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Influence of cracks on corrosion

Peter Schiessl

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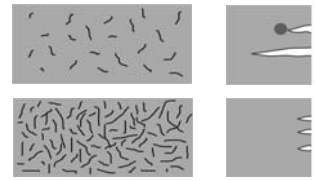
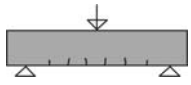
Concrete technology
(Early age shrinkage)



Eigenstresses
(Hydration heat, shrinkage, temperature gradients)

Restraint
(Hydration heat, shrinkage, temperature differences)

Load

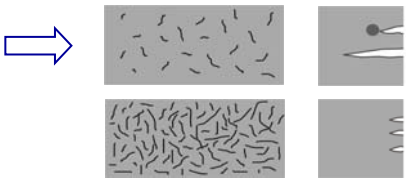


Environmental actions
(Corrosion, frost, sulphates, ASR)

varying

Causes of cracks

Concrete technology
(Early age shrinkage)



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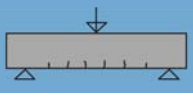

Environmental actions
(Corrosion, frost, sulphates, ASR)

varying

Crack widths limitation in standards

Reasons for limitation

- **Corrosion**
  - **Reinforcing steel** → Limitation of ΔA_s → $w_k \leq 0{,}3\ (0{,}4)$ mm
  - **Prestressing steel** → Avoidance of depassivation! → $w_k \leq 0 - 0{,}2$ mm
- **Water tightness**
  - **Transverse cracks** → Ensurance of self healing → $w \leq 0{,}15 - 0{,}2$ mm
- **Anchorage** → Avoidance of longitudinal cracks → $w \leq 0{,}4$ mm
- **Esthetics** → $w \leq 0{,}4$ mm

Crack widths limitation in standards

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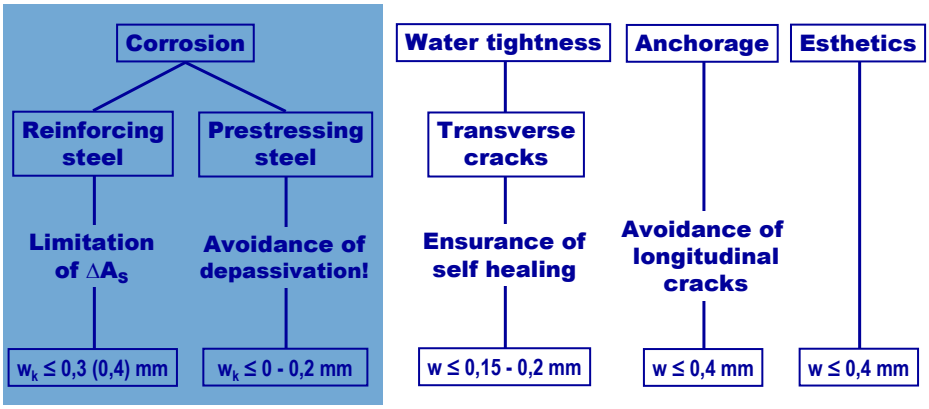
Reasons for limitation



Means of crack widths limitation

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Crack formulas

EC2:

$w_k = S_{r,\,max}\,(\varepsilon_{sm} - \varepsilon_{cm})$

Design rules

EC2:

Limitation of bar diameter or bar spacing

Relevance of crack widths for corrosion

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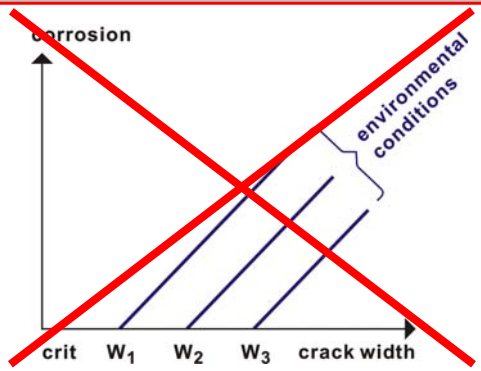
DIN 1045-72 CP 110

CEB-MC-78 EC 2 (draft)

Knowledge of the 60's



Protection of reinforcement against corrosion by the alkalinity of concrete - scheme

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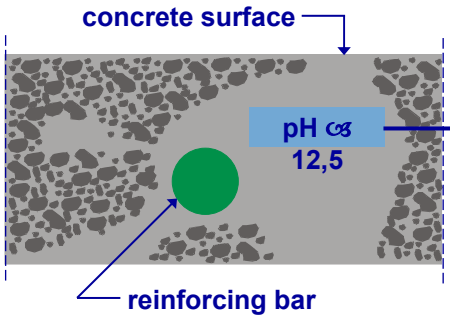
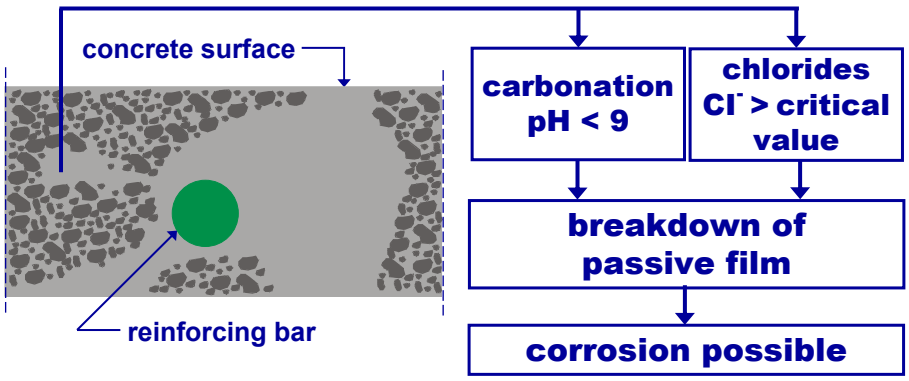


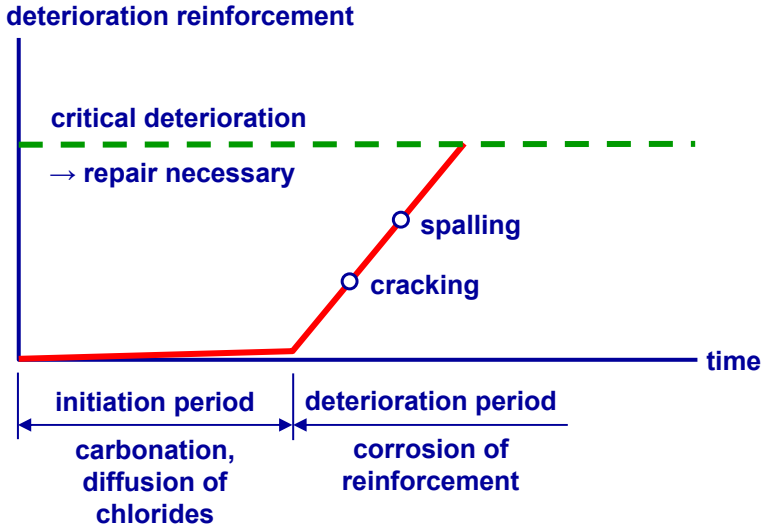
microscopic oxide layer (passive film)

dissolution of iron impossible

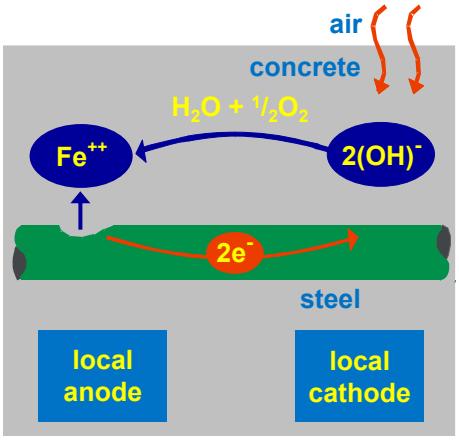
Corrosion of reinforcement after depassivation - scheme



Corrosion of steel in concrete – deterioration scheme (Tuutti)



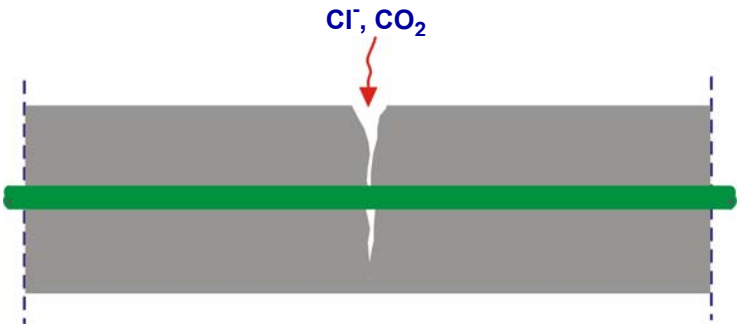
Corrosion of reinforcement

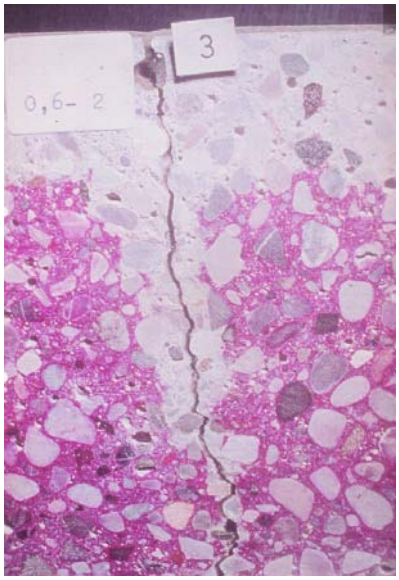


Preconditions for corrosion

- anodic dissolution of iron possible
- electrical conductivity of steel
- electrolytical conductivity of concrete (water)
- oxygen within the electrolyte
- potential differences (e.g. local depassivation)

Influence of cracks on corrosion




3
0,6- 2

Relation between crack width and corrosion

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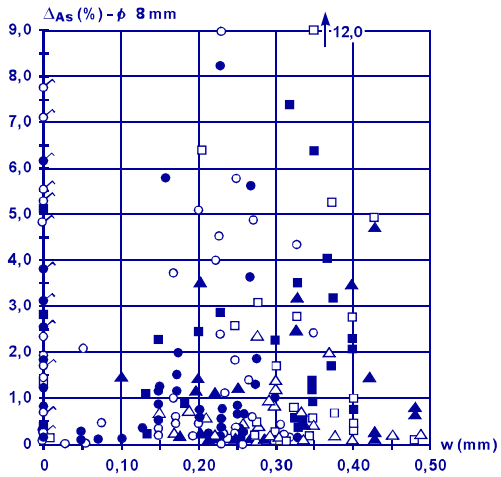
10 years outdoor exposure (Germany, without and with airborne salt)



Influence of cracks on corrosion

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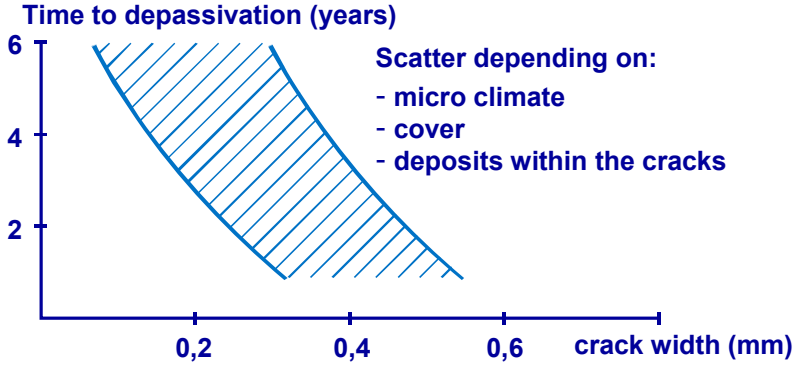
CO_2 and Cl^- penetrate much faster towards the reinforcement via cracks



Relation between crack width and corrosion

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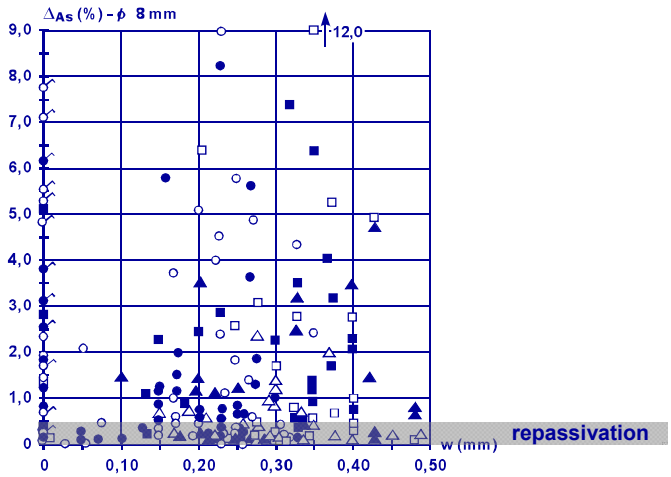

Corrosion of reinforcement in the area of cracks

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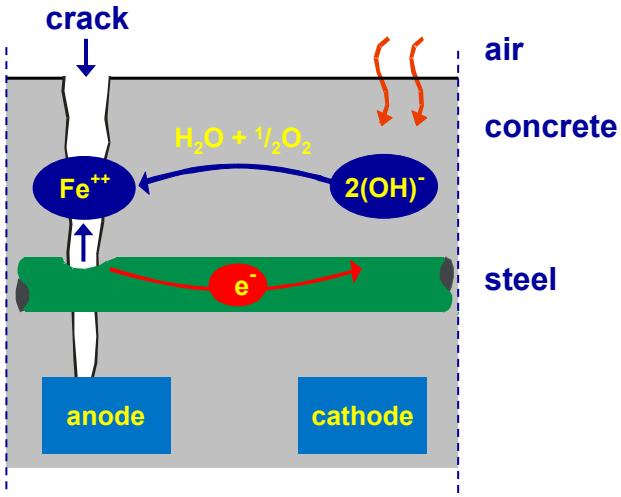
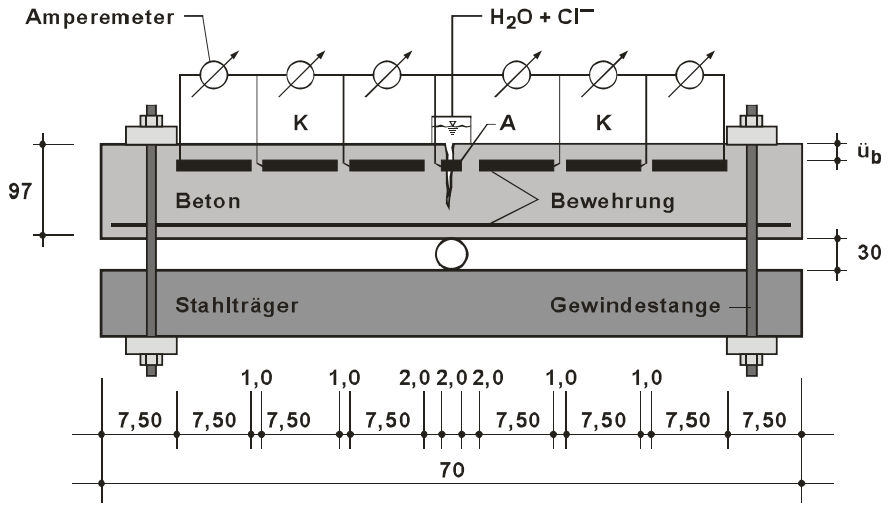
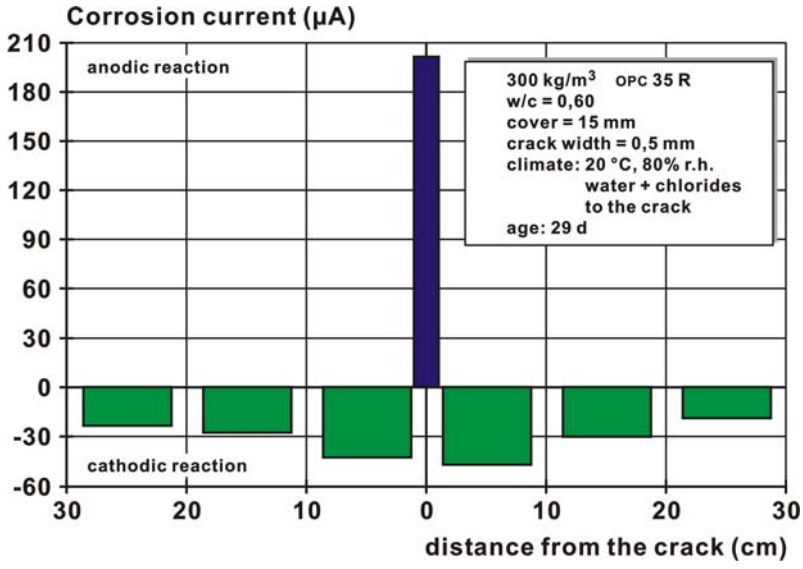


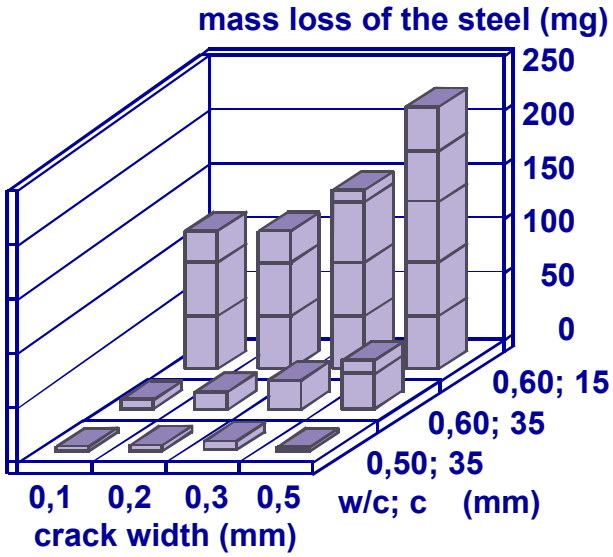
Measurement of corrosion in cracked concrete



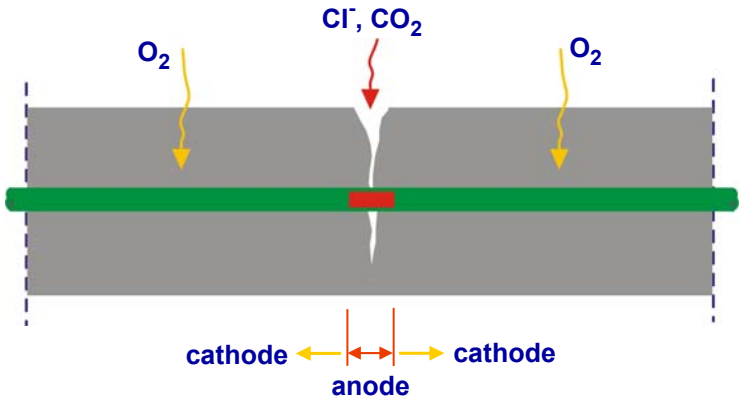
Corrosion of reinforcement in the area of cracks



Influence of cracks on corrosion



Influence of cracks on corrosion



Influence of cracks on corrosion

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Dominating factor

⇩

Quality of cover

Cracks – Durability Conclusions

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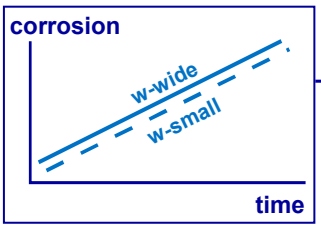

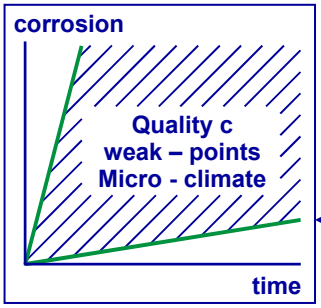

Corrosion rates remain small if

- **Good cover quality**
- **No spalling**
- **No weak points**

Other parameters than crack widths play the dominating role!

Cracks and Durability Practice - observations

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"Cover - Quality"
"Micro - climate" and "Weak points" within the structure dominating factors related to corrosion of reinforcement

Cracks as such are considered to exhibit damages
Crack widths w < 0,4 mm very seldom are causing serious corrosion
Exception: Transverse-cracks and chlorides

Brittle failures in the case of prestressing steels even with low corrosion attack; collapses in extreme cases!

Cracks – Corrosion Consequences

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No damages due to load induced cracking if A_s and c sufficient

No influence of crack width on corrosion (w = 0,15 - 0,35) → other criteria decisive

"accuracy" of crack formulae small

Crack width control by means of simple design rules (bar diameter and/or spacing)

No differentiation in admissible crack widths

Damages due to uncontrolled cracking due to restraint ($\sigma_s > R_e$)

Minimum reinforcement for restrained structural elements

1. $\sigma_s < R_e$
2. w

Cracks and Corrosion
- Special protection measures - Example

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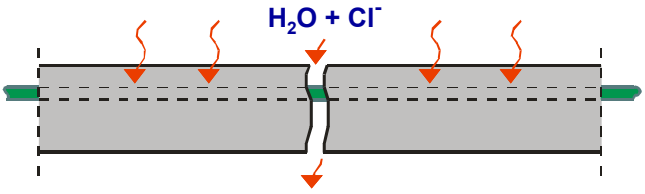
Chloride attack to concrete with "transverse"-cracks



- **Frequent wetting and drying**
- **High Cl^- - concentrations within the cracks after short periods**

Cracks and Corrosion
- Special protection measures - Example

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- **Crack width limitation does not help!**

⇨ **Special protection measures necessary!**

- **Avoid chloride attack - from the beginning! (Linings, claddings, coatings)**
- **Cathodic protection (prevention)**

Limitation of crack widths in RC- Structures

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Limitation of crack widths

- for corrosion control not necessary
- may be important for other reasons
  - water tightness
  - other functional requirements if reliant

Corrosion of prestressing Steel

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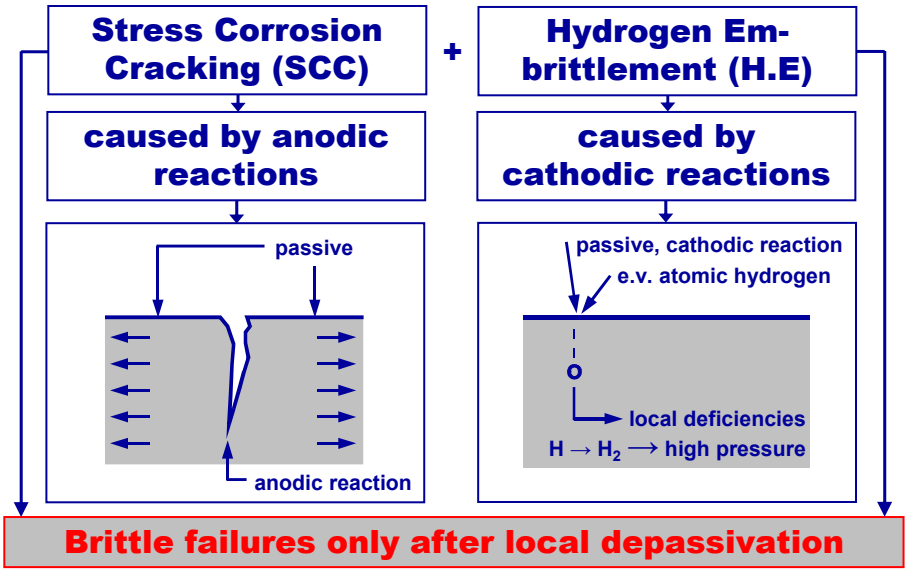


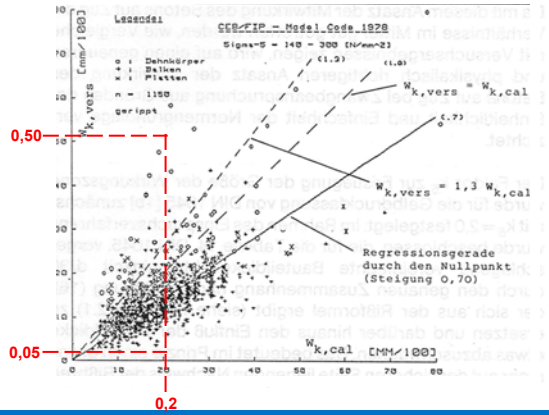
Corrosion protection of prestressing steel

Crack width limitation EC2	
Frequent loads	
wk ≤ 0,2	X0, XC1
wk ≤ 0,2	post tensioning XC2 – XC4
Decompression	XD, XS

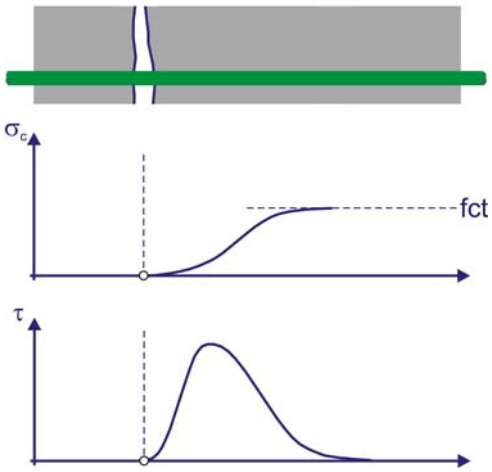
Prediction of crack widths using crack formular

Type of crack formular like EC2

Comparison of the results $w_{k,vers}$ width calculated values $w_{k,cal}$ 95 % fractile values



Reason for inaccuracy of all crack formulas



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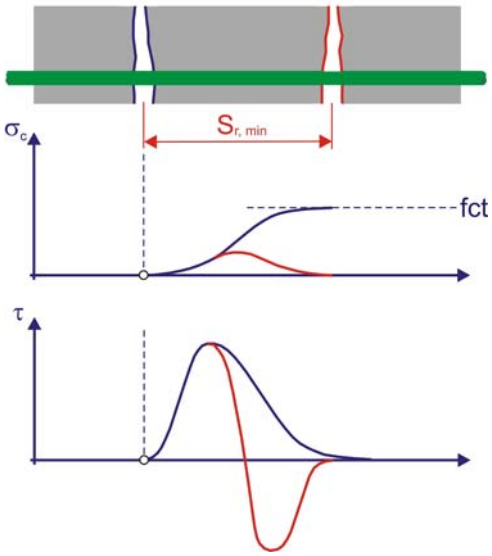

$$S_{r,\,max} \cong 2{,}0 \times S_{r,\,min}$$

$$S_{rm} = 1{,}5 \times S_{r,\,min}$$

$$w_k = \Sigma K \times S_{r,\,max} \times \varepsilon_{Sm}$$

$$f\,(f_{c\tau}\,,\, f_{ct})$$

Scatter !

Consequences of crack width limitation

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Structural consequences of rebar corrosion at cracks

- **Loss of cross section ΔA_s**

  Low risk of spalling due to limited corroding area

Possible measures to limit crack widths

- **Decrease of steel stress ⇨ costs !**
- **Decrease of cover ⇨ dramatic increase of corrosion !**
- **Decrease of bar diameter**

Consequences of decreasing bar diameter to reduce crack widths

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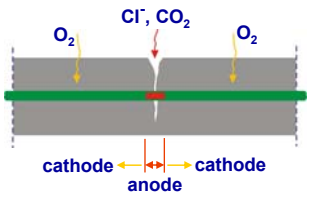

Decrease of bar diameter

⇩

Decrease of crack widths ⇨ **percentage of cracks with relevant corrosion decreases**

⇩

Decrease of crack spacing ⇨ **increase of number of crack per length unit**

Decreasing crack spacing

⇩

$A_{cathode}$ **decreases**

Decreasing crack width, decreasing bar diameter

⇩

A_{anode} **decreases**

$\frac{A_{cat}}{A_{an}}$ **= unchanged**

① **Number of cracks with relevant corrosion unchanged**

⇩

② **Corrosion depth t_c unchanged**

Consequences of decreasing bar diameter on corrosion

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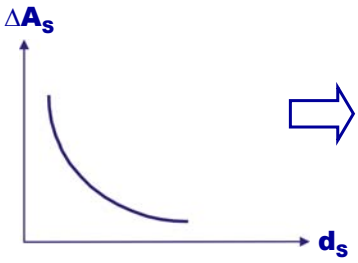
decrease unchanged

$$\text{Loss of cross section } \Delta A_s = 1 - \frac{(d_s - 2\,t_c)^2}{d_s^2}$$



Limitation of crack widths by decreasing bar diameter rather increases loss of cross section

Conclusion with respect to crack widths limitation and reinforcement corrosion

(Ordinary reinforced Concrete)

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- **Crack widths limitation by reducing bar diameters contra productive**
- **Other factors than crack widths decisive for corrosion rate (cover quality, micro climate)**
- **Provide extra protection in case of severe conditions (chloride attack, transverse cracks, horizontal surface e.g. parking decks). Crack width limitation does not help**
- **Crack width limitation may be important for others reasons**
- **Conclusion not transferable to prestressed structures (Avoid depassivation of prestressing steel !)**