GUIDELINES FOR THE DESIGN OF PLAIN JOINTED RIGID PAVEMENTS FOR HIGHWAYS

(Second Revision)

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GUIDELINES FOR THE DESIGN OF PLAIN JOINTED RIGID PAVEMENTS FOR HIGHWAYS

1. INTRODUCTION

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

In view of the subsequent upward revision of the legal limit on the maximum laden axle loads of commercial vehicles from 8160 kg to 10200 kg, appropriate modifications were incorporated in the first revision of the guidelines. The draft "Guidelines for the Design of Plain Jointed Rigid Pavements for Highways" was finalized by the erstwhile Rigid Pavement Committee (H-5) in its meeting held on the 13th January, 1997. The Highways Specifications & Standards (HSS) Committee in its meeting held on the 4th November, 1997 considered the draft and approved subject to certain modifications for placing before the Executive Committee and the Council. The Executive Committee in its meeting held on 24th August, 1998 and later by the Council in its 154th meeting held at Hyderabad on the 31st January, 1999 approved the draft and directed the Convenor of H-5 Committee to modify the same in light of the comments.

Keeping in view the advances made in the methods of analysis and design all over the world, a draft for further revision was initially prepared by the Rigid Pavement Committee under the Convenorship of Prof. C.E.G. Justo and was reviewed by Dr. B.B. Pandey. The draft was discussed in detail by the Rigid Pavement Committee in its meeting held on the 25th October, 1999 and a sub-committee consisting of Dr. R.M. Vasan, Dr. S.S. Seehra and Dr. S.C. Maiti was formed to examine the draft. In the meantime, the Technical Committees were reconstituted and it was felt that revised guidelines may be reconsidered by the Committee. The H-5 Committee in its meetings held on the 4th January, 2000 and 12th November, 2001 considered the draft guidelines alongwith various observations of sub-committee and a number of appendices and references were added for clarification of different clauses to the revised draft. The revised draft was finally cleared by H-5 Committee during its meeting held on the 10th May, 2002 for being placed before the HSS Committee. The personnel of H-5 Committee is given below:

Dr. L.R. Kadiyali	..	Convenor
S.S. Momin	..	Co-Convenor
M.C. Venkatesha	..	Member-Secretary

Members

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Corresponding Members

Kanti Bhushan Bhaumik	H.K. Kulshrestha
D.C. De	S.M. Sabnis
A.U. Ravi Shankar	

The HSS Committee in its meeting held on the 22nd May, 2002 approved the modified document as received from the Convenor, H-5 Committee. Subsequently, the Executive Committee approved the modified draft in its meeting held on 24th May, 2002 and later by the Council in its 166th meeting held at Panaji (Goa) on the 8th June, 2002 with certain comments and authorized the Convenor, HSS Committee to finalise the document. The document as modified in light of the comments of members was approved by the Convenor, HSS Committee on the 12th December, 2002 for printing.

2. SCOPE

The guidelines cover the design of plain jointed cement concrete pavements. The guidelines are applicable for roads having a daily commercial traffic (vehicles with laden weight exceeding 3 T) of over 150. They are not applicable to low volume Rural Roads.

3. GENERAL

The early approach to the design of rigid pavements was based on Westergaard's analysis. Recent advances in knowledge have led to vast changes in the design methodology. It is believed the guidelines contained in this document reflect the current knowledge on the subject.

The salient features of the revised guidelines are: -

(i) Computation of flexural stress due to the placement of single and tandem axle loads along the edge.

(ii) Introduction of the cumulative fatigue damage approach in the design.

(iii) Revision of criteria for design of dowel bars.

4. FACTORS GOVERNING DESIGN

4.1. The factors governing design considered are : single and tandem axle loads, their repetition, tyre pressure and lateral placement characteristics of commercial vehicles.

4.2. Wheel Load

Though the legal axle load limits in India have been fixed as 10.2, 19 and 24 tonnes for single axles, tandem axles and tridem axles respectively, a large number of axles operating on National Highways carry much higher loads than the legal limits. Data on axle load distribution of the commercial vehicles is required to compute the number of repetitions of single and tandem axles of different weights expected during the design period. For this purpose, an axle load survey may be conducted for a day, covering a minimum sample size of 10 per cent in both the directions. Higher axle loads induce very high stresses in the pavement and result in the consumption of fatigue resistance of concrete. Contribution of different axle load groups towards fatigue damage must be determined for pavement design. Tyre pressures and shape of the contact areas of the commercial vehicles also govern load stresses. For most of the commercial highway vehicles, the tyre pressure ranges from about 0.7 to 1.0 MPa but it is found that stresses in concrete pavements having thickness of 20 cm or more are not affected significantly by the variation of tyre pressure in the range

mentioned earlier. A tyre pressure of 0.8 MPa may be adopted for design.

For computation of stresses in the pavements, the magnitude of axle loads should be multiplied by Load Safety Factor (LSF). This takes care of unpredicted heavy truck loads. For important roads, such as, Expressways, National Highways and other Roads where there will be uninterrupted traffic flow and high volumes of truck traffic, the suggested value of LSF is 1.2. For roads of lesser importance having lower proportion of truck traffic, LSF may be taken as 1.1. For residential and other streets that carry small number of commercial traffic, the LSF may be taken as 1.0.

It is recommended that the basic design of the slab be done with a 98th percentile axle load, and the design thereafter checked for fatigue consumption for higher axle loads.

4.3. Design Period

Normally, cement concrete pavements have a life span of 30 years and should be designed for this period. When the traffic intensity cannot be predicted accurately for a long period of time, and for low volume roads, a design period of twenty years may be considered. However, the Design Engineer should use his judgement about the design life taking into consideration the factors, like, traffic volume, the traffic growth rate, the capacity of the road and the possibility of augmentation of capacity.

4.4. Design Traffic

Assessment of average traffic should normally be based on seven-day 24-hour count made in accordance with IRC: 9 "Traffic Census on Non-Urban Roads". The actual value of growth rate 'r' of heavy commercial vehicles should be determined. However, if actual data is not available, an average annual growth rate of 7.5 per cent may be adopted.

It may be noted that flexural stress caused by axle loads is maximum when the tyre imprint is tangential to the longitudinal edge. When the wheels are tangential to the transverse joints, stresses are lower and when the tyre position is even 15 cm away from the longitudinal edge, there is a significant reduction in the flexural stress. Observation of the lateral distribution characteristics of wheel paths for two-lane two-way roads in India indicates that very few vehicles travel along the edge. A design traffic of 25 per cent of the total two-lane two-way commercial vehicles may be considered as a very conservative estimate for design against fatigue failure. In case of four-lane and multi-lane divided highways, 25 per cent of the total traffic in the direction of predominant traffic may be taken for design of pavement. In case of new highway links, where no traffic count data is available, data from roads of similar classification and importance may be used to predict the design traffic intensity.

The cumulative number of repetitions of axles during the design period may be computed from the following formula :

$$C = \frac{365 \times A\{(1+r)^n - 1\}}{r} \quad (1)$$

Where

C = Cumulative number of axles during the design period.

A = Initial number of axles per day in the year when the road is operational.

r = Annual rate of growth of commercial traffic (expressed in decimals).

n = Design period in years.

Expected number of applications of different axle load groups during the design period can be estimated from the axle load spectrum.

In most design problems, it is expected that the weights and number of trucks travelling in each direction are fairly equal. This may not be true for roads, such as, haul roads in mine areas where many of the trucks haul full loads in one direction and return empty in the other direction. In such cases, a suitable adjustment should be made. It is recommended that the basic design of the slab be done with a 98^{th} percentile axle load, and the design thereafter checked for fatigue consumption for higher axle loads.

4.5. Temperature Differential

Temperature differential between the top and bottom of concrete pavements causes the concrete slab to warp, giving rise to stresses. The temperature differential 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 1.

4.6. Characteristics of Subgrade and Sub-Base

4.6.1. **Strength** : The strength of subgrade 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 cement concrete pavements is taken as 1.25 mm, the k-value is determined from the pressure sustained at this deflection. As

Table 1. Recommended Temperature Differentials for Concrete Slabs

Zone	States	Temperature Differential, °C in Slabs of Thickness			
		15cm	20cm	25cm	30cm
I	Punjab, U.P., Uttaranchal, Gujarat, Rajasthan, Haryana and North M.P., excluding hilly regions.	12.5	13.1	14.3	15.8
II	Bihar, Jharkhand, West Bengal, Assam and Eastern Orissa, excluding hilly regions and coastal areas	15.6	16.4	16.6	16.8
III	Maharashtra, Karnataka, South M.P., Chattisgarh, Andhra Pradesh, Western Orissa and North Tamil Nadu, excluding hilly regions and coastal areas.	17.3	19.0	20.3	21.0
IV	Kerala and South Tamil Nadu, excluding hilly regions and coastal areas.	15.0	16.4	17.6	18.1
V	Coastal areas bounded by hills.	14.6	15.8	16.2	17.0
VI	Coastal areas unbounded by hills.	15.5	17.0	19.0	19.2

k-value is influenced by test plate diameter, the standard test is to be carried out with a 75-cm diameter plate. IS:9214-1974, "Method of Determination of Modulus of Subgrade Reaction of Soil in the Field" may be referred for guidance in this regard. A frequency of one test per km per lane is recommended for

assessment of k-value, unless the foundation changes with respect of 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 given by :

$$k_{75} = 0.5 \times k_{30} \quad (2)$$

where, k_{75} and k_{30} are the k-values obtained on 75 cm and 30 cm diameter plates respectively. Equation 2 is regarded as approximate only. However, in case of layered construction, the tests with smaller plates give greater weightage to the stronger top layer, and direct conversion to 75 cm plate values by the above correlation somewhat over-estimates 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 subgrade strength would, thus, be during or soon after the monsoon when the subgrade would have attained its highest moisture content. Annexure-4 of IRC:37-2001 may be referred for further details.

In case the tests have to be conducted at some other period, especially during the dry part of the year, allowance for loss in subgrade 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 field moisture content and tested before and after the saturation. An approximate idea of k-value of a homogeneous soil subgrade may be obtained from its soaked CBR value using Table 2. It is advisable to have a filter layer above the subgrade for drainage of water to prevent (i) excessive softening of subgrade and (ii) erosion of the subgrade particularly under adverse moisture condition. Annexure-4 of IRC:37-2001 may be referred for further details.

TABLE 2. APPROXIMATE K-VALUE CORRESPONDING TO CBR VALUES FOR HOMOGENEOUS SOIL SUBGRADE

Soaked CBR value %	2	3	4	5	7	10	15	20	50	100
k-value (kg/cm²/cm)	2.1	2.8	3.5	4.2	4.8	5.5	6.2	6.9	14.0	22.2

The recommendations of IRC:15-2002 shall be followed and if the k-value tested on wet condition of the subgrade is less than 6.0 kg/cm²/cm, cement concrete pavement should not be laid directly over the subgrade. A Dry Lean Concrete (DLC) sub-base is generally recommended for modern concrete pavements, particularly those with high intensity of traffic. The sub-base of DLC should conform to "Guidelines for the Use of Dry Lean Concrete as Sub-base for Rigid Pavement, IRC:SP:49-1998". In the case of problematic subgrade, such as, clayey and expansive soils, etc. appropriate provisions shall be made for blanket course in addition to the sub-base as per the relevant stipulations of IRC:15-2002.

The approximate increase in k-values of subgrade due to different thicknesses of sub-bases made up of untreated granular, cement treated granular and dry lean concrete (DLC) layers may be taken from Tables 3 and 4. 7-day unconfined

compressive strength of cement treated granular soil should be a minimum of 2.1 MPa. Dry Lean Concrete should have a minimum compressive strength of 7 MPa at 7 days.

TABLE 3. K-VALUES OVER GRANULAR AND CEMENT TREATED SUB-BASES

k-value of subgrade, (kg/cm²/cm)	Effective k (kg/cm²/cm) over untreated granular layer sub-base of thickness in cm			Effective k (kg/cm²/cm) over cement treated sub-base of thickness in cm		
	15	**22.5**	**30**	**10**	**15**	**20**
2.8	3.9	4.4	5.3	7.6	10.8	14.1
5.6	6.3	7.5	8.8	12.7	17.3	22.5
8.4	9.2	10.2	11.9	--	--	--

TABLE 4. K-VALUES OVER DRY LEAN CONCRETE SUB-BASE

k-value of Subgrade kg/cm²/cm	2.1	2.8	4.2	4.8	5.5	6.2
Effective k over 100 mm DLC, kg/cm²/cm	5.6	9.7	16.6	20.8	27.8	38.9
Effective k over 150 mm DLC, kg/cm²/cm	9.7	13.8	20.8	27.7	41.7	--

The maximum value of effective k shall be 38.9 kg/cm²/cm for 100 mm of DLC and 41.7 kg/cm²/cm for 150 mm of DLC.

4.6.2. **Separation layer between sub-base and pavement** : Foundation layer below concrete slabs should be smooth to reduce the inter layer friction. A separation membrane of minimum thickness of 125 micron polythene is recommended to reduce the friction (Ref. IRC:15-2002) between concrete slabs and dry lean concrete sub-base (DLC).

4.6.3. **Drainage layer** : To facilitate the quick disposal of water that is likely to enter the subgrade, a drainage layer may be provided beneath the pavement throughout road width above the subgrade. The recommendations contained in IRC:15-2002 in this regard may be followed.

4.7. Characteristics of Concrete

4.7.1. **Design strength** : Since the concrete pavements fail due to bending stresses, it is necessary that their design is based on the flexural strength of concrete. The relationship between the flexural strength and compressive strength may be worked out as given in ***Appendix-5***. The mix should be so designed that the minimum structural strength requirement in the field is met at the desired confidence level. Thus, if

S^1 = characteristic flexural strength at 28 days.

S = target average flexural strength at 28 days.

Z_a = tolerance factor for the desired confidence level, known as the standard normal variate (Table 5).

σ = expected standard deviation of field test samples; if it is not known, it may be initially assumed as per IS:456-2000.

Then the target average flexural strength is given as

$$S = S^1 + Z_a \sigma$$

TABLE 5. VALUES OF STANDARD NORMAL VARIATE FOR DIFFERENT VALUES OF TOLERANCE (IS:10262)

Accepted proportion of low results (tolerance)	Quality Level	Standard Normal Variate, Z_a
1 in 15	Fair	1.50
1 in 20	Good	1.65
1 in 40	Very Good	1.96
1 in 100	Excellent	2.33

For pavement construction, the concrete mix should preferably be designed and controlled on the basis of flexural

strength. Flexural strength should be determined by modulus of rupture tests under third point loading. The preferred size of the beam should be 15 cm x 15 cm x 70 cm when the size of the aggregate is more than 19 mm. When the maximum size of aggregates is less than 19 mm, 10 cm x 10 cm x 50 cm beams may be used. IS:516 should be referred to for the test procedure.

4.7.2. **Modulus of elasticity and poisson's ratio** : The modulus of elasticity, E, and Poisson's ratio, μ, of cement 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 in the construction, this information may not always be available at the design stage. Even a 25 per cent variation in E and μ values does not have any significant effect on the flexural stresses in the pavement concrete. It is suggested that for design purposes, the following values may be adopted for concrete for the flexural strength of 4.5 MPa (see ***Appendix-5***).

Modulus of elasticity of concrete, E = Experimentally determined value. Or 3.0×10^5 kg/cm²

Poisson's ratio $\mu = 0.15$

4.7.3. **Coefficient of thermal expansion** : The coefficient of thermal expansion of concrete (α) of the same mix proportions varies with the type of aggregate. However, for design purposes, a value of $\alpha = 10 \times 10^{-6}$ per °C may be adopted in all cases.

4.7.4. **Fatigue behaviour of cement concrete** : Due to repeated application of flexural stresses by the traffic loads, a progressive fatigue damage takes place in the cement concrete slab in the form of gradual development of micro-cracks especially when the applied stress in terms of flexural strength of concrete is high. The ratio between the flexural stress due to the load and the flexural strength of concrete is termed as the stress ratio (SR). If the SR is less than 0.45, the concrete is expected to sustain infinite number of repetitions. As the stress ratio increases, the number of load repetitions required to cause cracking decreases. The relation between fatigue life (N) and stress ratio is given as :

$$N = \text{unlimited for } SR < 0.45$$

$$N = \left[\frac{4.2577}{SR - 0.4325}\right]^{3.268} \quad \text{When } 0.45 \leq SR \leq 0.55$$

$$\text{Log}_{10} N = \frac{0.9718 - SR}{0.0828} \quad \text{for } SR > 0.55$$

The values of fatigue life for different values of stress ratio are given in Table 6. Use of the fatigue criteria is made on the basis of Miner's hypothesis. Fatigue resistance not consumed by repetitions of one load is available for repetitions of other loads.

5. DESIGN OF SLAB THICKNESS

5.1. Critical Stress Condition

In-service cement concrete pavements are subjected to stresses due to a variety of factors, acting simultaneously. The severest combination of different factors that induce the maximum stress in the pavement will give the critical stress condition. The factors commonly considered for design of pavement thickness are: flexural stresses due to traffic loads and temperature differentials between the top and bottom fibres of the concrete slab, as the two are assumed to be additive

Table 6. Stress Ratio and Allowable Repetitions in Cement Concrete

Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions
0.45	6.279×10^7	0.66	5.83×10^3
0.46	1.4335×10^7	0.67	4.41×10^3
0.47	5.2×10^6	0.68	3.34×10^3
0.48	2.4×10^6	0.69	2531
0.49	1.287×10^6	0.70	1970
0.50	7.62×10^5	0.71	1451
0.51	4.85×10^5	0.72	1099
0.52	3.26×10^5	0.73	832
0.53	2.29×10^5	0.74	630
0.54	1.66×10^5	0.75	477
0.55	1.24×10^5	0.76	361
0.56	9.41×10^4	0.77	274
0.57	7.12×10^4	0.78	207
0.58	5.4×10^4	0.79	157
0.59	4.08×10^4	0.80	119
0.60	3.09×10^4	0.81	90
0.61	2.34×10^4	0.82	68
0.62	1.77×10^4	0.83	52
0.63	1.34×10^4	0.84	39
0.64	1.02×10^4	0.85	30
0.65	7.7×10^3		

under critical condition. The effects of moisture changes are opposite of those of temperature changes and are, not normally considered critical to thickness design.

The loads applied by single as well as tandem axles cause maximum flexural stresses when the tyre imprint touches the longitudinal edge as shown in Fig. 1. When the tyre imprints touch the transverse joints with or without dowel bar, part of

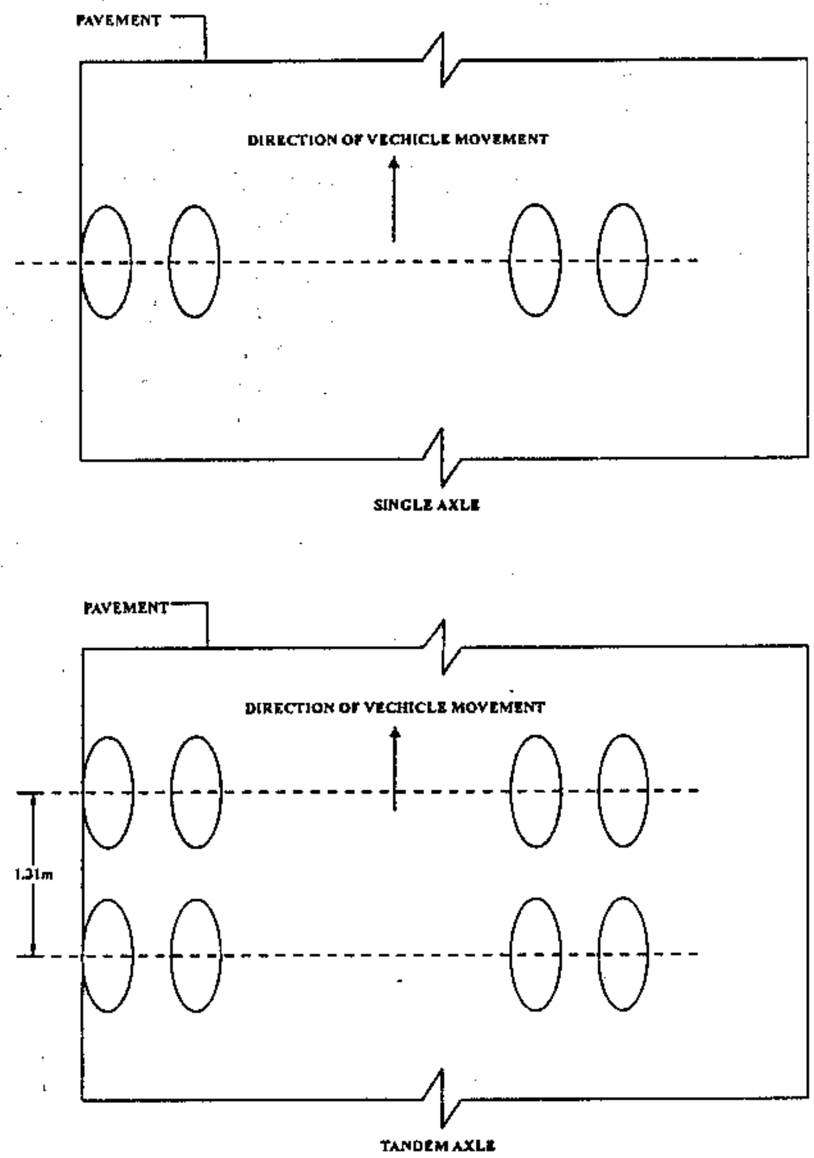


Fig. 1. Lateral Placement of Wheel

the load is transferred to the other side of the slab by aggregate inter-lock or dowel bar causing lower flexural stress both along the corner as well as along the transverse joint. In case the slab is cast panel by panel with a clear vertical break without any dowel bar or aggregate inter-lock, corner load stresses are critical when dual wheel system is at the corner. Tandem axles carrying twice the load of a single axle cause flexural stresses which are about 20 per cent lower than that of the single axle load because of superposition of negative bending moment due to one dual wheel load over the other. The average spacing of tandem axle is taken as 1.31 metres. Tandem and tridem axle loads may cause loss of subgrade because of higher deflection. In such case, additional design criterion of erosion can be included based on experience.

Cement concrete pavements undergo a daily cyclic change of temperature differentials, the top surface being hotter than the bottom during the day, and cooler during the night. The consequent tendency of the pavement slabs is to warp upwards (top convex) during the day and downwards (top concave) during the night. The restraint offered to this warping tendency by self-weight and the dowel bars of the pavement induces stresses in the pavement, referred to commonly as temperature warping stresses. These warping stresses are flexural in nature, being tensile at bottom during the day and at top during the 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 of such restraint for slabs without dowel bars. The restraint is maximum in the slab interior and somewhat less at the edge. Consequently, the temperature stresses induced in the pavement are maximum at the interior. Under the action of load applications, maximum stress is induced in the corner region if the joints are not provided with dowel bars, as the corner is discontinuous in two directions. The corner tends to bend like a cantilever, producing tension at the top during night hours, whereas, tension is produced during the day-time at the bottom of the slab in the interior as well as at the edge.

The maximum combined tensile stress 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 the 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. It is, therefore, necessary that the concrete slab is designed to withstand the stresses due to warping and wheel load at the edge region. It is also necessary to check the stress at the corner region if dowel bars are not provided at the transverse joints and if there is no possibility of load transfer by aggregate inter-lock.

5.2. Calculation of Stress

5.2.1. Edge stress

(a) **Due to load :** Since the loads causing failure of pavements are mostly applied by single and tandem axles, stresses must be determined for the condition shown in Fig. 1. Picket & Ray's chart can be used for stress computation in the interior as well as at the edge. Using the fundamental concept of

Westergaard and Picket & Ray's pioneering work, a computer programme IITRIGID developed at IIT, Kharagpur was used for the computation of stress for the edge load condition shown in Fig. 1. The stress charts for single axles as well as tandem axles are shown in ***Appendix-1*** for different magnitudes of single and tandem axle loads.

In the earlier version of IRC:58-1988, the calculation of load stresses was done as per Westergaard's equations modified by Teller and Sutherland. The use of these equations has its own limitations because they do not take into account the configuration of the wheels. Though, these equations give stresses which are not very much in variance with the stresses computed by the programme IITRIGID, it is commended that the stresses calculated from the programme IITRIGID be used in the design. However, the original Westergaard's equations as modified by Teller and Sutherland are enclosed in ***Appendix-6*** for information.

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

$$S_{te} = \frac{E\alpha tC}{2}$$

Where

S_{te} = temperature stress in the edge region, kg/cm²

E = modulus of elasticity of concrete, kg/cm²

t = maximum temperature differential during day between top and bottom of the slab, °C

α = coefficient of thermal expansion of cement concrete, per °C

C = Bradbury's coefficient, which can be ascertained directly from Bradbury's chart against values of L/l and B/l (Fig. 2)

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

W = slab width, or spacing between longitudinal joints, cm and

l = radius of relative stiffness, cm

$$= \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}$$

μ = Poisson's ratio

h = thickness of the concrete slab, cm

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

The values of Bradbury's coefficient C are presented in the form of chart in Fig. 2.

5.2.2. **Corner stress** : The load stress in the corner region may be obtained as per Westergaard's analysis, modified by Kelly, from the following equation:

$$S_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$$

Where

S_c = load stress in the corner region, other notations remaining the same as in the case of edge load stress formula, kg/cm^2

P = Wheel Load, kg

a = radius of equivalent circular contact area, cm

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

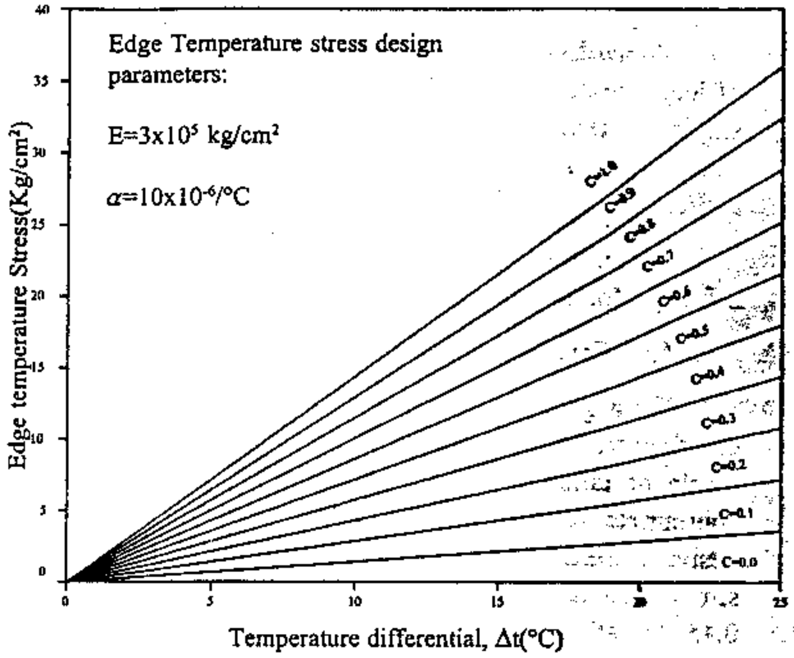


Chart for Determination of Coefficient C:

L/l or B/l	C	L/l or B/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. 2. Design Chart for Calculation of Edge Temperature Stress

5.3. Design Charts

Appendix-1 gives ready-to-use charts for the calculation of load stresses in the edge region of rigid pavement slabs for single and tandem axle loads of different magnitudes for sub-bases having k values in the range of 6, 8, 10, 15 and 30 kg/cm^2/cm.

A user friendly computer programme is also enclosed in a Floppy for computation of stresses at the edges.

5.4. Stress Ratio and Fatigue Analysis

For a given slab thickness and other design parameters, the flexural stress at the edge due to the application of a single or tandem axle loads may be determined using the appropriate stress chart. This stress value is divided by the design flexural strength of the cement concrete, to obtain the stress ratio in the pavement. If the stress ratio is less than 0.45, the allowable number of repetitions of the axle load is infinity. Cumulative fatigue damage is determined for different axle loads and the value of the damage should be equal to or less than one. The procedure of estimating fatigue damage is given in *Appendix-2*.

5.5. Erosion Consideration

AASHTO Road Test has indicated that there is an important mode of distress in addition to fatigue cracking that must be considered in the design. This is the erosion of material from the bottom of the pavement. Analysis by Portland Cement Association has indicated that the erosion was caused largely by tandem and multi-axle vehicles and that single axles were mostly responsible for fatigue cracking. Since tandem axles form a small part of the total commercial vehicles on Highways in India, erosion analysis is not necessary at present. Record of

pavement performance data including loss of erodible materials from the sub-base of the concrete pavements will be necessary for modification of the guidelines in future since erosion is dependent on the quality of sub-base, climate as well as the gross weight of vehicles. It is further recommended that paved shoulder should be provided upto 1.5 metres beyond the pavement to prevent erosion as well as entry of debris between the pavement slab and foundation when the slab curls upwards.

5.6. Hard Shoulder

In order to protect the foundation layers from loss of strength due to erosion, a number of measures are taken. Generally, dry lean concrete (DLC) sub-base is extended by 40 to 50 cm towards the shoulder. Additionally, full depth bituminous shoulder or tied cement concrete shoulder is constructed to protect the pavement edge. Widening rigid pavement to act as a shoulder has also been attempted. With such a shoulder, the load stresses at edges will reduce marginally.

5.7. Composite Rigid Pavement

Where the polythene separation layer between the concrete slabs and dry lean concrete (DLC) sub-base is eliminated a monolithic action of two layers results and this action can be exploited to reduce the pavement thickness. The layer below DLC has to be smooth and may warrant an antifriction layer to allow thermal movements to take place without any hindrance. The appropriate design procedure can be established only on the basis of extensive research.

5.8. Anchor Beam and Terminal Slab

During the hot season, the concrete slabs expand and this will result in the build-up of horizontal thrust on dirt-wall/abutment. To contain this thrust, RCC anchor beams are generally provided in the terminal slab. The terminal slab, therefore, will have to be reinforced to strengthen it. The details of the anchor beam and terminal slab are discussed in IRC:15-2002.

5.9. Recommended Design Procedure

Step 1 : Stipulate design values for the various parameters.

Step 2 : Decide types and spacing between joints.

Step 3 : Select a trial design thickness of pavement slab.

Step 4 : Compute the repetitions of axle loads of different magnitudes during the design period.

Step 5 : Calculate the stresses due to single and tandem axle loads and determine the cumulative fatigue damage (CFD).

Step 6 : If the CFD is more than 1.0, select a higher thickness and repeat the steps 1 to 5.

Step 7 : Compute the temperature stress at the edge and if the sum of the temperature stress and the flexural stress due to the highest wheel load is greater than the modulus of rupture, select a higher thickness and repeat the steps 1 to 6.

Step 8 : Design the pavement thickness on the basis of corner stress if no dowel bars are provided and there is no load transfer due to lack of aggregate inter-lock.

An illustrative example of design of slab thickness is given in *Appendix-2*. Though, the 28-day flexural strength of concrete is taken for design, it is worth noting that concrete

strength increases with age. The temperature gradient is highest only during summer months in the afternoon, when the volume of commercial vehicles is generally low. The total of thermal warping and wheel load stresses is generally lower than the simple algebraic addition. The moisture gradient across the depth of the concrete is generally opposite to that of the temperature gradient and hence the warping caused by temperature gradient is nullified to some extent by the moisture gradient. In view of the above factors, the above design methodology is likely to result in a much higher life of the pavement than considered.

6. DESIGN OF JOINTS

6.1. Spacing and Layout

Great care is needed in the design and construction of joints in Cement Concrete Pavements, as these are critical locations having significant effect on the pavement performance. The joints also need to be effectively sealed, and maintained well. The recommendations of the IRC:15, para 8 and Supplementary Notes para N.2 "Arrangement of Joints", may be followed with regard to joint layout and contraction joint spacings (Table 7).

Cement Concrete Pavements have transverse and longitudinal joints. Different types of transverse joints are:

i) Expansion joints
ii) Contraction joints
iii) Construction joints

Longitudinal joints are required in pavements of width greater than 4.5 m to allow for transverse contraction and warping.

TABLE 7. CONTRACTION JOINT SPACING (BASED ON IRC:15-2002)

Slab thickness, cm	Maximum contraction joint spacing, m
Unreinforced slabs	
15	4.5
20	4.5
25	4.5
30	5.0
35	5.0

Expansion joints may be omitted when dowels are provided at contraction joints except when the cement concrete pavements abut against permanent structures, like, bridges and culverts.

6.2. Load Transfer at Transverse Joints

6.2.1. 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 round dowel bars. Coated dowel bars are often used to provide resistance to corrosion. The coating may be a zinc or lead based paint or epoxy coating. Dowel bars enable good riding quality to be maintained by preventing faulting at the joints. For general provisions in respect of dowel bars, stipulations laid down in IRC:15, Supplementary Notes para : N.4.2 Dowel Bars, may be followed. For heavy traffic, dowel bar should be provided at the contraction joints.

6.2.2. From the experience all over the world, it is found that it is only the bearing stress in the concrete that is responsible for the performance of the joints for the dowel bars. High concrete bearing stress can fracture the concrete surrounding the dowel bar, leading to the looseness of the dowel bar and the deterioration of the load transfer system with eventual faulting of the slab.

Maximum bearing stress between the concrete and dowel bar is obtained from the equation as:

$$\sigma_{max} = \frac{KP_t}{4\beta^3 EI}(2+\beta z)$$

Where

$$\beta = \sqrt[4]{\frac{kb}{4EI}}$$

β = relative stiffness of the bar embedded in concrete

K = modulus of dowel/concrete interaction (dowel support, kg/cm²/cm)

b = diameter of the dowel, cm

z = joint width, cm

E = modulus of the elasticity of the dowel, kg/cm²

I = moment of inertia of the dowel, cm⁴

P_t = load transferred by a dowel bar.

Each dowel bar should transfer load that is less than the design load for the maximum bearing pressure. Following equation based on the expression given by the American Concrete Institute (ACI), Committee-225 may be used for calculation of the allowable bearing stress on concrete:

$$F_b = \frac{(10.16 - b)\, f_{ck}}{9.525}$$

Where

F_b = allowable bearing stress, kg/cm²

b = dowel diameter, cm

f_{ck} = ultimate compressive strength (characteristic strength) of the concrete, kg/cm² (400 kg/cm² for M40 concrete)

The dowel bars are installed at suitable spacing across the joints and the dowel bar system is assumed to transfer 40 per cent of the wheel load. For heavy traffic, dowels are to b provided at the contraction joints since aggregate inter-loc cannot be relied upon to affect the load transfer across the join to prevent faulting due to the repeated loading of heavy axles Joint width of 20 mm may be taken for stress computation i dowel bar at the expansion and contraction joint in view of th fact that under the dowel there is likely to be grinding c concrete taking place and consequent loss of suppor Recommended diameter and length of dowel bars are given i Table 8.

TABLE 8. RECOMMENDED DIMENSIONS OF DOWEL BARS FOR RIGID PAVEMENTS FOR AN AXLE LOAD OF 10.2 T

Slab thickness, cm	Dowel bar details		
	Diameter, mm	Length, mm	Spacing, mm
20	25	500	250
25	25	500	300
30	32	500	300
35	32	500	300

Note : The values given are for general guidance. The actual values shou be calculated for the axle load considered in the design.

Dowel bars are not satisfactory for slabs of sma thickness and shall not be provided for slab of less than cm thickness.

6.2.3. **Dowel group action** : When loads are appli at a joint, a portion of the load is transferred to the oth side of the slab through the dowel bars. The dowel b immediately below a wheel load carries maximum amount load and other dowel bars transfer progressively lower amou of loads. Repeated loading causes some looseness betwe the dowel bars and the concrete slab and recent stu indicates that the dowel bars within a distance of one radi

of relative stiffness (1.0 l) from the point of load application participate in load transfer. Assuming a linear variation of the load carried by different dowel bars within 1.0 l, maximum load carried by a dowel bar can be computed as illustrated in ***Appendix-3***.

7. TIE BARS FOR LONGITUDINAL JOINTS

7.1. In case opening of longitudinal joints is anticipated in service, for example, in case of heavy traffic, expansive subgrades, etc., tie bars may be designed in accordance with the recommendations of IRC:15-2002, Supplementary Note, para N.5 Tie Bars. For the sake of convenience of the designers the design procedure recommended in IRC:15-2002 is given here.

7.2. Design of Tie Bars

The area of steel required per metre length of joint may be computed using the following formula:

$$A_s = \frac{bfW}{S}$$

in which

A_s = area of steel in cm^2, required per m length of joint

b = lane width in metres

f = coefficient of friction between pavement and the sub-base/base (usually taken as 1.5)

W = weight of slab in kg/m^2 and

S = allowable working stress of steel in 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:

$$L = \frac{2SA}{B^{*} \times P}$$

in which

L = length of tie bar (cm)

S = allowable working stress in steel (kg/cm²)

A = cross-sectional area of one tie bar (cm²)

P = perimeter of tie bar (cm), and

B* = permissible bond stress of concrete (i) for deformed tie bars-24.6 kg/cm², (ii) for plain tie bars-17.5 kg/cm²

7.3. To permit warping at the joint, the maximum diameter of tie bars may be limited to 20 mm, and to avoid concentration of tensile stresses 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***.

7.4. 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 9.

8. REINFORCEMENT IN CEMENT CONCRETE SLAB TO CONTROL CRACKING

8.1. Plain concrete jointed slabs do not require reinforcement. Reinforcement, when provided in concrete pavements, is intended for holding the cracked faces tightly together, so as to prevent opening of the cracks and to maintain aggregate inter-lock required for load transfer. It does not increase the flexural strength of unbroken slab when used in quantities which are considered economical.

TABLE 9 : DETAILS OF TIE BARS FOR LONGITUDINAL JOINT OF TWO-LANE RIGID PAVEMENTS

Slab Thickness (cm)	Tie Bar Details				
	Diameter (d) (mm)	Max. Spacing (cm)		Minimum Length (cm)	
		Plain Bars	Deformed Bars	Plain Bars	Deformed Bars
15	8	33	53	44	48
	10	52	83	51	56
20	10	39	62	51	56
	12	56	90	58	64
25	12	45	72	58	64
	16	80	128	72	80
30	12	37	60	58	64
	16	66	106	72	80
35	12	32	51	58	64
	16	57	91	72	80

Note:

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

S = 1250 kg/cm² for plain bars, 2000 kg/cm² for deformed bars; bond stress for plain bars 17.5 kg/cm², for deformed bars 24.6 kg/cm².

8.2. Reinforcement in concrete slabs, when provided, 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 in the middle of the slab where the cracks occur first. 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:

$$A = \frac{LfW}{2S}$$

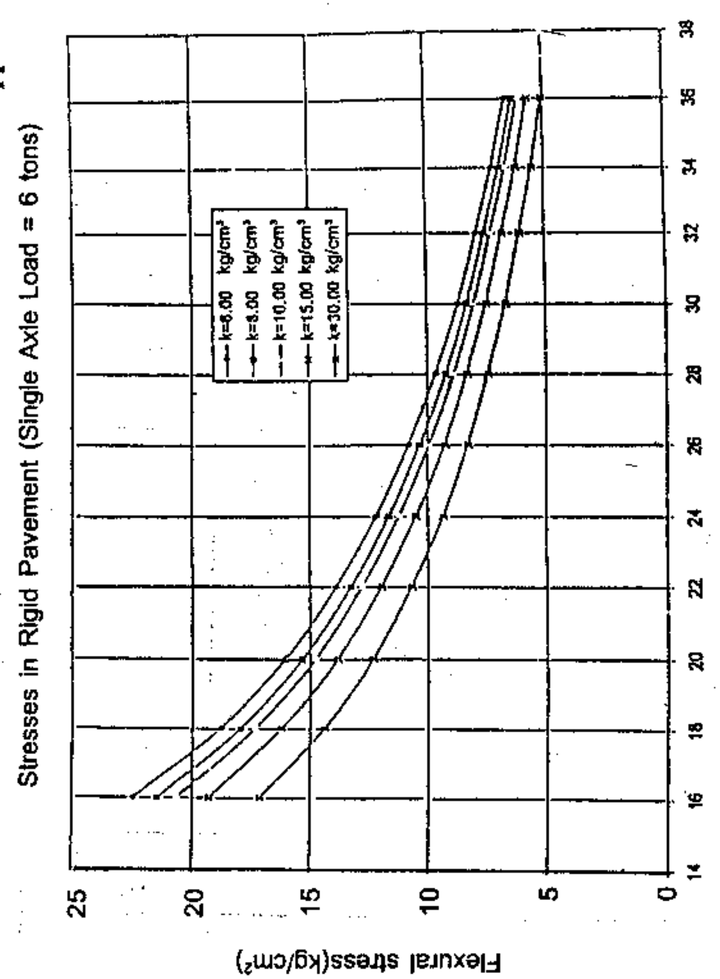
in which

- A = area of steel in cm² 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 sub-base/base (usually taken as 1.5),
- W = weight of slab in kg/m² and
- S = allowable working stress in steel in kg/cm² (usually taken as 50 to 60 per cent of the minimum yield stress of steel).

8.3. 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 from the top surface are more critical because of ingress of water when they open up, the general preference is for the placing of reinforcement about 50 mm below the surface. Reinforcement is often continued across longitudinal joints to serve the same purpose as tie bars, but it is kept at least 50 mm away from the face of the transverse joints and edge.

Appendix-1

Stresses in Rigid Pavement (Single Axle Load = 6 tons)



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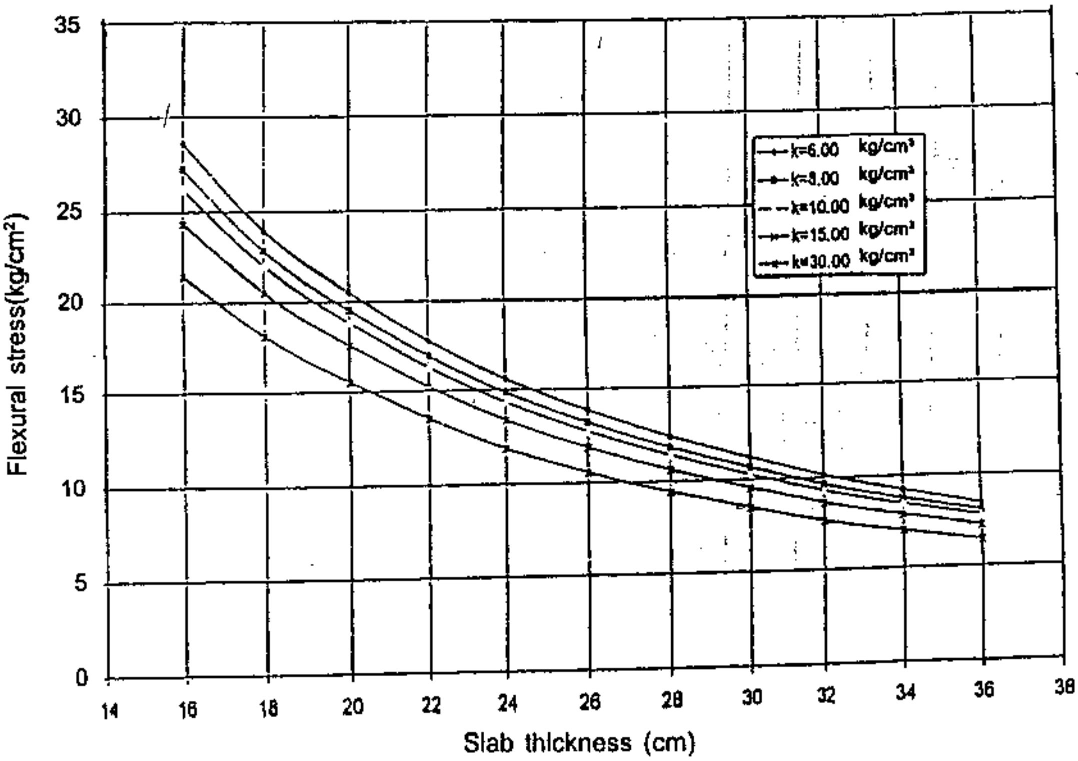
Stresses in Rigid Pavement (Single Axle Load = 8 tons)



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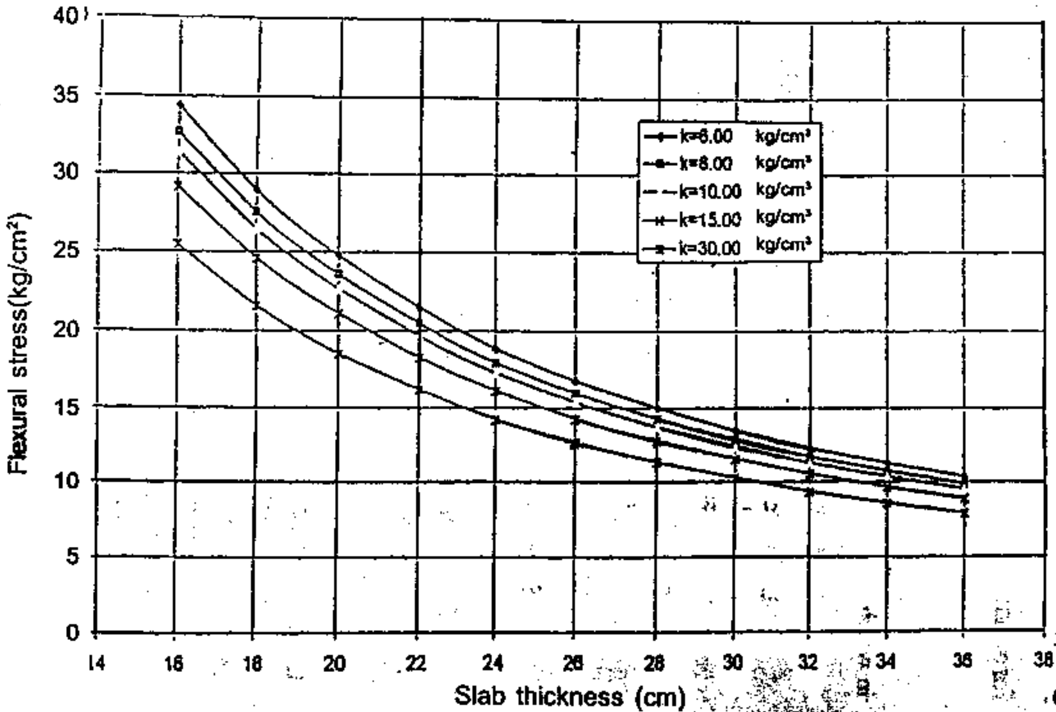
Stresses in Rigid Pavement (Single Axle Load = 10 tons)



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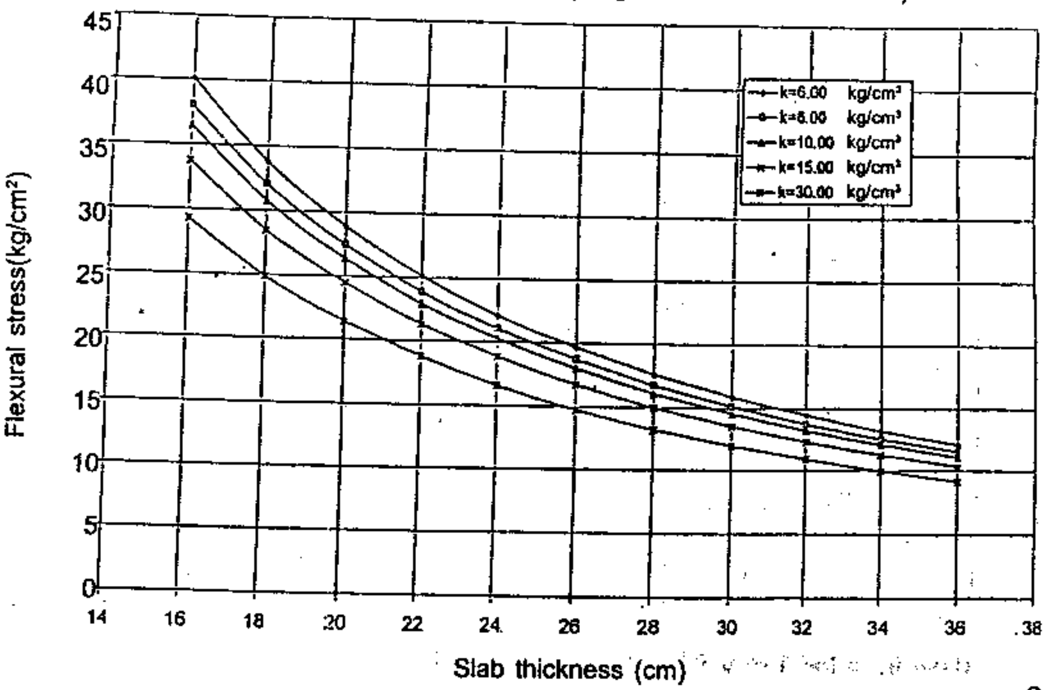
Stresses in Rigid Pavement (Single Axle Load = 12 tons)



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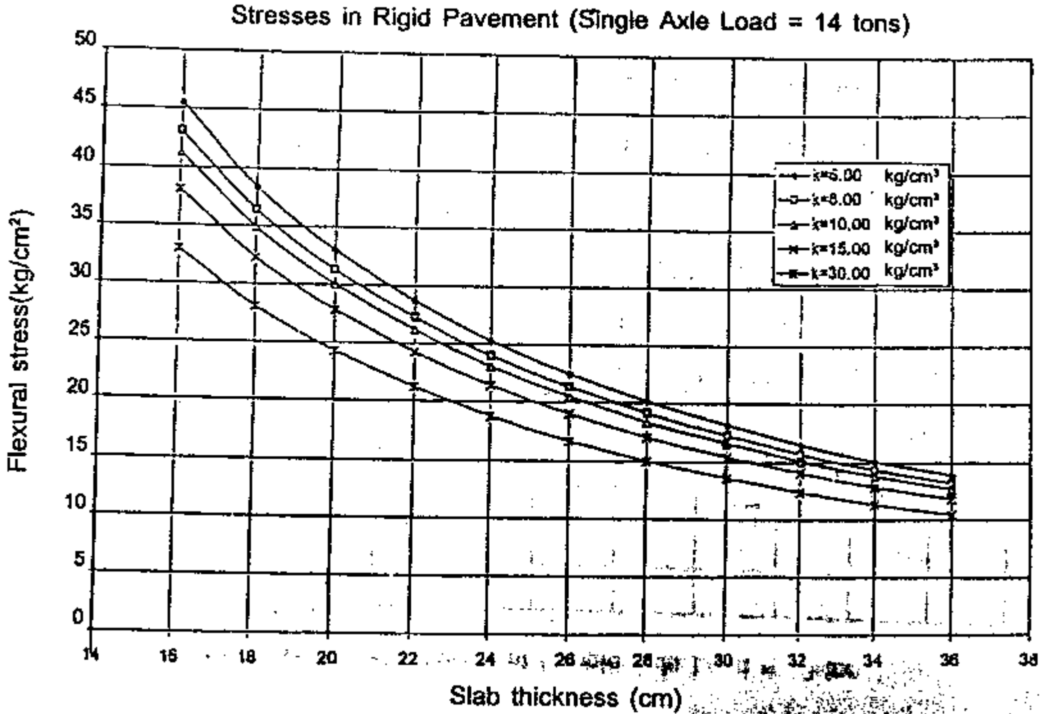
Stresses in Rigid Pavement (Single Axle Load = 14 tons)



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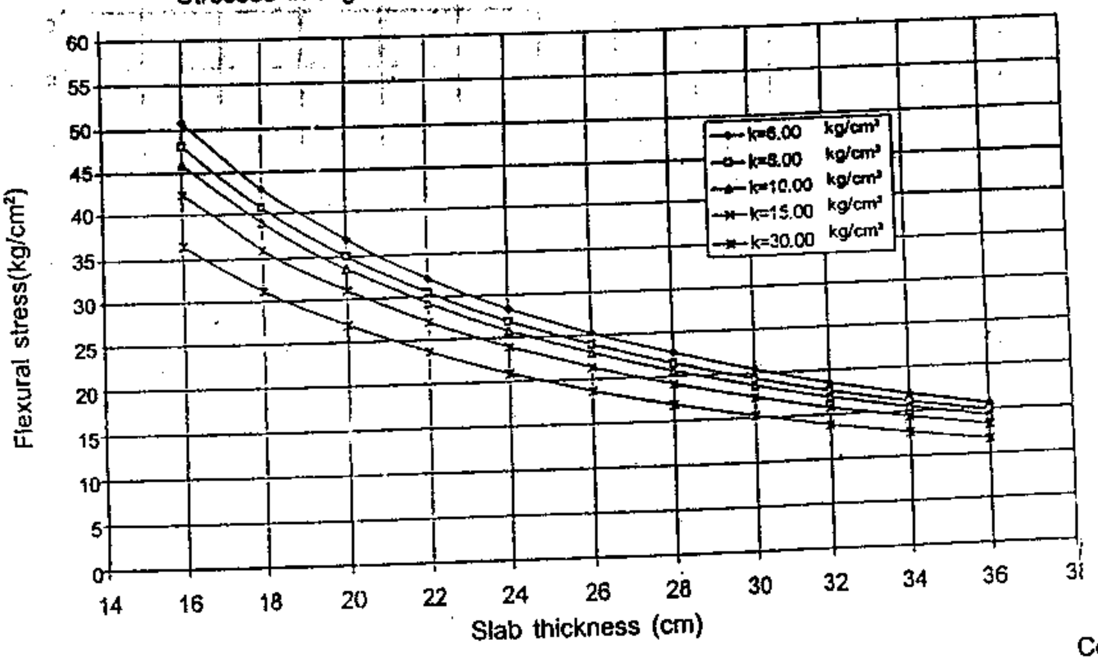
Stresses in Rigid Pavement (Single Axle Load = 16 tons)



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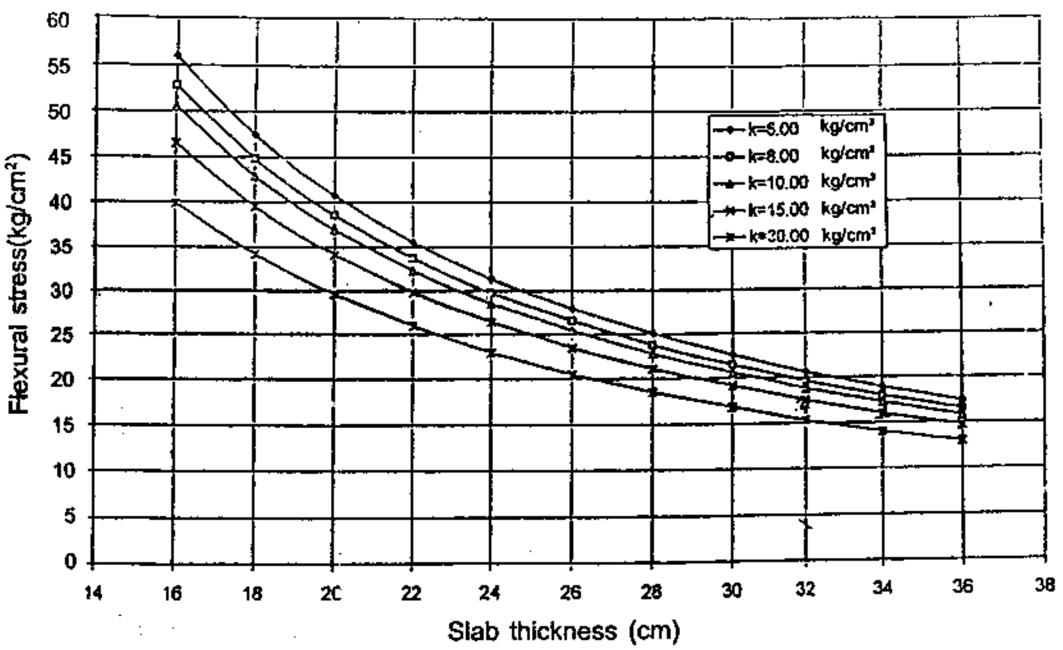
Stresses in Rigid Pavement (Single Axle Load = 18 tons)



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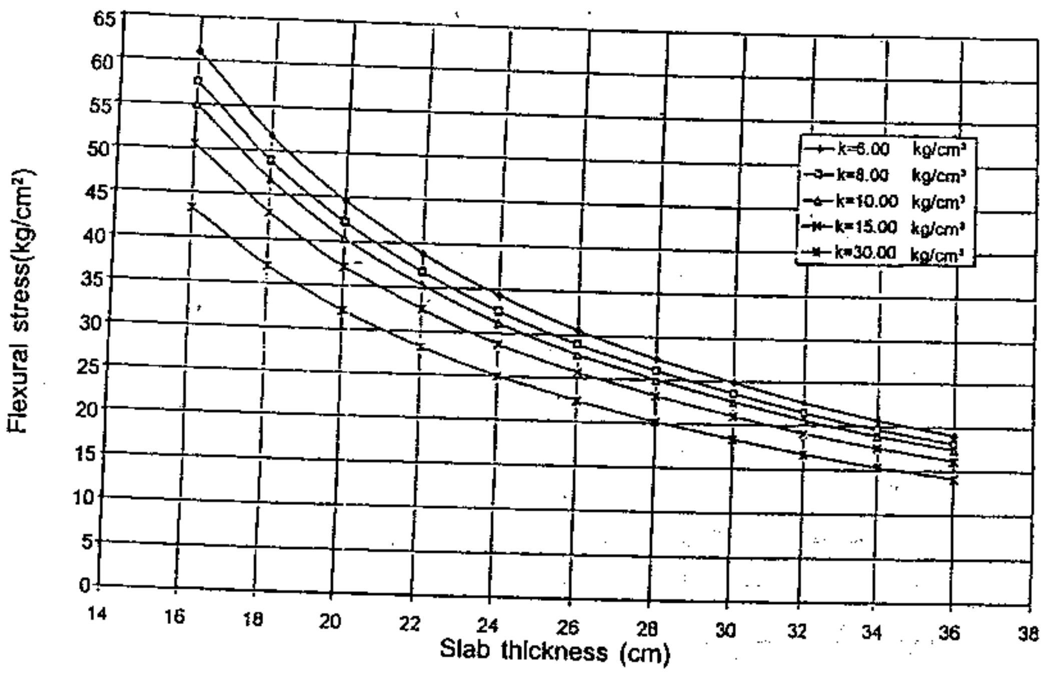
Stresses in Rigid Pavement (Single Axle Load = 20 tons)



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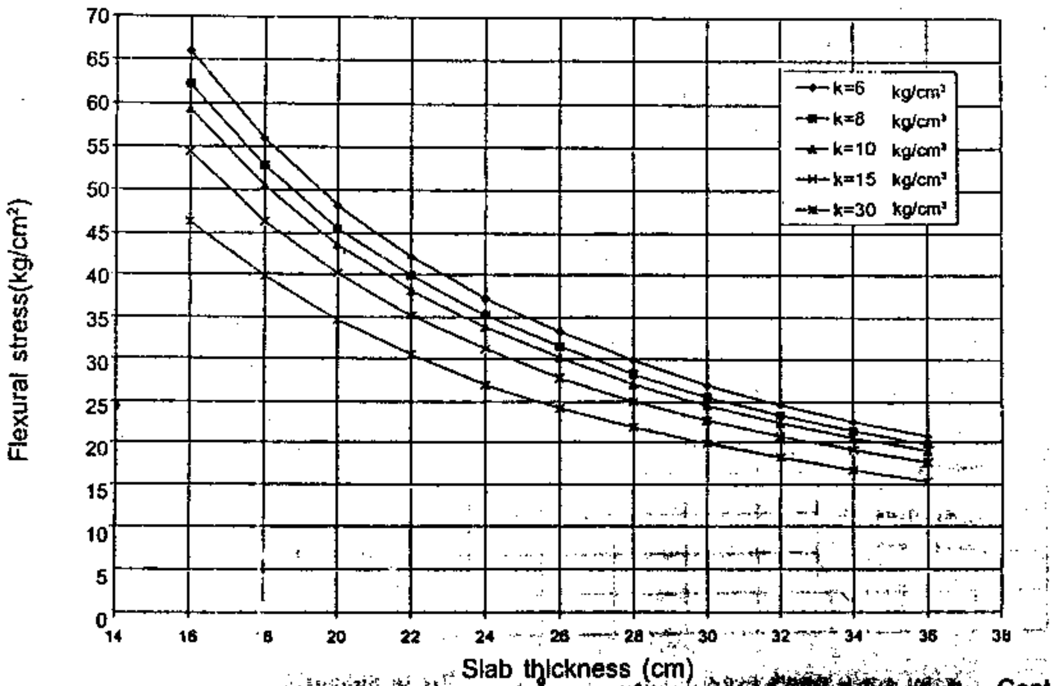
Stresses in Rigid Pavement (Single Axle Load = 22 tons)



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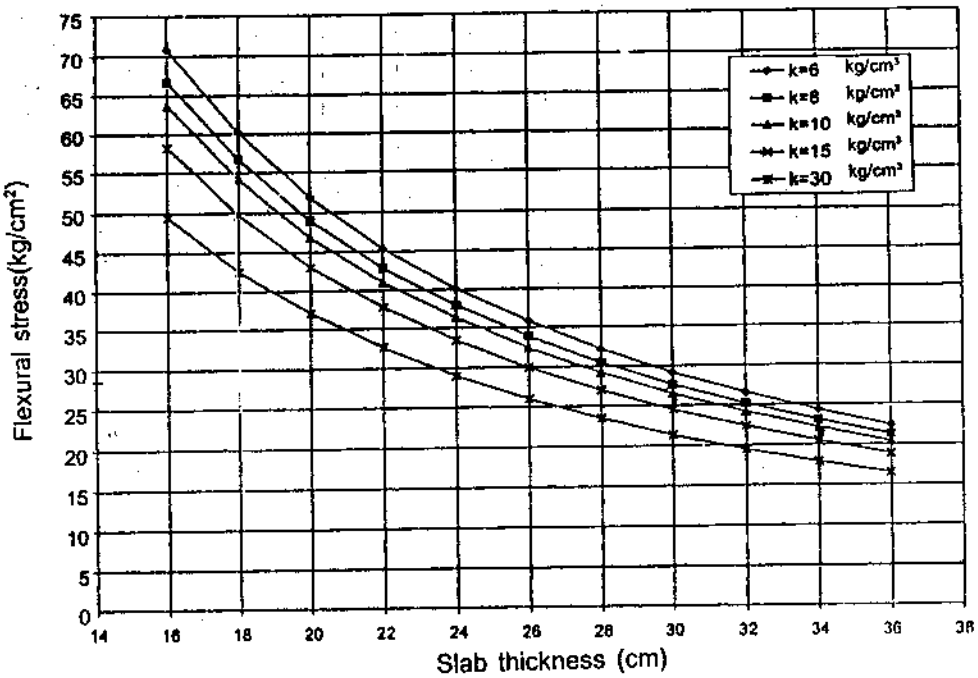
Stresses in Rigid Pavement (Single Axle Load = 24 tons)



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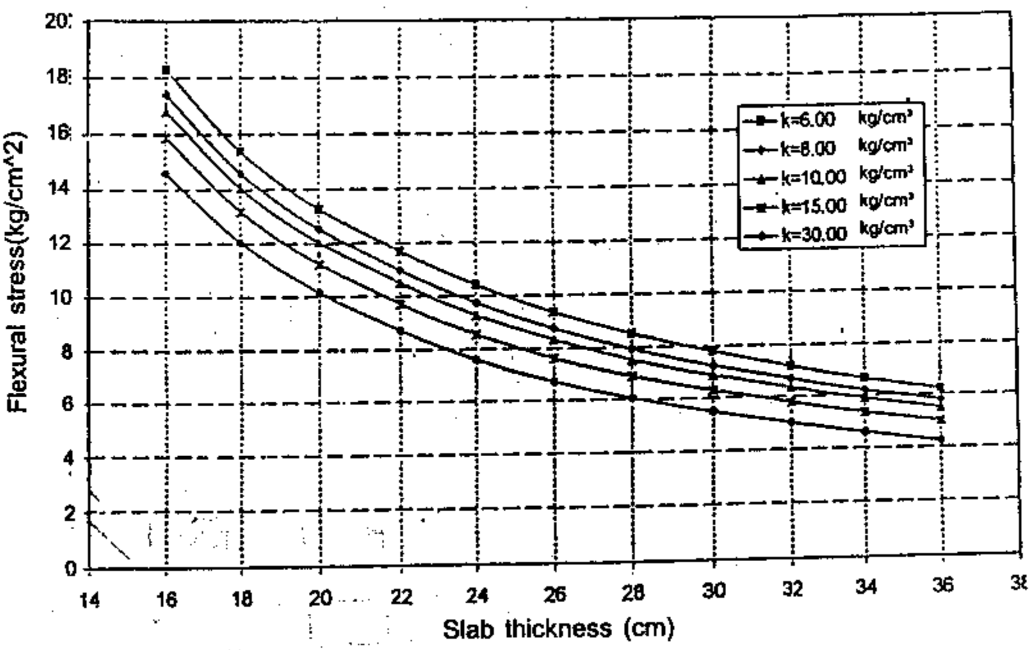
Stresses in Rigid Pavement (Tandem Axle Load 12 tons)



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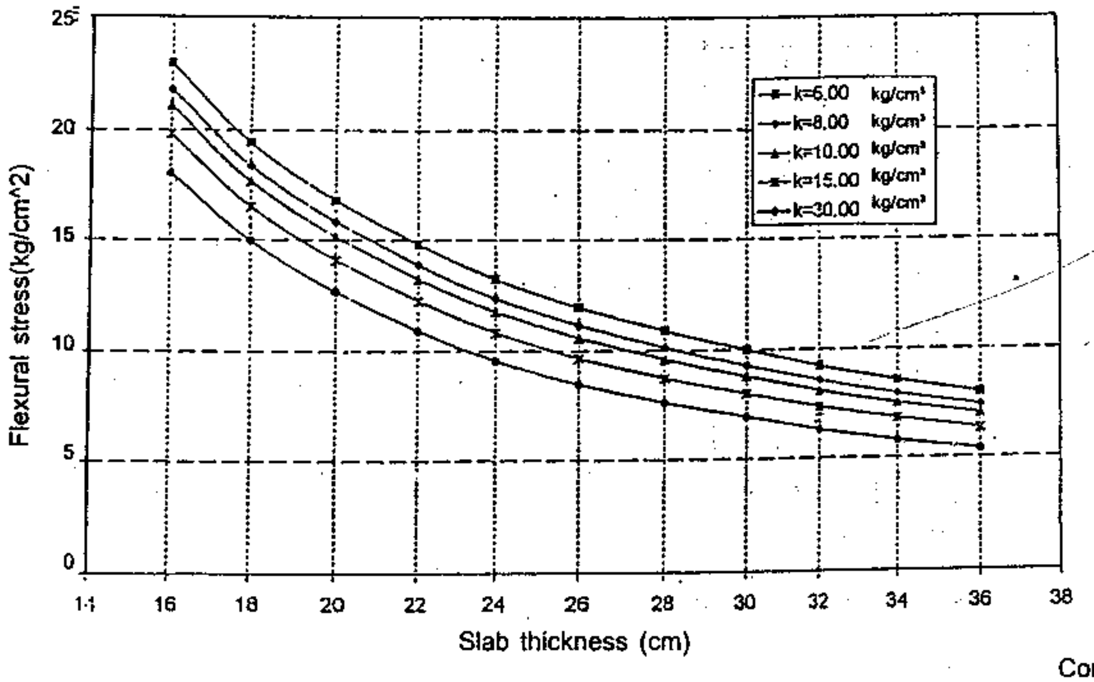
Appendix-1 (Contd.)

Stresses in Rigid Pavement (Tandem Axle Load 16 tons)



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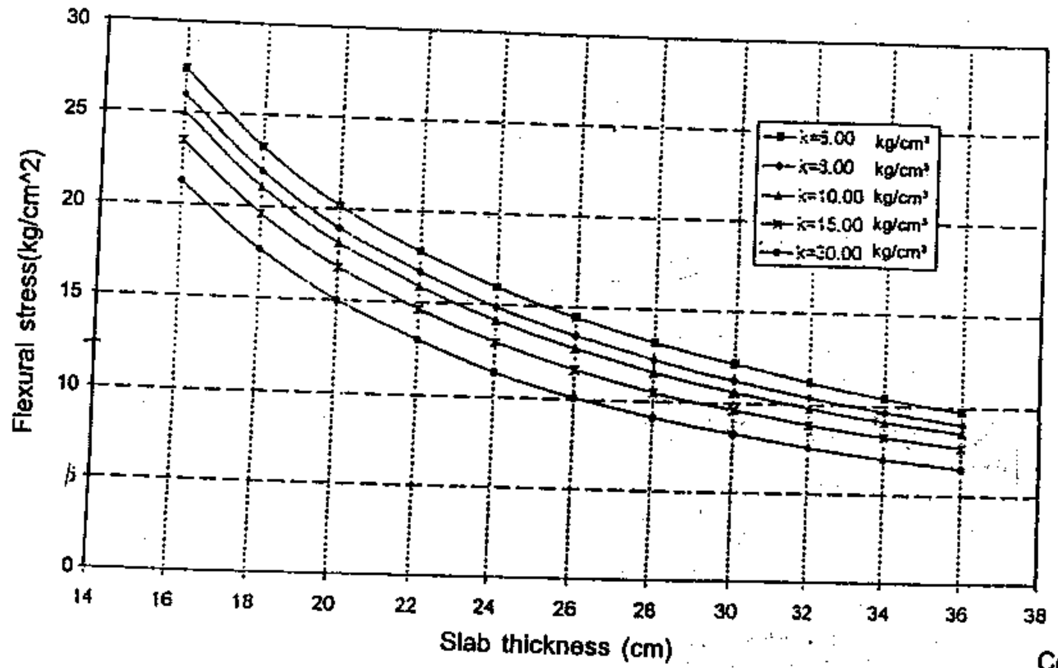
Stresses in Rigid Pavement (Tandem Axle Load 20 tons)



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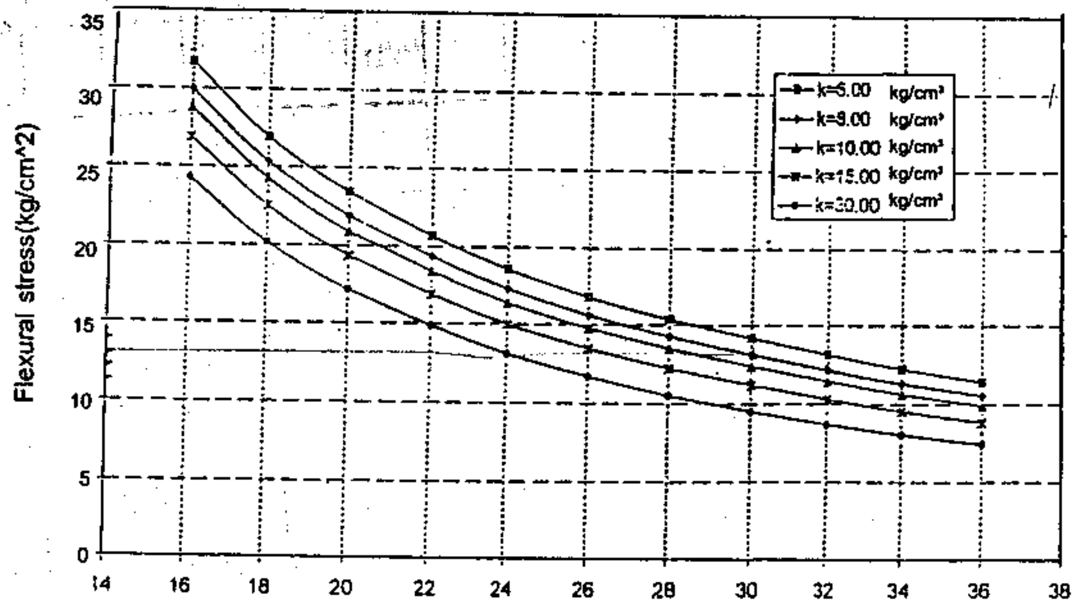
Stresses in Rigid Pavement (Tandem Axle Load 24 tons)



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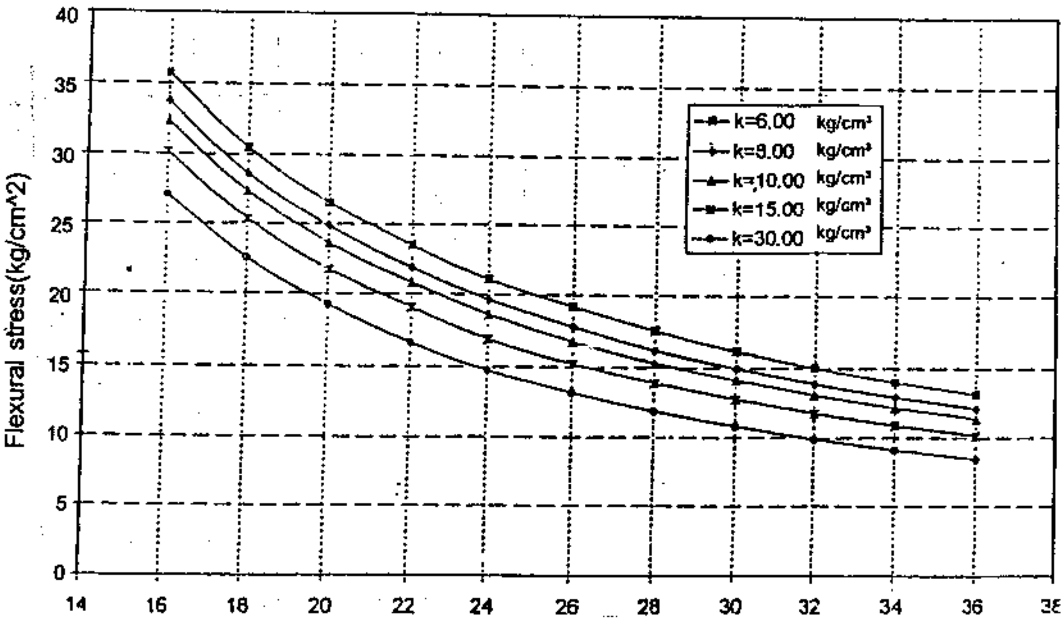
Stresses in Rigid Pavement (Tandem Axle Load 28 tons)



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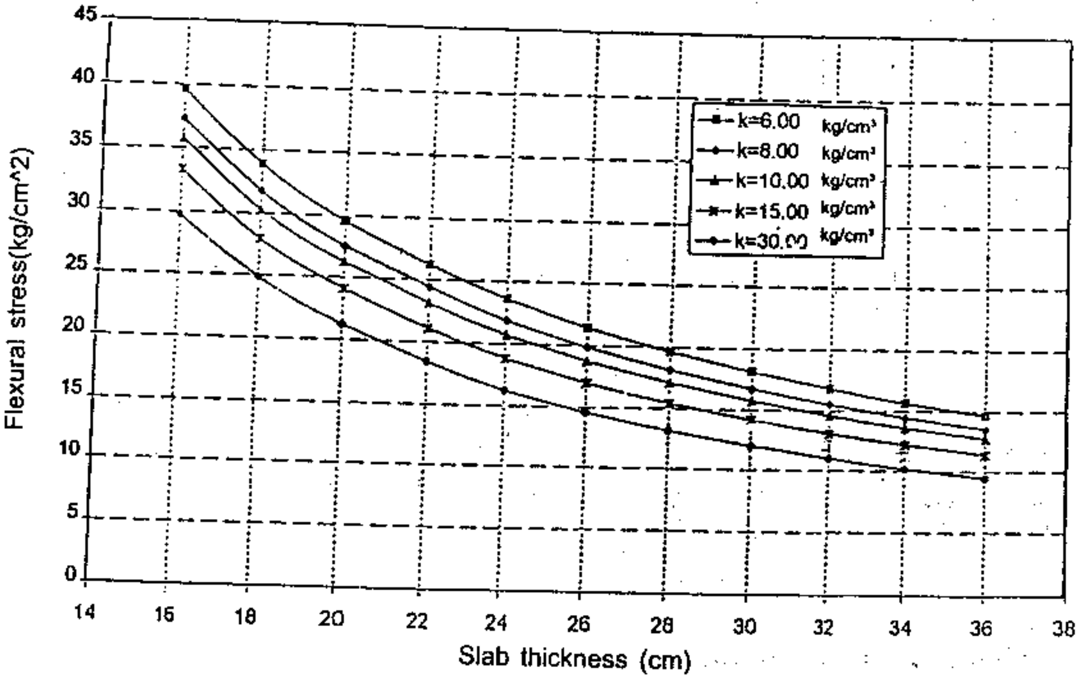
Stresses in Rigid Pavement (Tandem Axle Load 32 tons)



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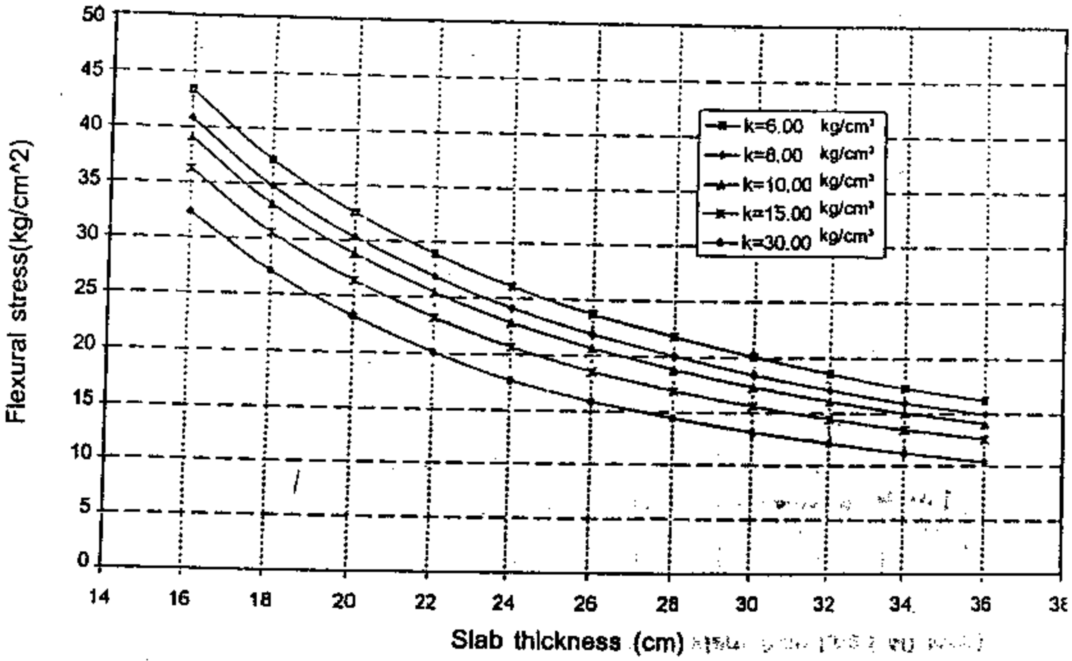
Stresses in Rigid Pavement (Tandem Axle Load 36 tons)



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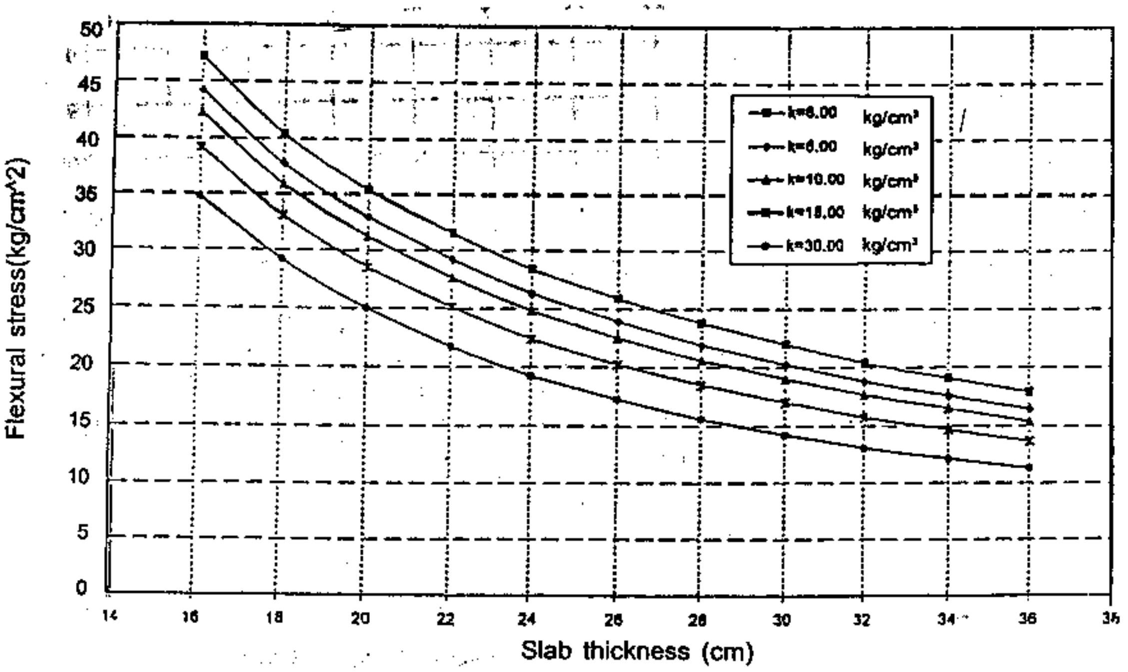
Stresses in Rigid Pavement (Tandem Axle Load 40 tons)



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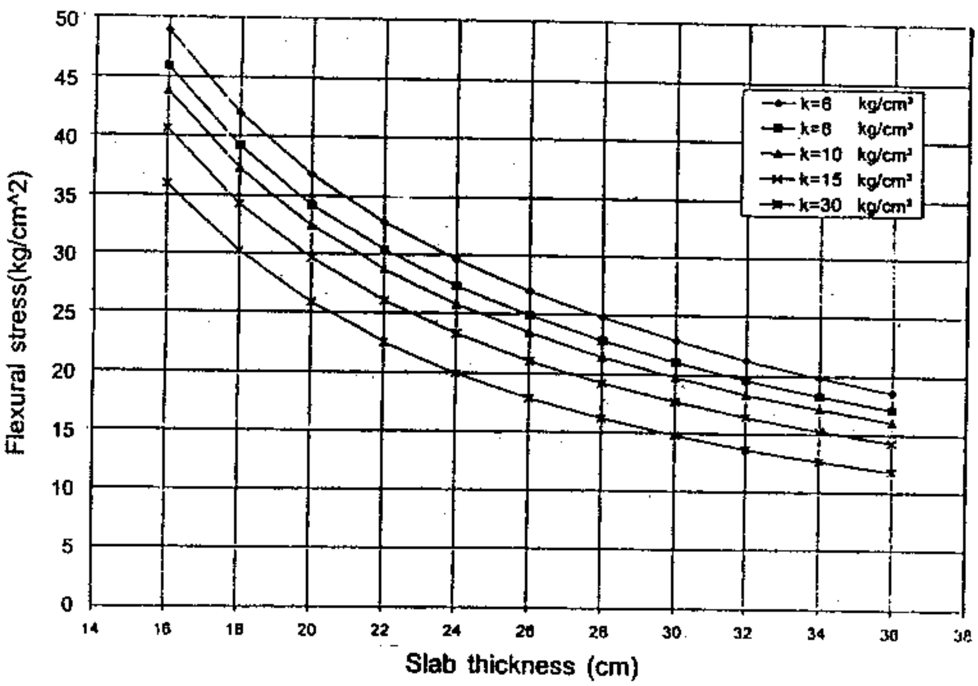
Stresses In Rigid Pavement (Tandem Axle Load 42 tons)



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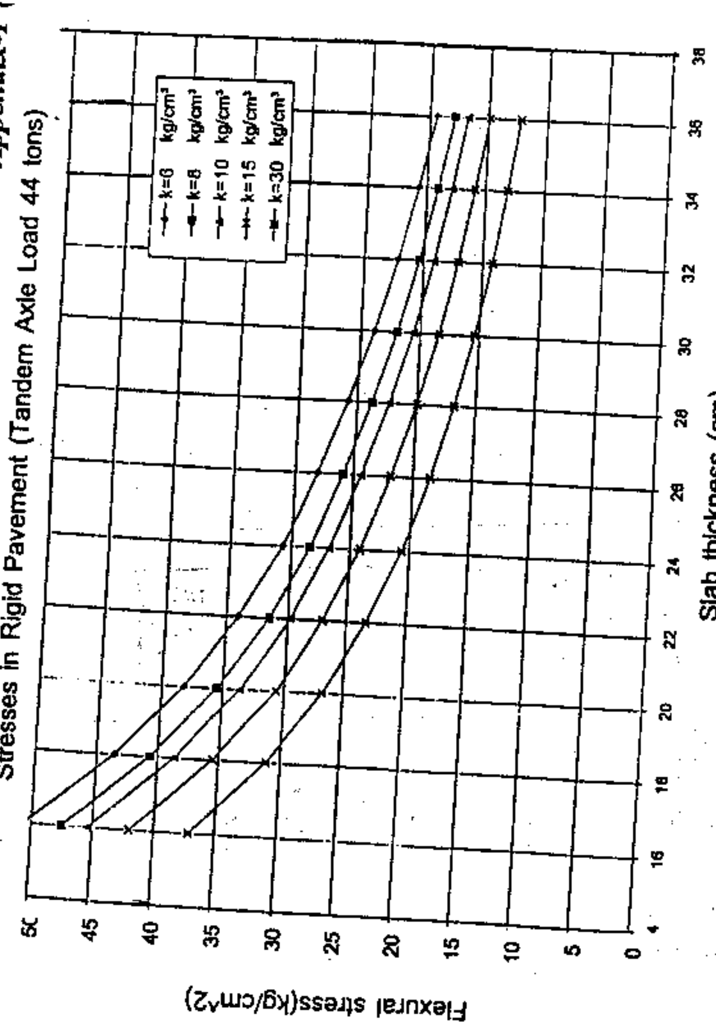
Appendix-1 (Contd.)



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Appendix-2

ILLUSTRATIVE EXAMPLE OF SLAB THICKNESS DESIGN

Example

A cement concrete pavement is to be designed for a two-lane two-way National Highway in Karnataka State. The total two-way traffic is 3000 commercial vehicles per day at the end of the construction period. The design parameters are:

Flexural strength of cement concrete	= 45 kg/cm²
Effective Modulus of subgrade reaction of the DLC sub-base	= 8 kg/cm³
Elastic modulus of concrete	= 3×10^5 kg/cm²
Poisson's ratio	= 0.15
Coefficient of thermal coefficient of concrete	= 10×10^{-6}/°C
Tyre pressure	= 8 kg/cm²
Rate of traffic increase	= 0.075
Spacing of contraction joints	= 4.5 m
Width of slab	= 3.5 m

The axle load spectrum obtained from axle load survey is given in the following:

Single Axle Loads		Tandem Axle Loads	
Axle Load class, tons	Percentage of axle loads	Axle Load class, tons	Percentage of axle loads
19-21	0.6	34-38	0.3
17-19	1.5	30-34	0.3
15-17	4.8	26-30	0.6
13-15	10.8	22-26	1.8
11-13	22.0	18-22	1.5
9-11	23.3	14-18	0.5
Less than 9	30.0	Less than 14	2.0
Total	93.0	Total	7.0

Design

Present Traffic = 3000 cvpd, Design life = 20 yrs, r = 0.075

Cumulative repetition in 20 yrs. = $3000 \times 365 \left[\frac{(1.075)^{20} - 1}{0.075}\right]$

= 47,418,626 commercial vehicles

Design Traffic = 25 per cent of the total repetitions of commercial vehicles = 11,854,657

Front axles of the commercial vehicles carry much lower loads and cause small flexural stress in the concrete pavements and they need not be considered in the pavement design. Only the rear axles, both single and tandem, should be considered for the design. In the example, the total number of rear axles is, therefore, 11,854,657. Assuming that mid point of the axle load class represents the group, the total repetitions of the single axle and tandem axle loads are as follows:

Single Axles		Tandem Axles	
Load in tonnes	Expected repetitions	Load in tonnes	Expected repetitions
20	71127	36	35564
18	177820	32	35564
16	569023	28	71128
14	1280303	24	213384
12	2608024	20	177820
10	27622135	16	59273
Less than 10	3556397	Less than 16	237093

Trial Thickness = 32 cm, Subgrade modulus = 8 kg/cm^3, design period = 20 yrs, Modulus of rupture = 45 kg/cm^2, Load safety factor = 1.2.

Axle load (AL), tonnes	AL x 1.2	Stress, kg/cm^2 from charts	Stress ratio	Expected repetition, n	Fatigue life, N	Fatigue life consumed
(1)	(2)	(3)	(4)	(5)	(6)	Ratio (5)/(6)
Single axle						
20	24.0	25.19	0.56	71127	94.1×10^3	0.76
18	21.6	22.98	0.51	177820	4.85×10^5	0.37
16	19.2	20.73	0.46	569023	14.33×10^6	0.04
14	16.8	18.45	0.41	128030	Infinite	0.00
Tandem axle						
36	43.2	20.07	0.45	35560	62.8×10^6	.0006
32	38.4	18.40	0.40	35560	Infinity	0.00
Cumulative fatigue life consumed						= 1.1706

The design is unsafe since cumulative fatigue life consumed should be less than 1.0.

Trial thickness = 33 cm

Axle load (AL), tonnes	AL x 1.2	Stress, kg/cm²	Stress ratio	Expected repetition, n	Fatigue life, N	Fatigue life consumed
(1)	(2)	(3)	(4)	(5)	(6)	(5)/(6)
Single Axle						
20	24.0	24.10	0.53	71127	2.16×10^5	0.33
18	21.6	21.98	0.49	177820	1.29×10^6	0.14
16	19.2	19.98	0.44	569023	Infinity	0.00
14	16.8	17.64	0.39	128030	Infinity	0.00
Tandem Axle						
36	43.2	19.38	0.43	35560	Infinity	0.00
Cumulative fatigue life consumed						= 0.47

The cumulative fatigue life consumed being less than 1, the design is safe from fatigue considerations.

Check for Temperature Stresses

Edge warping stress = $\frac{CE\alpha t}{2}$ = 17.3 kg/cm²

L = 450 cm

B = 350 cm

l = 103.5 (see below under corner stress)

∴ L/l = 4.4;

C = 0.55 from Fig. 2.

The temperature differential was taken as 21°C for the Karnataka region.

Total of temperature warping stress and the highest axle load stress = 24.10+17.3 = 41.4 kg/cm² which is less than 45 kg/cm², the flexural strength. So the pavement thickness of 33

cm is safe under the combined action of wheel load and temperature.

Check for Corner Stress

Corner stress is not critical in a dowelled pavement. The corner stress can be calculated value from the following formula:

$$\text{Corner Stress} : \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$$

The 98 percentile axle load is 16 tonnes. The wheel load, therefore, is 8 tonnes.

Radius of relative stiffness, $l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}$

E = 3×10^5 kg/cm²

h = 33 cm

μ = 0.15

k = 8 kg/cm³

Tyre pressure = 8 kg/cm²

$$\therefore l = \sqrt[4]{\frac{3 \times 10^5 \times 33^3}{12(1-0.15^2)k}}$$

= 103.5 cm

a = radius of area of contact of wheel.

Considering a single axle dual wheel,

$$a = \left[0.8521 \times \frac{P}{q\pi} + \frac{S}{\pi}\left(\frac{P}{0.5227 \times q}\right)^{0.5}\right]^{0.5}$$

Where

P = Load

S = C/c distance between two tyres = 31 cm

q = tyre pressure

$$= \left[0.8521 \times \frac{8000}{8 \times \pi} + \frac{31}{\pi}\left(\frac{8000}{0.5227} \times \frac{1}{8}\right)^{0.5}\right]^{0.5}$$

$$= [271.23 + 431.60]^{0.5}$$

$$= 26.51 \text{ cm}$$

$$\therefore \text{Corner Stress} = \frac{3 \times 8000}{33^2}\left[1 - \left(\frac{26.51 \times \sqrt{2}}{103.5}\right)^{1.2}\right]$$

$$= \frac{3 \times 8000}{33^2}[1 - 0.296]$$

$$= 15.52 \text{ kg/cm}^2$$

The corner stress is less than the flexural strength of the concrete, i.e., 45 kg/cm² and the pavement thickness of 33 cm assumed is safe.

Appendix-3

DESIGN OF DOWEL BARS

Design Parameters

Design wheel load = 98 percentile axle load is 16 tonne. The wheel load, therefore, is 8000 kg (dual wheel load)

Percentage of load transfer = 40

Slab thickness, h = 33 cm

Joint width, z = 2.0 cm

Radius of relative stiffness, l = 103.53 cm

Permissible bearing stress in concrete is calculated as under:

$$F_b = \frac{(10.16 - b) f_{ck}}{9.525}$$

f_{ck} = characteristic compressive strength of concrete cube (15 cm) after 28 days curing concrete = 400 kg/cm² for M-40 grade

b = diameter of the dowel bar = 3.2 cm (assumed)

$$F_b = \frac{(10.16 - 3.2)}{9.525} \times 400$$

$$= 292 \text{ kg/cm}^2$$

Assumed spacing between the dowel bars = 32 cm

First dowel bar is placed at a distance = 15 cm from the pavement edge

Assumed length of the dowel bar = 50 cm

Dowel bars upto a distance of 1.0 x radius of relative stiffness, from the point of load application are effective in load transfer.

Number of dowel bars participating in load transfer when wheel load is just over the dowel bar close to the edge of the slab = 1 + l/spacing = 1+103.53/32 = 4 dowels.

Assuming that the load transferred by the first dowel is P_t and assuming that the load on dowel bar at a distance of l from the first dowel to be zero, the total load transferred by dowel bar system

$$= \left(1+\frac{103.53-32}{103.53}+\frac{103.53-64}{103.53}+\frac{103.53-96}{103.53}\right)P_t$$

$$= 2.145\ P_t$$

Load carried by the outer dowel bar, P_t = (8000 x 0.4) / 2.145 = 1492 kg

Check for Bearing Stress

Moment of Inertia of Dowel = $\pi b^4/64$

$= \pi \times (3.2)^4/64$

$= 5.147\ cm^4$

Relative stiffness of dowel bar embedded in concrete =

$$\beta = \sqrt[4]{kb/4EI}$$

$$= \left[\frac{41500\times 3.2}{4\times 2.0\times 10^6\times 5.147}\right]^{1/4}$$

$$= 0.238$$

Bearing stress in dowel bar = $(P_t \times k) \times (2+\beta z)/(4\beta^3 EI)$

$$= \frac{1492\times 41500\{2+(0.238\times 2)\}}{4\times(0.238)^3\times 2.0\times 10^6\times 5.147}$$

= 276 kg/cm^2 which is less than 292 kg/cm^2

Hence, the dowel bar spacing and diameter assumed are safe.

Appendix-4

DESIGN OF TIE BARS

Design Parameters

Slab Thickness	:	33 cm
Lane width, b	:	3.5 m
Coefficient of friction, f	:	1.5
Density of concrete, kg/m^3	:	2400
Allowable tensile stress in plain bars, kg/cm^2 (As per IRC:21-2000)	:	1250
Allowable tensile stress in deformed bars, kg/cm^2 (As per IRC:21-2000)	:	2000
Allowable bond stress for plain tie bars, kg/cm^2	:	17.5
Allowable bond stress for deformed tie bars, kg/cm^2	:	24.6
Diameter of tie bar, d	:	12 mm

1. Spacing and length of the plain bar

Area of steel bar per metre width of joint to resist the frictional force at slab bottom

$$A_s = \frac{bfW}{S}$$

$$= \frac{3.5x1.5x0.33x2400}{1250}$$

$$= 3.326\ cm^2/m$$

Assuming a diameter of tie bar of 12 mm, the cross sectional area

$$A = \frac{1.2^2 x\pi}{4}$$

$$= 1.13\ sq.\ cm.$$

Perimeter of tie bar, P $= \pi d$

$= 3.77$ cm

Spacing of tie bars $= A/A_s$

$= 100 \times 1.13/3.326$

$= 33.97$ cm

Provide at a spacing of 34 cm c/c

Length of tie bar, L $= \dfrac{2 x S x A}{B x P}$

$$= \frac{2 x 1250 x 1.13}{17.5 x 3.77}$$

$= 42.82$ cm

Increase length by 10 cm for loss of bond due to painting and another 5 cm for tolerance in placement. Therefore, the length is

42.82 + 10 + 5 = 57.82 cm, Say 58 cm

2. Spacing and length of the deformed tie bar

Area of steel bar per metre width of joint to resist the frictional force at slab bottom

$A_s = \frac{bfW}{S}$

$= \frac{3.5 \times 1.5 \times 0.33 \times 2400}{2000}$

$= 2.079\ cm^2/m$

Spacing of tie bars $= A/A_s$

$= 100 \times 1.13/2.079$

$= 54.35$ cm

Provide at a spacing of 54 cm c/c

Length of tie bar, L $= \frac{2 \times S \times A}{B \times P}$

$= \frac{2 \times 2000 \times 1.13}{24.6 \times 3.77}$

$= 48.74$ cm

Increase length by 10 cm for loss of bond due to painting and another 5 cm for tolerance in placement. Therefore, the length is

48.74 + 10 + 5 = 63.74 cm, Say 64 cm

Appendix-5

FLEXURAL STRENGTH OF CEMENT CONCRETE

Flexural strength of plain concrete as per IS:456-2000 is given as

$$f_{cr} = 0.7 \times \sqrt{f_{ck}}$$

Where f_{cr} = flexural strength (modulus of rupture), N/mm^2

f_{ck} = characteristic compressive cube strength of concrete, N/mm^2

According to Croney and Croney

$f_{cr} = 0.49 \times f_{ck}^{0.55}$ for gravel aggregates and

$f_{cr} = 0.36 \times f_{ck}^{0.7}$ or crushed aggregates

For M40 concrete, f_{cr} values from the above three equations are obtained as 44.27(IS:456), 37.26 (gravel) and 47.61 kg/cm^2 (crushed rock) respectively. Hence, a flexural strength of 45 kg/cm^2 is recommended for M40 concrete. The relation between flexural strength and compressible strength depends upon the nature of aggregates, type of cement, additives and other factors. Flexural strength determined from flexure tests, therefore, should form the criterion for evaluating the strength of pavement concrete.

MODULUS OF ELASTICITY

Pavement concrete is subjected to dynamic loading and the ratio of static and dynamic moduli on the same concrete is found as 0.8. The modulus value increases both with age and strength but the variation is small.

As per IS:456-2000, Static modulus of elasticity E, is given as

$$E \text{ (in N/mm}^2) = 5000 \sqrt{f_{ck}}$$

Neville and Brooks recommend the following expression for computing static modulus from the cube compressive strength.

$$E \text{ (in N/mm}^2) = 9100\ f_{ck}^{0.33}$$

For M40 concrete, the moduli as per the above equations are 31623 and 30741 N/mm² respectively. According to BS:8110: (Part 2)-1985, the mean value of static modulus of elasticity is 28000 N/mm² for M40 concrete. The ACI Building Code 318-89 gives an E value of 32000 N/mm² for M40 concrete. Portland Cement Association of USA prescribes a value of 28000 N/mm² (4 x 106 psi) for the elastic modulus of pavement concrete. AASHTO gives design curves to, E values of 21000, 28000, 35000, 42000 and 49000 N/mm².

Croney and Croney, recommend E values between 35000 and 40000 N/mm².

In the light of the above, the E value of M40 concrete may be taken in the range 30741 to 31623. The recommended value of modulus of elasticity of pavement concrete is 3×10^5 kg/cm². Since E values figure only as fourth root in stress computation, a 25 per cent increase in E value increases the stress by 4 per cent only. A 33 per cent increase in μ value from 0.15 to 0.20 results in 4 per cent increase in stress. It may be noted that E increases and μ decreases with increase in strength of concrete.

Appendix-6

WESTERGAARD EQUATION

The load stresses in the critical edge region may be obtained as per Westergaard analysis, modified by Teller and Sutherland, from the following correlation in metric unit.

$$\sigma = 0.529\ P/h^2\ (1+0.54\ \mu)\ [4 \log_{10} (l/b) + \log_{10} b - 0.4048]$$

Where,

σ = load stress in the edge region, kg/cm²

P = design wheel load, kg

= half of the single axle load

= one-fourth of the tandem axle load

h = pavement thickness, cm

μ = Poisson's ratio for concrete

E = modulus of elasticity of concrete, kg/cm²

k = modulus of subgrade reaction, kg/cm³

l = radius of relative stiffness, cm

= $[E h^3/12 (1-\mu^2) k]^{1/4}$

b = radius of equivalent distribution of pressure

= a, for a/h>1.724

= $(1.6 a^2 + h^2)^{1/2} - 0.675 h$, for a/h<1.724

a = radius of load contact areas, assumed circular, cm

= $[(0.852.1\ P_d/q\pi) + (S/\pi)\ (P_d/0.5227\ q)^{1/2}]^{1/2}$ for single axle dual wheels

P_d = load on one tyre

S = c/c distance of two tyres in dual wheel assembly, 31 cm

q = tyre pressure, 8 kg/cm²