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WP6 - Thought for Eurocodes Upgrade

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New Eurocode on structures that incorporate FRP:
Flexural resistance of FRP reinforced concrete slabs and beams in fire

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FRP-RC structures in fire: theoretical models for EUROCODE

Mechanical properties of fiber reinforced polymer (FRP) significantly **deteriorate** when high temperatures arise

Softening of the resin:
- Loss of adhesion at interface FRP-concrete
- Reduction of strength in the FRP bars
- General decrease of performance of FRP-RC members

Italian Research project (PRIN)
EFFECTS OF HIGH TEMPERATURES ON THE PERFORMANCES OF CONCRETE SLABS REINFORCED WITH FRP BARS OR GRIDS

Experimental data on behavior at high temperatures of **FRP bars**

Full-scale tests on **FRP RC SLABS**

Papers on Journal

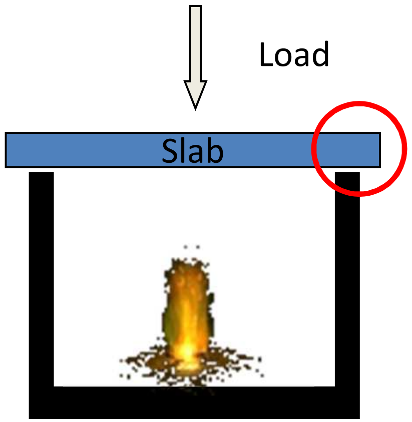
- E. Nigro, G. Cefarelli, A. Bilotta, G. Manfredi, E. Cosenza (2011). Fire resistance of concrete slabs reinforced with FRP bars. Part I: experimental investigations on the mechanical behavior. **COMPOSITES. PART B, ENGINEERING**, vol. 42, p. 1739-1750
- E. Nigro, G. Cefarelli, A. Bilotta, G. Manfredi, E. Cosenza (2011). Fire resistance of concrete slabs reinforced with FRP bars. Part II: experimental results and numerical simulations on the thermal field. **COMPOSITES. PART B, ENGINEERING**, vol. 42, p. 1751-1763,
- Nigro E., Cefarelli G., Bilotta A., Manfredi G., Cosenza E. (2012). Performance under fire situations of concrete members reinforced with FRP rods: bond models and design nomograms. **JOURNAL OF COMPOSITES FOR CONSTRUCTION**, vol. 16, p. 395-406,
- Nigro E., Cefarelli G., Bilotta A., Manfredi G., Cosenza E. (2012). Behaviour of FRP Reinforced Concrete Slabs in Case of Fire: Theoretical Models and Experimental Test. **ADVANCES IN STRUCTURAL ENGINEERING**, vol. 15, p. 637-652
- *Nigro E, Cefarelli G, Bilotta A, Manfredi G, Cosenza E (2013). Adhesion At High Temperature Of FRP Bars Straight Or Bent At The End Of Concrete Slabs.* ***JOURNAL OF STRUCTURAL FIRE ENGINEERING***
- *E. Nigro, G. Cefarelli, A. Bilotta, G. Manfredi, E. Cosenza (2014)* ***Guidelines*** *for flexural resistance of FRP reinforced concrete slabs and beams in fire* **COMPOSITES. PART B, ENGINEERING** – vol. 58 p. 103-112

Contribution to Eurocode to suggest:
- **DESIGN RELATIONSHIPS**
- **STRUCTURAL DETAILS**

WG4 - European Committee CEN 250
- Preparation of a Technical Report
- Conversion of the Technical Report into CEN TS on FRP
- Define a draft of Eurocode for FRPs in Structures

FIRE

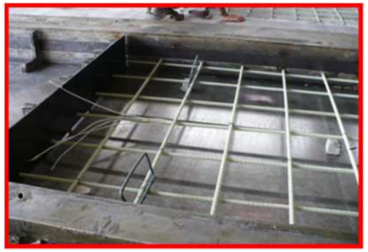
Experimental tests



Parameters

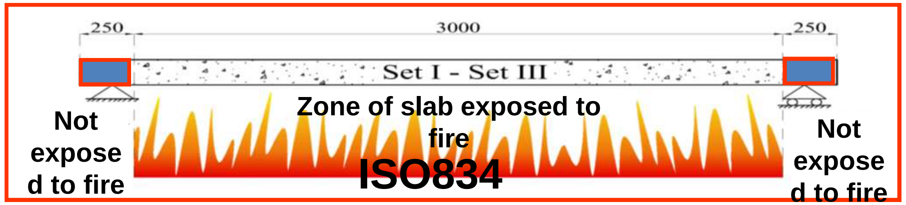
- ➢Concrete cover
- ➢Fire load level $\eta_{fi} = M_{Ed,fi}/M_{Rd}$ (40-60%)
- ➢Length of zone outside the furnace
- ➢Bars type (straight or bent)

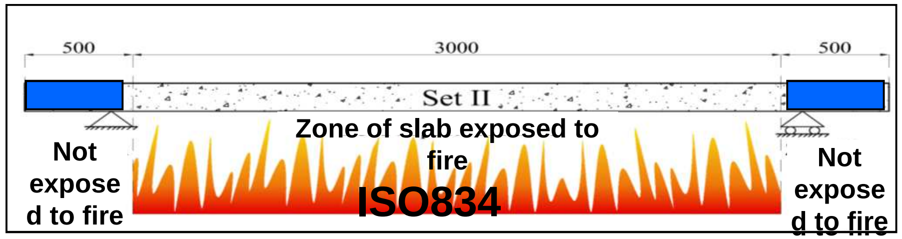
straight bars

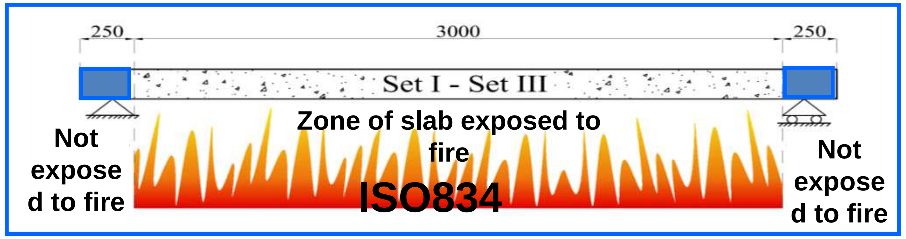


bent bars

Set	Slab	Concrete cover [mm]	Anchorage length [mm]	Fire endurance STAGE 1 η_{fi} [%]	Fire endurance STAGE 1 T_e [min]	Fire endurance STAGE 2 η_{fail} [%]	Failure mode
	S1			10	>180	55	Pull out
I	S2	32	250 straight bars	40	120	50	Pull out
	S3			60	60	-	Pull out
	S4			10	>180	100	Rupture
II	S5	51	500 straight bars	40	>180	85	Rupture
	S6			60	>180	100	Rupture
	S7			10	>180	60	Rupture
III	S8	32	250 bent bars	40	>180	45	Rupture
	S9			60	>180	90	Rupture





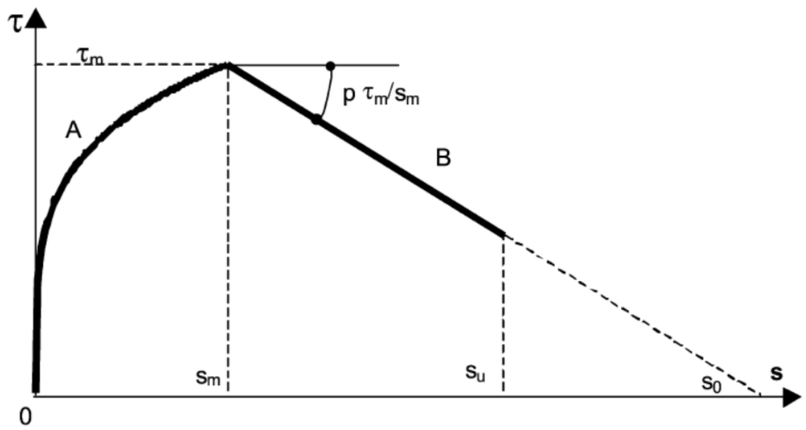


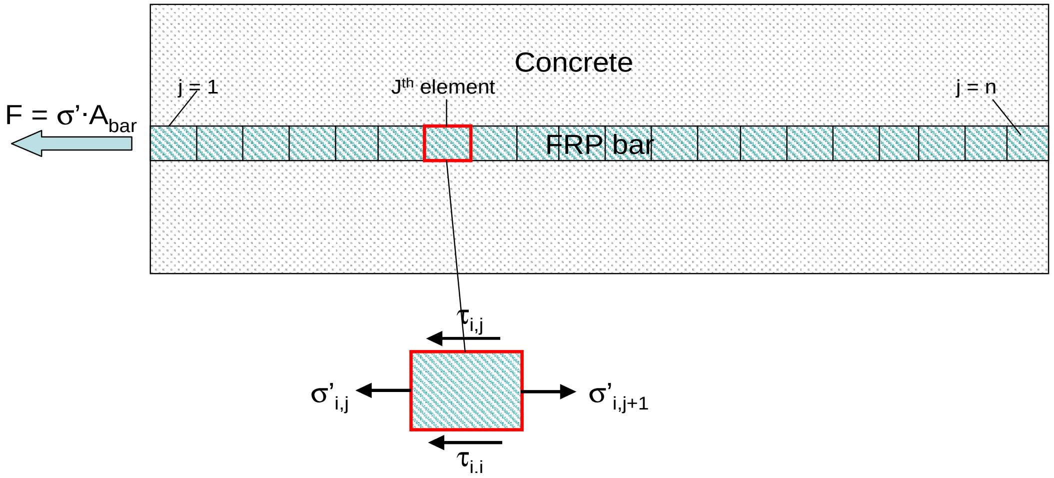
Main experimental results

- ✓ ***When the bars temperature achieves the glass transition value, there is a significant reduction of bond between FRP bars and concrete.***
- ✓ ***The mechanical behaviour of tested slabs has been characterized by the migration of bars stresses from the zone directly exposed to fire to the anchorage zone (i.e. the zone not directly exposed to fire action).***
- ✓ ***When the glass transition temperature is achieved in the zone directly exposed to fire, the structural behaviour depends mainly on the length of unexposed zone (anchorage length) and on the bars type (straight or bent).***

Bond models

Elingehausen et al. (1983)
modified by **Cosenza et al. (2002)**
bond law





ascending branch $s \le s_m$

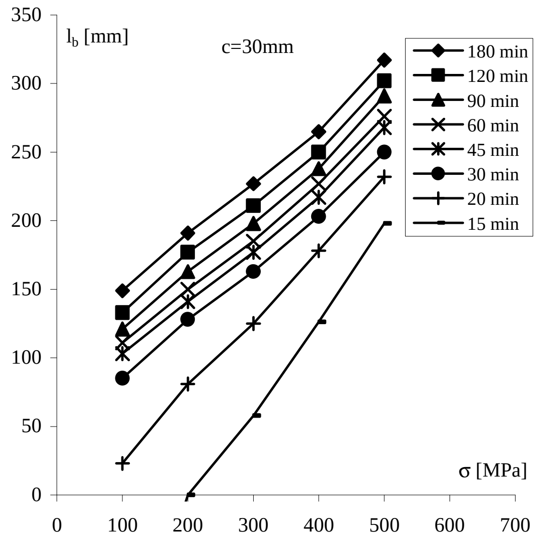
$$\tau_b(s) = \tau_m \cdot \left(\frac{s}{s_m}\right)^{\alpha}$$

softening branch $s > s_m$

$$\tau_b(s) = \tau_m \cdot \left(1 + p - p\frac{s}{s_m}\right)$$

$$\frac{d^2 s(z)}{dz^2} - \frac{4}{E(T(z))\phi}\tau^*\left(s(z), T(z)\right) = 0$$

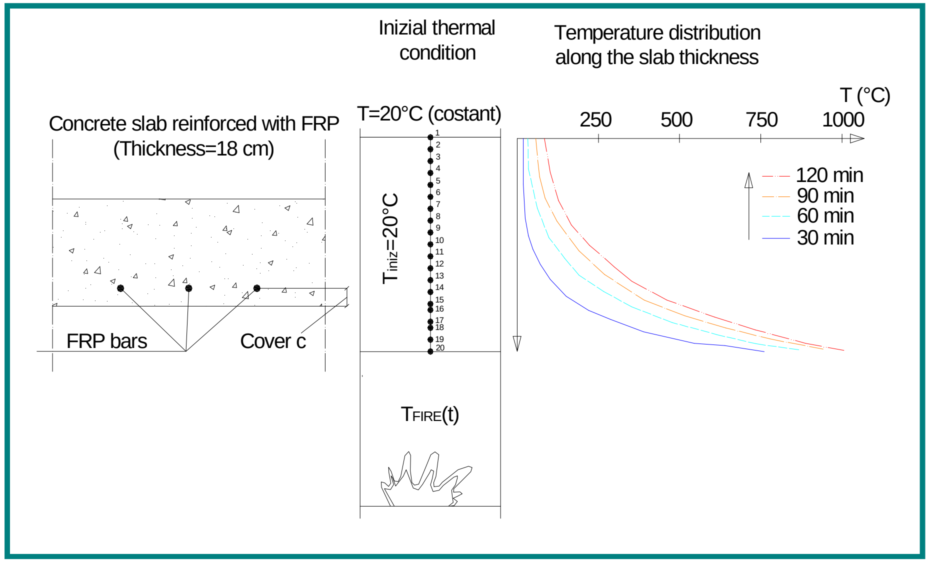
ABACI for the assessment of protected anchorage for straight bars



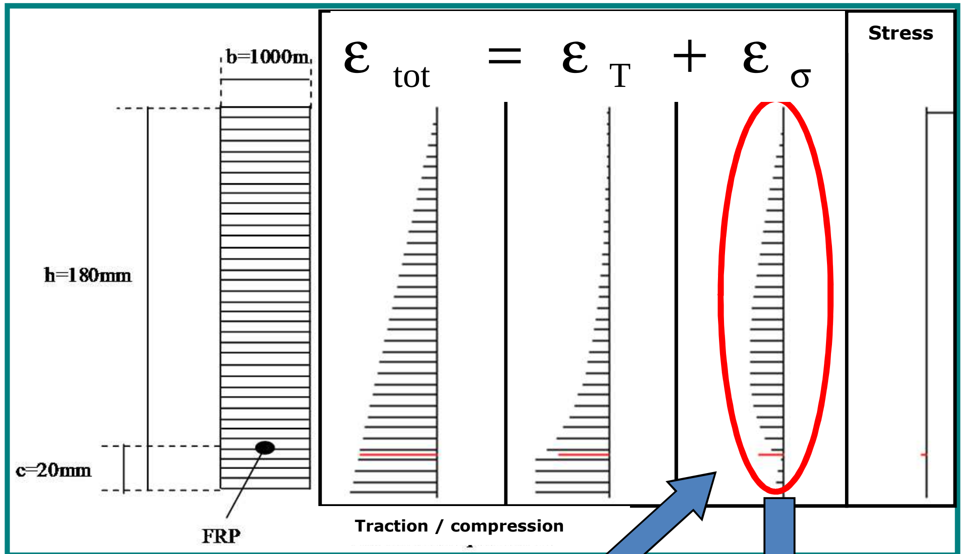
Flexural capacity calculation

Decoupling the thermal behaviour from the mechanical behaviour
as well as suggested by EN1992-1-2

Thermal Analysis



Mechanical Analysis



Law $\sigma - \varepsilon(T)$

$$\varepsilon_\sigma = \varepsilon_{tot} - \varepsilon_T$$

INCREMENTAL-ITERATIVE PROCEDURE

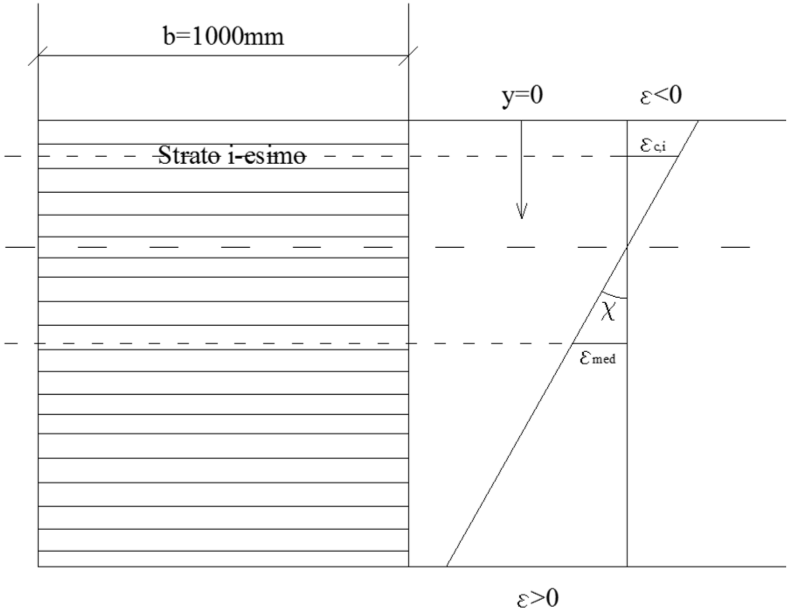
Nigro et al. 2008

determining the bending moment-curvature law of the critical cross-section in fire condition

- slab or beam cross-section is divided into a sufficient number of layers;
- external axial force $N_{ext}=0$ for pure bending;
- assigned a curvature χ_1 and the average strain ε_{med} of the cross-section;
- $\varepsilon_i = f(y_i, \chi_1)$;
- from the stress-strain law of the layer i:

$$\sigma_i = f(\varepsilon_{\sigma,i}, \theta_i)$$

$$\sigma_i = f(\varepsilon_i) \longrightarrow N_{int} = \sum_{1}^{n_c} A_{c,i} \cdot \sigma_{c,i} + \sum_{1}^{n_f} A_{f,i} \cdot \sigma_{f,i}$$



- Iterations varying the average strain ε_{med} of the section need up to satisfying the longitudinal equilibrium equation within a suitable error

$$(N_{int} - N_{est}) \le \delta$$

- Check of ultimate limit strains of the materials:

$$\varepsilon_{cls,i} \le \varepsilon_{cls,u}(T_i); \quad \varepsilon_{FRP,i} \le \varepsilon_{FRP,u}(T_i);$$

- Evaluation of the ultimate bending moment:

$$M_j = \sum_{1}^{n_c} A_{c,i} \cdot \sigma_{c,i} \cdot (y_{c,i} - y_G) + \sum_{1}^{n_f} A_{f,i} \cdot \sigma_{f,i} \cdot (y_{f,i} - y_G)$$

Simplified methods based on stress blocks

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