Standardisation of UHPC in Germany

Part II: Development of Design Rules

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Overview

- Introduction:
  Work of the Task Group „Design and Construction“
- Material Models:
  UHPC in Compression and Tension
- Ultimate Limit State (ULS):
  Design for Bending with or without Axial Force
- Conclusions and Outlook

Context

State of research
(e.g. DFG priority programme
in Germany)

Experience in practice
(from pilot projects)

Design rules for UHPC
as supplement to Eurocode 2
for Germany

Eurocode 2:
Design of concrete structures

International
design recommendations
for UHPC

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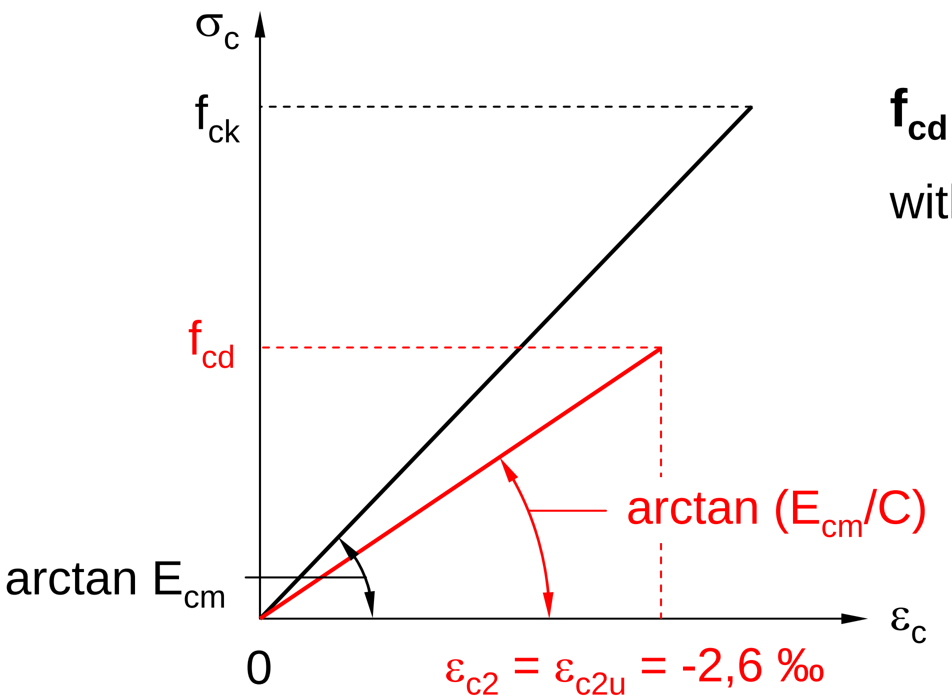
Table of Contents (Status-quo of Work)

Stress-Strain Relation for the Design of Sections



$$\mathbf{f_{cd} = \alpha_{cc} \cdot f_{ck} / \gamma_c}$$

with α_{cc} = 0.85

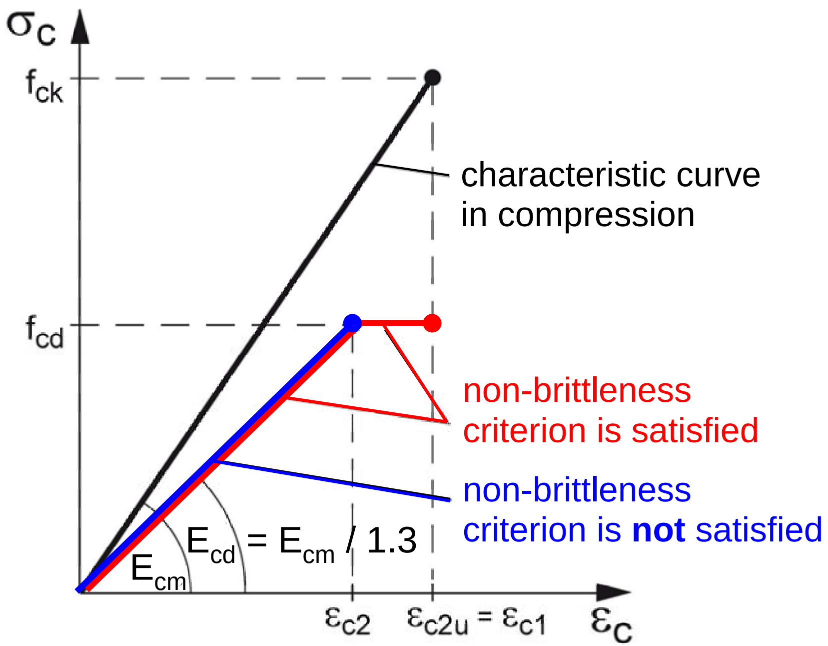
γ_c = 1.5

1.35 (high quality control)

adopted from strength classes C90/105 and C100/115

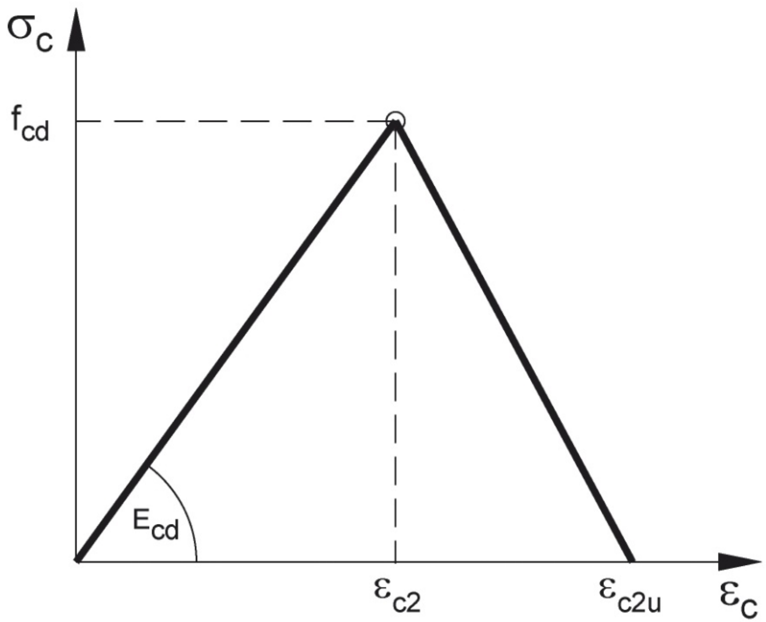
Additional Plastic or Softening Branch?

Linear-plastic (acc. to draft of fib-bulletin „UHPFRC“)



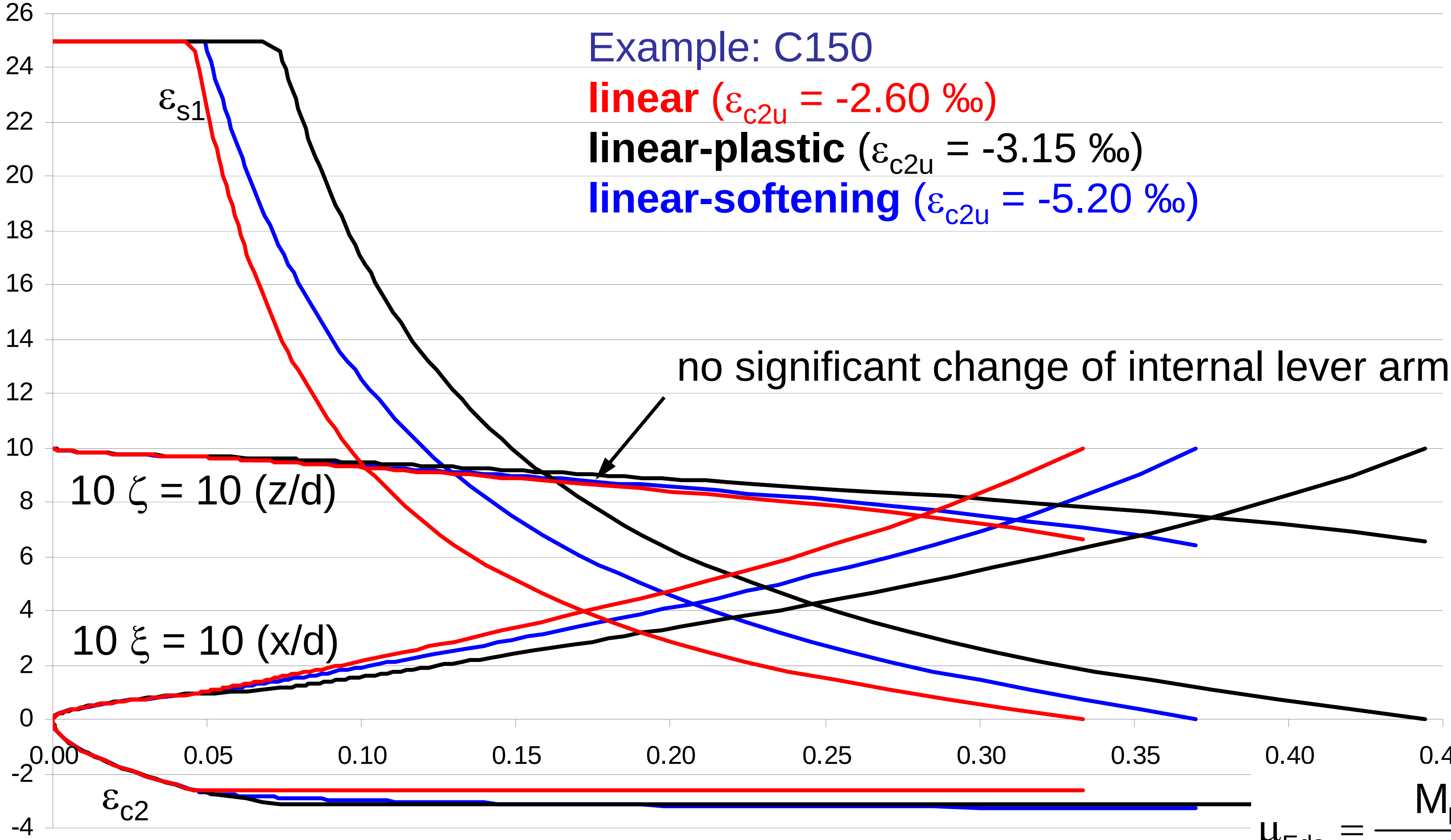
e.g.: ε_{c2} = -2.6 ‰
ε_{c2u} = -3.15 ‰ (C150)

Linear-softening



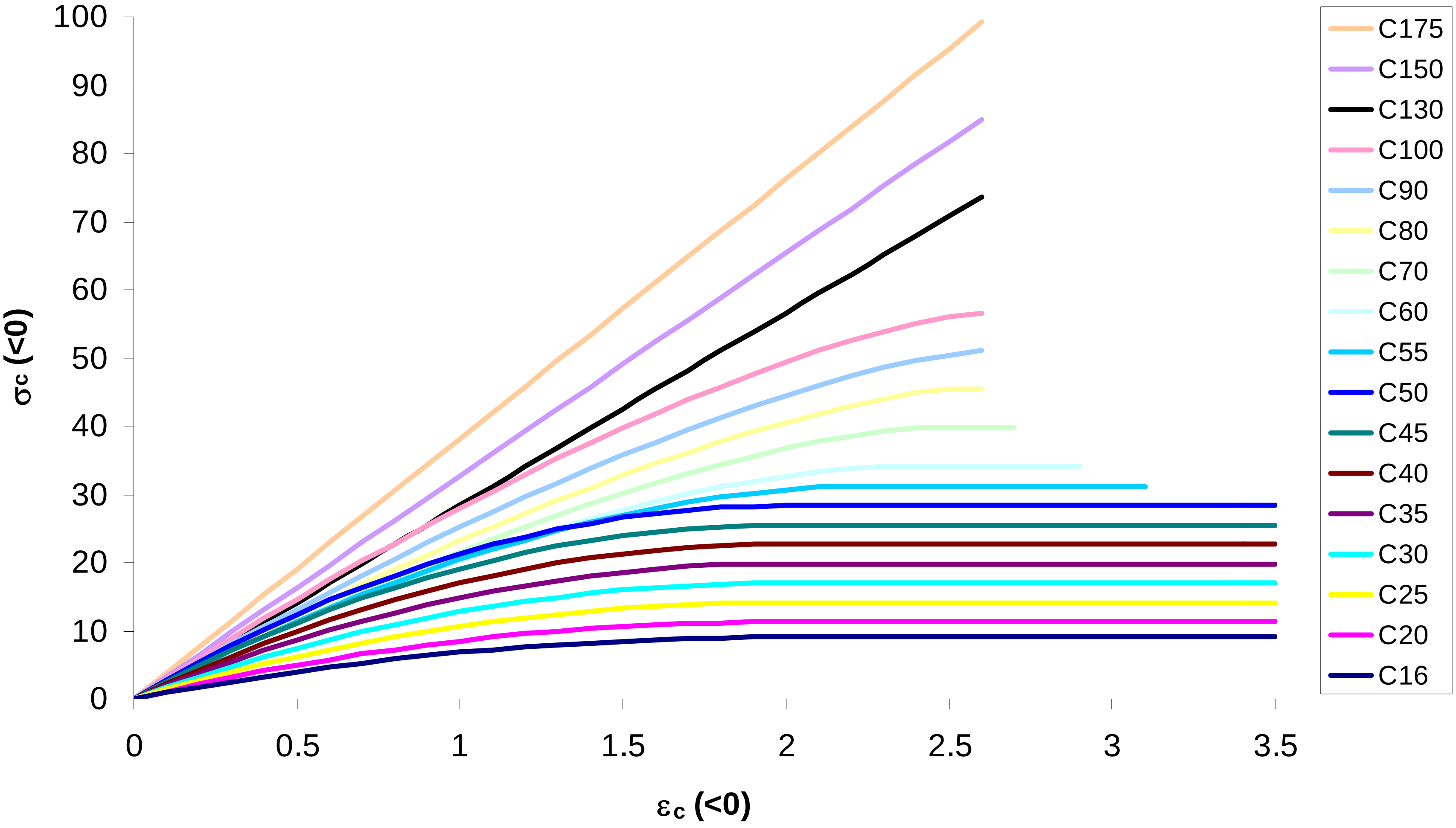
e.g.: ε_{c2} = -2.6 ‰
ε_{c2u} = -5.20 ‰

Impact of an Additional Plastic or Softening Branch



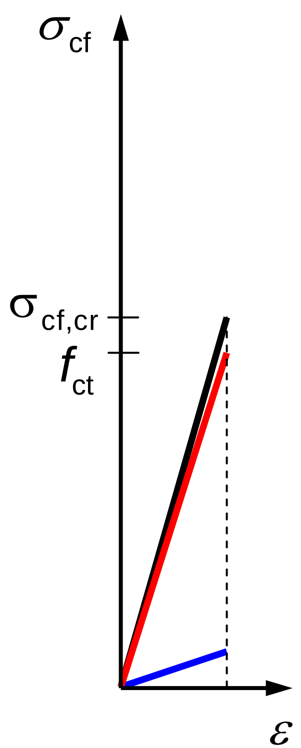
$$\mu_{Eds} = \frac{M_{Eds}}{b \cdot d^2 \cdot f_{cd}}$$

Overview: Stress-Strain Relations in Compression

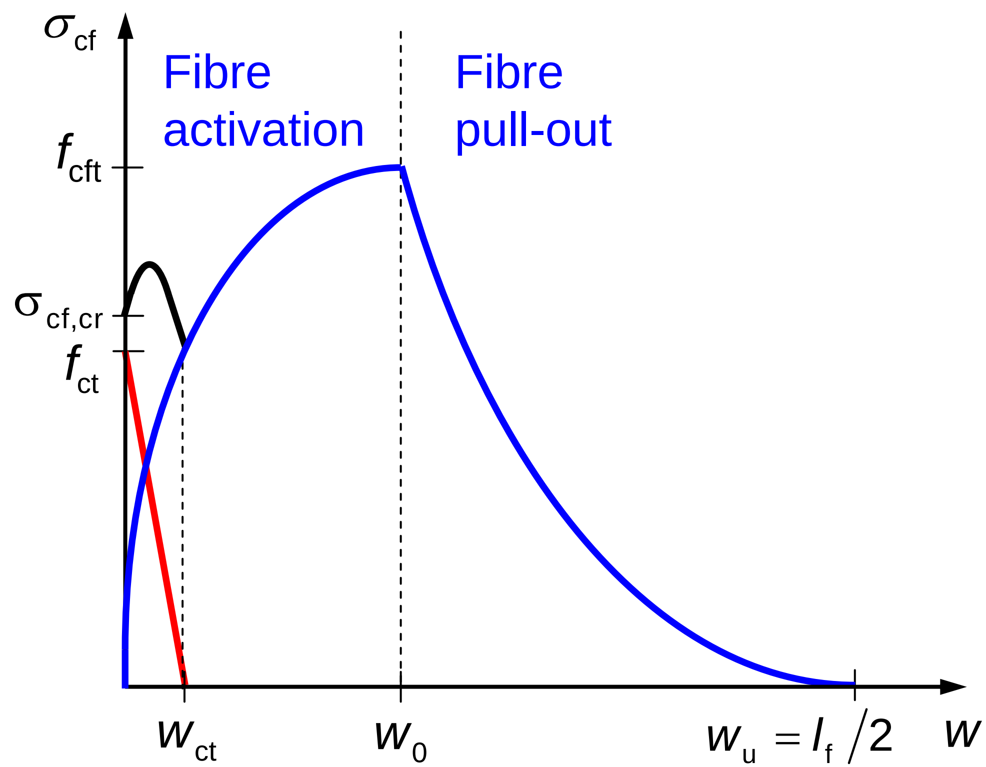


Tensile Behaviour of UHPFRC

Uncracked state:
Stress-strain relationship



Cracked state:
Stress-crack opening relationship



— Pure UHPC matrix — Pure fibre contribution — Superposition

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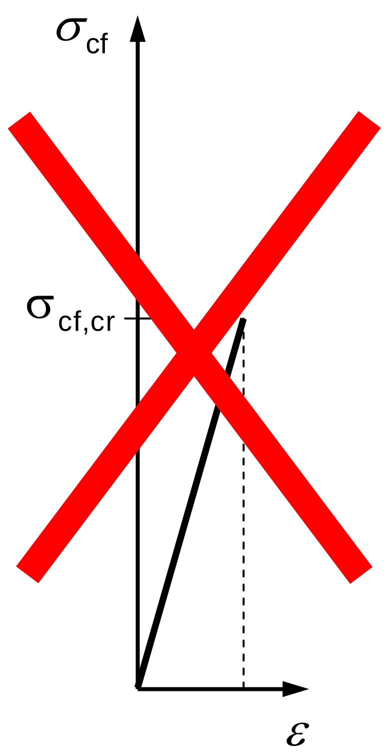
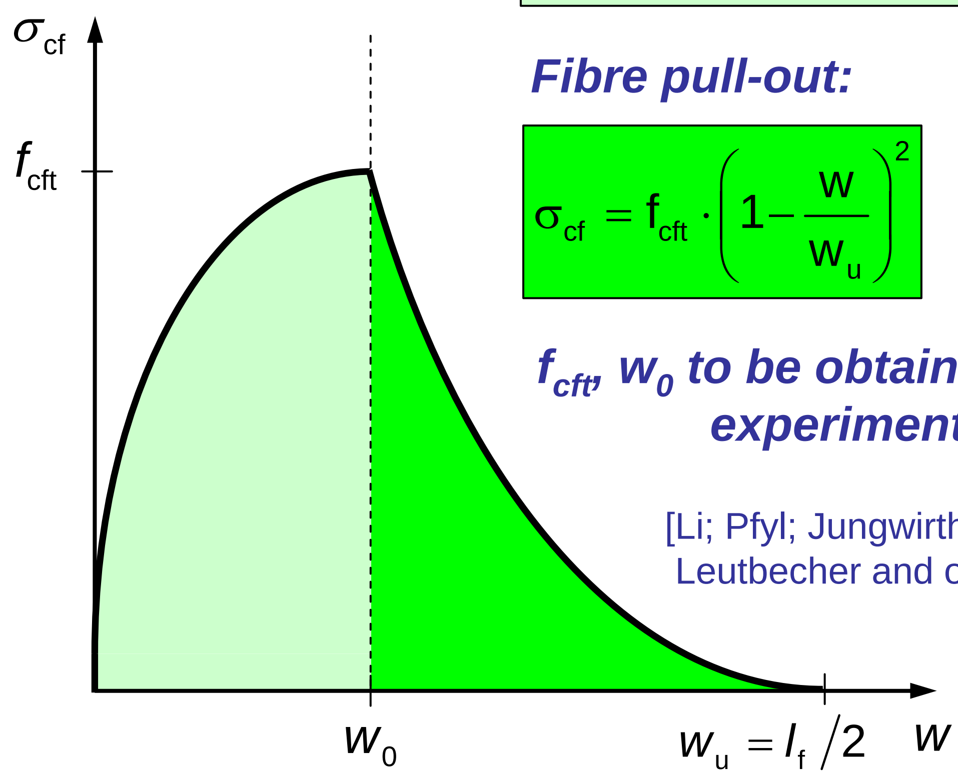
Consistency with RC Design Philosophy

Neglecting contribution of **UHPC matrix in tension**



Assuming **cracked cross-section**



Fibre activation:

$$\sigma_{cf} = f_{cft} \cdot \left(2\sqrt{\frac{w}{w_0}} - \frac{w}{w_0} \right)$$

Fibre pull-out:

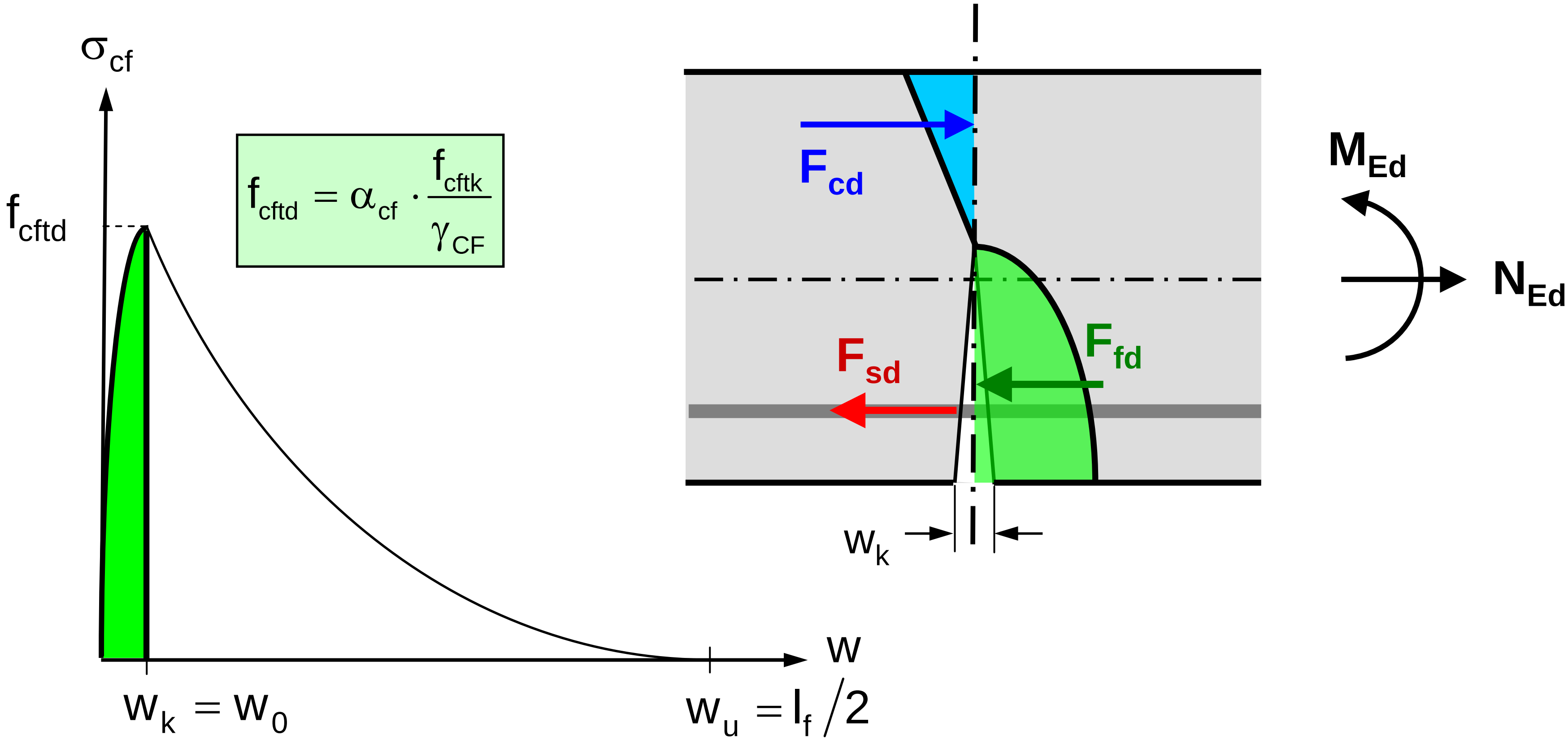
$$\sigma_{cf} = f_{cft} \cdot \left(1 - \frac{w}{w_u} \right)^2$$

f_{cft}, w_0 to be obtained experimentally!

[Li; Pfyl; Jungwirth; Leutbecher and others]

Design for Bending and Axial Force

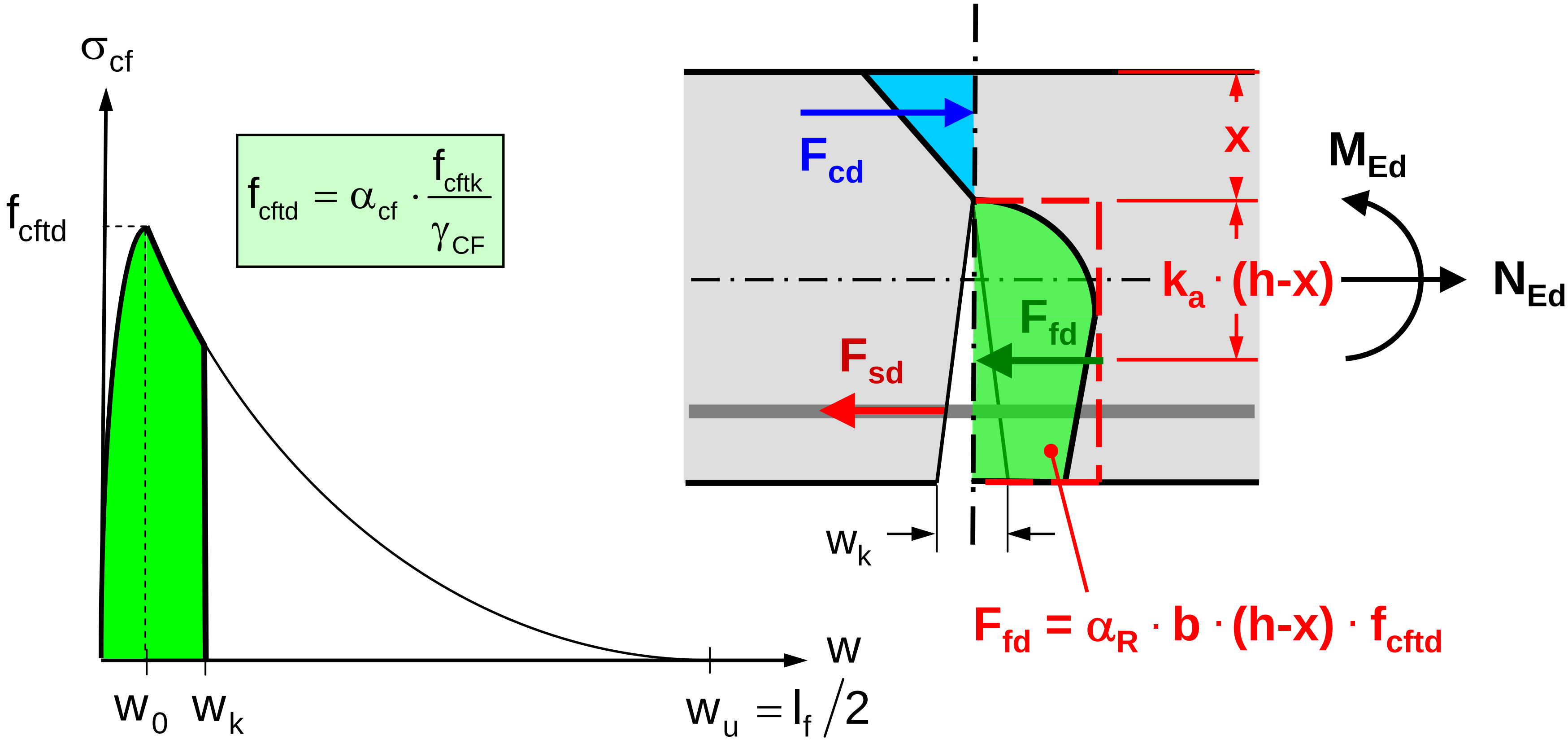
Equilibrium at cracked cross-section:



w_k = crack width at the tensile edge

Design for Bending and Axial Force

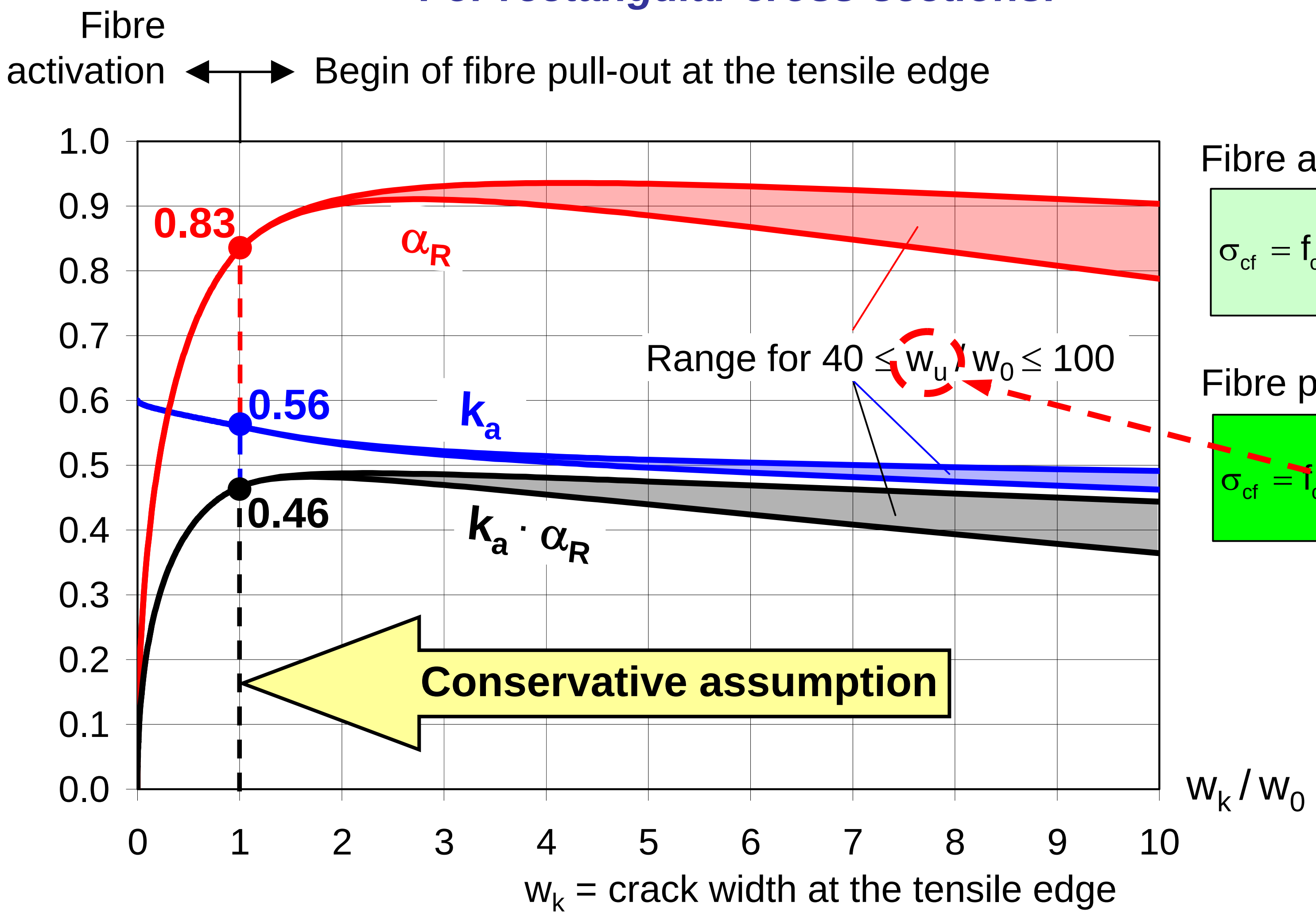
Equilibrium at cracked cross-section:



w_k = crack width at the tensile edge

Determining Fibre Contribution F_{fd}

For rectangular cross-sections:



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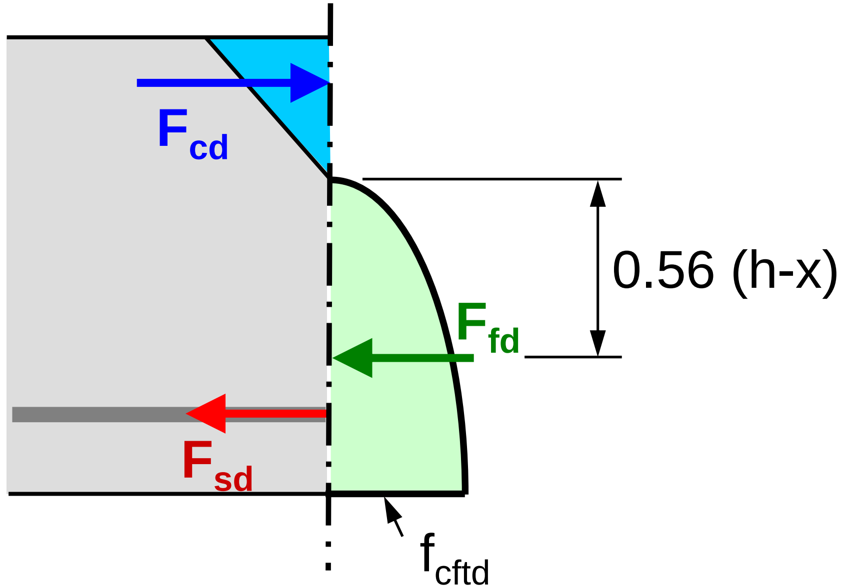
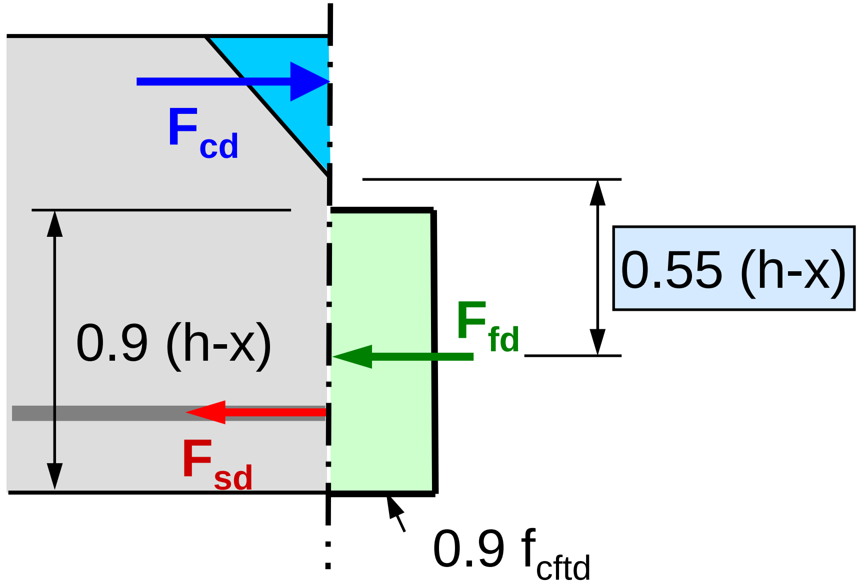
Simplification by „Stress Block“

From equations:

Simplification:

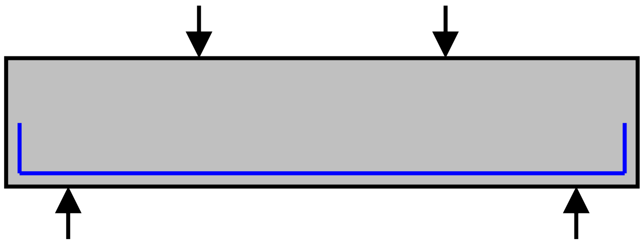


$$F_{fd} = 0.83 \cdot (h - x) \cdot b \cdot f_{cftd}$$



$$F_{fd} = 0.81 \cdot (h - x) \cdot b \cdot f_{cftd}$$

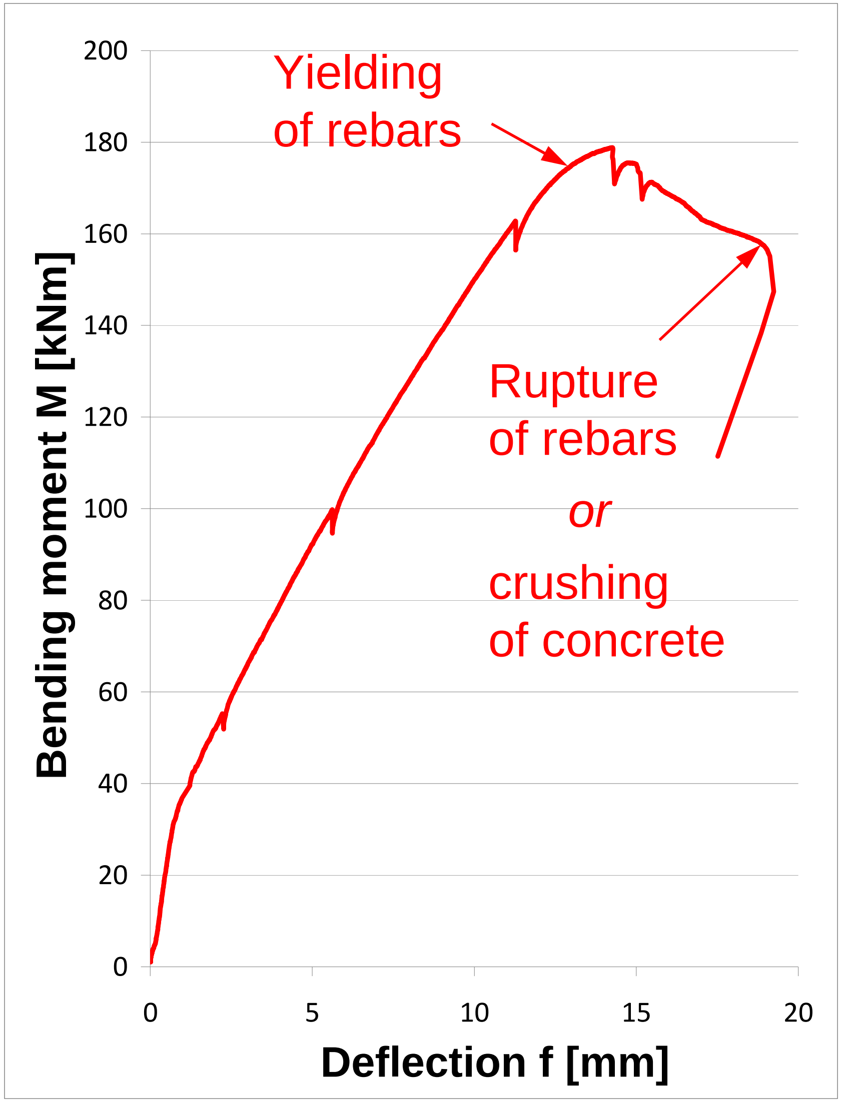
Observation in Bending Tests



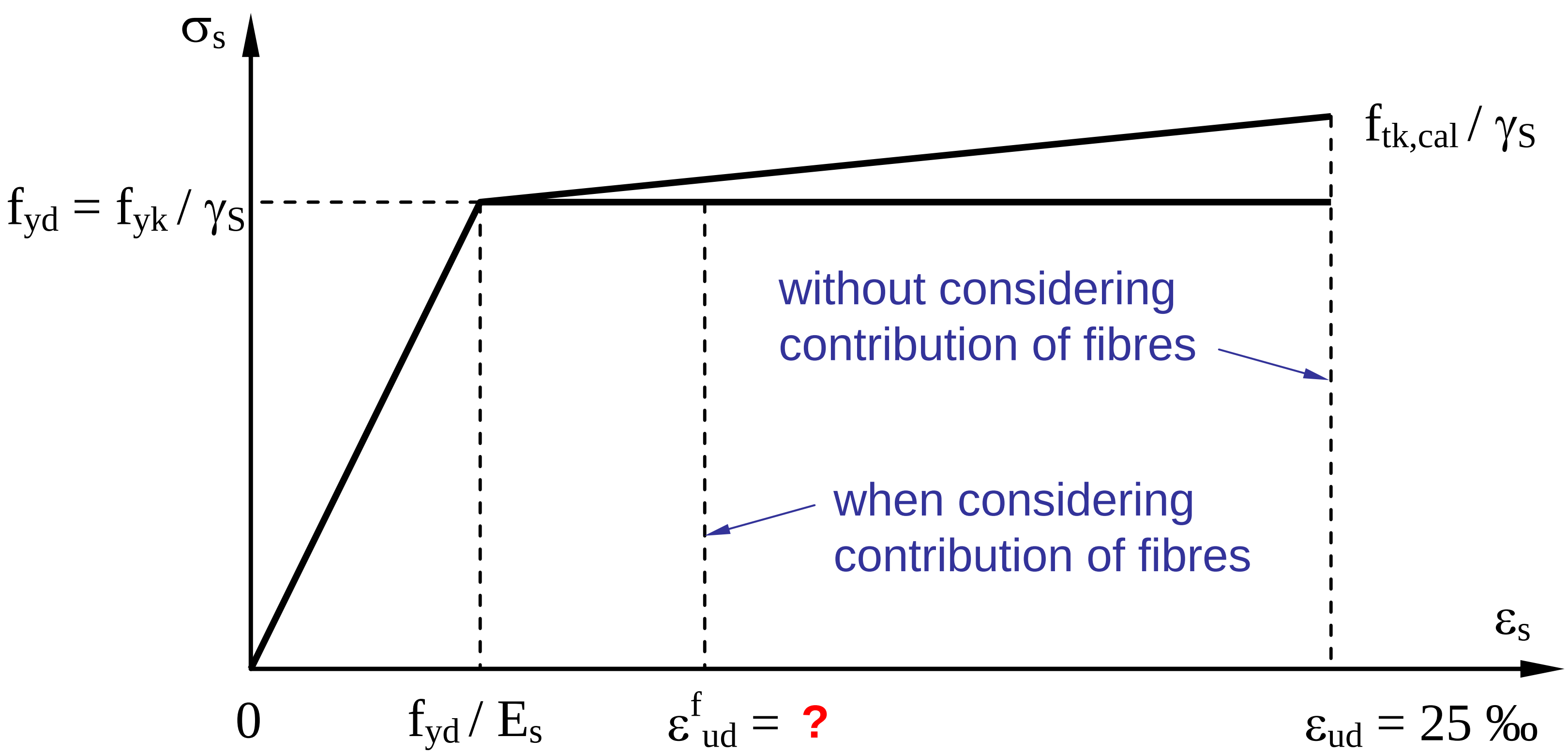
[Stürwald]

After onset of yielding:

- **Bearing capacity** is reached!
- **Ultimate strains** of concrete or reinforcing steel are **not reached**!



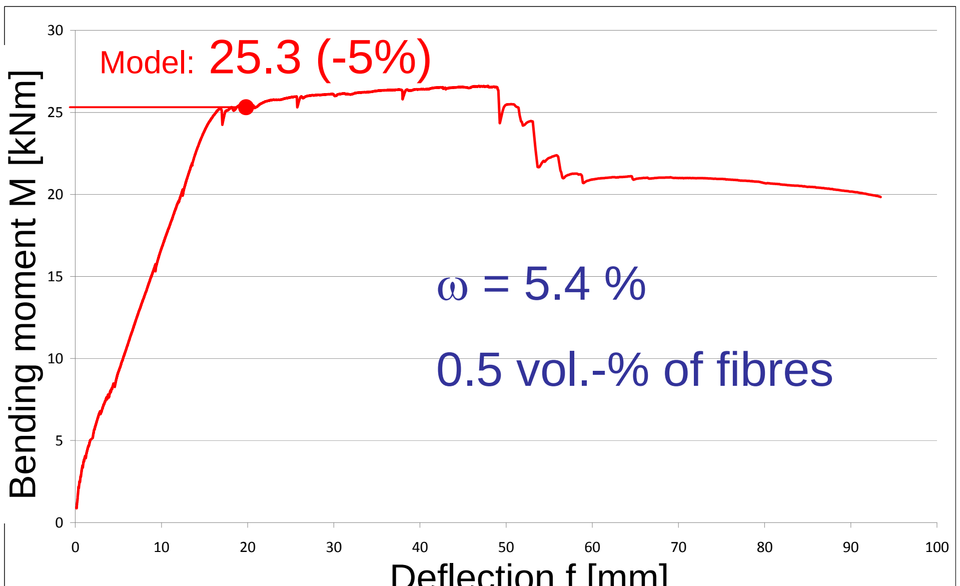
Modifying Stress-Strain Relation of Reinforcing Steel



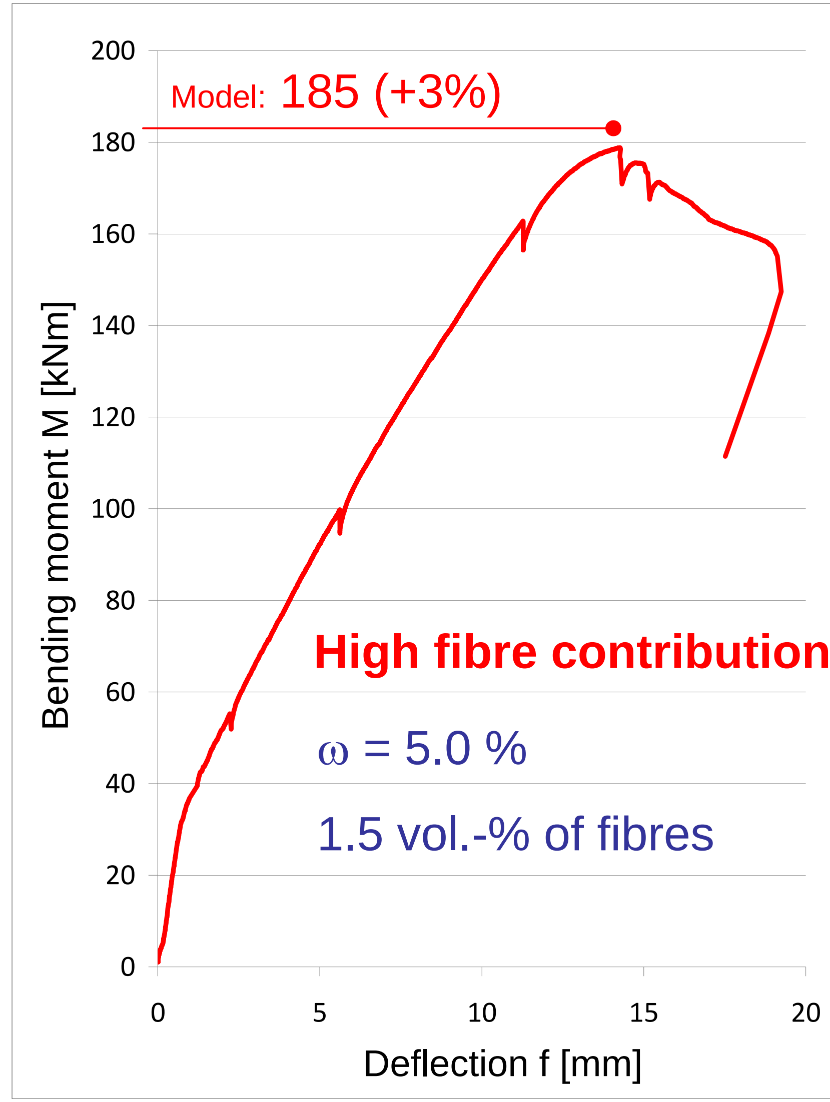
Assumption: $\varepsilon^f_{ud} = f_{yd} / E_s + 1$ ‰

Model vs. Test Results

(Tests by Stürwald)



Low fibre contribution



Conclusions and Outlook

Development of design rules as supplement to Eurocode 2

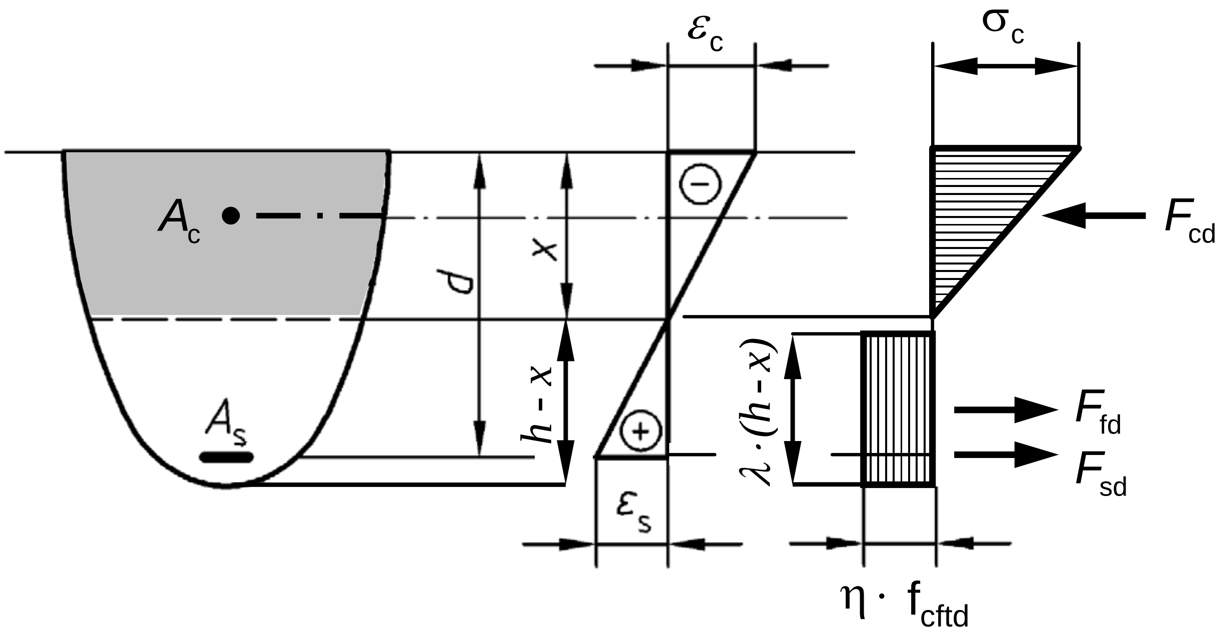
ULS:

- Linear stress-strain relation for UHPC in compression for design of sections,
- Design for bending should be consistent with design philosophy of RC: Focus on fibre action but neglecting UHPC matrix in tension,
- Stress distribution in tension zone according to linear distribution of crack width over height of tensile zone → Simplification by use of stress block,
- Simultaneous action of rebars and fibres: localisation of strains in one crack → Limitation of steel strains when considering the contribution of fibres,
- Discussion of models for shear, punching, and torsion is ongoing.

SLS:

- Proposals for crack width limitation, minimum reinforcement, control of deflections etc. available and under discussion.

Thank you very much for your attention!



Legend:

$\lambda = 0.9$

$\eta = 0.9$