Transportation Engineering

Short notes for B.Tech Civil · GATE CE

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1. Highway Development and Planning

- Modes of transport: road, rail, air, water, pipeline. Roads give door-to-door service and feed other modes.
- **Jayakar Committee (1927)** led to the Central Road Fund and IRC (1934).
- Road plans: Nagpur plan (1943, star and grid pattern), Bombay plan (1961), Lucknow plan (1981).
- **IRC** (Indian Roads Congress) writes the highway codes in India. **NHAI** develops National Highways.

➤ Road classification (Nagpur plan)

Road	Connects
National Highway (NH)	State capitals, ports, major cities
State Highway (SH)	District headquarters with NH
Major District Road (MDR)	Production and market areas within a district
Other District Road (ODR)	Rural areas to MDR / taluka
Village Road (VR)	Villages to each other and nearest road

- Urban roads: arterial, sub-arterial, collector, local streets.
- **Alignment** requirements: short, easy, safe, economical. Obligatory points decide the path.

2. Geometric Design of Highways

➤ Cross-section elements

- **Camber** = cross slope for drainage. Steeper on rough surfaces (earth roads) and flatter on bituminous / concrete roads.
- Lane width for single lane 3.75 m, two-lane 7.0 m (IRC).
- **Skid**: wheels lock and slide. **Slip**: wheel rotates more than it moves.

- Friction coefficient: longitudinal about 0.35 to 0.40 (IRC, depending on speed); lateral 0.15.

Sight distance

- **Stopping sight distance (SSD)** = lag distance + braking distance.

FORMULA SSD = $0.278\ V\ t + V^2 / (254\ f)$, V in km/h, t = reaction time (2.5 s per IRC), f = longitudinal friction. On gradient n: $V^2 / [254\ (f \pm 0.01n)]$.

EXAMPLE V = 80 km/h, t = 2.5 s, f = 0.35. Lag = 0.278 x 80 x 2.5 = 55.6 m. Braking = $80^2 / (254 \times 0.35)$ = 6400/88.9 = 72.0 m. SSD = 127.6 m.

- **Overtaking sight distance (OSD)** = d1 + d2 + d3.

FORMULA $d1 = 0.278\ Vb\ t$ (t = 2 s), $d2 = 0.278\ Vb\ T + 2s$, $s = 0.2\ Vb + 6$, $T = \sqrt{4s / a}$, $d3 = 0.278\ V\ T$ (V of opposing vehicle).

- **Intermediate sight distance (ISD)** = 2 × SSD. **Headlight sight distance** = SSD (used for valley curves).
- Two-way traffic on a single lane needs 2 × SSD.

Horizontal alignment

FORMULA Equilibrium: $e + f = V^2 / (127\ R)$. Design superelevation (IRC): $e = (0.75\ V)^2 / (127\ R)$, max e = 0.07 in plain areas (0.10 in hills), f = 0.15.

EXAMPLE V = 80 km/h, R = 300 m. $e = (60)^2/(127 \times 300) = 3600/38100 = 0.0945 > 0.07$, so take e = 0.07. Check f = 6400/38100 - 0.07 = 0.168 - 0.07 = 0.098 < 0.15. Safe.

- Ruling minimum radius: $R = V^2 / [127\ (e + f)]$.
- **Extra widening** on curves = mechanical + psychological:

FORMULA $We = n\ l^2 / (2R) + V / (9.5\ \sqrt{R})$, n = number of lanes, l = wheelbase.

- **Transition curve**: rate of change of centripetal acceleration $C = 80 / (75 + V)$, limited to 0.5 to 0.8 m/s^3.

FORMULA Length of transition $Ls = 0.0215\ V^3 / (C\ R)$. Shift $S = Ls^2 / (24R)$.

➤ Vertical alignment

- Gradients: ruling, limiting, exceptional, minimum (for drainage).
- **Grade compensation** on curves: $(30 + R)/R$ %, max $75/R$ %. Not needed for gradients flatter than 4%.
- Summit curves: designed for sight distance (parabola). Valley curves: designed for comfort and headlight sight distance (cubic parabola / parabola).

3. Traffic Engineering

- Traffic studies: volume, speed (spot speed, speed and delay), origin–destination, parking, accident studies.
- **PCU** (passenger car unit) converts mixed traffic to equivalent cars.
- **85th percentile speed** = safe speed limit. **98th percentile** = design speed (often). **15th percentile** = minimum speed limit.

➤ Fundamental relations

FORMULA $q = k\ v$ (flow = density x speed). Greenshields: $v = vf\ (1 - k/kj)$.

- Max flow $qmax = vf\ kj / 4$, at $k = kj / 2$ and $v = vf / 2$.
- **Time mean speed** ≥ **space mean speed** (equal only if all vehicles have the same speed).

EXAMPLE Free speed $vf = 60$ km/h, jam density $kj = 120$ veh/km. $qmax = 60 \times 120/4 = 1800$ veh/h, at $k = 60$ veh/km and $v = 30$ km/h.

➤ Signals and intersections

- Intersections: at grade (uncontrolled, rotary, signalised) and grade separated (flyover, cloverleaf, trumpet).
- **Rotary**: suitable for moderate traffic; weaving length decides capacity.

FORMULA Webster's optimum cycle length $Co = (1.5\ L + 5) / (1 - Y)$, L = total lost time per cycle, Y = sum of critical flow ratios (q/s).

EXAMPLE Lost time $L = 10$ s, $Y = 0.6$. $Co = (15 + 5)/(1 - 0.6) = 20/0.4 = 50$ s.

- Traffic signs: regulatory (mandatory), warning (cautionary), informatory.

4. Highway Materials

Test	Property
Aggregate impact value	Toughness
Aggregate crushing value	Strength
Los Angeles abrasion	Hardness
Flakiness / elongation index	Shape
Soundness	Durability (weathering)
Stripping value	Bitumen adhesion

Bitumen test	Property
Penetration (1/10 mm, 25°C, 100 g, 5 s)	Hardness / consistency (grade)
Ductility	Stretch before breaking
Softening point (ring and ball)	Temperature susceptibility
Flash and fire point	Safety while heating
Viscosity	Flow (VG grades: VG-10 to VG-40)

- **CBR test** for subgrade strength: load to penetrate 2.5 mm and 5 mm, compared with standard loads (1370 kg and 2055 kg). CBR is usually taken at 2.5 mm.
- **Marshall test**: stability (load) and flow (deformation) of bituminous mixes; used for mix design.

5. Pavement Design

Flexible pavement	Rigid pavement
Layers of bitumen and aggregates	Cement concrete slab
Load spread by grain-to-grain contact	Load spread by slab (beam) action
Design by CBR / IRC 37 (mechanistic-empirical)	Design by Westergaard / IRC 58
Low initial cost, high maintenance	High initial cost, low maintenance
Life about 10 to 20 years	Life about 30 years or more

- Flexible layers: subgrade, sub-base, base, binder course, surface course.

- **ESWL** (equivalent single wheel load) for dual wheels. Fourth power law: damage ∝ (axle load / standard axle)^4.

FORMULA Cumulative standard axles (IRC 37): N = 365 x [(1 + r)^n - 1] / r x A x D x F. A = initial traffic (CVPD), D = lane distribution, F = VDF, r = growth rate, n = design life.

➤ Rigid pavement

FORMULA Radius of relative stiffness l = [E h³ / (12 (1 - μ²) k)]^(1/4). k = modulus of subgrade reaction.

- Critical load positions: interior, edge, corner. Westergaard gave stress formulas for each.
- Joints: expansion, contraction, construction, longitudinal. **Dowel bars** transfer load across transverse joints; **tie bars** hold longitudinal joints.
- Temperature stresses: warping (day–night gradient) and frictional stresses.

➤ Pavement failures

- Flexible: rutting, fatigue (alligator) cracking, ravelling, potholes, bleeding.
- Rigid: scaling, joint spalling, pumping, corner cracks, faulting.

6. Railway Engineering

Gauge	Width
Broad gauge (BG)	1676 mm
Metre gauge (MG)	1000 mm
Narrow gauge (NG)	762 mm and 610 mm

- Track components: rails, sleepers, ballast, formation, fastenings.
- **Coning of wheels** (slope about 1 in 20) keeps the wheel set centred and helps on curves.
- **Creep**: longitudinal movement of rails. **Hogging**: bending of rail ends at joints.
- Points and crossings let trains change tracks. Signalling ensures safe spacing.

FORMULA Equilibrium cant $e = G V^2 / (127 R)$ (e in mm if G in mm, V km/h, R m). Cant deficiency = cant needed for max speed − actual cant.

7. Airport Engineering

- Runway orientation is chosen from a **wind rose** so the crosswind component stays within limits.
- **Basic runway length** is corrected for site conditions:
  - Elevation: +7% per 300 m above MSL.
  - Temperature: +1% for every 1°C that the airport reference temperature exceeds the standard temperature at that elevation.
  - Gradient: +20% for every 1% of effective gradient.
- Combined elevation and temperature correction should not exceed 35% (else check by special study).
- Parts of an airport: runway, taxiway, apron, terminal, hangar, control tower.

8. Most Asked Questions (practice)

1. Explain road classification as per Nagpur plan.
2. Derive the SSD formula; find SSD on an up gradient.
3. Find OSD for given overtaking and overtaken speeds.
4. Design superelevation for a given speed and radius (IRC method).
5. Find extra widening and length of transition curve.
6. Explain the speed–flow–density relations and find maximum flow.
7. Design a signal cycle by Webster's method.
8. Compare flexible and rigid pavements; explain IRC 37 design steps.
9. Explain bitumen tests and aggregate tests with their purpose.
10. Correct the basic runway length for elevation, temperature and gradient.

TIP GATE CE loves SSD, superelevation, Greenshields flow, Webster's cycle, CBR, ESA and runway corrections. Keep units (km/h vs m/s) consistent in every step.