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Internal Assessment Test 2 – October 2018

Sub:	Highway Geometric design				Sub Code:	10CV755	Branch :	CIVIL
Date:	17/10/2018	Duration:	90 mins	Max Marks: 50	Sem / Sec:	Exit Scheme		OBE

Answer any **FIVE FULL** Questions OUT OF **SIX** — MARKS | CO | RBT

1 (a) Describe briefly the effect of centrifugal force on horizontal curve having no super elevation. [8] CO2 L2

When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the centre of gravity of the vehicle. The centrifugal force developed depends on the radius of the horizontal curve and the speed of the vehicle negotiating the curve. This centrifugal force is counteracted by the transverse frictional resistance developed between the tyres and the pavement which enables the vehicle to change the direction along the curve and to maintain the stability of the vehicle. Centrifugal force P is given by the equation:

$$P = \frac{Wv^2}{gR} \qquad \text{(Eq. 4.9)}$$

Here

Here

- P = centrifugal force, kg
- W = weight of the vehicle, kg
- R = radius of the circular curve, m
- v = speed of vehicle, m/sec
- g = acceleration due to gravity = 9.8 m/sec^2

The ratio of the centrifugal force to the weight of the vehicle, P/W is known as the 'centrifugal ratio' or the 'impact factor'. Therefore centrifugal ratio, $(P/W) = (v^2/gR)$.

The centrifugal force acting on a vehicle negotiating a horizontal curve has the following two effects:

(i) Tendency to overturn the vehicle outwards about the outer wheels and

(ii) Tendency to skid the vehicle laterally, outwards

The analysis of stability of those two conditions against overturning and transverse skidding of the vehicles negotiating horizontal curves without superelevation are given below:

(i) Overturning effect

The centrifugal force that tends the vehicle to overturn about the outer wheels B on horizontal curve without superelevation is illustrated in Fig. 4.18. Let h be the height of the centre of gravity of the vehicle above the road surface and b be the width of the wheel base or the wheel track of the vehicle.

The overturning moment due to centrifugal force, P = P.h

This is resisted by the restoring moment due to weight of the vehicle W and is equal to (Wb / 2).

The equilibrium condition for overturning will occur when Ph = Wb/2, or when P/W = (b / 2h). This means that there is danger of overturning when the centrifugal ratio P/W or v^2/gR attains a values of b/2h.

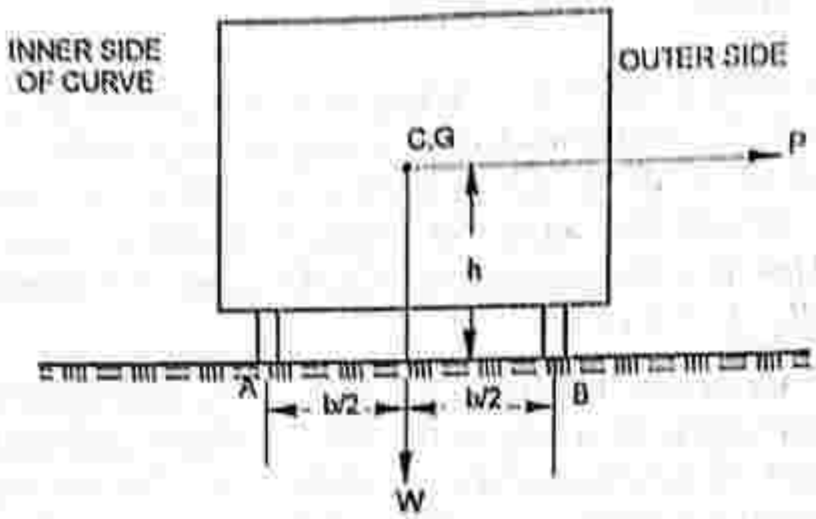
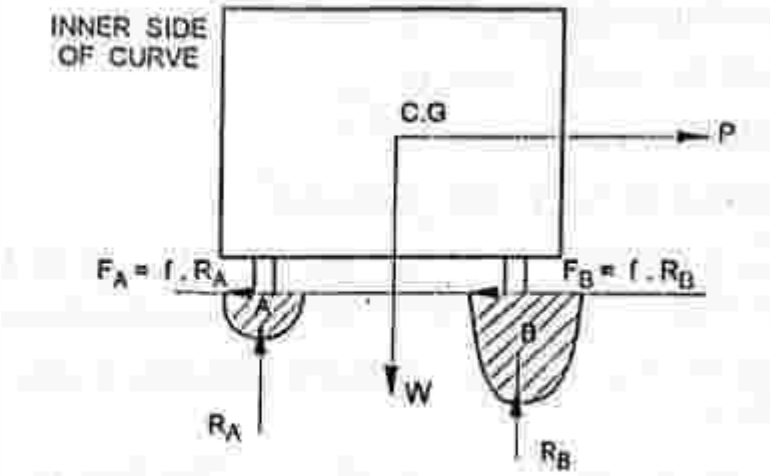


Fig. 4.18 Overturning effect due to centrifugal force

(ii) Transverse skidding effect

The centrifugal force developed has also the tendency to push the vehicle outwards in the transverse direction. The forces developed under this condition are shown in Fig. 4.19. If the centrifugal force developed exceeds the maximum transverse friction force or transverse skid resistance counteracting the centrifugal force, the vehicle will start skidding in the transverse direction.



SHADED AREAS SHOW THE PRESSURE UNDER THE INNER AND OUTER WHEELS A AND B

The equilibrium condition for the transverse skid resistance developed is given by:

$$P = F_A + F_B = f(R_A + R_B) = fW$$

In the above relation, f is the coefficient of friction between the tyre and the pavement surface in the transverse direction, R_A and R_B are normal reactions at the wheels A and B such that $(R_A + R_B)$ is equal to the weight W of the vehicle, as no superelevation has been provided in this case.

Since P = f W, the centrifugal ratio P/W is equal to 'f'. In other words when the centrifugal ratio attains a value equal to the coefficient of lateral friction, f there is a danger of lateral skidding.

Thus to avoid both overturning and lateral skidding on a horizontal curve, the centrifugal ratio should always be less than (b/2h) and also transverse friction coefficient, f.

The vehicle negotiating a horizontal curve with no superelevation has to fully depend on the coefficient of friction, f to resist the lateral skidding. If either the speed of the vehicle is high or the radius of the curve is less, the centrifugal force may increase to an extent to cause overturning or lateral skidding of the vehicle. In such a situation, if the friction coefficient, f is less than (b/2h), the vehicle would skid and not overturn. On the other hand if the value of (b/2h) is lower than f, the vehicle would overturn on the outer side before skidding. Thus the relative danger of lateral skidding and overturning depends on whether f is lower or higher than (b/2h).

If the pavement is kept horizontal across the alignment, the pressure on the outer wheels will be higher due to the centrifugal force acting outwards and hence the reaction R_B at the outer wheel would be higher. The difference in pressure distribution at inner and outer wheels has been indicated in Fig. 4.19. When the limiting equilibrium condition for overturning occurs the pressure at the inner wheels becomes equal to zero.

(b) Define Overtaking sight distance. [2] CO1 L1

The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as the 'minimum overtaking sight distance' (OSD) or the 'safe passing sight distance' available.

The overtaking sight distance, OSD is the distance measured along the centre of the road which a driver with his eye level at 1.2 m above the road surface can see the top of an object 1.2 m above the road surface. Refer Fig. 4.13.

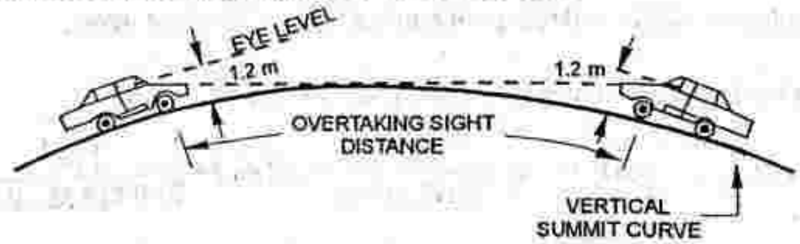


Fig. 4.13 Measurement of overtaking sight distance

2 (a)	The design of a highway is 80 kmph. There is a horizontal curve of radius 200 m on a certain locality. Safe limit of transverse coefficient of friction is 0.15. (a) Calculate the superelevation required to maintain this speed. (b) If the maximum superelevation of 0.07 is not to be exceeded, calculate the maximum allowable speed on this horizontal curve as it is not possible to increase the speed.	[8]	CO2	L3

Solution

design speed = 80kmph

$v = 80 \times 5/18 = 22.22\,m/s$

$R = 200\,m$

$f = 0.15$ (safe)

To calculate the superelevation,

Neglect friction & calculate e for 75% of v

$$e = \frac{(0.75v)^2}{gR}$$

$$= \frac{(0.75 \times 22.22)^2}{9.81 \times 200}$$

$$= 0.142 > 0.07$$

Limit $e = 0.07$

Check for speed restriction

$$e + f = \frac{v^2}{gR} \quad \text{(full speed)}$$

$e = 0.07$

$$f = \frac{(22.22)^2}{9.81 \times 200} - 0.07$$

$$= 0.18 > 0.15 \quad \text{Unsafe}$$

Speed restriction is required

Given → {increase of radius is not allowed}

$$e + f = \frac{v_R^2}{gR}, \quad e = 0.07,\ f = 0.15$$

$$v_R = \sqrt{0.22\,gR}$$

$$= \sqrt{0.22 \times 9.81 \times 200}$$

$$= 20.78\,m/s$$

Restricted speed in kmph $V_R = 20.78 \times \frac{18}{5}$

$= 74.75$ kmph

(b)	Write the expression for ruling radius and absolute minimum radius for a horizontal curve.	[2]	CO2	L1

$$R_{ruling} = \frac{V^2}{0.22 g}$$

"R" corresponding to V' (minimum design speed) is known as absolute minimum radius (R_{min})

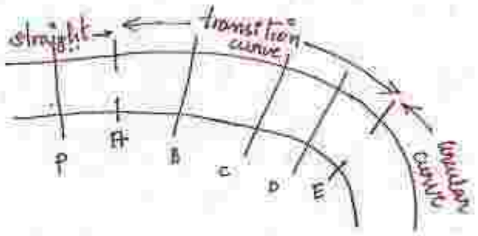
$$R_{min} = \frac{V'^2}{0.22 g}$$

... by IRC is given below

3	Explain how superelevation is attained on field.	[10]	CO2	L4

Attainment of superelevation on field.

The plan of a horizontal curve looks as shown.



In the straight portion of the curve, the road c/s is cambered as shown below.

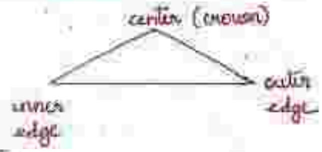


figure (a)

In the circular portion of the curve, the road c/s is superelevated as shown.

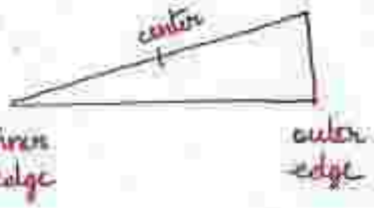


figure (b)

Hence the c/s must transition (change) from cambered (figure a) to superelevated (figure b) along the transition curve.

This "change" may be conveniently attained at a gradual and uniform rate through the length of horizontal transition curve. The full superelevation is attained by the beginning of the circular curve.

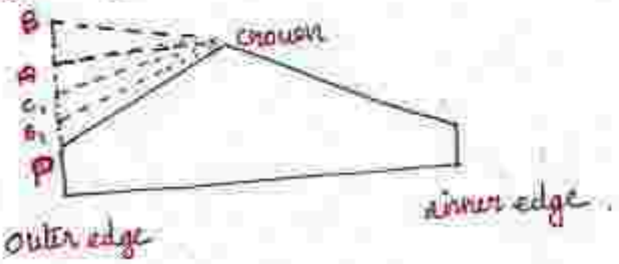
The attainment of superelevation may be split up in to two —

(a) Elimination of crown of the cambered section

(b) Rotation of the pavement to attain full superelevation.

a) Elimination of crown of the cambered s/n can be done in 2 ways —.

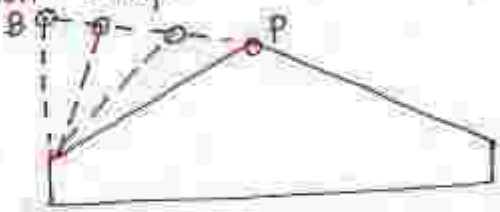
(i) Outer edge rotated about the crown.



The outer half of the cross-slope is first made level or horizontal (by rotating about the crown) at A which is the start of transition curve or the Tangent point. Subsequently the outer half is rotated about crown to a cross-slope equal to camber @ B.

The only drawback is the negative superelevation at the outer edge from P to A.

(ii) Crown Shifted Outwards



In this method the crown is progressively shifted outwards. This method is generally not adopted as the negative superelevation increases from P to B.

(b) Rotation of Pavement to attain full superelevation.

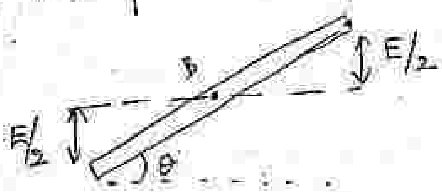
P to A making outer edge horizontal

A to B raising outer edge to camber

@ B the required camber is reached.

From B to E the pavement is rotated to attain full superelevation in the following ways —

(i) Rotating the pavement c/s about the centerline

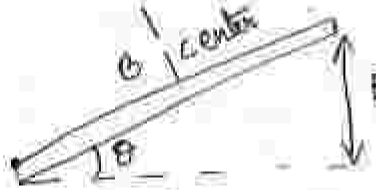


$\tan\theta = e = E/b$

Here the inner edge is depressed by $E/2$
The disadvantage of this method is drainage when the road is in plain terrain or when the road is not on an embankment.
The advantage is the centerline of the road remains unchanged. and the earthwork is balanced.

Hence this method is suitable for roads on embankments in low rainfall areas to facilitate longitudinal drainage.

(ii) Rotating the pavement c/s about the inner edge



$\tan\theta = e = \frac{E}{B}$

Here the outer edge is raised for an amount $= E = eB$. This method is suitable for roads on plain areas with heavy rainfall. The disadvantage is the vertical alignment of the road is changed.

The rate of introduction of superelevation as suggested by IRC

plain / rolling — 1 in 150

mountaineous & steep — 1 in 60

The superelevation is gradually attained on the transition curve, with the super-elevation required available at the start of the circular curve. In case a transition curve cannot be provided for some reason then $\frac{2}{3}$rd of the superelevation should be provided on straight curve & $\frac{1}{3}$rd at the start of circular curve.

4 (a)	Calculate the length of the transition curve and the shift for the following data: Design speed = 65 kmph Radius of circular curve = 220 m Pavement width including extra widening = 7.5 m Allowable rate of introduction of superelevation (pavement rotated about the center line) = 1 in 150	[8]	CO2	L3

Solution

$V = 65\ kmph$

$R = 220\ m$

$W + W_e = 7.5\ m$

$N = 150$

Length based on allowable rate of centrifugal acceleration, C

$$C = \frac{80}{75+V} = \frac{80}{75+65} = 0.57\ m/s^3$$

$C_{min} = 0.5$ $C_{max} = 0.8$ Hence $C = 0.57$ is accepted

$$L_s = \frac{V^3}{CR} = \frac{(65 \times 5/18)^3}{0.57 \times 220} = 47\ m \quad \text{—— (1)}$$

L_s: By allowable rate of introduction of superelevation

Rotated about centerline $L_s = \frac{Ne(W+W_e)}{2}$

Find 'e'

$$e + f^{0} = \frac{(0.75V)^2}{gR}$$

$e = 0.085 > 0.07$

Limit $e = 0.07$

$$e + f = \frac{V^2}{gR}$$

0.07

$$f = \frac{(65 \times 5/18)^2}{9.81 \times 220} - 0.07$$

$= 0.08 < 0.15$

$e = 0.07$ is safe for $V = 65$ kmph

Hence $L_s = \frac{150 \times 0.07 \times 7.5}{2}$

$= 39.4 m$ ——— (2)

L_s : As per IRC

Assuming plain & rolling terrain

$$L_s = \frac{2.7V^2}{R}$$

$$= \frac{2.7 \times 65^2}{220}$$

$$= 51.9 \text{ m} \quad \text{——— ③}$$

The highest of ①, ②, ③ is selected

$$\underline{\underline{L_s = 52 \text{ m}}}$$

Shift of TC –

$$S = \frac{L_s^2}{24R} = \frac{52^2}{24 \times 220} = \underline{\underline{0.51 \text{ m}}}$$

(b)	Write the expression for extra widening in pavement.	[2]	CO2	L1

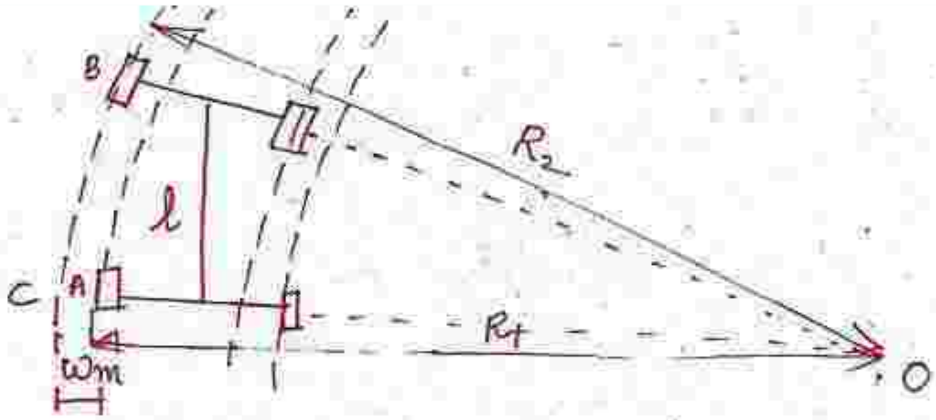
Widening of pavements can be split into –

① Mechanical Widening

② Psychological Widening

<u>Mechanical</u> <u>Widening</u>

The widening of pavement to account for off-tracking. (W_m)



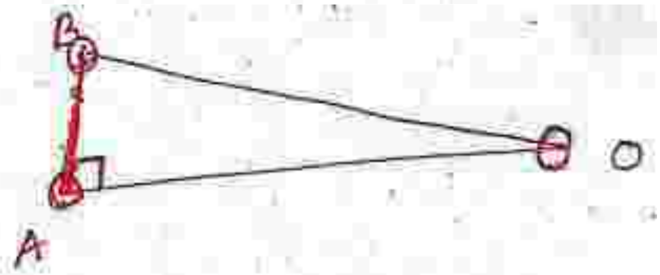
OA = R_1 = radius of path traversed by outer rear wheel, m

OB = R_2 = radius of path traversed by outer front wheel, m

R = mean radius of the horizontal curve.

$OC - OA = OB - OA = R_2 - R_1 = W_m$

In Δ OAB



$OB^2 = AB^2 + OA^2$

$R_2^2 = l^2 + R_1^2$

$R_1 = R_2 - W_m$

$R_2^2 = l^2 + (R_2 - W_m)^2$

$$(R_2 - W_m)^2 = R_2^2 - l^2$$

$$R_2^2 + W_m^2 - 2R_2 W_m = R_2^2 - l^2$$

$$W_m[W_m - 2R_2] = R_2^2 - l^2$$

$$W_m = \frac{l^2}{2R_2 - W_m}$$

$$\boxed{W_m = \frac{l^2}{2R}}$$ approximately

If there are 'n' number of traffic lanes

$$\boxed{W_m = \frac{nl^2}{2R}}$$

Psychological widening

$$W_{ps} = \frac{V}{9.5\sqrt{R}}$$ V is in kmph

$$W_{ps} = \frac{V}{34.2\sqrt{R}}$$ V is m/s

where V is design speed

R is the mean radius.

"W_{ps}" is provided because drivers have a tendency to maintain larger clearances with vehicles, for their overhangs etc.

Hence, the total widening on a horizontal curve is given by —

$$W_e = W_m + W_{ps}$$

$$W_e = \frac{nl^2}{2R} + \frac{V}{34.2\sqrt{R}}$$

where,

n — number of traffic lanes

l — length of wheel base of longest vehicle, m

l = 6.0 m.

5	The speeds of overtaking and overtaken vehicles are 70 kmph and 40 kmph, respectively on a two way traffic road. The average acceleration during overtaking may be assumed as 0.99 m/s2. (a) Calculate safe overtaking distance (b) What is the minimum length of overtaking zone?	[10]	CO2	L3

Given data:

Speed of overtaking vehicle, V = 70 kmph, therefore v = 70/3.6 = 19.4 m/sec

Speed of overtaken vehicle, V_b = 40 kmph, therefore v_b = 40/3.6 = 11.1 m/sec

Average acceleration during overtaking, a = 0.99 m/sec²

(a) Overtaking sight distance for two way traffic, vide Eq 4.7, OSD $= (d_1 + d_2 + d_3) = (v_b t + v_b T + 2s + vT)$ m

Reaction time for overtaking, t = 2 sec

$d_1 = v_b t = 11.1 \times 2 = 22.2$ m

$d_2 = v_b T + 2s$

$s = (0.7 v_b + 6) = (0.7 \times 11.1 + 6) = 13.8$ m

$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 13.8}{0.99}} = 7.47$ sec

$d_2 = 11.1 \times 7.47 + 2 \times 13.8 = 110.5$ m

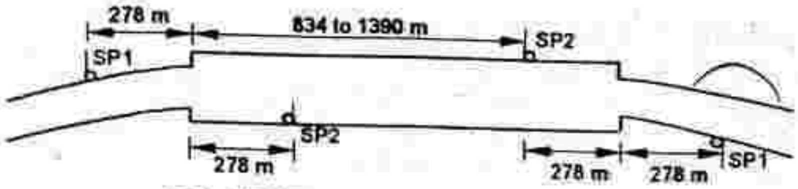
$d_3 = vT = 19.4 \times 7.47 = 144.9$ m

$OSD = d_1 + d_2 + d_3 = 22.2 + 110.5 + 144.9 = 277.6$ m, say 278 m

(b) Minimum length of overtaking zone = 3 (OSD) = 3 × 278 = 834 m

Desirable length of overtaking zone = 5 × (OSD) = 5 × 278 = 1390

(c) The details of the overtaking zone are shown in Fig. 4.16



SP1 - SIGN POST, "OVERTAKING SIGN AHEAD"
SP2 - SIGN POST, "END OF OVERTAKING ZONE"

6 Draw a neat sketch of the overtaking zone and show the positions of sign posts. Derive an expression for Overtaking sight distance. [10] CO2 L3

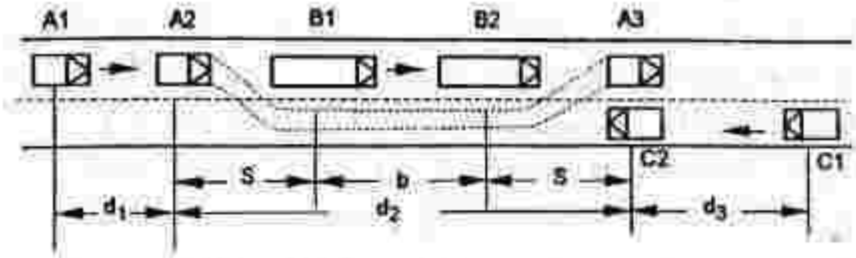


Fig. 4.14 Overtaking manoeuvre

The overtaking manoeuvre may be split up into three operations, thus dividing overtaking sight distance, OSD into three parts, d_1, d_2 and d_3.

- d_1 is the distance (m) travelled by the overtaking vehicle A during the reac time t (secs) of the driver, from position A_1 to A_2 before starting to overt the slow vehicle B
- d_2 is the distance (m) travelled by the vehicle A during the actual overtal operation during T (secs) from position A_2 to A_3
- d_3 is the distance (m) travelled by on-coming vehicle C during the ac overtaking operation of A during T (secs) from position C_1 to C_2

Assumptions made in the analysis

Assumptions made to calculate the values of d_1, d_2 and d_3 (m) are given below:

- the overtaking vehicle A is forced to reduce its speed from the design speed v (m/sec) to v_b (m/sec) of the slow vehicle B and move behind it, allowing a space s (m), till there is an opportunity for safe overtaking operation

- when the driver of vehicle A finds sufficient clear gap ahead, decides within a reaction time t (sec) to accelerate and overtake the vehicle B, during which the vehicle A moves at speed v_b (m/sec) through a distance d_1, from position A_1 to A_2
- the vehicle A accelerates and overtakes the slow vehicle B within a distance d_2 during the overtaking time, T (sec) between the position A_2 to A_3.
- the distance d_2 is split up into three parts (as shown in Fig. 4.14), (i) spacing s (m) between A_2 and B_1 (ii) distance b (m) travelled by the slow vehicle B between B_1 and B_2 during the overtaking manoeuvre of A and (iii) spacing s (m) between B_2 and A_3
- during this overtaking time T (sec), the vehicle C coming from opposite direction travels through a distance d_3 from position C_1 to C_2.

Determination of the components of OSD

(a) From position A_1 to A_2, the distance, d_1 (m) travelled by overtaking vehicle A, at the reduced speed v_b (m/sec) during the reaction time, t (sec) = v_b t (m). The IRC suggests that this reaction time 't' of the driver may be taken as 2.0 sec as an average value, as the aim of the driver is only to find an opportunity to overtake. Therefore, $d_1 = 2v_b$ (m)

(b) From position A_2, the vehicle A starts accelerating, shifts to the adjoining lane, overtakes the vehicle B, and shifts back to it original lane ahead of B in position A_3 during the overtaking time, T (sec). The straight distance between position A_2 and A_3 is taken as d_2 (m), which is further split into three parts, viz., $d_2 = (s + b + s)$, as shown in Fig. 4.14

(c) The minimum distance between position A_2 and B_1 may be taken as the minimum spacing s (m) between the two vehicles while moving with the speed v_b (m/sec). The minimum spacing between vehicles depends on their speed and is given by empirical formula, $s = (0.7\, v_b + 6)$, m

(d) The minimum distance between B_2 and A_3 may also be assumed equal to s (m) as mentioned above. If the overtaking time by vehicle A for the overtaking operation from position A_2 to A_3 is T (sec), the distance covered by the slow vehicle B travelling at a speed of v_b (m/sec) = b = v_bT (m). Thus the distance $d_2 = (b + 2s)$, m

(e) Now the time T depends on speed of overtaken vehicle B and the average acceleration 'a' (m/sec^2) of overtaking vehicle A. The overtaking time T (sec) may be calculated by equating the distance d_2 to (v_b T + 1/2 a T^2), using the general formula for the distance travelled by an uniformly accelerating body with initial speed v_b m/sec and 'a' is the average acceleration during overtaking in m/sec^2.

$$d_2 = (b + 2s) = \left(v_b T + \frac{aT^2}{2} \right)$$

In case the speed of overtaken vehicle (v_b or V_b) is not given, the same may be assumed as 4.5 m/sec or 16 kmph less than the design speed of the highway. Therefore, $v_b = (v - 4.5)$ m/sec or $V_b = (V - 16)$ kmph where v is the design speed in m/sec and V is the design speed in kmph.

The acceleration of the overtaking vehicle varies depending on several factors such as the make and model of the vehicle, its condition, load and the speed; actual acceleration also depends on the characteristics of the driver. As a general guide Table 4.8 may be used for finding the maximum acceleration of vehicles at different speeds. The average rate of acceleration during overtaking manoeuvre may be taken corresponding to the design speed.

Table 4.8 Maximum overtaking acceleration at different speeds

Speed		Maximum overtaking acceleration	
V, kmph	v, m/sec	A, kmph/sec	a, m/sec^2
25	6.93	5.00	1.41
30	8.34	4.80	1.30
40	11.10	4.45	1.24
50	13.86	4.00	1.11
65	18.00	3.28	0.92
80	22.20	2.56	0.72
100	27.80	1.92	0.53

$b = v_b T$, and therefore $2s = \frac{aT^2}{2}$

Therefore, $T = \sqrt{\frac{4s}{a}}$ secs, where $s = (0.7\, v_b + 6)$ m

Hence, $d_2 = (v_b T + 2s)$, m

(f) The distance travelled by vehicle C moving at design speed v (m/sec) during the overtaking operation of vehicle A i.e. during time T (sec) is the distance d_2 (m) between positions C_1 to C_2. Hence, $d_3 = v\,T$ (m)

Thus $OSD = (d_1 + d_2 + d_3) = (v_b t + v_b T + 2s + vT)$ m (Eq. 4.7)

In kmph units, Eq 4.7 works out as:

$$OSD = 0.28\, V_b t + 0.28\, V_b T + 2s + 0.28\, V.T \quad \text{(Eq. 4.8)}$$

Here

V_b = initial speed of overtaking vehicle, kmph

t = reaction time of driver = 2 sec

V = speed of overtaking vehicle or design speed, kmph

$T = \sqrt{\frac{4 \times 3.6s}{A}} = \sqrt{\frac{14.4s}{A}}$

s = spacing of vehicles = $(0.7\, v_b + 6)$ m = $(0.2\, V_b + 6)$ m

A = average acceleration during overtaking, kmph/sec.