

Highway Engineering (313323)

Model Question Paper — Set B · 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) Characteristics of road transport

2 M

1. Road transport gives door-to-door service and is very flexible in route and time.
2. Roads are used by many types of vehicles — fast and slow, motorised and non-motorised.
3. It needs comparatively small investment by the government; vehicles are owned by individuals/operators.
4. It is most economical for short distances and acts as a feeder to other modes.

(½ M each)

b) Right of way and kerb

2 M

(i) **Right of way (land width):** 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).

(ii) **Kerb:** The raised boundary (edge) between the pavement and the shoulder/footpath. It strengthens the pavement edge and guides traffic. Types: low (mountable), semi-barrier and barrier kerb.

(1 M each)

c) Purposes of camber

2 M

1. To drain off rain water from the road surface quickly.
2. To prevent entry of water into the pavement layers and subgrade, so that the subgrade does not become weak.
3. To keep the surface dry and so give better skid resistance (safety).
4. To help in separating the two lanes of traffic (vehicles keep to their side of the crown).

(½ M each)

d) Super-elevation and IRC formula

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

IRC design formula: $e = (0.75 V)^2 / (127 R) = V^2 / (225 R)$, where V = design speed in km/h, R = radius of curve in m; e limited to 7 % (plain terrain).

(Definition 1 M, formula 1 M)

e) Traffic volume study

2 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.

Uses:

1. Classification of roads and planning of road development.
2. Geometric design — number of lanes, width of carriageway, intersection design.

(Definition 1 M, two uses 1 M)

f) Components of a hill road

2 M

1. Breast wall
2. Retaining wall
3. Parapet wall
4. Catch water drain
5. Side drain
6. Road pavement / formation, hair-pin bends, cross drains

(Any four, ½ M each)

g) Desirable properties of subgrade soil

2 M

1. Stability — adequate strength (bearing capacity, CBR) under traffic loads.
2. Incompressibility — should not deform much under load.
3. Permanency of strength — strength should not reduce much on wetting.
4. Minimum changes in volume (swelling and shrinkage) with moisture.

(½ M each)

Q.2

a) Classification of roads — Nagpur Road Plan

4 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):** Main highways running through the length and breadth of the country, connecting state capitals, major ports, foreign highways and important cities. Built and maintained by the Central Government (MoRTH / NHAI).
2. **State Highways (SH):** Arterial roads of a state connecting district headquarters and important cities of the state with NHs or highways of neighbouring states. Maintained by State PWD.
3. **Major District Roads (MDR):** Important roads within a district serving areas of production and markets and connecting them with each other or with SH / NH.
4. **Other District Roads (ODR):** Roads serving rural areas of production, giving them outlet to market centres, taluka headquarters, railway stations, etc.
5. **Village Roads (VR):** Roads connecting villages or groups of villages with each other and with the nearest road of higher category.

(Classification 1 M, explanation 3 M)

b) Alignment and factors controlling it

4 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).

Factors controlling alignment:

1. **Obligatory points:** points through which the road must pass (bridge site, mountain pass, town) and points to be avoided (religious places, costly buildings, marshy land, lakes).
2. **Traffic:** alignment should suit the desire lines of traffic flow and future traffic.
3. **Geometric design:** ruling gradient, radius of curves and sight distances decide the alignment.
4. **Economy:** cost of earthwork, construction, maintenance and vehicle operation should be minimum; balance cutting and filling.
5. **Drainage and HFL:** good natural drainage; formation kept above highest flood level; minimum cross-drainage works.

(Definition 1 M, any four factors 3 M)

c) Gradient and IRC values

4 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 %).

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)

(IRC recommended gradients. On horizontal curves the gradient is reduced by grade compensation = $(30 + R)/R$ %, max 75/R %.)

(Definition 1 M, values 3 M)

d) Camber numerical — crown height and parabolic ordinates

4 M

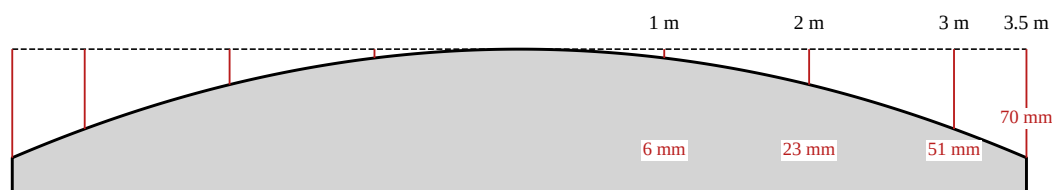
Given: W = 7.0 m, camber 1 in 50 (n = 50).

Height of crown above edges $h = (W/2) / n = 3.5 / 50 = 0.070 \text{ m} = 70 \text{ mm}$

Parabolic camber: equation of the parabola (crown as origin, x measured from centre, y downward): $y = 2x^2 / (n W) = 2x^2 / (50 \times 7.0) = x^2 / 175$. Check: at x = 3.5 m, $y = 12.25/175 = 0.070 \text{ m} = h$.

x from crown (m)	$y = x^2 / 175 \text{ (m)}$	y (mm)
0.0	0.0000	0.0
0.5	0.0014	1.4
1.0	0.0057	5.7
1.5	0.0129	12.9

2.0	0.0229	22.9
2.5	0.0357	35.7
3.0	0.0514	51.4
3.5	0.0700	70.0



Ordinates y below crown level (right half shown with values; left half same)

Fig.: Parabolic camber ordinates (vertical scale exaggerated)

(Crown height 1 M, formula 1 M, ordinates 2 M)

Q.3

a) Cross-section of flexible pavement and function of layers

4 M

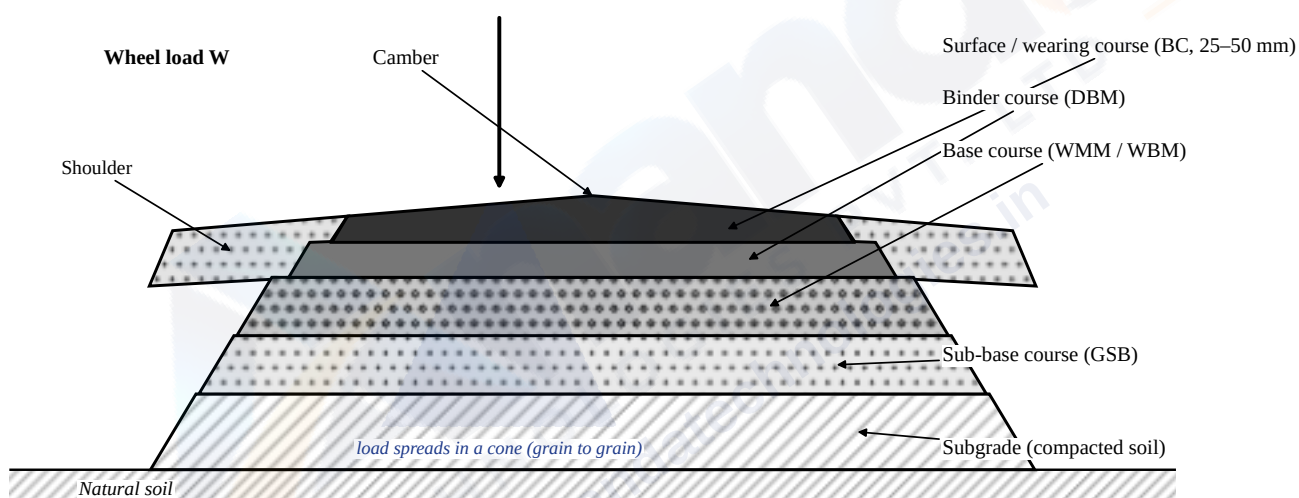


Fig.: Typical cross-section of a flexible pavement

- 1. 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.
- 2. Binder course (base coat):** Bituminous layer (DBM / BM) between the base and the wearing course; binds the wearing course to the base and distributes load. A prime coat / tack coat of bitumen is applied before laying for bond.
- 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. 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.

5. **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.

(Sketch 2 M, functions 2 M)

b) CBR test

4 M

California Bearing Ratio (CBR) is the ratio (in %) of the force required to penetrate a standard plunger into the soil specimen to the force required for the same penetration into a standard crushed-stone material. It is used for design of flexible pavement thickness (IRC:37). (IS 2720 Part 16)

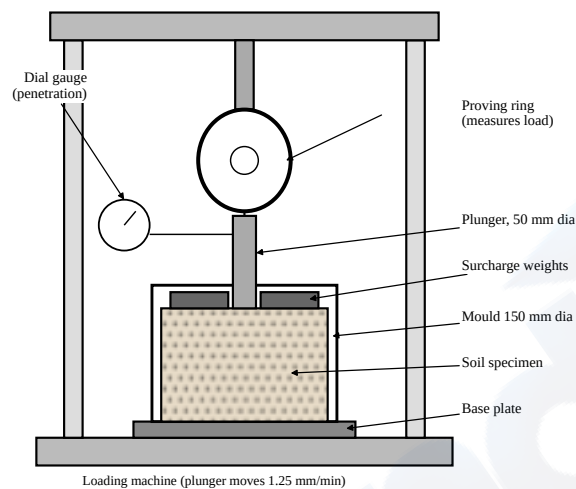


Fig.: CBR test apparatus (laboratory)

Procedure:

1. Prepare the soil at optimum moisture content and compact it in the CBR mould (150 mm dia, 175 mm high, with 50 mm spacer disc) in layers by standard rammer blows.
2. Remove the spacer disc, invert the mould, place surcharge weights (2.5 kg each, total normally 5 kg) and soak the specimen in water for 4 days (96 h) if soaked CBR is needed.
3. Place the mould on the loading machine; seat the plunger (50 mm dia) with a small seating load and set the load and penetration dial gauges to zero.
4. Apply load so that the plunger penetrates at **1.25 mm/min**; record loads at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm.
5. Plot the load–penetration curve (apply correction if the initial part is concave upward).
6. $CBR = (\text{test load} / \text{standard load}) \times 100$ at 2.5 mm (standard load 1370 kg) and at 5.0 mm (standard load 2055 kg). Normally the value at 2.5 mm is taken; if the 5.0 mm value is higher, the test is repeated and if again higher, the 5.0 mm value is adopted.

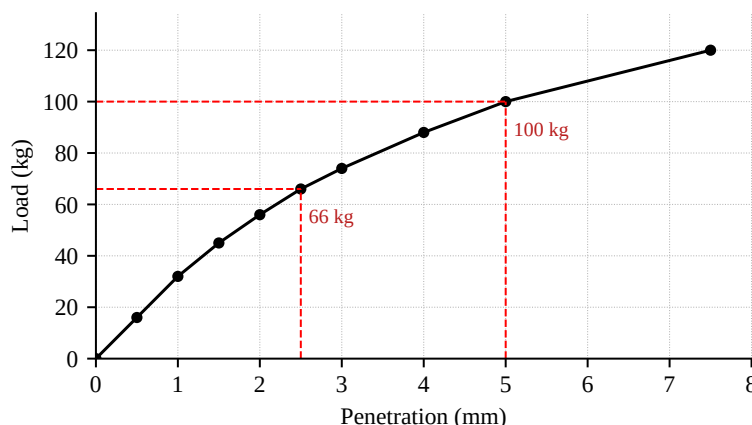


Fig.: Load-penetration curve (sample readings)

Example (sample readings above): CBR at 2.5 mm = $66/1370 \times 100 = 4.82\%$; CBR at 5.0 mm = $100/2055 \times 100 = 4.87\%$. Since the 5.0 mm value is slightly higher, the test is repeated as per IS; if confirmed, CBR = 4.9 %.

(Definition 1 M, sketch 1 M, procedure 2 M)

c) Alternate bay method

4 M

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.

(a) Alternate bay method: bays 1, 3, 5, 7 laid first; 2, 4, 6, 8 laid later; other half (9–16) later

Half B	9	10	11	12	13	14	15	16
Half A	1	2	3	4	5	6	7	8

(b) Continuous bay method: one half laid continuously with joints; traffic on other half

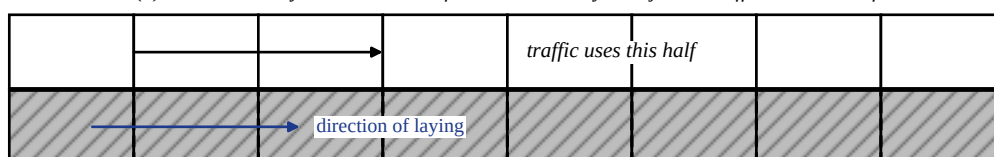


Fig.: Methods of laying cement concrete slabs (plan)

(Description 2 M, sketch 2 M)

d) Requirements of a good highway drainage system

4 M

1. Surface water from the carriageway and shoulders should drain off quickly (adequate camber and shoulder slope).
2. Side drains should have sufficient capacity and longitudinal slope to carry the water to an outlet.
3. Flow in side drains should not cause erosion; drains should be lined where needed.
4. Water from adjoining land and hill slopes should not enter the road (catch water drains).
5. Seepage and capillary water should not reach the subgrade; the highest water table should be kept well below the subgrade (about 1.0–1.2 m).

(Any four, 1 M each)

Q.4

a) Transition curve

4 M

A **transition curve** is a curve of gradually varying radius (from infinity at the tangent point to the radius R of the circular curve) provided between a straight and a circular curve.

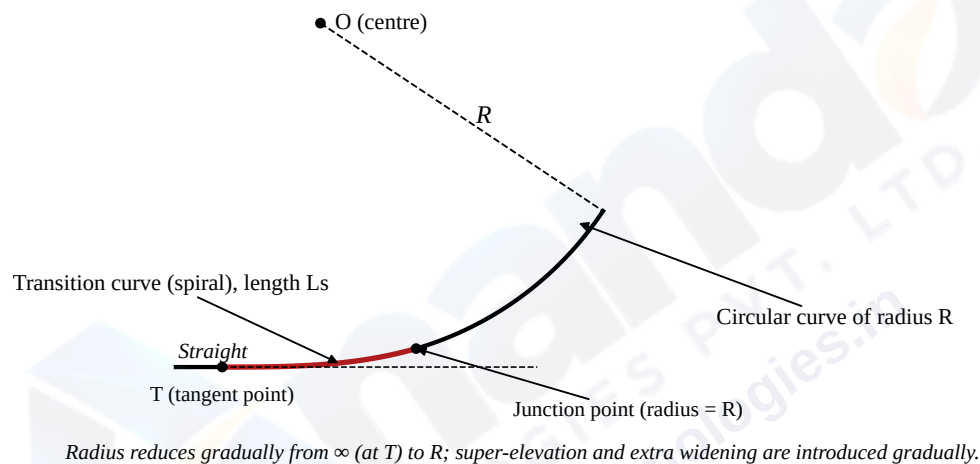


Fig.: Transition curve between tangent and circular curve

Purposes:

1. To introduce the centrifugal force gradually (from zero to maximum) and avoid sudden jerk.
2. To provide gradual introduction of super-elevation and extra widening.
3. To enable the driver to turn the steering gradually, giving smooth and safe riding.
4. To improve the appearance of the road. (Ideal shape: spiral / clothoid; other shapes: lemniscate, cubic parabola.)

(Sketch 2 M, purposes 2 M)

b) Clover leaf intersection

4 M

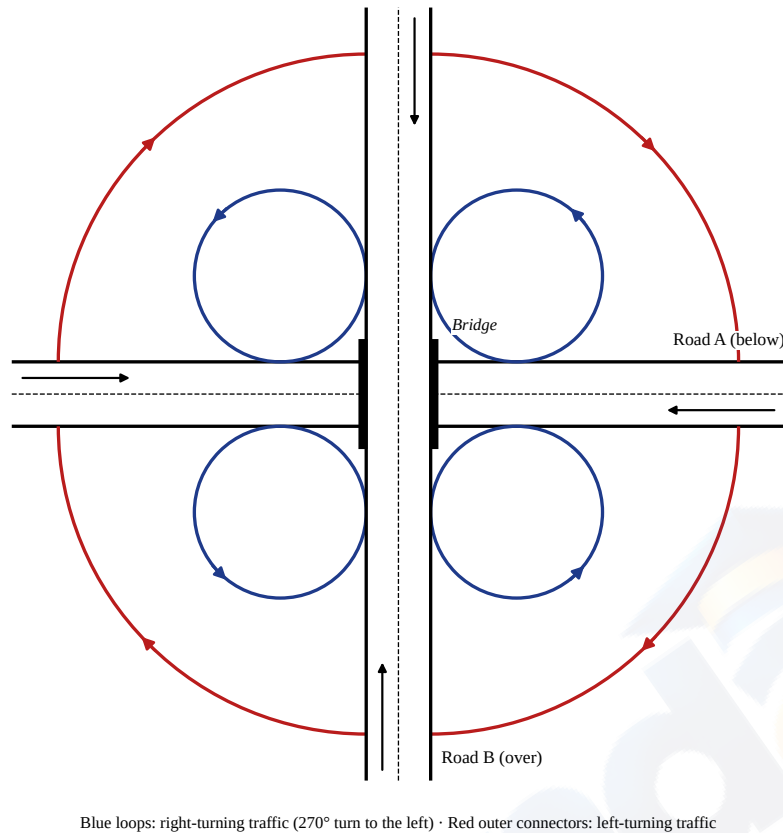


Fig.: Clover leaf intersection (grade separated) — keep-left traffic

- A **clover leaf** is a four-leg **grade-separated** intersection (interchange). One road passes over the other on a bridge, so through traffic of both roads moves without any crossing.
- Right-turning traffic uses the four **loops** (turning 270° to the left); left-turning traffic uses the four **outer connectors (ramps)**.
- **Advantages:** (1) all crossing conflicts are eliminated — very safe; (2) uninterrupted, high-capacity flow at high speed without signals.
- **Limitations:** large land area and high cost; longer travel for right turners; weaving between loops.

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

c) Failures of rigid pavement

4 M

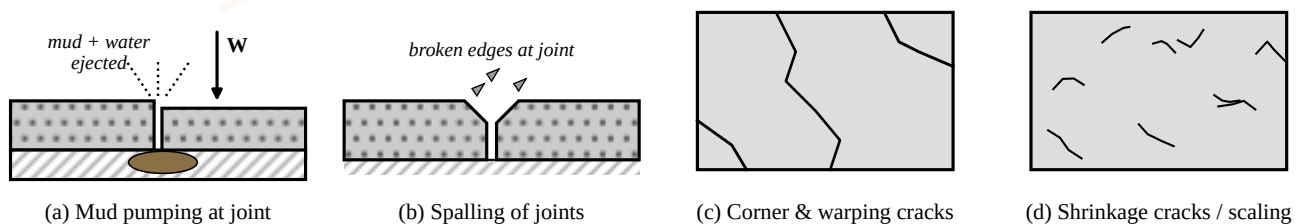


Fig.: Common failures of rigid pavement

1. **Scaling of cement concrete:** Peeling of thin surface layer due to over-finishing, excess fines/water, poor curing.
2. **Shrinkage cracks:** Fine cracks due to drying shrinkage of concrete when curing is inadequate.

3. **Joint spalling:** Breaking of slab edges at joints due to entry of stones (incompressibles) in joints or poor dowel alignment.
4. **Warping cracks:** Cracks near slab edges and joints due to temperature difference between top and bottom of slab when warping joints are not provided.
5. **Mud pumping:** Ejection of soil slurry and water through joints and edges under moving loads, due to poor subgrade, water entry and loss of support.

(Any four, 1 M each)

d) Procedure of pothole repair

4 M

1. **Marking:** mark a rectangular area around the pothole with sides parallel and perpendicular to the centre line, extending a little into sound pavement.
2. **Cutting and cleaning:** cut the marked area with vertical sides down to firm material; remove loose material, dust and water (compressed air / broom).
3. **Repair of base:** if the base is damaged, fill and compact it with WBM / WMM material.
4. **Tack coat:** apply a thin coat of bitumen emulsion / hot bitumen on the bottom and vertical sides for bond.
5. **Filling:** fill with hot (or cold) bituminous premix in layers.
6. **Compaction:** compact with hand rammer / plate compactor / roller, keeping the surface slightly above the surrounding level to allow for further compaction by traffic; seal the edges and open to traffic after cooling.

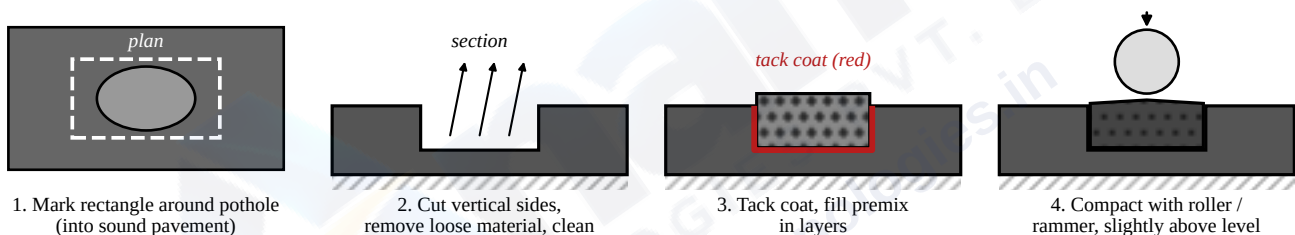


Fig.: Sequence of pothole repair (patching) in bituminous pavement

(Steps 2 M, sketch 2 M)

e) Cross-section of NH in cutting

4 M

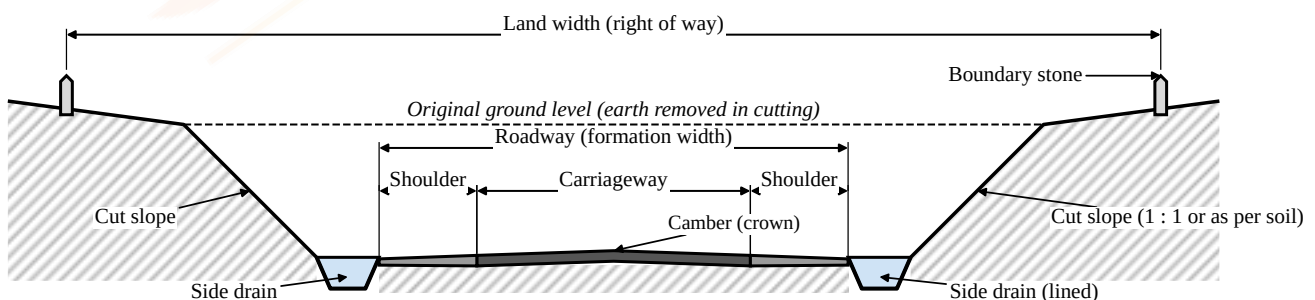


Fig.: Typical cross-section of National Highway in cutting (not to scale)

In cutting, side drains are provided at formation level on both sides (lined drains preferred); cut slopes depend on the type of soil or rock; land width is acquired up to the boundary stones.

(Sketch 2 M, labels 2 M)

Q.5

a) Overtaking sight distance numerical

6 M

Overtaking sight distance (OSD): The minimum distance open to the vision of the driver of a vehicle intending to overtake a slow vehicle ahead, with safety against traffic of the opposite direction, on a two-lane two-way road.

Given: speed of overtaking vehicle $V = 80$ km/h (= design speed, also taken for opposing vehicle), speed of overtaken vehicle $V_b = 64$ km/h, acceleration $a = 0.72$ m/s², reaction time for overtaking $t = 2.0$ s, two-way traffic.

$$v_b = 64/3.6 = 17.78 \text{ m/s}; \quad v = 80/3.6 = 22.22 \text{ m/s}$$

Step 1 — d_1 (distance by overtaking vehicle during reaction time) $= 0.278 V_b t = 0.278 \times 64 \times 2.0 = 35.58 \text{ m}$

Step 2 — Spacing s $= 0.7 v_b + 6 = 0.7 \times 17.78 + 6 = 18.44 \text{ m}$

Overtaking time T $= \sqrt{(4s / a)} = \sqrt{(4 \times 18.44 / 0.72)} = 10.12 \text{ s}$

Step 3 — d_2 $= v_b T + 2s = 17.78 \times 10.12 + 2 \times 18.44 = 216.85 \text{ m}$

Step 4 — d_3 (distance travelled by opposing vehicle during T) $= v T = 22.22 \times 10.12 = 224.95 \text{ m}$

OSD $= d_1 + d_2 + d_3 = 35.58 + 216.85 + 224.95 = 477.38 \text{ m}$ (say 478 m)

Minimum length of overtaking zone $= 3 \times \text{OSD} = 1433 \text{ m}$ (desirable $5 \times \text{OSD} = 2387 \text{ m}$).

$$d_1 = 0.278 V_b t \cdot d_2 = 0.278 V_b T + 2s \cdot d_3 = 0.278 V T$$

A = overtaking vehicle, B = slow vehicle (speed V_b), C = vehicle from opposite direction (speed V)

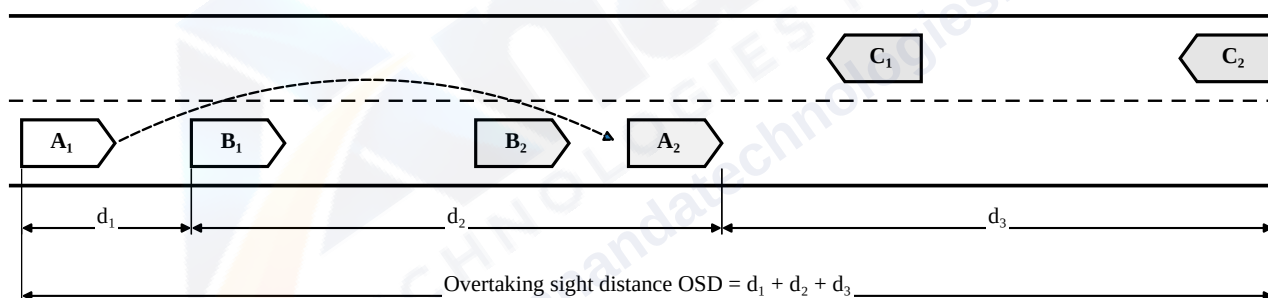


Fig.: Overtaking sight distance on a two-lane two-way road (plan)

(d_1 1 M, s and T 1.5 M, d_2 1 M, d_3 1 M, OSD 0.5 M, sketch 1 M)

b) Cross-section of hill road and functions of components

6 M

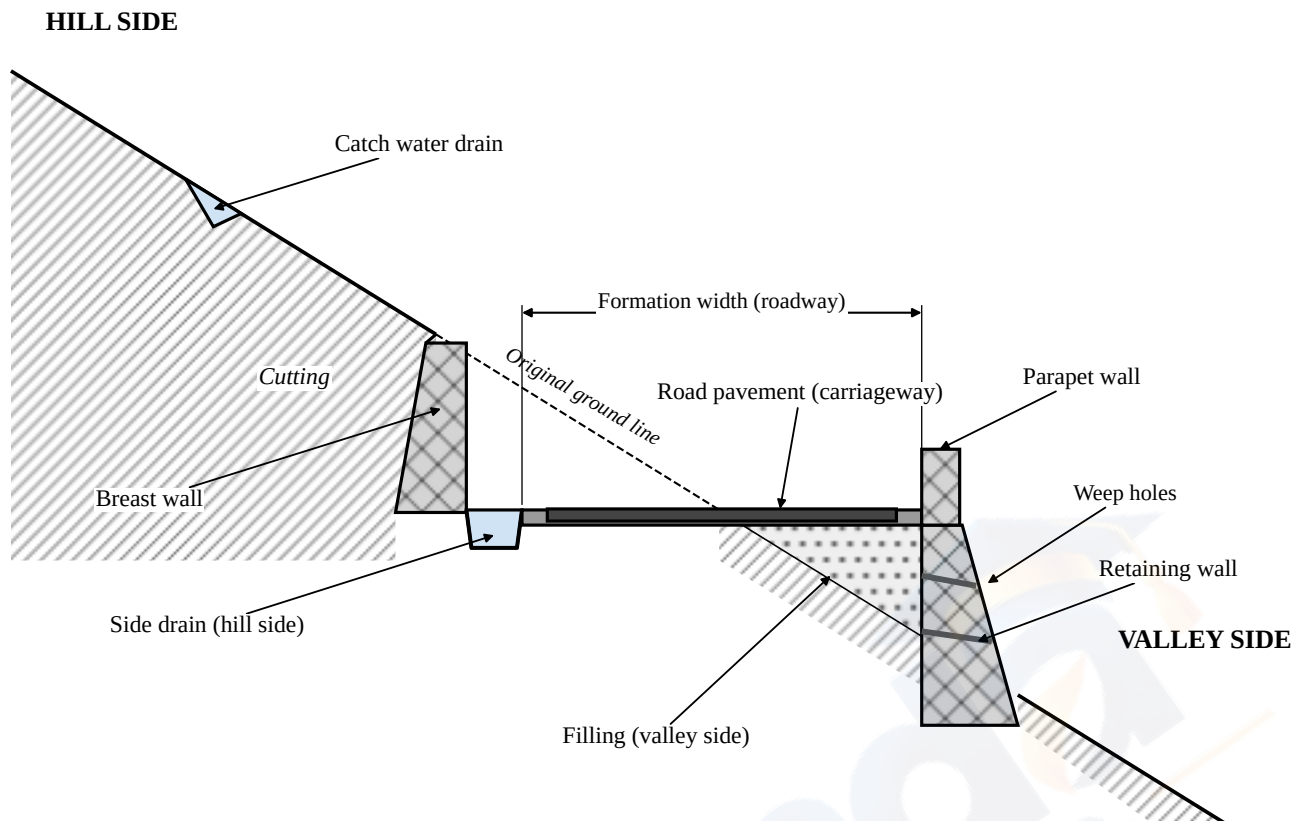


Fig.: Typical cross-section of a hill road (cut and fill on hill slope)

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.

(Sketch 3 M, functions 3 M)

c) Camber — types, factors and IRC values

6 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 %).

Types of camber:

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.

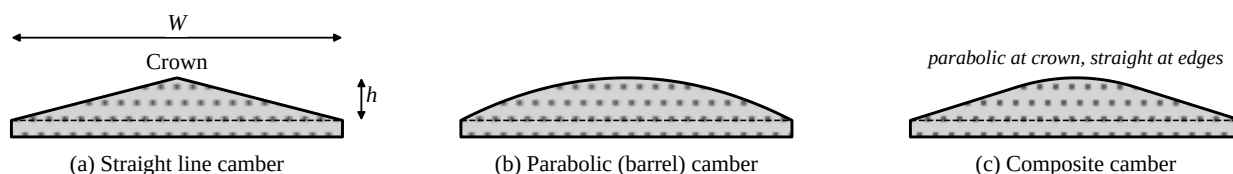


Fig.: Types of camber (vertical scale exaggerated)

Factors affecting camber:

1. **Type of pavement surface:** smooth, impervious surfaces (CC, bituminous) need less camber; rough, pervious surfaces (WBM, earth) need more.
2. **Amount of rainfall:** heavy rainfall areas need steeper camber than low rainfall areas.
3. **Width of pavement:** wider pavements need more height of crown for the same slope.
4. **Speed and comfort of vehicles:** too steep camber causes discomfort and tendency of vehicles to slide/overturn, so camber is limited.

IRC recommended camber:

Type of road surface	Heavy rainfall	Light rainfall
Cement concrete and high type bituminous surface	1 in 50 (2.0 %)	1 in 60 (1.7 %)
Thin bituminous surface	1 in 40 (2.5 %)	1 in 50 (2.0 %)
Water bound macadam (WBM) and gravel	1 in 33 (3.0 %)	1 in 40 (2.5 %)
Earth road	1 in 25 (4.0 %)	1 in 33 (3.0 %)

(IRC recommended camber; shoulders are given a cross slope about 0.5 % steeper than the pavement.)

(Definition 1 M, types with sketch 2 M, factors 1.5 M, IRC values 1.5 M)

Q.6

a) Causes and prevention of landslides

6 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.

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

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.
3. **Flattening or benching (terracing)** of slopes and removal of loose material from top.
4. **Vegetation / afforestation / turfing** to bind the soil and reduce erosion.
5. **Rock bolting, soil nailing, anchors, wire mesh and grouting** of loose rock.
6. **Avoid cutting the toe**, use controlled blasting; select alignment away from unstable zones.

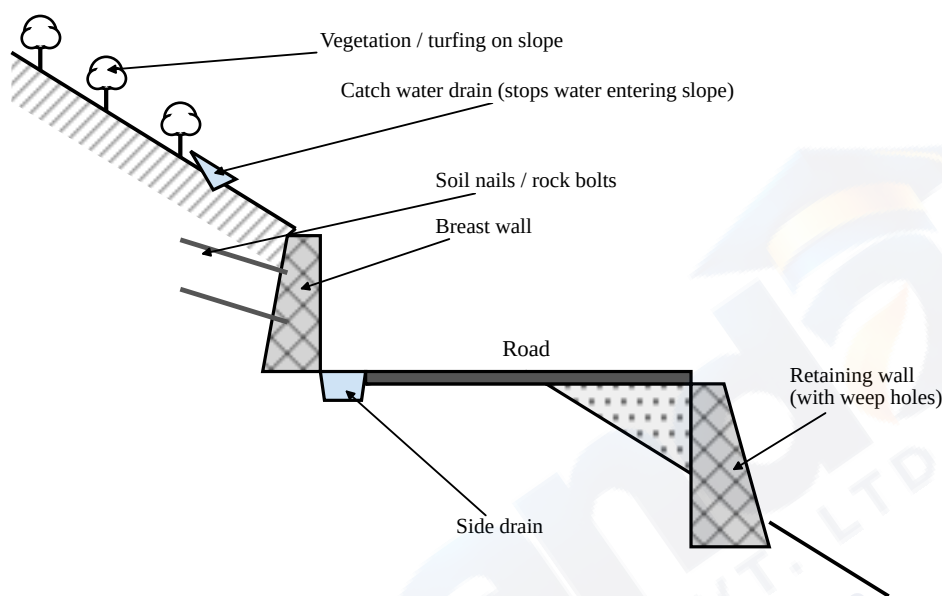


Fig.: Landslide prevention measures on a hill road

(Causes 2.5 M, preventive measures 2.5 M, sketch 1 M)

b) Road signs

6 M

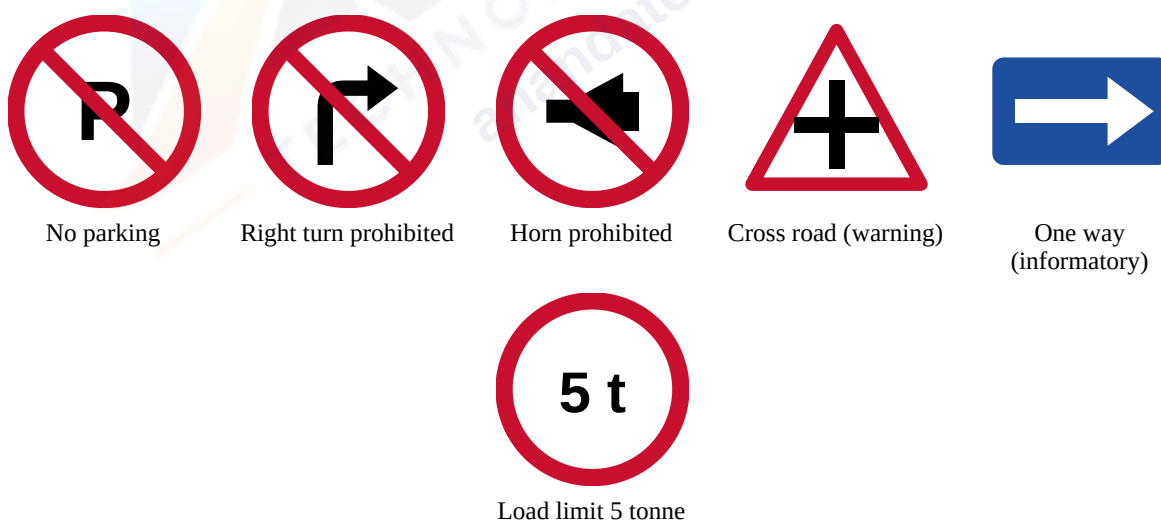


Fig.: Road signs (IRC:67)

- **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 sign)

c) Joints in CC pavement

6 M

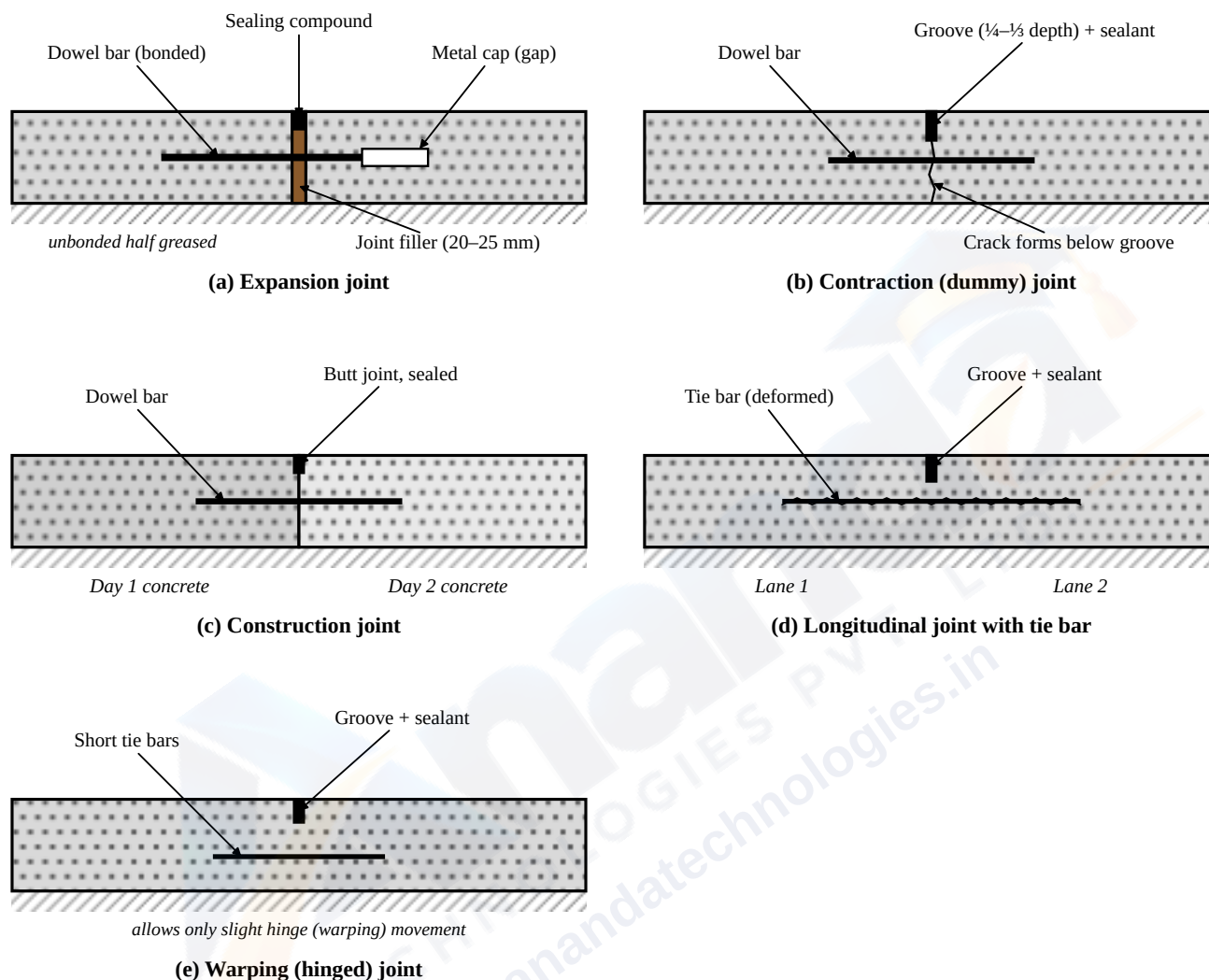


Fig.: Joints in cement concrete pavement

1. **Expansion joints:** 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.
2. **Contraction joints:** 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.
3. **Warping joints:** Hinged joints with short tie bars which relieve warping stresses caused by temperature difference between top and bottom of the slab.
4. **Construction joints:** Provided where concreting stops at the end of the day's work or due to interruption; butt type, preferably at the location of a contraction / expansion joint, with dowels.

5. **Longitudinal joints:** Provided when pavement width exceeds about 4.5 m, to divide it into lanes and prevent irregular longitudinal cracks; tie bars hold the two slabs together.
6. **Dowel bars:** Plain mild-steel round bars placed across transverse (expansion / contraction) joints at mid-depth; they transfer load from one slab to the next without preventing horizontal movement. One half is bonded, the other half greased and capped (typically 25–32 mm dia, about 500 mm long, 300 mm c/c).

(1 M for each joint with sketch)

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