Innovative materials and technologies for concrete structures

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ANALYTICAL STUDY ON TENSILE STRENGTH OF CURVED FRP REINFORCEMENT

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OUTLINE

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- Introduction
- Performance of curved FRP's
- Experimental Programme/ Results
- Analytical study
- Conclusions

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Introduction

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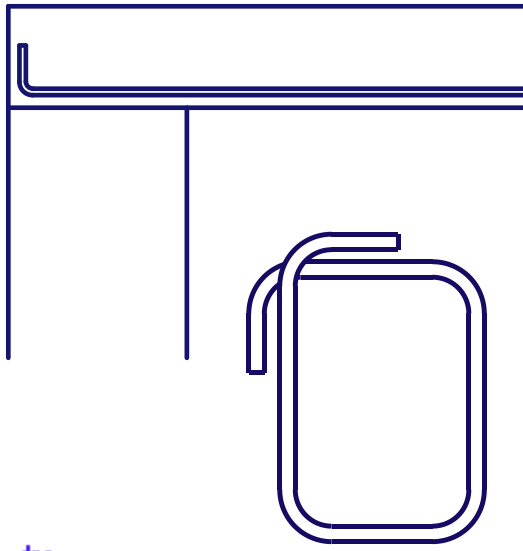
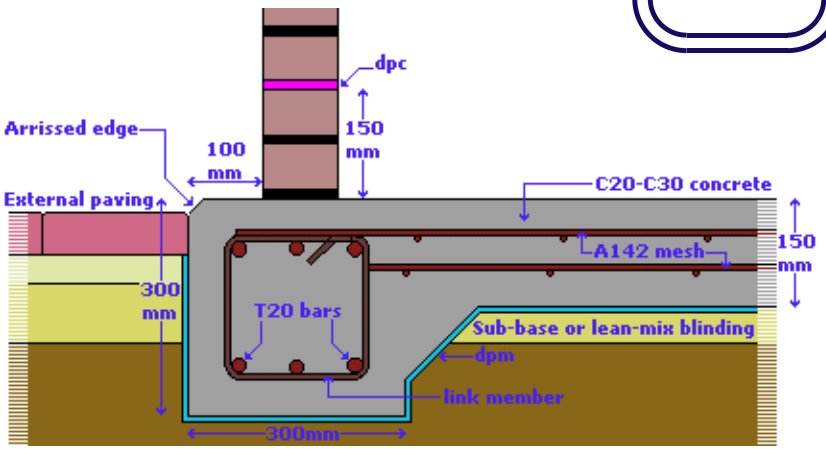


- End anchorages
- Element connection
- Shear reinforcement



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Introduction

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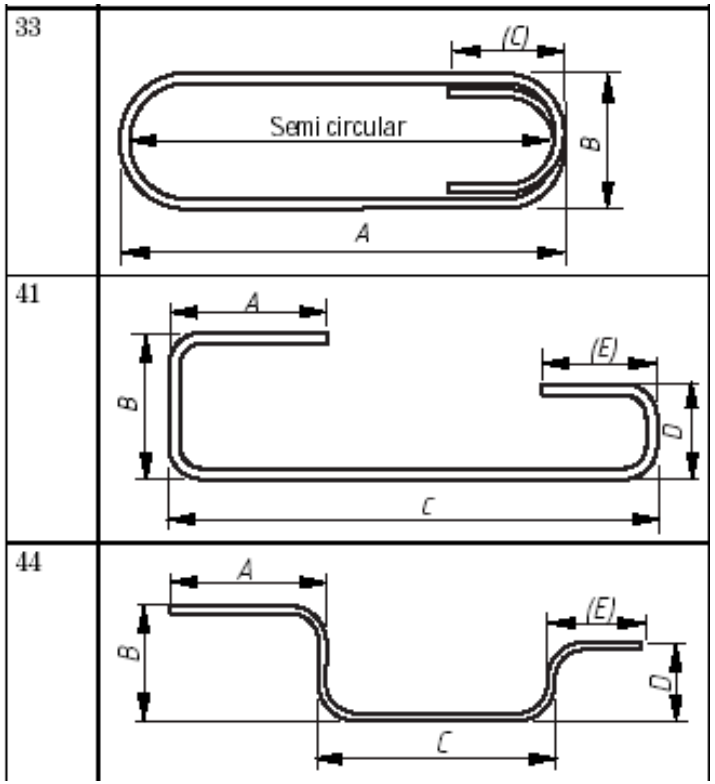

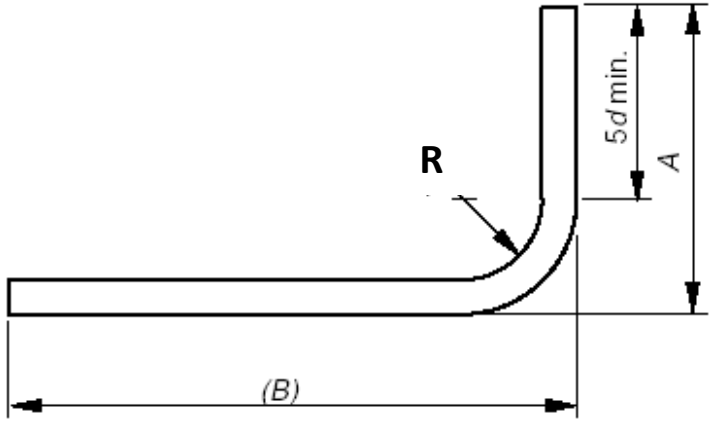

$R \geq 2d$

Standardised shapes (BS 8666)

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Plastic strain induced by bending

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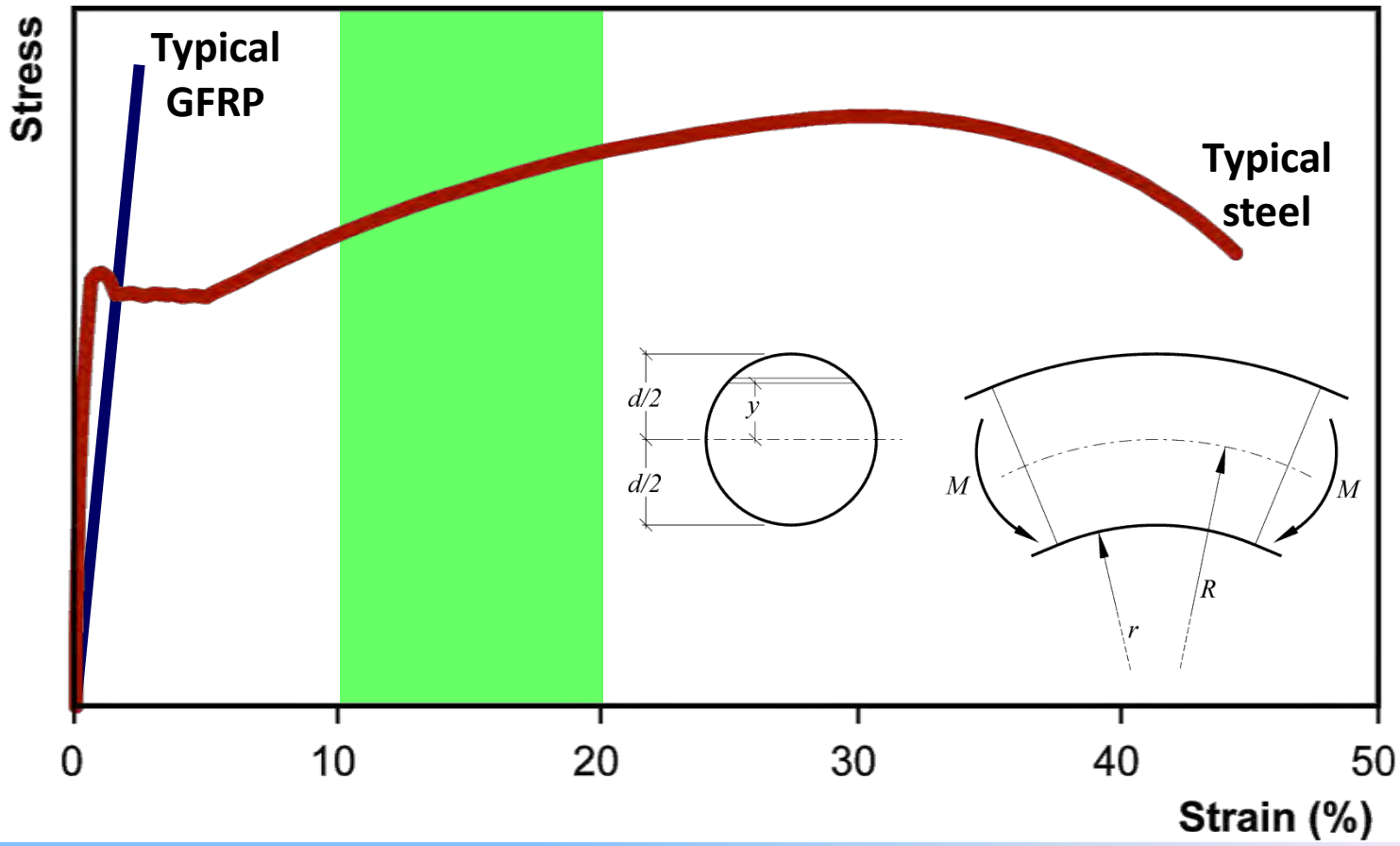

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Cold bending of FRP's

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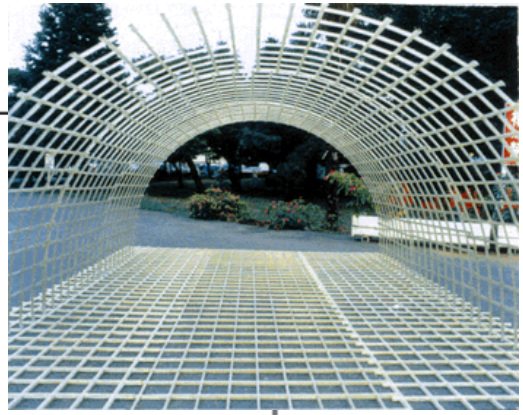

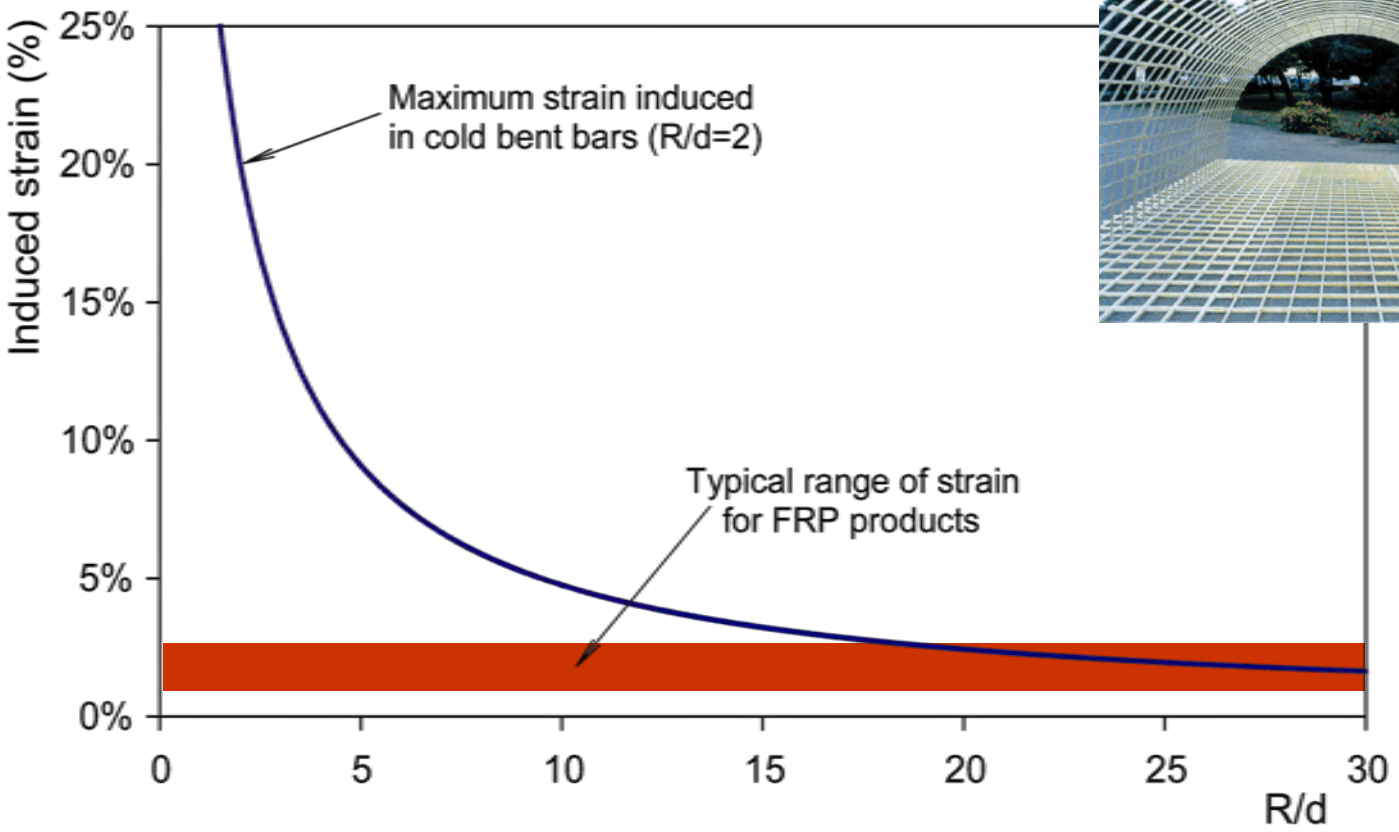

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Pre-bent FRP's

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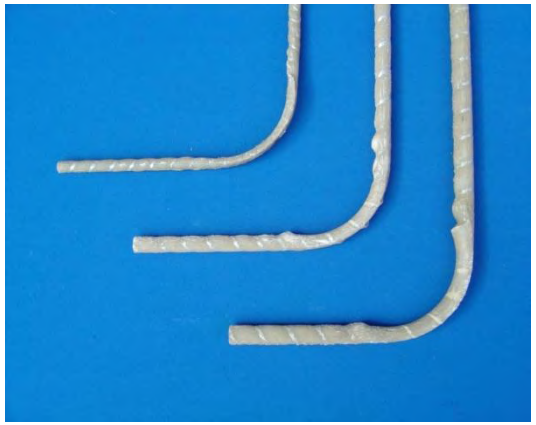
- **Thermosetting FRP's: can only be pre-bent at the factory**



- **Thermoplastic FRP's: could offer a valid solution for on-site bending of reinforcement**

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Performance of curved FRP's

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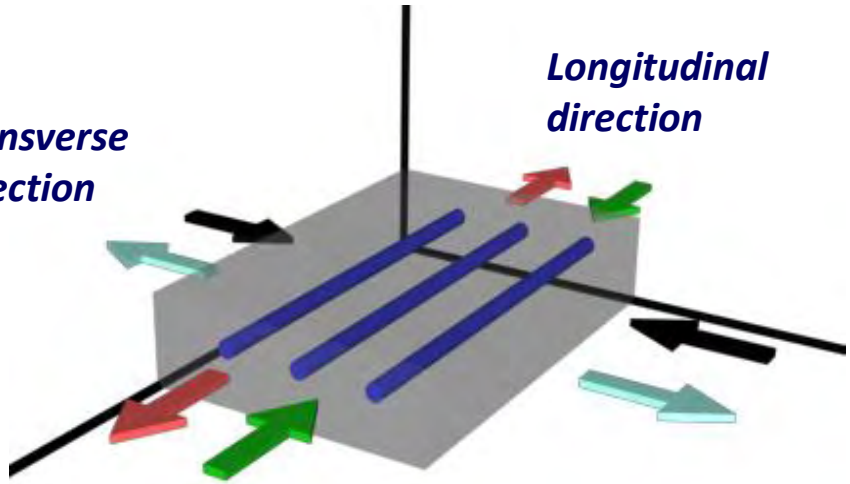
The tensile strength of FRP bars can be largely reduced when subjected to a biaxial state of stress



Premature failure at bent portion

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Code Provisions

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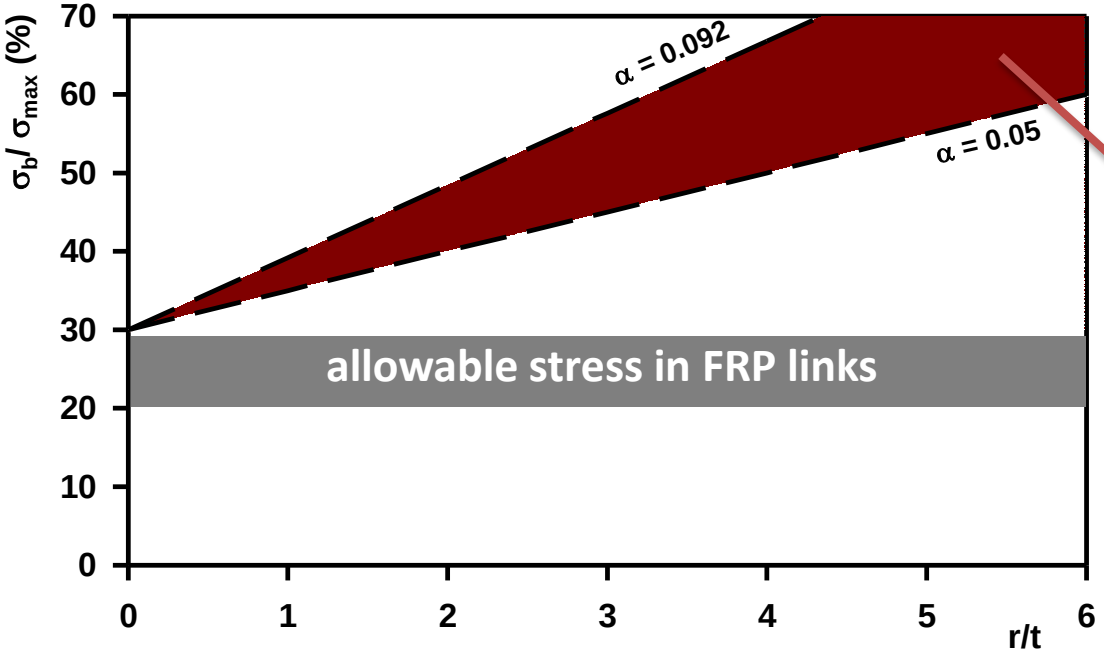
Design equation (JSCE)



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

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

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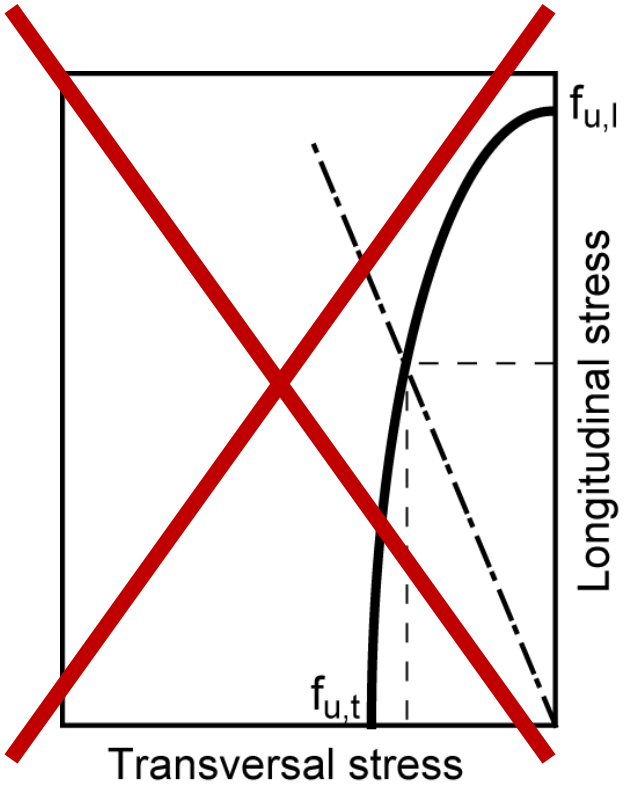
$$f_{fb} = \left(\alpha \frac{r_b}{d_b} + 0.3 \right) f_{fu} \leq f_{fu}$$

Bend geometry

- r/t

~~**Composite make-up**~~

- ~~type of fibres~~
- ~~type of resin~~
- ~~volume fractions~~



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Experimental Programme

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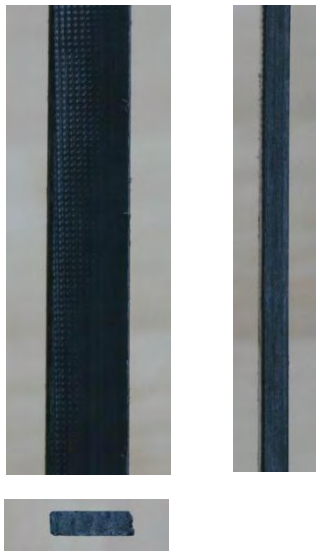
GFRP thermoplastic strip (10x3mm)



Properties	
Tensile strength (MPa)	720
Tensile modulus (GPa)	28
Ultimate strain (%)	1.9
Glass content (%v/v)	35
Density (g/cm^3)	1.48

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Experimental Programme

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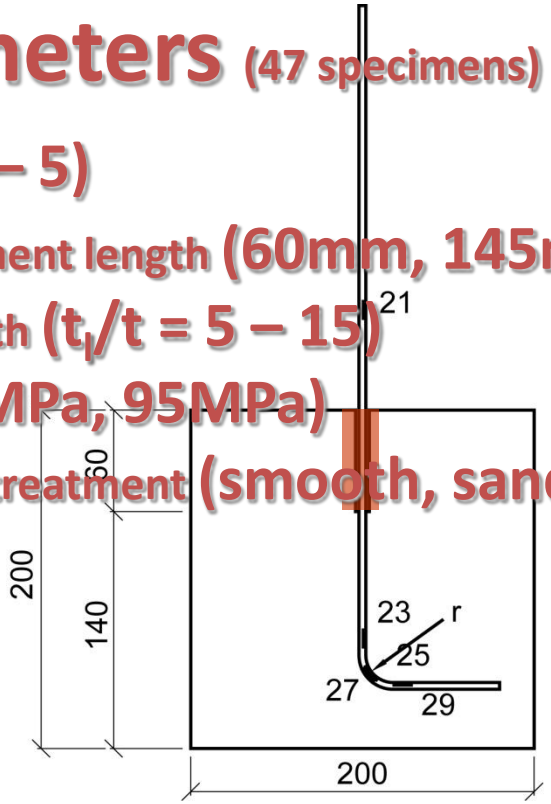
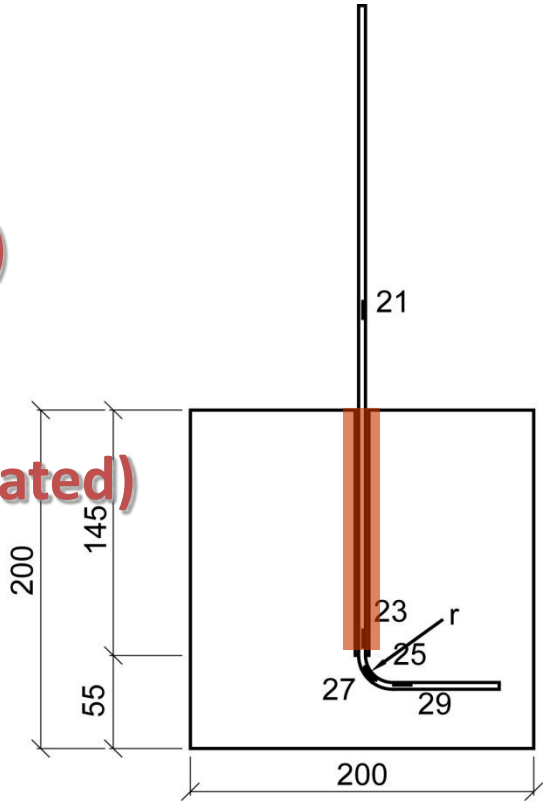
Parameters (47 specimens)

- R/t (2 – 5)
- embedment length (60mm, 145mm)
- tail length (t_l/t = 5 – 15)
- f_{cu} (45MPa, 95MPa)
- surface treatment (smooth, sand coated)



Type 2



Type 3

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Experimental Results

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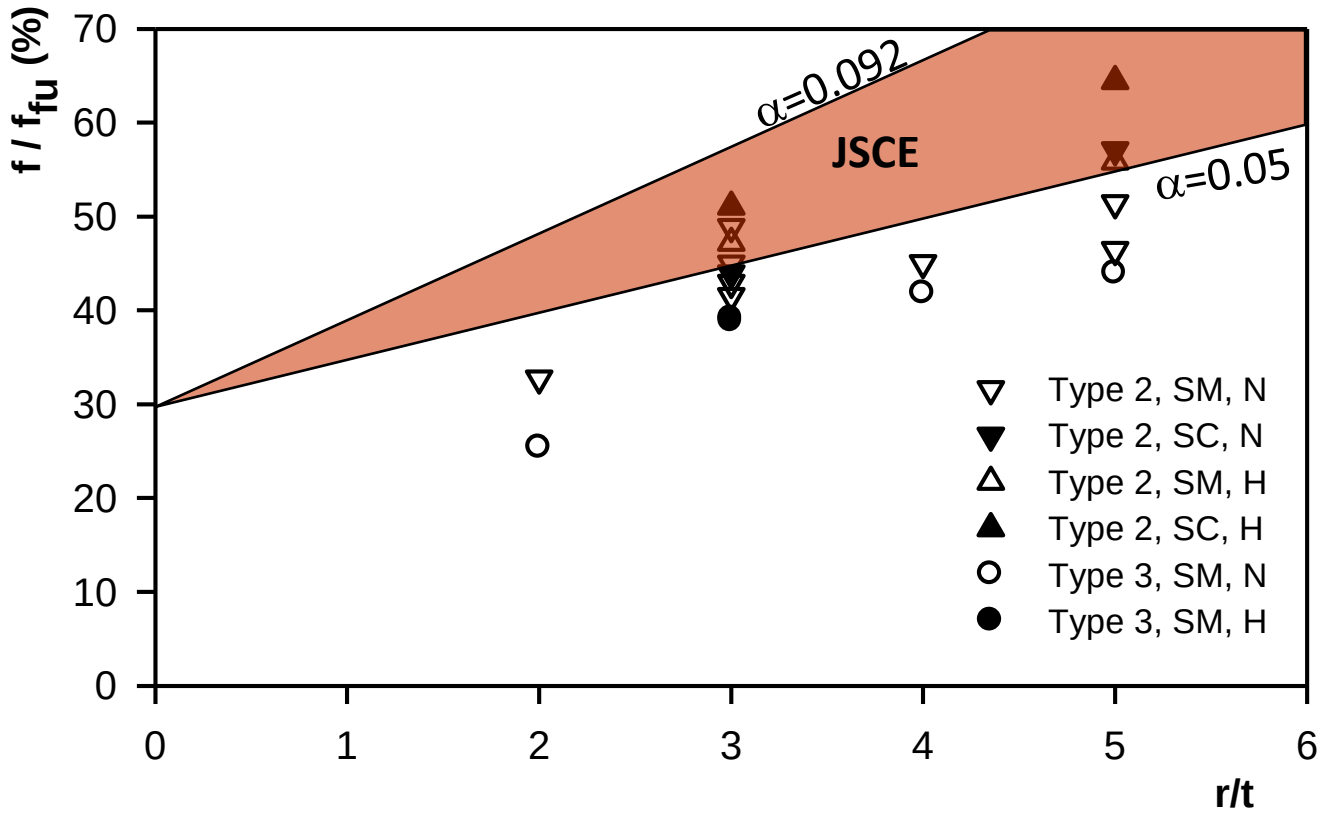

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A macromechanical approach

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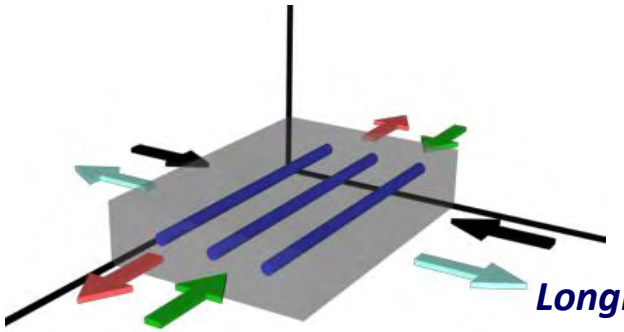
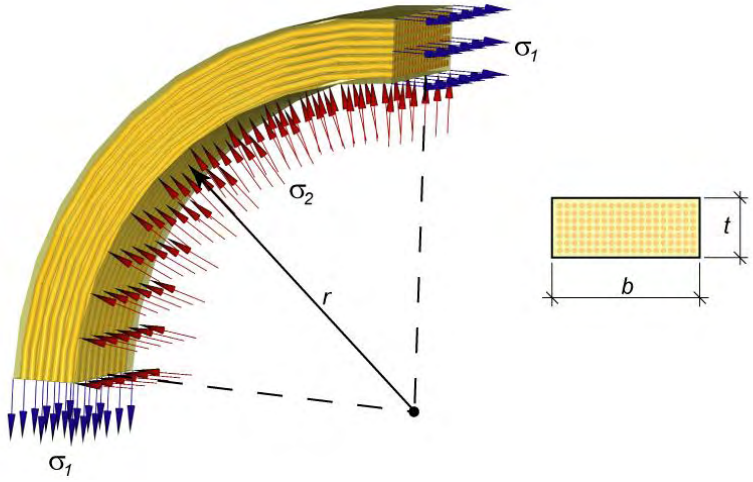


Transverse direction

Longitudinal direction



- **Force equilibrium**

$$\sigma_2 = \sigma_1 \frac{t}{r}$$

- **Failure criterion**

$$\frac{\sigma_1^2}{\sigma_{1,\max}^2} - \frac{\sigma_1 \sigma_2}{\sigma_{1,\max}^2} + \frac{\sigma_1^2}{\sigma_{2,\max}^2} = 1$$

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A macromechanical approach

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- **Predictive model**

$$\frac{\sigma_1}{\sigma_{1,\max}} = \frac{1}{\sqrt{1+\left(\frac{h}{R}\right)+\left(\frac{h}{R}\right)^2 \cdot \beta^2}}$$

- **Material testing**
- **Micromechanics**

$$\sigma_{2,\max} = \frac{1}{k_\sigma}\left(f_{mc} + \sigma_{rm}\right)$$

$$\beta = \frac{\sigma_{1,\max}}{\sigma_{2,\max}}$$

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A macromechanical approach

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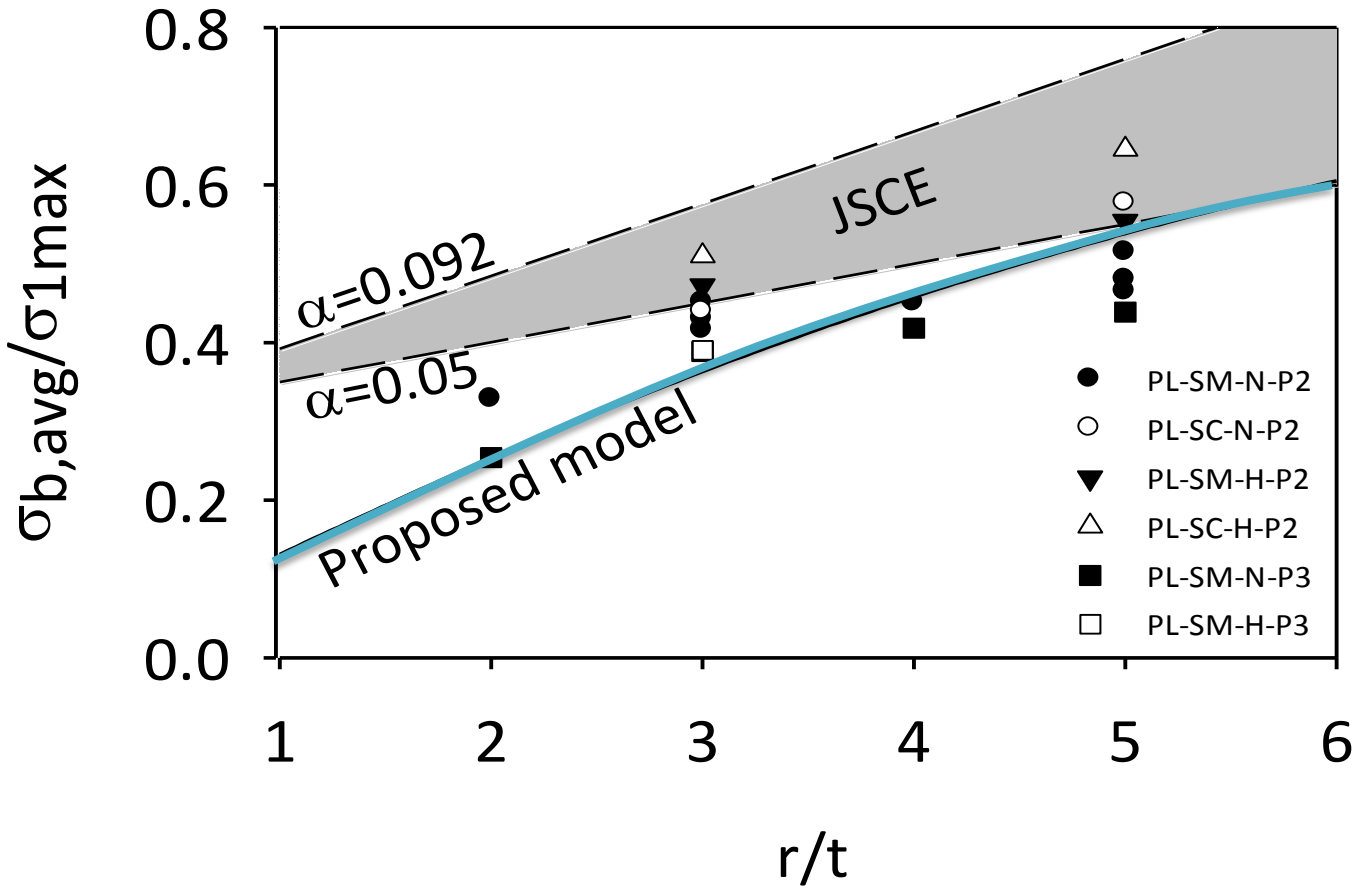

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Verifications

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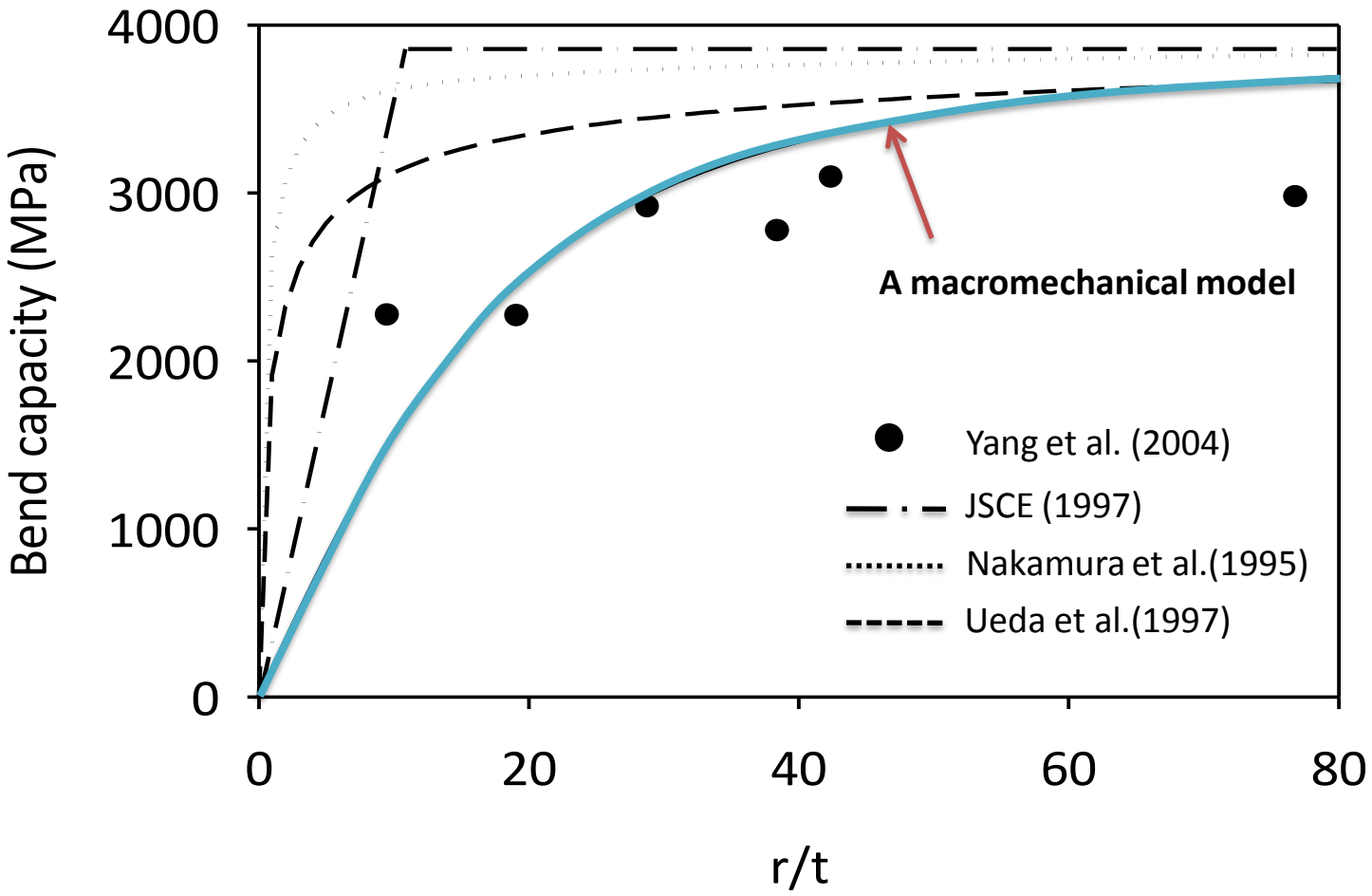

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Concluding Remarks

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- The capacity of the bent portion is not only a function of its geometry
- Values of r/t > 3-4 guarantee the development of 40% of the ultimate strength
- The macromechanical based model adequately captures strength degradation of bent bars

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