GUIDELINES FOR DESIGN AND CONSTRUCTION OF CEMENT CONCRETE PAVEMENTS FOR LOW VOLUME ROADS

(First Revision)

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GUIDELINES FOR DESIGN AND CONSTRUCTION OF CEMENT CONCRETE PAVEMENTS FOR LOW VOLUME ROADS

1 INTRODUCTION

IRC:SP:62 "Guidelines for the Design and Construction of Cement Concrete Pavement for Rural Roads" was published by Indian Roads Congress (IRC) in 2004. These guidelines served the profession well for about a decade. However, advancement in design and construction of the Rigid Pavement, H-3 Committee realised the necessity to revise existing guidelines.

Accordingly, the Rigid Pavement Committee (H-3) constituted a sub-group comprising Dr. B.B. Pandey S/Shri R.K. Jain, Satander Kumar, M.C. Venkatesh and P.L. Bongirwar for revision of IRC:SP:62. The Sub-group prepared initial draft and thereafter, same was discussed and deliberated in number of committee meetings. The H-3 Committee finally approved the revised draft guidelines in its meeting held on 8th June, 2013 for placing before the HSS Committee. The Highways Specifications and Standards Committee (HSS) approved this document in its meeting held on 19th July, 2013. The Executive Committee in its meeting held on 31st July, 2013 approved the same document for placing before the Council. The Council in its meeting held at New Delhi on 11th & 12th August, 2013 approved the draft "Guidelines for the Design and Construction of Cement Concrete Pavements for Low Volume Roads" for publishing.

The composition of H-3 Committee is as given below:

Corresponding Members

Vishal Thombre	D.C. De
Rajesh Madan	S.A. Reddi
Brig. Vinod Nakra	Dr. C.E.G. Justo

Ex-Officio Members

C. Kandasamy	------	Director General (Road Development) & Special Secretary, MoRTH & President, IRC
Vishnu Shankar Prasad	------	Secretary General, IRC

1.1 A large proportion of India's villages have been connected with all-weather roads due to the efforts made by National Rural Road Development Agency (NRRDA), Ministry of Rural Development, Government of India. Rural roads usually have low volume of traffic, consisting mostly of light transport vehicles, like agricultural tractors/trailers, light goods vehicles, buses, animal drawn vehicles, auto-rickshaws, motor cycles and bi-cycles. Some of the rural roads may also have light and medium trucks carrying sugarcane, quarry materials, etc. The most common composition of such roads is granular layer with or without thin bituminous surfacing. Another feature common to such roads is that their maintenance is neglected because of paucity of funds and poor institutional set-up, and the road asset created at a great cost is lost. The selection of pavement types for such roads should consider these factors.

1.2 Concrete pavements have been constructed on many rural roads under PMGSY programme. They are also being widely used on minor roads of cities carrying low volume of traffic because of their durability even under poor drainage conditions. Concrete pavements offer an alternative to flexible pavements especially where the soil strength is poor, the aggregates are costly and drainage conditions are bad. The choice of pavement type depends on these factors and the life-cycle cost. Concrete pavements can be (i) conventional screed-compacted concrete (ii) Roller Compacted Concrete (iii) Interlocking Concrete Block Pavements (ICBP) and (iv) concrete pavements with panel size 0.5 m x 0.5 m to 1.2 m x 1.2 m and depths ranging from 50 mm to 200 mm similar to Thin White Topping as per IRC:SP:76 in which the upper one third has a discontinuity created by sawing or by inserting three to five millimeter thick polyethylene strips which are left in the concrete. Self-Compacting Concrete (SCC) as per **Appendix III** can also be used since it is easy to pour and requires very little compaction. It has successfully been used in Maharashtra in different trials sections of rural roads.

1.3 Rural roads connecting major roads are sometimes required to carry construction or diverted traffic which may damage the concrete slabs. Some roads connect several villages and they are constructed in stages spread over several years and have to carry heavy construction traffic. Such factors may be considered while arriving at thickness of pavements.

1.4 It should be recognized that concrete pavements demand a high degree of professional expertise at the stages of design, construction and maintenance. The institutional set-up should be suitably strengthened to meet the required parameters of concrete pavements in remote places.

2 SCOPE

IRC:58 deals with design of concrete pavements for major roads carrying an average daily traffic exceeding 450 Commercial Vehicles Per Day (CVPD) with laden weight exceeding 30 kN. The guidelines contained in this document are applicable only to low volume roads with average daily traffic less than 450 Commercial Vehicles Per Day. The basic design concepts of IRC:58 may be relevant for arriving at pavement thickness in some cases as mentioned in Clause 1.3. This document covers the design principles of rigid pavements of low volume roads 3.75 m wide (minimum 3 m wide in hills) made up of conventional concrete, roller compacted concrete and self-compacting concrete. Transverse joints spacing ranging from 2.50 m to 4.00 m may be selected.

3 FACTORS GOVERNING DESIGN

3.1 Wheel Load

Heavy vehicles are not expected frequently on rural roads. The maximum legal load limit on single axle with dual wheels in India being 100 kN, the recommended design load on dual wheel is 50 kN having a spacing of the wheels as 310 mm centre-to-centre. Agricultural tractors and trailers also are being used to carry construction material and the single wheel load may rarely approach 50 kN.

3.2 Tyre Pressure

The tyre pressure may be taken as 0.8 MPa for a truck carrying a dual wheel load of 50 kN while for a wheel of tractor trailer; the pressure may be taken as 0.5 MPa. The effect of tyre pressure on the wheel load stresses for practical thickness of pavement is not significant.

3.3 Design Period

Concrete pavements designed and constructed as per the guidelines contained in this document will have a design life of 20 years or higher, as evidenced from the performance of roads constructed in the past in the country. The design methodology given in these guidelines is based on wheel load stresses. The repetitions of axle loads, curling stresses and the consumption of fatigue for different axle loads, which form the basis of design in IRC:58, need not be considered for low volume traffic except in special situations where heavy truck traffic is anticipated.

3.4 Design Traffic for Thickness Evaluation

For traffic less than 50 CVPD, only wheel load stresses for a load of 50 kN on dual wheel need be considered for thickness estimation since there is a low probability of maximum wheel load and highest temperature differential between the top and the bottom of the rigid pavement occurring at the same time. For traffic higher than 50 and less than 150 CVPD, thickness evaluation should be done on the basis of total stresses resulting from wheel load of 50 kN and temperature differential. For traffic exceeding 150 CVPD, fatigue can be a real problem and the guidelines consider thickness evaluation on the basis of fatigue fracture considering a reliability of 60 percent against a reliability of 90 percent adopted for IRC:58. 40 percent of the pavement slabs are expected to crack at the end of the design period against 10 percent cracking considered for high volume roads. For the fatigue analysis of a concrete pavement the cumulative number of commercial traffic at the end of design period can be estimated from the following formula.

$$N = A \times \left(\frac{(1+r)^n - 1}{r} \right) \times 365 \qquad \dots 3.1$$

where,

A	=	Initial CVPD after the completion of the road
r	=	rate of traffic increase in decimal (for 5 percent rate of increase in traffic, r = 0.05)
n	=	design period in years (recommended as 20 years)
N	=	total number of cumulative commercial vehicles at the end of the design period

An estimation of gross weight of vehicle and axle load can be made from the knowledge of goods that the vehicles carry. Approximate number of commercial vehicles having an axle load of about 100 kN as a percentage of total number of commercial vehicles may be estimated from the traffic survey. For A > 150 CVPD, a default value of ten percent of the values obtained from Equation 3.1 may be considered for cumulative fatigue analysis as illustrated later. In case the road is expected to carry a large volume of very heavy trucks on a regular basis, spectrum of axle loads may have to be considered to avoid damage to pavements and design concept of IRC:58 may be used.

3.5 Characteristics of the Subgrade

The strength of subgrade is expressed in terms of modulus of subgrade reaction, k, which is determined by carrying out a plate bearing test, using 750 mm diameter plate according to IS:9214-1974. In case of homogeneous foundation, test values obtained with a plate of 300 mm diameter, k_{300}, may be converted to give k_{750}, determined using the standard 750 mm dia. plate by the following correlation:

$$k_{750} = 0.5\ k_{300} \qquad \dots 3.2$$

Since, the subgrade strength is affected by the moisture content, it is desirable to determine it soon after the monsoon. Stresses in a concrete pavement are not very sensitive to minor variation in k values and hence its value for a homogeneous soil subgrade may be obtained from its soaked CBR value using **Table 3.1**. It can also be estimated from Dynamic Cone Penetrometer also as described in IRC:58.

Table 3.1 Approximate k Value Corresponding to CBR Values

Soaked subgrade CBR	2	3	4	5	7	10	15	20	50
k Value (MPa/m)	21	28	35	42	48	50	62	69	140

The minimum CBR of the subgrade shall be 4.

3.6 Sub-Base

3.6.1 A good quality compacted foundation layer provided below a concrete pavement is commonly termed as subbase. It must be of good quality so as not to undergo large settlement under repeated wheel load to prevent cracking of slabs. The provision of a sub-base below the concrete pavement has many advantages such as:

i) It provides a uniform and reasonably firm support

ii) It supports the construction traffic even if the subgrade is wet

iii) It prevents mud-pumping of subgrade of clays and silts

iv) It acts as a leveling course on distorted, non-uniform and undulating sub-grade

v) It acts as a capillary cut-off

3.6.2 *Sub-base types*

3.6.2.1 Traffic up to 50 CVPD

75 mm thick compacted Water Bound Macadam Grade III (WBM III)/Wet Mix Macadam (WMM) may be provided over 100 mm granular subbase made up of gravel, murrum or river bed material with CBR not less than 30 percent, liquid limit less than 25 percent and Plasticity Index less (PI) less than 6. If aggregates are not available within a reasonable cost, 150 mm of cement/lime/lime-flyash treated marginal aggregate/soil layer with minimum Unconfined Strength (UCS) of 3 MPa at 7 days with cement or at 28 days with lime/lime-flyash may be used. The stabilized soil should not erode as determined from wetting and drying test (IRC:SP:89).

3.6.2.2 Traffic from 50 to 150 CVPD

75 mm thick WBM III/WMM layer over 100 mm of granular material may be used as a subbase. Alternatively, 100 mm thick cementitious granular layer with a minimum unconfined strength (UCS) of 3 MPa at 7days with cement or 28 days with lime/lime-flyash over 100 mm thick cementitious naturally available materials with a minimum UCS of 1.5 MPa with cement at 7 days or with lime or lime-flyash at 28 days may be provided.

3.6.2.3 Traffic from 150 to 450 CVPD

150 mm thick WBM III/WMM over 100 mm of granular subbase may also be used. Alternately, 100 mm of cementitious granular layer with a minimum UCS of 3.0 MPa at 7 days with cement or at 28 days with lime or lime-flyash over 100 mm of cementious layer with naturally occurring material with a minimum UCS of 1.5 MPa at 7 days with cement or at 28 days with lime or lime-flyash. Cementitious marginal aggregates may be much cheaper than WBM/WMM in many regions having acute scarcity of aggregates.

The granular subbase and WBM layers should meet the requirement of MORD Specifications, Section 400(34). Quality of subbases varies from region to region and past experience on performance of concrete pavements in different regions is the best guide for the selection of the most appropriate subbases.

3.6.2.4 Commercially available IRC accredited stabilizers with no harmful leachate also may be used if found successful on trials.

3.6.3 *Effective modulus of subgrade reaction over granular and cement treated subbases*

For the granular subbases, the effective k value may be taken as 20 percent more than the k value of the sub-grade shown in **Table 3.1**. For the cementitious subbases, the effective k value may be taken as twice that of the subgrade. Recommendations for estimated of effective modulus of subgrade reaction over granular or cemented subbase are given in **Table 3.2**. Reduction in stresses in the pavement slab due to higher subgrade CBR is marginal since only fourth root of k matters in stress computation but the loss of support due to erosion of the poor quality foundation below the pavement slab under wet condition may damage the it seriously. The GSB layer with fines passing 75 micron sieve less than 2 percent can act as a good drainage layer and addition of 2 percent cement by weight of total aggregate will make it non-erodible. Most low volume roads with concrete pavements in built up area having WBM over GSB have performed well even under adverse drainage conditions.

Table 3.2 Effective k Values Over Granular and Cementitious Subbases

Soaked CBR	2	3	4	5	7	10	15	20	50
k Value over granular subbase (thickness 150 to 250 mm), MPa/m	25	34	42	50	58	60	74	83	170
k Value over 150 to 200 mm cementations sub base MPa/m	42	56	70	84	96	100	124	138	280

It should be ensured that embankment, the subgrade and the subbase shall be well compacted as per MORD specifications (34) otherwise heavy wheel loads may displace the subbase under adverse moisture condion leading to cracking of the unsupported concrete slab.

3.7 Concrete Strength

Since concrete pavements fail due to bending stresses, it is necessary that their design is based on the flexural strength of concrete. Where there are no facilities for determining the flexural strength, the mix design may be carried out using the compressive strength values and the following relationship:

$$f_f = 0.7 \sqrt{f_{ck}} \qquad \ldots 3.3$$

where,

f_f = flexural strength, MPa

f_{ck} = characteristic compressive cube strength, MPa

For Low volume roads, it is suggested that the 90 day strength may be used for design since concrete keeps on gaining strength with time. The 90 day flexural strength may be taken as 1.10 times the 28 day flexural strength or as determined from laboratory tests. 90 day compressive strength is 20 percent higher than the 28 day compressive strength. Heavy traffic may be allowed after 28 days.

The concrete mix should be so designed that the minimum flexural strength requirement in the field is met at the desired confidence level. For rural roads, the tolerance level (accepted proportion of low results), can be taken as 1 in 20. The normal variate, Z_a, for this tolerance level being 1.65, the target average flexural strength is obtained from the following relationship:

$$S = S^1 + Z_a \sigma \qquad \text{... 3.4}$$

where,

S	=	target average flexural strength, at 28 days, MPa
S^1	=	characteristic flexural strength, at 28 days, MPa
Z_a	=	normal variate, having a value of 1.65, for a tolerance factor of 1 in 20
σ	=	expected standard deviation of field test samples, MPa;

Table 3.3 gives the values of expected standard deviation of compressive strength.

Table 3.3 Expected Values of Standard Deviation of Compressive Strength

Grade of Concrete	Standard Deviation for Different Degrees of Control, MPa		
	Very Good	**Good**	**Fair**
M 30	5.0	6.0	7.0
M 35	5.3	6.3	7.3
M 40	5.6	6.6	7.6

Flexural strength can be derived from the Equation 3.3.

For pavement construction for rural roads, it is recommended that the characteristic 28 day compressive strength should be at least 30 MPa and corresponding flexural strength (third point loading) shall not be less than 3.8 MPa.

3.8 Modulus of Elasticity and Poisson's Ratio

The Modulus of Elasticity, E, of concrete and the Poisson's ratio may be taken as 30,000 MPa and 0.15 respectively.

3.9 Coefficient of Thermal Expansion

The coefficient of thermal expansion of concrete, α, may be taken as:

$$\alpha = 10 \times 10^{-6} \text{ per } ^{\circ}\text{C}.$$

3.10 Fatigue Behaviour of Concrete Pavement

For most rural roads, fatigue behavior is not important because of low volume of commercial vehicles. In case a rural road forms a connecting link between two important roads or if the road connects several villages, there can be significant amount of traffic consisting of buses and trucks due to agriculture, construction and social activities, and fatigue behavior of pavement slab may be considered in such cases. Fatigue equations of IRC:58 cannot be used because they are valid for 90 percent reliability. Following fatigue equation (MEPDG, **Appendix III**, IRC:58) for 60 percent reliability is recommended rural village roads.

$$\log_{10} N_f = \frac{SR^{-2.222}}{0.523} \qquad \ldots 3.5$$

Where N_f is fatigue life of a pavement subjected to stresses caused by the combined effect of wheel load of 50 kN and temperature gradient. If the number of heavy vehicles are large, fatigue analysis should be done for the spectrum axle load recommended in IRC:58. Influence of light commercial vehicles is negligible. Occasional heavy loads may not affect the pavements since the subgrade is weak only during certain period in the monsoons/post monsoon periods and only worst value of subgrade strength is considered in design. Concrete also keeps on gaining strength with time.

SR = stress ratio defined as: -

$$SR = \frac{\text{flexural stress due to wheel load and temperature}}{\text{flexural strength}}$$

4 DESIGN OF SLAB THICKNESS

4.1 Critical Stress Condition

Concrete pavements are subjected to stresses due to a variety of factors and the conditions which induce the highest stress in the pavement should be considered for analysis. The factors commonly considered for design of pavement thickness are traffic loads and temperature gradients. The effects of moisture changes and shrinkage, being generally opposed to those of temperature and are of smaller magnitude, would ordinarily relieve the temperature effects to some extent and are not normally considered critical to thickness design.

For the purpose of analysis, two different regions in a pavement slab edge and corner are considered critical for pavement design. Effect of temperature gradient is very less at the corner, while it is much higher at the edge. Concrete pavements undergo a daily cyclic change of temperature differentials, the top being hotter than the bottom during the day and opposite is the case during the night. The consequent tendency of the pavement slabs to curl upwards (top convex) during the day and downwards (top concave) during the night, and restraint offered to the curling by self-weight of the pavement induces stresses in the pavement, referred to commonly as curling stresses. These stresses are flexural in nature, being tensile, at bottom during the day, (**Fig. 4.1**) and at top during night (**Fig. 4.2**). As the restraint offered to curling at any section of the slab would be a function of weight of the slab, it is obvious that corners have very little of such restraint. Consequently the temperature stresses induced in the pavement are negligible in the corner region.

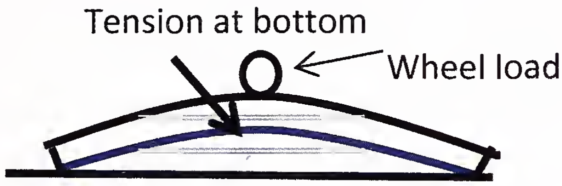


Fig. 4.1 Tensile Stresses at the Bottom Due to Curling During Day

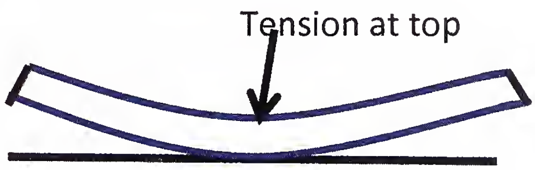


Fig. 4.2 Tensile Stresses at the Top Due to Curling During Night

The corner tends to bend like a cantilever; giving rise to tension at the top while the tension is at bottom in case for edge loading. Deflections due to wheel loads are larger at the corner causing displacement of weaker subgrade resulting in loss of support under repeated loading and consequent corner breaking. A shorter transverse joint spacing imparts safety to a panel due to load sharing by the adjacent slabs because of better load transfer across the transverse joints since dowel bars are not recommended in low volume roads except near a permanent structure.

Wheel load stresses for interior loading are lower than those due the edge and corner loading. For low volume roads carrying a low volume of traffic, heavy vehicles are not frequent and the chance that highest axle load will act when the temperature gradient also is highest is likely to be of rare occurrence. The maximum tensile stresses in the edge region of the slab will be caused by simultaneous occurrence of wheel loads and temperature differentials. This would occur during the day at the bottom in case of interior and edge regions.

4.2 Calculation of Stresses

4.2.1 *Edge stresses*

4.2.2.1 Load stresses at edge

Fig. 4.3 shows a slab subjected to a load through a dual wheel set of a commercial vehicle applied at the edge region.

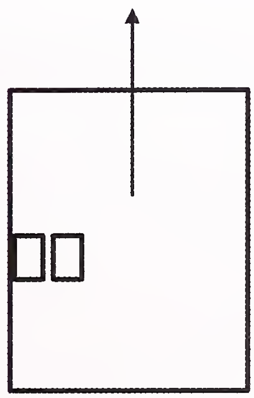


Fig. 4.3 Wheel Load at Pavement

Widely validated and accepted Westergaard's equation (15) for edge loading is recommended for the computation of edge stresses caused by single or dual wheel at the edge

$$\sigma e = \frac{3(1+\mu)P}{\pi(3+\mu)h^2}[\ln(\frac{Eh^3}{100ka^4})+1.84-\frac{4\mu}{3}+\frac{1-\mu}{2}+\frac{1.18(1+2\mu)a}{l}] \quad \text{... 4.1}$$

For μ = 0.15, Equation 4.1 reduces to Equation

$$\sigma_e = \frac{0.803P}{h^2}[4\log(\frac{l}{a})+0.666(\frac{a}{l})-0.034] \quad \text{... 4.2}$$

$$\delta_e = \frac{\sqrt{2+1.2\mu}P}{\sqrt{Eh^3k}}\left[1-(0.76+0.4\mu)\frac{a}{l}\right] \quad \text{... 4.3}$$

where,

σ_e = load stress in the edge region, MPa

δ_e = deflection at the edge due to a single wheel load

P = Single wheel Load, N

h = pavement slab thickness, mm

μ = Poisson's ratio for concrete

E = Modulus of elasticity for concrete, MPa

k = Modulus of subgrade reaction of the pavement foundation, MPa/m

l = radius of relative stiffness, mm

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

a = radius of the equivalent circular area in mm

= $(\frac{P}{\pi * p})^{0.5}$ where p is tyre pressure

The Equations 4.1 and 4.2 are valid only for circular area. Equation 4.3 can be used for the evaluation of in-place k value of the subgrade using FWD at the edge.

When a load is applied by a dual wheel, Equations 4.1 and 4.2 can be used for the stress computation due to dual wheel by computing the radius of the equivalent circular area as shown below.

The contact areas of two wheels and the area in-between the two contact areas shown in **Fig. 4.4** are obtained and the radius of the equivalent circular is then computed as given below.

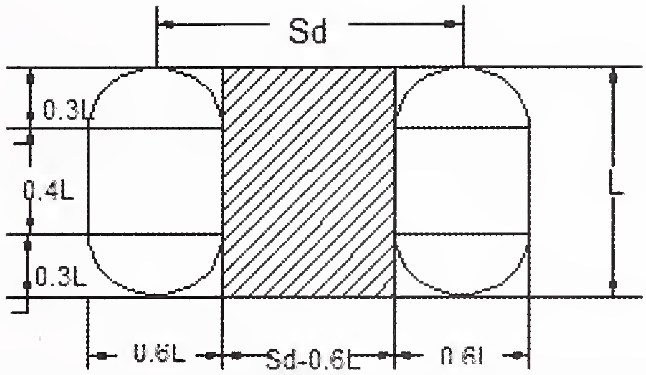


Fig. 4.4 Computation of Equivalent Radius of Contact Area for Dual Wheel Load

where,

L = Length of contact area

S_d = spacing between the centres of dual wheel

P_d = Load on one wheel of dual wheel set

$$L = \sqrt{\frac{P_d}{0.5227p}} \quad \text{where p is tyre pressure} \qquad \text{... 4.4}$$

The area of an equivalent circle is (**Fig. 4.4**)

$$\pi a^2 = 2 \times 0.5227L^2 + (S_d - 0.6L)\,L = 0.4454L^2 + S_d L \qquad \text{... 4.5}$$

Substituting L from Equation above yields

$$\pi a^2 = \frac{0.8521P_d}{p} + S_d\sqrt{\frac{P_d}{0.5227p}} \qquad \text{... 4.6}$$

The radius of equivalent circular contact area is

$$a = \sqrt{\frac{0.8521P_d}{p\pi} + \frac{S_d}{\pi}\left(\frac{P_d}{0.5227p}\right)^{\frac{1}{2}}} \qquad \text{... 4.7}$$

In case of dual wheel, the above value of a is to be used in the edge stress Equation 4.1 and the stresses are computed for the total wheelload.

A large edge deflection measured by Benkelman beam or FWD as compared to that computed from Equation 4.3 is indicative of loss of support.

4.2.1.2 Temperature stresses at edge

Bradbury's equation given by Equation 4.8 is recommended for the stress computation for the linear temperature gradient across the depth of the slab

$$\sigma_{te} = \frac{E\alpha t}{2}C \qquad \text{... 4.8}$$

α = Coefficient of thermal expansion

t = Temperature difference (°C) between the top and the bottom of the slab

σ_{te} = Temperature stress in the edge region, MPa

C = Coefficient depending upon the ratio of length(l) or width(b) and radius of relative stiffness.

The maximum temperature differential can be taken as bi-linear (**Appendix II**) and consists of both linear and non-linear parts. Equation 4.8 is used for the linear part only across the full depth. **Appendix II** gives equations for the computation of the curling stresses due to linear part from mid depth to the top surface. **Table 4.1** gives default values of temperature differentials in different zones in India as recommended by Central Road Research Institute over thirty years back. If data is available, local values of the temperature differential may be used.

Table 4.1 Recommended Temperature Differentials for Concrete Slabs

Zone	States	Temperature Differential °C in Slabs of Thickness		
		150 mm	200 mm	250 mm
i)	Punjab, Haryana, U.P., Uttranchal, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Arunachal Pradesh, Tripura, Himachal Pradesh, Rajasthan, Gujarat and North M.P., excluding hilly regions	12.5	13.1	14.3
ii)	Bihar, Jharkhand, West Bengal, Assam and Eastern Orissa excluding hilly regions and coastal areas	15.6	16.4	16.6
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
iv)	Kerala and South Tamil Nadu excluding hilly regions and coastal areas	15.0	16.4	17.6
v)	Coastal areas bounded by hills	14.6	15.8	16.2
vi)	Coastal areas unbounded by hills	15.5	17.0	19.0

For a given length and a width of a pavement slab, the C value is computed in the excel sheet attached with the guidelines through regression equations from the relation between l/l or b/l and C determined from Bradbury's curve where 'l' is value of radius of relative stiffness of the slab and the foundation.

The temperature gradient across the depth is usually non-linear and the maximum day temperature difference between the surface and the mid depth is nearly double of that between the mid depth and the bottom of the slab. This causes reduction in temperature stresses at the bottom as explained in the **Appendix II**.

4.3 Pavement Design

A programed excel sheet is provided for quick computation of thickness of pavements. Minimum pavement slab thickness shall be taken as 150 mm. Three cases are considered in the excel sheets for pavement design.

Case 1

Stresses due to 50 kN dual wheel load only for traffic less than 50 CVPD. Most of the low volume roads are likely to fall in this category

Case 2

Combined stresses due to 50 kN dual wheel load and temperature gradient for traffic greater than 50 and less than 150 CVPD

Case 3

Fatigue analysis for stresses due to 50 kN dual wheel load and temperature for traffic greater than 150 CVPD and less than 450 CVPD. Very few low volume roads may come under this category.

4.4 Reinforcement

Plain concrete jointed slabs for rural roads do not require reinforcement.

4.5 Recommended Design Procedure (Refer Illustrative Example Appendix I)

1) Select design wheel load (recommended as dual 50 kN), concrete flexural strength, effective modulus of subgrade reaction, modulus of elasticity of concrete, Poisson's ratio, coefficient of thermal expansion of concrete and zone and input them in the excel spread sheet.

2) Select a tentative design thickness of slab, k value, joint spacing and flexural strength of concrete.

3) If the total traffic is less than 50 CVPD for Case 1, only wheel load stresses are computed at the edge for a dual wheel loaded of 50 kN with a tyre pressure of 0.80 MPa.

4) If the computed edge stress is less than the 90 day modulus of rupture, the design is safe.

5) If the traffic is greater than 50 CVPD and less than 150 CVPD for Case 2, maximum edge stress is computed by adding wheel load stresses and curling stresses. Equation 4.7 gives the curling stresses in which 't', the linear part of the temperature gradient, is 0.667 of the temperature differential given in **Table 4.1**. The compressive stress due to bi-linear temperature variation as explained in **Appendix II** is subtracted from that due to the linear part to get the actual curling stress due to non-linear temperature gradient.

6) If the total of wheel load stress and the curling stress is less than the 90 day modulus of rupture, the design is safe and acceptable. Excel sheet does all the computations.

7) If the traffic is more than 150 CVPD and less than 450 CVPD, fatigue of concrete is considered for examination of the safety of the pavements. For a computed total stress due to wheel load and temperature, stress ratio (SR) is computed and the allowable load repetitions are obtained from the Equation 3.5. Assuming that only ten percent (default value) of the total traffic has axle loads are equal to 100 kN, compute the number of repetitions of 100 kN axle loads (dual wheel load = 50 kN) expected in 20 years. Ratio of expected repetition and allowable repetition is the cumulative fatigue damage and its value should be less than 1. The spread sheet gives all the computations and various trials can be made instantly. Traffic survey is very important when volumes of vehicles are large. If there are too many axle loads heavier than 100 kN, the fatigue damage is to be computed for the axle load spectrum using the fatigue Equation 3.5.

4.6 Pavement Thickness for Traffic up to 50 CVPD.

A sub-base of 75 mm WBM over 100 mm GSB is considered. The subgrade soil has a CBR value of 4 Percent. The effective k value over WBM is taken as 42 MPa/m (35 + 20 percent of 35 MPa/m). Thickness values for a dual wheel load of 60 kN are 160 mm for all the joint spacing of 2.50 m, 3.25 m and 4.00 m since temperature stresses are not considered. For other k values, excel sheet can be used to get the thickness. A minimum thickness of 150 mm is recommended even for higher modulus of subgrade reaction.

4.7 Pavement Thickness for Traffic from 50 to 150 CVPD

Table 4.2 gives slab thickness for traffic from 50 to 150 CVPD. The thickness given in the table is applicable to common subgrade soils, such as, clay, silt and silty clay, with a CBR value of 4 percent. A sub-base of 75 mm WBM over 100 mm GSB is considered. The effective k value over WBM is taken as 42 MPa/m (35 + 20 percent of 35 MPa/m). Thickness values are indicated for joint spacing of 2.50 m, 3.25 m and 4.00 m.

Table 4.2 Concrete Pavement Thickness for traffic between 50 and 150 CVPD and a Subgrade CBR of 4%

Joint Spacing in Metres	Pavement Thickness (mm) Wheel Load-50 kN					
	Zone-I	Zone-II	Zone-III	Zone-IV	Zone-V	Zone-VI
4.00	180	180	190	180	180	180
3.25	170	170	170	170	170	170
2.50	160	160	160	160	160	160

Note : Design thickness values are based on the 90 day flexural strength

4.8 Pavement Thickness for Traffic Greater than 150 CVPD

For traffic greater than 150 CVPD, fatigue also is to be considered and the thicknesses are shown in **Table 4.3** for M30 concrete for a traffic of 250 CVPD having a subgrade CBR of 8 percent. It has a cementitious base with a total thickness of 200 mm. The effective k value for design is 100 MPa/m (**Table 3.2**). Fatigue cracking of pavement slab is considered because of heavy traffic. Thicknesses for all six zones are given. Zone 3 has highest temperature differential and hence it gives the highest thickness because of higher curling stresses.

Table 4.3 Concrete Pavement Thickness over for a Traffic of 250 CVPD

Thickness of cementitious subbase = 200 mm, (100 + 100) take k = 100 MPa (subgrade CBR = 8) Percentage of CVPD with 50 kN dual wheel load = 10

Joint Spacing M	Pavement Thickness (mm)					
	Wheel Load-50 kN					
	Zone-I	Zone-II	Zone-III	Zone-IV	Zone-V	Zone-VI
4.00	240	250	260	260	250	250
3.25	220	230	240	230	230	230
2.50	200	210	210	210	210	210

Note : Design thickness values are based on the 90 day flexural strength

4.9 Roller Compacted Pavement

Roller Compacted Concrete Pavement (RCCP) as per MORD specifications (34) can also be used for the construction of pavements for low volume roads. RCCP is very popular for low volume roads in developed countries. In such pavements, the cracks may develop on its own to form joints. It has been successfully used in West Bengal also under PMGSY programme. Assuming a thickness of RCCP as 200 mm, the spacing of the cracks to be 6 m, an initial of traffic of 100 CVPD, a k value of 100 MPa/m , Zone I, 90 day modulus of rupture = 4.22 MPa, the total of wheel load and curling stress from excel sheet for a 200 mm slab = 3.60 MPa < 4.22 MPa. The thickness of 200 mm is appropriate.

5 JOINTS

5.1 Types of Joints

Low volume roads have generally a single-lane carriageway with a lane width of 3.75 m which is concreted in one operation. In some cases, the width may be lower than 3.75 m for narrow city streets and interior roads of villages. Thus, there is no need for a longitudinal joint for single-lane rural roads except when the pavement width is about 4.5 m in case of causeways.

Joints for low volume roads can be of four types as given below:

1) Contraction joints
2) Construction joints
3) Expansion joints
4) Longitudinal joints

5.2 Spacing of Joints

5.2.1 *Contraction joints*

These are transverse joints whose spacing may be kept as 2.50 m - 4.00 m. The curling stresses along the longitudinal direction depend to a great extent on the spacing of the transverse joints. If the joint spacing is 2.5 m, curling stresses are practically negligible as can be verified from the excel sheet of the guidelines. The contraction joints can be formed by sawing the pavement slabs within twenty four hours of casting of concrete. Practice abroad indicates that the narrow contraction joints 3 to 5 mm wide perform well with better riding quality. High Density Polyethylene (HDPE) strips 3 mm to 5 mm thick with suitable tensioning and intermediate support for keeping the strip in position can also be used for creating joints. HDPE strips are left in place. Metal strips and steel T-section are the other options for joint forming. The joint depth can extend from one fourth to one third the depth of the concrete. The details of the contraction joints are shown in **Figs. 5(a) to 5(o)**. Bituminous based sealants as per IS1834 can be used.

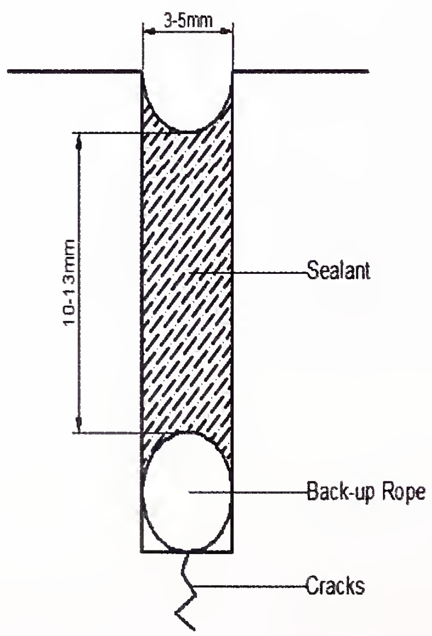


Fig. 5(a) Contraction/Construction Joint

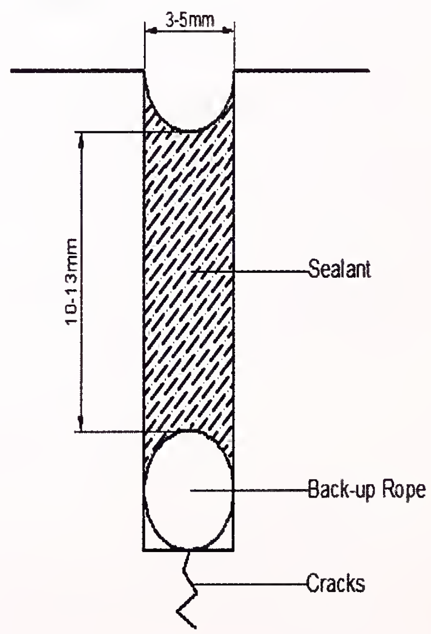


Fig. 5(b) Longitudinal Joint

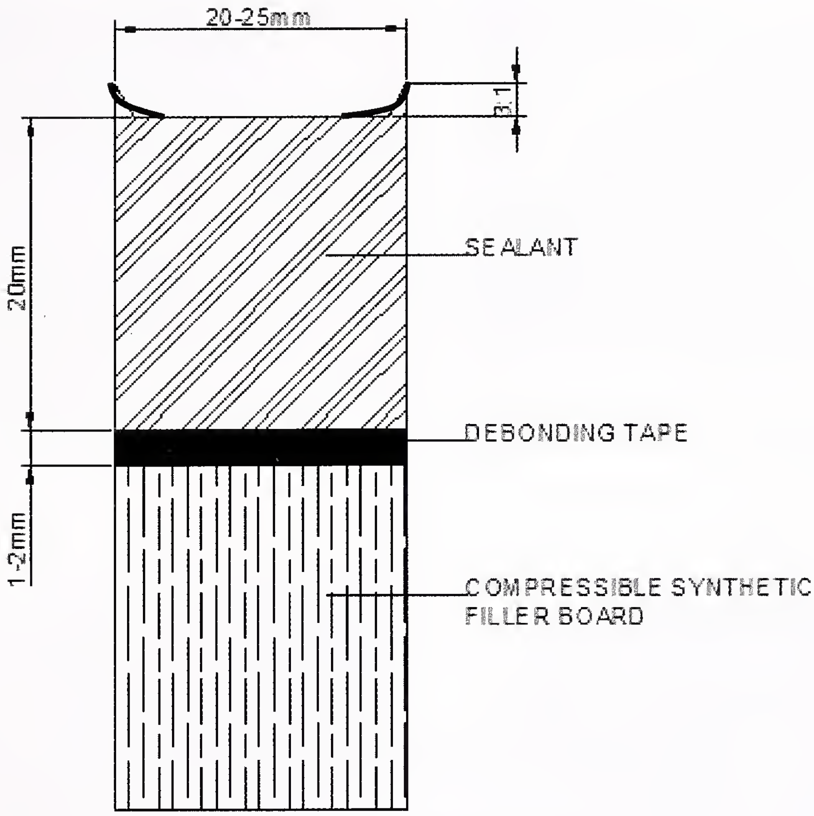
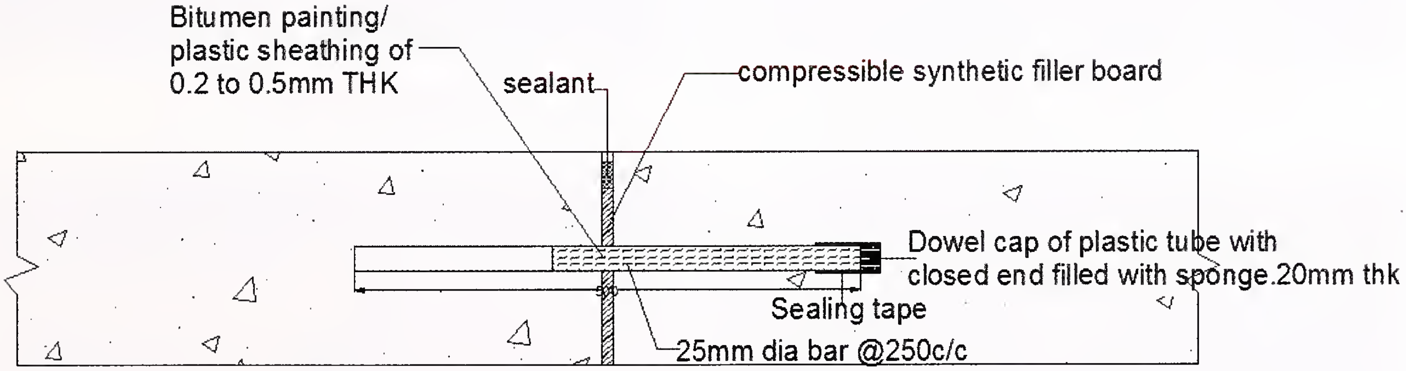
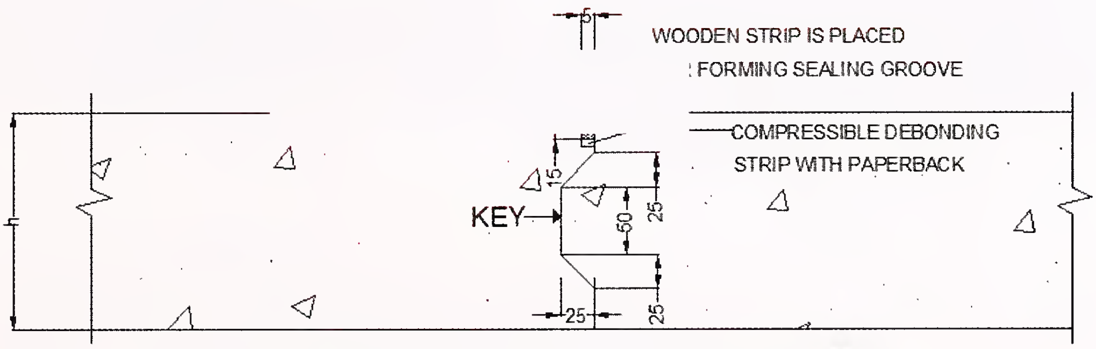


Fig. 5(c) Expansion Joint



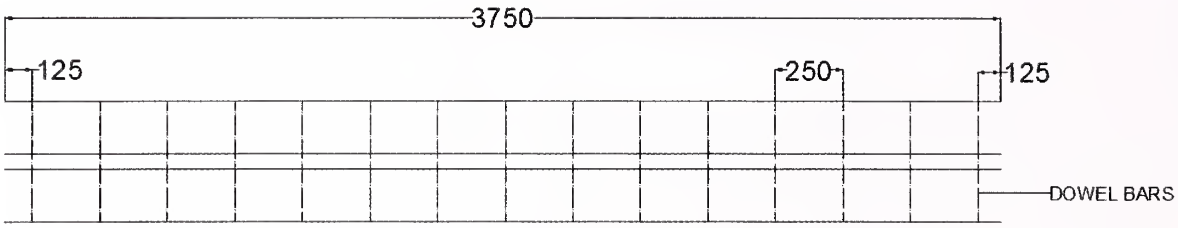
EXPANSION JOINT

Fig. 5(d) Details of an Expansion Joint with Dowel



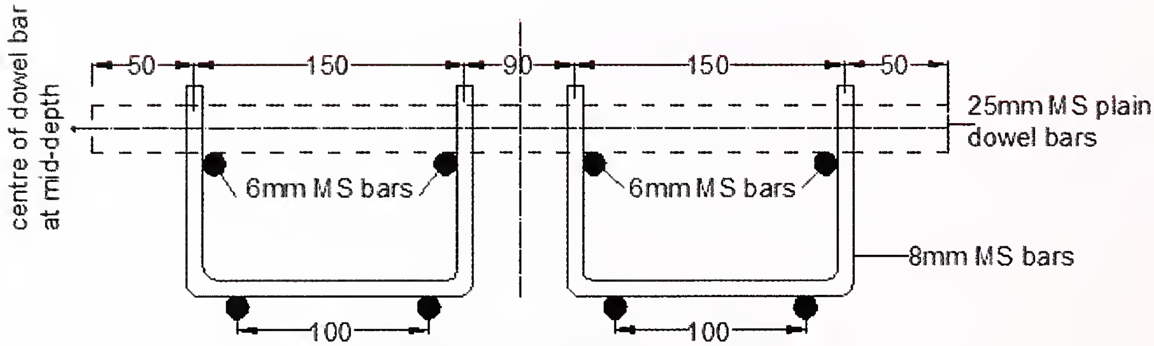
DETAILS OF KEYED CONSTRUCTION JOINT

Fig. 5(e) Construction Joints



Top view of Transverse joint showing Dowel bars

Fig. 5(f) Details of Dowel Bar Spacing in a 3.75m Wide Pavement Slab



Details of dowel bar assembly for Contraction joint
in concrete pavement for low volume roads

Fig. 5(g) Dowel Bar Cradles

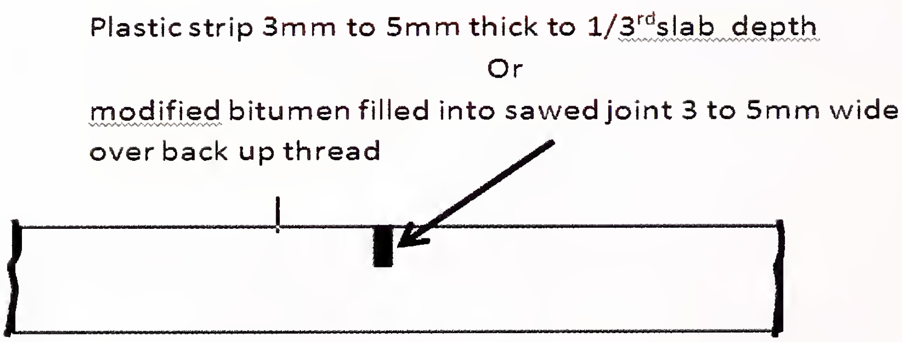


Fig. 5(h) Contraction Joints with Plastic Strip or Sawn Joint Filled with Hot Modified Bitumen

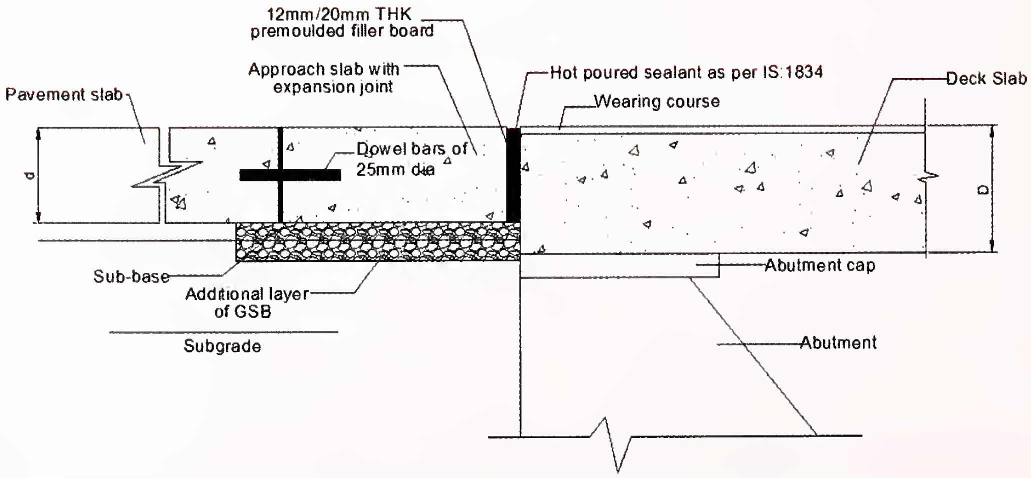


Fig. 5(i) Deck Slab and Expansion Joint in a Concrete Pavement

Fig. 5(j) A Close up View of Fixture of HDPE Separation Strip and Spacer Bar

Fig. 5(k) A View of HDPE Separation Strip and Spacer Bar

Fig. 5(l) Preparatory Work

Fig. 5(m) Typical Tightening Device

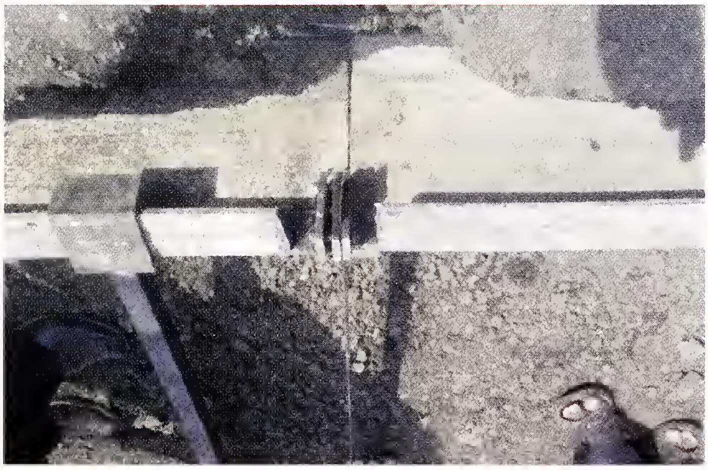


Fig. 5(n) Anchoring of Strip

Fig. 5(o) Completed Job-Strips in Stressed Position

5.2.2 *Construction joints*

Transverse construction joints shall be provided wherever concreting is completed after a day's work or is suspended for more than 90 minutes. **Fig. 5(e)** shows the details of a construction joint.

5.2.3 *Longitudinal joints*

Where the width of concrete slab exceeds 4.5 m as in the case of causeways, etc., it is necessary to provide a longitudinal joint as per the details shown in **Fig. 5(b)** in the mid-width of the slab.

5.2.4 *Expansion joints*

Transverse expansion joints are necessary for the concrete slabs abutting the bridges and culverts. The details of the joints are shown in **Figs. 5(c), 5(d) and 5(i)** .Two expansion joints may be provided near a culvert or a minor bridge to take care of expansion of the concrete slab as shown in **Fig. 5(i)**.

5.3 Load Transfer at Transverse Joints

Since low volume roads have lower wheel loads, the slab thickness can be in the range from 150 to 250 mm. The aggregate interlock at the contraction joints with discontinuity up to the one third/one fourth of the depth is itself adequate for load transfer and no dowel bars are necessary. **Figs. 5(a)** and **5(h)** show a contraction joint filled with hot poured modified bitumen. If slabs are cast in alternate panels, keyed joints can be formed as in **Fig. 5(e)**. Day's work should normally be terminated at a construction joint . At expansion joints, where the joints width may be 20 mm, dowel bars are required as shown in **Fig. 5(f)**. Dowel bars shall be 25 mm diameter, 450 mm long and spaced at 250 mm centre to centre. These shall be made out of MS steel plain bars, Fe 240.

In the case of Roller Compacted Concrete Pavements, the contraction joints may be formed by cutting joints concrete saw at the spacing of 8.0 m. If aesthetics of the road is not an important consideration, the sawing of joints may be omitted and the joints will form themselves by transverse cracking at regular intervals.

6 MATERIALS AND MIX DESIGN

6.1 Cement

Any of the following types of cement capable of attaining the design strength may be used.

i) Ordinary Portland Cement (OPC), 43 Grade, IS:8112
ii) Portland Blast Furnace Slag Cement conforming to IS:455
iii) Portland Pozzolana Cement (PPC) conforming to IS:1489 and
iv) Ordinary Portland Cement (OPC), 53 grade (blended with flyash)

If the soil has soluble salts like sulphates ($S0_3$) in excess of 0.5 percent of the soil, the cement used shall be sulphate resistant and shall conform to IS:12330. If the price of OPC, 43 grade and PPC is almost the same, preference may be given to PPC as it will result in a more durable concrete. If fly ash of required quality is available, a combination of OPC-43 and fly ash can be economical. OPC 53 grade is to be used only when a part of cement is replaced by flyash.

Cement may be supplied in packed form. For large sized projects, cement may be obtained in bulk form if a cement plant is nearby. Bulk cement shall be stored in vertical or horizontal silos. If cement in paper bags is proposed to be used, there shall be bag splitters with the facility to separate pieces of paper bags and dispose them off suitably. No paper pieces shall enter the concrete mix.

The mass of cementitious content (cement + fly ash/slag) or cement in the concrete mix used in rural roads shall not be less than 360 kg/cum and not more than 425 kg/cum.

6.2 Fly-Ash

Fly-ash can be used as a partial replacement of cement (OPC) up to an extent of 30 percent by weight of cementitious material if it needs the strength requirement. It reduces shrinkage and it also contributes to the development of long term strength because of the pozzolanic reaction. It reacts with the free lime liberated from cement thus inhibiting the alkali-silica reaction pond ash shall not be used.

Fly-ash shall conform to IS:3812-2004 and shall have the following properties shown in **Table 6.1**.

Table 6.1 Properties of Fly-Ash

1)	Specific surface area	Greater than 3,20,000 mm^2/gm
2)	Lime reactivity	Greater than 4.5 (N/mm^2)
3)	Loss on Ignition	Maximum 5 percent

6.3 Aggregates

6.3.1 Aggregates shall be natural material conforming to IS:383. The aggregates shall not be alkali-reactive. The limits of deleterious materials shall not exceed the values set out in IS:383. Incase the aggregates are not found to be free from dirt, the same may be washed and drained for at least 72 hours before batching. The coarse aggregates shall not have flakiness index more than 35 percent.

6.3.2 *Coarse aggregates*

Coarse aggregate shall consist of clean, hard, strong, dense, non-porous and durable pieces of crushed stone or crushed gravel and shall be devoid of pieces of disintegrated stone, soft, flaky, elongated, very angular or splintery pieces. The maximum size of coarse aggregate shall not exceed 25 mm. No aggregate which has water absorption of more than 5 percent shall be used in the concrete mix. Where the water absorption is more than 3 percent, the aggregates shall be tested for soundness in accordance with IS:2386 (Part V). After 5 cycles of testing, the loss shall not be more than 12 percent if sodium sulphate solution is used or 18 percent if magnesium sulphate solution is used. The Aggregates Impact Value (AIV) shall not be more than 30 percent.

Dumping and stacking of aggregates shall be done in an approved manner.

6.3.3 *Fine aggregates*

The fine aggregate shall consist of clean natural sand or crushed stone sand or a combination of the two and each individually shall conform to IS:383. Fine aggregate shall be free from soft particles, clay, shale, loam, cemented particles, mica and organic and other foreign matter. The fine aggregate shall not contain substances more than the following:

Clay lumps	1.0 percent
Coal and lignite	1.0 percent
Material passing IS sieve No. 75 micron	3.0 percent in natural sand and 8 percent in crushed sand produced by crushing rock.

6.3.4 *Blending of aggregates*

The coarse and fine aggregates shall be blended so that the material after blending shall conform to the grading given in **Table 6.2**. The same grading can be adopted in pavement constructed with roller compacted concrete.

Tarle 6.2 Aggregate Gradation for Concrete

Sieve Designation	Percentage Passing the Sieve by Weight
26.50 mm	100
19.00 mm	80-100
9.50 mm	55-75
4.75 mm	35-60
600 micron	10-35
75 micron	0-8

For concrete compacted by needle vibrators, screeds and hand tampers, the proportioning of the coarse and fine aggregates, cement and water should be done based on any standard procedure. Guidance in this regard may be had from IRC:44 or IS:10262. The workability at the point of placing shall be adequate for the concrete to be fully compacted and finished without undue flow.

6.3.5 *Water*

Water used for mixing and curing of concrete shall be clean and free from injurious amount of oil, salt, acid, vegetable matter or other substances harmful to the finished concrete. It shall meet the requirements stipulated in IS:456.

6.3.6 *Admixtures*

Admixtures conforming to IS:6925 and IS:9103 may be used to improve workability of concrete or extension of the setting time.

6.3.7 *Storage of materials*

6.3.7.1 General

All materials shall be stored in proper places so as to prevent their deterioration or satisfactory quality and fitness for the work. The storage space must also permit easy inspection, removal and storage of materials. All such materials, even though stored in approved godowns/places, shall be subjected to acceptance test prior to their immediate use.

6.3.7.2 Aggregates

Aggregate stockpiles may be made on ground that is denuded of vegetation, is hard and well drained. If necessary, the ground shall be covered with 50 mm wooden planks or gunny bags or hessian cloth.

Coarse aggregates shall be delivered to the site in two separate sizes. Aggregates placed directly on the ground shall not be removed from the stockpile within 150 mm of the ground until the final cleaning up of the work, and then only the clean aggregate will be permitted to be used. Rescreening of aggregates before use may be resorted to if aggregates are found contaminated with soil or excessive fine dust.

In the case of fine aggregates, these shall be deposited at the mixing site not less than 8 hours before use and shall have been tested and approved.

6.3.7.3 Cement

Cement shall be transported, handled and stored in the site in such a manner as to avoid deterioration or contamination. Cement shall be stored above ground level in perfecty dry and water-tight sheds and shall be stacked not more than eight bags high. Wherever bulk storage containers are used their capacity should be sufficient to cater to the requirement at site for a week and should be cleaned at least once every 3 months.

Each consignment shall be stored separately so that it may be readily identified and inspected and cement shall be used in the sequence in which it is delivered at site. Any consignment or part of consignment of cement which had deteriorated in any way, during storage, shall be subjected to tests, and if found sub-standard shall not be used in the works and shall be removed from the site.

Proper records on site in respect of delivery, handling, storage and use of cement shall be maintained at site and these records shall be available for inspection at all times. The daily test certificate issued by cement factory shall be collected and documented for future reference.

A monthly return shall be made showing the quantities of cement received and issued during the month and in stock at the end of the month.

6.4 Mix Design

6.4.1 *Roller compacted concrete pavement (RCCP)*

Mix design for RCCP is totally different from the design of mix for a conventional cement concrete pavement as the Abrahm's water/cement ratio law does not hold good. Roller Compacted Concrete is a zero-slump concrete. Details of mix design are given in the MORD Specifications (34).

The mix shall be proportioned by weight of all ingredients such that the desired target mean strength is achieved. The mix design shall be based on the flexural strength of concrete. The moisture content shall be selected so that mix is dry enough to support the weight of a vibratory roller, and yet wet enough to permit adequate distribution of paste throughout the mass during mixing, laying and compaction operations. The water content may be in range of 4 to 7 percent by weight of dry materials including cement. Trial mixes may be made with water contents in the range of 5-7 percent and shall be determined by trial mixes with water contents at 1.0 percent intervals. The optimum moisture content which gives the maximum density shall be established. The exact moisture content requirement in the mix shall be established after making field trial construction as explained in Clause 7.2.

Using the moisture content so established, a set of six beams and cubes shall be prepared for testing on the 7th and 28th days. If the flexural strength achieved is lower than the desired strength, the trials should be repeated after increasing the cement/fly ash content till the desired strength is achieved.

6.4.2 *Concrete compacted by vibratory screeds, needle vibrators, hand tampers and plate compactors*

Mix design for concrete compacted by screeds, needle vibrators and hand tampers shall be done on the basis of any recognized procedure, such as, IRC:44 "Guidelines for Concrete Mix Design for Pavements". The mix design is initially carried out in the laboratory, keeping in view the desired characteristic strength, the degree of workability, water-cement ratio, size of aggregates. A slump of 30 to 50 mm at paving site may be acceptable for compaction by hand-operated machines.

6.4.3 *Self compacting concrete*

Self Compacting Concrete (SCC) can flow easily and requires little compaction. It consists of additional ingredients like ultra-water reducer and silica fumes. It may cost a little higher but it can be conveniently placed. Trial stretches in Maharashtra for rural roads were done with success.

6.4.3 *Design mix*

The laboratory trial mixes shall be tried out in the field, and any adjustments that are needed are carried out during the trial length construction.

7 CONSTRUCTION

7.1 Sub-base

The Concrete pavement for rural roads shall be laid on a properly compacted sub-base which shall be constructed on a subgrade of selected coarse grained soil of 300 mm thickness. The sub-base may be composed of granular material or stabilized soil material as listed below: -

a) Granular material

   i) Water Bound Macadam (WBM)

   ii) Wet Mix Macadam (WMM)

   iii) Well-graded granular materials, like, natural gravel, crushed slag, crushed concrete, brick metal, laterite, kankar, etc. conforming to IRC:63

   iv) Well-graded soil-aggregate mixtures conforming to IRC:63

b) Stabilised soil with cementitious material as per IRC:89

Local soil or moorurn stabilized with cement, lime, lime-fly ash, lime rice husk ash as found appropriate giving a minimum unconfined strength as Clauses 3.6.2.3 and 3.6.2.3 after 7 days and 28 days of curing for cement and lime/lime-flyash respectively, may be used. Commercially available proprietary stabilizers may also be used if they are found to give good performance in different trials in India. These stabilizers should not have leachate which may pollute underground water or the water in nearby fields. Accelerated curing at 50ºC up to three days may be correlated with 28 day strength for quick results. Reference may be made to IRC:SP:89 for guidance as regards design of mixes with cement or lime or lime-soil mixtures. For proprietary soil stabilsers marketed commercially, laboratory tests should be done thoroughly to evaluate the design parameter. Soil and stabilisers can be mixed easily by rotovators which are widely used by farmers. The thickness will be as per Clause 3.6.2.

7.2 Construction of Trial Length

In order to determine and demonstrate the suitability of the construction equipment and methodology, a trial length of at least 30 m shall be constructed outside the main road and shall be laid on two different days. Mixes shall be produced from the mixers intended to be used in the actual construction. The laying operation also shall be done by employing roller proposed in the case of Roller Compacted Concrete Pavement and screeds, etc. in the case of normal concrete. Flowability of Self-Compacting Concrete (SCC) and the working of pouring equipment can be examined. After the construction of the trial length in the case of Roller Compacted Concrete, the in-situ density of the freshly laid material shall be determined by sand replacement method with 200 mm diameter density holes. Three density holes shall be made at locations equally spaced along a diagonal that bisects the trial length and the average of the three densities shall be determined. This reference density shall be used for determining the field density of day-to-day work. The density during the normal work shall not be less than 97 percent of this reference density. These density holes shall not be made within the strip 500 mm from the edges. In case of screed-vibrated concrete pavement, the in-situ density of the cores shall be such that the air voids are not more than 3 percent. The air-voids shall be derived from the difference between the theoretical maximum dry density of the concrete calculated from the specific gravities of the constituents of the concrete mix and the average value of the three direct density measurements on cores. The crushing strength of cylindrical cores shall be determined and the corresponding crushing strength of cubes determined by the formula:

Crushing strength of cylindrical specimens =0.8 x crushing strength of cubes

When the height to diameter ratio is 2

The crushing strengths of cylinders with height to diameter ratio between 1 and 2 may be corrected to a standard cylinder of height to diameter ratio of 2 by multiplying with the correction factor obtained from the following equation:

$$f = 0.11\,n + 0.78 \qquad \text{... 7.1}$$

where,

f = correction factor

n = height to diameter ratio

The number of cores shall be a minimum of three. The concrete in the work represented by the core test shall be considered acceptable if the average equivalent cube strength of the cores is at least 85 percent of the cube strength of the grade of concrete specified for the corresponding age and no individual core has strength less than 75 percent. Flexural strength is of vital importance for thickness design of pavement.

Since it is difficult to get cores of sufficient height for the compression test, a better method can be to make use of Indirect Tensile Strength (ITS), also known as split tensile strength. Even in a core of height 150 mm, two test samples can be made for ITS test.

Flexural strength of concrete can also be obtained from the relation

$$F_{ITS} = 0.67\, f_f \qquad \text{... 7.2}$$

where,

F_{ITS} is the ITS of the cored sample

Trials must be done to sort out various problems that may arise before the construction of the pavement slab begins. The trial length shall satisfy surface levels and regularity, and demonstrate that the joint- forming methodology is satisfactory. The hardened concrete shall be cut over 3 m width and reversed to inspect the bottom surface for any segregation taking place. The trial length shall be again constructed after making necessary changes in the gradation of the mix to eliminate segregation of the mix. It shall be ensured that the lower surface shall not have honey-combing and the aggregates shall not be held loosely at the edges.

Paving should be done continuously and the contraction joints will have to be cut with a concrete saw or discontinuity can be made by preplacing 3 to 5 mm HDPE strips, metal strips or steel T-section to one third the depth of the pavement slab from the surface.

After the trial length is found to be satisfactory and is approved, the material, mix properties, moisture content, cement/fly ash content, mixing, laying, compaction plant and entire construction procedure shall not be changed. In case any change is desired, the entire procedure shall be repeated.

7.3 Batching and Mixing

The batching plant/concrete mixer shall be capable of proportioning the materials by weight, each type of material being weighed separately. The capacity of the batching and mixing shall be at least 25 percent higher than the proposed capacity for the laying arrangements. The type of the mixer may be selected subject to demonstration of its satisfactory performance during the trial length construction. The rated capacity of the mixer shall not be less than 0.3 cum. The weighing mechanism shall be checked periodically and calibrated, to yield an accuracy of ± 2 percent in the case of aggregates and ± 1 percent in the case of cement, fly ash and water. When fly ash is added, the mixing time shall be increased by a minute to ensure proper mixing.

7.4 Transporting

The mix shall be discharged immediately from the mixer, transported directly using wheel barrows, iron pans or tippers to the point where it is to be laid and protected from the weather by covering with tarpaulin during transit. The concrete shall be transported continuously to feed the laying equipment to work at a uniform speed in an uninterrupted manner.

7.5 Formwork

All side forms shall be of mild steel channel sections of depth equal to the thickness of the pavement. The sections shall have a length of at least 3.0 m. Wooden forms shall be capped along the inside upper edge with 30-50 mm angle iron well recessed and kept flush with the face of the wooden forms. The forms shall be held firmly in place by stakes driven to the ground. The supply of forms shall be sufficient to permit them to be taken out only after 12 hours after the concrete has been placed. All forms shall be cleaned and oiled each time they are used. The forms shall be jointed neatly and set correctly to the required grade and alignment.

Bulkheads of suitable dimensions shall be used at construction joints. Formwork can be dispensed with if a paver is used.

7.6 Placing Concrete

Concrete shall be deposited on the sub-base to the required depth and width in successive batches and in continuous operation. Care shall be taken to see that no segregation of materials results. The placing and spreading can be done by a paver, if available, or by manual means. In the latter case spreading shall be as uniform as possible and shall be accomplished by shovels. While being placed, the concrete shall be rodded with suitable tools so that the formation of voids or honeycomb pockets is avoided. Semi self-compacted concrete can be poured directly over the compacted sub-base requiring little compaction.

7.7 Compaction

7.7.1 The compaction shall be carried out immediately after the material is laid with necessary surcharge (extra loose thickness) and leveled. The spreading, compacting and finishing of the concrete shall be carried out as rapidly as possible and the operation shall be so arranged as to ensure that the time between the mixing of the first batch of concrete in any transverse section of the layer and the final finishing of the same shall not exceed 90 minutes when the concrete temperature is above 25 and below 30°C and 120 minutes if less than 25°C. This period may be reviewed in the light of the results of the trial length but in no case shall it exceed 2 hours. Work shall not proceed when the temperature of the concrete exceeds 30°C. The concreting shall be terminated when the ambient temperature is 5°C during descending temperature. It is desirable to stop concreting when the ambient temperature is above 35°C. Night concreting may be resorted to when the day temperature in summer is not congenial for concreting. After compaction has been completed, roller shall not stand on the compacted surface for the duration of the curing period except during commencement of next day's work near the location where work was terminated the previous day in the case of RCCP.

7.7.2 *Compaction by vibratory roller*

Double drum smooth-wheeled vibratory rollers of minimum 80 to 100 kN static weight are considered to be suitable for rolling the Roller Compacted Concrete. In case any other roller is proposed, the same shall be got approved after demonstrating its satisfactory performance. The number of passes required to obtain maximum compaction depends on the thickness of the concrete, the compatibility of the mix, and the weight and type of the roller, etc. The total requirement of rollers for the job shall be determined during trial construction by measuring the in-situ density and the scale of the work to be undertaken.

In addition to the number of passes required for compaction there shall be a preliminary pass without vibration to bed the lean concrete down and again a final pass without vibration to remove roller marks and to smoothen the surface.

Special care and attention shall be exercised during compaction near joints, kerbs, channels, side forms and around gullies and manholes. In case adequate compaction is not achieved by the roller at these points, use of plate vibrator shall be made.

The final concrete surface on completion of compaction shall be well closed, free from movement under roller and free from ridges, low spots, cracks, loose material, pot-holes, ruts or other defects. The final surface shall be inspected immediately on completion and all loose, segregated or defective areas shall be corrected by using fresh lean concrete material laid and compacted. For repairing honeycombed surface, concrete with aggregates of size 10 mm and below shall be spread and compacted. It is necessary to check the level of the rolled surface for compliance. Any level/thickness deficiency should be corrected after applying concrete with aggregates of size 10 mm and below after roughening the surface. Similarly, the surface regularity also should be checked with 3 m straight edge. The deficiency should be made up with concrete with aggregates of size 10 mm and below during the rolling operation.

7.7.3 In the case of roller compacted concrete, the compaction shall be continued so as to achieve 97 percent of the compaction achieved in the trial length. The densities achieved at the edges, i.e., 0.5 m from the edge shall not be less than 95 percent of that achieved during the trial construction.

7.7.4 *Compaction by screed vibrators*

Compaction shall be achieved by a vibrating hand screed. As soon as concrete is placed, it shall be struck off uniformly and screeded to the cross-section desired. Needle vibrators may be employed to ensure compaction near the forms. The entire surface shall then be vibrated with screed resting on the side forms and being drawn ahead with a sawing motion, in combination with a series of lifts and drops alternating with lateral shifts. The aim of this first operation being compaction and screeding to the approximate level required. The surface shall then be closely inspected for any irregularities with a profile checking template and any needed correction made by adding or removing concrete, followed by further compaction and finishing in the second run.

7.8 Finishing

In the case of normal concrete just before the concrete becomes non-plastic, the surface shall be belted with a two-ply canvas belt not less than 200 mm wide and at least 1.0 m longer than the width of the slab. Hand belts shall have suitable handles to permit controlled uniform manipulation. The belt shall be operated with short strokes transverse to the carriageway centre line and with a rapid advance parallel to the centre line.

After belting, and as soon as surplus water, if any, has risen to the surface, the pavement shall be given a broom finish with an approved clean steel or fibre broom not less than 450 mm wide. The broom shall be pulled gently over the surface of the pavement from edge to edge. Adjacent strokes shall be slightly overlapped. Brooming shall be perpendicular to the centre line of the pavement and so executed that the corrugations thus produced shall be uniform in character and width, and not more than 1.5 mm deep. Brooming shall be completed before the concrete reaches such a stage that the surface is likely to be torn or unduly roughened by the operation. The broomed surface shall be free from porous or rough spots, irregularities, depressions, and small pockets, such as, may be caused by accidentally disturbing particles of coarse aggregate embodied near the surface.

After belting and brooming have been completed, but before the concrete has taken its initial set, the edges of the slab shall be carefully finished with an edge tool of 6 mm radius, and the pavement edge left smooth and true to line.

7.9 Transverse Joints

The contraction joints 3 to 5 mm wide shall be cut as soon as the concrete has undergone initial hardening and is hard enough to take the load of the joint sawing machine without causing damage to the slab. The sawing operation should be completed within 24 hours. The depth of sawing should be from 1/4 to 1/3 of the depth of the slab.

Alternatively, the joint can also be formed by pressing a mild steel T-section into the fresh concrete. Due care is to be exercised to remove bulging which may affect the riding quality. Metal strips of 3 mm to 5 mm width can also be placed before placement of concrete. HDPE strips 3 mm to 5 mm wide also can be used for creating contraction joints.

Transverse construction joints shall be placed wherever concreting is completed after a day's work or is suspended for more than 90 minutes. These joints shall be provided at the location of contraction joints. At all construction joints, steel bulk-heads shall be used to retain the concrete while the surface is finished. The surface of the concrete laid subsequently shall conform to the grade and cross-sections of the previously laid pavement. When positioning of bulk-head/stop-end is not possible, concreting to an additional 1 or 2 m length may be carried out to enable the movement of joint cutting machine so that joint grooves may be formed and the extra 1 or 2 m length is cut out and removed subsequently after concrete has hardened.

Expansion joints are provided at abutments of bridges and culverts. The width of the expansion joint shall be 20 mm.

The typical details of various joints are given from **Figs. 5(a) to (o)**. Crumb Rubber Modified Bitumen (CRMB) can be hot poured, to seal the joints. A thin synthetic rope should be inserted into the groove to prevent sealing compound from entering into the cracks. Such thin joints have better riding quality and no further widening is necessary. CRMB has the flexibility, durability and it is resistant to age hardening. If strips of HDPE 3 mm to 5 mm wide are used, no sealing is necessary since the strips are left embedded in the concrete.

7.10 Curing

As soon as the concrete surface is compacted, curing shall commence.

The initial curing shall be done by the application of curing compound followed by covering the pavement surface entirely with wetted burlap or jute mats. The covering shall be maintained fully wetted and in position for 24 hours after the concrete has been placed. The burlap shall be placed from suitable bridges without having to walk on the freshly laid concrete.

After the initial curing, the final curing shall be done by ponding or continuing with wetted burlap. Ponding shall consist of constructing earthen dykes of clay of about 50 mm height transversely and longitudinally, spreading a blanket layer of sand over the exposed pavement and thoroughly wetting the sand covering for 14 days. The wetted burlap also shall be placed for 14 days.

7.11 Removal of Forms

Forms shall be removed only after the concrete has set for at least 12 hours. They shall be carefully removed without causing damage to the edge of the pavement. After the removal of forms, the ends shall be cleaned and any honey-combed areas pointed with 1:2 cement-sand mortar, after which the sides of the slab shall be covered with earth to the level of the slab. In case the adjoining soil has more than 0.5 percent sulphates, the sides may be painted with bituminous tack coat.

7.12 Opening to Traffic

The freshly laid concrete shall be protected by suitable barricades to exclude traffic. No heavy commercial vehicles carrying construction materials shall be allowed for a period of 28 days. Tractor trailers without any construction materials and light commercial vehicles may be allowed after 14 days.

7.13 Sealing of Joints

The sawn joints which are 3 to 5 mm wide can be filled with hot poured crumb rubber or polymer modified bitumen. Precautions shall be taken so that the sealant shall not spill on the exposed surface of the concrete. The sealant shall be poured from a kettle having a spout. A reference may be made to IRC:57 for details.

7.14 Surface Regularity

The surface shall be checked for surface regularity with a straight edge of 3 m length. The tolerance in this length shall not exceed 8 mm.

7.15 Quality Control

At least six beam and six cube specimens shall be sampled, one set of three cubes and beams each for 7 day and 28 day strength tests for every 100 cum of concrete or a day's work. A quality control chart indicating the strength values of individual specimens shall be maintained. Further guidance may be taken from IRC:SP:11 "Handbook of Quality Control for Construction of Roads and Runways".

7.16 Cracks in Concrete Slabs

The cement concrete slabs may develop cracks if proper care is not taken either during construction stage or during post-construction period. The cracks develop in cement concrete slabs primarily due to plastic shrinkage or drying shrinkage soon after the construction.

Protecting green concrete by mist spray of water or by covering with wet hessian helps in avoiding formation of cracks. In case the slab is constructed continuously with a view to cut joints with concrete saw, this exercise should be done soon after the concrete sets, may be as early as 6-7 hours in summer months.

7.17 Acceptance Criteria for Cracked Concrete Slabs

Concrete slabs may develop cracks of minor to serious nature unless appropriate precautions are taken to prevent their occurrence either during the construction phase or post-construction period. Cracks can appear generally due to the following reasons:

a) Plastic shrinkage of concrete surface due to rapid loss of moisture during hot summer

b) Drying shrinkage

c) High wind velocity associated with low humidity

d) High ambient temperature

e) Delayed sawing of joints

f) Rough and uneven surface of the base on which concrete slabs are constructed

g) Combination of the above factors

The slabs with full depth cracks are totally unacceptable as it amounts to structural failure. Besides, other cracks which are deep and are likely to progress in depth with time are also to be considered as serious in nature. Fine crazy cracks, however, are not serious. The acceptance criteria for cracked concrete slabs are:

i) The length of single crack in any panel shall not be more than 750 mm, even though its depth is less than half of the slab depth.

ii) The cumulative length of cracks with depth of crack less than half the depth of slab in a panel shall not be more than 1250 mm.

iii) Slabs with cracks which are penetrating to more than half of the slab depth shall not be accepted.

REFERENCE

1) Ioannides, A.M., Thompson, M.R., and Barenberg, E.J. (1985). "Westergaard Solutions Reconsidered." Transportation Research Record, 1043, Transportation Research Board, Washington, D.C., 13-23.

2) Bhatnagar, R.K. (1991). "Stresses in Concrete Pavements". M. Tech. Thesis, Transportation Engineering, IIT-Kharagpur.

3) Bradbury, R.D. (1938), Reinforced Concrete Pavements. Wire Reinforcement Inst., Washington, D.C.

4) Chou, Y.T. (1981). "Structural Analysis Computer Programs for Rigid Multi Component Pavement Structures with Discontinuities WESLIQID and WESLAYER." Technical Report 1, 2, and 3. U. S. Army Engineering Waterways Experiment Station, Vicksburg, Miss., May.

Appendix I
(Refer Clause 4.5)

ILLUSTRATIVE EXAMPLE OF DESIGN OF A CEMENT CONCRETE PAVEMENT FOR RURAL ROADS

Example

Cement concrete pavements are to be designed for Rural Roads in Uttar Pradesh having traffic volumes of (i) 45 (ii) 140 and (iii) 200 commercial vehicles per day consisting vehicles, like, agricultural tractors/trailers, light goods vehicles, heavy trucks, buses. The soil has a soaked CBR value of 4 percent. 75 mm water bound macadam grade III over (i) 100 mm GSB and (ii)150/200 mm cementitious granular are to be used as subbases (ref Clause 3.6.2).

Design

Design wheel load = 50 kN, Tyre pressure = 0.80 MPa

From **Table 1**, the k value corresponding to a CBR value of 4 = 35 MPa/m

Sub-base

75 mm thick WBM over 100 mm GSB/150 mm/200 mm cementitious subbase

Effective k Value

The k value over granular bases can be increased by 20 percent (para 2.5)

Effective k value = 1.20 x 35 = 42 MPa/m

Effective k over 150 mm/200 mm cementitious subbase = 2 x 35 = 70 MPa/m

Minor variation in k value is little effect on stresses

Concrete Strength

Adopt a 28 day compressive strength of 30 MPa.

28 day flexural strength = $f_f = 0.7\sqrt{f_c}$ = 3.834 MPa

90 day flexural strength = 1.10 x 3.834 MPa

= 4.22 MPa

Design Thickness for Traffic of 45 CVPD

Trial thickness = 150 mm, joint spacing = 3.75 mm

Since the volume of traffic = 45 CVPD, temperature stresses need not be considered since occurrence of heavy vehicles and maximum temperature gradient at the same time is least likely

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Edge Load Stress

k = 42 MPa/m for granular subbase

From the excel sheet, edge load stress for a dual wheel load = 4.34 MPa>MR = 4.22 MPa,

If the same load is applied by a single wheel of a tractor trailer whose tyre pressure is only 0.5 MPa, the stress is 4.37 MPa > MR (4.22 MPa)

Hence the design is unsafe for k = 42 MPa/m

The pavement is unsafe even for a tractor trailer carrying the same load at a lower tyre pressure.

K = 70 MPa (Cementitious subbase)

Stress for a dual wheel load of 50 kN = 3.985 MPa < 4.22 MPa hence safe for a thickness of 150 mm over 150 mm cementitious subbase.

Stronger subbase gives a reduced bending stress

Trial thickness = 160 mm for GSB

Stress due to dual wheel load of 50 kN, wheel load stress = 3.93 < 4.22 MPa, hence the 160 mm thickness stress is safe for 160 mm slab laid over 75 mm WBM and 100 mm GSB.

Concrete keeps on gaining strength with time and one year flexural strength is 20 percent higher than the 28 day strength

The designer has to exercise his/her judgment in the estimation of traffic and thickness

design traffic = 140 CVPD

Consider a trial thickness of 170 mm and joint spacing of 3.75 m

Temperature differential 't' (For UP, Zone no. = 1 from Table 4.1)

Inputting the Zone number in the excel yields, the temperature differential, 't' is automatically inputted. The load stresses is maximum when the wheel is at the longitudinal edge. Hence Bradbury's coefficient is computed for the longitudinal edge. All computation is done on the excel sheet

Granular subbase = 175 mm, Cementitioius subbase = 200 mm

K = 42 MPa/m over granular subbase

K = 70 MPa/m over cementitious subbase

Granular subbase

The total of wheel load and the temperature stresses due to 50 kN dual wheel load = 4.25 > 4.22 MPa and hence the design is unsafe.

If the joint spacing is 2.5 m, the stress = 3.64 MPa and hence the design is safe for 170 mm slab

For the joint spacing of 3.75 m, increase the thickness to 180 mm

the computed stress = 3.89 MPa, and hence the design is safe.

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Adopt 180 mm with 3.75 m joint spacing for granular subbase

It can thus be seen that 170 mm slab is safe for 2.50 m joint spacing while 180 mm is needed for 3.75 m spacing

Cemented subbase

Temperature curling stresses can be reduced by adopting a lower joint spacing while wheel load also reduces marginally by decreasing the spacing

K = 70 MPa/m for 150/200 mm cementitious subbase

Trial thickness = 170 mm for 3.75 m joint spacing

Stress = 4.15 MPa < 4.22 MPa, hence safe

Designers have to consider all the factors in selecting the joint spacing. Saw cutting or plastic strips can be used to create shorter joint spacings. Cost and convenience will determine the adoption of the types of joints. It is necessary to provide a non-erodible subbase to avoid lack of subgrade support

Pavement design for traffic = 200 CVPD

Fatigue fracture of concrete should be considered for design. Total of wheel load and temperature stresses are considered in fatigue analysis. Since concrete keeps on gaining strength even after 90 days, there is residual strength even though fatigue analysis indicates end of pavement life

Design life = 20 years

The entire computation is shown in the excel sheet. Every designer can develop his/own spread sheet for the computation since the approach is simple.

Assume a thickness of 200 mm and a joint spacing of 4 m over 250 mm GSB

The cumulative fatigue damage is 193.31. Hence it is unsafe. It should be less than 1

Assume a joint spacing of 2.5 m.

The pavement is still unsafe safe since the cumulative fatigue damage is 2.49.

Take thickness = 220 mm for 4.00 joint spacing. Pavement is still unsafe since the cumulative fatigue damage = 9.62

Consider a joint spacing of 2.50 m

The pavement is safe since cumulative fatigue damage is 0.01

A designer can exercise various options of joint spacing using the spread sheet and adopt the thickness and transverse joint spacing according his/her resources.

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Appendix II

(Refer Clause 4.2.1.2)

2.1 Analysis of Stresses Caused by Non-Linear Temperature Distribution

The temperature distribution across the slab thickness is usually non-linear though linearity has been assumed in thickness design in earlier versions of IRC:SP:62 and IRC:58. The actual temperature variation across the depth of a pavement (**Fig. II-1a**) can be taken as the sum of a uniform and a nonlinear temperature variation. The nonlinear variation can be further approximated by bilinear variation and the temperature variation can be split as shown in **Figs. II-1(b), (c) and (d)**. The total stress due to thermal-loading condition is obtained by adding algebraically the bending stresses due to the linear temperature and the nonlinear temperature part. **Fig. II-2** (Venkatasubramanian 1964) shows temperature measurements made at the surface, 1/4th depth, the mid depth, the 3/4th depth and at the bottom for a 203.2 mm thick slab. The measurements were made at Kharagpur in Eastern India. When the surface of the concrete has its maximum or minimum daily temperatures, the temperature difference between the surface and the mid depth can be more than double the difference between the mid depth and the bottom. Similar observations were reported by Croney and Croney (1991). In the present analysis it is considered that the temperature difference between the top surface and the mid depth is double that between mid depth and the bottom during the day hours when the traffic is higher on low volume roads.

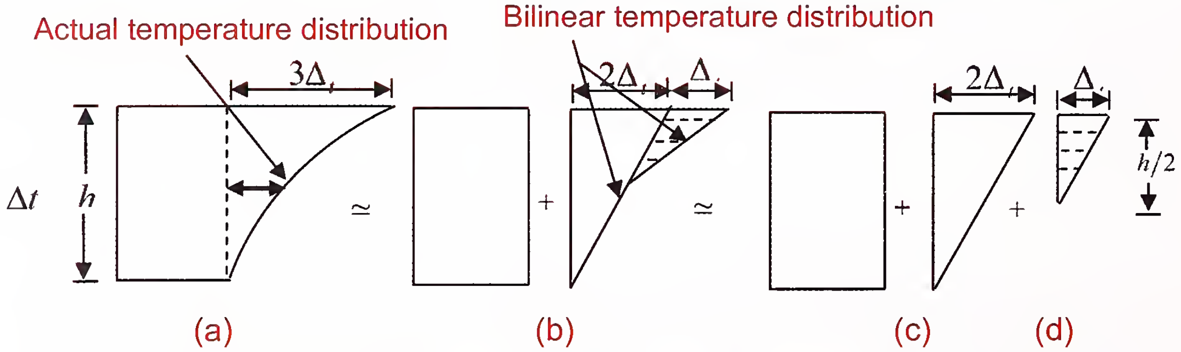

Fig. II-1 Components of Nonlinear Temperature Distribution during Day Time

The total stress due to thermal-loading condition is obtained by adding algebraically the bending stresses due to linear temperature part which extends through full depth of slab and linear temperature part which extends only to top half of the slab.

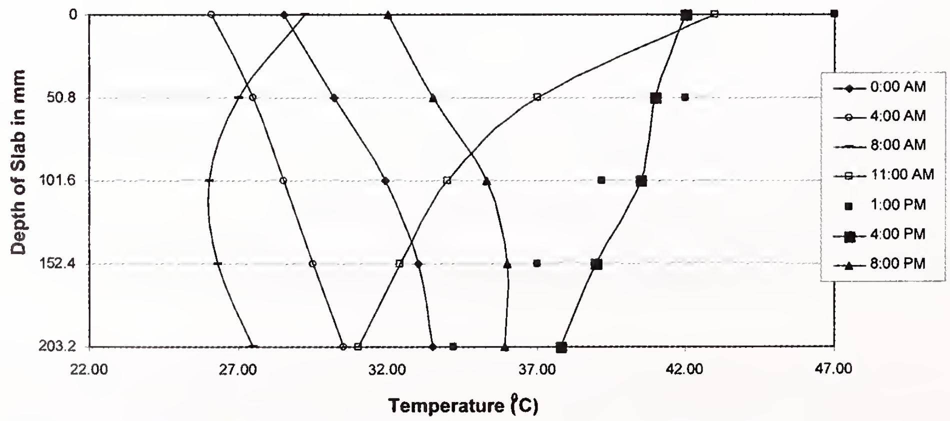

Fig. II-2 Temperature Variation (°C) in a 203.2 mm Concrete Slab March 30-31, 1963

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From the **Fig. II-2** and others (Venkatasubramanian 1964, Choubane et.al 1993) it can be observed that the difference in temperature between surface and underface of the slab is higher during day time as compared to the difference at night. During night time this difference is approximately half of that during day time. It can also be observed that during day time the temperature variation is highly nonlinear as compared to night time variation.

The slab with the linear temperature variation extending to the full depth of the slab is analyzed by Bradbury's theory. The linear temperature variation over half the depth of the slab causes internal bending stresses in the pavement and was analyzed by using classical plate bending theory.

2.2 General Plate Bending Theory Formulation

If the plate is subjected to the action of tensile or compressive forces acting in the x and y direction and uniformly distributed along the sides of the plate, the corresponding bending moment is equal to

$$M = D\left(\frac{\partial^2 w}{\partial x^2} + \mu \frac{\partial^2 w}{\partial y^2}\right) \quad \text{... II-1}$$

where,

$$D = \frac{Eh^3}{12(1-\mu^2)} \quad \text{... II-2}$$

$$\text{Bending Stress, } \sigma = \frac{6M}{h^2} \quad \text{... II-3}$$

2.3 Day and Night Time Curling

During the day time, the upper half of the slab will tend to bend due to linear temperature distribution between the top and the middle surface but lower half will have no effect and it remains in its original position (horizontal) if free to do so and consequently the upper and the lower halves will tend to have different radii of curvature as shown in **Fig. II-3**. The reverse is the trend during the night hours as shown in **Fig. II-4**.

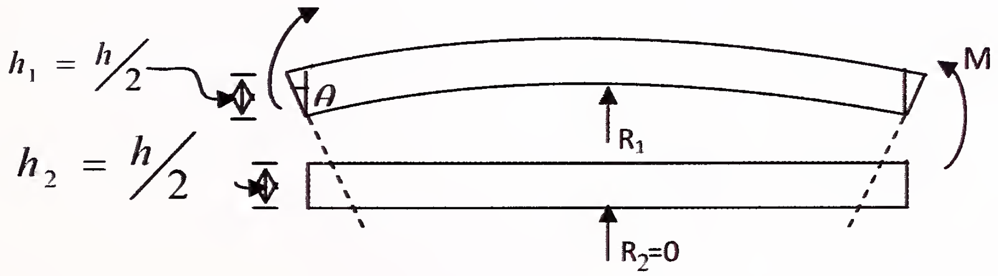

Fig. II-3 Bending of Upper and Lower Halves of Slab When Free to Bend

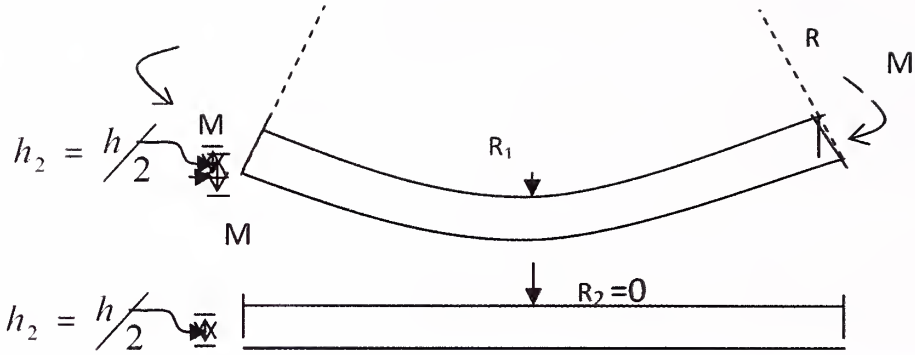

Fig. II-4 Bending of Upper and Lower Halves of Slab When Free to Bend

The real slab is a monolithic mass and will curl up or warp down as one unit with a common radius of curvature of $\frac{R_1 + R_2}{2}$ (**Figs. II-5 and II-6**) and internal stresses will be set up due to internal bending moments M as shown in **Figs. II-3 & 2-4** to annul the different curvatures of the upper and the lower parts. This causes compressive stresses at the top and the bottom and tensile stresses at mid depth during day time and tensile stresses at top and bottom and compressive stresses at mid depth during night time. The values of stresses can be approximately estimated from geometrical compatibility as shown below.

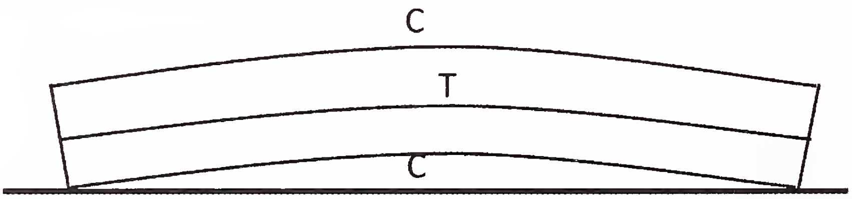

Fig. II-5 Tensile and Compressive Stresses due to Internal Bending Moments During Day Time

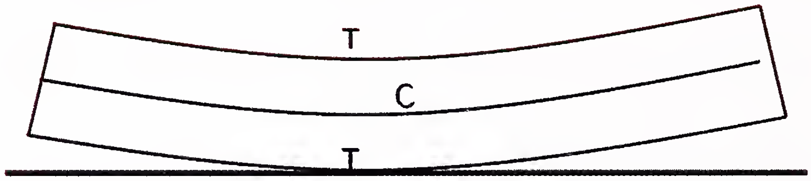

Fig. 11-6 Tensile and Compressive Stresses due to Internal Bending Moments During Night time

a) In the interior close to the center, the bending moment is given as

$$M = D\left(\frac{\partial^2 w}{\partial x^2} + \mu \frac{\partial^2 w}{\partial y^2}\right) \quad \text{... 18}$$

Since curvatures in the two directions are equal,

$$M = D \frac{\partial^2 w}{\partial x^2} (1 + \mu) \quad \text{... 19}$$

$$\text{Interior Stress, } \sigma_i = \frac{6m}{h^2} = \frac{E\alpha_t \Delta_t (1+\mu)}{4(1-\mu^2)} \quad \text{... 20}$$

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b) Along the edge, the bending moment is given as

$$M = D \frac{\partial^2 w}{\partial x^2} \quad \text{... 21}$$

$$\text{Edge stress, } \sigma_e = \frac{6M}{h^2} = \frac{E\alpha\Delta_t}{4(1-\mu^2)} \quad \text{... 22}$$

For $\alpha = 10^{-5}$, E = 30,000 MPa, μ = 0.15, $\sigma_e = 0.0767\ \Delta_t$ (Compressive at the bottom)

If the temperature differential is $3\Delta_t$, Bradbury's equation is used for the computation of curling stresses for $2\ \Delta_t$ and the compressive curling stress is subtracted to obtain the net curling stresses. The compressive curling stresses for various temperature differentials are shown in **Table I-1**.

Table I-1 Nonlinear Part Temperature Stresses, Daytime

Temperature Difference °C	Edge Curling Stresses, MPa (Compressive)	Interior Curling Stresses, MPa (Compressive)
8	-0.20	-0.23
13	-0.33	-0.38
17	-0.43	-0.44
21	-0.53	-0.61

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Appendix III

(Refer Clause 1.2)

SELF-COMPACTING CONCRETE

1 INTRODUCTION

A constant strive to improve performance and productivity led to the development of Self-Compacting Concrete (SCC). Traditionally Placed Concrete (TPC) mix is compacted with the help of external energy inputs from vibrators, tamping or similar actions. On the other hand, SCC mix has special performance attributes of self-compaction/consolidation under the action of gravity.

For mould ability, a concrete mix irrespective of being TPC or SCC should have the ability to fill the formwork as well as encapsulate reinforcing bars and other embedment in fresh state maintaining homogeneity. In case of TPC, it is achieved by means of ensuring a minimum level of slump at fresh state and placing it with the help of external energy. However, a fresh SCC mix shall have appropriate workability under the action of its self-weight for filling all the space within form work (filling ability), passing through the obstructions of reinforcement and embedment (passing ability) and maintaining its homogeneity (resistance to segregation).

High deformability can be achieved by appropriate employment of super plasticizer, maintaining low water powder ratio and Viscosity Modifying Agent (VMA), if needed. These are the basics to achieve the flowability and viscosity of a suspension to achieve self-compacting properties. The rheological characteristics of fresh concrete mix is not only necessary for workability to achieve desired mould ability but they also help in achieving desired in-situ strength and durability attributes at the hardened state. The difference between the SCC and TPC exists in the performance requirements during fresh state; not much in terms of performance requirements in hardened state such as strength and durability.

The advantages of SCC are enhanced productivity, and reduction of costly labour and noise discomfort at construction site. Improved surface finish and quality of hardened concrete as well as improvement of working condition are few of the great potentials of SCC. Usage of higher dosages of fly ash in SCC enhances its flow ability which in turn reduces the usage of costly chemical admixtures. The SCC is, therefore, another option considering these properties for rigid pavement of village road noting the fact that a dense compacted concrete in line and level is a prime requirement for village road. Minimum efforts in vibration mean an ordinary screed is enough to get surface in line and level to obtain a dense concrete. SCC can thus be a solution for rigid pavement of village roads.

While the material cost of SCC has generally been higher than conventional concrete, but due to development of new admixtures, the differential cost is much reduced. Marginal increased initial cost is compensated to a great extent considering such advantages as reduction in construction time and a higher ultimate durability of the structure and it may finally become cost effective. Standard manual/guidelines for usage of SCC in India are not available, but

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they are available in developed countries as cited in references and a working detail is given in the following.

2 TERMS AND DEFINITIONS

For the purposes of this publication, the following definitions apply:

Mineral Admixtures

Pozzolanic materials conforming to relevant Indian Standards may be used, provided uniform blending with cement is ensured. Finely-divided inorganic material used in concrete in order to improve certain properties or to achieve special properties. This publication refers to pozzolanic materials defined in IS 456-2000 as: Mineral Admixtures.

Chemical Admixture

Material added during the mixing process of concrete in small quantities related to the mass of cementitious binder to modify the properties of fresh or hardened concrete.

Binder

The combined cement and mineral admixture.

Filling Ability

The ability of fresh concrete to flow into and fill all spaces within the formwork, under its own weight.

Flow Ability

The ease of flow of fresh concrete when unconfined by formwork and/or reinforcement.

Fluidity

The ease of flow of fresh concrete.

Mortar

The fraction of the concrete comprising paste plus those aggregates less than 4.75 mm.

Paste

The fraction of the concrete comprising powder, water and air, plus admixture, if applicable.

Passing Ability

The ability of fresh concrete to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking

Powder (Fines)

Material of particle size smaller than 0.125 mm (125 μ)

Note : It includes fractions in the cement, cement additives as flyash, silica fumes and aggregate specially crushed sand

Robustness

The capacity of concrete to retain its fresh properties when small variations in the properties or quantities of the constituent materials occur

Self-Compacting Concrete (SCC)

Concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction.

Segregation Resistance

The ability of concrete to remain homogeneous in composition while in its fresh state

Slump-Flow

The mean diameter of the spread of fresh concrete using a conventional slump cone

Thixotropy

The tendency of a material (e.g. SCC) to progressive loss of fluidity when allowed to rest undisturbed but to regain its fluidity when energy is applied

Viscosity

The resistance to flow of a material (e.g. SCC) once flow has started.

Note : In SCC it can be related to the speed of flow T_{500} in the Slump-flow test or the efflux time in the V-funnel test described in the Annexures III-1 and III-2

Viscosity Modifying Admixture (VMA)

Admixture added to fresh concrete to increase cohesion and segregation resistance.

3 RHELOGY PROPERTIES

3.1 Rheology

Self-compaction of fresh concrete is described as its ability to fill the formwork and encapsulate reinforcing bar/available space only through the action of gravity while maintaining homogeneity. The ability is achieved by designing the concrete to have suitable inherent rheological properties. SCC can be used in most applications where traditionally vibrated concrete is used.

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Rheology is the study of flow and deformations of all forms of matter. The basic property influencing the performance of the fresh concrete in casting and compaction is its rheological behavior. Rheology has thus been central in the development of SCC. Rheology of concrete, mortar as well as paste is important for understanding the behavior and optimisation processes.

3.2 Workability

In workability terms, self-compactability signifies the ability of the concrete to flow after being discharged from the pump hose, a skip or a similar device only through gravity to fill intended spaces in formwork to achieve a zero-defect and uniform-quality concrete. Self-compactability in a fresh state property can be characterized by three functional requirements:

Filling Ability

Resistance to Segregation

Passing Ability

3.2.1 *Filling ability*

SCC must be able to deform or change its shape very well under its self-weight. The meaning of the filling ability includes both the flow, in terms of how far from the discharge the concrete can flow (deformation capacity), and the speed with which it flows (velocity of deformation). Using the slump flow measurement, the deformation capacity can be evaluated as the final flow diameter of the concrete measured after the concrete has completely stopped deforming. The velocity of deformation can in the same method be evaluated as the time it takes the concrete to reach a certain deformation.

To achieve a good filling ability, there should be a good balance between the deformation capacity and velocity of deformation.

3.2.2 *Resistance to segregation*

Concrete should not show tendency to segregate during movement. SCC should not have any of the following segregation parameters in either flowing or stationary state;

- Bleeding of water
- Paste and aggregate segregation
- Coarse aggregate segregation leading to blocking
- Non-uniformity in air-pore distribution

To avoid the segregation of water from the solids, it is essential to reduce the amount of movable water in the mixture. Movable water can be reduced by using low water content and low W/P. (Water/Powder) It is also possible to use powder material (Materials having size less than 0.125 mm (125 micron) with high surface area since more water can be retained on the surface of the powder material. Segregation resistance between water and solids can also be improved by increasing the viscosity of water through the use of VMA.

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The other categories of segregation can be solved by having a paste phase which is capable of carrying the aggregate particles. This can be done by increasing the cohesion between the paste phase and aggregate phase through the use of low w/p or by using VMA.

3.2.3 *Passing ability*

For SCC with excellent filling ability & segregation resistance, blocking will occur in the following conditions:

- The maximum size of the aggregate is too large
- The content of large-sized aggregates is too high

The blocking tendency is increased if the concrete has a tendency for segregation of coarser aggregate particles. Thus blocking can occur even if the maximum aggregate size is not excessively large.

4 SPECIFICATION

4.1 General

The filling ability and stability of self-compacting concrete in the fresh state can be defined by four key characteristics. Each characteristic can be addressed by one or more test methods:

Characteristic	Preferred test method(s)
Flowability	Slump-flow test
Viscosity (assessed by rate of flow)	T_{500} Slump-flow test or V-funnel test
Passing ability	L-box test
Segregation	Segregation resistance (sieve) test

The above tests are fully described in EN 12350-2. Since the SCC is intended to be used for rigid pavement for roads and the roads are in grades and camber, the acceptable values of parameters will have to be fixed by trials and carrying out field observations. Slump flow of 400 mm and V cone of 8 seconds if observed would meet the requirement for village roads as seen by several experiments.

Slump Flow & V-funnel test methods for SCC are described in Annexures III-1 and III-2

4.2 Segregation Resistance

Visual observations during the Slump flow test and/or measurement of the T_{500} time can give additional information on the segregation resistance. There should not be any visible signs of segregation.

5 CONSTITUENT MATERIALS

5.1 General

The constituent materials for SCC are the same as those used in traditional vibrated concrete conforming to IS:456.

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5.1.1 *Minimum Cement*

The durability requirements conforming to IS:456 of the minimum cement content for the given exposure conditions should be adhered to.

5.2 Mineral Admixtures

5.2.1 *General*

Due to the fresh property requirements of SCC, inert and pozzolanic/hydraulic additions are commonly used to improve and maintain the cohesion and segregation resistance. The addition will also regulate the cement content in order to reduce the heat of hydration and thermal shrinkage.

The additions are classified according to their reactive capacity with water:

Pozzolanic	Fly Ash conforming to Grade I of IS:3812(Part-1)
	Silica fumes
	Rice husk ash
	Metakaoline having fineness between 700 – 900 m^2/kg
Hydraulic	GGBS conforming to IS:12089

5.2.2 *Fly ash*

Fly ash has been shown to be an effective addition for SCC providing increased cohesion and reduced sensitivity to changes in water content. However, high levels of fly ash may produce a paste fraction which is so cohesive that it can be resistant to flow. Fly ash conforming to IS:3812 (Part-1) 2003 shall be used. Some of the important requirements of fly ash are listed below:

Sr. No.	Requirement	Limit	
1	Total Sulpher as SO_3 (%)	Max	5.0
2	Total Chloride (%)	Max	0.05
3	LOI (%)	Max	5.0
4	Fineness (m^2/kg)	Min	320
5	Particles retained on 45 m IS sieve	Max	34

5.3 Aggregates

Normal-weight aggregates should conform to IS:383 and meet the durability requirements of IS:456.

All normal concreting sands are suitable for SCC. Both crushed or rounded sands can be used.

The amount of fines less than 0.125 mm is to be considered as powder and is very important for the rheology of the SCC. A minimum amount of fines (arising from the binders and the sand) must be achieved to avoid segregation.

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5.3.1 *Coarse aggregate*

Coarse aggregates conforming to IS:383 are appropriate for the production of SCC.

5.3.2 *Fine aggregate/sands*

The influence of fine aggregates on the fresh properties of the SCC is significantly greater than that of coarse aggregate. Particles size fractions of less than 0.125 mm should be include the fines content of the paste and should also be taken into account in calculating the water powder ratio.

The high volume of paste in SCC mixes helps to reduce the internal friction between the sand particles but a good grain size distribution is still very important. Many SCC mix design methods use blended sands to match an optimized aggregate grading curve and this can also help to reduce the paste content. Some producers prefer gap-graded sand.

5.4 Admixtures

High range water reducing admixtures conforming to IS:9103 are an essential component of SCC. Viscosity Modifying Admixtures (VMA) may also be used to help reduce segregation and the sensitivity of the mix due to variations in other constituents, especially to moisture content.

5.4.1 *Superplasticiser/high range water reducing admixtures*

The admixture should bring about the required water reduction and fluidity but should also maintain its dispersing effect during the time required for transport and application. The required consistence retention will depend on the application.

High efficiency Poly carboxylate based high range water reducer having a consistent performance should be used.

5.4.2 *Viscosity modifying admixtures*

Admixtures that modify the cohesion of the SCC without significantly altering its fluidity are called Viscosity Modifying Admixtures (VMA). These admixtures are used in SCC to minimize the effect of variations in moisture content, fines in the sands or its grain size distribution, making the SCC more robust and less sensitive to small variations in the proportions and condition of other constituents.

5.5 Mixing Water

Water conforming to IS:456 should be used in SCC mixes.

6 BASIC MIX DESIGN

There is no standard method for SCC mix design and many academic institution and company dealing with admixtures, ready-mixed concrete, precast concrete etc. have developed their own mix proportioning methods.

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Mix designs often use volume as a key parameter because of the importance of the need to fill the voids between the aggregate particles. Some methods try to fit available constituents to an optimized grading envelope. Another method is to evaluate and optimize the flow and stability of first the paste and then the mortar fractions before the coarse aggregate is added and the whole SCC mix tested.

Table III-1 Typical Range of SCC Mix Composition for M30 to M40 Grade of Concrete

Constituent	Quantity (kg/m³)	Quantity (Ltrs/m³)
Water	155 – 175	155 – 175
Powder	375 – 600	
Fine Aggregates	40 – 60% of the total Aggregate weight	
Coarse Aggregates	750 – 1000	270 – 360
w/p (water/paste volume)	-	0.76 to 1.0
Cement	240 to 290 kg	
Fly ash	160 to 210 Kg	
Paste Volume		34 to 38%
Water/Binder (cement + flyash)		Max 0.4

Mix proportion for aggregate as per IS:10262 gives good guidelines for the quantity of aggregate which can be followed. Several experiment of mix design can be done and upper and lower bound of aggregate size curves established by series of trial mixes for M30 to M40 grade of concrete. A range of mix composition is given in **Table III-1**. The upper and lower limits and the typical combined grading in a trial are shown in **Table III-2** and **Fig. III-1**.

Table III-2 Combined Gradation of Aggregate for Mix Design of M30 to M40 Grade of Concrete

IS Sieve	20 mm	10 mm	Crushed sand	Natural sand	Combined (as adopted in lab trial)	Recommended upper limit	Recommended lower limit
% age							
20 mm	97.25	100	100	100	99.03	95	100
10 mm	1.13	95.75	100	100	64.65	50	70
4.75 mm	0.02	0.40	91.65	100	48.63	35	55
2.36 mm	0.00	0.28	62.35	100.00	33.06	25	45
1.18 mm	0.00	0.00	39.90	100.00	21.15	15	35
0.600 mm	0.0	0.0	27.40	100.00	14.52	10	30
0.300 m	0.00	0.00	19.95	100.00	10.57	3	15
0.150 m	0.00	0.00	13.50	100.00	7.16	6.00	0
0.075	0.00	0.00	8.30	0.00	4.4	4.5	0

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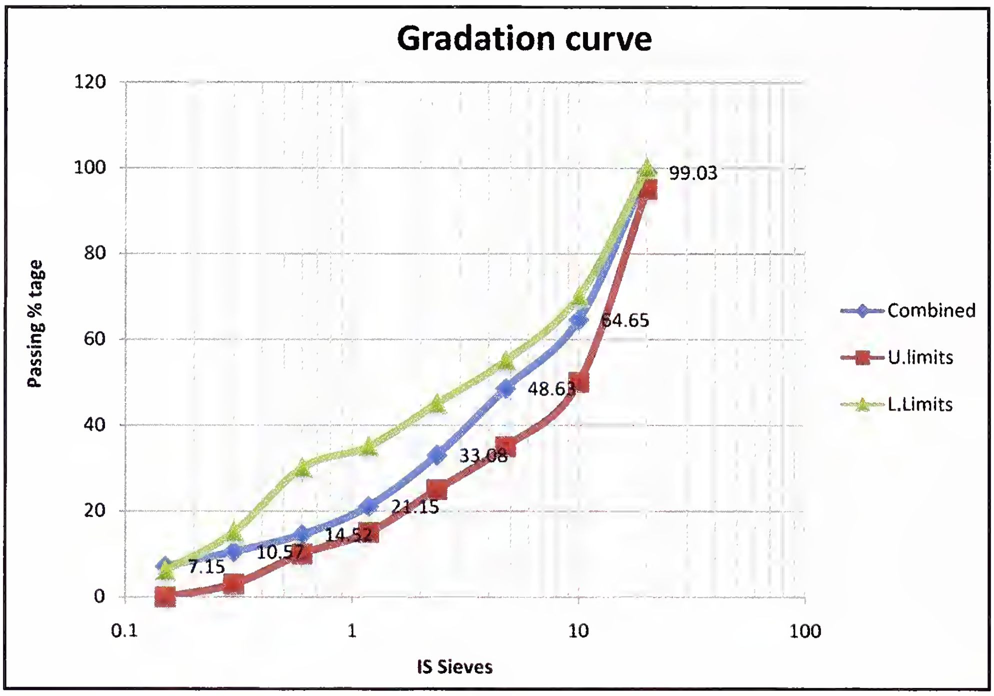

Fig. III-1 Upper and Lower Limits of aggregate gradations and Combined gradation for SCC

Trial mixes-Several trial mixes can be evolved for M 30 grade of concrete and typical proportion of various ingredients are given in **Table III-3** can form the basis for different trials

Table III-3 Quantities of Materials for Trial Mixes

Ingredient	Trial 1 kg/Cubic Meter	Trial 2 kg/Cubic Meter
Cement	260	270
Fly ash	200	180
Crushed sand (0 to 4.75 mm)	988	893
5 to 10 mm Coarse aggregate	221	384
10 to 20 mm coarse aggregate	664	473
Water	165.6	171
w/c	0.36	0.38
Special admixture	0.8%	0.9%

8 CURING

Curing is important for all concrete but especially so for the top-surface of elements made with SCC. These can dry quickly because of the increased quantity of paste, the low water/fines ratio and the lack of bleed water at the surface. Initial curing should therefore commence as soon as practicable after placing and finishing in order to minimise the risk of surface crusting and shrinkage cracks caused by early age moisture evaporation.

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Test Methods

TESTING FRESH CONCRETE : SLUMP-FLOW TEST - 1

Introduction

The slump-flow diameter is a test to assess the flowability and the flow rate of self-compacting concrete in the absence of obstructions. It is based on the slump test described in EN 12350-2. The result is an indication of the filling ability of self-compacting concrete.

1 Scope

This document specifies the procedure for determining the slump-flow diameter for self-compacting concrete. The test is not suitable when the maximum size of the aggregate exceeds 40 mm.

2 Principle

The fresh concrete is poured into a cone as used for the IS:9103 slump test. The largest diameter of the flow spread of the concrete and the diameter of the spread at right angles to it are then measured and the mean is the slump-flow.

3 Apparatus

The apparatus shall be in accordance with EN 12350-2 except as detailed below:

3.1 Baseplate, made from a flat plate with a plane area of at least 900 mm x 900 mm on which concrete can be placed. The plate shall have a flat, smooth and non-absorbent surface with a minimum thickness of 2 mm. The surface shall not be readily attacked by cement paste or be liable to rusting. The construction of the plate shall be such as to prevent distortion. The deviation from flatness shall not exceed 3 mm at any point when a straight edge is placed between the centres of opposing sides.

The centre of the plate shall be scribed with a cross, the lines of which run parallel to the edges of the plate and with circles of 200 mm diameter and 500 mm diameter having their centres coincident with the centre point of the plate. See **Fig. 1**.

3.2 Rule, Graduated from 0 mm to 1000 mm at Intervals of 1 mm.

3.3 Stop Watch, Measuring to 0.1 s.

3.4 Weighted Collar (Optional), Having a Mass of at Least 9 kg.

Note : the weighted collar allows the test to be carried out by one person.

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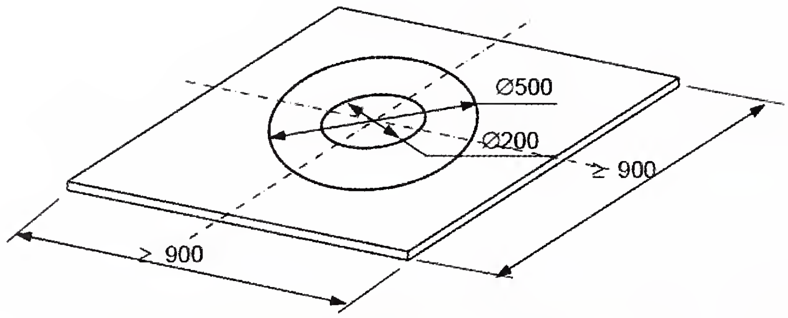

Fig. 1 Base Plate Reference Clause 4.1

4 TEST SAMPLE

The sample shall be obtained in accordance with IS:1199.

5 PROCEDURE

Prepare the cone and base plate as described in EN 12350-2. Fit the collar to the cone if being used. Place the cone coincident with the 200 mm circle on the base plate and hold in position by standing on the foot pieces (or use the weighted collar), ensuring that no concrete can leak from under the cone.

Fill the cone without any agitation or rodding, and strike off surplus from the top of the cone. Allow the filled cone to stand for not more than 30 s; during this time remove any spilled concrete from the base plate and ensure the base plate is damp all over but without any surplus water.

Lift the cone vertically in one movement without interfering with the flow of concrete. Without disturbing the base plate or concrete, measure the largest diameter of the flow spread and record as d_m to the nearest 10 mm. Then measure the diameter of the flow spread at right angles to d_m to the nearest 10 mm and record as d_r to the nearest 10 mm.

Check the concrete spread for segregation. The cement paste/mortar may segregate from the coarse aggregate to give a ring of paste/mortar extending several millimetres beyond the coarse aggregate. Segregated coarse aggregate may also be observed in the central area. Report that segregation has occurred and that the test was therefore unsatisfactory.

6 TEST RESULT

The slump-flow is the mean of d_m and d_r expressed to the nearest 10 mm.

7 TEST REPORT

The test report shall include:

a) Identification of the test sample;
b) Location where the test was performed;
c) Date when test performed;
d) Slump-flow to the nearest 10 mm;
e) Any indication of segregation of the concrete;

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f) Time between completion of mixing and performance of the tests;

g) Any deviation from the procedure in this document.

The report may also include:

i) The temperature of the concrete at the time of test;

j) Time of test.

TESTING FRESH CONCRETE : V-FUNNEL TEST - 2

Introduction

The V-funnel test is used to assess the viscosity and filling ability of self-compacting concrete.

1 SCOPE

This document specifies the procedure for determining the V-funnel flow time for self -compacting concrete. The test is not suitable when the maximum size of the aggregate exceeds 20 mm.

2 PRINCIPLE

A V-shaped funnel is filled with fresh concrete and the time taken for the concrete to flow out of the funnel is measured and recorded as the V-funnel flow time.

3 APPARATUS

3.1 V-funnel, made to the dimensions (tolerance ± 1 mm) in **Fig. 1**, fitted with a quick release, watertight gate at its base and supported so that the top of the funnel is horizontal. The V-funnel shall be made from metal; the surfaces shall be smooth, and not be readily attacked by cement paste or be liable to rusting.

3.2 Container, to hold the test sample and having a volume larger than the volume of the funnel and not less than 12 liters.

3.3 Stop watch, measuring to 0.1 s.

3.4 Straight Edge, for Striking off Concrete Level with the Top of the Funnel

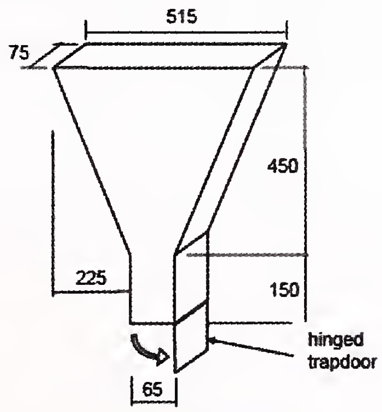

Fig. 1 V-Funnel

4 TEST SAMPLE

A sample of at least 12 ltrs shall be obtained.

5 PROCEDURE

Clean the funnel and bottom gate, the dampen all the inside surface including the gate. Close the gate and pour the sample of concrete into the funnel, without any agitation or rodding, then strike off the top with the straight edge so that the concrete is flush with the top of the funnel. Place the container under the funnel in order to retain the concrete to be passed. After a delay of (10 ± 2) s from filling the funnel, open the gate and measure the time t_v, to 0.1 s, from opening the gate to when it is possible to see vertically through the funnel into the container below for the first time. t_v is the V-funnel flow time.

6 TEST REPORT

The test report shall include:

a) Identification of the test sample;

b) Location where the test was performed;

c) Date when test performed;

d) V-funnel flow time (t_v) to the nearest 0.1 s;

e) Time between completion of mixing and performance of the tests;

f) Any deviation from the procedure in this document.

The report may also include:

h) The temperature of the concrete at the time of test;

i) Time of test.

REFERENCES

1. IS:1199, Testing fresh concrete – Part 1: Sampling.

2. EN 9103, Testing fresh concrete – Part 2: Slump test.

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(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the code/guidelines/manual, etc. from the date specified therein)