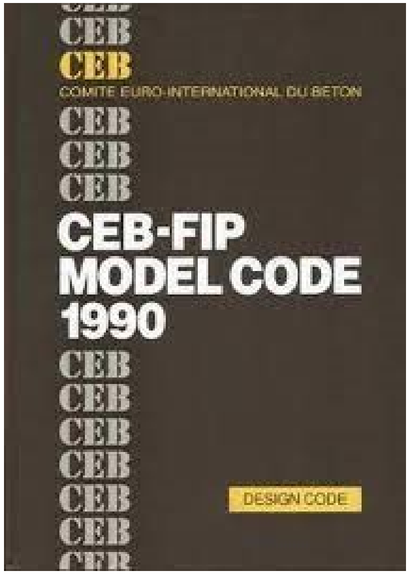
MC2020 Approach to the assessment of concrete structures

Stufib, October 11th 2023

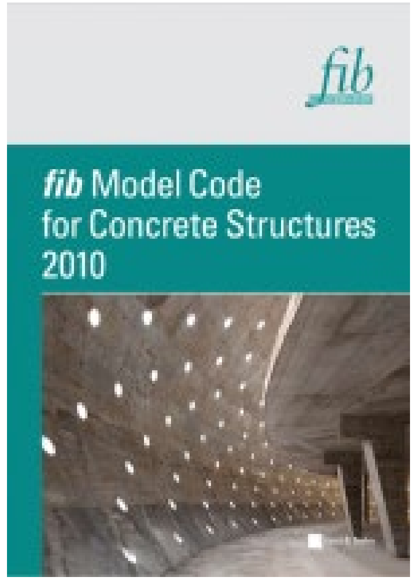
Joost Walraven

Delft University of Technology

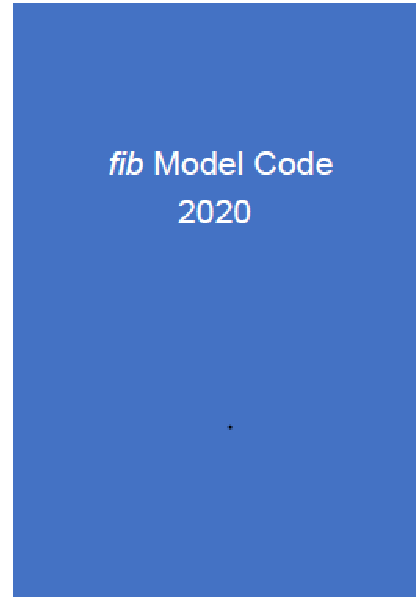
Development of priorities in *fib* Model Codes



Improvement of ULS en SLS models

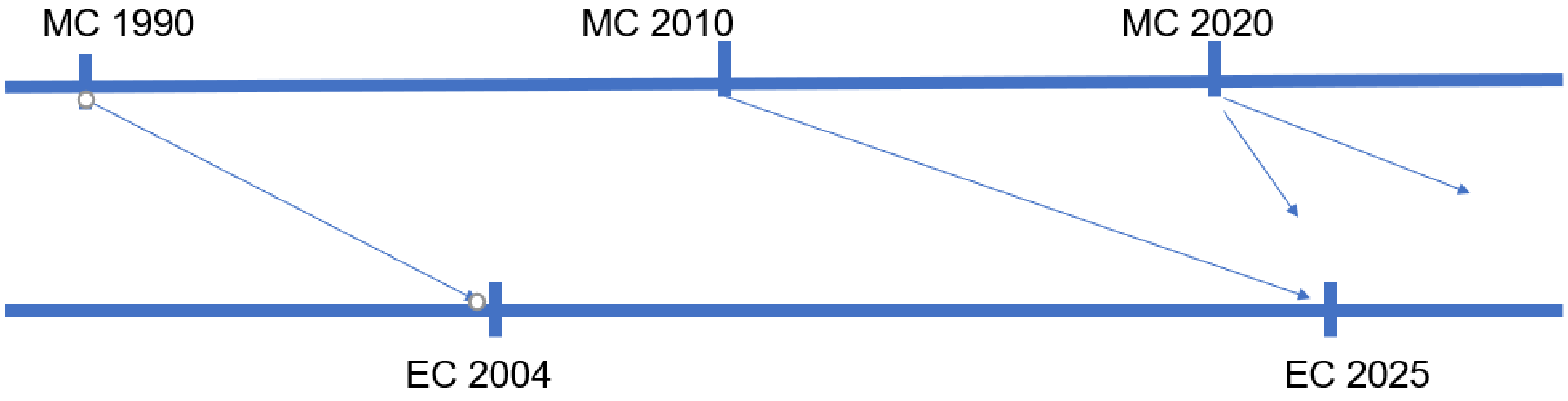


- Introduction of durability models
- Introduction of Levels of Approximation (LoA)
- Principles of life cycle management



- Design of new and assessment of existing structures
- Further refinement of behavioural models
- Introduction of sustainability as a leading principle

New ideas about design and assessment to be introduced in new codes.



Flow of new ideas: through *fib* Model Codes into Eurocodes

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Design of new structures and assessment of existing structures

Do we need one integral code for the design of new and the assessment of existing structures? Or should separate codes be preferred?

Categories of structures to be regarded:

- Existing structures without deterioration but subject to higher loads than assumed in the original design
- Existing structures with deterioration
- Existing structures with non-compliant details

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Content of Model Code 2020

Part I: Scope and Terminology
Part II: Basic Principles
- 3. Sustainability perspective
- 4. Principles of performance-based approaches
- 5. Life cycle management
- 6. Principles of quality and information management
- 7. Principles of execution
- 8. Principles of conservation
- 9. Principles of circularity and dismantlement
- 10. Implementation of quality and information management during LCM

Part III: Principles of structural performance evaluation
- 11. Structural performance evaluation framework
- 12. Principles of structural design and assessment

Part IV: 13. Actions on structures
Part V: Input data for materials
- 14. Concretes: mechanical properties, carbonation, chloride ingress, freeze -thaw attack, chemical attack, internal expansion mechanisms, leaching, abrasion,

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Content of Model Code 2020

Part V (cont) 15. Reinforcing steel
16. Prestressing and prestressing systems
17. Non-metallic reinforcement
18. Fibre reinforced concrete
19. Materials and system for protection, repair and strengthening

Part VI: Input data for interfaces
20-22. Bond of embedded steel reinforcement
23: Concrete to concrete
24: Concrete to steel
25: Anchorages in concrete

Part VII: Design and assessment (585 p.)
26. Conceptual design
27. Approach to design
28: Approach to assessment
29: Structural analysis
30: Evaluation of structural performance
(for new and existing structures) (446 p.)

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Content of Model Code 2020

Part VII (cont) 31. Evaluation of other aspects of social performance
32. Evaluation of environmental performance
33. Evaluation of economic efficiency
Part VIII Execution
Part IX Conservation
Part X Circularity and dismantlement

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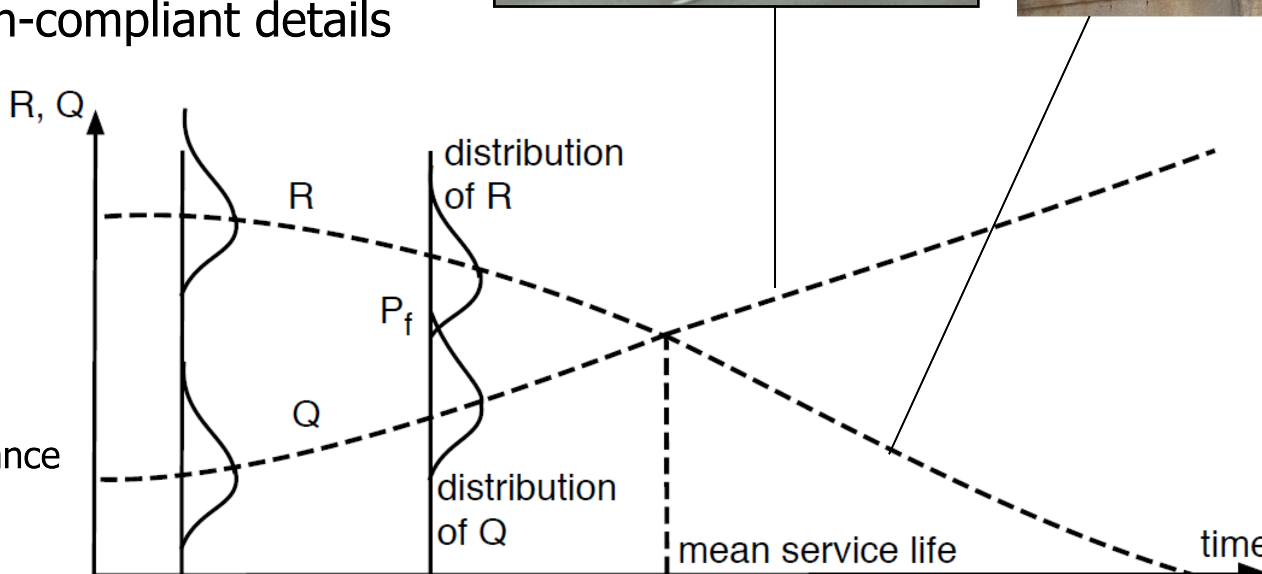
Determination of structural safety and its development in time: main aspects

- Determination of bearing capacity as accurately as possible;
- Influence of deterioration: actual state and development in time;
- Effect of non-compliant details



R = Resistance
Q = Load

Determination of structural safety and its development in time

- Determination of bearing capacity as accurately as possible
- Influence of deterioration in time: actual state and future development
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Use of Level of Approximation approach in the Model Code for any aspect of bearing capacity;
Overview of assessment levels in chapter 28 ("Approach to assessment"):

A0: informal qualitative assessment;
A1: measurement-based determination of load effects;
A2: Assessment based on codes, design and visual inspection (partial factors).
A3: Partial factor method, based on supplementary site investigation (refined models)
A4: Modified target reliability – modification of partial factors;
A5: Full probabilistic assessment

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A2: Partial factor method, based on document review and visual inspection
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Target reliability for assessment of existing structures (ULS)

The target reliability levels for existing groups of structures, may differ from those for new structures, for:

- Economic reasons
- Societal reasons
- Sustainability considerations

See chapter 11.3.2.3 "Target reliability levels for assessment of existing structures"

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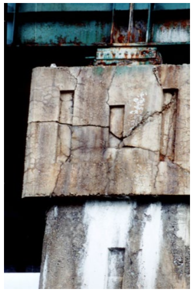
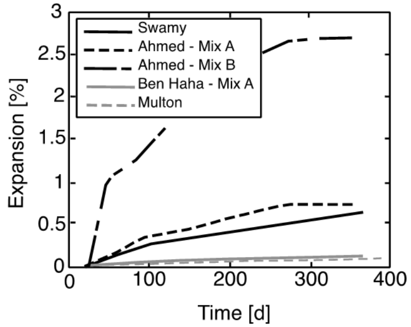
Chapter 14: Concrete (93 p.)

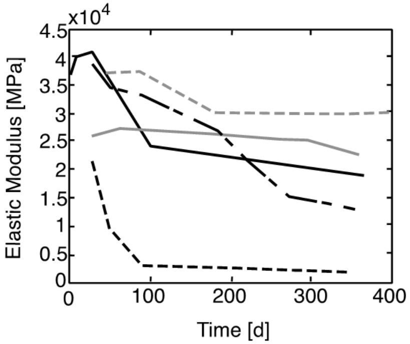
14.7: Transport of liquids, gases and ions in hardened concrete

14.8 Properties describing/defining durability:

- chloride ingress
- freeze-thaw deterioration
- chemical attack
- internal expansion mechanisms: ASR, Delayed ettringite formation
- leaching
- abrasion, erosion and cavitation







Determination of structural safety and its development in time

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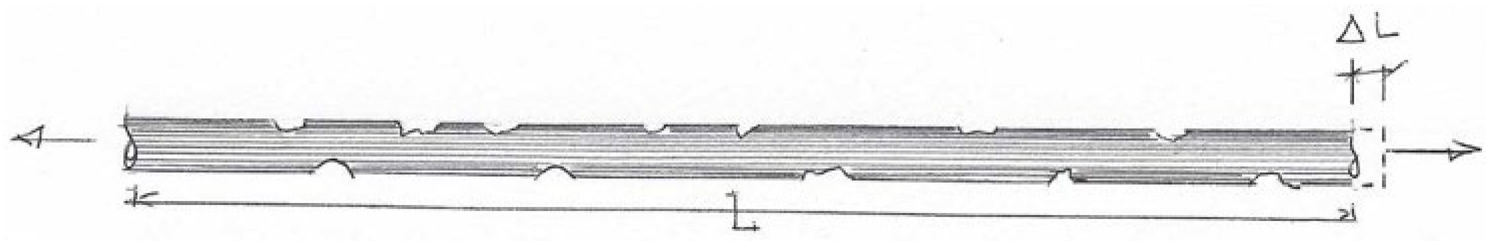
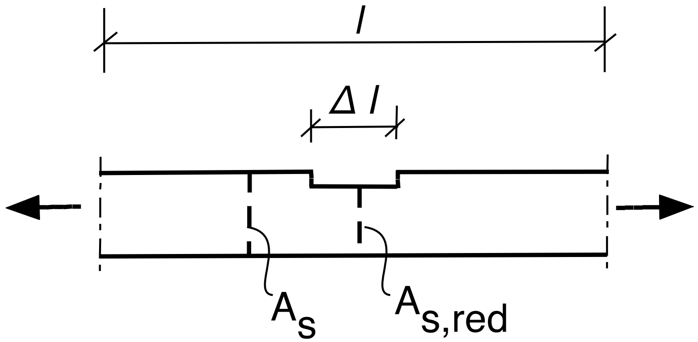
Chapter 15: Reinforcing steel

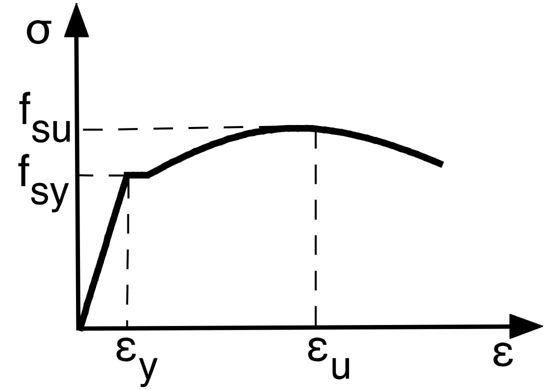
15.11.2 Reinforcing steel with deterioration or defects:
- reduction of cross-sectional area
- reduction of ductility



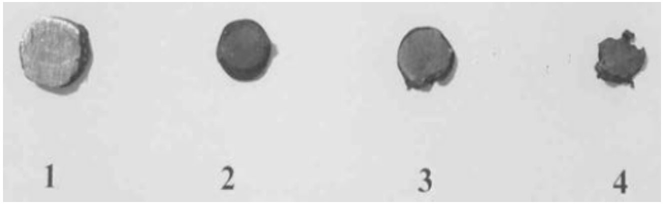
Steel bar with cross-section variation due to pitting corrosion

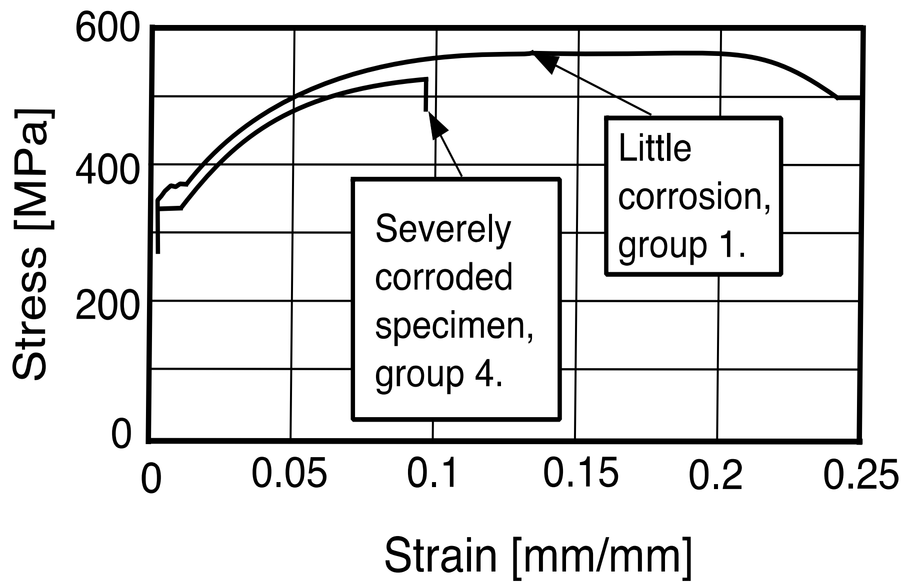
Effect of pit geometry on properties of rebars





Depending on pit geometry and
σ - ε relation of undamaged steel:
- reduction of tensile capacity
- reduction of ultimate strain
- or both





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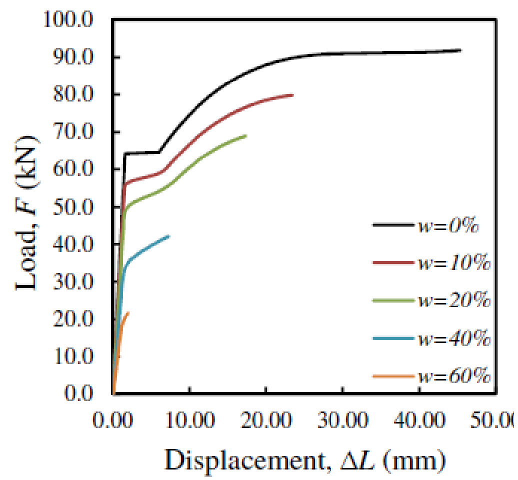
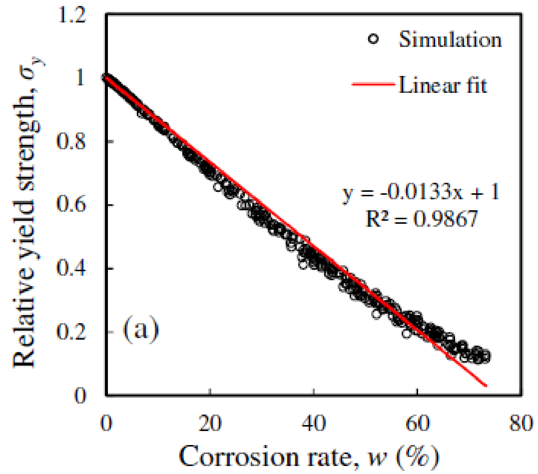
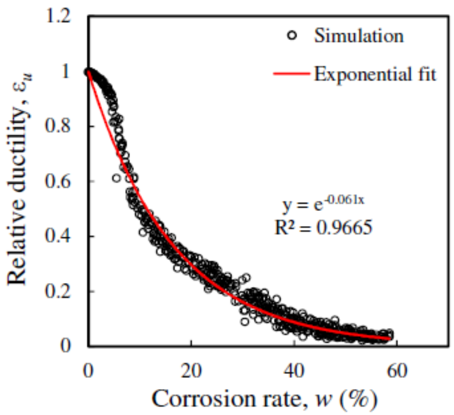






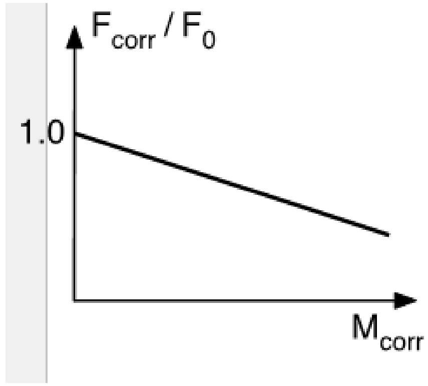
Properties of steel with pitting corrosion

Results of Zeng et al. Shenzhen University 2021, Construction and Building Materials, Oct. 2020

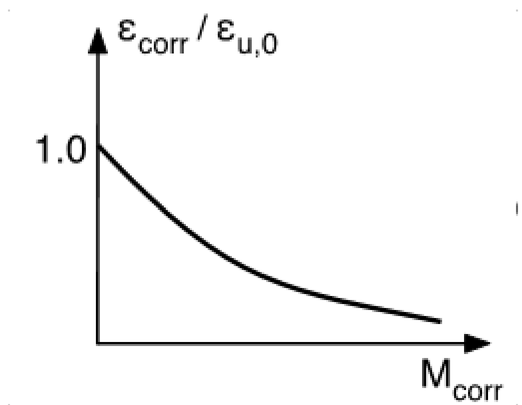
Change of mechanical properties of reinforcing steel due to corrosion

MC 2020 Ch. 15.11.2

(a)



(b)



(a) Loss of axial tensile strength due to loss of weight by corrosion M_{corr} in %: $F_{corr}/F_0 = 1- \alpha M_{cor}$

(b) Loss of ultimate strain due to loss of weight by corrosion M_{corr} in %: $\varepsilon_{u,corr}/\varepsilon_{u0} = e^{-\beta M}$

Case considered	Type of corrosion	α	β
$F_{y,corr}/F_y$	Uniform	1.45	-
	Pitting	2.0	-
$F_{t,corr}/F_t$	Uniform	1.25	-
	Pitting	1.85	-
$\varepsilon_{u,corr}/\varepsilon_u$	Uniform	-	2.0
	Pitting	-	5.5

Determination of structural safety and its development in time

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Assessment of structures with deteriorated materials

As much as possible use is made of the models for non-deteriorated structures:

Chapter 30: "Evaluation of structural performance", (446 p.)
Chapter 30.1.11 "Evaluation of structural safety (ULS) for deteriorated structures":

- Structures affected by ASR;
- Structures with corroded reinforcement;
- Structures damaged by freeze-thaw effects;
- Structures subjected by sulphate attack.

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Structural behaviour of concrete structures with ASR

Chapter 30.1.11.2

- Diagnosis for ASR
- Extent of condition analysis for ASR
- Monitoring ASR-affected structures
- Impact ASR on plain concrete properties
- Impact of ASR on axial capacity of reinforced concrete elements
- Impact of ASR on flexural capacity of concrete members
- Impact ASR on shear capacity
- Impact ASR on punching shear capacity
- Impact ASR on anchorage of deformed reinforcing bars
- Potential of reinforcing bar fracture in ASR-adduced concrete
- Analysis of ASR-affected reinforced concrete structures

Free expansion: crack formation in all directions

Restrained expansion: crack formation only in X-direction

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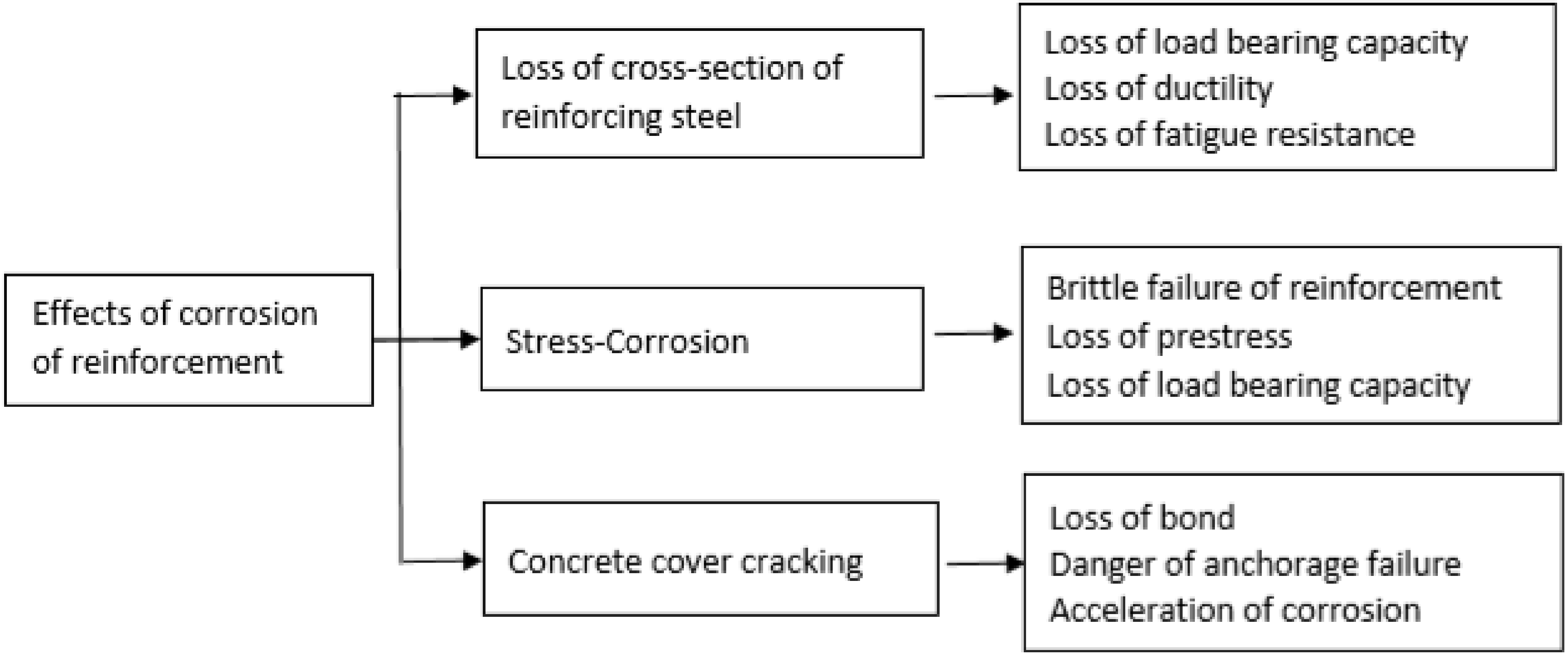
Structural behaviour of concrete structures with corroded reinforcement

Chapter 30.1.11.3



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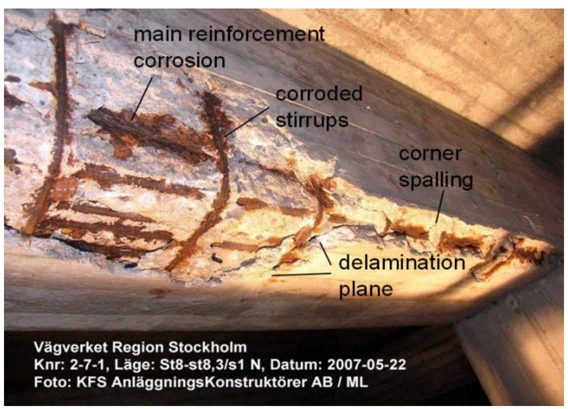
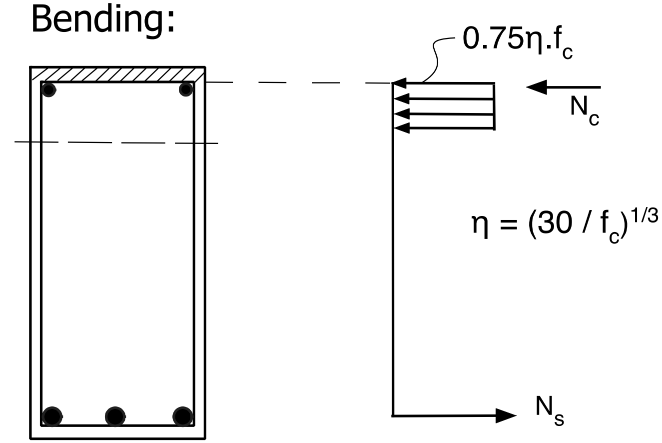


Example: Assessment of structures with corroded reinforcement

Bending:



- Reduction of concrete strength in compression zone due to splitting effect of corroded reinforcement
- Reduction of cross-sectional area of reinforcing steel
- Reduction of bond strength due to corrosion
- Reduction of anchorage strength due to corrosion

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Determination of structural safety and its development in time

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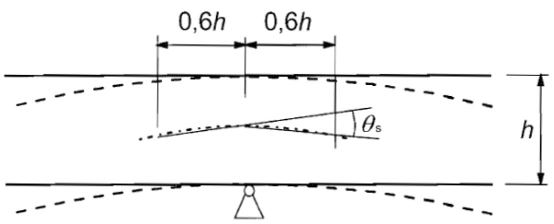
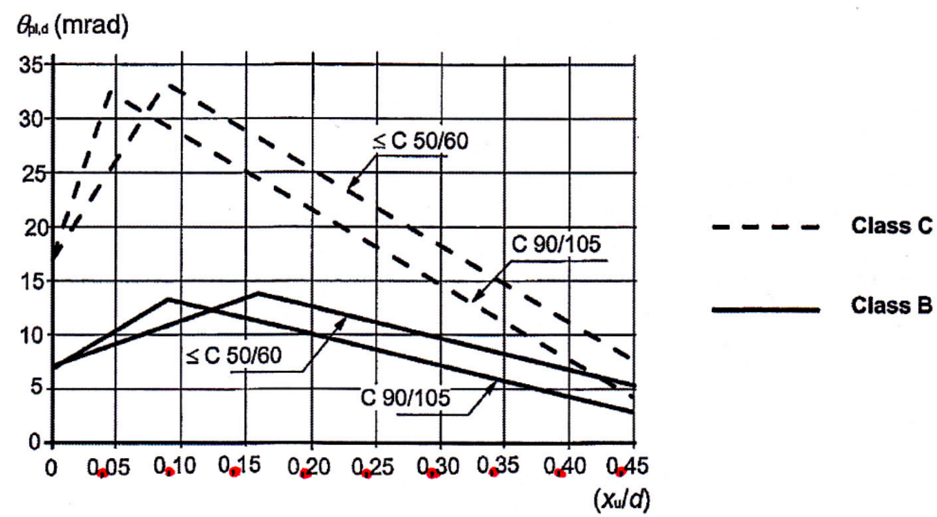


maximum design rotation is $1.2h \cdot \theta_{pl.d}$

Rotation capacity



- Reduction of rotation capacity due to loss of ultimate strain due to reinforcement corrosion

Uncorroded reinforcement:
Class B: $(f_t/f_y)_k \geq 1.08$ and $\varepsilon_{uk} \geq 5‰$
Class C: $(f_t/f_y)_k \geq 1.15$ and ≤ 1.35 and $\varepsilon_{uk} \geq 7.5‰$

Assessment of the bearing capacity of structures with deteriorated or damaged components

7.4.9 Effects of deterioration on the shear capacity (LoA 2)

$$V_{Rd,det} = V_{Rdc,det} + V_{Rds,det}$$

Design shear resistance of corroded member

Concrete contribution

Contribution of shear reinforcement

$$V_{Rd,c} = k_v \frac{\sqrt{f_{ck}}}{\gamma_c} z b_w$$

Including bond reduction factor k_b for long. reinforcement

$$V_{Rds,det} = z \cdot cot\theta \cdot \frac{A_{sw,red} \cdot f_{ywd}}{s}$$

Strut angle to be limited because of reduced ductility of reinforcing steel

Shear resistance of members with corroded shear reinforcement and longitudinal reinforcement

Effects of deterioration on the shear bearing resistance

$$V_{Rd\,max,det} = k_{c,det}\frac{f_{ck}}{\gamma_c} b_{w,det} z_{det} \cdot sin\theta cos\theta$$

Upper limit of design shear due to crushing of concrete struts

Strength reduction factor for concrete in struts

Reduced concrete web width due to deterioration

Reduced inner lever arm by loss of cover

Limited strut rotation

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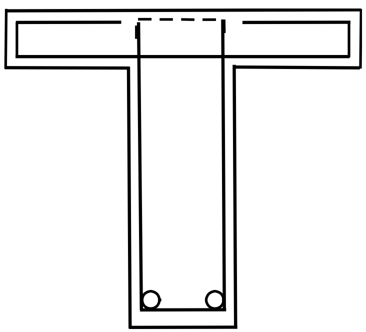
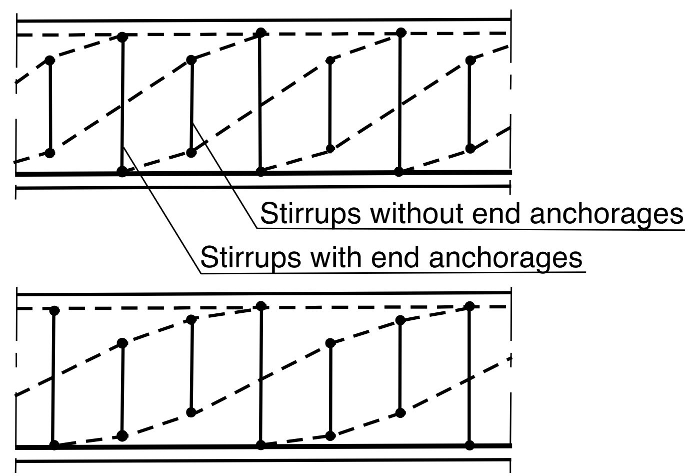
Assessment of the bearing capacity of structures with deteriorated or damaged components

7.4.9 Effects of deterioration on the shear capacity (LoA 2)

Applicability of models for the specific case of deterioration should be verified



Stirrups with anchorage
capacity reduced by corrosion



“Engineering solution”(Regan)

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Safety of structures with non-compliant details

- Determination of bearing capacity as accurately as possible
- Influence of deterioration in time: actual state and future development
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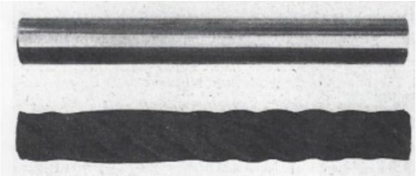
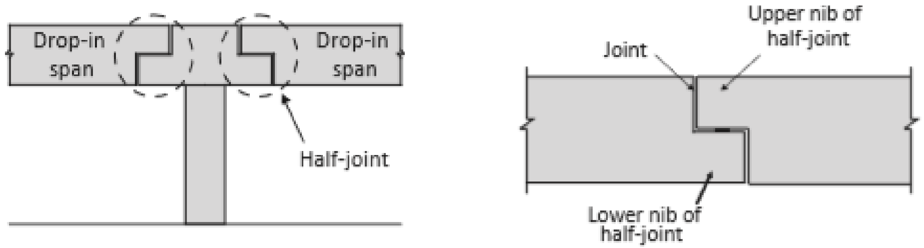
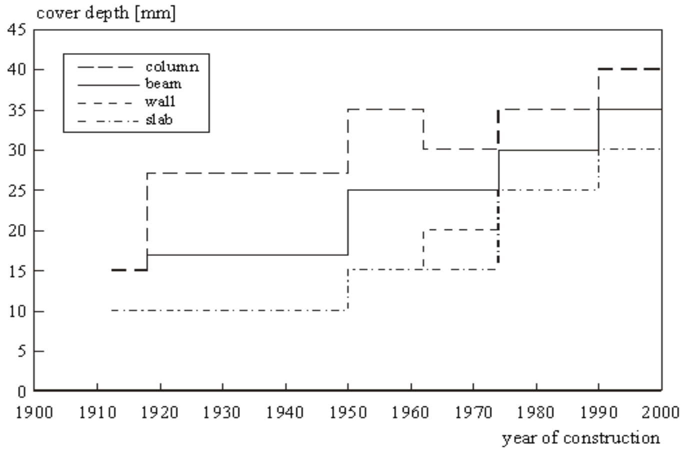
30.1.12 Evaluation of structures with non-compliant detailing: principles



Plain reinforcing steel instead of ribbed steel

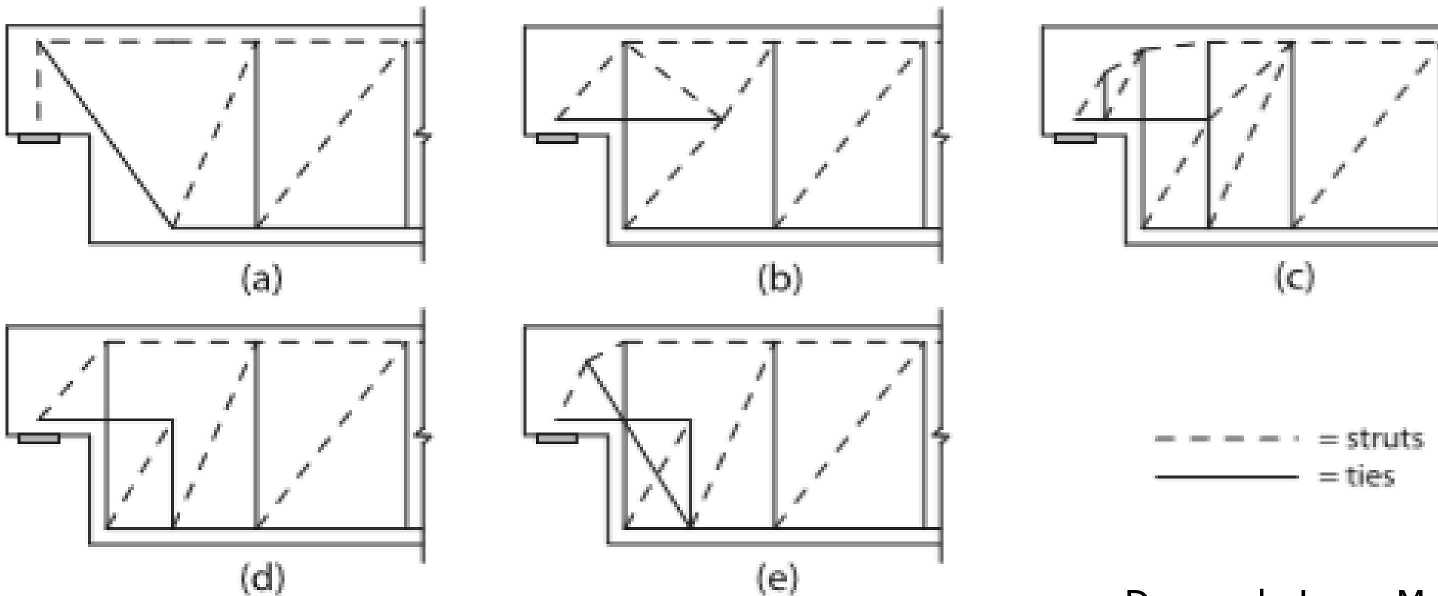


Half-joints in precast bridge girders, designed before the introduction of the strut and tie models



Development of required concrete cover in time

National investigation of safety of half-joints in the UK



Desnerck, Lees, Morley, Engineering Structures 2016 and 2018

To be verified whether a suitable strut and tie model can be found based on given placement, cross-sectional area and anchorage length of reinforcement.
But: more types of defects, and combinations, than expected!

Non-compliant detailing and durability

Non-compliant details should not only be considered in relation to structural safety (ULS) but also to service life.

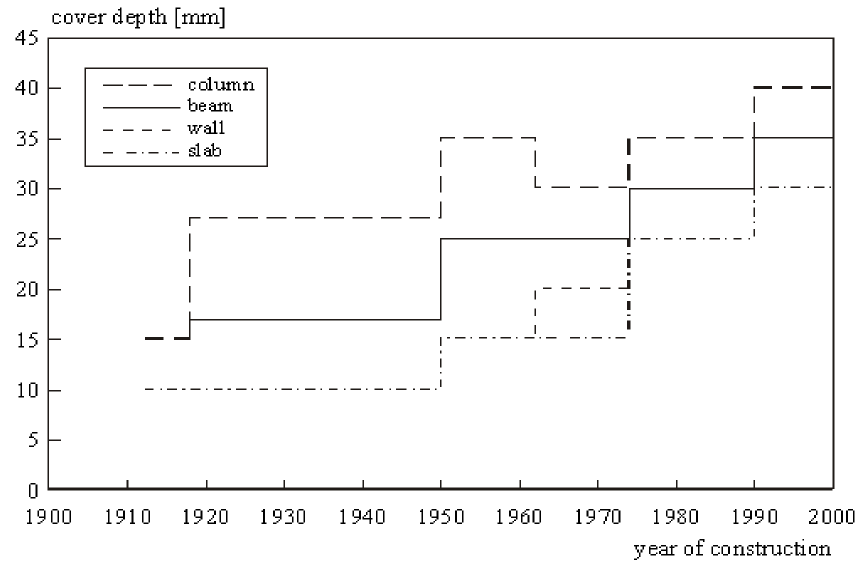
Chloride profiles to be derived from drilled cylinders

$$C(x,t) = C_s - (C_s - C_i) \cdot [erf \frac{x}{2 \cdot D_{app}(t) \cdot t}]$$

Analysis based on measurements of chloride profiles and concrete cover for predicting the probability of degrees of corrosion

Basic considerations are found in MC 2020 Chapter 30.6

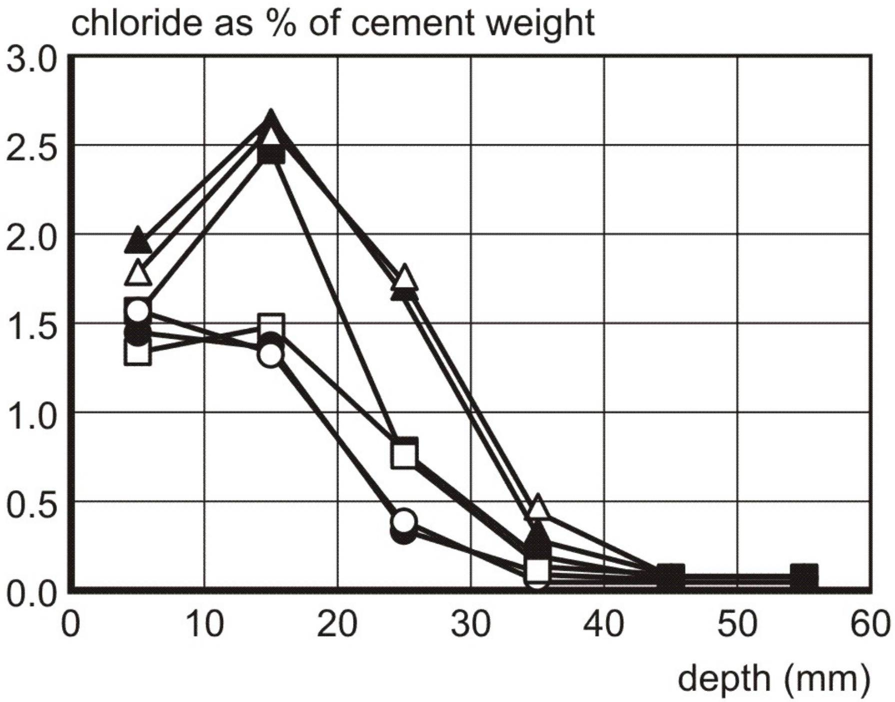
Development of minimum cover in the Netherlands from 1900 -2000



Chapter 30.6 Evaluation of condition limit states (CLS) associated with durability (36p.)

Probabilistic treatment of chloride attack?

Chloride profiles derived from 6 cores in an area of 1 m^2 (Eastern Scheldt Barrier)



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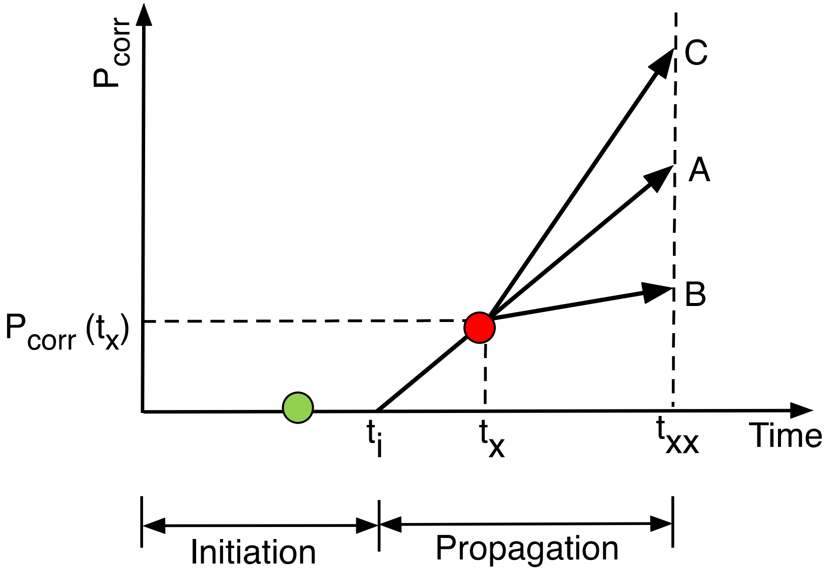
Evaluation of condition limit states associated with durability



- Mechanical properties well-known, mostly function of concrete strength after 28 days
- Models calibrated with many tests
- High Level of Accuracy realistic

- Mechanical properties to be measured at structure
- Larger variability of concrete properties in structure
- Behavioural models derived for design with undamaged components
- Future development not always well predictable
- Prudence required for application of high level of approximation

Summary MC 2020

- MC 2020 is a new code, which gives an integral basis for both the design of new structures and the assessment of existing structures.

- For the assessment of existing structures three categories are considered:
- structures loaded to a level higher than assumed in the original design;
- structures which have lost a part of their bearing capacity due to deterioration;
- structures designed according to outdated codes (with non-conforming details).

For those categories in the *fib* MC 2020 extended practical information is given, enabling in-depth analysis.

fib Bulletin 111

Modelling Structural Performance of Existing Concrete Structures

State-of-the-Art Report

September 2023