

Highway Engineering (313323)

Model Question Paper — Set A · 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) Categories of roads — Nagpur Road Plan

2 M

The **Nagpur Road Plan (1943)** — the first 20-year road development plan of India (1943–63) prepared at the conference of Chief Engineers at Nagpur — classified roads into five categories:

1. **National Highways (NH)**
2. **State Highways (SH)**
3. **Major District Roads (MDR)**
4. **Other District Roads (ODR)**
5. **Village Roads (VR)**

(½ M each for any four; all five expected)

b) Camber and IRC values

2 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 %).

Surface (heavy rainfall)	IRC camber
High type bituminous surface	1 in 50 (2.0 %)
WBM road	1 in 33 (3.0 %)

(Definition 1 M, values 1 M)

c) Passenger Car Unit (PCU)

2 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.

PCU values (IRC:64, rural roads): Passenger car = 1.0, Motor cycle/scooter = 0.5, Truck/bus = 3.0, Bullock cart = 8.0.

(Definition 1 M, any two values 1 M)

d) Landslide

2 M

Landslide: The sudden movement or sliding of a mass of earth, rock or debris down a hill slope under gravity, when the shearing resistance of the slope material is exceeded by the forces causing sliding.

It commonly occurs in hilly areas during heavy rains and blocks or damages hill roads.

e) Requirements of an ideal alignment

2 M

1. **Short** — the alignment between two terminal points should be as short as possible.
2. **Easy** — easy to construct, maintain and operate vehicles with easy gradients and curves.
3. **Safe** — safe for construction and maintenance (stable slopes, embankments) and for traffic (adequate sight distance, curves).
4. **Economical** — total cost of construction, maintenance and vehicle operation should be minimum.

(½ M each)

f) Carriageway and formation width

2 M

- (i) **Carriageway**: The width of the pavement used for movement of vehicles. IRC: single lane 3.75 m, two-lane 7.0 m (without kerbs), multi-lane 3.5 m per lane.
- (ii) **Formation width (roadway)**: The top width of the road embankment or the bottom width of cutting, excluding side drains = carriageway + shoulders (+ median). For a two-lane NH in plain terrain = 12 m.

(1 M each)

g) Necessity of highway maintenance

2 M

1. Roads deteriorate due to traffic, weather (rain, heat) and ageing; maintenance keeps them in good condition.
2. To preserve the large investment made in road construction and increase its life.
3. To keep the surface smooth and safe — reduces accidents and vehicle operating cost.
4. To repair minor defects (cracks, potholes) before they develop into major failures.

(½ M each)

Q.2

a) Modes of transportation; advantages of road transport

4 M

Modes of transportation:

- **Roadways (highways)** — roads of all types; most flexible, door-to-door service.
- **Railways** — for bulk goods and large number of passengers over long distances.
- **Waterways** — inland water transport (rivers, canals) and ocean transport; cheapest for heavy, bulky goods.
- **Airways** — fastest mode; for long distance, costly and light, valuable goods.
- Other modes: **pipelines** (oil, gas, water) and **ropeways** (hilly areas).

Advantages of road transport:

1. Gives **door-to-door service**; goods are not handled many times.
2. **Flexible** — route and time of travel can be changed as needed.
3. Cheaper and quicker for **short distances** and for perishable goods.
4. Requires less capital investment than railways and airways.

(Modes 2 M, advantages 2 M)

b) Factors affecting design speed; IRC values

4 M

1. **Class / importance of road** — NH and SH have higher design speeds than ODR and VR.
2. **Type of terrain** — plain, rolling, mountainous or steep (cross slope of ground).
3. **Volume and composition of traffic** — fast or mixed slow traffic.
4. **Cost of construction** — higher speed needs flatter curves and gradients, i.e. more cost.

Road	Ruling design speed (plain)	Minimum design speed (plain)
National Highway (NH)	100 km/h	80 km/h
Major District Road (MDR)	80 km/h	65 km/h

(Factors 2 M, values 2 M)

c) Cross-section of NH in embankment

4 M

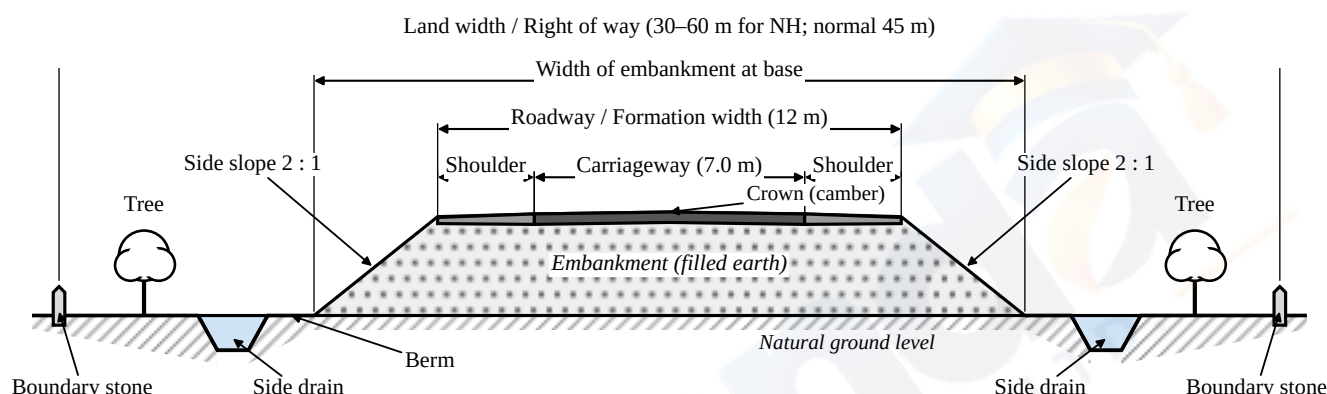


Fig.: Typical cross-section of National Highway in embankment (not to scale)

Carriageway 7.0 m (two-lane), shoulders 2.5 m each, formation width 12 m, side slopes 2 : 1, side drains beyond berm, land width normally 45 m for NH in open area.

(Neat sketch 2 M, labels 2 M)

d) SSD for 80 km/h on level road and 3 % ascending gradient

4 M

Given: Design speed $V = 80$ km/h, reaction time $t = 2.5$ s, coefficient of longitudinal friction $f = 0.35$.

Formula (IRC): $SSD = \text{Lag distance} + \text{Braking distance} = 0.278 V t + V^2 / (254 f)$ (on gradient n %: $V^2 / 254 (f \pm 0.01 n)$)

Step 1 — Lag distance $= 0.278 \times 80 \times 2.5 = 55.60$ m

(i) On level road — Braking distance $= V^2 / (254 \times 0.35) = 6400 / 88.90 = 71.99$ m

$SSD = 55.60 + 71.99 = 127.59$ m $\approx$ say 128 m

(ii) On 3 % ascending gradient: Braking distance $= 80^2 / [254 (0.35 + 0.03)] = 6400 / 96.52 = 66.31$ m

$SSD = 55.60 + 66.31 = 121.91$ m $\approx$ say 122 m

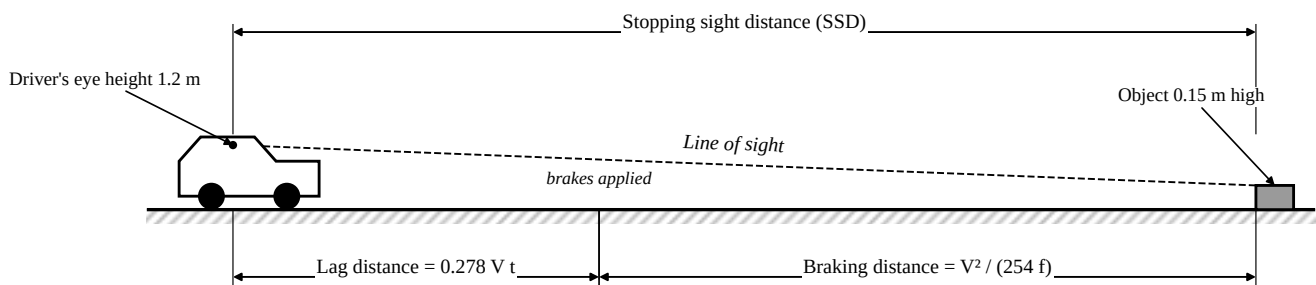


Fig.: Stopping sight distance (SSD) = lag distance + braking distance

On an ascending gradient the component of weight helps braking, so the braking distance and SSD are less than on level road.

(Lag distance 1 M, level SSD 1.5 M, gradient SSD 1.5 M)

Q.3

a) Super-elevation

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 $e = E / B = \tan \theta$.

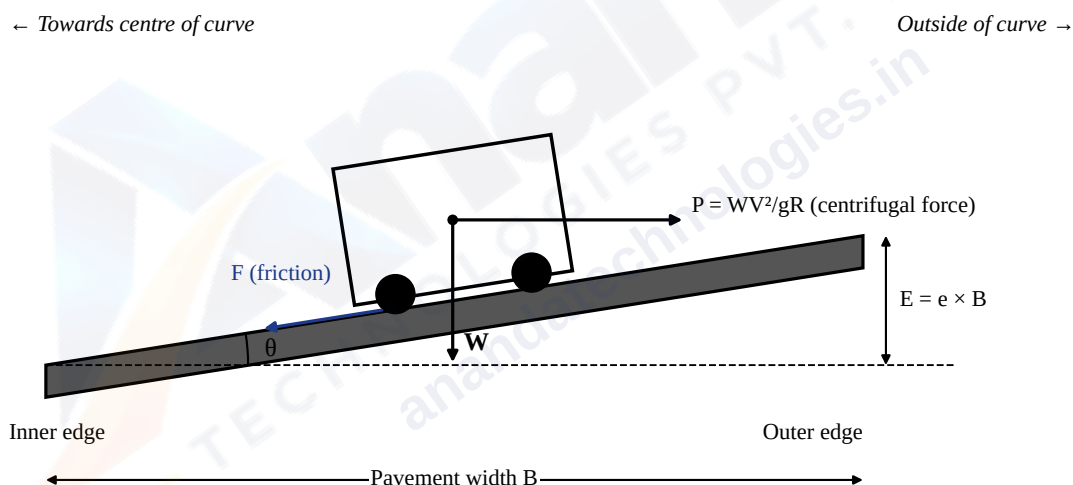


Fig.: Super-elevation — outer edge raised, forces on a vehicle moving on a curve

- Design formula (IRC): $e = (0.75 V)^2 / (127 R) = V^2 / (225 R)$, with V in km/h and R in m — i.e. centrifugal force of 75 % design speed is counteracted by super-elevation alone.
- General equation: $e + f = V^2 / (127 R)$, with lateral friction $f = 0.15$ (IRC).
- Maximum super-elevation (IRC): **7 %** in plain and rolling terrain and in snow-bound hill roads; **10 %** in hill roads not bound by snow; **4 %** on urban roads with frequent intersections.
- Minimum super-elevation = camber of the road (for drainage).

(Definition 1 M, sketch 1.5 M, IRC values 1.5 M)

b) Flexible vs rigid pavement

4 M

Point	Flexible pavement	Rigid pavement
Flexural strength	Negligible or very low	High; acts like a slab (beam)
Load transfer	By grain-to-grain contact through layers; load spreads in a cone	By slab action over a wide area of subgrade
Deformation	Deformation of subgrade is reflected on the surface	Surface does not follow small deformation of subgrade
Design basis	Based on CBR / load distribution (IRC:37)	Based on flexural strength of concrete (Westergaard's theory, IRC:58)
Initial (construction) cost	Low	High
Maintenance cost	High (periodic surfacing)	Low
Durability / design life	Less, about 10–15 years	More, about 30 years or more
Flexibility	Flexible; adjusts to small settlements of subgrade	Rigid; cracks if subgrade settles unevenly

(½ M per point)

c) Softening point test (ring and ball)

4 M

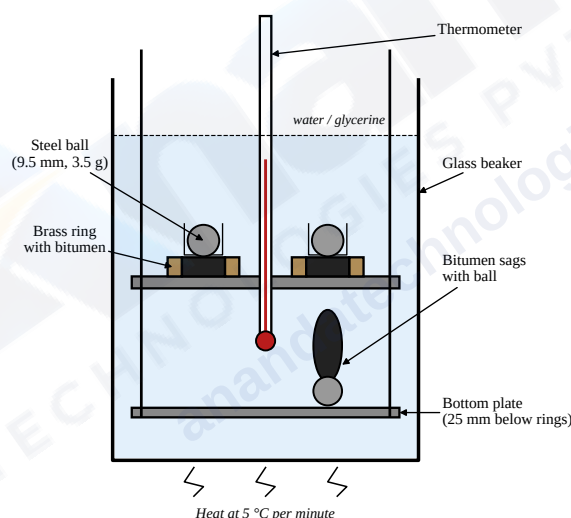


Fig.: Ring and ball apparatus for softening point of bitumen

Object: To find the temperature at which bitumen attains a particular degree of softening (IS 1205).

1. Heat the bitumen sample till fluid and pour it into the two brass rings placed on a metal plate coated with glycerine–dextrine (to avoid sticking).
2. Allow to cool in air for about 30 minutes; trim off excess bitumen with a hot knife.
3. Assemble the rings in the ring holder; place the ball guides and a steel ball (9.5 mm dia, 3.5 g) at the centre of each ring.
4. Place the assembly in the beaker filled with distilled water (for softening point up to 80 °C) at 5 °C; the bottom plate is 25 mm below the rings. Keep for 15 minutes.

5. Heat the water so that temperature rises at a uniform rate of 5 °C per minute.
6. As bitumen softens, the ball sinks with the bitumen. Note the temperature at which the bitumen with the ball touches the bottom plate.
7. The mean of the two temperatures is reported as the **softening point** of the bitumen.

(Sketch 1 M, procedure 3 M)

d) Causes of landslides

4 M

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.
5. **Deforestation** — removal of vegetation which binds the soil.
6. **Weathering of rocks** and unfavourable geology (strata dipping towards the road, joints, faults).

(Any four, 1 M each)

Q.4

a) Expansion and contraction joints

4 M

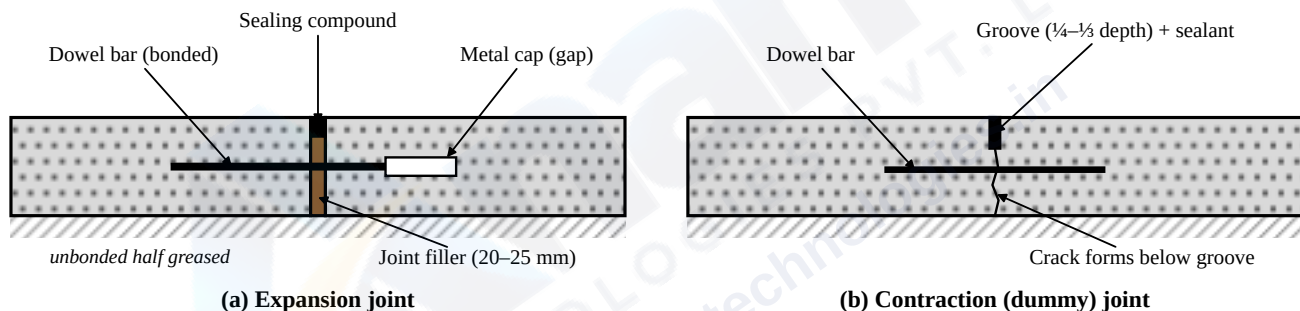


Fig.: Joints in CC pavement

- Full-depth joints (gap about 20–25 mm) which allow the slab to expand when temperature rises. Filled with compressible joint filler (bitumen-impregnated board) and sealed at top; dowel bars provided for load transfer.
- Dummy (partial-depth) joints formed by sawing a groove $\frac{1}{4}$ to $\frac{1}{3}$ of slab depth; they control cracking due to shrinkage and fall of temperature (crack forms below the groove). IRC spacing about 4.5 m.

(Each labelled sketch 2 M)

b) Rotary intersection

4 M

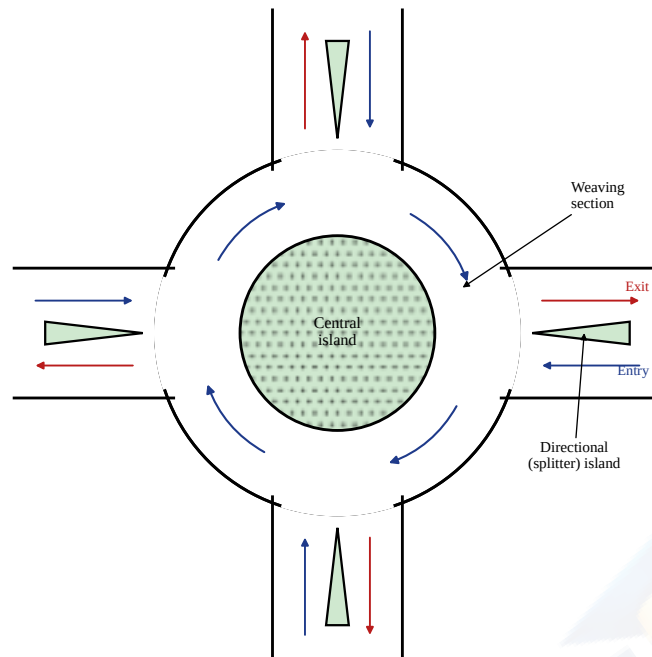


Fig.: Rotary intersection (traffic moves clockwise, keep-left rule)

- A **rotary** is an enlarged road intersection in which all converging vehicles move round a large central island in one direction (clockwise in India, keep-left rule) before weaving out to the desired road.
- Crossing conflicts are converted into **merging, weaving and diverging** at small angles.
- Components: central island, directional (splitter) islands at entries, entry and exit curves, weaving sections.
- **Advantages:** orderly one-way flow; severe crossing conflicts eliminated; no signals or traffic police needed; suitable for 4 or more legs and moderate traffic.
- **Limitations:** needs large area; not suitable for very heavy traffic or heavy pedestrian flow; longer travel for right-turning vehicles. (IRC design speed: 40 km/h rural, 30 km/h urban.)

(Sketch 2 M, explanation 1 M, advantages 1 M)

c) Failures of flexible pavement

4 M

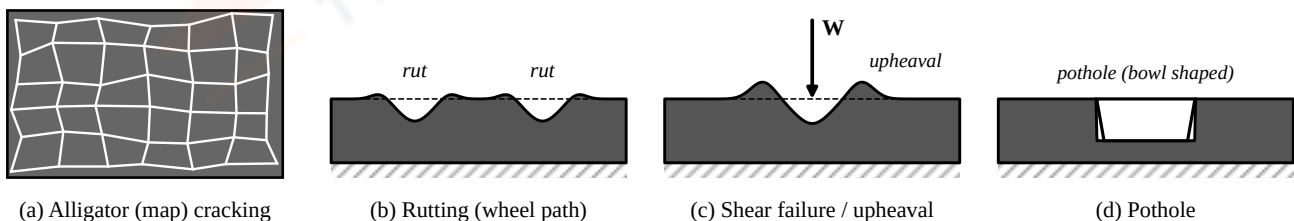


Fig.: Common failures of flexible pavement

1. **Alligator (map) cracking:** Interconnected cracks forming small blocks like crocodile skin; due to fatigue under repeated loads, weak base/subgrade, ageing of bitumen.
2. **Rutting / consolidation of layers:** Longitudinal depressions along wheel paths due to further compaction of layers, poor compaction during construction, excess bitumen.

3. **Shear failure (upheaval):** Upheaval of material at the sides of the loaded area due to weak subgrade or base and heavy loads.
4. **Potholes:** Bowl-shaped holes due to entry of water, poor drainage, insufficient binder and loss of bond, weak spots.

(Any four with sketch, 1 M each)

d) Subsurface drainage

4 M

Subsurface drainage means removal or diversion of water below the road surface (ground water, seepage and capillary water) so that the subgrade remains dry and strong. Methods:

1. **Lowering of water table:** longitudinal drains (trenches with perforated pipes and filter material) are provided on both sides below the road; transverse drains are added where the water table is very high. The water table is kept about 1.0–1.2 m below the subgrade.
2. **Control of seepage flow:** where seepage comes from a higher side (hill side, cutting), an intercepting drain (pipe in trench with filter) is provided to cut off the seepage.
3. **Control of capillary rise:** a capillary cut-off layer of coarse granular material (or an impermeable bituminous layer) is placed between the subgrade and the pavement.

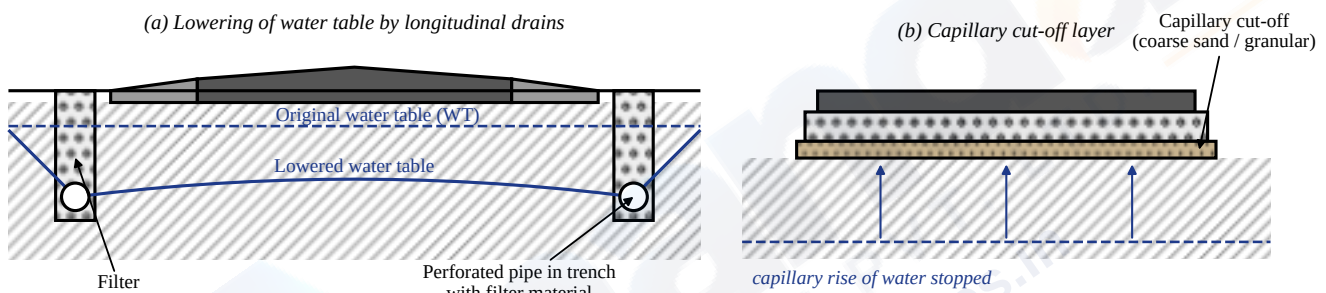


Fig.: Subsurface drainage

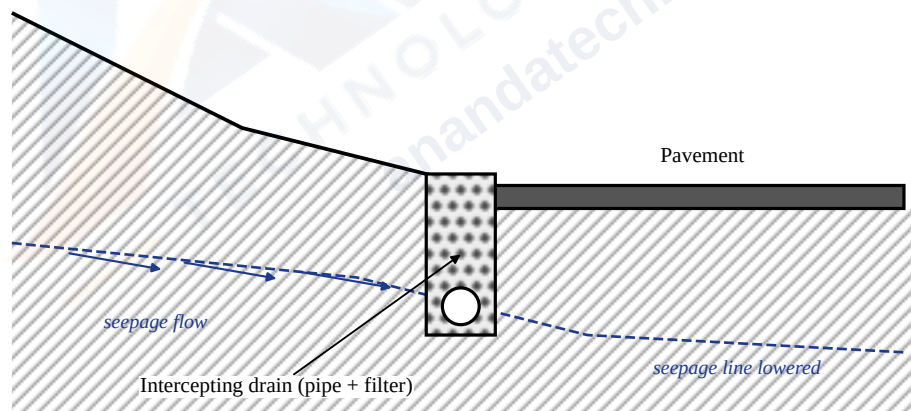


Fig.: Intercepting drain to control seepage flow (hill side / cutting)

(Explanation 2 M, sketches 2 M)

e) Cross-section of hill road

4 M

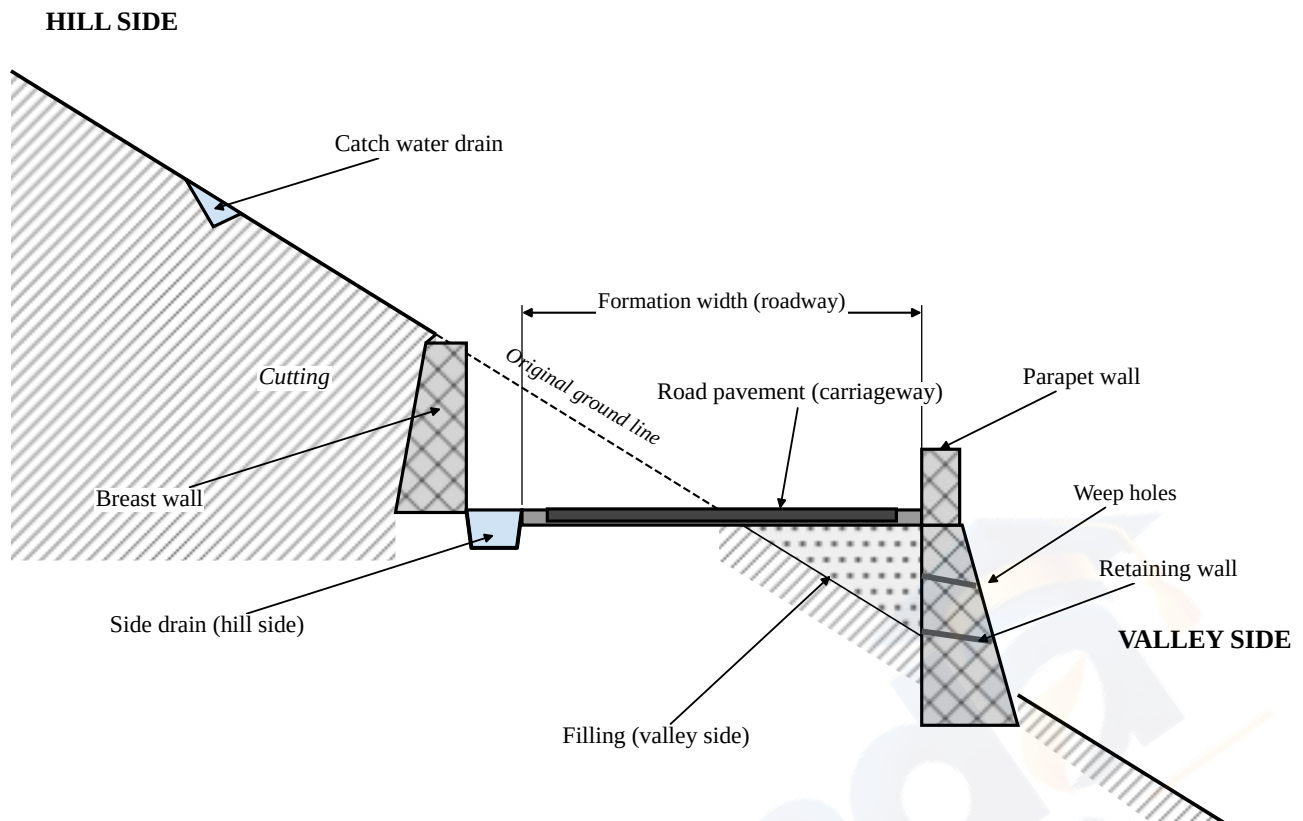


Fig.: Typical cross-section of a hill road (cut and fill on hill slope)

- **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.
- **Retaining wall** — Wall on the valley side to retain the filled earth of the road formation and support the road.
- **Parapet wall** — Low wall or guard rail built on the valley side above road level as a safety barrier for vehicles and pedestrians.
- **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.
- **Side drain** — Drain on the hill side of the road which collects water from the road surface and the cut slope.
- **Road pavement (formation)** — Carriageway with shoulders; on curves provided with super-elevation and extra widening; hair-pin bends where required.

(Sketch 2 M, any six labels 2 M)

Q.5

a) Design of super-elevation ($V = 65 \text{ km/h}$, $R = 120 \text{ m}$)

6 M

Given: $V = 65 \text{ km/h}$, $R = 120 \text{ m}$, 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):

$$e = (0.75 V)^2 / (127 R) = V^2 / (225 R) = 65^2 / (225 \times 120) = 4225 / 27000 = \mathbf{0.1565}$$

Step 2: $e = 0.1565 > e_{\max} = 0.07$. Hence limit $e = 0.07$.

Step 3 — Check friction at full design speed: $f = V^2 / (127 R) - e = 4225 / (127 \times 120) - 0.07 = 0.2772 - 0.07 = \mathbf{0.2072}$

Since $f = 0.207 > 0.15$ (permissible), the speed must be restricted.

Step 4 — Allowable speed: $e + f = V_a^2 / (127 R) \rightarrow V_a = \sqrt{[127 R (e + f)]} = \sqrt{[127 \times 120 \times (0.07 + 0.15)]} = \mathbf{57.9 \text{ km/h}}$

Provide $e = 0.07$ and put a speed-limit sign of about **55 km/h** on the curve (rounded down to a multiple of 5).

Raising of outer edge with respect to inner edge $E = e \times B = 0.07 \times 7.0 = \mathbf{0.490 \text{ m}}$ ($\approx 490 \text{ mm}$)

Result: Provide super-elevation $e = 0.07$ (7 %), outer edge raised by 0.49 m; the safe speed on the curve is limited to about 58 km/h, so a speed-limit sign of 55 km/h is provided.

(e for 75 % speed 1 M, check with $e_{\max}$ 1 M, friction check 1.5 M, allowable speed 1.5 M, raising of edge 1 M)

b) Types of gradients and IRC values

6 M

Gradient: The rate of rise or fall of the road along its length with respect to the horizontal, expressed as 1 in n or as a percentage (e.g. 1 in 30 = 3.33 %).

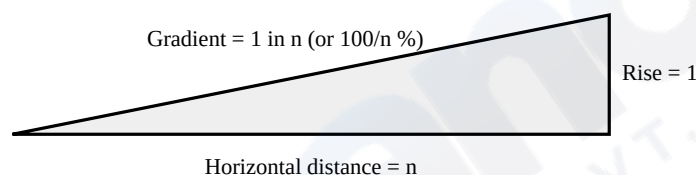


Fig.: Gradient — rise per unit horizontal length

- Ruling gradient:** The maximum gradient within which the designer tries to design the vertical profile of the road; it is the normal design gradient.
- Limiting gradient:** Steeper than ruling gradient; used where topography makes ruling gradient too costly, over limited lengths.
- Exceptional gradient:** Steeper than limiting gradient; used only in extraordinary situations over short stretches (not exceeding about 100 m at a stretch).
- Average gradient:** Total rise or fall between two points divided by the horizontal distance between them; used in planning hill roads.
- Floating gradient:** The gradient on which a vehicle moving at constant speed continues to move without applying power or brakes (tractive effort just balances resistance).
- Minimum gradient:** The minimum longitudinal slope needed for drainage of side drains — about 1 in 500 for concrete (lined) drains and 1 in 200 for open earthen drains.

Terrain	Ruling	Limiting	Exceptional
Plain and rolling	3.3 % (1 in 30)	5 % (1 in 20)	6.7 % (1 in 15)
Mountainous and steep terrain (height above MSL > 3000 m)	5 % (1 in 20)	6 % (1 in 16.7)	7 % (1 in 14.3)

Steep terrain up to 3000 m above MSL	6 % (1 in 16.7)	7 % (1 in 14.3)	8 % (1 in 12.5)
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(IRC recommended gradients. On horizontal curves the gradient is reduced by grade compensation = $(30 + R)/R$ %, max 75/R %.)

(Types 3 M, IRC values 3 M)

c) Horizontal and vertical curves

6 M

(i) **Horizontal curves** are provided where the direction of the road changes in the horizontal plane:

1. **Simple circular curve:** A single arc of constant radius connecting two straights (tangents).
2. **Compound curve:** Two or more circular arcs of different radii turning in the same direction, meeting at a common tangent point.
3. **Reverse curve:** Two circular arcs turning in opposite directions with a common tangent; should be avoided at high speed or separated by a straight / transition.
4. **Transition (spiral) curve:** A curve of gradually changing radius (from infinity to R) introduced between a straight and a circular curve.

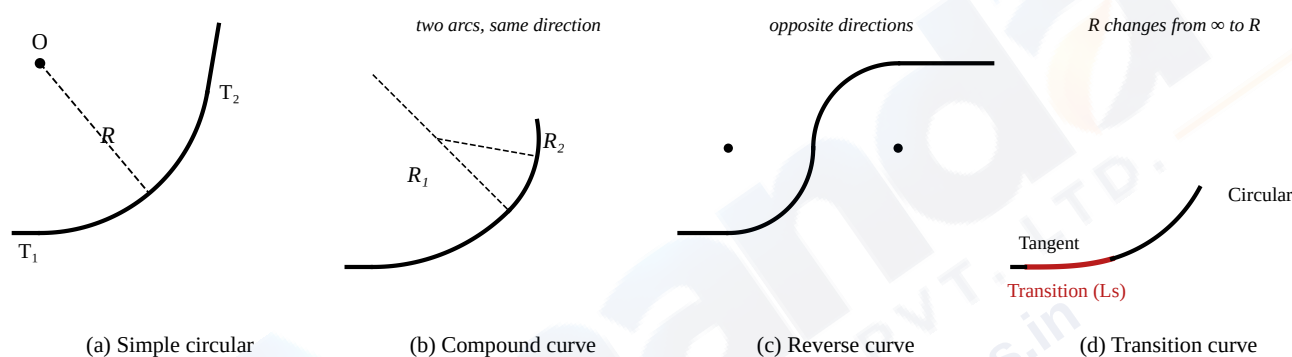


Fig.: Types of horizontal curves (plan)

(ii) Vertical curves:

- **Vertical curves** are provided at the junction of two different gradients in the longitudinal profile, to change the gradient smoothly. Generally a **square parabola** is used.
- **Summit curve (convex upward):** formed when an ascending gradient meets a descending gradient, or a gradient changes to a flatter / steeper one so that the curve is convex. It is designed mainly for **sight distance** (SSD / OSD), since the road beyond the summit is hidden. Centrifugal force acts upward, so comfort is not a problem.
- **Valley (sag) curve (concave upward):** formed when a descending gradient meets an ascending gradient (or a flatter one). It is designed for **comfort** (centrifugal force acts downward, adding to weight and causing impact) and for **head-light sight distance** at night. Transition curves (cubic parabola) are preferred.

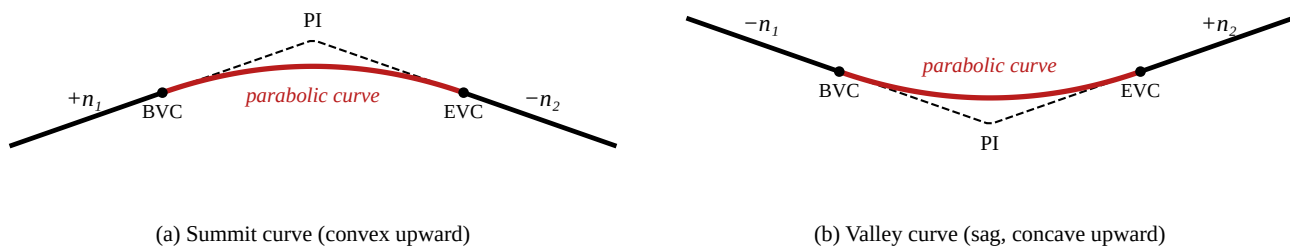


Fig.: Vertical curves — summit (convex) and valley (sag) curves

(Horizontal curves 3 M, vertical curves 3 M)

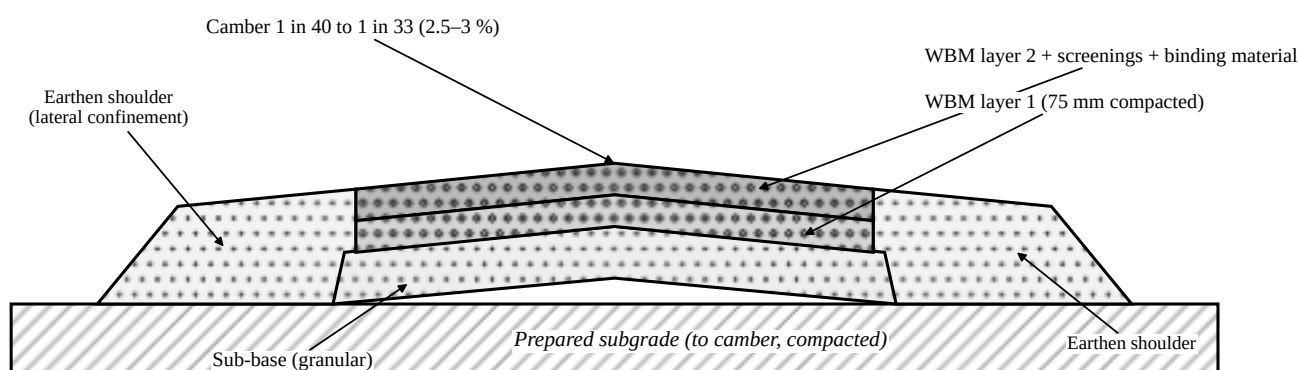
Q.6

a) Construction of WBM road

6 M

Water Bound Macadam (WBM) is a road layer of crushed coarse aggregates mechanically interlocked by rolling, with voids filled by screenings and binding material and bound together with water. Construction steps:

1. **Preparation of foundation (subgrade / sub-base):** Remove vegetation and loose material; shape the subgrade to the required camber and grade; compact it. An existing surface is scarified.
2. **Lateral confinement:** Construct earthen shoulders (or kerbs) on both sides to the thickness of the WBM layer, so that aggregates do not spread out.
3. **Spreading coarse aggregates:** Spread crushed stone aggregate (e.g. 63–45 mm or 53–22.4 mm grading) uniformly to the required loose thickness and camber using templates; each layer normally 75 mm compacted (about 100 mm loose).
4. **Dry rolling:** Roll with a three-wheeled power roller (8–10 t) or vibratory roller, from edges towards centre with half-width overlap (on super-elevated curves from inner edge to outer edge), till the aggregates are interlocked and do not creep.
5. **Application of screenings:** Spread screenings (smaller aggregate) in thin layers to fill the voids, with dry rolling and brooming.
6. **Sprinkling and grouting:** Sprinkle water, sweep and roll; the wet screenings fill the voids.
7. **Application of binding material:** Spread binding material (e.g. moorum / kankar dust, PI < 6) in thin layers, sprinkle water and roll till a slurry forms ahead of the roller wheels.
8. **Setting and drying:** Allow the layer to dry overnight; fill hungry spots with screenings / binding material and roll lightly.
9. **Opening to traffic:** Open to traffic after drying, or provide the next WBM layer / bituminous surfacing.



Coarse aggregate interlocked by rolling; voids filled with screenings + binding material and water-bound

Fig.: Cross-section of a WBM road

(Steps 4 M, sketch 2 M)

b) Road signs

6 M

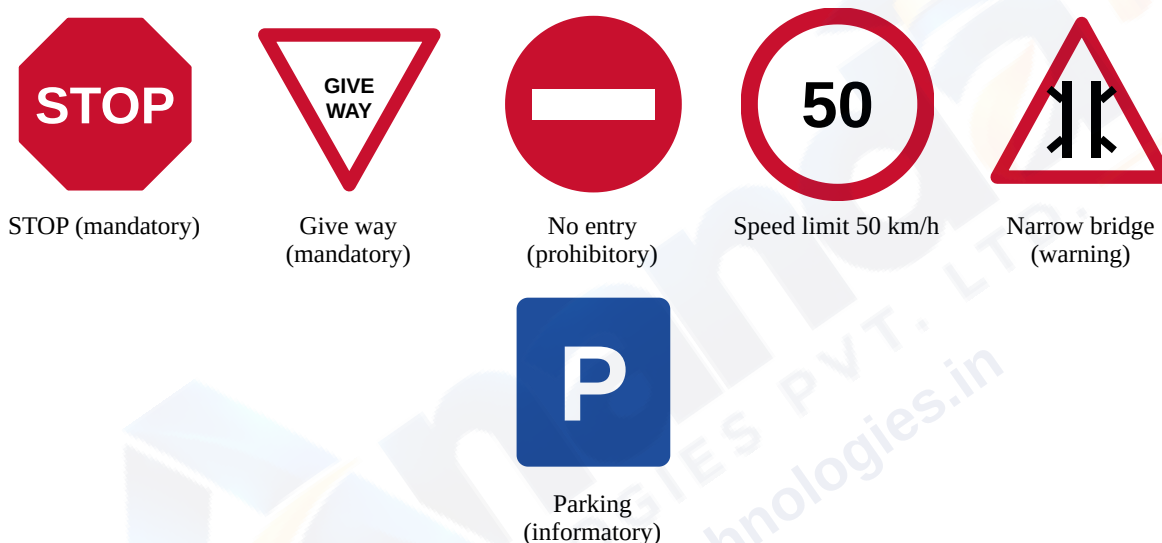


Fig.: Road signs (IRC:67)

- **Mandatory / regulatory signs:** circular; prohibitory signs have red border (with red bar for 'prohibited'); compulsory signs are blue discs. STOP is an octagon and GIVE WAY an inverted triangle. Violation is an offence.
- **Cautionary / warning signs:** equilateral triangle with apex upward, red border, white background and black symbol — warn of hazards ahead.
- **Informatory signs:** rectangular, blue or green background — give information on direction, distance, facilities.

(1 M for each correctly drawn sign)

c) Alternate bay method; comparison with continuous bay method

6 M

Alternate bay method:

1. The width of the road is divided into two halves (lanes), and each half is divided into bays (panels) of suitable length, equal to the joint spacing.
2. Concrete is laid in **alternate bays** (1, 3, 5, ...) of one half first, while traffic uses the other half.

3. After the concrete of these bays has hardened (few days), the remaining bays (2, 4, 6, ...) of the same half are concreted, using the hardened bays as side forms.
4. After curing of the first half, traffic is diverted to it and the second half is concreted in the same way.
5. **Advantages:** traffic is not stopped fully; shrinkage of the first bays takes place before the next bays are cast; working space is available.
6. **Disadvantages:** large number of construction joints; slow progress; riding quality is poorer; traffic movement on one half is difficult.

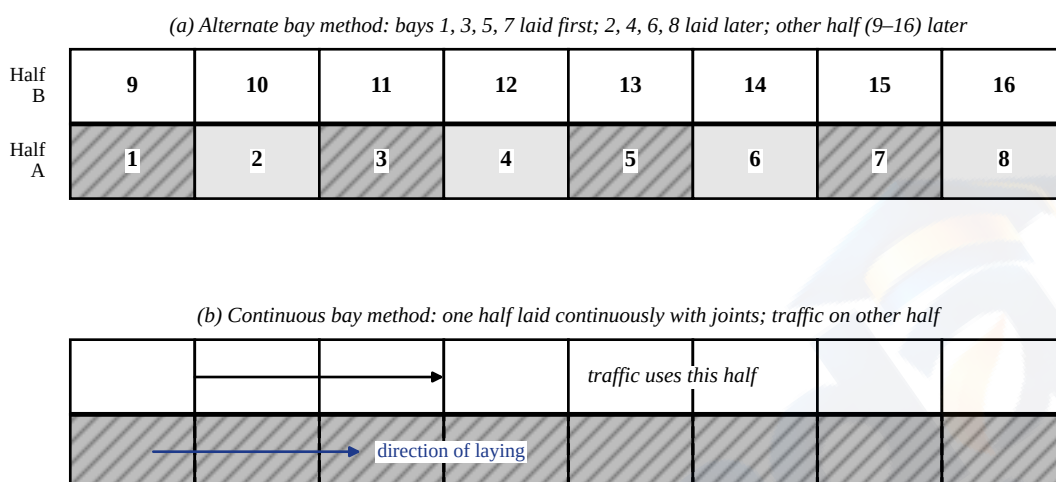


Fig.: Methods of laying cement concrete slabs (plan)

Alternate bay method	Continuous bay method
Concrete laid in alternate bays; gaps filled later	Concrete laid continuously bay after bay in one half
More construction joints	Fewer construction joints
Slow progress	Faster progress; suits mechanised paving
Shrinkage of first bays occurs before adjacent bays are cast	Shrinkage controlled by contraction joints
Poorer riding quality	Better riding quality

(Method 2.5 M, sketch 1.5 M, comparison 2 M)

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