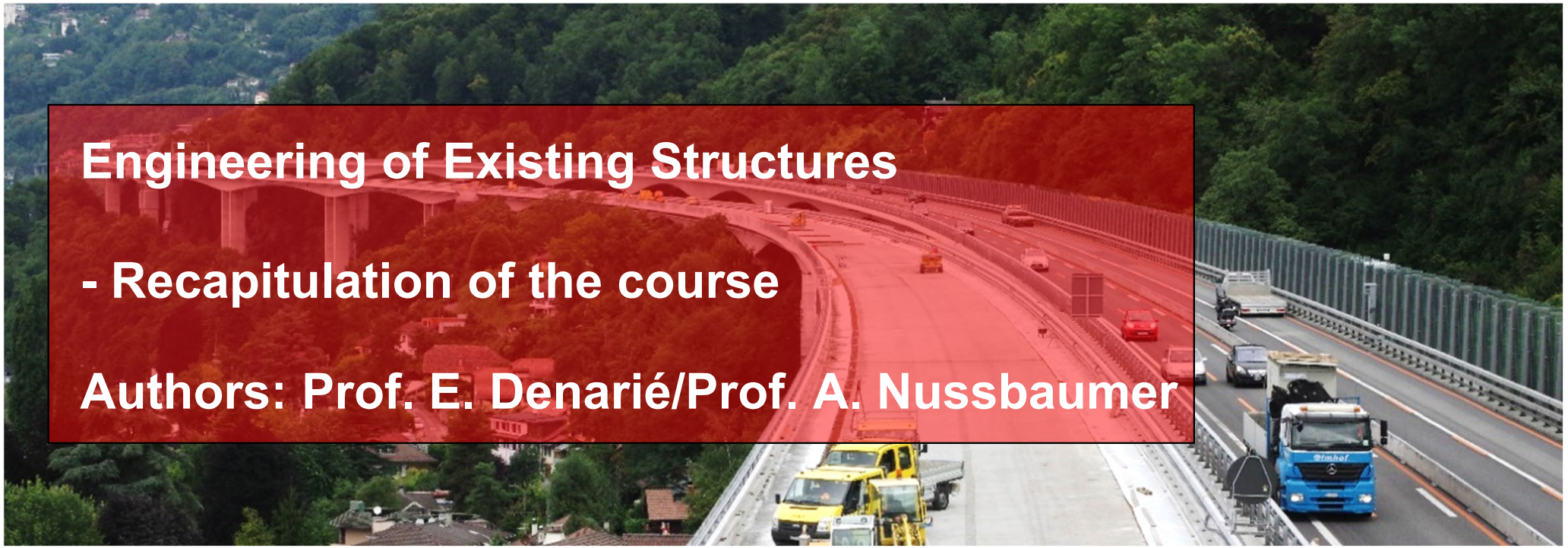
Engineering of Existing Structures - CIVIL-511
Civil Engineering - Master 1 and 3
Teachers: Prof. Emmanuel Denarié, Prof. Alain Nussbaumer



Engineering of Existing Structures

- Recapitulation of the course

Authors: Prof. E. Denarié/Prof. A. Nussbaumer

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Recapitulation of the course

Methodology for engineering of existing structures

➔ Routine condition surveys, monitoring

➔ Examination

- Evaluation of value
- Condition evaluation
- Updating of:
  - structural model
  - effect of actions
  - resistances

➔ Upon needs, recommandation of:

- urgent safety measures
- intervention

➔ Keep structure documentation up to date

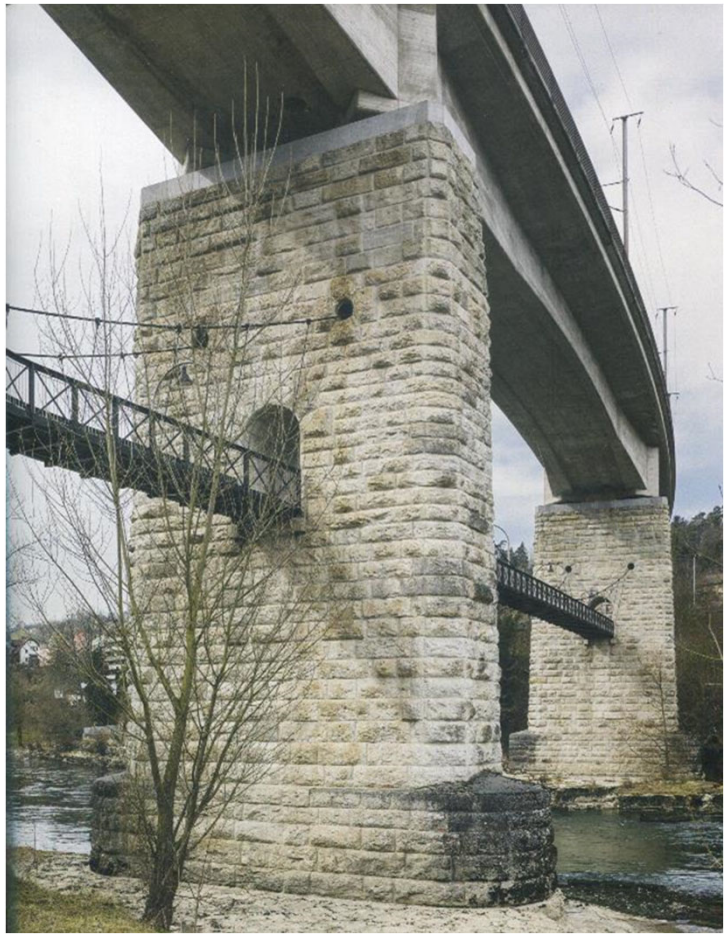
➔ Avoid as far as possible construction interventions

➔ Check proportionality of interventions

➔ Preserve cultural value

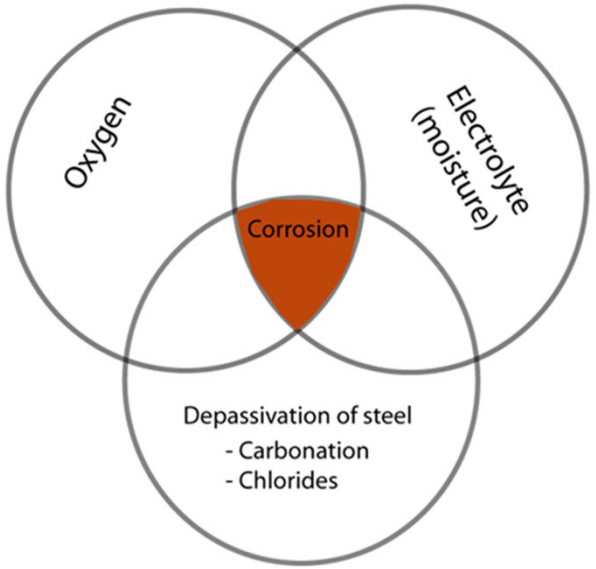
Chapter 1

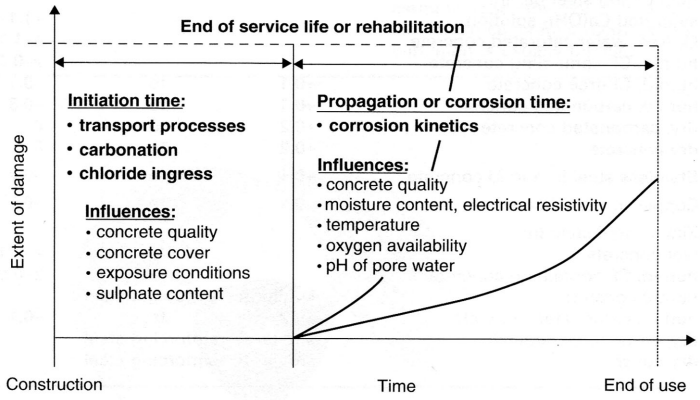
- Terminology of engineering of existing structures
- Value of existing structures
- Methodology after SIA 269
- Methodology different from that applicable to the design of new structures and not usable for them.



Chapter 2

- Exposure classes
- Transport phenomena
- Driving forces of deterioration phenomena
- Necessary factors
- Heterogenous structure of cementitious composites
- Initiation vs Propagation
- Carbonation
- Corrosion with carbonation and/or Chlorides

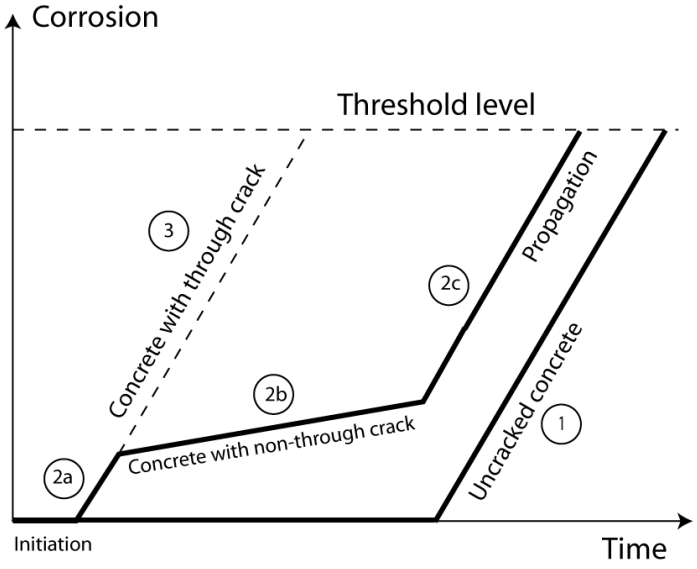


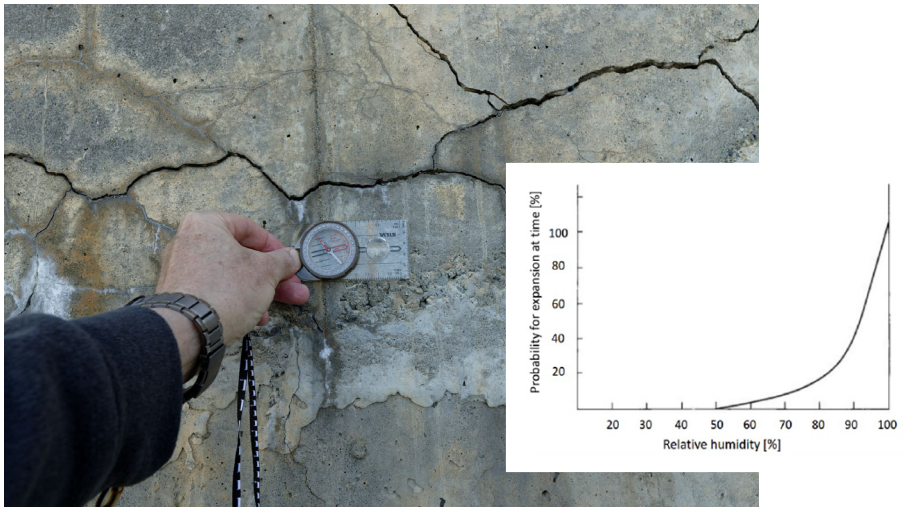


1.5 Extent of corrosion damage over time. The initiation period depends on a variety of parameters such as concrete quality and concrete cover. The propagation period is governed mainly by the electrolyte resistance influenced by temperature and moisture content and to a smaller part by electrochemical reaction resistances.

Chapter 3

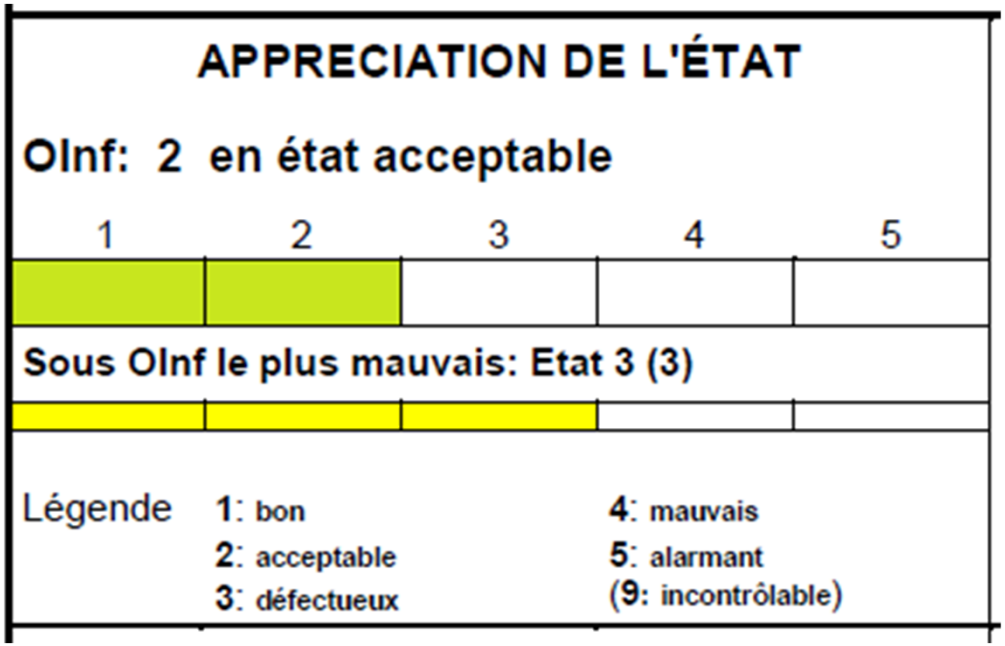
- Effects of cracking on corrosion
- Freeze-thaw attack
- De-icing salts
- Entrained air
- Swelling reactions
- AAR
- Sulphates attack (external and internal)
- Effect of liquid water and RH





Chapter 4

- Examination
- Stepwise approach
- Condition survey
- Risk-based visual inspection
- Assessment of structural safety and serviceability
- Degree of Compliance "n", on the basis of updated resistances and action effects.



$$n = \frac{R_{d,act}}{E_{d,act}} \geq 1$$

Chapter 5: $E_{d,act} = \gamma_{F,act} \cdot E_{k,act}$

Updating of actions, effects of actions

- Statistical, semi-probabilistic analysis, of data, measurement
- Relationship COV ↘ - $\gamma_{i,act}$ ↘
- $\gamma_{F,act}$ includes model uncertainty
- Of permanent actions: $G_{Ed,act} = \gamma_{Gi,act} \cdot G_{mean}$
- Of a variable action:
  - According to effective and planned use (incl. suppl. safety measures)
  - Traffic loads: $Q_{Ed,act} = \gamma_{Qi} \cdot \alpha_{Qi,act} \cdot Q_{rep}$
  - Of dynamic effects: road, track condition ⇔ very low in CH
  - Of climatic actions: site relevant new info, return period, ref. period = observ. block max
  - Of accidental actions: based on risk analysis

Road bridges (same LM1 model):

Bridge type		Span [m]	$\alpha_{Q1,act}$	$\alpha_{Q2,act}$	$\alpha_{qi,act}$, $\alpha_{qr,act}$
Beam	Box girder	20–80	0,70[1) 2)]	0,50[1) 2)]	0,50[1)] (0,70[2)])
	Two girders	20–80			0,40[1)] (0,70[2)])
	Multiple girders	15–35			

Railway bridges (different load models):

Track class	Nominal axle load Q_{act} [kN]	Geometrical properties of the model vehicles, dimensions in m
C3	200	1,5 ↓ 1,8 ↓ 4,50 ↓ 1,8 ↓ 1,5 — 11,10
C4	200	1,5 ↓ 1,8 ↓ 3,40 ↓ 1,8 ↓ 1,5 — 10,00
D3	225	1,5 ↓ 1,8 ↓ 5,90 ↓ 1,8 ↓ 1,5 — 12,50

Chapter 6

- Updated material properties, effect of age
- Updating of resistances
- Verification of structural safety and serviceability
- Exploit all possible reserves in existing structures

➔ Materials level

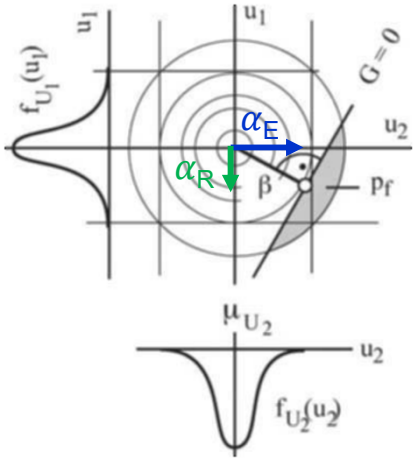
➔ Verification methods

- Focus on relevant properties, materials, and risk situations

$$R_{d,act} = \frac{\eta_{act} R_{k,act}}{\gamma_{M,act}}$$

Chapter 7

- Detailed examination: deterministic, semi-probabilistic (partial factors), or probabilistic verification (*G = R-E*)
- Focus: only where $n = R_{act}/E_{act} \ll 1$
- Which distribution (SIA 269, app. C)?
  - $G_{Ed,act} \Rightarrow$ **normal dist.**
    $E_{d,act} = E_{m,act}\,(1 + \alpha_E \beta_0 v_{E,act})$
  - $G_{Ed,act}$, $A_{d,act} \Rightarrow$ Gumbel law
  - $R_{d,act} \Rightarrow$ normal or log-norm. dist.
    $R_{d,act} = R_{m,act}\,(1 + \alpha_R \beta_0\, v_{R,act})$
- Check distribution law adequacy using probability plots or Q-Q plots
- Important cases: degradation, condition evaluation
- Limit state type 4, fatigue: need structural model behavior under service loads



α_i limit state sensibility factors

α_E = 0,7 effects of leading actions
α_E = 0,3 effects of accompanying actions
α_R = −0,8 ultimate resistances, of key importance
α_R = −0,3 of secondary importance

P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
$\beta = -\Phi^{-1}(P_f)$	1,28	2,33	3,09	3,72	4,26	4,75	5,20

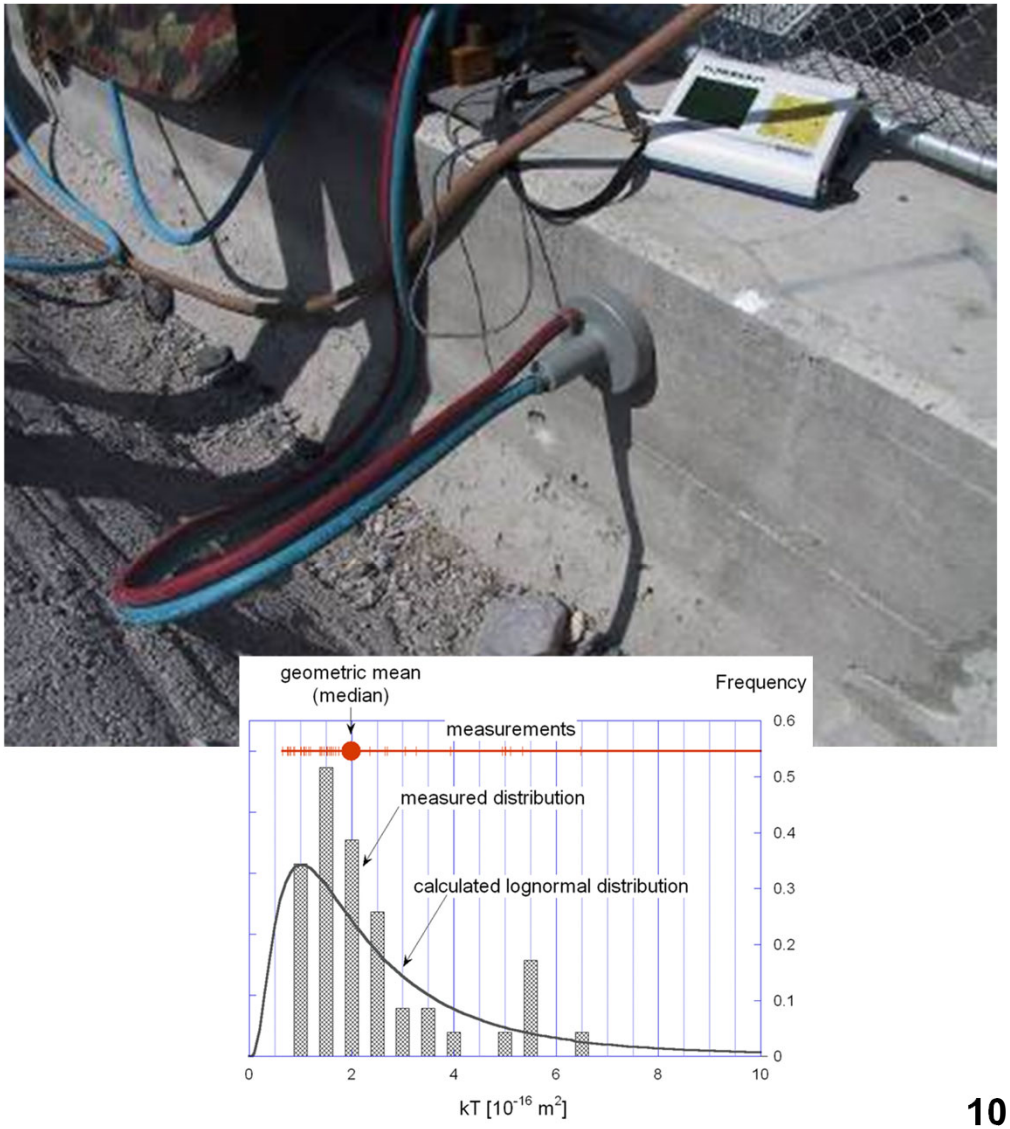
Source: EN 1990, Table C.2

	Consequences of structural failure		
Efficiency of intervention EF_M (see section on *Proportionality of safety-related interventions*)	Minor $\rho < 2$	Moderate $2 < \rho < 5$	Serious $5 < \rho < 10$
Low: $EF_M < 0,5$	3,1	3,3	3,7
Medium: $0,5 \le EF_M \le 2,0$	3,7	4,2	4,4
High: $EF_M > 2,0$	4,2	4,4	4,7

Source: SIA 269, Appendix B, Table 2

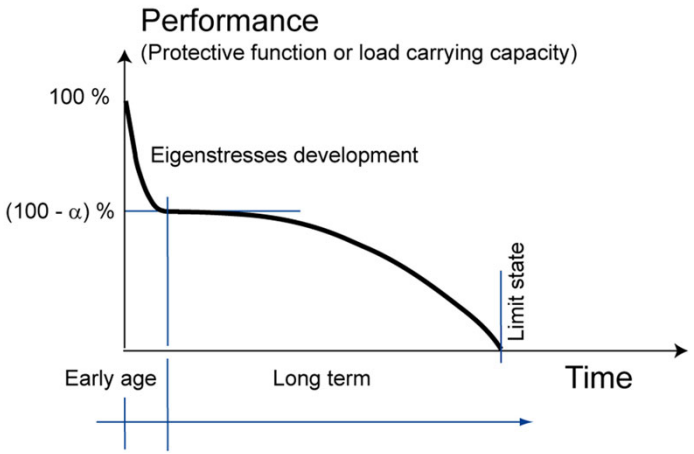
Chapter 8

- In depth condition assessment
- NDT methods
- Properties of cover concrete
- Water and gas permeability, resistivity
- Location of rebar
- Corrosion potential
- Georadar

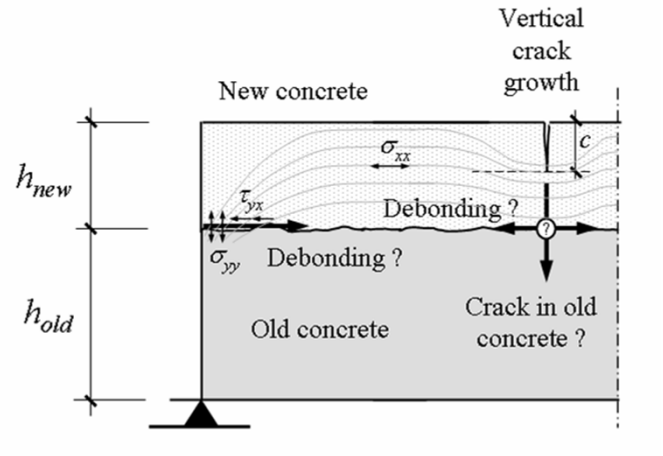


Chapter 9

- Thermomechanical effects
- Restraint (axial and Flexural)
- Mitigation of thermally induced through cracking at early age
- Concrete cooling (liquid N_2, ice, cooling pipes)
- Simplified design method



$$\mu = \frac{\sigma_{new,2}}{\sigma_{full}} = \frac{\sigma_{full} - \sigma_N - \sigma_{M,2}}{\sigma_{full}} = 1 - \mu_N - \mu_M$$



Chapter 10

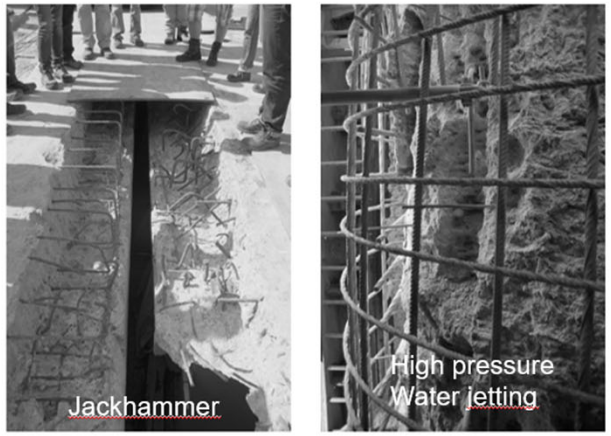
- Interventions on cover concrete
- Principles of intervention
- Electrochemical methods
- Realkalization
- Chlorides extraction
- Cathodic protection
- Hydrophobic impregnation, coatings
- Corrosion Inhibitors
- Replacement of cover concrete
- UHPFRC

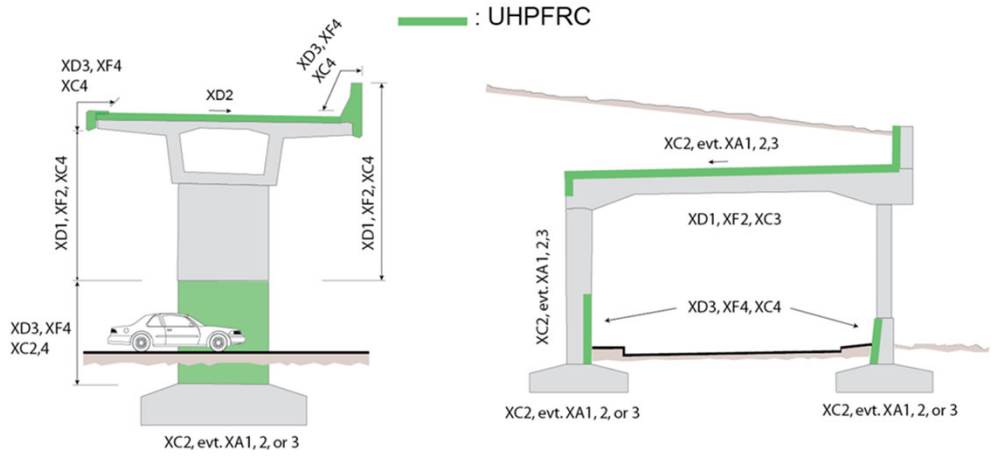
Table 1.1 Principles for repair and protection for damages of the concrete

Principle no.	*Principle and its definition*
Prinicple 1 [P1]	Protection against ingress
Prinicple 2 [MC]	Moisture control
Prinicple 3 [CR]	Concrete restoration
Prinicple 4 [SS]	Structural strengthening
Prinicple 5 [PR]	Physical resistance
Prinicple 6 [RC]	Resistance to chemicals

Table 1.2 Principles for protection against reinforcement corrosion

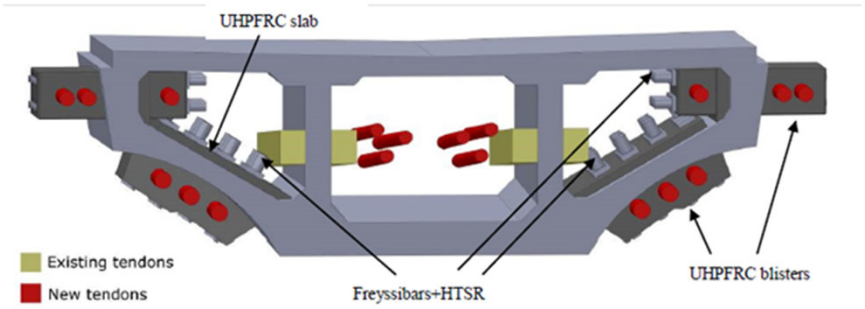
Principle no.	*Principle and its definition*
Prinicple 7 [RP]	Preserving or restoring passivity
Prinicple 8 [IR]	Increasing resistivity
Prinicple 9 [CC]	Cathodic control
Prinicple 10 [CP]	Cathodic protection
Prinicple 11 [CA]	Control of anodic areas

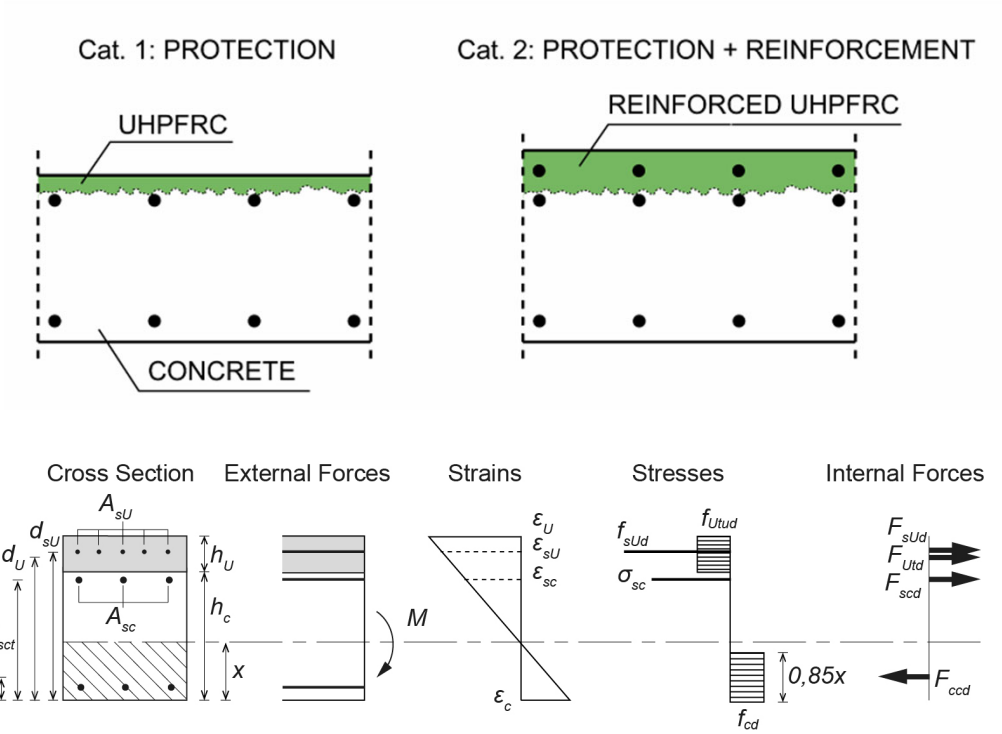




Chapter 11

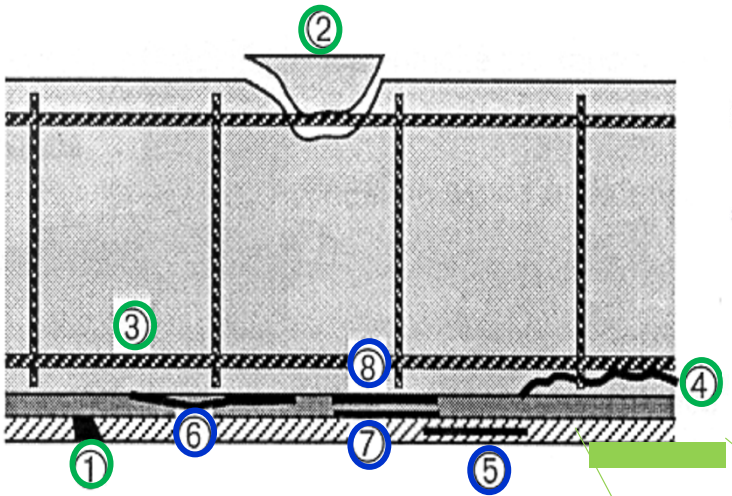
- Reinforcement
- External prestressing
- Glued CFRP lamellas
- R-UHPFRC
- Orientation effects of fibers
- Synergy effects UHPFRC/rebar
- R-UHPFRC/RC structural members
- Analytical modelling
- Bending, Shear, Fatigue

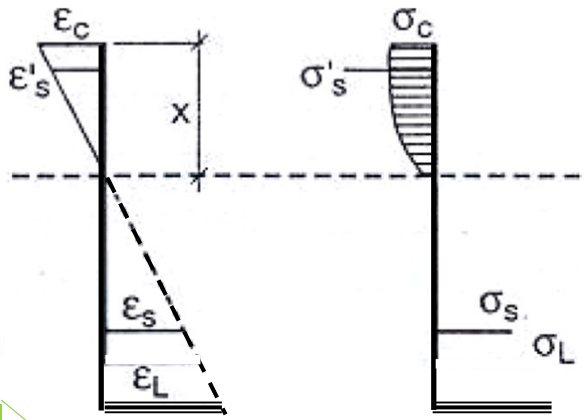




Chapter 12

- Glued CFRP lamellas
- prSIA166 (armatures collées): of elements made out of concrete, masonry, wood, steel
- Increase of
  - Bending strength of slabs, beams
  - Shear strength of beams
  - Same direction(s) as rebars
  - Fatigue endurance esp. if prestressed
- Composite element, elastic design, strain limitations





Design and verification

Quality assurance (products, installation)

$$\Delta K_{II,d} \leq \Delta K_{II,th}(1 - \Delta K_{I,d}/\Delta K_{I,th})$$

Anchorage

Chapter 13

- Proportionality of interventions
- Cost/benefit ratio
- Efficiency of intervention measures EF_M
- PE-UHPFRC
- Life-Cycle Analysis
- CO_2 emissions
- Embodied Energy
- Global Warming Potential, *GWP*
- Cumulative Energy Demand, *CED*
- Ecological Scarcity, *UBP*

$$EF_M = \frac{\Delta R_M}{SC_M}$$