slab panel, longitudinal girder and cross girder. Present study is mainly focuses on design of longitudinal girder by IRC: 112-2011 and IRC: 21-2000. In India, till now girders are designed and constructed according to Indian road congress guidelines as per IRC: 21-2000 code in which working stress method is used. Recently Indian road congress has introduced another code IRC: 112-2011 for design of prestress and RCC bridges using limit state method. In regards to this, present study has been performed to know how design of IRC-112 differs from IRC-21 and an attempt is made to study undefined parameters of IRC: 112-2011 such as span to depth (L/d) ratio.

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### 3.2 Design of t-bridges

T-beam, used in construction, is a load-bearing structure of reinforced concrete with a t-shaped cross section. The top of the T-shaped cross section serves as a flange or compression member in resisting compressive stresses. The web of the beam below the compression flange serves to resist shear stress and to provide greater separation for the coupled forces of bending. Fig.1 components of T- beam bridge

# Design of bridges

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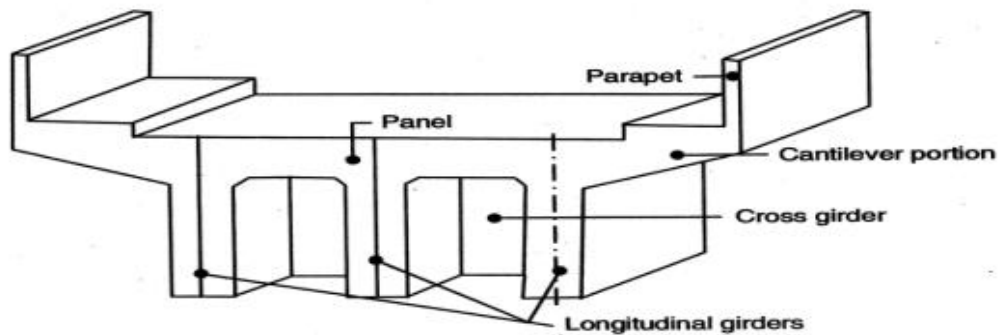


Fig.1 components of T- beam bridge

A beam and slab bridge or T- beam bridge is constructed when the span is between 10 -25 m. The bridge deck essentially consists of a concrete slab monolithically cast over longitudinal girders so that the T-beam effect prevails. To impart transverse stiffness to the deck, cross girders or diaphragms are provided at regular intervals. The number of longitudinal girders depends on the width of the road. Three girders are normally provided for a two lane road bridge. T-beam bridges are composed of deck slab 20 to 25cm thick and longitudinal girders spaced from 1.9 to 2.5m and cross beams are provided at 3 to 5m interval

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A typical tee beam bridge generally comprises the longitudinal girder, continuous deck slab between the tee beams and cross girders to provide lateral rigidity to the bridge deck. It is known that the bridge loads are transmitted from the deck to the superstructure and then to the supporting substructure elements. It is rather difficult to imagine how these loads get transferred. If a vehicle is moving on the top of a particular beam, it is reasonable to say that, this particular beam is resisting the vehicle or truck load. However, this beam is not alone; it is connected to adjacent members through the slab and cross girders. This connectivity allows different members to work together in resisting loads. The supporting girders share the live load in varying proportions depending on the flexural stiffness of the deck and the position of the live load on the deck. The distribution of live load among the longitudinal girders can be estimated by any of the following rational methods.

1. Courbon's method
2. Guyon Massonet method
3. Hendry Jaegar method

Courbon's Method Among the above mentioned methods, Courbon's method is the simplest and is applicable when the following conditions are satisfied: • The ratio of span to width of

## Design of bridges

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deck is greater than 2 but less than 4. • The longitudinal girders are interconnected by at least five symmetrically spaced cross girders. • The cross girder extends to a depth of at least 0.75 times the depth of the longitudinal girders. Courbon's method is popular due to the simplicity of computations as detailed below: When the live loads are positioned nearer to the kerb as shown below.

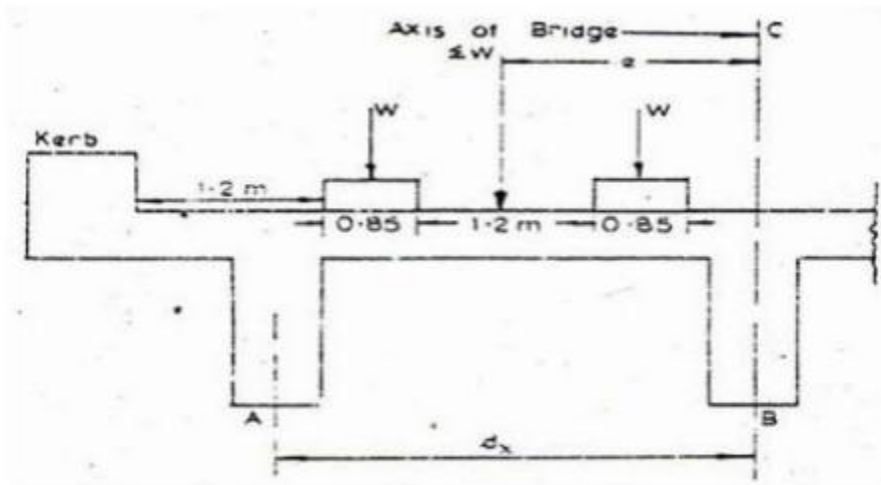


Fig. 2 Position of live loads

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The center of gravity of live load acts eccentrically with the centre of gravity of the girder system. Due to this eccentricity, the loads shared by each girder are increased or decreased depending upon the position of the girders. This is calculated by Courbon's theory by a reaction factor given by

$$R_x = \frac{\sum W}{n} \left[ 1 + \left( \frac{\sum I}{\sum dx^2 \times I} \right) \times dx \times e \right]$$

Where,  $R_x$  = Reaction factor for the girder under consideration

$I$  = Moment of inertia of each longitudinal girder

$dx$  = Distance of the girder under consideration from the central axis of the bridge

$W$  = Total concentrated live load

# Design of bridges

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n = Number of longitudinal girders

e = Eccentricity of live load with respect to the axis of the bridge.

The live load bending moments and shear forces are computed for each of the girders. The maximum design moments and shear forces are obtained by adding the live load and dead load bending moments. The reinforcement in the main longitudinal girders are designed for the maximum moments and shears developed in the girders.

## 3.3 Problems

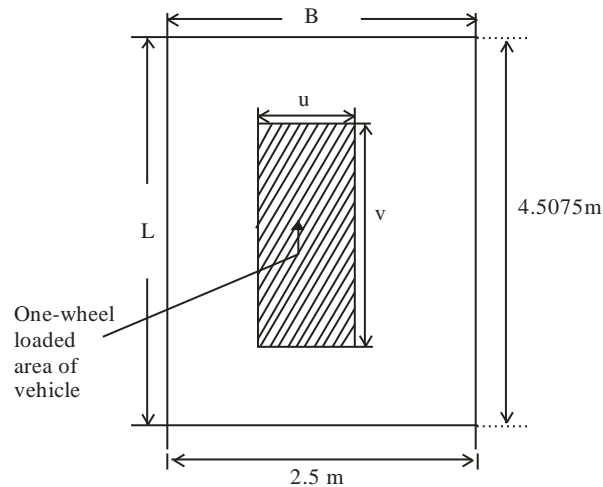
### **AVAILABLE DATA:**

- Effective span of T-beam bridge: 18.33m
- Total length of bridge: 55m
- Clear width of carriage way 7.5m (IRC 5: 1998 & IRC 6: 2014)
- Kerb width: 600mm (both side, pedestrians are allowed)
- Parapet: 1000 mm × 150 mm × 150 mm @ 1.5m c/c with 3-cast iron pipes as railing
- Camber: 1 in 100 (37.5 mm at center linearly varying to zero at kerbs)
- Wearing coat: 80mm
- Kerb height above pavement: 200mm (insurmountable type)
- Kerb type: full safety ensured **notes4free.in**
- Total kerb height above deck slab: 280 mm
- Clear depth of Longitudinal girders: 1400 mm
- Width of longitudinal girder: 400mm
- Width of cross girder: 300mm
- Clear depth of cross girder: 1400 mm
- Deck slab thickness: 250 mm
- Cantilever slab: 400 mm at girder face; linearly varying @ 0.11 to ends i.e. 200 mm
- Total overall depth of the super structure: 1800mm
- c/c spacing of longitudinal girders: 2500 mm
- c/c spacing of cross girders: 4507.50 mm
- clear distance of cantilever span from face of girder: 1800mm
- Grade of concrete: M<sub>35</sub>
- Design strength:  $f_{cd} = 0.67f_{ck}/\gamma_m$  MPa (Annex – A2 of IRC 112: 2011)
- Grade of steel : Fe<sub>415</sub> (IS 1786 : 2000)
- Design strength of steel :  $f_y/1.15 = 0.87f_y$  MPa (clause-15.2.3.3 of IRC 112:2011)
- Poisson's ratio:  $\mu = 0.2$  (Annex-B; B-3-1 of IRC 112:2011 )
- Analysis of deck slab: Piegaud's curve

### **DESIGN OF INTERIOR SLAB PANEL:**

## Design of bridges

The slab is supported on four sides by longitudinal and cross girders which c/c spacing is as shown in the figure above. The slab thickness is 250 mm and breadth and length respectively are 2.5m and 4.5075 m. the effective span will be taken as the clear span of the slabs since these are the continuous slabs. So effective width  $B_{eff} = 2.1\text{m}$  and effective length  $L_{eff} = 4.2075\text{m}$ .



**Fig-1 (Interior Slab Panel with one wheel of Tracked Vehicle)**

### **Bending Moment of the Slab Panel due to Dead Load**

$$\text{Weight of slab} = 0.25 \times 1 \times 1 \times 25 = 6.25 \text{ kN/m}^2$$

$$\text{Weight of wearing coat} = 0.080 \times 22 \times 1 \times 1 = 1.76 \text{ kN/m}^2$$

$$\text{Weight of camber} = 0.45 \text{ kN/m}^2$$

$$\text{Total dead weight} = 8.46 \text{ kN/m}^2$$

As Pieguaud's curve is used in design,  
hence  $K = B/L = 2.5/4.5075 = 0.55$

Also dead load moment is to be computed and hence  $u/B = 1.0$  and  $v/L = 1.0$

Using Pieguaud's curve for  $K=0.5$ ,  $u/B = 1.0$  and  $v/L=1.0$ ,  
 $m_1=0.047$  and  $m_2=0.004$

Also for  $K=0.6$ ,  $u/B = 1.0$  and  $v/L = 1.0$ ,  
 $m_1=0.047$  and  $m_2 = 0.016$

After interpolation, we find that  $m_1=0.047$  and  $m_2=0.0145$

Total dead load on the slab is given by  $= 8.46 \times 2.5 \times 4.5075 = 95.33$

Short span moment is  $M_B = 95.33 (0.047 + 0.20 \times 0.0145) = 4.76 \text{ kN-m}$

## Design of bridges

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Long span moment is  $M_L = 95.33 (0.0145+0.20 \times 0.047) = 2.28 \text{ kN-m}$

Since these are continuous slabs, a continuity factor of 0.8 will be multiplied. So final end moment is given by  $M_{BF} = 3.81 \text{ kN-m}$  and  $M_{BL} = 1.824 \text{ kN-m}$

### **Bending Moment due to Live Load:**

#### **a. IRC class AA tracked Vehicle:**

The wheel is placed at the center of the slab as shown in the figure previously. For maximum bending moment to be occurred, the load dispersion is taken to be occurring through wearing coat only. The load is disperses at  $45^\circ$  through the wearing coat as per Annex-B of IRC 112:2011.

Hence  $u = 0.85 + 2 \times 0.080 = 1.01 \text{ m}$  and  $v = 3.60 + 2 \times 0.080 = 3.76 \text{ m}$

Hence  $u/B = 0.404$ ,  $v/L = 0.8342$  and  $K = B/L = 2.5/4.5075 = 0.55$ .

Referring to Piegquad's curve,

For  $K = 0.5$ , and for above  $u/B$  and  $v/L$  values,

$m_1 = 0.084$ ,  $m_2 = 0.009$

Similarly for  $K = 0.6$ , we get

$m_1 = 0.095$  and  $m_2 = 0.03$

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After interpolating, we get

$m_1 = 0.089$  and  $m_2 = 0.019$

Short span bending moment is given by, (taking continuity into account)

$M_B = 0.8 \times 350 \times (0.089 + 0.2 \times 0.019) = 25.984 \text{ kN-m}$

$M_L = 0.8 \times 350 \times (0.019 + 0.2 \times 0.089) = 10.304 \text{ kN-m}$

As per IRC 6:2010, clause – 208.3, for tracked vehicles, the impact factor is 10% for spans up to 40m.

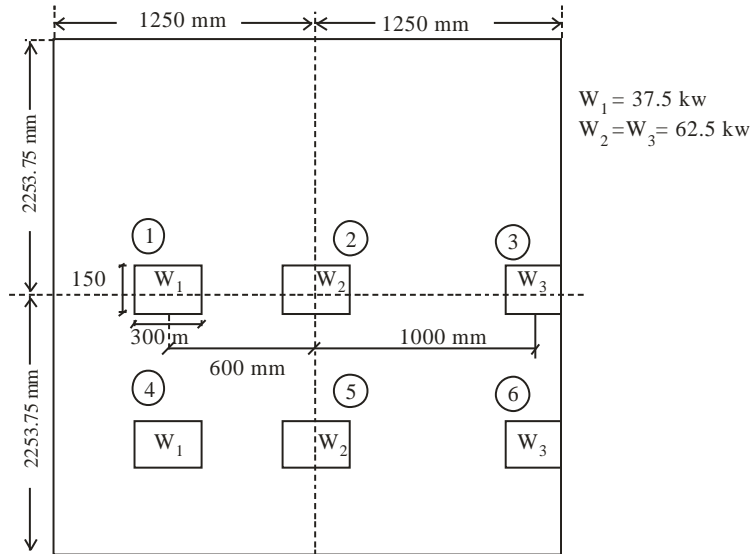
So  $M_B = 28.58 \text{ kN-m}$  and  $M_L = 11.334 \text{ kN-m}$

#### **b. IRC class-AA wheeled vehicle:**

Following different references and guides on bridge engineering, it's clearly understood that though tracked vehicle gives the severest effect along short span/direction but along long span, the wheeled vehicle gives severest effect. By going through "Essentials of Bridge Engineering: D.J Victor" and "R.C.C design: B.C. Punmia, A.K Jain and A.K Jain" we find the following load positioning gives the severest effect among other combinations.



## Design of bridges



**Fig-2 (Loading of wheeled vehicle for severest effect)**

Also as per IRC 6:2014 specifications, no other vehicles can come on to the panel during the above arrangement.

### **Bending Moment calculation due to Wheel Load -2:**

Tyre contact dimension : 300 mm × 150 mm notes4free.in

So  $u = 0.3 + 2 \times 0.080 = 0.460$  m and  $v = 0.15 + 2 \times 0.080 = 0.310$  m

The value of  $u/B = 0.184$  ,  $v/L = 0.069$  and  $B/L = 0.55$

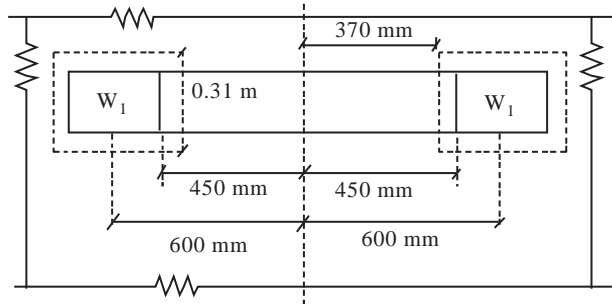
Using Pieguaud's curve,  $m_1 = 0.22$  and  $m_2 = 0.20$

Hence  $M_{B1} = 62.5 (0.22 + 0.2 \times 0.2) = 16.25$  kN-m and  $M_{L1} = 62.5 (0.2 + 0.22 \times 0.2) = 15.25$  kN-m

### **Bending Moment due to Wheel Load -1**

Since Pieguaud's curve is applicable to only symmetrical loading pattern, it cannot be used directly for unsymmetrical loading. In order to calculate the moment, a dummy load having equal magnitude will be arranged at equal distance as per real load from the center of slab or from the vertical axis of the slab. The arrangement is shown in the figure.

## Design of bridges



**Fig-3 (Bending moment calculation due to Wheel Load-1)**

So  $u = 2(u_1 + x) = 2(0.46 + 0.37) = 1.66\text{m}$  and  $v = 0.31\text{m}$

Load intensity =  $37.5 / (.31 \times .46) = 262.973 \text{ kN/m}^2$

$K = B/L = 0.55$ ,  $u/B = 0.664$  and  $v/L = 0.069$

Hence  $m_1 = 0.12$  and  $m_2 = 0.14$

$M_B = (0.12 + 0.2 \times 0.14) 262.973 \times 1.66 \times 0.31 = 20.03 \text{ kN-m}$

Similarly  $M_L = 22.193 \text{ kN-m}$

\* Now  $u = 2x = 2 \times 0.37 = 0.74$  and  $v = 0.31$

$K = 0.55$ ,  $u/B = 0.296$  and  $v/L = 0.069$

From Pieguaud's curve,  $m_1 = 0.18$  and  $m_2 = 0.18$

$M'_B = 13.38 \text{ kN-m}$  and  $M'_L = 13.622 \text{ kN-m}$

Hence total moment is given by,

$M_{B2} = (20.03 - 13.38) \times 0.5 \text{ kN-m} = 3.325 \text{ kN-m}$

$M_{L2} = (22.193 - 13.622) \times 0.5 \text{ kN-m} = 4.285 \text{ kN-m}$

### **Bending Moment due to Wheel Load-3:**

\* Now in this case  $u = 2(0.46 + 0.77) = 2.46\text{m}$ ,  $v = 0.31 \text{ m}$

Load intensity is  $62.5 / (.31 \times .46) = 438.3 \text{ kN/m}^2$

$K = 0.55$ ,  $u/B = 0.984$  and  $v/L = 0.069$

From Pieguaud's curve,  $m_1 = 0.09$  and  $m_2 = 0.09$

$M_B = 36.10 \text{ kN-m}$  and  $M_L = 36.10 \text{ kN-m}$

\* Taking  $u = 2x = 2 \times 0.77 = 1.54$  and  $v = 0.31$ ,

$K = 0.55$ ,  $u/B = 0.616$  and  $v/L = 0.069$

Hence  $m_1 = 0.125$  and  $m_2 = 0.14$

$M'_B = 32.01 \text{ kN-m}$  and  $M'_L = 34.52 \text{ kN-m}$

$M_{B3} = [36.10 - 32.01] \times 0.5 = 2.045 \text{ kN-m}$

$M_{L3} = [36.10 - 34.52] \times 0.5 = 0.79 \text{ kN-m}$

## Design of bridges

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### **Bending Moment due to Wheel Load at - 5:**

\*  $u = 0.46\text{m}$ ,  $v = 2(v_1+x) = 2(0.31 + 1.045) = 2.71\text{m}$

Load intensity =  $62.5/(0.46 \times 0.31) = 438.3 \text{ kN/m}^2$

$K = 0.55$ ,  $u/B = 0.184$ ,  $v/L = 0.60$

So  $m_1 = 0.125$  and  $m_2 = 0.0306$

$M_B = 71.57 \text{ kN-m}$  and  $M_L = 30.35 \text{ kN-m}$

\*  $u = 0.46\text{m}$  and  $v = 2x = 2 \times 1.045 = 2.09\text{m}$

$K = 0.55$ ,  $u/B = 0.184$  and  $v/L = 0.464$

From Piéguaud's curve,  $m_1 = 0.1441$  and  $m_2 = 0.043$

$M_B' = 64.30 \text{ kN-m}$  and  $M_L' = 30.25 \text{ kN-m}$

So  $M_B = 3.635 \text{ kN-m}$  and  $M_L = 0.05 \text{ kN-m}$

### **Bending Moment due to wheel Load at - 4:**

\*  $u = 2(u_1+x) = 2(0.46+0.37) = 1.66\text{m}$  and  $v = 2(v_1+y) = 2(0.31+1.045) = 2.71\text{m}$

$K = 0.55$ ,  $u/B = 0.664$  and  $v/L = 0.601$

Coefficient  $m_1 = 0.09205$  and  $m_2 = 0.027$

After multiplying with  $(u_1+x)(v_1+y)$  with both coefficients,

$m_1' = 0.1015$  and  $m_2' = 0.0304$

\*  $u = 2x = 2 \times 0.37 = 0.74\text{m}$ ,  $v = 2y = 2 \times 1.045 = 2.09\text{m}$

$K = 0.588$ ,  $u/B = 0.296$  and  $v/L = 0.464$

So  $m_1 = 0.134$  and  $m_2 = 0.0405$

Multiplying with  $xy$ ,

we get  $m_1' = 0.052$  and  $m_2' = 0.016$

\*  $u = 0.74\text{m}$ ,  $v = 2.71\text{m}$

$K = 0.55$ ,  $u/B = 0.296$  and  $v/L = 0.601$

$m_1 = 0.12$  and  $m_2 = 0.03$  and multiplying with  $x(v_1+y) = 0.5013$ ,

$m_1' = 0.060$  and  $m_2' = 0.015$

\*  $u = 1.66 \text{ m}$  and  $v = 2.09\text{m}$

$K = 0.55$ ,  $u/B = 0.664$  and  $v/L = 0.464$

$m_1 = 0.095$  and  $m_2 = 0.038$

Multiplying with  $y(u_1+x) = 0.87$ ,

$m_1' = 0.083$  and  $m_2' = 0.033$

So  $m_1 = [(0.1015+0.052)-(0.060+0.083)] = 0.0105$

$m_2 = [(0.0304+0.016)-(0.015+0.033)] \approx 0$

$M_{B4} = \frac{37.5}{0.46 \times 0.31} [0.0105 + 0.2 \times 0] = 2.761 \text{ kN-m}$

## Design of bridges

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$$M_{L4} = \frac{37.5}{0.46 \times 0.31} [0.2 \times 0.0105 + 0] = 0.552 \text{ kN-m}$$

### **Bending Moment due to Wheel Load at -6:**

- \*  $1 \text{ u} = 2[u_1+x] = 2[0.46+0.77] = 2.46 \text{ m}$  and  $v = 2[v_1+x] = 2[0.31+1.045] = 2.71 \text{ m}$   
 $K = 0.55$ ,  $u/B = 0.984$  and  $v/L = 0.601$   
 $m_1 = 0.068$ ,  $m_2 = 0.02$   
 $[u_1+x][v_1+y] = 1.23 \times 1.355 = 1.67$   
 $m_1' = 0.113$  and  $m_2' = 0.0334$
- \*  $2 \text{ u} = 2x = 1.54 \text{ m}$  and  $v = 2y = 2.09 \text{ m}$   
 $K = 0.55$ ,  $u/B = 0.616$  and  $v/L = 0.464$   
 $m_1 = 0.097$ ,  $m_2 = 0.038$   
 $xy = 0.804$   
Hence  $m_1' = 0.078$  and  $m_2' = 0.0305$
- \*  $3 \text{ u} = 2[u_1+x] = 2.46 \text{ m}$  and  $v = 2y = 2.09 \text{ m}$   
 $K = 0.55$ ,  $u/B = 0.984$  and  $v/L = 0.464$   
 $m_1 = 0.074$  and  $m_2 = 0.03$   
 $y(u_1+x) = 1.285$   
 $m_1' = 0.095$  and  $m_2' = 0.038$
- \*  $4 \text{ u} = 2x = 1.54 \text{ m}$  and  $v = 2(v_1+y) = 2.71 \text{ m}$   
 $K = 0.55$ ,  $u/B = 0.616$  and  $v/L = 0.601$   
 $m_1 = 0.092$  and  $m_2 = 0.025$   
Multiplying  $x(v_1+y) = 1.043$  with above coefficients,  
 $m_1' = 0.096$  and  $m_2' = 0.026$

So final coefficients are,

$$m_1 = [(0.113+0.078)-(0.095+0.096)] = 0$$

$$m_2 = [(0.0334+0.0305)-(0.038+0.026)] \approx 0$$

The resulting moment is given by,

$$M_{B6} = M_{L6} = 0 \text{ kN-m}$$

Total bending moment is given by,

$$M_B = 16.25 + 3.325 + 2.045 + 3.635 + 2.761 = 28.016 \text{ kN-m}$$

$$M_L = 15.25 + 4.285 + 0.79 + 0.05 + 0.552 = 20.93 \text{ kN-m}$$

Applying continuity and impact,

$$M_B = 28.016 \times 0.8 \times 1.18 = 26.45 \text{ kN-m}$$

$$M_L = 20.93 \times 0.8 \times 1.18 = 19.76 \text{ kN-m}$$

The impact factor is taken as 18% as per clause-208.4 of IRC 6: 2014. It can be seen that the moment along short span for tracked load is greater while the wheel load bending moment

## Design of bridges

along the longer span is severer. Hence the moment for tracked load will be taken along shorter direction and moment along longer direction will be considered from wheel load in the design of d **SHEAR FORCE CALCULATION FOR INTERIOR SLAB PANEL:**

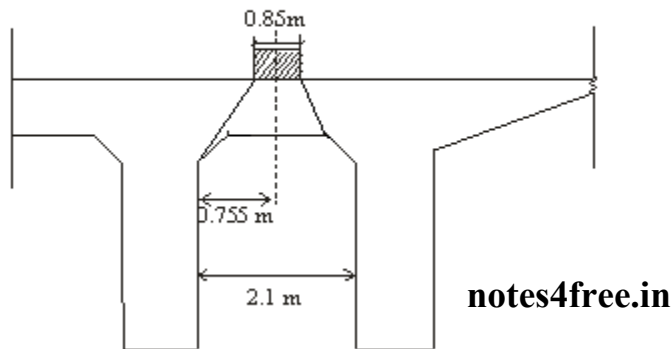
### 3.6.4.1 Wheel Load Shear:

Following IRC-112:2011 (B-3.3, Annex- B-3), the dispersion of load through wearing coat & slab will be at 45°.

Hence dispersion of load is given by  $0.85+2(0.08+0.25) = 1.51\text{m}$ .

For maximum shear to occur, the load dispersion should be within face of girder.

So wheel load will be kept at least  $1.51/2=0.755\text{m}$  from the longitudinal girder face; as shown in the figure.



**Fig-12 (Load dispersion through deck slab)**

Referring IRC-112:2011, clause-B 3.2 (page-278),

$$b_{ef} = \alpha a (1 - a/l_0) + b_1$$

$$b/l_0 = \frac{4.2075}{2.1} = 2.003 > 2.00$$

$$\alpha = 2.6$$

$$l_0 = 2.1$$

$$a = 0.755\text{m}$$

$$b_1 = 3.6 + 2 \times 0.08 = 3.76\text{m}$$

$$b_e = 2.6 \times 0.755 (1 - 0.755/2.1) + 3.76$$

$$= 5.017\text{m}$$

Load per meter width is

$$= \frac{350}{5.017} = 69.763$$

$$\text{Maximum shear force} = \frac{69.763 \times (2.1 - 0.755)}{2.1}$$

$$= 44.681 \text{ kN/m}$$

Shear force with impact due to tracked vehicle = 49.15 kN/m

### 3.6.4.2 Dead load shear:

Total dead weight =  $8.46 \text{ KN/m}^2$

Total dead load shear =  $\frac{8.46 \times 2.1}{2} = 8.883 \text{ kN/m}$

### 3.6.5 DESIGN BENDING MOMENT AND SHEAR FORCE:

Total  $M_B = 3.81 + 28.58 = 32.39 \text{ KN-m}$

$M_I = 1.824 + 19.76 = 21.584 \text{ KN-m}$

Total shear force =  $(8.883 + 49.15) \text{ KN/m}$   
 $= 58.03 \text{ KN/m}$

Since we have considered limit state method the above load values will be 1.5 times that of calculated as per Annex A2 of IRC: 112-2011

So  $M_B = 48.585 \approx 50 \text{ kN-m}$

$M_I = 32.376 \approx 33 \text{ kN-m}$

$V_u = 87.045 \text{ kN/m}$

Minimum effective depth as per maximum bending moment is given by

$$d = \sqrt{\frac{50 \times 10^6}{(0.36 \times 35 \times 0.48 \times 10^3 \times (1 - 0.416 \times 0.48))}}$$

$$= 101.635 \text{ mm}$$

As per table – 14.2, clause – 14.3.2.1 (page 142) of IRC–112: 2011,

Clear cover =  $40 + 8 = 48 \text{ mm}$

So,  $d = 250 - 48 = 202 \text{ mm} > 101.63 \text{ mm}$  [notes4free.in](http://notes4free.in)

Using 16 mm- $\phi$  bars, cover for short span =  $210 - 8 = 202 \text{ mm}$  and cover for long span =  $202 - 16 = 186 \text{ mm}$ .

### REINFORCEMENT DETAILS FOR INTERIOR SLAB PANEL:

#### (i) Area of steel along short direction

$$(A_{st})_B = \frac{0.5 \times 35}{415} \times \left[ 1 - \sqrt{1 - \frac{4.6 \times 50 \times 10^6}{35 \times 10^3 \times 202^2}} \right] \times 10^3 \times 202$$

As per clause -16.6.1.1 of IRC:112-2011

$$(A_{st})_{\min} = 0.26 \times \frac{f_{ctm}}{f_{yk}} \times b_t d$$

From table -6.5 (Page-38) of IRC :112-2011

$$F_{ctm} = 2.8 \text{ N/mm}^2$$

$$F_{yk} = 415 \text{ N/mm}^2$$

$$b_t = 1000 \text{ mm}$$

$$D = 202 \text{ mm}$$

$$(A_{st})_{\min} = 354.351 \text{ mm}^2$$

Also same clause specified

$$(A_{st})_{\min} = 0.0013 b_t d$$

$$= 262.6 \text{ mm}^2$$

## Design of bridges

$$(A_{st})_{\max} = 0.025A_c$$

$$= 0.025 \times 250 \times 1000 = 6250 \text{ mm}^2$$

Spacing of bars as per clause-16.6.1.1(4) of IRC-2011 is,

$$s_{\max} < 2h = 2 \times 250 = 500 \text{ mm}$$

In our case, spacing of 16 mm  $\emptyset$  bars is

$$S = \frac{1000 \times \pi / 4 \times 16^2}{716.008}$$

$$= 280.811 \text{ mm} > 250 \text{ mm}$$

Also as per clause-15.2.1 (2) of IRC:112-2011,

The clear distance between the parallel main reinforcing bars should not be less than  $d_g + 10 = 20 + 10 = 30 \text{ mm}$  and  $20 \text{ mm}$ , whichever is greater

$D_g$  = aggregate size = assumed 20mm for slabs, providing 16 mm- $\emptyset$  bars @ 225mm c/c

$$((A_{st})_B)_{\text{provided}} = \frac{1000 \times \pi / 4 \times 16^2}{225}$$

$$= 893.61 \text{ mm}^2$$

Also as per clause -12.2.2, page – 120 of IRC:112-2011, under rare combination of loads, the maximum tensile stress limits to  $0.8 f_y$  is to avoid inelastic strain, undesirable cracking/deformation of structure and also to account for long term creep.

We have calculated the steel area taking  $f_{yd} = 0.87 f_{yk}$  ( as per cl-15.2.3.3 IRC:112-2011)

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Considering the worst case i.e rare combination of loads, additional steel area required  $= 1 - \frac{0.8}{0.87}$   
 $= 0.080 = 8\%$  of required steel area.

$$\text{So } 8\% \text{ of } (A_{st})_{\text{required}} = \frac{8}{100} \times 716.005 = 57.28 \text{ mm}^2$$

$$A_{st} \text{ to be provided} = 716.005 + 57.28 = 773.28 \text{ mm}^2 < 893.61 \text{ mm}^2 \quad (\text{ok})$$
$$(A_{st})_{B\text{prov.}} = 893.61 \text{ mm}^2$$

### (ii) Area of steel along long direction

Providing 12mm- $\emptyset$  bars,

$$(A_{st})_L = \frac{0.5 \times 35}{415} \times \left[ 1 - \sqrt{1 - \frac{4.6 \times 33 \times 10^6}{35 \times 10^3 \times 190^2}} \right] \times 10^3 \times 190 = 480.53 \text{ mm}^2$$

$$(A_{st})_{\min} = 0.26 \times \frac{f_{ctm}}{f_{yk}} \times b_f \times d \quad (\text{cl-16.6.1, IRC:112-2011})$$

$$F_{ctm} = 2.8 \text{ N/m}^2 \quad (\text{table-6.5 of IRC:112-2011})$$

$$(A_{st})_{\min} = 0.26 \times \frac{2.8}{415} \times 1000 \times 190 = 333.301 \text{ mm}^2$$

## Design of bridges

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Also as per same clause ,

$$(A_{st})_{\min} = 0.0013b_t d = 247 \text{ mm}^2$$

$$(A_{st})_{\max} = 0.025A_c = 0.025 \times 250 \times 1000 = 6250 \text{ mm}^2$$

Spacing of bars as per clause-16.6.1.1(4 of IRC:112-2011 is,

$$S_{\max} < 2h = 2 \times 250 = 500 \text{ mm or } 250 \text{ mm ( smaller value is taken)}$$

$$S = \frac{1000 \times \pi / 4 \times 12^2}{480.53} = 235.36 \text{ mm}$$

Hence providing spacing of bars @175 mm c/c & using 12mm  $\emptyset$  bars

$$((A_{st}))_{\text{provided}} = \frac{1000 \times \pi / 4 \times 12^2}{175} = 646.30 \text{ mm}^2$$

Also as per clause-15.2.1(2) of IRC:112-2011, the clear distance between the parallel main reinforcing bars should not be less than  $d_g + 10 = 20 + 10 = 30$  mm or 20 mm (larger value is taken).

Also as per clause-12.2.2, P-120 of loads ,the max tensile stress in steel is limited to  $0.8f_{yk}$  to avoid inelastic stain ,undesirable cracking/deformation of structure & also to account for long term creep.

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$$\text{Hence more area required is } = \left(1 - \frac{0.8}{0.87}\right) (A_{st})_{\text{required}}$$

$$= 0.08 \times 480.53 = 38.44 \text{ mm}^2$$

$$(A_{st})_{\text{required for creep cracking}} = 480.53 + 38.44 = 518.97 \text{ mm}^2 < 646.30 \text{ mm}^2$$

$$(A_{st})_{L,\text{prov}} = 646.30 \text{ mm}^2$$

deck slab

### DESIGN OF CROSS GIRDER

#### DESIGN OF CROSS GIRDER:

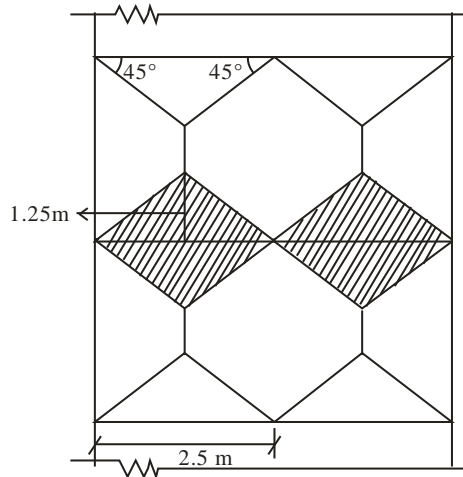
$$\text{Self-weight} = 0.3 \times 1.4 \times 25 = 10.5 \text{ kN/m}$$

Slab load will be distributed as shown below



## Design of bridges

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**Fig-4 (Dead load distribution from slab on Cross Girder)**

Dead load from slab =  $2 \times 0.5 \times 2.5 \times 1.25 \times 8.46 = 26.4375$

So udl load =  $\frac{26.4375}{2.5} = 10.575 \text{ kN/m}$

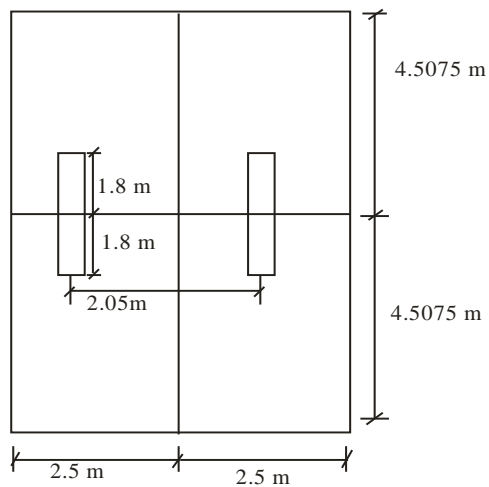
Total load (dead weight) =  $21.075 \text{ kN/m}$

Assuming rigid cross girder,

Reaction on longitudinal girder is =  $\frac{21.075 \times 5}{3} = 35.125 \text{ kN}$

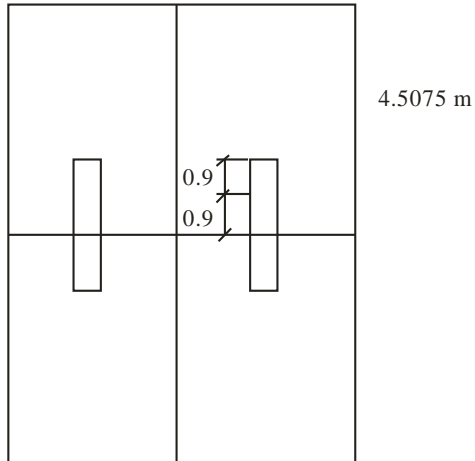
For max. Bending moment, the loads should be kept at equal distance from intermediate longitudinal girder of both sides of cross girder.

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## Design of bridges

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**Fig-4(Wheel load arrangement for maximum bending moment on Cross Girder)**

Now for calculating load, following diagram may be provided at beneficial

Load on cross girder from one wheel

$$= 2 \times \frac{350}{2} \times \frac{(4.5075 - 0.9)}{4.5078} = 280.12 \text{ kN}$$

Reaction on each longitudinal girder

$$= \frac{280.12 \times 2}{3} = 186.75 \text{ kN}$$

Max. Bending moment on cross girder under load =  $186.75 \times 1.475 = 275.456 \text{ kN-m}$

In checking impact,  $M_c = 303 \text{ kN-m}$

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Dead load moment under wheel load ,

$$= 35.125 \times 1.475 - 21.075 \times \frac{(1.475)^2}{2} = 28.884 \text{ kN-m}$$

Total design moment =  $332 \text{ kN-m}$

Ultimate moment =  $M_u = 498 \text{ kN-m}$

Since the cross girder fixed at intermediate girder, (-)ve moment will exist.

As per D.J victor, Essential Bridges Engineering, referring to Morrice-Little method, distribution coefficient =  $0.416$

So negative moment =  $0.146 \times 498 \approx 73 \text{ kN-m}$

Since its flange d beam, assuming neutral axis in side flange,

$M_u = 21241.143 \text{ kN-m} \gg \gg \gg 498 \text{ kN-m}$

$$(A_{st})_{+ve} = \frac{498 \times 10^6}{0.87 \times 415 \times 1660 \times (1 - 0.416 \times \frac{250}{1600})} = 886.45 \text{ mm}^2$$

Providing 4-20mm  $\phi$  bars

$$(A_{st})_{provided} = 1256.64 \text{ mm}^2$$

Provision of 4-16-mm  $\phi$  bars at top will give

$$(A_{st})_{-ve} = 804.25 \text{ mm}^2 > (A_{st})_{required} = 135.152 \text{ mm}^2$$

Provide 4-12mm  $\phi$  bars each face uniformly as side reinforcement.

## SHEAR CHECK FOR CROSS GIRDERS:

Cl-10.3.2 of IRC:112-2011

$K=1.33$

$V_{min}=0.281$

$\sigma_{cp}=0$

$\rho_1=2.618 \times 10^{-3}$

$V_{Rdc}=[0.12 \times 1.33 \times (80 \times 2.618 \times 10^{-3} \times 35)^{0.33} \times 300 \times 1600]=147.831 \text{ kN}$

$V_{Rdc.min}=0.281 \times 300 \times 1600=134.880 \text{ kN}$

Design shear  $V_{Ed}=1.5[186.75+35.125]=332.8125 \text{ kN}$

Extra shear to be resisted by stirrups is  $=184.98 \approx 185 \text{ kN}$

Providing 8mm dia -4 legged stirrups

$A_{sw}=201 \text{ mm}^2$

Spacing(s)= 519.43mm, 8mm  $\phi$  4-legged @300mm c/c

Again shear reinforcement ratio

$\rho_w = \frac{A}{s \times b_w \times \sin \alpha}$  (cl-16.5.2 of IRC 112:2000)

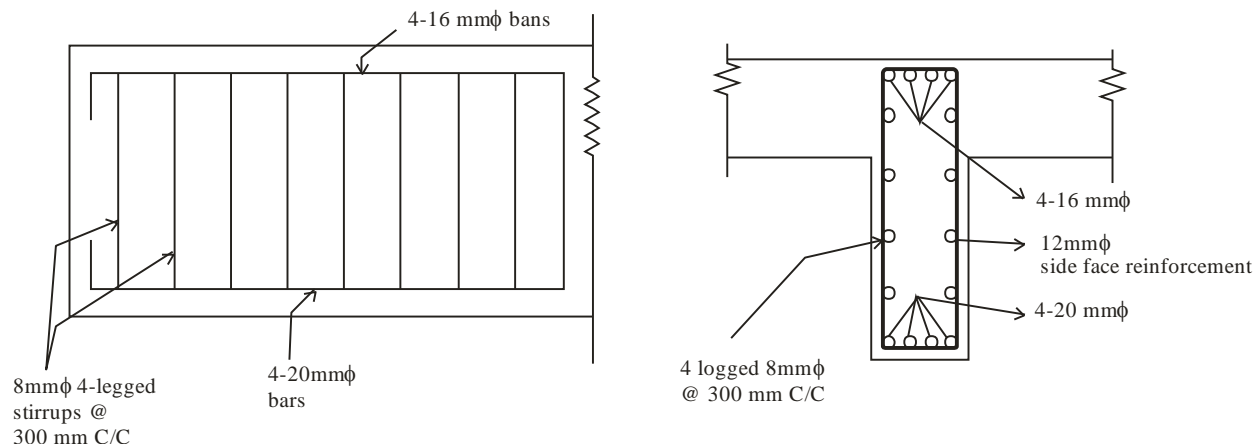
$=1.2899 \times 10^{-3}$

$(\rho_w) = \frac{0.072 \times \sqrt{35}}{415} = 1.026 \times 10^{-3}$

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Assuming  $(\rho_w)_{min}$ ,

$s = \frac{201}{300 \times 1 \times 1.026 \times 10^{-3}} = 653.021 \text{ mm} > 300 \text{ mm} (ok)$



**Fig 5 (Reinforcement detailing of Cross Girder)**

Clause -16.5.2 of IRC:112-2011(6, 7, 8,9,) specifies that

$s_{min}=d_g+10=30 \text{ mm}$

## Design of bridges

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40mm

$$2\phi_s = 2 \times 8 = 16\text{mm}$$

$$S_{\max} = 0.75d(1 + \cot\alpha) = 0.75 \times (1 + 0) = 1245\text{mm}$$

As per the Clause -16.5.3 of IRC:112-2011,

The links will not to be of greater spacing of following

$$1/8 \text{ (perimeter of member)} = 487.5\text{mm}$$

or 350mm

Our provision of 300mm (okay)

### **MODIFIED ANCHORAGE FOR BARS AT THE ENDS OF GIRDERS:**

At the ends of girders, bearing available is only 450mm. hence standard 90 bend as per fig 15.2 of irc:112-2011 will be provided.

So modified  $l_{b.net}$  will be

$$l_{b.net} = 0.7 \times l_b \times 1 = 0.7 l_b$$

$$l_b = 903\text{mm (for } 30\text{mm } \phi \text{ bars)}$$

$$l_b = 843\text{mm (for } 28\text{mm } \phi \text{ bars)}$$

$$(l_{b.net})_{O.G} = 632\text{mm}$$

$$(l_{b.net})_{I.G} = 590\text{mm}$$

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### 3.4 Course outcomes

1. Design of longitudinal girder
2. Design of cross girder

### 3.5 Further study

1. <https://nptel.ac.in/courses/105105165/18>

2. [https://www.in.gov/dot/div/contracts/design/lrfd/05\\_Section%204\\_Deck\(E\).PDF](https://www.in.gov/dot/div/contracts/design/lrfd/05_Section%204_Deck(E).PDF)

## Module 4

### 4.1 Introduction

### 4.2 Design of Box culverts

### 4.3 Design of Pipe Culverts

### 4.4 Course Outcomes

### 4.5 Further Reading

## 4.1 Introduction

Box culverts are the ideal solution to a wide range of construction applications. Their traditional use is for diverting watercourses. Available in a wide range of sizes, the versatility of these structures has seen them used for many other applications. These include attenuation tanks, pedestrian subways, access shafts, service tunnels, sea outfalls, road crossings and a variety of other applications. In all cases where strength, durability and economy are of paramount importance.

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## 4.2 DESIGN OF BOX CULVERTS

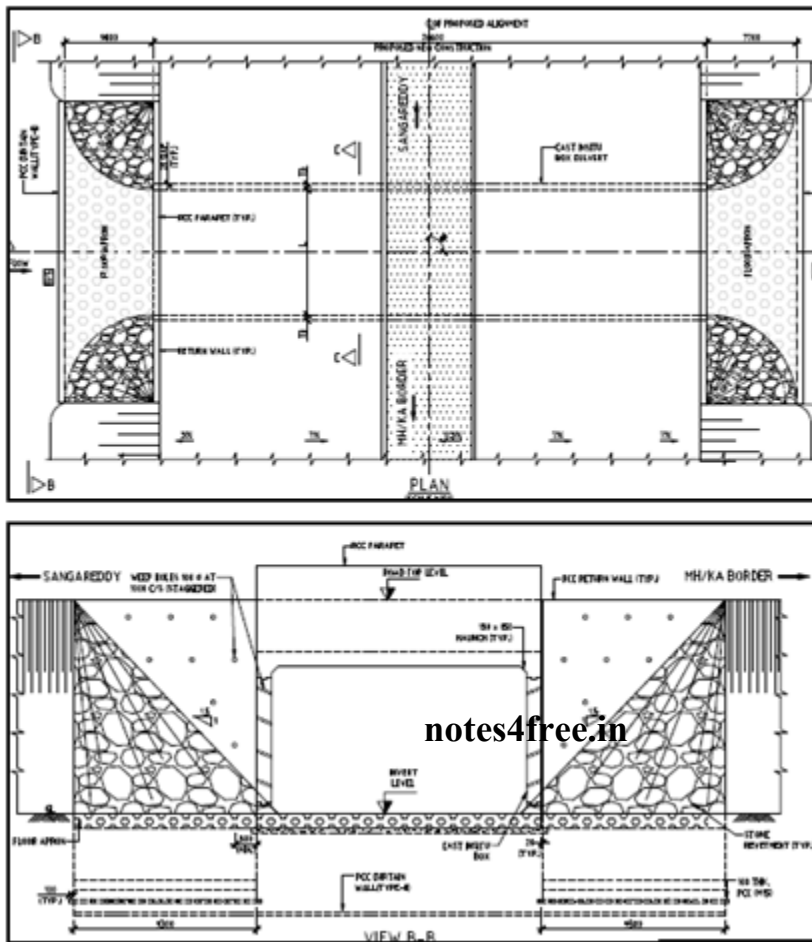
A culvert is a structure that allows water to flow under a road, railroad, or similar obstruction. Typically embedded so as to be surrounded by soil, a culvert may be made from a pipe, reinforced concrete or any other material. Box Culverts are cross-drainage structures built beneath roadways which are box shaped as the name suggests. They are less than or equal to 6m in span along the longitudinal direction of the road

### Details Of The Structure

The basic design data required for analysis of the structure is as follows:

1. Clear span
2. Clear height
3. Dimension of Box Culvert
4. Depth of fill and wearing coat
5. Width of carriage way
6. Soil Properties

# Design of Bridges



Plan and sectional elevation of a Box Culvert

## DESIGN OF BOX SECTION

The critical case is taken for maximum shear force and maximum bending moment condition at the critical sections

## DESIGN FOR FLEXURE

The effective depth for the top slab, bottom slab and side wall are calculated by deducting the clear cover and depth of stirrup and diameter of the reinforcement bar.

The effective depth required is calculated as per the following procedure and the depth is checked if safe or not. If not section dimensions need to be revised.

# Design of Bridges

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*Effective depth required,  $d_{req} = (M/Qb)^{1/2}$*

***M – Bending Moment***

*at the section required*

***Moment at the section***

$$Q = (1/2) \times j \times k \sigma_{cbc}$$

$$j = 1 - (k/3)$$

$$k = (280/(3 \sigma_{cbc})) / (280/(3 \sigma_{cbc}) + \sigma_{st})$$

*$\sigma_{cbc}$  &  $\sigma_{st}$  are the permissible flexural strength in steel and concrete respectively*

The area of steel required is calculated as per the following formula and adequate steel is provided and spacing of bars are computed. The steel provided has to be greater than the minimum steel required that is 0.12% of the gross area of section.

***Area of steel required,  $A_{st\ req} = M/(\sigma_{st}jd)$***   
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## DESIGN FOR SHEAR

The critical cases for shear force in the maximum bending moment and maximum shear force conditions are considered at the critical sections 2, 5, 8 & 9.

The design shear stress is computed as follows (Cl. 304.7 IRC 21-2000):

$$\text{Design Shear Stress, } \tau_v = V / (b \times d)$$

*b – breadth of the member*

*d – effective depth of the member*

*V – Design Shear across the section*

The value of design shear stress must be less than the maximum shear stress allowed in the section as per IRC 21-2000 table 12A. The permissible shear stress,  $\tau_c$  is determined based on the percentage of steel provided as given in table 12B IRC 21-2000, and the shear reinforcement is computed for the unbalanced shear force.

# Design of Bridges

**Vertical Shear Reinforcement,  $A_{sw} = V_s \times S / (\sigma_s \times d)$**

$A_{sw}$  – Total Cross-sectional area of stirrup legs

$V_s = V - \tau_c \times b \times d$

$S$  – Spacing of the stirrups

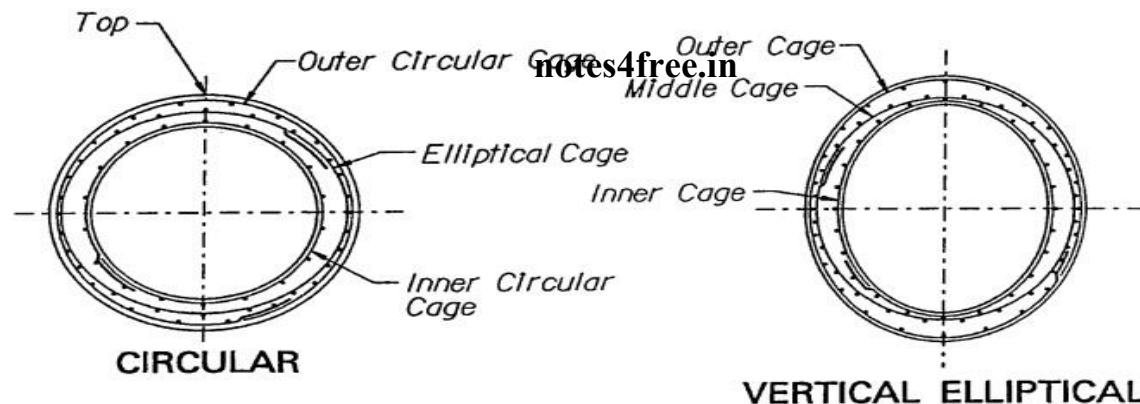
$\sigma_s$  – Permissible tensile stress in shear reinforcement

$d$  – effective depth

## 4.3 Pipe Culvert

Pipe culverts are the most common types of culverts due to competitive price and easy installation. They are found in different shapes such as circular, elliptical and pipe arch. Generally, their shapes depend on site conditions and constraints. Pipe culverts on a small scale represent normal pipes like concrete pipes.

Pipe-arch culverts provide low clearance, openings suitable for large waterways, and are more aesthetic. They may also provide a greater hydraulic advantage to fishes at low flows and require less road fill.



### Advantages of Pipe Culvert

The main features of pipe culverts are:

It can be constructed of any desired strength by proper mix design, thickness, and reinforcement.

They are economical.

These pipes can withstand any tensile stresses and compressive stresses.

The crossing of water is under the structure.

### Disadvantages of Pipe Culvert

The main disadvantage of pipe culvert is that it can be easily corroded at the crown because of bacteria's organic matter and release of harmful gas, which is known as Crown corrosion.



## 4.4 ASSIGNMENT QUESTIONS

1. What is the difference between box culvert and pipe culvert?

2 Design a reinforced concrete box culvert having a clear way vent way of 3m by 3m.the super imposed load dead load on culvert is 12.5kn/m<sup>2</sup>. The live load on the culvert is 50kn/m<sup>3</sup>.Density of soil at the site is 18kn/m<sup>3</sup> angle of repose =30° adopt M 20 grade concrete and Fe415 steel for steel

## 4.5 Further reading

1. [https://precast.org/wp-content/uploads/2014/08/Box\\_Culvert\\_Presentation.pdf](https://precast.org/wp-content/uploads/2014/08/Box_Culvert_Presentation.pdf)

2. <https://fpmccann.co.uk/box-culverts>

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## MODULE 5

### 5.1 Introduction

### 5.2 Bearings

### 5.3 Piers

### 5.4 Assignment Questions

### 5.5 Further Reading

### 5.1 Introduction

Bearings can be termed as the mechanical part of a bridge structure. The earliest bridges were built of high mass of stones, bricks or timber material. Temperature difference accounts for expansion and reduction in these bridges, but with small temperature gradients because of the high mass of the bridge material. Bridges made of timbers reacts more to moisture content and weather conditions than thermal actions from temperature difference, but timber bridges are constructed with several joints which enables sectionalized movement in the bridges. With sophistication in the design and construction of bridges coupled with demands of bridges for heavy loads, large volume of traffic, longer life span, high durability, difficult barriers etc. lead to bridges being constructed with steel, reinforced and prestressed concrete or composite material. To aid the movement in the present type of bridge structures bearings have been adopted. The earliest types of bridge bearings are made of steel, but with problems of durability, degradations, flexibility and maintenance different types of bridge bearings have been developed to suite different designs and requirements. Current studies are aimed towards further development of bridge bearings to support and transfer larger forces with higher level of durability for lifespan that matches the bridge lifespan whilst enabling bridge flexibility at a cost effective means.

### 5.2 Bearings

#### **Role of bridge bearings**

Bridge bearings are connections that transfer forces between the bridge superstructure (deck) and the substructures (pier, viaduct or abutment). Temperature difference such as increase in temperature causes the bridge structure to expand/elongate along its length, thereby causing movements in the bridge structure and vice versa, decrease in temperature causes the bridge to reduce in length. During seismic occurrence the bridge foundations take up forces and transfer to the entire bridge structure causing rigorous vibration and movements of the bridge. The bridge structure also vibrates and moves in reaction to forces from heavy traffic (trains, vehicles etc.). Creep, shrinkage and elastic deformation all result in movement of the bridge structure.

#### Causes of movement in bridges

- In general, movements in bridges can be summarized to the following sources:
- Movements due to shrinkage and creep
- Movements due to traffic loads
- Movements due to dead load of the bridge structure itself
- Movements due to lateral forces acting on the bridge structure such as wind loads
- Movements due to temperature changes
- Movements as a result of settlements in supports (uniform and differential settlements) –
- Movements as a result of soil pressure on abutments
- Movements due to horizontal loads such as accelerating, braking, skidding and traction force
- Movements as a result of impact forces such as vehicles colliding with bridge structures (railings, kerbs, edge beams etc.), vehicles colliding with other vehicles, boats and ships colliding with piers

### 5.2.1 Functions of bridge bearings

- Connects the bridge superstructure to the substructure.
- Accommodates and transfers dynamic forces and vibrations without causing wear or destruction to the substructure.
- Enables movement (translational, vertical or rotational) of the bridge structure in reactions to loads.
- Controls the movement in bridge structure; direction and degree wise.
- Ensures that deformations, which occur in the superstructure of the bridge, donot lead to large forces and moments in the substructure.
- Can be used to adjust the dynamic properties of the bridge.
- Bearings reduce shear on the head of the piers, viaducts or abutments.
- Recent bridge bearings are designed to act as seismic protectors that arrest and dissipate energy during earthquakes and other seismic activities.

### 5.2.3 Classification of bridge bearings

According to support principle - Fixed or clamped bearing; permits rotation but no transverse or longitudinal movement –

Hinge or pin; permits rotational movement while at the same time preventing longitudinal movement –

Movable bearing; permits both rotational and translational movements - Guided bearing; permits only translational movements

According to material –

Steel bearing - Rocker/Linear bearing

Roller bearing

Sliding plate bearing

- Combined roller and rocker bearing
- Rubber and combined bearing
- Laminated elastomeric bearing
- Plain elastomeric bearing
- Lead rubber bearing

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3. According to design

Pot bearings

Spherical bearings

Elastomeric bearings

Disc bearings

ILM (incremental launch) bearings

Lifting and measuring bearings

Deformation bearings

Special bearings

4 Seismic isolation bearings

Friction pendulum bearings

Lead rubber bearings

High damping rubber bearings

### 5.2.4 Expansion joint

An **expansion joint** or **movement joint** is an assembly designed to safely absorb the temperature-induced expansion and contraction of construction materials, to absorb vibration, to hold parts together, or to allow movement due to ground settlement or earthquakes. They are commonly found between sections of buildings, bridges, sidewalks, railway tracks, piping systems, ships, and other structures.

Building faces, concrete slabs, and pipelines expand and contract due to warming and cooling from seasonal variation, or due to other heat sources. Before expansion joint gaps were built into these structures, they would crack under the stress induced

Modular expansion joints are used when the movements of a bridge exceed the capacity of a single gap joint or a finger type joint. A watertight system, invented by the Swiss company Mageba, is designed on a modular basis and can be tailored to satisfy the specific requirements of almost any structure. Modular multiple-gap expansion joints can accommodate movements in every direction and rotations about every axis. They can be used for longitudinal movements of as little as 160 mm, or for very large movements of well over 3000 mm. The total movement of the bridge deck is divided among a number of individual gaps which are created by horizontal surface beams. The individual gaps are sealed by watertight elastomeric profiles, and surface beam movements are regulated by an elastic control system. The drainage of the joint is via the drainage system of the bridge deck. Certain joints feature so-called “sinus plates” on their surface, which reduce noise from over-passing traffic by up to 80%

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### 5.3 Piers

Any bridge structure is a combination of two components: substructure and super structure. For bridges with bearings, all the components which transfer the loads from bearing to the ground is called substructure. Substructure consists of bridge pier, abutments, wing walls, piles etc. while the superstructure consists of deck, girders or any part on which the traffic moves safely such as road way, girders, arches, etc. In this article we try to discuss about the piers, its function and its types.

Bridge Pier support the spans of the bridge and transfer the loads from superstructure to the foundation. Piers should be strong enough to take the both vertical and horizontal load. Its main function is to transfer the load from the bridge superstructure foundation below it. They are subjected to huge axial loads and bi-axial moments and shear forces in transverse and longitudinal direction. Said that, pier are usually compression elements of a bridge. Piers are referred as Bents as well.

Bridge piers are designed for following design limit states; Service Limit state – Crack width, Stresses in concrete and steel; Ultimate limit state – Ultimate flexure capacity, shear; Extreme Events – Earthquake, Vessel and vehicle impact, fatigue

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### 5.3.1 Types of Piers

Type of piers to be used in the bridge depends upon the type of bridge, sub-soil conditions as well as the procedure adopted for the construction of bridge. The bridge can be broadly divided into two parts:

1. Solid piers
2. Open piers

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#### 1. Solid piers:

These piers have solid and impermeable structure. The generally used materials used for the construction of these type of piers are bricks, stone Masonry, mass concrete or RCC, etc. They may be further classified as:

Solid masonry piles

Solid RCC piles

Solid Masonry piers:

The piers which are constructed with brick masonry, stone masonry, concrete etc. are known as solid masonry piers. Sometimes it is seen that in solid masonry piles the outer portion is constructed with the stone masonry and the inner part is filled with the help of mass concrete. In this way it can save the cost of construction.

Solid RCC Piers:

## Design of Bridges

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The solid piers which are constructed with the reinforcement are called RCC piers. These piers are generally rectangular in cross-section and are generally used where the height of the piers are more and the solid masonry piers will not be strong enough to bear the load and can be uneconomical.

### 2. Open piers

The piers which are open i.e which allows the water to pass through the structure are called as open piers. Open piers can be classified into the following types:

Cylindrical piers

Column bents

Trestle piers or Trestle bent

Pile bents

Special or typical framed piers

Cylindrical piers:

The piers which are constructed with the mild steels or cast iron cylinder in which the concrete are filled are known as cylindrical piers. These are used for bridges having moderate height. Sometimes horizontal and diagonal steel bracing are also provided for additional stability.

These are generally used for the bridges of large height. These are generally constructed over barge services.

Trestle piers or Trestle bent:

It consist of column with bent cap at the top. As per the latest recommendation the hinges may also be provided. It is generally used for flyovers and elevated roads. These are suitable for bridges where water current is slow and river bed is sufficiently firm.

Pile piers or Pile bents:

These are used where the ground is unstable and the low piers are required. In these type of piers number of steel or RCC piles are driven into the ground provided with the cap at their top to support the main girder. It is the common variation of multicolumn bent. It is generally used for the type of bent on low height and short span structure.

### Typical Framed Piers:

These are the latest type of piers used in the bridges. In these piers the effective span length for girders get reduced. Hence the construction will be economical. The disadvantage of these type of piers is the accumulations of debris e.g falling trees large floating materials, etc. Column piers or column bent:

### **5.3.3 Classification of Bridge Piers based on Force Transfer Mechanisms**

Based on the type of forces the pier is subjected to, bridge piers are classified as Fixed and Free piers. In a most simple explanation, the piers supporting a fixed bearing are called fixed piers and those supporting free bearings are called free piers. Fixed piers are subject to transverse and longitudinal forces whereas free piers transfer only axial forces from the bearing to the foundations. For multispan bridges, the number of fixed and free piers depend on the the length of bridge, size of pier and magnitude of long & trans forces superstructure can be subjected to. For regular multi span continuous bridges under 200-300m one fixed pier is provided.

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### 5.4 Assigninment Questions

1. Explain different types of bearing?
2. Explain different types of piers?

### 5.5 Further Reading

1. [https://www.fhwa.dot.gov/bridge/lrfd/fc\\_9.cfm](https://www.fhwa.dot.gov/bridge/lrfd/fc_9.cfm)
2. <https://www.scribd.com/document/185645517/Design-Example-Pier>