CONCRETE BRIDGES

Bridges are the structures that allow movement of highway and railway traffic over natural or artificial gaps in the topology of the area such as canals, rivers, gap between hills and difference of level in crossing roads etc.

Selection of type of bridge mainly depends on:

- local conditions,
- availability and cost of materials,
- volume of traffic,
- site requirements,
- geographical conditions,
- aesthetics and
- expected economic return, etc.

The design of bridges is further influenced by:

- **the required clearances,**
- **erection possibilities,**
- **foundation choices and**
- **hydraulic characteristics of the stream, if one is involved.**

For example, a longer span may become economical in case the piers are very expensive to construct.

There are many structural differences between a building and a bridge, some of these are:

1. Bridges are designed for heavy and concentrated moving loads whereas buildings are usually designed for static distributed loads.
2. The impact of moving loads is quite considerable as compared with residential and official buildings.

3. Fatigue may become a problem and hence may reduce the strength due to large number of loading cycles.

4. Greater part of the structure is exposed to atmosphere.

5. The controlling design specifications for bridges are provided by organizations different from those dealing with the building design.

For example, AASHTO Specification may be employed for bridges in place of AISC Specification for steel buildings.

Bridges are classified depending on their use into the following categories:

1. Foot or pedestrian bridge used to carry pedestrian traffic, bicycles or small hand driven carts.
2. Highway bridges.
3. Railway bridges.
4. Combined highway and railway bridges.
5. A bridge that enables one form of land communication over the other (called Over-Bridge).

Deck of Bridge

- A deck is the actual carriageway of the bridge.
- It consists of concrete or orthotropic slab and wearing surface.
- Stringers and floor beams are also present for larger decks in addition to the slab.
- In case of longer bridges, the deck is supported over the longitudinal main members.

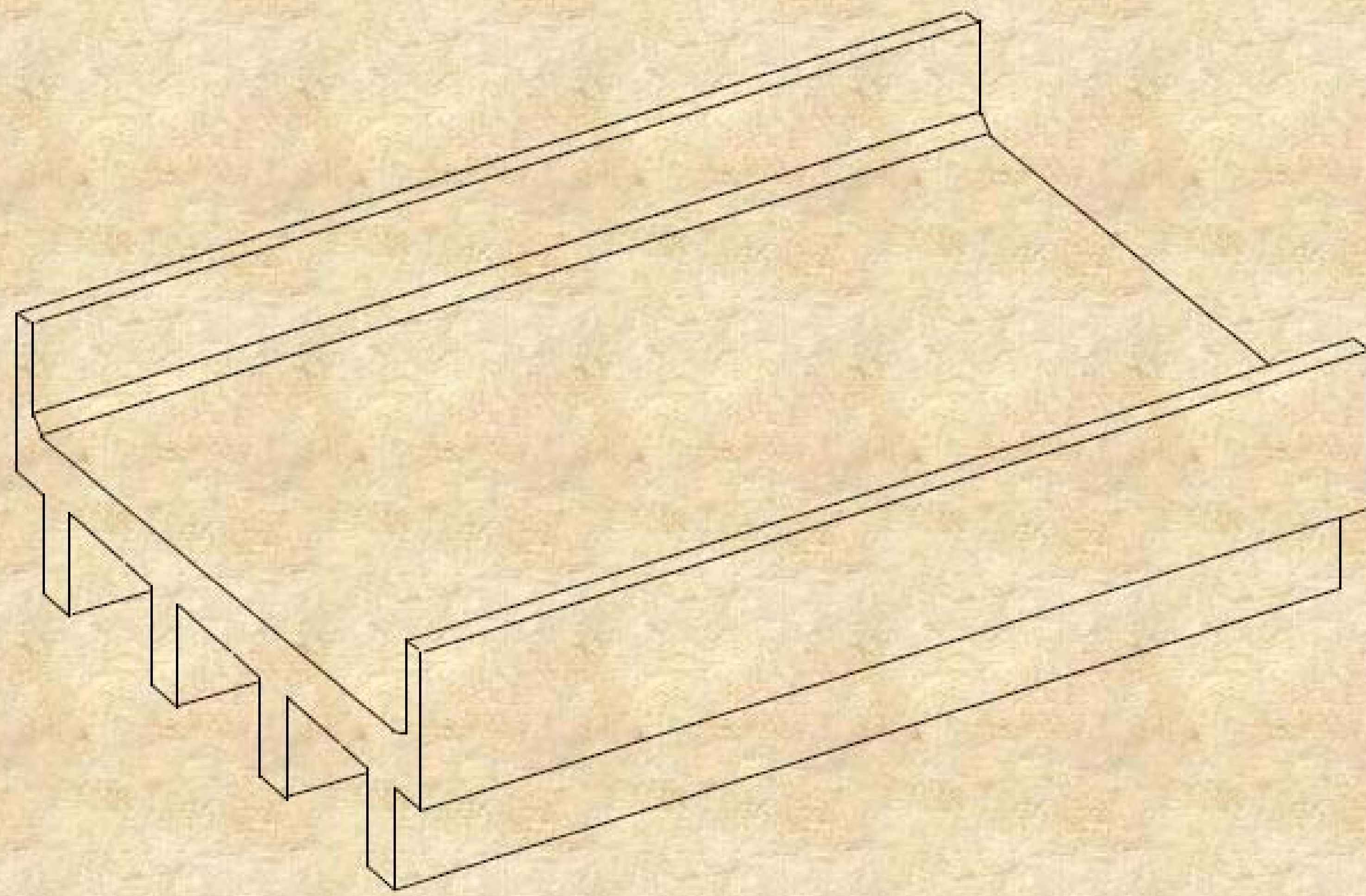


Fig. 21.1. Typical Deck with Longitudinal
Reinforced Concrete Beams.

- Depending upon the position of the longitudinal supporting elements with respect to the deck, the bridges may be deck type or through type.
- A ***Deck Bridge*** is a bridge built at or near the top level of the main supporting members of the superstructure, which hang below the deck and are not visible from the bridge.
- In case of ***Through Bridge***, the carriageway is supported at the bottom of the main supporting members that are visible while traveling on the bridge.

BASIC TERMS

- ***Bridge:*** A structure that spans on opening or gap, 6 m or larger, such as a waterway (river, canal or creek), a valley, another roadway or railway lines.
- Further, the term bridge is used for structures built to continue traffic flow, pedestrian traffic or utility lines across a gap in a passage.

- ***Bridge Crossing Or Grade-Separation Structure:*** A bridge crossing means the intersection between a bridge and a roadway at roadway at a different elevation.
- ***Access Bridge:*** It is a pedestrian bridge of short span used to link adjacent buildings at various heights.
- ***Pedestrian Over-Crossing:*** A pedestrian bridge constructed over a road at ground level.
- ***Pedestrian Under-Crossing:*** A highway bridge constructed over a pedestrian passage or bridge.

- ***Over-Crossing:*** A bridge constructed for a country or city road over a state highway.
- ***Overhead:*** It is the part of a highway constructed over rail-lines.
- ***Under-Crossing:*** A state highway bridge to allow the country or city road to pass under the highway.
- ***Viaduct:*** A bridge constructed over a valley.
- ***Skew Bridge:*** A bridge whose longitudinal axis is not perpendicular to the face of its supports.

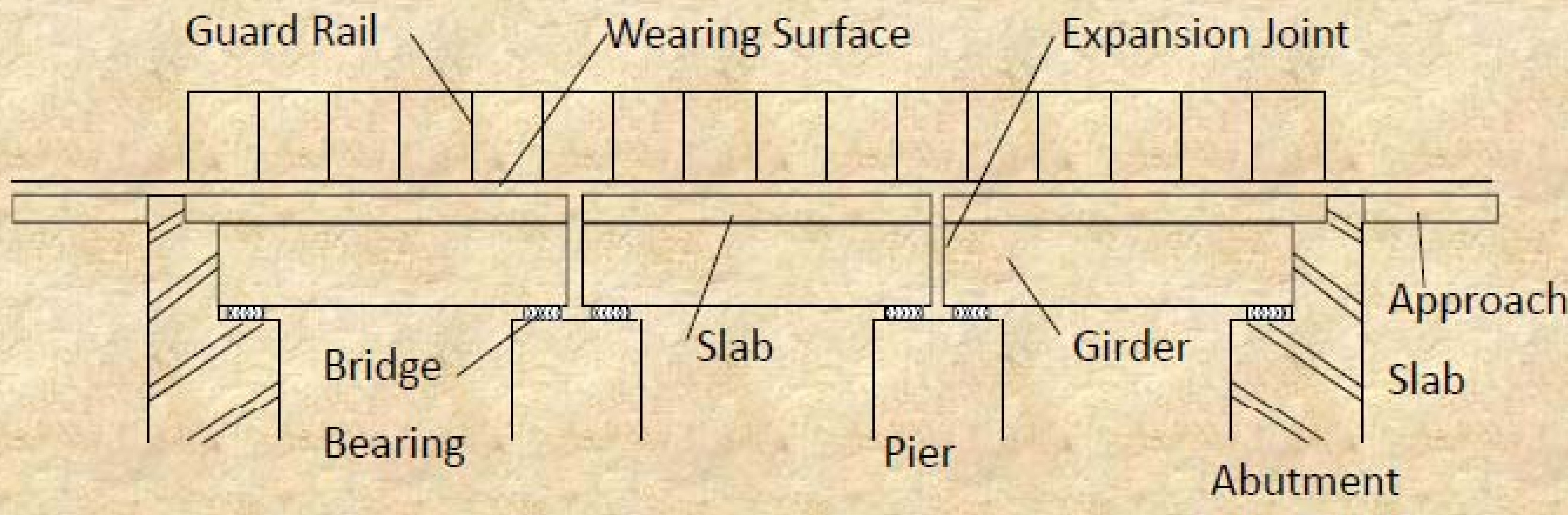
- ***Bailey Bridge:*** A bridge consisting of removable panels developed by British engineers during World War II for temporary use.
- ***Culvert:*** The structure made for the passing of a small drain or the other water channel under a road or a railway line.

- ***Interchange:*** An intersection of two highways containing ramps and structures to provide flow of traffic from one highway to the other with no disturbance to the straight-going traffic.
- An interchange may be a two-level, three-level or four level interchange, used for roadways at two, three or four different levels, respectively.

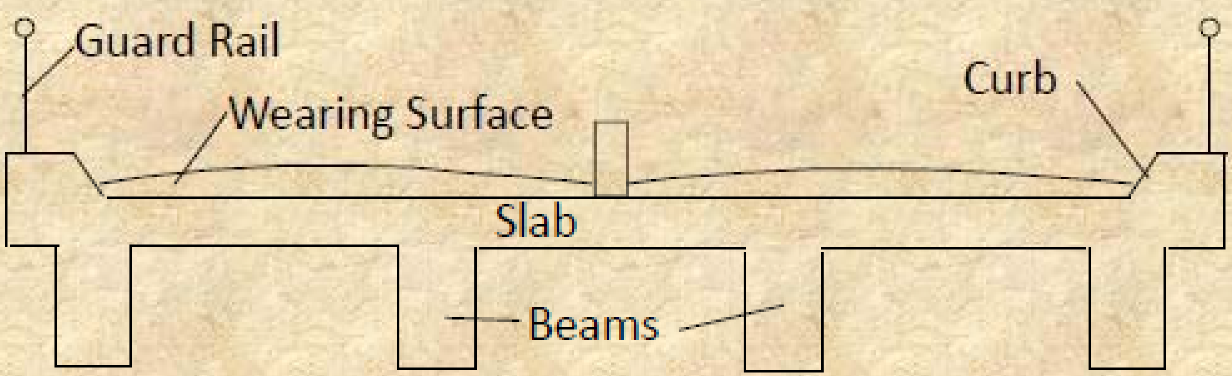
PARTS OF A CONCRETE BRIDGE

- ***Super-Structure:*** This is the portion of bridge above the bridge bearings. In an ordinary reinforced concrete bridge, this includes the slab, beams, wearing surface, expansion joints and guardrails.
- ***Sub-Structure:*** This includes the bridge bearings and all the components below the bearings and is used to support the super-structure. Sub-structure includes piers, abutments, piles, pile-caps and caissons.

- ***Abutment:*** This is the bridge support provided at the ends of the bridge, where the opening starts (Fig. 21.2). The abutment simultaneously acts as a retaining wall to retain material at end of the gap.
- ***Approach Road:*** A road constructed at two ends of the bridge for smooth flow of traffic between the bridge and the road to protect the bridge structure from accidental damages (Fig. 21.2).



Longitudinal Section of a Slab Beam Bridge



Cross- Section of a Slab Beam Bridge

- ***Bridge Deck:*** Bridge floor that supports vehicular traffic including slab, beams, guard rails and wearing surface (Fig. 21.2) is called bridge deck.
- ***Stringers:*** Longitudinal beams directly supporting the bridge deck slab are called stringers. Their orientation is parallel to the traffic flow. If transverse floor beams are provided, the stringers rest on them.
- ***Floor Beams:*** Transverse beams that support stringers and transfer loads to side trusses, plate girders or stiffening girders of suspension cables.

- ***Wearing Surface:*** Wearing surface is a layer of concrete or asphalt material provided over decks. This is used to protect the structural integrity of the deck from wear and tear caused by the traffic (Fig. 21.2).
- ***Diaphragm:*** A short beam used between adjacent parallel stringers to provide them lateral stability and to distribute loads among them.

- ***Piers:*** Intermediate supports provided to bridges between the abutments are called piers. These may consist of one or more columns supporting a continuous bridge or two simple spans of a multi-span bridge (Fig. 21.2).
- ***Caisson:*** This type of bridge foundation consists of a hollow shell that is sunk into position to carry the foundation to a considerable depth in order to reach a suitable bearing stratum. Three types of caissons are box caissons, open caissons and pneumatic caissons.

- ***Box Caisson*** is open at the top and closed at the bottom. it is constructed on land surface and is floated to the site, where it is sunk on prepared bearing stratum.
- ***Open Caisson / Well*** is open at both ends and is built at the required site. It is sunk by digging the earth from the inside.
- ***Pneumatic Caisson*** is closed at the top but open at the bottom. It is filled with compressed air to force the water out. This is used for a water depth of 12 m to 34 m.

- ***Piles:*** These are columns that transfer the super-structure loads to a greater soil depth, through skin friction or through end bearing on a firm stratum.
- ***Pile Cap:*** This is a rigid flexural member provided above the ground to connect a group of piles together. Its functions are to make the piles stable, reduce their effective lengths and to more uniformly distribute the applied loads.

- ***Transom:*** This is a transverse beam provided over the piers to support the loads from the longitudinal girders from one or from both sides. The girders may rest on this transom beam at a location different from the piers underneath.
- ***Scour Depth:*** This is the depth up to which the foundation material may be eroded due to flowing water.

- Scour occurs when the bed velocity of the stream exceeds the velocity that can move the particles of the bed material.
- Under abutments, it is usually taken equal to 1.5*D*, whereas under piers, it is taken as 2.0*D*.
- The parameter *D* denotes the depth of water in the stream; the hydraulic mean depth may be calculated from the known discharge by using the Lacey's formula as under:

$$D \text{ (in meters)} = 0.473 \left(\frac{Q}{f}\right)^{1/3}$$

Where Q is the discharge in cumecs and f is the Lacey's silt factor, having the following approximate values:

Average Punjab soils	$f = 0.8$
Silt	$f = 0.4$ to 1.0
Sand	$f = 1.0$ to 1.5
Stones	$f = 1.5$ to 24

- ***Baffle, Dwarf, Drop, Curtain Or Wing Wall:*** It is a thin wall used as a shield or protection against the scouring action of a stream (Fig. 21.3).
- ***Causeway:*** It is a small submersible bridge.
- ***Guard Rail:*** A side barrier or protection consisting of a rail supported on posts to protect falling down of out-of-control vehicles or pedestrians into the gap (Fig. 21.2).

Bridge Abutment

- The bridge abutment provides support to the bridge at the ends and also retains the soil adjoining the gap in earth's surface. It typically consists of breast wall, wing wall and footing as shown in Figs. 21.3 and 21.4.
- The ***breast wall*** provides the vertical support to the beams or girders and acts as a retaining wall for the backfill. It can be designed as a cantilever in a vertical direction or by using the two-way action, considering the support of wing walls for the horizontal loading.

- ***Wing walls*** are used to provide confinement to the earth in a direction parallel to the longitudinal axis of the bridge. The full width of the wing walls may be carried into the footing according to the requirements of earth confinement and in some cases may also be flared in plan view.

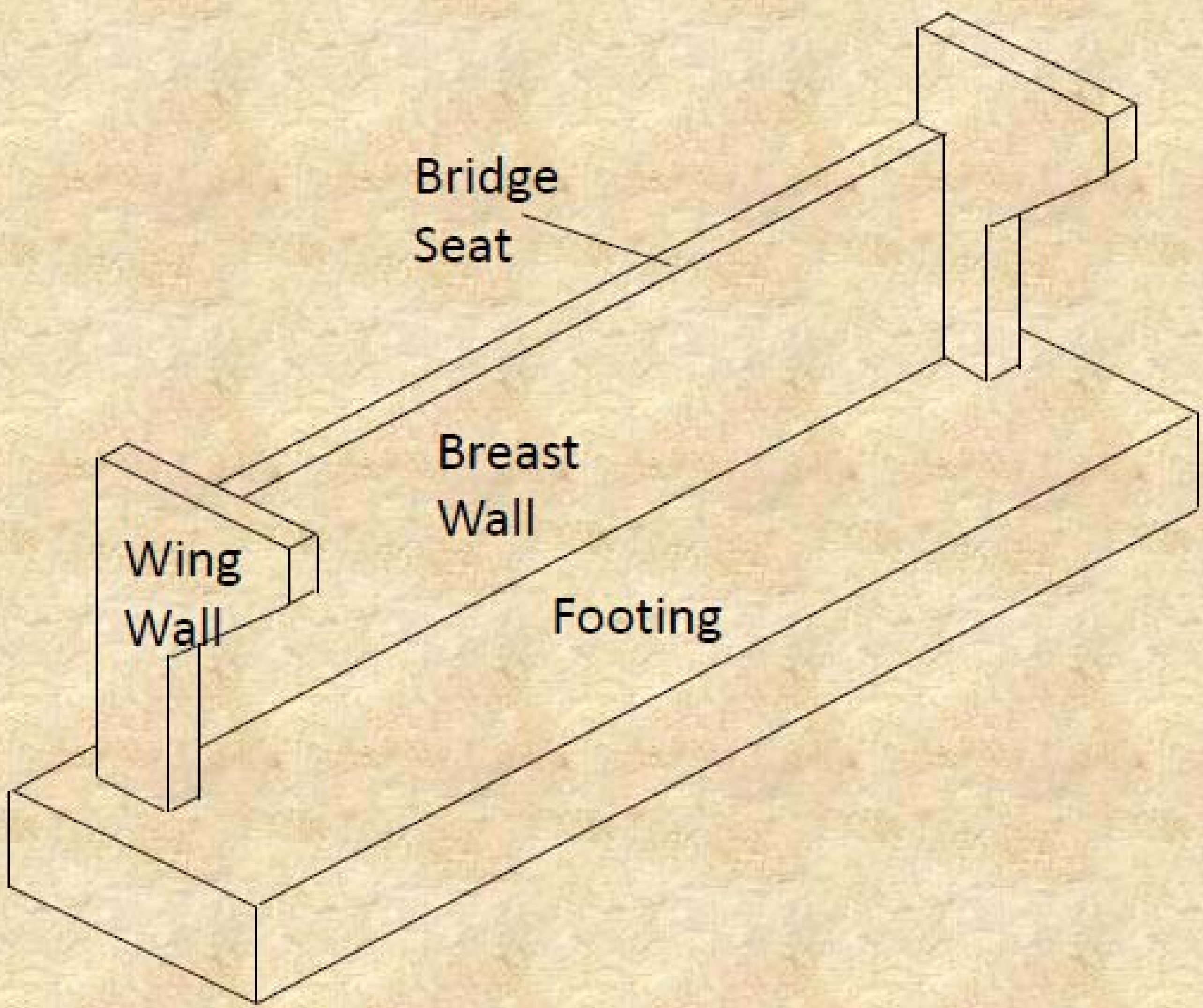


Fig. 21.3. Right End Abutment of a Bridge.

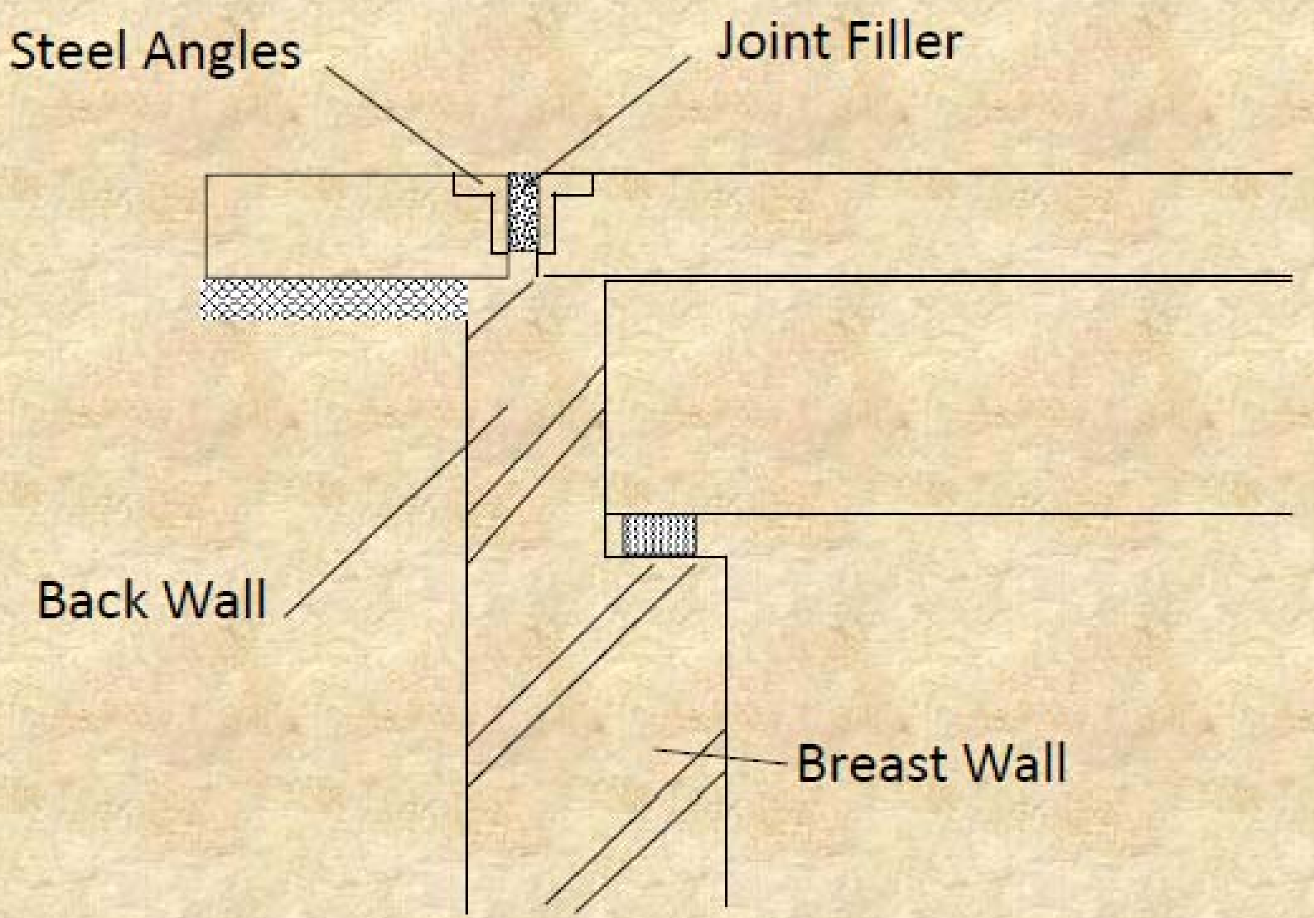


Fig. 21.4. Typical Joint Details at an Abutment.

Diaphragms

- These are 150 to 200 mm thick walls or beams with minimum reinforcement that are provided perpendicular to the girders connecting them together at their ends or at more locations if the span of the girders is greater than 12 m.
- The intermediate diaphragms are placed at mid-span or at third-points of the girders.
- These diaphragms help in lateral distribution of concentrated loads and they also provide lateral stability to the girders.

Bridge Bearings

- The bridge bearings must be designed to allow length changes due to temperature, shrinkage and creep.
- Usually one end is made hinged while the other end slides.
- For spans greater than 15 m, provision must be made at the bearings to allow rotation due to vertical bending of the girders.

- For spans lesser than 15 m, expansion support may be provided only by steel plates sliding against one another.
- For larger spans, rotations and sliding capacities may be provided by sophisticated arrangement of pins, rollers, rockers and curved bearing plates.

- Recently, for appreciable spans, elastomeric pads of poly-tetra-fluoro-ethylene (TFE) bearings are used to provide horizontal and rotational movements.
- ***Elastomeric pads*** consist of laminations of elastomer cast together with bonded steel plates placed in-between the elastomer layers, as shown in Fig. 21.5.
- Horizontal movement is provided by shearing of the pad and vertical movement is provided by differential compressing of the elastomer.

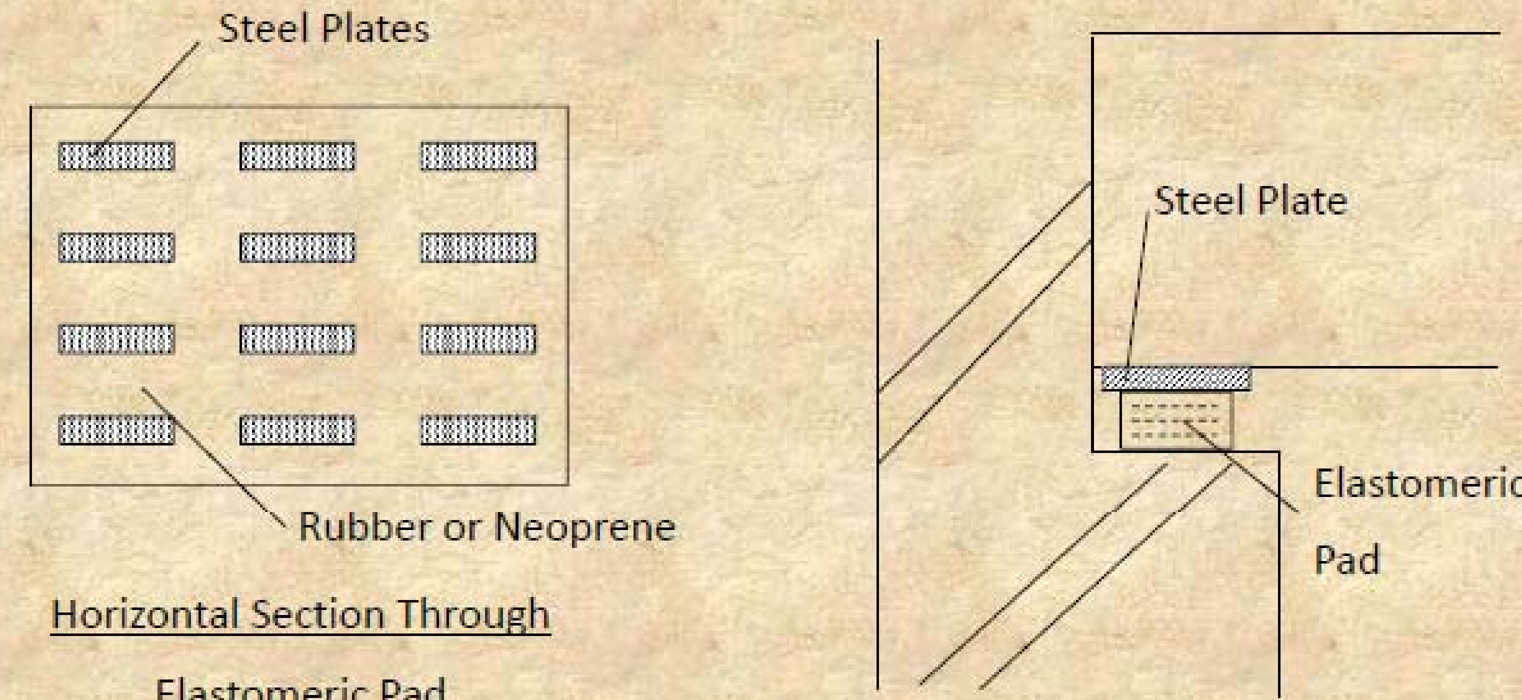


Fig. 21.5. Details of Elastomeric Pad.

- TFE surface is made to slide against a stainless-steel surface and the assembly reduces the friction against sliding.
- A limited rotation capacity is provided by the differential shortening of the elastomer layers while larger rotation capacities may be developed by the simultaneous presence of elastomeric pads, curved surfaces and hinges.

Expansion Joints

- For smaller spans, angle sections are anchored in concrete at the two ends and a bituminous filler material is inserted in the gap, as in Fig. 21.4.
- However, this type of joint has considerable maintenance problems due to the intrusion of foreign materials into the joints and the structural failure and level difference created at the joints due to moving loads.

- Presently, the gaps are left at larger distances and special castings are used to maintain a smooth horizontal alignment while permitting horizontal sliding.

TYPES OF CONCRETE BRIDGES

Bridges may be classified on the basis of their following characteristics:

- Material of construction.
- Span lengths.
- Structural forms.
- Span types.
- Load paths.
- Usage and position.
- Deck type.

TYPICAL DECK TYPES

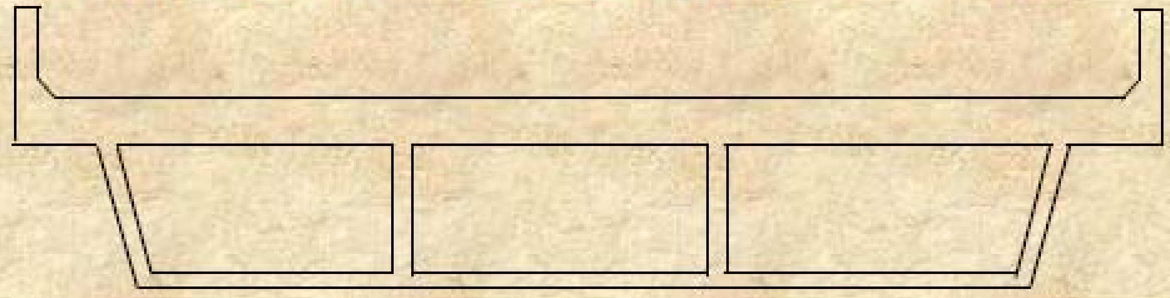


Fig.21.6. Monolithic Concrete Slab over Concrete Multi-Cell Boxes.

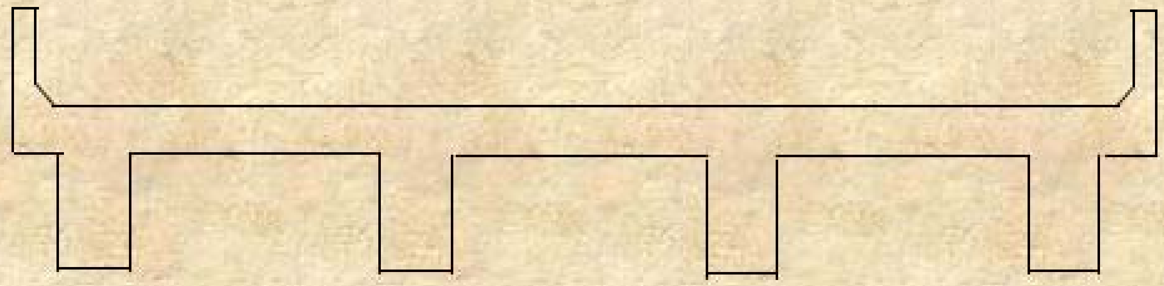


Fig.21.7. Monolithic Concrete Slab over Cast-In-Place Tee Beams.

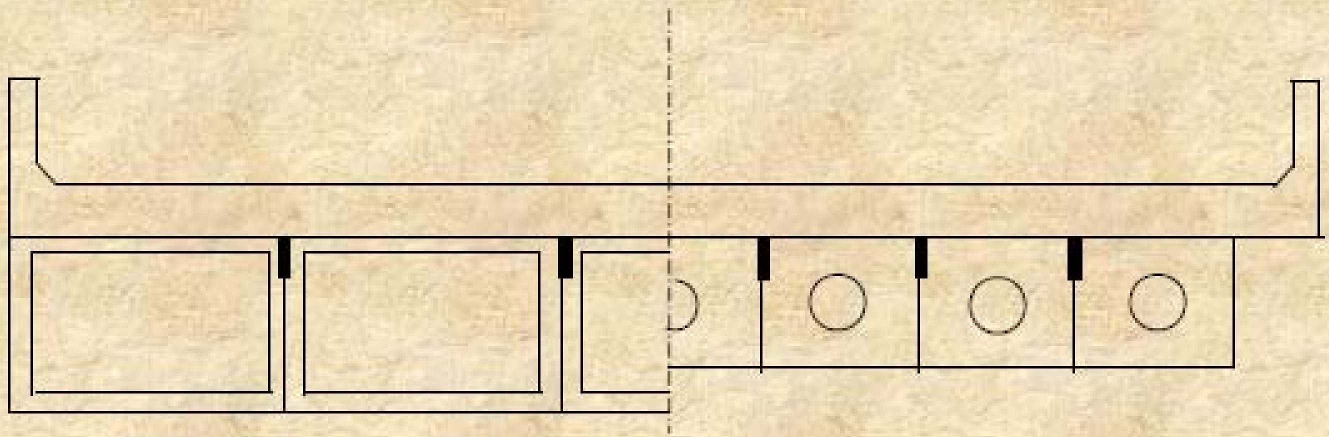


Fig.21.8. Cast-In-Place Concrete Slab over Precast Solid, Voided or Cellular Boxes with Shear Keys.

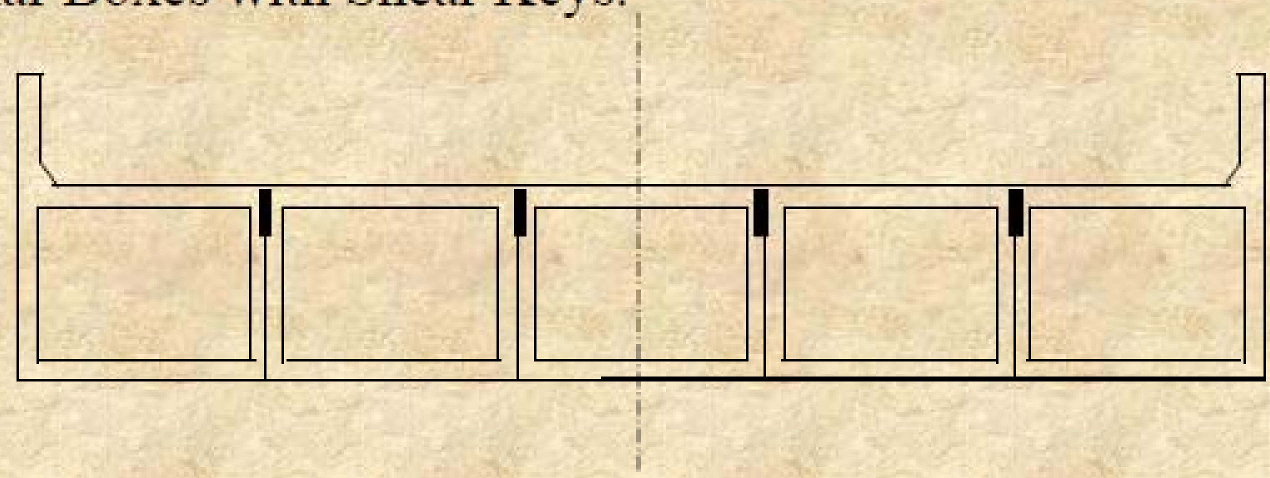


Fig.21.9. Integral Slab and Precast Solid, Voided or Cellular Concrete Boxes with Shear Keys Joined by Transverse Post-Tensioning.

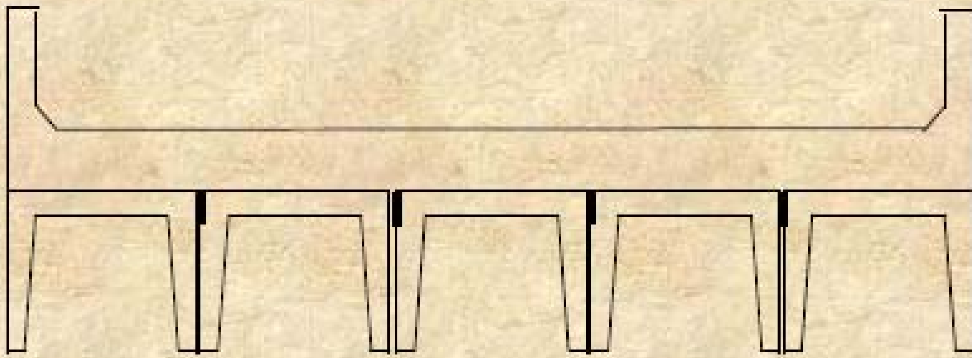


Fig.21.10. Cast-In-Place Concrete Slab over Precast Concrete Channel Sections with Shear Key.

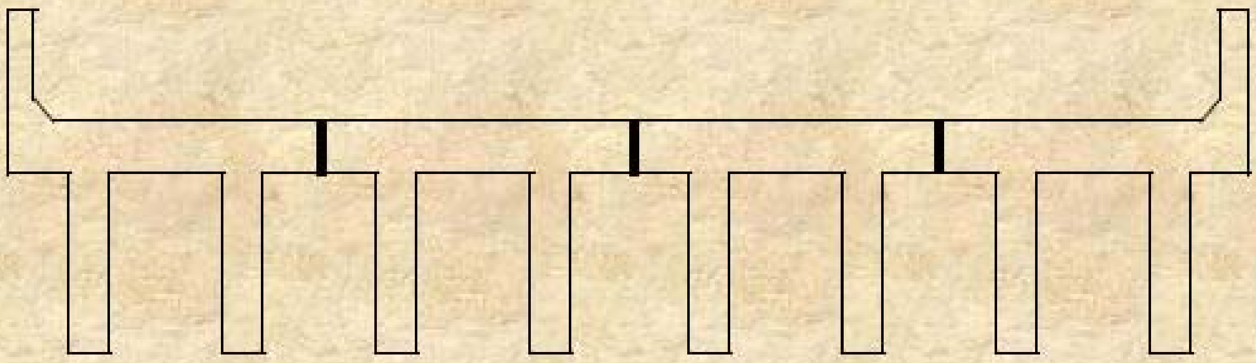


Fig.21.11. Integral Concrete Slab with Precast Concrete Double Tee Sections with Shear Keys and Transverse Post-Tensioning.

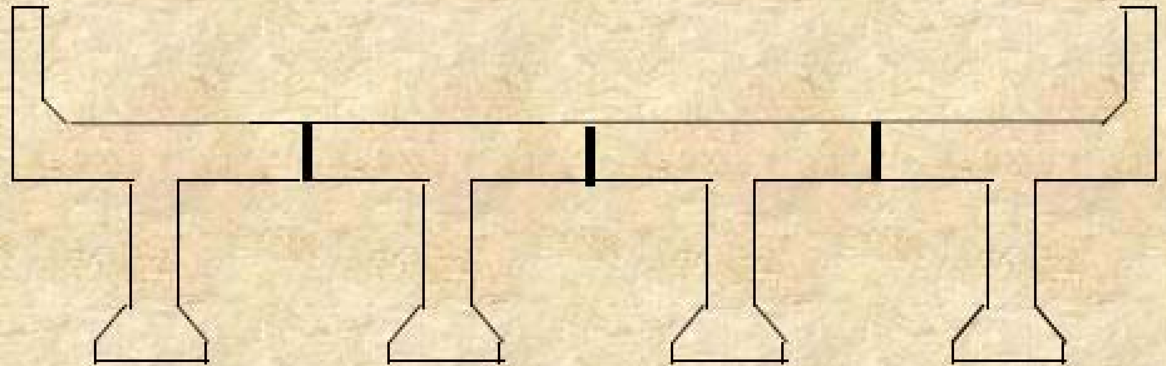


Fig.21.12. Integral Concrete Slab with Precast Concrete Tee Sections with Shear Keys and Transverse Post-Tensioning.

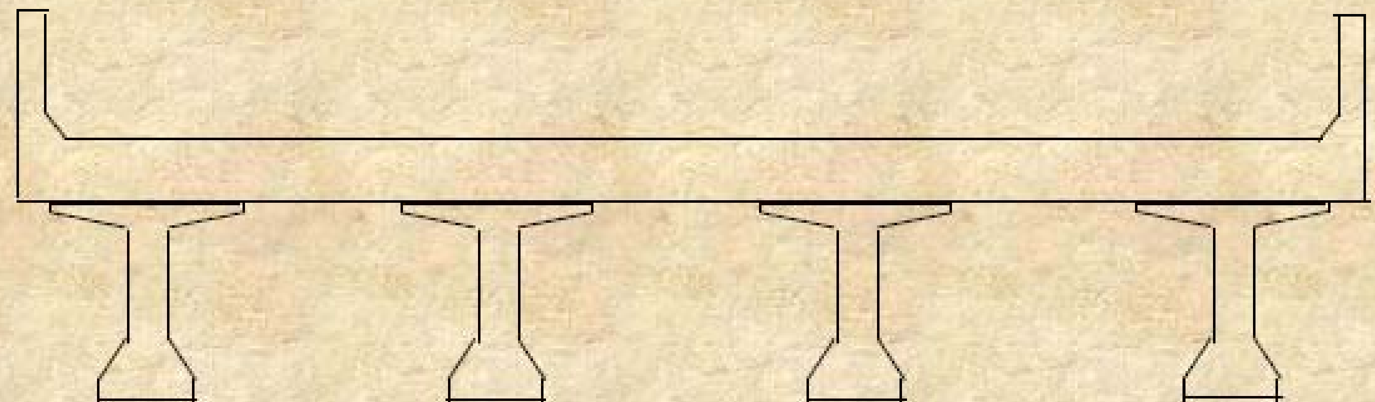


Fig.21.13. Cast-In-Place or Precast Concrete Slab over Precast Concrete I or Bulb-Tee Sections.

Bridge Types Based On Material Of Construction

- Steel bridges, truss bridges, plate girder bridges, suspension bridges and prestressed steel bridges, etc.
- Concrete bridges, slab bridges and slab and beam bridges, etc.
- Prestressed concrete bridges.
- Timber bridges.
- Bridges made with advanced composite materials.

Bridge Types Based On Span Lengths

- **Short span bridges** are those in which a single design vehicle on the span gives the critical design forces. An approximate range of span for these types of beams is 6 to 38 m. Some designers consider this range to be 6 to 20 m.
- Bridges with spans less than 6 m may be classified as **culverts**.

- **Medium span bridges** are those for which the design is controlled by a train of moving vehicles. An approximate range is 38 (may be taken as 20 m) to 125 m.
- **Large span bridges** are those in which design is controlled by train of stationery vehicles with minimum headway distance. However, the vehicles may be of varying size and weight. These bridges have spans in excess of 125 m.

Types Depending On Structural Forms

Simple Slab Bridges: These bridges consist of one-way slabs having a span of 3 to 7.5 m.

- The main steel is provided parallel to traffic and distribution steel is provided perpendicular to traffic, as shown in Fig. 21.14.

Simple Slab Bridges With Edge Beams: These bridges are similar to simple span bridges with the difference that edge beams projecting upwards or downwards are also provided.

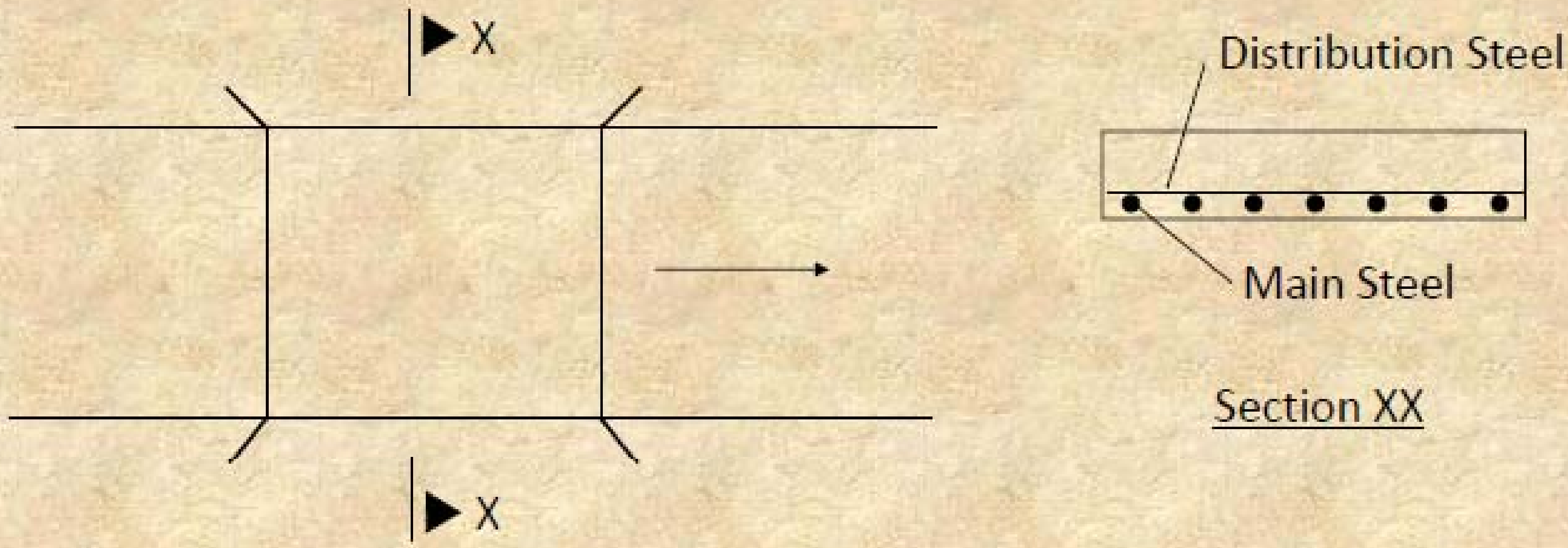


Fig. 21.14. A Typical Slab Bridge.

Beam And Slab Bridges: In this case the slab is supported on ordinary reinforced concrete monolithic beams, as shown in Fig. 21.15.

The main steel for the slab is placed transverse to the traffic and the distribution steel is placed along the traffic.

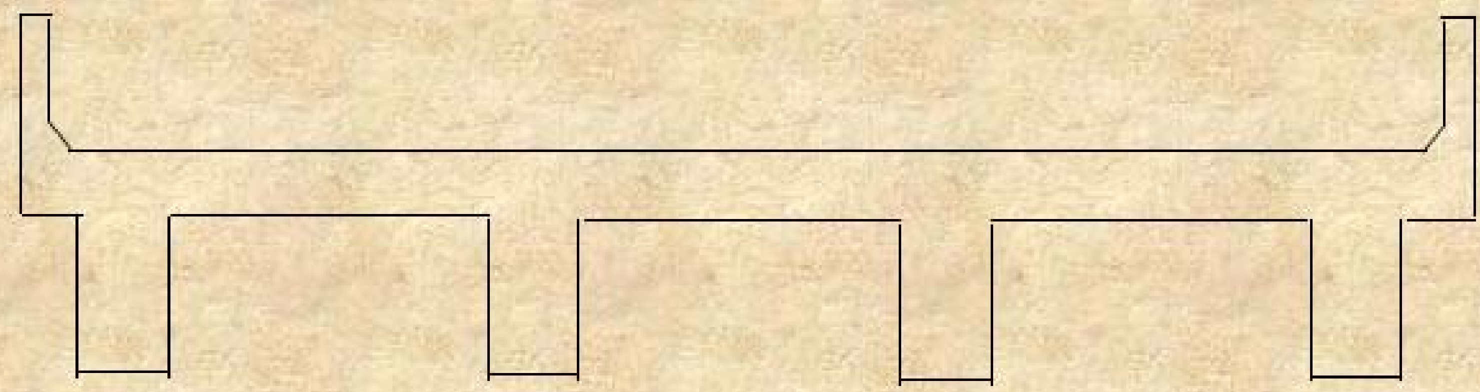


Fig. 21.15. A Typical Beam and Slab Bridge.

Prestressed Precast Girder Bridges: In this type of bridge, the slab is supported over prestressed concrete girders (Fig. 21.16).

Transverse diaphragms are provided at regular interval for lateral distribution of loads and to provide lateral stability to the girders.

Shear connectors are provided between the slab and the girders to get composite behavior.

The girders are placed parallel to the traffic.

The main steel for the slab is placed perpendicular to the traffic.

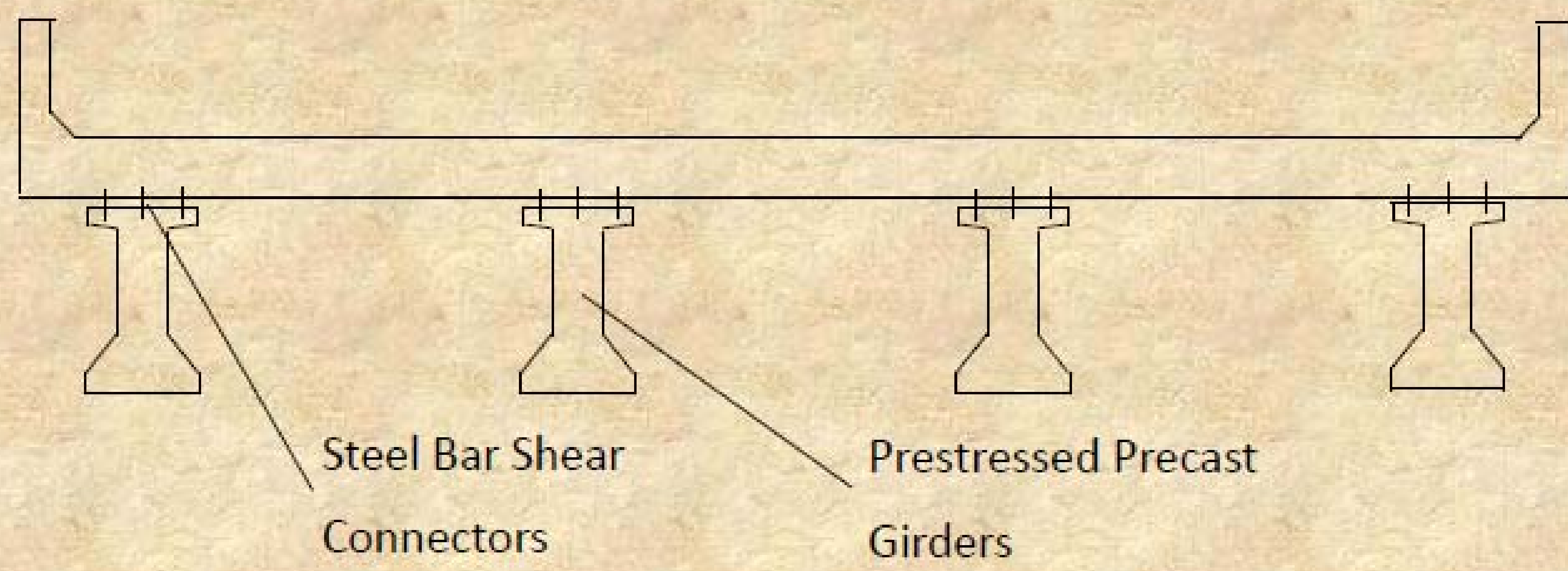
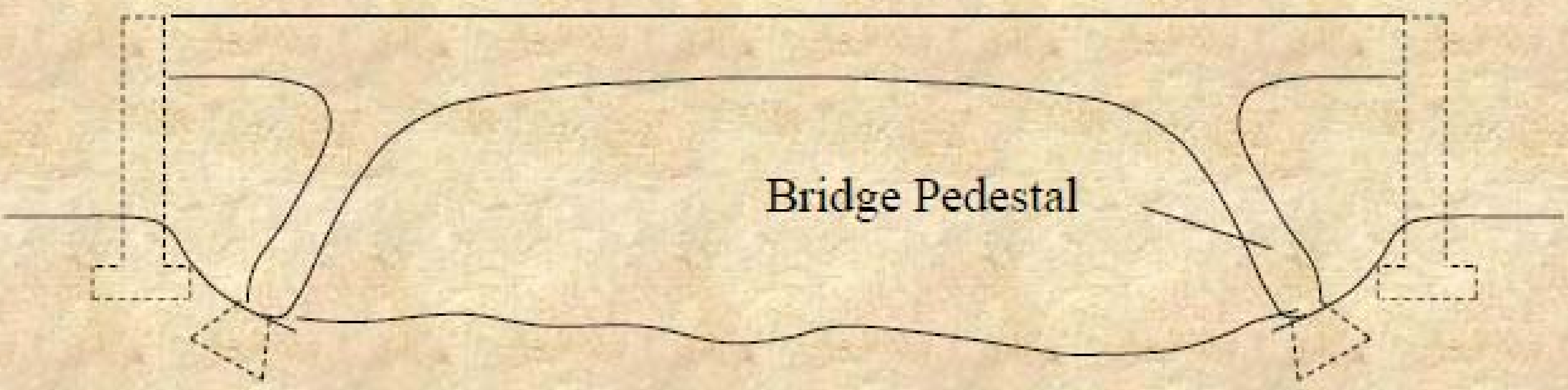


Fig. 21.16. A Typical Prestressed Girder Bridge.

Rigid Frame Bridges: These bridges are supported on vertical or slanted monolithic legs (Fig. 21.17).



Arch Bridges: Two types of arch bridges are shown in Figs. 21.18 and 21.19.

A true arch transfers loads to its foundations by pure compression.

However, presence of moving concentrated loads produces some bending.

Large horizontal thrusts are produced in most of the arches, which are to be safely transferred to the foundations.

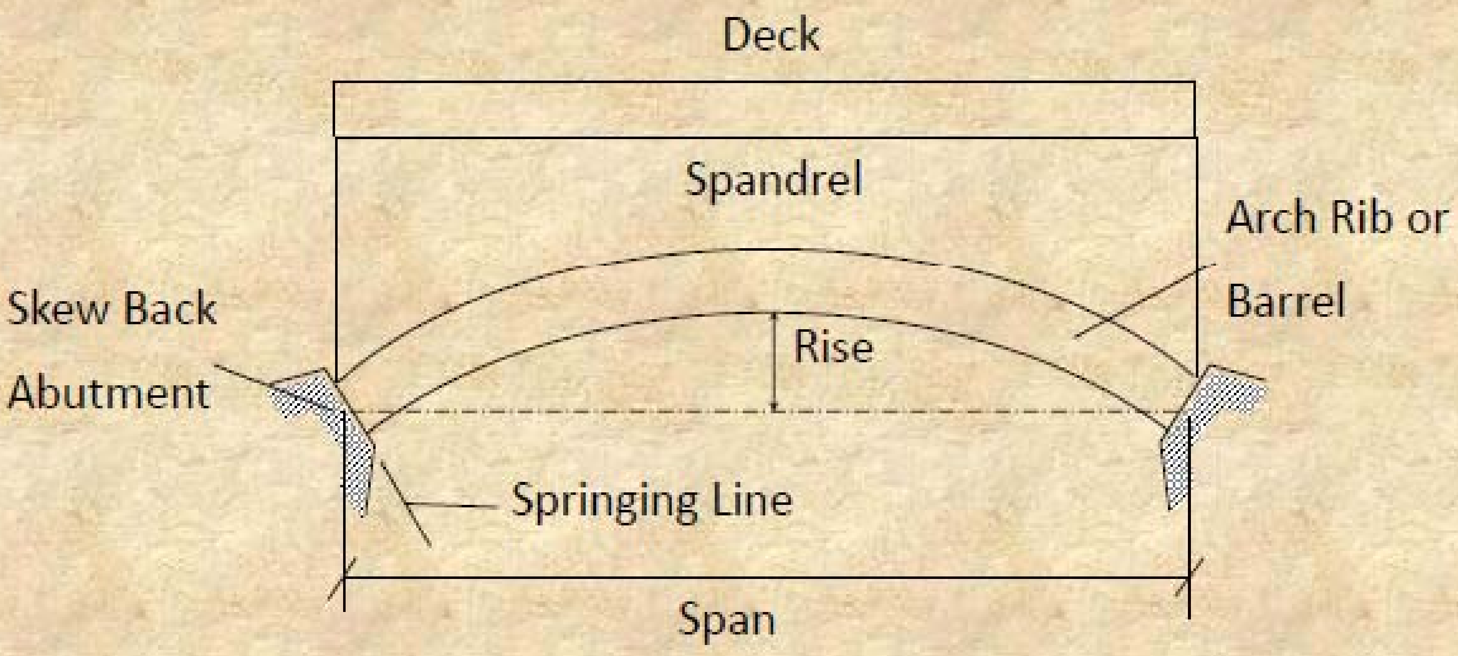


Fig. 21.18. A Masonry Arch Bridge.

The space between the deck and the arch is called the ***spandrel***.

In case of a through-arch bridge, the arches are entirely above the deck and ties are used to support the deck.

In case of half-through-arch bridges, the deck is built at some intermediate level between the springing and the crown.

If deck is constructed over the arch, it is a simple arch bridge.

The arch may be fixed, two-hinged or three-hinged.

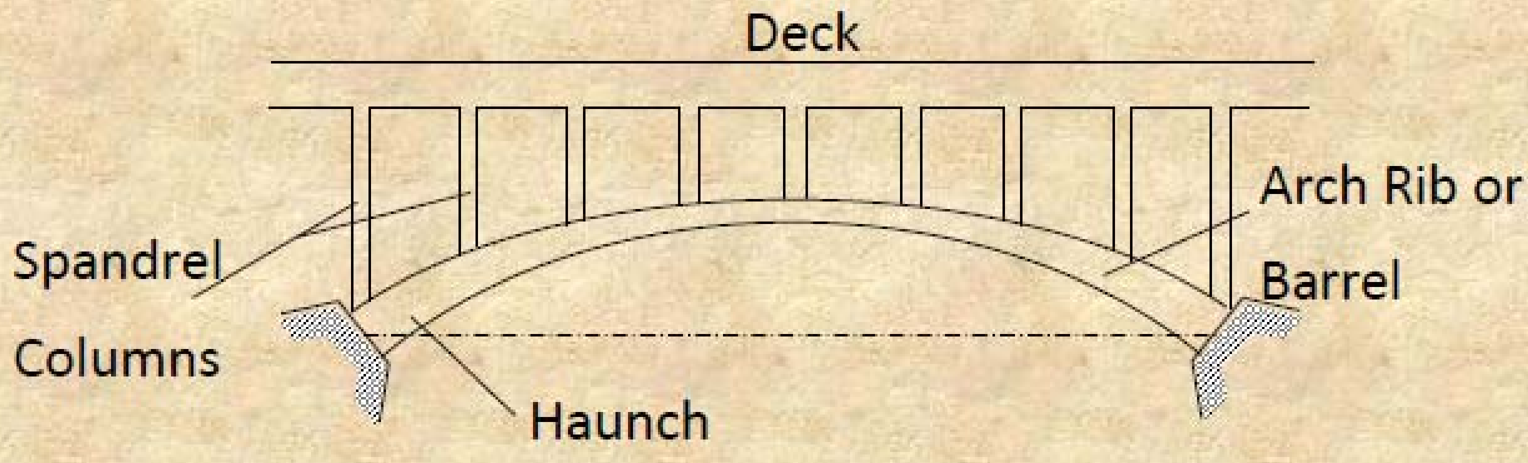
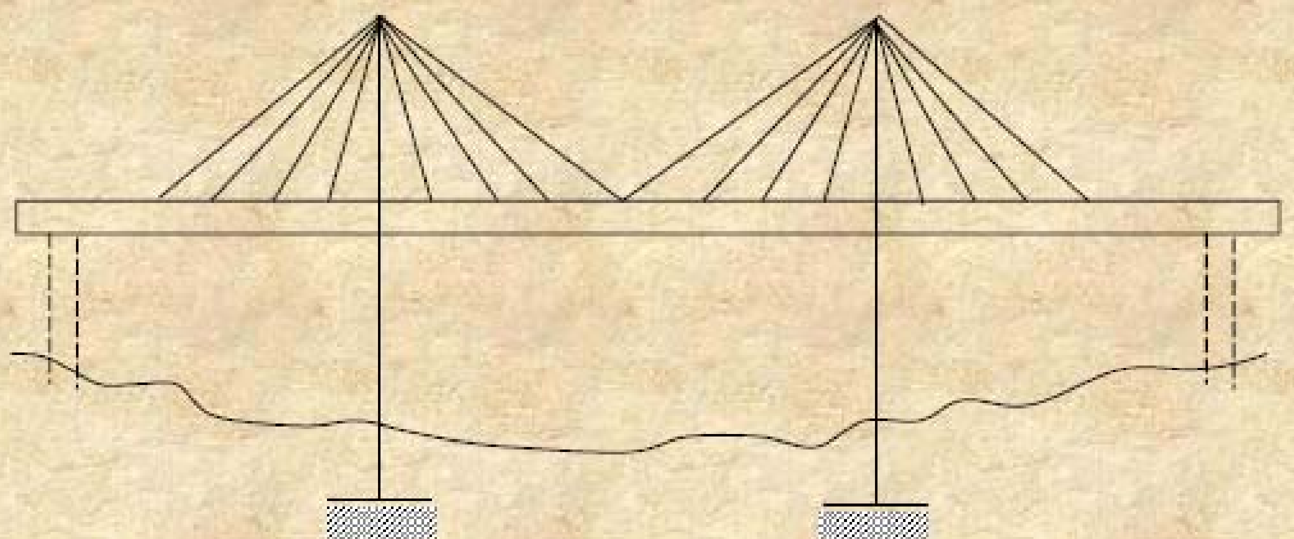


Fig. 21.19. Open Spandrel Arch Bridge.

Cable Stayed Bridges: These are the bridges where the super-structure is supported at several intermediate points by inclined cables or stays radiating from the towers, over which these are made continuous (Fig. 21.20).



Suspension Bridges: These bridges are used for the longest spans.

The deck is supported on stiffening girders that are hung from the suspension cables by vertical ties.

The ends of the suspension cables are secured at the anchorages made up of masonry or concrete.

A schematic view of suspension bridge is presented in Fig. 21.21.

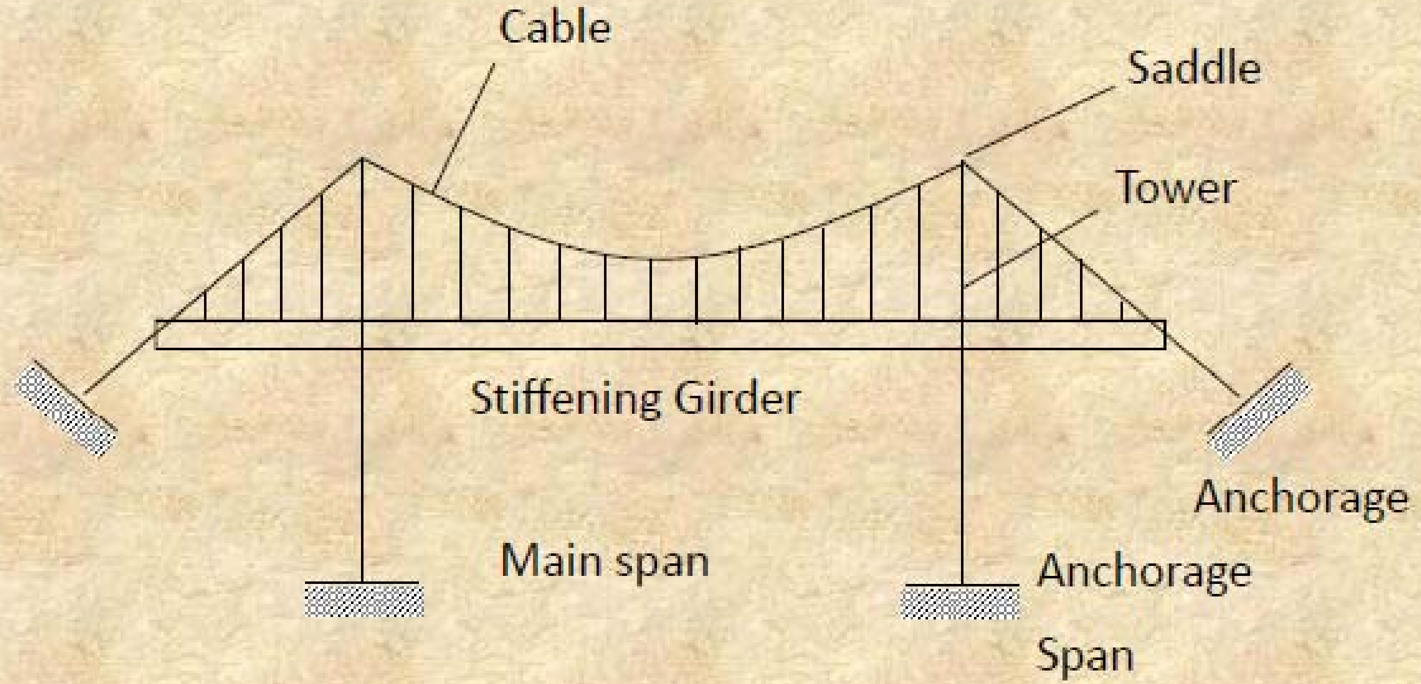
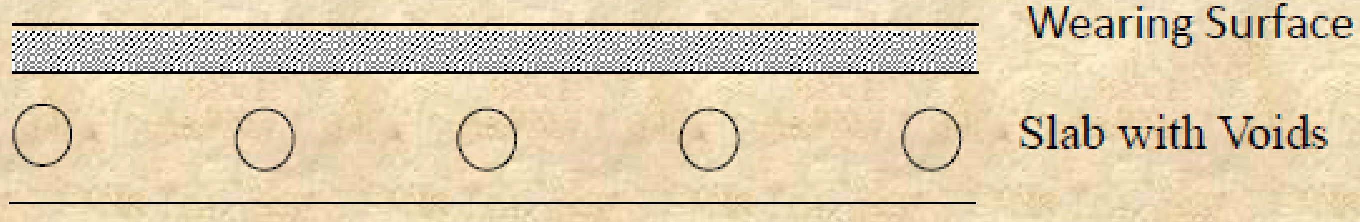


Fig. 21.21. Suspension Bridges.

Voided Slab Bridges: These bridges are the slab bridges that are to be used for relatively larger spans.

For this purpose, the slab is made with voids, as in Fig. 21.22, to reduce the dead load.



Box Girder Bridges: Relatively longer bridge spans may be covered by post-tensioned prestressed concrete box girders that are cast in segments, as shown in Fig. 21.23.

The work may be carried out in incremental launching from both sides.

The balanced cantilever method is used to carry the units at the point of their assembly.

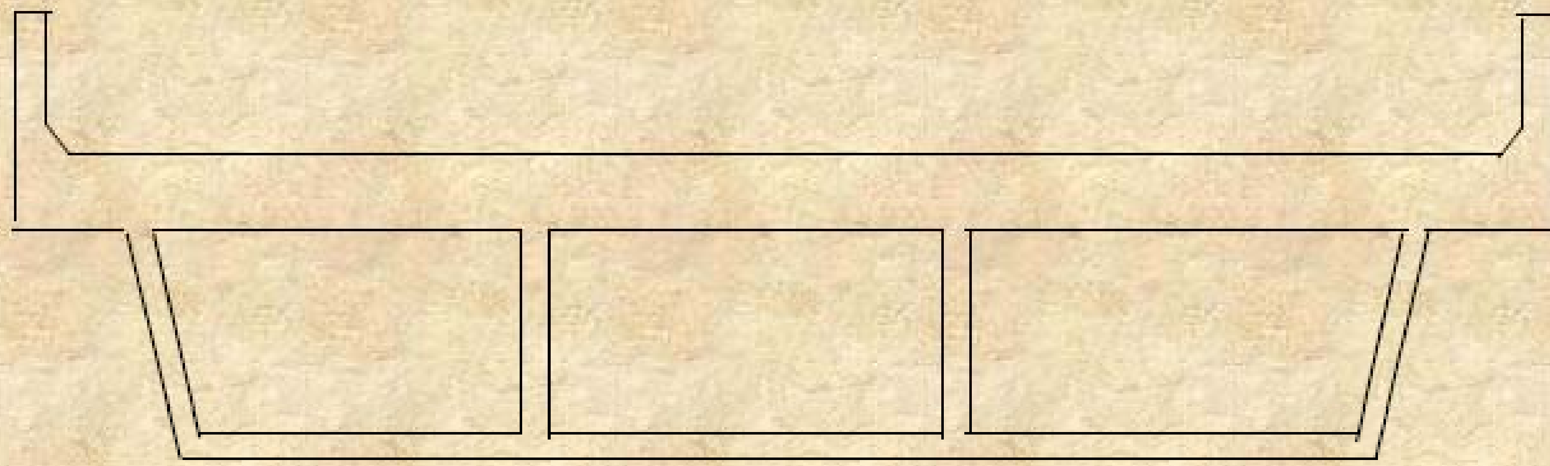


Fig. 21.23. Box Girder Bridges.

Types Depending On Structural Forms

- The bridges may be consisting of simple or continuous spans.
- Multiple simple spans may also be used in series to cover larger gaps if piers may be constructed within the opening.
- In a continuous beam, maximum moments are produced at the supports but having values considerably lesser than the simple spans.

- The positive moments near mid-spans are much lesser than even the negative moments.
- The advantages of continuous spans are reduced self weight due to smaller cross-sections, greater stiffness and fewer deflections, less bearing and expansion joints and more overload capacity in the plastic range due to larger redundancy.

Types Depending On Load Path

- The bridges may be classified into one-dimensional or two-dimensional systems depending on the load path.
- In case of one-dimensional system, load is only distributed longitudinally, such as in a slab bridge.
- Load is distributed in both longitudinal and transverse directions in a two-dimensional system, such as in a slab-stringer bridge.

- This system is more efficient for medium and large span bridges.
- The super-structure of a bridge may also be made by using a three-dimensional system, such as single, double or triple layer grids made up of skeletal elements with a slab at the top.

Movable Bridges: Movable bridges are used for roads where the bridge-level is not sufficiently higher than the water level to navigation through the water course.

There are three types of movable bridges; namely, bascule bridge, lift bridge and swing bridge.

- In ***bascule bridge***, the entire or half span opens upwards by rotating at the end support. These are used for shorter spans but provide maximum vertical clearance for the watercourse.
- A ***lift bridge*** moves as a whole in the vertical direction over towers at both ends. This type of bridge is suitable for larger spans but relatively less clearance over the water surface.
- A ***swing bridge*** rotates in a horizontal plane about a center pivot or a turntable provided over a center-pier that is constructed within the waterway.

BASIC DEFINITIONS

- ***Core width*** is defined as the width of the monolithic deck without the overhangs.
- ***End Zone*** is that part of the structure where, due to the structural or load discontinuity, normal beam theory does not apply.
- ***Equivalent Strip*** is defined as an isolated predefined width of the deck in the longitudinal or transverse direction which when designed individually represents the full design of the deck and the same design is used throughout.

- ***Footprint*** is the specified wheel contact area over the roadway.
- ***Force Effect*** is defined as a deformation, stress or stress resultant caused by the applied loads, imposed deformations or volumetric changes.
- If the transverse continuity between the deck and the webs of cellular cross-section exists, ***Frame Action*** is said to be developed in longer bridges.

- ***Lever Rule*** means the statical summation of moments about any point to calculate the reaction at some other point.
- ***Skew Angle*** is defined as the angle between the centerline of a bridge support and a line normal to the roadway centerline.
- Two closely spaced and interconnected axles of equal weight are together called a ***Tandem***.

Design Lane

- The design lane has a width equal to the lesser of 3600 mm or width of the traffic lane.
- Roadway widths from 6000 to 7200 mm shall have two design lanes, each equal to one-half the roadway width.
- The number of design lanes is taken as the integer part of the result when the clear roadway width in mm between curbs is divided by 3600.

General Terms Related With Design

- The design lane has a width equal to the lesser of 3600 mm or width of the traffic lane.
- Roadway widths from 6000 to 7200 mm shall have two design lanes, each equal to one-half the roadway width.
- The number of design lanes is taken as the integer part of the result when the clear roadway width in mm between curbs is divided by 3600.

If the design lanes are more than one, reduction factor of Table 21.1 is applied on the live load force effect called **Multiple Presence Factor** denoted by m.

Table 21.1. Multiple Presence Factors.

Number of Loaded Lanes	**Multiple Presence Factor** ***m***
1	1.20
2	1.00
3	0.85
> 3	0.65

Design Vehicular Live Load

- H20 means a highway truck with two axles and weighing 20 tons.
- HS20 means a highway truck similar to H20 truck but having a semi-trailer with one additional axle.
- H15 and HS15 are defined in a similar way.
- The new specification uses HL93 (highway loading of 1993).

- In case of HL93 loading, the vehicular live load on the bridge roadway consists of a combination of design truck (or design tandem) and the design lane load.
- The loads shall occupy a width of 3000 mm transversely within a design lane
- All design lanes must be loaded simultaneously by the truck or tandem and the lane loads.

Design Truck (HL-93)

- A standard truck consists of front axle of 35 kN, rear truck axle of 145 kN at 4.3 m spacing from the front axle and trailer axle of 145 kN having a variable spacing of 4.3 to 9.0 m from the truck rear axle.
- The spacing of trailer axle producing the maximum force effect must be used.

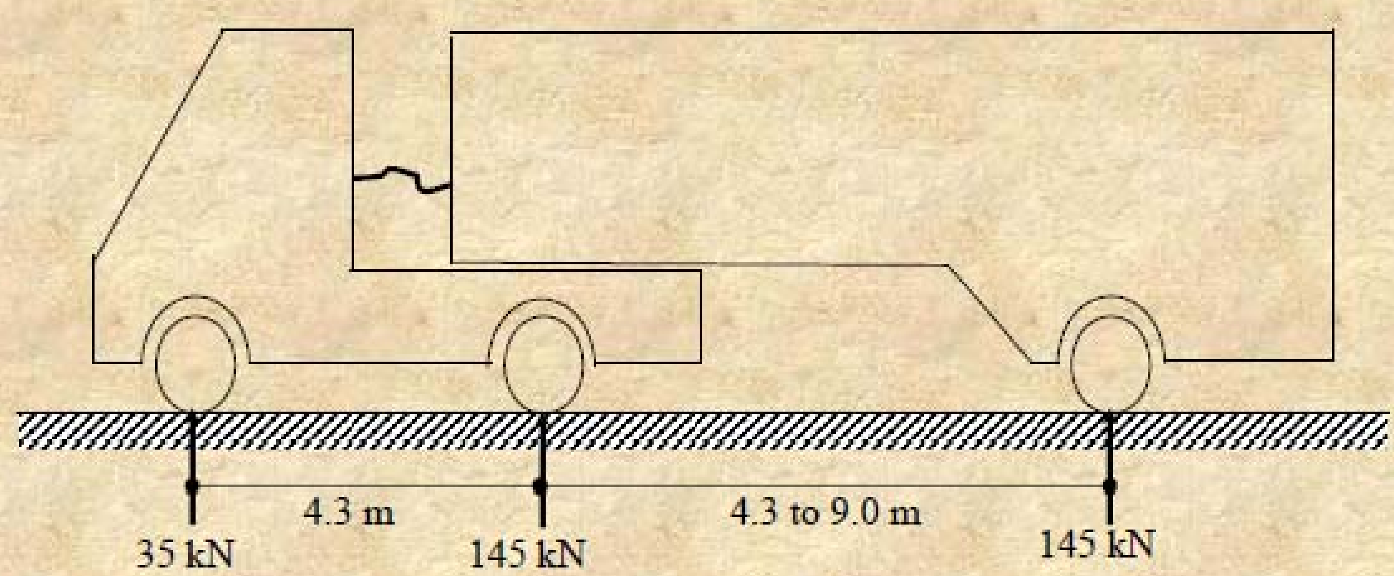


Fig. 21.25a. Longitudinal View of HL-93 Design Truck Showing Axle Loads.

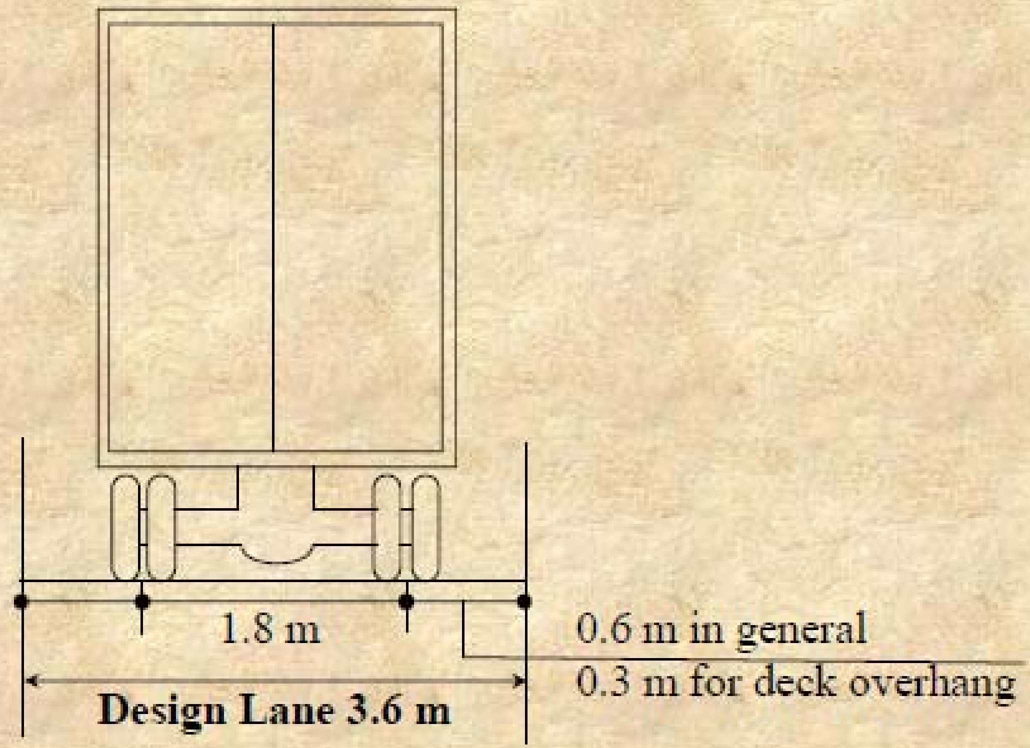


Fig. 21.25b. Back View of Truck Showing Transverse Clearances.

Figure 21.25. AASHTO Standard Truck Loading.

- Dynamic load allowance of 33 % is to be applied on these loads.
- The design truck or tandem shall be placed transversely at 300 mm from the face of curb or railing for the design of bridge overhang and 600 mm from edge of the design lane for the design of all other components.

- For both negative moment between points of dead load contraflexure and reaction at interior piers, 90 % of the effect of two design trucks spaced 15 m between the front axle of one truck and trailer axle of the other may be considered.
- The distance between the two 145 kN axles of both the trucks must be taken equal to 4.3 m.
- A simultaneous action of 90 % of design lane must also be included.

Design Tandem (HL-93)

- The design tandem shall consist of a pair of 110 kN axles at a longitudinal spacing of 1200 mm with the transverse center-to-center spacing of the wheels being 1800 mm.
- Dynamic load allowance of 33 % is to be applied on these loads.
- For negative moment and reaction at the interior supports, pair of tandem may be considered at a spacing of 8 to 12 m.

Design Lane Load (HL-93)

- The design lane load shall be 9.3 kN/m along the length, having a width of 3000 mm.
- The load intensity becomes 3100 N/m^2.
- Dynamic load allowance is not to be applied on lane loading.

Pedestrian Loads

- A pedestrian load of 3600 N/m^2 is used on all sidewalks simultaneously with the vehicular design live load.
- Separate bridges for pedestrian and bicycle traffic should be designed for a live load of 4100 N/m^2.
- The dynamic load allowance is not considered for these loads.

Pakistan Code Of Practice Loading For Highway Bridges (1967)

The highway loading according to the Pakistan Code of Practice for Highway Bridges consists of Class A, Class B and Class AA loadings.

Table 21.2. Load of Trucks/Tanks.

Standard Truck/Train	Weight of Truck/Tank *W* (kN)
Class A	275
Class B	165
Military Tank	700

Table 21.3. Ground Contact Dimensions.

Axle Load	**Longitudinal Tire Contact Length** B_L	**Transverse Tires Contact Width** B_T
(kN)	**(mm)**	**(mm)**
110.4	255	510
66.4, 69.0	205	380
27.6	150	205
41.5	150	305
16.6	125	180

Table 21.4. Design Transverse Spacing Between Trucks (J).

Clear Road Width R_w **(m)**	**Distance - J For Most Critical Design Condition** **(mm)**
5.0 or less	0
5.0 to 5.5	$800\ (R_w - 5)$
5.5 to 7.3	$400 + 450\ (R_w - 5.5)$
Above 7.3	1210

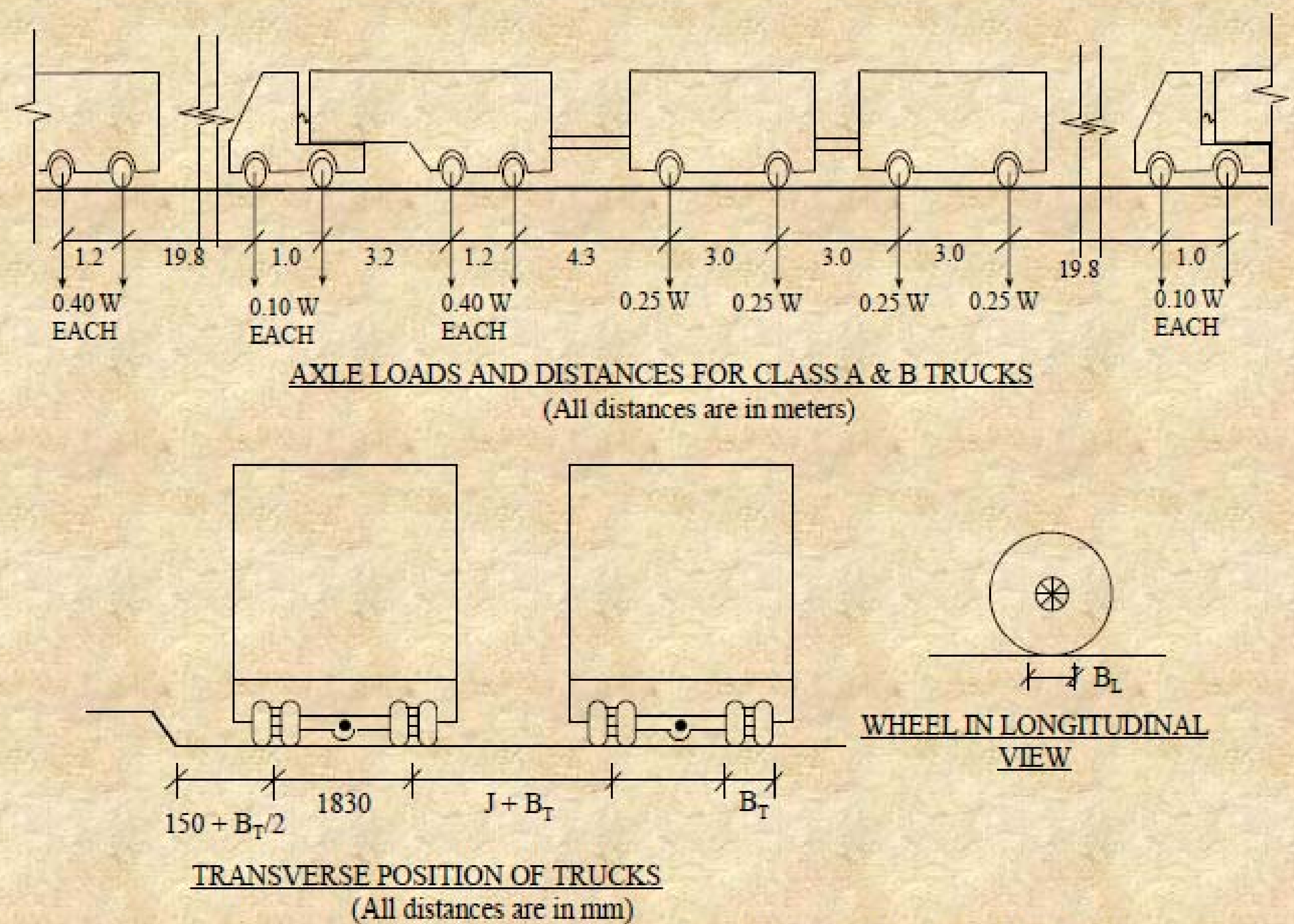
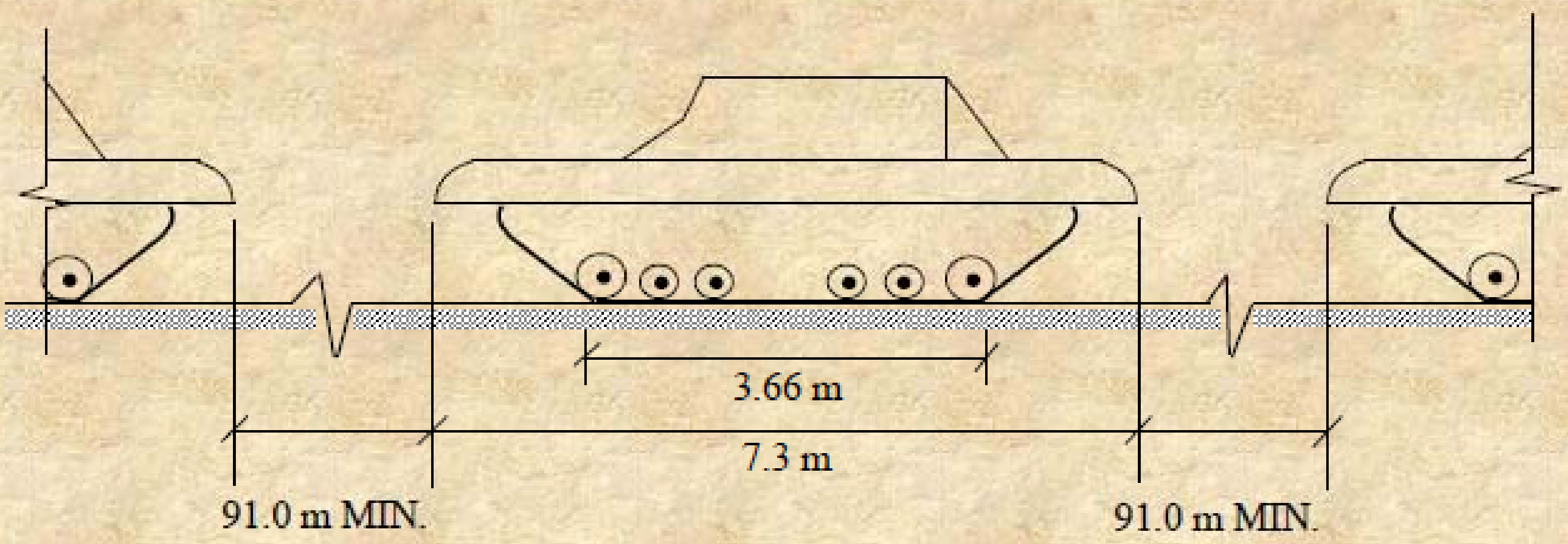


Fig. 21.26. Class A and B Loadings.



LONGITUDINAL TANK VIEW

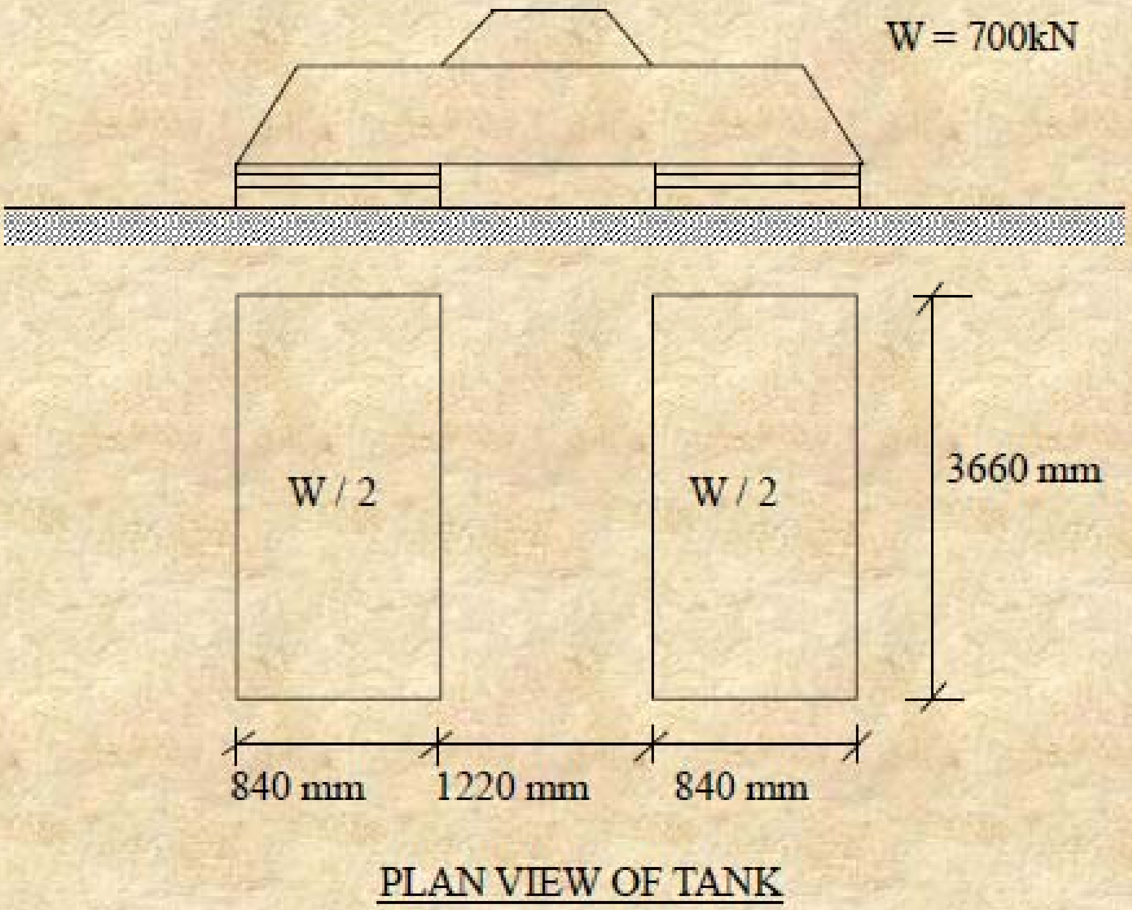


Fig. 21.29. Class AA (Tank) Loading.

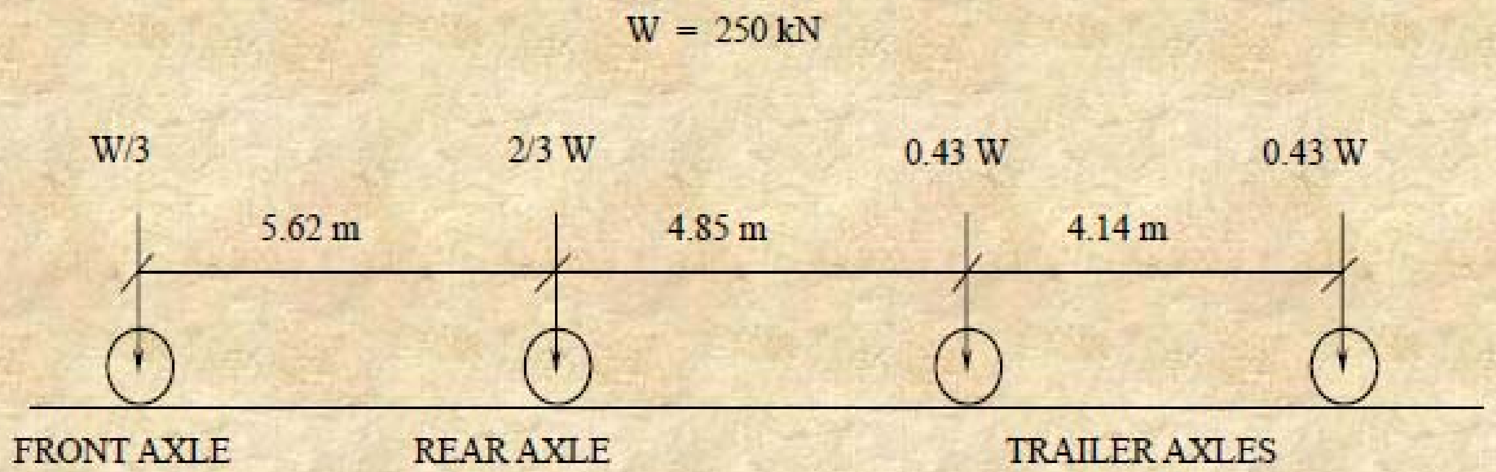


Fig. 21.27. Axle Loads For Mercedes Benz Truck.

DISTRIBUTION OF LIVE LOAD

- The truck loads on the bridge deck are moving at different locations along the width and length of the slab.
- When these loads occupy certain critical positions, maximum forces occur in the members.
- For approximate design of the deck, usually one-dimensional analysis is carried out considering only the girder.
- In such cases, it becomes very important to find the effect of loads along the lateral direction of the member.

- The position and contribution of various loads along the lateral direction to analyze 1-D members for an actual 2-D structure and to find the design forces is called ***distribution of the live loads***.
- Estimating contribution of the transversely placed loads (with respect to direction of traffic movement) over the centerline of a particular member, spanning along the length of the bridge, is called ***lateral distribution of loads***.
- During the lateral distribution, the combined action of all the structural members in resisting the applied loads is considered.

- Thus, by the lateral distribution, equivalent loads are obtained at the members having the transverse load effect included in them.
- These equivalent loads are then placed along the length of the member according to the criteria of maximum forces in case of moving loads.
- Maximum force effects are then obtained from this ***longitudinal distribution of the loads***.

- However, for beams or slab strips placed transverse to the traffic direction, longitudinal distribution of loads is to be performed first to get the equivalent loads.
- These equivalent loads are then placed transversely at suitable locations to get extreme forces.
- This method of performing manual 1-D analysis is called **Approximate Method of Analysis**.

DEFLECTION CHECK

The deflection check in bridges is optional but shall always be performed for the live load alone.

The larger deflection out of the following cases is considered:

- Deflection due to design truck alone but including the dynamic load allowance.
- One-fourth of the above deflection plus deflection due to design lane load.

The maximum allowable live load deflection may be as under:

- 0nly vehicular load on the roadway - span / 800.
- Pedestrian load is present with or without other loads - span / 1000.
- Vehicular load on cantilever arms - span / 300.
- Pedestrian load on cantilever arms - span / 375.

In place of checking the actual live load deflections, following optional criteria for span-to-depth ratios may be utilized:

Let,

S = the slab length (mm)

L = the span length of beams (mm)

Reinforced Concrete Slabs

Simple spans: $$\frac{1.2\,(S+3000)}{30}$$

Continuous spans: $$\frac{(S+3000)}{30} \geq 165\ mm$$

MINIMUM DEPTH FOR DURABILITY

The depth of the concrete slab to be used as a deck should not be less than 175 mm. The wearing surface is separately provided. NHA recommends 220 mm.

Minimum Overhang Thickness: The minimum overhang thickness of concrete decks for crash resistance should be 200 mm if it supports a deck-mounted post system, 300 mm for a side-mounted post system and 200 mm in case it supports concrete parapets or barriers.

Depth of RC T-Beams

Simple spans: 0.070 L

Continuous spans: 0.065 L

MINIMUM COVER TO REINFORCEMENT

Minimum cover is required for durability, easy placing of concrete and to provide resistance against splitting due to bond stresses.

The cover to steel, for w/c ratios greater than 0.4 and lesser than 0.5, should have the minimum values given in the following Table 21.6.

Table 21.6. Minimum Clear Cover for Unsupported Main Reinforcing Steel.

Situation	**Cover (mm)**
Direct exposure to salt water	100
Direct exposure to earth	75
Interior beams up to No. 35 Bar.	40
Top deck surface subjected to shear	60
Bottom of cast-in-place slabs up to No. 35 Bar	25

Permanent Loads

DD	=	down drag
DC	=	dead load of structural components and non-structural attachments
DW	=	dead load of wearing surface
EH	=	horizontal earth pressure load
ES	=	earth surcharge load
EV	=	vertical pressure from dead load of earth fill

Transit Loads

BR	=	vehicular braking force
CE	=	vehicular centrifugal force
CR	=	creep
CT	=	vehicular collusion force
CV	=	vessel collision force
EQ	=	earthquake
FR	=	friction
IC	=	ice load
IM	=	vehicular dynamic load allowance
LL	=	vehicular live load
LS	=	live load surcharge

PL	=	pedestrian live load
SE	=	settlement
SH	=	shrinkage
TG	=	temperature gradient
TU	=	uniform temperature
WA	=	water load and stream pressure
WL	=	wind on live load
WS	=	wind load on structure

Load Combinations

The total factored load shall be taken as:

$$Q = \eta \, \Sigma \, \gamma_i \, q_i$$

where	η	=	load modifier
	γ_i	=	load factors
and	q_i	=	individual loads

Most common load combination with semi-ductile components and connections ($\eta_D = 1.0$), some redundant members ($\eta_R = 1.0$) and moderate importance ($\eta_I = 1.0$) is:

$$\eta = (1.0)(1.0)(1.0) = 1.0$$

$$Q = 1.25\ \text{DC} + 1.5\ \text{DW} + 1.75\ (\text{LL} + \text{IM} + \text{PL})$$

Effective Flange Width Of Beams

Interior Beams

The effective flange dimension (b) is the minimum out of the following:

i) $L / 4$

ii) $12\ h_f$ + greater of web thickness or one-half the width of the top flange of the girder

iii) average spacing (s) of adjacent beams

Exterior Beams

The effective flange dimension (b) is equal to half of b for interior beams plus the minimum of the following:

i) $L / 8$

ii) $6\ h_f$ + greater of half of web thickness or one-quarter the width of the top flange of the basic girder

iii) width of the overhang

Design Formulas

For simplicity, here we will use ACI formulas for flexural and shear design in place of the AASHTO equivalents.

SLAB BRIDGE

Edge Support

At lines of discontinuity, the edge of the deck is either to be strengthened or be supported by a beam or other line component (AASHTO).

When the primary direction of the deck is transverse or if the deck is composite with a concrete barrier, no additional edge beam is required.

When decks span in the direction of traffic, the width of longitudinal edge strips, with or without an edge beam, may be taken as the sum of the following parameters:

a. the distance between the edge of the deck and the inside face of the barrier,
b. 300 mm, and
c. one-half of the full strip width.

However, this width is to be taken between 1800 mm and the full strip width.

Live Load Strip Width

Equivalent width (E) of longitudinal strips per lane (one lane loaded condition) is:

$$E = 250 + 0.42\sqrt{L_1 W_1}$$

Equivalent width of longitudinal strips per lane (more than one lanes loaded) is:

$$E = 2100 + 0.12\sqrt{L_1 W_1} \leq W / N_L$$

where

L_1	=	modified span length
	=	lesser of the actual span or 18000 mm
W_1	=	modified edge-to edge width of bridge
	=	lesser of actual total width including barriers, etc., or 18000 mm for multi-lane loading
	=	lesser of actual width or 9000 mm for single lane loading
W	=	actual edge-to-edge width of bridge
N_L	=	number of design lanes
	=	integer part of W / 3600

In cases where the traffic lanes are less than 3600 mm wide, the number of design lanes is considered equal to the number of traffic lanes.

Here, the width of the design lane is taken equal to the width of the traffic lane.

Further, roadway widths from 6000 to 7200 mm should have two design lanes, each equal to one-half the roadway width.

Distribution Steel

The secondary reinforcement, at the bottom for positive moment, must have the following minimum amount:

1. For primary reinforcement parallel to the traffic

   $$\text{Min. reinforcement} = \frac{1750}{\sqrt{S}} \leq 50\ \%$$

2. For primary reinforcement perpendicular to the traffic

   $$\text{Min. reinforcement} = \frac{3840}{\sqrt{S}} \leq 67\ \%$$

Maximum Spacing Of Slab Main Steel

In walls and slabs, the spacing of main reinforcement is not to exceed lesser of 1.5 times the slab thickness and 450 mm.

Shrinkage And Temp. Reinforcement

For components less than 1200 mm thick, the min. area of steel in each direction is to be as under:

$$A_s \geq 0.75 \frac{A_g}{f_y}$$

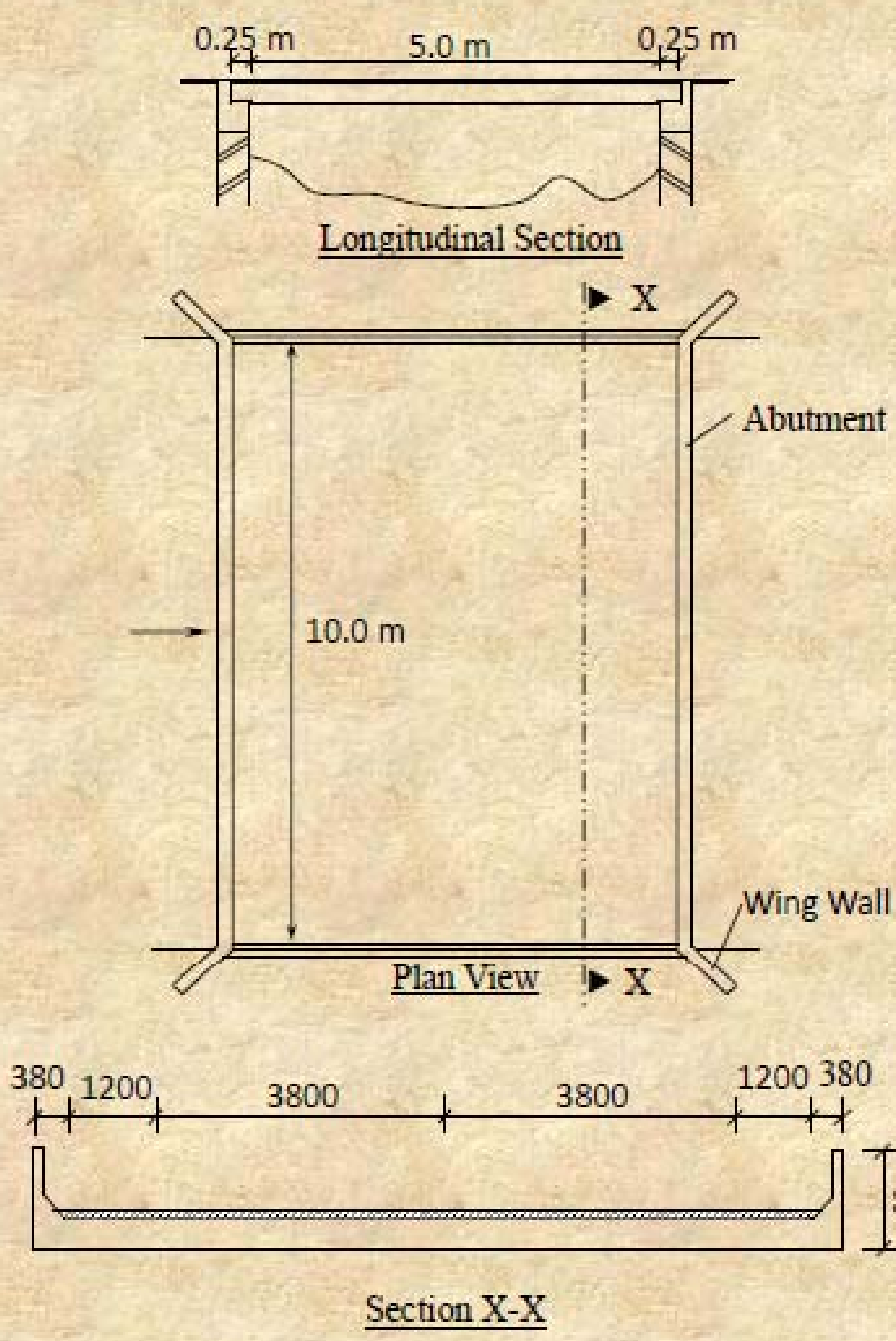
This steel is to be equally distributed on both faces.

However, for members 150mm or less in thickness, this steel may also be placed in a single layer.

The max. spacing of such reinforcement is to be lesser than 3.0 times the component thickness and 450 mm.

Example 21.1:

Design a simply supported solid slab bridge of 5.0 m clear span (Fig. 21.30). Ignore the fatigue effect. The loading is HL-93 and wearing surface consists of 75 mm thick bituminous wearing coat. Use $f_c' = 25$ MPa, $f_y = 420$ MPa and self weight of barrier is 4.65 kN/m. The roadway consists of two lanes of 3.8 m width, two 1.2 m wide sidewalks and barriers of 380 mm on each side.


0.25 m
5.0 m
0.25 m
Longitudinal Section
X
Abutment
10.0 m
Wing Wall
Plan View
X
380
1200
3800
3800
1200
380
865
Section X-X

Solution:

Clear span = 5.0 m

Effective span = S = 5500 mm

Clear width = $3.8 \times 2 + 1.2 \times 2$ = 10 m

Lane width = 3.8 m

Sidewalks = 1.2 m each

Loading = HL-93

f_c' = 25 MPa

f_y = 420 MPa

Self weight of barrier = 4.675 kN/m

$$h_{\min} = \frac{1.2\,(S + 3000)}{30} \geq 220 \text{ mm}$$

$$h_{\min} = \frac{1.2\,(5500 + 3000)}{30} = 340 \text{ mm}$$

(say 350 mm with 10 mm sacrificial surface)

Live Load Strip Width

One Lane Loaded

L_1 = lesser of the 5500 mm or 18000 mm

= 5500 mm

W_1 = lesser of W (= 10,760 mm) and 9000 mm

= 9000 mm

Equivalent width of strips, $E = 250 + 0.42\sqrt{L_1 W_1}$

− 3205 mm

Multiple Lanes Loaded

N_L = number of design lanes

= INT (W / 3600)

= INT (10000 / 3600) = 2

Multiple presence factor, $m = 1.0$

W = clear roadway width = 10000 mm

L_1 = lesser of the 5500 mm or 18000 mm

= 5500 mm (as before)

W_1 = lesser of W (= 10,760 mm) and 18000 mm

= 10760 mm

$$E = 2100 + 0.12\sqrt{L_1 W_1} \leq W / N_L$$

$$= 2100 + 0.12\sqrt{5500 \times 10760} \leq 10000 / 2$$

$$= 3023 \leq 5000 = 3023 \text{ mm}$$

(say 3020 mm)

Note:- Smaller lane width out of one-lane and multiple lanes loaded is more critical. However, single lane load has to be multiplied with multiple presence factor of 1.2, which is not to be applied for multiple lane loads.

Exterior Strip Width

Exterior strip width = the distance between the edge of deck and inside face of the barrier

$+$ 300 mm $+$ one-half the full strip width

$\leq$ *E* and 1800 mm

$=$ 380 + 300 + 3023 /2

$\leq$ 3023 and 1800 mm

$= 2192 \leq 1800$

$=$ 1800 mm

$\therefore$ Load of one wheel with multiple presence factor of 1.2 will be critical.

Impact Factor

Impact factor = $1 + IM / 100 = 1.33$

Maximum Live Load Shear Per Lane

Interior Strip – Truck Load

For a span of 5.5m, rear axle of truck and axle of trailer may only be on the span for the most critical condition.

The maximum shear may be found from the influence line for shear force shown in Fig. 21.31.

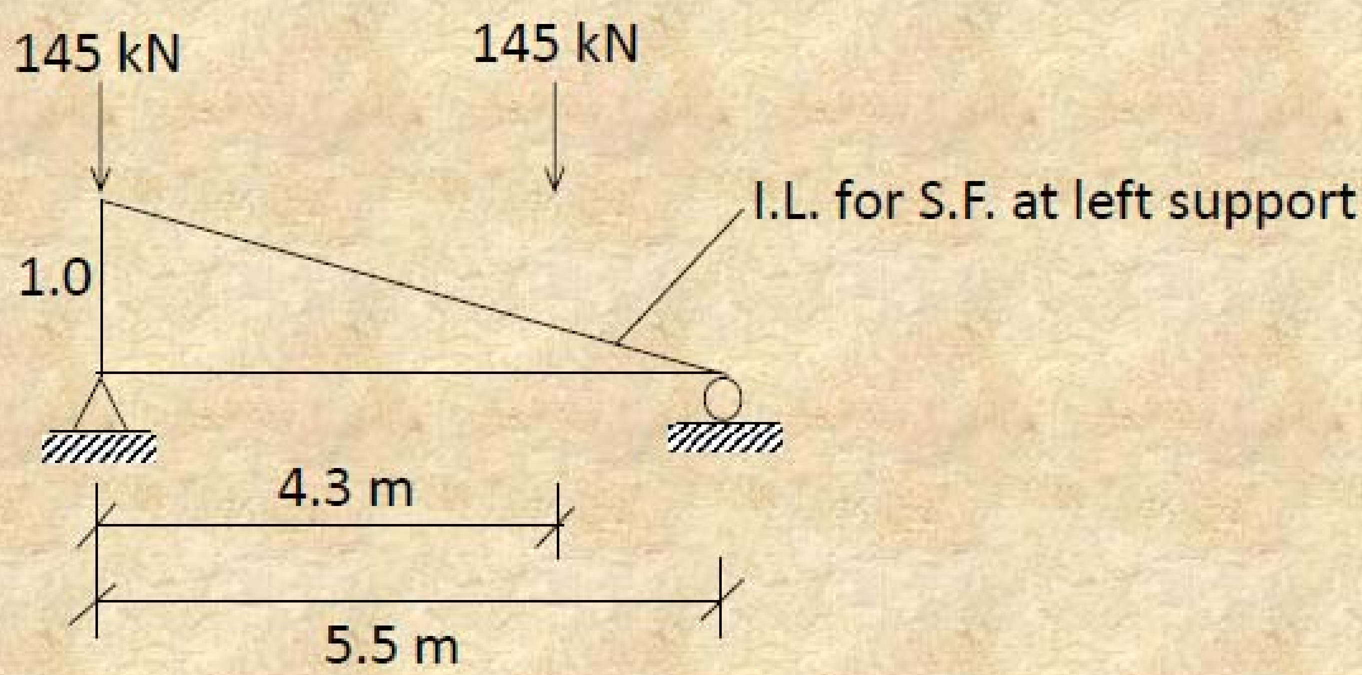


Fig. 21.31. Position of Axle Loads for Maximum Shear.

$$V_{tr} = 145\,(1 + 1.2 / 5.5) = 176.61 \text{ kN}$$

Interior Strip – Lane Load

The maximum shear may be found from the influence line for shear force or by directly considering simply supported member subjected to uniformly distributed load.

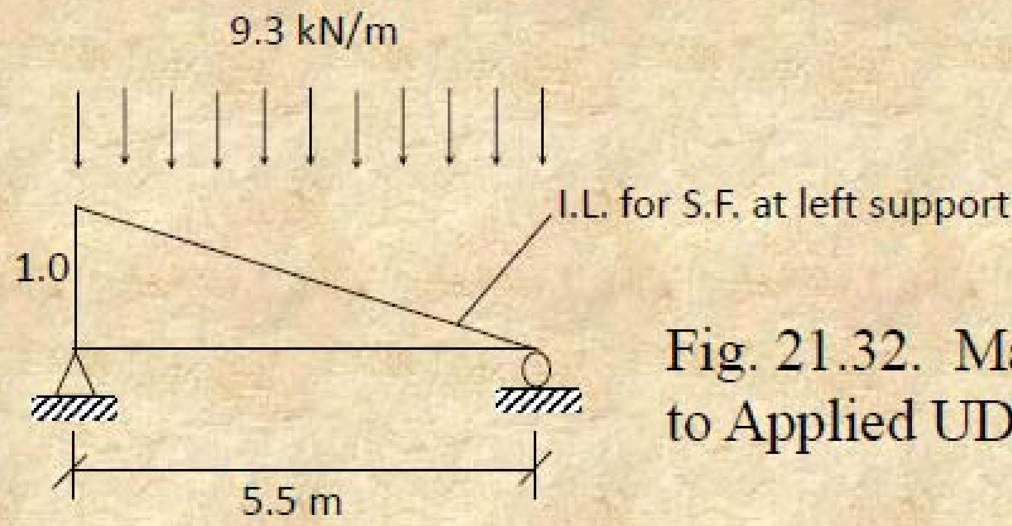


Fig. 21.32. Maximum Shear Due to Applied UDL.

$$V_{ln} = (0.5)\,(9.3)\,(5.5) = 25.58 \text{ kN}$$

Interior Strip – Tandem Load

The maximum shear may be found from the influence line for shear force shown in Fig. 21.33.

$$V_{td} = 110\,(1.0 + 4.3 / 5.5) = 196 \text{ kN}$$

$$\therefore \quad V_{LL+IM} = 1.33 \times 196 + 25.58 = 286.26 \text{ kN}$$

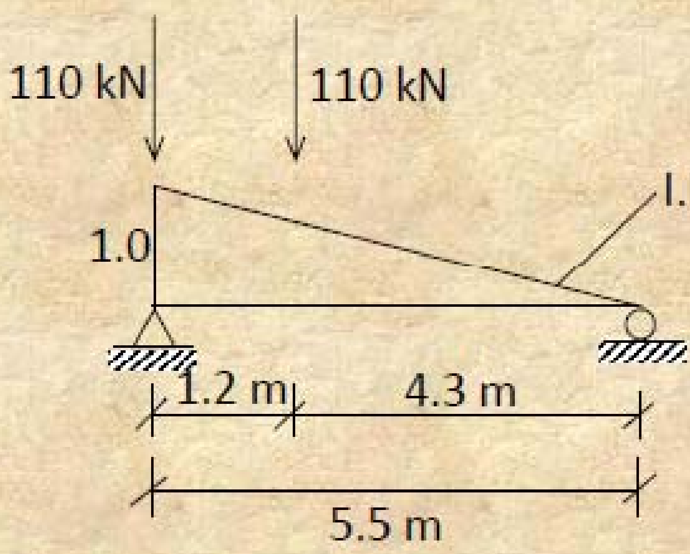


Fig. 21.33. Position of Tandem Loads for Maximum Shear.

Maximum Live Load Bending Moment Per Lane

Interior Strip – Truck Load

The central maximum bending moment will be calculated in place of the absolute maximum positive moment because the difference in values is usually less and the dead load moment is the maximum here. The position of loads for the maximum moment is shown in Fig. 21.34.

$$M_{tr} = \frac{145 \times 5.5}{4} = 199.38 \text{ kN-m}$$

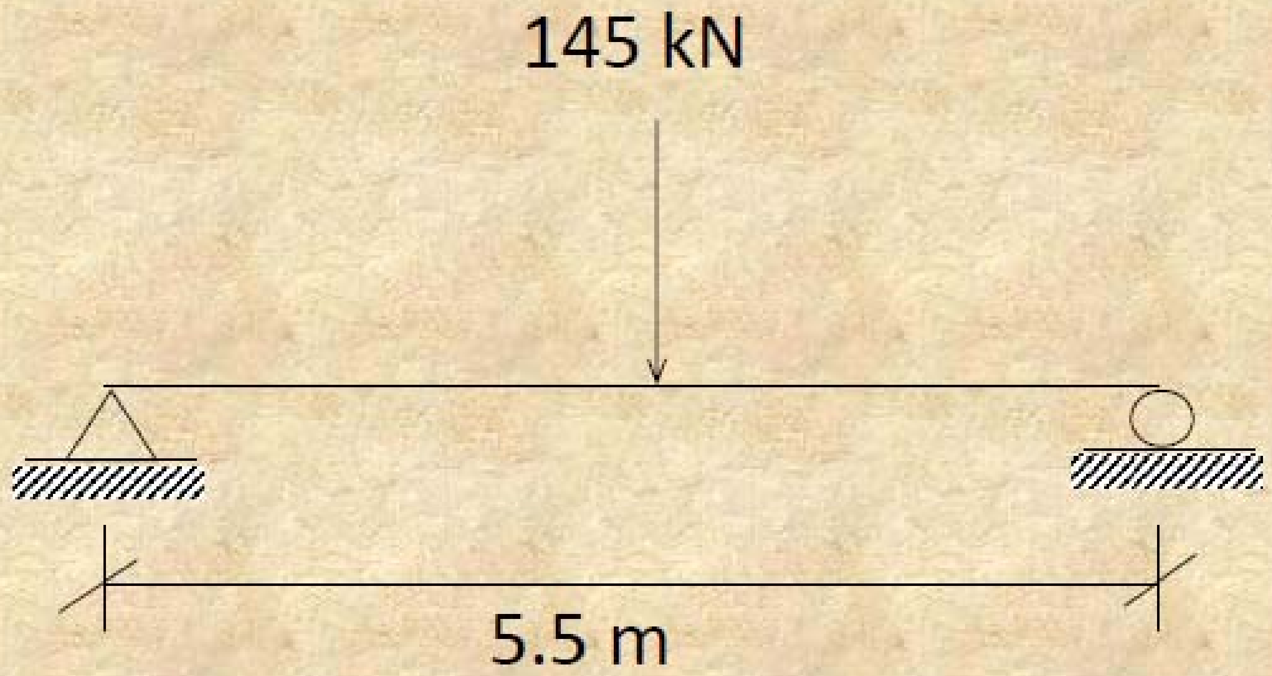


Fig. 21.34. Position of Axle Loads for Maximum Central Moment.

$$M_{\mathrm{tr}} = \frac{145 \times 5.5}{4} = 199.38 \text{ kN-m}$$

Interior Strip – Lane Load

$$M_{\mathrm{ln}} = \frac{9.3 \times 5.5^2}{8} = 35.17 \text{ kN-m}$$

Interior Strip – Tandem Load

The maximum bending moment may be found by using Fig. 21.35.

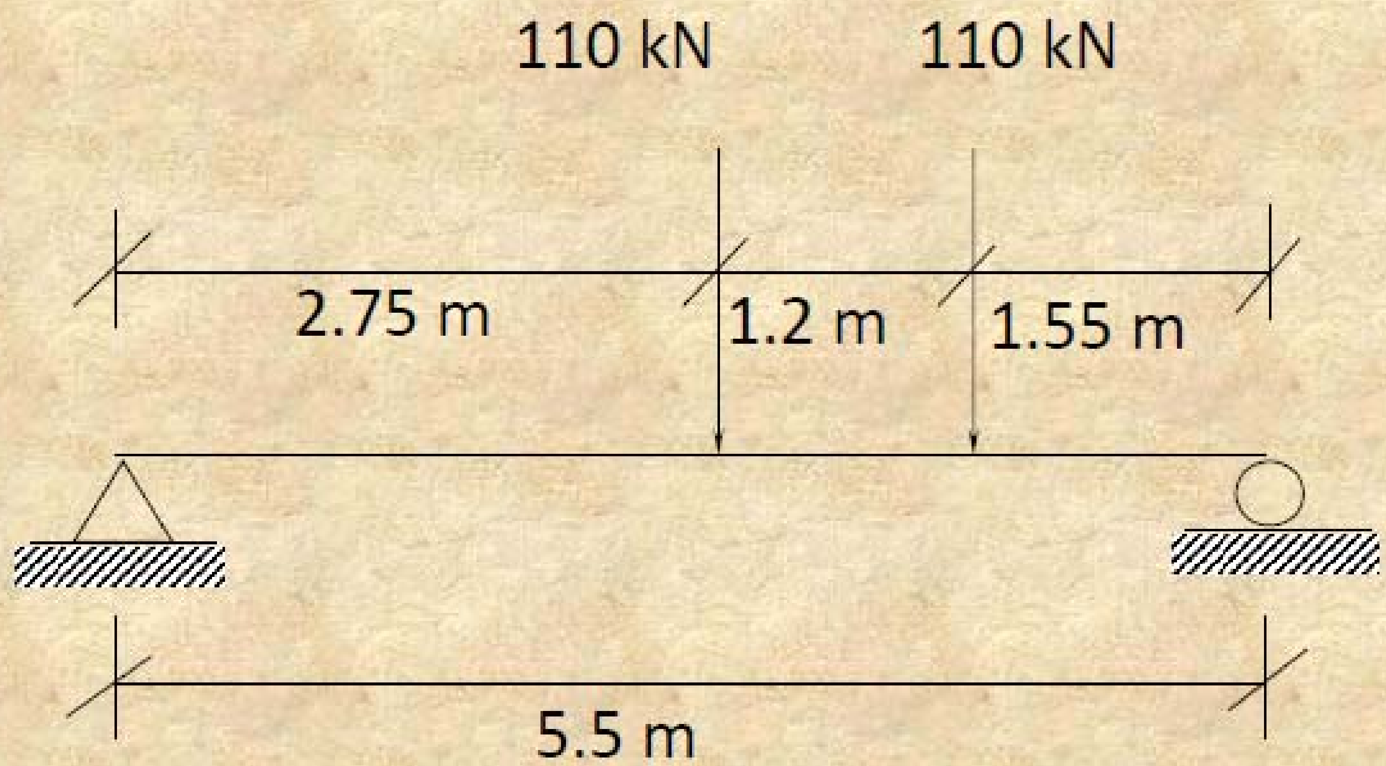


Fig. 21.35. Position of Tandem Loads for Maximum Central Moment.

$$M_{td} = 86 \times 2.75 = 236.50 \text{ kN-m}$$

$$\therefore M_{LL+IM} = 1.33 \times 236.50 + 35.17$$
$$= 349.72 \text{ kN-m}$$

Live Load Shear And Moment For Edge Strip

The shear and moment will be half of that of full strip, but with a multiple presence factor of 1.2.

Live Load Shear And Moment Per unit Width

Interior Strip

V_{LL+IM} = 286.26 / 3.02

= 94.79 kN per 1 m width

M_{LL+IM} = 349.72 / 3.02

= 115.80 kN-m per 1 m width

Exterior Strip

V_{LL+IM} = 286.26 / 2 / 1.80 × 1.2

= 95.42 kN per 1 m width

M_{LL+IM} = 349.72 / 2 / 1.80 × 1.2

= 116.58 kN-m per 1 m width

Dead Load Shears Per unit Width

Interior Strip

Deck slab, DC: $w_{DC} = \frac{350}{1000} \times 2400 \times \frac{9.81}{1000}$

$= 8.24$ kN/m per meter width

Density of bituminous wearing surface

$= 2250$ kg/m^3

Deck wearing surface, DW:

$w_{DW} = \frac{75}{1000} \times 2250 \times \frac{9.81}{1000}$

$= 1.66$ kN/m per meter width

$V_{DC} = 0.5 \times 8.24 \times 5.5 = 22.66$ kN per 1 m width

$V_{DW} = 0.5 \times 1.66 \times 5.5 = 4.57$ kN per 1 m width

Exterior Strip

Assume the barrier (4.65 kN/m) load to be spread over the entire exterior strip. Further, the wearing surface is not present for the width of the barrier.

Deck slab, DC: $w_{DC} = 8.24 + \frac{4.65}{1.800}$

$= 10.83$ kN/m

$$V_{DC} = (0.5)(10.83)(5.5) = 29.77 \text{ kN}$$

Deck wearing surface, DW: $w_{DW} = \frac{1.66(1800 - 380)}{1800}$

$= 1.31$ kN/m

$$V_{DW} = (0.5)(1.31)(5.5) = 3.60 \text{ kN}$$

Dead Load Moments Per unit Width

Interior Strip

w_{DC} = 8.24 kN/m per meter width

w_{DW} = 1.66 kN/m per meter width

$$M_{DC} = \frac{8.24 \times 5.5^2}{8} = 31.16 \text{ kN-m per 1 m width}$$

$$M_{DW} = \frac{1.66 \times 5.5^2}{8} = 6.28 \text{ kN-m per 1 m width}$$

Exterior Strip

$$w_{DC} = 10.83 \text{ kN/m per meter width}$$
$$w_{DW} = 1.31 \text{ kN/m per meter width}$$

$$M_{DC} = \frac{10.83 \times 5.5^2}{8} = 40.95 \text{ kN-m per 1 m width}$$

$$M_{DW} = \frac{1.31 \times 5.5^2}{8} = 4.96 \text{ kN-m per 1 m width}$$

Let,

$\eta = \eta_D \, \eta_R \, \eta_I = 0.95$

$U = \eta \, [1.25 \, DC + 1.50 \, DW + 1.75 \, (LL + IM)]$

Design Shear And Moment

Interior Strip

$V_u = 0.95 \times [1.25 \times 22.66 + 1.50 \times 4.57 + 1.75 \times 94.79]$

$= 191.01$ kN per meter

$M_u = 0.95 \times [1.25 \times 31.16 + 1.50 \times 6.28 + 1.75 \times 115.80]$

$= 238.47$ kN-m per meter

Exterior Strip

$$V_u = 0.95 \times [1.25 \times 29.77 + 1.50 \times 3.60 + 1.75 \times 95.42]$$

$$= 199.12 \text{ kN per meter}$$

$$M_u = 0.95 \times [1.25 \times 40.95 + 1.50 \times 4.96 + 1.75 \times 116.58]$$

$$= 249.51 \text{ kN-m per meter}$$

<u>Design For Flexure</u>

Interior Strip

M_u = 238.47 kN-m per meter

h = 350 with 10 mm sacrificial surface

d = 350 – 10 – 25 – 25 / 2 ≅ 302 mm

Let $a = d/4 \cong 75$ mm

$$A_s = \frac{M_u}{\phi f_y (d - \frac{a}{2})} = \frac{238.47 \times 10^6}{0.9 \times 420 \times (302 - 75/2)}$$

$$= 2385 \text{ mm}^2 \text{ per meter}$$

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{2385 \times 420}{0.85 \times 25 \times 1000} = 47 \text{ mm}$$

$$A_s = 2265 \text{ mm}^2 \text{ per meter}$$

$$a = 45 \text{ mm}$$

$$A_s = 2257 \text{ mm}^2 \text{ per meter}$$

$$= 2.257 \text{ mm}^2 \text{ per mm [\#20 @ 125 mm c/c]}$$

$$a = 45 \text{ mm}$$

$A_{s,\,min} = 0.0018\ b\ h$ (ACI Provision)

$= 0.0018 \times 1000 \times 350$

$= 630\ mm^2$ per meter (OK)

Exterior Strip

M_u = 249.51 kN-m per meter

Let $a \cong 45$ mm

$$A_s = \frac{249.51 \times 10^6}{0.9 \times 420 \times (302 - 45/2)} = 2362 \text{ mm}^2 \text{ per meter}$$

$$a = \frac{2362 \times 420}{0.85 \times 25 \times 1000} = 47 \text{ mm}$$

A_s = 2370 mm^2 per meter

= 2.370 mm^2 per mm [#20 @ 125 mm c/c]

Distribution Steel

%age of distribution steel $= \dfrac{1750}{\sqrt{S}} \leq 50\ \%$

$= \dfrac{1750}{\sqrt{5500}} = 24\ \%$

Interior strip distribution steel

$= 0.24 \times 2257 = 542$ mm^2 per m

Exterior strip distribution steel

$= 0.24 \times 2370 = 569$ mm^2 per m

[#10 @ 175 mm c/c]

Maximum spacing of bars = lesser of 1.5 h and 450 mm = 450 mm

Shrinkage And Temperature Reinforcement

For components less than 1200 mm thick,

$A_{s,\,min} = 0.0018\, b\, h$ (for both layers)

$= 0.0018 \times 1000 \times 350 = 315\ mm^2$ per m for one layer

[#10 @ 300 mm c/c]

Maximum spacing of bars = lesser of 3.0 h and 450 mm = 450 mm

Check For Shear Strength

$$\phi_v V_n = 0.9 \times 0.17\sqrt{25} \times 1000 \times 302 / 1000$$

$$= 231.03 \text{ kN} > V_u = 199.12 \text{ kN} \quad \text{(OK)}$$

The reinforcement details are given in Fig. 21.36.

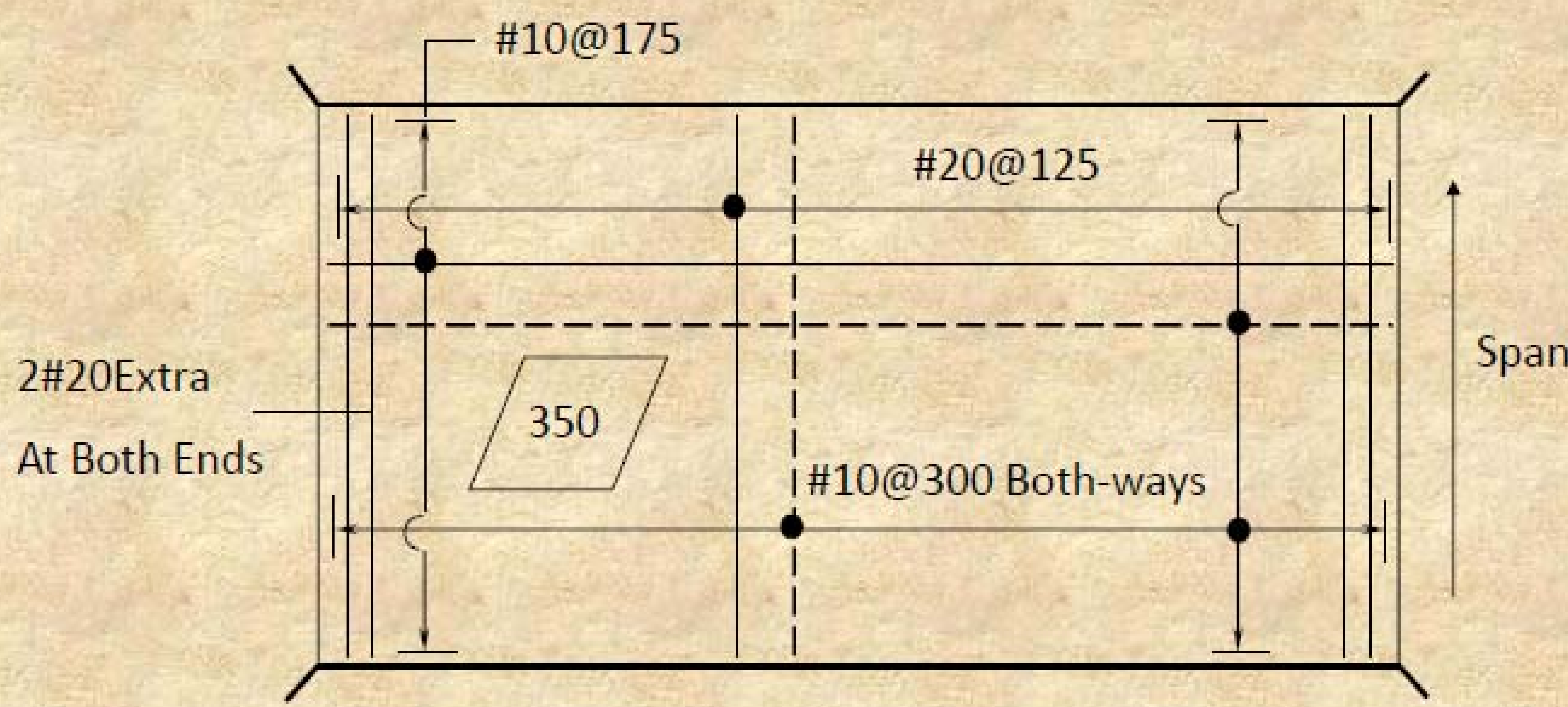


Fig. 21.36. Bridge Slab Reinforcement Details.