IRC:SP:46-2013

GUIDELINES FOR DESIGN AND CONSTRUCTION OF FIBRE REINFORCED CONCRETE PAVEMENTS

(First Revision)

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NOTATIONS AND ABBREVIATIONS

f_{ct}	=	Peak flexural strength, in MPa
f_{ctk}	=	Characteristics flexural strength, in MPa
f_{ctm}	=	Mean of flexural strength of test specimens, in MPa
f_{e150}	=	Equivalent flexural strength (in post crack regime), in MPa
f_{e150k}	=	Characteristics equivalent flexural strength, in MPa
f_{e150m}	=	Mean equivalent flexural strength of test specimens, in MPa
R_{e150}	=	$f_{e150k} \div f_{ctk}$ or $f_{e150m} \div f_{ctm}$ [a ratio]
k	=	Modulus of sub-grade reaction, in MPa/m
E	=	Modulus of elasticity of concrete, in MPa
F5	=	Characteristic Flexural strength 5 MPa of concrete (concrete grade by flexural strength)
AASTHO	=	American Association of State Highways and Transportation Officials
ACI	=	American Concrete Institute
ASTM	=	American Society for Testing of Materials
CFD	=	Cumulative Fatigue Damage
DIN	=	Deutsches Institut für Normung (German Standard)
EN	=	Europäische Norm (European Standard)
EOT	=	Early Opening to Traffic
FHWA	=	Federal Highway Administration, USA
FRC	=	Fibre Reinforced Concrete
GGBS	=	Ground Granulated Blast-furnace Slag
IS	=	Indian Standard
ISO	=	International Standard Organization
JCI	=	Japanese Concrete Institute
JSCE	=	Japanese Society of Civil Engineers
Macro Fibres	=	Fibre ≥ 0.2 mm diameter

Micro Fibres	=	Fibre < 0.2 mm diameter
OPC	=	Ordinary Portland Cement
Purchaser	=	Sub organization or wing carrying out the construction
PPC	=	Portland Pozzolana Cement
PSC	=	Portland Slag Cement
PQC	=	Pavement Quality Concrete
SCM	=	Supplementary Cementitious Materials
SFRC	=	Steel Fibre Reinforced Concrete
SF paver	=	Slip Form paver
S-N	=	Stress ratio – Load repetition relation
Supplier	=	Sub organization or wing producing the FRC
TF36R	=	Task Force 36 Report, by FHWA
TR34	=	Technical Report 34 by Concrete Society UK

GUIDELINES FOR DESIGN AND CONSTRUCTION OF FIBRE REINFORCED CONCRETE PAVEMENTS

1 INTRODUCTION

IRC:SP:46 "Steel Fibre Reinforced Concrete for Pavements" was published in 1997. These guidelines served the profession well for more than a decade. However, in the meantime polymeric fibres have been developed for use in pavements. The Rigid Pavement Committee (H-3) felt the necessity to include the polymeric fibres in the guidelines. Therefore, H-3 Committee decided to revise the IRC:SP:46 with enhanced scope. For this task, a sub-group under the convenorship of Shri L.K. Jain including Shri P.L. Bongirwar, Dr. S.C. Maiti, Shri J.B. Sengupta as Members and Prof. Ravindra Gettu (invitee) was formed in the meeting of H-3 Committee held on 16th April, 2012. The Rigid Pavement Committee (H-3) discussed the draft which was prepared by the sub-group in series of meeting. The Rigid Pavement Committee (H-3) approved the final draft in its meeting held on 6th October, 2012 for placing before the HSS Committee. The Highways Specifications and Standards Committee (HSS) approved this document in its meeting held on 13th December, 2012. The Executive Committee in its meeting held on 19th December, 2012 approved this document. Finally, the Council approved this document in their meeting held on 8th January, 2013 at Coimbatore and authorized the Convenor, Rigid Pavement Committee (H-3) to incorporate the comments of Council members and place the same before the HSS Committee before publishing. Accordingly, H-3 Committee modified the draft which was approved by the HSS Committee in its meeting held on 19th July, 2013.

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

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Vishnu Shankar Prasad	:	Secretary General, IRC

2 SCOPE

2.1 This document provides the guidelines for the use of Fibre Reinforced Concrete (FRC) in pavements. The aspects that are peculiar to FRC and those that differ from conventional Pavement Quality Concrete (PQC) are discussed. In addition, the procedures for the design of FRC pavements and for the characterisation of FRC toughness & flexural strength test are detailed.

The fibres (both steel and polymeric) considered here, are to be added during the mixing of the concrete or to the already mixed concrete such that they are thoroughly dispersed in the matrix.

2.2 This document deals only with short length (up to 60 mm) discontinuous fibres used in pavement concrete.

2.2.1 Use of asbestos, carbon and, cellulose fibre, as well ultra high performance ('ductal') concrete is excluded from this document. Use of fibres in other forms like tows, cables, tendons, rods, mats etc. are also not covered in this document.

2.3 This document is for use of fibres in cement based matrix such as concrete, micro-concrete, and used in concrete pavement and related repair applications.

2.4 The design and construction of sub-grade and sub-base layer(s) below the FRC pavement shall conform to the requirements of IRC:58-2011 and IRC:15-2011. For guidance the documents given in References should be referred for issues not fully dealt in this document.

2.5 Fibres can improve the performance of concrete (or cement based matrix):-

i) During and before the attainment of substantial strength, and

ii) During the service life of the member.

2.6 FRC is useful in concrete pavement to control cracking (plastic shrinkage, reflection etc.) to enhance inherent flexural strength, to impart high toughness and to provide post crack ductility.

3 APPLICATIONS OF FRC

3.1 FRCs are advantageous in many applications. In simple cost comparison with concrete without fibres, FRC may appear to be costly in the beginning. However, advantages of FRC, more than justify the additional cost. Improvements in crack control and post cracking behaviours are the main advantages of FRC. FRC gives improved flexural toughness (ability to absorb energy after cracking), impact resistance, and flexural fatigue endurance.

3.2 Initially, fibres were used as secondary reinforcement or for crack control in less critical concrete elements. Now, these are used as the main (structural) reinforcement in slab on grade, industrial floors, pavements, and as the structural base. These can also be used in sub-bases for pavement or cement treated sub-bases which are susceptible to shrinkage cracking. In general fibre concrete can be used in all applications where plain concrete can be used.

3.2.1 FRC with higher flexural strength, shear strength, toughness, fatigue endurance and better post crack behaviour, is needed for concrete pavements, runways, bridge decks, wearing coats etc. SFRC and PSFRC (Polymeric Structural FRC) has been used in a number of highway pavement, airport pavements, and bridge decks with fibre content 0.5% to 1.5% by volume (say 40 to 120 kg/m^3 for steel fibres, and 4.5 to 14 kg/m^3 for polypropylene fibres). FRC is also useful in upper layer of two lift construction of concrete pavement. The mix design for the same (upper layer) may prefer harder aggregates and smaller in size. FRC with or without adding silica fume (up to 10% by weight of cementious materials) is also useful in pavements.

3.2.2 FRC having significant residual strength at large deformation (i.e. deflection/crack width or strain), can be successfully utilized for pavements.

3.2.3 Ultra thin and thin concrete overlays on bituminous layers need concrete with high straining capacity (ductility). By inclusion of fibre, the strength, the toughness and the endurance are enhanced without significantly changing the modulus of elasticity of the concrete. Thus FRC is one of the most competitive pavement materials, if the mechanistic design system is applied for optimizing the performance levels. For taking this advantage the design method has to radically change.

For ultra thin and thin overlays (white topping), following shall be the limiting parameters for PQC consisting of FRC:

FRC Thickness	Minimum Value of f_{e150k} / f_{ctk}
50 mm	0.4
100 mm	0.3

3.2.4 On cracked concrete pavements, overlay has to resist sympathetic (or reflex) cracking; there FRC is can give satisfactory performance. At the positions of reflex cracking, FRC can take significant deformation after cracking and before disintegrating. In such a case only part (say two third) of peak flexural strength may be utilized for stress design, and remaining capacity to be utilized for control over reflex cracking. At present data on the toughness requirement is not available for this application.

3.3 FRC has been used to provide durable concrete pavements with improved cracking resistance and reduction in the required slab thickness. However, the main properties associated with FRC such as ductility and toughness are to be reflected in the current design procedures.

3.4 FRC has better control over plastic shrinkage cracking, and is resistant to drying shrinkage. For resisting cracks (due to plastic shrinkage and plastic settlement) in very young age of concrete (1 to 8 hours) micro fibres like polymeric (e.g. polypropylene) are used in low volume fraction say minimum 0.1% by volume of concrete (i.e. 0.91 kg/m^3 for polypropylene fibres) to 0.2% by volume of concrete.

3.5 Normally micro fibres of about 20 mm length give better performance. Polymeric micro fibres are used to control plastic shrinkage cracking in bridge decks, suspended slab, slab-on-grade, pavements, white toppings, wearing coat, etc. Most fine diameter (8 to 32 μm) micro fibres with a high specific fibre surface area are particularly effective in reducing plastic shrinkage cracking. Slight change in length of fibre does not significantly affect the control over plastic shrinkage cracking. Micro polymeric fibres for plastic shrinkage control in dosage of 0.1% by volume of concrete are combined with any macro fibres needed for enhancing flexural strength and toughness.

In next stage while concrete is hardening, for crack resisting (due to temperature and shrinkage) the fibres having higher modulus of elasticity (near that of immature concrete) are suitable. For controlling drying shrinkage cracks, macro fibres (polymeric or steel etc.) can be used in combination with micro fibres at total dosages of 0.3% or more by volume of concrete, in which 0.1% is micro fibres to control plastic shrinkage, and remaining will be macro fibres for enhancing the flexural strength and toughness of concrete. For these applications, length of fibres can be 20 to 60 mm.

In hardened concrete fibre of much higher modulus of elasticity (nearly equal to or more than concrete) are effective in crack resistance. For both of these actions (plastic shrinkage and structural strength) a blend of micro polymeric and macro fibres may give an economical option. Hence to control cracks in all stages of concrete, hybrid fibres can be more effective.

For pavements and slab-on-grade usefulness of macro fibre is proved due to higher impact resistance, higher flexural toughness, higher stress ratio for flexural fatigue endurance and post cracking residual strength, in addition to some control over shrinkage cracking.

3.6 For pavements with macro (steel or polymeric) fibres, usually FRC having characteristic flexural strength 5 to 8 MPa may be used.

At Mumbai and Thane in some overlays and thin white topping M60 grade concrete with polymeric fibres has been used, and the performance of overlay, so far is good.

The flexural toughness of concrete may be increased significantly with macro polymeric fibres or steel fibres dosages 0.4 to 1.0% by volume of concrete. Fibre dosages above 1.5% by volume of concrete can give strain hardening effect.

3.6.1 For plain concrete the stress ratio for flexural fatigue endurance (at 2 million test cycles) is usually 0.45 to 0.5, whereas for FRC with high dosages of steel fibres it can be from 0.65 to 0.9. Higher factor 0.7 and above can not be used, unless results of specific investigations are available. For load reversal the fatigue strength is only slightly less. If micro polymeric fibres are used in small dosage (<0.3% by volume of concrete) for plastic shrinkage control, the endurance stress ratio 0.45 will remain.

3.6.2 If micro polymeric fibres are used in higher dosages (0.3% or more by volume of concrete) for plastic shrinkage control, the endurance stress ratio can be taken as 0.5 in place of 0.45 for plain concrete.

3.6.3 From AASHTO-AGC-ARTBA TF36R "The use and State of Art – Practice of Fibre Reinforced Concrete", 2001, following is quoted:

> "*Properly designed FRC mixtures will have fatigue endurance of over 2 million cycles at 65 to 90 percent of the static flexural strength for non reversed loading, and slightly less endurance when fully reversed loading is used.*"

3.7 Shear strength of FRC is significantly higher. In all cases, durability of fibre concrete is significantly better.

3.7.1 In SFRC crack widths upto 0.3 mm have no adverse effect on corrosion of steel fibres. In long term, steel fibres within 2.5 mm from surface may be susceptible to corrosion and its effect on structural capacity is insignificant, except discolouration at the surface in the long run.

3.8 Use of virgin polypropylene monofilament fibres 32 μm size (optimum size) at about 1.5 kg/m³ dosages in high strength concrete, inhibit explosive spalling in the event of a fire. If subjected to fire hazard on a pavement, compared to plain concrete, FRC with polymeric fibres will show a better durability.

3.9 FRC has improved resistance to blast and impact actions, where high toughness is required.

3.10 Structural FRC can be usefully deployed in the following areas:

i) Concrete pavements (PQC/overlays, thin and ultra-thin white topping) for roads, runways and bridge decks.

ii) Overlays for rehabilitation or strengthening of roads, runways, bridge decks.

iii) Thin or ultra thin overlays where overhead clearance is critical.

iv) Rotaries, intersections, and locations where odd shapes of pavement are required.

v) Toll plaza with only polymeric fibres or in combination with steel fibers.

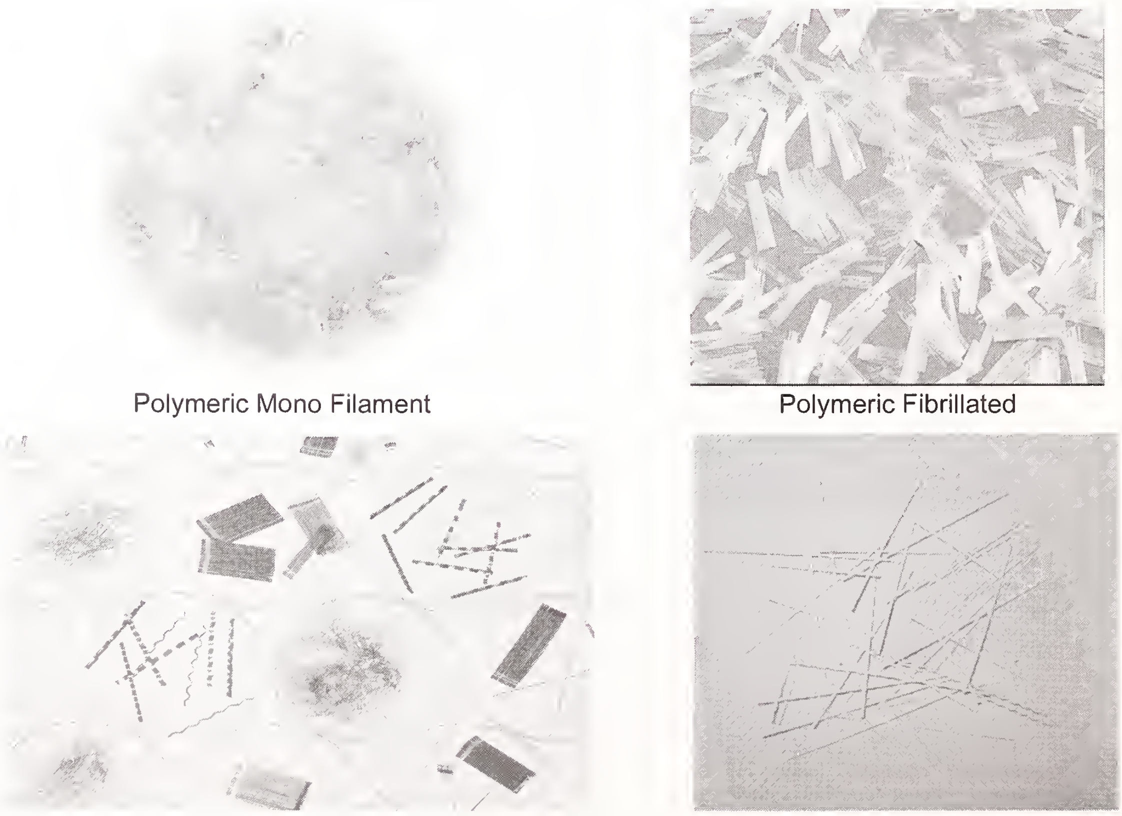
3.11 FRC pavement can be opened to traffic earlier if the flexural strength of concrete of about half the specified value can be achieved at an age of 1 to 3 days only, by choosing an appropriate mix proportion and fiber content.

4 PRODUCTION AND DELIVERY OF FRC

4.1 Fibres

4.1.1 *Steel fibres*

Steel fibres should have an ultimate tensile strength of at least 800 MPa. Fibres can be straight or deformed. The manufacturer shall declare the shape of the fibre. Photos of different shapes of steel fibres are given in **Fig. 1**.



Polymeric Mono Filament

Polymeric Fibrillated

Steel Fibres

Polymeric Macro Fibres

Fig. 1 Types of Fibres

Fibres can be supplied loose or collated (i.e., glued with a water-soluble adhesive that dissolves during the mixing of concrete). Collated fibres have a lower tendency of balling.

When steel fibres are supplied with a coating (e.g. zinc coating), the type and characteristic quantity of coating shall be declared by the manufacturer, along with details of any adverse reactions that could occur in an alkaline environment such as within concrete.

As a guide, for improving performance, steel fibres hooked end and having lengths of about 50 to 60 mm may be used.

4.1.2 *Polymeric fibres*

Polymeric fibres with low elastic modulus are not expected to increase the load-resisting capacity of the concrete significantly, at low dosages. Such micro fibres are monofilament or in fibrillated form, and vary in lengths from about 12 mm to 40 mm. These fibres are normally used to control plastic shrinkage cracking.

Macro Polymeric fibres in 30 to 60 mm length, of higher elastic modulus can increase the toughness and the strength capacity of the FRC pavement. Macro fibres have diameter more than 0.2 mm. Micro fibres are in 12 to 40 mm length and have diameter less than 0.2 mm.

For Tests of Polymeric Fibres Refer **Appendix E**.

4.2 Aggregate Size

Maximum size of aggregate shall depend upon the thickness of the pavement and the average spacing of well dispersed fibres in concrete.

For most applications nominal maximum size of aggregate could be 20 mm. However, as per IRC:15, maximum size of aggregate shall not exceed 31.5 mm. Suitable grading of the aggregate shall be adopted.

A sample grading is given in **Table 1** for initial trials for macro fibre reinforced concrete. The final grading in the successful mix may differ from the range in the **Table 1**.

Table 1: Grading of Aggregates for FRC with Macro Fibres

Sieve Size	Percentage Passing for Different Maximum Size of Aggregate			
	10 mm	13 mm	20 mm	25 mm
25 mm	100	100	100	94 – 100
20 mm	100	100	94 - 100	76 – 82
12.5 mm	100	93 - 100	70 - 83	65 – 76
10 mm	96 - 100	85 - 96	61 - 73	56 – 66
4.75 mm	72 - 84	58 - 78	48 - 56	45 – 53
2.36 mm	46 - 57	41 - 53	40 - 47	36 - 44
1.18 mm	34 - 44	32 - 42	32 - 40	29 - 38
600 micron	22 - 33	19 - 32	20 - 30	19 - 28
300 micron	10 - 18	9 - 18	9 - 19	8 - 20
150 micron	2 - 9	2 - 9	2 - 9	2 - 8
75 micron	0 - 3	0 - 2	0 - 2	0 - 2

Above grading is for macro fibre 0.65 to 1 mm diameter and dosages of about 0.5 to 1% by volume of concrete. [*Derived from ACI 544.1*]

In case of performance oriented (purchase option) specifications, the supplier can use a maximum size of aggregate not exceeding that given in the specifications or smaller.

4.2.1 As the number of fibres in a unit volume of concrete increases, the spacing between the fibres reduces. This poses a limit on maximum size of coarse aggregate and its percentage fraction in the mix. Larger aggregate size may interfere with the uniform dispersion of fibres. Coarse aggregate of 20 mm maximum size is suitable for low volume fraction up to about 0.3% by volume of concrete for polymeric micro fibres. It is also suitable for macro fibres up to 1.0% by volume (i.e. 80 kg/m^3 for steel fibres). However, these limits are qualitative indications and can change as the size (equivalent diameter) of the fibre changes. In actual case trials should be undertaken to derive maximum efficiency from the fibre in a particular mix.

For increasing dosages of fibres and decreasing equivalent diameter, the spacing of fibres will be smaller, thus the maximum size of aggregate may suitably be reduced to 15 mm, 12 mm or even 10 mm as required. The proportion of coarse aggregate, for optimized performance of FRC will also be suitably reduced. The aggregate size should result in satisfactory workability, cohesiveness in concrete, and the uniform dispersion of fibres, as proven by trials beforehand.

4.2.2 For bridging the cracks and for good performance, length of fibre may be 2 to 3 times the nominal maximum size of aggregate. However, the method of dosing, mixing and other construction processes may impose a limit lower than that which can give better properties in hardened concrete. In case of pumped concrete length of fibre may not be more than 2/3rd of the diameter of the FRC delivery pipe.

4.2.3 The permissible flakiness and elongation (combined) index could be up to a maximum of 35% for total aggregate 10 mm and 20 mm together. However, coarse aggregate having maximum combined flakiness and elongation index up to 25% shall be preferred. It is recommended that for aggregate fraction 10 mm and below, flakiness and elongation (combined) index could be smaller.

4.2.4 To achieve proper bond of concrete with fibres, the finer material (i.e. size of cementitious particles e.g. cement and flyash etc.) in the mix should be enough in relation to the total surface area of the fibers. Continuous grading and presence of enough particles, one fifth to one twentieth of fibre size are important to achieve efficient fibre concrete mix. This effect may not be significant for macro fibres (diameter > 0.2 mm) in dosage < 0.4% by volume or for micro fibres < 0.1% by volume of concrete. To keep shrinkage low the OPC content shall be restricted, while increasing the total cemetitious material. Thus flyash content can be higher than that permitted in normal concrete.

4.2.5 The fine aggregate content shall be 45-68% of total aggregate, depending on the maximum size of coarse aggregate (more % with smaller aggregate size), and increasing with dosages of fibre.

Table 2 shows range of proportions for fibre reinforced concrete for pavement application. This table is for guidance for an initial trial mix. However, the final mix proportion after successful trials may differ from the guidance in the Table.

Table 2: Typical Range of Constituent in FRC Mixes

	Maximum Size of Aggregate		
Mix parameters	**10 mm**	**20 mm**	**31.5 mm**
Fibre content in % volume			
Micro fibres	0.5 to 1.0	0.2 to 0.6	0.1 to 0.3
Macro fibres	1.0 to 3.0	0.3 to1.0	0.3 to 0.6
Cementitious content kg/m³	400 - 520	380 - 500	350 - 430
Water/cementitious ratio #	0.30 to 0.40	0.30 to 0.45	0.30 to 0.50
% fine to total aggregate	50 - 68	45 - 60	40 - 50
Entrained air content *	4 - 8	4 - 6	3 - 5

\# Based on effective coefficient for cementitious (mineral admixture), say 0.4 for flyash.

* For Freeze thaw resistance.

4.3 Mix Proportioning

Mix proportioning is to achieve the targeted and desirable properties in fresh and hardened state of concrete. Use of any method to arrive at mix proportioning, which gives the desired performance, is permitted. Past experience and trials can guide the proportioning process. The aim of mix proportioning shall also be, to enhance the performance efficiency of the fibers in the concrete. In mix proportioning consider the fibre as an additional constituent to a concrete, and the mix may not be same for concrete without fibres and with fibres.

Mix proportioning shall conform to the requirement of transporting, laying and compacting the FRC pavement. The required properties of fresh/plastic concrete may differ significantly with the methods of construction and equipment to be deployed.

4.3.1 Cement OPC (IS:8112, IS:12269, IS:8041), slag cement (PSC- IS:455), PPC (IS:1489-1) can be used. Cement strength at 28 days shall not be less than 43 MPa. Blending (or multiple blending) with mineral admixtures (additives) shall be done at the batch mixing plant or high efficiency mixers like pan mixers or twin shaft mixers.

4.3.2 As per IRC:15 the flyash content will be about 20% of total cementitious material. However, with the written permission of the Engineer it can go up to 35%; and the usual range is 20 to 35%.The GGBS (Ground Granulated Blast-Furnace Slag) content can be 25 to 50% of total cementitious material. The silica fume 5 to 10% is required for high strength concrete, and for enhancing abrasion resistance. Multiple blending duly optimized, is permitted for better performance of FRC.

4.3.3 For a properly proportioned FRC mix, there may not be any significant reduction (< 5%) in compressive strength of FRC compared to the concrete without fibres.

4.3.4 It is necessary to arrive at the mix proportion such that it does not bleed. In bleeding concrete micro polymeric fibres tend to rise up to the top surface of concrete, causing reduction in the quantity of fibres in the mix.

4.3.5 Water content of concrete shall normally be 140 to 180 kg/m^3 of concrete. For F5 (flexural strength 5 MPa) concrete free water content should not be more than 160 kg/m^3. And ratio of water to cementitious content also should not exceed 0.4.

Typically the dosages of superplasticizer (naphthalene base or melamine base) could be 0.4 to 1.4% of cementitious content. Poly-carboxylic based superplasticizer can be used in smaller dosages for normal FRC, or in > 0.5% for free flow or self compacting concrete. Actual dosages shall be worked out from trials.

4.3.6 The proportioning should also consider the parameters to avoid balling of fibres. Higher cohesiveness of the mix can reduce chances of balling. The mix should be cohesive enough to hold the fibres, without segregation.

For the mix to be efficient for the fibres, the grading curve (graph of sieve size and percentage passing) of aggregates (coarse and finer together) could be drifted towards finer side.

4.3.7 The combined grading curve of coarse and fine aggregates down up to 75 µm (micron) size should be checked for getting smooth grading. The percentage passing through 300 micron sieve should be 7 to 20%, if maximum size of aggregate in mix is 20 mm. The finer material will increase as the dosages of fibre will increase from 0.2% to 1% by volume of concrete. It should be noticed that in this regard use of crushed sand becomes desirable.

It is preferable to use natural fine aggregate of zone 3. If it is not available, the available fine aggregate can be modified by combining with crushed sand or by mixing a small percentage (4 to 8%) of crusher fines, thus to improve the continuous grading.

With fibres, their surface area adds to the total surface area of aggregates; and the surface area increases with the dosages of fibres and inversely with finer size (equivalent diameter) of fibre. Hence for optimum performance of fibre's contribution in concrete, the quantity of fines required in the concrete may increase with increasing surface area of fibres. By addition of fibres, the demand of particles smaller than fibre size can increase.

4.3.7.1 Total finer material including cement, mineral admixtures (flyash etc.) and finer portion of finer aggregate, together passing through 300 micron sieve should not be less than 400 kg/m^3, if fibre dosages is more than 0.1% by volume of concrete. For fibre dosages of about 0.3% by volume of concrete, finer material may be about 450 kg/m^3, and still higher for higher dosages of fibres say up to 540 kg/m^3.

4.3.8 It is economical to have the higher grade of concrete getting maximum possible flexural strength, compatible with the materials, the construction methodology and quality management. Where fibres are used only to control plastic shrinkage cracking the minimum grade of concrete should be F4.5 (4.5 MPa characteristic flexural strength) at 28 days age, as per IRC:58 and IRC:15. As the aim of fibres is to maximize the flexural strength of the FRC, preferably minimum grade of FRC will be F5 (characteristic flexural strength 5 MPa) or more, where contribution of fibres is accounted in the design. Refer **Appendix C** for a typical mix proportion.

4.3.9 The concrete mix proportioning shall be valid for the range of workability required on a project. For this purpose the dosages of chemical admixture (plasticizer) could be divided in two parts, the minimum dosages and the provisional dosages.

4.3.10 For freeze and thaw resistance air content in concrete should be typically 4 to 6%.

4.4 Workability (Slump) of Concrete

Workability deals with entire range of mobility and fluidity, from driest to wettest possible fresh or plastic concrete. Workability requirements are largely influenced by method and equipment for pavement construction, and to some extent by thickness of concrete, spacing of reinforcement if any etc.

4.4.1 For concrete laid by slip-form paver, workability requirement may range between 20 mm to 50 mm of slump at the time of placing, depending on the temperature of concrete, the ambient temperature at the time of laying and the speed of laying (in m/minute). If the workability is more than the critical value required, the concrete edge left fresh by paver will not be able to retain proper shape and may bulge. Under conditions of 16°C ambient temperature almost a no slump (<10 mm) concrete may be required, and for concrete temperature 30°C, 50 mm slump concrete may be required. Actual slump requirement should be assessed for the particular concrete and the environmental conditions, based on the trials in field. For a particular situation the range of workability (variation minimum to maximum i.e. workability window) is quite small for slip-form method of construction. Workability corrections may be required every few hours.

4.4.1.1 To maintain required workability at the time of placing, it will have to be adjusted at the production site, keeping in view the ambient temperature and the haulage distance from production site to laying site. This will be achieved by trials in the field. The adjustment or fine tuning of workability is permitted during construction keeping in view the ambient temperature and relative humidity. FRC can be transported in transit mixer, and in case of harsh mix with short haulage transportation in tippers covered with tarpaulin can be permitted.

4.4.2 For concrete laid by fixed form paver, workability requirement may range between 35 mm to 75 mm depending up on the temperature of concrete, the ambient temperature and effectiveness of the method of compaction adopted. For concrete laid without paver, consolidated by screed vibrator higher slump (60 to 100 mm) may be required. These limits will not be applicable to pumped concrete, which may require a slump of 120 to 160 mm.

4.4.3 Most common method to measure workability is by slump cone (IS:1199), which can measure with an accuracy of ±20 mm for low (20 to 75 mm) and medium slump (50 to 100 mm), and ±30 mm for high slump (> 100 mm). For low slump concrete degree of compacting method or Vee-Bee (Vebe time) method are better suitable for workability test, which may be 20 to 7 seconds. For workability tests refer IS:1199 (ISO 1920-2, EN 12350-2 to 5, DIN 1048).

4.4.4 With addition of fibres to concrete, its workability gets reduced, and a fibre concrete mix also needs proper workability for placing and compaction.

4.4.5 For increasing workability of concrete mix, plasticizer (or super plasticizer) in suitable dosages may be added. For compensating the loss of workability due to time delay, retarders (or retarding plasticizer) would be required at the first mixing. By addition of plasticizer at the time of delivery (i.e. second dose with adequate mixing), proper workability could be achieved for delayed deliveries. Re-dosing of plasticizer is permitted to improve the slump by 40 mm maximum, provided this provisional dosage is also accounted in the mix proportioning and trial mix exercises to achieve specified strength.

4.4.6 For proper workability management, it is necessary to keep the temperature of concrete as being placed, within a narrow range. With variations in the temperature of concrete, the loss of workability of the mix and thus the dosing of admixture would change. Hence temperature of concrete at mixer and at pouring should be noted. At the time of pouring of concrete its temperature should not exceed 30°C as per IRC:15. Temperature of concrete in the batch mix plant will normally be around 25°C.

4.5 Dosing of Fibres

4.5.1 For construction, the dosage of fibre shall be specified in kg/m³ of concrete. For a batch of concrete to be produced, the fibres shall be weighed accurately (-0 +6% of specified quantity). In case of micro fibres, the quantity of fibre in a pack should be suitable for one batch of mix.

4.5.2 Fibres will be dispensed in clump-free state such that a homogenous and uniform distribution is obtained with no balling effect.

4.5.3 Speed of flow of fibre into the mixer would dependent on the mixer type, the aspect ratio of fibres, the dosages of fibres (mass of fibre per batch of concrete), etc. Method of dosing recommended by the manufacturer of the fibre should be given due consideration. Method of dosing and appropriate speed of dosing should be checked by trials.

4.5.3.1 Fibres may be added to the feed belt of the coarse aggregate in a batch mixing plant. The other option is to add fibres in to the mixer during or at the end of the feeding of mix constituents. In most cases the fibres are added after the aggregates are fed in to the mixer, and while cementitious material being added.

4.5.4 A vibrating screen or other device for separating fibres (from each other) may be required to avoid clumping of fibres prior to mixing with concrete. Dosing of fibres could be done with different types of equipment. The types of equipment could be – (i) vibrating hopper and a chute, (ii) vibrating hopper and a belt conveyor or screw conveyor, (iii) blower or pneumatic placer, etc.

4.5.5 It is noted that in hot and dry climate addition of fibres by pneumatic placer has a drying and heating effect on concrete, thereby reducing the workability drastically and also the setting time. Hence this method of dosing should be carefully evaluated and may require higher dosages of retarders and plasticizer.

4.5.6 Fibres could be added either manually (only on smaller projects) or by dosing equipment, which allows loose fibres to be added as a stream during mixing and not added in lots at any instant, except if otherwise recommended by the manufacturer of fibres (e.g. glued/bundled/in degradable bags). The stream of fibres added to mixer shall be at a nearly uniform rate such that the fibre dosage is added in a period recommended by the manufacturer or as established by trials, while the mixer is mixing the materials.

4.5.7 **Table 3** gives the nominal fibre dosages in kg/m^3 for different volume fractions of fibre. Volume fraction of fibre is the ratio of volume of fibre to gross volume of compacted concrete, expressed in percentage. In this document wherever the fibre dose is indicated in %, it is the volume fraction of concrete.

Dosages in kg/m^3 = 10 × (fibre volume in %) × (specific gravity of fibre material) ... (1)

Table 3 : Fibre Dosages by Volume Fraction (%) and Equivalent Dosages in kg/m^3

Fibre Volume	Steel Fibre	Polypropylene Fibre
0.1%	8 kg/m^3	0.9 kg/m^3
0.2%	16 kg/m^3	1.8 kg/m^3
0.3%	24 kg/m^3	2.7 kg/m^3
0.4%	32 kg/m^3	3.6 kg/m^3
0.5%	40 kg/m^3	4.5 kg/m^3
0.75%	60 kg/m^3	6.8 kg/m^3
1.0%	80 kg/m^3	9.0 kg/m^3
1.5%	120 kg/m^3	14 kg/m^3
2.0%	160 kg/m^3	18 kg/m^3

Specific gravity (density) of steel is taken as 7.85, and that of polypropylene as 0.91.

4.6 Mixing FRC

Concrete shall be mixed such that the mix is uniform and the fibres are dispersed through out the mass uniformly. Tests on samples taken at different points in the discharge from mixer could show the degree of uniformity. Variations in slump, air content and compressive strength of concrete sampled from different points of time for discharge could also indicate the short fall in uniformity of mixing.

The mixing efficiency is indicated by the variations in the proportion of coarse aggregate in a sample of recorded size. However, with FRC, it is also necessary to evaluate variations in the proportion of fibres. In addition to such test, regularly the mixed concrete should be inspected visually to ensure that the mixing is uniform and fibres are well dispersed.

For a mixer, reducing a batch size and/or increasing the mixing time can enhance the mixing efficiency. Mixing efficiency test is highly important for tilting drum mixers or mixers other than pan mixers and twin shaft mixers.

4.6.1 Mixing time for FRC can be 15 to 25% higher compared to concrete without fibres. Pan mixer or twin shaft mixers are highly efficient, and can do a good job with 20 seconds of mixing time.

4.6.2 For each FRC job, optimum time for uniform mixing should be found by trials, and same may change, as the ingredients change, more specially the fibre content. Mixing time will also change with working rpm of the mixer and with wear of the blades.

4.6.3 The mixing time shall be as per the recommendations of mixer manufacturer for FRC and verified by mixer efficiency test.

4.6.4 In case of self compacting concrete, the major dosages of plasticizer may be added after the fibres are put into the concrete.

4.7 Fibre Balling

Tendency of fibres to get entangled with each other, tending to clump or form a ball shape is called as fibre balling (i.e. lump of un-dispersed fibres forming three dimensional unit). The ball or a lump of fibres in concrete mix has significant air entrapped, and is devoid of aggregates. FRC shall be free of fibre balls when delivered.

4.7.1 One should study the causes of fibre balling, and the conditions which tend to form the ball. The whole operation of dosing and mixing should be engineered (designed) such that chances of balling are eliminated, i.e. high level of reliability should be achieved in the process. From the zone of entry of fibres, movements in the mixer should carry the fibres away into the mix faster than they are added. Balls are formed while fibres get stacked up during handling if carried too fast. Fibres should not be allowed to pile up or slide down the vanes of partially filled drum, that otherwise will result in balling.

4.7.2 Chances of balling are higher with higher dosages (% volume of concrete) of fibres, and also higher with higher aspect ratio. Harsh mixes (not fluid enough or not workable enough) take longer time to mix the fibres without balling. If fibres are added to mixer first while the other materials (aggregate) are not enough to keep the fibres away from each other, the balls may form. Within mixer, absence of different types of particle motions may give rise to balling. Inefficient mixer or that with worn out blades can have tendency to produce balls. Trials should confirm that the specified dosages of fibres of given aspect ratio can be mixed uniformly, without causing balling action.

4.7.3 If at all any fibre ball is noticed in the concrete, it should be removed by hand picking. The loss of fibres by way of balls should not be more than 5% of the dose specified otherwise the FRC will be rejected.

4.8 Unit Weight of FRC

As per IS:1199, the unit weight of FRC is determined similar to that of conventional concrete. Significant lowering of the unit weight of fresh FRC could indicate the incorporation of air due to inappropriate mix proportioning. Large variations in the unit weight could indicate the non-uniform dispersion of fibres within the concrete.

4.9 Homogeneity of Fibre Dosage

The content of fibre shall be checked from samples obtained from fresh concrete. It is recommended that the number of samples shall be at least 6, each with a volume of concrete contained in a bucket of 10 litres capacity.

4.9.1 Each fresh concrete sample will be placed over a 5 mm sieve and washed with water to remove the fine contents. From the remaining mass of aggregates and fibres, the fibres are to be separated manually, dried and weighed. The average weight of fibres obtained is used to determine the nominal fibre dosage, which shall not be less than 90% of the specified fibre dosage. For steel fibres, a magnet or an electromagnet can be used to extract the fibres.

4.9.2 In case, the content of fibres has to be estimated in hardened concrete, 12 cores of at least 100 mm diameter should be extracted from the PQC layer. Each core should be trimmed to a uniform length and crushed, after recording the dimensions and weight of each core. The fibres should be separated and weighed to ascertain the nominal fibre content for each core. Individual value of fibre content shall not be less than 85% of the specified fibre dosage and the average of all samples should be above 90% of the specified fibre dosage.

4.10 Placing and Finishing

In most cases transporting, placing, compacting and finishing can be done by conventional methods of concrete pavement construction.

Compaction should be done by surface/screed vibrators, with due care to avoid over vibration. Use of immersion (needle/internal/poker) vibrator put nearly vertical, should be avoided as far as possible, because their use can disturb the orientation of fibres and may align more fibres in a vertical direction. Gang of immersion vibrators (as with slip-form pavers) put nearly horizontal, are acceptable for pavement, because this may cause more fibres to align horizontally, resulting in advantage for flexural strength of the slab. For more details refer IRC:15 and ACI 544.3.

4.10.1 Most operations of handling, placing, finishing, extreme weather concreting, curing and protection are similar to conventional concrete as in IRC:15. For more details specialized literature on concrete construction and pavement construction may be referred.

4.10.2 Steel fibre reinforced concrete can be finished with conventional tools and equipment, with minor refinements in techniques and workmanship are needed. Screeding is carried out by steel bar/roller/flat section with rounded edges.

Steel float is used behind the paver. The protruding steel fibres should be pressed in green concrete, so that the same are sunk into the concrete. After that the surface can be floated and textured as per requirement. Any exposed steel fibre protruding out from the top surface should to be cut or grinded.

4.10.3 Most operations of protection, texturing (or tinning) and curing are similar to conventional concrete as per IRC:15. The newly laid concrete shall be covered against rapid drying and cured immediately after the finishing operations have been completed. Initial curing can be done by application of a curing membrane followed by the spreading of wet hessian (or jute cloth) and moistening it regularly, or by ponding. Curing shall be done for a minimum period of fourteen days.

4.10.4 Thin pavement concrete (or overlays) in FRC are more susceptible to lapses in curing, hence requires more precautions and closer supervision. Fibres help in controlling shrinkage cracking, and the provision of micro fibres is recommended for resisting plastic shrinkage cracking, however, all the precautions for early age curing are important such as mist spray or fogging or fuming the surface within one hour of placing concrete. These precautions are required till wet curing or spray of curing compound is done. Thin bonded overlays need uninterrupted curing for its development of bond with the layers below.

4.10.5 The cutting of grooves shall be done just after the initial setting of the concrete to produce a contraction joint. This could range between 6 hours to 24 hours depending on the concrete used and the ambient conditions. Grooves should be cut using a water-cooled diamond-edged disc saw. The groove should be perpendicular to the longitudinal axis of the carriageway and made to a depth of one-third of the thickness of the FRC layer. The spacing of contraction joint is normally 20 to 36 times the thickness of the FRC layer, and not more than 4.5 to 5.0 m. The Longitudinal groove should also be cut simultaneously to about one third depth of slab.

4.11 Properties of FRC in Hardened State

4.11.1 The compressive strength of concrete is determined as for conventional concrete as per IS:516. Care should be taken to ensure that internal needle/poker vibrator is not used to compact the any test specimens of FRC, as it will cause significant non-uniformity in the distribution of fibres and coarse aggregates in the specimen.

4.11.2 It is to note that micro-fibres are not expected to increase the strength of the concrete. Reduction of strength of the concrete significantly, may indicate an inefficient mix proportioning or in adequate mixing of the FRC.

4.11.3 Flexural strength and toughness of FRC are the most important parameters for design and quality control. The test described in **Appendix B** gives the recommended procedure for determining the flexural strength (f_{ct}) and the equivalent flexural strength (f_{e150}). The characteristic values of both parameters (f_{ctk} and f_{e150k}) are used in the design of the FRC pavement.

4.11.4 In the absence of sufficient data for the determination of the characteristic value, the characteristic equivalent flexural strength of FRC can be taken as:

$$f_{e150k} = 0.7\, f_{e150m} \qquad \dots (2)$$

where f_{e150m} is the mean equivalent flexural strength obtained from tests on a set of at least 6 specimens.

4.11.5 In absence of sufficient data for statistical analysis, the characteristic strength

$$f_{ctk} = 0.7\, f_{ctm}\,; \qquad \dots (3)$$

And where the standard deviation for the compressive strength is likely to be less than 7% of average value, take $f_{ctk} = 0.8\, f_{ctm}$ ... (4)

Here f_{ctk} is characteristic strength, and f_{ctm} is mean strength as obtained from test results.

5 SPECIFYING FIBRE REINFORCED CONCRETE

If concrete supply is from a ready mixed concrete plant, the requirements of IS:4926 and IRC:SP:96 shall be satisfied.

5.1 While specifying fibre concrete irrespective of options given in Clause 5.3, following criteria shall be finalised based on method of handling, placing, compacting concrete and the exposure conditions.

i) Type of FRC, nominal maximum size of aggregate, target workability range, air content (for durability against freeze-thaw), temperature of concrete, minimum compressive strength of concrete,

ii) Maximum and minimum limits of cement content and, maximum and minimum limits of mineral admixtures.

iii) In most cases type of coarse and fine aggregates may also be specified.

iv) Grade of concrete by flexural strength,

v) Type of cement i.e. OPC, PPC or PSC.

5.1.1 Where an organization (or a contractor) executing a construction work is producing concrete and also carrying out the construction activities, its sub organization (or wing) producing concrete shall be treated as supplier of concrete, and the sub organization (or wing) carrying out the construction shall be treated as purchaser of concrete.

5.2 There can be different approaches or basis of specifying concrete under a contract. The main distinction is the prescriptive approach and the performance approach.

The manufacturer/supplier (producing concrete) prior to the actual delivery of concrete shall furnish a statement to the purchaser (executing the construction), enlisting the data as per Clause 9.1.2 of IS:456, and also the following information for each cubic meter of concrete:

a) Sources, relative densities, sieve analyses, and saturated surface-dry masses of fine and coarse aggregates,

b) the dry masses of cement and supplementary cementitious materials (mineral admixtures/additives),

c) the type, size, dimensions, and weight of fibres, the quantities,

d) types and names of chemical admixtures and their dosages (also specify provisional dosages if any), the air entraining admixtures if any, and

e) the amount of mixing water per cubic meter of concrete that will be used in the manufacture of each class of concrete ordered by the purchaser.

5.2.1 The manufacturer shall also furnish evidence satisfactory to the purchaser that the materials to be used and the proportions selected will produce fibre reinforced concrete of the performance requirements and the quality specified.

5.3 Options of Purchaser

Purchaser shall stipulate detailed specifications, and the requirements. It is recommended that to the extent possible, performance approach (option A) should be opted.

5.3.1 *Option A (Performance Approach)*

The purchaser specifies the following and requires the contactor/supplier/manufacturer to take full responsibility for mix proportioning.

a) Compressive strength of concrete at 28 days, and optionally also at 7 days, 56/90 days.

b) Flexural tensile strength, characteristic value f_{ctk} as per the method given in the **Appendix B**,

c) Equivalent flexural strength, characteristic value f_{e150k}

d) Optionally maximum and minimum limits of cement, cementitious materials mineral admixture and additives content, and the maximum limiting value of water cement ratio can be specified. The minimum dosages of fibres may be specified.

e) The purchaser while choosing the concrete also assumes responsibility for the requirements of placeability and finishability. A general responsibility on durability will be carried to the extent specified in the specifications.

f) It should be noted that, for getting the specified ratio of f_{e150k} / f_{ctk} (i.e. R_{e150}), the dosages of fibre may be higher than the minimum specified.

5.3.2 *Option B (Prescriptive Approach)*

The specification designer/purchaser assume the responsibility of designing and proportioning the concrete mix for the intended purpose. The prescriptive approach is not recommended and it is discouraged.

DESIGN OF FRC PAVEMENTS

6 GENERAL ASPECTS OF DESIGN

6.1 In general the design and construction of layers below FRC pavement shall conform to the requirements of IRC:15 and IRC:58. The FRC pavement design will also be guided by IRC:58. The CBR of the natural or modified sub-grade shall not be less than 8%, and k value (modulus of sub-grade reaction) not less than 50 MPa/m (or 0.05 N/mm^3 or 5 kg/cm^3).

6.1.1 The concrete pavement in FRC shall have a sub-base which may have single or multiple layers. Sub-base may consists of dry lean concrete, cement treated sub-base, existing bituminous/asphalt base etc. In exceptional cases where the stiffness of the sub-grade is very high, a drainage layer, with bituminous or cementitious binder, should be provided below FRC base (PQC) for the purpose of effective drainage of water. In conditions of problematic sub-grade (like clayey soils) consideration of minimum thickness of road crust will be considered.

6.1.1.1 At top of sub-base (i.e. at bottom of PQC), the composite modulus of sub-grade reaction (k value) shall not normally be less than 100 MPa/m (or 0.10 N/mm^3 or 10 kg/cm^3). This k value needed will be further higher as the thickness of PQC reduces.

6.1.2 The sub-grade shall comply with the requirements of IRC:15 and IRC:58. Its modulus of sub-grade reaction (i.e. k value) shall not be less than 50 MPa/m (or 0.05 N/mm^3 or 5.0 kg/cm^3). If k value is less than 80 MPa/m, a layer should be added over sub-grade (and below sub-base) so as to improve the composite k value on that layer to at least 80 MPa/m (or 0.08 N/mm^3 or 8 kg/cm^3).

6.1.3 While accounting for the k value as a design input, the value should be evaluated such that it is a characteristic value i.e. a reliable value which has very little chance (1 in 20) of being not exceeded. Hence in case of few test results, it shall be the lowest possible value. It should be noted that k value changes from spot to spot due to heterogeneity (not being perfectly uniform) of layers, deterioration over the design life of the rigid pavement and moisture variations. While k value test is done, usually for convenience of loading the plate size taken is smaller than the 750 mm diameter standard size. Due to smaller loaded area the influence of the flexibility of lower layers of strata are not adequately accounted and hence test value appears to be higher and need correction for the composite value. This correction is in addition to plate size correction for a thick layer of one type of strata. Also with load repetition or sustained load the stiffness reduces. Hence it is necessary to arrive at the design k value, after discounting the value estimated by test.

6.1.4 FRC pavement layer, if not designed as bonded or semi-bonded composite pavement, a separation membrane shall be laid over the sub-base. Such a membrane has two basic functions. The first is to de-bond the base (PQC) from the sub-base and to allow the top PQC layer to contract. At the joint, the horizontal movement of the slab is about 1 mm due to temperature and shrinkage strain. The top surface of the sub-base should be as per design profile and smooth to allow this movement. If such a movement is restricted additional stress due to restraining of linear displacement will also be accounted in the design. In normal design procedure as given in IRC:58, such stress (due to restraining of linear displacement) is not accounted in the design. Second function of the separation membrane is the impermeability.

6.1.4.1 Impermeable membrane of virgin polyethylene (LDPE) as separation sheet, can be used. Thickness should allow the movement between two layers. Hence it will depend upon the roughness of the top of sub base. Internationally polyethylene sheet is not being used, and geo-textile about 5 mm thick is recommended. Flexible bituminous layer (DBM-1 thickness about 50-75 mm) as a separation layer can also be provided to reduce the friction to the contraction.

6.1.4.2 The separation layer (or sheet) may not be provided where joint spacing is ≤ 12 (15 for structural FRC) times the thickness of PQC even if the PQC layer is designed as unbonded pavement.

6.1.5 For calculating the stress in PQC in unbonded systems, the composite modulus of sub-grade reaction (k value) at the bottom of the slab (PQC) is to be estimated as an input value for design, which is at top of sub-base as a composite action with the layers below. This k value for design shall be evaluated by direct k value test or by estimate based on the other test data as may be available, with correction for various conditions and variances. For estimate the data from Table 2, 3 and 4 of IRC:58 (or IRC:15 Table 9, 10 and 11) may be utilized.

6.1.5.1 For calculating the stress in PQC in bonded system, the composite modulus of sub-grade reaction (k value) at the bottom of the composite slab (PQC + bonded sub-base) i.e. at bottom of sub-base is to be estimated as an input value for design. This composite modulus of sub-grade reaction (i.e. k value) is at bottom of sub-base as a combined action with the layers below, and determined as above (Clause 6.1.5).

6.1.6 For FRC pavement thickness 200 mm or more, use of load transfer devices (such as dowel bars) may be considered, to reduce the stresses due to edge load. For pavement thickness less than 200 mm such devices are considered as not reliable. Refer IRC:58 for design of dowel and tie bars.

6.1.6.1 For pavement with structural FRC ($f_{e,150k} \geq 0.3 f_{ctk}$), the thickness limit in above be considered as 150 mm (in place of 200 mm).

6.1.7 To control contraction cracking, longitudinal and contraction joints shall be designed as per IRC:58 (for pavement without reinforcement bars).

Temperature Stress Shall be Estimated Similar to Plain Concrete Pavement.

6.2 The design procedures for FRC pavement will change as its toughness increases. Hence there are two different regimes for the design.

a) FRC having low dosages of fibres or less effective fibres, exhibiting $f_{e150k} < 0.3\ f_{ctk}$, i.e. toughness improvement in FRC is not substantial, or f_{e150k} not being specified.

b) FRC having substantial toughness; this situation can be by using significant dosages of effective fibres. Here $f_{e150k} \geq 0.3 f_{ctk}$. Values referred above will be as per Clause 4.11, and determined as in the test procedure described in **Appendix B**.

6.3 For design, modulus of elasticity (E) of the FRC should be determined as tangent modulus, from flexural toughness test on the beam sample as specified in **Appendix B**. Alternately modulus of elasticity (E) could be determined from compression test. In absence of E value from the test, based on the characteristic compressive strength of concrete, E value can be taken as per the guidance in IRC:58.

6.3.1 For design, Poisson's ratio (μ) could be determined from compression test. In absence of the value from test, μ value can be taken as per the guidance in IRC:58.

6.4 For bonded overlays, the reduced thickness of FRC can be designed as per IRC:SP:76.

6.5 The size of panel (between the joint) and the saw cut timing are important for design.

6.6 In thin un-doweled overlays (white tops) the critical stress location is the corner, and the failure may be due to corner breaking and debonding.

7 DESIGN FOR FRC

Check on the design thickness of pavement as per provisions in Section 7 will be required for all cases of FRC having low or high toughness.

7.1 Pavements with FRC of low toughness ($f_{e,150k} < 0.3\ f_{ctk}$), shall be designed as per the procedure given in IRC:58, and where applicable using IRC:SP:76. The fibres are taken to contribute mainly in controlling plastic shrinkage and temperature induced cracks. However, for fatigue endurance, the limiting stress ratio will be taken as specified below (in place of 0.45 in IRC:58). Relationship of S-N is given in **Appendix A** for endurance limit of 0.50 and above.

7.1.1 The design value of peak flexural strength shall be conformed by the beam test procedure given in **Appendix B**. If such facilities are not available, alternately it can be determined from flexural beam test conforming to IS:516.

7.1.2 In FRC if polymeric fibres are used in dose less than 0.3% by volume, for fatigue endurance, the limiting stress ratio will be taken as 0.45 (as in IRC:58).

7.1.3 In FRC if polymeric fibres are used in dose more than 0.3% by volume (mainly to control plastic shrinkage cracks), or in FRC with steel or any other fibres having low toughness (falling under 6.2 (a), i.e. $f_{e150k} < 0.3 f_{ctk}$), for fatigue endurance, the limiting stress ratio will be taken as 0.50; see A1 of **Appendix A**.

7.2 Pavements with FRC having high toughness (falling under 6.2 (b) i.e. $f_{e150k} \geq 0.3 f_{ctk}$), shall be designed as per the procedure given in IRC:58. For fatigue endurance, the limiting stress ratio will be taken as 0.6 (in place of 0.45 in IRC:58). Relationship of S-N is given in A2 of **Appendix A** for endurance limit of 0.60.

7.2.1 The fatigue endurance limit of 0.7 can be used for design, if test of the specific FRC for fatigue data conform to the S-N relation for 0.7.

7.2.2 The design value of peak flexural strength shall be conformed by the beam test procedure given in **Appendix B**.

7.2.3 In addition to the stress and fatigue damage check as in 7.1 and 7.2, the ultimate moment capacity check as in Section 8 shall also be applied for FRC qualifying under 6.2(b) and 7.2. The ultimate moment capacity check (as per Clause 8) will not be applicable to FRC not qualifying under 6.2(b).

8 ULTIMATE MOMENT CAPACITY CHECK

For FRC having high toughness, in addition to that the check as in Section 7.2, following check will be required on the design thickness of FRC pavement.

8.1 FRC pavement with high toughness, satisfying the requirements of 6.2 (b), shall also be checked as per the provisions in this section, utilizing plasticity of FRC and nonlinear analysis for the maximum design load. The design approach described here is based on yield line analysis (i.e. plastic structural response) of the pavement slab along the lines of the procedure given by the UK Concrete Society TR 34.

8.2 Since ultimate load analysis considers the ultimate strength, instead of just the first crack strength, it seems to be generally acceptable for the design of slabs with fibres. Consequently, some plastic behaviour can be assumed during the failure of such slab systems (TR-34-2003). The structural design of FRC pavements subject to wheel loads involves a two-step process of calculating the ultimate moments acting for a given configuration of maximum wheel loads followed by identifying the necessary resistance that must hold up to the acting stresses.

8.3 Experimental studies on SFRC slabs have shown that the fibres do not have any significant (for dosages normally used) influence on the first crack load and, therefore, do not increase the cracking load. Nevertheless, the studies demonstrate that the ultimate failure loads can be higher by up to 60% and that the key parameters governing the ultimate failure loads are the sub-base reaction, fibre type and dosage. It has been concluded that failure can be considered as the appearance of a crack at the top of the slab (due to negative bending moment). In such a case, the stresses due to the positive moment, as shown in **Fig. 2**, are resisted by the cracked fibre concrete while the stresses due to the negative moment are resisted by the uncracked concrete strength i.e., the maximum stress would be the flexural strength of SFRC.

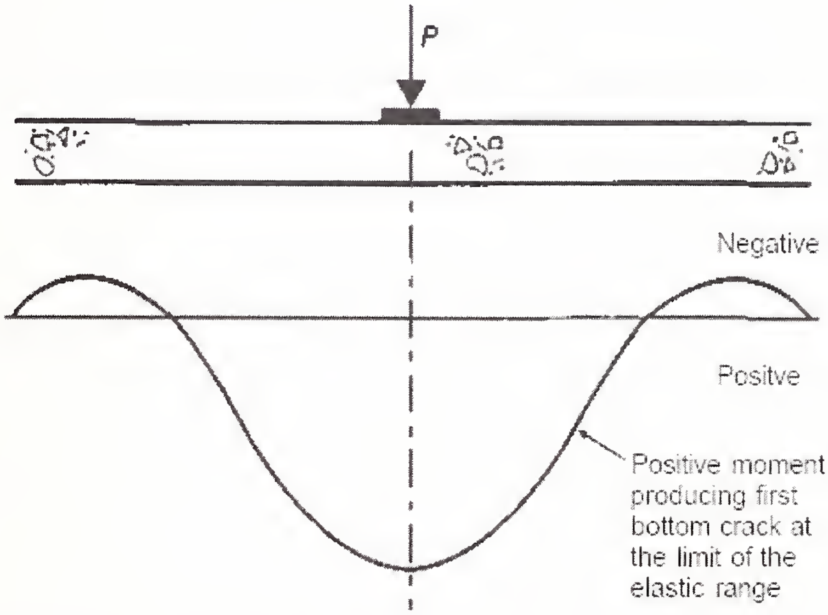


Fig. 2 Moment Distribution and Cracking Pattern in a Concrete Ground Supported Slab at the Time of Initiation of First Crack at the Bottom (from TR 34-2003)

8.4 Therefore, the limit moment of resistance of the slab is calculated as $M_o = M_n + M_p$ assuming redistribution of moments. In the limiting condition, both the positive moment of resistance (M_p) and the negative moment of resistance (M_n) are considered additive. Accordingly, the relationship between the yielding moments for different loading cases, in an interior location (i.e., away from the edges), can be written as:

$$\frac{M_n + M_P}{P_u} = f\left(\frac{c}{l}\right) \qquad \text{... (5)}$$

where *P* is the applied load, *c* is the radius of the area under distributed load and *l* is the elastic rigidity radius (i.e., radius of relative stiffness).

$P_u = \gamma_f P$, where γ_f is the load factor with minimum value 1.2

8.5 The radius of relative stiffness can be calculated as:

$$l = \left[\frac{E\ h^3}{12\ (1 - \mu^2)\ k}\right]^{1/4} \qquad \text{... (6)}$$

Where *E* is the modulus of elasticity of concrete, *μ* is the Poisson's ratio of concrete, *k* is the sub-grade modulus of reaction obtained as discussed in Section 6.1, and *h* is the thickness of the concrete slab.

8.6 The ultimate moment due to the load may be determined from any suitable inelastic techniques like the Meyerhof's ultimate load analysis, the Losberg's yield line analysis or numerical analysis. However, the applicability of inelastic analysis has to be ensured with respect to the fibre dosage and type used since inadequate fibre or may not allow enough plastic rotation capacity in the slab to render inelastic analysis suitable for design.

Consequently, inelastic design can be used only when $f_{e150k} \geq 0.3 f_{ctk}$, where f_{e150k} and f_{ctk} are, respectively the characteristic values of the equivalent flexural strength and flexural strength of FRC determined using the procedure described in **Appendix B**.

8.7 The required residual positive bending moment capacity of the slab can be represented as $M_p = (f_{e150k} / \gamma_m) \times (h^2/6)$ and, since the fibres do not affect the (first) cracking stress, the negative moment capacity is obtained as $M_n = (f_{ctk} / \gamma_m) \times (h^2/6)$, where h is the thickness of slab. Strength values shall be divided by partial material factor to get the design strengths. Hence

$$M_0 = (f_{ctk} + f_{e150k}) \times (h^2/6) / \gamma_m \qquad \text{... (7)}$$

Where γ_m is the partial safety factor for concrete strength, for which the usual value would be 1 to 1.2.

8.8 An illustrative Example of FRC Pavement Design is given in **Appendix D**.

9 NORMATIVE REFERENCES

Indian Roads Congress

IRC:15-2011	Standard Specifications and Code of Practice for Construction of Concrete Roads
IRC:58-2011	Guidelines for the design of Plain Jointed Rigid Pavements for Highways.
IRC:SP:76-2008	Tentative Guidelines for Conventional, Thin and Ultra-Thin White Topping (under revision).

Indian Standards

IS:455:1989	Specifications for Portland slag cement (Amendments 6).
IS:456:2000	Code of practice for plain and reinforced concrete (Amendments 4).
IS:516:1959	Method of test for strength of concrete (Amendments 2).
IS:1199:1959	Method of sampling and analysis of concrete.
IS:1489-1:1991	Specifications Portland pozzolana cement, Part 1 Flyash based (Amendments 5).
IS:3812 Part 1-2003	Specification for pulverized fuel ash : Part 1 For use as pozzolana in cement, cement mortar and concrete.
IS:3812 Part 2-2003	Specification for pulverized fuel ash : Part 2 For use as admixutre in cement mortar and concrete.

IS:4634:1991	Method for testing performance of batch-type concrete mixers.
IS:4926:2003	Ready Mixed Concrete- Code of Practice (Amendment 1).
IS:7861 Part 1	Code of Practice for Extreme Weather Concreting : Recommended Practice for Hot Weather Concreting (Amendment 1).
IS:8041:1990	Specifications for Rapid Hardening Portland Cement (Amendments 4).
IS:8112:1989	Specifications for 43 Grade Ordinary Portland Cement (Amendments 9).
IS:9013:1978	Method of Making, Curing and Determining Compressive Strength of Accelerated Cured Concrete Test Specimens (Amendment 1).
IS:9103:1999	Specifications for Admixtures for Concrete (Amendments 2).
IS:12269:1987	Specifications for 53 Grade Ordinary Portland Cement (Amendments 9).

American Concrete Institute

ACI 544.1R- 96	State-of-the-Art Report on Fibre Reinforced Concrete.
ACI 544.2R- 89	Measurement of Properties of Fibre Reinforced Concrete.
ACI 544.3R- 08	Guide for Specifying, Proportioning, and Production of Fibre Reinforced Concrete.
ACI 544.4R- 88	Design Considerations for Steel Fibre Reinforced Concrete
ACI 544.5R- 10	Report on the Physical Properties and Durability of Fibre-Reinforced Concrete

Indian Concrete Institute

ICI TC 01.01	Guideline for Selection, Specification and Acceptance of Fibre and Fibre Concrete (to be published).
ICI TC 01.02	Test Method for Fibre Reinforced Concrete – Reference Concretes (Draft)
ICI TC 01.03	Test Method for Fibre Reinforced Concrete – Flexural Strength and Toughness (Draft)
ICI TC 01.04	Steel Fibres - Definitions, Specifications and Conformity (Draft)
ICI TC 01.05	Polymeric Fibres - Definitions, Specifications and Conformity (Draft)

Others References

AASHTO-AGC-ARTBA-TF-36	The use and State-of the Practice of Fibre Reinforced Concrete, 2001.

ACI 360R-10	Guide to Design of Slabs-on-Ground
ACI 325.13R-06	Concrete Overlays for Pavement Rehabilitation.
ASTM C 1609/M(10)	Standard Test Method for Flexural Performance of Fibre Reinforced Concrete (Using Beam with Third-Point Loading).
ASTM C 1116/M(09)	Standard Specification for Fibre-Reinforced Concrete
ASTM A 820A/M(06)	Standard Specification for Steel Fibres for Fibre-Reinforced Concrete.
ASTM C 1399 (04)	Standard Test Method for Obtaining Average Residual-Strength of Fibre-Reinforced Concrete.
CS TR 34 (2003)	Concrete Industrial Ground Floors, a Guide to Design and Construction, The Concrete Society, UK.
EN 206-1:2000	Concrete- Part 1: Specifications, Performance, Production and Conformity
EN 12350-2	Testing Fresh Concrete - Part 2.
EN 14651: 2005	Test Method for Metallic Fibred Concrete – Measuring the Flexural Tensile Strength (Limit of Proportionality (LOP), Residual).
EN 14845-1:2006	Test Method for Fibres in Concrete, Part 1: Reference Concretes.
EN 14845-2:2006	Test Method for Fibres in Concrete, Part 2: Effect on Concrete.
EN 14889-1:2006	Fibres in Concrete: Steel Fibres – Definitions, Specifications and Conformity.
EN 14889-2:2006	Fibres in Concrete : Polymer Fibres – Definitions, Specifications and Conformity.
FHWA HIF-07-030,	
FIB Model Code 2010.	
ISO 13270	Steel Fibres for Concrete – Definitions and Specifications.
ISO 1920-2	Testing of Concrete – Part 2: Properties of Fresh Concrete
ISO 22965-1	Concrete – Part 1: Method of Specifying and Guidance for the Supplier
JSCE : Part III-2	Method of Test for Steel Fibre Reinforced Concrete, SF1 to SF7– 1984.

Appendix A
(Refer Clause 7.1)

S-N RELATIONSHIP

S-N relations are given below by equations:

Equation for curve can be plotted on a semi-log graph with Stress Ratio (SR) on vertical axis (Y axis), and numbers of cycles of load (N) on horizontal axis (X axis) on a log scale (i.e. $\mathrm{Log}_{10}N$).

Normally equation (or curve) is in two parts. First part is an equation for straight line and second part is an equation for a curve.

Equations are given for notional endurance factor of 0.50, 0.60 and 0.70.

A1. Endurance limit 0.50 :

a) Straight line relation for *SR* from 1 to 0.576

(extended line meets $SR = 0.50$ at $N = 2\times10^6$)

$\mathrm{Log}_{10}N = (0.9800 - SR) / 0.07618,$ ... (A1)

or $SR = 0.980 - 0.07618\ \mathrm{Log}_{10}N;$ ... (A2)

At $SR = 0.576$, $N = 2.00\times10^5$

b) From $SR = 0.576$ or less, relation is a curve.

$N = [3.7375 / (SR - 0.480)]^{3.333},$ ... (A3)

or $SR = (3.7375 / N^{0.300}) + 0.480;$ ... (A4)

at $N = 3.73\times10^7$, $SR = 0.50$; at $N = \infty$, $SR = 0.48$;

Based on (a) and (b) above values are tabulated in **Table A1**.

Table A1 : Stress Ratio and Allowable Repetitions in FRC For Endurance Ratio 0.50

Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions
SR	*N*	*SR*	*N*	*SR*	*N*
0.50	3.73×10^{07}	0.60	9.73×10^{04}	0.70	4737
0.51	9.66×10^{06}	0.61	7.19×10^{04}	0.71	3501
0.52	3.70×10^{06}	0.62	5.32×10^{04}	0.72	2588
0.53	1.76×10^{06}	0.63	3.93×10^{04}	0.73	1913
0.54	9.58×10^{05}	0.64	2.90×10^{04}	0.74	1414
0.55	5.73×10^{05}	0.65	2.15×10^{04}	0.75	1045
0.56	3.67×10^{05}	0.66	1.59×10^{04}	0.76	772
0.57	2.48×10^{05}	0.67	1.17×10^{04}	0.77	571
0.58	1.78×10^{05}	0.68	8670	0.78	422
0.59	1.32×10^{05}	0.69	6409	0.79	231

A2. Endurance limit 0.60 :

a) Straight line relation for SR from 1 to 0.627

(extended line meets $SR = 0.60$ at $N = 2\times10^6$).

$\text{Log}_{10}N = (0.9900 - SR) / 0.06189,$ ... (A5)

or $SR = 0.990 - 0.06189\ \text{Log}_{10}N;$ ... (A6)

At $SR = 0.627$, $N = 5.00\times10^5$

b) From $SR = 0.627$ or less , relation is a curve.

$N = [2.9212 / (SR - 0.570)]^{3.333},$ ... (A7)

or $SR = (2.9212 / N^{0.300}) + 0.570;$ ... (A8)

at $N = 4.25\times10^6$, $SR = 0.60$; at $N = \infty$, $SR = 0.570$;

Based on (a) and (b) above values are tabulated in **Table A2**.

Table A2 : Stress Ratio and Allowable Repetitions in FRC For Endurance Ratio 0.60

Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions
SR	N	SR	N	SR	N
0.60	4.25×10^{06}	0.67	1.48×10^{05}	0.74	10950
0.61	1.63×10^{06}	0.68	1.02×10^{05}	0.75	7548
0.62	7.74×10^{05}	0.69	7.04×10^{04}	0.76	5203
0.63	4.21×10^{05}	0.70	4.85×10^{04}	0.77	3587
0.64	4.52×10^{05}	0.71	3.34×10^{04}	0.78	2472
0.65	3.12×10^{05}	0.72	2.30×10^{04}	0.79	1704
0.66	2.15×10^{05}	0.73	1.59×10^{04}	0.80	1175

A3. Endurance limit 0.70 :

a) Straight line relation for SR from 1 to 0.714

(extended line meets $SR = 0.70$ at $N = 2\times10^6$)

$\text{Log}_{10}N = (1.00 - SR) / 0.04761,$ ... (A9)

or $SR = 1.00 - 0.04761\ \text{Log}_{10}N;$ ... (A10)

At $SR = 0.714$, $N = 1.00\times10^6$

b) From $SR = 0.714$ or less, relation is a curve.

$N = [4.0381 / (SR - 0.65)]^{3.333},$ ... (A11)

or $SR = (430381 / N^{0.300}) + 0.65;$ ... (A12) at $N = 2.28\times10^{7}$, $SR = 0.70$; at $N = \infty$, $SR = 0.650$;

Based on (a) and (b) above values are tabulated in **Table A3**.

Table A3 : Stress Ratio and Allowable Repetitions in FRC For Endurance Ratio 0.70

Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions
SR	*N*	*SR*	*N*	*SR*	*N*
0.70	2.28×10^{06}	0.75	1.78×10^{05}	0.80	15878
0.71	1.23×10^{06}	0.76	1.10×10^{05}	0.81	9789
0.72	7.61×10^{05}	0.77	6.78×10^{04}	0.82	6036
0.73	4.69×10^{05}	0.78	4.18×10^{04}	0.83	3721
0.74	2.89×10^{05}	0.79	2.58×10^{04}	0.84	2294

Appendix B
(Refer Clause 4.11.3)

RESIDUAL FLEXURAL STRENGTH AND TOUGHNESS TEST

B.1 Recommended procedure for the determination of flexural strength and equivalent flexural strength of fibre reinforced concrete is given.

B.1.1 For drafting this procedure, the JSCE-SF4 and ASTM C 1609 standards have been used as the bases.

B.2 Scope

B.2.1 This appendix provides the guidelines for testing and evaluating the flexural strength and the equivalent flexural strength (as a measure of the toughness) of fibre reinforced concrete by third point loading configuration on (un-notched) moulded test specimens. This test method is intended for fibres not longer than 60 mm. The method can also be used for a combination of fibres of same or different materials.

B.2.2 References given in bracket (of ISO/EN/ASTM, etc.) are for guidance.

B.3 Normative Reference

IS:516–1959 (2 amendments), Methods of tests for strength of concrete.

IS:9399-1979 Specification for apparatus for flexural testing of concrete.

EN 12390–4 Testing hardened concrete-Part 4: Compressive strength-Specification of testing machines.

B.4 Terms and Definitions

B.4.1 *net deflection,* δ - the deflection measured at mid-span of a flexural beam specimen, exclusive of any extraneous effects due to seating or twisting of the specimen on its supports or deformation of the support and loading system.

B.4.2 *first-peak load,* P_{max} - the load value at the first point on the load-deflection curve (similar to Fig. B4) where the slope is zero.

B.4.3 *first-peak deflection,* δ_{ct} - the net deflection value at first-peak load.

B.4.4 *load-deflection curve* - the plot of load versus net deflection of a flexural beam specimen loaded to the end-point deflection.

B.4.5 *mean flexural strength,* f_{ctm} - the stress value obtained when the peak load value (mean of specimens tested) is inserted in the equation of modulus of rupture.

B.4.6 *equivalent flexural load,* P_{en} - the load representing the average capacity in the post peak region up to a specified deflection of l/n ; value taken at n = 150.

B.4.7 *equivalent flexural strength* f_{en} - the stress value representing average strength in the post peak region up to a specified deflection of l/n; values taken at n = 150 or at n = 600.

B.4.8 *residual flexural strength,* f_{rn} - the stress value representing the strength in the post peak region obtained when the load value P_{rn} at a specified deflection of l/n is inserted in the equation of modulus of rupture.

B.4.9 *equivalent flexural strength ratio,* R_{en} - value of equivalent flexural strength normalized with respect to mean (of peak) flexural strength. Normally expressed for n = 150.

B.5 Principle

The flexural behaviuor of fibre reinforced concrete is evaluated by the enhanced post cracking capacity expressed in terms of a set of toughness parameters obtained from the load - deflection (P-δ) curve of the third-point loading test. Typical test set-up is shown in **Fig. B1**.

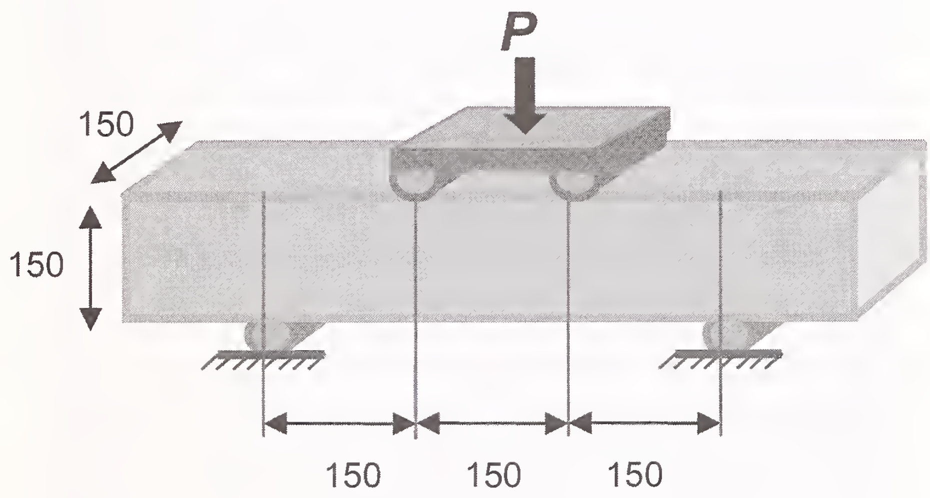


Fig. B1 : Test Set-up for Beam Test at Third Point Loading

B.6 Apparatus

B.6.1 **Moulds:** Standard beam moulds for producing hardened concrete specimens, of non absorbent, rigid material, not attacked by cement paste, of a size 150 mm × 150 mm × 700 mm. Moulds of shorter length, of at least 550 mm long, can be used to decrease the weight of the specimen.

B.6.2 Caliper, capable of reading the dimensions of test specimens to an accuracy of 0.1 mm.

B.6.3 Rule (ruler/scale), capable of reading the dimensions of test specimens to an accuracy of 1 mm.

B.6.4 It is recommended that the testing machine meets the machine class 1 requirements in EN 12390-4, capable of operating in a controlled manner, i.e. producing a constant rate of displacement (net deflection of specimen beam), and with sufficient stiffness to avoid unstable zones in the load-deflection curve.

B.6.5 If the testing is done in a machine with piston or crosshead (stroke) displacement control, it should be ensured that at least one data point is captured for a drop of 15% of the peak load. This is to ensure that the load drop is not unstable just after the peak load in order to establish a stable load-deflection curve.

B.6.6 Testing machines that use load control are not suitable for the test.

B.6.7 The loading and specimen support system shall be capable of applying third-point loading to the specimen without eccentricity or torque. The fixtures normally used for flexural testing are suitable with the qualification that supporting rollers shall be able to rotate on their axes and shall not be placed in grooves or have other restraints that prevent their free rotation (see **Fig. B2**).

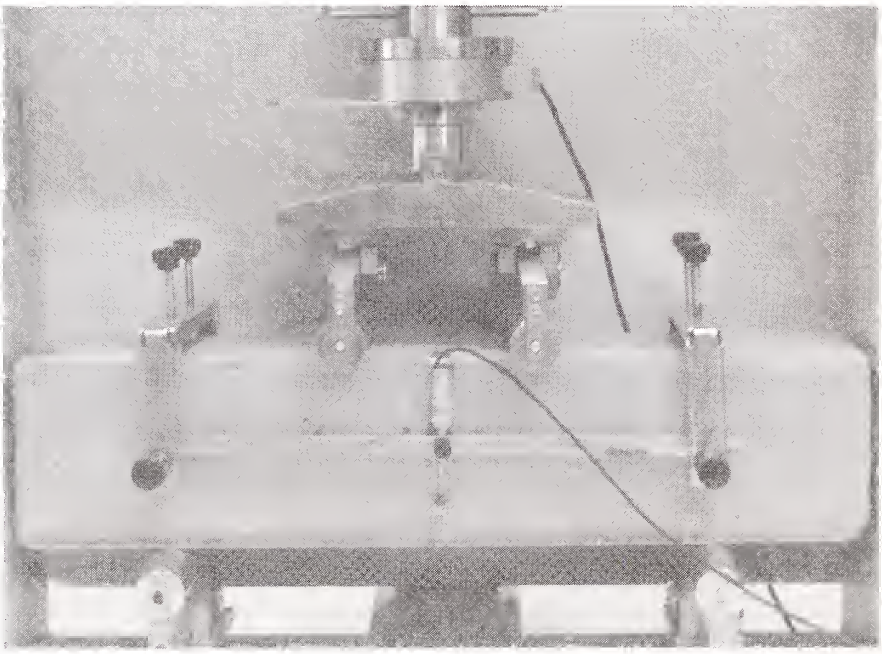


Fig. B2 : Loading Arrangement for Test Specimen

B.6.8.1 It is preferred that all rollers shall be manufactured from steel and shall have a circular cross-section with a diameter of 30 mm ±1 mm. They shall be at least 10 mm longer than the width of the test specimen. They shall have a smooth and clean surface. The four rollers (shown in **Fig. B2**), including the two upper ones, shall be capable of rotating freely around their axis. Except one roller at bottom, other three shall be capable of rotating in a plane perpendicular to the longitudinal axis of the test specimen. For the requirements of roller for supports or load, refer IS:9399.

B.6.8.2 The distance between the centers of the supporting rollers (i.e. the span length) shall be set equal to 450 mm ±1 mm. All rollers shall be adjusted to their correct position with all distances within an accuracy of ±1 mm.

B.6.9 Load measuring device shall be capable of measuring loads to an accuracy of 10 N.

B.6.10 Deflection measurement: Devices such as electronic transducers or electronic deflection gages shall be located in a manner that ensures accurate determination of the net deflection at the mid-span exclusive of the effects of seating or twisting of the specimen on its supports. Accordingly two transducers or similar digital devices mounted on the yoke at mid span, one on each side, to measure deflection through contact with appropriate brackets (preferably S-shaped) glued onto the specimen at the top surface and placed along the vertical edges at mid span are recommended. The yoke has to be fixed using screw heads placed at the level of mid depth of the specimen to ensure that the distance between the two yoke frames do change during deflection of the specimen (see **Fig. B2**). The accuracy of the transducers should be equal to or better than 1 micron.

B.6.11 Data recording system: A data acquisition system capable of digitally recording and storing load and deflection data 10 times per second (i.e. a sampling frequency of 10 Hz) is suitable.

B.6.12 Equipment: All weighing, measuring and testing equipment shall be calibrated and regularly inspected according to documented procedures, frequencies and criteria. Devices for calibration (such as standard weights and measures, proving rings etc.) shall be authenticated by competent authority and be certified.

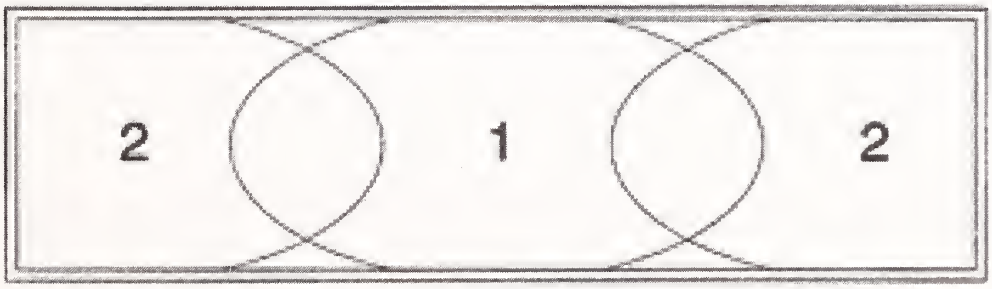
B.7 Test Specimens

B.7.1 The specimen should have a cross sectional dimension of 150 mm × 150 mm, with a length between 550 to 700 mm. These dimensions are valid for concretes having aggregates with maximum size of up to 25 mm and fibres of up to 60 mm in length.

B.7.2 The tolerances on the cross-sectional dimensions of the test specimens shall be within ± 2%.

B.7.3 *Preparation and curing of test specimens*

B.7.3.1 The procedure to be followed for filling the mould with fibre reinforced concrete is indicated in **Fig. B3**; the quantity of concrete being added in central portion at a time (increment 1) should be more than twice that of increment 2. The mould shall be filled fully in the middle and approximately 90% of the height of the mould in end portions. The mould shall be topped up and leveled while being compacted with minimum disturbance to the middle portion. Compaction shall be carried out by external vibration and external tapping.



1 and 2 - Order of Filling
Fig. B3 : Procedure for Filling the Mould

B.7.3.2 Only a high frequency vibrating table suitable for compaction of the concrete in the beam moulds shall be used. Care should be taken not to allow fibres to segregate (by settling down/floating up) by too long a duration of vibration. Care shall be taken to avoid realignment of fibres from the random nature.

B.7.3.3 In the case of self-compacting fibre concrete, the mould shall be filled and leveled off without any compaction. External tapping can be used if required.

B.7.4 *Curing*: The test specimens shall be cured according to IS:516 (EN 12390-2), unless specified otherwise. They shall be cured at (27 ±2)°C in the moulds for 24 h after casting, either under polyethylene sheeting or at not less than 95% relative humidity, then demoulded and cured for a further period as per requirement (normally for next 27 days) under moist condition of >95% relative humidity. Testing shall normally be performed at 28 days (or at the specified) age of the specimen.

B.7.5 During transportation of the specimens from field to test laboratory, care should be taken to avoid jerks, heavy vibrations and damage to the surface.

B.8 Testing Procedure

B.8.1 Preparation and positioning of test specimens

B.8.1.1 Average depth from the top to the bottom of the specimen and average width, for sections at middle one third portion of the span (l/3 = 150 mm), shall be determined from four measurements to the nearest 0.1 mm accuracy, using calipers. The width will be measured at bottom, within middle one third portion of the span of beam.

B.8.1.2 The test span (l) shall be 450 mm.

B.8.1.3 The test specimen must be turned on the side perpendicular with respect to the position as cast before placing it on the supports. The specimen shall be placed in the testing machine, correctly centered and with the longitudinal axis of the specimen at right angles to the longitudinal axis of the upper and lower rollers.

B.8.1.4 The deflection measuring set up should be fixed as mentioned in Section B.6.10 to avoid any extraneous deformations.

B.8.1.5 Before applying the load it shall be ensured that all loading and supporting rollers are resting evenly against the test specimen.

B.8.2 Rate and range of loading - The rate of loading should be so as to achieve the peak load within 3 to 8 minutes of initiation of loading. Beyond the drop in load after the peak, the rate of loading can be increased so as to terminate the test in about 45 minutes. In general the net deflection rate should be between 0.01 mm/min to 0.06 mm/min up to a net deflection of about 0.1 mm and later about 0.1 to 0.24 mm/min. However, the optimum rate of loading may be arrived at based on the response of the machine and the sensitivity of the control system. The general deflection limit is 3 mm as for the majority of toughness calculation equations the area under load-deflection curve up to a deflection of l/150 mm are required.

B.8.3 Tests during which the crack starts outside the middle third shall be rejected.

B.8.4 Normally, results from at least 6 specimens are required to obtain representative values of the parameters. This may require that a set of at least 8 specimens be prepared for testing purposes since the one or two specimens may fail in an unstable manner or exhibit cracking outside the middle third. However, all test results shall be reported.

B.9 Calculation

B.9.1 All load and deflection data required for further calculations shall be obtained from the digital data stored from the test.

B.9.2 Peak load (P_{max}) is obtained as peak value of load determined as the point where the slope of the load- deflection curve is zero. If two peaks are present or in the case of strain hardening, the highest load within a deflection limit of 0.05 mm shall be taken as peak load.

B.9.3 Flexural strength (Modulus of Rupture, MOR) is obtained for the peak load Pmax (Section B.9.2) as

$$f_{ct} = \frac{P_{\max} \times l}{bd^2} \qquad \text{... (B1)}$$

where,

f_{ct} = the flexural strength in MPa,

P_{max} = first peak load in N,

l = the span length in mm,

b = the average width of the specimen in mm, and

d = the average depth of the specimen in mm.

B.9.3.1 The flexural strength f_{ctm} will be the average of f_{ct} from 6 (or more) test specimens.

B.9.3.2 Record the number rounded to the nearest 0.05 MPa as the flexural strength.

B.9.3.3 The average dimension determined as in Section 8.1.1 shall be used for calculations of stress in each specimen.

B.9.4 The equivalent flexural strength and equivalent flexural strength calculated up to the specified deflection is to be reported.

B.9.5 Equivalent flexural strength (f_{en}) – the average flexural strength up to a specified deflection l/n obtained from the equivalent load calculated (P_{en}) corresponding to the deflection, where n shall have values 600 or 150. See typical plot in **Fig. B5**.

$$f_{en} = \frac{P_{en} \times l}{bd^2} \qquad \text{... (B2)}$$

B.9.5.1 Equivalent load up to specified deflection of l/n to be obtained from the load deflection curve as

$$P_{en} = \frac{T_{en}}{\delta_n} \qquad \text{... (B3)}$$

where T_{en} is the area under the load deflection curve up to l/n deflection as shown in the Fig. B4 below. Normally n = 150.

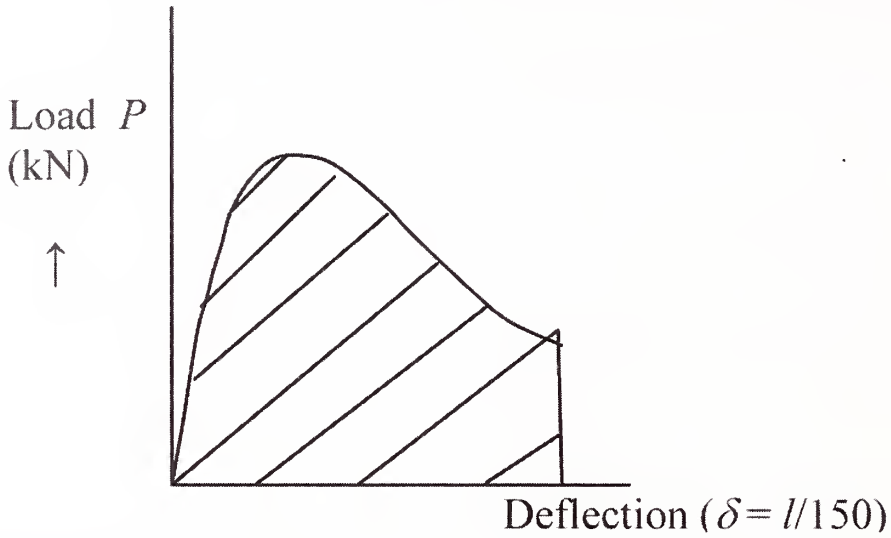


Fig. B4 : Typical Load-deflection Curve Indicating the Area Calculation

B.10 Report

B.10.1 Report on fibre reinforced concrete for the set of test specimens shall record the following information:

a) Identification of the test specimen,

b) Details, if known, regarding the mix composition, workability as slump in mm, fibre type (including, material, length, diameter and tensile strength), fibre dosage (in kg/m^3),

c) Date and time of casting and testing of FRC specimen,

d) Curing history, and storage conditions,

e) Condition of specimen at test (shape edge damage etc.) and moisture condition of specimen at test (moist/surface dry etc.),

f) Average dimensions of each specimen, nearest to 0.1 mm,

g) Rate of deflection/displacement/straining used,

h) Load – deflection curve of each specimen,

i) Flexural strength in MPa for each specimen and the mean value,

j) Equivalent flexural strength to nearest 0.01 MPa for individual value, and in 0.1 MPa for average value,

k) Number of specimens tested,

l) Reference to this Standard on test,

m) Any deviation from this Standard.

B.11 Symbols for Flexural Strength

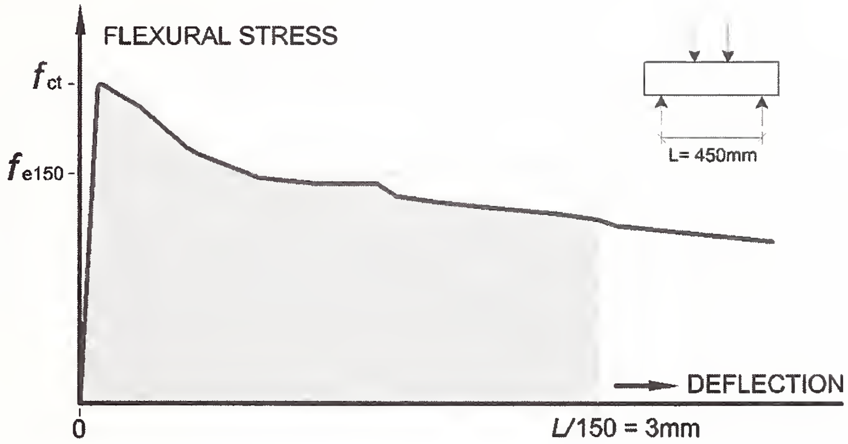


Fig. B5 : Typical Flexural Stress – Deflection Diagramme

f_{ct} = Peak flexural strength,

f_{e150} = Equivalent (post cracking residual) flexural strength = {Area under curve}/{3 mm = l / 150, i.e deflection at n = 150}
Suffix "m" represents average value for number of specimens tested,

"k" represents characteristic value (to be matched with specified value)

$R_{e150} = f_{e150m} / f_{ctm}$, R_{e150} value from tests be more than designed/specified value.

Appendix C
(Refer Clause 4.3.8)

TYPICAL MIX PROPORTIONS

C1 Characteristic flexural strength 5.5 MPa at 90 days and 5.0 MPa at 28 days.

Cement 360 Kg/m^3, flyash 90 kg/m^3, natural sand 326 kg/m^3, crushed sand 326 kg/m^3, coarse aggregate (20mm) 726 kg/m^3, coarse aggregate (10mm and below) 484 kg/m^3, admixture 4.5 kg/m^3, polypropylene micro fibres 0.9 kg/m^3, water 154.5 kg/m^3.

Appendix D
(Refer Clause 8.8)

ILLUSTRATIVE EXAMPLE OF FRC PAVEMENT DESIGN

Example 1 :

A Fibre Reinforced Concrete (FRC) pavement is to be designed for a four lane divided National Highway with two lanes in each direction in the state of Bihar. Design the pavement for a period of 30 years; Lane width = 3.5 m, transverse joint spacing = 4.5 m.

It is expected that the road will carry, in the year of completion of construction, about 3000 commercial vehicles per day in each direction. Axle load survey of commercial vehicles indicated that the percentages of front single (steering) axle, rear single axle, rear tandem axle and rear tridem axle are 45%, 15%, 25% and 15% respectively. The percentage of commercial vehicles with spacing between the front axle and the first rear axle less than 4.5 m is 55%. Traffic count indicated that 60% of the commercial vehicles travel during night hours (6 PM to 6 AM).

Details of axle load spectrum of rear single, tandem and tridem axles are given in **Table D.1**. Front (steering) axles are not included. The average number of axles per commercial vehicle is 2.35 (due to the presence of multi-axle vehicles).

Table D.1 : Axle Load Spectrum for Example

Single Axle		Tandem Axle		Tridem Axle	
Axle Load Class kN	Frequency (% of single axles)	Axle Load Class kN	Frequency (% of Tan--dem axles)	Axle Load Class kN	Frequency (% of Tri--dem axles)
185-195	18.15	380-400	14.5	530-560	5.23
175-185	17.43	360-380	10.5	500-530	4.85
165-175	18.27	340-360	3.63	470-500	3.44
155-165	12.98	320-340	2.5	440-470	7.12
145-155	2.98	300-320	2.69	410-440	10.11
135-145	1.62	280-300	1.26	380-410	12.01
125-135	2.62	260-280	3.9	350-380	15.57
115-125	2.65	240-260	5.19	320-350	13.28
105-115	2.65	220-240	6.3	290-320	4.55
95-105	3.25	200-220	6.4	260-290	3.16
85-95	3.25	180-200	8.9	230-260	3.10
<85	14.15	<180	34.23	<230	17.58
	100		100		100

Solution for Example 1.

Since the design requirement is for a high traffic volume FRC pavement (> 500 cpvd), fatigue design is needed in this case. The following steps detail the procedure followed.

a) Selection of modulus of sub-grade reaction:-

- Effective CBR of compacted sub-grade = 8%.
- Modulus of sub-grade reaction = k = 50.3 MPa/m.
- Provide DLC sub-base, thickness 150 mm with a minimum 7 day compressive strength of 10 MPa
- Effective modulus of sub-grade reaction of combined foundation of compacted sub-grade and DLC sub-base (from Table 4 by interpolation) = k = 285 MPa/m
- Provide a de-bonding layer of polythene sheet between the DLC and the FRC slab

b) Selection of FRC properties

- M 40 grade cement concrete
- 90-day mean compressive strength of cement concrete = f_{ck} = 52 MPa
- Cold-drawn steel fibres with hooked ends having length of 60 mm and aspect ratio of 80.
- Dosage of steel fibres = 15 kg/m^3
- 28-day characteristic flexural strength = 4.7 MPa
- 90-day characteristic flexural strength = 1.1× 4.7 MPa = 5.2 MPa = f_{ctk}
- Characteristic equivalent flexural strength at 3 mm deflection, f_{e150k} = 1.6 MPa

c) Design of FRC pavement using yield line analysis

- Check for minimum equivalent flexural strength: 1.6 MPa > 0.3 × 3.13 MPa (= 0.94 MPa). So, inelastic design method can be used.
- The relationship between the yielding moments can be written as :-

$$\frac{M_n + M_p}{P} = f\left(\frac{a}{l}\right) \quad \text{... (D1)}$$

where P is the total applied load, a is the radius of the area of load contact and l is the radius of relative stiffness.

- For single axle, as in this case, a is given as:-

$$a = \sqrt{\frac{P}{\pi\tau}} \quad \text{... (D2)}$$

P = Load on one tyre = 190/2 kN = 95 kN (since the highest single axle load is the critical case). Design load = 1.2 × 95 = 114 kN (load factor taken as 1.2),

τ = Tyre pressure = 0.8 MPa

On substituting the above values, we get a = 238. 1 mm

- Take Trial thickness slab, h = 170 mm

Radius of relative stiffness, $l = \sqrt[4]{\dfrac{Eh^3}{12(1-\mu^2)k}}$ = 0.458 m ... (D3)

- a/l = 238.1/458 = 0.52, which is greater than 0.2
- Critical resisting moments will be the lower of those calculated for the single wheel load at the centre of the slab and for the load at the edge of the slab.

Allowable load obtained from Meyerhof's inelastic analysis at the limiting moment in each case is given by –

Single wheel load at the centre of the slab

$$P_u = \frac{(f_{e,150k} + f_{ctk})4\pi h^2}{\left(a - \dfrac{a}{3l}\right)6} = 344 \text{ kN} \quad \text{... (D4)}$$

For load at the edge of the slab

$$P_u \frac{(\pi(f_{e,150k} + f_{ctk}) + 4f_{ctk})h^2}{\left(1 - \dfrac{2a}{3l}\right)6} = 201 \text{ kN} \quad \text{... (D5)}$$

The maximum allowable load (the lower of the two) 201 kN > 114 kN (i.e., factored load on one tyre). So, the assumed dosage and thickness are sufficient for the design failure load.

d) Check of Design Traffic for Fatigue Analysis:-

- Design period = 30 years
- Annual rate of growth of commercial traffic (expressed in decimal) = 0.075
- Two way commercial traffic volume per day = 6000 commercial vehicles/ day
- Percent of Traffic in predominant direction = 50% (3000 CVs in each direction)
- Total two-way commercial vehicles during design period,

$$C = 6000 \times 365 \times \left[\frac{1.075^{30} - 1}{0.075}\right] = 226{,}444{,}692 \text{ CVs} \quad \text{... (D6)}$$

- Average number of axles (steering/single/tandem/tridem) per commercial vehicle = 2.35
- Total two-way axle load repetitions during the design period

  = 226,444,692 × 2.35 = 532,145,025 axles

- Number of axles in predominant direction = 532,145,025 × 0.5 = 266,072,513
- Design traffic after adjusting for lateral placement of axles (25% of predominant direction traffic for multi-lane highways) = 266,072,513 × 0.25 = 66,518,128
- Night time (12 hour) design axle repetitions = 66,518,128 × 0.6 (60% traffic during night time) = 39,910,877
- Day time (12 hour) design axle repetitions = 66,518,128 × (1 - 0.6) = 26,607,251
- Day time six-hour axle load repetitions = 26,607,251 / 2 = 13,303,626
- Hence, design number of axle load repetitions for bottom-up cracking analysis = 13,303,626
- Night-time six-hour axle load repetitions = 39,910,877/2 = 19,955,439
- Percent of commercial vehicles having the spacing between the front (steering) axle and the first axle of the rear axle unit = 55%
- Hence, the six-hour night time design axle load repetitions for top-down cracking analysis (wheel base < 4.5 m) = 19,955,439 × 0.55 = 10,975,491
- The axle load category-wise design axle load repetitions for bottom-up and top-down fatigue cracking analysis are given in the following **Table D.2**.

Table D.2

Axle Category	Proportion of the Axle Category	Category Wise Axle Repetitions for Bottom-up Cracking Analysis	Category Wise Axle Repetitions for Top-Down Cracking Analysis
Front (steering) single	0.45	5986632	4938971
Rear single	0.15	1995544	1646324
Tandem	0.25	3325906	2743873
Tridem	0.15	1995544	1646324

e) Cumulative Fatigue Damage (CFD) analysis for Bottom-up Cracking (BUC) and Top-down Cracking (TDC) and Selection of Slab Thickness :-

- Effective modulus of subgrade reaction of foundation, k = 138 MPa/m
- Elastic Modulus of concrete, E = 30,000 MPa
- Poisson's ratio of concrete, $\mu = 0.15$
- Unit weight of concrete, $\rho = 24$ kN/m^3

- Design 90-day flexural strength of concrete = f_{ctk} = 5.2 MPa
- Maximum day-time Temperature Differential in slab (for bottom-up cracking) = 16.8°C (for Bihar)
- Night-time Temperature Differential in slab (for top-down cracking) = (day-time difference)/2 + 5 = 13.4°C

Fatigue Design Case 1

FRC pavement with tied concrete shoulder and with dowel bars across transverse joints

Trial thickness of slab, h = 0.17 m

- Radius of relative stiffness, l = 0.458 m
- Beta factor in the stress equations will be 0.66 for doweled transverse joints for carrying out TDC analysis
- The relationship between fatigue life (N) and stress ratio is
  N = unlimited for SR < 0.6

$$N = \left[\frac{2.9212}{SR - 0.51}\right] \text{ when } 0.6 < SR < 0.627$$

$$\text{Log}_{10}N = \frac{0.99 - SR}{0.06189} \text{ for } SR > 0.627$$

Cumulative fatigue damage analysis Day-time (6 hour) is given in **Table D.3**.

Table D.3 : Cumulative Fatigue Damage Analysis for Bottom-up Cracking

Bottom-up Cracking, Fatigue Analysis for Day-time (6 hour) traffic and Positive Temperature Differential				
Rear Single Axles				
Expected Repetition. (ni)	**Flex Stress MPa #**	**Stress Ratio (SR)**	**Allowable Rep. (Ni)**	**Fatigue Damage (ni/Ni)**
1	2	3 $\frac{(2)}{5.2MPa}$	4	5 (1)/(4)
362191	5.13	1.037	0.2	Very high
347823	4.91	0.992	0.9	380256
364586	4.69	0.948	4.8	76751
259022	4.47	0.904	25	10500
59467	4.25	0.860	128	464.19
32328	4.04	0.815	665	48.59
52283	3.82	0.771	3455	15.13
52882	3.60	0.727	17942	2.95
52882	3.38	0.682	93176	0.70
64855	3.16	0.638	483879	0.13
64855	2.94	0.594	infinity	0.00
282369	2.83	0.572	infinity	0.00
1995544	Fatigue Damage from single axles			Very high

\# Flexural stress calculated using equation as per IRC:58-2011 **Appendix V** for Single axle – Pavement with tied shoulders – (Eqn (V1, V2, V3))

The total fatigue damage is very high so the assumed thickness is not sufficient. Redesign using higher thickness.

Trial thickness of slab, h = 0.24 m (all lower values of h give inadequate design)

- Radius of relative stiffness, = 0.593 m
- Beta factor in the stress equations will be 0.66 for doweled transverse joints for carrying out TDC analysis.

Cumulative fatigue damage analysis Day-time (6 hour) is given in **Table D.4**.

Table D.4 : Cumulative Fatigue Damage Analysis for Bottom-up Cracking

Bottom-up Cracking Fatigue Analysis for Day-time (6 hour) traffic and Positive Temperature Differential									
Rear Single Axles					Rear Tandem Axles				
Expected Repetiti--ons. (ni)	Flex. Stress MPa*	Stress Ratio (SR)	Allowable Repetitions (Ni)	Fatigue Damage (ni/Ni)	Expected Rep. (ni)	Flex Stress MPa**	Stress Ratio (SR)	Allow. Rep. (Ni)	Fatigue Damage (ni/Ni)
1	2	3	4	5 (1)/(4)	1	2	3	4	5 (1)/(4)
362191	3.06	0.619	990020	0.37	482256	2.64	0.428	∞	0.0
347823	2.95	0.597	∞	0.00	349220	2.54	0.413	∞	0.0
364586	2.84	0.574	∞	0.00	120730	2.44	0.399	∞	0.0
259022	2.73	0.552	∞	0.00	83148	2.34	0.384	∞	0.0
59467	2.62	0.530	∞	0.00	89467	2.24	0.369	∞	0.0
32328	2.51	0.508	∞	0.00	41906	2.14	0.355	∞	0.0
52283	2.40	0.486	∞	0.00	129710	2.04	0.340	∞	0.0
52882	2.29	0.463	∞	0.00	172615	1.94	0.325	∞	0.0
52882	2.18	0.441	∞	0.00	209532	1.84	0.311	∞	0.0
64855	2.07	0.419	∞	0.00	212858	1.74	0.296	∞	0.0
64855	1.96	0.397	∞	0.00	296006	1.65	0.282	∞	0.0
282369	1.91	0.386	∞	0.00	1138458	1.60	0.274	∞	0.0
1995544	Fatigue Damage from Single Axles			0.37	3325906	Fatigue Damage from Tandem Axles			0

* Flexural stress calculated using equation as per IRC:58-2011 Appendix V for Single axle – Pavement with tied concrete shoulders – (Eqn (V.1, V.2, V.3)

** Flexural stress calculated using equation as per IRC:58-2011 Appendix V for Tandem axle – Pavement without concrete shoulders – (Eqn (V.10, V.11, V.12)

Table D.5 : Cumulative Fatigue Damage Analysis for Top-down Cracking

Top-down Cracking Fatigue Analysis for Night-time (6 hour) traffic and Negative Temperature Differential														
Rear Single Axles					**Rear Tandem Axles (Stress for 50% of axle load)**					**Rear Tridem Axles (Stress for at 33% of axle load)**				
1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
298808	2.77	0.56	∞	0	397862	2.81	0.57	∞	0	86103	2.54	0.51	∞	0
286954	2.70	0.54	∞	0	288107	2.73	0.55	∞	0	79847	2.48	0.50	∞	0
300783	2.62	0.53	∞	0	99603	2.66	0.53	∞	0	56634	2.42	0.49	∞	0
213693	2.55	0.51	∞	0	68597	2.58	0.52	∞	0	117218	2.36	0.47	∞	0
49060	2.47	0.50	∞	0	73810	2.51	0.50	∞	0	166443	2.29	0.46	∞	0
266670	2.39	0.48	∞	0	34573	2.43	0.49	∞	0	197723	2.23	0.45	∞	0
43134	2.32	0.47	∞	0	107011	2.36	0.47	∞	0	256333	2.17	0.44	∞	0
43628	2.24	0.45	∞	0	142407	2.28	0.46	∞	0	218632	2.11	0.42	∞	0
43628	2.17	0.44	∞	0	172864	2.21	0.44	∞	0	74908	2.05	0.41	∞	0
53506	2.09	0.42	∞	0	175608	2.13	0.43	∞	0	52024	1.99	0.40	∞	0
53506	2.02	0.41	∞	0	244205	2.05	0.41	∞	0	51036	1.92	0.39	∞	0
232955	1.98	0.40	∞	0	939288	2.02	0.41	∞	0	289424	1.89	0.38	∞	0
1646324	Fatigue damage from Single axles			0	2743873	Fatigue damage, Tandem axles			0	1646324	Fatigue damage from Tridem axles			0

Column 1: Expected Repetitions (ni); Column 2: Flexural Stress MPa; Column 3: Stress Ratio (SR); Column 4: Allowable Repetitions. (Ni); Column 5: Fatigue Damage factor (ni/Ni).

Flexural stress calculated using equation as per IRC:58-2011 Appendix V – Eq^n (V.13) for top down cracking with 0.66 as β.

Cumulative fatigue damage analysis night-hours (6 hour) is given in **Table D.5**.

The total fatigue damage is computed from the above tables as:-

- For Bottom-Up Cracking (BUC) case: Total CFD = 0.37 + 0 = 0.37
- For Top-Down Cracking (TDC) case: Total CFD = 0
- Governing case of the two above is BUC with CFD = 0.37 < 1.00, which is OK.

Above tabulated in **Table D.6**.

Hence, the trial thickness of 240 mm is found to be adequate for pavement with concrete tied shoulders.

FINAL DESIGN: Grade of concrete – M40

Thickness of slab = 240 mm

FRC with tied shoulders and doweled transverse joints.

Minimum fibre dosage 15 kg/m^3 for steel fibres 60 mm length and aspect ratio of 80

Required characteristic 28-day flexural strength = 3.14 MPa

Required characteristic 28-day equivalent flexural strength = 1.6 MPa

Fatigue design case 2:

FRC pavement without tied concrete shoulder and without dowel bars
(This case is chosen as it is the most critical condition)

Trial thickness of slab, h = 0.3 m (all lower values of h give inadequate design)

- Radius of relative stiffness, = 0.701 m
- Beta factor (β) in the stress equations will be 0.66 for doweled transverse joints for carrying out TDC analysis

Table D.6 Cumulative Fatigue Damage Analysis for Bottom-up Cracking

Bottom-up Cracking Fatigue Analysis for Day-time (6 hour) traffic and Positive Temperature Differential									
Rear Single Axles					Rear Tandem Axles				
Expected Rep. (ni)	**Flex Stress MPa***	**Stress Ratio (SR)**	**Allowable Rep. (Ni)**	**Fatigue Damage (ni/Ni)**	**Expected Rep. (ni)**	**Flex Stress MPa****	**Stress Ratio (SR)**	**Allowable Rep. (Ni)**	**Fatigue Damage (ni/Ni)**
1	**2**	**3** $\frac{(2)}{5.2MPa}$	**4**	**5** **(1)/(4)**	**1**	**2**	**3** $\frac{(2)}{5.2MPa}$	**4**	**5** **(1)/(4)**
362191	2.85	0.631	622617	0.58	482256	2.41	0.533	infinity	0.0
347823	2.75	0.608	1473999	0.24	349220	2.33	0.515	infinity	0.0
364586	2.64	0.585	infinity	0.00	120730	2.24	0.496	infinity	0.0
259022	2.54	0.562	infinity	0.00	83148	2.16	0.478	infinity	0.0
59467	2.44	0.539	infinity	0.00	89467	2.07	0.459	infinity	0.0
32328	2.33	0.516	infinity	0.00	41906	1.99	0.440	infinity	0.0
52283	2.23	0.492	infinity	0.00	129710	1.91	0.422	infinity	0.0
52882	2.12	0.469	infinity	0.00	172615	1.82	0.403	infinity	0.0
52882	2.02	0.446	infinity	0.00	209532	1.74	0.385	infinity	0.0
64855	1.91	0.423	infinity	0.00	212858	1.66	0.366	infinity	0.0
64855	1.81	0.400	infinity	0.00	296006	1.57	0.348	infinity	0.0
282369	1.75	0.388	infinity	0.00	1138458	1.53	0.338	infinity	0.0
1995544	Fatigue Damage from Single Axles			0.818	3325906	Fatigue Damage from Tandem Axles			0

* Flexural stress calculated using equation as per IRC:58-2011 Appendix V for Single axle – Pavement without concrete shoulders – (Eqn (V.4,V.5,V.6))

** Flexural stress calculated using equation as per IRC:58-2011 Appendix V for Tandem axle – Pavement without concrete shoulders – (Eqn (V.10,V.11,V.12)

Table D.7 Cumulative Fatigue Damage Analysis for Top-down Cracking

Top-down Cracking Fatigue Analysis for Night-time (6 hour) traffic and Negative Temperature Differential														
Rear Single Axles					Rear Tandem Axles (Stress computed at 50% of axle load)					Rear Tridem Axles (Stress computed at 33% of axle load)				
1	2	3 $\frac{(2)}{5.2MPa}$	4	5 (1)/(4)	1	2	3 $\frac{(2)}{5.2MPa}$	4	5 (1)/(4)	1	2	3 $\frac{(2)}{5.2MPa}$	4	5 (1)/(4)
298808	2.99	0.60	1861769	0.16	397862	3.03	0.61	1454823	0.27	86103	2.51	0.51	∞	0
286954	2.93	0.59	infinity	0	288107	2.96	0.60	infinity	0	79847	2.47	0.50	∞	0
300783	2.86	0.58	infinity	0	99603	2.89	0.58	infinity	0	56634	2.43	0.49	∞	0
213693	2.80	0.56	infinity	0	68597	2.83	0.57	infinity	0	117218	2.39	0.48	∞	0
49060	2.73	0.55	infinity	0	73810	2.76	0.56	infinity	0	166443	2.35	0.47	∞	0
266670	2.66	0.54	infinity	0	34573	2.70	0.54	infinity	0	197723	2.31	0.47	∞	0
43134	2.60	0.52	infinity	0	107011	2.63	0.53	infinity	0	256333	2.27	0.46	∞	0
43628	2.53	0.51	infinity	0	142407	2.56	0.52	infinity	0	218632	2.23	0.45	∞	0
43628	2.47	0.50	infinity	0	172864	2.50	0.50	infinity	0	74908	2.20	0.44	∞	0
53506	2.40	0.48	infinity	0	175608	2.43	0.49	infinity	0	52024	2.16	0.43	∞	0
53506	2.33	0.47	infinity	0	244205	2.37	0.48	infinity	0	51036	2.12	0.43	∞	0
232955	2.30	0.46	infinity	0	939288	2.33	0.47	infinity	0	289424	2.10	0.42	∞	0
1646, 324	Fatigue damage from Single Axles			0.16	2743873	Fatigue damage from Tandem Axles			0.27	1646324	Fatigue damage from Tridem Axles			0

Column 1: Expected Repetitions (ni); Column 2: Flexural Stress MPa; Column 3: Stress Ratio (SR); Column 4: Allowable Repetitions. (Ni); Column 5: Fatigue Damage Factor (ni/Ni).

Flexural stress calculated using equation as per IRC:58-2011 Appendix V –Eqn (V.13) for top down cracking with 0.66 as β.

The total fatigue damage is computed from the above tables as:-

- For Bottom-Up Cracking (BUC) case: Total CFD = 0.818 + 0 = 0.818
- For Top-Down Cracking (TDC) case: Total CFD = 0.16 + 0.27 + 0 = 0.43
- Governing case of the two above is BUC with CFD = 0.818 < 1.00, which is OK

  Hence, the trial thickness of 300 mm is found to be adequate.

FINAL DESIGN

Grade of concrete – M40

Thickness of slab = 300 mm

FRC without tied shoulders and un-doweled transverse joints.

Minimum fibre dosage = 15 kg/m^3 for steel fibres of 60 mm length and aspect ratio of 80.

Required characteristic 28-day flexural strength = 3.14 MPa

Required characteristic 28-day equivalent flexural strength = 1.6 MPa

Appendix E
(Refer Clause 4.1.2)

TESTS FOR POLYMERIC FIBRES

Following parameters of the fibers should normally be checked.

1) Fibre length (l) in mm.
2) Equivalent diameter (d) in mm or micron (μm)
3) Aspect ratio ($l/d = \lambda$)
4) Ultimate strength of fibre in N/m² (MPa)
5) Elongation at breaking in %.
6) Melting point in °C.
7) Specific gravity of the fiber.

For guidance on acceptance of fibres, sampling and control tests, at user's end, refer document ICI 01.01, Guideline for selection, specification and acceptance of fibre and fibre concrete (to be published shortly).

For characteristics of the fibres, their specifications and quality regime during manufacturing, refer document ICI 01.05, Polymeric Fibers - Definitions, Specifications and Conformity.

(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)