

SREENIVASA INSTITUTE OF TECHNOLOGY AND MANAGEMENT STUDIES, CHITTOOR
(AUTONOMOUS)

Approved by AICTE, New Delhi, Affiliated to JNTUA, Ananthapuramu.



LECTURE NOTES

Subject Name: BRIDGE ENGINEERING (PE) &23CIV472A

Year / Branch: IVB.TECH-VII SEM

Regulation: R23

Prepared By: K.SUMALATHA



IV B.Tech. - VII Semester

23CIV472A	BRIDGE ENGINEERING	L	T	P	C
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PRE-REQUISITES: A Course on Structural analysis and design of reinforced structures.

COURSE EDUCATIONAL OBJECTIVES:

1. To explain the loading standards
2. To study the design of deck slab bridge.
3. To study the design of the T-beam bridge
4. To study the design of the plate girder bridge and rocker and roller bearings
5. To explain features, forces acting on piers and abutments

UNIT I: INTRODUCTION TO LOADING STANDARDS (9)

Highway Bridge Loading Standards- Impact Factor- Railway Bridge Loading Standards (B.G. ML Bridge) Various Loads in Bridges. IRC Bridge loading standards.

UNIT II: DECK SLAB BRIDGE (9)

Introduction – Effective Width Method of Analysis Design of Deck Slab Bridge (Simply Supported) Subjected to Class AA Tracked Vehicle Only.

UNIT III: BEAM AND SLAB BRIDGE (T-BEAM BRIDGE) (9)

General Features – Design of Interior Panel of Slab – Pigeauds Method – Design of a T-Beam Bridge Subjected to Class AA Tracked Vehicle Only.

UNIT IV: DESIGN OF PLATE GIRDER BRIDGE AND BEARINGS (9)

Plate Girder Bridge: Introduction – Elements of a Plate girder and their Design. Design of a Deck Type Welded Plate Girder.

Bridge bearings: General Features – Types of Bearings – Design Principles of Steel Rocker & Roller Bearings.

UNIT V: INTRODUCTION TO PIERS & ABUTMENTS (9)

General Features – Bed Block – Materials Piers & Abutments Types of Piers – Forces Acting on Piers – Stability Analysis of Piers – General Features of Abutments – Forces Acting on Abutments – Stability Analysis of Abutments.

Total Hours: 45



COURSE OUTCOMES:

On successful completion of the course, students will be able to		Pos
CO1	Understand the loading standards	PO1, PO2
CO2	Design the deck slab bridge	PO1, PO2, PO3, PO5
CO3	Design the T-beam bridge	PO1, PO2, PO3, PO5
CO4	Design the plate girder bridge and rocker and roller Bearings	PO1, PO2, PO4
CO5	Understand the Stability analysis of pier and abutment	PO1, PO4

TEXTBOOKS:

1. Ponnu Swami," Bridge Engineering", Tata Mcgraw Hill Company, New Delhi
2. N. Krishnam Raju," Design of Bridges", Oxford & IBH, Publishing Company Pvt.Ltd. Delhi

REFERENCE BOOKS:

1. B.C. Punmia, Ashok Kumar Jain and Arun KumarJain," Design of Steel Structures", Laxmi Publications, New Delhi.
2. D.J.Victor, " Essentials of Bridge Engineering", Oxford IBH Publishers Ltd
3. T.R.Jagadish & M.A.Jayaram, "Design of Bridges Structure", Prentice Hall of India Pvt., Delhi.
4. Relevant – IRC & Railway Bridge Codes.

REFERENCE WEBSITES:

<https://nptel.ac.in/courses/105/105/105105165/>

CO\PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO.1	2	3	-	-	-	-	-	-	-	-	-	-
CO.2	1	2	2	-	1	-	-	-	-	-	-	-
CO.3	1	2	2	-	1	-	-	-	-	-	-	-
CO.4	2	2	-	1	-	-	-	-	-	-	-	-
CO.5	2	-	-	1	-	-	-	-	-	-	-	-
CO*	1.6	2.25	2	1	1	-	-	-	-	-	-	-

INTRODUCTION TO BRIDGES

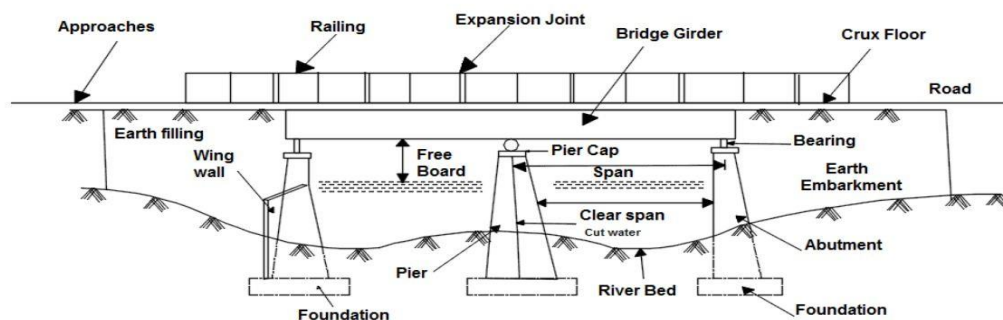
Bridge Engineering deals with various aspects of bridge construction such as selection of site, surveys, data to be collected, documents and drawings required for bridge project and maintenance.

Bridge is a structure facilitating a communication route for carrying road traffic or other moving loads over a depression or obstruction such as river, stream, channel, road or railway. The communication route may be a railway track, a roadway, footpath, a cycle track or a combination of them.

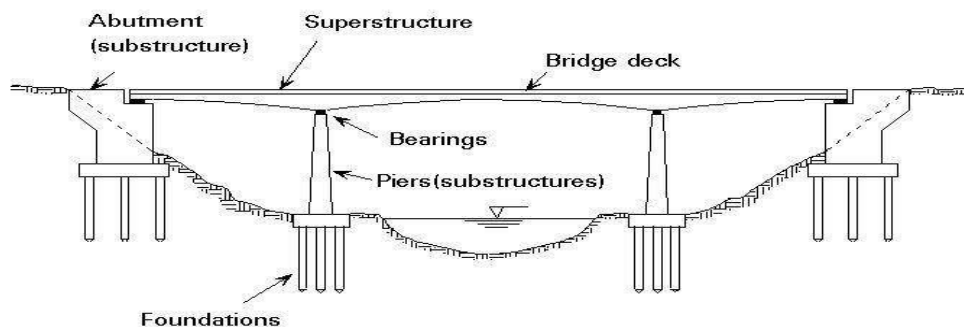
Components of a Bridge:

The major parts of a bridge are:

1. Substructure
2. Superstructure
3. Adjoining structure



Component Parts of the Bridge structure



Substructure:

- The structure of the bridge below the level of bearing is known as the Substructure.
- The function of Substructure is to support the superstructure components and transmit their loads safely to the subsoil.
- It consists of the following:
 - a) **Abutments:**
 - Abutments are the end supports of a bridge structure.
 - It plays the role of retaining walls to resist lateral movement of earthen fill of the bridge approach.
 - b) **Piers:**
 - Piers provide intermediate support between two bridge spans.
 - Piers mainly support the bridge element and transfer the load to the foundation.
 - Piers are known as compression members of a bridge.
 - c) **Wing Walls:**
 - It is one of the earth retaining structures in the bridge.
 - They are located adjacent to the abutments and act as retaining walls.
 - The wing wall retains soil for abutment, roadway, and approach embankment, which can be at a right angle to the abutment or splayed at different angles.

Superstructure:

- The components of the bridge above the bearing are known as superstructures.
- It consists of the following:
 - a) **Beams and girders:**
 - Both have a similar function to support the roadway and prevent bending. Girder is also one type of beam support. Where loads are heavy girders are used instead of beam support.
 - Beam has a rectangle cross-section, whereas girders have composed of I-shaped cross-sections with two load-bearing flanges and a web for stabilization.
 - b) **Bearing:**
 - A bearing is provided between the bridge girder and the pier cap. The main function of the bearing to allow free movement or vibration of the top superstructure and reduce effect stress to reach the bridge foundation.
 - c) **Arch & Cable:**
 - Arches are used for arch bridge construction and cable is used for suspension, cable-stayed bridges, etc. For different types of bridge construction arches and cables play a vital role.

d) Parapet Wall & Handrails:

- The parapet is one of the safety components of any bridge which prevent the vehicle from falling off where there is a drop.
- It is also useful for restricting views, preventing rubbish from passing below, and acting as a noise barrier.

e) Flooring:

- It is top surface of bridge roadway on vehicle travel. It is made of concrete or a bituminous road.

Adjoining Structures:

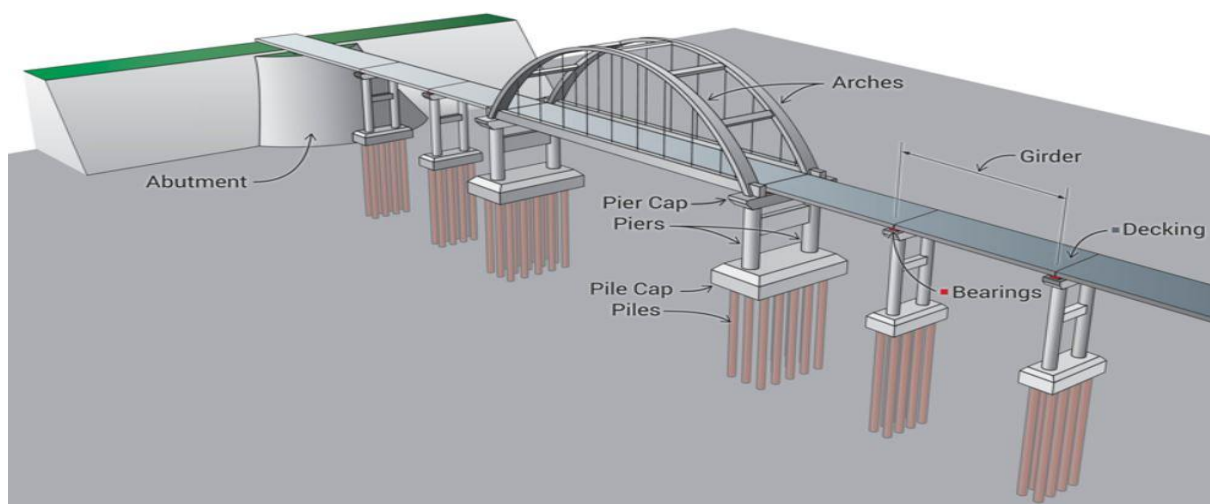
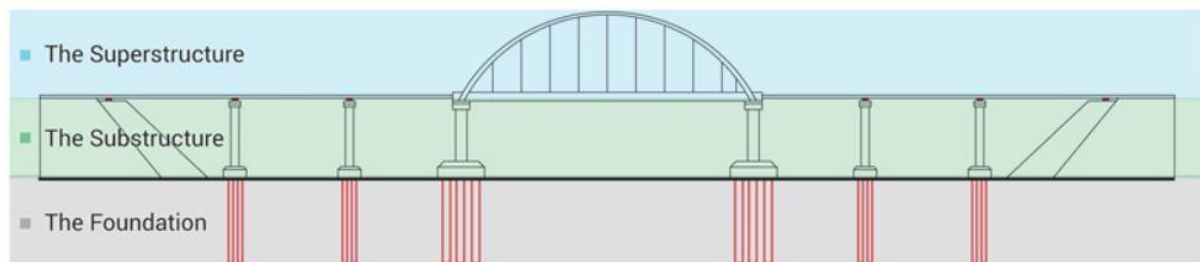
It consists of the following:

a) Approaches:

- It is structured and constructed at the starting or ending of any bridge. Its main function is to provide smooth and easy entry or exit from the bridge.

b) Guard Stones:

- They are used to restrict traffic on a particular lane or sometimes as road railing but are generally positioned to protect a specific object, such as a corner of a street or the side of a gate.



Classification of Bridges:

1. Based on Materials used for construction:

a) Timber bridge:

- Bridges are constructed using timber materials are called timber bridges.
- These types of bridges are constructed for short spans.
- Timber bridges are not sufficient for heavy loading.
- It is designed for pedestrians, low weight transport.
- These types of the bridge are constructed where timber is easily available.



b) Masonry Bridges:

- In the Masonry Bridge stones and bricks are used as construction materials.
- Masonry bridges are durable as compare to Timber Bridge. It is suitable for a shorter span.



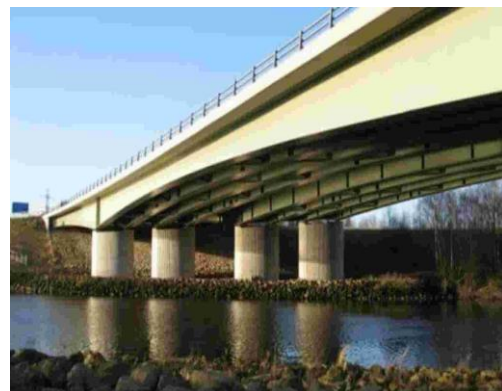
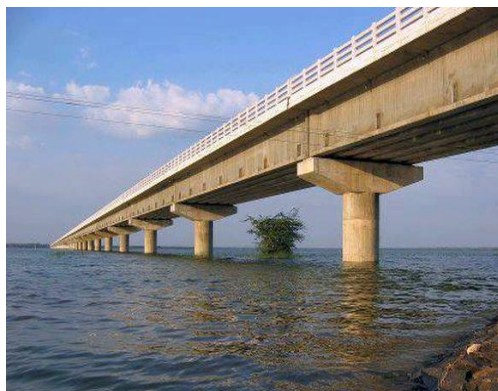
c) Steel Bridge:

- Steel bridges are constructed using steel cables or bars.
- Steel bridges are more durable as compared to Timber Bridge.
- They can also carry a heavy load and are suitable for a long span.
- Steel bridges are built for many projects like railways, highways, for supporting gas lines, pipelines, oil lines, etc.



d) Reinforced Cement Concrete Bridge:

- In RCC Bridge, Reinforced concrete is used as a construction material.
- This type of bridge is more stable and durable.
- It is suitable for long-span as well as heavily loaded traffic.
- Nowadays RCC-type bridges are widely used. It is generally used for constructing fly-over and highway bridges.



e) Pre-stressed Concrete Bridge:

- Pre-stressed concrete is placed under compression before applying the loads.
- The construction of a pre-stressed bridge deck slab is made with the use of concrete blocks.
- This type of bridge is suitable for short to long spans.
- The pre-stressed concrete bridge is having a heavy load-carrying capacity.
- A pre-stressed concrete bridge is requiring high tensile steel, which is more expensive than ordinary mild steel.



f) Composite Bridge:

- The bridges constructed by the combinations of more than one or two construction materials are known as Composite bridges.
- Pre – Stress Bridge is one of the best examples of composite material because Pre-stress girder overlaying the RCC deck slab in which RC slab and Girder are two different kinds of materials.

2. According to Purpose:

a) Aqueduct:

- An aqueduct is a structure, which is used to transport water from one place to another place over an obstacle.



b) Foot Bridge:

- Foot Bridge is generally constructed for humans to cross the roads or rail route or any canal by foot.
- Vehicles are not allowed in this bridge



c) Railway Bridge:

- Railway Bridge is used for the movement of trains over an obstacle.
- In that case, Steel Bridges are widely used.



d) Highway bridge:

- High way or road Way Bridge is used for road transportation.
- These are constructed over rivers or another routes to allow road way traffic.
- Girder type bridges are used as highway bridges over rivers or canals.



3. Based on Level of Crossing:

a) Over Bridge:

- To pass over another route (railway or highway), a bridge is constructed to allow traffic. This is called over bridge or fly over bridge.



b) Under Bridge:

- If over bridge is not possible, an underground type bridge is constructed to pass another route. This is called under bridge.



4. Based on Span:

a) Culvert Bridge:

- When the bridge span length is below 6 meters then it is called as Culvert Bridge.



b) Minor Bridge:

- If the bridge span length is in between 8 to 30 meters, then it is called minor bridge.



c) Major Bridge:

- For major bridge, the span is generally about 30 to 120 meters.



d) Long Span Bridge:

- When the span of bridge is more than 120 meters then it is termed as long span bridge.



5. Based on Span Relation:

a) Simple Bridge:

- Simple bridge is like simply supported beam type which consist two supports at its ends. For shorter spans, simple bridges are suitable.



b) Continuous Bridge:

- If the bridge span is very long, then we have to build more supports in between end supports. This type of bridge is termed as continuous bridge.



c) Cantilever Bridge:

- Cantilever types of bridges have only supported at one end and another end is free to space. Generally, two cantilever portions are joined to make way to the vehicles or humans.



6. Based on Position Of Floor:

a) Deck Bridge:

- In case of Deck Bridge, super structure or floor of bridge is positioned in between the high flood level and formation level.



b) Through Bridge:

- In case of through bridge, Super structure of bridge is completely above the formation level.



c) Semi-Through Bridge:

- If the super structure of bridge is partly above and partly below the formation level, then it is called as semi-through bridge.



7. Based on Alignment:

a) Straight or Square Bridge:

- Straight or square are the bridges which are at right angles to the axis of the river.



b) Skew Bridge:

- Skew bridges are not at right angles to the axis of the river.



Requirements of an ideal bridge

An ideal bridge meets the following requirements to fulfil the three criteria of efficiency, effectiveness and equity.

- It serves the intended function with utmost safety and convenience.
- It is aesthetically sound.
- It is economical.

BRIDGE SITE INVESTIGATION AND PLANNING

Selection of Bridge site

The selection of a site for bridges requires considerable investigations.

1. A site which is on a straight reach of the drainage should be selected. The curved reach of drainage should be avoided as far as possible.
2. The stream at bridge side should have permanent, firm, straight and high banks.
3. The stream at the Bridge site should be well defined and as narrow as possible.
4. The site should be sufficiently away from the confluence point.
5. There should be no scouring and silting of the stream at the bridge site.
6. A site which offers a square crossing should be selected as far as possible.
7. The site which offers more advantageous foundation condition should be preferred.
8. A site which is sufficiently away from the landslides and subsidence should be preferred.
9. The site should not interfere adversely with any other bridges, weirs, regulators, dams, etc in the vicinity.
10. There should be a minimum obstruction to natural waterway at the bridge site.
11. The stream at the bridge site should be free from costly river training works.
12. The bridge should provide proximity to the direct alignment of the communication route to be served.

Bridge Alignment

Depending upon the angle which the bridge makes with the axis of the river, the alignment can be of two types:

a) Square Alignment: -

- In this, the bridge is at right angle to the axis of the river.

b) Skew Alignment: -

- In this the bridge is at some angle to the axis of the river which is not a right angle.

BRIDGE HYDROLOGY

Determination of Flood Discharge

As per IRC recommendation the maximum discharge which a bridge on a natural stream should be designed to pass should be determined by the following methods:-

- From the rainfall and other characteristics of the catchment.
 - By the use of an empirical formula applied to the region
 - By a rational method, provided it is possible to evaluate for the region concerned the various factors employed in the method
- From the hydraulic characteristics of the stream such as cross-sectional area, and slope of the stream allowing for velocity of flow.
- From the records available, if any, of discharges observed on the stream at the site of the bridge, or at any other site in its vicinity.

Empirical Methods:

- The flood discharge can be evaluated by using various empirical formulae involving area of the catchment and some coefficient depending upon the location of the catchment.
- In these methods area of a basin or a catchment is considered mainly. All other factors which influence peak flow are merged in a constant.
- A general equation may be followed in the form:-

$$Q = CA^n$$

Where, Q = Peak flow or rate of maximum discharge

C = a constant for the catchment

A = area of catchment & 'n' is an index

1. Dicken's Formula:

$$Q = CA^{3/4}$$

Where Q = Maximum flood discharge in m³/sec

A = Area of the catchment in m²

C = A coefficient of discharge

Region	Value of C
Northern India	11.4
Central India	13.9 – 19.5
Western India	22.2 - 25

- The maximum value of C is 35.
- This formula is applicable for moderate size catchments of river of North & Central India.

2. Ryve's Formula:

- It is applicable to South Indian catchments.

$$Q = CA^{2/3}$$

Where Q = Maximum flood discharge in m³/sec

A = Area of the catchment in m²

C = A coefficient of discharge

Region	Value of C
Area within 24 Km from the coast	6.75
Area within 24 to 161 Km from coast	8.45
Limited area near hills	10.00

3. Inglis Formulae

- This formula is used only in Maharashtra.

$$Q = \frac{123A}{\sqrt{A+10.4}} \text{ in cumecs}$$

Where, Q = Maximum flood discharge in m³/sec

A = Area of the catchment in m²

Rational Methods

- This method is applicable for the determination of flood discharge for small culverts only.
- In order to arrive at a rational approach, a relationship has been established between rainfall and runoff under various circumstances.
- The size of flood depends upon the following factors:
 - Intensity of rainfall
 - Distribution of rainfall
 - Duration of rainfall
 - Catchment area
 - Slope of catchment
 - Shape of catchment
 - Porosity of soil
 - Vegetable cover
 - Initial State of witness

Waterway

The area through which the water flows under a bridge superstructure is known as the waterway of the bridge.

Linear Waterway:

- The length available between extreme edges of water surface at the highest flood level (H.F.L), measured at right angles to the abutment faces of a bridge is called the linear waterway of the bridge.
- This is equal to the sum of all the clear spans.

Natural waterway:

- The unobstructed area of the river or stream through which the water flows at the bridge site.

Due to the construction of a bridge the natural waterway gets contracted thereby increasing the velocity of flow under a bridge. This increased velocity results into heading up of water on the upstream of the river or stream, known as afflux.

While fixing the waterway of a bridge the following guiding principles must be kept in mind to ensure the safety of the structure.

- The increased velocity due to afflux should not exceed the permissible velocity under the bridge.

S.No	Nature of bed	Permissible velocity in m/s
1	Clay	2.10
2	Sandy clay	1.50
3	Very fine sand	0.60 to 0.90
4	Fine sand	0.90 to 0.50
5	Fine gravel	1.50 to 1.80
6	Rocky soil	3.00
7	Rock	4.20 to 6.00

- There should not be too much heading up of water surface above the bridge, when it is necessary to restrict the waterway to such an extent that the resultant afflux will cause the stream to discharge at erosive velocities, protection against damage by scour should be afforded by deep foundation, curtain or cut of walls, rip rap, stream bed pavement, bearing piles, sheet piles or other suitable means.
- The freeboard for high level bridges should not be less than 600 mm.
- Clearance should be allowed according to navigational requirements.

Economic Span

The economic span of a bridge is the one which reduces the overall cost of a bridge to be a minimum. Overall cost of a bridge depends upon the following factors:

- Cost of material and its nature
- Availability of skilled labour
- Span length
- Nature of stream to be bridged
- Climatic and other conditions

Considering only the variable items the cost of super-structure increases and that of the sub-structure decreases with an increase in the span length. Thus most economic Span Length is that which satisfies the following:-

The cost of the super- structure= the cost of the sub structure

The derivation for the economic span can be established on the basis of the following assumptions:

- i. The bridge has equal span lengths.
- ii. Cost of supporting structure of superstructure varies as the square of span length.
- iii. Cost of flooring and parapets varies directly as the span.
- iv. Cost of one pier and its foundation is constant.
- v. Cost of abutments and their foundation is also constant.

Let, L = Total length of the bridge

l = Span length

$$n = \text{Total number of spans} = \frac{L}{l}$$

P = Cost of one pier with its foundation

A_1 = Cost of one abutment with its foundation

A_2 = Cost of one approach

T = Total cost of the bridge

According to assumptions (i) & (ii):

$$\text{Cost of one span of superstructure} = (\alpha_1 l^2 + \alpha_2 l)$$

There are $(n - 1)$ number of piers, and two abutments.

The total cost of bridge = Cost of Superstructure
+ Cost of Substructure
+ Cost of Approaches

i.e.

$$T = n ((\alpha_1 l^2 + \alpha_2 l) + 2A_1 + 2A_2 + (n - 1) P$$

Replacing $n = \frac{L}{l}$

$$T = \frac{L}{l} ((\alpha_1 l^2 + \alpha_2 l) + 2A_1 + 2A_2 + (\frac{L}{l} - 1) P) \\ = L\alpha_1 l + \alpha_2 L + P \frac{L}{l} - P + 2A_1 + 2A_2$$

$$\text{Therefore, } \frac{dT}{dl} = \alpha_1 l + 0 - \frac{PL}{l^2}$$

For T to be minimum,

$$\frac{dT}{dl} = 0$$

$$\text{Or } \alpha_1 l - \frac{PL}{l^2} = 0$$

$$\text{Or } \alpha_1 = \frac{P}{l^2}$$

$$\text{Or } P = \alpha_1 l^2$$

$$\text{Or Economic span, } l = \sqrt{\frac{P}{\alpha_1}}$$

i.e.

cost of supporting system of one span is equal to cost of one pier. In other words, cost of sub-structure is equal to the cost of super-structure.

The general equation of the above method is given as:

$$l = K\sqrt{P}$$

Where,

l = the length of economic span,

K = the constant,

P = the cost of one pier.

The IRC, with a little modification, has recommended the following principle:

Cost of variable part of super-structure = Cost of variable part of sub-structure

Afflux

When a bridge is constructed, the structures such as abutment and piers cause the reduction of the natural waterway area. Therefore, to carry the maximum flood discharge, the velocity under the bridge increases. This increased velocity gives rise to a sudden heading up of water on the upstream side of the stream. This phenomenon of heading up of water is known as afflux.

- Greater the afflux greater will be the velocity under the downstream side of the bridge and greater will be the depth of scour and consequently greater will be the depth of foundations required.

Empirical Formulae for calculation of afflux:

(a) Marriman's Formula:

$$h_a = \frac{V^2}{2g} \{(A/Ca)^2 - (A/A_1)\}$$

Here,

h_a = Afflux in metres

V = Velocity of approach in m/s

A = Natural waterway area at the site in m^2

a = Contracted area in m^2

A_1 = The enlarged area upstream of the bridge in m^2

C = Coefficient of discharge = $0.75 + 0.35(a/A) - 0.1(a/A)^2$ approximately

(b) Molesworth Formula:

$$h_a = \left[\frac{V^2}{17.9} + 0.015 \right] \{(A/a)^2 - 1\}$$

Here,

h_a = Afflux in metres

V = Velocity of approach in m/s

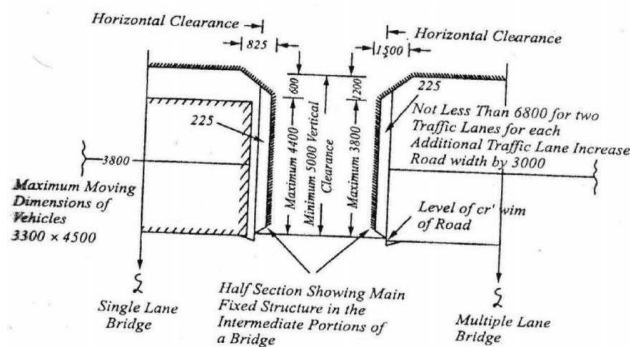
A = Natural waterway area at the site in m^2

a = Contracted area in m^2

Clearances

To avoid any possibility of traffic striking any structural part clearance diagrams are specified. The horizontal clearance should be the clear width and the vertical clearance the clear height, available for the passage of vehicular traffic.

For a bridge constructed on a horizontal curve with super-elevated road surface, the horizontal clearance should be increased on the side of the inner kerb by an amount equal to 5m multiplied by the super-elevation. The minimum vertical clearance should be measured from the super-elevated level of the roadway.



Freeboard

Free board is the vertical distance between the designed high flood level, allowing for the afflux, if any, and level of the crown of the bridge at its lowest point.

It is essential to provide the free board in all types of bridges for the following reasons:-

- Free Board is required to allow floating debris, fallen tree trunks and approaches waves to pass under the bridge.
- Free board is also required to allow for the afflux during the maximum flood discharge due to contraction of waterway.
- Free board is required to allow the vessels to cross the bridges in case of navigable rivers.

The value of free-board depends upon the types of the bridge.

S.No	Type of bridge	Freeboard
1	High level bridges	600mm
2	Arch bridges	300mm
3	Girder bridges	600 to 900mm
4	Navigational streams	2400 to 3000mm

BRIDGE FOUNDATIONS

A foundation is the part of the structure which is in direct contact with the ground. It transfers the load of the structure to the soil below.

Before deciding upon its size, we must ensure that:

- (i) The bearing pressure at the base does not exceed the allowable soil pressure.
- (ii) The settlement of foundation is within reasonable limits
- (iii) Differential settlement is too limited as not to cause any damage to the structure.

Foundation may be classified under two categories:

1. Shallow foundation
2. Deep Foundation

According to Terzaghi, a foundation is said to be shallow if its depth is equal to or less than its width. In case of deep foundation, the depth is greater than its width and it cannot be prepared by open excavation.

Types of Bridge Foundation

The selection of foundation type suitable for a particular site depends on the following considerations:

- i. Nature of Subsoil
- ii. Nature and extent of difficulties, e.g. presence of boulder, buried tree trunks, etc. Likely to be met with, and
- iii. Availability of expertise and equipment.

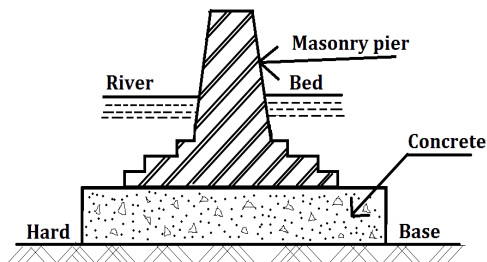
Depending upon their nature and depth, bridge foundation can be categorized as follows:

- 1) Open Foundation,
- 2) Raft Foundation,
- 3) Pile Foundation,
- 4) Well foundation,

Open Foundations in Bridges

An open foundation or spread foundation is a type of shallow foundation. This is the most common type of foundation and can be laid using open excavation by allowing natural slopes on all sides.

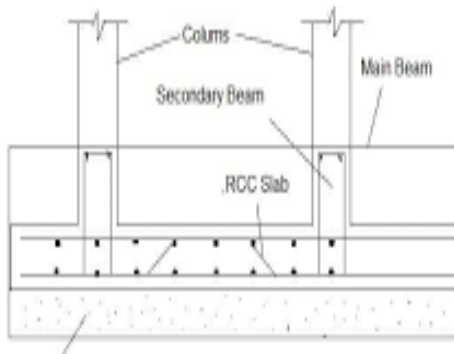
- This type of foundation is practicable for a depth of about 5m and is normally convenient above the water table.
- The base of the pier or abutment is enlarged or spread to provide individual support.
- Since spread foundations are constructed in open excavation, therefore, they are termed as open foundation.
- This type of foundation is provided for bridges of moderate height built on sufficiently firm day ground.
- The piers in such cases are usually made with slight batter and provided with footings widened at bottom.
- Where the ground is not stiff the bearing surface is further extended by a wide layer of concrete at the bottom.



Raft Foundations in Bridges

A raft or mat foundation is a combined footing that covers the entire area beneath a bridge and supports all the piers and abutments.

- When the allowable soil pressure is low, or bridge loads are heavy, the use of spread footing would cover more than one-half of the area, and it may prove more economical to use raft foundation.
- They are also used where the soil mass contains compressible lenses so that the differential settlement would be difficult to control.
- The raft tends to bridge over the erratic deposits and eliminates the differential settlement.
- Raft foundation is also used to reduce the settlement above highly compressible soils by making the weight of bridge and raft approximately equal to the weight of the soil excavated.
- A raft may undergo large settlements without causing harmful differential settlement. For this reason, almost double the settlement of that permitted for footings is acceptable for rafts.
- Usually when hard soil is not available within 1.5 to 2.5 m a raft foundation is adopted.
- The raft is composed of reinforced concrete beams and a relatively thin slab underneath.



Pile Foundations in Bridges

The pile foundation is a construction for the foundation of a bridge pier or abutment supported on the piles.

- A pile is an element of construction composed of timber, concrete or steel or a combination of them.
- Pile foundation may be defined as a column support type of foundation which may be cast in-situ or precast.
- The piles may be placed separately or they may be placed in form of a cluster throughout the length of the pier or abutment.
- This type of construction is adopted when the loose soil extends to great depth.
- The load of the bridge is transmitted by the piles to hard stratum below or it is resisted by the friction developed on the sides of piles.



Classification of piles:

Piles are broadly classified into two categories:

- A. Classification based on the function
- B. Classification based on the materials and composition

Classification based on the function:

1. Bearing Pile
2. Friction Pile
3. Screw Pile
4. Compaction Pile
5. Uplift Pile
6. Batter Pile
7. Sheet Pile

Classification based on the function

1. Cement concrete piles
2. Timber Piles
3. Steel Piles
4. Sand Piles
5. Composite Piles

Pile Driving

The process of forcing a pile into the ground is termed as pile driving. The equipments required for pile driving are pile frames, pile hammers, leads and winches.

A. Pile Frame:

- The pile frames are made of steel having height varying between 10 to 25 m.
- The pile frame consists of platforms for supporting driver, engine, winches, etc.

B. Pile Hammer:

- The hammer is guided between two parallel steel members known as leads.
- Hammers are of the following types:
 - i. Drop hammers
 - ii. Single acting steam hammers
 - iii. Double acting steam hammers
 - iv. Differential acting steam hammers
 - v. Diesel hammers
 - vi. Vibratory

Drop Hammers:

- A drop hammer is lifted and allowed to fall on the head of a pile.
- The weight of hammer varies from 1 to 4 tonnes.
- The height of fall varies from 1.50 to 6 m.

Single acting steam hammer:

- The hammer is raised either by steam or compressed air and then it is allowed to drop by gravity alone.
- The weight of hammer is about 2 tonnes.
- The fall is about 1 m and the number of blows is about 60 per minute.

Double acting steam hammer:

- The hammer is raised and lowered either by steam or compressed air.
- It operates with succession of rapid blows.
- The hammer is fully closed in a steel case.
- The weight of hammer is about 500 kg. But together with steam pressure, it has an effective weight of about 3 tonnes.
- The number of blows per minute is about 100 to 200.

Differential acting steam hammer:

- The hammer combines the advantages of single acting and double acting steam hammers.
- The weight of hammer is about 2 tonnes and height of fall is about 1 m.
- The number of blows per minute is 100 to 200.

Diesel hammer:

- The hammer is a small, light weight, self-contained and self-activating type, using gasoline for fuel. They are mobile in nature.

Vibratory hammer:

- In this type of hammer the driving unit vibrates at high frequency.

C. Leads:

- They are employed to guide the hammer and pile.
- For drop hammer fixed leads are used.
- Leads may be movable which can be adjusted as required.

D. Winches:

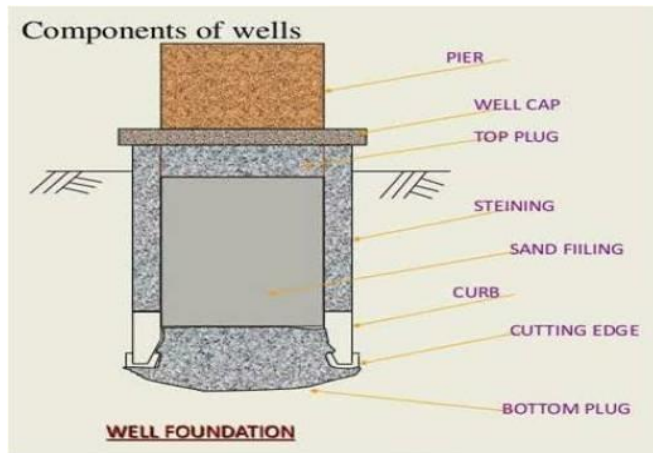
- These are required to lift the hammer and pile.
- They may be of light type with a single drum or of heavy type with double or triple drums.
- They may also be fitted with reversing gear.

Well Foundations in Bridges

Well foundation is a type of deep foundation which is generally provided below the water level for bridges. Caissons or wells have been in use for foundations of bridges and other structures since Roman and Mughal periods. The term 'caisson' is derived from the French word *caisse* which means box or chest. Caissons are preferred in sandy soils.



Components of Well Foundation:



Types of Well or Caisson:

There are three types of caissons or well are commonly utilized, which are as follows:

- i. Open Caissons
- ii. Box Caissons
- iii. Pneumatic Caissons

Open Caissons:

- Open caissons are similarly called the Well foundations, which are caissons in which the top and bottom of the caisson are open during the construction. An open caisson may be rectangular, oblong, or circular in the plan.
- They are used on sandy or soft bearing stratum liable to scour and where no firm bed is available for large depth below the surface.
- They are generally built of timber, metal, reinforced concrete or masonry.
- They form the most common type of deep foundations for bridges in India.

Box Caissons:

- A box caisson is a strong watertight vessel open at top and close at the bottom.
- They are generally built of timber, reinforced concrete and steel.
- This type of caisson is suitable where bearing stratum is available at shallow depth and where loads are not very heavy.

Pneumatic Caissons:

- A pneumatic caisson is open at bottom and closed at top.
- This is useful at locations where it is not possible to adopt wells.
- They are suitable when the depth of water is more than 12m.
- In this the compressed air is used to remove water from the working chamber and the foundation work is carried out in dry conditions.

Sinking of Well:

The Sinking of the Well Foundation is carried out through the following Steps.

i. Laying of Curbs

In dry ground excavate up to 50 cm in river bed and place the cutting edge at the required position. If the curb is to be laid under water and depth of water is greater than 5 m, prepare Sand Island and lay the curb. If depth of water exceeds 5 m built curb in dry ground and float it to the site.

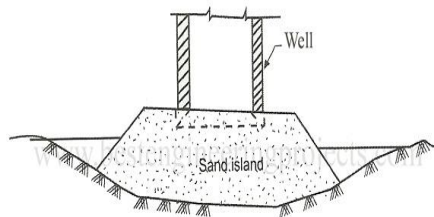


Fig 1 A Typical Sand Island

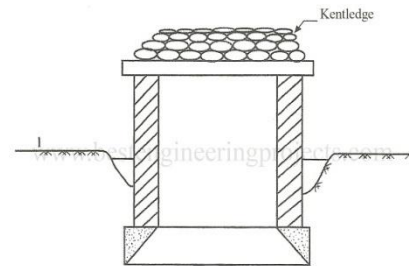


Fig 2 Loading Steining by Kentledge

ii. Construction of Well Steining

The steining should be built in short height of 1.5 m initially and 3 m after a 6 m grip length is achieved. The verticality should be maintained. The aim of the well sinking is to sink the well vertically and at the correct position. The following precautions are to be taken as far as possible.

Precautions:

The following precautions should be taken during well sinking.

- Outer surface should be regular and smooth.
- Radius of the curb should be 2 to 4 cm larger than the radius of the steining.
- Cutting edge should be of uniform thickness and sharpness.
- Dredging should be done uniformly on all sides.

Sinking Operation:

The following operation is carried out while sinking the caisson.

- Excavate material under the inside of well curb mechanically or manually
- Allow the well to remain vertical.
- Up to a depth of 1 m, excavation underwater can be made manually. When the depth of water exceeds 1 m excavate by Jhams or grabs.
- When well goes on sinking skin friction increases and weight of well decreased due to buoyancy.
- When the well does not sink, sunk by applying kentledge. If this operation is not sufficient jet outside the well or grease the outside
- Go on adding sections of steining (2 to 5 m in length) up to the required founding strata.

Problem of Sinking:

Generally the following problems are encountered while sinking a well.

Tilt and Shift- Adopt the following measures if tilt exceeds 1/60.

- Dredge at the higher side. Not effective at greater depths.

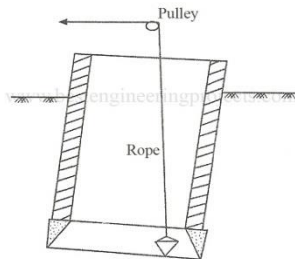


Fig 3 Dredging the Well

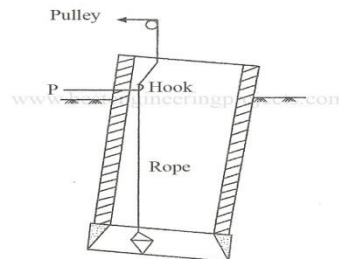


Fig 4 Dredging the well

- Make a hole on steining on higher side, hole is made near the ground level and excavation is carried out by diving. If possible de-water and excavate on the higher side.
- Construct eccentric welded framed bracket and load the platform thus made with 400 to 600 tons load.

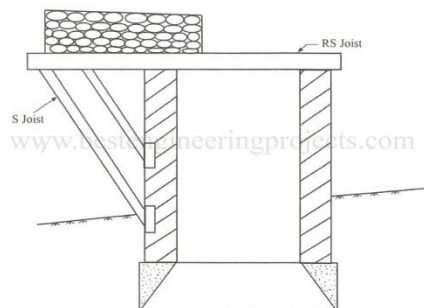


Fig 5 Eccentric Loading

- Jett on the high side of well. Excavate under cutting edge by dewatering or by divers.
- Insert wooden slippers or hooks under the cutting edge.

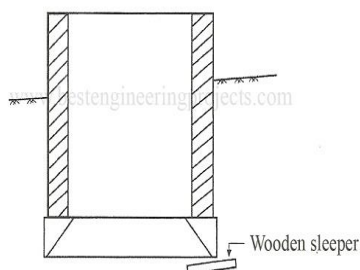


Fig 6 Provision of Wooden Slipper

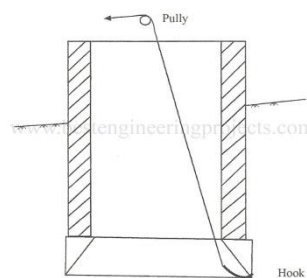


Fig 7 Hooking the Well

- Pull the well.

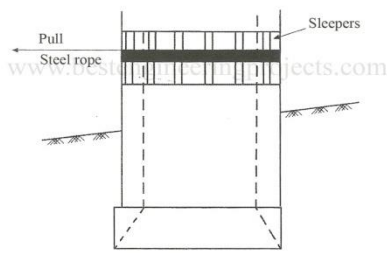
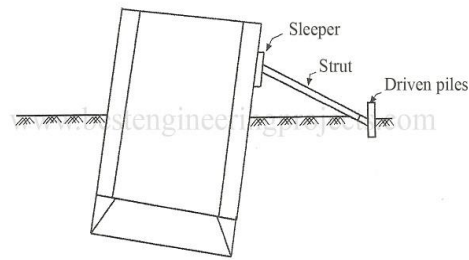


Fig 8 Pulling the Well

- Strut the well.



Fif 9 Strutting of the Well

- Push the well.

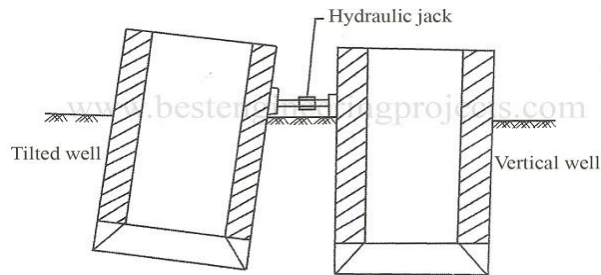


Fig 10 Pushing of the well

Cofferdam

Cofferdams are temporary structures used where construction is being carried out in areas submerged in water. They are most commonly used to facilitate the construction or repair of dams, piers and bridges.

- The aim of a cofferdam is to be as watertight as possible to create a dry area in which to complete the required building works, or at least to limit water ingress to a safe level that can be pumped away.
- Cofferdams must be able to withstand very high pressures and can create a hazardous situation if they are installed incorrectly.
- They are usually constructed using steel sheet piles driven into the ground and supported by internal braces and cross braces. Timber sheet piles, concrete or a combination of materials can also be used.
- A cofferdam can be any shape. Its design will be depend on the depth required, the required working area, soil conditions, fluctuations in the water level, and so on.



Types of Cofferdam:

Earthen Cofferdam:

- This is a simple form of cofferdam suitable for areas of shallow water with low current velocity, where a sloped earthen embankment is built up around the area to be enclosed. The bank should be a combination of clay and sand or clay and gravel.

Rock-fill Cofferdam:

- If the water to be retained is not shallow enough for an earthen cofferdam, stone or rubble can be used instead. The stones are built up in the required shape of the cofferdam, and voids filled with earth, gravel or stone-chips.

Single-walled Cofferdam:

- This type of cofferdam is most suitable when the area to be enclosed is particularly small and the water is of a deeper level, roughly 4-6 m. Guide piles made of timber are driven into the ground and bracing constructed before sheet piles are driven into place and secured to the bracing using bolts.

Double-walled Cofferdam:

- Single-walled cofferdams become unfeasible as larger areas are required in deeper water, and so double-walled cofferdams are sometimes necessary. Two walls are built with a gap between them, the thickness of which is dependent upon the depth of water.
- The general rule is for the thickness of the wall to equal the depth of water up to 3 m, greater depths require 3 m plus half the excess depth. The two wall faces are connected at the top using steel rods placed at close intervals.

Crib Cofferdam:

- This is commonly used in deep waters where the ground is particularly hard. The sheet piles are supported by a horizontal framework of timbers, known as cribs, which form pockets to be filled with earth or stones.
- This is constructed on land prior to being moved into position in the water.
- The crib is sunk into position, the internal space filled with stone or other material and timber or steel piles are then driven around the boundary of the crib.

Cellular Cofferdam:

- This type of cofferdam is most suitable for deep water areas, most commonly for during marine construction such as dams and wharves. Straight web steel sheet piles are driven into the ground to form a series of inter-connected cells of specific shapes which are filled with clay, sand or gravel to enable the structure to withstand the lateral forces of the water pressure.

BRIDGE SUBSTRUCTURES

The substructure of the bridge consists of the portion of the bridge that supports the entire structure on the given surrounding soil.

The bridge substructure consists of the following elements:

- i. Piers
- ii. Abutments
- iii. Wing walls
- iv. Foundations for piers and abutments

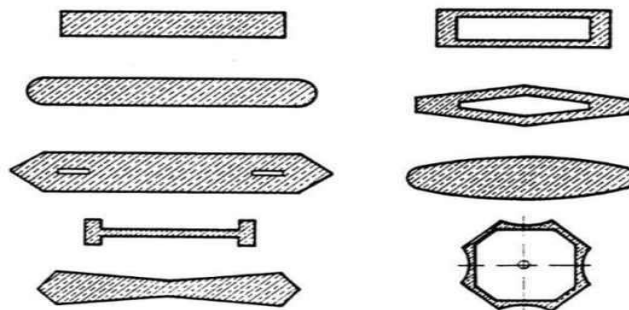
Bridge Piers:

- Bridge piers are the intermediate supports of the superstructures.
- Bridge Piers 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.
- Bridge piers may be built using concrete, stone, or metal. Concrete is commonly specified as construction materials provided that the pier is submerged in water since metal is prone to rust in water.
- It is constructed in many locations like waterways, dry lands on which highway systems are built as overpasses.
- The bridge piers can be constructed to be substantially attractive and strong in order to withstand both vertical and horizontal loads. It also does not hinder water flow or tide if the bridge spans the water.

Cross-sectional Shapes of Piers:



(Pier Cross-section Shapes for Over Crossings or Viaducts on Land)



(Pier Cross-section Shapes for River and Waterway Crossings)

Types of Bridge Piers:

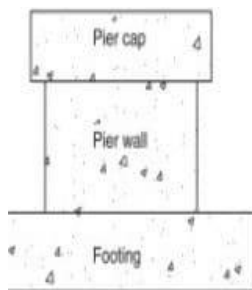
Based on the Structure of Piers:

Piers are categorized into two major types based on its structure.

- i. Solid piers
- ii. Open piers

Solid Piers:

Solid piers possess solid and impermeable structure, and usually constructed from bricks, stone Masonry, mass concrete or reinforced concrete. Solid piers are categorized into solid masonry piers and solid reinforced concrete piers.

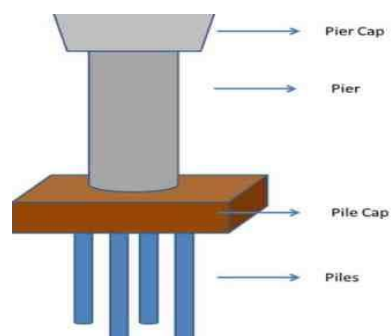


Solid Masonry Piers:

- It is constructed from brick masonry, stone masonry, and concrete.
- For economic reasons, the outer part of solid masonry pier is built from stone masonry and the inner part is filled with the help of mass concrete.

Solid Reinforced Concrete Piers:

- Solid reinforced concrete piers are mostly constructed from reinforced concrete and commonly rectangular in cross-section.
- It is used in the case where the height of the piers is more and the solid masonry piers would not be strong enough to bear the load and can be uneconomical.

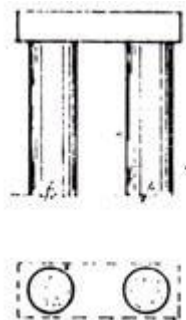


Open Piers:

Open piers permit the passage of water through the structure and classified into the following types:

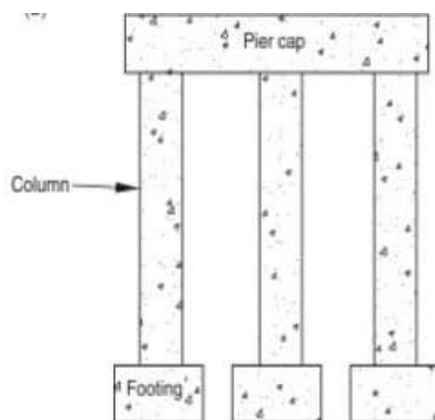
Cylindrical Piers:

- Cylindrical piers consist of cast iron or mild steel cylinders which are filled with concrete.
- These are suitable for bridges with moderate height.
- In certain cases, horizontal and diagonal steel bracing may be used to improve stability.



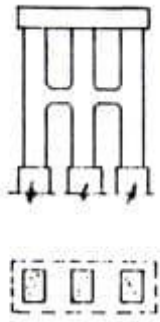
Column Piers or Column Bent:

- This type of pier is suitable for bridge with significant height. It consists of a cap beam and supporting columns forming a frame.
- Column bent piers can either be used to support a steel girder superstructure or be used as an integral pier where the cast-in-place construction technique is used.
- The columns can be either circular or rectangular in cross section. They are by far the most popular forms of piers in the modern highway system.



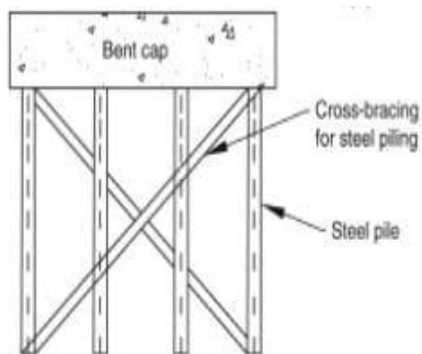
Trestle piers or Trestle bent:

- It consists 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 this type of piers numbers 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.



Bridge Abutments:

- A bridge abutment is a vertical structure that connects the deck of a bridge to the ground. It is constructed at the end of a bridge span.
- It transmits weight from the bridge superstructure to the ground. It also connects the bridge to the roadway and retains the roadway base materials from the bridge spans.
- Bridge abutments are built with brick masonry, stone masonry, precast concrete blocks, and RCC. They come in different shapes and sizes.
- The type of abutments selected is determined by available space, geologic factors of the bridge site, and project budget.

Parts of Bridge Abutment

Bridge Seat

- Bridge seat is a horizontal shelf that supports the bridge deck and is located close to or on top of an abutment. These would hold the end of a span on the embankment, while those placed along a span will offer support to reduce protracted stress.

Wing Walls

- Wing walls are only seen in abutments that link to the embankment. They are short retaining walls that provide stability and prevent erosion. Wing walls can be seen on the right side of the photograph but are not represented in the figure.

Back Wall

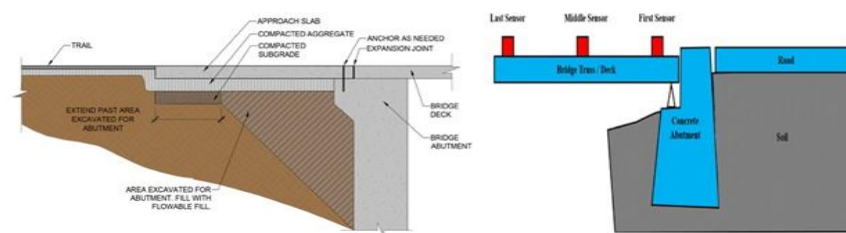
- This type of wall is only found in embankment walls. Back walls are built vertically at the ends of the majority of bridges. The expansion joints of the bridge span/deck are supported by the back walls.

Abutment Pile

- An abutment pile is the strand of the Abutment that connects the Abutment's ground foundation to the bridge's seat. The length of the pile is determined by the bridge's height and the depth of the obstruction (stream, river, and canal).

Abutment Footing

- The abutment footing is also known as the bridge foundation. The footing is what ties the pile to the ground. The footing is wider and heavier. The function of the footing is to keep the abutment from sinking into the ground.



Functions of Abutments

- Load transmission from a superstructure to its foundation components.
- Self-weight, lateral loads (such as earth pressure), and wind loads must be resisted or transmitted.
- To provide support for one edge of an approach slab.
- To maintain the equilibrium of an arch bridge's vertical and horizontal force factors, Abutment.

Types of Bridge Abutments:

1. Gravity Abutment:

- The typical gravity abutment is the most common type of abutment, and it includes the bridge seat, back wall, footing, and wing walls to hold the bridge's deck while including a retaining wall for the embankment. Usually, the wing walls are placed parallel to the bridge seat or at a slight, backward angle into the embankment.

2. U-Abutment:

- This U-abutment is a form of abutment that differs from a gravity abutment in the angle of the wing walls. These are placed at a perpendicular angle to the bridge seat, extending toward the embankment and away from the bridge.

3. Spill-Through Abutment:

- Spill-through abutments usually support the bridge periodically through its span. While they do not include wing walls or a back wall to retain the embankment, the deck rests on a beam supported by columns or a short wall. Water or roadways are able to pass between the supports. The length of the support structure varies to accommodate the distance between the level bridge and the changing terrain below.

4. Pile Bent Abutment:

- The pile bent abutment is a variant on a spill-through abutment that replaces the wall-like supports with a series of piles, or columns, to hold the support beam.

5. Stub Abutment:

- A stub abutment, also known as a perched abutment, is a relatively short abutment built after completing the embankment. The embankment can be compacted without the abutment interfering, and the abutment building can be delayed if necessary. These abutments are as short as possible and placed at the top of fill embankments.

6. Cantilever Abutment:

- A Cantilever Abutment serves multiple functions: one is to retain soil behind the bridge's ends, and the other supports the bridge superstructure. Stub abutments are the name given to some types of wall abutments. These abutments are installed at the top of fill embankments and are designed to be as short as feasible. Stub abutments frequently only hold somewhat higher soils than the superstructure's thickness.

7. Full Height Abutment:

- This type of abutment is common in congested and metropolitan regions where structural depth is required. It's essentially a high-height abutment for low-level roadways built to sustain the entire construction.

8. Semi-stub Abutment:

- Semi-stub abutment is between the full-height and stub-abutment heights. These abutments are built between the embankments' top and bottom. They are known as Semi-Stub abutments because they are larger than stub abutments but shorter than full-height abutments.

Broadly, abutments are classified under the following two categories,

- I. Abutment with wing walls
- II. Abutment without wing walls

I. Abutment with wing walls:

In this category, the abutments are provided with wing walls which may be

- a) Straight wing walls
- b) Splayed wing walls
- c) Return wing walls

II. Abutment without wing walls:

In this category, the following types of abutments are in general use:

- a) Buried abutments:
- b) Box abutments
- c) Tee abutments
- d) Arch abutments

Wing Walls:

- A wing wall is a structural member located at the end of a bridge structure.
- When it is constructed integrally with the abutment, it is termed as cantilever wing wall and when separated from the abutment with expansion or construction joint, it is called an independent wing wall.
- The function of the wing wall is to retain the fill that supports the roadway and provide protection against erosion.
- Wing wall is not a main load-carrying capacity element in a bridge structure, but its size, capacity, and connection to the abutment stem may influence the performance of the entire bridge structure.

Types of Wing Walls:

Depending upon the type of material used the wing walls are categorised into two types:

- a) Masonry wing walls
- b) Reinforced concrete wing walls

Depending upon the orientation to abutments wing walls are classified as follows:

- a) Straight wing walls
- b) Splayed wing walls
- c) Return wing walls

Straight Wing Walls:

- They are suitable for small bridges, on drains with low banks and for railway bridges in cities.
- In case of hard and rocky foundation, the wing walls may be constructed in steps.
- When the soil is loose, the foundation should be taken to a uniform depth.

Splayed Wing Walls:

- They are constructed generally at 45° with abutment and are straight or curved in plan.
- Their top is 0.5 m thick and their face batter is 1 in 12 and back batter is 1 in 6.
- They are suited for the crossing of a river.
- They are also adopted when the road has to narrow on crossing the bridge, or when two or more roads meet at the approach.

Return Wing Walls:

- These are walls built at right angles to the abutment at its both ends.
- They are designed to retain the earth filling of the approach road.
- Their top width is 1.5 m face is vertical, and the back is given either a batter of 1 in 4 or stepped back.
- They are suitable where the banks are high and rocky.

Bridge Approaches:

- The approaches are the lengths of the communication route at both ends of the bridge.
- The alignment and levels of the approaches are affected by the design and layout of the bridge.
- As per IRC recommendations they should have a minimum straight of 15 m on either side of a bridge. This length of 15m may be increased where necessary to provide minimum sight distance for the design speed. This straight length of approach should have a minimum surfaced width equal to the roadway on the bridge itself.

Types of Approaches:

- In the case of high level bridges and culverts, the approaches are provided in embankment, while for submersible bridges and causeways, they are in a cutting.
- In case of arch and suspension bridges, sometimes it is economical to cover only the central major portion of bridge. The approaches in such cases may be provided in the form of series of small spans from the banks to the main structure.
- In urban areas where land is costly, the approaches are made of retaining walls constructed on either end of road width, and the earth work is filled in the middle. This type, though higher in initial cost, is economical to maintain.
- If the approach is in filling, borrow pits should not be dug close to the embankment to avoid risk of parallel flow being developed which may endanger safety of the embankment.

CULVERTS AND CAUSEWAYS

Culvert:

A culvert is a tunnel-like structure that is constructed to allow water to flow under a road, railroad, or similar obstruction to provide cross drainage or to take electrical or other cables from one side to the other. This system is enclosed by soil or ground.

- In the case of a highway where a culvert is constructed to cross the small traffic pass on it etc., the culvert length of span may be about 4.5 m. similarly, in the case of a railway track, the maximum length of span can be about 6 m and it should not be greater than this limit.

Types of Culverts:

Following are the types of culverts generally used in construction,

1. Pipe culvert
2. Box culvert
3. Arch culvert
4. Slab culvert

Pipe Culvert:

- A pipe is used to move water away at an excavated place, and then it is known as a pipe culvert.
- The pipes culvert is made from R.C.C., cast iron, steel, etc.
- Pipe culverts are available in different shapes such as circular, elliptical, and pipe arch and their shape selection depend on on-site conditions.
- These culverts may be used of single in number or multiple, if the width of the span or channel is greater, we will go for multiple pipe culverts. Generally, they are used for a larger flow, and an installation of a single pipe culvert, we can use the larger diameter size culvert.
- The range of diameter of the pipe culvert is between 1m to 6m.
- The pipe culvert is chosen for smaller types of drainage works, which pass through the embankment of road or railway.



Box Culvert:

- Box culverts are in rectangular shape and generally constructed by concrete. Reinforcement is also provided in the construction of box culvert.
- These are used to dispose rain water. So, these are not useful in the dry period. They can also be used as passages to cross the rail or roadway during dry periods for animals etc.
- Because of sharp corners these are not suitable for larger velocity.
- Box culverts can also be provided in multiple numbers.
- For a single span of 3 m or for a double span of 6 m width, such type of culverts can be used. The thickness range of the R.C.C slab should be kept within 1.25 to 2.5 m.
- Box culvert is economical due to there is no need to provide a separate foundation and also rigidity.
- This culvert's construction is preferable, especially in loose soil conditions, and for a larger span and also it requires a good foundation, and not be used for larger velocity.



Arch Culvert:

- Arch culvert is similar to pipe arch culvert but in this case an artificial floor is provided below the arch.
- For narrow passages it is widely used.
- The artificial floor is made of concrete and arch also made of concrete. Steel arch culverts are also available but very expensive.
- The arch culverts are not provided with the piers to the sides of the abutment.



Slab Culvert:

- Slab culvert, a type of culvert, could be three-sided or simply a deck slab. It is embedded in the soil on both sides.
- The slab provides a bridge over the distance.
- Slab culverts can replace box culverts if no artificial flooring is necessary.
- Slab culverts do not have bottom slabs, therefore, the natural flow of water is maintained and natural bottom substrate remains intact.
- The safety of high-velocity vehicles is not affected by slab culvert as it doesn't have any sharp corner.
- While constructing the slab culvert, a series of slabs are laid to form the bridge-like structure. After that, a pavement surface is placed on top to serve the purpose as the road.
- The standard span length ranges from 8' to 48'.



Causeways

Paved dips, also known as bed level causeways, are structures consisting of gentle and shallow depressions in the road where the water is allowed to flow over the road. The full road width is paved with a cement concrete bed, and curtain walls are provided on the upstream and downstream sides to prevent scour.

Types of Causeways:

1. Low level causeway
2. High level causeway

Low Level Causeway:

- If a causeway has not vent to flow the water then it is called low level causeway. It is also known as Irish bridge.
- The beds of small rivers or streams, which remains dry for most of the year, or generally passable without a bridge.
- This involves heavy earth work in cutting for bridge approaches. Banks of such types of streams are cut down at an easy angle.

- For streams or rivers in plains having sandy beds, it is often sufficient to lay bundles of grass over and across the sandy tracks.
- For crossing the important traffic it is essential to lay a metal or paved or concrete road to prevent against possible scour and undermining a cut off or dwarf wall usually 60 cm deep on upstream side and 120 to 150 cm on downstream side is provided.
- For steep banks the road way is carried across the stream at higher level than the bed level.
- In this case masonry construction equal to the width of route and of desired height may be provided. The wearing surface is provided over the filling.
- In this case an apron of concrete or masonry should be provided on the downstream side to guard against scouring action.



High Level Causeway:

- A high level causeway is submersible road bridge designed to be over topped in floods. Its formation level is fixed in such a way as not to cause interruption to traffic during flood for more than three days at a time or for more than six times in a year.
- They are provided with abutments and piers, floors and slabs or arches to form the required no of openings.
- The slopes of approaches are kept as 1 in 20.
- When velocity is high and stream bed is soft the aprons could be of concrete or harder masonry up to a certain distance similarly the road can be formed of cement concrete slab or stone blocks set in cement mortar.
- A sufficient no of openings are provided to allow the normal flood discharge to pass through them with the required clearance.



2

Bridge Loading Standards

2.1 EVOLUTION OF BRIDGE LOADING STANDARDS

The earliest bridge loading standards in some countries were first formulated to regulate heavy military vehicles and were generally specified by local authorities. The loadings often consisted of steam rollers and some form of traction engines. The earliest specifications of highway bridge loadings originated from the need to transport heavy military vehicles in U.K and Europe. This resulted in the introduction of the Ministry of transport's first 'Standard Loading Train' in the U.K in 1932 and the original loading standards of many European countries.

In the United Kingdom, these standards formed the basis for the present type HA loading of BS: 153¹. In the U.S.A, a loading standard consisting of truck trains and equivalent loads was introduced by the American Association of State Highway Officials (AASHO) in 1935. It is significant to note that in some of the developing countries like India, the first loading standards were introduced nationally in 1937. Critical studies have been done to study the significant differences in the loading standards of various countries by Seni² and Rajagopalan³. The impact allowance was observed to vary considerably in different countries. In a recent survey made for the International Federation, Galambos⁴ has reported that many countries are planning revisions of their highway bridge loading standards based on the research investigations.

The first loading standard (IRC: 6) in India was published by the Indian Roads Congress in 1958 and subsequently reprinted in 1962 and 1963. The Section-II of the code dealing with loads and stresses was revised in the second revision published in 1964. The metric version was introduced in the third revision of 1966. The IRC: 6 Code has been revised to include the

combination of loads, forces and permissible stresses in the Fourth revision published in 2000⁵.

2.2 INDIAN ROADS CONGRESS BRIDGE LOADING STANDARDS

Highway bridge decks have to be designed to withstand the live loads specified by the Indian Roads Congress. The different categories of loadings were first formulated in 1958 and they have not changed in the subsequent revisions of 1964, 1966 and 2000.

The standard IRC loads specified in IRC: 6-2000 are grouped under four categories as detailed below:

1. IRC Class AA Loading

Two different types of vehicles are specified under this category grouped as tracked and wheeled vehicles. The IRC Class AA tracked vehicle (simulating an army tank) of 700 kN and a wheeled vehicle (heavy duty army truck) of 400 kN are shown in Fig. 2.1.

All the bridges located on National Highways and State Highways have to be designed for this heavy loading. These loadings are also adopted for bridges located within certain specified municipal localities and along specified highways. Alternatively, another type of loading designated as Class 70 R is specified instead of Class AA loading.

2. IRC Class 70 R Loading

IRC 70 R loading consists of the following three types of vehicles.

- (a) Tracked vehicle of total load 700 kN with two tracks each weighing 350 kN.
- (b) Wheeled vehicle comprising 4 wheels, each with a load of 100 kN totaling 400 kN
- (c) Wheeled vehicle with a train of vehicles on seven axles with a total load of 1000 kN.

The tracked vehicle is somewhat similar to that of Class AA, except that the contact length of the track is 4.87 m, the nose to tail length of the vehicle is 7.92 m and the specified minimum spacing between successive vehicles is 30 m. The wheeled vehicle is 15.22 m long and has seven axles with the loads totaling to 1000 kN. The bogie axle type loading with 4 wheels totaling 400 kN is also specified. The details of IRC Class 70 R loading vehicles are shown in Fig. 2.2.

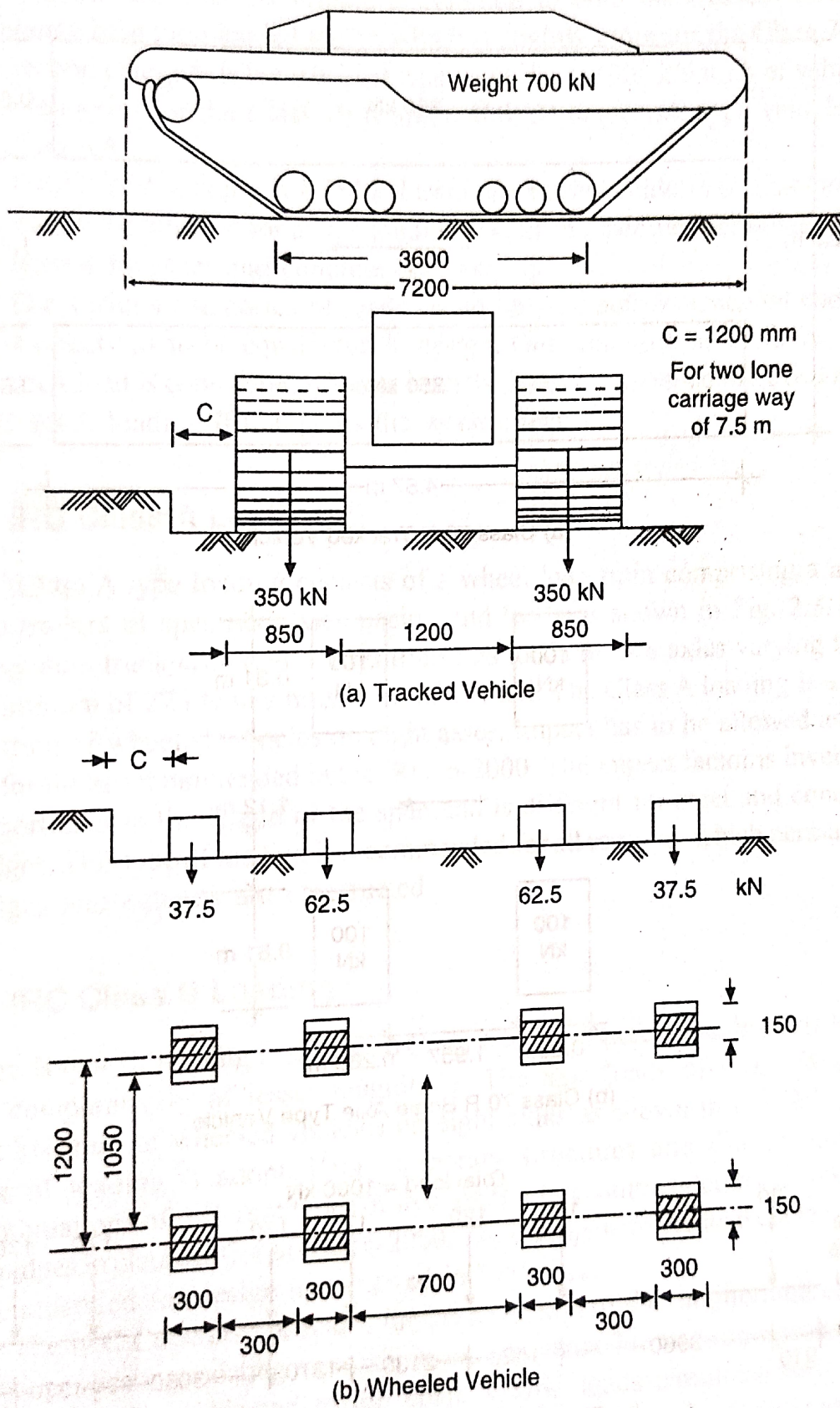
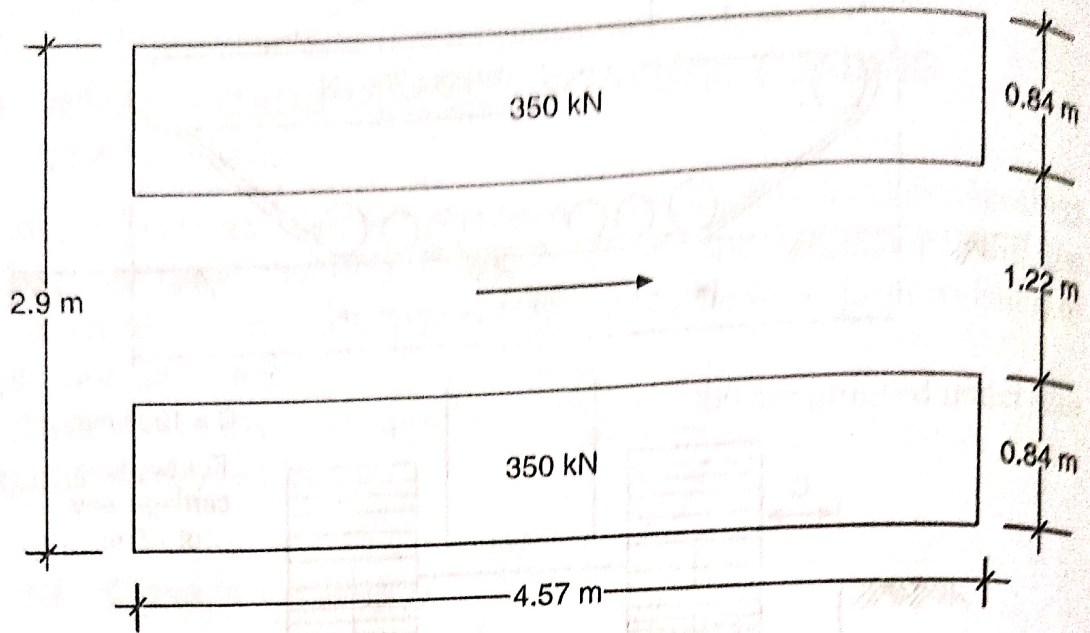
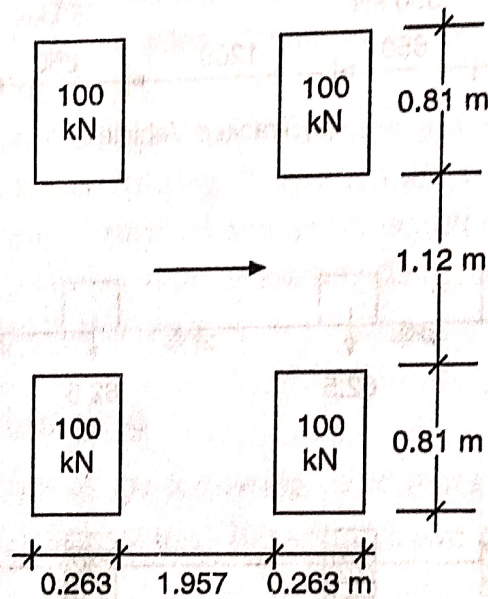


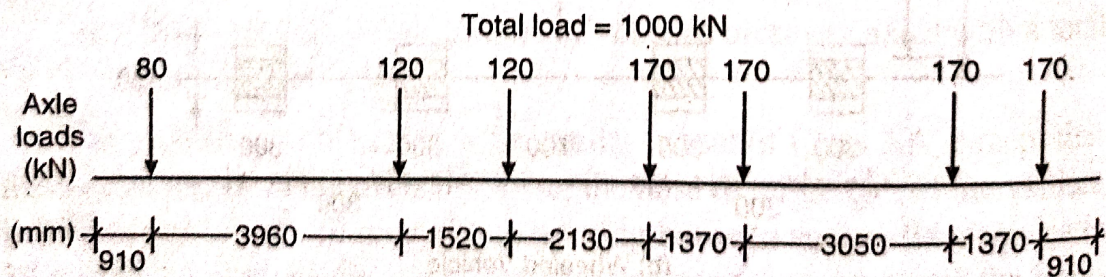
Fig. 2.1 I.R.C. Class AA Tracked and Wheeled Vehicles.



(a) Class 70 R Tracked Vehicle



(b) Class 70 R Bogie Axle Type Vehicle



(c) Class 70 R Wheeled Vehicle Loading

Fig. 2.2 I.R.C. Class 70 R Tracked and Wheeled Vehicles.

The 700 kN tracked vehicle is common to both the classes, the only difference being the loaded length which is slightly more for the Class 70 R. The second category is the wheeled type comprising 1000 kN train of vehicles on seven axles for the Class 70 R and a 400 kN bogie axle type vehicle for the Class AA.

The Class A loading is a 554 kN train of wheeled vehicles on eight axles. Impact is to be allowed for all the loadings as per the specified formulae which is different for steel and concrete bridges.

The various categories of loads are to be separately considered and the worst effect has to be considered in design. Only one lane of Class 70 R or Class AA load is considered whereas both the lanes are assumed to be occupied by Class A loading if that gives the worst effect.

3. IRC Class A Loading

IRC Class A type loading consists of a wheel load train comprising a truck with trailers of specified axle spacing and loads as shown in Fig. 2.3. The heavy duty truck with two trailers transmits loads from 8 axles varying from a minimum of 27 kN to a maximum of 114 kN. The Class A loading is a 554 kN train of wheeled vehicles on eight axles. Impact has to be allowed as per the formulae recommended in the IRC: 6-2000. The impact factor is inversely proportional to the length of the span and is different for steel and concrete bridges. This type of loading is recommended for all roads on which permanent bridges and culverts are constructed.

4. IRC Class B Loading

Class B type of loading is similar to Class A loading except that the axle loads are comparatively of lesser magnitude. The axle loads of Class B are a 332 kN train of wheeled vehicles on eight axles as shown in Fig. 2.3. This type of loading is adopted for temporary structures and timber bridges. Combinations of different types of live loads are recommended for the design of bridges in clause 207.4 of IRC: 6-2000. The carriageway live load combination recommended for design is compiled in Table 2.1.

The IRC Code also provides for the reduction of the longitudinal effects on bridges accommodating more than two traffic lanes due to the low probability of all lanes not subjected to the characteristic loads simultaneously. The reduction in longitudinal effect recommended is 10 percent for three lanes and 20 percent for four lanes or more. However, it should be ensured that the reduced longitudinal effects are not less severe than the longitudinal effect resulting from simultaneous load on two adjacent lanes.

TABLE 2.1 Live Load Combinations
(Table 2 of IRC: 6-2000)

Sl. No	Carriage way width	Number of lanes for design purposes	Load combination
1	Less than 5.3 m	1	One lane of class A considered to occupy 2.3 m. The remaining width of carriage way shall be loaded with 5 kN/m ²
2	5.3 m and above but less than 9.6 m	2	One lane of Class 70 R or Two lanes of Class A
3	9.6 m and above but less than 13.1 m	3	One lane of Class 70 R for every two lanes with one lane of Class A on the remaining lane or 3 lanes of Class A
4	13.1 m and above but less than 16.6 mm	4	One lane of Class 70 R for every two lanes with one lane of Class A for the remaining lanes, if any, or one lane of Class A for each lane.
5	16.6 m and above but less than 20.1 m	5	_____ do _____
6	20.1 m and above but less than 23.6 m	6	_____ do _____

Note: The width of the two lane carriage way shall be 7.5 m as per clause 112.1 of IRC: 5-1998

2.3 HIGHWAY BRIDGE LOADING STANDARDS OF DIFFERENT COUNTRIES

A brief survey of the highway bridge loadings prescribed in some countries based on work of Raina⁶ is compiled below:

1. British Standard Loadings

The British standards prescribe two main types of loadings designated as HA and HB loading. The HA type loading is designated as the normal design loading and consists of

- (a) A uniformly distributed loading carrying from 318.6 kN/m for 1 m loaded length(span) to 5.8 kN/m for 900 m loaded length(span) (as per the loading curve shown in Fig 2.4) and a knife edge load of 120 kN per lane which are inclusive of impact. There is no reduction in the intensity of HA loading for up to two lanes of traffic.

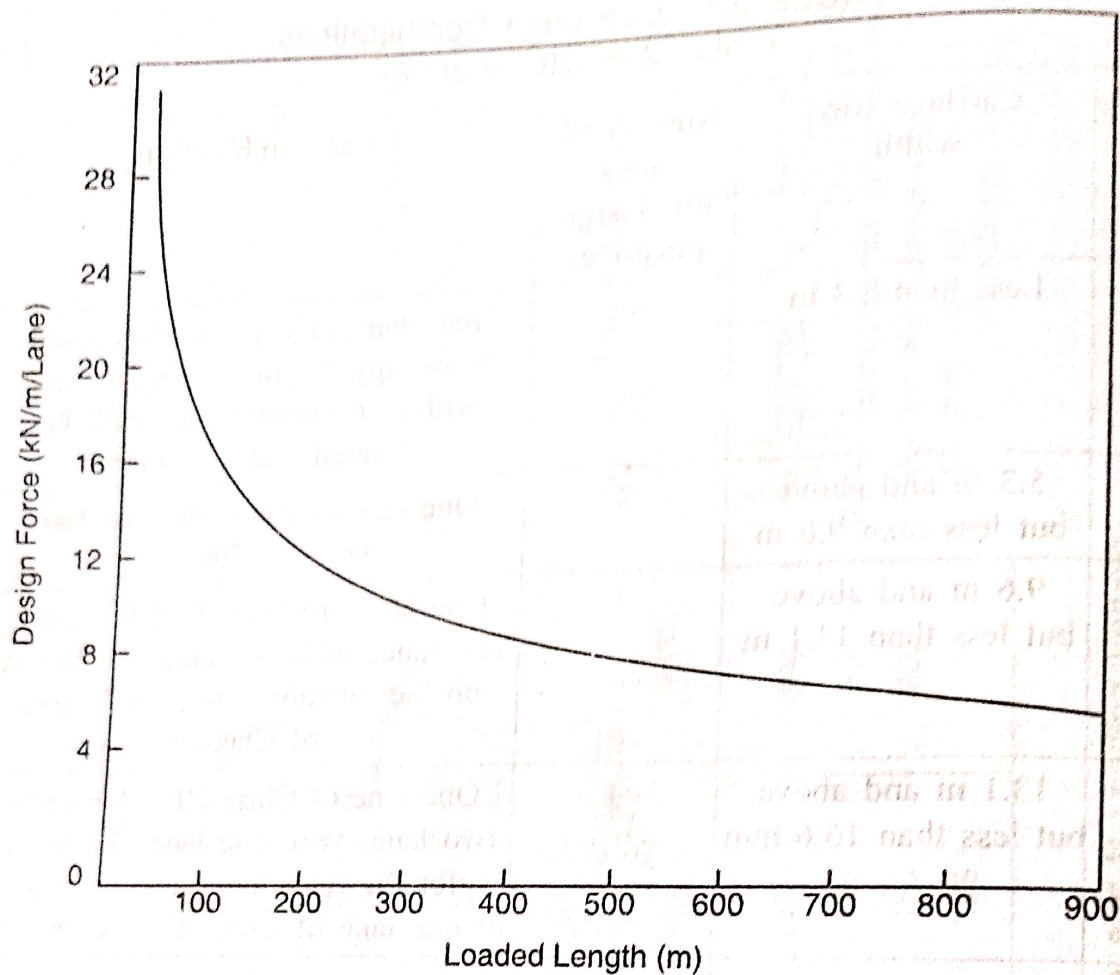


Fig. 2.4 Loading Curve for type HA-Loading
(British Standard Loading-UK).

- (b) And alternative axle load is also specified on which impact must be considered. This loading system consists of two loads each of 112 kN in line transversely to the direction of traffic flow speed at 0.9 m. The uniformly distributed load has a constant value of 31.5 kN·m of lane for loaded length for 6.5 m to 23 m. For span below 6.5 m, separate curers for the uniformly distributed load are specified. Two lanes are always considered as occupied by full type HA loading while all other lanes in excess of two are considered as occupied by one third of the full lane loading. The standard design lane width is 3 m. In considering the effects of the 112 kN wheel loads, an over stress 25% is permitted. An impact allowance of 25% is specified for this type of HA loading.
- (c) Type HB loading is an abnormal unit loading. The number of units per axle (4 axles in all) specified in the UK for bridges carrying the heaviest class of load is 45, amounting to a total load of 1800 kN. This is idealized on four axles which allows for the weight of tractors accompanying trailers. With this loading an overstress of 25% is allowed. No allowance is to be made for impact. Only one

lane is to be loaded with HB type loading, all other lanes being considered as occupied by one-third full lane HA loading only if its presence results in worst effect. The plan view of Type HB loading is shown in Fig 2.5. These loading are followed in Malaysia, Sri Lanka, Kenya and Rhodesia.

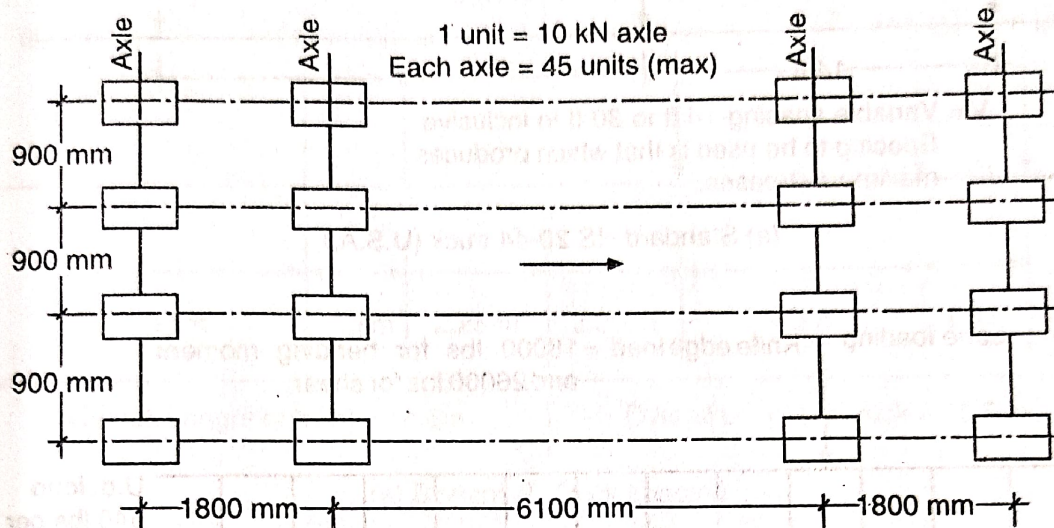


Fig. 2.5 Plan View of HB Loading
(British Standard Loading-UK).

2. AASHTO (American Association of State Highway Transport Officials) Loading

The American Association of Highway and Transportation Officials (AASHTO), has prescribed the heaviest loading designated as HS 20-44. This type of loading is followed in USA, Australia, Bangladesh, Canada, Ethiopia, Philippines and Turkey. This loading comprises of a heavy tractor truck with a semi-trailer of a total load of 320.3 kN or the corresponding lane loading. The lane loading consists of a uniformly distributed load of intensity 9.3 kN/m together with a knife edge load of 80 kN for bending moment and 115.7 kN for shear force computations. In addition, impact effect is to be added for both the cases as recommended by the AASHTO recommendations. While designing bridges, both the truck and lane loading should be considered and the one which gives the worst effect is to be adopted.

When truck loading is used, only one truck is considered for each traffic lane for the whole of its length. Also there is no reduction in load intensity for up to two lanes of traffic loaded.

In USA, Canada and Australia, AASHTO loadings comprise of standard HS 20-44 truck or HS 20-44 lane loading (shown in Fig 2.6) are used.

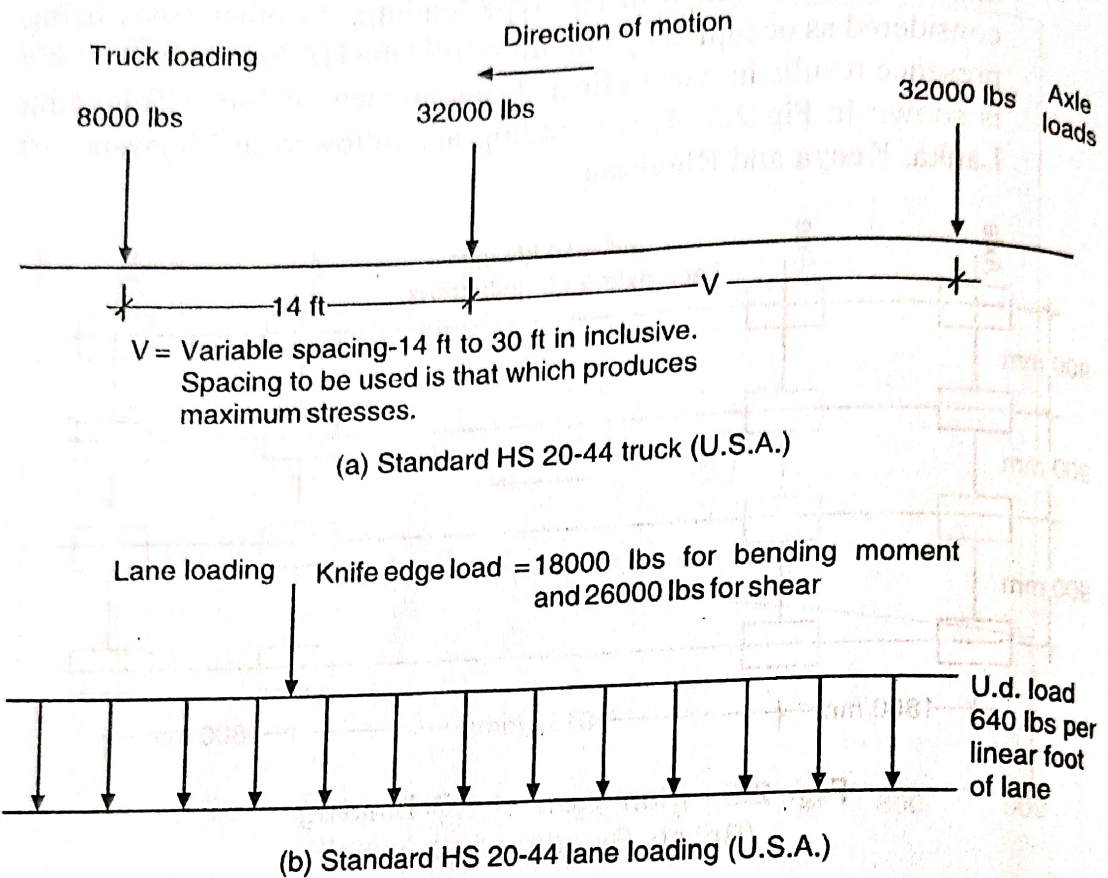


Fig. 2.6 AASHTO Loadings (U.S.A.).

3. French Highway Loadings

The highway loadings prescribed in France are categorized as system A and system B loads. System A loading is expressed in an empirical form given by

$$\text{U.d Load A}(L) = \left\{ 230 + \frac{3600}{L + 12} \right\} \text{ kg/m}^2$$

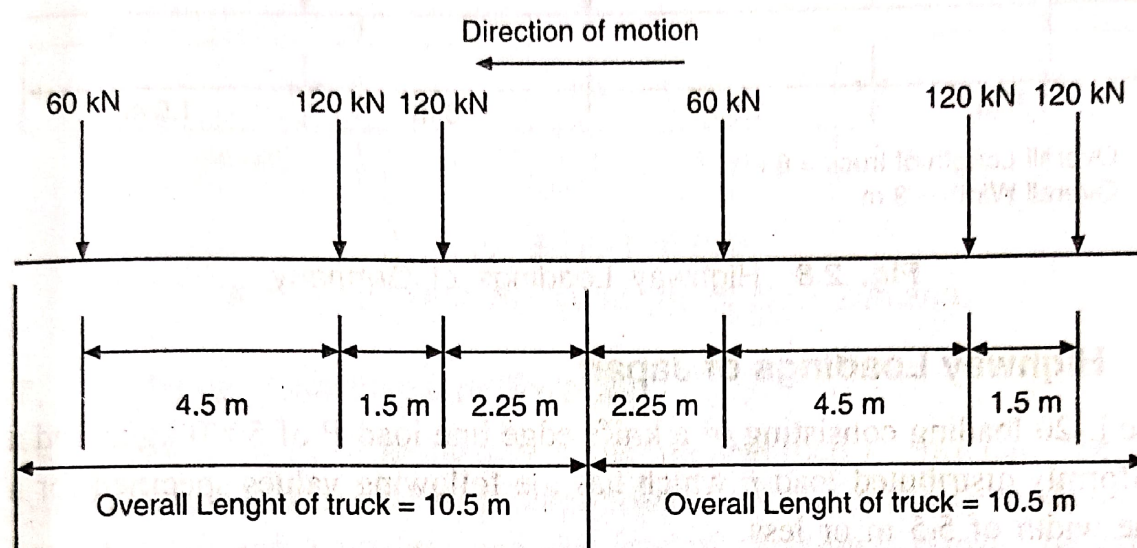
Where L = Loaded length in meters.

The uniformly distributed load $A(L)$ obtained from the above formula is to be multiplied by a coefficient a_1 whose value is 1.0 up to two lanes and then reduces with an increase in the number of lanes. Also $a_1 \cdot A(L)$ should be not less than $(400 - 0.2 L) \text{ kg/m}^2$.

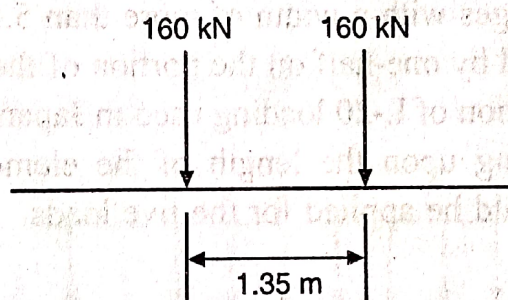
In the case of class 1 roads, if the lane width is different from the standard lane width of 3.50 m, the value of $A(L)$ is to be multiplied by the coefficient a_2 so as to keep the total load per linear metre of lane unaltered for any loaded length.

System B loads are grouped as B_c and B_t where B_c comprises of truck loading with wheel loads (as shown in Fig 2.7(a)) and B_t is made up of tandem

axle loading (as shown in Fig 2.7(b)). System A loading is inclusive of impact. For system B loading, impact factor is expressed as an empirical expression depending on the length of the element in metres, the permanent weight of the bridge and the maximum load of the truck.



(a) System B_c Truck Loading



(b) System B_t Tandem Axle Loading

Fig. 2.7 Highway Loadings of France.

4. Highway Loadings of Germany

Two types of loadings are specified in for highway bridge design in Germany. The Class 60 loading consists of a 600 kN truck together with a uniformly distributed load of 5 kN/m^2 in the portion of the lane not occupied by the truck. The substitute uniformly distributed load for the 60 t truck is 33.3 kN/m^2 . The standard design lane width is 3.0 m. There is no reduction in intensity of load for up to two lanes of traffic. For the area outside the main lanes, a uniformly distributed load of 3 kN/m^2 is specified (Refer Fig 2.8). Impact factor is expressed by a formula depending upon the governing length.

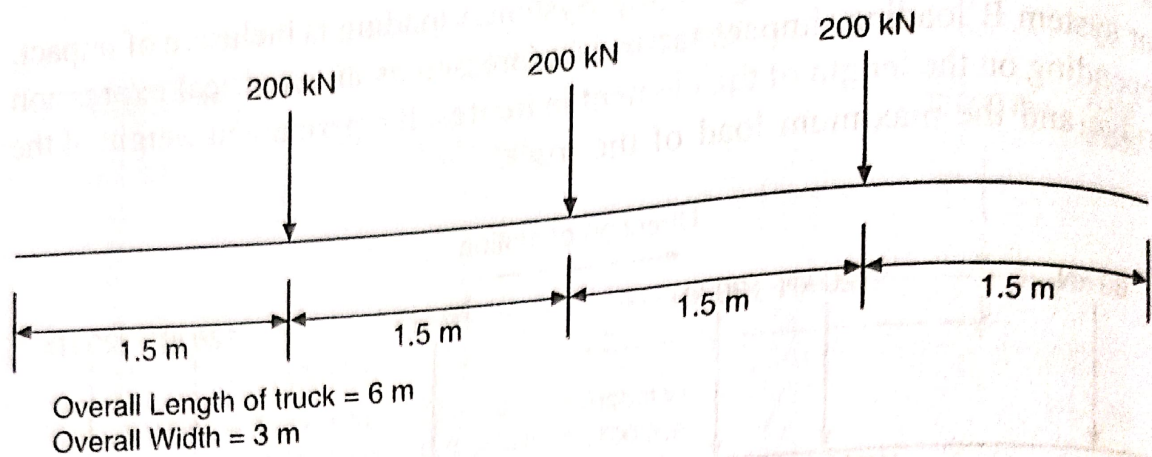


Fig. 2.8 Highway Loadings of Germany.

5. Highway Loadings of Japan

The L-20 loading consisting of a knife edge line load P of 5000 kg/m and a uniformly distributed load p which has the following values specified for a lane width of 5.5 m or less.

For $L < 80$ m, $p = 350 \text{ kg/m}^2$

For $L > 80$ m, $p = (430 - L) \geq 300 \text{ kg/m}^2$

In the case of bridges with a width of more than 5.5 m, the values of P and p are to be reduced by one-half on the portion of the road way in excess of 5.5 m. The composition of L-20 loading used in Japan is shown in Fig 2.9. Impact factor depending upon the length of the element expressed as an empirical formula should be applied for the live loads.

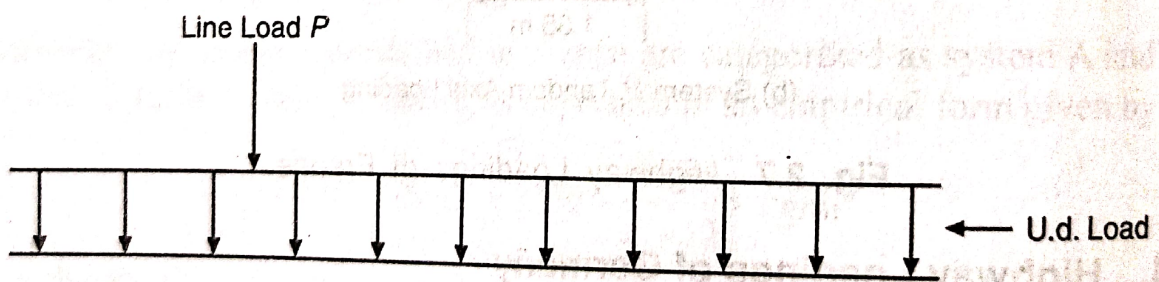


Fig. 2.9 Highway Loadings of Japan.

6. Highway Loadings of New Zealand

The design load prescribed per lane is the same as that of AASHTO loading comprising HS20-44 truck. Alternately H20-S16-T16 truck loading (Fig 2.10) is also specified. Between the two, the loading which gives the worst effects should be considered. The standard design lane is 3 m. The impact allowance is the same as that given by the AASHTO without specifying

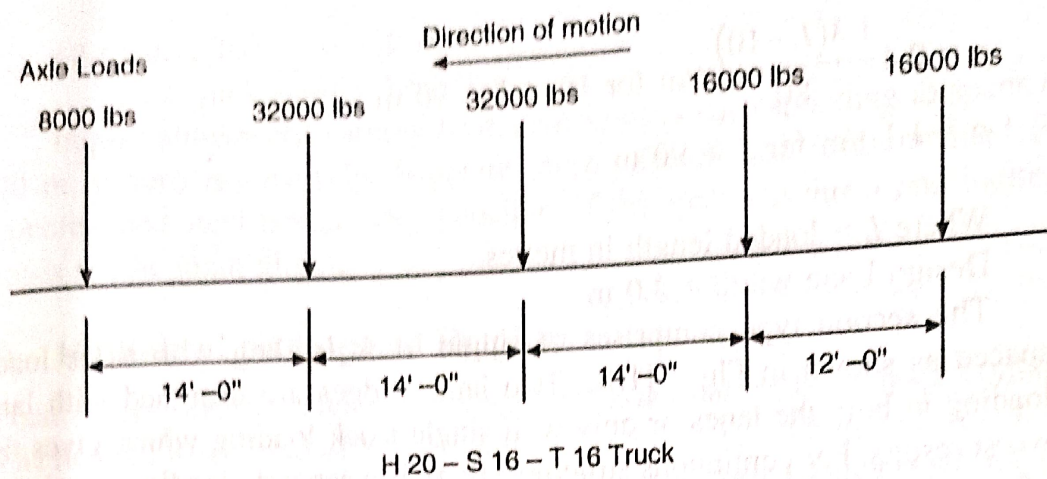


Fig. 2.10 Highway Loadings of New Zealand.

7. Highway Loadings of Sweden

Two different types of highway loading are specified in Sweden. The first type consists of uniformly distributed load of ' p ' t/m which depends on the loaded length and a concentrated axle load of 14 t (Fig 2.11(a)). The values of p are specified as follows:

$$p = 2.4 \text{ t/m for } L < 10 \text{ m}$$

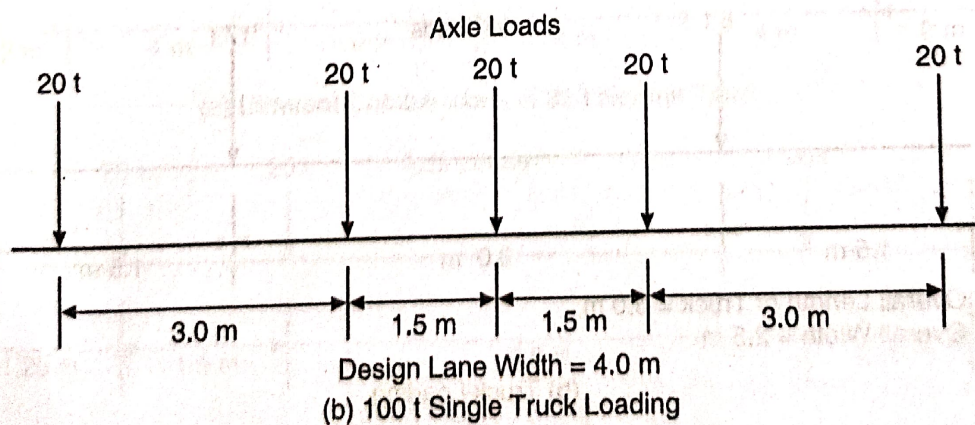
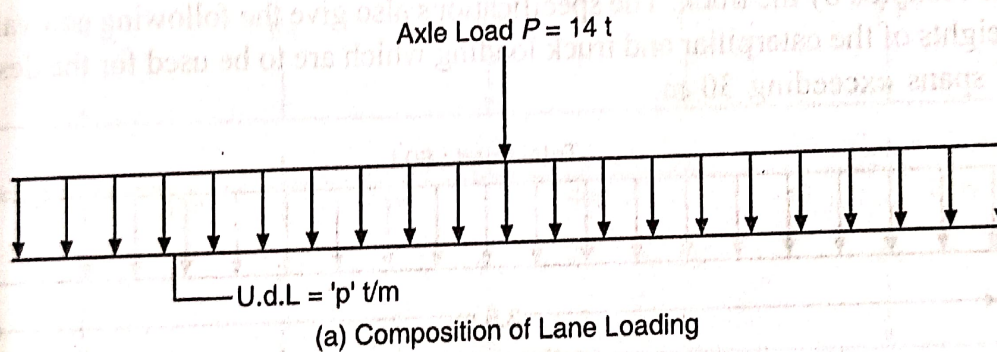


Fig. 2.11 Highway Loadings of Sweden.

$$p = 2.4 \frac{1.3(L-10)}{80} \text{ t/m for } 10 < L < 90 \text{ m}$$

$$p = 1.1 \text{ t/m for } L > 90 \text{ m}$$

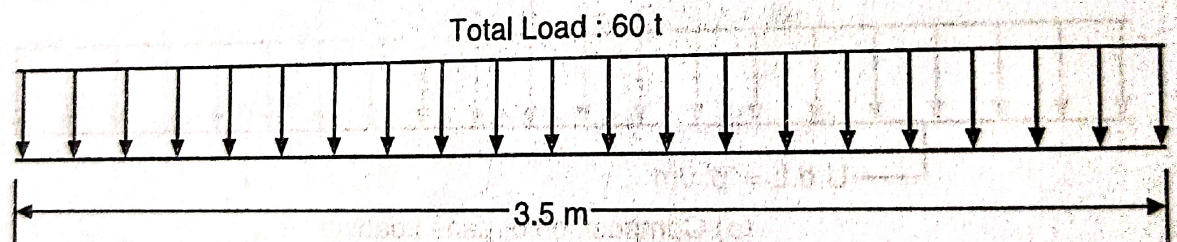
Where L = loaded length in metres.

Design Lane width = 3.0 m

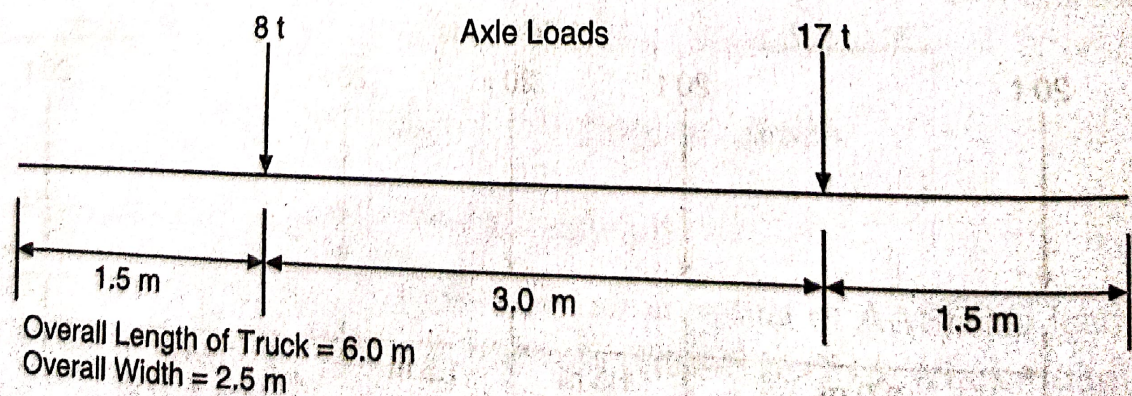
The second type comprises of single truck loading with axles loads spaced as shown in Fig 2.11(b). Two lane bridges are designed with lane loading in both the lanes or only with single truck loading which gives the worst results. For continuous structures there is a separate loading consisting of two axle loads and a uniformly distributed load.

8. Highway Loadings of Austria

Austrian loadings consist of tracked and truck loadings. The tracked loading with the overall length of the caterpillar being 6 m and overall width 3 m is 60 t as shown in Fig. 2.12(a). No allowance for impact is to be made for uniformly distributed load. The truck loading with axle loads is shown in Fig 2.12(b). The axle loads may be increased by 40% for impact effects. A uniformly distributed load of 0.5 t/m² is prescribed for the portion of the lane not occupied by the truck. The specifications also give the following equivalent weights of the caterpillar and truck loading which are to be used for the design of spans exceeding 30 m.



(a) Tracked Loading



(b) Truck Loading

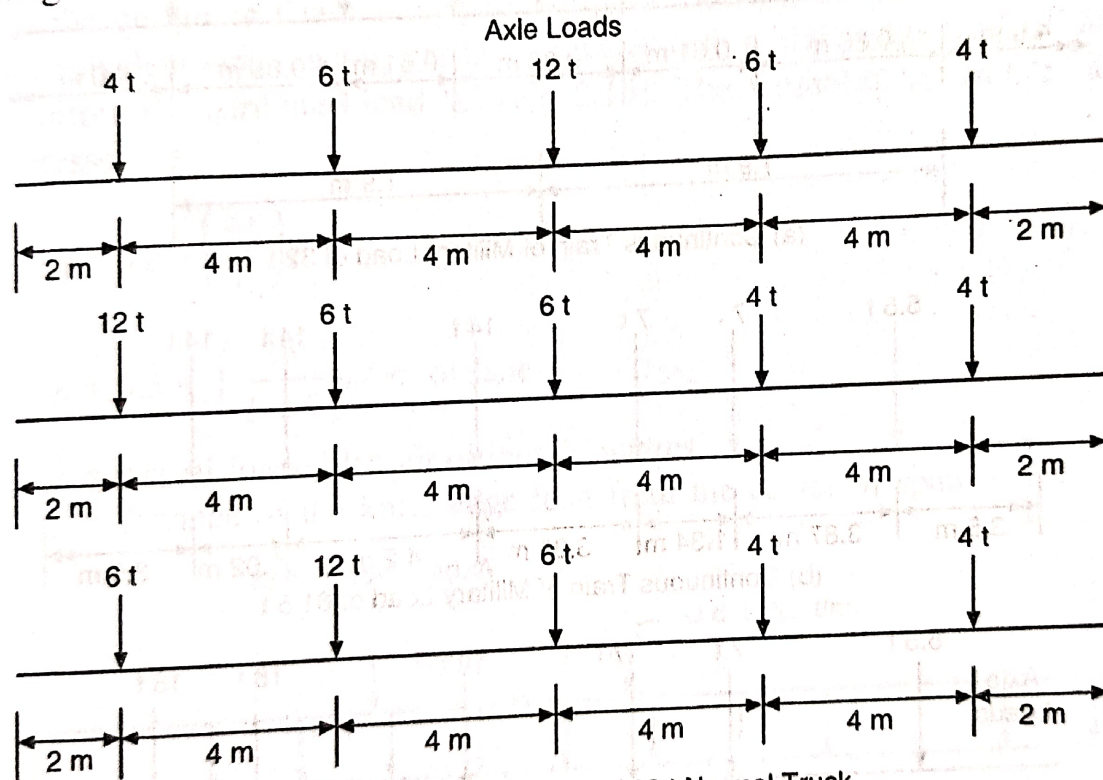
Fig. 2.12 Highway Loadings of Austria.

60 t caterpillar ——— 3.33 t/m^2
 25 t truck ——— 1.67 t/m^2

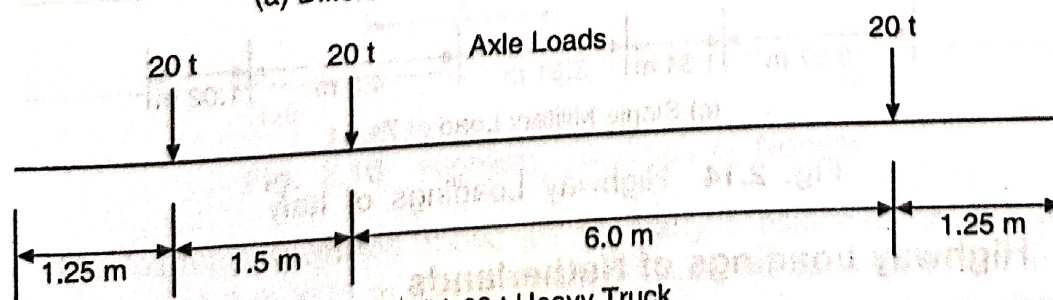
Impact allowances varying from zero to 40% corresponding to spans of 70 m to zero respectively. Separate impact factors are recommended for concrete and steel bridges as a function of the span and direct and indirect loads on the main girder.

9. Highway Loadings of Belgium

Loadings specified in Belgium are categorized as normal and heavy truck loading. The normal truck load of 32 t can have different combinations as shown in Fig. 2.13(a). Heavy truck loading of 60 t comprising 3 axles is shown in Fig. 2.13(b). Impact factor is expressed by a formula depending upon span, speed of vehicle, moving loads and dead weight and static deflection due to dead weight.



(a) Different Combinations of 32 t Normal Truck

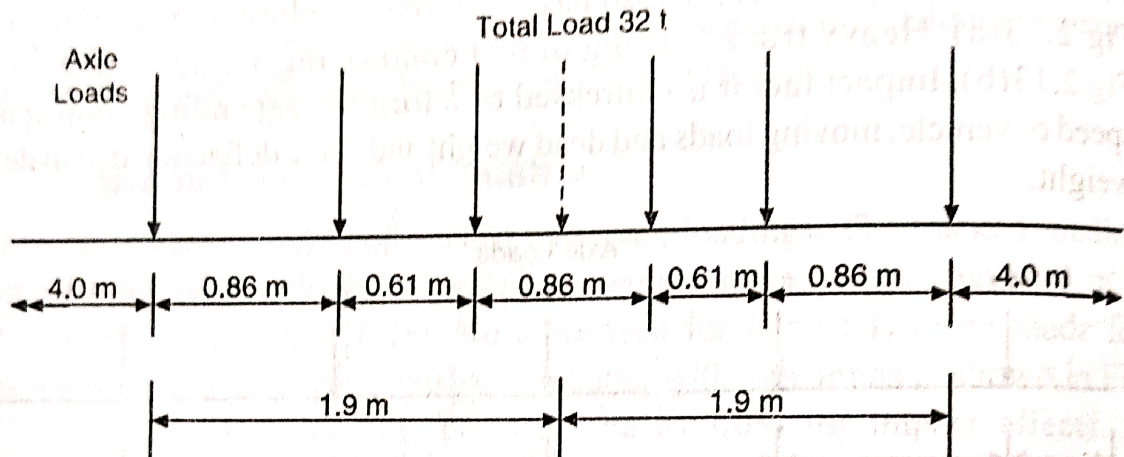


(b) 60 t Heavy Truck

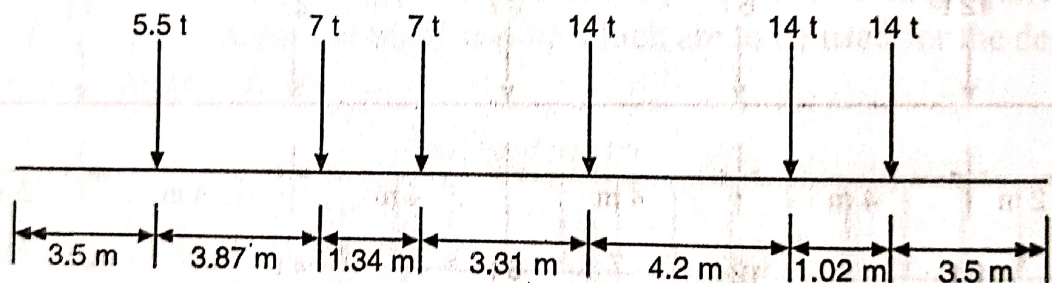
Fig. 2.13 Highway Loadings of Belgium

10. Highway Loadings of Italy

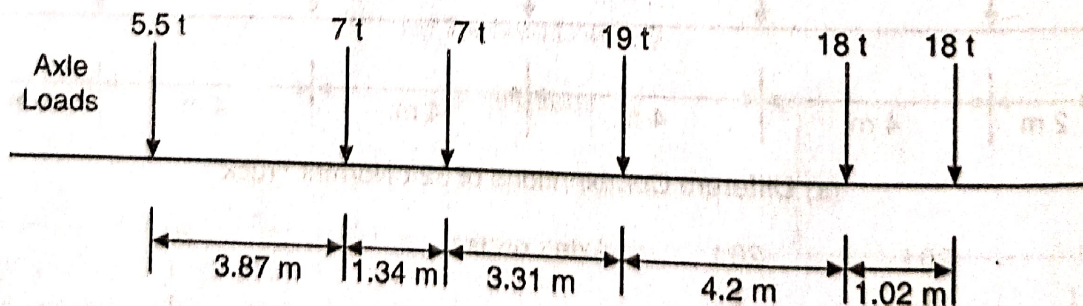
Highway bridges of Category 1 should be designed for different trains of military loads prescribed in the standards. Three different types of axles (Fig 2.14) are to be used and the worst effect should be taken for design. The total load of trains consists of 32 t, 61.5 t and 74.5 t. The width of the three types of loadings is 3.5 m. Alternately, an equivalent uniformly distributed load having different values for bending moment and shear is also specified for the design of highway bridges. Impact factor specified by a formula depend upon the span length of the bridge.



(a) Continuous Train of Military Load of 32 t



(b) Continuous Train of Military Load of 61.5 t



(c) Single Military Load of 74.5 t

Fig. 2.14 Highway Loadings of Italy.

11. Highway Loadings of Netherlands

The highest class of loading in Netherlands is the Class 60 loading consisting of a 600 kN vehicle of three axles of 200 kN each plus a uniformly distributed

load of 4 kN/m^2 (Fig 2.15). The impact factor depending upon the span length is expressed by an empirical formula depending upon the span length.

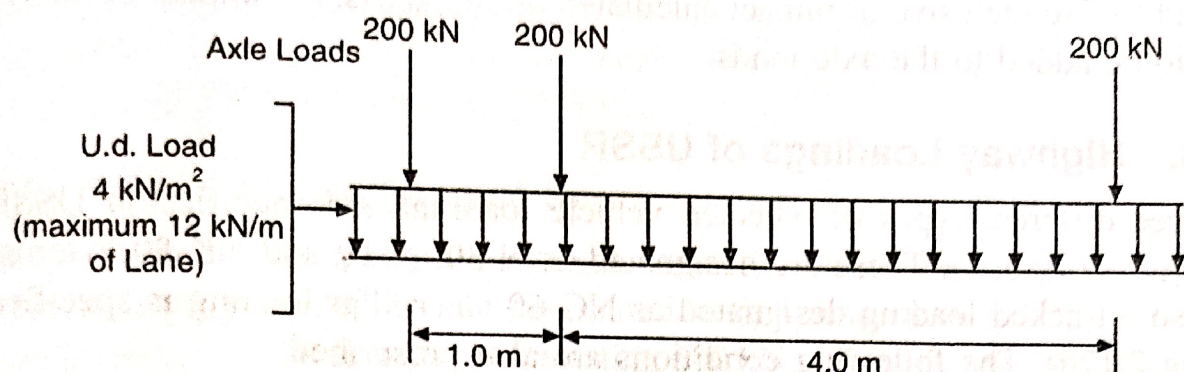


Fig. 2.15 Highway Loadings of Netherlands.

12. Highway Loadings of Norway

For the design of Class 1 type bridges, the loadings specified consists of an equivalent lane loading per lane together with a knife edge load 'A' and a uniformly distributed load 'p' (Fig 2.16). The variables 'A' and 'p' are expressed as

$$A = 12 + \left(\frac{8x}{L} \right) t$$

$$p = 0.5 + \left(\frac{35}{L+5} \right) t / m \text{ of lane}$$

L = Actual loaded length of lane in metres.

x = distance of the knife edge load from the center of span

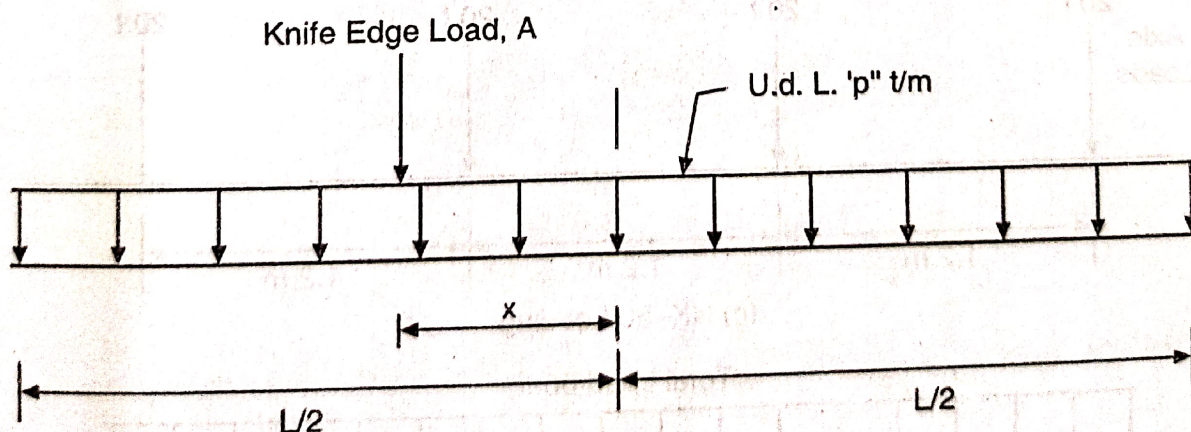


Fig. 2.16 Highway Loadings of Norway.

The loadings specified above are normally considered for lane widths varying from 3.0 to 3.75 m. For two lane bridges, the full equivalent loading is assured on both the lanes. Besides the lane loading, the structure is designed for a local loading of two axles each of 13ft. It is assumed that 38.5% impact

is to be added to the heaviest axle and it is unnecessary to add any impact to the remaining axles. The values of knife edge load, 'A' and uniformly distributed load 'p' are inclusive of impact calculated on this basis. An impact of 38.5% is to be added to the axle loads.

13. Highway Loadings of USSR

Three different types of wheeled vehicle loadings are specified in USSR (Fig 2.17 a, b, c). These are designated as N-30, N-10 and NK-80 loading. Also a tracked loading designated as NG-60 caterpillar loading is specified (Fig 2.17d). The following conditions are also prescribed:

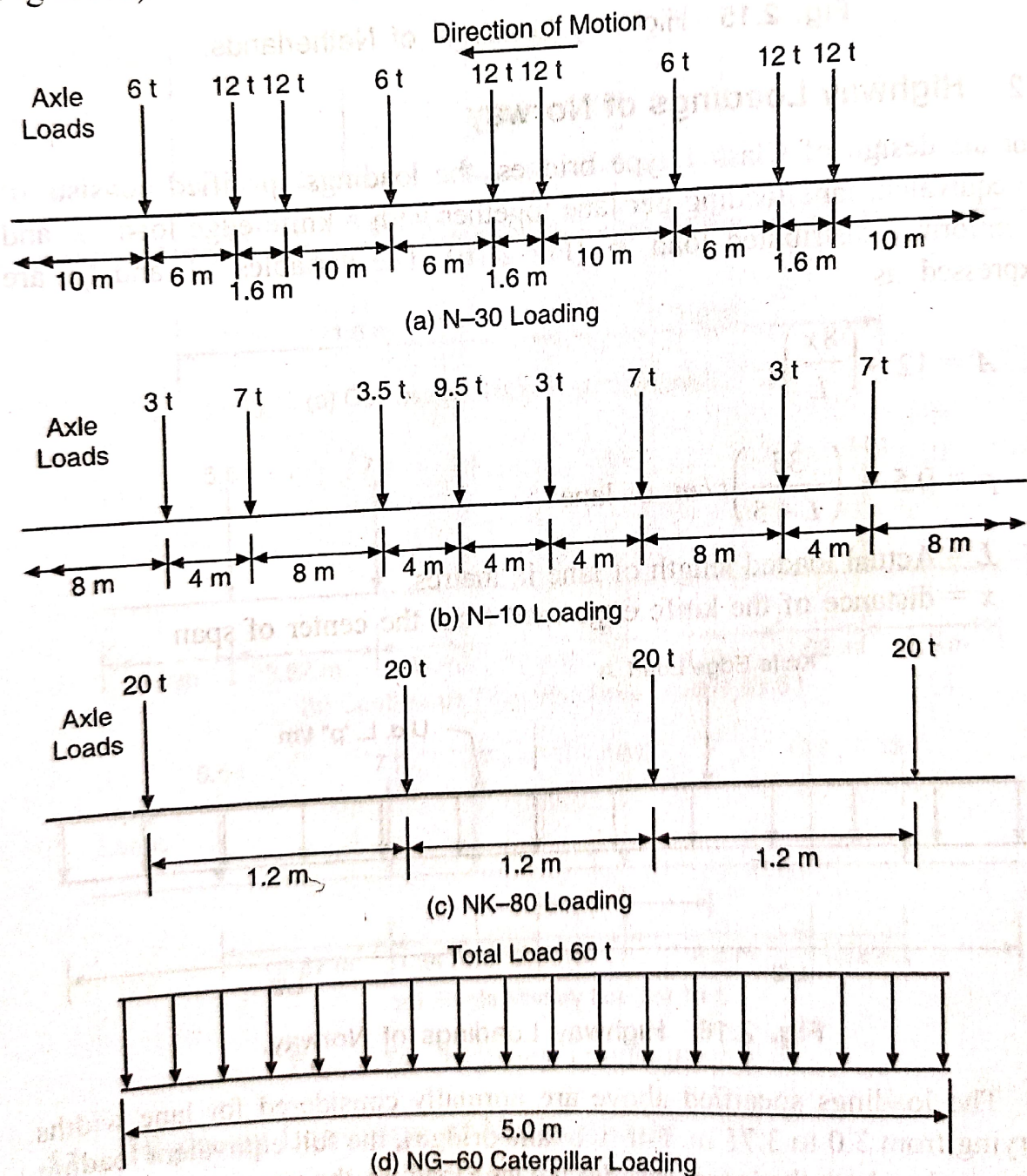


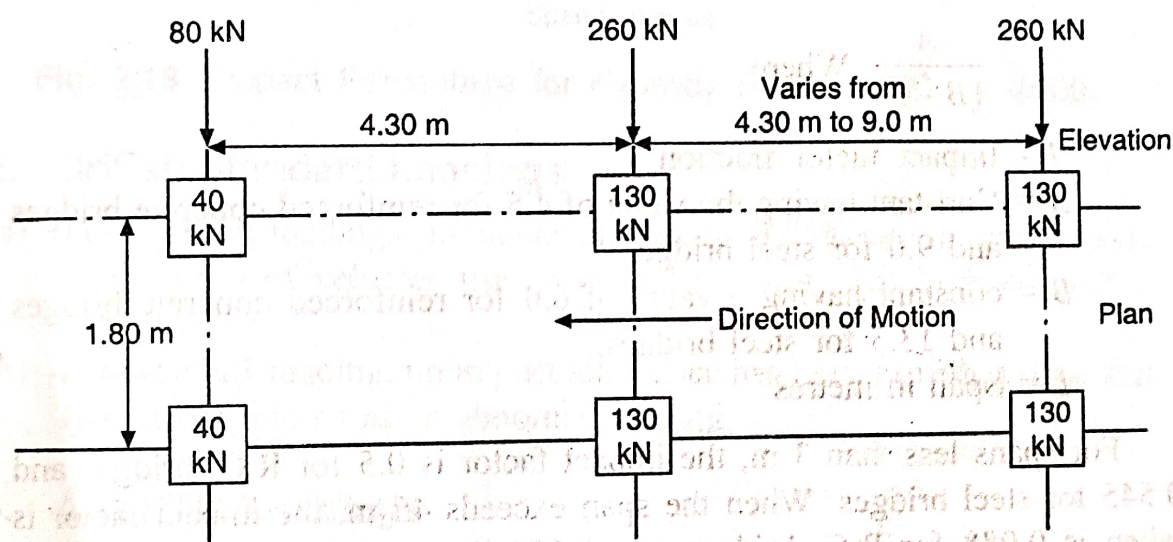
Fig. 2.17 Highway Loadings of USSR.

- (i) The design load should be either (a) or (b) whichever produces the maximum effect.
- (ii) Impact allowance as per AASHTO specification
- (iii) For more than two lanes loaded, reduction factor on live load effect as per AASHTO specification.

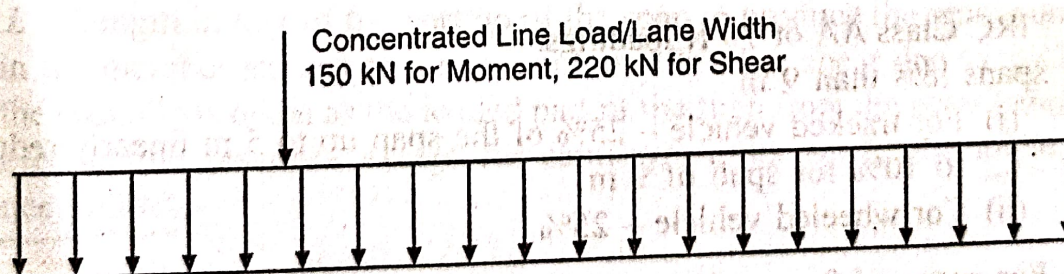
14. Highway Loadings of Saudi Arabia

Highway bridge loadings of Saudi Arabia comprise of both heavy truck wheeled vehicle loading and uniformly distributed load. The truck of three axle loads comprise of 80, 260 and 260 kN; totaling 600 kN with only one truck allowed per lane in the longitudinal direction.

The uniformly distributed load is of intensity 20 kN/m per lane width with a concentrated live load per lane width of 150 kN for moment computation and 220 kN for shear force calculations. The axle loads and uniformly distributed load are shown in Fig 2.18(a) and (b) respectively.



(a) 600 kN Truck (Each Lane can be Loaded by a truck but only Truck/Lane Longitudinally)



Uniformly Distributed Load
20kN/m run per lane Width on each Lane

(b) Uniformly Distributed Load

Fig. 2.18 Highway Loadings of Saudi Arabia.

2.4 IMPACT FACTORS

Impact factors are generally applied to the moving wheel or distributed loads to enhance their magnitude to include their dynamic effects on the bridge deck. The impact allowance is generally expressed as a fraction of the applied live load and is expressed as an empirical expression involving constants and the span length of the bridge deck. The impact factor is always inversely proportional to the length of the span and is different for reinforced concrete and steel bridges.

The impact factors to be considered for different types of live loads of various countries are as follows:

1. Indian Standard Loadings

(a) IRC Class A loading

The impact allowance is expressed as a fraction of the applied load and is computed by the expression

$$I = \frac{A}{(B + L)} \quad \text{Where}$$

I = Impact factor fraction

A = Constant having the value of 4.5 for reinforced concrete bridges and 9.0 for steel bridges.

B = constant having a value of 6.0 for reinforced concrete bridges and 13.5 for steel bridges.

L = Span in metres

For spans less than 3 m, the impact factor is 0.5 for R.C. bridges and 0.545 for steel bridges. When the span exceeds 45 m, the impact factor is taken as 0.088 for R.C. bridges and 0.154 for steel bridges. The impact percentages for highway bridges can also be directly obtained from the curves of IRC code⁵ given in Fig. 2.19.

(b) IRC Class AA or 70 R loadings.

For spans less than 9 m

(i) For tracked vehicle – 25% of the span up to 5 m linearly reduced to 10% for span of 9 m

(ii) For wheeled vehicle – 25%

For spans of 9 m and more,

For tracked vehicle- for R.C. Bridges, 10% up to a span of 40 m and in accordance with Fig 2.19 for spans exceeding 40 m. For steel bridges, 25% for spans up to 23 m and as per Fig 2.19 for spans exceeding 23 m.

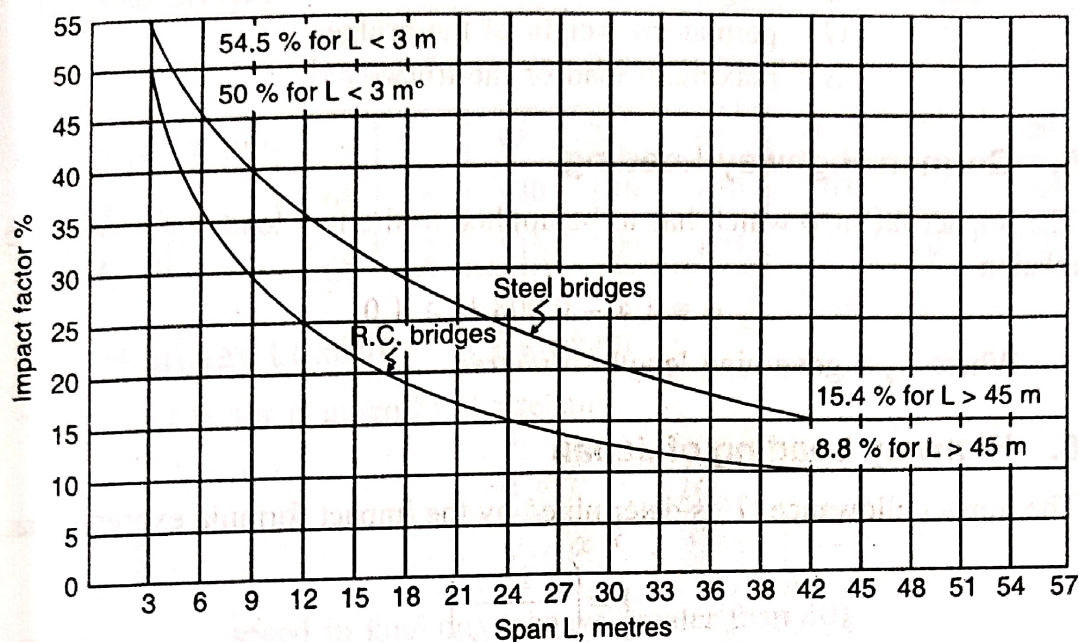


Fig. 2.19 Impact Percentage for Highway Bridges (IRC : 6-2000).

2. British Standard Loadings

- For type HA loadings, an impact allowance of 25% on the heaviest axle in the train of vehicles from which the loading has been derived is provided.
- For type HB loading, no impact allowance has been provided since this type is considered as an abnormal loading.

3. AASHTO Loadings

$$\text{Impact allowance} = \frac{50}{L + 25},$$

where L = Length in feet of the portion of the span to produce the maximum stress in the member subject to a maximum of 30%. For shear due to truck loads, the span (L) is taken as the loaded part of the span from the point being considered to the reaction, except for cantilever arms where the impact allowance is 30%.

4. French Highway Loadings

System A loading is inclusive of impact.

For system B loads, the impact factor ' ∂ ' is expressed by the formula,

$$\partial = 1 + \frac{0.4}{(1 + 0.2L)} + \frac{0.6}{1 + 4(G/S)}$$

Where L = length of the element in metres
 G = permanent weight of the bridge
 S = maximum load of the truck

5. German Highway Loading

The impact factor ϕ which has to be applied to the live load is given by the relation

$$\phi = 1.4 - 0.008 L_{\phi} \geq 1.0$$

Where L_{ϕ} = governing length in metres

6. Highway Loading of Japan

The impact allowance ' I ' is determined by the impact formula expressed as,

$$I = \left(\frac{20}{50 + L} \right)$$

Where L = Length of the element in metres.

7. Highway Loadings of New Zealand

The impact allowance is the same as that specified by the AASHTO but there is however no upper limit is prescribed.

8. Highway Loadings of Sweden

An impact allowance of 40% is to be applied for the axle loads. However no Allowance for impact is to be made for the uniformly distributed load and for the single truck loading.

9. Highway Loadings of Austria

The following impact factors are specified for concrete and steel bridges.

(i) Concrete bridges

Impact Factor for Different Spans

Span Length (m)	0	10	30	50	70
Direct Loaded Main Girder	1.40	1.30	1.20	1.10	1.00
Indirect Loaded Main Girder	1.40	1.25	1.10	1.00	1.00

Impact Factor for Floor Slab = 1.4

(ii) Steel bridges

Impact Factor for Different Spans

Span length (m)	2	6	10	20	40	60	80	100
Lane – I	1.64	1.61	1.30	1.18	1.10	1.07	1.05	1.04
Lane – II	1.32	1.20	1.15	1.09	1.05	1.03	1.02	1.02

10. Highway Loadings of Belgium

The impact factor is given by the relation

$$\phi = 1 + \frac{0.377^v}{\sqrt{L/\alpha}} \sqrt{1 + \frac{2Q}{P}}$$

where v = speed in km/hour (always greater than 60)

L = span length in metres

$\alpha = (L/f_s)$

f_s = static deflection in metres due to dead weight

Q = moving loads on the bridge deck in tones

P = dead weight of the bridge in tones

11. Highway Loadings of Italy

The impact factor ϕ expressed as a function of span length L is given by the Formula,

$$\phi = 1 + \frac{(100 - L)^2}{100(250 - L)}$$

This relation is applicable for spans up to 100 m.

For spans exceeding 100 m, the value of ϕ is unity.

12. Highway Loadings of Netherlands

The impact coefficient 'S' for bridges carrying normal traffic given by the formula,

$$S = 1 + \frac{40}{(100 + L)}$$

where L is the span in metres.

2.6 Indian Railway Bridge Loading Standards

Railway bridge loadings^{8,9} should conform to the specifications of the Indian Railway Standards (IRS) prescribed by the Ministry of Railways, Government of India. The various loads to be used are specified in the IRS Bridge rules. Specific recommendations are available for the design of steel, R.C.C, P.S.C, masonry and plain concrete arch bridges in the relevant bridge codes.

→ The railway tracks are classified according to the importance of traffic as main and branch lines. The three types of gauges used in the Indian Railways are.

- (1) Broad gauge (BG): 1676 mm (5'-6")
- (2) Metre gauge (MG): 1000 mm (3'-3.375")
- (3) Narrow gauge (NG): 762 mm (2'-6")

At present, the Indian Railways have adopted the unigauge policy with the broad gauge as the standard gauge throughout the country. Consequently many important old lines are being converted into broad gauge.

→ The various loads and forces to be considered in the design of bridge members are:

- (1) Dead and live loads
- (2) Dynamic effects
- (3) Centrifugal force due to curvature of track
- (4) Temperature and frictional effects
- (5) Racking force
- (6) Wind and earthquake forces

IRS Bridge Rules recommends the use of equivalent uniformly distributed loads (EUDL) on each track and also the coefficient of dynamic augment (CDA) for spans varying from 1 to 130 m for both BG and MG as shown in Tables 2.6 and 2.7.

The equivalent loads specified for the computation of bending moment and shear forces can directly be used in place of the various wheel loads of the rolling stock. Hence except in the case of special bridges like the Rigid Frame, balanced cantilever and Suspension bridges, the designer can directly use the equivalent loads in place of the basic wheel loads. The Impact Factors (CDA) listed in the Tables are for single track spans of BG and MG based on the relation:

$$CDA = 0.15 + \frac{8}{(6 + L)} < 1.0 \quad \text{where } L = \text{span}$$

For main girders of double track spans, the value specified above is multiplied by a reduction factor of 0.72.

Bridges located in the seismic zones have to be designed to resist the stresses produced due to seismic effects conforming to the recommendations in the Indian Standard Code IS: 1893–1975¹⁰.

Rail Gauge –

- It may be defined as the clear horizontal distance between the inner face (flanges) of the two rails forming a track.

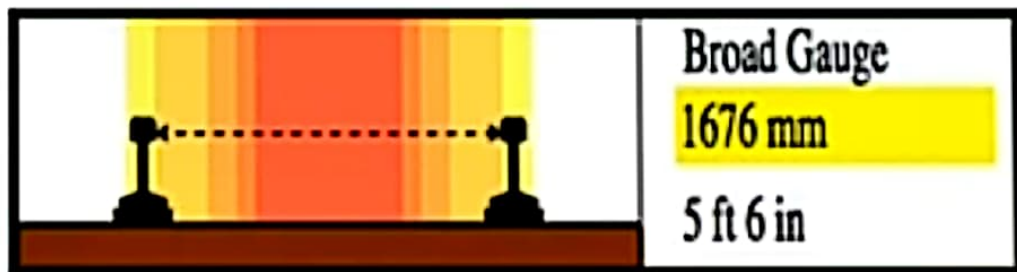
Types of Gauge practiced in India

1. Broad Gauge – (1.676 m)
2. Metre Gauge – (1.000 m)
3. Narrow Gauge – (0.762 m & 0.610 m)

	Light Gauge 610 mm 2 ft
	Narrow Gauge 762 mm 2 ft 6 in
	Meter Gauge 1000 mm 3 ft 3 3/4 in
	Broad Gauge 1676 mm 5 ft 6 in

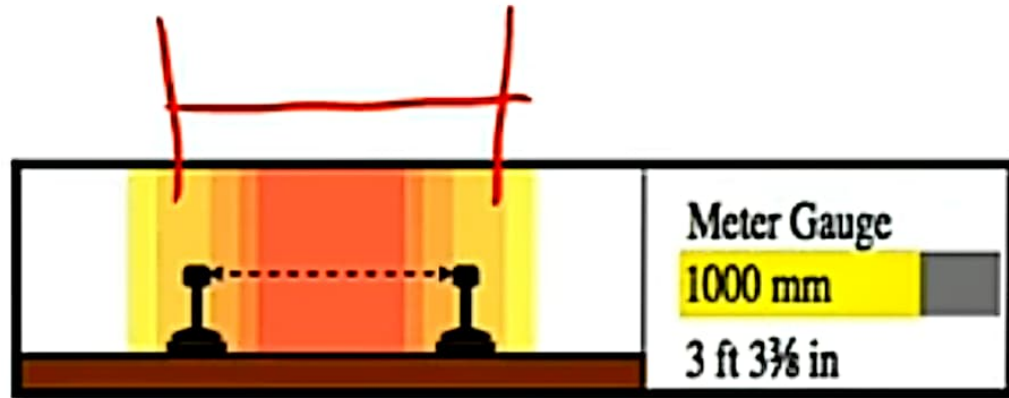
Broad Gauge (B.G.) –

- In broad gauge, the clear horizontal distance between the inner flanges of two rails forming a track is 1.676 m or 1676 mm 5'-6".
- It is the standard gauge of India. It is the broadest gauge of world.
- At the places, where the traffic is high and area is plain, broad gauge is recommended. The total construction cost for such a gauge is generally heavy.



Metre Gauge (M.G.) –

- In metre gauge, the clear horizontal distance between the inner falnges of two rails forming a track is 1.000 m or 1000 mm or 3'-6".
- However it was adopted for under developed area such as Rajasthan, inner parts of Andhra Pradesh etc.
- On these tracks, traffic is medium and is likely to increase.





Narrow Gauge (N.G.) –

- In narrow gauge, the clear horizontal distance between the inner flanges of two rails forming a track is either 0.762 m or 762 mm , 0.610 m or 610 mm or 2'-6" or 2'-0".
- In case of hilly area where traffic is low, areas are not likely to develop so soon, narrow gauge of different size is recommended.
- The gauge of 610 mm is also called feeder gauge or light gauge and is commonly used for feeding raw materials to big government manufacturing concerns as well as the private factories, such as steel plants, oil refineries and sugar factories etc.

	Light Gauge
	610 mm 2 ft
	Narrow Gauge
	762 mm 2 ft 6 in



Standard Gauge –

- The distance between the two tracks in this railway gauge is 1435 mm (4 ft 8½ in).
- In India, standard gauge is used only for urban rail transit systems like Metro, Monorail and Tram.
- Till 2010, the only standard gauge line in India was the Kolkata (Calcutta) tram system. All metro lines coming in urban areas will be made only in the standard gauge because it is easy to get rolling stock for the standard gauge as compared to the Indian gauge.
- By 2016, the lines that are in operation are Delhi Metro, Rapid Metro Rail Gurgaon, Bangalore Metro and Mumbai Metro

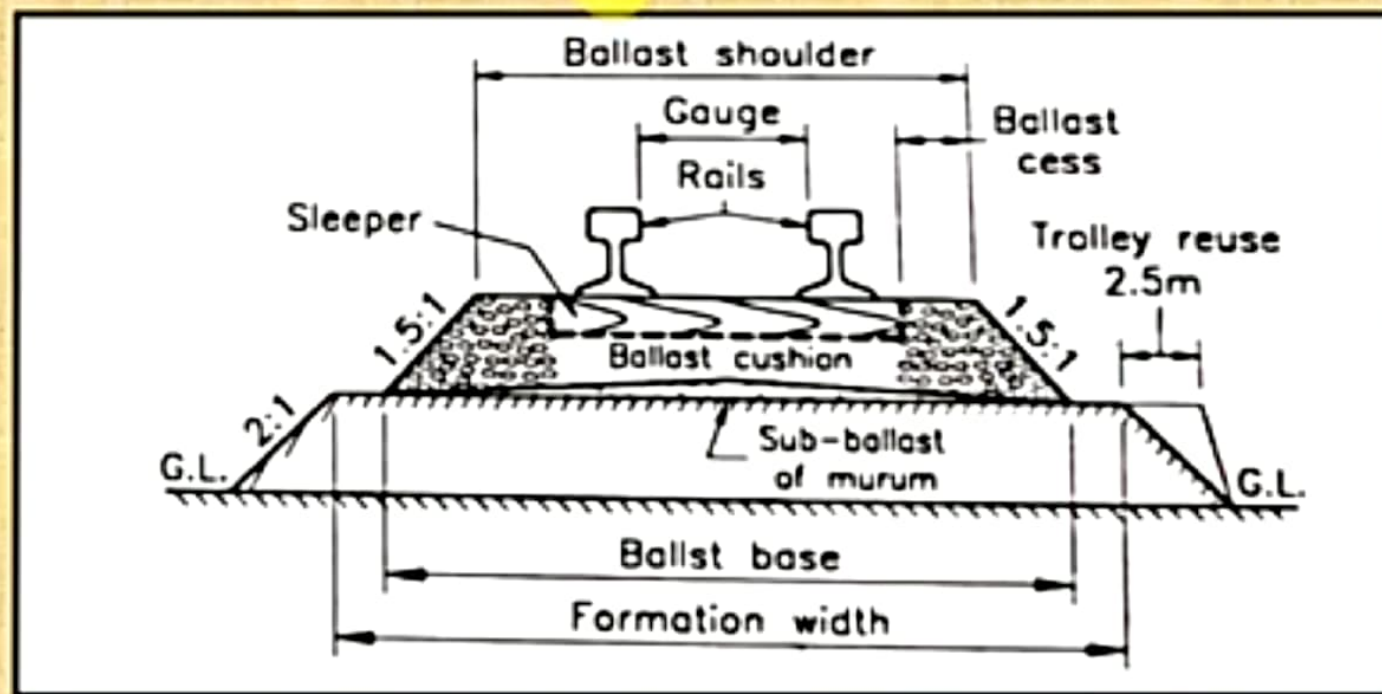


Gauges in Railway Track



Objective Type Question

The 'Gauge' of a railway track is defined as the clear distance between inner or running faces of two track rails. The distance between the inner faces of a pair of wheels is called the "wheel gauge".



Unit - 2

1. Design a reinforced Concrete slab culvert for a national Highway Crossing to suit the following data:

Carriage way - Two lane [7.5m Wide]

foot path - 1m on either side

Clear span - 6m

Wearing Coat - 80mm

Width of bearing - 400mm

Materials : M₂₅ Grade of Concrete & Fe₄₁₅ Grade HYSD bars.

Loading :- IRC class-AA tracked vehicle

Design the reinforced Concrete in the and Sketch the details of Reinforcement in the longitudinal and Cross sections of the Slab. The design ~~slab~~ should conform to the Specifications of IRC : 6-2000 & IRC : 21-2000 Codes.

Data :-

Clear span = 6m

Width of bearing = 400mm

IRC Class-AA tracked vehical loading

M₂₅ Grade of Concrete & Fe₄₁₅ Grade HYSD bars.

Step-1 :- [From IRC 21-2000 ; Table 9, 10]

$$\sigma_{cb} = 8.33 \text{ N/mm}^2$$

$$\sigma_{st} = 200 \text{ N/mm}^2$$

$$m = 10$$

$$n = \left[\frac{1}{1 + \frac{\sigma_{st}}{m \sigma_{cb}}} \right]$$

$$n = \left[\frac{1}{1 + \frac{200}{10 (8.33)}} \right] \Rightarrow 0.29$$

$$j = \left(1 - \frac{n}{3} \right) \Rightarrow \left(1 - \frac{0.29}{3} \right) \Rightarrow 0.9$$

$$\begin{aligned} Q &= \frac{1}{2} \cdot \sigma_{cb} \cdot n \cdot j \\ &= \frac{1}{2} \times 8.33 \times 0.29 \times 0.9 \\ &= 1.1 \end{aligned}$$

Step-2:- Depth of slab;

Assume thickness of slab = 80 mm per meter of span
 overall thickness of slab = (80 × 6) ⇒ 480 mm

Adopt Overall depth D = 500 mm

using 20mm ϕ HYSD bars with clear cover of 30mm

$$\begin{aligned} \text{Effective depth} &= 500 - [30 + 10] \\ &= 460 \text{ mm} \end{aligned}$$

$$\text{Width of bearing} = 400 \text{ mm}$$

Effective span;

$$\text{i) Clear span + Effective depth} = (6 + 0.46) = 6.46 \text{ m}$$

$$\text{ii) Centre to Centre of bearing} = (6 + 0.40) = 6.4 \text{ m.}$$

$$\therefore \text{Effective length 'L'} = 6.4 \text{ m}$$

for 5m - 25%
9m - 10%

Interpolation;
5 - 0.25
6.4 - ?
9 - 0.1

$$0.25 = \frac{0.1 - 0.25}{9 - 5} \times (6.4 - 5)$$

$$\Rightarrow 0.197$$

Impact factor for span 6.4 $\rightarrow$ 0.197 (or) 19.7%

Effective length of loading = Contact length + 2 [Thickness of Deck Slab + W.C.]

$$= 3.6 + 2(0.5 + 0.08)$$

$$= 4.76 \text{ m}$$

Effective width of loading (b_e) = $Kx \left(1 - \frac{x}{L}\right) + b_w$

$$x = 3.2 \text{ m} ; L = 6.4 \text{ m} ; B = 9.5 ; \text{ratio} = \frac{B}{L} = \frac{9.5}{6.4} \Rightarrow 1.48.$$

$$\text{IRC:- 21-2000 } K = 2.48$$

$$K = 1 + \frac{b}{L} \Rightarrow 1 + \frac{9.5}{6.4}$$

$$K = 2.48$$

$$x = \frac{L}{2} \Rightarrow \frac{6.4}{2} \Rightarrow 3.2 \text{ m}$$

$$b_w = [0.85 + 2(\text{wearing coat})]$$

$$= [0.85 + 2(0.08)]$$

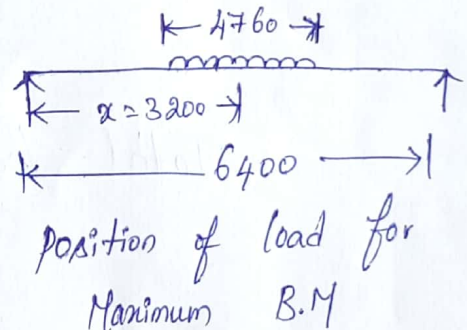
$$= 1.01 \text{ m}$$

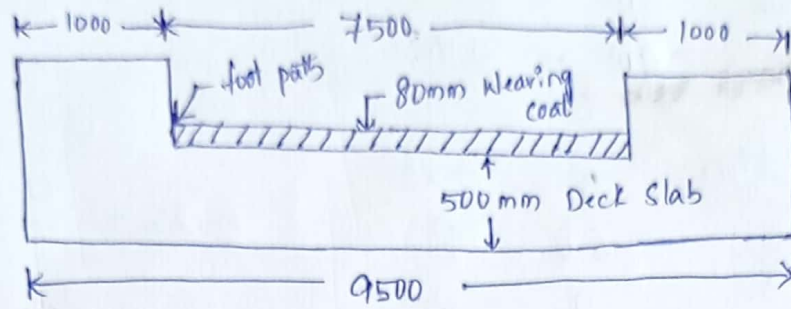
$$b_e = Kx \left[1 - \frac{x}{L}\right] + b_w$$

$$= 2.48 \times 3.2 \left[1 - \frac{3.2}{6.4}\right] + 1.01$$

$$= 7.936 [0.5] + 1.01$$

$$\boxed{b_e = 5 \text{ m}}$$





Cross Section of Deck Slab

Step-3

Dead load Bending Moment:-

$$\begin{aligned} \text{Dead Weight of slab} &= \text{Thickness of slab} \times \text{unit Weight of RCC} \\ &= 0.5 \times 24 \Rightarrow 12 \text{ KN/m}^2 \end{aligned}$$

$$\begin{aligned} \text{Dead Weight of Wearing Coat} &= \text{Thickness of W.C} \times \text{unit Weight of Bitumen} \\ &= 0.08 \times 22 \\ &= 1.76 \text{ KN/m}^2 \end{aligned}$$

$$\begin{aligned} \text{Total load} &= [12 + 1.76] \\ &\Rightarrow 14 \text{ KN/m}^2 \end{aligned}$$

$$\begin{aligned} \text{Dead load Bending Moment (M)} &= \frac{w l^2}{8} \\ &= \frac{14 \times (6.4)^2}{8} \\ &= 72 \text{ KN-m} \end{aligned}$$

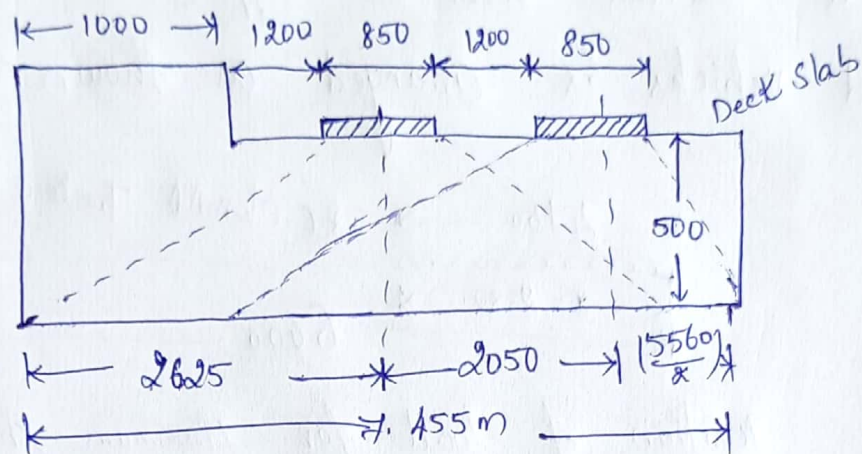
Step-4

Live load Bending Moment:-

Bending Moment will be Maximum for IRC Class AA Tracked Vehicles.

Impact factor for IRC Class AA Tracked Vehicle.

The tracked vehicle is placed close to the kerb with the required minimum clearance a as shown in figure.



Net effective width of dispersion = 7.455 m

Total load of two tracks with Impact = $700 + [700 \times 0.197]$
 $(P) = 838 \text{ kN}$

$$\text{Intensity of load} = \frac{P}{A} \Rightarrow \frac{838}{(4.76 \times 7.455)} \quad \therefore (A = L \times b)$$

$$\Rightarrow 23.61 \text{ kN/m}^2$$

$$R_A = R_B = \frac{23.61 \times 4.76}{2}$$

$$= 56.1918 \text{ kN}$$

Taking Moment about 'B'

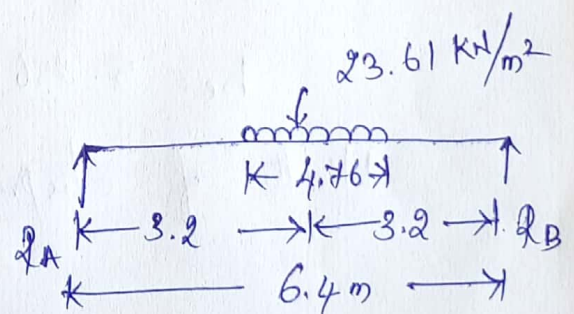
$$M_{\text{max}} = R_B \times \frac{L}{2} - \frac{wL^2}{8}$$

$$= 56.198 \times \frac{6.4}{2} - \frac{23.61 (4.76)^2}{8}$$

$$= 56.198 \times 3.2 - 66.86$$

$$= 112.96 \approx 113 \text{ kN-m}$$

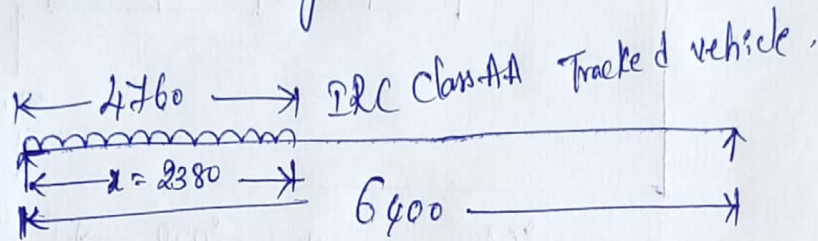
$$\text{Total design B.M} = [113 + 72] = 185 \text{ kN-m}$$



Step-5

Shear force due to class AA tracked vehicles;

For Maximum shear at support, the IRC Class AA Tracked vehicle is arranged as shown in figure.



Position of load for Maximum shear.

Effective width of Dispersion is given by.

$$b_e = kx \left[1 - \frac{x}{L} \right] + b_w$$

Where;

$$x = 2.38$$

$$B/L = 1.48$$

[∴ From IRC 21-2000 Table]

$$B = 9.5 \text{ m}$$

$$k = 2.84$$

$$L = 6.4 \text{ m}$$

$$b_e = 2.84 \times 2.38 \left[1 - \frac{2.38}{6.4} \right] + 1.0$$

$$b_e = 5.256 \text{ m}$$

$$\text{Width of Dispersion} = \left[2625 + 2050 + \frac{5256}{2} \right] \\ = 7303 \text{ mm}$$

$$\text{Average intensity of load} = \frac{838}{(4.76 \times 7.303)} = 24.1 \text{ kN/m}^2$$

$$\text{Shear force } V_A = \frac{24.1 \times 4.76 \times (6.400 - 2.380)}{6.4} \\ = \left[\frac{24.1 \times 4.76 \times 4.020}{6.4} \right]$$

$$\Rightarrow 72 \text{ kN}$$

$$\text{Dead load shear} = \frac{14 \times 6.4}{2} \Rightarrow 45 \text{ kN}$$

$$\therefore \text{Total Design S.F} = (72 + 45) \Rightarrow 117 \text{ kN},$$

Step-6

Design of * Deck Slab :-

Effective depth required is

$$d = \sqrt{\frac{M}{Q_b}} \Rightarrow \left[\frac{185 \times 10^6}{200 \times 0.9 \times 460} \right] \Rightarrow 2234 \text{ mm}$$

$$\text{Spacing of } 20 \text{ mm } \phi \text{ bars} = \left[\frac{1000 \times \frac{\pi}{4} \times (20)^2}{2234} \right]$$

$$= 140 \text{ mm}$$

$$\text{Spacing (S)} = \left[\frac{A_{st}}{A_{st}} \times 1000 \right]$$

$$\text{No. of bars 'n'} = \frac{A_{st}}{A_{st}} \Rightarrow \frac{2234}{\frac{\pi}{4} \times 20^2}$$

$$'n' \Rightarrow 8 \text{ No. of bars}$$

provide 20mm diameter bars @ 140mm c/c at

Main reinforcement.

* Distribution reinforcement :-

$$M = [0.3 M_L + 0.2 M_D]$$

$$= [0.3 \times 113 + 0.2 (72)]$$

$$= 49 \text{ kN-m.}$$

$$A_{st} = \frac{M}{\sigma_{st} \cdot J \cdot d} \Rightarrow \frac{49 \times 10^6}{(200 \times 0.9 \times 444)} \Rightarrow 613 \text{ mm}^2.$$

using 12 mm ϕ

$$n = \frac{A_{st}}{A_{st}} \Rightarrow \frac{613}{\pi/4 (12)^2}$$

$$n = \frac{613}{113} \Rightarrow 6 \text{ Nos.}$$

$$\text{Spacing} = \frac{A_{st}}{A_{st}} \times 1000$$

$$= \frac{\pi/4 (12)^2}{613} \times 1000$$

$$= 184 \text{ mm.}$$

provide 12 mm ϕ @ 184 mm c/c spacing 6 Nos.

Step-7

Check for shear stresses;

IRC 21-2000 Table 12B & 12A & 12C

$$\text{Design shear stress } \tau_v = \frac{V_u}{bd}$$

$$\Rightarrow \frac{117 \times 10^3}{(1000 \times 460)}$$

$$\Rightarrow 0.254 \text{ N/mm}^2$$

Area of reinforcement at supports $A_{st} = 2242 \text{ mm}^2$

$$A_{st} = 2242 \text{ mm}^2$$

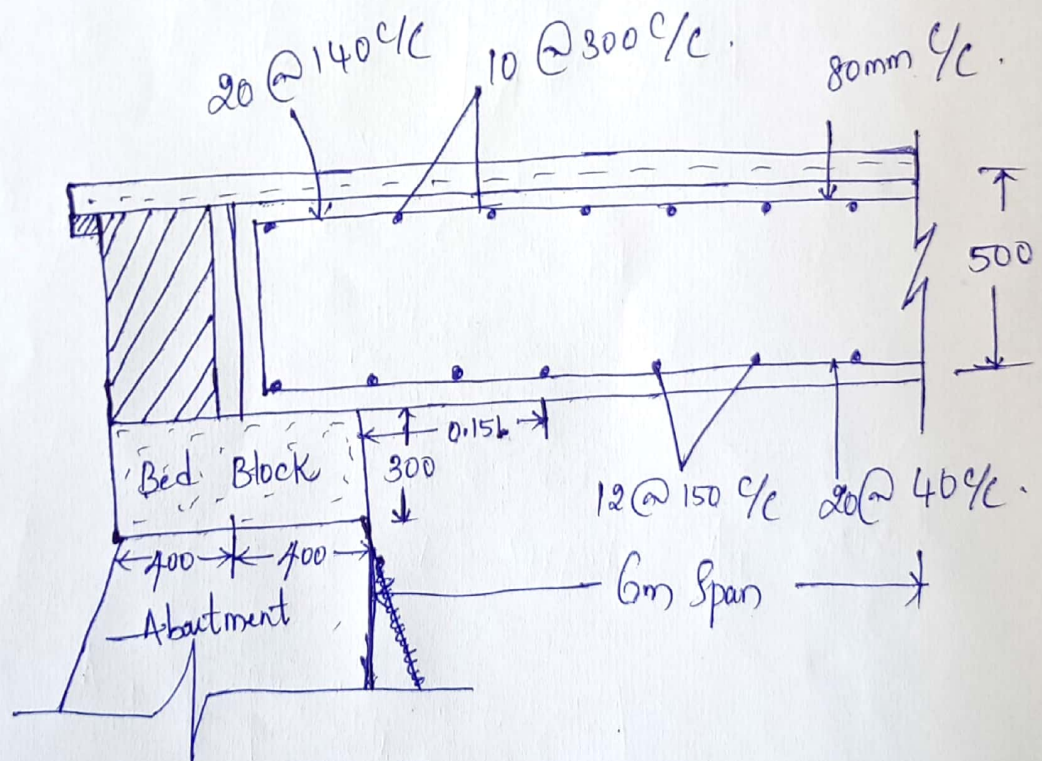
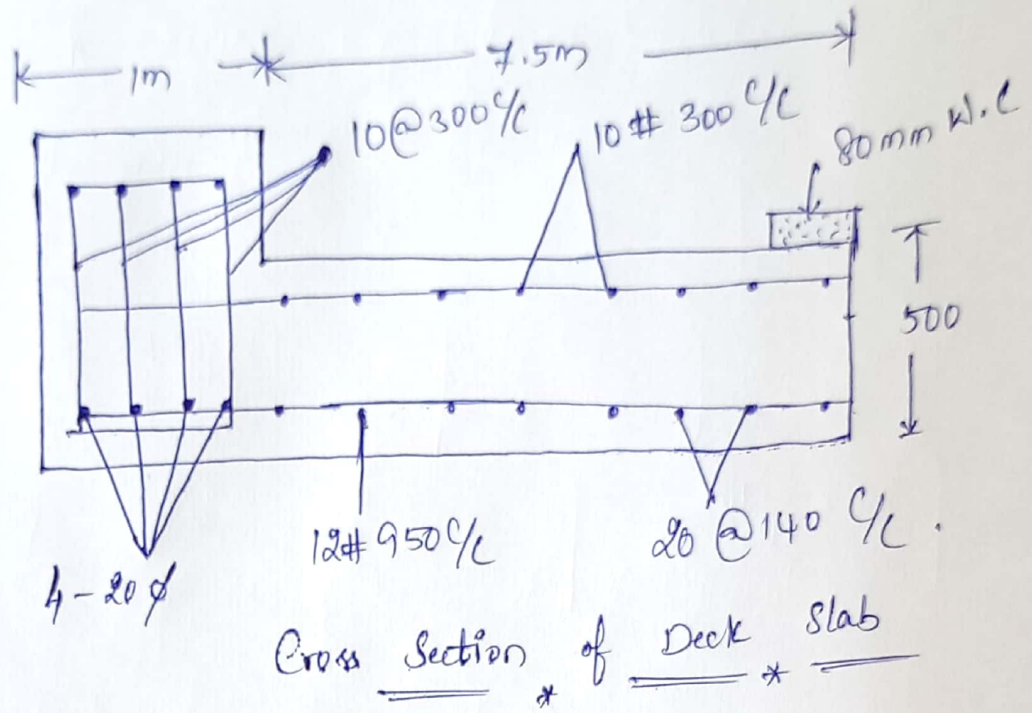
$$A = \frac{100 A_{st}}{bd} \Rightarrow \frac{100 \times 2242}{1000 \times 46} \Rightarrow 0.48$$

IRC - 21-2000 Table '12B'

$$\tau_c = 0.30 \text{ N/mm}^2$$

$\tau_v < \tau_c$ Hence it is Safe.

Hence shear stress is within the safe permissible limits.



UNIT-II

DECK SLAB BRIDGE

IRC : 21 - 2000 code

Design a Reinforced concrete slab culvert for a national Highway crossing to suit the following data.

carriage way - two lane (7.5M wide)

Foot Paths - 1M on either side.

clear span - 6M.

wearing coat = 80 mm

width of bearing = 400 mm

Materials: M-25 Grade concrete & Fe415 Grade HYSD bars

Loading - IRC class AA tracked vehicle.

Design the Reinforced concrete slab deck and sketch the details of reinforcements in the longitudinal and cross section of the slab. The design should conform to the specifications of IRC : 6-2000 and IRC 21-2000 code.

Sol: Given Data.

clear span = 6M

width of bearing = 400 mm

IRC class AA tracked vehicle loading

M-25 grade concrete & Fe415 Grade HYSD bars.

Permissible Stresses:

$$\sigma_{cbc} = 8.33 \text{ N/mm}^2$$

IRC : 21-2000 [Table 9, 10]

Tensile stress (σ_{st}) = 200 N/mm² - For 415 grade of steel.

compressive bearing stress (σ_{cbc}) = 8.33 N/mm² - For M20 grade concrete

$$\text{Modular ratio } (m) = \frac{280}{3 \times \sigma_{cbc}}$$

$$= \frac{280}{3 \times 8.33}$$

$$m = 10.51 \approx m = 10$$

$$\text{Lever arm } (J) = 1 - \frac{k}{3}$$

$$k = \frac{m \sigma_{cbc}}{m \sigma_{cbc} + 200} = \frac{10 \times 8.33}{10 \times 8.33 + 200} = \frac{83.3}{283.3} = 0.29$$



$$k = 0.29$$

$$J = 1 - \frac{k}{3} = 1 - \frac{0.29}{3} = J = 0.9$$

Bending moment coefficient

$$Q = \frac{1}{2} \times \sigma_{cbc} \times k \cdot J$$

$$= \frac{1}{2} \times 8.33 \times 0.29 \times 0.90$$

$$Q = 1.1$$

Step 2:

Effective depth of the slab & Effective Span.

Assume thickness of slab at 80mm per metre

overall thickness of slab = $(80 \times 6) = 480 \text{ mm}$

Adopt overall depth of slab = 500mm

$$D = 500 \text{ mm}$$

Effective depth of slab = $500 - 40 = 460 \text{ mm}$

$$d = D - d'$$

$$d = 460 \text{ mm}$$

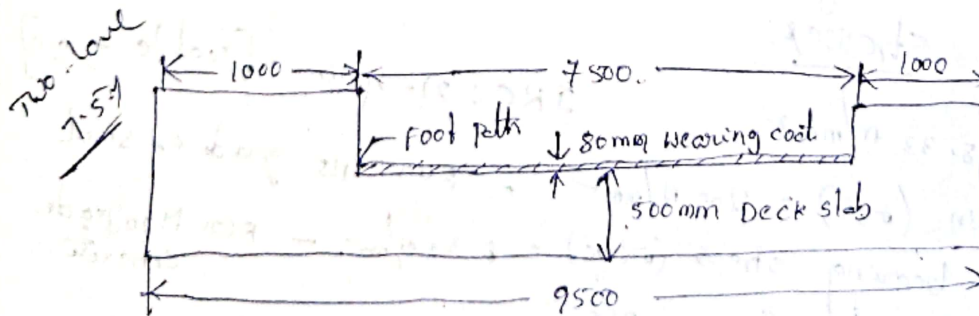
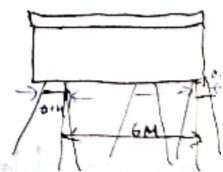


Effective Span:

(i) clear span + Effective depth = $(6 + 0.46) = 6.46 \text{ m}$

(ii) Centre to centre of bearings = $\frac{0.4}{2} + 6 + \frac{0.4}{2} = 6.4 \text{ m}$

$\therefore$ Effective Span $L = 6.4 \text{ m}$



Dead Load bending moments: $t \times \text{unit weight}$

Dead weight of slab = $0.15 \times 24 = 12 \text{ kN/m}^2$

Dead weight of w.c. = $(0.08 \times 22) = 1.76 \text{ kN/m}^2$

total load = $\frac{\text{Thickness} \times \text{unit weight}}{13.76} \approx 14 \text{ kN/m}^2$

$$\text{Bending moment} = \frac{Wl^2}{8} = \frac{14 \times (6.4)^2}{8} = 72 \text{ kNm}$$

Live Load bending moment:

Bending moment will be maximum for IRC class AA tracked vehicle.

The impact factor for IRC class AA tracked vehicle is 25% for 5m span.

$$5\text{m} - 25\%$$

$$9\text{m} - 10\%$$

$$\left. \begin{array}{l} 5 - 0.25 \\ 6.4 - ? \\ 9 - 0.1 \end{array} \right\} = 0.25 + \frac{(0.1 - 0.25)}{(9 - 5)} * (6.4 - 5)$$

$$= 0.25 + \frac{0.15}{4} + 1.4 = 1.68 \text{ M.}$$

$$\text{Impact factor for span } 6.4 = \frac{6.1975}{6.4} = 1.197$$

$$\text{Effective length of loading} = 3.6 + 2(0.08 + 0.5) = 4.76 \text{ m.}$$

$$L_e = L + 2(l_s + l_w)$$

$$\text{Effective width of slab } b_e = k \alpha \left[1 - \frac{\alpha}{L} \right] + b_w$$

$$k = 1 + \frac{b}{L} = 1 + \frac{9.5}{6.4} = 2.48 \text{ M}$$

$$\alpha = \frac{L}{2} = \frac{6.4}{2} = 3.2 \text{ M}$$

$$b_w = 0.85 + 2[\text{wearing coat}] \Rightarrow 0.85 + 2(0.05)$$

$$b_w = 1.01 \text{ M}$$

$$b_e = 2.48 \times 3.2 \left[1 - \frac{3.2}{6.4} \right] + 1.01 \Rightarrow 7.936(0.5) + 1.01$$

$$= 3.968 + 1.01$$

$$b_e = 5 \text{ M}$$

$$\text{Total load with impact} = 700 \times 1.197 = 838 \text{ kN}$$

$$\text{Intensity of load} = \frac{F}{A} = \frac{83.8}{[4.76 \times 5]} = 35.21 \text{ kN/m}^2$$

$$200 > 100\% \Rightarrow 0.192$$



$$R_A = R_B = \frac{35.21 \times (4.76)}{2} = 83.79 \text{ kN}$$

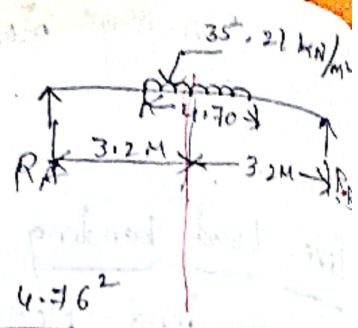
Taking moment about "B"

$$M_{\max} = R_B \times \frac{L}{2} - \frac{wL^2}{8}$$

$$= 83.79 \times 3.2 - \frac{35.21 \times 4.76^2}{8}$$

$$= 268.128 - 99.72$$

$$M_{\max} = 168.408 \text{ kNm}$$



step-6: calculation of B.M and shear force;

$$M = \text{Dead load B.M} + \text{Live load B.M}$$

$$= 70.45 + 168.408$$

$$M = 238.85 \text{ kNm}$$

$$\text{Total shear force (V_u)} = \frac{\text{Dead load S.F}}{S.F} + \frac{\text{Live load S.F}}{S.F}$$

$$= 44 + 83.79$$

$$V_u = 127.79 \text{ kN}$$

Design of deck slab.

$$\text{Main steel bars } A_{st} = \frac{M}{\sigma_{st} \times J \times d} = \frac{238.85 \times 10^6}{(230 \times 0.9 \times 460)}$$

$$A_{st} = 2500 \text{ mm}^2$$

$$n = \frac{2500}{\frac{\pi}{4} (20)^2} = \frac{A_{st}}{a_{st}} = 8$$

Provide 8 bars of 20mm diameter i.e. steel bars

$$\text{spacing (s)} = \frac{a_{st}}{A_{st}} \times 1000$$

$$= \frac{\frac{\pi}{4} (20)^2}{2500} \times 1000$$

$$= 125 \text{ mm} \approx 120 \text{ mm}$$

Provide 8 bars of 20mm dia of steel bars at 120mm c/c spacing.

Distribution steel bars;

$$A_{st} = \frac{M}{\sigma_{st} \times j \times d}$$

where $M = 0.3 M_L + 0.2 M_D$
 $= 0.3 \times 168.40 + 0.2 \times 170.45$

$$M = 64.61 \text{ kNm}$$

$$A_{st} = \frac{64.61 \times 10^6}{230 \times 0.90 \times 460} = 678.53 \text{ mm}^2$$

$$n = \frac{678.53}{\frac{\pi}{4} \times 10^2} = 8 \text{ bars}$$

$$S = \frac{a_{st}}{A_{st}} \times 1000 = \frac{\frac{\pi}{4} (10)^2}{678.53} \times 1000 = 120 \text{ mm/c}$$

check for shear stress

$$\tau_v = \frac{V_u}{bd} = \frac{127.79 \times 10^3}{1000 \times 460} = 0.27 \text{ N/mm}^2$$

$$P_t = \frac{100 A_{st}}{bd} = \frac{100 \times 2500}{1000 \times 460} = 0.54$$

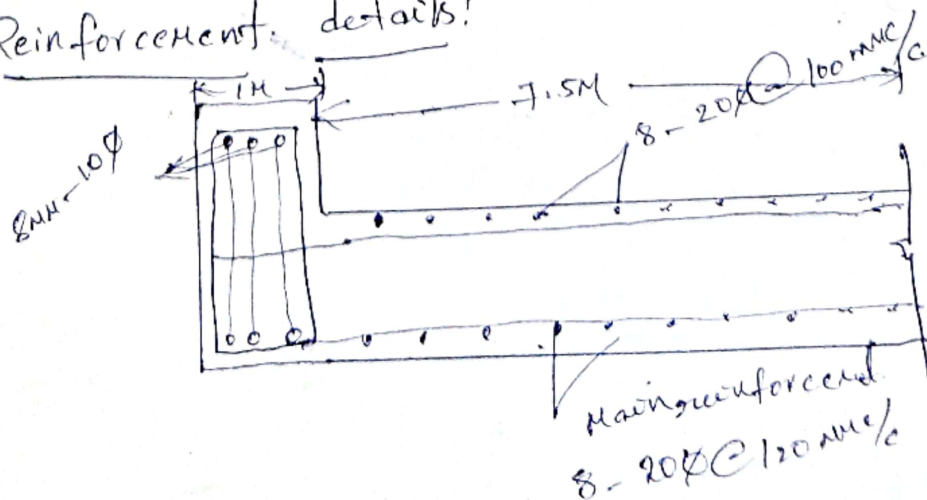
From IS-456 2000 concrete code book page no 73 we got the shear stress in concrete τ_c
 $\tau_c = 0.54 \text{ N/mm}^2$

$$\tau_v < \tau_c$$

hence it is safe

Hence shear stress is within the safe permissible limits.

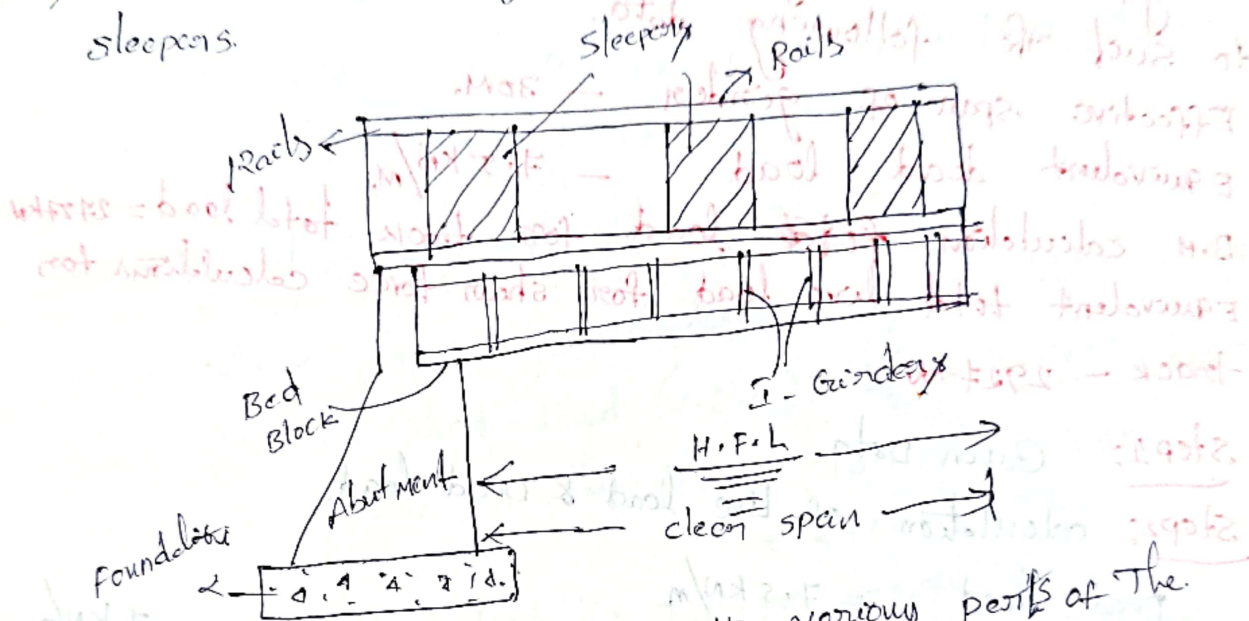
Reinforcement details:



fig(a) cross-sectional view.

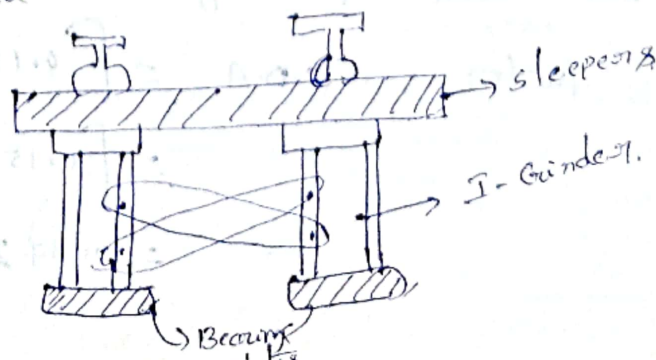
PLATE GIRDER (or) COMPOSITE BRIDGE

- plate girders are the most common type of steel bridges. It is generally used for railways crossing of stream and rivers.
- plate girder bridge for simply supported the length is ranging from 20 m to 30 m.
- For continuous bridge the length is upto 150 m.

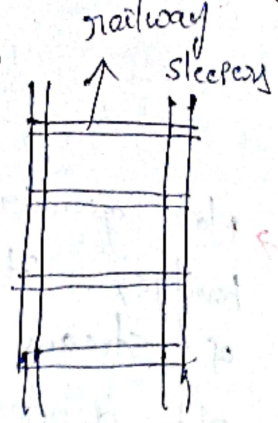


The above fig shows the various parts of the Plate Girder.

- The top of the plate girder shows the sleepers & rails.
- Between the top slab and bed blocks we have provide the bearing pad.
- The main purpose of the bearing pad is to distribute live loads & dead loads.



Sleepers: sleepers are the members for supporting and fixing the rails at the gauge.



Design the deck type welded plate girder bridge to suit the following data.

Effective span of girder — 30M.

Equivalent dead load — 7.5 kN/m.

B.M calculation ~~for~~ load for track total load = 2727 kN

Equivalent total live load for shear force calculations for track — 2927 kN.

Step 1: Given Data.

Step 2: calculation of live load & Dead load.

$$\text{Dead load} = 7.5 \text{ kN/m}$$

$$\text{self height} = [0.2L + 1] = [0.2 \times 30 + 1] = 7 \text{ kN/m}$$

$$\text{Total Dead load} = 7.5 + 7 = 14.5 \text{ kN/m}$$

$$\text{Equivalent live load for B.M calculation for track} = 2727 \text{ kN}$$

$$\text{Total live load per girder} = \frac{2727}{2} = 1363.5 \text{ kN}$$

$$\text{Equivalent live load for shear for track} = 2927 \text{ kN}$$

$$\text{Total live load per girder} = \frac{2927}{2} = 1463.5 \text{ kN}$$

$$\text{Impact factor, C.I.A} = \left[0.15 + \frac{8}{(6+L)} \right]$$

$$= \left[0.15 + \frac{8}{(6+30)} \right]$$

$$= 0.372$$

Step 3: B.M. with Dead load

$$\text{B.M. due to dead load} = \frac{wl^2}{8} = \frac{14.5 \times 30^2}{8} = 1631.25 \text{ kNm}$$

$$\text{B.M. due to live load} = \frac{wl}{4} = \frac{1363.5 \times 30}{4} = 10226.25 \text{ kN}$$

$$\text{B.M. due to impact on live load} = 10226.25 \times 0.372 = 3804.16 \text{ kNm}$$

$$\begin{aligned} \text{Total B.M.} &= (\text{B.M.})_{L.L} + (\text{B.M.})_{D.L} \\ &= 10226.25 + 3804.16 + 1631.25 \text{ kNm} \\ &= 15661.665 \text{ kNm} \end{aligned}$$

Step 4: Calculation of shear forces

$$\text{Shear force due to live load} = \frac{w}{2} = \frac{1463.5}{2} = 731.75 \text{ k}$$

$$\text{Shear force due to dead load (V.D.L)} = \frac{wl}{2} = \frac{14.5 \times 30}{2} = 217.5 \text{ k}$$

$$\begin{aligned} \text{Shear force due to impact} &= 731.75 \times 0.370 \\ &= 270.7475 \text{ kN} \end{aligned}$$

$$\text{Total live load} = 731.75 + 270.74 = 1003.916 \text{ kN}$$

$$\begin{aligned} \text{Total shear force} &= (S.F.)_{L.L} + (S.F.)_{D.L} \\ &= 1003.916 + 217.5 \\ &= 1221.5 \text{ kN} \end{aligned}$$

Step 5: proportioning of truss section.

web plate:

$$\begin{aligned} \text{Approximate depth of girder} &= \frac{1}{8} \text{ to } \frac{1}{10} \text{ times of span} \\ &= \frac{30}{8} \text{ to } \frac{30}{10} \\ &= 3 \text{ meters} \end{aligned}$$

$$\text{Depth of web} = \frac{V}{\tau_v \times t} = \frac{1221.5 \times 10^3}{85 \times 12} = 1800 \text{ mm}$$

(Assume t = thickness of web plate = 12 mm (not less than 8 mm))
1800 mm x 12 mm.

Try the web plate dimension

Note: τ_v = Average shear stress specified as 85 N/mm² for mild steel with an yield stress of 236 N/mm² as per ISRC-24

Step 6 - Flange plates

$$\text{Area of flange } (A_f) = \left[\frac{\pi}{\sigma_b \cdot d} - \frac{A_w}{6} \right]$$

Where

$$\sigma_b = \frac{d}{t} > 35 \quad (141)$$

$$\frac{d}{t} < 35 \quad (130)$$

$$\sigma_b = 230 \quad \checkmark / \text{mm}$$

$$A_f = \left[\frac{15661.665}{230 \times 800} - \frac{1800 \times 12}{6} \right]$$

$$A_f = 6879 \text{ mm}^2$$

$$\text{Width of flange } (b) = \frac{L}{40} \text{ to } \frac{L}{60}$$

$$= \frac{30000}{40} \text{ to } \frac{30000}{60}$$

$$= 750 \text{ to } 500$$

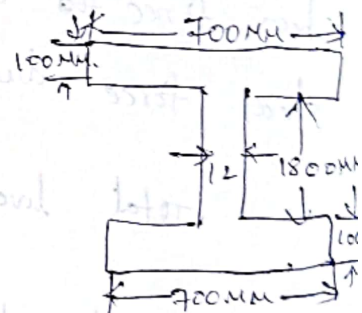
$$b = 700 \text{ mm}$$

$$\text{Thickness of flange} = \frac{A_f}{b} = \frac{58708.68}{700}$$

$$= 83.0124$$

$$\approx 100 \text{ mm}$$

Try the flange plate of 700x100mm.



S.NO	Area	Distance (x)	Distance in y-direction
1	(700x100) 70000 = a ₁	x ₁ = $\frac{700}{2} = 350$	$\frac{100}{2} = 50 = y_1$
2	(1800x12) 21600 = a ₂	x ₂ = 350 mm	$100 + \frac{1800}{2}$ y ₂ = 1000 mm
3	(700x100) 70000 = a ₃	x ₃ = 350 mm	y ₃ = $100 + 1800 + 100$ 1950 mm

$$\text{centroid in x-direction } \bar{x} = \frac{a_1 x_1 + a_2 x_2 + a_3 x_3}{A_1 + A_2 + A_3}$$

$$\bar{x} = \frac{70000(350) + 21600(350) + 70000(350)}{70000 + 21600 + 70000}$$

$$\bar{x} = 350 \text{ mm}$$

$$\bar{y} = \frac{a_1 y_1 + a_2 y_2 + a_3 y_3}{A_1 + A_2 + A_3}$$

$$= \frac{70000(50) + 21600(1000) + 70000(1950)}{70000 + 21600 + 70000}$$

$$\bar{y} = 1000 \text{ mm}$$

INTRODUCTION TO PIERS & ABUTMENTS

General features - Road bridge - materials, piers & Abutments
 types of piers - Forces Acting on piers - stability Analysis
 of piers - General features of Abutments - forces acting
 on Abutments - stability Analysis of Abutments.

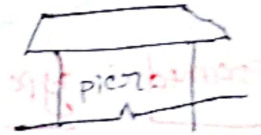
Types of piers:

Depending upon the size and dimension of the span Super-structure the following types of piers are generally used.

- solid type of pier.
- Trestle type of pier.
- Hammer type of pier.
- Cellular type of pier.
- Framed type of pier.

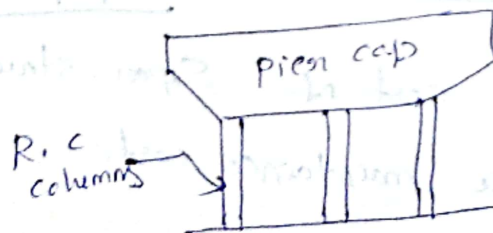
(a) Solid type of pier:

The solid type of pier it is generally built up using stone masonry (or) brick (or) concrete this type of pier used for small bridges.



(b) Trestle type of pier:

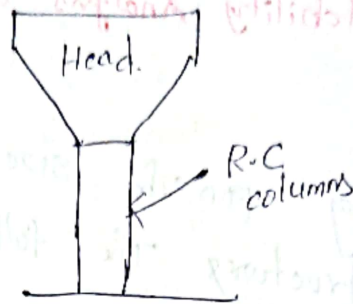
A trestle type of pier comprises of a number of reinforced concrete columns with a connecting cap @ the top of the pier as shown in fig. The main purpose of the trestle type of pier for flyovers and elevated roadways to cross the roads.



(b) Trestle type pier.

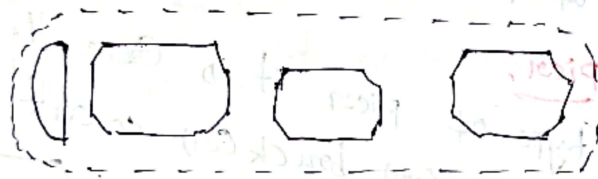
Hammer head pier consists of massive single pier with cantilever caps on opposite sides equal to the head of hammer.

This type of pier used in elevated roadways & girder bridges



Cellular type of pier

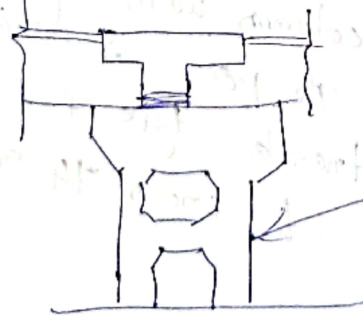
This type of pier generally used in multiple traffic. It is economical to use cellular type of R.C pier. Cellular type of pier require costly shuttering & additional labour requirement.



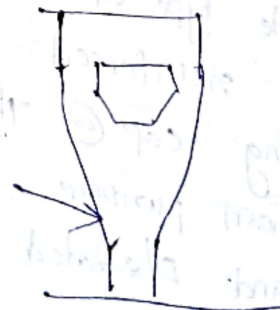
For tall piers slip forming can be adopted.

Framed type of pier:

In the case of framed type of pier it is monolithic joints b/w vertical or inclined or horizontal members shown in fig.



R.C frame

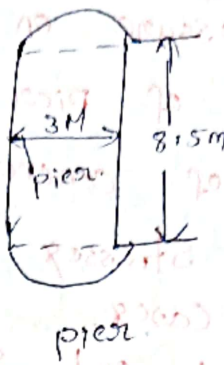
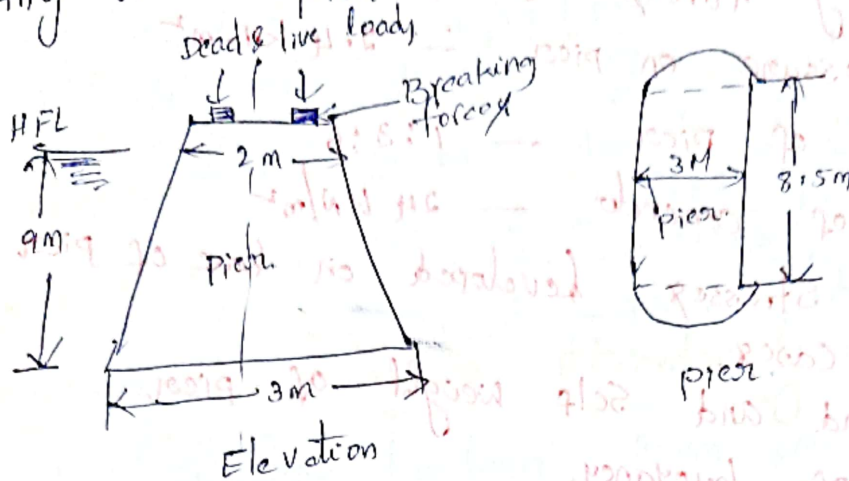


→ It is same the cost of Super structure.

→ It is increase the maintenance cost.

Stability Analysis of piers:

The following figure shows the various forces acting on the pier listed below.



Forces acting on pier:

Dead load from each span = 2000 kN
live load on one span = 1000 kN

Reaction due to breaking force = 140 kN

wind pressure on pier = 2.4 kN/m²

materials of pier = 1.3 ~~kN/m²~~

mat. Density concrete = 24 kN/m³

Weight of pier = (2.4 x 3) = 7.2 kN

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Weight of pier = (2.4 x 3) = 7.2 kN

① Dead load from each span = 2000 kN ;
 Reaction due to Live load on one span = 1200 kN
 breaking force = 140 kN
 wind pressure on pier = 2.4 kN/m²
 materials of pier = 1:3:6
 Density of concrete = 24 kN/m³
 calculate the stresses developed on base of pier due to following cases.

1. Dead load and self weight of pier.
2. Effect of buoyancy.
3. Due to Eccentricity of live load.
4. Due to longitudinal breaking forces.
5. Due to wind pressure.

Estimate the maximum and minimum stresses developed @ base of pier due to the combination of various loads.

Step-1: Given Data.

Step-2: stresses due to dead loads and self weight of pier:

Dead load from superstructure = $(2 \times 2000) = 4000 \text{ kN}$

$$\begin{aligned} \text{Self weight of pier} &= \frac{1}{2} (a+b) h \times h \\ &= \frac{1}{2} [2+3] 10 \times 8.5 \times 24 \\ &= 5100 \text{ kN.} \end{aligned}$$

$$\text{Total direct load} = 5100 + 4000 = 9100 \text{ kN}$$

$$\begin{aligned} \text{compressive stress @ base of pier} &= \frac{9100}{(8.5 \times 3)} \\ &= 356.8 \text{ kN/m}^2 \end{aligned}$$

Effect of buoyancy:

$$\text{width of pier @ H.F.L} = 1.9 \text{ m}$$

$$\begin{aligned} \text{Volume of pier} &= \frac{1}{2} (a+b) h \times 8.5 \\ &= \frac{1}{2} [1.9+3] 9 \times 8.5 \\ &= 187.4 \text{ m}^3 \end{aligned}$$

Weight of pier due to buoyancy $= V \times \rho$
 $\rho = \text{Density of water} = 9.81 \text{ kN/m}^3 \approx 10 \text{ kN/m}^3$
 $= V \times \rho$

$\therefore 187.4 \times 10 = 1874 \text{ kN}$
 weight of pier due to buoyancy $= 1874 \text{ kN}$

tensile stress @ base due to buoyancy

$$= - \left(\frac{1874}{8.5 \times 3} \right)$$

$$= - 73.5 \text{ kN/m}^2$$

Step-3: Stress due to Eccentricity of live load.

Reaction due to live load from one span $= 1000 \text{ kN}$

acting at Eccentricity of $e = 0.5 \text{ m}$

Moment @ base $M = \text{load} \times \text{Eccentricity}$
 $= 1000 \times 0.5 = 500 \text{ kN-m}$

Section modulus $= \left(\frac{db^2}{6} \right) = \frac{8.5 \times 3^2}{6} = 12.75 \text{ m}^3$

Stresses developed @ base of pier due to Eccentricity of live load.

$$= \frac{1000}{(8.5 \times 3)} \pm \left(\frac{500}{12.75} \right)$$

$$= 39.2 \pm 39.2$$

$$\sigma_{\text{max}} = 78.4 \text{ kN/m}^2$$

$$\sigma_{\text{min}} = 0$$

Step-4: Stresses due to Longitudinal breaking forces.

Breaking force @ breaking level $= 1400 \text{ kN}$

Moment @ outside of the pier $= (1400 \times 10) = 14000 \text{ kN-m}$

Stresses @ base $= \pm \left(\frac{M}{Z} \right) = \left(\frac{14000}{12.75} \right) = \pm 109.8$

Step-5: Stresses due to wind load

total wind pressure on the pier $= (\text{Area} \times \text{wind intensity})$
 $= \frac{1}{2} (2.13 \times 10) \times 24$

$$= 60 \text{ kN}$$

Assuming the wind to act mid height of the pier.

Moment about base of pier $= (60 \times 5) = 300 \text{ kNm}$

Section modulus @ base $(Z) = \frac{bd^2}{6} = \frac{3 \times 8.15^2}{6}$

$= 36.125 \text{ M3}$

Stresses developed @ base due to wind loads

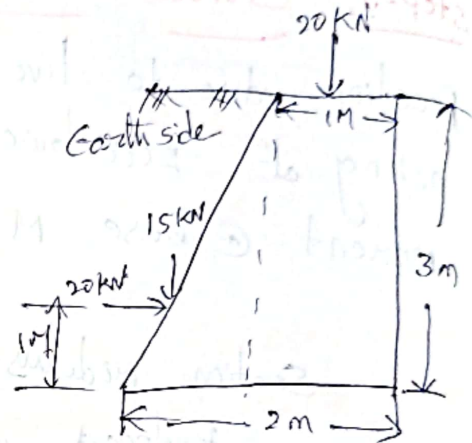
$= \pm \left(\frac{M}{Z} \right) = \pm \left(\frac{300}{36.125} \right)$

$= \pm 8.3 \text{ kN/m}^2$

Stability Analysis of abutments:

→ stone masonry abutment.

→ The above figure shows the section of a stone masonry abutment used for a highway bridge together with the forces acting per unit length of abutments.



→ safe bearing capacity of soil $= 150 \text{ kN/m}^2$

→ coefficient of friction b/w masonry and soil $= 0.5$

→ Density of stone masonry $= 25 \text{ kN/m}^3$

Compute the stresses developed at the base and check for stability of the abutment.

Bearing capacity: the capacity of soil to support the loads applied to the ground.

Analysis of forces:

→ Total vertical forces

$W = W_1 + W_2 + W_3 + W_4$

W = Total vertical forces.

W_1 = Weight of rectangular portion of abutment.

W_2 = " " " " triangular " " "

W_3 = live & dead loads

W_4 = vertical load due to earth.

Step 1: Given data.

Step 2: vertical loads,

$$\begin{aligned}W_1 &= \text{Area} \times \text{unit weight} = b \times d \times 25 = 1 \times 3 \times 25 = 75 \text{ kN} \\W_2 &= \text{Area} \times \text{unit weight} = \frac{1}{2} \times b \times d \times 25 = \frac{1}{2} \times 1 \times 3 \times 25 = 37.5 \text{ kN} \\W_3 &= 20 \text{ kN} \quad [\text{Due to dead \& live loads}] \\W_4 &= 15 \text{ kN} \quad [\text{Due to earth fill}] \\ \text{Total vertical loads } W &= W_1 + W_2 + W_3 + W_4 \\ &= 75 + 37.5 + 15 + 20 \\ &= 147.5 \text{ kN}.\end{aligned}$$

Step 3: calculation of Moments,

Moment of Rectangular position of abutments

$$\begin{aligned}M_1 &= 75 \times 0.5 = 37.5 \text{ kN}\cdot\text{m} \\M_2 &= 37.5 \left[1 + \frac{b_3}{3} \right] = \left[37.5 \times \left[1 + \frac{1}{3} \right] \right] = 49.89 \text{ kNm} \\M_3 &= 15 \left[1 + \frac{2b_3}{3} \right] = \left[15 \left[1 + \frac{2 \times 1}{3} \right] \right] = 25.05 \text{ kNm} \\M_4 &= -20 \text{ kNm}\end{aligned}$$

$$\begin{aligned}\text{Total Moments (M)} &= M_1 + M_2 + M_3 + M_4 \\ &= 37.5 + 49.89 + 25.05 - 20 \\ &= 92.44 \text{ kNm}.\end{aligned}$$

Step 4: Eccentricity of resultant force from centre of base.

$$\begin{aligned}\bar{x} &= \frac{M}{W} = \frac{92.44}{147.5} = 0.69 \text{ m} \\e &= \left[\frac{b}{2} - \bar{x} \right] = \left[\frac{2}{2} - 0.69 \right] = 0.31 \text{ m} \\e &< \frac{b}{6} \quad \text{--- compressive.} \\e &> \frac{b}{6} \quad \text{--- tensile.}\end{aligned}$$

The stresses are compressive. nature $e < 0.33$

Step 5: Maximum Base pressure.

$$P = \frac{W}{b} \left[1 \pm \frac{6e}{b} \right] = \frac{147.5}{2} \left[1 + \frac{6(0.31)}{2} \right] = 142.33 \text{ kN/m}^2$$

$P < \text{S.B.C of soil}$

$$P_{\min} = \frac{W}{b} \left[1 - \frac{6e}{b} \right] = 5.16 \text{ kN/m}^2$$

Step 6:

$$\begin{aligned}(\text{f.o.s})_{\text{sliding}} &= \frac{\text{Resting forces}}{\text{sliding force}} = \frac{73.75}{20} = 3.68 > 2.0 \\ \text{Resting force} &= W \times u = 147.5 \times 0.5 = 73.75 \text{ kN}.\end{aligned}$$

safe against sliding.

