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Current Guidelines

- **Japanese guidelines: JSCE - 1997**
  “Recommendation for Design and Construction of Concrete Structures using Continuous Fiber Reinforcing Materials”;

- **European document: fib TASK GROUP 9.3 - 1999**
  “FRP Reinforcement for RC Structures”;

- **Canadian guidelines for bridges: CAN/CSA-S6_00 - 2000**
  “Canadian Highway Bridge Design Code”;

- **Canadian guidelines for buildings: CAN/CSA-S806_02 - 2002**
  “Design and Construction of Building Components with Fibre-reinforced Polymers”;

- **American guidelines: ACI 440.1R-06 - 2006**
  “Guide for the Design and Construction of Concrete Reinforced with FRP Bars”.

NEW : ITALIAN GUIDELINES CNR-DT 203/06 - 2006

http://www.cnr.it/sitocnr/IICNR/Attivita/NormazioneeCertificazione/DT203_2006.html

1) Materials
2) Basis of Design
3) Appendix A (manufacturing techniques of FRP bars and grids)
4) Appendix B (test methods for characterising FRP bars)
5) Appendix C (technical data sheet for FRP bars)
6) Appendix D (tasks and responsibilities of professionals)
7) Appendix E (calculating deflections and crack widths for concrete flexural members reinforced with FRP bars)

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CNR-DT 203/2006
CNR-DT 203/2006

Materials

Materials used: bars and grids, made of thermosetting resins and glass, carbon or aramid fibers

Issue faced:
Performing test methods to characterize large dimensions FRP bars

- No risks during test due to screening provided by RC column against dust and micro-fibers scatterings

2) Basis of Design

**Flexure : Ultimate Limit State**

Possible flexural modes of failure:

1. Maximum concrete compressive strain reached, \( \varepsilon_{cu} = 0.0035 \)
2. Maximum FRP tensile strain reached (linear elastic behavior up to failure),

\[
\varepsilon_{fd} = 0.9\eta_a \cdot \frac{\varepsilon_{fk}}{\gamma_f}
\]

- \( \varepsilon_{fd} \) – design tensile strain of FRP bars
- \( \eta_a \) – environmental conversion factor
- \( \varepsilon_{fk} \) – characteristic tensile strain of FRP bars
- \( \gamma_f \) – safety factor for FRP bars, set equal to 1.5

**NEXT STEP : RELIABILITY ASSESSMENT** of \( \gamma_f \)

2) Basis of Design

**Flexure : Service Limit State (SLS)**

Stress limitation

Deflection control

Cracking control

\[ \text{E}_f \lt \text{E}_s \quad \Rightarrow \quad \text{Serviceability issues} \]

2. **Deflection control** :

\[ f = f_1 \beta_1 \beta_2 \left( \frac{M_{cr}}{M_{\text{max}}} \right)^m + f_2 \left[ 1 - \beta_1 \beta_2 \left( \frac{M_{cr}}{M_{\text{max}}} \right)^m \right] \]

\( m \) : factor accounting for bond properties of FRP bars, set equal to 2 unless different values are provided by manufacturers through specific tests prescribed.
2) Basis of Design

*Flexure : SLS*

3. **Cracking control** :

Characteristic crack width (EC2 Model):

\[ w_k = \beta s_{rm} \varepsilon_{fm} \]

- \( s_{rm} \) - Average distance between cracks:
  \[ s_{rm} = 0.50 + 0.25k_1k_2 \frac{d_b}{\rho_r} \]

- \( \varepsilon_{fm} \) - Average strain:
  \[ \varepsilon_{fm} = \frac{\sigma_f}{E_f} \left[ 1 - \beta_1 \beta_2 \left( \frac{\sigma_{fr}}{\sigma_f} \right)^m \right] \]

\( m \) : bond factor

**NEXT STEP : ASSESS the RELIABILITY LEVEL of SLS PROVISIONS USING FACTOR \( m \)**

*The new Italian Code for Composites in Constructions : the CNR-DT 203/2006*
2) Basis of Design

**Shear: ULS**

✓ Members without shear reinforcement:

\[
V_{Rd} = \min \{ V_{Rd,ct}, V_{Rd,max} \}
\]

Concrete contribution to the shear capacity:

\[
V_{Rd,ct} = 1.3 \left( \frac{E_t}{E_s} \right)^{1/2} \cdot \tau_{Rd} \cdot k \cdot (1.2+40\rho_1) \cdot b \cdot d
\]

- \( \tau_{Rd} \) - Design shear stress
- \( k \) - Coeff. ranging between 1.0 and 1.6
- \( \rho_1 \) - Longitudinal reinforcement ratio
- \( b \) \& \( d \) - Section width and effective depth

EC2-like formula obtained through calibration based on experimental data available
2) Basis of Design

**Shear: Calibration of** $V_{Rd,ct}$

**Basic formula for steel (EC2):**

$$V_{Rd,ct}^{steel} = \tau_{Rd} \cdot k \cdot (1.2 + 40\rho) \cdot b \cdot d$$

**After calibration:**

$$V_{Rd,ct}^{FRP} = 1.3 \left( \frac{E_f}{E_s} \right)^{1/2} \cdot V_{Rd,ct}^{steel}$$

**Comparison of DT 203/06 formulation with Canadian and American formulations:**

- 79 specimens tested used for comparison
- Trend line of DT 203 eq. very similar to that of Canadian eq.
- DT 203 eq. gives the least mean value of $V_{exp}/V_{pred}$ (1.33) and cov (26 %)
- When considering reduction factors, all $V_{exp}/V_{pred}$ values were greater than 1.

**The new Italian Code for Composites in Constructions: the CNR-DT 203/2006**
Typical Applications of FRP bars

Bridge decks: (excellent resistance to corrosion)

Floodway Bridge – Winnipeg Manitoba

Photo Courtesy of Hughes Bros, USA

Tunnel boring applications: (easy to cut)

Hospital rooms: (magnetic transparency)

Lincoln Hospital, NE (USA)