: Bridge Engineering:

Introduction:

Bridge is a structure providing passage over an obstacle. without closing the way underneath it.

↳ The passage may be for a
- road
- railway
- pedestrians
- canal or pipeline etc.

↳ As per NRS-2045, bridge is such a cross-drainage structure whose span length is more than 6m. If span length is less than 6m, it is termed as culvert.

Ideal bridge:

↳ Bridge which satisfys all requirements is called as ideal bridge

Characteristics of an ideal bridge:

1. Axis of bridge and direction of flow of river should be perpendicular as far as possible.
2. Line of ideal bridge should not show any deviation from line of approach road at either end.
3. The bridge should be absolutely in level. If it has to be in gradient, it should conform to that of roadway on both sides of the bridge.
4. If the length of bridge is large, camber may be provided throughout the length.
5. The width of bridge should be adequate to cater present as well as future day traffic.
6. The bridge should be able to carry standard loading with a reasonable factor of safety.

vii. The bridge crossing a stream should not produce undue obstruction.

viii. Foundation should be able to carry the imposed load.

ix. The bridge as a whole should fit to surrounding landscape.

x. The ideal bridge should provide services to sewerage, water supply, telephones etc.

xi. There should be adequate provision for drainage of road surface.

xii. The bridge should be economical in cost and maintenance.

Ideal location of a bridge site:

↳ It is necessary to select a site at which bridge can be built economically satisfying the demands of traffic, stream, safety and aesthetics.

characteristics of ideal bridge site:

i. River reach should be straight.

ii. The river bank should be stable.

iii. The width of river channel should be minimum.

iv. The site should be sufficiently avoidable from confluence points.

v. There should not be the necessity of extensive river training work.

vi. There should be availability of hard strata or non-erodable foundations.

vii. There should be no excessive scouring and silting at bridge site.

viii. There should be minimum obstruction to natural waterway.

ix. There should be sufficient clearance for high flood level.

x. Absence of excessive underwater construction work.

xi. Easy availability of construction materials.

Bridge site selection:

↳ Factors to be considered for bridge site selection are:

1. River morphology:
   - ↳ River flow characteristics.
   - ↳ River type, cross current, meandering, type of soil.
   - ↳ straight reach of river
   - ↳ Narrow width.
   - ↳ steady flow in the river.

2. Geological and geotechnical investigation:
   - ↳ River bed should be stable and non-erodable (less scouring)
   - ↳ River bank: rock area (less river training works)
   - ↳ soil engineering properties: coheison (c), friction angle(ϕ
   - ↳ less liable to liquefaction.
   - ↳ Avoid landslide prone zone.

3. Hydrologic and hydraulic parameter:
   - ↳ River linear waterway (lacey perimeter).

$$P = c\sqrt{Q}$$

$$; \quad c = 4.5 \text{ to } 6$$

   - ↳ Maximum flood discharge
   - ↳ Return period
   - ↳ scouring depth (minimum)

$$D_{s.m} = 1.34\left(\frac{q^2}{K_{eff}}\right)^{1/3}$$

mean scouring depth.

4. Traffic study:

↳ traffic volume, intensity, bridge loading (live load)

5. Material survey:

↳ construction material availability.

Conclusion:

↳ The bridge site should be selected such that it should be

- Technically feasible
- Economically viable
- Environmentally sustainable
- Aesthetic factor (landscape)

Classification of bridge:

↳ Bridge can be classified based on:

I. Superstructure
II. Material
III. structural system
IV. Span length
V. Service
VI. support condition
VII. Profile

1. Superstructure:

Bridge types based on superstructure:

a. Slab bridge
b. T-beam bridge
c. Box girder bridge
d. Arch bridge
e. Truss bridge
f. Cable stayed bridge
g. suspension bridge

1. Based on material:

a. Timber bridge

b. Brick bridge

c. RCC bridge

d. steel bridge

e. Pre-stressed concrete bridge

f. composite bridge

III. Based on span:

↳ "Nepal Bridge standard - 2067" classifies bridge as:

a. Culvert (span < 6m)

b. Minor bridge (span ≤ 25m and total length ≤ 50m)

c. Major bridge (span > 25m and total length > 50m)

d. Special bridge (- concrete bridge > 50m)
- truss bridge > 100m
- arch bridge, cable stayed bridge,
- suspension bridge.

IV. Based on structural system:

a. Beam system (slab bridge, T-beam bridge)

b. Truss system (Truss bridge)

c. Arch system (Arch bridge)

d. suspension cable system (suspension bridge)

V. Based on service:

a. Temporary bridge

b. Permanent bridge.

VI. Based on support condition.

a. simply supported bridge.
b. cantilever bridge
c. continuous bridge
d. Rigid frame bridge.

VII. Based on profile:

a. straight bridge.
b. skewed bridge.
c. curve bridge

*: Components of bridge:

The components of bridge are:

a. super-structure
b. Bearing.
c. sub-structure
d. Appertunances and site releated structure.

a. Super-structure:

↳ structural components above bearing level.
↳ includes footpath, railing, wearing course, deckslab
↳ primary member (longitudional girder)
↳ secondary member (cross girder)
↳ arch, suspension cable etc. includes in it.

b. Bearing

↳ Mechanical devices used to transmit the load of super-structure to sub-structure by allowing some rotational and translational movement.

c. Sub-structure:

↳ structural component below the bearing level which transmit load from super-structure safely to sub-structure.

↳ It includes:

- Abutment: end support of bridge which retains earth pressure, water force (static & dynamic)
- Pier: intermediate support resisting hydro-static and hydro-dynamic force i.e water current.
- Abutment and pier cap.
- Foundation (open foundation, deep foundation, well foundation.)

d. Appertenances and site releated structure:

↳ Non-structural components and serve in the overall functioning of the structure.

- embankment and slope protection structure
- approach slab
- river training structure

Based on super-structure: explanation.

1. Slab bridge:

↳ Main load resisting member is deck slab.

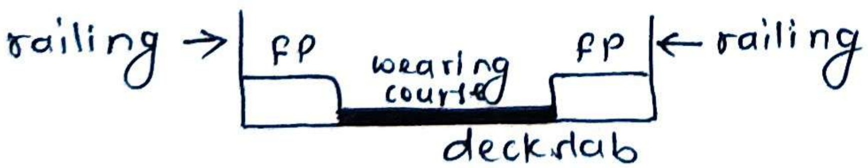


fig: x-section of slab bridge

Positive aspect:
- → increases free board above HFL.
- → lateral load distribution is better. (due to slab action)
- → better appearance.

Negative aspect:
- → uneconomical design for longer span.
- → for longer span dead load increase in slab.

Recommended span:
- → (8-10)m RCC, upto 15m for pre-stressed concrete.

2. T-beam bridge:
- ↳ main load resisting member are deck slab, longitudional & girder and cross girder.

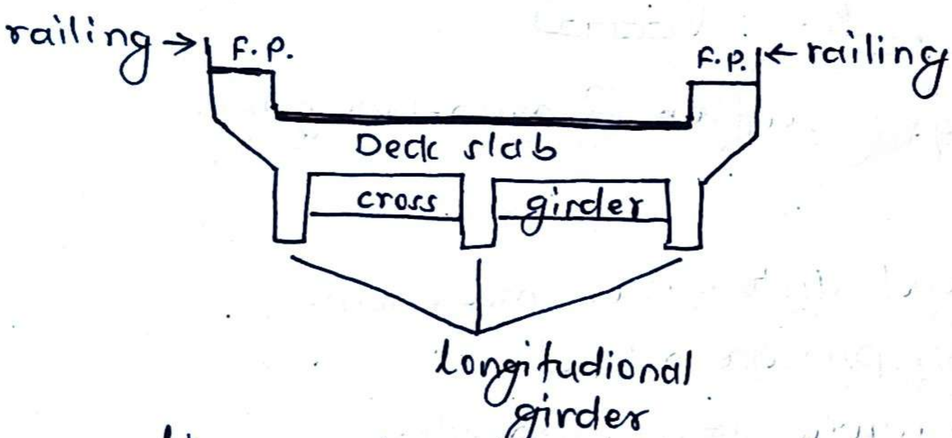


fig: x-section of T-beam bridge

Positive aspect:
- → easy for construction due to monolithic construction
- → more rigidity due to L-beam, x-beam and deck slab

Negative aspect:
- → less vertical clearance above HFL.
- → bulky appearance (less aesthetic).
- → dead load increases

Recommended span:

→ upto 25m, RCC, upto 35m for pre-stressed concrete

3. Box-girder bridge:

↳ Main load resisting member is girder.

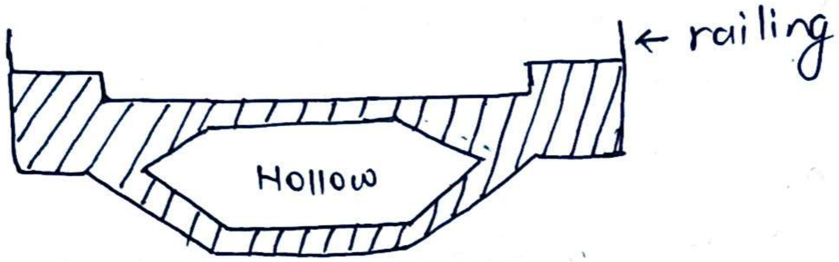


fig: x-section of box-girder.

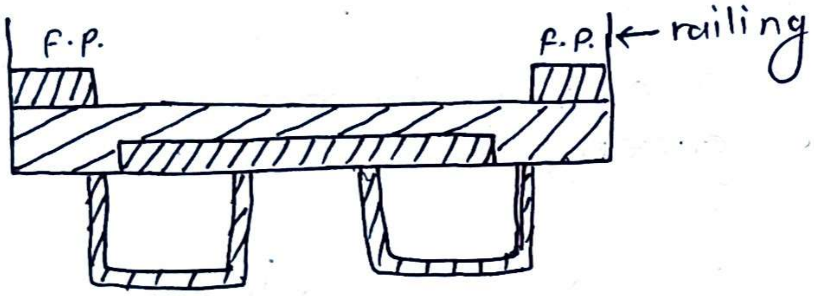


fig: x-section of multi-box girder

Positive aspect:

→ good lateral load distribution mechanism.
→ no. of bearing, pier are reduced.
→ mainly used in curved bridge profile
→ preferred pre-cast.

Negative aspect:

→ high technology required, costly.
→ high degree of supervision
→ highly skilled labour.

Recommended span:

→ upto 60 m RCC,

4. Truss bridge:

↳ Main load resisting structural member is truss system. (tension chord or compression chord).

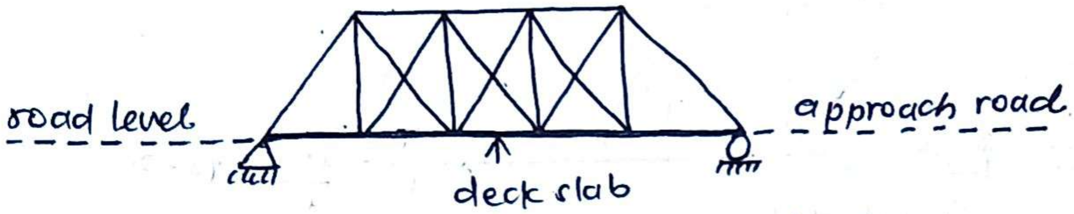


fig: through type truss.

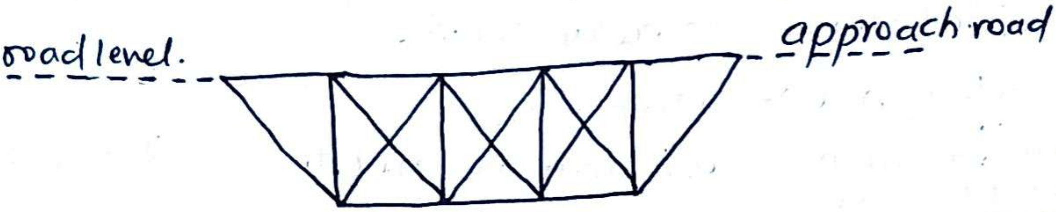


fig: deck type truss.

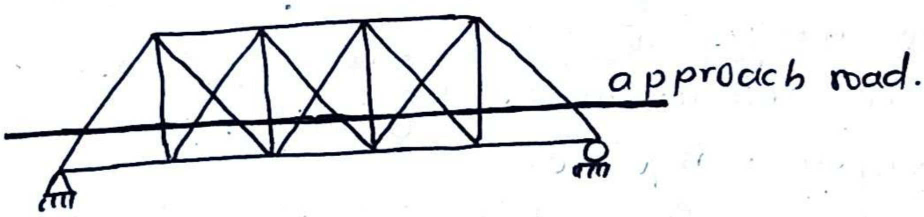


fig: semi-trough type truss.

Positive aspect:

→ speed of construction is fast.

→ economical construction.

→ minimum internal stress (i.e. only axial force)

Negative aspect:

→ regular maintenance required (corrosion, loosing joints etc)

→ fast fatigue phenomena.

→ bulky appearance.

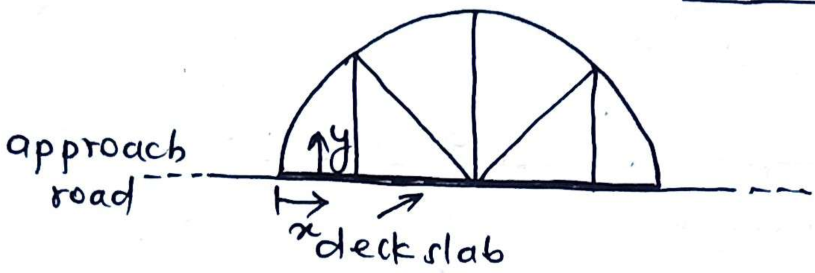
Recommended span:

→ Upto 100 m generally.

5. Arch bridge:

↳ Main load resisting member is arch system.

$\boxed{\text{arch must be square parabola}}$



$$y = \frac{4hx}{l}(l-x)$$

fig: x-section of arch bridge

Positive aspect:

→ due to horizontal thrust, it reduces B.M.

→ economical design (x-section slim)

→ proportioning of arch is such that its profile resists minimum internal force.

• funicular shape arch ⇒ BM = 0, SF = 0

Negative aspect:

→ formwork costly.

→ complex construction methodology.

→ skill manpower required.

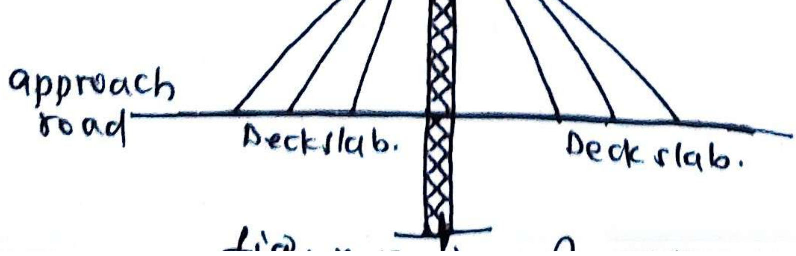
→ aesthetic purpose is governing factor.

Recommended span:

→ upto 150 m for pre-stressed concrete, steel structure

6. cable stayed bridge:

↳ Main load resisting member is tower and cable.



Positive aspect:

- no. of pier, bearing, foundation are greatly reduced.
- cable is always designed for tension.
- tower transmits compressive load to foundation.
- for longer span suitable, to avoid underwater construction.

Negative aspect:

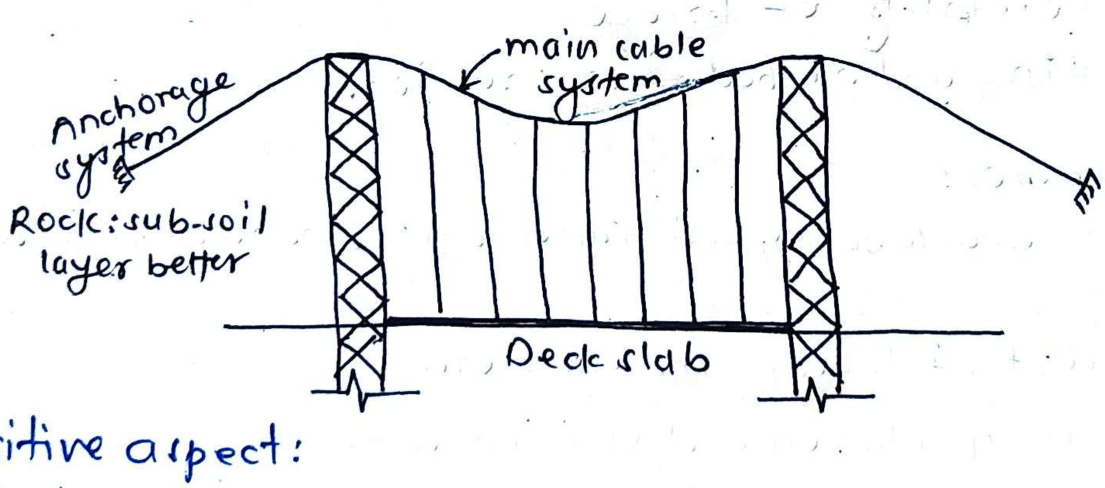
- high experienced workmanship.
- high degree of supervision.
- high skilled manpower.
- costly technique.

Recommended span:

- upto 600m generally.

6. Suspension bridge:

- Main load resisting member is cable system.



Positive aspect:

- gives better appearance
- requires less no. of expensive bearing, piers etc.
- cover long span.

Negative aspect:

- stable foundation required
- more expensive for short span
- requires through maintenance
- initial investment cost is high

*: Recommended span.

- upto 1.5 km generally.

Selection of appropriate type of bridge:

↳ Selection of appropriate type of bridge structure is most critical and most challenging part of design of bridge.

*: Governing factors for the selection of appropriate type of bridge are:

a. Technical factor
b. Economical factor
c. Environmental factor
d. Aesthetical factor.

a. Technical factor:

↳ Related with the technical requirements such as:

(i) span coverage
(ii) Hz. and Vt. clearance
(iii) sub-soil condition.
(iv) Durability of bridge
(v) Time and method of construction.

b. Economical factor:

↳ Related with availability of fund and financial resources such as

(i) cost of labours, materials etc
(ii) Transportation and erection cost.
(iii) cost of construction
(iv) maintenance cost. etc

c. Environmental factor:

↳ Related with the impact of structure on environment, marine life, human life and plant life.

d. Aesthetical factor:

↳ Releated with the quality of beauty and functionality. such as:

(i) Appearance
(ii) colour
(iii) Proportion
(iv) contrast
(v) scale
(vi) order
(vii) functionality etc

↳ considering all these factors, we can select appropriate type of bridge.

a. Based on span length:

↳ short span length: RCC slab-bridge, T-beam bridge

↳ long span length: suspension bridge, cable stayed bridge

b. Based on duration of service:

↳ short period: temporary bridge

↳ long period: steel, RCC, arch bridge etc.

c. Based on geological and geotechnical consideration:

↳ Hard rock at low depth: RCC slab bridge, T-beam bridge

↳ low to moderate strength strata at top: cable stayed, suspension cable bridge

d. Based on aesthetic consideration:

↳ High aesthetic consideration: cable stayed, suspension cable arch bridge

↳ low aesthetic consideration: RCC T-beam, slab bridge

e. Based on economy:

↳ High budget: cable stayed, suspension cable, arch.

↳ Low budget: RCC slab bridge, T-beam bridge etc.

*! Load, forces and stress to be considered for the design of appropriate type of bridge:

↳ As per Nepal bridge standard-2067, for design of bridge IRC loading or AASTHO loading should be considered unless and otherwise specified, always use IRC loading.

↳ As per IRC-6 : 2016 standard specification and code for practice for road bridge; part-II (Load and load combination)

↳ The following are the load forces and stress to be considered for design of appropriate type of bridge:

(i) Dead load: self weight of super structure & sub-structure.

(ii) Live load: vehicular load. exam

(iii) Impact load: dynamic load (due to vehicle)

(iv) longitudional force:
   - longitudional force due to braking effect.
   - longitudional force due to tractive effect
   - longitudional force due to frictional effect.

(v) Earth pressure force.

(vi) Water current : (hydrostatic & hydrodynamic)

(vii) Misfit: fabrication error, erection error.

(viii) shrinkage, creep effect.

(ix) Earthquake load (lateral dynamic load). exam

Description:

① Live load : vehicular moving load:

IRC loading:

- Normal load
  - includes wheels vehicles
    - a. IRC Class 'A' loading
    - b. IRC class 'B' loading
- Abnormal load
  - Includes wheels and tracked vehicles
    - a. IRC class '70R' loading.
    - b. IRC class 'AA' loading.
- special vehicle load:
  - includes loading due to special vehicle

a. IRC class 'A' loading:

- IRC class 'A' type loading consists of wheel vehicles train comprising a driving unit and trailer unit of specified axle load.
- IRC class 'A' loading is normally adopted on all roads on which permanent bridge and culverts are constructed.
- Bridge designed for class 'A' loading should be checked for class '70R' and class 'AA' loading.
- one train of class 'A' loading occupies one lane of carriageway of bridge.

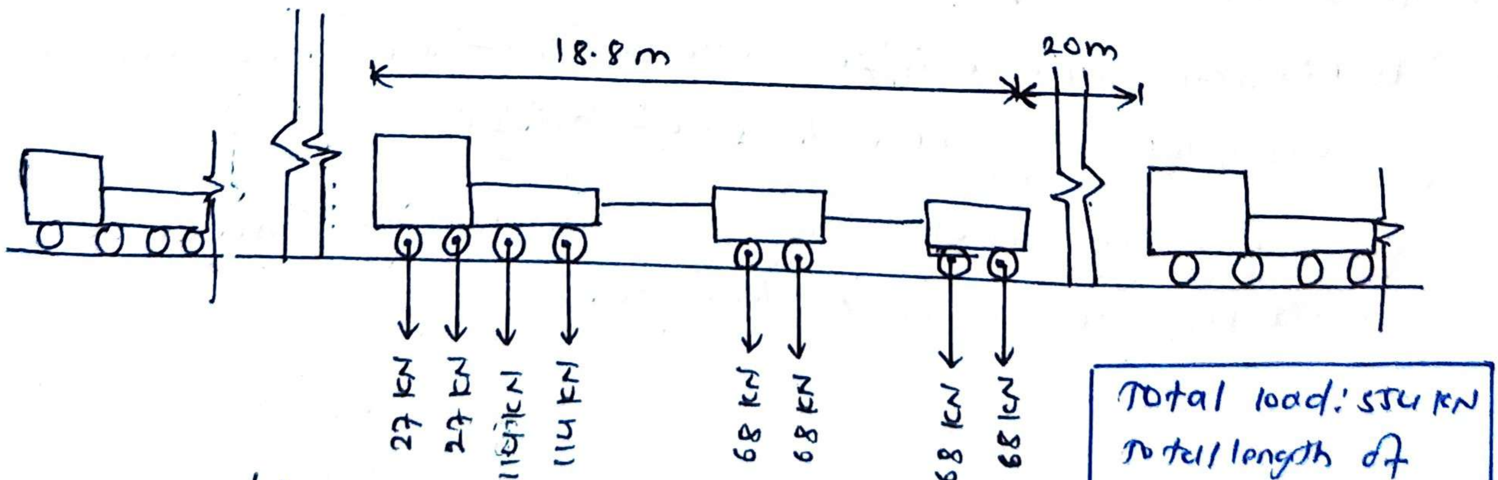


fig: L-section of passing vehicle:

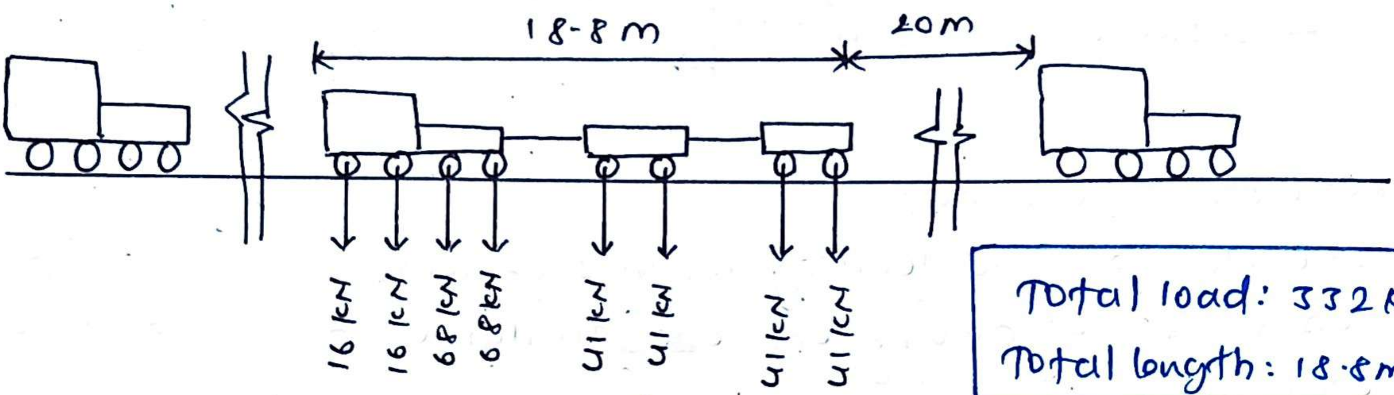
Application:
- To design T-beam girder.

b. IRC class 'B' loading:

↳ similar to class 'A' loading but axle load having smaller magnitude.

↳ Applicable for temporary bridge (timber bridge, short period functioning bridge)

↳ One train of class 'B' loading occupies one lane of carriage



Total load: 332 kN
Total length: 18.8m

fig: L-section of passing vehicle.

c. IRC '70R' loading:

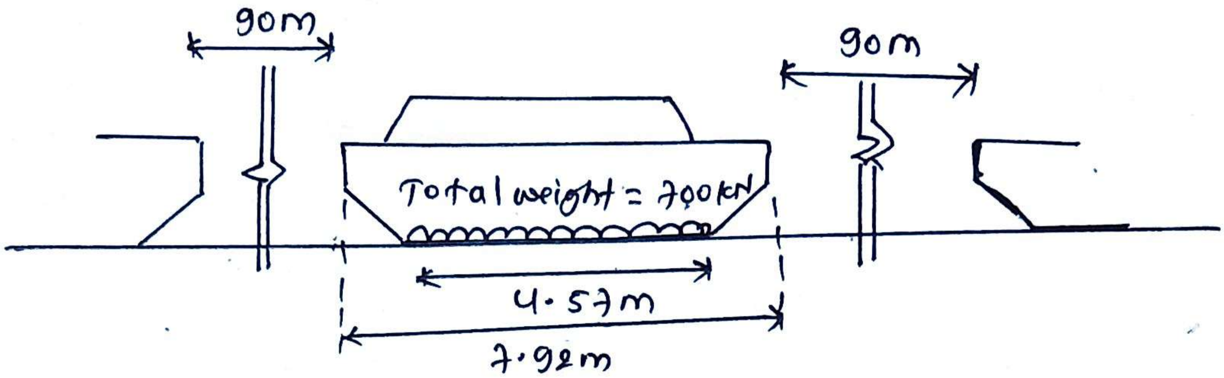
↳ This is a revised version of class 'AA' loading and consists of tracked and wheeled vehicles.

↳ It is adopted on all type of road on which permanent bridge is to be constructed.

↳ For multilane bridge, one train of class '70R' loading occupies every two lane of bridge.

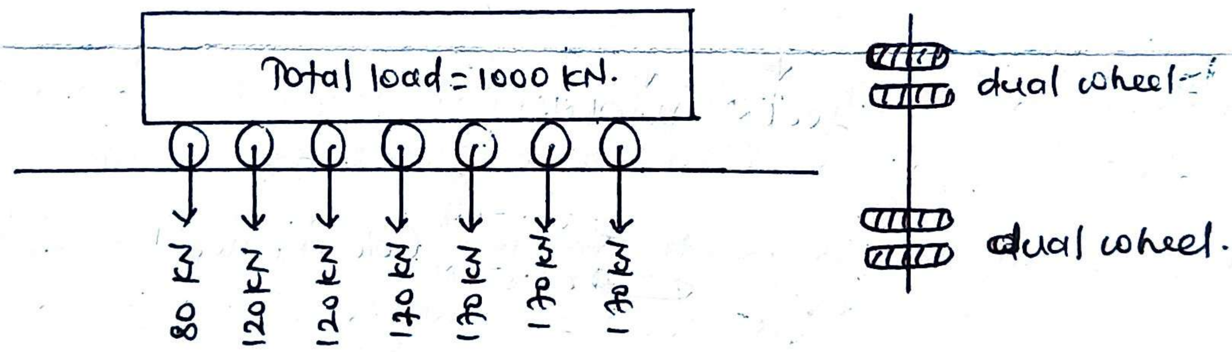
↳ Bridge designed for class '70R' loading should be checked for class 'A' loading.

(i) IRC class '70R' tracked vehicle:



(ii) IRC class '70R' wheeled vehicle:

↳ seven axled wheel load.



d. IRC class 'AA' loading:

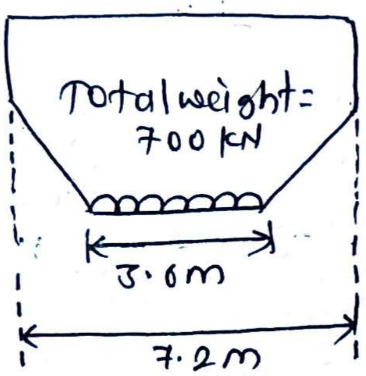
↳ It consists of either wheeled vehicle or tracked vehicle.

↳ One train of class 'AA' loading consists of every two lane of bridge.

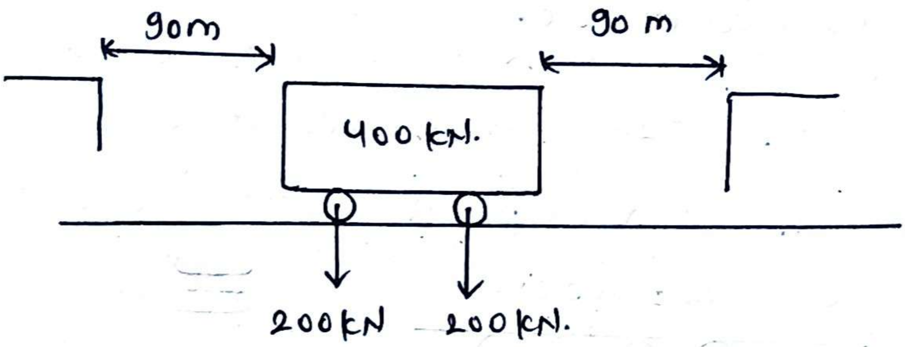
↳ Adopted for design of road bridge for national highway.

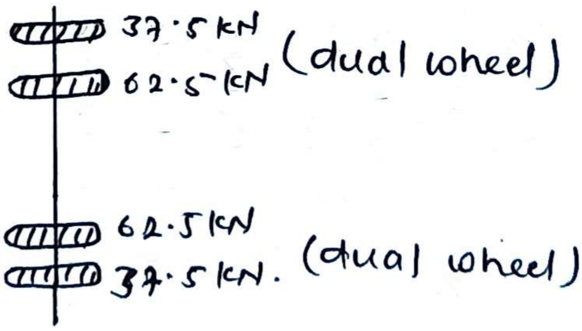
↳ Bridge designed for class 'AA' loading should be checked for class 'A' loading.

① IRC class 'AA' tracked vehicle:



⑪ IRC class 'AA' wheeled vehicle:





e. IRC class special vehicle loading:

↳ Adopted for design of new bridge in selected corridor as may be decided by the concerned authority where passag of trailer vehicle carrying strator unit, turbine unit, heavy equipment and machinery may occurs occasionally.

↳ Special multi-axle hydraulic trailer vehicle (prime mover wi 20 axle trailer, GVW = 385 ton = 3850 kN).

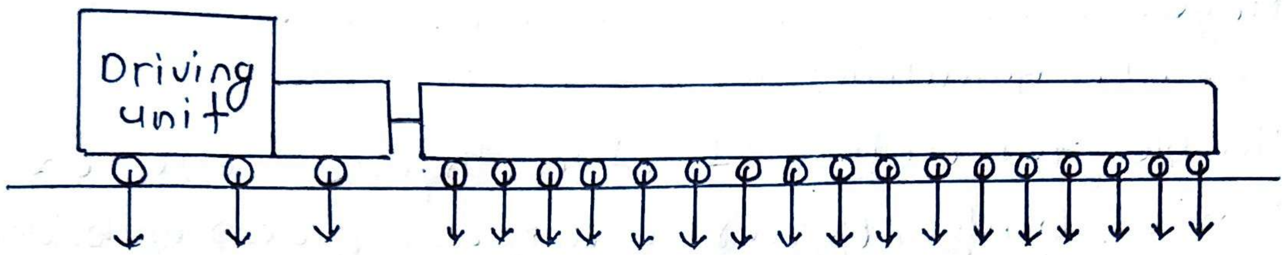


fig: IRC class special vehicle loading.

*: Live load combination:

*! Seismic load calculation:

↳ IRC: SP-114 : 2018 provides a guidelines for seismic design of bridge.

A. Scope of the Guideline!

1. Applicable for assesment of earthquake forces and design of bridge, flyover, underpass, pedestrian bridge, submersible bridge and utility bridge.

2. Applicable for bridges with design life upto 100 years and shall be designed for design basis earthquake (DBE) only.

3. Applicable for seismic evaluation and strengthening of existing bridge i.e. retrofitting.

4. Ductile detailing of pier (plastic hinge formation).

B. Relaxation clauses:

↳ seismic load should not be considered for following types of bridge:

1. Culverts and minor bridge upto 10m length in all seismic zone should not be designed for seismic load.

2. Bridge is seismic zone (II) and (III) which satisfies both condition
   - total length ≤ 60 m
   - span length ≤ 15m

   } seismic load should not be considered.

3. Dynamic earth pressure on abutment during earthquake shall not be considered in zone (II) and (III).

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c. Design philosophy:

1. Under design basis earthquake (DBE), a moderate earthquake which occurs frequently and causes moderate damage i.e. controllable damage.

   example:

   - moderate crack within permissible limit
   - design life upto 100 years.

2. Under maximum consider earthquake (MCE), large earthquake which occurs once during the life of a structure

   example:

   - major damage of bridge takes place
   - uncontrollable damage but not totally collapse.
   - design life > 100 years.

Q. Methods of seismic load calculation:-

1. Elastic seismic Acceleration Method (ESAM) or seismic coefficient method:

   ↳ static linear analysis should be performed.

   Application of ESAM:

   (i) low to medium height of pier with small span length.

   (ii) Structure is analysed with fundamental mode of vibration.

   (iii) Pier height of bridge less than 30m.

   (iv) Bridge having no abrupt or unusual change in mass, stiffness or geometry along its span.

   (v) Straight profile i.e. not curved or skew bridge.

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∴ Horizontal seismic force $(F_H) = A_h \times W$

; where A_h = design horizontal seismic coefficient.

$$A_h = \left(\frac{Z}{2}\right) \times \left(\frac{I}{R}\right) \times \left(\frac{S_a}{g}\right)$$

; where Z = zone factor depends on type of zone

eg: Z = 0.36 for zone(V).

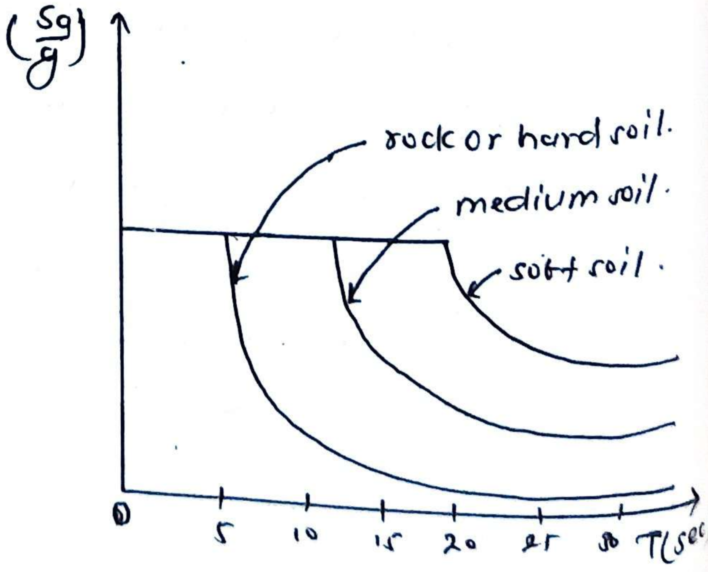
I = Importance factor.

- Normal bridge = 1
- Important bridge = 1.2
- Special bridge = 1.5

R = Response Reduction factor.

- R = 1 for bearing and expansion joint.
- R = 3 for ductile detailing of pier.

$\left(\frac{S_a}{g}\right)$ = design response spectrum value. obtained from.



2. Elastic Response spectrum Method (ERSM):

Application of ERSM

(i) suitable for more complex structural system i.e. curved profile, skew bridge.

(ii) continuous bridge, bridge with large difference in pier height. i.e. abrupt change in mass, stiffness.

(iii) structure is analysed with fundamental as well as other modes of vibration.

(iv) Dynamic linear analysis is carriedout.

(v) principle of superposition holds good.

(vi) Pier height more than 30 m.

(vii) Arch bridge of span more than 80 m.

(viii) cable stayed bridge, suspension bridge etc मा लाग्छ!

Procedure for ERSM:

step (i): Formulation of an appropriate mathematical model consisting of lumped mass system using 2D beam element.

step (ii): Determine modal frequency and mode shape (modal run)

step (iii): Determine total response by combining response in various modes by modal combination procedure.
eg: square root of sum of square (SRSS) method.
complete quadratic combination (CQC) method.

step (iv): calculation of base shear value for each modes using modal combination procedure.

3. Time-History Method: (THM):

↳ Dynamic non-linear analysis method.

↳ special seismic devices such as damper, isolator, shock transmission unit are provided.

Application of THM:

(i) In bridge where pier height are extremely high, unusual change in mass stiffness (complex).

(ii) Liquefaction potential site near by field i.e active seismic fault within 10 km periphery.

Procedure:

(i) Identify material non-linear properties.

(ii) select seismic demand i.e. ground acceleration based on record of past earthquake.

Method of lateral load distribution in bridge deck analysis:
↳ several methods for lateral load distribution are:

a. Courbon's method
b. Distribution coefficient method
c. Effective width method
d. Method of Elastic support.
e. AASTHO method.
f. Finite element method.

a. Courbon's method:

↳ Distribution of bridge deck slab load into longitudional girder.

↳ Simple, powerful and highly popular method for longitudional girder analysis.

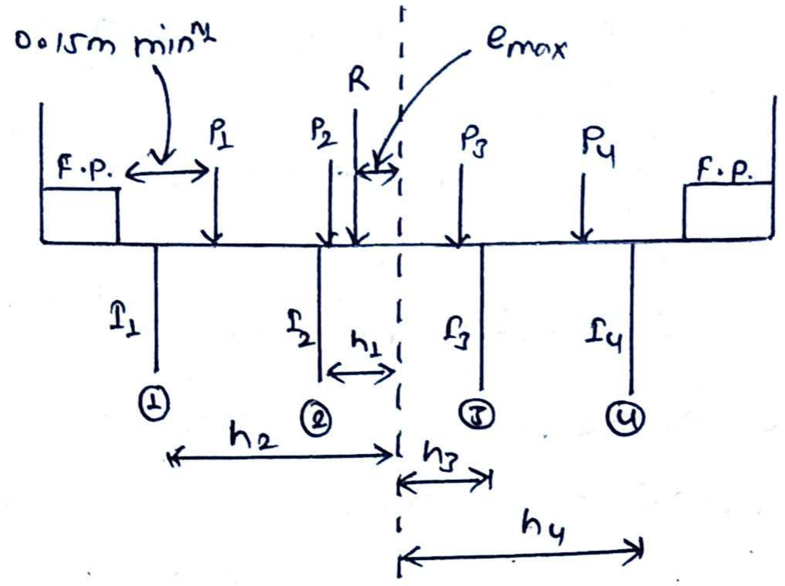
*: conditions of use:

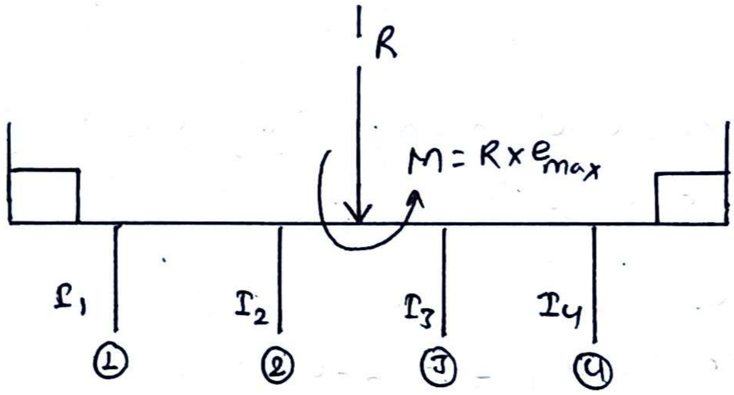
(i) Bridge deck slab ($\frac{L}{B} = 2-4$)

(ii) No. of cross beam interconnecting longitudional girder should be minimum 5.

(iii) Depth of cross girder should be equal to 0.75 times the depth of longitudional girder.

↳ Here, deck slab distributes load to longitudional girder.





Here, R is the resultant of live load.

P_1, P_2, P_3 & P_4 are the trains of live load.

I_1, I_2, I_3 & I_4 are the MOI of girder 1, 2, 3 and 4 respectively.

- load shared by first girder.

$$= \left[\frac{R \times I_1}{\Sigma I}\right] + \left[\frac{M \times h_1 \times I_1}{\Sigma I h^2}\right]$$

- load shared by second girder.

$$= \left[\frac{R \times I_2}{\Sigma I}\right] + \left[\frac{M \times h_2 \times I_2}{\Sigma I h^2}\right]$$

- load shared by third girder.

$$= \left[\frac{R \times I_3}{\Sigma I}\right] - \left[\frac{M \times h_3 \times I_3}{\Sigma I h^2}\right]$$

- Load shared by fourth girder.

$$= \left[\frac{R \times I_4}{\Sigma I}\right] - \left[\frac{M \times h_4 \times I_4}{\Sigma I h^2}\right]$$

b. Distribution coefficient method:

- This method is based on orthographic plate theory.
- Used to determine load on each girder.
- Distribution coefficient depends upon torsional and stiffness.

$$\text{Distribution coefficient } (K) = \frac{\text{load carried by specified girder}}{\text{avg. load per girder.}}$$

$$K = \frac{\left(\frac{P}{n} + \frac{P e x_i}{\Sigma x_i^2}\right)}{(P/n)}$$

$$K = \left(1 + \frac{e n x_i}{\Sigma x_i^2}\right)$$

- Distribution coefficient is defined as the load carried by specified girder to the average load per girder.
- It is denoted by 'K'.

Cases:

case (i): If number of wheels are positioned on transverse deck slab then,

$$K = \frac{\Sigma P}{n}\left(1 + \frac{e n x_i}{\Sigma x_i^2}\right)$$

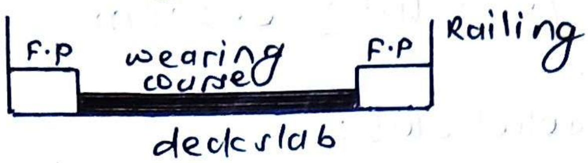
case (ii): If girder have different MOI:

$$K = \frac{\Sigma P}{n}\left(1 + \frac{e n x_i I_i}{\Sigma I_i x_i^2}\right)$$

Structural design of slab bridge:

*: slab bridge:

↳ main load resisting member is deck slab.



Positive aspect:

↳ increased F.B above HFL.

↳ lateral load distribution is better.

↳ better appearance.

Negative aspect:

↳ uneconomical design for longer span.

↳ dead load increases drastically for longer span.

Recommended span:

↳ (8-10) m for RCC, upto 15m for pre-stressed concrete.

Design procedure:

step:1 planning and pre-liminary design of slab bridge:

Planning: functional planning:

↳ site selection, traffic volume, type of bridge, profile of bridge, no. of lane.

↳ settlement and land acquisition.

Preliminary design:

↳ no. of lane

- single lane 4.5 to 4.75 m
- intermediate lane = 6 m
- double lane = 7.5m.

↳ railing height (h) $\geq$ 1.1 m

↳ width of footpath (b) $\geq$ 0.6 m each side.

↳ Height of foot path (H) $\geq$ 0.225 m

↳ Thickness of solid slab:

- From deflection control criteria:

$$D = \left(\frac{span}{15}\right) \text{ to } \left(\frac{span}{12}\right) \text{ for simple slab.}$$

$$D = \left(\frac{span}{25}\right) \text{ to } \left(\frac{span}{20}\right) \text{ for continuous slab.}$$

Step: 2 load calculation:

↳ Dead load: self weight, footpath, railing, wearing coat etc

↳ Live load: IRC-6: 2016 → IRC loading.

↳ Seismic load: IRC-SP 114: 2018

Step: 3 Structural analysis of solid slab:

↳ It involves calculation of..

- Max^m longitudional bending moment.
- Max^m longitudional shear force
- Max^m transverse bending moment.

<u>Note:</u> All these are analysed considering 1m width of slab.

- Max^m longitudional bending moment:

(i) considering dead load

$$DL(BM) = \frac{wl^2}{8}$$

(ii) considering live load

LL (BM) = ... using IRC for
- tracked load.
- wheeled load.

∴ Max^m longitudional BM = DL(BM) + LL(BM)

- Maximum transverse bending moment:
  ↳ from codal provision.

$$= 0.2 \times DL(BM) + 0.3 \times LL(BM).$$

- Maximum longitudional shear force:
  ↳ considering
  Dead load = ---
  Live load = ---

Step: 4 Design of solid slab:

- Calculation of depth of slab:

$$(M_{u,lim})_{long.\ BM.} = 0.138\, f_{ck}\, b d^2$$

$$\Rightarrow d = \sqrt{\frac{M_u}{0.138\, f_{ck}\, b}}$$

If $d_{provided} > d$, design singly reinforced slab

If $d_{provided} < d$, design doubly reinforced slab.

• Calculation of longitudional reinforcement: $(A_{st})_L$

$$M_{u_L} = 0.87 f_y (A_{st})_L \left(d - \frac{f_y (A_{st})_L}{f_{ck} \cdot b}\right)$$

$(A_{st})_L =$ ----

↳ check for $(A_{st})_{min}$ & spacing.

• calculation of transverse bottom reinforcement. $(A_{st})_b$.

$$M_{u_t} = 0.87 f_y (A_{st})_b \left(d - \frac{f_y (A_{st})_b}{f_{ck} \cdot b}\right)$$

↳ check for $A_{st\,min}$ & spacing.

Step: 5 check for shear and deflection:

↳ calculate longitudional max^m SF.

↳ Nominal shear stress: (τ_v)

↳ Design shear strength (τ_c)

• If $\tau_v < k\tau_c$, no shear reinforcement.

• If $k\tau_c < \tau_v < \tau_{c\,max}$, design shear reinforcement.

for deflection,

$$\left(\frac{l}{d}\right)_{actual} < \left(\frac{l}{d}\right)_{permissible} \text{ (ok)}.$$

step: 6 Detailing

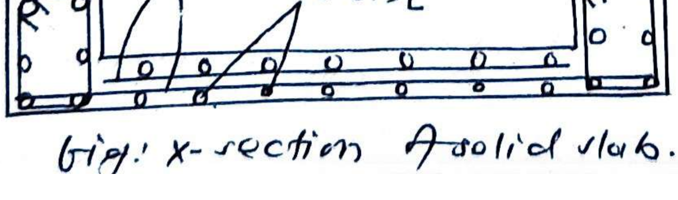


Fig: X-section of solid slab.

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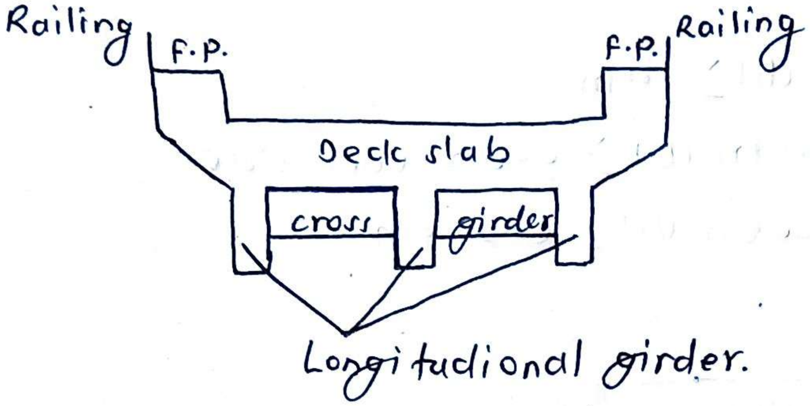
*: Design of T-beam bridge:

T-beam bridge:

- main load resisting structural member are deck slab, longitudional girder, cross girder.



Positive aspect:

- easy construction due to monolithic construction.
- more rigidity due to L-beam, x-beam and deck slab.

Negative aspect:

- less vertical clearance above HFL.
- Bulky appearance
- Dead load increases drastically.

Recommended span:

- generally span upto 20 m, RCC
- span upto 35 m, prestressed.

*: Design procedure:

Step: 1 Planning and pre-liminary design:

Planning: functional planning:

- site selection, type of bridge, profile of bridge, traffic volume, number of lane.

Preliminary design:

↳ No. of lane

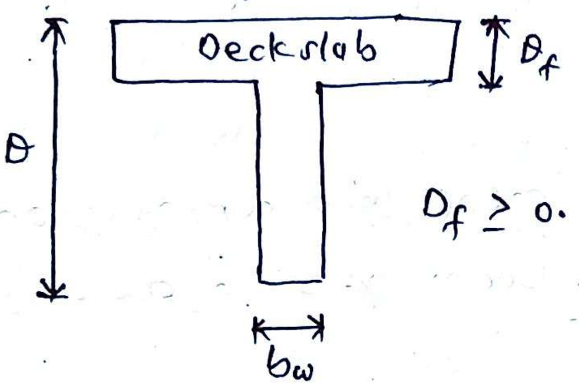
- single lane = 4.5 to 4.75 m
- intermediate lane = 6 m
- two lane = 7.5 m

↳ railing height (h) ≥ 1.1 m

↳ width of footpath (b) ≥ 0.6 m each side

↳ height of footpath (H) ≥ 0.225 m

↳ T-beam:



$D_f \geq 0.2 m$

↳ Depth of T-beam from deflection control criteria.

$$D = \frac{span}{15} \text{ to } \frac{span}{20}, \text{ for simple span.}$$

$$D = \frac{span}{20} \text{ to } \frac{span}{25}, \text{ for continuous span.}$$

↳ width of deck slab (b_w) = 0.6 to 1m

↳ spacing of longitudional girder (s) = 2-3 m.

↳ spacing of cross girder = 4 to 5 m

↳ depth of cross girder = $\frac{3}{4}$ depth of longitudional girder.

↳ No. of cross girder = min^m 5.

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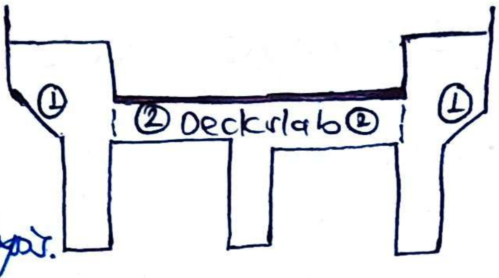
step: 2 Load calculation:

↳ Dead load: self weight, footpath, railing, wearing coat etc.

↳ live load: IRC-6 : 2016 → IRC loading

↳ seismic load: IRC SP: 114 - 2018

step: 3: structural analysis of deckslab, longitudional girder and cross girder:



①: cantilever slab.

②: restrained slab.

*: Deckslab analysis.

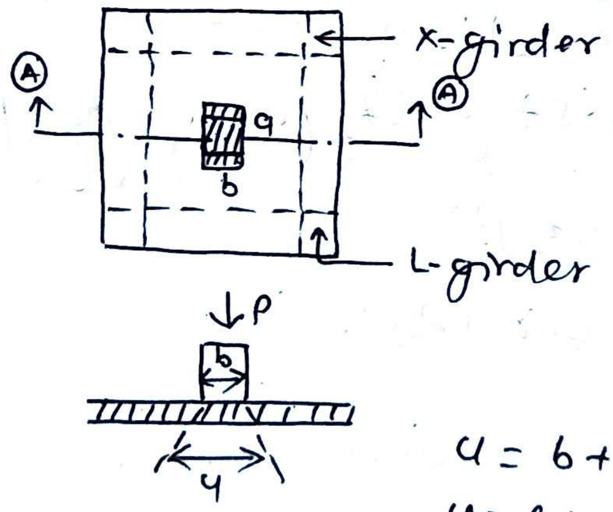
a. Cantilever slab:

↳ effective width method is used.

b. Fixed or restrained slab:

↳ calculate maximum BM from dead load.

↳ Calculate maximum BM from live load: Pigeaud's method.



$u = b + 2h$

$v = l + 2h$.

- a & b are dimension of tyre contact area
- μ = poisson's ratio
- m_1 & m_2 are moment coefficients.

$M_1 = (m_1 + \mu m_2) P$

$M_2 = (m_2 + \mu m_1) P$

; where M_1 & M_2 are bending moment along short and long span.

*: Longitudional girder analysis:

↳ Dead load distribution

↳ Live load distribution : courbon's method.

*: cross-girder analysis:

↳ generally $0.75 \times max^m$ BM in longitudional girder.

step:4 Design of T- beam:

- Longitudional girder:

↳ Depth of girder

$$M_{u\,max} = 0.138\, f_{ck}\, d^2$$

$$\Rightarrow d_{req} = \sqrt{\frac{M_{u\,max}}{0.138\, f_{ck}\, b}} = ---$$

Adopt $d \geq d_{req}$.

↳ Tension bar (A_{st_1}):

$$M_{u,lim} = 0.87\, f_y\, A_{st_1} \left(d - \frac{f_y A_{st_1}}{f_{ck} b}\right)$$

↳ Tension bar (A_{st_2}):

↳ compression bar (A_{sc}):

step:5 Check for shear and deflection:

Nominal shear stress (τ_v).

Design shear strength (τ_c).

If $\tau_v > \tau_c$, design shear reinforcement.

step: 6 Reinforcement detailing:

↳ provide sufficient

- development length
- curtailment
- splicing.

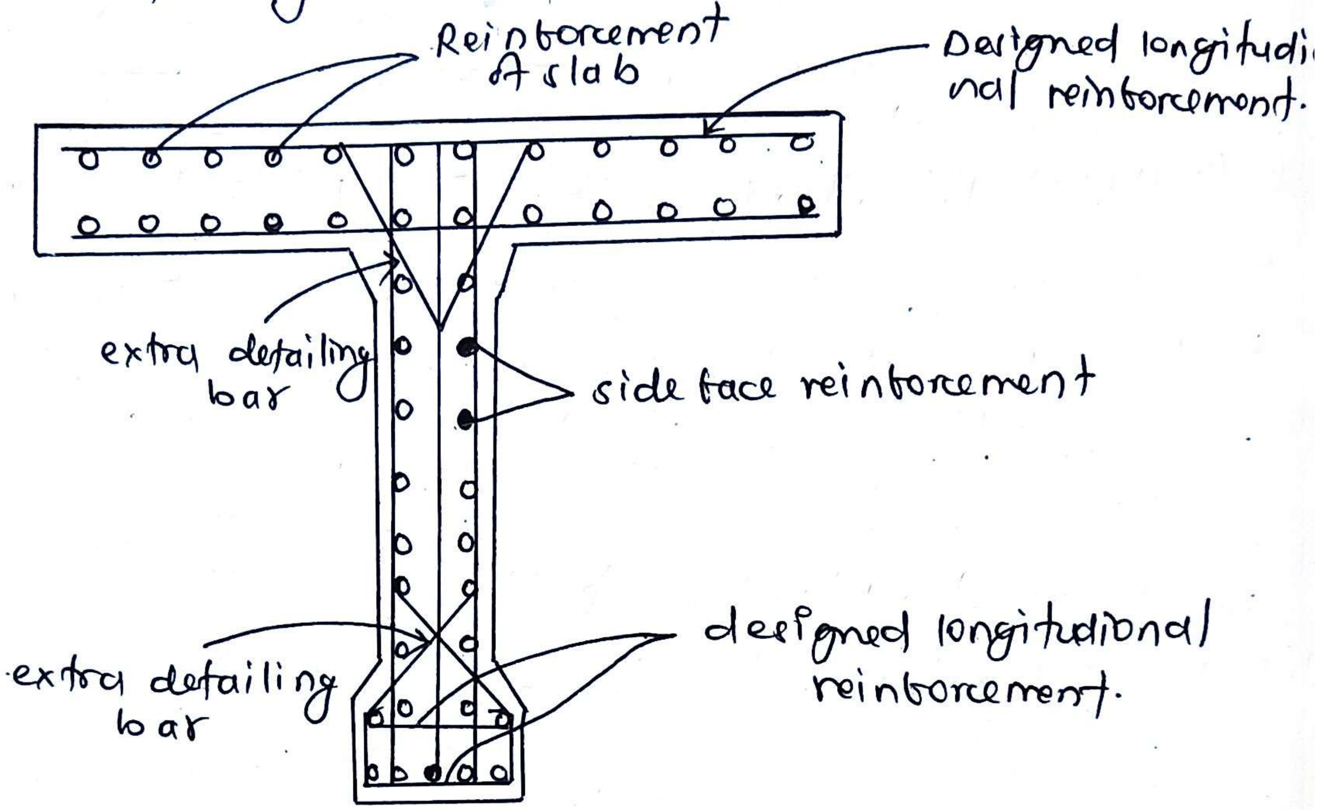


fig: detailing.

Structural analysis of longitudional girder:
(Use of ELB)

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Failure of bridge in Nepal:

*! Status of bridge in Nepal: website date: BMS

↳ According to department of roads (DoR) data, till 2022 AD

- there are approximately 2800 number of bridge in strategic road network (SRN).
- there are approximately 1200 number of bridge in local road network (LRN).

↳ Therefore total no. of bridge in nepal = 4000 Nos.

↳ In an average 1m bridge construction costs 10 lakhs.

↳ In an average length of one bridge is 50m.

∴ Total length of bridge = 4000 × 50
= 2,00,000m.

↳ Avg. total bridge assets = 20,0000 × 10 lakhs
= 200 billions.

*! Failure of bridge in Nepal:

↳ In 2021, total 22 Nos of bridge (under construction and operation) failed.

↳ Jogighat bridge failure in 2017 → pile / pile settlement.

↳ Kamala bridge (postal highway) → pier settlement

*: causes of failure of bridge:

a. Design lapses.

b. Construction defects.

c. Maintenance lacking.

a. Design lapses:

(i) Insufficient number of geotechnical investigation.

↳ lack of borehole drill test

↳ proper soil type study lacks

(ii) Hydrological and hydraulic issues.

↳ return period of 100 yrs needs to be revised.

↳ linear waterway needs to be accessed.

↳ sufficient scouring depth to be provided.

- mean scouring depth, $d_{sm} = 1.34\left(\frac{q_b^2}{K_{eff}}\right)^{1/3}$

; where $q_b = \frac{\text{flood discharge}}{\text{linear waterway}}$

$K_{eff} = 1.76\sqrt{d_{mm}}$

- max^m scour depth $(d_{max}) = 2 \times d_{sm} \rightarrow$ pier

$= 1.27\, d_{sm} \rightarrow$ abutment.

↳ minimum depth of foundation = max^m scour depth + grip length

b. construction defects:

↳ lack of supervision, weak quality control.

↳ temporary support failure

c. lack of maintenance:

↳ River training work, sedimentation flush, Retrofitting strengthening, bearing replacement etc.

*: Economic span length of bridge:

↳ The span length of bridge for which the total cost of bridge will be minimum is known as economic span of bridge.

Derivation:

Let the ratio of cost of one span to one pier be 'R'

$$R = \frac{S}{P} \Rightarrow S = RP$$

for 'n' number of span, there are $(n-1)$ number of pier.

∴ The overall cost of considered bridge is.....

$$C = nS + (n-1)P$$

$$C = n \times RP + (n-1)P$$

for C to be minimum,

$$\frac{dC}{dn} = 0$$

$$RP + (-1)P = 0$$

$$RP = P$$

$$\therefore R = 1$$

i.e. $\frac{S}{P} = 1 \Rightarrow S = P$ ------ (*)

Hence economical span of bridge is one for which cost of one span is equal to cost of one pier.

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