

Highway Engineering (313323)

Model Question Paper — Set C · Model Answers

IRC values used in these answers are those given in IRC:73, IRC:SP:23, IRC:66, IRC:67 and IRC:64 as taught in MSBTE text books. Figures are not to scale.

Q.1

a) Modes of transportation

2 M

1. Roadways (highways)
2. Railways
3. Waterways (inland and ocean)
4. Airways
5. (also pipelines and ropeways)

(½ M each for any four)

b) Road alignment

2 M

Alignment: The position or layout of the centre line of a highway on the ground is called its alignment. It includes horizontal alignment (straight paths and horizontal curves) and vertical alignment (gradients and vertical curves).

A good alignment should be short, easy, safe and economical.

c) Design speed

2 M

Design speed: The speed adopted for the geometric design of a road (sight distance, radius of curves, super-elevation, extra widening, etc.). IRC gives a *ruling* design speed (normally adopted) and a *minimum* design speed (where site conditions do not permit the ruling value).

IRC ruling design speed for NH in plain terrain = **100 km/h** (minimum design speed 80 km/h).

(Definition 1 M, value 1 M)

d) Shoulder and side slope

2 M

(i) **Shoulder:** The portion of the roadway between the outer edge of the carriageway and the edge of the formation. It is used for emergency stopping and gives lateral support to the pavement. IRC recommended minimum width 2.5 m.

(ii) **Side slopes:** The slopes given to the sides of an embankment or cutting for stability of earthwork. Generally 2 : 1 (H : V) in embankment and 1 : 1 or flatter in cutting, depending on soil.

(1 M each)

e) Types of roads by material

2 M

1. Earth roads
2. Gravel roads
3. Murrum (moorum) roads
4. Water bound macadam (WBM) roads

5. Bituminous roads
6. Cement concrete roads

(Any four, $\frac{1}{2}$ M each)

f) Summit curve and valley curve

2 M

Summit curve: A vertical curve with convexity upward, formed when an ascending gradient meets a descending gradient (or a flatter one).

Valley (sag) curve: A vertical curve with concavity upward, formed when a descending gradient meets an ascending gradient (or a flatter one).

(1 M each)

g) Surface drainage

2 M

Surface drainage is the collection and removal of rain water from the road surface and the adjoining land (by camber, shoulder slope, side drains and cross drains) and its disposal to a natural outlet, so that water does not stand on the road or enter the pavement and subgrade.

Q.2

a) Objectives of geometric design

4 M

1. To provide safe, comfortable and efficient movement of traffic at the design speed.
2. To provide adequate sight distances (SSD, OSD) and proper horizontal and vertical curves, super-elevation and extra widening.
3. To fix suitable cross-section elements — carriageway, shoulders, camber — for the expected traffic.
4. To keep gradients within limits so that vehicles move without much loss of speed.
5. To minimise accidents and the total cost (construction + maintenance + vehicle operation).
6. To provide proper drainage, good appearance and scope for future widening.

(Any four, 1 M each)

b) SSD for two-way traffic on single-lane road

4 M

Given: Design speed $V = 50$ km/h, reaction time $t = 2.5$ s, coefficient of longitudinal friction $f = 0.37$, brake efficiency $\eta = 80\%$.

Formula (IRC): $SSD = \text{Lag distance} + \text{Braking distance} = 0.278 V t + V^2 / (254 f)$

Step 1 — Lag distance $= 0.278 \times 50 \times 2.5 = 34.75$ m

Step 2 — Effective friction $= f \times \eta = 0.37 \times 0.8 = 0.296$

Step 3 — Braking distance $= V^2 / (254 \times 0.296) = 2500 / 75.18 = 33.25$ m

$SSD = 34.75 + 33.25 = 68.00$ m

Two-way traffic on single-lane road: both vehicles must be able to stop, so required sight distance $= 2 \times SSD = 2 \times 68.00 = 136.00$ m (say 137 m)

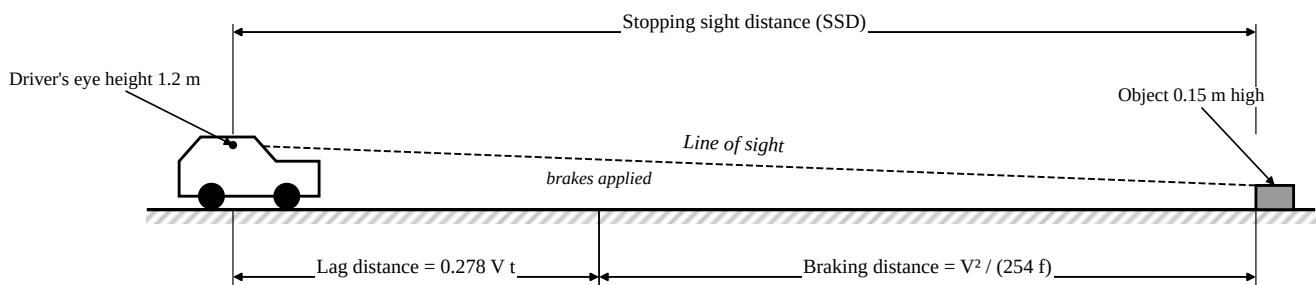


Fig.: Stopping sight distance (SSD) = lag distance + braking distance

(Lag distance 1 M, effective f and braking distance 1.5 M, SSD 0.5 M, two-way value 1 M)

c) Factors affecting gradient

4 M

1. **Nature of terrain** (plain, rolling, hilly).
2. **Type and power of vehicles** — heavy trucks slow down on steep grades.
3. **Design speed** of the road.
4. **Drainage** — a minimum gradient is needed for side drains.
5. **Cost of earthwork** — flatter grades need more cutting and filling.

(Any four, 1 M each)

d) Super-elevation and derivation of $e + f = V^2/127R$

4 M

Super-elevation (cant / banking): The raising of the outer edge of the pavement with respect to the inner edge, throughout the length of a horizontal curve, to counteract the effect of centrifugal force and reduce the tendency of the vehicle to overturn or skid. It is expressed as the ratio $e = E / B = \tan \theta$.

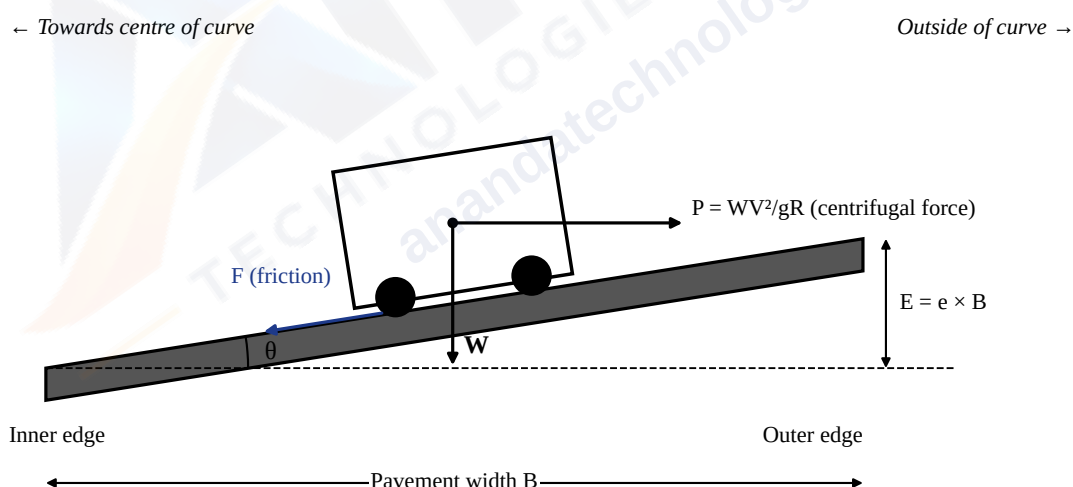


Fig.: Super-elevation — outer edge raised, forces on a vehicle moving on a curve

Derivation: Let W = weight of vehicle, P = centrifugal force = $W v^2 / (g R)$, θ = angle of super-elevation, f = coefficient of lateral friction. Considering equilibrium along the inclined road surface:

$$P \cos \theta = W \sin \theta + f (W \cos \theta + P \sin \theta)$$

$$\text{Dividing by } W \cos \theta: P/W = \tan \theta + f + f (P/W) \tan \theta \rightarrow (P/W)(1 - f \tan \theta) = \tan \theta + f$$

Since $e = \tan \theta$ and the product $f \cdot e$ is very small, it is neglected: $e + f = P / W = v^2 / (g R)$

With v in m/s = $V/3.6$ (V in km/h) and $g = 9.81 \text{ m/s}^2$: $e + f = V^2 / (3.6^2 \times 9.81 \times R) = V^2 / (127 R)$

(Explanation and sketch 1.5 M, derivation 2.5 M)

Q.3

a) Camber and its types

4 M

Camber (cross slope): The slope given to the road surface in the transverse direction, from the crown (centre) towards the edges, to drain off rain water from the surface. It is expressed as 1 in n or as a percentage (e.g. 1 in 50 = 2 %).

1. **Straight line camber** — two straight slopes meeting at the crown; easy to construct, used for rigid (CC) pavements.
2. **Parabolic (barrel) camber** — curved (parabolic) profile; flat at the crown and steeper at the edges; preferred by fast vehicles.
3. **Composite camber** — parabolic at the centre (crown) and straight towards the edges.

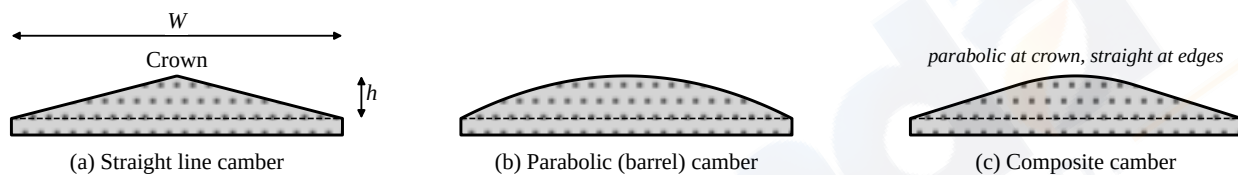


Fig.: Types of camber (vertical scale exaggerated)

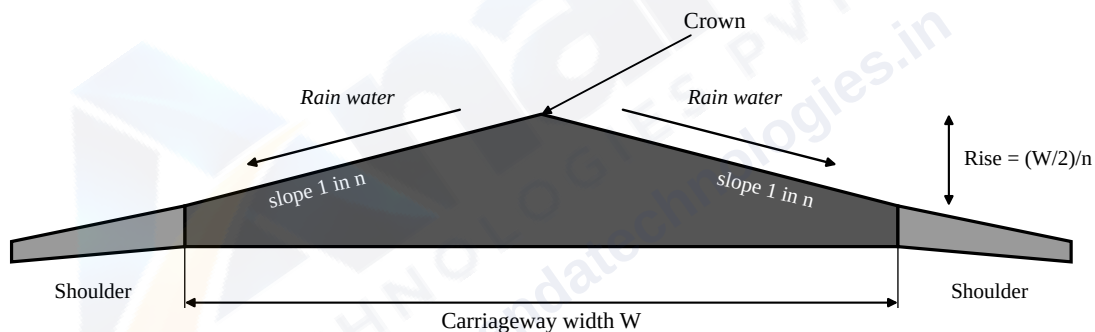


Fig.: Camber — cross slope from crown to edges

(Definition 1 M, sketches 3 M)

b) Properties of bitumen; necessity of extraction test

4 M

Desirable properties of bitumen:

1. Good **adhesion** to aggregates (binding property).
2. **Waterproof** and resistant to action of water (stripping).
3. Suitable **viscosity** at the time of mixing and laying (workability).
4. Adequate **ductility** — should not crack in cold weather.

Necessity of extraction test:

- To find the actual bitumen (binder) content of a bituminous mix taken from the plant or the road.
- To check that the mix conforms to the job-mix formula — quality control during construction.

- The recovered aggregates are used to check gradation; too little bitumen causes ravelling, too much causes bleeding.

(Properties 2 M, necessity 2 M)

c) Functions of layers of flexible pavement

4 M

1. **Subgrade:** Top 500 mm of natural / compacted soil on which the pavement rests. It is the foundation of the pavement and receives the load finally; it must be well compacted and stable.
2. **Sub-base course:** Layer of granular material (GSB, gravel, moorum) below the base. It distributes load, acts as a drainage layer and prevents intrusion of fine subgrade soil into the base.
3. **Base course:** Main load-bearing layer of good quality material (WBM, WMM, crushed stone). It spreads the wheel load over a wider area of sub-base.
4. **Wearing course (surface course):** Top layer in direct contact with wheels, e.g. bituminous concrete, premix carpet, surface dressing. Gives a smooth, dense, skid-resistant and waterproof surface; resists abrasion and protects the base from water.

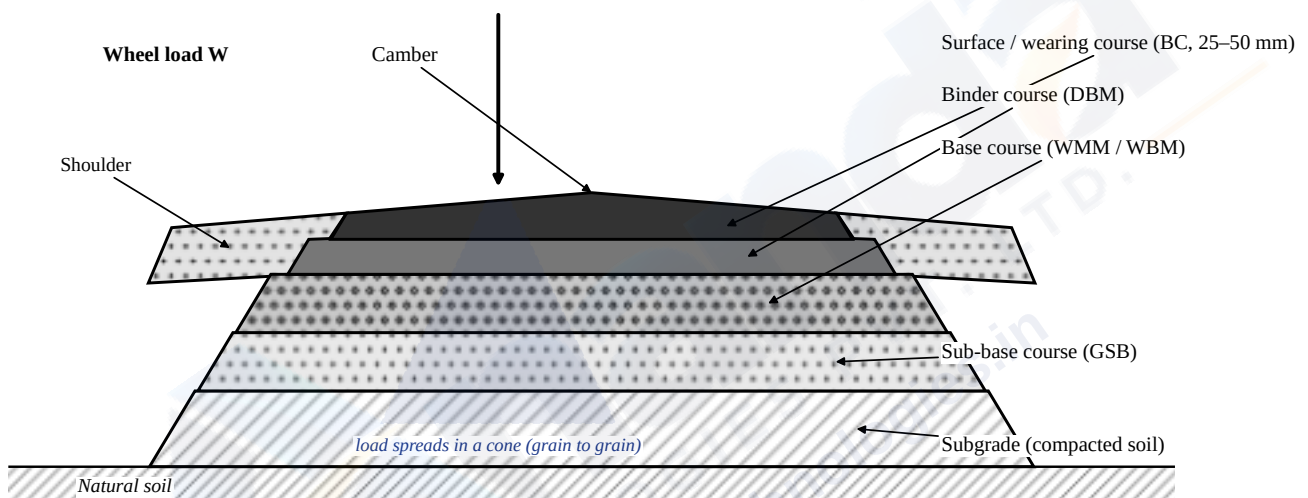


Fig.: Typical cross-section of a flexible pavement

(1 M for each layer)

d) Causes and prevention of landslides

4 M

Causes:

1. **Heavy rainfall** — water saturates the soil, increases its weight and pore pressure and reduces shear strength.
2. **Steep slopes and cutting of the toe** of slopes during road construction (removal of lateral support).
3. **Improper drainage** — seepage and percolation of water into the hill slope.
4. **Earthquakes, blasting and vibrations** from traffic and construction.

Preventive measures:

1. **Proper drainage** — catch water drains above the road, side drains, sub-surface drains and weep holes to remove water quickly.
2. **Retaining walls and breast walls** to support slopes; gabion walls and toe walls.

(Causes 2 M, measures 2 M)

Q.4

a) Rigid vs flexible pavement

4 M

Point	Rigid pavement	Flexible pavement
Load transfer	By slab action over a wide area of subgrade	By grain-to-grain contact through layers; load spreads in a cone
Initial (construction) cost	High	Low
Durability / design life	More, about 30 years or more	Less, about 10–15 years
Joints	Expansion, contraction and other joints required	No joints required

(1 M each)

b) Traffic volume study — purposes and methods

4 M

Traffic volume study: The counting of the number of vehicles (classified by type and direction) crossing a section of road per unit time — vehicles per hour or per day. Traffic volume is expressed in PCU per hour / per day.

Purposes:

1. Classification of roads and planning of road development.
2. Geometric design — number of lanes, width of carriageway, intersection design.
3. Structural design of pavement (number of commercial vehicles per day).
4. Design of traffic control measures — signals, islands, one-way streets.

Methods of counting:

1. **Manual count** — observers record vehicles by type and direction on tally sheets.
2. **Mechanical / automatic count** — pneumatic tube, inductive loop, infra-red, radar counters.
3. **Moving observer method** — counting from a moving test vehicle.
4. **Video / photographic method** — recording and later counting.

(Definition 1 M, purposes 1.5 M, methods 1.5 M)

c) Traffic control devices

4 M

Device	Use
Traffic signs	Regulatory (mandatory), warning (cautionary) and informatory signs — give information, orders and warnings to road users.
Road markings	Centre line, lane lines, stop line, zebra crossing, edge lines, arrows — guide and regulate traffic and pedestrians.
Traffic signals	Coloured lights (red, amber, green) — control conflicting movements at intersections by allotting time to each.

Traffic islands	Raised areas — channelise traffic, divide opposite flows and give refuge to pedestrians; rotary islands.
Others	Delineators, guard rails, road studs (cat's eyes), speed breakers / rumble strips, barricades — guide and slow down traffic.

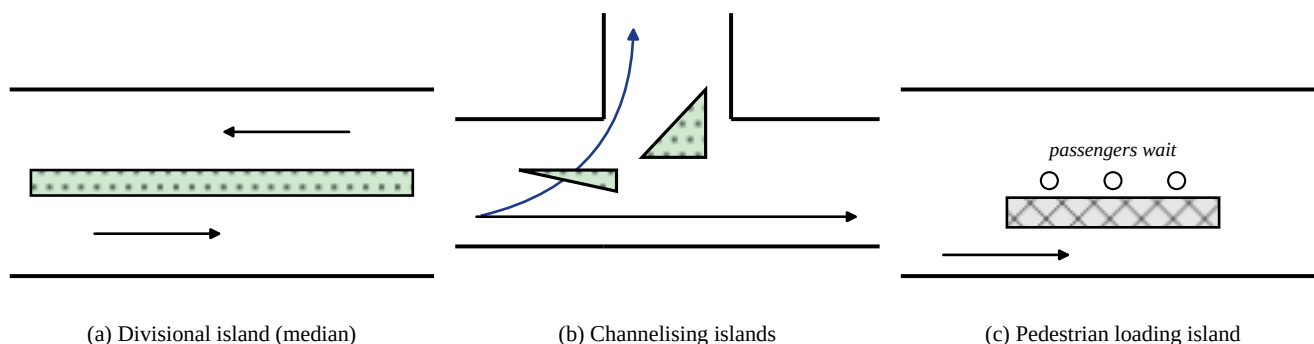


Fig.: Types of traffic islands

(Any four devices with use, 1 M each)

d) Surface drainage system and drain with grating

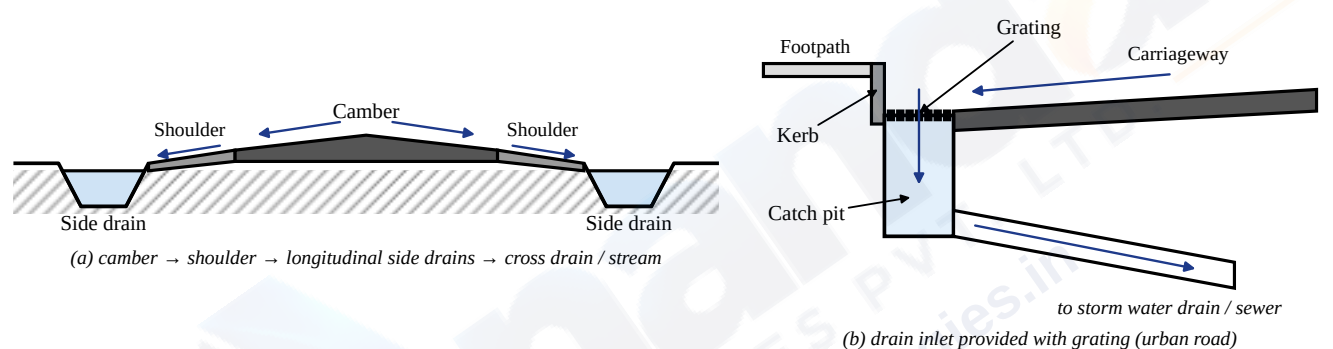
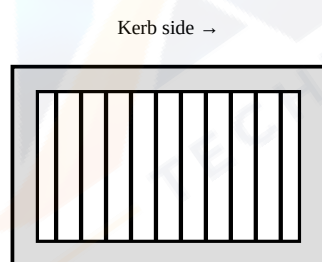
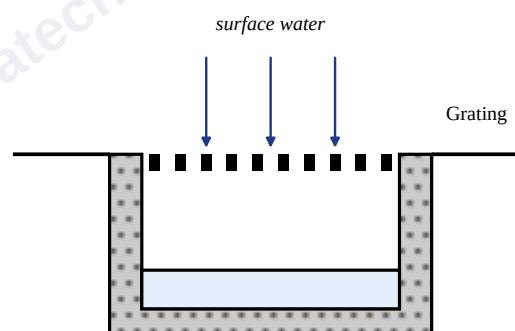


Fig.: Surface drainage of road — (a) rural road with side drains, (b) urban road with kerb and grating inlet



(a) Plan: CI / steel grating on frame



(b) Section: masonry / RCC drain

Fig.: Drain provided with grating — plan and section

- Rain water flows from the crown to the edges due to camber, then over the shoulders (steeper cross slope) into longitudinal side drains.
- Side drains carry water with a minimum longitudinal slope to cross drains (culverts) or natural streams.
- On urban roads, water flows along the kerb channel to inlets covered by gratings, then through catch pits into the storm water drain.

(Cross-section 2 M, grating drain 1 M, explanation 1 M)

e) Remedial measures for potholes and ruts

4 M

Pothole formation — remedial measures:

1. Repair by patching: cut the pothole to a rectangular shape with vertical sides, clean, apply tack coat, fill with bituminous premix and compact slightly above surface.
2. Repair the damaged base layer before patching, if needed.
3. Improve surface and subsurface drainage and seal cracks early so that water cannot enter.

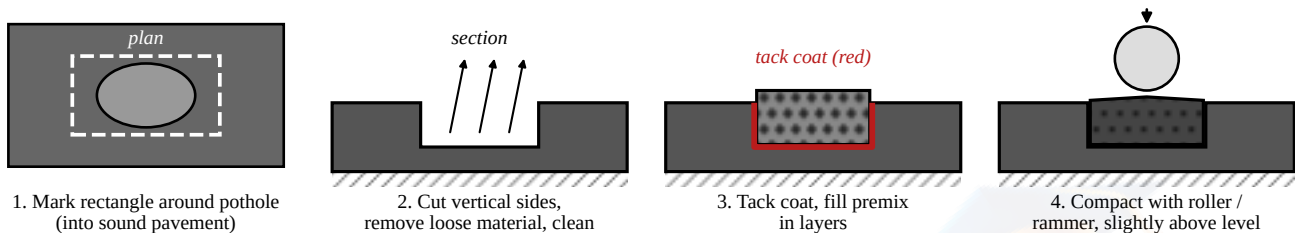


Fig.: Sequence of pothole repair (patching) in bituminous pavement

Rut formation — remedial measures:

1. Shallow ruts: fill and level with bituminous premix / micro-surfacing and roll; or mill and overlay.
2. Deep ruts due to weak base/subgrade: remove the failed layers, strengthen (re-compact / replace) base and subgrade, then relay the surface.
3. Use well-designed, properly compacted stable mixes (modified bitumen) and control overloading.

(Potholes 2 M, ruts 2 M)

Q.5

a) Super-elevation and extra widening ($V = 80 \text{ km/h}$, $R = 300 \text{ m}$)

6 M

(A) Design of super-elevation

Given: $V = 80 \text{ km/h}$, $R = 300 \text{ m}$, pavement width $B = 7.0 \text{ m}$, $f = 0.15$, plain terrain ($e_{\max} = 7\%$ as per IRC).

Step 1 — Super-elevation for 75 % of design speed, neglecting friction (IRC):

$$e = (0.75 V)^2 / (127 R) = V^2 / (225 R) = 80^2 / (225 \times 300) = 6400 / 67500 = \mathbf{0.0948}$$

Step 2: $e = 0.0948 > e_{\max} = 0.07$. Hence limit $e = 0.07$.

Step 3 — Check friction at full design speed: $f = V^2 / (127 R) - e = 6400 / (127 \times 300) - 0.07 = 0.1680 - 0.07 = \mathbf{0.0980}$

Since $f = 0.098 < 0.15$ (permissible), the design is safe with $e = \mathbf{0.07 (7\%)}$; speed need not be restricted.

(B) Extra widening

Given: number of lanes $n = 2$, wheel base $l = 6.1 \text{ m}$ (IRC design vehicle), $R = 300 \text{ m}$, $V = 80 \text{ km/h}$.

Mechanical widening W_m $= n l^2 / (2R) = 2 \times 6.1^2 / (2 \times 300) = 74.42 / 600 = \mathbf{0.124 \text{ m}}$

Psychological widening $W_{ps} = V / (9.5 \sqrt{R}) = 80 / (9.5 \times \sqrt{300}) = 80 / 164.54 = \mathbf{0.486 \text{ m}}$

Total extra widening $W_e = 0.124 + 0.486 = \mathbf{0.610 \text{ m}}$ (provide 0.6 m)

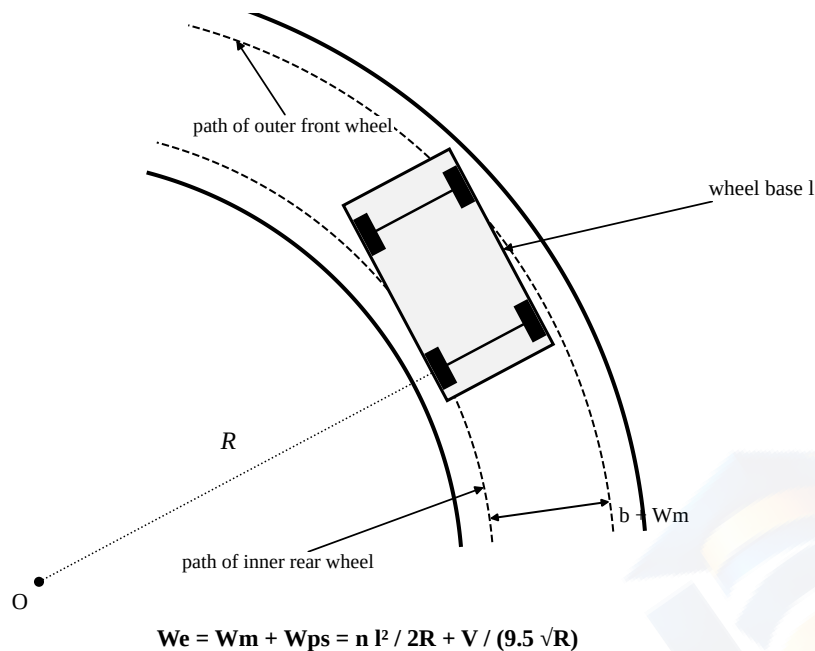


Fig.: Extra widening on a curve — off-tracking of rear wheels (mechanical widening)

(IRC table also gives 0.6 m extra width for a two-lane road with radius 101–300 m.)

(C) Raising of outer edge for widened pavement $B = 7.0 + 0.6 = 7.6 \text{ m}$: $E = e \times B = 0.07 \times 7.6 = \mathbf{0.532 \text{ m}}$ ($\approx 532 \text{ mm}$)

(Super-elevation 3 M, extra widening 2 M, raising of edge 1 M)

b) Construction of cement concrete pavement

6 M

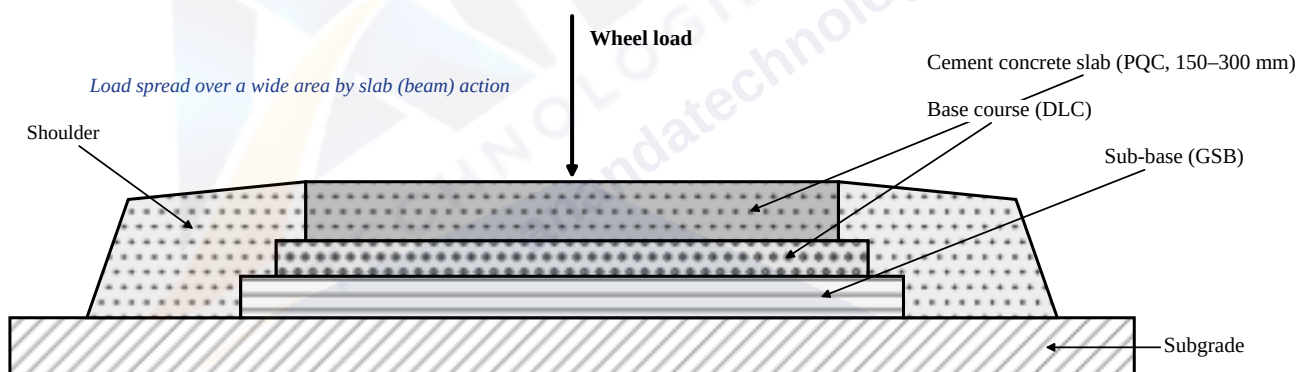


Fig.: Typical cross-section of a rigid (cement concrete) pavement

- 1. Preparation of subgrade and sub-base:** subgrade compacted to required density and camber; sub-base / base (e.g. DLC, WBM) laid and compacted; a separation membrane (polythene) is placed if specified.
- 2. Placing of forms:** steel side forms fixed to line and level; dowel bars, tie bars and joint fillers placed in position.
- 3. Batching and mixing:** concrete of specified grade (e.g. M40 for PQC) mixed in a mixer / batching plant.

4. **Placing and spreading:** concrete placed uniformly over the full width and depth without segregation.
5. **Compaction:** by needle vibrators and screed (surface) vibrators.
6. **Finishing:** floating with longitudinal float, belting, brooming / tining for skid-resistant texture, edging of joints.
7. **Curing:** initial curing with wet hessian / curing compound for 24 hours, then ponding / wet sand for about 14 days (minimum).
8. **Joints:** grooves of contraction joints sawn and all joints sealed with sealing compound.
9. **Opening to traffic:** after the concrete gains strength (about 28 days).

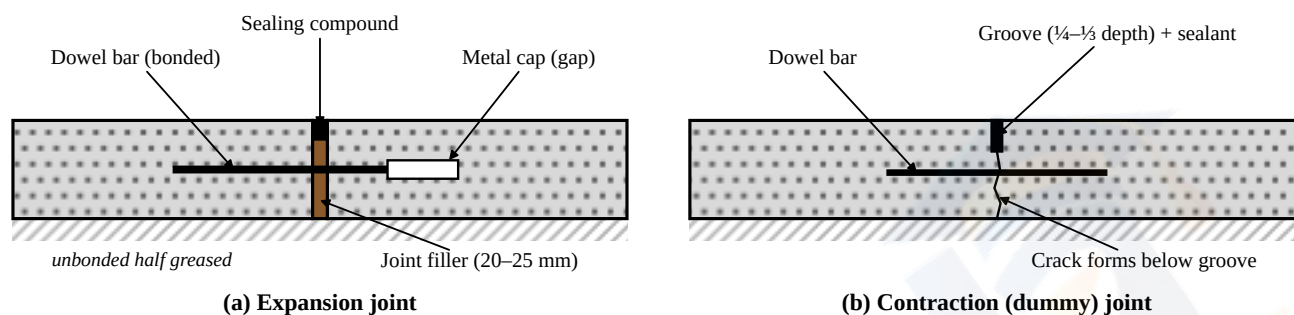


Fig.: Expansion and contraction joints

(Sequence 4 M, sketches 2 M)

c) NH in embankment and purpose of cross-section elements

6 M

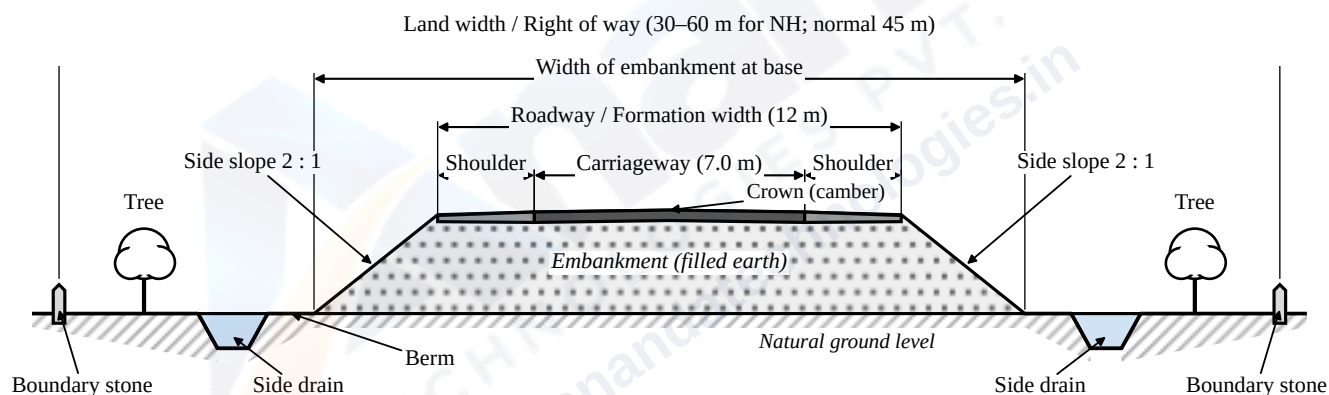


Fig.: Typical cross-section of National Highway in embankment (not to scale)

1. **Right of way:** The width of land acquired for the road along its alignment, within which all road elements (carriageway, shoulders, side drains, slopes, future widening) are accommodated. IRC: for NH/SH in plain open area normal 45 m (range 30–60 m). It also controls ribbon development and allows future widening.
2. **Side slopes:** give stability to the embankment / cutting and prevent slips and erosion.
3. **Road margin:** The portion beyond the carriageway and shoulders within the land width — used for parking lanes, cycle tracks, footpaths, frontage roads and guard rails.
4. **Side drains:** Longitudinal drains on both sides of the road which collect water from the road surface and the adjoining land and carry it to an outlet.
5. **Berms:** A horizontal strip of land left between the toe of an embankment and the side drain or borrow pit; it protects the toe from erosion.

6. **Temporary land:** Land taken temporarily during construction for stacking materials, diversions, labour camps and borrow pits; returned after the work.

(Sketch 3 M, purposes $\frac{1}{2}$ M each)

Q.6

a) Components and drainage of hill road

6 M

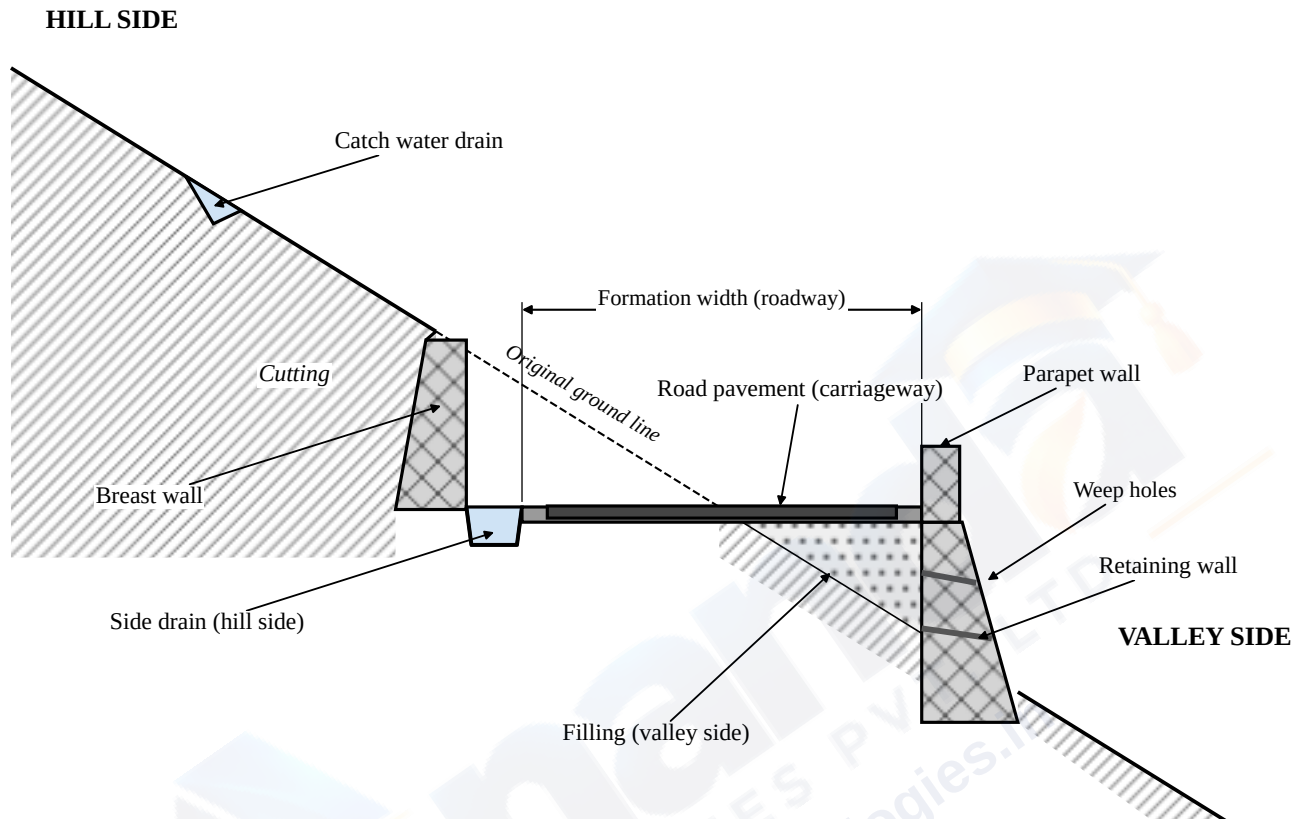


Fig.: Typical cross-section of a hill road (cut and fill on hill slope)

1. **Breast wall:** Wall built on the hill side along the cut face to retain the cut slope and prevent slipping of earth/rock on to the road.
2. **Retaining wall:** Wall on the valley side to retain the filled earth of the road formation and support the road.
3. **Parapet wall:** Low wall or guard rail built on the valley side above road level as a safety barrier for vehicles and pedestrians.
4. **Catch water drain:** Drain on the hill slope above the road which intercepts water flowing down the hill and carries it to a cross drain.
5. **Side drain:** Drain on the hill side of the road which collects water from the road surface and the cut slope.
6. **Road pavement (formation):** Carriageway with shoulders; on curves provided with super-elevation and extra widening; hair-pin bends where required.

Drainage of hill roads:

1. **Catch water drains** are cut on the hill slope above the road to intercept water coming down the hill.

2. **Side drains** are provided only on the hill side; the road is given a cross slope (camber / one-way slope) towards the hill side drain.
3. **Cross drains** — scuppers, culverts, causeways — are provided at frequent intervals to carry water from side drains and catch water drains to the valley side.
4. **Sub-surface drains** and **weep holes** in breast and retaining walls remove seepage water.
5. Water is not allowed to flow over the valley-side slope uncontrolled (to avoid erosion and landslides).

(Sketch 2 M, components 2 M, drainage 2 M)

b) Warning, mandatory and informatory signs

6 M

(i) **Warning (cautionary) signs** — triangular, red border:



Right hand curve
(warning)



School ahead
(warning)

(ii) **Mandatory (regulatory) signs** — circular:



Compulsory turn left
(mandatory)

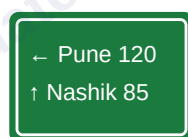


U-turn prohibited

(iii) **Informatory signs** — rectangular, blue/green:



First-aid post
(informatory)



Direction sign
(informatory)

Fig.: Road signs (IRC:67)

(1 M for each sign)

c) PCU and traffic volume in PCU/h

6 M

Passenger Car Unit (PCU): The number of passenger cars to which one vehicle of a given type is equivalent in its effect on traffic flow (depending on its size and speed). A passenger car = 1 PCU. Traffic of mixed vehicles is converted into PCU for design.

Vehicle type (IRC:64)	PCU
Passenger car, jeep, auto-rickshaw	1.0

Motor cycle / scooter	0.5
Light commercial vehicle	1.5
Truck / bus	3.0
Truck-trailer, tractor-trailer	4.5
Cycle	0.5
Cycle rickshaw	2.0
Bullock cart	8.0

Calculation:

Vehicle type	Vehicles / h	PCU factor (IRC:64)	PCU / h
Passenger car / jeep	420	1	420
Motor cycle / scooter	650	0.5	325
Bus	85	3	255
Truck	110	3	330
Light commercial vehicle	60	1.5	90
Cycle	140	0.5	70
Bullock cart	12	8	96
Total	1477		1586

Traffic volume = 1586 PCU per hour (total 1477 vehicles per hour).

(Definition 1 M, PCU values 2 M, calculation 3 M)

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