Embedded FRP reinforcement

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EUROCODES

EN 1992

Design of concrete structures

2nd generation of Eurocode 2 on concrete structures

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Contents

1. Objectives
2. Introduction
3. Basis of design and materials
4. Structural analysis – Durability
5. Ultimate Limit States
6. Serviceability Limit States
7. Detailing of FRP reinforcement
8. Conclusions

1. OBJECTIVES

SUMMARY OF MAIN ASPECTS INTRODUCED IN (INFORMATIVE) ANNEX R OF EC2

- Includes a brief summary of the contens of the paper:
  - E. Oller, L. Torres, A. De Diego. Embedded Fibre Reinforced Polymer (FRP) Reinforcement in Concrete Structures According to the New Version of Eurocode 2. Hormigón y Acero 2023; 74 (299-300): 199-210. https://doi.org/10.33586/hya.2022.3098
  - All references supporting the contents can be found in the indicated paper.

2. INTRODUCTION

FIBRE REINFORCED POLYMER (FRP)

- Formed by a polymeric **matrix** (resin) reinforced with continuous **fibres**
- **Fibres** mostly provide the mech. props.: Glass (G), Carbon (C) Aramid (A), Basalt (B).
- **Matrix** acts as a binder, transfers shear stresses, provides integrity and protection: Vinylester, Polyester, Epoxi, ...

=

GFRP
AFRP
CFRP
BFRP

- **Surface treatment** for bond: sand coating, indentations, undulations, etc.

2. INTRODUCTION

APPLICATIONS

- Some examples in which FRP may be an alternative

Corrosion in **aggressive environments**:

- Marine environments, Salts, Bridge decks
- Industrial facilities
- Sewage treatment, …

2. INTRODUCTION

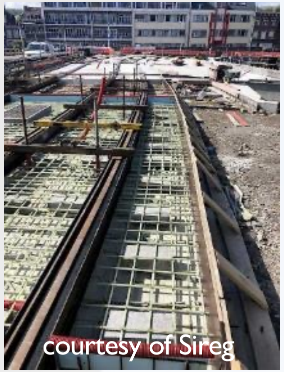
APPLICATIONS

Soft eyes

Panels

Medical/Research facilities

Electrical facilities



Tramway

Cutability: Temporary appl.

Thermal isolation

Electromagnetic fields

2. INTRODUCTION

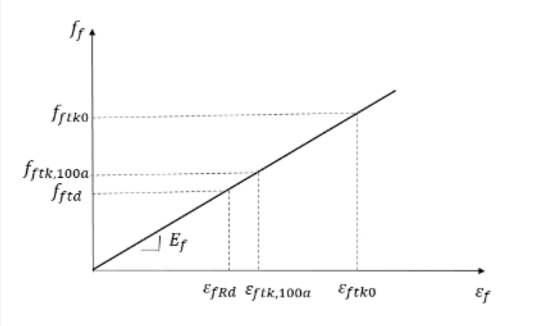
SOME CODES, GUIDELINES

- ACI 440.11-22 - GFRP **(USA)**
- CAN/CSA S806-12 R17 – Buildings **(CAN)**
- CAN/CSA S6:19 (CAN) – Highway bridges **(CAN)**
- CNR DT 203-2006 **(IT)**
- AFGC 2021 **(FR)**
- JSCE 1997 **(JP)**
- BRI-Building Research Institute 1997 **(JP)**
- fib Bulletin 40 2007
- fib MC 2010, fib MC 2020 (in progress)

- **New EC 2** (Informative Annex R): covers bars or mesh of **GFRP and CFRP**; does not cover prestressing

3. BASIS OF DESIGN AND MATERIALS

- **Linear elastic** behaviour up to failure



Design situation	γ_{FRP}
ULS (Persistent and transient)	1,50
Accidental	1,10
Serviceability	1,00

Based on reliability index β = 3.8, $ff_{tk,100a}$ and f_{ftk0}.
Reduction can be applied if supplier can prove required reliability [20].

- Mechanical props. depend on **fibre/volume fraction**
- **Modulus of elasticity lower** than that of steel ($E_{fR} \geq 40000$ MPa)
- **Strenght** can vary with the diameter (↓ if Ø↑)
- Design should be based on the **nominal cross sectional area**

3. BASIS OF DESIGN AND MATERIALS

- **FRP** materials experience creep rupture under sustained loading (reduction in f_{ftk0})
- The **design tensile strength** is defined from the **long-term strenght**: $f_{ftd} = \frac{f_{ftk,100a}}{\gamma_{FRP}}$
- **When not provided** by the supplier, a formula based on conservative coefficients is proposed:

$$f_{ftk,100a} = C_t \cdot C_c \cdot C_e \cdot f_{ftk0}$$

C_t: Temperature effects (1,0 indoor; 0,8 outdoor)

C_c: Sustained vs. short-term load (0,35 GFRP; 0,8 CFRP)

C_e: Ageing effects (0,70)

See procedures in Background Document of EC2 [20]

It is seen that a **conservative value** might be obtained for f_{ftd}:

$$f_{ftd} = \frac{f_{ftk,100a}}{\gamma_{FRP}} = \frac{C_t \cdot C_c \cdot C_e \cdot f_{ftk0}}{\gamma_{FRP}} = \frac{0{,}8 \cdot 0{,}35 \cdot 0{,}7}{1{,}5} f_{ftk0} = 0{,}13 \cdot f_{ftk0}$$

4. STRUCTURAL ANALYSIS – DURABILITY (CONCRETE COVER)

STRUCTURAL ANALYSIS:

- Linear analysis with **redistribution and plastic analysis** are **not allowed**.
- Design by **strut and tie** models and **stress fields is not covered**.

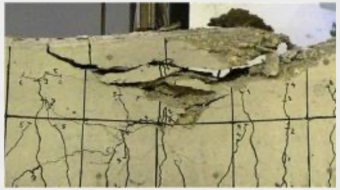
CONCRETE COVER:

- The same phylosophie as for steel RC: $\boldsymbol{c_{nom}} = \boldsymbol{c_{min}} + \Delta \boldsymbol{c_{dev}}$; $c_{min} = max\{c_{min,dur} + \sum \Delta c; c_{min,b}; 10\ mm\}$
- For FRP, $\boldsymbol{c_{min,dur}} = \mathbf{0}$
- In absence of more accurate information $c_{min,b} \geq 2\varnothing$, but at least $c_{min,b} \geq 1{,}5\phi$ and $c_{min,b} \geq 10$ mm.

5. ULTIMATE LIMIT STATES

BENDING

- **Usual assumptions** for calculation (equilibium, compatibility, material properties)
- **Concrete crushing** and **FRP tensile failure** are allowed



- **Main differences**: absence of yielding, large variety of products/properties
- **Compression reinforcement is not considered** for the resistance (high scatter in results, lack of reliability)

5. ULTIMATE LIMIT STATES

SHEAR

- Based on the **same formulation as in the main text (CSCT)**, introducing some modifications
- **Members w/o shear reinforcement:** factor E_{fR}/E_s is introduced in eqs. for the shear stress resistance to consider the effect of **lower stiffness** of longitudinal reinforcement

$$\tau_{Rdc,min} = \frac{11}{\gamma_v}\sqrt{\frac{f_{ck}}{f_{ftk0}} \cdot \frac{E_{fR}}{E_s} \cdot \frac{d_{dg}}{d}}$$

$$\tau_{Rd,c} = \frac{0,66}{\gamma_V} \cdot \left(100 \cdot \rho_{lf} \cdot \frac{E_{fR}}{E_s} \cdot f_{ck} \cdot \frac{d_{dg}}{d}\right)^{\frac{1}{3}} \geq \tau_{Rdc,min}$$

- **Members requiring shear reinforcement** an additive equation includes concrete contribution

$$\tau_{Rd,f} = \tau_{Rd,c} + \rho_w \cdot f_{fwRd} \cdot cot\theta \leq 0,17 \cdot f_{cd}$$

$$f_{fwRd} = f_{fwk,100a}/\gamma_{FRP} \leq \varepsilon_{fwRd} \cdot E_{fwR}$$
$$\varepsilon_{fwRd} = 0,0023 + 1/15 \cdot E_{fR} \cdot A_{fl} \cdot (0,8 \cdot d)^2 \cdot 10^{-15} \leq 0,007$$
$$cot\theta = 0,8$$

Use of additive approach leads to $\cot\theta = 0.8$ chosen for ease of use on the side of safety; FRP strain limited to avoid shear compression failure; capacity of struts modified with $\nu = 0.35$ due to larger deformations [20].

6. SERVICEABILITY LIMIT STATES

STRESS LIMITATION AND CRACK CONTROL

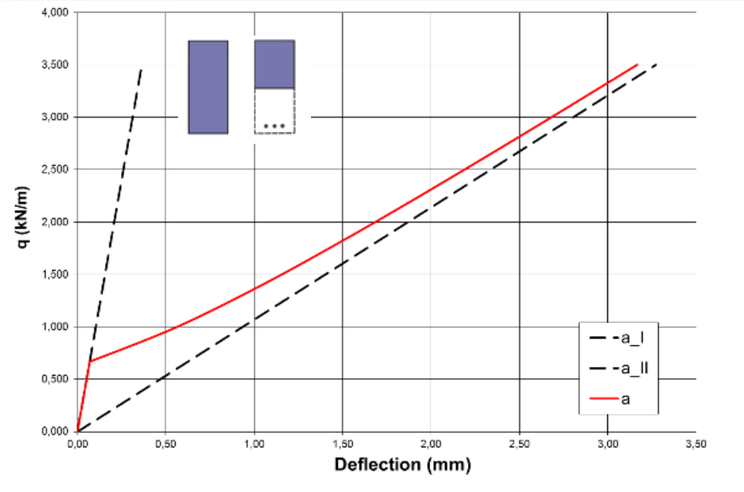
- The **general equations** in the main text **apply (9.2.2, 9.2.3.)**, provided that **FRP properties** are used.
- **Similar bond as steel** reinforcement is assumed.
- Simplified procedures in Annex S do not apply.

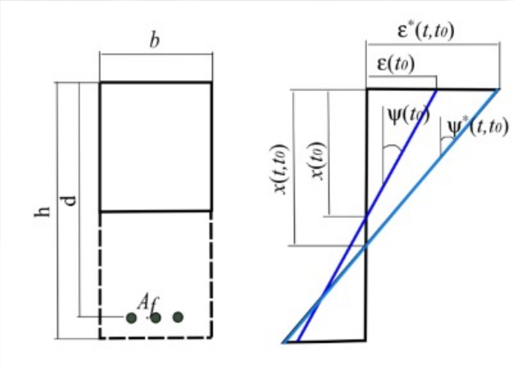
- Annex R includes **specific tables** for stress and crack widht **limits** for FRP reinforcement, in which
  - Crack widhts are limited for **appearance to $w_{lim,cal}$ = 0.4 mm** (implies no need for durability reasons)
  - In **absence of appearance** and other specific conditions this limit **may be relaxed to 0.7 mm.**

6. SERVICEABILITY LIMIT STATES

DEFLECTIONS

- **General equations** in 9.3.4 apply, both for short and long-term.
- **Limits of *L/d*** in 9.3.2 and **simplified approach** in 9.3.3 **do not apply** (calibrated for steel RC).





$$\alpha_\delta = (1-\zeta)\alpha_{\mathrm{I}} + \zeta\alpha_{\mathrm{II}}$$

$$\zeta = 1 - \beta_{\mathrm{t}}\left(\frac{\sigma_{\mathrm{sr}}}{\sigma_{\mathrm{s}}}\right)^2 \geq 0$$

$$E_{\mathrm{c,eff}} = \frac{1{,}05 \cdot E_{\mathrm{cm}}}{1+\varphi(t,t_0)}$$

$$\left(\frac{1}{r}\right)_{\varepsilon_{\mathrm{cs}}} = \frac{E_{\mathrm{s}}}{E_{\mathrm{c,eff}}}\varepsilon_{\mathrm{cs}}\frac{S_{\mathrm{s}}}{I_{\mathrm{g}}}$$

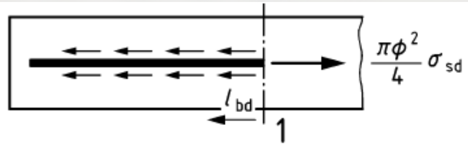
7. DETAILING OF FRP REINFORCEMENT

GENERAL ASPECTS

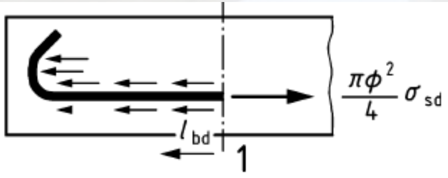
- In general, the **main text can be applied except for specific rules** given in Annex R.
- **Bending or rebending on site is usually not possible** (for thermosetting bars). Thermosetting bars must be manufactured with final requited configurations. Lap splices are allowed.

ANCHORAGE

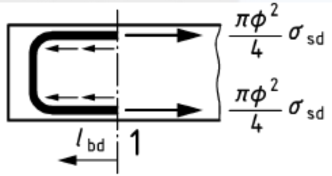
- Only **methods in Fig. 11.2 a), b), c)** of the main text may be used for FRP reinforcement



a) Anchorage of straight bars 11.4.2



b) Anchorage of bends and hooks 11.4.4



c) U-bar loops 11.4.6

7. DETAILING OF FRP REINFORCEMENT

ANCHORAGE

- The anchorage lenght is given by the eq. in the main text with **some modifications related to η_σ, c_d and minimum values**

$$l_{bd} = k_{lb} \cdot k_{cp} \cdot \phi \cdot \left(\frac{\sigma_{ftd}}{217}\right)^{\eta_\sigma} \cdot \left(\frac{25}{f_{ck}}\right)^{\frac{1}{2}} \cdot \left(\frac{\phi}{20}\right)^{\frac{1}{3}} \cdot \left(\frac{1{,}5 \cdot \phi}{c_d}\right)^{\frac{1}{2}} \geq \begin{cases} 10 \cdot \phi \\ \frac{\phi}{4} \cdot \frac{\sigma_{ftd}}{f_{bd,100a}} \end{cases}$$

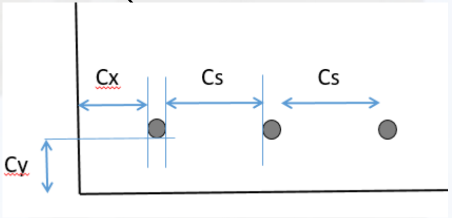
$\eta_\sigma = 1.0$ for $\sigma_{ftd} \leq 217$; 1.5 for $\sigma_{ftd} \geq 217$

$f_{bd,100a} = 1.5$ MPa, unless more accurate information on the product

k_{cp} = casting effects (main text)

k_{lb} = persistent o transient design situation (main text)

$c_d = \min\,\{0.5c_s;\ c_x;\ c_y\}$



MEMBERS AND PARTICULAR RULES

- Annex R gives some **specific rules for beams, slabs, walls or deep beams**. No specific rules are provided for columns and foundations.

8. CONCLUSIONS

- **FRP embedded reinforcement** has been incorporated for the **first time** in **EC2** in the informative Annex R.

- FRP reinforcement has been **already applied in many projects**, where profit can be taken from its behaviour in front of corrosion, electromagnetic fields or cuttability.

- **Main differences** in design between FRP and steel reinforcement arise from the **linear elastic** behaviour up to failure, **lower modulus** of elasticity and the **long-term strength** of FRP under sustained stresses.

- Due to the lower modulus of elasticity, **SLS often govern the design**.

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Thank you for your attention

Lluís Torres