Use of fibers in construction elements

The following writ describes the use of fibers as reinforcement in load-bearing concrete structures, in accordance with standards and authorities. The calculations, developed by the undersigned, Daniel Fester Henningsen, Civil Engineer and Technical Specialist at PPCD ApS, are based on constitutive laws, and known engineering methods, and thus lean on *Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings, EN 1992-1-1, European Committee for Standardization* (hereinafter referred to as *EN2*).

Background
One of the primary references used for practical calculations of e.g. the torque capacity and the shearing capacity of a given concrete construction with fibers as reinforcement is *Concrete Industrial Ground Floors - A Guide to Design and Construction, Technical Report No. 34, Concrete Society, 4th Edition* (Hereinafter referred to as *TR34*). These calculations are based on recognized, tension strain assumptions ie. constitutive laws of the cross section in question, where the neutral axis is found based on assumptions about the pressure and tensile zone. This method is analogous to the method of *EN2* for conventional reinforcement.

The above-mentioned stress-strain curves have been found using the standardized three-point beam test, cf. *EN 14651 Test method for metallic fibre concrete*. Measuring the flexural tensile strength (hereinafter referred to as *EN14651*). Although *EN14651* concerns metallic fibers, the method for obtaining the so-called *flexural tensile strength* values is approved as long as the fibers are approved according to *EN 14889-2:2006 Fibres for concrete, Part 2: Polymer fibres. Definitions, specifications and conformity* (Hereinafter referred to as *EN14889*). The fibers used in practice, with dosages based on the calculations, have specifically been tested according to *EN14651* and CE-marked according to *EN14889*.

Standard
EN2 does not define reinforcement as only conventional reinforcement, and therefore does not exclude fibers as reinforcement. Thus, reinforcement is just a generic material that imbues concrete structures with tensile and flexural bearing capacity, as well as other additional features such as reduction of shrinkage cracks, shear capacity, etc.

The existing *EN2* describes general rules, such as the stress strain relationship from which the stress distribution in a given cross section can be derived, and e.g. the moment capacity found. This must be done on the basis that the material parameters are justified, such as by standardized tests. This procedure is precisely the one used in the calculations for the fiber reinforced concrete.

For inclusion of non-linear calculation and plasticity theory calculation, see *Chapter 5.7: Non-linear analysis* in *EN2* (see quotation below), which states that if appropriate non-linear material models are used, these can be used in calculations in both ULS and SLS (Ultimate Limit State and Serviceabilty Limit State). The non-linear material models are provided on the basis of previously mentioned *EN14651*, which is why the calculations further accommodate *EN2*.

Chapter 5.7 non-linear analysis: *(1) Non-linear methods of analysis may be used for both ULS and SLS, provided that equilibrium and compatibility are satisfied and an adequate non-linear behaviour for materials is assumed. The analysis may be first or second order.*

It is thus concluded that the calculations used for fiber reinforced concrete are included in *EN2*, although fiber reinforced concrete is not directly mentioned by name in EN2, since all methods and material parameters obtained are based on standards.

Building regulations 2018

The building regulations 2018 (hereinafter referred to as *BR18*) mention in § 344(2), that design must be done in accordance with i.a. *Eurocode 0: Basic of structural design, EN 1990, European Committee for Standardization* (hereinafter referred to as *EN0*), and *Eurocode 1: Actions on structures, EN 1991, European Committee for Standardization* (hereinafter referred to as *EN1*), parts 1-1 to 1-7 . § 345 states that, especially for concrete structures, the design planning must take place in accordance with, inter alia, *EN2*. As is concluded above, the calculations for fiber reinforcement justify these requirements.

In addition to the fact that fiber reinforced concrete is not mentioned directly by name in *EN2*, *BR18* does also mention in § 356 that "*§ 344(2) to § 351 and §§ 353-355 may be derogated from if it can be ensured and documented by other means that derogation is safe, and if a safety level as described in § 344(2)(1) can be achieved.*" This documentation is available, with partial coefficients on the loads according to *EN0*, as well as partial coefficients on the materials according to *EN1*, and common calculation methods (constitutive laws), which are also evident from *EN2*.

Applications

At a meeting between NCC A/S, COWI A/S, and PPCD ApS regarding potential applications for fiber reinforced concrete - either fiber reinforcement alone, or in composite with conventional reinforcement - a table was drawn up that lists the structural elements where fiber reinforcement is an option. There was absolute consensus on the table, without further debate. The table can be found as the document *Application areas with fiber reinforced concrete*, or viewed at the end of this document. In construction elements with the possibility of plastic redistribution of the loads, there was in particular no doubt about the possibility of using fibers as reinforcement. These structural elements included foundations, ground slabs, strip foundations and point foundations. There was a more in-depth debate on walls, beams, and columns, where the lack of opportunity for plastic redistribution of the loads is a bigger issue. Thus, in these structural elements, conventional reinforcement in composite with fiber reinforcement should be used.

Responsibility
Finally, please note that the responsibility for all calculations lies with the adviser, as it is their documentation that, cf. previously mentioned § 356 in *BR18*, must be approved by the relevant authorities. This responsibility is described in *BR18(1)*, here especially sections 16-19. I.e. the responsibility, if the concrete recipe and the workmanship have been carried out as directed, is incumbent on the person carrying out the documentation.

Kind regards,

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Table overview

Application areas for fiber reinforced concrete

The below table indicates in which concrete construction elements, fiber reinforced concrete can be used.

Construction element	Fiber reinforcement only	Composite of fiber reinforcement and conventional reinforcement	Fiber reinforcement not possible (Only conventional reinforcement)
Point foundation	✓		
Strip foundation	✓		
Bottom plate		✓	
Ground slab	✓	✓	
Top plate	✓	✓	
Screed	✓		
Walls	✓	✓	
Columns			✓
Beams/Lintels		✓	
Plates/Decks		✓	

Application areas with a tick in both *Fiber reinforcement alone* and *Composite of fiber reinforcement and conventional reinforcement* columns, indicates that it depends on the situation and for what purpose the fiber reinforcement is used.

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Note: The above table is indicative only for which concrete constructions, fiber reinforcement can be used. Reinforcement and dimensioning of any construction should always be evaluated by a consultant, and the undersigned does not assume any responsibility for any constructions, in which they are not involved in a consulting capacity.