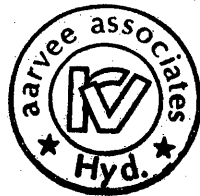


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GUIDELINES  
FOR  
THE DESIGN OF RIGID  
PAVEMENTS  
FOR  
HIGHWAYS

(First Revision)



THE INDIAN ROADS CONGRESS

1991

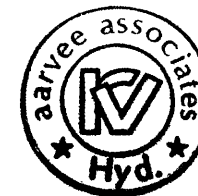
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## GUIDELINES FOR THE DESIGN OF RIGID PAVEMENTS FOR HIGHWAYS

### 1. INTRODUCTION

Guidelines for the Design of Rigid Pavements for Highways were approved by the Cement Concrete Road Surfacing Committee in their meeting held at Chandigarh on the 11th March, 1973. These were approved by the Specifications & Standards Committee in their meeting held on 31st January and 1st February, 1974. The Guidelines were then approved by the Executive Committee and the Council in their meetings held on the 1st May and 2nd May, 1974 respectively.

In view of the recent upward revision of the legal limit on the maximum laden axle-loads of commercial vehicles from 8160 kg. to 10200 kg. (new legal maximum wheel load 5100 kg.), appropriate modifications have become necessary in some sections of the Guidelines.

Accordingly, the Cement Concrete Road Surfacing Committee of the Indian Roads Congress in their 17th meeting held at Nagpur on 8th January, 1984 (personnel given below) considered and approved certain changes :

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	A Rep. of C.P.W.D.
	D G. (R.D.)

—*Ex-officio*

The amendments were considered by the Specifications & Standards Committee in their meeting held at New Delhi on the 21st August, 1985 and were returned back to Cement Concrete Road Surfacing Committee for further consideration. The draft was then finalised by Dr. M.P. Dhir Convenor and Shri S.S. Sehra Member- Secretary of the reconstituted Committee. The draft received from the Cement Concrete Road Surfacing Committee was reconsidered by the Highways Specifications & Standards Committee in their meeting held on 25th April, 1988 at New Delhi and approved. These amendments received the approval of the Executive Committee and the Council in their meetings held on 26th April and 7th May, 1988 respectively.

## 2. GENERAL

Rigid pavement design commenced with the classical analysis of Westergaard in 1926. Most of the subsequent work, till recently, aimed at modifications and adaptations of Westergaard's work either with a view to match better with the actual performance and test data, or simplify the analysis for easier design. Of late, there is a noticeable trend towards the development of ultimate load analysis in this field, and consequent upon the AASHO Road Test, attempts have been made also to apply the serviceability-performance criteria to rigid pavement design. They are, however, still in a developing stage.

Some of these methods take only traffic loads into account, ignoring such environmental factors as temperature changes in the pavement, which may substantially limit its load-carrying capacity. There are other factors, like impact, load repetitions, etc., the effects of which though understood qualitatively, are not yet conclusively established quantitatively. Nevertheless, for a rational design, their effects should be incorporated to the extent possible with the existing knowledge.

It is with the objective of simplifying this task and to promote the scientific design of rigid pavements that these guidelines have been drawn.

## 3. DESIGN PARAMETERS AND ASSESSMENT OF THEIR DESIGN VALUE

### 3.1. Traffic Parameters

3.1.1. **Design wheel load :** The design wheel load should be the maximum wheel load of the predominant heavy vehicle

likely to use the pavement in the normal course. In case of public highways, it will obviously be governed by the prevailing legal limits on the maximum laden weight of commercial vehicles. It is currently taken at 5100 kg.

In addition to the design wheel load, the maximum tyre inflation pressures for the vehicles should also be ascertained, so as to enable determination of tyre contact area through which the load is transmitted to the pavement. For most commercial highway vehicles, this ranges from about 5.3 to 7.3 kg/cm<sup>2</sup>.

3.1.2. **Traffic intensity :** Passage of traffic results in repetitive loading of the pavement, thereby inducing fatigue effects in the concrete. These effects, while not of much consequence in case of low traffic intensities because of considerable time lag between successive passes, assume greater importance in case of heavily trafficked pavements, as the fatigue strength of concrete reduces with increase in the number of load repetitions it is required to sustain.

While a rigorous approach would require the assessment of total number of design load repetitions during intended design life of a pavement including due allowance for lighter and heavier loads through the use of appropriate equivalency factors, a more practical approach is to classify the pavements, for the purpose of making fatigue allowance, according to traffic intensity range expected.

Since traffic intensity is a growing phenomenon, the heaviest intensity will occur at the end of the design life of a pavement. However, it is generally considered adequate if the traffic is projected to a period of 20 years after construction, since in the initial stages the traffic intensity will be much less than that at the end of the design life.

For traffic prediction on main highways, the following correlation may be adopted :

$$T = P(1+r)^{n+20} \quad \dots (1)$$

with  $T$  = design traffic intensity in terms of number of commercial vehicles (laden weight  $\geq$  3 tonnes) per day,

$P$  = traffic intensity at last traffic count,

$r$  = annual rate of increase of traffic intensity, and

$n$  = number of years since last traffic count and commissioning the new concrete pavement.

The traffic intensity *P* for assessment of design traffic intensity *T* should normally be a seven day average based on 24-hour counts, in accordance with IRC : 9-1972 : Traffic Census on Non-Urban Roads (First Revision). However, in exceptional cases, where such data are not available, an average of three day counts may be used as an approximation. Based on growth rate of traffic over the past few years, a value of 7.5 per cent is suggested for 'r' for rural roads for the time being, wherever actual data are not available.

In case of new highway links, where no traffic count data will be available, data from highways of similar classification and importance may be used to predict the design traffic intensity.

The pavement classification based on design traffic intensity, suggested for adoption for rigid pavement design, is given in Table 1.

TABLE 1. TRAFFIC CLASSIFICATION FOR RIGID PAVEMENT DESIGN

Traffic classification	Design Traffic Intensity : Vehicles (laden weight $\geq 3$ tonnes) per day at the end of design life
A	0-15
B	15-45
C	45-150
D	150-450
E	450-1500
F	1500-4500
G	Above 4500 and all expressway

### 3.2. Environmental Parameters

3.2.1. **Temperature differential:** Temperature differential between top and bottom of concrete pavements is a function of solar radiation received by the pavement surface at the location, losses due to wind velocity, etc., and thermal diffusivity, of concrete, and is thus affected by geographical features of the pavement location.

As far as possible, values of actually anticipated temperature differentials at the location of the pavement should be

adopted for pavement design. For this purpose, guidance may be had from Table 2.

TABLE 2. RECOMMENDED TEMPERATURE DIFFERENTIALS IN CONCRETE ROADS

Zone	States	Temp. differential in °C in slabs of thickness				
		10 cm	15 cm	20 cm	25 cm	30 cm
I.	Punjab, U.P., Rajasthan, Gujarat, Haryana and North M.P., excluding hilly regions and coastal areas	10.2	12.5	13.1	14.3	15.8
II.	Bihar, West Bengal, Assam and Eastern Orissa, excluding hilly regions and coastal areas	14.4	15.6	16.4	16.6	16.8
III.	Maharashtra, Karnataka South M.P., Andhra Pradesh, Western Orissa and North Madras excluding hilly regions and coastal areas	14.75	17.3	19.0	20.3	21.0
IV.	Kerala and South Madras, excluding hilly regions and coastal areas	13.2	15.0	16.4	17.6	18.1
V.	Coastal areas bounded by hills	12.8	14.6	15.8	16.2	17.0
VI.	Coastal areas unbounded by hills	13.6	15.5	17.0	19.0	19.2

Note : The above mentioned table has been prepared on the basis of actual observations by Central Road Research Institute, New Delhi.

3.2.2. **Mean temperature cycles :** Mean temperature cycles-daily and annual of concrete pavements affect the maximum spacing of contraction and expansion joints in the pavement and design values for these factors would be required if it is desired to adopt the maximum safe spacing of expansion joints. However, these factors are dependent upon the geographical location of the pavement, and data thereon are generally not available readily. Somewhat conservative recommendations for maximum expansion joint spacing have, therefore, been framed as guidelines on the basis of actual temperature data collected at selected locations in different parts of the country.

### 3.3. Foundation Strength and Surface Characteristics

3.3.1. **Strength :** The foundation strength, in case of rigid

pavements, is expressed in terms of modulus of subgrade reaction,  $K$ , which is defined as pressure per unit deflection of the foundation as determined by plate bearing tests. As the limiting design deflection for concrete pavements is taken at 1.25 mm, the  $K$ -value is determined from the pressure sustained at this deflection. As  $K$ -value is influenced by test plate diameter, the standard test is run with a 75 cm dia. plate, beyond which the effect of diameter has been found to be negligible. A frequency of one test per km per lane is recommended for assessment of  $K$  value, unless foundation changes with respect to subgrade soil type, of sub-base or the nature of formation (i.e. cut or fill) when additional tests may be conducted.

In case of homogeneous foundation, test values obtained with plates of smaller diameter may be converted to the standard 75 cm plate value by experimentally obtained correlations, e.g,

$$K_{75} = 0.5 K_{30} \quad \dots(2)$$

with  $K_{75}$  and  $K_{30}$  as the  $K$  values obtained on 75 cm and 30 cm dia. plates respectively. However, in case of layered construction, as in the case of sub-base, the tests with smaller plates give greater weightage to the stronger top layer, and direct conversion to 75 cm plate values by the above correlations somewhat overestimates the foundation strength, and such conversion must be regarded as very approximate only.

The subgrade soil strength, and consequently the strength of the foundation as a whole, is affected by its moisture content. The design strength obviously must be the minimum that will be available under the worst moisture conditions encountered. The ideal period for testing the foundation strength would thus be after the monsoons when the subgrade would have attained its highest moisture content.

In case the tests have to be conducted at some other time, especially during the dry part of the year, allowance for loss in strength due to increase in moisture must be made. For this purpose, an idea of the expected reduction in strength on saturation of the subgrade may be had from laboratory CBR tests on subgrade soil samples compacted at field density and moisture content and tested before and after saturation. An approximate idea of  $K$  value of a homogeneous soil subgrade may be had directly from its CBR value using Table 3. A more elaborate procedure involves correlation through consolidation tests on unsoaked and soaked samples.

TABLE 3 APPROXIMATE  $K$  VALUE CORRESPONDING TO CBR VALUES FOR HOMOGENEOUS SOIL SUBGRADES

CBR value (%)	2	3	4	5	7	10	20	50	100
$K$ -value (kg/cm <sup>2</sup> )	2.08	2.77	3.46	4.16	4.84	5.54	6.92	13.85	22.16

The recommendations of IRC : 15-1981 shall be followed and a  $K$ -value of less than 5.5 kg/cm<sup>2</sup> tested on the subgrade shall not be permitted. In case of rocky subgrades with a  $K$ -value of 5.5 kg/cm<sup>2</sup> and higher, the pavement may be laid directly thereon or after providing a levelling course, if required. In case of problematic subgrades such as clayey and expansive soils, etc., appropriate provisions shall be made for a blanket course in addition to the sub-base as per the relevant stipulations of IRC: 15-1981, reproduced in *Appendix 1*.

**3.3.2. Foundation surface characteristics :** The foundation surface characteristics, viz., its smoothness or roughness, determine the extent of resistance to slab movement during expansion and contraction on account of foundation restraint, and affect joint spacings. The maximum safe spacing increases with increase in surface roughness of the foundation in case of expansion joints, and decreases in case of contraction joints.

For the purpose of determination of joint spacings, different types of foundations generally adopted may be classified into three categories, viz., very smooth, smooth and rough, according to their surface characteristics, as given in Table 4. As the foundations normally adopted in the country fall within the last two categories, only these two categories have been considered in formulating recommendations for expansion joint spacings.

TABLE 4. CLASSIFICATION OF DIFFERENT TYPES OF RIGID PAVEMENT FOUNDATIONS ACCORDING TO THEIR SURFACE CHARACTERISTICS

Surface roughness characteristics	Type of foundation
Very Smooth	Compacted sand and gravel. Smooth foundation covered with waterproof paper
Smooth	Compacted sand, gravel and clinker, stabilised soil. Rough foundation covered with waterproof paper
Rough	Water-bound macadam, soil-gravel mix, rolled lean concrete, lime-pozzolana concrete, etc.

### 3.4. Concrete Characteristics

3.4.1. **Design strength :** As stresses induced in concrete pavements are due either to bending or its prevention, their design is necessarily based on the flexural strength of concrete. For economical design, the design value adopted for flexural strength of pavement concrete should not be less than 40 kg/cm<sup>2</sup>. This strength value, however, should not be confused with the mix design strength. The mix has to be so designed as to ensure the minimum structural strength requirements in the field with the desired confidence level. Thus if :

$s$  = structural design value for concrete strength,

$\bar{s}$  = mix design value for concrete strength,

$t$  = tolerance factor for the desired confidence level,

$\sigma$  = expected standard deviation of field test samples, based on a knowledge of the type of control, viz. very good, good or fair, feasible at site.

$$\text{then } s = \bar{s} + t \cdot \sigma \quad \dots (3)$$

so that to achieve the desired minimum structural strength  $s$  in the field, the mix design in the laboratory has to be made for somewhat higher strength,  $\bar{s}$  making due allowance for the type and extent of quality control feasible in the field.

For pavement construction, the concrete mix should preferably be designed and controlled on the basis of flexural strength. If that is not possible, correlation between flexural and compressive strengths should be established on the basis of actual tests on additional samples made for the purpose at the time of mix design. Quality control can then be exercised on the basis of compressive strength, so long as the mix materials and proportions remain substantially unaltered. Even though it is customary to assume 280 kg/cm<sup>2</sup> as compressive strength corresponding to 40 kg/cm<sup>2</sup> flexural strength, such general assumptions should be avoided as far as possible in view of the variety of factors which influence the correlation between the two strengths.

For general guidance, the value of  $t$  and  $\sigma$  for concrete compressive strength value of 280 kg/cm<sup>2</sup> are given in Table 5 for different degrees of quality control. For design of cement concrete mix, IRC: 44-1972 Tentative Guidelines for Cement Concrete Mix Design for Road Pavements (for non-air entrained and continuously graded concrete) may be followed.

TABLE 5. CONCRETE MIX DESIGN STRENGTH FOR DIFFERENT DEGREES OF QUALITY CONTROL, FOR STRUCTURAL DESIGN VALUE OF 280 kg/sq. cm FOR CONCRETE COMPRESSIVE STRENGTH

Degree of quality control	Tolerance level	Tolerance factor, $t$	Coefficient of variation	Mix design strength kg./sq.cm.	Standard deviation kg/sq.cm.
Very good	1 in 15	1.50	7%	315	22
Good	1 in 15	1.50	10%	330	33
Fair	1 in 10	1.20	15%	350	52

**Notes :** *Very good quality control :* Control with weigh batching, use of graded aggregates, moisture determination of aggregates, etc. Rigid and constant supervision by the quality control team.

*Good quality control :* Control with weigh-batching, use of graded aggregates, moisture determination of aggregates, etc. Constant supervision by the quality control team.

*Fair quality control :* Control with volume-batching for aggregates. Occasional checking of aggregate moisture. Occasional supervision by the quality control team.

3.4.2. **Modulus of elasticity and Poisson's ratio:** The modulus of elasticity,  $E$ , and Poisson's ratio,  $\mu$  of concrete are known to vary with concrete materials and strength. The elastic modulus increases with increase in strength, and Poisson's ratio decreases with increase in the modulus of elasticity. While it is desirable that the values of these parameters are ascertained experimentally for the concrete mix and materials actually to be used at the construction, this information may not always be available at the design stage. In such cases, it is suggested that for design purposes, the following values may be adopted for concrete in the 38-42 kg/cm<sup>2</sup> flexural strength range :

$$\begin{aligned} \text{Modulus of elasticity of concrete, } E &= 3 \times 10^5 \text{ kg/cm}^2 \\ \text{Poisson's ratio, } \mu &= 0.15 \end{aligned}$$

3.4.3. **Coefficient of thermal expansion :** The coefficient of thermal expansion,  $\alpha$ , of concretes of the same mix proportions varies with the type of aggregate, being in general high for siliceous aggregates, medium for igneous rocks and low for calcareous ones. However, for design purposes, a value  $\alpha = 10 \times 10^{-6}/^\circ\text{C}$  may be adopted in all cases.

## 4. DESIGN OF SLAB THICKNESS

### 4.1. Critical Stress Condition

Concrete pavements in service are subjected to stresses due



to a variety of factors, acting simultaneously, the severest combination of which inducing the highest stress in the pavement will give the critical stress condition. The factors commonly considered for design of pavement thickness are traffic loads and temperature variations, as the two are additive. The effects of moisture changes and shrinkage, being generally opposed to those of temperature and of smaller magnitude, would ordinarily relieve the temperature effects to some extent, and are not normally considered critical to thickness design.

For purposes of analysis, three different regions are recognised in a pavement slab—corner, edge and interior—which react differently from one another to the effect of temperature differentials, as well as load application.

The concrete pavements undergo a daily cyclic change of temperature differentials, the top being hotter than the bottom during day, and cooler during night. The consequent tendency of the pavement slabs to warp upwards (top convex) during the day and downwards (top concave) during the night, and restraint offered to this warping tendency by self-weight of the pavement induces stresses in the pavement, referred to commonly as temperature stresses. These stresses are flexural in nature, being tensile at bottom during the day and at top during night. As the restraint offered to warping at any section of the slab would be a function of weight of the slab upto that section, it is obvious that corners have very little such restraint. The restraint is maximum in the slab interior, and somewhat less at the edge. Consequently the temperature stresses induced in the pavement are negligible in the corner region, and maximum at the interior.

Under the action of load application, maximum stress is induced in the corner region, as the corner is discontinuous in two directions. The edge being discontinuous in one direction only, has lower stress, while the least stress is induced in the interior where the slab is continuous in all directions. Furthermore, the corner tends to bend like a cantilever, giving tension at the top, interior like a beam giving tension at bottom. At edge, main bending is along the edge like a beam giving maximum tension at bottom.

The maximum combined tensile stresses in the three regions of the slab will thus be caused when effects of temperature differentials are such as to be additive to the load effects. This would occur during the day in case of interior and edge regions, at the

time of maximum temperature differential in the slab. In the corner region, the temperature stress is negligible, but the load stress is maximum at night when the slab corners have a tendency to lift up due to warping and lose partly the foundation support. Considering the total combined stress for the three regions, viz., corner, edge and interior, for which the load stress decreases in that order while the temperature stress increases, the critical stress condition is reached in the edge region where neither of the load and temperature stresses are the minimum. It is, therefore, felt that both the corner and the edge regions should be checked for total stresses and design of slab thickness based on the more critical condition of the two.

#### 4.2. Calculation of Stresses

##### 4.2.1. Edge stresses

(a) **Due to load :** The load stress in the critical edge region may be obtained as per Westergaard analysis and modified by Teller and Sutherland from the following correlation (metric units) :

$$\sigma_{le} = 0.529 \frac{P}{h^2} (1 + 0.54 \mu) \left( 4 \log_{10} \frac{1}{b} + \log_{10} b - 0.4048 \right) \dots (4)$$

with  $\sigma_{le}$  = load stress in the edge region, kg/cm<sup>2</sup>,

$P$  = design wheel load, kg,

$h$  = pavement slab thickness, cm,

$\mu$  = Poisson's ratio for concrete,

$E$  = modulus of elasticity for concrete, kg/cm<sup>2</sup>,

$K$  = reaction modulus of the pavement foundation, kg/cm<sup>3</sup>,

$l$  = radius of relative stiffness, cm

$$= 4 \sqrt{\frac{Eh^3}{12(1-\mu^2)K}} \dots (5)$$

$b$  = radius of equiv. distribution of pressure

$$= a \text{ for } \frac{a}{h} > 1.724$$

$$= \sqrt{1.6a^2 + h^2} - 0.675 h \text{ for } \frac{a}{h} \leq 1.724 \dots (6)$$

and  $a$  = radius of load contact, cm, assumed circular.

The values of  $l$  and  $b$  can be ascertained directly from Tables 6 and 7. For ready reference, 4-figure log tables are included in Appendix 2.

**TABLE 6. RADIUS OF RELATIVE STIFFNESS,  $l$ , FOR DIFFERENT VALUES OF PAVEMENT SLAB THICKNESS,  $h$ , AND FOUNDATION REACTION MODULUS,  $K$ , FOR CONCRETE  $E = 3.0 \times 10^6$  kg/cm<sup>2</sup>**

$h$ (cm)	Radius of relative stiffness $l$ (cm) for different values of $K$ (kg/cm <sup>2</sup> ) <sup>a</sup>				
	$K=6$	$K=8$	$K=10$	$K=15$	$K=30$
15	61.44	57.18	54.08	48.86	41.09
16	64.49	60.02	56.76	51.29	43.31
17	67.49	62.81	59.40	53.67	45.14
18	70.44	65.56	62.01	56.03	47.07
19	73.36	68.28	64.57	58.35	49.06
20	76.24	70.95	67.10	60.63	50.99
21	79.08	73.59	69.60	63.89	52.89
22	81.89	76.20	72.08	65.13	54.77
23	84.66	78.80	74.52	67.33	56.62
24	87.41	81.35	76.94	69.31	58.45
25	90.13	83.88	79.32	71.68	60.28

**TABLE 7. RADIUS OF EQUIV. DISTRIBUTION OF PRESSURE SECTION,  $b$ , IN TERMS OF RADIUS OF CONTACT,  $a$ , AND SLAB THICKNESS,  $h$**

$a/h$	$b/h$	$a/h$	$b/h$
0.0	0.325	1.0	0.937
0.1	0.333	1.1	1.039
0.2	0.357	1.2	1.143
0.3	0.387	1.3	1.250
0.4	0.446	1.4	1.358
0.5	0.508	1.5	1.470
0.6	0.580	1.6	1.582
0.7	0.661	1.7	1.695
0.8	0.747	1.724	1.724
0.9	0.840	>1.724	$a/h$

(b) **Due to temperature :** The temperature stress at the critical edge region may be obtained as per Westergaard analysis, using Bradbury's coefficient, from the following correlation :

$$\sigma_{te} = \frac{E\alpha\Delta t}{2} \cdot C \quad (7)$$

with  $\sigma_{te}$  = temperature stress in the edge region,

$\Delta t$  = maximum temperature differential during day between top and bottom of the slab,

$\alpha$  = coefficient of thermal expansion of concrete,

$C$  = Bradbury's coefficient, which can be ascertained directly from Bradbury's chart against values of  $L/l$  and  $W/l$ ,

$L$  = slab length, or spacing between consecutive contraction joints,

$W$  = slab width, and

$l$  = radius of relative stiffness.

Values of the coefficient,  $C$ , based on the curves given in Bradbury's chart, are given in Table 8.

**TABLE 8. VALUES OF CO-EFFICIENT 'C' BASED ON BRADBURY'S CHART**

$L/l$ or $W/l$	$C$
1	0.000
2	0.040
3	0.175
4	0.440
5	0.720
6	0.920
7	1.030
8	1.075
9	1.080
10	1.075
11	1.050
12 and above	1.000

4.2.2. **Corner stresses:** The load stress in the corner region may be obtained as per Westergaard's analysis, as modified by Kelley, from the following correlation :

$$\sigma/c = \frac{3P}{h^2} \left[ 1 - \left( \frac{a\sqrt{2}}{l} \right) \right] 1.2 \quad \dots(8)$$

with  $\sigma/c$  = load stress in the corner region, other notations remaining the same as in the case of the edge load stress formula.

The temperature stress in the corner region is negligible as the corners are relatively free to warp, and may be ignored.

4.3. Design Charts

Figs. 1 and 2 give ready-to-use design charts for calculation of load stresses in the edge and corner regions of rigid pavement

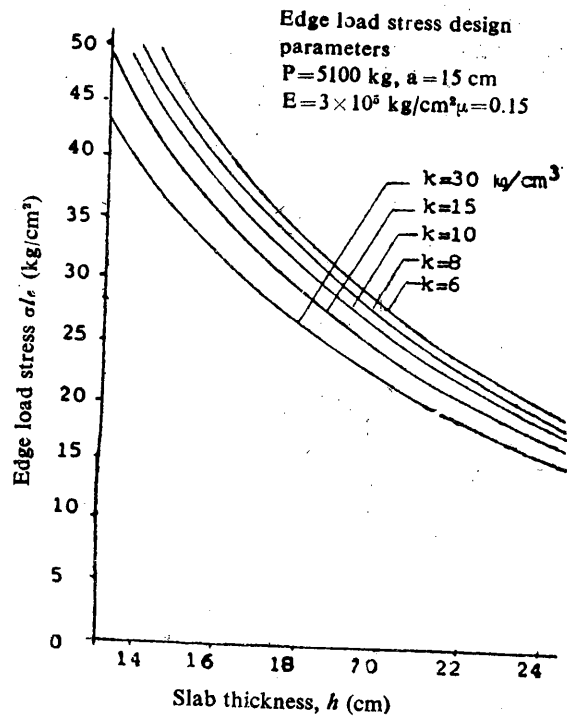


Fig. 1. Design chart for calculation of edge load stress

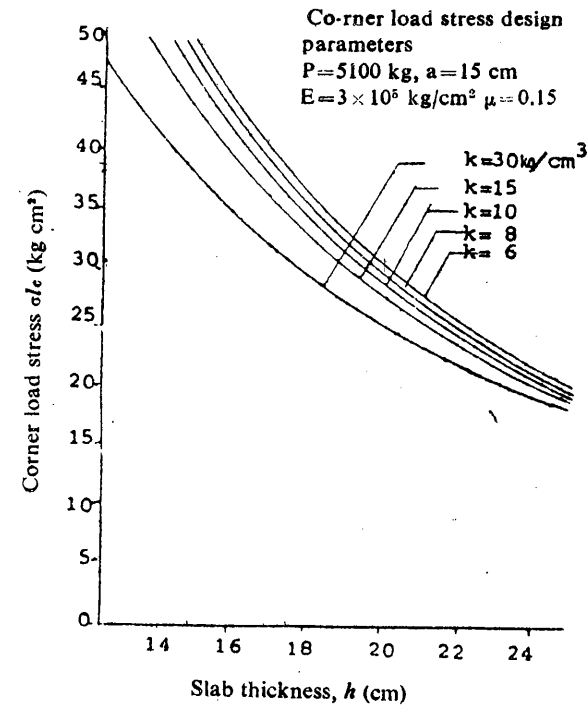
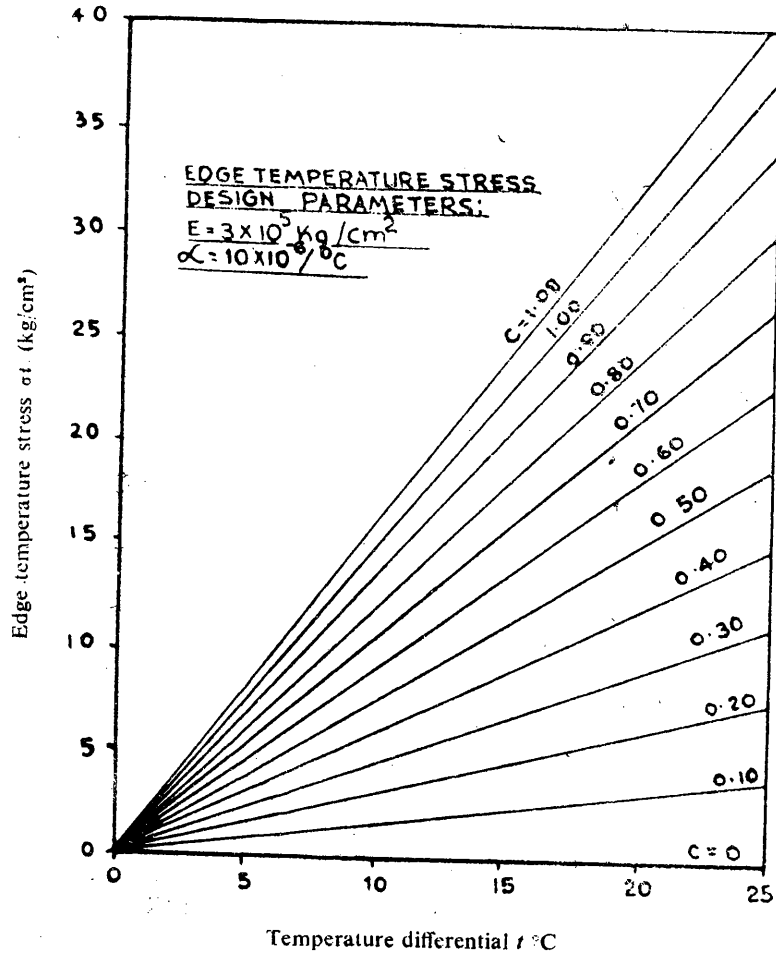


Fig. 2. Design chart for calculation of corner load stress

slabs for the design wheel load of 5100 kg. Fig. 3 gives a design chart for calculation of temperature stresses in the edge region.

4.4. Recommended Design Procedure

- Step 1 : Stipulate design values for the various parameters.
- Step 2 : Decide joint spacing and land-widths (vide para 5.1).
- Step 3 : Select tentative design thickness of pavement slab.
- Step 4 : Ascertain maximum temperature stress for the critical edge region from Equation (7) or Fig. 3.
- Step 5 : Calculate the residual available strength of concrete for supporting traffic loads.
- Step 6 : Ascertain edge load stress from Equation (4) or Fig. 1, and calculate factor of safety thereon.



Temperature differential  $t$  °C  
Chart for determination of coefficient  $C$

$L/l$ or $W/l$	$C$	$L/l$ or $W/l$	$C$
1	0.000	7	1.030
2	0.040	8	1.077
3	0.175	9	1.080
4	0.440	10	1.075
5	0.720	11	1.050
6	0.920	12	1.000

Fig. 3. Design chart for calculation of edge temperature stress

- Step 7 : In case the available factor of safety is less than or far in excess of 1, adjust the tentative slab thickness and repeat steps 3 to 6 till the factor of safety is 1 or slightly more. Denote the corresponding slab thickness as  $h_s$ .
- Step 8 : Check for adequacy of thickness in the corner region by ascertaining corner load stress from Equation (8) of Fig. 1 and readjust the thickness  $h_s$ , if inadequate;
- Step 9 : Adjust  $h_s$  for traffic intensity. The adjusted design thickness,  $h$ , may be obtained from  

$$h = h_s + h_t \quad \dots(9)$$

The values of  $h_t$  may be taken from Table 9.

TABLE 9. RIGID PAVEMENT THICKNESS ADJUSTMENT FACTOR,  $h_t$ , FOR TRAFFIC INTENSITY

Traffic classification	A	B	C	D	E	F	G
$h_t$ (cm)	-5	-5	-2	-2	+0	+0	+2

Note : See Table 1 for Traffic Classification.

An illustrative example of design of slab thickness is given in Appendix 3.

## 5. DESIGN OF JOINTS

### 5.1. Spacing and Layout

The recommendations of the IRC : 15-1981, para 8 and Supplementary Notes para N. 2 "Arrangement of Joints", may be followed with regard to joint layout and contraction joint spacings

As regards expansion joints, it is possible to adopt much greater spacings than recommended in the Code. Based on a recent study by the Central Road Research Institute which gives the maximum spacing of expansion joints that can be adopted for concrete pavements in India, from a consideration of daily and annual temperature variations in the pavements in different parts of the country, degree of foundation roughness as well as the season of construction, the maximum recommended spacings of expansion joints are given in Table 10.

TABLE 10. RECOMMENDED SPACING OF JOINTS IN RIGID PAVEMENTS FOR HIGHWAYS

(a) Expansion Joint Spacings (based on CRRI Study) (for 25 mm wide expansion joints)

Period of construction	Degree of foundation roughness	Maximum expansion joint spacing (m)		
		Slab thickness (cm)		
		15	20	25
Winter (Oct-March)	Smooth	50	50	60
	Rough	140	140	140
Summer (April-Sept)	Smooth	90	90	120
	Rough	140	140	140

Notes : 1. See Table 4 for classification of different types of foundation layers according to degree of roughness.

(b) Contraction Joints Spacings (based on IRC : 15-1981)

Slab thickness (cm)	Maximum contraction joint spacing (m)	Weight of reinforcement in welded fabric (for reinforced pavements only) (kg m <sup>2</sup> )
<i>Unreinforced Slabs</i>		
10	4.5	—
15	4.5	—
20	4.5	—
<i>Reinforced Slabs</i>		
10	7.5	2.2
15	13.0	2.7
20	14.0	3.8

5.2. Load Transfer at Transverse Joints

5.2.1. Load transfer to relieve part of the load stresses in edge and corner regions of pavement slab at transverse joints is provided by means of mild steel dowel bars. For general provi-

sions in respect of dowel bars, stipulations laid down in IRC : 15-1981, Supplementary Notes para N. 4.2 "Dowel Bars", may be followed. The method of design of dowel bars as per Bradbury's analysis is recommended.

5.2.2. Design of dowel bars : The dowel bar system may be designed on the basis of Bradbury's analysis which gives the following formulae for load transfer capacity of a single dowel bar in shear, in bending and in bearing on concrete :

$$\bar{P} = 0.785 d^2 f_s' \quad \text{(shear)} \quad \dots (10)$$

$$\bar{P} = \frac{2 d^3 f_c}{r + 8.8z} \quad \text{(bending in the bar)} \quad \dots (11)$$

$$\bar{P} = \frac{f_c r^2 d}{12.5 (r + 1.5z)} \quad \text{(bearing on the concrete)} \quad \dots (12)$$

with  $\bar{P}$  = load transfer capacity of a single dowel bar,

$d$  = diameter of dowel bar,

$r$  = length of embedment of dowel bar,

$z$  = joint width,

$f_s'$  = permissible shear stress in dowel bar,

$f_s$  = permissible flexural stress in dowel bar, and

$f_c$  = permissible bearing stress in concrete.

For balanced design, for equal capacity in bending and bearing, the length of embedment of dowel is first obtained by equating  $\bar{P}$  values from equations (11) and (12) as follows, for the assumed joint width  $z$  and dowel diameter  $d$  :

$$r = 5d \left[ \frac{f_s}{f_c} \frac{r + 1.5z}{r + 8.8z} \right]^{\frac{1}{2}} \quad \dots (13)$$

Knowing  $z$ ,  $d$  and  $r$ , the load transfer capacity of a single dowel is determined from the equations (11) and (12) given above.

To calculate the spacing of dowel bars, the required capacity factor,  $n$ , is first determined from :

$$n = \frac{\text{load transfer capacity required from the dowel system}}{\text{load transfer capacity of a single dowel bar}} \quad \dots (14)$$

The distance on either side of the load position upto which the dowel bars are effective in load transfer is taken as  $1.8 l$ , where  $l$  is the radius of relative stiffness (Equation 6).

Assuming linear variation of the capacity factor for a single dowel bar from 1.0 under the load to 0 at a distance of  $1.8 l$  therefrom, the capacity factors for the dowel system are calculated for different spacings. The spacing which conforms to the required capacity factor,  $n$ , is selected for adoption. An example of the design of dowel bars is given in *Appendix 4*.

5.2.3. Dowel bars are not satisfactory for slabs of small thickness, and shall not be provided for slabs less than 15 cm thick.

TABLE 11. DESIGN DETAILS OF DOWEL BARS FOR RIGID HIGHWAY PAVEMENTS

Design loading	Slab thickness (cm)	Dowel bar details		
		Diameter (mm)	Length (mm)	Spacing (mm)
5100 kg	15	25	500	200
	20	25	500	250
	25	25	500	300

Note : The recommended details are based on the following values of different design parameters;  $f_s = 1400 \text{ kg/cm}^2$ ;  $f_c = 100 \text{ kg/cm}^2$ ;  $E_s = 3.0 \times 10^5 \text{ kg/cm}^2$ ;  $\mu = 0.15$ ;  $K_s = 8.3 \text{ kg/cm}^2$ ; max. joint width = 20 mm; design load transfer = 40 per cent.

5.2.4. Typical dowel bar designs for use in 20 mm wide expansion joints for highway pavements, for 40 per cent load transfer are given in Table 11. In case of dummy contraction joints, aggregate interlock is relied upon to provide load transfer to some extent, and dowel bars are not provided, ordinarily. Dowel bars shall, however, be provided in case of full depth construction joints.

### 5.3. Tie Bars for Longitudinal Joints

5.3.1. In case opening of longitudinal joints is anticipated in service, for example, in case of heavy traffic, sidelong ground,

expansive subgrades, etc., tie bars may be designed in accordance with the recommendations of IRC: 15-1981, Supplementary Note, para N. 5 Tie Bars For the sake of convenience of the designers the design procedure recommended in IRC: 15-1981 is given herein.

5.3.2. **Design of the bars :** The area of steel required per m length of joint may be computed by using the following formula :

$$A_s = \frac{bfW}{S} \quad \dots (15)$$

in which

- $A_s$  = area of steel in  $\text{cm}^2$  required per m length of joint,
- $b$  = distance between the joint in question and the nearest free joint or edge in m,
- $f$  = coefficient of friction between pavement and the subgrade (usually taken as 1.5),
- $W$  = weight of slab in  $\text{kg/m}^2$ , and
- $S$  = allowable working stress of steel in  $\text{kg/cm}^2$ .

The length of any tie bar should be at least twice that required to develop a bond strength equal to the working stress of the steel. Expressed as a formula, this becomes:

$$L = \frac{2SA}{B^*P} \quad \dots (16)$$

in which

- $L$  = length of tie bar (cm)
- $S$  = allowable working stress in steel ( $\text{kg/cm}^2$ )
- $A$  = cross-sectional area of one tie bar ( $\text{cm}^2$ )
- $P$  = perimeter of tie bar (cm), and
- $B^*$  = permissible bond stress in (i) deformed tie bars—24.6  $\text{kg/cm}^2$ , (ii) Plain tie bars—17.5  $\text{kg/cm}^2$

5.3.3. To permit warping at the joint the maximum diameter in case of tie bars may be limited to 20 mm, and to avoid concentration of tensile forces they should not be spaced more than 75 cm apart. The calculated length,  $L$ , may be increased by 5-8 cm to account for any inaccuracy in placement during construction. An example of design of tie bar is given in *Appendix 4*.

5.3.4. Typical tie bar details for use at central longitudinal joint in double-lane rigid pavements with a lane width of 3.50 m are given in Table 12.

TABLE 12. DETAILS OF TIE BARS FOR CENTRAL LONGITUDINAL JOINT OF TWO-LANE RIGID HIGHWAY PAVEMENTS

Slab thickness (cm)	Tie bar details			
	Diameter (mm)	Maximum spacing (cm)	Minimum length (cm)	
			Plain bars	Deformed bars
15	8	38	40	30
	10	60	45	35
20	10	45	45	35
	12	64	55	40
25	10	30	45	35
	12	45	55	40
	14	62	65	46

Note : The recommended details are based on the following values of different design parameters :

$f_s = 1400 \text{ kg/cm}^2$ ,  $B^* = 17.5 \text{ kg/cm}^2$  for plain bars and  $24.6 \text{ kg/cm}^2$  for deformed bars,  $f = 1.5$ ,  $W = 24 \text{ kg/m}^2/\text{cm}$  of slab thickness.

## 6. DESIGN OF REINFORCEMENT

6.1. Reinforcement, when provided in concrete pavements, is intended for holding the fractured faces at the cracks tightly closed together, so as to prevent deterioration of the cracks and to maintain aggregate interlock thereat for load transfer. It does not increase the flexural strength of unbroken slab when used in quantities which are considered economical. Where the slabs are provided adequately with joints to control cracking, such reinforcement has no function.

6.2. Reinforcement in concrete slabs is designed to counteract the tensile stresses caused by shrinkage and contraction due to temperature or moisture changes. The maximum tension in the steel across the crack equals the force required to overcome friction between the pavement and its foundation, from the crack to the nearest joint or free edge. This force is the greatest when the crack occurs at the middle of the slab. Reinforcement is designed for this critical location. However,

for practical reasons, reinforcement is kept uniform throughout the length, for short slabs.

The amount of longitudinal and transverse steel required per  $m$  width or length of slab is computed by the following formula:

$$A = \frac{LfW}{2S} \quad \dots (17)$$

in which

$A$  = area of steel in  $\text{cm}^2$  required per  $m$  width or length of slab,

$L$  = distance in  $m$  between free transverse joints (for longitudinal steel) or free longitudinal joints (for transverse steel).

$f$  = coefficient of friction between pavement and subgrade (usually taken as 1.5),

$W$  = weight of slab in  $\text{kg/m}^2$ , and

$S$  = allowable working stress in steel in  $\text{kg/cm}^2$  (usually taken as 50 to 60 per cent of the minimum yield stress of steel).

6.3. Since reinforcement in the concrete slabs is not intended to contribute towards its flexural strength, its position within the slab is not important except that it should be adequately protected from corrosion. Since cracks starting with higher tensile stress at the top surface are more critical when they tend to open, the general preference is for the placing of reinforcement about 50 mm below the surface. Reinforcement is often continued across dummy groove joints to serve the same purpose as tie bars, but at all full depth joints it is kept at least 50 mm away from the face of the joint or edge.

**EXTRACTS FROM IRC : 15-1981 "STANDARD SPECIFICATIONS  
AND CODE OF PRACTICE FOR CONSTRUCTION OF  
CONCRETE ROADS,, (Second Revision)**

**6. PREPARATION OF SUBGRADE AND SUB-BASE**

**6.1. General**

The subgrade or sub-base for laying of paving concrete slabs shall comply with the following requirements :

- (1) that no soft spots are present in the subgrade or sub-base ;
- (2) that the uniformly compacted subgrade or sub-base extends at least 300 mm on either side of the width to be concreted ;
- (3) that the subgrade is properly drained ;
- (4) that the minimum modulus of subgrade reaction obtained with a plate bearing test shall be 5.5 kg/cm<sup>2</sup>

The manner of achieving these requirements shall be determined depending upon the type of subgrade or sub-base on which concrete is to be laid, and the following requirements in respect of the various types shall be satisfactorily met. The construction procedures for subgrade and sub-bases should follow relevant IRC specifications, and quality control should be exercised as laid down in IRC : SP-11.

**6.2. Subgrade**

6.2.1. Where the type of soil in the formation of the road is of a quality to ensure the requirements in the aforementioned para, no intermediate sub-base need be used. The top 150 mm layer of the formation shall be compacted at or slightly above the optimum moisture content to the exact profile shown in the drawing. It shall be checked for trueness by means of a scratch template (see IRC : 43-1972 for details) resting on the side forms and set to the exact profile of the base course. The template shall be drawn along the forms at right angles to the centre line of the road. Unevenness of the surface as indicated by the scratch points shall not exceed 12 mm in 3 m. The surface irregularities in excess of this shall be properly rectified and the surface rolled or tamped until it is smooth and firm. The subgrade shall be prepared and checked at least two days in advance of concreting.

6.2.2. Where no sub-base is considered necessary and concrete is laid directly on the prepared subgrade, the subgrade, shall be in moist condition at the time the concrete is placed. If necessary, it should be saturated with water not less than 6 hours nor more than 20 hours in advance of placing concrete. If it becomes dry prior to the actual placing of the concrete, it shall be sprinkled with water taking care to see that no pools of water or soft patches are formed on the surface. It is desirable to lay a layer of water-proof paper whenever concrete is laid directly over soil subgrade. Where such a layer of waterproof paper is proposed to be placed between concrete and the subgrade, the moistening of the subgrade prior to placing of the concrete shall be omitted.



**6.3. Sub-base**

6.3.1. Where the subgrade is of a type not satisfying the requirements of para 6.1., a Sub-base layer should be provided before laying the concrete. The sub-base may be of granular material, stabilised soil or semi-rigid material as listed below :

**(a) Granular material**

- (i) one layer flat brick soling having joints filled with sand under one layer of water bound macadam conforming to IRC : 19-1977.
- (ii) Two layers of water bound macadam.
- (iii) Well-graded granular materials like natural gravel, crushed slag, crushed concrete, brick metal, laterite, kankar, etc. conforming to IRC : 63-1975.
- (iv) Well-graded soil aggregate mixtures conforming to IRC : 63-1976.

**(b) Stabilised soil**

Local soil or moorum stabilised with lime or lime-fly ash or cement, as appropriate to give a minimum soaked CBR of 50 after 7 days curing. For guidance as regards design of mixes with lime or cement, reference may be made to IRC : 51 and 50 respectively

**(c) Semi-rigid material**

- (i) Lime-burnt clay puzzolana concrete. The lime-pazzolana mixture should conform to L.P. 40 or L.P. 20 of IS : 4098-1967. The 28 day compressive strength of the concrete should be in the range of 40-60 km/cm<sup>2</sup>.
- (ii) Lime-fly ash concrete conforming to IRC : 60-1976.
- (iii) Lean cement concrete or lean cement-fly ash concrete conforming to IRC : 74-1979.

6.3.2. Thickness of sub-base should be 15 cm when the material used is of any of the types listed in paras 6.3.1. (a) and (b). This may, however, be reduced to 10 cm for semi-rigid materials in para 6.3.1. (c). The sub-base should be constructed in accordance with the respective specification and the surface finished to the required lines, levels and cross-section.

6.3.3. Where the subgrade consists of heavy clay (L.L. >50) such as black cotton soil, the sub-base should be laid over a 15 cm thick blanket course consisting of non-plastic granular material like local sand, gravel, kankar, etc. or local soil stabilised with lime.

6.3.4. In water-logged areas and where the sub-grade soil is impregnated with deleterious salts such as sodium sulphate etc. in injurious amounts\*\* a capillary cut-off should be provided before constructing the sub-base, vide details given in para 6.4.

6.3.5. The sub-base or blanket course, as the case may be, shall be laid over a properly compacted subgrade to give uniform support.

\*\*Sulphate concentration (as sulphur trioxide) more than 0.2% in subgrade soil and more than 0.3% in ground water.

6.3.6. The sub-base shall be in moist condition at the time the concrete is placed. There shall, however, be no pools of water or soft patches formed on the sub-base surface. In case where a sand layer is placed between the sub-base and pavement concrete, a layer of water-proof paper shall be laid over the sand layer. No moistening of the sub-base shall be done in this case.

**6.4. Capillary Cut-off**

6.4.1. As a result of migration of water by capillarity from the high water table, the soil immediately below the pavement gets more and more wet and this leads to gradual loss in its bearing value besides unequal support. Several measures such as depressing the sub-soil water table by drainage measures, raising of the embankment and provision of a capillary cut-off are available for mitigating this deficiency and should be investigated for arriving at the optimum solution. However, where deleterious salts in excess of the safe limits are present in the subgrade soil, a capillary cut-off should be provided in addition to other measures.

6.4.2. The capillary cut-off may be a layer of coarse or fine sand, graded gravel, bituminised material, or an impermeable membrane. Layer thicknesses recommended for different situations are given in Table 4.

TABLE 4. RECOMMENDED THICKNESS OF SAND/GRADED GRAVEL LAYER FOR CAPILLARY CUT-OFF

Sl. No.	Situation	Thickness of layer cm		
		Coarse sand (mean dia 0.64 mm)	Fine sand (mean dia 0.18 mm)	Graded gravel (40 mm and down without fines)
1.	Water table at the same level as the subgrade surface	15	45	15
2.	Embankment about 0.6—1.0 m high	12	35	11
3.	Embankment about 0.6—1.0 m high but with the top 15 cm subgrade layer being of sandy soil having PI of 5 or less and sand content not less than 50 per cent	10	30	8

6.4.3. Cut-off with bituminised or other materials may be provided in any of the following ways :

**(i) Bituminous impregnation using primer treatment**

50 per cent straight run bitumen (80-100) with 50 per cent high speed diesel oil or its equivalent in two applications of 1 kg sq. m. each, allowing the first application to penetrate before applying the second one. These applications should be given under the roadbed as well as onto the sides.

(ii) **Heavy-duty tar felt**

Enveloping sides and bottom of the roadbed with heavy-duty tar felt.

(iii) **Polyethylene envelope**

Enveloping sides and bottom of the roadbed with polyethylene sheets of at least 400 gauge.

(iv) **Bituminous stabilise soil**

Providing bituminous stabilised soil in a thickness of at least 4 cm.

**Note :** Experience on the successful use of the above capillary cut-offs is, however, limited.

6.4.4. For more details about mitigating the adverse effects of high water table, reference may be made to IRC : 34-1970 "Recommendations for Road Construction in Waterlogged Areas".

**6.5. Frost Affected Areas**

6.5.1. In frost affected areas, the sub-base may consist of any of the specifications given in 6.3.1. (a), (b) or (c) excepting that in the case of the items 6.3.1. (b) and 6.3.1. (c), the compressive strength of the stabilised or semi-rigid material cured in wet condition shall be at least 35kg/cm<sup>2</sup> at 7 days. For moderate conditions, such as those prevailing in areas at an altitude of 3,000 m and below, the thickness of frost affected depth will be about 45 cm. For protection against frost, the balance between the frost depth (45) cm and total pavement thickness should be made up with non-frost susceptible material.

6.5.2. For extreme conditions, such as those prevailing in areas above an altitude of 3,000 m, the foundation may be designed individually for every location after determining the depth of frost.

6.5.3. The suggested criteria for the selection of non-frost susceptible materials are as follows :

- (i) **Graded gravel :** Not more than 8 per cent passing 75 micron sieve  
Plasticity index not more than 6. Liquid limit not more than 25.
- (ii) **Poorly graded sands,** generally 100 per cent passing 4.75 mm sieve :
  - Max. 10 per cent passing 75 micron sieve
  - Max. 5 per cent passing 50 micron sieve
- (iii) **Fine uniform sand,** generally 100 per cent passing 425 micron sieve :
  - Max. 18 per cent passing 75 micron sieve
  - Max. 8 per cent passing 50 micron sieve

Appendix 2

LOGARITHMS

		Mean difference									
		1	2	3	4	5	6	7	8	9	
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	

(Contd.)

LOGARITHMS

Appendix 2 (Contd.)

	Mean difference									
	0	1	2	3	4	5	6	7	8	9
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5404	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152

(Contd.)

LOGARITHMS

Appendix 2 (Contd.)

	Mean difference									
	0	1	2	3	4	5	6	7	8	9
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7539	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8084	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8704	8716	8727	8733	8739	8745	8751	8757	8763
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859

(Contd.)

LOGARITHMS

Appendix 2 (Contd.)

	Mean difference									
	1	2	3	4	5	6	7	8	9	
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

ANTILOGARITHMS

	Mean difference									
	1	2	3	4	5	6	7	8	9	
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581

(Contd.)

Antilogarithms (Contd.)

	Mean difference									
	0	1	2	3	4	5	6	7	8	9
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624

(Contd.)

Antilogarithms (Contd.)

	Mean difference									
	0	1	2	3	4	5	6	7	8	9
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083
.49	3090	3097	3105	3112	3119	3126	3133	3142	3148	3155
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159

(Contd.)

Antilogarithms (Contd.)

	Mean difference									
	0	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295
.80	6310	6324	6339	6350	6368	6383	6397	6412	6427	6442
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592

(Contd.)

Antilogarithms (Contd.)

	Mean difference									
	0	1	2	3	4	5	6	7	8	9
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977

## Appendix 3

## AN ILLUSTRATIVE EXAMPLE OF DESIGN OF SLAB THICKNESS

## 1. Design Parameters

Location of pavement Delhi  
 Design wheel load  $p=5100$  kg  
 Present traffic intensity = 300 veh/day  
 Design tyre pressure  $p=7.2$  kg/cm<sup>2</sup>  
 Foundation Strength  $k=6$  kg/cm<sup>3</sup>  
 Concrete flexural strength  $f_R=40$  kg/cm<sup>2</sup>  
 Other concrete parameters  
 $E=3.0 \times 10^5$  kg/cm<sup>2</sup>  
 $u=0.15$   
 $=10 \times 10^{-6}$  °C

## 2. Design Procedure

Step 1. As in para 1 above.

Step 2. Joint spacing and lane-widths

Contraction Joint spacing  $L=4.5$  m  
 Lane width,  $W=3.5$  m

Step 3. Tentative design value of slab thickness,  
 $h=22$  cm

Step 4. Temperature stress for edge region.

(i) From Table 2 for 22 cm thick pavement slabs in Delhi max. value of temperature differential.  
 $t$  = about 13.5°C

(ii) for  $h=22$  cm ;  $E=3.0 \times 10^5$  kg/cm<sup>2</sup>  
 From Table 6,  $l=81.89$  cm  
 $\therefore L/l=5.5, W/l=4.3$   
 From Table 8,  $C_L=0.82, C_W=0.52$

(iii) From Fig. 3, for  $C=0.82$  and  $t=13.5$  °C  
 $\sigma t e=16.0$  kg/cm<sup>2</sup>

Step 5. Residual concrete strength for supporting loads

$$f_L = f_R - \sigma t e = 40.0 - 16.0 = 24.0 \text{ kg/cm}^2$$

Step 6. Load Stress for edge region

From Fig. 1, for  $h=22$  cm,  $k=6$  kg/cm<sup>3</sup>  
 $\sigma l_e=23.4$  kg/cm<sup>2</sup>

Step 7. Available factor of safety on load stress

$$f_L / \sigma l_e = \frac{24.0}{23.4} = 1.03 > 1 \therefore \text{O.K.}$$

Step 8. Corner load Stress

From Fig. 2,  $\sigma l_c = 26.8$  kg/cm<sup>2</sup>  $< f_R \therefore$  O.K.

Step 9. Adjustment for traffic intensity

Design traffic intensity

$$T = 300 (1 + 0.975)^{20}$$

$$= 300 \times 4.25$$

$$= 1275, \text{ which falls under traffic classification } E \text{ (Table 1)}$$

From Table 9

Required thickness adjustment = 0

Design thickness of pavement slab = 22 cm

## Appendix 4

### AN ILLUSTRATIVE EXAMPLE OF DESIGN OF DOWEL BARS AND TIE BARS

#### 1. DOWEL BARS

##### 1.1. Design Parametres

Design wheel load=5100 kg

Design load transfer=40%

Slab thickness,  $h=22$  cm

Joint width,  $z=20$  cm

Permissible flexural stress in dowel bar= $1400$  kg/cm<sup>2</sup>

Permissible shear stress in dowel bar= $1000$  kg/cm<sup>2</sup>

Permissible bearing stress on concrete= $100$  kg/cm<sup>2</sup>

$K$  - value on sub-base= $8$  kg/cm<sup>2</sup>/cm

Other concrete parameters :

$L=3 \times 10^5$  kg/cm<sup>2</sup>

$u=0.15$

##### 1.2. Design Procedure

Steps 1 : Dowel length

Assume Dowel diameter,  $d=2.5$  cm

Then, for equal capacity in bending and bearing, from Eqn (13)

$$r = 5 \times 25 \times \left[ \frac{(1400}{100} \times \frac{r+3}{r+17.6}) \right]^{\frac{1}{2}}$$

which gives on solution,  $r=40.5$  cm

So that dowel length,  $L=r+z=40.5+2=42.5$  cm  
say 45 cm

Step 2 : Load transfer capacity of single dowel

From equations (10), (11) and (12), load transfer capacity of a single dowel is obtained

$$\begin{aligned} \bar{P} \text{ (in shear)} &= 0.705 d^2 f_s \\ &= 0.785 \times 2.5 \times 2.5 \times 1000 \\ &= 4900 \text{ kg} \end{aligned}$$

$$\begin{aligned} \bar{P} \text{ (in bending)} &= \frac{2d^3 f_b}{r+8.8z} \\ &= \frac{2 \times 2.5 \times 2.5 \times 2.5 \times 1400}{40.5+17.6} = 753 \text{ kg} \end{aligned}$$

$$\begin{aligned} \bar{P} \text{ (in bearing)} &= \frac{f_c r^2 d}{12.5(r+1.5z)} \\ &= \frac{100 \times 40.5 \times 40.5 \times 2.5}{12.5(40.5+3)} \\ &= 754 \text{ kg} \end{aligned}$$

Taking the least of these values for design purposes,  
 $\bar{P} 753$  kg

Step 3 : Capacity factor required of dowel system Load transfer capacity of the dowel system  
 $= 5100 \times 40\% = 2040$  kg

$$\therefore \text{required capacity factor} = \frac{2040}{753} = 2.70$$

Step 4 : Spacing of dowel bars

Fork= $8$  kg/cm<sup>2</sup>/cm,  $l=76.20$  (from Table 6)

Considering the joint corner, the distance over which dowel bars are effective in load transfer= $1.8 \times l = 1.8 \times 76.2 = 137.0$  cm about.

Assuming a dowel spacing of 25 cm

Available capacity factor

$$\begin{aligned} &= 1 + \frac{137-25}{137} + \frac{137-50}{137} + \frac{137-75}{137} \\ &= 4 - \frac{150}{137} = 4 - 1.09 \\ &= 2.91 \end{aligned}$$

which is slightly greater than the required capacity factor of 2.70. Hence adopt 25 cm as dowel spacing.

#### 2. TIE BARS

##### 2.1. Design Parameters

Slab thickness,  $h=22$  cm

Slab width,  $b=3.35$  m

No. of lanes to be tied= $2$

Coefficient of friction between payment and subgrade= $f=1.5$

Weight per m<sup>2</sup> of concrete slab,  $w=528$  kg

Allowable working tensile stress in steel  $S=1400$  kg/cm<sup>2</sup>

Maximum Permissible bond stress,  $B$  in :

(i) Plain tie bars= $17.5$  kg/cm<sup>2</sup>

(ii) Deformed bars= $24$  kg/cm<sup>2</sup>

##### 2.2. Design Procedure

Step 1 : Diameter and spacing of tie bars

Weight per m<sup>2</sup> of concrete slab,  $W=528$  kg



∴ Area of steel required per m width of joint

$$A_s = \frac{bfW}{S} = \frac{3.35 \times 1.5 \times 528}{1400} = 1.89 \text{ cm}^2/\text{m}$$

Assuming dia of tie bars;  $d=10$  mm

$A$  = cross section of one tie bar = 78.54 mm<sup>2</sup>

$P$  = Perimeter of tie bar = 31.42 mm

∴ No. of tie bars required per m,  $N = \frac{A_s}{A} = \frac{1.89}{0.7854}$ , and

$$\text{Spacing of tie bars} = \frac{100}{N} = \frac{100 \times 0.7854}{1.89} = 41.5 \text{ cm Say } 42 \text{ cm}$$

Step 2 : Length of the tie bars :

$$\text{Length of tie bar} = \frac{2sA}{B P} = \frac{2 \times 1400 \times 78.54 \times 10}{B \times 100 \times 31.42}$$

$L = 40$  cm for plain tie bars.

and 29.2 cm for deformed tie bars

Increasing about 5 cm for tolerance in placement

$L = 45$  cm for plain tie bars

and  $L = 35$  cm for deformed tie bars

## LIST OF OTHER CEMENT CONCRETE ROAD STANDARDS

		Rs. P.
1.	IRC: 15-1981	Standard Specifications & Code of Practice for Construction of Concrete Roads (Second Revision) 16-00
2.	IRC: 43-1972	Recommended Practice for Tools, Equipment and Appliances for Concrete Pavement Construction 12-00
3.	IRC: 44-1972	Tentative Guidelines for Cement Concrete Mix Design (for Road Pavements for non-air entrained and continuously graded concrete (First Revision) 8-00
4.	IRC: 57-1974	Recommended Practice for Sealing of Joints in Concrete Pavements 3-00
5.	IRC: 59-1976	Tentative Guidelines for the Design of Gap Graded Cement Concrete Mixes for Road Pavements 5-00
6.	IRC: 60-1976	Tentative Guidelines for the Use of Lime-flyash Concrete as Pavement Base or Sub-Base 5-00
7.	IRC: 61-1976	Tentative Guidelines for the Construction of Cement Concrete Pavements in Hot-Weather 5-00
8.	IRC: 68-1976	Tentative Guidelines on Cement-Flyash Concrete for Rigid Pavement Construction 6-00
9.	IRC: 74-1979	Tentative Guidelines for Lean-Cement Concrete and Lean Cement Flyash Concrete as a Pavement Base or Sub-Base 8-00
10.	IRC: 76-1979	Tentative Guidelines for Structural Strength Evaluation of Rigid Airfield Pavements 10-00
11.	IRC: 77-1979	Tentative Guidelines for Repair of Concrete Pavements using Synthetic Resin 15-00
12.	IRC: 84-1983	Code of Practice for Curing of Cement Concrete Pavements 8-00
13.	IRC: 85-1983	Recommended Practice for Accelerated Strength Testing and Evaluation of Concrete for Road and Airfield Constructions 8-00
14.	IRC: 91-1985	Tentative Guidelines for Construction of Cement Concrete Pavements in Cold Weather 8-00
15.	IRC: 101-1988	Guidelines for Design of Continuously Reinforced Concrete Pavement with Elastic Joints 12-00
16.	IRC: SP: 11-1977	Handbook of Quality Control for Construction of Roads and Runways (Second Revision) 32-00

17.	IRC: SP: 16-1977	Surface Evenness of Highway Pavement	7-00
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20.	MOST	Ministry of Surface Transport (Roads Wing), Specifications for Road and Bridge Works (Second Revision)	80-00
21.	MOST	Ministry of Shipping & Transport (Roads Wing) Manual for Maintenance of Roads	24-00

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45.	The Director General	(Road Development) & Addl. Secretary to the Govt. of India (K. K. Sarin) —Ex-officio
46.	The Secretary	Indian Roads Congress (Ninan Koshi) —Ex-officio