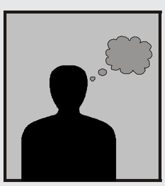
2020

MADE EASY WORKBOOK



Detailed Explanations of Try Yourself *Questions*

Civil Engineering

Highway Engineering

MADE EASY

MADE EASY Publications

1 Highway Planning and Geometric Design

Detailed Explanation of Try Yourself Questions

T1 : Solution

Given data:

$n_1 = -\frac{1}{20}$; $n_2 = +\frac{1}{30}$; v = 80 kmph = 22.22 m/sec; C = 0.60 m/sec^3; t = 2.5 sec; f = 0.35

Deviation angle, $N = n_1 - n_2 = -\frac{1}{20} - \frac{1}{30} = \frac{-3-2}{60} = -\frac{1}{12}$

Length of valley curve for comfort condition is given by

$$L = 2\left[\frac{Nv^3}{C}\right]^{1/2} = 2\left[\frac{1}{12} \times \frac{(22.22)^3}{0.6}\right]^{1/2} = 78.07 \text{ m}$$

Neglecting the ascending and descending gradients at the valley curve and calculating sight distance as per the equation given below, we get

$$S = vt + \frac{v^2}{2gf} = 22.22 \times 2.5 + \frac{(22.22)^2}{2 \times 9.81 \times 0.35} = 127.45 \text{ m}$$

If $L > SSD$, then $L = \frac{NS^2}{1.5 + 0.035S} = \frac{1}{12} \times \frac{(127.45)^2}{1.5 + 0.035 \times 127.45} = 227.09 \text{ m}$

As this value is higher than *SSD* of 127.45 m, the assumption is correct. The valley curve length based on headlight sight distance being higher than that based on comfort condition, the design length of the valley curve is 227.09 m or say 228 m.

The valley curve is assumed to be of parabolic shape when its length is calculated as per the head light sight distance criterion.

T2 : Solution

Length of wheel base, $l = 6$ m

Radius, $R = 225$ m

Number of lanes, $n = 2$

$V = 80$ kmph

$\therefore$ Extra width of pavement, $W_e = W_m + W_{ps} = \dfrac{nl^2}{2R} + \dfrac{V}{9.5\sqrt{R}}$

$$= \frac{2 \times 6^2}{2 \times 225} + \frac{80}{9.5\sqrt{225}} = 0.16 + 0.56 = 0.72 \text{ m}$$

(i) Length of transition curve (L_s) by rate of change of centrifugal acceleration:

$$C = \frac{80}{75 + V} = \frac{80}{75 + 80} = 0.516$$

$\therefore$ Length of transition curve based on rate of change of centrifugal acceleration

$$L_S = \frac{0.0215 V^3}{CR} = \frac{0.0215 \times 80^3}{0.516 \times 225} = 94.81 \text{ m}$$

(ii) By rate of introduction of superelevation, E:

Now, superelevation

$$e = \frac{V^2}{225R} = \frac{80^2}{225 \times 225} = 0.1264 > 0.07$$

Hence provide, $e = 0.07$

Check for coefficient of friction, $f = \dfrac{V^2}{127R} - 0.07 = \dfrac{80^2}{127 \times 225} - 0.07 \approx 0.15$

$\therefore$ Provide, $e = 0.07$

Total width of pavement $= 6 + 0.72 = 6.72$ m

Total rise of outer edge of pavement with respect to centre line

$$= \frac{E}{2} = \frac{eB}{2} = \frac{0.07 \times 6.72}{2} = 0.2352 \text{ m}$$

Rate of introduction of superelevation

1 in N = 1 in 150

$\therefore$ $L_s = 0.2352 \times 150 = 35.28$ m

(iii) By IRC formula the minimum length:

$$L_s = \frac{2.7V^2}{R} = \frac{2.7 \times 80^2}{225} = 76.8 \text{ m}$$

$\therefore$ Adopt the highest value of the three i.e., 91.81 m or say 95 m as the design length transition curve.

T3 : Solution

Summit curve are designed for sight distance.

$$SSD = 0.278 \times Vt_r + \frac{V^2}{254f}$$

$$= 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.35}$$

$$= 44.48 + 71.99$$

$$= 127.47 \text{ m}$$

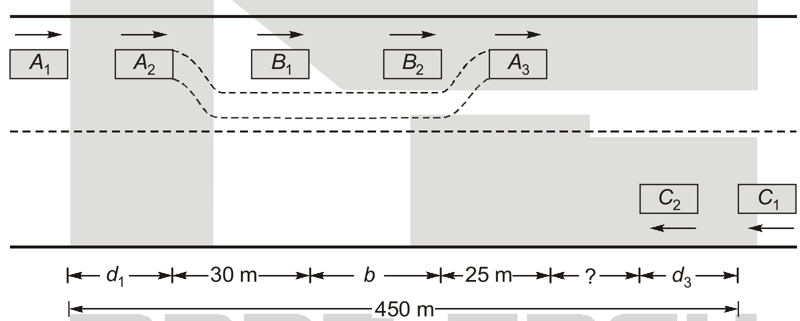
Assume $L > SSD$

$\Rightarrow$ $$L = \frac{NS^2}{4.4} \quad ; N = (+4\%) - (-6\%) = 10\% = 0.1$$

$\Rightarrow$ $$L = \frac{0.1 \times (127.47)^2}{4.4} = 369.27 \text{m}$$

Assumption is right i.e., $L > SSD$ and therefore, $L = 369.27$ m

T4 : Solution



Both car A and truck B were travelling at speed of 40 kmph

$$V_b = 40 \times \frac{5}{18} = 11.11 \text{m/sec}$$

Speed of car C = design speed of highway

$$V = 80 \text{ kmph} = 22.22 \text{ m/sec}$$

Initial distance between A and C = 450 m when car A is at A and Car C is at C

Reaction time, t = 2 sec

Distance covered by C during these 2 sec

$$= V \times t = 22.22 \times 2 = 44.44 \text{ m}$$

Distance covered by car A in reaction time

$$d_1 = 11.11 \times 2 = 22.22$$

At the start of overtaking operations, distance between A and B = 30 m.

At the end of overtaking operations, distance between *B* and *A* = 25 m.

Total distance covered by car *A* during overtaking = 30 + b + 25
where b is the distance covered by truck *B* in overtaking time *T*

$$b = 11.11 \times T \quad \ldots(i)$$

Distance covered by *A* during overtaking time '*T*' is

$$= VT + \frac{1}{2}aT^2 \quad \ldots(ii)$$

Equating (i) and (ii), we have

$$30 + 11.11 \times T + 25 = 11.11 \times T + \frac{1}{2} \times 1.20T^2$$

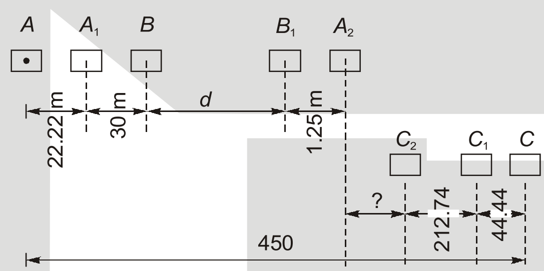
or $T = 9.574$ sec

Distance covered during overtaking operation by *A*

$$= 30 + VT + 25$$
$$= 55 + 11.11 \times 9.574$$
$$= 55 + 106.37 = 161.37 \text{ m}$$

Similarly during overtaking time *T*, distance covered by car

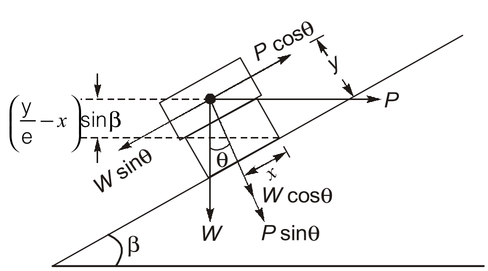
$$C = V'T$$
$$= 22.22 \times 9.574 = 212.73 \text{ m}$$



Final distance between *A* and *C* after completion of overtaking

$$= 450 - (212.73 + 44.44) - (22.22 + 30 + d + 25)$$
$$= 450 - 257.17 - 77.22 - 106.37$$
$$= 9.24 \text{ m}$$

T5 : Solution



Given, For $\frac{y}{x} \geq 2$

Speed = 1.2 × 60 = 72 km/hr = 20 m/sec

For $\frac{y}{x} \geq 3$

Speed = 1.2 × v

For overturning, $P\cos\theta \cdot y \geq (W\cos\theta + P\sin\theta)x$

$$\Rightarrow \quad \frac{y}{x} \geq \frac{W\cos\theta + P\sin\theta}{P\cos\theta}$$

$$\Rightarrow \quad \frac{y}{x} \geq \left(\frac{W}{P} + \tan\theta\right)$$

$$\therefore \quad \tan\theta = e = 0.05$$

$$\Rightarrow \quad \frac{y}{x} \geq \left(\frac{W}{P} + 0.05\right)$$

$$\because \quad P = \text{Centrifugal force} = \frac{mv^2}{R}$$

and W = Weight of vehicle = mg

$$\Rightarrow \quad \frac{P}{W} = \frac{V^2}{Rg}$$

$$\Rightarrow \quad \frac{W}{P} = \frac{R \cdot g}{V^2}$$

$$\because \quad \frac{y}{x} = 2$$

$$\therefore \quad 2 \geq \frac{gR}{V^2} + 0.05$$

$$\Rightarrow \quad 2 = \frac{gR}{V^2} + 0.05$$

$$\Rightarrow \quad 2 - 0.05 = \frac{9.81R}{(0.278 \times 72)^2} = \frac{9.81R}{(20)^2}$$

$$\Rightarrow \quad R = 79.51 \text{ m}$$

Now, if $\frac{y}{x} = 3$

then, $3 = \frac{gR}{V^2} + 0.05$

$$\Rightarrow \quad 3 = \frac{9.81 \times 79.51}{(V)^2} + 0.05$$

$$V = 16.26 \text{ m/sec} = 58.536 \text{ kmph}$$

$$\therefore \quad \text{New speed limit} = \frac{V}{1.2} = \frac{58.536}{1.2} = 48.78 \text{ kmph}$$

■■■■

2 Traffic Engineering

Detailed Explanation of Try Yourself Questions

T1 : Solution

The table given below shows the value of cumulative frequency perecentage :

Speed range, Kmph	Mid speed kmph	Frequency, *f*	Frequency, %	Cumulative Frequency, %
1	2	3	4	5
0 – 10	5	12	1.41	1.41
10 – 20	15	18	2.12	3.53
20 – 30	25	68	8.00	11.53
30 – 40	35	89	10.47	22.00
40 – 50	45	204	24.00	46.00
50 – 60	55	255	33.00	76.00
60 – 70	65	119	14.00	90.00
70 – 80	75	43	5.06	95.06
80 – 90	85	33	3.88	98.94
90 – 100	95	9	1.06	100.00
	Total	**850**	**100.00**	

Using the values of mid-speed and cumulative frequency % of above Table,

(i) Design speed of highway = 98^{th} percentile speed = 82.58 kmph

(ii) Lower speed limit for regulation = 15^{th} percentile speed = 28.3 kmph

(iii) Upper speed limit for regulation = 85^{th} percentile speed = 61.43 kmph

(iv) Modal average speed = 55 kmph

T2 : Solution

We will be solve this problem by using the standard equation derived in the previous discussed cases.

$$v_{A3} = \sqrt{254 f s_{A2}} = \sqrt{254 \times 0.4 \times 15} = 39.04 \text{ kmph}$$

$$v_{B3} = \sqrt{254 \times 0.4 \times 36} = 60.48 \text{ kmph}$$

Using equation 5.13 and 5.14, speeds of vehicles just before collision,

$$v_{A2} = \frac{W_B}{W_A} v_{B3} \sin B - v_{A3} \cos A$$

$$= \frac{6}{4} \times 70.9 \times \sin 60 - 45.8 \cos 50 = 62.66 \text{ kmph}$$

$$v_{B2} = \frac{W_B}{W_A} v_{A3} \sin A + v_{B3} \cos B$$

$$= \frac{4}{6} \times 45.8 \sin 50 + 70.9 \cos 60 = 58.84 \text{ kmph}$$

Original speeds of vehicles before application of brakes are obtained using equation 5.19

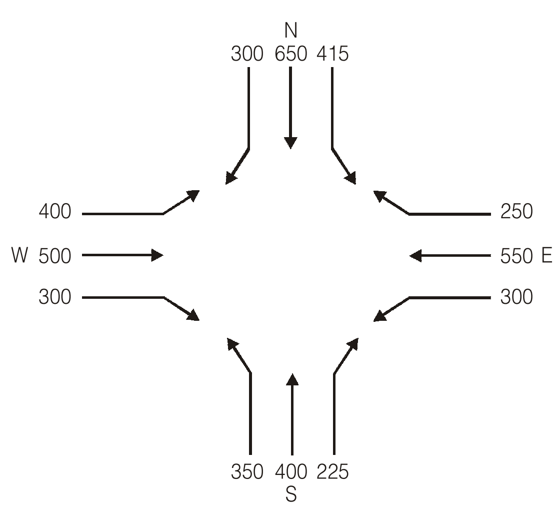
$$v_{A1} = \sqrt{254 f s_{A1} + v_{A2}^2} = \sqrt{254 \times 0.4 \times 38 + 62.66^2} = 88.24 \text{ kmph}$$

$$v_{B1} = \sqrt{254 f s_{B1} + v_{B2}^2} = \sqrt{254 \times 0.4 \times 20 + 58.84^2} = 74.12 \text{ kmph}$$

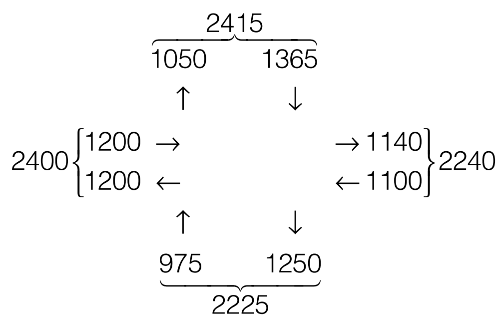
Thus the original speeds of vehicles A and B before the application of brakes are 88.24 and 74.12 kmph respectively.

T3 : Solution

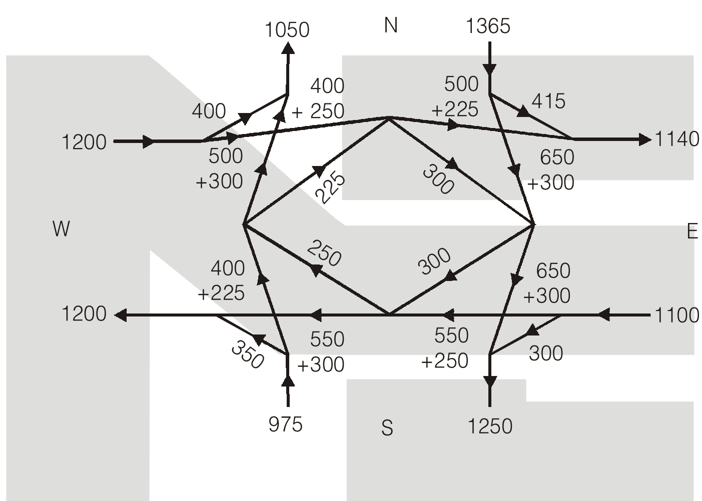
The traffic in PCU per hour is depicted in figure below:



The traffic in PCU per hour on each leg is depicted below:



The traffic assigned to the network is shown in figure below:



The maximum 2 way flow in the intersection leg (North) is 2415 PCU/hr and the maximum in one direction is 1365 PCU/hr.

For a carriageway width of 15 m, width of carriageway at entry and exit is taken as 10.0 m. The width of non-weaving section is also kept as 10.0 m

$$\text{Width of weaving section, } W = \frac{e_1 + e_2}{2} + 3.5 = \frac{10 + 10}{2} + 3.5 = 13.5 \text{ m}$$

As per IRC, the weaving length L is taken between 30 to 60 for 30 kmph design speeds so that W/L = 0.12 to 0.4

$\therefore$ Let us take $L = 50$ m

The maximum weaving occurs in E – S direction, therefore proportion of weaving traffic is given by

$$p = \frac{(650 + 300) + (550 + 250)}{(650 + 300) + (550 + 250) + 300 + 300} = 0.745$$

Average width of entry (e_1) and width of non-weaving section (e_2) is given by

$$e = \frac{e_1 + e_2}{2} = \frac{10 + 10}{2} = 10 \text{ m}$$

$$\therefore \qquad Q_p = \frac{280\,W(1+e/W)(1-p/3)}{(1+W/L)}$$

$$= \frac{280 \times 13.5 \times \left(1+\frac{10}{13.5}\right)\left(1-\frac{0.745}{3}\right)}{1+\frac{13.5}{50}}$$

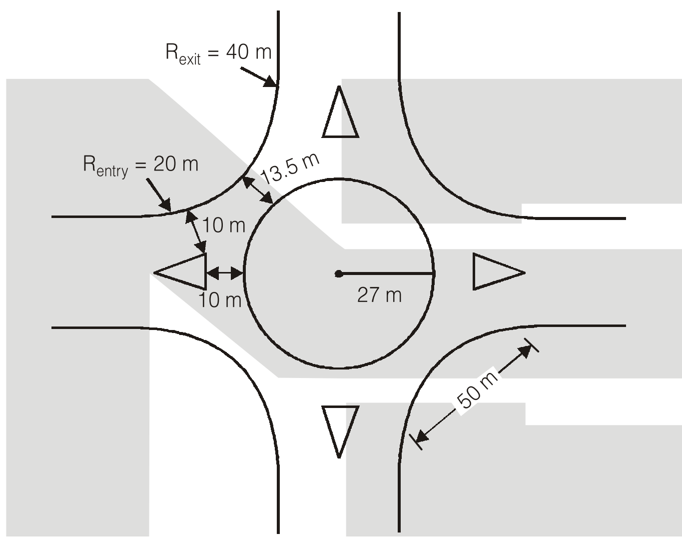
$$= 3894.46 \text{ PCU per hour } (> 2415; \text{ Hence OK})$$

IRC recommends radius at entry as 15 to 25 m for 30 kmph speed.

IRC recommends minimum radius of central island as 1.33 times the radius at entry.

Let us assume radius at entry as 20 m

$\therefore$ Radius of central island = 1.33 × 20 = 26.6 = 27 m



The radius of rotary at exit is taken as 2 times the radius at entry i.e. 2 × 20 = 40 m

3 Pavement Design

Detailed Explanation of Try Yourself Questions

T1 : Solution

Given data:

Modulus of elasticity of concrete, $E = 3 \times 10^5$ kg/cm²

Thermal coefficient of concrete, $e = 10 \times 10^{-6}$ per °C

Temperature difference between the top and bottom of slab, t = 15°C

Poisson's ratio, $\mu = 0.15$

$C_x = 0.80$ and $C_y = 0.45$

The warping stress at the interior region may be given as

$$S_i = \frac{Eet}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$$

$$\Rightarrow \quad S_i = \frac{3\times10^5 \times 10\times10^{-6}\times15}{2} \times \left[\frac{0.80+(0.15\times0.45)}{1-(0.15)^2}\right]$$

$$\Rightarrow \quad S_i = 19.97 \text{ kg/cm}^2$$

The warping stress at the edge region is given by

$$S_e = \left.\begin{matrix}\dfrac{C_x Eet}{2} \\ \dfrac{C_y\, Eet}{2}\end{matrix}\right\} \text{whichever is higher}$$

$$\frac{C_x\, Eet}{2} = \frac{0.80\times3\times10^5\times10\times10^{-6}\times15}{2} = 18 \text{ kg/cm}^2$$

$$\frac{C_y Eet}{2} = \frac{0.45\times3\times10^5\times10\times10^{-6}\times15}{2} = 10.125 \text{ kg/cm}^2$$

$$\therefore \quad S_e = 18 \text{ kg/cm}^2$$

The warping stress at corner region may be given as

$$S_c = \frac{Eet}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

where, a = radius of contact = 15 cm

l = radius of relative stiffness

But $$l = \left[\frac{E\,h^3}{12k(1-\mu^2)}\right]^{1/4}$$

where, h = thickness of concrete pavement slab = 32 cm

k = modulus of subgrade reaction = 6 kg/cm^3

$$\therefore \quad l = \left[\frac{3\times10^5\times(32)^3}{12\times6(1-0.15^2)}\right]^{1/4} = 108.71 \text{ cm}$$

$$\therefore \quad S_c = \frac{Eet}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

$$\Rightarrow \quad S_c = \frac{3\times10^5\times10\times10^{-6}\times15}{3(1-0.15)}\sqrt{\frac{15}{108.71}}$$

$$\Rightarrow \quad S_c = 6.56 \text{ kg/cm}^2$$

T2 : Solution

Expansion joint spacing = L_s

$$= \frac{\delta'}{100C\,(T_2 - T_1)}$$

$$\delta' = \frac{1}{2}\times(\text{expansion joint gap}) = 1.25 \text{ cm}$$

$$\therefore \quad L_s = \frac{1.25}{100\times10^{-5}\times30} = 41.7 \text{ m}$$

Contraction joint spacing

$$L_c = \frac{2S_c\times10^4}{W.f} = \frac{2\times0.8\times10^4}{2400\times1.5} = 4.4 \text{ m}$$

T3 : Solution

$$S_i = Q_i\frac{P}{h^2}$$

As we know $$l = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$$

$E = 2\times10^7$ kN/m^2

h = 21 cm = 0.21 m

$k = 3.6 \times 10^4$ kN/m³

$\mu = 0.15$

$$\therefore \quad l = \left[\frac{2\times10^7\times(0.21)^3}{12\times3.6\times10^4\times(1-0.15^2)}\right]^{1/4} = 0.81 \text{ m} = 81 \text{ cm}$$

Wheel load, $P = 40.8$ kN

Tyre pressure, $p = 600$ kN/m²

Let radius of wheel load = a

$$\therefore \quad p = \frac{P}{\pi a^2}$$

$$\therefore \quad a = \sqrt{\frac{P}{\pi p}} = \sqrt{\frac{40.8}{\pi\times600}} = 0.147 \text{ m} = 14.7 \text{ cm}$$

Now,

$$1.724\,h = 1.724 \times 0.21 = 0.36 \text{ m} = 36 \text{ cm}$$

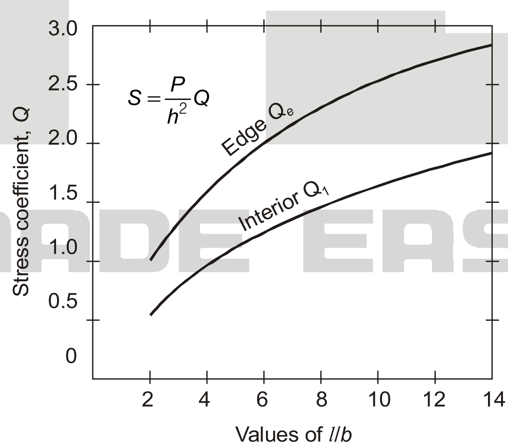
$$\Rightarrow \quad a < 1.724\,h$$

$$\therefore \quad b = \sqrt{1.6a^2+h^2} - 0.675h = \sqrt{1.6\times(14.7)^2+21^2} - 0.675\times21$$

$$= 13.87 \text{ cm}$$

$$\therefore \quad \frac{l}{b} = \frac{81}{13.87} = 5.84$$

Now, from figure for, $\frac{l}{b} = 5.84$



Interior stress coefficient $Q_i = 1.3$

$Q_e = 2$

$$\therefore \text{ Wheel load stress} \quad S_i = \frac{P}{h^2}\times Q_i = \frac{40.8}{(0.21)^2}\times1.3 = 1202.72 \text{ kN/m}^2$$

$$S_e = \frac{40.8}{(0.21)^2}\times2 = 1850.3 \text{ kN/m}^2$$

■■■■

4 Highway Material & Construction

Detailed Explanation of Try Yourself Questions

T1 : Solution

The volume of the paraffin coated sample can be obtained as the difference of the weight loss while immersed in water and the volume of the paraffin used.

Thus, Bulk volume of the sample $= (1295.8 - 703.7) - \dfrac{(1295.8 - 1245.2)}{0.8} = 528.85\ m^3$

(i) Bulk specific gravity of the mixture (G_{mb})

$$G_{mb} = \frac{M_{mix}}{\text{bulk volume of the mix}}$$

$$G_{mb} = \frac{1245.2}{528.85} = 2.355$$

Bulk specific gravity of the aggregate (G_{sb})

$$G_{sb} = 95 \div \left(\frac{55}{2.50} + \frac{30}{2.60} + \frac{10}{2.65}\right) = 2.546$$

(ii) Void in mineral aggregate

$$\text{VMA} = \left(1 - \frac{G_{mb}}{G_{sb}} \times P_s\right) \times 100$$

($P_s \Rightarrow$ Fraction of aggregate present by total mass of mixture)

$$VMA = \left(1 - \frac{2.355}{2.546} \times 0.95\right) \times 100 = 12.13\%$$

(iii) Air voids, $VA = \left(1 - \dfrac{G_{mb}}{G_{mm}}\right) \times 100$

$$VA = \left(1 - \frac{2.355}{2.441}\right) \times 100 = 3.52\%$$

(iv)
$$VFB = \frac{VMA - VA}{VMA} \times 100$$

$$VFB = \frac{12.13 - 3.52}{12.13} \times 100 = 70.98\%$$

(v) Effective specific gravity of aggregate in mixture, G_{se}

$$G_{se} = (M_{\text{mix}} - M_b) \div \left(\frac{M_{\text{mix}}}{G_{mm}} - \frac{M_b}{G_b}\right)$$

$$G_{se} = (100 - 5) \div \left(\frac{100}{2.441} - \frac{5}{1.10}\right) = 2.608$$

$$P_{ab} = \left(1 - \frac{G_{sb}}{G_{se}}\right) \times 100$$

$$P_{ab} = \left(1 - \frac{2.546}{2.608}\right) \times 100 = 2.377\%$$

So, the percentage absorbed bitumen is 2.5% of the total weight of the mix.

T2 : Solution

The graphical plot is shown below. From the graph we find out that correction is needed to calculate CBR value

After correction,

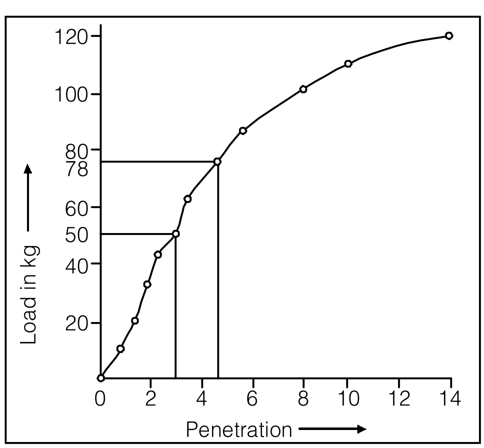
load at 2.5 mm penetration = 51 kg

5 mm penetration = 83 kg

Area of plunger = 19.6 cm^2

$$\text{Pressure for 2.5 mm penetration} = \frac{50}{19.6}\ \text{kg/cm}^2$$

$$\text{Pressure for 5.0 mm penetration} = \frac{78}{19.6}\ \text{kg/cm}^2$$



(i) CBR value of soil at 2.5 mm

$$= \frac{\text{Pressure of plunger at 2.5 mm penetration of soil}}{\text{Pressure for standard crushed store at 2.5 mm}} \times 100$$

$$= \frac{50}{19.6} \times \frac{100}{70} = 3.64\%$$

(ii) CBR of soil 5.0 mm $= \frac{78}{19.6} \times \frac{100}{105} = 3.79\%$

Hence adopt CBR value = 3.79%

Normally the CBR value at 2.5 mm penetration which is higher than that at 5.0 mm is reported as the CBR value of the material. However, if the CBR value obtained from the test at 5.0 mm penetration is higher that at 2.5 mm, then the test is to be repeated for checking. If the check test again gives similar results, the higher value obtained at 5.0 mm penetration is reported as the CBR value.

T3 : Solution

	Wt (gm)	Sp. gravity
Aggregate I	825	2.63
Aggregate II	1200	2.51
Aggregate III	325	2.46
Aggregate IV	150	2.43
Bitumen	100	1.045

Wt of mould = 1100 gm

V = 475 cc

$$G_{bulk\ (m)} = \frac{1100}{475} = 2.316$$

$$G_{theo\ (t)} = \frac{825 + 1200 + 325 + 150 + 100}{\left(\frac{825}{2.63} + \frac{1200}{2.51} + \frac{325}{2.46} + \frac{150}{2.43} + \frac{100}{1.045}\right)}$$

$$= \frac{2600}{1081.331} = 2.4045$$

(a) % of Air voids $= \frac{G_t - G_m}{G_t} \times 100 = \frac{2.4045 - 2.316}{2.4045} \times 100 = 3.68\%$

(b) % of bitumen by volume

$$\text{Volume of solids} = \left(\frac{825}{2.63} + \frac{1200}{2.51} + \frac{325}{2.46} + \frac{150}{2.43} + \frac{100}{1.045}\right) = 1081.311 \text{ cc}$$

Volume of mould = 475 cc

$$V_{bitumen} = \frac{\frac{100 \times 1100}{1.045 \times 2600}}{475} \times 100 = 8.523\%$$

(c) VMA $= V_b + V_v$

$= 8.523 + 3.681$

$= 12.20\%$

■■■■