FRP REINFORCEMENT FOR DURABLE CONCRETE STRUCTURES

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What are FRPs?

**Fibres**
Provide strength and stiffness
- carbon, glass, aramid, basalt

**Matrix**
Protects and transfers load between fibres
- epoxy, vinyl ester

**Composite**
Fibres and matrix affect short term and long term properties
FRP products
Applications
Applications
Where we are!

• Huge diversity of Commercial Products
• FRP reinforcement market is growing Internationally
• First Generation Design Guidelines in Europe, North America and Japan
• Need for training Engineers
• Need for testing standards
fib bulletin 40

- fib TG 9.3
- En-Core Marie Curie RT Network

FRP reinforcement in RC structures
Main Design Issues

The diagram shows the stress-strain relationships for CFRP, AFRP, and GFRP compared to reinforcing steel. CFRP has the highest stress capacity, followed by AFRP and GFRP. The diagram illustrates the yielding point for each material as well.
Serviceability limit State

• Limit on concrete and FRP stress; creep, stress corrosion, durability

• Deflection limitations same as for steel RC
  • Eurocode equations OK, new dimensioning rules

• Crack width limitations can be relaxed
  • Strain based equations OK
Design for Flexural Capacity

• Basic principles of section analysis apply
• Concrete crushing or FRP rupture failure
  • \textit{fib} bulletin 40:
    - Concrete crushing $\rightarrow$ Over reinforced
    - $A_{fmin} \rightarrow M_u > M_{cr}$
    - $\gamma_m$ necessary?
Design for Shear Capacity
Steel RC relies on:

\[ V = V_c + V_s \]

\[ V_s = f_y \cdot A_w \cdot d \]

\[ V = V_c + V_s \]
Design for Shear Capacity
Strain Approach:

\[ A_f \cdot \frac{E_f}{E_s} \]

Maximum allowable strain

0.25% -> 0.45%
Failure of shear links

The tensile strength of FRP bars is largely reduced when subjected to a biaxial state of stress

\[ f_{fb} = \left( \alpha \frac{r_b}{d_b} + 0.3 \right) f_{fu} \leq f_{fu} \]

- \( r_b \) is the radius of the bend in the bar
- \( d_b \) is the nominal diameter of the FRP bar
- \( f_{fu} \) is the design strength of a straight portion of the bar
Bond Failure Mechanisms

Concrete

Bar fibers

Bar resin

Failure interface in concrete

Failure interface in resin
Bond and Tension Stiffening

- Design equations (modified from steel)

Research required

- Testing
- Models
- Effect on Tension Stiffening
Design Philosophy Issues

• Different predominant failure mode
  • Influence of Partial safety factors; failure type
  • Safety levels

• Structural reliability of FRP RC elements is variable

• Resistance capacity margins
  • Is there a hierarchy? Should there be?
Resistance Capacity Margins

FMH: Flexure - Shear - Bond
- Flexural Resistance
- Shear Resistance
- Bond Resistance
- Applied Load

Relative Frequency

\( \mu_{\text{Load}} \) \hspace{2cm} \mu_{\text{flexure (compression)}} \hspace{2cm} \mu_{\text{shear}} \hspace{2cm} \mu_{\text{bond}}

Resistance-Capacity
Design Philosophy

- More economic design
- More reliable design
- Defined resistance capacity margins
- Can accommodate innovation
Concluding remarks

• Use of FRP reinforcement on the increase
• First generation of design guidelines exist
• Second generation being developed