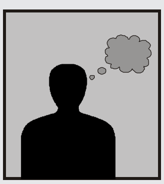
2019

RANK Improvement WORKBOOK



Answer key and Hint of Objective & Conventional *Questions*

Civil Engineering

Highway Engineering

MADE EASY Publications

1 Highway Geometric Design

LEVEL 1 Objective Questions

1.	(720)
2.	(a)
3.	(c)
4.	(c)
5.	(c)
6.	(d)
7.	(d)
8.	(d)
9.	(b)
10.	(b)
11.	(b)
12.	(a)

LEVEL 2 Objective Questions

13.	(80.11)
14.	(b)
15.	(b)
16.	(d)
17.	(b)
18.	(432.70)
19.	(a)
20.	(a)
21.	(a)
22.	(a)
23.	(26.8)
24.	(c)
25.	(d)
26.	(d)
27.	(d)

LEVEL 3 Conventional Questions

Solution : 1

Total stopping sight distance = 110.29 m

Solution : 2

(i) Primary system of NH = 268 km

(ii) Secondary system consisting of SH = 536 and MDR = 1080, total length = 1616 km

(iii) Tertiary system of Rural Roads consisting of ODR and VR = of length = 9104 km

(iv) Total road length = 10,988 km

Solution : 3

Length of transition curve = 70.32 m

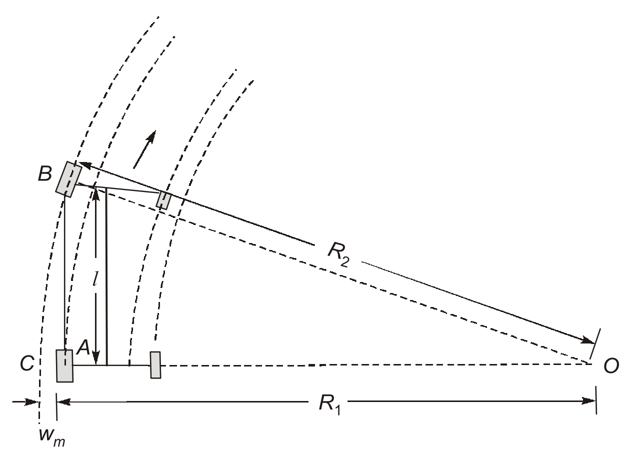
Solution : 4

Length of valley curve = 200 m

Lowest point is situated at a distance of 104.44 mm from starting point.

Solution : 5

The widening required to account for off-tracking due to rigidity of wheel based is called mechanical widening. It is referred as W_m.



Here, R_1 = Radius of path traversed by outer gear wheel, *m*

R_2 = Radius of path traversed by outer front wheel, *m*

W_m = Off-tracking or mechanical widening, *m*

l = length of wheel base, *m*

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

from ΔOAB, $OA^2 = OB^2 - AB^2$

$$R_1^2 = R_2^2 - l^2$$

But $R_1 = R_2 - W_m$

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

or, $$R_2^2 - 2R_2 \cdot W_m + W_m^2 = R_2^2 - l^2$$

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

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

$\therefore$ $$W_m \cong \frac{l^2}{2R} \qquad [W_m << R_2]$$

Here, R is the mean radius of curve.

The mechanical widening calculated above is required for one vehicle negotiating a horizontal curve along one traffic lane. Hence, for a road having n traffic lanes, as n vehicles can off-track simultaneously, the total mechanical widening required is,

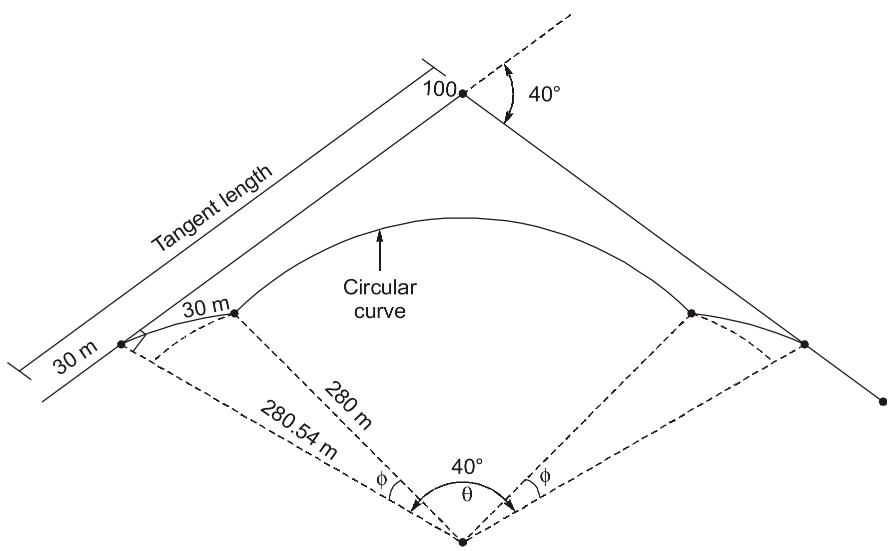
$$W_m = \frac{nl^2}{2R}$$

Solution : 6

(a) Stopping sight distance = 281.82 m

(b) Overtaking sight distance = 394 m

Solution : 7



chainage at point of intersection = 100

Chainage at start of first transition curve = 100 – 6.6 = 93.4 chains

Chainage at beginning of circular curve = 93.4 + 3 = 96.4 chains

Chainage at the beginning of second transition curve

= 96.4 + 6.77 = 103.17 chains

Solution : 8

Safe operating speed = 75.70 kmph

■■■■

2 Traffic Engineering

LEVEL 1 Objective Questions

1. (0.1353)
2. (c)
3. (b)
4. (a)
5. (d)
6. (d)
7. (d)
8. (a)
9. (c)
10. (c)
11. (b)
12. (c)
13. (c)
14. (a)
15. (a)

LEVEL 2 Objective Questions

16. (a)
17. (b)
18. (d)
19. (a)
20. (d)
21. (b)
22. (d)
24. (a)
25. (a)
26. (c)
27. (22402.137)
28. (b)
29. (c)
30. (b)

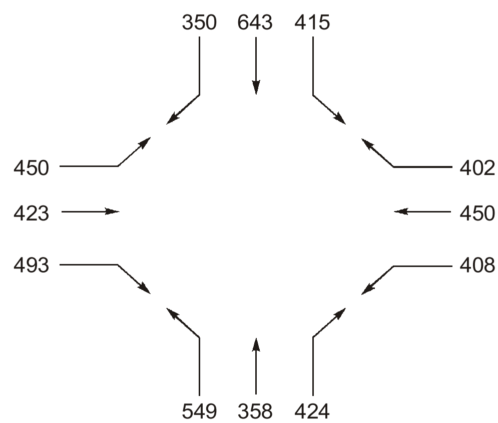
LEVEL 3 Conventional Questions

Solution : 1

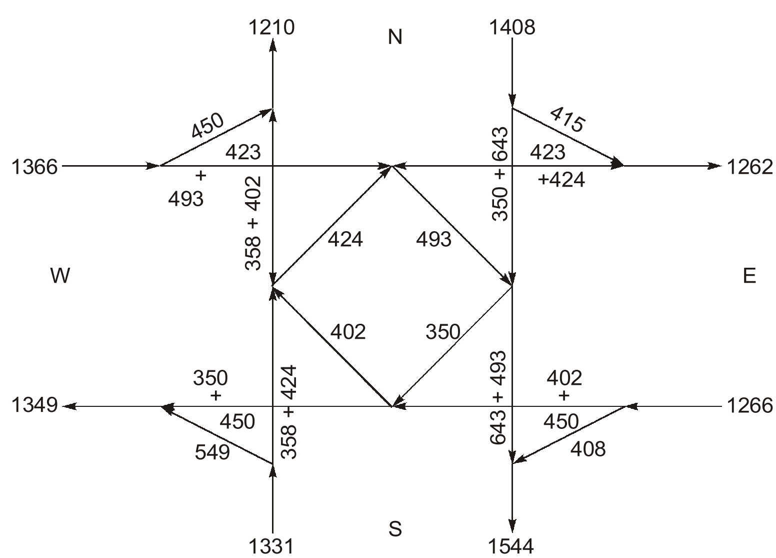
$N \approx 3$ lanes

Solution : 2

The traffic in terms of PCU's from each leg is depicted in figure given below:



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



Maximum 2-way flow in the intersection leg (South) is 2875 PCUs/hour.

The rotary is located in an Urban section and hence a design speed of 30 kmph. Since the intersection legs carry almost equal traffic, a round-shaped central island will be adopted. Entry angle and exit angle equal to 45° each.

For a carriage way width of 15 m, width of carriageway at entry and exit is taken as 10.0 m.

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

Let us take

$$L = 50 \text{ m} \quad \left(\frac{W}{L} = \frac{13.5}{50} = 0.27\right)$$

$$0.12 < \frac{W}{L} < 0.4$$

Maximum weaving occurs in E-S section

$$P = \frac{1136 + 852}{350 + 1136 + 852 + 408} = 0.72$$

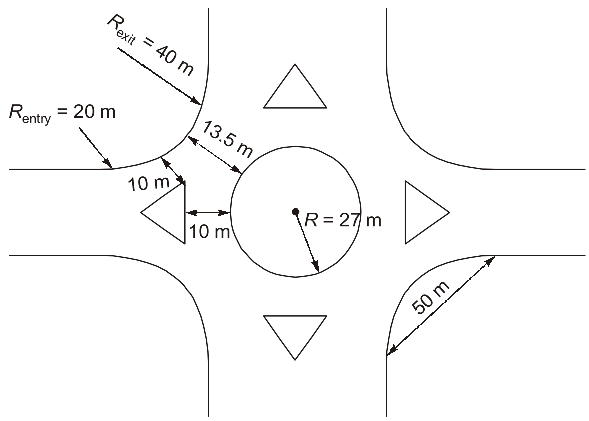
$$Q_P = \frac{280 \times 13.5 \times \left[1 + \frac{10}{13.5}\right]\left[1 - \frac{0.72}{3}\right]}{1 + \frac{13.5}{50}} \approx 3938 \text{ PCU/hr}$$

Q_P = 3939 PCU/hour > 2875 PCUs/hour. Hence OK

Assuming R_{entry} = 20 m [15 m to 25 m – IRC]

$R_{central\ island}$ = 133 × 20 = 26.6 m = 27 m

R_{exit} = 2 × 20 = 40 m



Solution : 3

(i) 73.06 s, (ii) 26.18 s, 34.82 s

Solution : 4

33.47 kmph, 30.14 kmph

Solution : 5

$$v_{min} = \sqrt{\frac{2(M+m)gh}{M}}$$

Solution : 6

Available reserved capacity = 636.56 PCU/hr

Solution : 7

595.4 PCU_s/hr, 42 kmph, 46.15 kmph

Solution : 8

0.2 veh/s, $2e^{-2}$

Solution : 9

V_A = 22.31 kmph, V_B = 33.19 kmph

■■■■

3 Pavement Design

LEVEL 1 Objective Questions

1.	(d)
2.	(b)
3.	(d)
4.	(b)
5.	(c)
6.	(b)
7.	(b)
8.	(a)
9.	(c)

LEVEL 2 Objective Questions

10.	(b)
11.	(c)
12.	(b)
13.	(c)
14.	(c)
15.	(13.46)
16.	(18.73)
17.	(a)
18.	(c)
19.	(d)

LEVEL 3 Conventional Questions

Solution : 1

Loads at 2.5 mm and 5.0 mm penetration (after correction) are 50 kg and 77.5 kg respectively.

$$\text{Area of plunger used in CBR test} = \frac{\pi}{4} \times 5^2 = 19.60 \text{ cm}^2$$

$$\text{Pressure at 2.5 mm penetration} = \frac{55}{19.60} = 2.80 \text{ kg/cm}^2$$

$$\text{Pressure at 5 mm penetration} = \frac{77.5}{19.6} = 3.95 \text{ kg/cm}^2$$

$$\text{CBR value of soil at 2.5 mm} = \frac{\text{Pressure on Plunger at 2.5 mm Penetration for soil}}{\text{Pressure as above for standard crushed stone}}$$

$$= \frac{2.80}{70} \times 100 = 4\%$$

$$\text{CBR value of soil at 5 mm} = \frac{3.95}{105} \times 100 = 3.76\%$$

$$\text{Adopt CBR} = 4\%$$

Major roads are designed for atleast a period of 10 years.

$$A = P[1 + r]^{n + 10}$$

$$n = \text{Construction Period} = 3 \text{ years}$$

$$A = 2000\left[1 + \frac{8}{100}\right]^{3 + 10} = 5439.25 \text{ veh/day}$$

There is no use of traffic data in US corps of engineers design formula.

$$\text{thickness} = t = \sqrt{\frac{1.75P}{\text{CBR\%}} - \frac{P}{\pi \cdot p}}$$

As subgrade soil CBR = 4% (which is less than 12%), this method can be used.

Thickness of pavement above soil subgrade

$$= \sqrt{\frac{1.75 \times 4100}{4} - \frac{4100}{\pi\ .6}} = 39.70 \text{ cm}$$

$$\text{Thickness of pavement above sandy soil} = \sqrt{\frac{4100 \times 1.75}{10} - \frac{4100}{\pi \times 6}} = 22.36 \text{ cm}$$

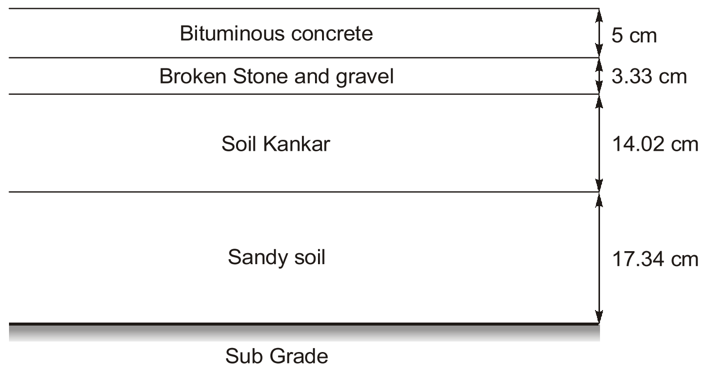
$$\text{Thickness of sandy soil required} = 39.7 - 22.36 \text{ cm} = 17.34 \text{ cm}$$

$$\text{Thickness of pavement above soil-kankar} = \sqrt{\frac{4100 \times 1.75}{25} - \frac{4100}{\pi \times 6}} = 8.33 \text{ cm}$$

$$\text{Thickness of soil-kankar required} = 22.36 - 8.33 = 14.02 \text{ cm}$$

$$\text{Thickness of Bituminous concrete} = 5 \text{ cm}$$

Thickness of broken stone and gravel = 8.33 – 5 = 3.33 cm



(Pavement Section)

Solution : 2

$$a = \text{Radius of contact area} = \sqrt{\frac{P}{\pi p}}$$

$$P = 5100 \text{ kg}$$

$$p = 7 \text{ kg/cm}^2$$

$$a = \sqrt{\frac{5100}{\pi \times 7}} = 15.23 \text{ cm}$$

$$A = \text{Design deflection} = 0.25 \text{ cm}$$

[Assumed as nothing mentioned]

Assuming the pavement to consist of single layer of base course material only; the pavement thickness is given by:

$$T_b = \left\{\sqrt{\left(\frac{3P \times y}{2\pi E_s A}\right)^2 - a^2}\right\}\left(\frac{E_s}{E_b}\right)^{\frac{1}{3}}$$

$$T_b = \left\{\sqrt{\left(\frac{3 \times 5100 \times 1.25 \times 0.8}{2 \times \pi \times 90 \times 0.25}\right)^2 - 15.23^2}\right\}\left(\frac{90}{900}\right)^{\frac{1}{3}}$$

$$T_b = 49.73 \text{ cm}$$

Let 7 cm bituminous mat layer with $E = 900$ kg/cm^2 equivalent to thickness t_b of base course.

$$\frac{t_b}{T} = \left(\frac{E_{\text{bitumen}}}{E_{\text{base course}}}\right)^{\frac{1}{3}}$$

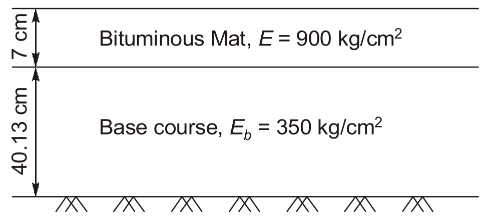
$$\frac{t_b}{7} = \left(\frac{900}{350}\right)^{1/3}$$

$$t_b = 9.59 \text{ cm}$$

Therefore the required base course thickness

$$= 49.73 - 9.59 = 40.13 \text{ cm}$$

Pavement section consist of 40.13 cm base course and 7 cm thick bituminous mat.



Soil subgrade, $E_s = 90$ kg/cm^2

Solution : 3

It is a two lane pavement

Let us calculate the cumulative number of standard axle load.

$$N_S = \frac{365A\left[\left(1+\frac{r}{100}\right)^n - 1\right] \times D \times F}{\frac{r}{100}}$$

r = growth factor = 5%

$$A = \text{Initial traffic} \times \left[1+\frac{r}{100}\right]^m$$

m = Construction period = 2 year

n = design life = 15 years

D = Vehicle Damage factor

F = Lane distribution factor = 0.75 [two land single carriage way]

$$N_S = \frac{365 \times [1.05^{15} - 1] \times 0.75 \times 1.05^2 \times [(150 \times 2.5) + (250 \times 3.5)]}{\frac{5}{100}}$$

N_S = 8.14 MSA

Total pavement thickness can be obtained by interpolation from pavement design catalogue (IRC : 37 2001)

Total pavement thickness for CBR = 6% and traffic 8.14 MSA = 586 mm

Final pavement composition

(a) Bituminous surfacing = 40 mm BC + 65 DBM

(b) Road base = 250 mm grannular base

(c) Subbase = 230 mm grannular subbase

Subbase should have a minimum CBR of 30% as traffic is greater than 2 MSA and should have a minimum thickness of 150 mm for traffic less than 10 MSA.

Base course minimum thickness = 150 mm for traffic greater than 2 MSA.

So our design is safe according to guidelines by IRC 37 : 2001.

Solution : 4

$$\text{Radius of relative stiffness } l = \left[\frac{E \cdot h^3}{12 \cdot K \cdot (1-\mu^2)}\right]^{\frac{1}{4}}$$

$$= \left[\frac{3 \times 10^5 \times 20^3}{12 \times 15 \times (1 - 0.15^2)}\right]^{\frac{1}{4}} = 60.8 \text{ cm}$$

Equivalent radius of resisting section,

$$b = \sqrt{1.6a^2 + h^2} - 0.675\,\text{h}$$

$$b = \sqrt{1.6 \times 15^2 + 20^2} - 0.675 \times 20 \qquad [a < 1.724 \times h]$$

$$= 14.06 \text{ cm}$$

Wheel load stress at edge by wester guard

$$= \frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{l}{B}\right) + 0.359\right]$$

$$= 0.572 \times \frac{5100}{20^2}\left[4\log_{10}\frac{60.8}{14.06} + 0.359\right] = 21.17 \text{ kg/cm}^2$$

Wheel load stress at corner $= \dfrac{3P}{h^2}\left[1 - \left(\dfrac{\sqrt{2} \cdot a}{l}\right)^{0.60}\right]$

$$= \frac{3 \times 5100}{20^2}\left[1 - \left(\frac{\sqrt{2} \times 15}{60.8}\right)^{0.60}\right] = 24.9 \text{ kg/cm}^2$$

Warping stresses

$$= 17.91 \text{ kg/cm}^2$$

$$t_1 = \text{temperature differential during day}$$

$$= 0.6 \times 20 = 12°\text{C}$$

$$t_2 = \text{temperature differential during night} = 0.4 \times 20 = 8°\text{C}$$

$$\frac{L_x}{l} = \frac{450}{60.8} = 7.40$$

$$\frac{L_y}{l} = \frac{350}{60.8} = 5.76$$

From the table given in question $C_x = 1.00,\ C_y = 0.84$

Maximum warping stress at edge during the day

$$= \frac{E\alpha t_1}{2} \cdot C_x$$

$$= \frac{1}{2} \times 3 \times 10^5 \times 10 \times 10^{-6} \times 12 \times 1$$

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

Maximum warping stress at cooper $= \dfrac{E \cdot \alpha \cdot t_2}{3(1-\mu)}\sqrt{\dfrac{a}{l}}$

$$= \frac{3 \times 10^5 \times 10 \times 10^{-6} \times 8}{3 \times (1 - 0.15)} \times \sqrt{\frac{15}{60.8}}$$

$$= 4.67 \text{ kg/cm}^2$$

$$\text{Frictional stress at edge} = \frac{W \cdot L_x f}{2 \times 10^4}$$

$$= \frac{2400 \times 4.5 \times 1.5}{2 \times 10^4} = 0.81 \text{ kg/cm}^2$$

$$\text{Frictional stress at corner} = 0$$

Critical combination of stress in summer mid-night = load stress + warping stress – friction stress

$$= 21.17 + 18 - 0.81 = 38.36 \text{ kg/cm}^2$$

Critical combination of stress in summer midnight at corner = 17.91 + 4.67 = 22.58 kg/cm^2

Solution : 5

Spacing between contraction joints in plain CC pavement,

$$L_e = \frac{2S_e}{Wf} \times 10^4 = \frac{2 \times 0.8 \times 10^4}{2400 \times 1.4} = 4.76 \text{ m}$$

Maximum spacing suggested by the IRC is 4.5 m for plain CC pavements and so adopt L_e = 4.5 m

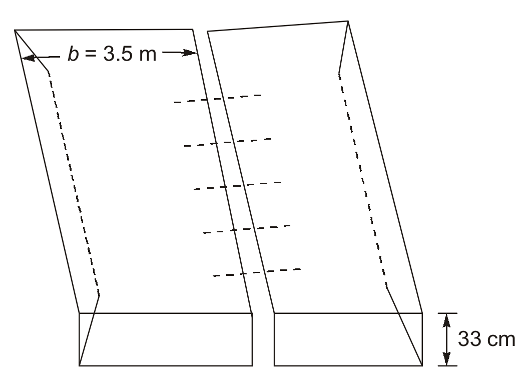
Spacing between expansion joints, $L_e = \dfrac{\delta'}{100C(T_2 - T_1)}$

$$= \frac{1.1}{100 \times 10 \times 10^{-6} \times 26} = 42.3$$

Therefore provide spacing of expansion joints = 9 × 4.5 = 40.5 m

(As 10 × 4.5 = 45.0 m which is higher than 42.3 m, expansion joints are provided after eight contraction joints or after the ninth slab).

Solution : 6



By equating, total subgrade friction = total tension developed in tie bars

$$A_s S_s = b \times \frac{h}{100} \times w \times f$$

$$A_s = \frac{bfhw}{100S_s}$$

Here, A_S = area of steel per meter length of joint, cm^2

b = distance between joint and nearest force edge = 3.5 m

h = thickness of pavement = 33 cm

f = coefficient of fricton between pavement and subgrade = 1.5

w = unit weight of cement concrete = 2400 kg/cm^3

S_s = allowable tensile stress in deformed bars = 2000 kg/cm^3

[*Assume deformed bar is used for tie bars]

$$\therefore \quad A_S = \frac{3.5 \times 1.5 \times 33 \times 2400}{100 \times 2000} = 2.1\,\text{cm}^2/\text{meter}$$

Using 1 cm diameter deformed bars having area of cross section as = 0.785 cm^2

$$\text{So the spacing of tie bars} = \frac{100 \times 0.785}{2.1} = 37.76 \text{ cm}$$

$$\cong 37 \text{ cm spacing of tie bar.}$$

Length of tie bar;

Equating total tensile force in tie bar = bond strength between tie bar and concrete

Hence,
$$a_s S_s = \frac{L_t}{2} P S_b$$

$$L_t = \frac{2 a_s S_s}{P S_b}$$

Putting,
$$a_s = \frac{\pi d^2}{4} \text{ and } P = \pi d$$

$$L_t = \frac{d S_s}{2 S_b}$$

Here, S_b = allowable bond stress in deformed bar = 24.6 kg/cm^2

d = dia. of tie bar

$$\therefore \quad L_t = \frac{1 \times 2000}{2 \times 24.6} = 40.65 \text{ cm} \cong 42 \text{ cm}$$

Total length of tie bar = 42 cm

So use 1 cm diameter bars of length 42 cm at 37 cm c/c

Solution : 7

Length of Dowel Bar, L

Assume the diameter of the dowel bar, d = 2.5 cm

Given data: design wheel load, P = 4000 kg; radius of relative stiffness, θ = 90 cm; thickness of pavement, h = 20 cm; Joint width, δ = 3 cm; Permissible stress in shear, F_s = 1000 kg/cm^2; Permissible stress in bending, F_f = 1500 kg/cm^2; Permissible stress in bearing, F_b = 100 kg/cm^2; Load capacity of dowel system = 40% of P = 40% of 4000 = 1600 kg

In order to obtain balanced design for equal capacity in bending and hearing; the length of dowel bar is obtained by

$$L_d = 5d\left[\frac{Ff}{F_b} \times \frac{L_d + 1.5\delta}{L_d + 8.8\delta}\right]^{1/2} = 5 \times 2.5\left[\frac{1500}{100} \times \frac{L_d + 1.5 \times 3}{L_d + 8.8 \times 3}\right]$$

$$= 12.5\left[15 \times \frac{L_d + 4.5}{L_d + 26.4}\right]^{1/2}$$

This can be solved by trial method.

Let us start with $L_d = 45$ cm

1st trail; $L_d = 12.5\left[15 \times \frac{45 + 4.5}{45 + 26.4}\right]^{1/2} = 40.31 < 45$ cm

2nd trial; $L_d = 40$ cm

$$L_d = 12.5 \times \left[15 \times \frac{40 + 4.5}{40 + 26.4}\right]^{1/2} = 39.63 \text{ cm} < 40 \text{ cm}$$

3rd trial; $L_d = 39$ cm

$$L_d = 12.5 \times \left[15 \times \frac{43.5}{65.4}\right]^{1/2} = 39.48 > 39 \text{ cm}$$

Therefore, total length of embedment, $L_d = 39$ cm

Min. Length of dowel bar required, $L = L_d + d = 39 + 3 = 42$ cm

Therefore, provide 2.5 cm diameter dowel bars of length 45 cm

Load transfer capacity of single dowel bar, P'

$$P'(\text{shear}) = 0.785 d^2 F_S = 0.785 \times 2.5^2 \times 1000 = 4902 \text{ kg}$$

$$\text{Actual value of } L_d = 45 - \delta = 45 - 3 = 42 \text{ cm}$$

$$P'(\text{bending}) = \frac{2d^3 F_f}{L_d + 8.8\delta} = \frac{2 \times 2.5^3 \times 1500}{(42 + 8.8 \times 3)} = 685.31 \text{kg}$$

$$P'(\text{bearing}) = \frac{F_b L_d^2 d}{12.5(L_d + 1.5\delta)} = \frac{100 \times 42^2 \times 2.5}{12.5(42 + 1.5 \times 3)} = 758.7 \text{ kg}$$

Taking the lowest of three values for design, load

Capacity of a dowel bar, $P'(\text{design}) = 685.31$ kg

Given, Load capacity of dowel group $= 40\%$ of $P = 40\% \times 4000 = 1600$ kg

Required capacity factor for dowel group $= \frac{1600}{685.31} = 2.33$

Spacing of Dowel Bars

Effective distance upto which there is load transfer

$= 1.8 \times$ radius of relative stiffness

$= 1.8 \times l = 1.8 \times 90 = 162$ cm

Assuming a trial spacing of 30 cm between the dowel bars, the capacity factor available for the group

$$= 1 + \frac{162 - 30}{162} + \frac{162 - 60}{162} + \frac{162 - 90}{162} + \frac{162 - 120}{162} + \frac{162 + 150}{162}$$

$$= 6 - \frac{460}{162} = 3.22$$

This value is much more than load capacity factor of 2.33

So assume spacing 40 cm

So capacity factor $= 1+\frac{162-40}{162}+\frac{162-80}{162}+\frac{162-120}{162}+\frac{162-160}{162}$

$$= 5-\frac{400}{162} = 2.53$$

this value is closed to 2.33

so provide spacing of 40 cm

Therefore, provide 2.5 cm dia dowel bars of total length 45 cm at 40 cm spacing.

■■■■

4 Highway Materials

LEVEL 1 Objective Questions

1. (b)
2. (b)
3. (c)
4. (d)
5. (c)
6. (c)
7. (b)
8. (a)

LEVEL 2 Objective Questions

9. (b)
10. (c)
11. (c)
12. (21.72)
13. (d)
14. (2.30)
15. (d)
16. (a)