भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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व्यापक परिचालन मसौदा

हमारा संदर्भ: सीईडी 46 /टी-10 **21 मई 2025**

तकनीकी समिति: भारत की राष्ट्रीय भवन निर्माण विषय समिति, सीईडी 46

प्राप्तकर्ता :

1. **सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य**
2. **राष्ट्रीय भवन निर्माण संहिता विषय समिति, सीईडी 46 के सभी सदस्य**
3. **सीईडी 46 की उपसीमितयों और अन्य कार्यदल के सभी सदस्य**
4. **रुचि रखने वाले अन्य निकाय।**

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न हैं:

प्रलेख संख्या	शीर्षक
सीईडी 46 (27966) WC	**भारत की राष्ट्रीय भवन निर्माण संहिता भाग 6 संरचनात्मक डिजाइन अनुभाग 5 संरचनात्मक कंक्रीट** [SP7(भाग 6/अनुभाग 5) *का चौथा पुनरीक्षण*] (आई सी एस नंबर: 01.120: 91.040.01)

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इस पर अमल करने में आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयां आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 22 जून 2025

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा **ced46@bis.gov.in** पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, **www.manakonline.in** के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

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यह प्रलेख भारतीय मानक ब्यूरो की वैबसाइट **www.bis.gov.in** पर भी उपलब्ध हैं।
धन्यवाद।

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(द्वैपायन भद्र)
वैज्ञानिक 'ई' एवं प्रमुख (सिविल अभियांत्रिकी विभाग)

सलंग्न: उपरिलिखित

भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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Website: www.bis.org.in , www.bis.gov.in

WIDE CIRCULATION DRAFT

Our Reference: CED 46/T-10 **21 May 2025**

National Building Code of India Sectional Committee, CED 46

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of the National Building Code Sectional Committee, CED 46
3. All Members of Subcommittees, Panels and Working Groups under CED 46
4. All other interests

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	Title
CED 46 (27966) WC	**National Building Code of India Part 6 Structural Design Section 5 Structural Concrete** [*Fourth Revision of* SP 7 (Part 6/Sec 5)] (ICS No. 01.120: 91.040.01)

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 22 June 2025

Comments if any, may please be made in the enclosed format and emailed at ced46@bis.gov.in or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, www.manakonline.in.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website www.bis.gov.in.

Thanking you,

Yours faithfully,

Sd/-
(Dwaipayan Bhadra)
Scientist 'E' / Director & Head
(Civil Engineering Department)

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail to ced46@bis.gov.in shall be appreciated**.

Doc. No.: CED 46 (27966) WC

BIS Letter Ref: CED 46/T-10

Title: National Building Code of India Part 6 Structural Design Section 5 Structural Concrete [*Fourth Revision of* SP 7 (Part 6/Sec 5)] (ICS No. 01.120: 91.040.01)

Last date of comments: **22 June 2025**

Name of the Commentator/ Organization: ________________________________

Clause/ Para/ Table/ Figure No. commented	Comments/Modified Wordings	Justification of Proposed Change

NOTE- Kindly insert more rows as necessary for each clause/table, etc

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Draft **National Building Code of India**

PART 6 STRUCTURAL DESIGN

Section 5 Structural Concrete

[*Fourth Revision of* SP 7 (Part 6/Section 5)]

(ICS No. 01.120: 91.040.01)

National Building Code Sectional Committee, CED 46

Last Date for Comments: 22 June 2025

C O N T E N T S

KEY INFORMATION

The provisions of NBC 2016 in its Part 6/Section 5A and 5B are respectively based on IS 456:2000 IS 1343:2012 (and their as-on-date amendments) thereby bringing parity in the requirements (in NBC and IS 456 & IS 1343).

With the ongoing exercise in BIS for the revision of IS 456 (merging in it the IS 1343), this proposed chapter for the revised NBC is worded in such a way that it enables to have the continued applicability of the as-on-date editions of IS 456 and IS 1343 at any point of time. Thus, as and when revised IS 456 is published, the provisions in NBC automatically mean the use of only that revised standard available at any given point of time.

National Building Code Sectional Committee, CED 46

FOREWORD

This Code (Part 6/Section 5) covers the structural design aspects of plain and reinforced concrete and also the prestressed concrete.

This Section 5 was first published in 1970 as Subsections 5A 'Plain and reinforced concrete' and 5B 'Prestressed concrete' of SP 7 (Part 6) and which were subsequently revised in 1983, 2005 and 2016.

In this fourth revision of the Code, it has been decided to merge the Subsections 5A and 5B into one Section 5 'Structural concrete'.

This Section is largely based on IS 456:2000 'Code of practice for plain and reinforced concrete (fourth revision)' (including its 6 amendments) and IS 1343: 2012 Prestressed concrete – Code of practice (*second revision*)' (including its amendment no. 1) both of which are currently under revision and are being merged into the fifth revision of IS 456, titled 'Structural Concrete – Code of practice' at the time of the publication of the Code.

In the 2016 version of the Code, in addition to the provisions of IS 456, provisions relating to special concrete namely self-compacting concrete, high performance concrete and steel fibre reinforced concrete were introduced in clauses 16A, 16B and Annex A. The same are now given in Annex B, C and D respectively. In this version of the Code, the following changes are made:

a) Informative annex (Annex A) on updated provisions regarding materials for making concrete is introduced.
b) Criteria for structural safety of tall concrete buildings is introduced.
c) Comprehensive provisions on design and detailing of buildings and structures are updated (from the erstwhile Annex F of NBC) and included in Annex E.

Major changes have been envisaged in the revision of IS 456 (amalgamating IS 1343). In the absence of availability of finalized version of revised IS 456, at the time of the revision of the Code, the provision of design as per existing IS 456 : 2000 and IS 1343 : 2012 have been continued through appropriate reference to the same.

The fifth revision of IS 456 introduces a holistic design philosophy that emphasizes that concrete structures shall not only be strong but also safe, durable, serviceable under expected loads, and resilient in the face of extreme and accidental events. To this end, the standard stipulates that structural design shall meet six design criteria that are, **strength**, **serviceability**, **durability**, **robustness**, **integrity**, and **restorability**. Each of these criteria is associated with performance objectives and corresponding design requirements, ensuring that structural behaviour is assessed comprehensively across its entire lifecycle, including performance during and after any adverse events.

The design philosophy outlined in the above revised standard includes the classification of the design process into the **prescriptive process** and the **closed-loop process**. The prescriptive process follows conventional rule-based checks and is applicable to structures where only the basic three criteria (strength, serviceability, and durability) are of concern. In contrast, the closed-loop process is intended for important or critical structures and involves a more rigorous approach, requiring not only quantitative compliance for the first three criteria but also qualitative and performance-based verification for robustness, integrity, and restorability. This two-tier approach introduces flexibility in application while ensuring that safety and resilience are not compromised, especially in vital infrastructure. By integrating modern concerns like post-disaster repairability (restorability), progressive collapse prevention (integrity), and resistance to accidental actions (robustness), the design philosophy ensures that structures are not just built to withstand known demands but also prepared for uncertainties. It promotes reliability, sustainability, and long-term performance.

The revision of IS 456 highlights that structural analysis should correctly capture how structures behave under all types of loads, including static, dynamic, and accidental forces. For regular structures, linear static analysis is generally sufficient. However, for structures affected by dynamic forces like earthquakes, wind, or machine vibrations, dynamic analysis is necessary. In critical cases, the standard also recommends using non-linear dynamic analysis to better reflect the actual behaviour of materials and structures. This approach moves towards more detailed and performance-based analysis to improve safety, serviceability, durability, and resilience in concrete structures.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to the revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

For the purpose of deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

Code users are requested to share their inputs/comments on the draft particularly w.r.t the changes listed above in the foreword; and especially on those text highlighted in yellow in this draft.

Important Explanatory Note for Users of the Code

In any Part/Section of this Code, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Accepted standard [6-5(4)] refers to the Indian Standard(s) give at serial number (4) of the list of standards given at the end of this Part/Section, that is, IS 269: 2015 'Ordinary Portland cement - Specification *(Sixth Revision)*'.

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Draft **National Building Code of India**

PART 6 STRUCTURAL DESIGN

Section 5 Structural Concrete

[*Fourth Revision of* SP 7 (Part 6/Section 5)]

(ICS No. 01.120: 91.040.01)

National Building Code Sectional Committee, CED 46	**Last Date for Comments: 22 June 2025**

1 SCOPE

This section (Part 6/Section 5) deals with the general structural use of plain, reinforced, and prestressed concrete.

2 TERMINOLOGY

For the purpose of this section, the definitions given in accepted standards [6-5(1)] shall apply.

3 MATERIALS

3.1 All materials used in plain, reinforced and prestressed concrete construction shall conform to Part 5 'Building Materials' as available.

4 STRUCTRAL DESIGN USING PLAIN, REINFORCED AND PRESTRESSED CONCRETE

4.1 The provision relating to design and general structural use of plain, reinforced and prestressed concrete, including on:

a) materials, including special concrete, workmanship, inspection and testing
b) general design consideration
c) special design requirements for structural members and systems
d) structural design: limit state method

shall be in accordance with good practices contained in Sections 2, 3, 4 and 5 of [6-5(2)] and Sections 2, 3 and 4 of [6-5(28)].

NOTE **–** At the time of publication of this section, IS 456 and IS 1343 were under revision, with IS 1343 being amalgamated into IS 456. Once the revised IS 456 is published, it shall replace the provisions given in this section.

The informative Annex A to this Code suggests the updated list of materials and few tests. Users are encouraged to investigate the possibility of applying the provisions given in Annex A which are listed in consonance with the provisions regarding materials in [6-5(2)].

4.2 Structural Safety of Tall Reinforced Concrete (RC) Buildings

For criteria for structural safety of tall reinforced concrete (RC) buildings of heights greater than 50 m and less than 250 m, normally intended for use as residential, office and other commercial buildings, reference may be made to the good practice, [6-5(32)].

5 EARTHQUAKE RESISTANT DESIGN AND DETAILING OF STRUCTURES

The provision of this clause will be added suitably after the finalization/publication of Part 1 and 2 of ‘Earthquake resistant design and detailing of structures — Code of Practice Part 1 General Provisions and Part 2 Buildings (*Second Revision of* IS 13920)- circulated earlier by BIS as CED 39 (25407)WC and CED 39 (25408)WC.

ANNEX A

(*Informative, Foreword and Clause* 4.1)

MATERIALS FOR MAKING CONCRETE

A-1 AGGREGATES

A-1.1 Normal Weight Aggregates

Aggregates derived from natural sources and other than natural sources (manufactured aggregates such as iron slag, copper slag, bottom ash from thermal power plants, recycled concrete aggregates and recycled aggregates), shall comply with the requirements of IS 383. These are natural or synthetic aggregates with in-place density (unit weight) between 22.40 to 27.00 kN/m^3.

A-1.2 Heavyweight Aggregates

Natural or synthetic aggregates with in-place density (unit weight) more than 27.00 kN/m^3 and can range up to 45.00 kN/m^3 for aggregates other than steel. Steel aggregates (if used) will have further higher density. Heavy weight aggregate is most commonly used for radiation shielding, counterweights and other applications where a high mass-to-volume ratio is desired. Goethite, Limonite, Barite, Illmenite, Magnetite, Hematite, Ferrophosphorus and Steel are some examples of heavy weight aggregate.

A-1.3 Lightweight Aggregates

Natural or synthetic with in-place density (unit weight) between 14.40 to 18.40 kN/m^3. The lightweight is due to the cellular or high internal porous structure, which gives this type of aggregate a low specific gravity. The most important aspect of lightweight aggregate is the porosity. They have high absorption values, which requires a modified approach to concrete proportioning. Light weight aggregates namely sintered fly ash aggregates may be used for making light weight structural concrete (a type of special concrete). Sintered flyash coarse aggregates when used shall conform to [6-5(3)].

A-2 CEMENT

A-2.1 For general use in plain, reinforced and prestressed concrete construction, cement used shall be any of the following and the type selected should be appropriate for the intended use:

a) Ordinary Portland cement conforming to [6-5(4)]
b) Portland slag cement conforming to [6-5(5)]
c) Portland pozzolana cement (fly ash based) conforming to [6-5(6)]
d) Portland pozzolana cement (calcined clay based), conforming to [6-5(7)]

e) Composite cement conforming to [6-5(8)] and containing a declared clinker content not less than 45 percent, fly ash content not more than 25 percent and a minimum 28-day compressive strength of 43 MPa can be used for reinforced concrete construction.
f) Portland calcined clay limestone cement conforming to IS [6-5(33)]. At locations where temperatures are predominantly below 15 °C for 6 months, the use of Portland Calcined Clay Limestone Cement shall not be permitted in underground structures and structural elements in contact with ground water.'

A-2.2 Other cements as given below can be used for specific applications:

a) Sulphate resisting Portland cement conforming to [6-5(9)]
b) Microfine Ordinary Portland Cement conforming to [6-5(10)]
c) Hydrophobic cement conforming to [6-5(11)]
d) Low heat Portland cement conforming to [6-5(12)]
e) Rapid-hardening Portland cement conforming to [6-5(13)]
f) High alumina cement conforming to [6-5(14)]
g) Supersulphated cement conforming to [6-5(15)]
h) White Cement conforming to [6-5(16)]

A-3 WATER

A-3.1 Water used for mixing and curing shall be clean and free from excessive amounts of total dissolved solids (TDS), oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to steel and setting and strength development of concrete.

A-3.2 Types of Water

In general, the suitability of water for the production of concrete depends upon its origin. Water to be used for mixing and curing of concrete shall be any of the types described below. Any type of water to be used for mixing and curing shall be tested as per stated procedures and shall meet all the requirements given in **A-3.3.**

A-3.2.1 *Potable Water*

This water is considered as suitable for use in concrete if meeting the requirements of IS 10500 wherein the chloride content shall be limited to 500 PPM and alkalinity is less than or equal to 25 ml (**A-3.3**). Such water needs no further testing. In case of any doubt it shall be tested for conformity according to **A-3.3**.

A-3.2.2 *Natural Surface Water*

This water, if found suitable, can be used in concrete but shall satisfy the requirements of **A-3.3**.

A-3.2.3 *Treated Water*

Appropriately treated water, conforming to **A-3.3,** from industrial, municipal and other sources can be used in concrete**.**

A-3.2.4 *Water Recovered from Processes in the Concrete Industry*

This includes:

a) water that was part of surplus concrete,
b) water used to clean the inside of the stationery mixers, mixing drums of truck mixer or agitators and concrete pumps,
c) process water from sawing, grinding and water blasting of hardened concrete.

This water may be taken from:

a) Basins provided with suitable equipment that distributes the solid matter evenly throughout the water;
b) Sedimentation basins or similar installations, provided the water is left in the basin for a sufficient amount of time to allow the solids to settle properly.

Water recovered from process in the concrete industry contains varying concentrations of very fine particles, the size of which is generally less than 0.25 mm. Water recovered from processes in the concrete industry or combined water can be used provided the following requirements are met:

a) The additional mass of solid material in the concrete resulting from the use of water recovered from processes in the concrete industry shall be less than 1 percent mass fraction of the total mass of aggregates present in the concrete.

b) The amount of recovered water shall be spread as evenly as possible over a day's production.

A-3.2.5 *Water from Other Sources*

A-3.2.5.1 *Recycled water*

Water recovered from concrete production operation or water generated from sewage, greywater or storm water systems and treated to a standard that is appropriate for its intended use.

A-3.2.5.2 *Desalinated water*

Desalinated water conforming to **A-3.3** can be used. However normal sea water or brackish water shall not be used for mixing of concrete. because of presence of harmful salts.

A-3.3 Requirements for Preliminary Inspection of Mixing and Curing Water

A-3.3.1 *Preliminary Inspection*

The water shall be examined for oil and fats, detergents, colour, suspended matter, odour and humic matter shall meet the requirements given in Table 1 in accordance with test procedures stated below.

A small subsample shall be assessed as soon as possible after sampling. Bring any material that has settled back into suspension by shaking the sample. Pour 80 ml of the sample into a 100 ml measuring cylinder. Seal with a suitable stopper and shake the cylinder vigorously for 30 s. Smell the sample for any odours other than those of clean water. If in doubt about the odour, test the water for its odour level in accordance with national regulations for potable water. The odour level of the water shall be lower than the maximum level accepted for potable water. Observe the surface for foam. Set the cylinder in a place free from vibration and allow to stand for 30 min. After 2 min, check the sample for the continuing presence of foam and signs of any oils or fats. After 30 min have elapsed, observe the apparent volume of the settled solids and the colour of the water. Measure the pH using indicator paper or a pH meter. Then, add 0.5 ml hydrochloric acid, mix and then smell or test for the presence of hydrogen sulfide.

Put 5 ml of the sample into a test tube. Bring it to a temperature between 15 °C and 25°C by allowing it to stand indoors. Add 5 ml of 3 percent sodium hydroxide solution, shake and leave for 1 h. Observe the colour.

Table 1 Requirements for Preliminary Inspection of Mixing Water
(*Clause* A-3.3.1)

Sl No.	**Parameter**	**Requirements**
(1)	(2)	(3)
i)	Oils and fats	Not more than visible traces
ii)	Detergents	Any foam should disappear within 2 min.
iii)	Colour	Water not from sources classified as potable: the colour shall be assessed qualitatively as pale yellow or pale
iv)	Odour	Water from sources classified as potable: no smell, except the odour allowed for potable water and a slight smell of cement; where blast-furnace slag is present in the water, a slight smell of hydrogen sulfide
		Water from other sources: no smell, except the odour allowed for potable water; no smell of hydrogen sulfide after addition of Hydrochloric Acid

Sl No.	Parameter	Requirements
(1)	(2)	(3)
v)	PH value	6.0-8.5
vi)	Humic Matter	The colour shall be assessed qualitatively as yellowish / brown or paler after addition of NaOH

A-3.3.2 Permissible limits for solids shall be as given in Table 2.

Table 2 Maximum Permissible Limit for Solids for Mixing and Curing Water
(*Clause* **A-3.3.2**)

Sl No.	Parameter	Tested as per	Maximum Permissible Limit	
			For mixing water	For curing water
(1)	(2)	(3)	(4)	(5)
i)	Organic	[6-5(16)]	200 mg/l	200 mg/l
ii)	Inorganic	[6-5(16)]	3000 mg/l	3000 mg/l
iii)	Sulphate (as SO_3^-)	[6-5(17)]	400 mg/l	800 mg/l
iv)	Chloride (as Cl^-)	[6-5(18)]	2000 mg/l for concrete not containing embedded steel and 500 mg/l for reinforced concrete work*.	500* mg/l for reinforced concrete or prestressed concrete work and 2000 mg/l for concrete not containing embedded steel.
v)	Suspended Matter	[6-5(19)]	2000 mg/l	2000 mg/l

*
1000 mg/l chloride in water for reinforced concrete work (but not for prestressed concrete) can be permitted provided the chloride content of hardened concrete is checked at the time of concrete mix design and conform to requirement of total chloride content in the concrete.

A-3.4 Testing and Requirements of Curing Water

Permissible limits for solids shall be as given in Table 8. Water used for curing should not produce any objectionable stain or unsightly deposition on the concrete surface. The presence of tannic acid or iron compounds is objectionable.

A-3.5 Sampling of Water Concrete Making and Curing

A sample of water not less than 5 litres shall be taken. The sample of water taken for testing shall represent the water proposed to be used for concreting with due account being paid to seasonal variation. The sample shall be stored in a clean container previously rinsed out with similar water.

A-4 ADMIXTURES

A-4.1 Admixtures can be used to:

a) Alter the composition of concrete by replacing some of the cement in the concrete by pozzolanic and hydraulic reaction (and are called mineral admixtures or supplementary cementitious materials)

b) Enhance a certain function of concrete (and are called chemical admixtures).

c) The following types of admixtures shall be used in production of concrete.

A-4.2 Mineral Admixtures/Supplementary Cementitious Materials (SCMs)

SCMs as given below may be used as part replacement of cement. They can be pozzolanic material or reactive mineral admixture or combination of both.

A-4.2.1 *Fly Ash (Pulverized Fuel Ash)*

Fly ash conforming to [6-5(21)] may be used as part replacement of ordinary Portland cement. For concrete having steel, the replacement level of fly ash shall be restricted to 35 percent by weight of cementitious material wherein fly ash shall have a minimum fineness of 280 m^2/kg and lime reactivity of 4.5 N/mm^2 or more.

A-4.2.2 *Silica Fume*

Silica fume conforming to [6-5(22)] may be used as part replacement of cement. Silica fume is usually used in proportion of 3 to 10 percent of the cementitious content of a mix. The total replacement by fly ash and silica fume shall not be more than 35 percent for reinforced cement concrete. The total replacement by GGBF slag and silica fume/Ultrafine ground granulated blast furnace slag (UFGBS) shall not be more than 60 percent for reinforced cement concrete.

The above limits shall also apply where PPC or PSC is used. The fly ash or slag content mentioned on the bag shall be considered.

Only for mass concrete, structures below ground (not exposed to atmosphere) and for plain concrete, the use of more than one type of mineral admixture with ordinary Portland cement or a mineral admixture with blended cements such as PPC and PSC can be permitted after necessary trials (to control heat of hydration). However, silica fume may be used as an additional mineral admixture in reinforced concrete subjected to limits specified above. Uniform blending of the mineral admixtures with the cement should be ensured. In such cases, fly ash and GGBS together may be used within following limits:

Total replacement (*Max*)	= 45 percent of total cementitious content
Fly ash (*Max*)	= 20 percent
GGBS (*Max*)	= 25 percent

A-4.2.3 *Metakaolin*

Metakaolin conforming to [6-5(23)] may be used as pozzolanic material in concrete as part replacement of ordinary Portland cement only. The replacement level shall be maximum up to 15 percent.

A-4.2.4 *Ground Granulated Blast Furnace Slag (GGBS)*

GGBS conforming to [6-5(24)] may be used as part replacement of ordinary Portland cement. For concrete having embedded steel, the replacement level of GGBS shall be restricted to 50 percent by weight of cementitious materials. For resistance to sulphate and alkali aggregate reaction, GGBS up to 60 percent can be used.

A-4.2.5 *Ultrafine Ground Granulated Blast Furnace Slag (UFGBS)*

UFGBS conforming to [6-5(25)] may be used as part replacement of cement. The replacement level shall be up to 20 percent.

A-4.2.6 *Ultrafine Fly Ash*

Ultrafine fly ash produced through classification route and conforming to [6-5(26)] may be used as part replacement of ordinary Portland cement. The replacement level shall be up to 20 percent.

A-4.3 Chemical Admixtures

A-4.3.1 Chemical admixtures, as mentioned in Table 3 if used, shall comply with [6-5(27)]. Previous experience with and data on such materials should be considered in relation to the likely standards of supervision and workmanship to the work being specified.

Table 3 Types of Chemical Admixtures and their Constituents
(*Clause* A-4.3.1)

Sl No.	Type of admixture	Typical active constituents
(1)	(2)	(3)
i)	Air-entraining	Salts of wood resins Some synthetic detergents Salts of sulfonated lignin Salts of petroleum acids Salts of proteinaceous material Fatty and resinous acids and their salts Tall oils and gum rosin salts Alkylbenzene sulfonates

Sl No.	Type of admixture	Typical active constituents
(1)	(2)	(3)
		Salts of sulfonated hydrocarbons
ii)	Retarding	Unrefined Lignosulphonate containing Sugars Modified Derivatives of unrefined Lignosulphonate containing Sugars Hydroxycarboxylic Acids and their Salts Carbohydrates including Sugars Heptonates related to Sugars and Starches
iii)	Accelerating	Calcium chloride Triethanolamine Sodium thiocyanate Sodium formate or Calcium formate Sodium nitrite or Calcium nitrite Calcium nitrate Aluminates Silicates
iv)	Water-reducing	Lignosulfonic acids and their salts Hydroxylated carboxylic acids and their salts Polysaccharides Melamine polycondensation products Naphthalene polycondensation products Polycarboxylates
v)	High range water-reducing : Normal and Retarding	Melamine sulfonate polycondensation products Naphthalene sulfonate polycondensation products Polycarboxylates
vi)	Shrinkage reducing	Polyoxyalkylene alkyl ether Propylene glycol
vii)	Corrosion inhibiting	Amine carboxylates aminoester organic emulsion Calcium nitrite Organic alkyidicarboxylic Chromates Phosphates Hypophosphites Alkalis Fluorides
viii)	Permeability-reducing admixture	
	Non-hydrostatic conditions (PRAN)	Long-chain fatty acid derivatives (stearic, oleic, caprylic capric) Soaps and oils (tallows, soya-based) Petroleum derivatives (mineral oil, paraffin,) Fine particle fillers (silicates, talc)
	Hydrostatic conditions (PRAH)	Crystalline hydrophilic polymers (latex, water-soluble, or liquid polymer).

A-4.3.2 Chemical admixtures can be achieved by a spectrum of materials and manufacturing processes, but shall comply with [6-5(27)]. Further,

a) The workability, compressive strength and the slump loss of concrete with and without the use of admixtures shall be established during the trial mixes before use of admixtures.
b) The relative density of liquid admixtures shall be checked for each drum containing admixtures and compared with the specified value before acceptance.
c) If two or more admixtures are used simultaneously in the same concrete mix, data shall be obtained to assess their interaction and to ensure their compatibility.
d) Admixtures shall neither impair durability of concrete nor combine with the constituent to form harmful compounds nor increase the risk of corrosion of reinforcement.
e) The chloride content of admixtures shall be independently tested for each batch before acceptance.

A-4.3.3 The amount of admixture added to a mix shall be recorded in the production record. Additional dose of admixture may be added at project site and mixed adequately in mixer itself to regain the workability of concrete (if necessary) with mutual agreement between the producer/supplier and the purchaser/user of concrete. But, the producer/supplier shall assure the ultimate quality of concrete supplied by him and maintain record of quantity and time of addition.

A-4.3.4 Shrinkage compensating admixtures shall not be used in structural concrete.

A-5 FIBRES

Fibres may be added to concrete for special applications to enhance select properties. But, such fibers shall be approved by the competent authority on the recommendation of a duly constituted competent peer review committee. In any case, the presence of fibers shall not be taken advantage of in the estimation of strength.

A-6 REINFORCEMENT

A-6.1 Reinforcing bars and prestressing strands shall be specified in accordance with the provisions of good practice [6-5(2) and (28)], respectively.

A-6.2 Reinforcement couplers shall comply with the relevant clauses of accepted standard [6-5(29)].

A-6.3 If glass fibre reinforced polymer bars are used, the material shall conform to the requirement of accepted standard [6-5(30)].

A-6.4 Welded wire reinforcement shall conform to the requirements of accepted standard [6-5(31)].

A-6.5 Prestressing accessories shall comply with the requirements of good practice [6-5(28)].

ANNEX B

(Foreword)

SELF COMPACTING CONCRETE

B-1 GENERAL

The Self Compacting Concrete (SCC) is highly flowable, non-segregating concrete that fills uniformly and completely every corner of formwork by its own weight without the need for any compaction and encapsulates reinforcement or any other embedment. The provisions relating to its application areas, features, mix proportioning principles, and production and engineering properties are given hereunder. The provisions for concrete making materials and concrete as given in [6-5(2)] 'Materials, Workmanship, Inspection and Testing' shall apply to SCC except where different provisions or departures have been indicated hereunder.

B-2 APPLICATION AREAS

SCC may be used in *in-situ* concrete or for precast concrete applications. It is particularly appropriate for sections with highly congested reinforcement such as, nuclear power plant structures, machine foundations, piers and abutments; and areas having restricted access to concrete placement and compaction like shafts in hydropower structures. SCC is also suitable for the construction of tunnel lining sections and casting of concrete-filled steel tubular columns. SCC may also be used for columns and beams in normal construction with appropriate formwork design.

SCC may be produced in a batching plant on site or in ready-mixed concrete plant and transported to site by transit mixers. It may be placed either by pumping or other placement methods into horizontal or vertical forms.

B-3 FEATURES OF FRESH SELF COMPACTING CONCRETE

The features of fresh SCC are:

a) Filling ability (Flowability),
b) Passing ability,
c) Segregation resistance, and
d) Viscosity.

B-3.1 Filling Ability (Flowability)

Filling ability of SCC determines its ability to flow into and fill all spaces within the formwork, under its own weight. The filling ability is tested using slump-flow test.

B-3.1.1 *Procedure*

Slump flow test shall be carried out in accordance with accepted standard [6-5(34)].

B-3.1.2 *Classes of slump-flow and their application*

There are three classes of slump-flow, as follows:

a) *SF*1 (slump flow 550 mm - 650 mm) - This class of SCC is appropriate for,

   1) unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point (such as slabs),
   2) casting by a pump injection system (such as tunnel linings), and 3) sections those are small enough to prevent long horizontal flow (example, piles and some deep foundations).

b) *SF*2 (slump flow 650 mm - 750 mm) is suitable for many normal applications (example, walls, columns)

c) *SF*3 (slump flow 750 mm - 850 mm) is typically produced with a small maximum size of aggregates (less than 20 mm) and is used for vertical applications in structures having congested reinforcement, structures with complex shapes, etc. *SF*3 will often give better surface finish than *SF*2 for normal vertical applications but segregation resistance is more difficult to control.

B-3.2 Passing Ability (Free from Blocking at Reinforcement)

Passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation. If there is little or no reinforcement, there may be no need to specify passing ability as a requirement. L-box test is generally carried out to check the passing ability and the procedure shall be in accordance with accepted standard [6-5 (34)]. In this test, the height of the concrete left in the vertical section (h_1) and at the end of the horizontal section (h_2) is measured. The ratio of h_2/h_1 is calculated as the blocking ratio; which shall be between 0.8 and 1.0.

B-3.3 Segregation Resistance (Stability)

Segregation Resistance is the ability of fresh concrete to remain homogeneous in composition while in its fresh state. Segregation resistance is generally carried out using sieve test to check this property of fresh concrete.

B-3.3.1 *Procedure*

Segregation resistance (sieve) test shall be carried out in accordance with accepted standard [6-5 (34)].

B-3.3.2 *Test Results*

There are two classes of segregation resistance, namely *SR*1 and *SR*2. For *SR*1 class, segregation resistance should be above 15 percent and $\leq$ 20 percent, and for *SR*2 it should be $\leq$ 15 percent.

*SR*1 is generally applicable for thin slabs and for vertical applications with a flow distance of less than 5 m and a confinement gap greater than 80 mm. *SR*2 is preferred in vertical applications if the flow distance is more than 5 m with a confinement gap greater than 80 mm in order to take care of segregation during flow. Segregation resistance becomes an important parameter with higher slump-flow classes and/or the lower viscosity class, or if placing conditions promote segregation. If none of these apply, it is usually not necessary to specify a segregation resistance class.

B-3.4 Viscosity

Viscosity can be assessed by the V-funnel flow time. Concrete with a low viscosity will have a very quick initial flow and then stop. Concrete with a high viscosity may continue to creep forward over an extended time.

B-3.4.1 *Procedure*

Viscosity by V-funnel test is carried out in accordance with accepted standard [6-5 (34)]. A V-shaped funnel is filled with fresh concrete and the time taken for the concrete to flow out of the funnel is measured and recorded as the V-funnel flow time.

B-3.4.2 *Test results*

The viscosity is divided into two classes, namely *V*1 and *V*2. For *V*1 class, the time taken to pass the concrete from V-funnel shall be $\leq$ 8 seconds and for *V*2 class, it shall be above 8 s and $\leq$ 25 s.

*V*1 has good filling ability even with congested reinforcement. It is capable of selfleveling and generally has excellent surface finish. *V*2 class viscosity is more likely to exhibit thixotropic effects, which may be helpful in limiting the formwork pressure or improving segregation resistance. But it may cause negative effects on surface finish and sensitivity to stoppages or delays between successive lifts.

B-4 MIX PROPORTIONING

B-4.1 Mix Proportion Principles

The principles listed below shall be followed:

a) Lower coarse aggregate content;
b) Increased paste content;
c) Low water/powder ratio (*see* Note);

d) High range superplasticizer; and
e) Viscosity modifying admixture, if required.

NOTE - Powder is the material of particle size smaller than 0.125 mm. It includes this size fraction in the cement, mineral admixtures and aggregate.

B-4.2 Mix Design Procedure

For mix design procedure, reference may be made to good practice [6-5(35)].

B-5 PRODUCTION OF SELF COMPACTING CONCRETE

B-5.1 General

SCC is less tolerant to changes in constituent characteristics and batching variances as compared to conventional concrete. Accordingly, it is important that all aspects of the production and placing processes are carefully supervised.

The production of SCC should be carried out in plants where the equipment, operation and materials are suitably controlled under a Quality Assurance Scheme. It is important that all personnel who will be involved in the production and delivery of SCC are adequately trained including practical demonstrations.

B-5.2 Constituents

SCC is more sensitive than conventional concrete to variation in the physical properties of its constituents and especially to changes in aggregate moisture content, grading and shape. So, more frequent production checks are necessary. The moisture content of aggregates should be continuously monitored and the mix adjusted to account for any variation.

Storage of constituent materials for SCC shall be same as that for materials for conventional concrete. However, as the SCC mix is more sensitive to variations, special precautions shall be taken for storage of aggregates, which should be properly stored to avoid cross-contamination between different types and sizes and protected from weather to minimize the fluctuation of surface moisture content and movement of fines. Ground stock should be stored in purpose-built partitioned bays, which should allow free drainage of excess moisture in the aggregates and rainwater.

B-5.3 Mixing Equipment and Trial Mixes

SCC shall be produced with efficient forced action concrete mixers. The time necessary to achieve complete mixing of SCC may be longer than for conventional concrete due to reduced frictional forces and to fully activate the superplasticizer.

B-5.4 Formwork

Formwork should be watertight and grout tight when placing SCC. The need to design the formwork for water tightness is greater than conventional formwork so as to avoid honeycombs and surface defects. The high fluid nature of SCC may lead to higher formwork pressure than conventional concrete, especially when the casting rate is high. As a result of the highly fluid nature of SCC, a high placement rate is likely and should be anticipated. Formwork designs, that accommodate the expected liquid head formwork pressure, can allow unrestricted placement rates and permit fast casting rate of the SCC. It is recommended to design the formwork for full liquid head.

B-5.5 Curing

Curing is essential for all concrete, and early protection of exposed surfaces is essential to preventing rapid moisture loss that could lead to plastic shrinkage cracking. The top-surface of elements made with SCC can dry quickly because of the increased quantity of paste, the low water/fines ratio and the lack of bleed water at the surface. Initial curing should therefore commence as soon as practicable after placing and finishing in order to minimize the risk of surface crusting and shrinkage cracks caused by early age moisture evaporation.

B-6 ENGINEERING PROPERTIES

B-6.1 General

SCC and conventional concrete of similar compressive strength have comparable properties.

B-6.2 Compressive Strength

SCC with a similar water-cement ratio usually have a slightly higher strength compared to conventional concrete due to the lack of vibration giving an improved interface between the aggregate and hardened paste.

B-6.3 Tensile Strength

SCC may be supplied with any specified concrete grade. For a given concrete grade, the tensile strength may be safely assumed to be the same as the one for a conventional concrete as the volume of paste (cement + fines + water) has no significant effect on tensile strength.

B-6.4 Static Modulus of Elasticity

Increasing the paste volume may decrease the modulus of elasticity, E_c. As SCC has higher paste content than conventional concrete, some difference can be expected and the E_c may be somewhat lower and should be adequately covered by the safe assumptions in design.

If SCC does have a slightly lower E_c than conventional concrete, in prestressing work, this will affect the relationship between the compressive strength and the camber due to pre-tensioning or post-tensioning. For this reason, careful control should be exercised over the strength at the time when the pre-tensioning and post-tensioning strands or wires are released.

B-6.5 Creep

Due to the higher volume of cement paste, the creep coefficient for SCC may be expected to be higher than for conventional concrete of equal strength, but such differences are small and shall be covered by the safe assumptions in design.

B-6.6 Shrinkage

As concrete compressive strength is related to the water-cement ratio, in SCC with a low water-cement ratio drying shrinkage reduces, but with increased cementitious content and increased water content the drying shrinkage and autogenous shrinkage can increase.

B-6.7 Durability

SCC is free from shortcomings due to improper compaction and result in consistently low and uniform permeability, offering less weak points for deleterious actions of the environment.

ANNEX C
(*Foreword*)

HIGH PERFORMANCE CONCRETE

C-1 GENERAL

High Performance Concrete is a concrete whose ingredients, proportions and production methods are specifically chosen to meet special performance and uniformity requirements. The higher performance requirements may be:

Sl No	*Higher Performance Requirements*	*Remarks/Applications*
i)	High resistance to deterioration of reinforced concrete due to carbonation	This is to help achieve longer service life. This is particularly applicable in semi-arid regions
ii)	High resistance to chloride attack/ingress	This is for longer service life of reinforced concrete exposed to severe chloride environment/coastal environment
iii)	High resistance to abrasion	This may be required in concrete structures, like parts of hydraulic structures exposed to continuous abrasive action due to silt, such as spillways/glacis; and concrete pavements exposed to heavy traffic
iv)	High resistance to impact	This may be required in structures like blast resistant structures and spillways
v)	Improvement in flexure and shear performance	This is required in bridge girders, joints of RCC framed structure, shear walls, etc
vi)	High resistance to cracking due to shrinkage (plastic and drying shrinkage)	This may be required in concrete/mortar used for repair of distressed concrete structures, etc

High strength concrete generally improves performance of all above parameters. The concrete mix proportioning for high strength concrete may be carried out in accordance with the good practice [6-5A(35)]. However, special measures are needed to further improve the specific performance requirements. As a guide, the measures given in **C-2** may be adopted. For further details, expert literature may be referred.

C-2 MEASURES FOR IMPROVING SPECIFIC PERFORMANCE REQUIREMENTS

C-2.1 Resistance to Carbonation

Resistance to carbonation of concrete is dependent mainly upon:

a) Type of binder, content of binder and *p*H value of concrete; and
b) Permeability of concrete.

Addition of silica fume, GGBS and fly ash improve denseness and reduce permeability, thus increasing resistance to ingress of carbon dioxide and moisture (needed for carbonation). The addition of fly ash above 35 percent tends to lower the alkalinity, and thus the resistance to carbonation. Lower water-cement ratios and higher grades of concrete can be adopted to improve performance in this case. Minimum OPC content is essential for adequate carbonation resistance for different exposure conditions.

Carbonation resistance can be checked by using accelerated carbonation tests (using 3 to 4 percent CO_2 concentrations for minimum 70 days exposure) at mix proportioning stage. For quality assurance purpose, rapid tests like rapid chloride ion penetration test (RCPT), air permeability test or electrical resistivity test may be used. Their values may be established by correlation with accelerated carbonation test values at mix proportioning stage.

C-2.2 Resistance to Chloride Ingress

To improve performance of concrete exposed to chloride environment, two aspects need to be considered.

a) Total initial chloride content in concrete should be minimized; and
b) Permeability of concrete should be low.

Whereas chloride content of concrete can be controlled by checking chloride content of mix ingredients, the permeability of concrete can be reduced by careful selection of mix proportions and by use of supplementary cementing materials, either through use of blended cements like PPC and PSC or by direct addition of mineral admixtures, like fly ash, GGBS and silica fume. To control permeability, durability test of resistance to chloride ions shall be carried out by using chloride diffusion test by immersion or ponding method (using 3 percent NaCl exposure for 90 days) at mix proportioning stage. For quality assurance purpose rapid tests corresponding values like rapid chloride ion penetration test (RCPT) or electrical resistivity test shall be carried out. Corresponding values for these tests shall be established by developing a correlation with chloride diffusion test (by immersion/ponding) at mix proportioning stage.

C-2.3 Resistance to Abrasion

To ensure good performance against abrasion, following points should be considered:

a) Use of higher grades of concrete;
b) Use of good quality strong aggregate;
c) Use of silica fume; and
d) Use of steel fibres (suited for increasing abrasion resistance in spillways/glacis, etc).

Test methods for measuring abrasion resistance are:

1) Revolving disc type test.
2) Under water abrasion resistance test using steel balls.

For further details regarding test methods and criteria, specialist literature may be referred.

C-2.4 Improving Performance in Flexure, Shear, Impact, Ductility and Energy Absorption

Resistance to impact is generally increased when the strength of concrete is high and energy absorption is high. Energy absorption and toughness can be increased by use of steel fibres in concrete. Whereas addition of steel fibres, glass or carbon fibres improves flexural and shear strength also, the use of synthetic fibres like polypropylene fibres do not significantly improve the above properties. Polypropylene fibres do however reduce shrinkage cracking and are suitable for concrete/mortar used for concrete repairs.

For checking impact resistance, falling weight impact test can be used, wherein number of blows for crack initiation in small concrete slab panel are counted.

For further details regarding test methods and criteria, specialist literature may be referred. The use of steel fibre reinforced concrete shall be further governed by **C-2.4.1.**

C-2.4.1 *Use of Steel Fibre Reinforced Concrete (SFRC)*

Following properties of concrete can be improved by using SFRC:

a) Ductility,
b) Toughness and energy absorption,
c) Abrasion, and
d) Flexural strength and shear strength.

Compressive and direct tensile strength gain in flexural and direct tensile strength is very significant when higher percentage of steel fibres are used which give the concrete a strain hardening effect (increase in ultimate load after initial crack). However significant improvements are achieved in strain softening zone also.

Steel fibres having aspect ratio 60 to 80 may be incorporated in concrete of different grades to improve the ductility of concrete. Fibre content varying from 0.5 to 2.5 percent volume may be incorporated in to the concrete to improve different mechanical and durability characteristics. However higher addition can cause problems in uniform mixing and placing of concrete which need to be checked at mix proportioning stage before using the mix . Corrosion of steel fibres can also occur particularly in lower grades, so use of coated fibres and higher grades of concrete are recommended. Alternatively, a plain concrete cover of few mm can also be provided.

Design of steel fibre reinforced concrete (SFRC) for structural performance shall be in accordance with Annex D.

ANNEX D
(*Clause* C-2.4.1)

DESIGN OF STEEL FIBRE REINFORCED CONCRETE

D-1 GENERAL

This annex shall apply where steel fibres are used to improve the performance and capacity of reinforced and prestressed concrete structures.

The design of steel fibre reinforced concrete (SFRC) at both the ultimate and serviceability limit states shall be based on the stress (σ) ≠ strain (ϵ) relationships for SFRC as specified in **D-3.3** (*see* Note 1).

Steel fibres shall not be relied upon in plastic hinge regions for strength requirements (*see* Note 2).

Steel fibres shall not be relied upon at constructions joints for either serviceability or strength requirements. Design procedure in this clause is for steel-fibre-reinforced concrete with a softening classification only (*see* Fig. 1). Hardening SFRC and the use of synthetic fibres is beyond the scope of this annex.

NOTES

1 When using brittle fibres that rely on a fibre pullout failure mechanism to obtain member ductility, care is required for cases where a significant number of fibres fracture or where fibres result in local crushing of the concrete due to the local forces imposed on the matrix by the fibres. Fibre fracture may occur where the bond between the fibre and the matric is high, and this is more likely in a high strength concrete combined with fibres of high bond capacity and of lower strength steels.

2 The anchorage capacity of steel fibres may be lost in areas where crack widths exceed about 3.5 mm. Cracking of this magnitude can be expected in regions where plastic rotations are expected.

D-2 DEFINITIONS

For the purposes of this annex the following definitions shall apply:

D-2.1 Crack Mouth Opening Displacement (CMOD) – The width of a crack shall be measured at its mouth in a flexural tensile test. To measure the CMOD, a displacement transducers/clip gauge shall be mounted along the longitudinal axis at the mid width of the test specimen (beam with nominal size of 150 mm x 150 mm and length L so that 550 mm < L < 700mm).

D-2.2 Crack Opening Displacement (COD) – The width of a single localized crack, taken as an average on four sides, for a direct tensile test on a strain softening SFRC dog-bone shaped specimen in accordance with **D-3.3.7**.

D-2.3 Steel Fibre Reinforced Concrete (SFRC) – A mixture of concrete and steel fibres.

D-2.4 Hardening Behaviour – A material that displays an enhanced strength with increasing crack widths beyond that measured at the point of initial cracking of the cementitious matrix.

D-2.5 Softening Behaviour – A material that exhibits a loss of strength upon cracking.

D-2.6 Target Dosage – The specified quantity of fibres in kilograms per cubic metre of concrete (kg/m^3).

D-3 PROPERTIES OF SFRC

D-3.1 General

SFRC shall be classified in terms of both its characteristic compressive (cylinder) strength (f'_c) (*see* **D-3.2**) and its characteristic residual tensile strength ($f'_{1.5}$) (*see* **D-3.3.3**).

D-3.2 Compressive Strength

The characteristic compressive strength of SFRC at 28 days (f'_c) shall be determined in accordance with good practice [6-5(36)].

In the absence of more accurate data, the mean value of the in situ compressive strength (f_{cmi}) shall be taken as 90 percent of the mean value of the cylinder strength (f_{cm}).

NOTE – The compressive strength of steel fibre reinforced concrete (SFRC) should be determined by means of standard tests on concrete cylinders. The addition of steel fibres to concrete in conventional dosages (less than 100 kg/m^3) does not change the compressive properties of the concrete.

D-3.3 Tensile Properties

D-3.3.1 *Classification*

SFRC shall be classified as either softening or hardening as shown in Fig. 1. Hardening SFRC is outside the scope of this annex.

NOTES

1. A hardening material is defined as one with a tensile strength equal to or greater than 1.1 times the strength of the matrix without fibres and taken at a crack opening displacement (COD) of equal to or greater than 0.3 mm.
2. A hardening material is one where multiple cracks can occur prior to crack localization. For material hardening to occur, the fibre dosage is typically such that the strength of the SFRC is at least 10 percent greater than the strength of the same concrete mix without fibres. The value of COD of 0.3 is sufficiently high such that matrix contribution to the strength of

the composite is minimal and the tension at this point is substantially taken by the fibres alone. Hardening SFRC is outside of the scope of this annex.

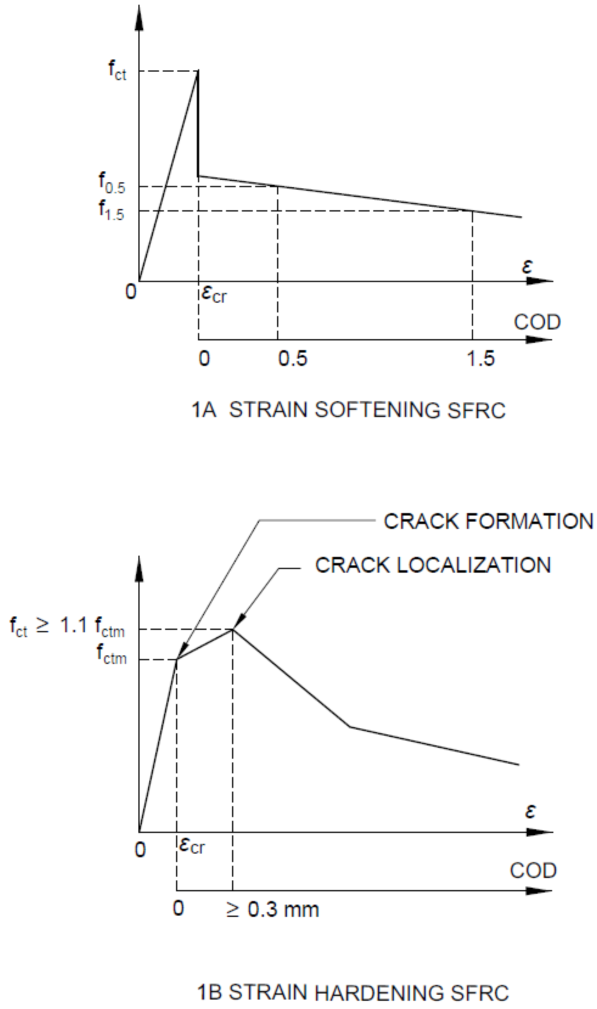


FIG. 1 CLASSIFICATION OF SFRC

D-3.3.2 *Matrix Tensile Strength*

The matrix tensile strength of the softening SFRC (f_{ct}) shall be obtained using flexural tensile testing, in accordance with good practice [6-5(15)].

When only the characteristic compressive (cylinder) strength (f'_c) has been determined, the mean and characteristic flexural tensile strength of SFRC shall be calculated in accordance with [6-5(2)].

NOTE – For strain softening SFRC, the peak strength of the composite may be approximated as the strength of the concrete mix without fibres.

D-3.3.3 *Residual Tensile Strength*

The standard characteristic residual tensile strength grades ($f'_{1.5}$) are 0.4 MPa, 0.6 MPa, 0.8 MPa, 1.2 MPa, 1.6 MPa and 2.0 MPa.

The characteristic residual tensile strengths of concrete at 28 days ($f'_{1.5}$) shall be determined statistically from tests carried out in accordance **D-3.3.4** or **D-3.3.5.**

NOTE – The characteristic residual tensile strength depends on the fibre-matrix bond strength, which is usually a function of the compressive strength of the parent concrete, as well as the fibre content. It may be unrealistic to specify a high value of $f'1.5$ when using a relatively low value of $f'c$.

D-3.3.4 *Determination of Strength by Direct Testing*

The characteristic residual tensile strength ($f'_{1.5}$) shall be obtained using direct tensile tests as specified in **D-3.3.7**.

Alternatively, where matched direct and indirect testing has been undertaken in accordance with **D-3.3.6** for similar SFRC mixtures, the characteristic residual tensile may be determined as:

$$f'_{1.5} = k_{\mathrm{R,4}}\, f'_{\mathrm{R,4}}$$

Where $f'_{\mathrm{R,4}}$ is determined in accordance with **D-3.3.8** and calculated statistically, and the factor $k_{\mathrm{R,4}}$ determined from **D-3.3.6**.

For the purposes of this clause, similar SFRC mixtures are defined as having the same,

a) fibre type and content,
b) water to cementitious material ratio,
c) maximum aggregate particle size, and
d) compressive strength (f'_c).

NOTES

1 In calculating the characteristic strength, the population may be treated normally distributed and the strength determined in accordance with accepted standard. A confidence level of 75 percent shall be used that 95 percent of the population exceeds the characteristic value.
2 The sample standard deviation shall not exceed 25 percent.

D-3.3.5 *Determination of Strength by Indirect Testing*

The characteristic residual tensile strength ($f'_{1.5}$) may be obtained using indirect tests as specified in **D-3.3.8** and calculated as:

$$f'_{1.5} = 0.4 f'_{\mathrm{R,4}} - 0.07 f'_{\mathrm{R,2}}$$

D-3.3.6 *Residual Tensile Strength-Residual Flexural Strength Relationship*

The relationship between residual tensile strength and the residual flexural strength shall be obtained by matched using the same SFRC mixture. Residual tensile strength specimens shall be prepared and tested in accordance with **D-3.3.7**. Residual flexural tensile tests shall be in accordance with the procedure as mentioned below:

The average width of the specimen and distance between the tip of the notch and the top of the specimen in the mid-span section shall be determined from two measurements to nearest 0.1 mm width and distance in the notch port of the specimen using calipers.

When the CMOD is measured, the displacement transducer shall be mounted along the longitudinal axis at mid width of test specimen such that the distance 'y' between the bottom of specimen and line of measurement is 5 mm or less as mentioned in Fig. 2.

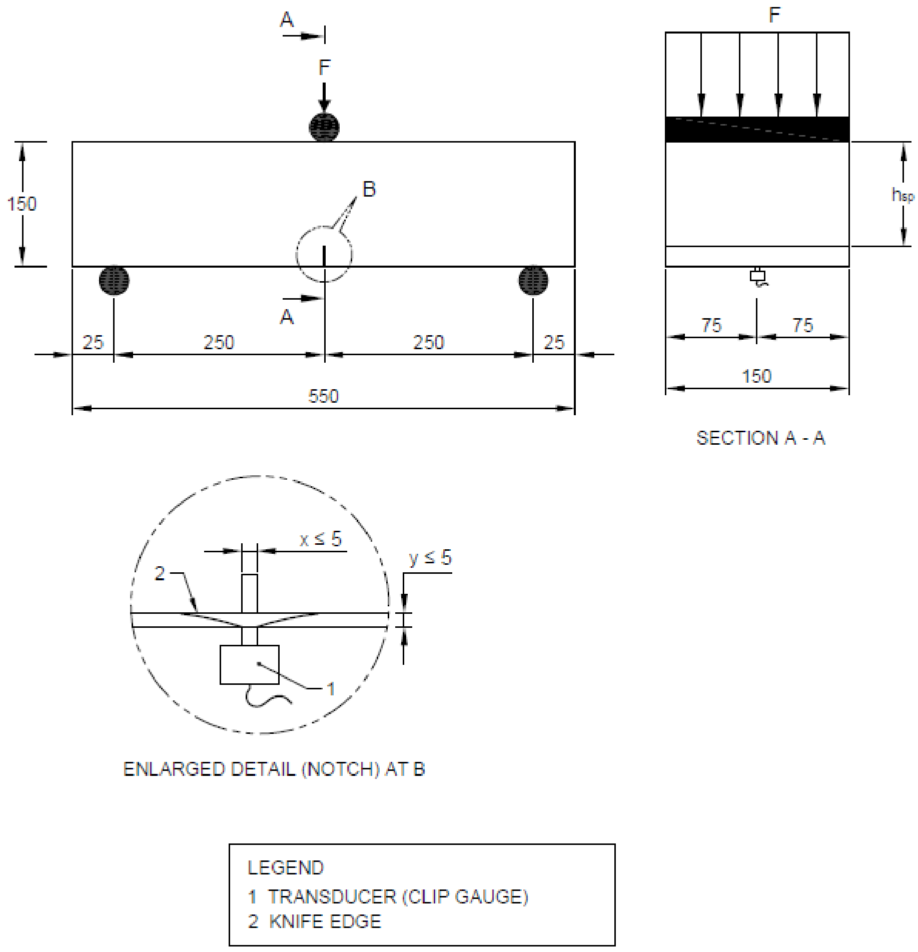


FIG. 2 ARRANGEMENT FOR RESIDUAL FLEXURAL TENSILE TEST

a) The concrete mix shall be batched to ensure a uniform distribution of fibres, the SFRC shall be placed in the moulds in a manner that does not interfere with the distribution of the fibres and, the SFRC shall be compacted using lightly applied external vibration; and
b) A minimum of 12 specimens shall be tested.

The reference factor $k_{R,4}$ shall be determined as-

$$k_{R,4} = f_{1.5m}/f_{R,4m}$$

where

$f_{1.5m}$ = mean residual tensile strengths corresponding to a COD of 1.5 mm, determined in accordance with **D-3.3.7**.

$f_{R,4m}$ = mean residual flexural tensile strengths corresponding to a CMOD of 3.5 mm, determined in accordance with **D-3.3.8**.

NOTE – The residual tensile strength (as obtained from a direct tensile test) is a fundamental material property of SFRC. This clause allows the concrete producer and steel fibre manufacturer to correlate the direct tensile strength of their particular SFRC mix design with the flexural tensile strength.

D-3.3.7 *Residual Tensile Strength Test*

The residual tensile strength shall be obtained using the testing arrangement shown in Fig. 3 and with the following criteria:

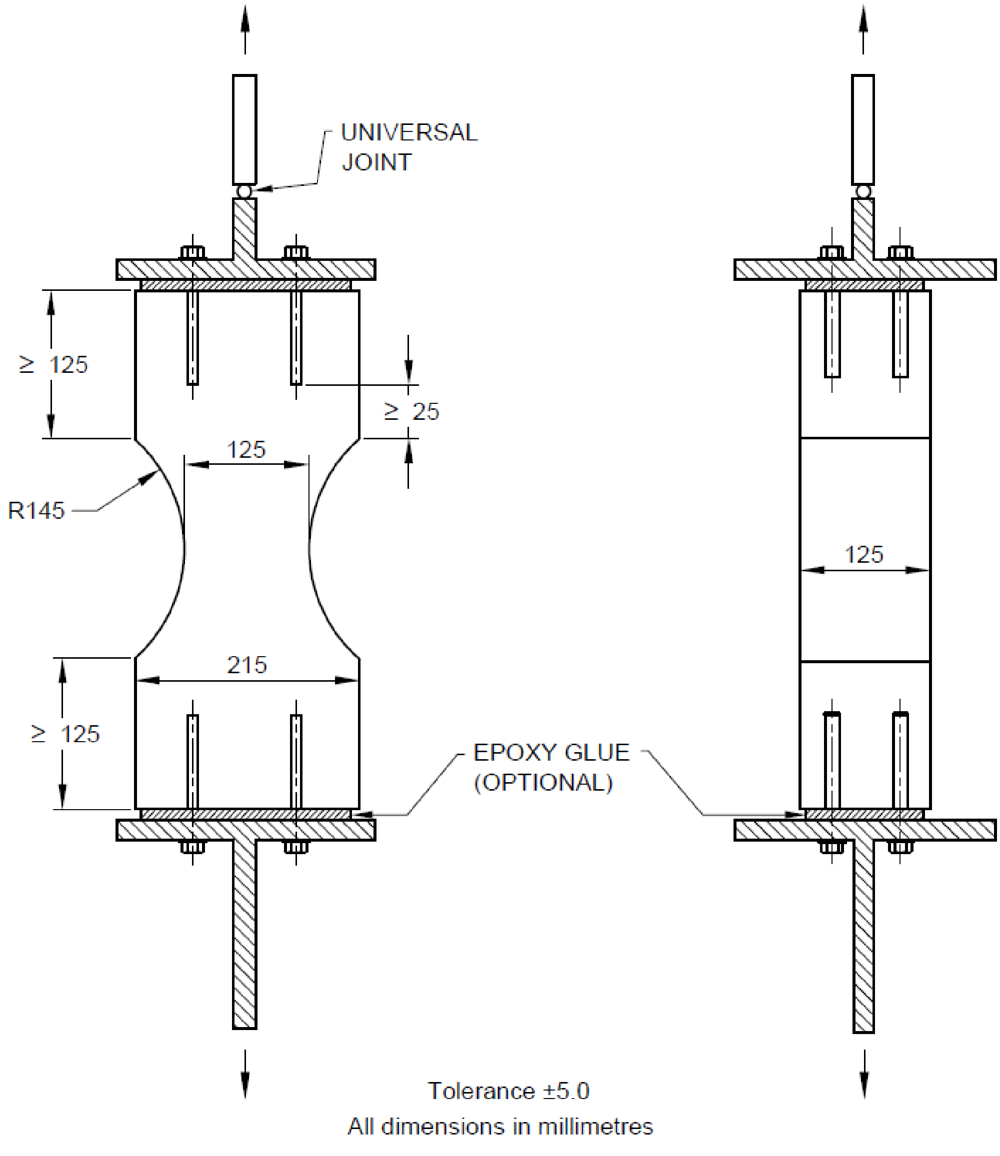
a) The critical section shall be where the cross sectional area is a minimum.
b) The SFRC mix shall be batched to ensure a uniform distribution of fibres, and shall be placed in the moulds in a manner that does not interfere with the distribution of the fibres. The SFRC shall be compacted using lightly applied external vibration.
c) The specimen shall be connected to the testing machine in such a manner that the machine does not apply a load to the specimen during the process of tightening of the grips and prior to testing.
d) One end of the specimen shall be connected to the testing machine through a universal joint such that no moment is applied to the end of the specimen.
e) Displacement measurements shall be taken on each of the four sides with the COD taken as the average of these measurements.
f) A minimum of twelve specimens shall be tested.
g) Tests where the failure of the specimen is outside of the testing region, or where the results are influenced by the test specimen boundaries, shall be retested.
h) The characteristic values of the tensile strength $f_{0.5}$ and $f_{1.5}$, corresponding to CODs of 0.5 mm and 1.5 mm, respectively, shall be determined statistically as the 95 percentile confidence value assuming the population is normally distributed.
j) The mean values of $f_{0.5m}$ and $f_{1.5m}$, corresponding to CODs of 0.5 mm and 1.5 mm, respectively, shall be determined statistically as the 50th percentile confidence value assuming the population is normally distributed.

The stress results obtained from the test shall be multiplied by the three-dimensional orientation factor k_1, where,

$$k_1 = \frac{1}{0.94 + 0.6\ell_f/b} \leq 1$$

And ℓ_f is the length and *b* is taken as the average of the width and depth of the specimen taken at the critical section.

NOTE –The factor k_1 removes the influence of the boundaries on the fibre distribution and converts the results of the test to a state where the fibres can be considered to be randomly orientated in three-dimensional space.



NOTE – There is considerable discussion in the literature on whether the ends of the specimens should be fixed at each end, pinned at each end or fixed at one end and pinned at the other. The adoption of one pinned and one fixed end is a pragmatic decision between the ideal condition (fixed at each end) and limitations in manufacturing of specimens that are perfectly square at their ends for alignment within the testing machine. With both ends fixed any misalignment induces a moment in the specimen during gripping. This moment can induce a tensile stress on one side of the specimen, weakening the specimen. In some situations, the moment induced may be sufficient to crack the concrete. The inclusion of the universal joint at one end eliminates residual tensions that may result from the gripping procedure.

FIG. 3 TESTING ARRANGEMENT FOR DIRECT TENSION

D-3.3.8 *Residual Flexural Tensile Strength*

The residual flexural tensile strength ($f_{R,j}$) shall be determined from 3 point notched bending tests on 150 mm square section prisms. The notch depth shall be 25 mm and the test conducted in accordance with **D-3.3.6.** The force *F* shall be plotted against the crack mouth opening displacement (CMOD), as shown in Fig. 4, and the residual flexural stress calculated as:

$$f_{R,j} = \frac{3F\text{j}L}{2bh_{sp}^2}$$

where b = width of the specimen, in mm h_{sp}= distance between tip of the notch and top of cross section, in mm

L = span, in mm

F_{Rj}= load recorded at CMOD$_j$ (*see* Fig. 4)

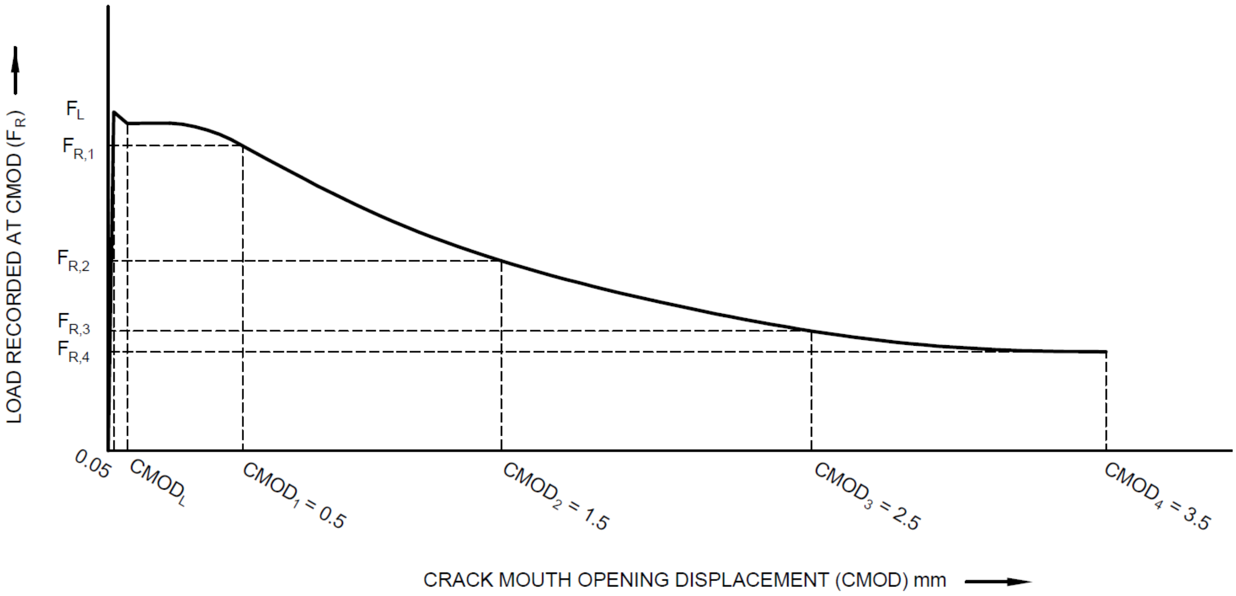


FIG. 4 LOAD VERSUS CMOD FOR RESIDUAL FLEXURAL TENSION

D-3.4 Modulus of Elasticity

The mean modulus of elasticity at the appropriate age (E_{cj}) shall be determined in accordance with good practice [6-5(36)].

NOTE – The addition of steel fibres to concrete in conventional dosages (100 kg/m^3 and less) does not change the elastic modulus of the concrete.

D-4 DESIGN OF REINFORCED SFRC MEMBERS

D-4.1 General

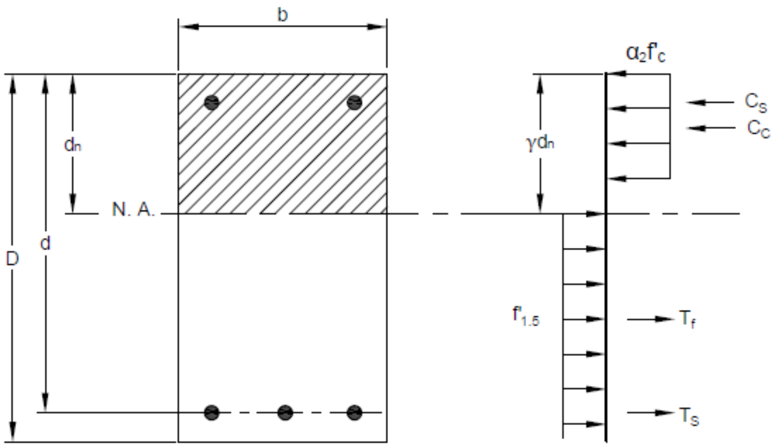
This clause applied to reinforced and prestressed beams subjected to any combination of shear force, bending moment and axial force. This clause does not apply when torsion acts in conjunction with shear or to non-flexural members.

D-4.2 Strength of Beams in Bending and Combined Bending and Axial Force

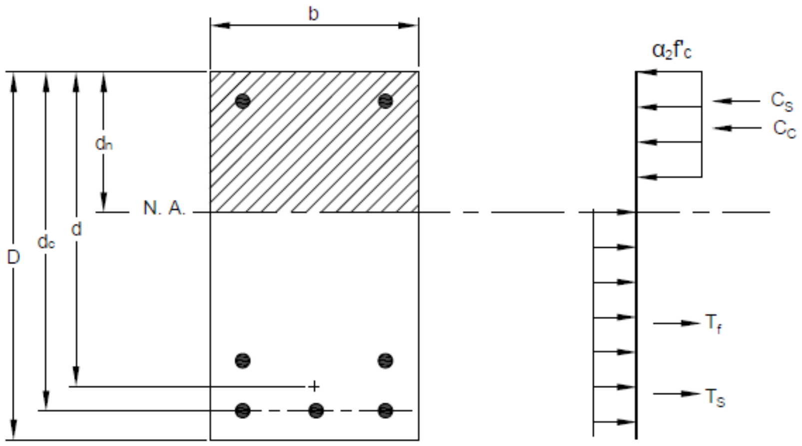
Calculations for strength of cross sections in bending shall incorporate equilibrium and strain-compatibility considerations and be consistent with the following assumptions:

a) Plane sections normal to the axis shall remain plane after bending.
b) Stress in the fibre reinforced concrete in that part of the cross section in tension shall be taken to be $f'_{1.5}$, where $f'_{1.5}$ is the characteristic residual tensile stress determined in accordance with **D-3.3.3**.
c) Distribution of compressive stress shall be determined from a stess-strain relationship for the concrete.

The strength of a section in bending, or in combined bending and axial force, shall be determined using rectangular stress blocks for the concrete in compression and concrete in tension, as shown in Fig. 5.



5A SINGLE TENSILE REINFORCEMENT LAYER



5B MULTIPLE TENSILE REINFORCEMENT LAYERS

FIG. 5 STRESS BLOCKS AND FORCES ON REINFORCED SFRC SECTION

D-4.3 Minimum Reinforcement Requirements for Bending

The minimum tensile reinforcement shall be not less than that determined using the principles given in this annex, excluding fibres.

D-4.4 Strength of Beams in Shear

D-4.4.1 *Design Shear Strength of a Beam*

The design shear strength of a beam shall be taken as $\emptyset V_u$

where,

$$V_u = V_{uc} + V_{uf} + V_{us}$$

Where V_{uc} and V_{us} are determined from **39** of [6-5(2)] and V_{uf} is determined from **D-4.4.2**.

Notwithstanding the above equations, the fibres component to the shear strength of a beam, V_{uf}, shall not exceed the greater of 0.3 V_u and that determined by **D-4.4.3** with V_{us} taken as zero.

D-4.4.2 *Contribution to Shear Strength by Steel Fibres*

The contribution of the fibres to the ultimate shear strength (V_{uf}) of an SFRC beam shall be calculated from the following equation:

$$V_{uf} = 0.7 k_{\theta} b_v d_o f'_{1.5}$$

Where,

$$k_{\theta} = \cot \theta_v \leq 1.28$$

θ_v = the angle between the axis of the concrete compression strut and the longitudinal axis of the member and shall be taken as not less than 38°

D-4.4.3 *Minimum Shear Reinforcement*

The minimum contribution from the total of the transverse steel reinforcement and fibres shall satisfy the following:

$$(V_{us} + V_{uf})_{min} \geq 0.1 b_v d_o \sqrt{f'_c} \ and \geq 0.6 b_v d_o$$

D-4.5 Design for Serviceability Limit States

D-4.5.1 *General*

When an SRFC cross sectional is uncracked, the full cross section shall be assumed to be active and both concrete and steel are assumed to be elastic in tension as well as in compression.

When an SRFC cross section is cracked, the SFRC shall be assumed to be elastic in compression, and capable of sustaining a tensile stress equal to 1.1 $f'_{1.5}$.

> NOTE – Prior to cracking, linear elastic behaviour is assumed for the SFRC, reinforcement and the bonded tendons in both tension and compression. After cracking, the SFRC in tension is assumed to carry a tensile stress of 1.1 $f'_{1.5}$, while the SFRC in compression, the reinforcement and the bonded tendons are assumed to be linear elastic.

D-4.5.2 *Stress Limits*

D-4.5.2.1 *Concrete*

The maximum compressive stress in the concrete at the serviceability limit states shall not exceed $0.6 f_{cm}(t)$. Under permanent effect loading, the maximum compressive stress in the concrete shall not exceed $0.4 f_{cm}(t)$.

NOTES

1. The satisfaction of limits on the concrete tensile stress at the serviceability limit state is not necessary if the member performance is satisfactory at the ultimate limit state.
2. Compressive stresses are limited to avoid large time-dependent deformations and to ensure creep behaviour remains linear with respect to stress. Restrictions on the tensile stress in SFRC are not necessary provided the member satisfies all other requirements at the strength and serviceability limit states.

D-4.5.2.2 *Reinforcing steel*

To avoid any inelastic deformation that could lead to large, permanently open cracks, tensile stresses in the reinforcement at the serviceability limit states shall not exceed $0.8f_{sy}$.

D-4.5.3 *Minimum Reinforcement for Crack Control*

The minimum amount of longitudinal reinforcement required to obtain controlled crack formation shall be:

$$A_{\mathrm{st,min}} = k_1 k_\mathrm{c} k_\mathrm{p} f_{\mathrm{ct,ef}} - 1.1 f'_{1.5} \frac{A_{\mathrm{ct}}}{f_{\mathrm{s,max}}} \geq 0.0 \text{ (mm}^2\text{)}$$

where

$A_{\mathrm{st,min}}$ = minimum area of reinforcement required within the tensile zone (mm^2). If $A_{st,\mathrm{min}}$ is zero only steel fibres are necessary to control cracking.

A_{ct} = area of concrete within the tensile zone (mm^2). The tensile zone is that part of the cross section calculated to be in tension just before formation of the first crack.

$f_{\mathrm{s,max}}$ = maximum stress permitted in the reinforcement immediately after formation of the crack.

$f_{\mathrm{ct,ef}}$ = tensile strength of the concrete effective at the time when the cracks may first be expected to occur (MPa). Values of $f_{\mathrm{ct,ef}}$ shall be obtained from $0.6\sqrt{f_{\mathrm{cm}}}$ but not less than 3.0 MPa and f_{cm} is the mean concrete compressive strength at the time cracking is expected to occur.

k_c = coefficient that takes account of the nature of the stress distribution within the section immediately prior to cracking. The relevant stress distribution is that resulting from the combined effects of loading and restrained imposed deformations:

= 1.0 for pure tension ($e = M/N = 0$)

= 0.6 for pure bending

k_1 = coefficient which allows for the effect of non-uniform self-equilibrating stresses due to non-linear shrinkage or temperature profiles through the member depth. In the absence of more detailed analysis, k_1 may be taken as 0.8.

k_p = a coefficient that takes account of the level of prestress and is given by:

$$k_p = 1 - \frac{\sigma_{cp}}{k k_c . f_{ct,ef}} \left(1 - k_c + 2.4 \frac{e}{D} - 6 k_c \frac{e}{D} \right)$$

e/D = ratio of the eccentricity of the prestressing force on the cross section, *e*, measured from the centroidal axis of the uncracked section to the overall depth of the cross section, *D.*

σ_{cp} = average intensity of the effective prestress (P_e/A_g)

D-4.5.4 *Deflection Control*

D-4.5.4.1 *General*

The deflection of an SFRC member shall be calculated using the procedures outlined in **D-4.5.4.2** and **D-4.5.4.3**. Allowance shall be made for the expected load history, the expected construction procedure and any anticipated deflections resulting from deformation of forms or settlement of props.

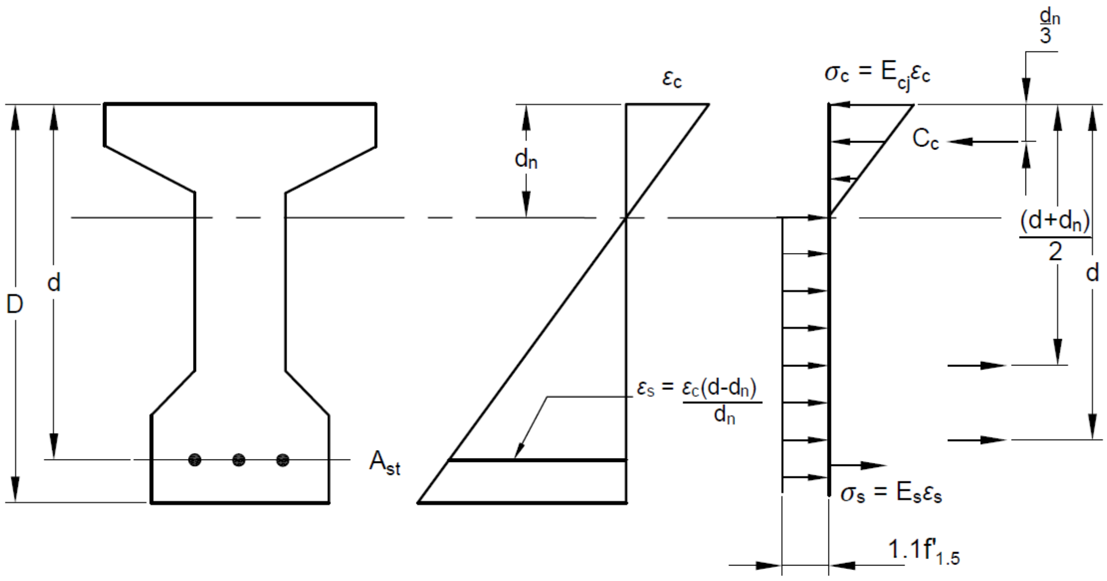
D-4.5.4.2 *Short-term deflection*

The short-term deflections due to external loads and prestressing, which occur immediately on their application, shall be calculated using the value of E_{cj} determined in accordance with this annex and the value of the effective second moment of area of the member (I_{ef}). The value of I_{ef} may be determined from the values of I_{ef} at nominated cross sections as follows:

a) For a simply supported span, the value at mid-span.
b) In a continuous beam,
   1) For an interior span, half the mid-span value plus one quarter of each support value; or
   2) For an end span, half the mid-span value plus half the value at the continuous support.
c) For a cantilever, the value at the support.

For the purpose of the above determinations, the value of I_{ef} at each of the cross sections nominated in items (a) to (c) is obtained from the instantaneous curvature $k_i = M^*_s/(E_{cj}\, I_{ef})$ calculated as the slope of the strain diagram in Fig. 6B and obtained by satisfying the requirements for rotational and horizontal equilibrium of the stress distribution in Fig. 6C.

NOTE – The procedure for calculating short-term deflection is consistent with the approach in this annex. Short-term deflection of a cracked section is calculated based on the assumed stress and strain distribution shown in Fig. 6. The assumption of a uniform tensile stress in the cracked region of the SFRC is considered to be reasonable for the determination of the neutral axis location and curvature and, hence, for the determination of the effective second moment of area (I_{ef}).



6A SELECTION 6B STRAIN 6C STRESS 6D FORCES

FIG. 6 STRESS AND STRAIN DISTRIBUTION ON A CRACKED SECTION SUBJECTED TO APPLIED IN-SERVICE BENDING MOMENT (M^*_S)

D-4.5.4.3 *Long-term deflection*

For reinforced and prestressed SFRC flexural members, that part of the deflection that occurs after the short term deflection shall be calculated as the sum of,

a) The shrinkage component of the long-term deflection, determined from the design shrinkage strain of concrete (ε_{cs}) and the principles of mechanics;
b) The additional long-term creep deflections, determined from the design creep coefficient of concrete (φ_{cc}) and the principles of mechanics.

In the absence of more accurate calculations, the additional long-term deflection of a reinforced SFRC beam due to creep and shrinkage may be calculated by multiplying the short-term deflection caused by the sustained loads by a multiplier, k_{cs}, as follows:

$$k_{cs} = \left[2 - 1.2\left(\frac{A_{sc}}{A_{st}}\right)\right] \geq 0.8$$

NOTE – For the calculation of long-term deflection, two alternative approaches are specified.

For reinforced and prestressed beams, the shrinkage and creep components of the long-term deflection may be calculated separately using the material data specified in the annex and the principles of mechanics. The shrinkage component of the long-term deflection may be readily determined from the shrinkage-induced curvatures calculated at the critical sections along the span of the beam using the design shrinkage strain, (ε_{cs}). The creep component of long-term deflection may be obtained from the creep-induced curvatures at the critical sections under the sustained service loads using the creep coefficient for concrete, (φ_{cc}).

Alternatively, for reinforced concrete beams and slabs, the additional long-term deflection caused by creep and shrinkage may be approximated by multiplying the short-term or immediate deflection caused by the sustained load by the deflection multiplier k_{cs}. The deflection multiplier depends on the ratio A_{sc}/A_{st}, where A_{sc} is the area of the longitudinal reinforcement in the compressive zone of the cracked section (that is, between the neutral axis and the extreme compressive fibre of the cracked cross section) and A_{st} is the area of the tensile reinforcement.

D-5 DURABILITY

The minimum concrete grade and cover for SFRC in respective exposure classification shall be as for concrete without fibres and shall apply to the steel reinforcement only. SFRC shall not be used in exposure classification C1 or C2.

NOTES

1 Steel fibres do not require concrete cover as specified for steel reinforcement.

2 SFRC may not be suitable in some exposure classification U environments.

3 Fibres close to the surface are subject to corrosion and may result in surface staining. This will not impact durability.

D-6 FIRE

The structural performance of SFRC for fire shall be determined in accordance with this annex. The material properties for SFRC shall be as specified for concrete in this annex except that to characteristic residual tensile stress of SFRC at elevated temperatures ($f'_{1.52\theta}$) shall be either,

a) taken as ($f'_{1.52\theta}$) = $k_{\theta 1} \times f'_{1.5}$ where $k_{\theta 1}$ is given in Table 4; or

b) determined statistically from tests.

Table 4 Elevated Temperature Coefficient for Residual Tensile Stress of SFRC

(*Clause* A-6)

Temperature of SFRC °C	0	100	500	700	1200
$\boldsymbol{k_{\theta 1}}$	1.0	1.0	0.6	0.1	0.0

NOTE – Linear interpolation between the values is permitted.

D-7 PRODUCTION OF SFRC

D-7.1 Fibres

Steel fibres shall comply with accepted standard. The 'Certificate of Conformity' shall be supplied on request to the relevant authority.

NOTE – Till the availability of a separate Indian Standard Specification for Steel Fibres, reference may be made to ASTM A820:2022 'Standard Specification for Steel Fibers for Fiber-Reinforced Concrete'.

D-7.2 Mixing of Fibres

Fibres of the type and quantity specified shall be added in a controlled process ensuring that they are dispersed uniformly through the concrete mix. If added after the main mixing process, the concrete shall be remixed until the fibres have been completely dispersed throughout the batch.

NOTES

1 Balling of fibres should be avoided.

2 A record of fibre content should be recorded for each batch.

D-7.3 Pre-Construction Testing of Materials

Pre-construction testing in the form of initial type tests shall be undertaken in accordance with Table 5.

New initial type tests shall be undertaken when any of the following occur:

a) The concrete composition changes.
b) At least one source material of the concrete changes.
c) The results of compressive tests undertaken as per this annex do not meet the specification.
d) At least once in a period of 12 months.

The pre-construction tests shall be performed with the same personnel, materials and equipment that will be used during production.

Table 5 Pre-Construction Tests
(*Clause* D-7.3)

Sl No.	**Material**	**Inspection/Test**	**Purpose**
(1)	(2)	(3)	(4)
i)	Steel fibres	a) Check delivery note	Verify that the delivery is in accordance with the order, and is shipped from the correct source

Sl No.	Material	Inspection/Test	Purpose
(1)	(2)	(3)	(4)
		b) Check conformity label	Verify that the fibres have the correct conformity label which matches the corresponding Certificate of Conformity
ii)	Steel fibre content in the fresh concrete	Testing according to **D-2.5** on the basis of 9 samples	Conformity with the target dosage. Verify homogeneous distribution of the steel fibres in the mix
iii)	Steel fibre concrete performance	Check limit of proportionality, and post-crack flexural strength in accordance with **D-3.3.6** on a minimum of 12 beams	Verify, if the performance is in accordance to the specification. The performance level serves as the reference for continuous production control

NOTE – The strength of the population may be treated as normally distributed and the characteristic strength determined in accordance with this annex. A confidence level of 75 percent shall be used such that 95 percent of the population exceeds the characteristic value. For a sample of 12 specimens, the characteristic strength may be calculated from the mean strength using characteristic strength = mean strength × (1 – 1.84 ×COV). The coefficient of variation (COV as a percentage) shall not exceed 25 percent.

D-7.4 Factory production control

Factory production control is accordance with Table 6 shall be undertaken to establish a production process for the steel fibre reinforced concrete, and shall include the following:

a) Checking the correct concrete constituents are being used in production.
b) Steel fibres are checked against specified requirements.
c) Compressive tests undertaken in accordance with good practice [6-5 (36)].
d) Fibre content and distribution.

Table 6 Routine Production Control
(*Clause* D-7.4)

Sl No.	Subject	Inspection/Test	Purpose	Frequency
(1)	(2)	(3)	(4)	(5)
i)	**Equipment inspection**			
	Automatic dosing equipment for steel fibres	a) Visual inspection	Assure correct functioning of dosing device	Once per production day
		b) Control of accuracy	Avoid improper fibre dosage	On installation Periodically

Sl No. (1)	Subject (2)	Inspection/Test (3)	Purpose (4)	Frequency (5)
				In case of doubt
ii)	**Materials inspection**			
	Steel fibres	a) Check delivery note	Verify that the delivery is in accordance with the order, and is shipped from the correct source	Each delivery
		b) Check conformity requirements	Verify that the fibres matches the corresponding Certificate of Conformity	Each delivery
		c) Visual control, measure fibre dimensions	Compare the fibre geometry with the fibres used for ITT	Each delivery
iii)	**Production process inspection**			
	a) Fibres content-record	Record the quantity added	Check the content	Every batch
	b) Fibre content in the fresh concrete	Testing according to **A-7.5**	Conformity with the target dosage Verify homogenous distribution of the steel fibres in the mix	Beginning of each day and every /50m^3 (manual dosing) and /150 m^3 (auto dosing)
	c) Concrete mix	Visual Check	Correct mixing with correct fibre type and even fibre distribution without balling	Daily
iv)	**Finished product inspection**			
	Steel fibre Concrete Performance	Check limit of proportionality, and post-crack flexural strength in accordance with **A-3.3.6**	Check performance level of the specification	2 beams every other day of production

D-7.5 Determining the Steel Fibre Content

Steel fibre content shall be measured from samples taken from the production concrete, by volume of concrete.

In addition,

a) a sample shall be taken from the batch of concrete at unloading from the first third, middle third and final third of the batch;
b) each sample shall be a minimum of 10 litre;
c) the sample container shall be filled in one continuous pour and where possible directly from the discharge chute; and
d) wash out or magnetic separation only shall be used.

The conformity of the correct steel fibre dosage is proven if the criteria in Table 7 are met.

Table 7 Criteria of Acceptance for Steel Fibre Dosage
(*Clause* D-7.5)

Sl No. (1)	**Test Control** (2)	**Test Control** (3)	**Criteria** (4)
i)	Each sample	Each partial test	≥ 0.80 of the specified target dosage
ii)	Average of 3 samples from the batch	Each test	≥ 0.85 of the specified target dosage
iii)	Continuous control: average of >3 tests	Continuous control average of >3 tests	≥ 0.90 of the specified target dosage

D-7.6 Sampling, Testing and Assessment for Compliance of Hardened SFRC

When concrete is specified by parameters other than strength grade, the method of production control and, if required, project control shall be specified together with the relevant compliance criteria.

Methods of control and assessment shall provide a reliable operating characteristic curve so that,

a) concrete with a proportion defective of 0.05 has a probability of acceptance of at least 50 percent; and
b) concrete with a proportion defective of 0.30 has a probability of rejection of at least 98 percent.

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of the Code. The latest version of a standard shall be adopted at the time of enforcement of the Code. The standards listed may be used by the Authority as a guide in conformance with the requirements of the referred clauses in the Code.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Part/Section.

Sl. No.	**IS No.**	**Title**
(1)	4845 : 1968	Definitions and terminology relating to hydraulic cement
	6461	Glossary of terms relating to cement:
	(Part 1) : 2024	Concrete aggregates *(first revision)*
	(Part 2) : 2024	Materials (other than cement and aggregate) *(first revision)*
	(Part 3) : 2024	Concrete reinforcement *(first revision)*
	(Part 4) : 2024	Types of concrete *(first revision)*
	(Part 5) : 2024	Formwork for concrete *(first revision)*
	(Part 6) : 2024	Equipment, tool and plant *(first revision)*
	(Part 7) : 2024	Mixing, laying, compaction, curing and other construction aspect *(first revision)*
	(Part 8) : 2024	Properties of concrete *(first revision)*
	(Part 9) : 2024	Structural aspects *(first revision)*
	(Part 10) : 2024	Tests and testing apparatus *(first revision)*
	(Part 11) : 2024	Prestressed concrete *(first revision)*
	(Part 12) : 2024	Miscellaneous terms *(first revision)*
(2)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
(3)	9142 (Part 2) 2018	Artificial lightweight aggregate for concrete - Specification: Part 2 sintered fly ash coarse aggregate *(first revision)*
(4)	269: 2015	Ordinary Portland cement - Specification *(sixth revision)*
(5)	455:2015	Portland slag cement - Specification *(fifth revision)*
(6)	1489 (Part 1):2015	Portland pozzolana cement - Specification: Part 1 fly ash based *(fourth revision)*
(7)	1489 (Part 2):2015	Portland pozzolana cement - Specification: Part 2 calcined clay based *(fourth revision)*
(8)	16415:2015	Composite cement - Specification

(9)	12330:1988	Specification for sulphate resisting portland cement
(10)	16993:2018	Microfine ordinary portland cement - Specification
(11)	8043:1991	Hydrophobic portland cement - Specification *(second revision)*
(12)	12600:1989	Portland cement, low heat – specification
(13)	8041:1990	Rapid hardening portland cement – Specification *(second revision)*
(14)	6452:1989	High alumina cement for structural use - Specification *(first revision)*
(15)	6909:1990	Super sulphated cement - Specification *(first revision)*
(16)	8042:2015	White portland cement - Specification *(third revision)*
(17)	3025 (Part 18) : 2022	Methods of sampling and test (physical and chemical) for water and wastewater Part 18 volatile and fixed solids (total, filterable and non-filterable at 550 C *(second revision)*
(18)	3025 (Part 24/Sec 1) : 2022	Methods of sampling and test (physical and chemical) for water and wastewater Part 24 Sulphates Section 1 Gravimetric and turbidity methods *(second revision)*
(19)	3025 (Part 32) :1988	Methods of sampling and test (physical and chemical) for water and wastewater: Part 32 Chloride *(first revision)*
(20)	3025 (Part 17) :2022	Methods of sampling and test (physical and chemical) for water and wastewater Part 17 non-filterable residue total suspended solids at 103 C - 105 C *(second revision)*
(21)	3812 (Part 1) :2013	Pulverized fuel ash - Specification: Part 1 for use as pozzolana in cement, cement mortar and concrete *(third revision)*
(22)	15388:2003	Silica fume - Specification
(23)	16354:2015	Metakaolin for use in cement, cement mortar and concrete - Specification
(24)	16714:2018	Ground granulated blast furnace slag for use in cement, mortar and concrete - specification

(25)	16715:2018	Ultrafine ground granulated blast furnace slag - specification
(26)	19058 : 2024	Ultrafine fly ash - Specification
(27)	9103:1999	Concrete admixtures -Specification *(first revision)*
(28)	1343 : 2012	Prestressed concrete - Code of practice (*second revision*)
(29)	16172 : 2023	Reinforcement couplers for mechanical splices of steel bars in concrete - Specification (*first revision*)
(30)	18256 : 2023	Solid round glass fibre reinforced polymer (GFRP) bars for concrete reinforcement - Specification
(31)	1566 : 1982	Specification for Hard-Drawn steel wire fabric for concrete reinforcement *(second revision)*
(32)	16700 : 2023	Criteria for structural safety of tall concrete buildings (*first revision*)
(33)	18189 : 2023	Portland calcined clay limestone. cement — Specification
(34)	1199 (Part 6) : 2018	Fresh Concrete — Methods of Sampling, Testing and Analysis Part 6 Tests on fresh self compacting concrete (*first revision*)
(35)	10262:2019	Concrete Mix Proportioning — Guidelines (*second revision*)
(36)	4031 (Part 5) : 1988	Methods of physical tests for hydraulic cement Part 5: Determination of initial and final setting times