Performance based concrete design: Actual and future situation in Switzerland with a focus on carbonation

fib Hungarian Group, BME, Budapest

Thursday, 12th October 2023

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https://ingenieurberatung.ch/

Content

Content

Concrete types (buildings and civil engineering) Actual Swiss requirements

LV: Limiting Values; m: medium; h: high

Designation	0 (Null)	A	B	C	D	E	F	G
Exposure classes (CH)	X0	XC2	XC3	XC4, XF1	XC4, XD1, XF2	XC4, XD1, XF4	XC4, XD3, XF2	XC4, XD3, XF4
Max. w/z- / w/z_{eq}-Wert	--	0,65	0,60	0,50	0,50	0,50	0,45	0,45
Minimum cement cont. z_{min}, [kg/m^3]	--	280	280	300	300	300	320	320
Strength class	C12/15	C20/25	C25/30	C30/37	C25/30	C25/30	C30/37	C30/37
Durability tests								
Carbonation resistance	no	no	yes (LV)	yes (LV)	yes (LV)	yes (LV)	no	no
Chloride resistance	no	no	no	no	no	no	yes (LV)	yes (LV)
Freeze thaw resistance					yes (m)	yes (h)	yes (m)	yes (h)
ASR resistance	no	no	no	(yes (LV))	yes (LV)	yes (LV)	yes (LV)	yes (LV)
Sulfate/chemical resistance	no	no	no	Only , if required				

Water conductivity / penetration is required in some cases (underpass or parts of buildings in ground water.

Introduction of Swiss durability tests

FPC: factory production control

Property	Document, Test	Remarks
Water conductivity (WL)	SIA 262/1, Annex A	(1968: Water penetration) 1989: Introduction 2003: FPC (2013: Water penetration)
Carbonation resistance	SIA 262/1, Annex I	2013: Introduction, incl. FPC
Chloride resistance	SIA 262/1, Annex C	2003: Introduction, incl. FPC
Frost resistance	SIA 162/1 (2003 withdrawn, but still used)	1968: Introduction 1989: (adopted)
Freeze thaw resistance	SIA 262/1, Annex C	1989: Introduction 2003: FPC
ASR resistance	SIA 262/1, Annex G	2012: Introduction (SBB: 2006; ASTRA: 2007) FPC: every 5 years or in case of important changes of the composition
Sulfate resistance	SIA 262/1, Annex D	2003: Introduction

1968, 1989, 2003: New versions of the Swiss standard for concrete structures (SIA 262)

Durability of concrete and main influences

RH: Relative humidity, PSD: Pore size distribution

Property	Most important parameters (very simplified)				
	w/c or w/B	w/$CaO_{reactive}$	w/$SiO_{2,\ reactive}$	Entrained air	Na_2O_{eq}
Carbonation resistance	+	+++ RH, PSD			
Chloride resistance	+		+++ and PSD, exposure cond., incl. carbonation		
Freeze thaw resistance	+			+++ minimum temp.	
ASR resistance	+	+	+		++ and reactivity of aggregates and exposure conditions
Leaching resistance	+	++	++		

Durability of concrete: Main research publications

Property	Publications [1)]	Download [1)]
Carbonation resistance	2019-1, 2018-1, 2012-5	+
Chloride resistance	2002-2, 2017-1, 2016-1a	+
Freeze thaw resistance	2020 2016-1b	+ -
ASR resistance	2013-1 2006-7	+ -
Leaching resistance	S. Greve-Dierfeld, fib 2022	Paper available

[1)] Download form website Hunkeler Ingenieurberatung: https://ingenieurberatung.ch/indexEN.htm#publikationen

➔ **Based on the research and experiences a new area with mix designs for concrete without provisions on minimum cement content, w/c ratio, k-values a.s.o. became possible.**

➡ **New Annex ND to SN EN 206**

Content

Annex ND to SN EN 206

- The purpose of this National Annex ND on performance-based design methods for concrete is to enable more innovation in terms of sustainability and concrete performance.
- Concretes according to national annex ND must fulfil the existing limit values for concrete performance in Switzerland analogous to conventional concretes.
- The composition of the concrete, the type and quantity of cement, type I and II additives and the quantity of water added shall be selected in such a way that all the required fresh and hardened concrete properties are achieved, and the corrosion protection of any reinforcement is ensured.
- No provisions for e.g., minimum cement content, w/c ratio or k-values are given.

sia

Schweizer Norm
Norme Suisse
Norma Svizzera

prSIA 262.051+A2/ND Bauwesen

EN 206:2013+A2:2021/ND

Béton – Spécification, performances, production et conformité – Annexe nationale ND à SN EN 206 :2013+A2 :2021

Concrete – Specification, performance, production and conformity –National annex ND to SN EN 206:2013+A2:2021

Beton – Festlegung, Eigenschaften, Herstellung und Konformität – Nationaler Anhang ND zur SN EN 206:2013+A2:2021

Vernehmlassung Entwurf
prSN EN 206:2013+A2:2021/ND:2023-07

Wir bitten Sie, den Entwurf zu prüfen und allfällige Stellungnahmen nach den Ziffern der Norm geordnet einzureichen an: SN206@sia.ch

Bitte verwenden Sie zu diesem Zweck das elektronische Formular, das Sie unter www.sia.ch/vernehmlassungen finden. Stellungnahmen in anderer Form können wir leider nicht berücksichtigen.

Die Vernehmlassungsfrist läuft bis **27. Oktober 2022**

Dieser Entwurf hat keine Gültigkeit und darf nicht angewendet werden.

Referenznummer
prSN EN 206:2013+A2:2021/ND:2023-07 de

Herausgeber
Schweizerischer Ingenieur- und Architektenverein
Postfach, CH-8027 Zürich

Anzahl Seiten: 9

Preisgruppe: xx

Annex ND to SN EN 206 (Draft Hunkeler, 2020)

Concrete requirements to reduce crack risks in lengthy (thick) elements – A pilot application in Tüscherz/Switzerland

FHWA – ASTRA Technology Exchange Concrete Bridges,
06-13-2023, Ittigen Switzerland

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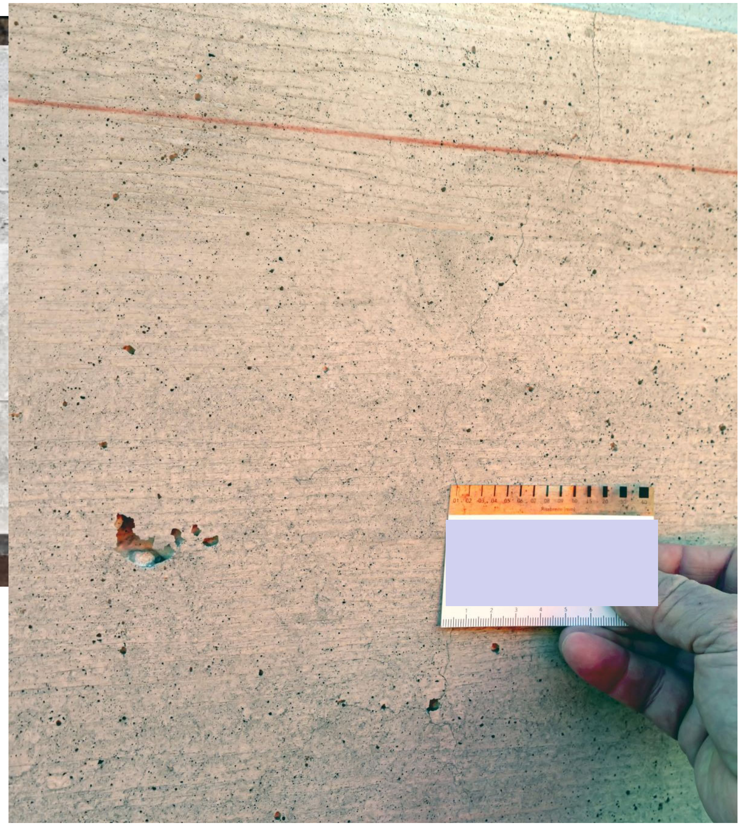
Appearance of parapet with standard concrete type G
(1½ years after concreting)

Cracks with crack widths up to 0.3 mm and lime deposits at the lower end of the outside

Appearance of parapet with new concrete type G-ND
(1½ years after concreting)



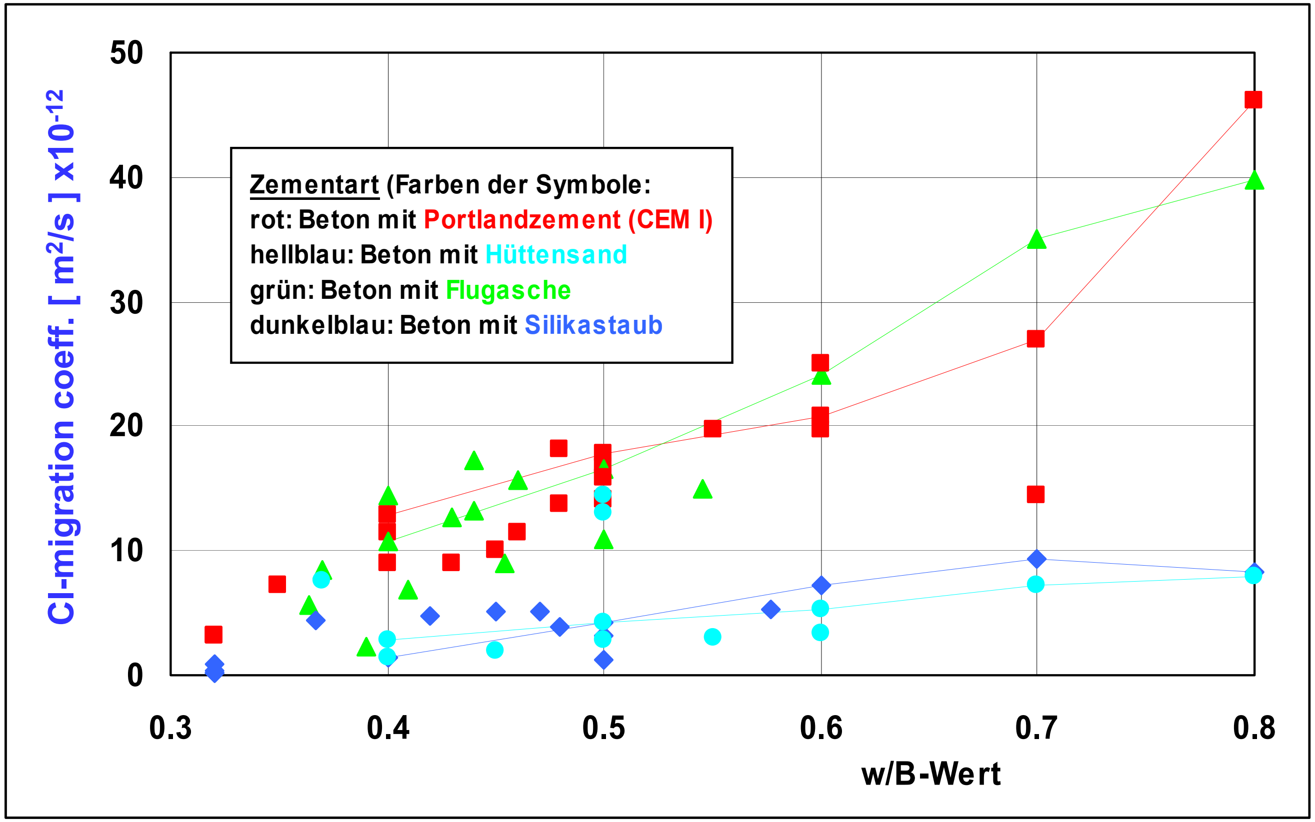
Fine crack pattern with crack widths of 0.1 up to max. 0.2 mm and no lime deposits on the outside,

Content

Durability tests: Major problems to be solved

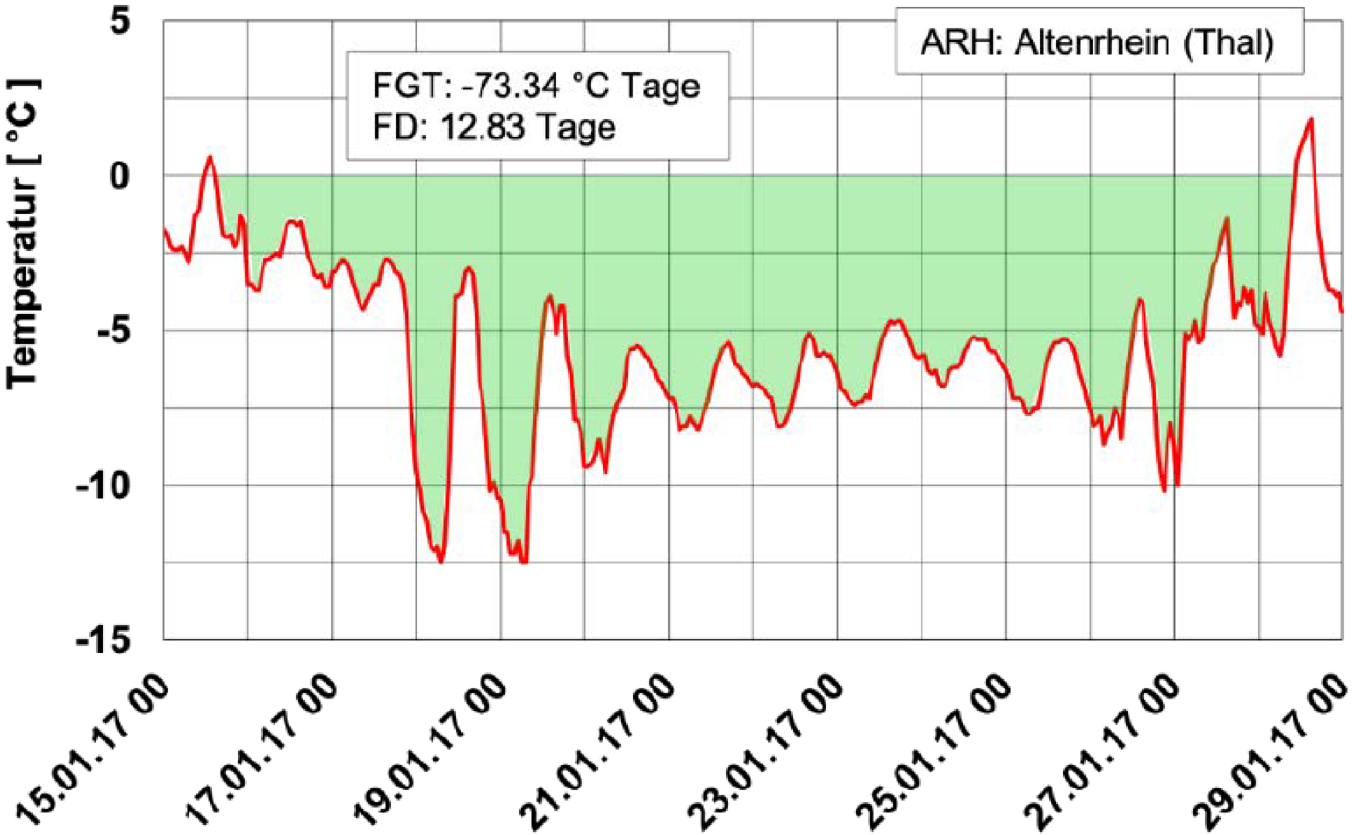
- Carbonation resistance (lab test and modelling): Influence of RH and its dependency of concrete composition, i.e. cement type, w/c ratio. New cement types might cause premature reinforcement corrosion.
- Chloride resistance (lab test and modelling): aging factor, combination with carbonation.
- Freeze Thaw resistance: details of test procedure: minimum temperature, number and duration of cycles, missing link between lab results and field experiences. Large scatter. No models available.
- ASR resistance: long term efficiency of current measures, missing field measurements of younger structures. No models available (no “safe” correlation to Na_2O_{eq}).

Durability test: Chloride resistance



It was a long way for engineers (clients, designers) to accept that CEM I is by far not the best solution for XD3 exposure conditions!

Durability test: Freeze-thaw resistance

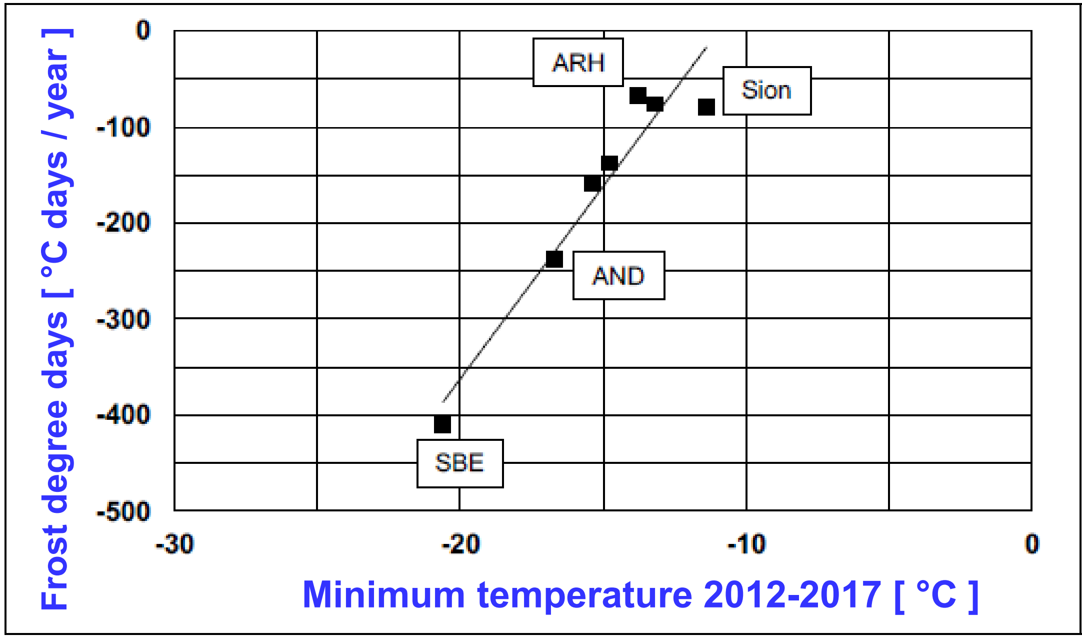


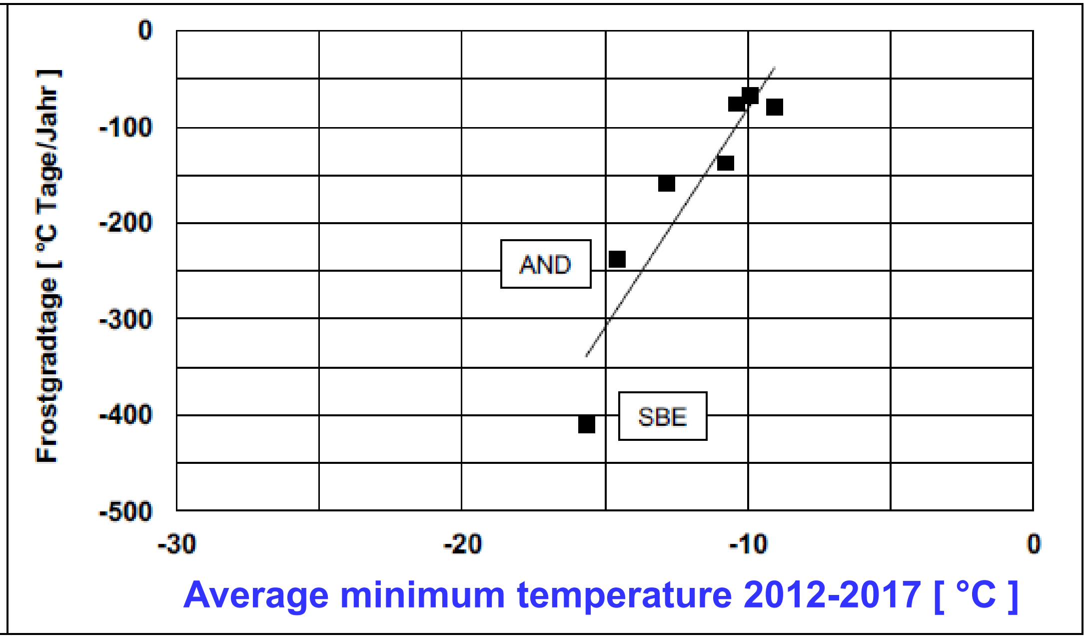
For a very long time the number of cycles with crossing 0 °C was considered as a main factor. But this number is not a critical parameter.

It is better to use:

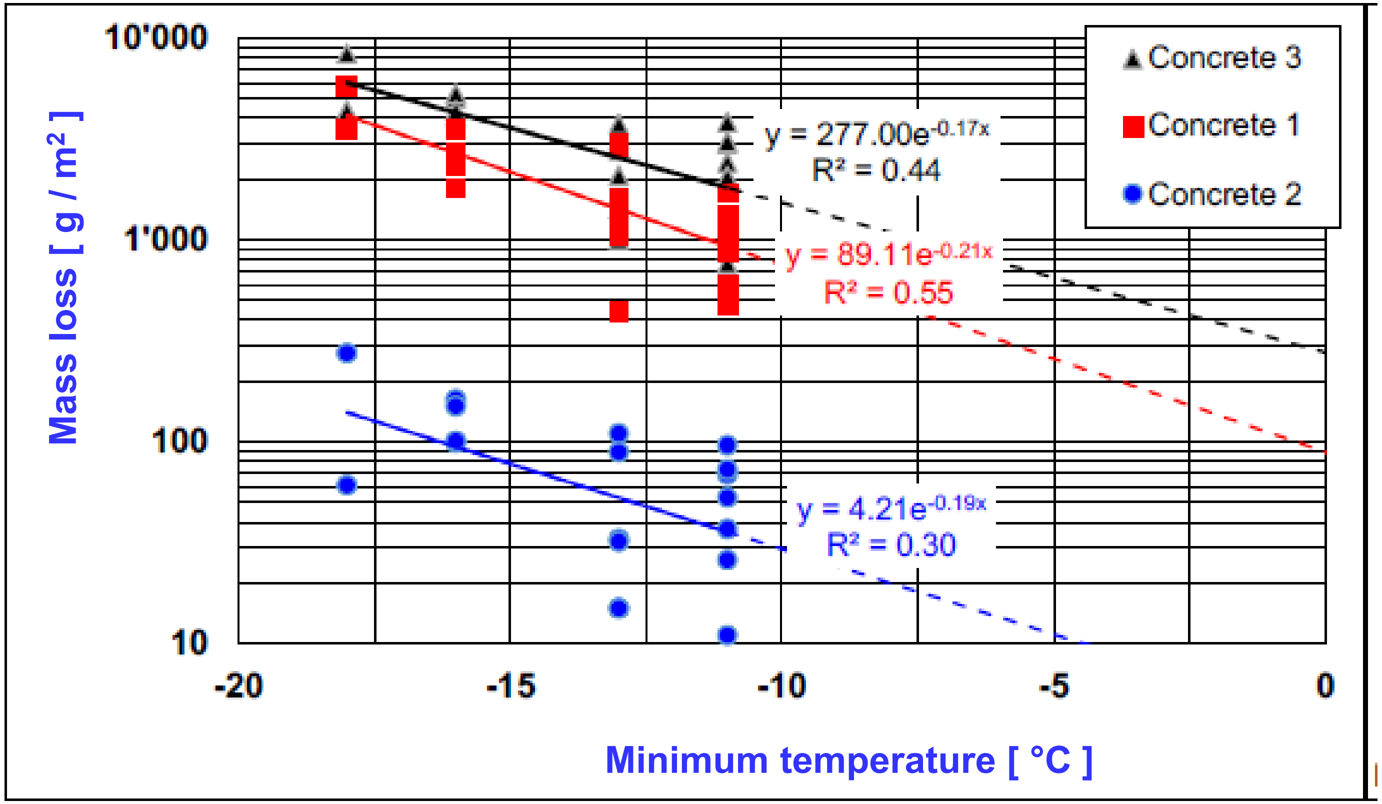
- **Frost degree days (FGT): green area under curve.**
- **Minimum temperature**
- **Frost duration (FD)**

Durability tests: Freeze-thaw resistance



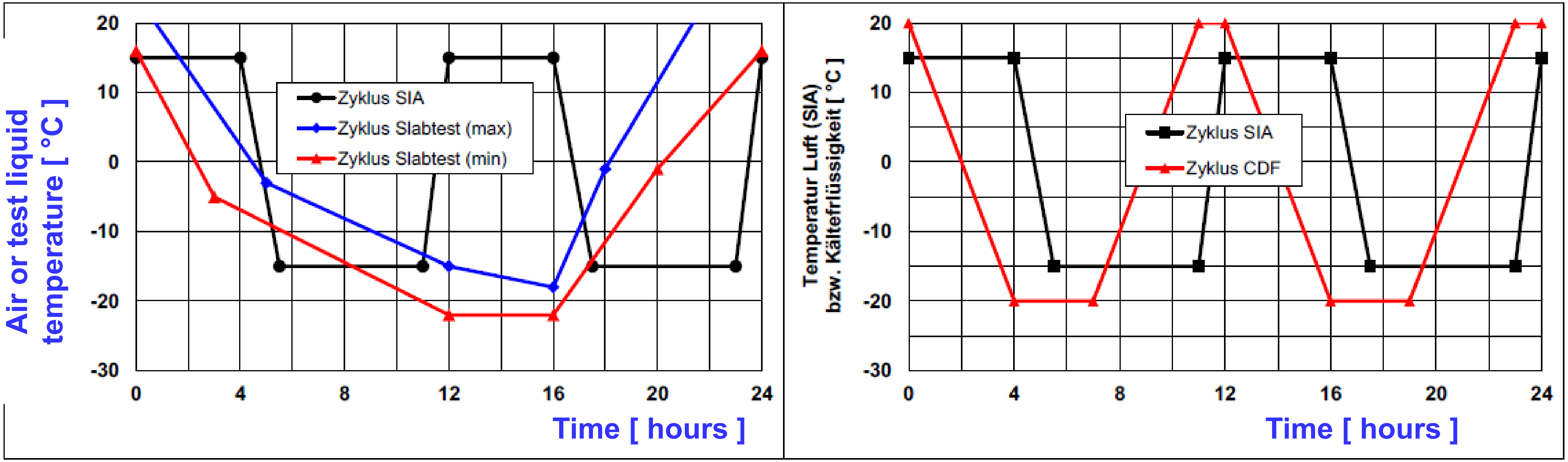


Durability tests: Freeze-thaw resistance

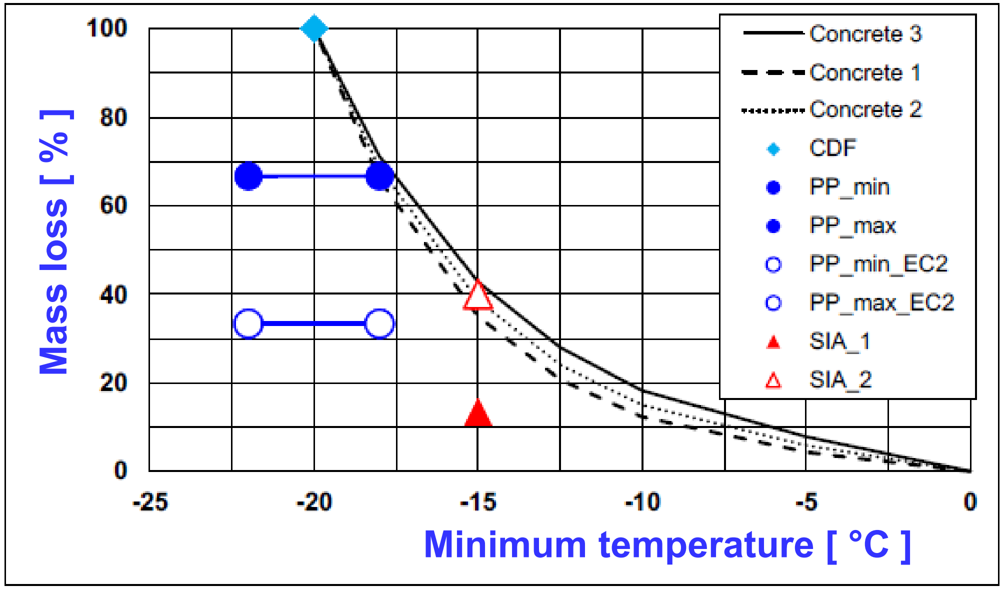


Correlation:
The lower the minimum temperature during testing is, the higher is the mass loss.

Durability tests: Test cycles SIA, CDF and slab test



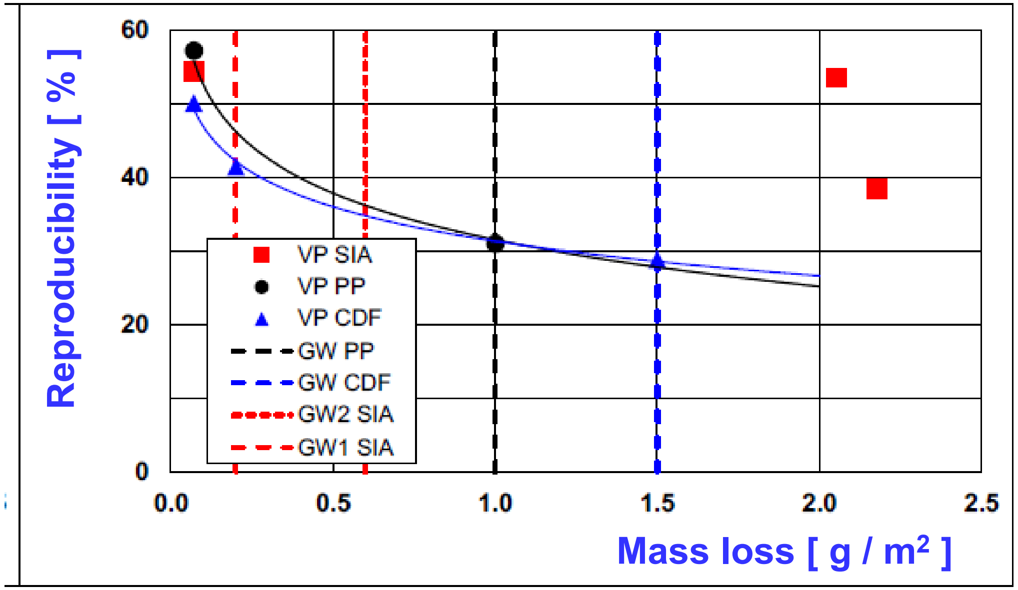
Durability tests: Test cycles SIA, CDF and slab test



The lower the minimum temperature during testing, the higher the mass loss.

The limiting values of the three tests (CDF, Slab test, SIA) fit quite well, except the new Swedish proposals (PP_…_EC2).

The reproducibility depends on the rigour of the test: (SIA < slab test < CDF)



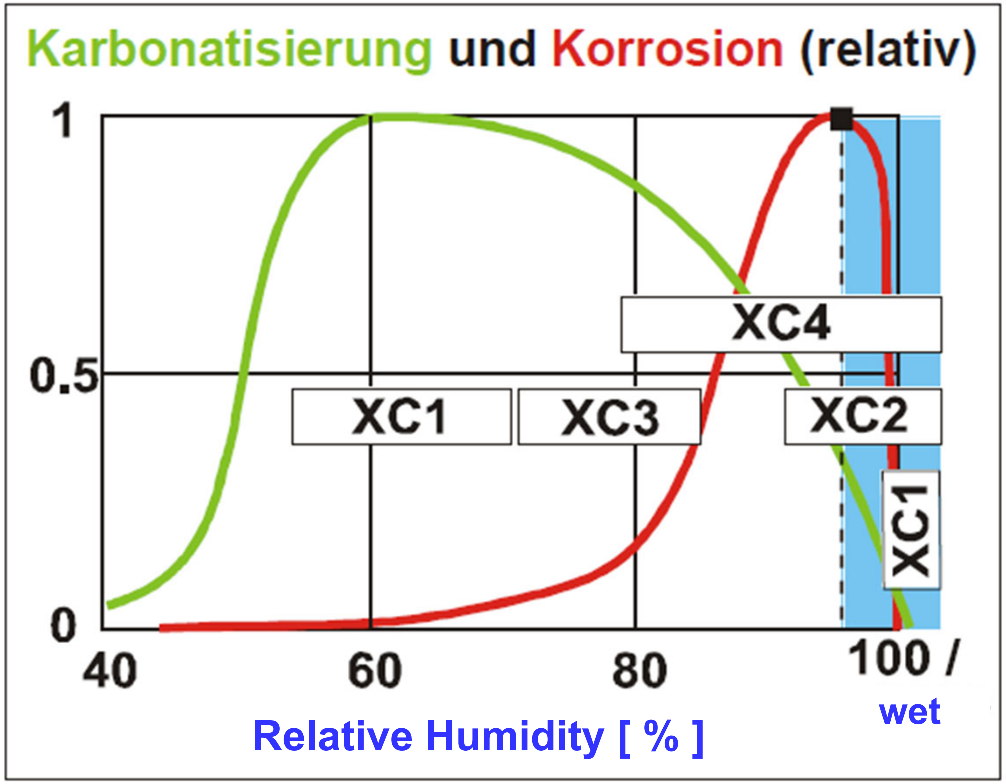
Content

1. Durability: Actual Swiss situation
2. New Annex ND to SN EN 206
3. Comments to some Swiss durability tests
4. Carbonation and corrosion rate (XC3 and XC4)
5. Eurocode EC2 (2^{nd} Generation): carbonation / concrete cover
6. Leaching as a potential risk in the future
7. Summary

Carbonation and corrosion

Difference between XC3 and XC4

- XC3: Carbonation is rather fast, corrosion rate is rather low
- XC4: Carbonation is rather slow, corrosion rate is rather high



Carbonation and corrosion

Difference between XC3 and XC4

XC4: with rain

Edge effect

XC3: without rain

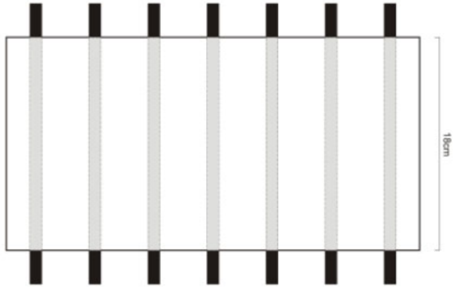
Carbonation – Laboratory and field studies

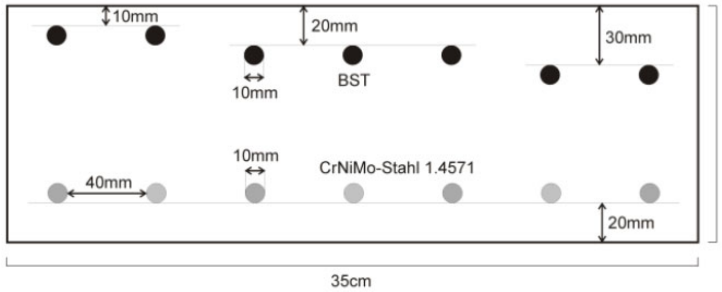
Long term carbonation measurements at three sites in “Stevenson Screens”

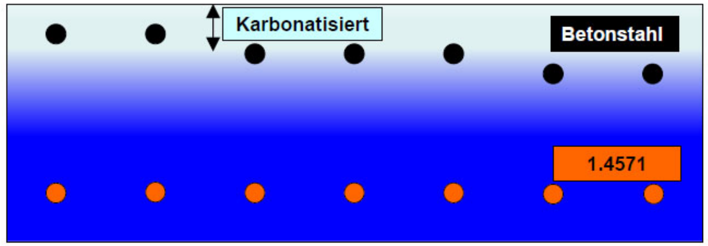
Simulation of XC3, i.e., sheltered exposure conditions

Carbonation – Laboratory and field studies

- Long term corrosion measurements

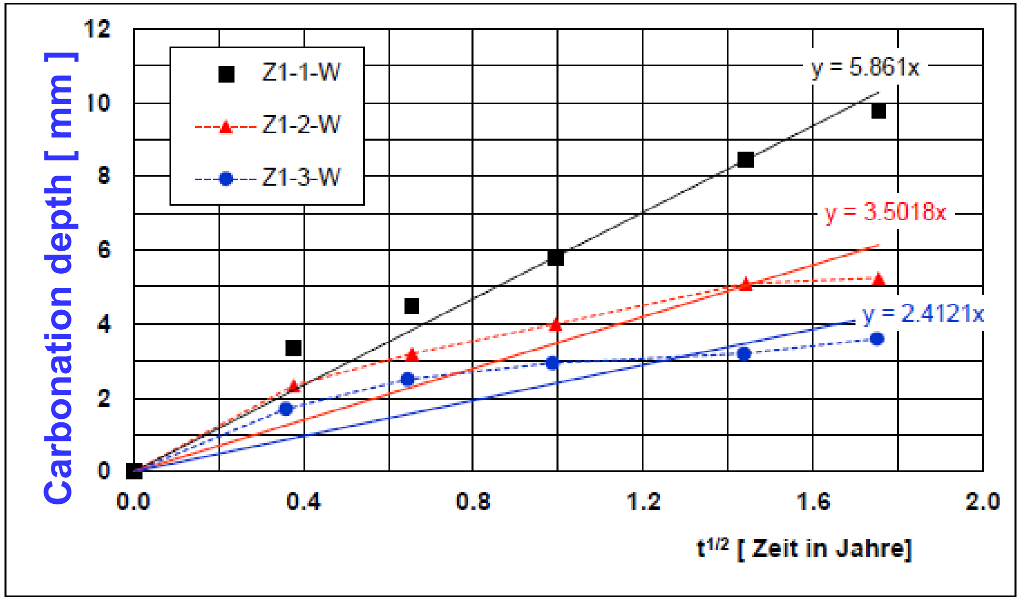


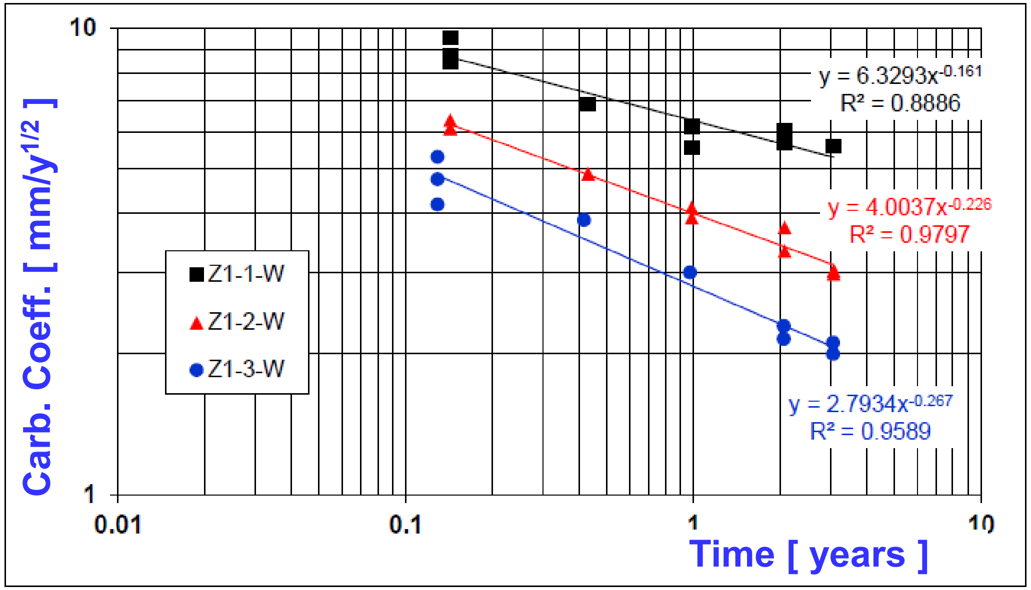




Water was periodically poured on the surface to simulate XC4

Carbonation rate under sheltered conditions (XC3)

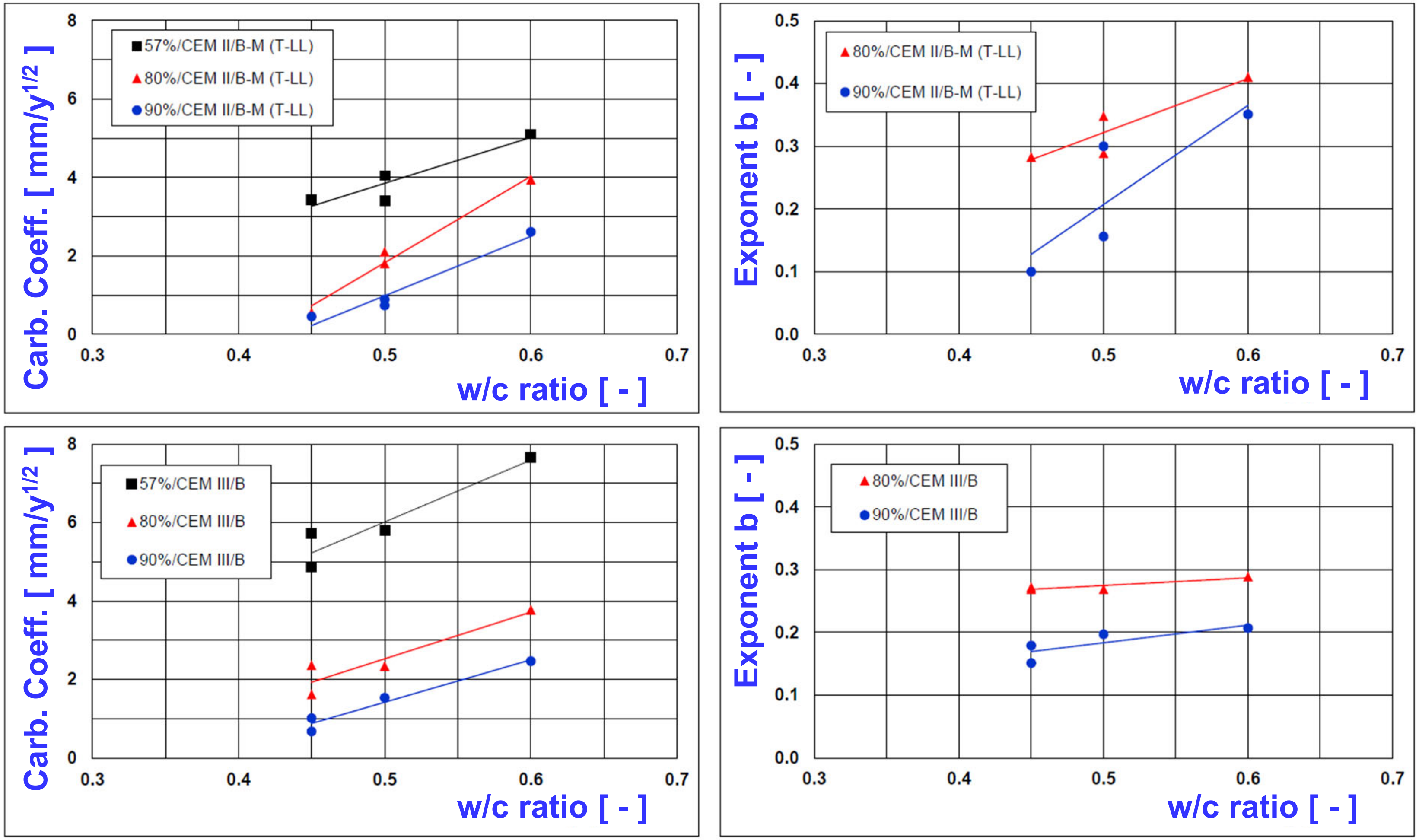




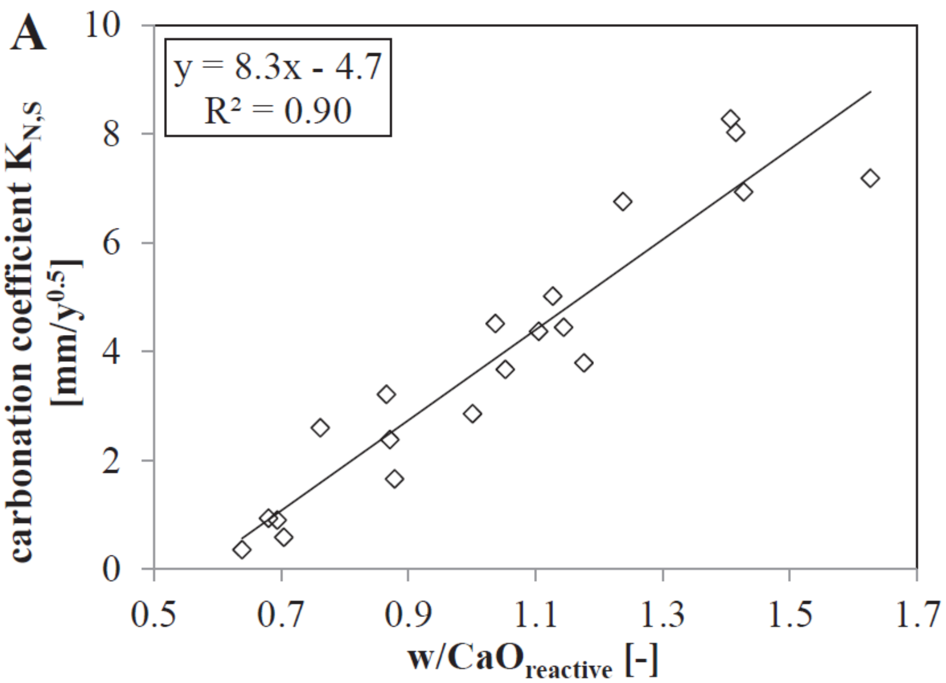
➔ √t-law is not valid under humid conditions (RH > 60/65%)

➔ Carbonation coefficient decreases with time (aging)

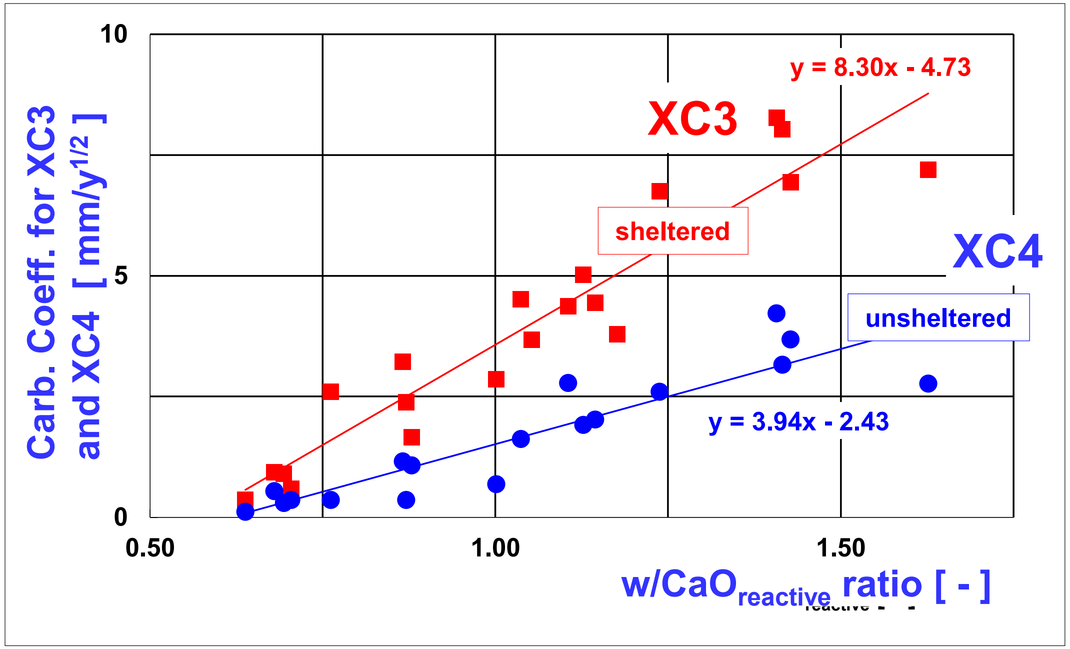
Carbonation rate under sheltered conditions (XC3)



Carbonation rate: w/CaO as an auxiliary parameter

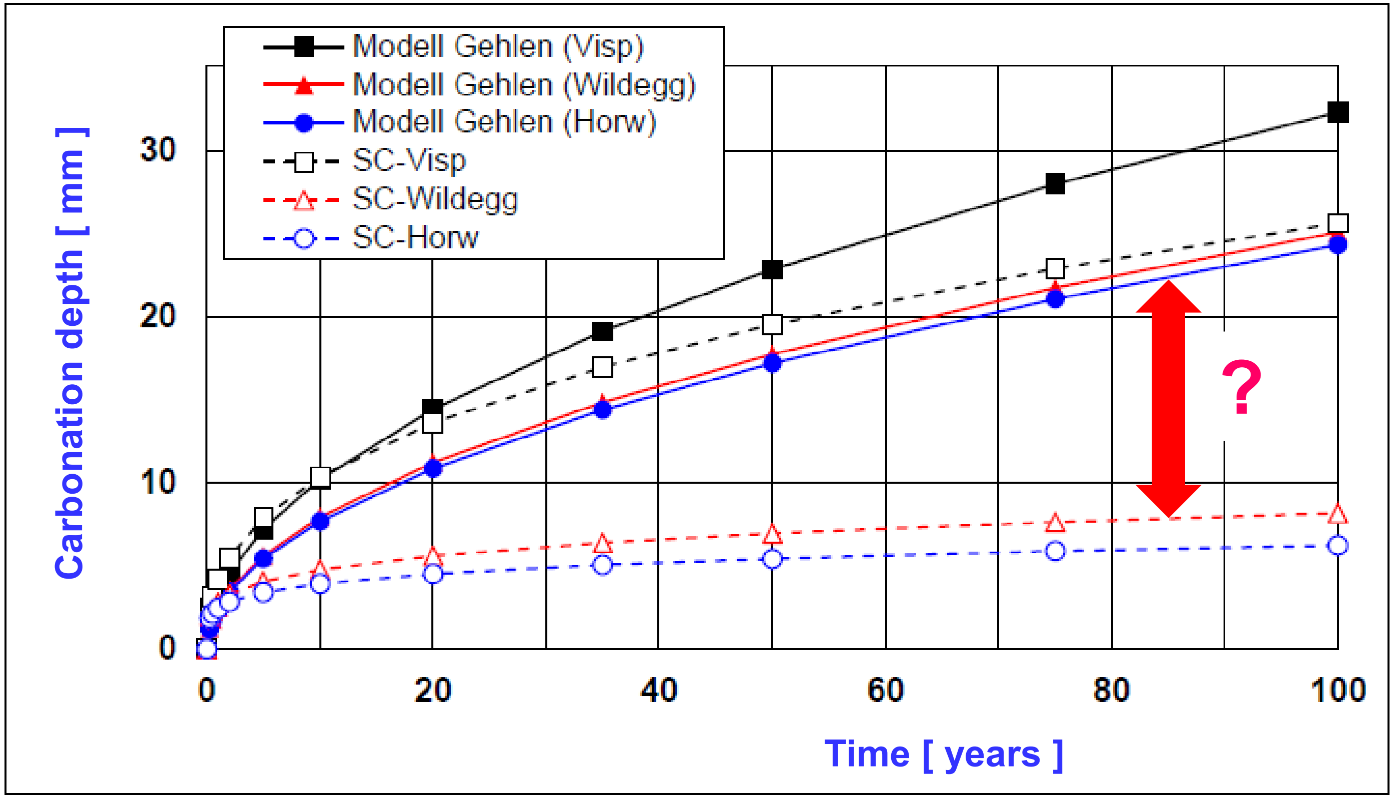


Leemann 2018



Data from Leemann et al. 2015, 2017

Carbonation rate – Modelling

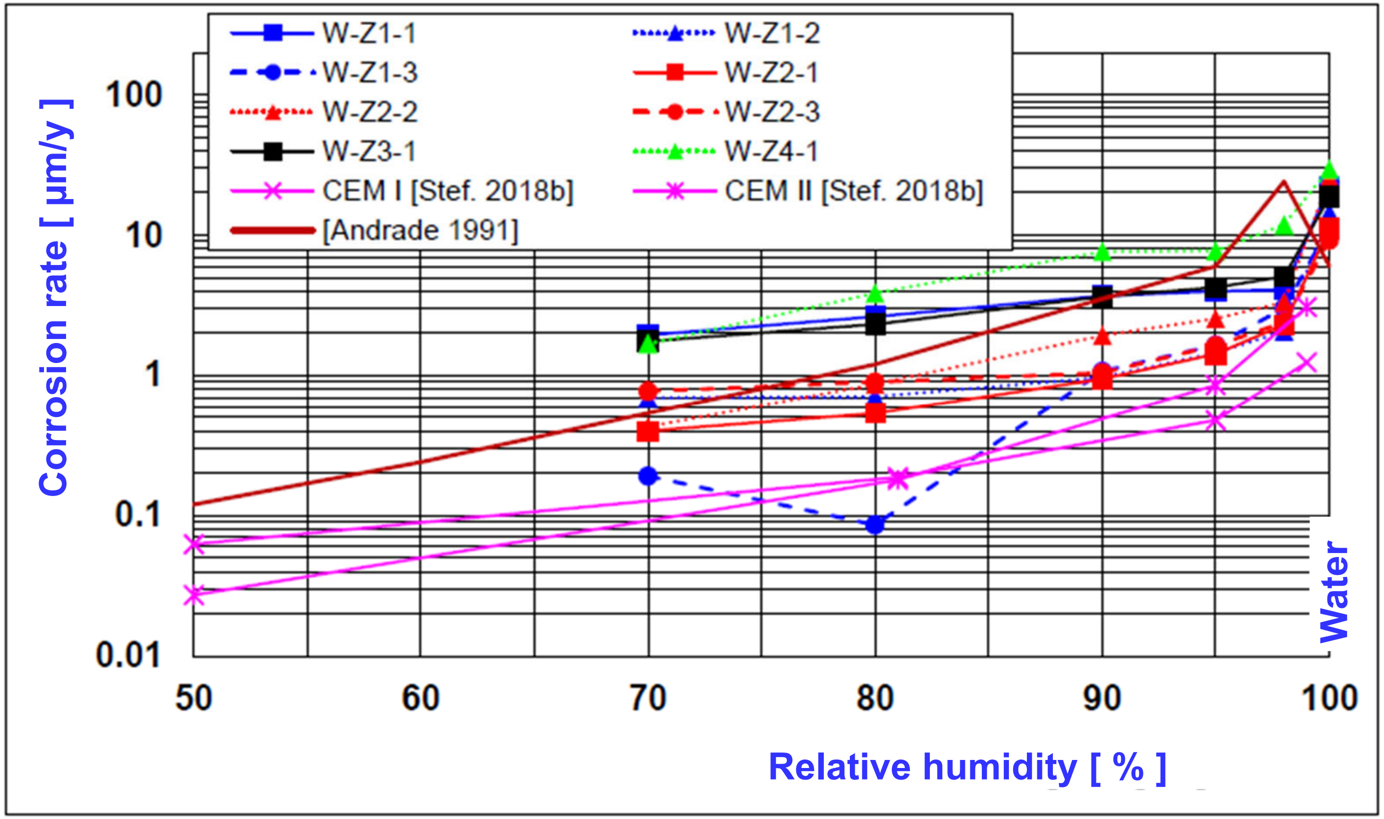


Relative humidity:

- Visp: 65-70%
- Horw: 75-80%
- Wildegg: 75-80%

➔ Model Gehlen is much too conservative in some cases!

Corrosion rate under sheltered conditions

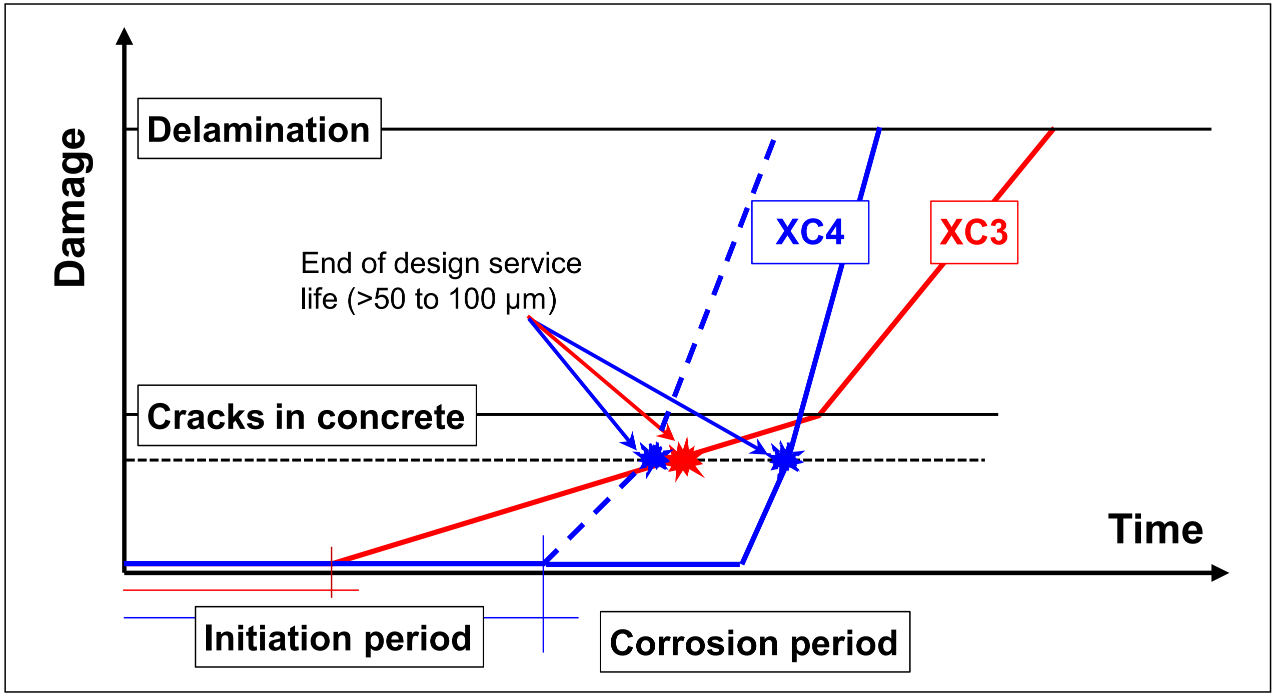


RH, %	Average corr. rate, µm/y	COV, %
70%	1.0	66
80%	1.5	82
90%	2.6	84
95%	3.1	67
98%	4.3	71
100% (water)	17.8	39

Difference between XC3 and XC4

- The decisive parameter is the relative humidity!

➔ Under humid-wet condition (R >80% and exposed to rain) the carbonation rate dominates the service life since under such conditions the corrosion rate is fast and the corrosion period leading to cracks is short and might not be considered.

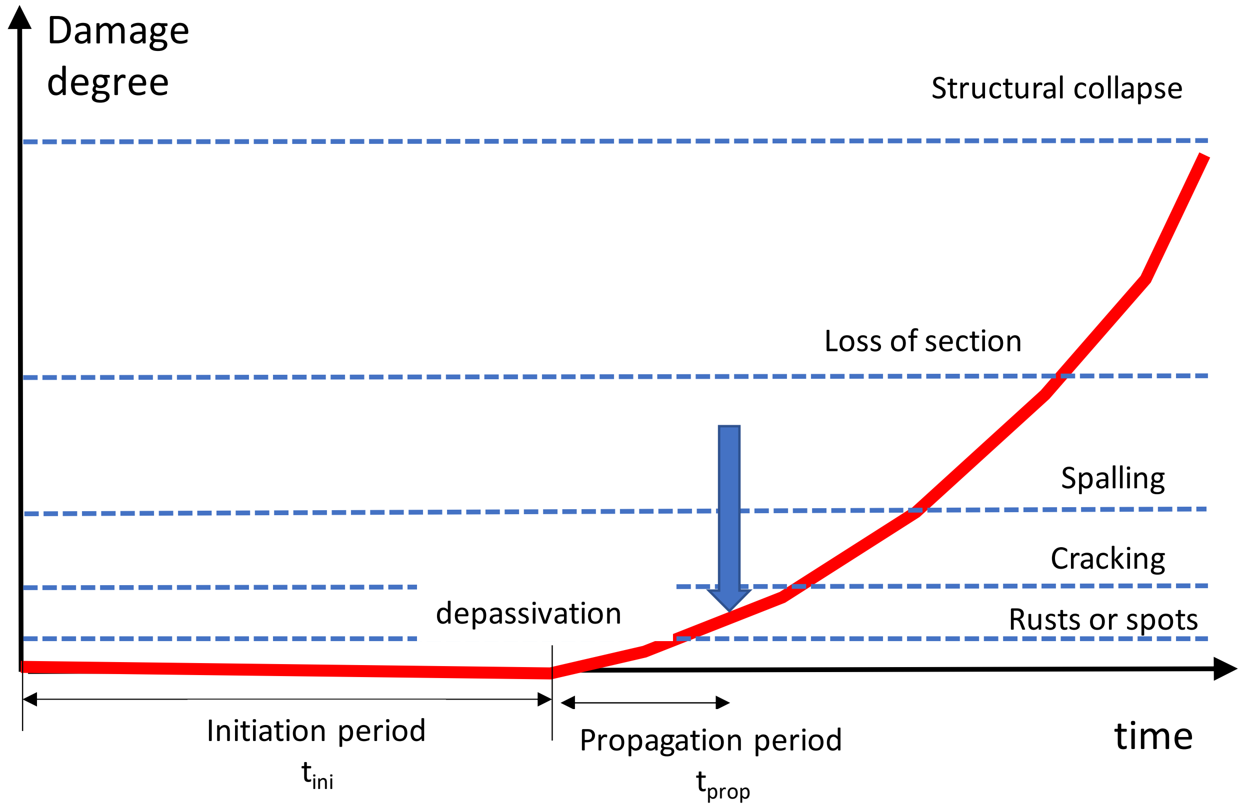


Content

Eurocode 2 - Design of concrete structures

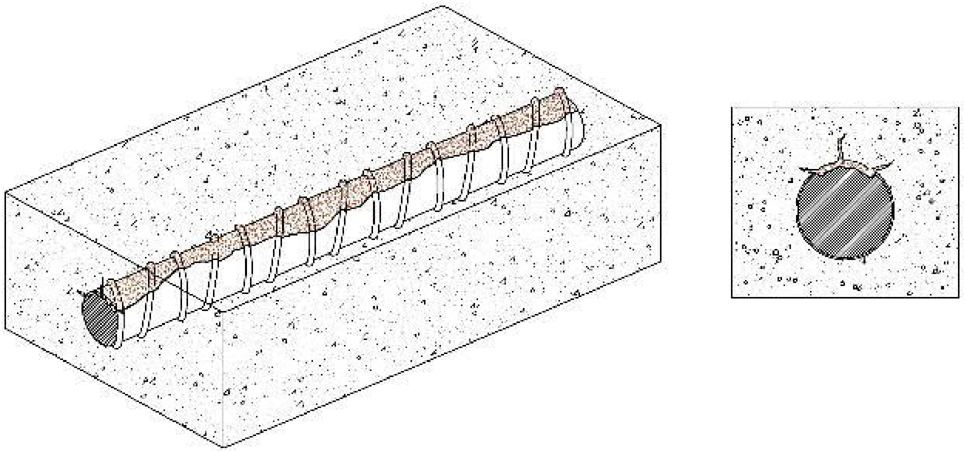
Modelling including the corrosion process

- Corrosion period is taken into account for evaluation the concrete covers
- Important for XC3



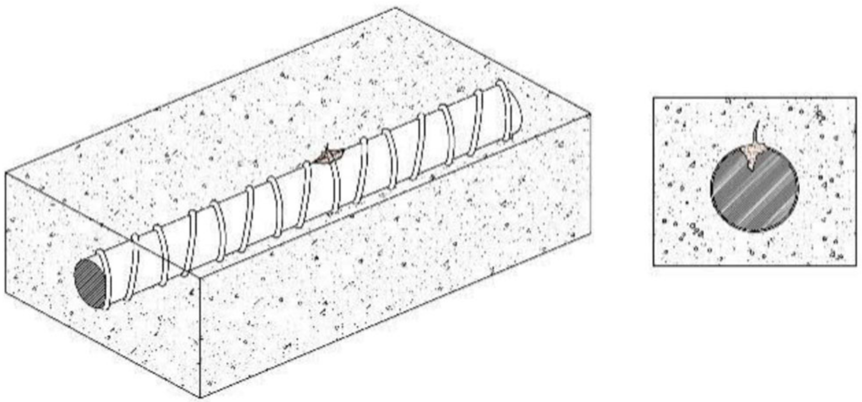
Schematic illustration of the limit state regarding general corrosion and localized corrosion

A) General surface corrosion (carbonation)



End of service life: crack width of 50 µm.

B) Localised pitting corrosion (chloride attack)



End of service life: pit depth of 500 µm.

Eurocode 2 - Design of concrete structures

Part 1-1: General rules and rules for buildings, bridges and civil engineering structures (April 2023)

➔ Background Document for prEN1992-1-1:2020, section 6 Durability,

- CEN/TC 250/SC 2/WG 110 N 350, Draft 2021-06-09 /MH
- CEN/TC 250/SC 2 N2087, 31. March 2023

Eurocode 2 - Design of concrete structures
Concrete cover

$$c_{nom} = c_{min} + \Delta c_{dev}$$

Δc_{dev} allowance for deviation; see Table 6.7 (NDP)

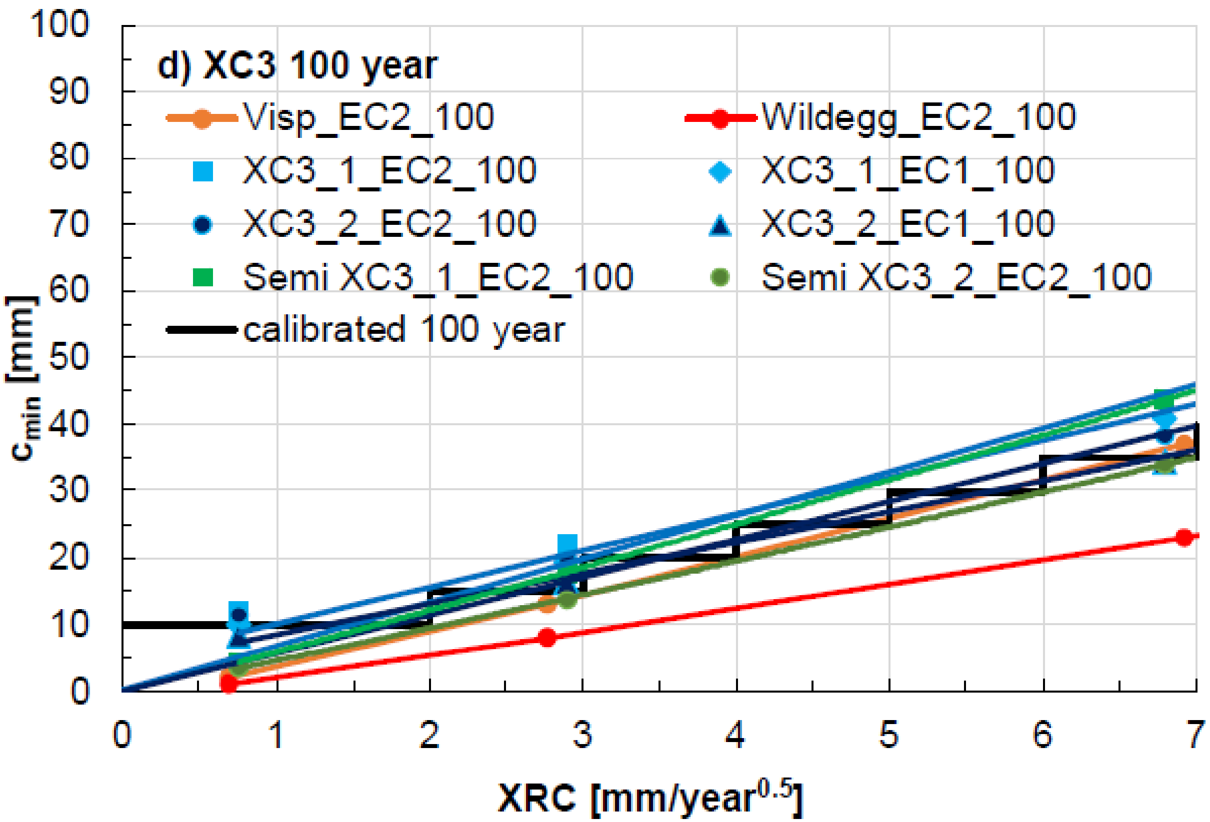
$$c_{min} = \max\{c_{min,dur} + \Sigma\Delta c;\ c_{min,b};\ 10\ \text{mm}\}$$

Table 6.5 — Minimum cover $c_{min,b}$ for reinforcing steel

Steel type	$c_{min,b}$ [a]
Separated bars	Diameter of bar
Bundled bars	Equivalent diameter ϕ_b (see 11.4.3)
[a] Where the specified maximum aggregate size D_{upper} is > 32 mm, the minimum cover $c_{min,b}$ should be increased by 5 mm.	

Eurocode 2 – Concrete cover $c_{min,dur}$

Modelling in TG 10 of CEN/TC 250/SC 2/WG 1 - Discussions



- Modelling by a French, Danish, Spanish und Swiss group

➔ To reach a consensus was very difficult.

Concrete cover $c_{min,dur}$ in dependency of ERC and design service life with reliability index β = 1.5

Table 6.3 (NDP) — Minimum concrete cover $c_{min,dur}$ for carbon reinforcing steel — Carbonation

ERC	Exposure class (carbonation)							
	XC1		XC2		XC3		XC4	
	Design service life (years)							
	50	100	50	100	50	100	50	100
XRC 0,5	10	10	10	10	10	10	10	10
XRC 1	10	10	10	10	10	15	10	15
XRC 2	10	15	10	15	15	25	15	25
XRC 3	10	15	15	20	20	30	20	30
XRC 4	10	20	15	25	25	35	25	40
XRC 5	15	25	20	30	25	45	30	45
XRC 6	15	25	25	35	35	55	40	55
XRC 7	15	30	25	40	40	60	45	60

NOTE 1 XRC classes for resistance against corrosion induced by carbonation are derived from the carbonation depth [mm] (characteristic value 90 % fractile) assumed to be obtained after 50 years under reference conditions (400 ppm CO_2 in a constant 65 %-*RH* environment and at 20 °C). The designation value of XRC has the dimension of a carbonation rate [mm/√(years)].

NOTE 2 The recommended minimum concrete cover values $c_{min,dur}$ assume execution and curing according to EN 13670 with at least execution class 2 and curing class 2.

NOTE 3 The minimum covers can be increased by an additional safety element $\Delta c_{dur,\gamma}$ considering special requirements (e.g. more extreme environmental conditions).

- This is the result of a controversial and lengthy discussion in TG 10.
- CEN members can choose their own way to handle this provisions.

→ National Application Document or National Annex

Concrete cover $c_{min,dur}$ acc. to EC2, Table 6.3:

Difference to Swiss calculations

Exposure class	XC1		XC2		XC3		XC4	
Design service life (years)	50	100	50	100	50	100	50	100
XRC Class	Difference Swiss calculations / EC2							
XRC 0,5	0	0	0	0	0	0	0	0
XRC 1	0	0	0	0	0	5	0	5
XRC 2	0	5	0	5	5	15	5	10
XRC 3	0	5	5	10	10	15	5	10
XRC 4	0	10	5	10	10	10	5	15
XRC 5	5	15	10	15	5	15	5	15
XRC 6	5	15	10	15	10	20	10	20
XRC 7	5	20	10	20	10	20	10	20

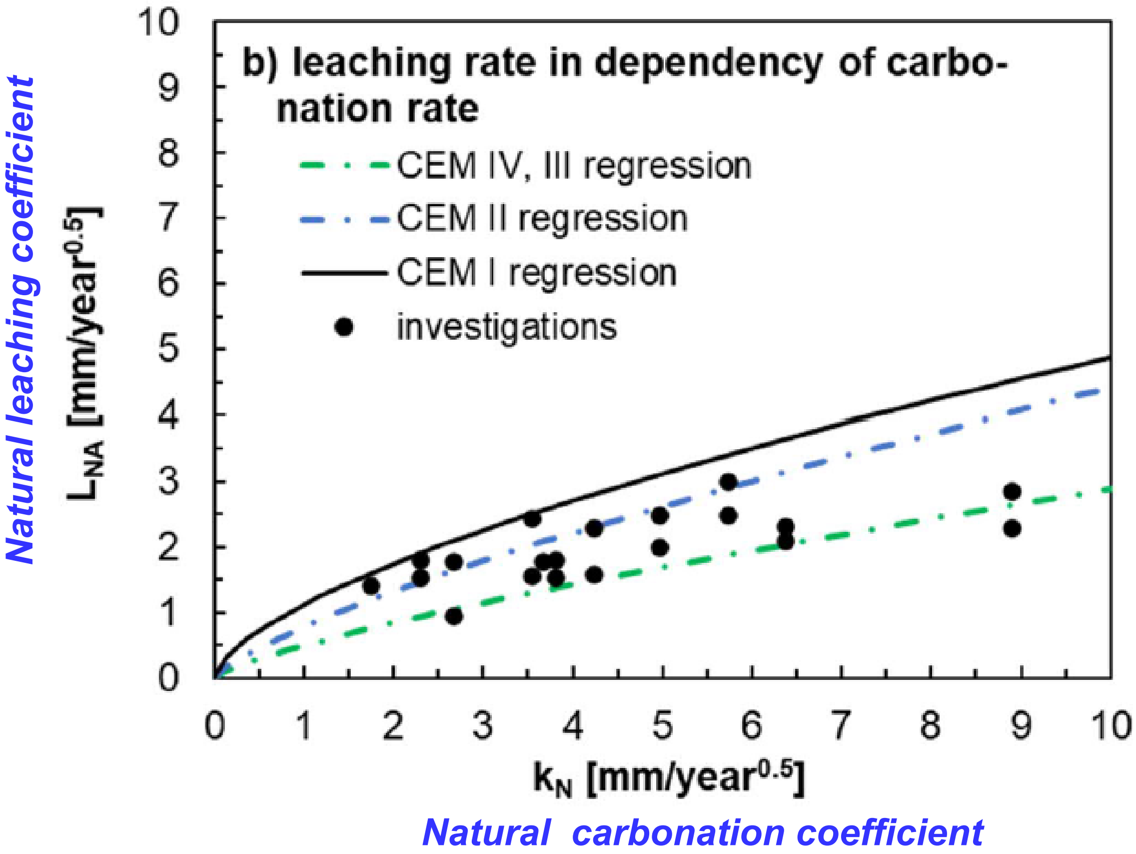
- **The values in Table 6.3. are up to 20 mm higher than the Swiss values.**
- Higher covers causes additional costs and environmental load (e.g., CO_2 emissions).

➔ We need better models!

➔ Models should be improved based on further experimental evidence, e.g., field studies (lab-field: transfer coefficient).

Content

Leaching as a potential risk in the future (XC2)



- Leaching is not taken into account in Table 6.3(NDP).
- In the future, leaching is going to be more important due to the use low clinker containing concrete.
- There is no accepted European test procedure.
- In the meantime, one can use the carbonation resistance test. See diagram on left hand side.

➔ Increase concrete cover for XC2 by 5-10 mm.

Ref.: S. Greve-Dierfeld, fib 2022

Content

Summary

- Durability tests and limiting values are available (with some uncertainties) for all relevant hardened concrete properties with experiences of more than 10 years.
- This allows new concrete design procedures without requirements on minimum cement content, w/c ratio, k-values etc.
- Currently a new annex to the Swiss concrete standard SN EN 206 is in the enquiry, which should lead to more sustainable concrete recipes.
- There is still a lot to do … ☺ or ☹

Thank you for your attention

Fritz Hunkeler – Curriculum vitae

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2021	Hunkeler Ingenieurberatung, Möriken, Senior Consultant (concrete, corrosion, durability)
2019-2020	Merz Ingenieurberatung GmbH, Möriken, Senior Consultant (concrete, corrosion, durability)
2011-2019	TFB AG, Wildegg, Senior Consultant (concrete, corrosion, durability)
1994-2011	TFB AG, Wildegg, CEO and Co-owner, Senior Consultant (concrete, corrosion, durability)
1984-1994	Swiss Society for Corrosion Protection (SGK), Member of the Executive Board, Consultant
1988-2002	Lectureship at ETH Zurich for civil engineers: "Corrosion and Corrosion Protection in Civil Engineering" and "Protection of Reinforced Concrete Structures"
1981-1986	ETH Zurich, Institute for Building Materials, Senior Assistant (Prof. Dr. H. Böhni)
1981	MIT Cambridge, Boston/USA, postdoctoral study
1976-1980	ETH Zurich, IBWK, Assistant and PhD thesis (Prof. Dr. H. Böhni)
1975	ETH Zurich, Degree as dipl. Ing. ETH