ANNEX 14

Recommendations for using concrete with fibres

1 Scope

The specifications and requirements included in the main articles of this Code relate to concretes which do not incorporate fibres in their mass. As a result, some additional and specific recommendations must be given for cases where fibres are used in concrete, given that these may alter some of its properties, in order to improve certain types of performance, whether in the fresh state, at an early age or when hardened. The following are expressly outside the scope of this Annex:

- Concretes with polymers (impregnated with polymers, made of polymers or modified with polymers).
- Concretes produced using fibres other than those indicated in this Annex as acceptable for use in concrete.
- Concretes in which the distribution and/or orientation of the fibres is intentionally forced.
- Concretes with a dosage of fibres higher than 1,5% by volume.

For the purposes of this Annex, fibre-reinforced concrete (FRC) is defined as concrete which includes in its composition discrete short fibres which are randomly distributed in its mass. The provisions generally apply to all types of fibre, although it should be borne in mind that the existing fundamental knowledge base relates to steel fibres which is reflected to a certain extent in that knowledge.

This concrete can be used for structural and non-structural purposes. Using fibres in concrete has a structural purpose where their contribution is taken into account in the calculations of any of the ultimate or serviceability limit states and where they partially or totally replace the reinforcement in certain applications. It shall be considered that fibres have no structural function when they are included in the concrete for other purposes, such as improving fire resistance or controlling cracking.

Fibres may be added to plain, reinforced or prestressed concrete and this may be done by using any of the various systems for incorporating fibres in concrete which are approved practice. Where there is no such approved practice, the system used must be explained.

This Annex mentions certain national and international standards which relate to the subject of this Annex and which may serve as support or reference.

Each drawing of the structure must include a concrete classification table which shall indicate the additional conditions to be met by concrete with fibres, as set out in Article 39.2 of this Code.

The classification proposed in this Annex reflects the basic specifications which are required when fibres have a structural purpose. In addition to the properties which are implicit in the concrete classification according to Article 39.2 of this Annex, the Specific Technical Specifications must include those additional characteristics required of concrete with fibres and also the test methods for verifying these characteristics and the values which must be met by these characteristics. In all cases, a proposed dosage must be indicated with the following details:

- Dosage of fibres in kg/m^3
- Type, dimensions (length, effective diameter, slenderness), shape and tensile strength of the fibre (in N/mm^2), in the case of fibres with a structural purpose.

However, the effectiveness of the various fibres available on the market can be very variable and the conditions of availability of the product or the site conditions may recommend a modification of some of the characteristics specified in the specifications, whether in relation to the type, dimensions and therefore the dosage of fibres needed to obtain the same properties. As a result, when concrete is designated by its properties, the dosage indicated in the Specific Project Technical Specifications must be understood as a guideline. Before starting the concreting, the supplier shall propose a site-specific dosage and shall perform the prior tests in accordance with Annex 22 of this Code. In light of the results, the Project Management shall accept the proposed dosage or request new proposals.

2 Additions to the text of this Code

Below are the recommendations for using concrete with fibres, with reference to the relevant Titles, Chapters, Articles and Sections of this Code.

TITLE 1. DESIGN BASES

CHAPTER 3. ACTIONS

Article 10. Characteristic values of actions

10.2. Characteristic values of permanent actions

The density and usual dosages of fibres shall not alter the characteristic specific gravity values of concrete with fibres compared to those of concrete without these.

CHAPTER 4. MATERIALS AND GEOMETRY

Article 15. Materials

15.3. Partial safety factors for materials

For the Ultimate Limit States and for the Serviceability Limit States, the partial safety factors given in the main articles (Table 15.3) shall be maintained as it is understood that the incorporation of fibres under normal conditions does not alter the uncertainties leading to the estimation of these values.

TITLE 2. STRUCTURAL ANALYSIS

CHAPTER 5. STRUCTURAL ANALYSIS

The incorporation of fibres alters the non-linear behaviour of structural concrete, particularly under tension, thereby preventing the opening and propagation of cracks. As a result, carrying out a non-linear analysis may be particularly recommended in cases where the fibres constitute an important part of the concrete's reinforcement.

In addition, given the ductility introduced by the presence of fibres, the principles for applying the linear analysis method with limited redistribution and the plastic calculation methods are regarded as valid, when the requirements for applying these, as specified in Article 19, are met.

The plastic or ultimate moments shall be determined in accordance with section 39.5 and, for solid slabs, it shall be considered that the fracture lines have sufficient rotational capacity if the depth of the neutral fibre in the Ultimate Limit State (ULS) of simple bending is less than 0,3 d. The structural assessments for these purposes must be carried out using tests which represent the real conditions.

The use of structural fibres may increase the width of the compression struts; this can be taken into account in the strut and tie rod models. As a result, the combination of conventional reinforcement and fibres may form an alternative for reducing the amount of conventional reinforcement in D-Regions where there is a high density of reinforcement preventing the correct concreting of the element.

TITLE 3. TECHNOLOGICAL PROPERTIES OF MATERIALS

CHAPTER 6. MATERIALS

Fibres. Definitions

Fibres are short elements with a small cross-section which are incorporated in the mass of the concrete in order to give it certain specific properties.

In general, those fibres which provide greater fracture energy to plain concrete can be classed as structural fibres (in the case of structural fibres, their contribution can be taken into account when calculating the response of the concrete section). Those fibres which, without taking this energy into account in the calculation, improve certain properties such as, for example, control of shrinkage cracking, increase of fire resistance, abrasion, impact and others, can be classed as non-structural fibres.

The geometric characteristics of fibres (Length (l_f), Equivalent diameter (d_f), Slenderness (λ)) shall be established in accordance with UNE 83500 Part 1 and UNE 83500 Part 2. Furthermore, depending on their nature, fibres shall be classed as:

- Steel fibres
- Polymer fibres
- Other inorganic fibres

The effectiveness of fibres can be assessed in terms of the fracture energy, expressed in Joules (J), which will be determined for cast concrete using UNE 83510. Alternatively, in order to reduce the dispersion and testing times, the Designer or, where applicable, the Project Management shall assess, under their responsibility, the use of other procedures, such as the Barcelona double-punch test carried out on a cylindrical test piece of 15x15 cm.

Steel fibres

These fibres must comply with UNE 83500-1 and, depending on the manufacturing process, are classed as: drawn (Type 1), strip-cut (Type II), melt extracted (steel shavings) (Type III) and others (for example, molten steel fibres) (Type IV). The shape of the fibre has an important effect on the bond characteristics of the fibre with the concrete and may be very varied: straight, undulated, corrugated, shaped with different-shaped ends, etc.

It is recommended that the length of the fibre (l_f), is at least twice the size of the largest aggregate. It is common to use lengths of 2,5 to 3 times the maximum aggregate size. In addition, the diameter of the pumping pipe means that the fibre length must be less than two-thirds of the pipe diameter. However, the fibre length must be sufficient to ensure the necessary bond with the matrix and to prevent pull-out occurring too easily.

Small-diameter fibres of equal length allow the number of these per unit weight to be increased and make the framework or mesh of fibres more dense. The spacing between fibres is reduced when the fibre is finer, making this more efficient and allowing an improved redistribution of the load or stresses.

Polymer fibres

Plastic fibres are formed using an extruded and previously cut polymer material (polypropylene, high-density polyethylene, aramid, polyvinyl alcohol, acrylic, nylon, polyester).

These may be uniformly added to the concrete, mortar or slurry. They are governed by UNE 83500-2 and, depending on the manufacturing process, are classed as: extruded monofilaments (Type 1), fibrillated films (Type II).

Their dimensions may vary along with their diameter and format:

Micro-fibres: < 0,30 mm diameter
Macro-fibres: ≥ 0,30 mm diameter

Macro-fibres may collaborate structurally as their length can vary (from 20 mm to 60 mm) but this must be in proportion to the maximum aggregate size (length ratio of 3:1 fibre: maximum aggregate size).

Micro-fibres are used to reduce cracking due to plastic shrinkage of the concrete, particularly in pavements and floors, but they cannot assume any structural function. They are also used to improve fire resistance and, in this case, the number of fibres per kg should be very high.

In addition, due to their physical/chemical characteristics, micro-fibres are characterised by their fibre frequency which indicates the number of fibres present in 1 kg and which depends on the fibre length and particularly on its diameter.

Other inorganic fibres

With regard to this type of fibre, those included in this Annex are glass fibres which are the ones currently usually used in the field of concrete. Other fibres are not included as, although they exist, they are used for other applications outside the field of concrete.

Glass fibres

This type of fibre may be used provided that its adequate behaviour during the working life of the structural element is guaranteed, given the potential problems of deterioration in this type of fibre as a result of the alkalinity of the environment.

Given that FRCs can experience significant reductions in strength and tenacity due to exposure to the environment, the appropriate measures must be taken in relation to both the fibre and the cement matrix in order to ensure its protection. In this respect, fibres may have a surface protective layer made of an epoxy material which reduces their affinity with calcium hydroxide, a process responsible for weakening the compound.

Article 31. Concretes

31.1 Composition

When the fibres used are metallic, the total chloride ion contributed by the components shall not exceed 0,4% of the cement weight.

31.2 Quality conditions

When fibres are used, the quality conditions or characteristics required in terms of the concrete in the Specific Project Technical Specifications shall include the maximum length of the fibres.

When fibres have a structural function, the values of the residual characteristic tensile strength due to bending, $f_{R,1,k}$ *and* $f_{R3,k}$, as specified in Article 39, shall be included.

When fibres with other functions are used, the methods for verifying the suitability of the fibres for this purpose shall be specified.

31.3 Mechanical characteristics

For the purposes of this Code, the flexural strength of concrete refers to the strength of the product unit or mix and is determined from the flexural fracture test results. At least three of these tests must be carried out on prismatic test pieces of a width equal to 150 mm, height equal to 150 mm and length equal to 600 mm, at 28 days of age, produced, stored and tested in accordance with EN 14651.

When the element to be designed has a depth less than 12,5 cm or when the concrete offers flexural hardening with a residual flexural strength $f_{R,1,d}$ higher than the tensile strength $f_{ct\,d}$,, it is recommended that the dimensions of the test piece and the preparation method are adapted to simulate the actual behaviour of the structure and that the test is carried out using unnotched test pieces.

For structural elements working as a slab, other alternative types of test may be used, provided that these are confirmed by a conclusive experimental campaign. When the deviation between the results for one product unit exceeds certain limits, the process followed must be verified in order to ensure that these results are representative.

In order to ensure that a product unit is uniform, the difference between the results for a group of three test pieces (difference between the highest and lowest results, divided by the mean value of the three), taken from the same mix, may not exceed 35%.

The criteria laid down in this Code for determining the value of the tensile strength, $f_{ct,}$, using the results of the indirect tensile test are valid provided that these refer to the limit of proportionality.

For compressive stresses, the stress-strain curve for concrete with fibres shall not be any different from that in the main articles as it may be considered that the addition of fibres does not significantly alter the behaviour of the concrete under compression.

The test proposed in UNE-EN 14651 provides the load-crack opening diagram for concrete (Figure A.14.1). Using the load values corresponding to the limit of proportionality (F_L) and to the crack openings of 0,5 mm and 2,5 mm (F_1 and F_3 respectively), the flexural strength value ($f_{ct,fl}$)) and the corresponding residual flexural strength values, : $f_{R,1}$ and $f_{R,3}$, can be determined.

The flexural strength and residual flexural strength values according to said standard EN 14651 are calculated by assuming a linear elastic distribution of stresses at the fracture point.

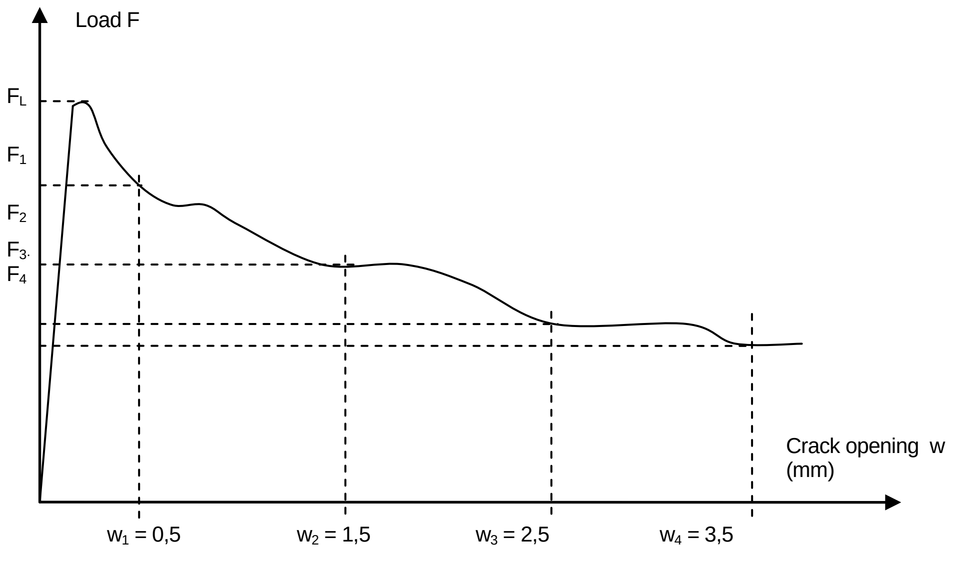

Figure A.14.1 Typical load-crack opening diagram

Using these values, the tension calculation diagram can be determined as indicated in Article 39. Other diagrams which directly define these constituent equations may also be used, provided that the results are endorsed by conclusive experimental campaigns and the specialised bibliography.

31.4 Minimum strength value

So that fibres can be regarded as having a structural function, the residual characteristic tensile strength due to bending $f_{R,1,k}$ shall not be less than 40% of the limit of proportionality and $f_{R,3,k}$ shall not be less than 20% of the limit of proportionality (see Article 39.1).

31.5 Workability of concrete

The use of fibres in concrete can cause a loss of workability, the magnitude of which will depend on the type and length of the fibre used and also on the quantity of fibres incorporated. This factor must particularly be taken into account when determining the consistency of concrete where the fibres are added on site.

In the case of concrete with fibres, it is recommended that the consistency of the concrete is not less than 9 cm of slump in the Abrams cone (although this depends on the type of application and placing system). In this case, the Abrams cone test is not particularly suitable and it is recommended that the consistency is tested in accordance with the tests proposed in UNE EN 12350-3 or UNE 83503.

TITLE 4. DURABILITY

CHAPTER 7. DURABILITY

Article 37. Durability of concrete and reinforcements

37.2.4 Covers

The use of concrete reinforced with fibres with a structural function eliminates the need to use mesh reinforcement which the Guidelines require to be placed in the middle of covers exceeding 50 mm.

37.2.8 Use of fibre-reinforced concrete (this part does not correspond to any corresponding article in the Code)

In general, fibre-reinforced concrete may be used in all exposure classes. In the general exposure classes IIIb, IIIc and IV and in specific exposure class F, its use must be justified by means of experimental tests where carbon steel fibres are used. A viable alternative is to use stainless, galvanised or corrosion-resistant steel.

In the case of specific exposure classes due to chemical attack (Qa, Qb and Qc), steel and synthetic fibres may be used following a study proving the non-reactivity of the chemical agents with these materials (not including the concrete).

37.3.6 Resistance of the concrete to erosion

In general, the use of steel fibres improves the resistance to erosion.

TITLE 5. CALCULATION

CHAPTER 8. MATERIAL DATA FOR THE DESIGN

Article 39. Characteristics of concrete

39.2. Classification of concrete

Concretes shall be classified using the following format (which must be included in the design drawings and in the Specific Project Technical Specifications for the design):

T - R / f-R1-R3 / C / TM-TF / A

where:

- *T* Identifier which will be HMF for plain concrete, HAF for reinforced concrete and HPF for prestressed concrete

R Specified characteristic compressive strength, in N/mm^2

f Identifier of the type of fibre which will be A in the case of steel fibres, P in the case of polymer fibres and V in the case of glass fibre

R1,R3 Specified residual characteristic flexural strength $f_{R,1,k}$ and $f_{R,3,k}$, in N/mm^2

C Initial letter of the type of consistency, as defined in Article 31.5

TM Maximum aggregate size in millimetres, defined in Article 28.2

TF Maximum length of the fibre, in mm

A Designation of the environment, in accordance with Article 8.2.1

As regards the specified residual characteristic flexural strengths, it is recommended that the following series is used, provided that the minimum value required in Article 30.5 is exceeded:

1,0 - 1,5 - 2,0 - 2,5 - 3,0 - 3,5 - 4,0 - 4,5 - 5,0 - etc.

In this series, the figures indicate the specified residual characteristic flexural strengths of the concrete at 28 days, expressed in N/mm2.

Where the fibres have no structural function, the symbols R1 and R3 must be replaced by: "CR" in the case of fibres for shrinkage control, "RF" in the case of fibres for improving the fire resistance and "O" in other cases.

In the case of concretes designated by dosage, the following formula is recommended:

T - D - G/f/C/TM/A

where G is the fibre content, in kg/m^3 of the concrete, as prescribed by the applicant. The other parameters have the meaning indicated in the main articles. In this case, it must be guaranteed that the type, dimensions and characteristics of the fibres coincide with those indicated in the Specific Project Technical Specifications.

39.4 Design strength of concrete

The value of the corresponding characteristic design strength, $f_{R,1,k}$ and $f_{R,3,k}$, divided by a partial safety factor γ_c, which shall take the values indicated in Article 15, shall be regarded as the design residual flexural strengths of the concrete, $f_{R,1,d}$ and $f_{R,3,d}$. It is possible to work with residual tensile strengths, provided that the experimental validity of the approach is proven. Correlations with the bending results may be sought.

39.5 Design tensile stress-strain diagram of concrete with fibres

In order to calculate the sections subject to normal stresses in the Ultimate Limit States, one of the following diagrams shall be used:

- Rectangular diagram: In general, the diagram in Figure A.14.2, characterised by the design residual tensile strength, $f_{ctR,d}$, shall be used.

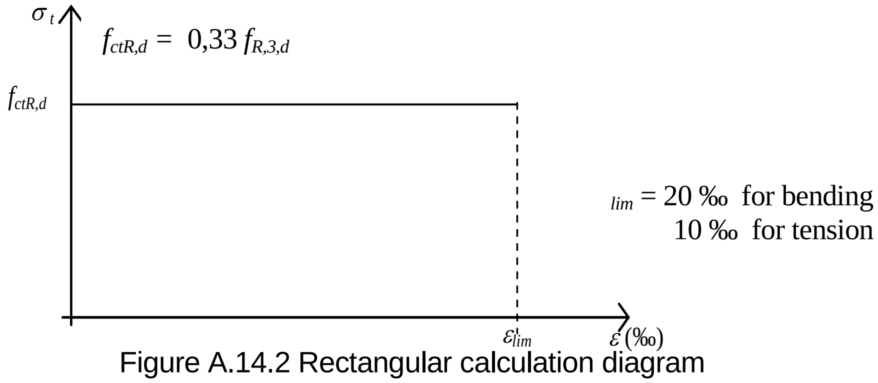

Figure A.14.2 Rectangular calculation diagram

- Multilinear diagram: For applications requiring an adjusted calculation, the stress (σ)- strain (ε) diagram in Figure A.14.3 shall be used, defined by a design tensile strength f_{ctd} and design residual tensile strengths $f_{ctR1,d}$ and $f_{ctR3,d}$, associated with both strains ε_1 and ε_2 under post-peak conditions, where:

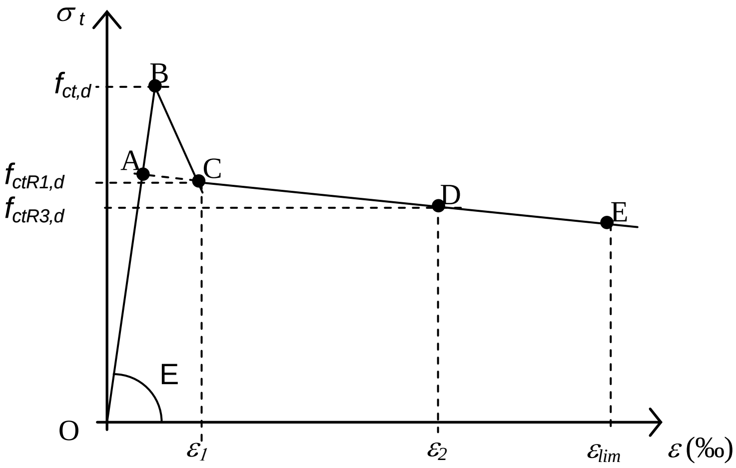

Figure A.14.3. Multilinear calculation diagram.

Where

f_L Load corresponding to the limit of proportionality

$f_{ct,d}$ = 0,6 $f_{ct,fl,d}$

$f_{ctR1,d}$ = 0,45 $f_{R,1,d}$

$f_{ctR3,d}$ = k_1 (0,5 $f_{R,3,d}$ - 0,2 $f_{R,1,d}$)

k_1 = 1 for sections subject to bending and 0,7 for sections subject to tension

ε_1 = 0,1 + 1000*$f_{ct,d}$ / $E_{c,0}$

ε_2 = 2,5/l_{cs}

ε_{lim} = 20‰ for sections subject to bending and 10‰ for sections subject to tension

l_{cs} Critical length (in metres) of the calculated element which may be determined using the expression

l_{cs} = min (s_m, $h - x$)

where: x = depth of the neutral axis

h-x = distance from the neutral axis to the most highly tensioned end

s_m = mean distance between cracks. Unless justified data is available, the values in Table A.14.1 may be used for s_m.

Table A.14.1 Reference values for s_m

Elements without traditional reinforcement or with very little reinforcement and fibre concrete with a bending behaviour with softening ($f_{R,1} < f_L$ and $f_{R,2} < f_L$)	H (depth of the member)
Fibre-reinforced concrete, with $f_{R,3,d} < 2$ kN/mm^2	s_m calculated in accordance with Article 49.2.4
Elements with fibre concrete with a bending behaviour with hardening ($f_{R,1} > f_L$ and/or $f_{R,2} > f_L$)	Shall be determined experimentally as indicated in Article 31.3
Other cases	The specialised bibliography shall be consulted

Note: To simplify matters, elements with very little reinforcement shall be regarded as those in which the geometric quantity of traditional tension reinforcement is less than one per thousand.

The effect of the A-B-C peak may be important when a non-linear analysis is carried out, particularly for small strains. In other cases, the simplified bilinear diagram, formed of the straight lines corresponding to the elastic section O-A and the extension of the straight line C-E to point A, and also considering a rigid behaviour with $E = \infty$, may be used for the fracture calculation.

Other calculation diagrams shall be accepted provided that the results obtained using these satisfactorily coincide with the results produced by the rectangular diagram indicated in Figure A.14.2 or are on the safe side.

39.8 Creep of concrete

When using synthetic fibres for structural purposes, the manufacturer must indicate the concrete's coefficient of creep, with the results being confirmed experimentally.

39.9 Poisson's rate

The fibres individually or as a group must have a Poisson's rate similar to that of concrete if the mesh effect is to be taken into account at structural level.

CHAPTER 10. ULTIMATE LIMIT STATE CALCULATIONS

Article 42. Failure Limit State under normal forces

42.1.2 Basic assumptions

The ultimate loadbearing capacity of sections in which the fibres have a structural function shall be calculated using any of the diagrams defined in Article 39.5 as a calculation diagram for concrete under tension.

42.1.3 Deformation domains

These are deemed to be the same as for a structure with conventional concrete.

42.2.2 Concrete confinement effect

Fibres with a structural function provide a concrete confinement effect similar to that of transverse reinforcements. In order to quantify the confinement effect produced by the fibres, the specialised bibliography must be consulted.

42.3.2 Simple or compound bending

In those cases where fibres with a structural function are used, either alone or in combination with traditional reinforcement, the following limitation must be observed:

$$A_p\, f_{pd} \frac{d_p}{d_s} + A_s\, f_{yd} + \frac{z_f}{z} A_{ct}\; f_{ctR,d} \geq \frac{W_1}{z} f_{ctm} + \frac{P}{z}\left(\frac{W_1}{A} + e\right)$$

where:

$z_f\, A_{ct}\, f_{ctR,d}$	Contribution of the fibres
z_f	Lever arm for the tension in the concrete
A_{ct}	Tensioned area of the concrete
$f_{ctR,d}$	Design residual tensile strength in the rectangular diagram

In the case of rectangular sections with or without passive reinforcement, the following simplified expression may be used in which there is no need to determine the tensioned area of the concrete.

$$A_s\, f_{yd} + 0{,}4\, A_c\, f_{ctR,d} \geq 0{,}04\, A_c\, f_{cd}$$

This limitation is justified as a guarantee to prevent fragile fracture of the concrete. The action of the traditional reinforcements and the fibres is complementary in this respect and therefore the limitation constitutes a minimum fibre content requirement for elements without traditional reinforcements and the possibility of reducing, and even eliminating, the requirement for minimum traditional reinforcements in elements with a sufficient content of structural fibres. This limitation does not apply for slabs resting on the ground.

42.3.4 Simple or compound tension

In the case of concrete sections subject to simple or compound tension which contain two main reinforcements and fibres, the following limitation must be observed:

$$A_p\, f_{pd} + A_s\, f_{yd} + A_c\, f_{ctR,d} \geq 0{,}20\, A_c\, f_{cd}$$

42.3.5 Geometric ratios (amount of reinforcement)

The values in Table 42.3.5 of the minimum geometric ratios which must be provided in all cases in the various types of structural element, depending on the steel used, may be reduced in the case of concrete with fibres by an equivalent mechanical quantity:

$$A_c\, f_{ctR,d}$$

where: A_c and $f_{ctR,d}$ have the meaning given above.

Article 44. Failure Limit State under shear

44.1 Failure ULS due to shear forces: General considerations

The contribution of the fibres shall be taken into account in the loadbearing capacity of the tie rods.

44.2.3.2.3. Fibre-reinforced concrete members with and without shear reinforcement (this part does not correspond to any article in the Code)

Where there are bent longitudinal bars which are taken into account in the calculation as shear reinforcement, at least one-third of the shear strength must be provided by the contribution of the steel fibres or, where applicable, by the joint contribution of the steel fibres and vertical stirrups. In all cases, the minimum quantity of shear reinforcement is established and shall be provided as indicated in Article 44.2.3.4.1 of this Code.

The failure shear stress due to tension in the web is equivalent to:

$$V_{u2} = V_{cu} + V_{su} + V_{fu}$$

where:

V_{cu} Contribution of the concrete to the shear strength given in Article 44.2.3.1.

V_{su} Contribution of the transverse reinforcement of the web to the shear strength. Same as Article 44.2.3.2.2.

V_{fu} Contribution of the steel fibres to the shear strength.

$V_{fu} = 0{,}7\ \xi\ \tau_{fd}\ b_0\ d$

where:

$\xi = 1+\sqrt{\frac{200}{d}}$ with d in (mm) and $\xi \leq 2$ (same as Article 44.2.3.2.1)

τ_{fd} Design value of the increment in shear strength due to the fibres, taking the value: $\tau_{fd} = 0{,}5\ f_{ctR,d}$ (N/mm^2).

In the case of T-sections, the contribution of the flanges may be taken into account through a multiplying coefficient k_f in the expression of V_{fu}. This coefficient may be determined using the following expression:

$$k_f = 1 + n \cdot \left[\frac{b_f}{b_0}\right] \cdot \left[\frac{h_f}{d}\right] \text{ with } k_f \leq 1{,}5$$

where:

h_f Height of the flanges in mm

b_f Width of the flanges in mm

b_0 Width of the web in mm

$n = \frac{b_f - b_w}{h_f} \leq 3$ and $n \leq \frac{3 \cdot b_w}{h_f}$

44.2.3.4.1 Transverse reinforcements

The minimum quantity of shear reinforcement, whether in the form of Steel Fibre-Reinforced Concrete and/or vertical stirrups, shall be provided where the following ratio is met:

$$V_{su} + V_{fu} \geq \frac{f_{ct,m}}{7{,}5} b_0\, d$$

44.2.3.4.2 Longitudinal reinforcements

In the case of structures made of concrete reinforced with fibres with a structural function; (V_{su}+V_{fu}) must be used in the expressions in the main article in place of V_{su}.

44.2.3.5 Longitudinal shear between the flanges and web of a beam

It has been confirmed experimentally that fibres with a structural function can significantly contribute to the resistance of flange-web longitudinal shear stress. In order to take account of this contribution, conclusive experimental campaigns or endorsed scientific publications must be used.

Article 46. Failure Limit State due to punching

46.6 Fibre-reinforced concrete slabs (this part does not correspond to any article in the Code)

Fibres can improve punching strength. An initial approach is to take account of their contribution by using a loadbearing stress in the critical surface equivalent to:

$$\tau_{fd} = 0{,}5\ f_{ctR,d} \quad (\text{N/mm}^2)$$

However, this value may be significantly higher, but this must be proven experimentally if it is to be used.

Article 47. Failure Limit State due to longitudinal shear stress in joints between concretes

47.3 Provisions in relation to reinforcements

It shall only be considered that the fibres contribute to the slip resistance in the case of joints which are strengthened transversely, where the dimensions of the keys are comparable to that of the fibre itself.

TITLE 7. EXECUTION

CHAPTER 13. EXECUTION

Article 69. Reinforcement production, reinforcing and assembly processes

69.5.1. Anchorage of passive reinforcements
69.5.1.1. General

Fibres improve the anchorage characteristics where these are used together with passive and active reinforcements. This factor may be taken into account in the calculations in this article provided that this is confirmed by experimental tests which prove that this is the case.

Article 71. Production and use of concrete

71.3 Production of concrete

71.3.2. Dosage of constituent materials

71.3.2.4. Water

The increase in the consistency due to the use of fibres must always be offset by the addition of water-reducing admixtures, without altering the specified water dosage.

71.3.2.6. Fibres (this part does not correspond to any article in the Code)

The effectiveness of the various types of fibre can vary a great deal. As a result, it is recommended that the concrete is designated by its properties and that the type and dosage of fibres are defined in the prior tests. Although a minimum fibre content is not specified, when steel fibres with a structural function are used, it is not recommended to use dosages less than 20 kg/m^3 of concrete.

The selection of the type and dosage of fibres will depend on their effectiveness and their influence on the consistency of the concrete. The maximum length will comply with the conditions stipulated in this Annex. The increase in slenderness of the fibres and the use of high dosages can increase their mechanical efficiency, but can also cause a reduction in the consistency and a greater risk of the formation of fibre balls which separate from the concrete ("hedgehogs").

The upper limit of the fibre content is set at 1,5% by volume of the concrete. The use of very high dosages requires the granular structure of the concrete to be significantly altered. For these cases, it is recommended that the specialised bibliography is consulted.

The provisions in the Chapter on materials in this Annex must be taken into account. The fibre dosage shall be determined by weight.

When fibres are used, the fibre dosage shall be determined by weight, using weighing machines and scales other than those used for aggregates. Where automatic dosing machines are used, these must be calibrated with the frequency determined by the manufacturer. The fibre weight tolerance shall be ±3 per 100.

71.2.4. Mixing equipment

The check that the mix produced by a fixed or mobile mixer is uniform must include the verification that the maximum difference tolerated between the fibre content results determined according to UNE 83512 -1 or UNE 83512 -2 from two samples taken from the concrete discharge (1/4 and 3/4 of the discharge) is less than 10%.

71.3.3. Mixing

Mixing is a critical phase in producing concrete with fibres due to the risk of tangling of the fibres, thus forming "hedgehogs". This risk can be reduced by good dosage with a sufficient content of fine aggregate, but is increased by excessively long transport and particularly when the fibre content is high and these are very slender. The filling order may also be decisive. As a general rule, fibres must be added together with the aggregates, preferably with the coarse aggregate at the start of the mix. It is not advisable to make the fibres the first component of the mix.

In the case of steel fibres, when the concrete is to be transported over a long distance, the addition of fibres on site may be proposed. As a result, a sufficiently fluid concrete must be provided to facilitate the travel of the fibres to the bottom of the drum and an on-site dosing system must be provided which guarantees the accuracy indicated in Article 71.2.3. The fibres must be poured in slowly (between 20 and 60 kg per minute) with the drum rotating at its maximum speed until the uniform distribution of the fibres in the mass of concrete is guaranteed.

71.3.4. Designation and characteristics

Concrete produced at a concrete-mixing plant may be designated by its properties or by its dosage. In both cases, for concrete with fibres, the following must at least be specified:

- Material forming the fibres, and their maximum length
- In the case of fibres with a structural function, the specified residual characteristic tensile strengths due to bending $f_{R,1,k}$ and $f_{R,3,k}$, in N/mm^2

- In the case of fibres without a structural function, the functions of the fibres or the characteristics of these guaranteeing their effectiveness for this purpose.

71.4.2. Supply of the concrete

The delivery note must contain the following data:

- Specification of the concrete: Designation in accordance with section 39.2.
- Material, type, dimensions (length, characteristics of the section and equivalent diameter, slenderness) and characteristics of the shapes (shaped at the ends, undulated, etc.) of the fibres.
- Fibre content in kilograms per cubic metre (kg/m^3) of concrete, with a tolerance of ±3%.

The list of the fibre characteristics may be replaced by a reference to their full commercial designation, supported by a data sheet previously accepted by the Technical Management and available in the site book.

71.5 Placing of concrete

71.5.1. Pouring and placing of concrete

Concrete must be poured and placed in such a way that no additional transport of the concrete on site is required. Interruptions in the concreting must be avoided as these could cause irregularities in the distribution of the fibres.

When the concrete is placed on site using a hopper, the diameter of the discharge outlet must be greater than 30 cm to facilitate pouring.

71.5.2. Compacting of concrete

Due to the fact that using fibres reduces the workability of concrete, greater compacting energy will be required. However, the response to vibration of concrete with fibres is better than that of a traditional concrete which is why, for the same slump in the Abrams cone, a shorter vibration time is required.

Compacting leads to a preferential orientation of the fibres. In general these tend to settle parallel to the surface resting against formwork, particularly if surface vibrators are used. This effect is only local but may be significant in thin elements.

The use of internal vibrators may generate zones with too much concrete and too few fibres in the zone where the vibrator has been placed, and also some orientation in the direction tangential to the external diameter of the vibrator.

TITLE 8. CONTROL

CHAPTER 16. CONFORMITY CONTROL OF PRODUCT

Article 85. Specific criteria for checking the conformity of the component materials of the concrete

85.6 Other concrete components (this part does not correspond to any article in the Code)

85.6.1 Specifications (this part does not correspond to any article in the Code)

Are those corresponding to Articles 29 and 30 and the ones that the Project Technical Specifications could include.

85.6.2 Tests (this part does not correspond to any article in the Code)

- Before to the start of the works the effect of fibers will be checked according to the tests referred in Article 86. Consequently, the trade marks, tipes and fibre doses being admissible. The continuity of the composition and the characteristics shall be guarantied by the corresponding Producer.
- Along the period of execution of the work it shall be controlled that the fibres used are those accepted as in the previous paragraph.
- The Work Management could require, if necessary, the checking of the properties exigible to the fibres.

85.6.3 Aceptation or rejection criteria

Failure of any of the specifications will be a sufficient condition to qualify the fibre as ones not suitable for the concretes.

Any possible modification of the commercial mark, the type or the dosage of the fibres that is going to be used, with regard to what has been accepted in the tests prior to the beginning of the work, will imply their non use until, after the accomplishment with these modifications of the tests foreseen in 81.4.2, Project Manager authorizes their acceptance and use in the work.

Article 86. Control of the concrete

The control of the quality of the concrete of fibres will include that of the type and contents of fibres, and in the event of fibres with structural function, that of their residual strength according to the method that establishes the Project Technical Specifications, besides the control specified in the articles in this Code.

86.1. General criteria for the conformity control of the concrete

Where the fibres had a structural function, in adition to the tests specified in the articles,the flexural test of three speciments for each batch used for control, according to UNE-EN 14651, had to be done in order to determine the values of the residual strength $f_{R,1,m}$ *y* $f_{R,3,m}$ at 28 days of age. The fibre content, according to UNE 83512-1 o UNE 83512-2 , shall be obtained In every batch.

When according to specifications in 30.3, other types of alternative tests are selected for the control of the residual flexural strength of the concrete; these will have to be contrasted by a concluding experimental campaign. The Project Manager will determine previously the values of reference to obtain during the tests and the criteria of acceptance and rejection.

According to has been indicated in the part of materials of this Annex, Project Manager will be able to value, under his responsibility, the use of other procedures that facilitate the control, as it can be the case of the Barcelona test of double punching, carried out on cilinder speciment of 15 x 15 cm.

86.3. Testing

In the case of concretes of fibres with consistency less below 9 cm of seat in the Abrams cone it is recommended to use other methods as the Consistometer Vb in agreement with EN 12350-3 or the inverted cone according to UNE 83503.

86.3.2. Tests on the strength of the concrete

Before the beginning of the concreting the accomplishment of previous tests or characteristic tests, which are respectively described in the Articles 86 and 87, is necessary.

When there is experience, well documented and sufficient, so much in materials, included the type and trademark of the planned fibres, as in dosage and instalations (for example the concrete mixing plants), only the test for control would be neccesary.

86.5.5. Control of the strength of the concrete at 100%

The criteria of definition of lots will coincide with what has been specified in the articles.

The control of the residual flexural strength to flexotracción as UNE-EN 14651 will be carried out on 2 batches by lot. In these batches the control of the contents in fibres will be done as UNE 83512-1 or UNE 83512-2.

When the result of the control of contents in fibres in one batche of the lot was inferior by 10% to the stipulated value, the control of residual flexural strength shall be extended to all the batches on which samples are taken for determining the compressive resistance of the concrete.

The analysis of results and the estimators to use to obtain the corresponding characteristic values from the results of the tests will be the same that the ones included in the Articles for the resistance to compression.

86.5.6. Indirect control of the strength of the concrete

This tipe control does not apply to the concretes with fibres with structural function.

86.7. Decisions arising from the control

When in a lot of a work with strength control implemented, it happens $f_{R,j,est} \geq f_{R,j,k}$ such lot shall be accepted.

If were $f_{R,j,est} < f_{R,j,k}$,, for lack of an explicit forecast of the case in the Project Technical Specificationss of the work and without prejudice of the planned contractual sanctions (to see 4.4), it will be proceeded as it follows:

- If Si $f_{R,j,est} \geq 0{,}9\, f_{R,j,k}$,, the lot will be accepted.
- If $f_{R,j,est} < 0{,}9\, f_{R,j,k}$,, it will be proceeded to carry out, for decision of the Project Management or at the request of any of the parts, the studies or pertinent complementary tests.

If it would be detected some variation in the aspect, dimensions or shape of the fibres, the preliminary tests would be performed again.

86.8. Tests on additional information for the concrete

The extraction of core samples, carried out in accordance with Article 101, leads to cylindrical speciments on those that can not be applied the tests of reference for the determination of the mechanical flexural characteristics of the concrete of fibres. Since this verification will not be able to be carried out, it can be replaced by other tests that allow estimating the resilience of the concrete as, for example, the Barcelona test of double punching.

CHAPTER 17 CONTROL OF THE CONSTRUCTION

Article 92. General criteria for the control of the construction

In the table 92.5, the following construction units, specific of fibre concretes, shall be included:

- Type of fibres used alter the control of fibres contents
- Storage conditions for fibres
- Procedure to add fibres to the concrete mix

The maximum sizes of these inspection units shall be defined in the corresponding project, depending on the characteristics of the work.

A 22. Preliminary and characteristic tests of concrete

A22.1 Preliminary tests

In concretes with fibres the preliminary tests take special importance for the definition of the fibres to use and their dosage. When the fibres had structural function the preliminary tests will include the preparation of at least four series of of speciments proceeding from different batches, of six speciments each for test at the 28 days of age, by every dosage that it is wanted to establish, and will be operated in agreement with UNE-EN 14651 to determine the average values of the residual flexure strength:

$$f_{R,1,m} \ y \ f_{R,3,m}.$$

In order to define the values of resistance to be obtained in the preliminary tests, when the coefficient of variation of this test is unknown, only as an informative reference, it can be taken as:

$$f_{R,j,k} = 0{,}7 \ f_{R,j,m}$$

A22. 2 Characteristic tests for strength

When the fibres have structural function the tests will include, besides the ones specified in the Articles, the test of three speciments per batch in agreement with UNE-EN 14651 to determine the values of the residual flexural strength $f_{R,1,m}$ *y* $f_{R,3,m}$, at the 28 days of age. In every batch of this type will be determined also the contents in fibres UNE 83512-1 or UNE 83512-2.

The analysis of results and the estimators to use to obtain the corresponding characteristic values from the results of the tests will be the same ones referred in the Articles for the resistance to compression.