



Engineering of Existing Structures - CIVIL-511

Civil Engineering - Master 1 and 3

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Engineering of Existing Structures

- Recapitulation of the course

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Recapitulation of the course

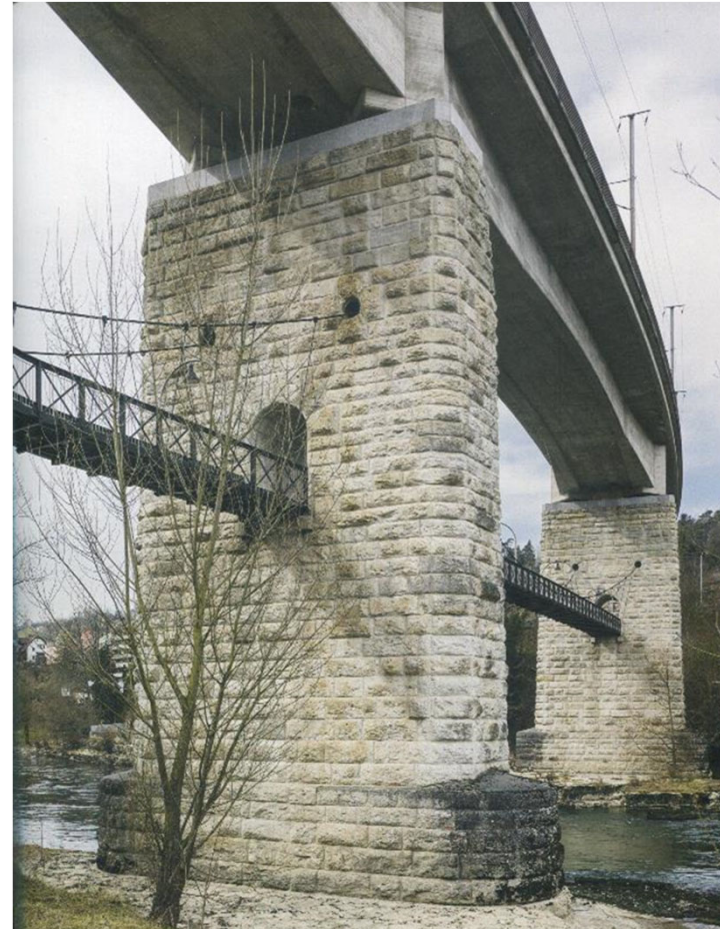
Methodology for engineering of existing structures

- Routine condition surveys, monitoring
- Examination
 - Evaluation of value
 - Condition evaluation
 - Updating of:
 - structural model
 - effect of actions
 - resistances
- Upon needs, recommendation 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

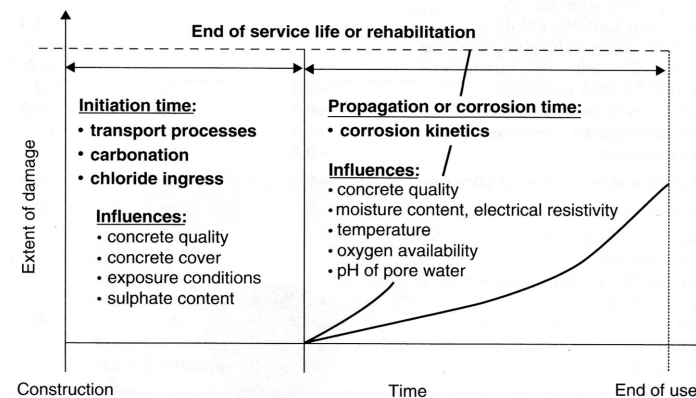
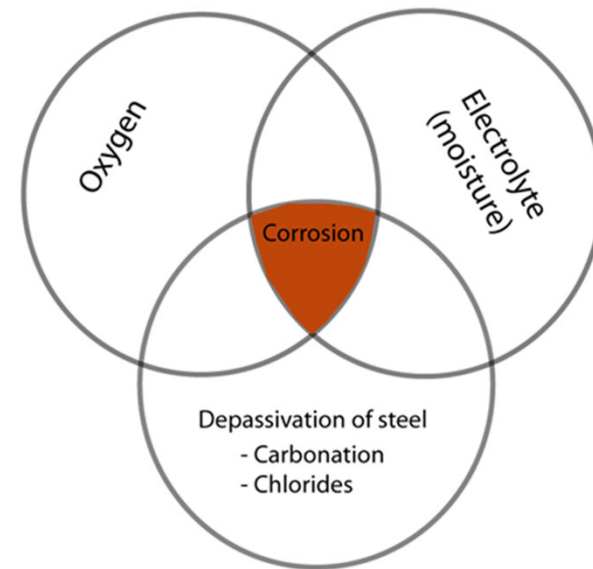
Chapter 1

- 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

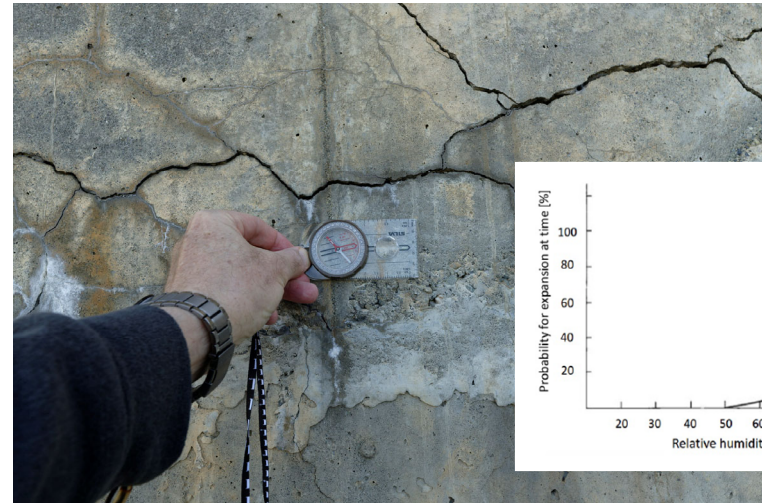
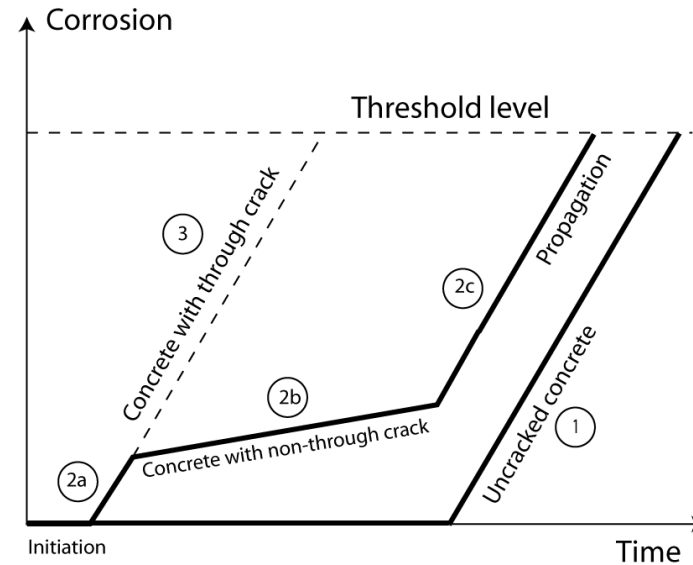
- Exposure classes
- Transport phenomena
- Driving forces of deterioration phenomena
- Necessary factors
- Heterogenous structure of cementitious composites
- Initiation vs Propagation
- Carbonation
- Corrosion with carbonation and/or Chlorides



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.

APPRECIATION DE L'ÉTAT				
OInf: 2 en état acceptable				
1	2	3	4	5
Sous OInf le plus mauvais: Etat 3 (3)				
Légende	1: bon 2: acceptable 3: défectueux		4: mauvais 5: alarmant (9: incontrôlable)	

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

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	NEW: 0,9	NEW: 0,9	0,50 ⁽¹⁾ (0,70 ⁽²⁾)
	Two girders	20–80	0,70 ^(1) 2)	0,50 ^(1) 2)	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			
		Q_{act}	Q_{act}	Q_{act}	Q_{act}
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.**

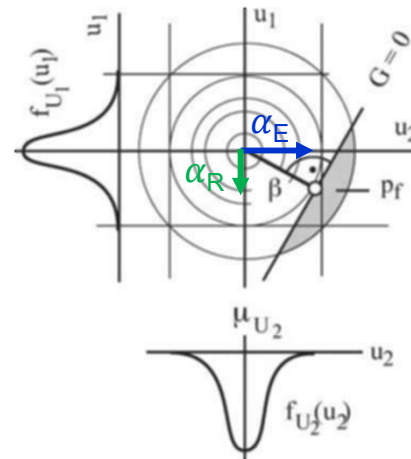
$$E_{d,act} = E_{m,act} (1 + \alpha_E \beta_0 v_{E,act})$$

- $G_{Ed,act} A_{d,act} \Rightarrow$ Gumbel law

- $R_{d,act} \Rightarrow$ normal or log-norm. dist.

$$R_{d,act} = R_{m,act} (1 + \alpha_R \beta_0 v_{R,act}) - \Delta R < 0$$

- 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

- $\alpha_E = 0,7$ effects of leading actions
- $\alpha_E = 0,3$ effects of accompanying actions
- $\alpha_R = -0,8$ ultimate resistances, of key importance
- $\alpha_R = -0,3$ 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

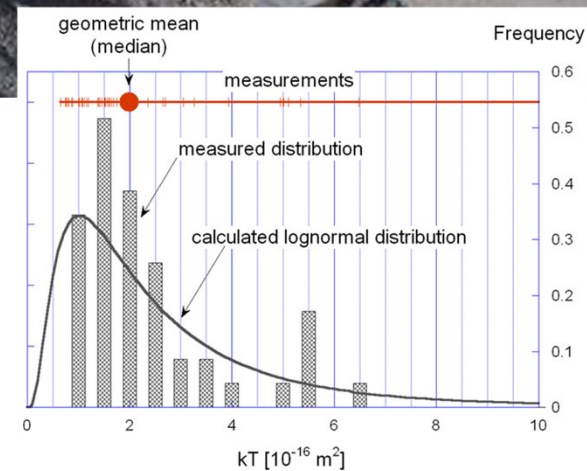
Source: EN 1990, Table C.2

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

Source: SIA 269, Appendix B, Table 2

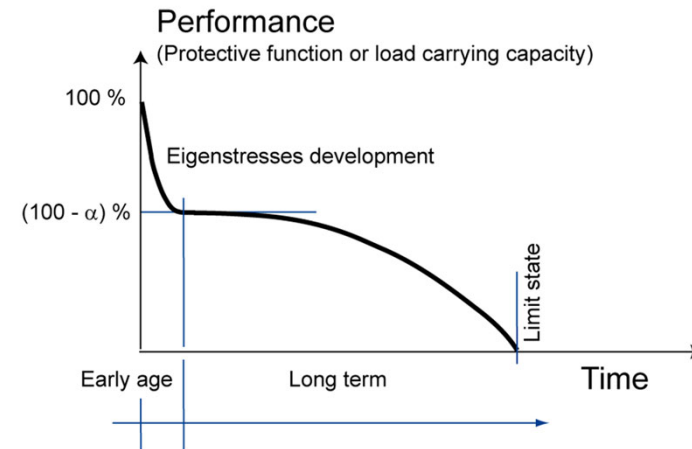
Chapter 8

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

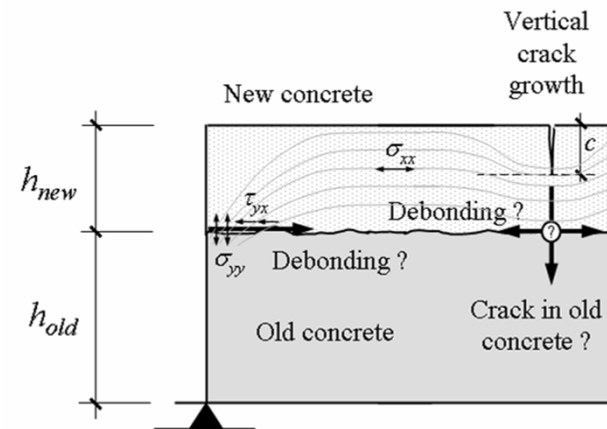


Chapter 9

- Thermomechanical effects
- Restraint (axial and Flexural)
- Mitigation of thermally induced cracking at early age
- Concrete cooling (liquid N₂, 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

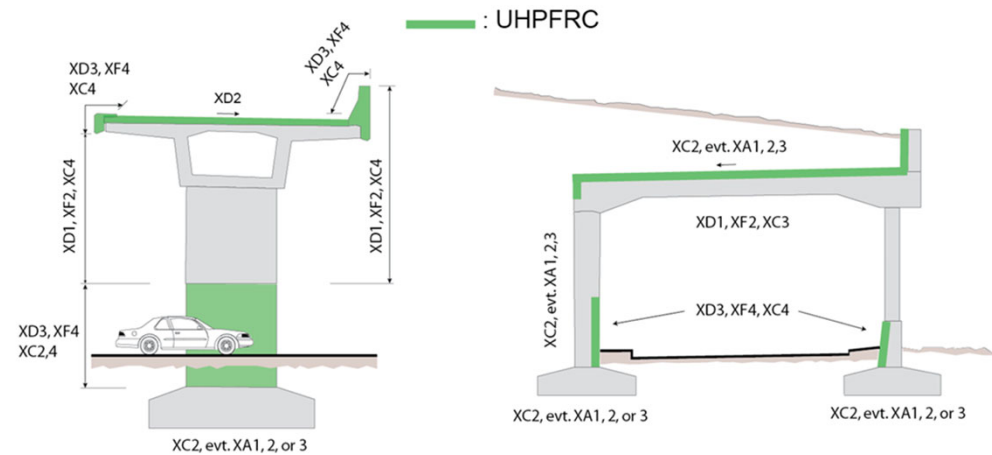
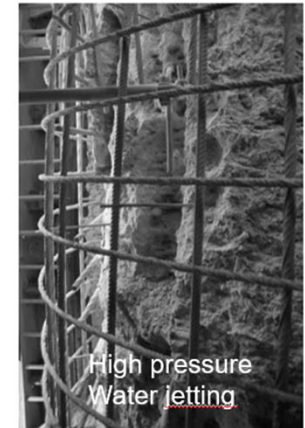
- Interventions on cover concrete
- Principles of intervention
- Electrochemical methods
- Realkalization
- Chlorides extraction
- Cathodic protection
- Hydrophobic impregnation, coatings
- Corrosion Inhibitors
- Replacement of cover concrete
- UHPFRC

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

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

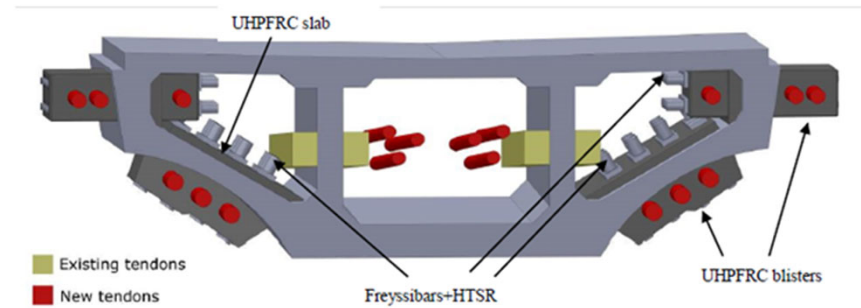
Table 1.2 Principles for protection against reinforcement corrosion

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



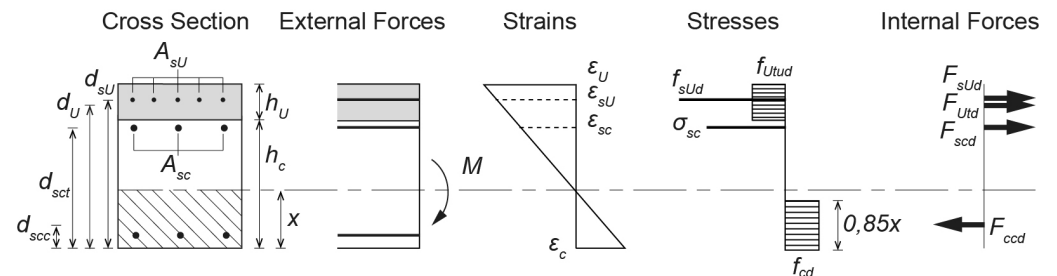
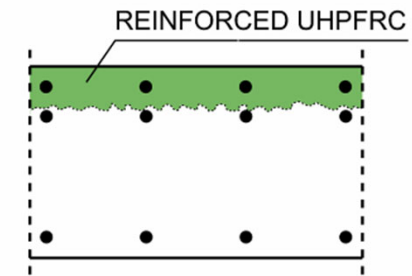
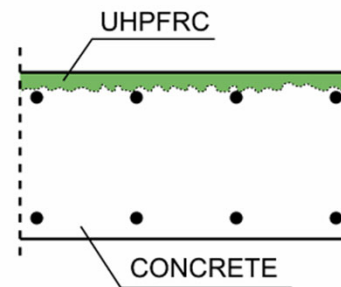
Chapter 11

- 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



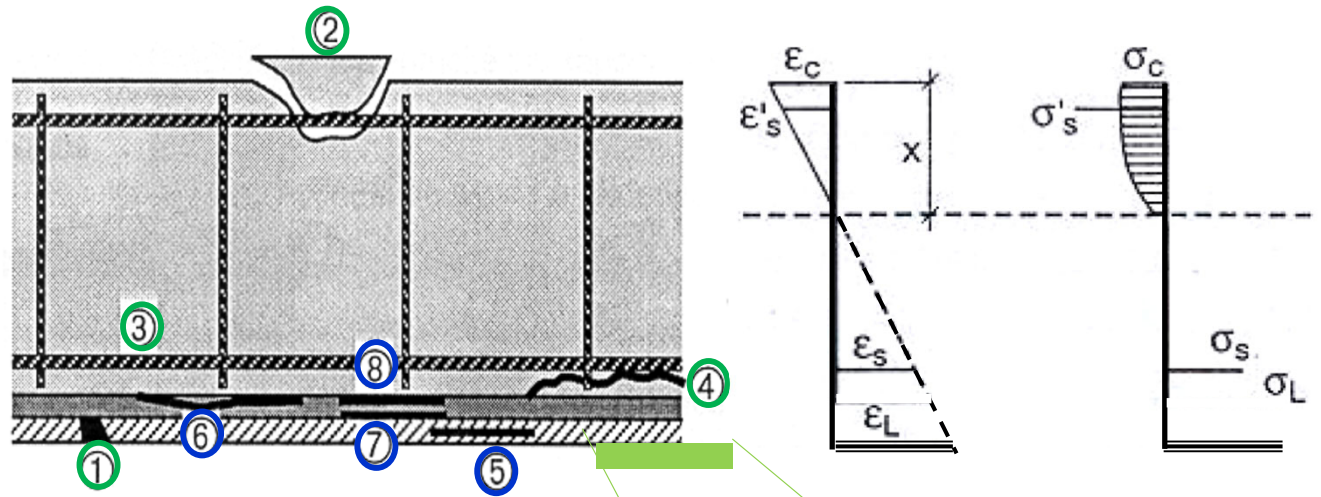
Cat. 1: PROTECTION

Cat. 2: PROTECTION + REINFORCEMENT



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



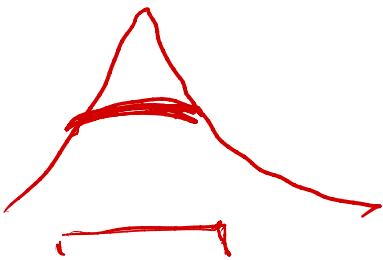
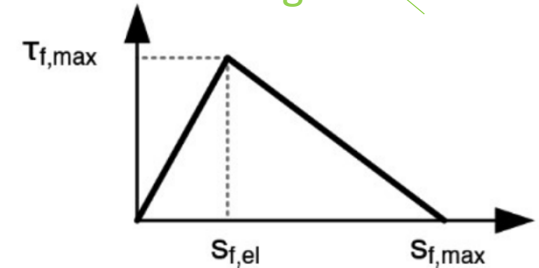
Design and verification

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
- CO₂ emissions
- Embodied Energy
- Global Warming Potential, GWP
- Cumulative Energy Demand, CED
- Ecological Scarcity, UBP



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

