Durability Performance-Based Specifications and Control: the Swiss Approach

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Objectives

- Present the evolution of Swiss Standards regarding Durability, from prescriptive to performance (P2P)
- Discuss in some detail the main Milestones of the process, focusing on steel corrosion
- Present foreseeable consequences of the new approach for Concrete Construction

Structure of Swiss Standards for Concrete

SN 505 262:‘03 (Eurocode 2)
"Concrete Construction"

- Materials
- Structural Analysis + Dimensioning
- Detailing
- Execution

ACI 318

SN EN 206-1:‘00
"Concrete: Specification, performance, production and conformity"

- Raw Materials
- Exposure Classes
- Production/Delivery
- Requirements
- Conformity Control

ASTM C94

SN 505 262/1:‘03
"Concrete Test Methods"

- Water sorptivity
- Chloride Migration
- Air-Permeability on site

ASTM C….

Main Milestones in P2P

Modification of Swiss Standards	**Swiss Std. (US equiv.)**
2000: Adoption of EN206-1 (Prescriptive)	SN EN 206-1 (ASTM C94)
2003: Adoption of Water Sorptivity q_w, and Chloride Migration D_{Cl} tests as „durability“ performance indicators of concrete production	SN 505 262/1 (ASTM C1585) (AASHTO TP64)
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2003: Recognition of role of „covercrete impermeability“ and need of site assessment	SN 505 262/1 (ACI 318)
2003: Adoption of kT test as „durability“ performance indicator of site concrete	SN 505 262/1 (ASTM C??)
2009: Limits for site kT_{max} specified by FHWA	VSS 641 (FHWA)
2012?: Limits for site kT_{max} → Swiss Standards	SN 505 262 (ACI 318)

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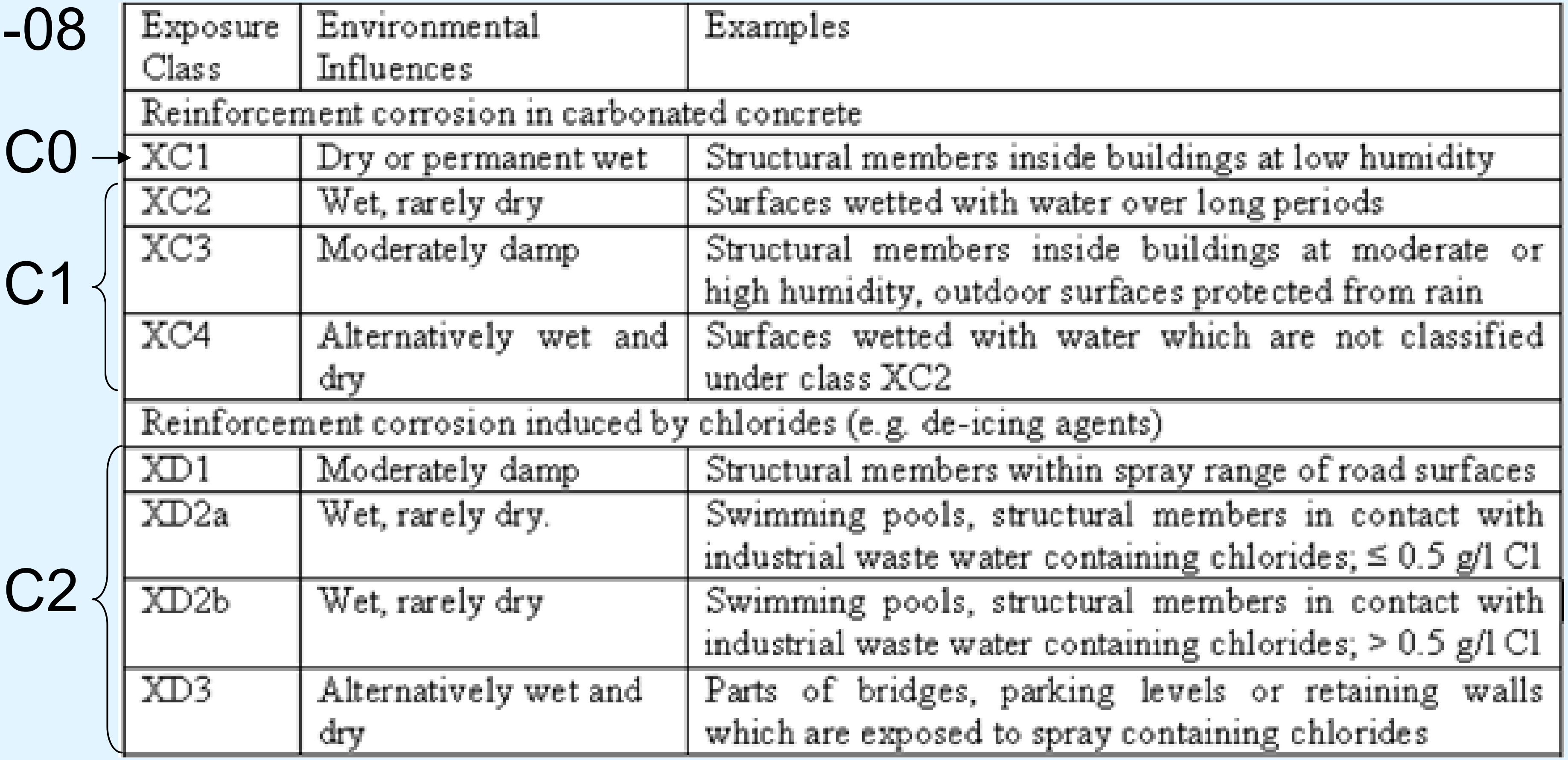
Corrosion Exposure Classes after SN EN 206-1:00

Eq. ACI 318-08



Exposure Class	Environmental Influences	Examples
Reinforcement corrosion in carbonated concrete		
XC1	Dry or permanent wet	Structural members inside buildings at low humidity
XC2	Wet, rarely dry	Surfaces wetted with water over long periods
XC3	Moderately damp	Structural members inside buildings at moderate or high humidity, outdoor surfaces protected from rain
XC4	Alternatively wet and dry	Surfaces wetted with water which are not classified under class XC2
Reinforcement corrosion induced by chlorides (e.g. de-icing agents)		
XD1	Moderately damp	Structural members within spray range of road surfaces
XD2a	Wet, rarely dry.	Swimming pools, structural members in contact with industrial waste water containing chlorides; ≤ 0.5 g/l Cl
XD2b	Wet, rarely dry	Swimming pools, structural members in contact with industrial waste water containing chlorides; > 0.5 g/l Cl
XD3	Alternatively wet and dry	Parts of bridges, parking levels or retaining walls which are exposed to spray containing chlorides

2000: EN 206-1 adopted by Swiss Standards

Example for Corrosion induced by Carbonation and Chlorides

Year	**Exposure Class** →	Carbonation (~ACI 318 C1)				Chlorides (~ACI 318 C2)			
		XC1	XC2	XC3	XC4	XD1	XD2a	XD2b	XD3
2000	$\text{Strength}_{\text{Cyl}}$ $\text{Class}_{\text{min}}$	25	25	25	30	25	25	30	30
	C_{min} (kg/m³)	280	280	280	300	300	300	320	320
	w/c_{max}	0.65	0.65	0.60	0.50	0.50	0.50	0.45	0.45

ACI 318 C0 and C1:
$f'c_{\text{min}}$ = 17.5 MPa
w/c_{max} = ---

ACI 318 C2:
$f'c_{\text{min}}$ = 35 MPa
w/c_{max} = 0.40

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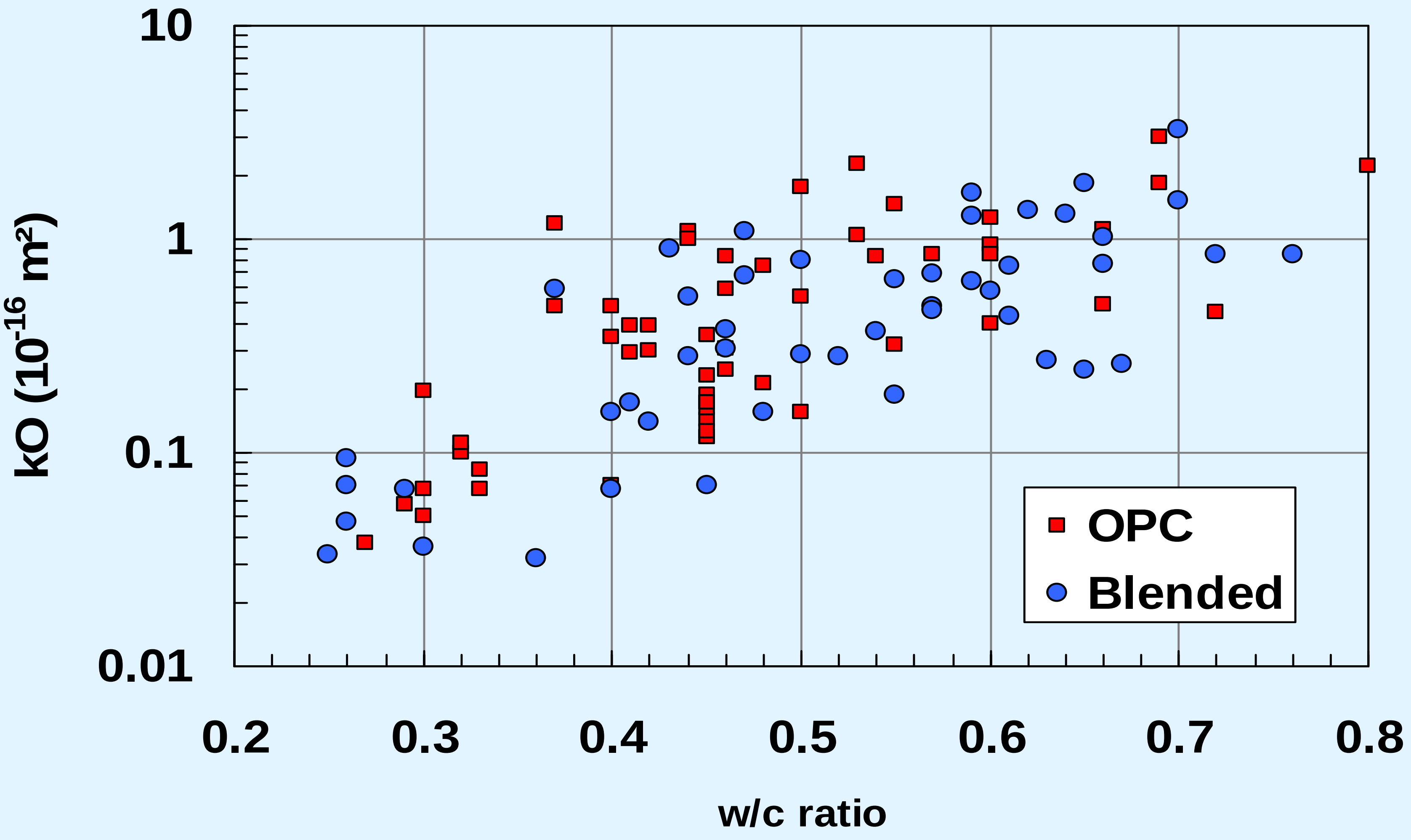
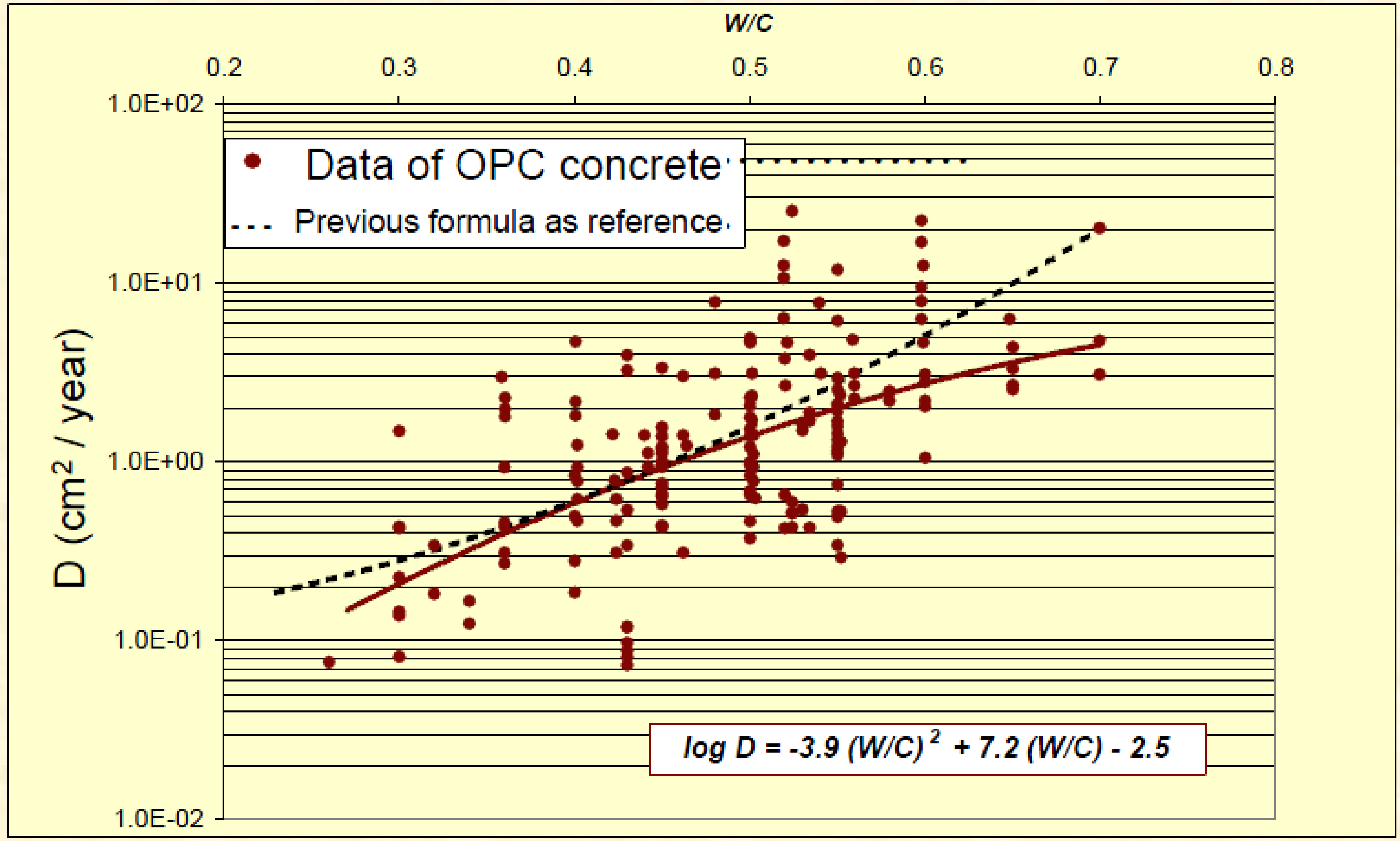
Permeability to O_2 (kO) vs water/cement ratio



kO: RILEM-Cembureau test

Cl^- Diffusion vs w/c ratio (JSCE-Japan)



Year 2000

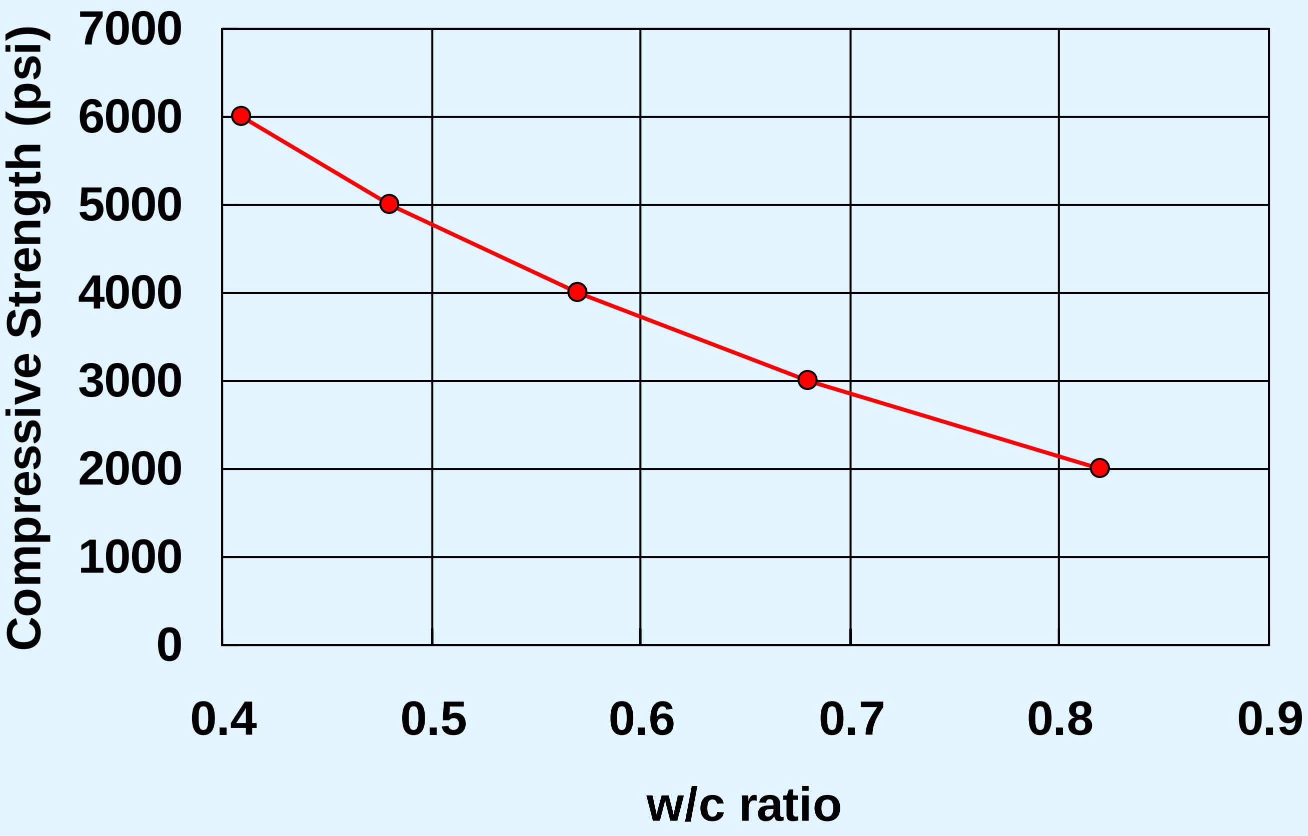
Purely prescriptive specification of mix design

'Covercrete'
Quality = K^{-1}

K = Penetrability

DESIGN	PRACTICE	CONTROL
Specification of w/c_{max} ☹	**Concrete Production + Delivery** →	**w/c ???** ☹
	Execution: • Placing • Compaction • Finishing • Curing →	**Visual Inspection** ☹

Relation Strength vs w/c (ACI 211)



Why don‘t we specify w/c_{max}= 0.50 for f‘c= 3500 psi?

Because we have agreed on a test to measure f‘c

The test is far from perfect, since the result depends on:

- The slenderness of the specimen (cylinder, cube), much different than in real life
- The capping material for cylinders, absent in real life
- The rate of loading, much higher than in real life
- The moisture content, much higher than in real life

Yet, we have been used to accept the results as a good indicator of the strength used for structural design.

Hence, agreeing on meaningful tests for durability is a crucial step in the P2P process.
This has been achieved in Switzerland.

Main Milestones in P2P

Modification of Swiss Standards	**Swiss Std. (US equiv.)**
2000: Adoption of EN206-1 (Prescriptive)	SN EN 206-1 (ASTM C94)
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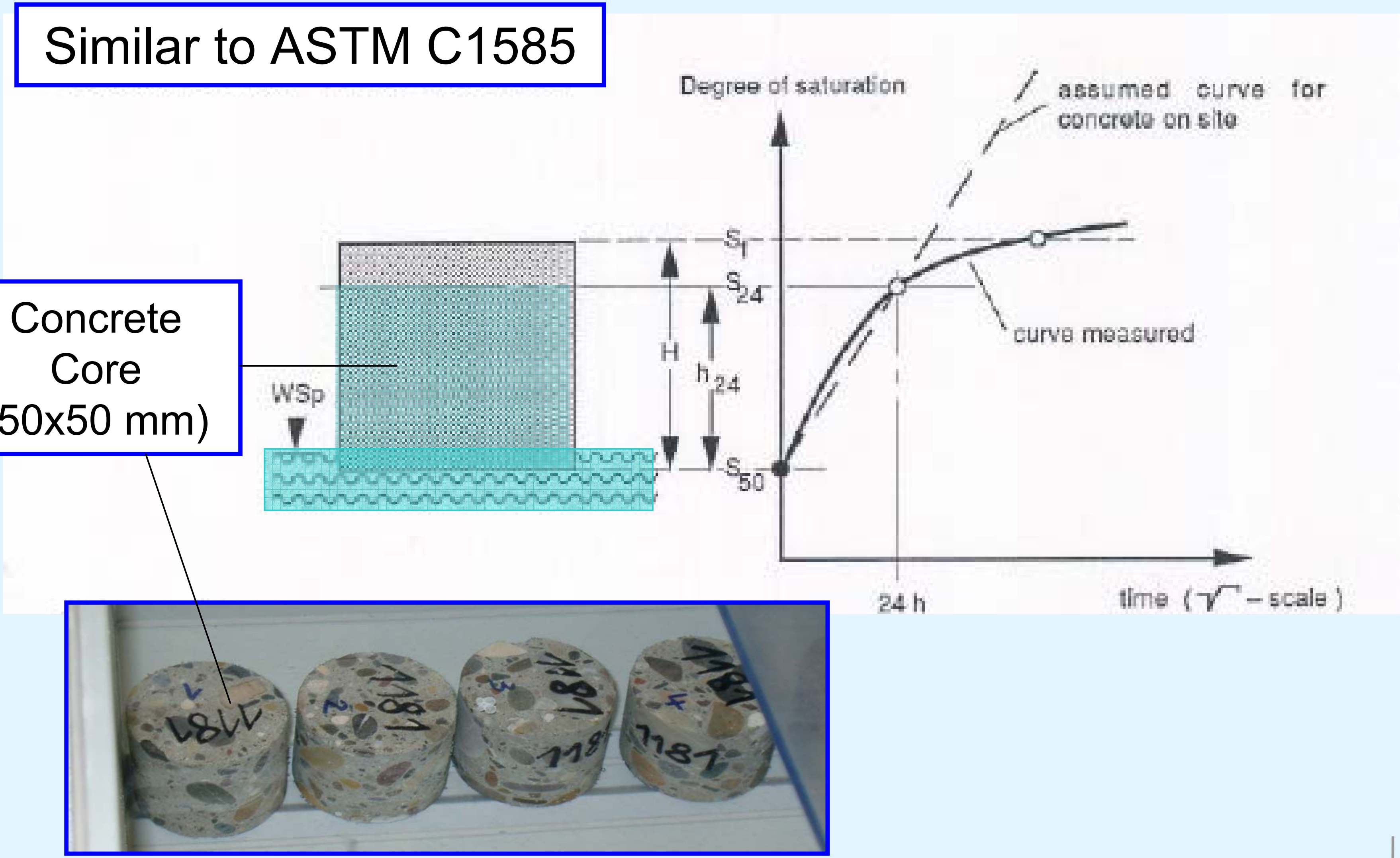
Capillary Suction: Standard SN 505 262/1-A

Similar to ASTM C1585

Concrete Core (50x50 mm)



Capillary Suction: Standard SN 505 262/1-A

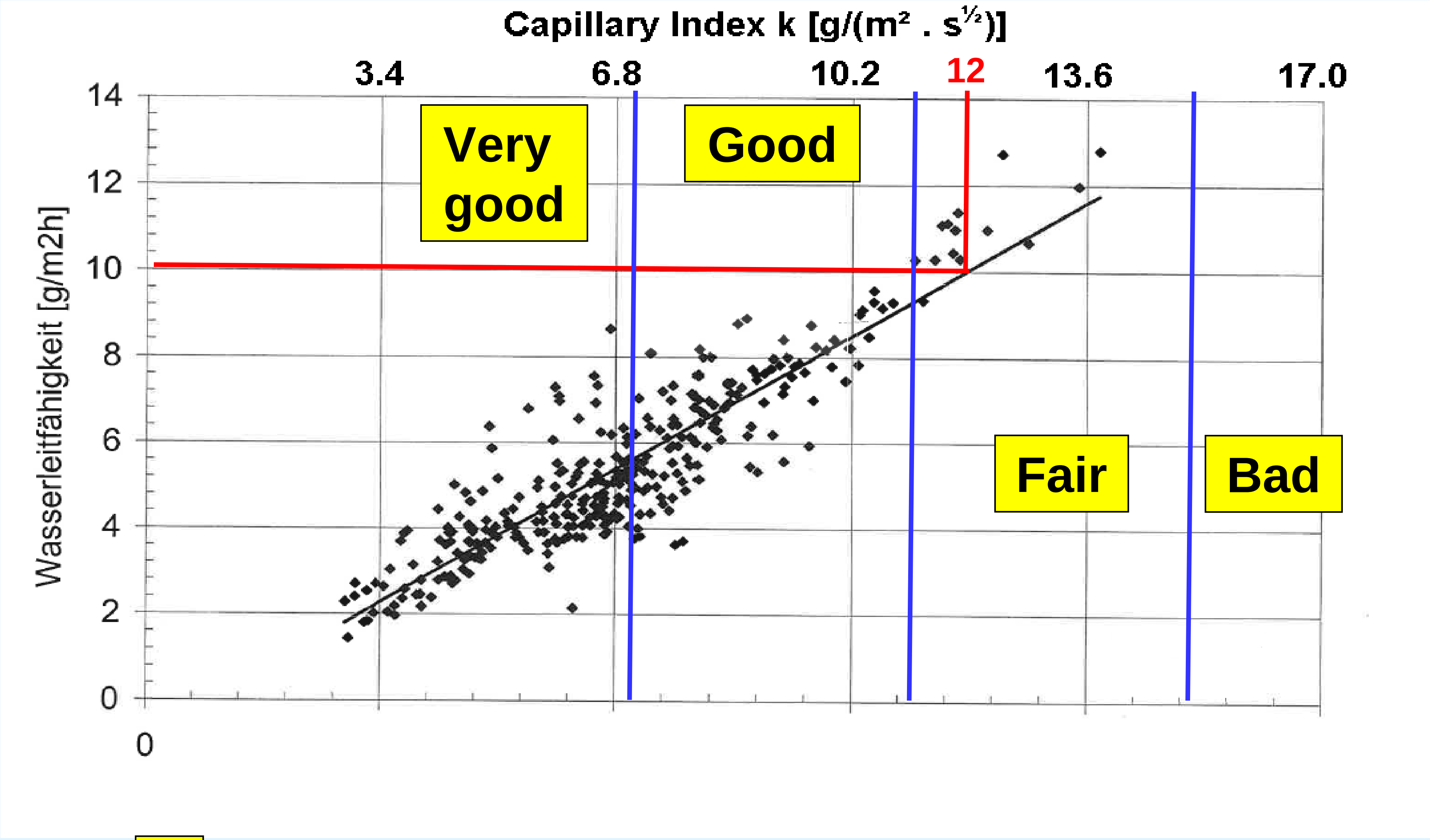
$$q_w = \frac{M_{24}}{t_{24}} \frac{U_E/2}{U_E - U_B} \frac{h_{24}}{400}$$

q_w = „water conductivity“ (Wasserleitfähigkeit) [g/(m^2 . h)]
M_{24}= water absorbed per unit area in 24 h [g/m^2]
h_{24}= capillary rise after 24 h [mm]
t_{24}= 24 [h]
U_E= capillary porosity of sample [-]
U_B= capillary porosity filled with water at t=0 [-]
400 = 2*d [mm], assuming d=200 mm
d = element thickness [mm]

$$k = m_t / (A \, . \, t^{½})$$

k = "capillarity index" @ 24 h [g/m^2/s$^{0.5}$]

Relation between q_w and k

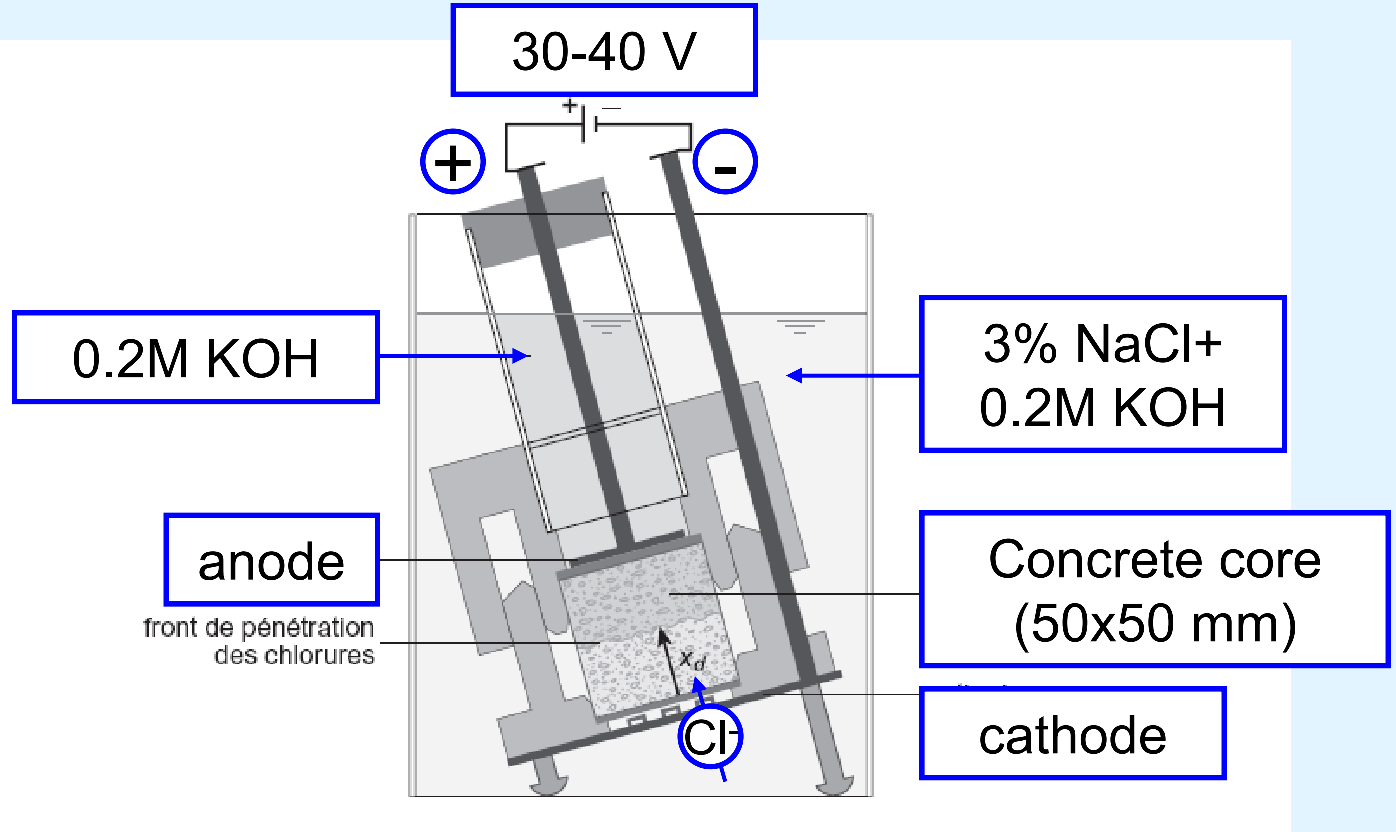


🟨 **Classes proposed by Torrent and Frenzer (1995)**

Cl^- Migration, Standard SN 505 262/1-B

Similar to
AASHTO TP 64

(NordTest NT BUILD
492:1999)



30-40 V

+

-

0.2M KOH

3% NaCl+
0.2M KOH

anode

Concrete core
(50x50 mm)

cathode

Cl^-

Cl^- Migration, Standard SIA 262/1-B:2003

Cl^- Migration, Standard SIA 262/1-B:2003

- After the test (16 or 24 h), the cylinder is split (Brazilian test) and the depth of Cl^- penetration (x_d) is revealed and measured by spraying a solution based on $AgNO_3$.
- The chloride migration coefficient D_{Cl} is computed as:

$$D_{Cl} = \frac{z}{t}\left(x_d - 1{,}5462\sqrt{z\,x_d}\right) \qquad [m^2/s]$$

with $$z = 8{,}619 \cdot 10^{-5}\,\frac{h\,T}{U} \qquad [m]$$

h = cylinder height (m)
T = mean temperature of both solutions during test (°C)
U = mean of applied voltage at initiation and end of test (V)
t = test duration (s)

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2008: Specification of limits for q_w and D_{Cl}

Year	**Exposure Class**	**Carbonation (~ACI C1)**				**Chlorides (~ACI 318 C2)**			
	→	XC1	XC2	XC3	XC4	XD1	XD2a	XD2b	XD3
2000	Strength Class$_{min}$	25/ 30	25/ 30	25/ 30	30/ 37	25/ 30	25/ 30	30/ 37	30/ 37
	C_{min} (kg/m³)	280	280	280	300	300	300	320	320
	w/c$_{max}$	0.65	0.65	0.60	0.50	0.50	0.50	0.45	0.45
2008	q_{wmax} (g/m²h)	---	---	---	10	10	10	---	---
	$D_{Cl\ max}$ (10^{-12} m²/s)	---	---	---	---	---	---	10	10
Minimum Frequency*					4 tests /year 1 test / 500 m^3			4 tests /year 1 test/125 m^3	

* Typical: can be reduced for experienced producers and/or for high production rates

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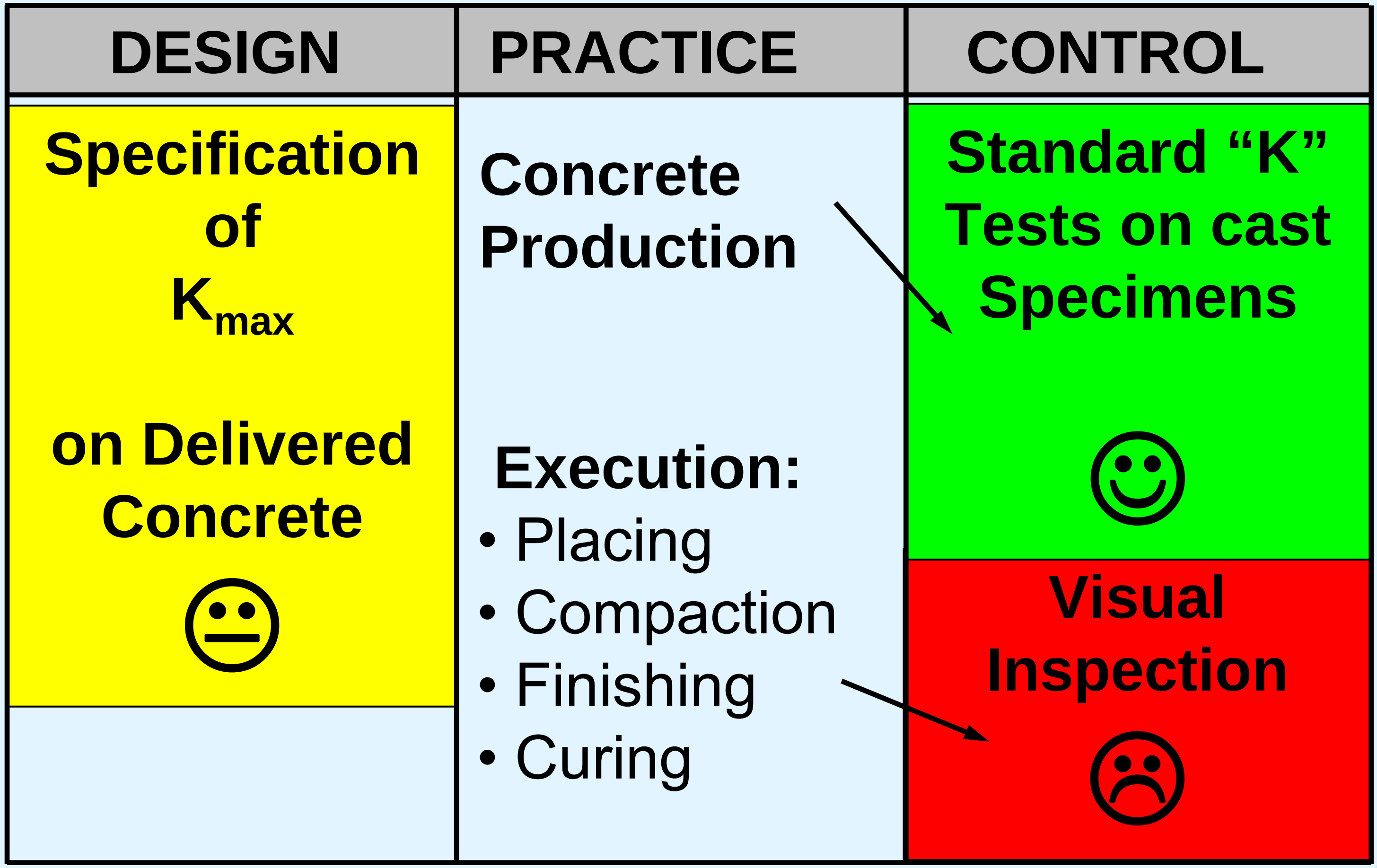
Year 2008

Performance specification of concrete as produced

‘Covercrete’ Quality = K^{-1}

K = Penetrability



DESIGN	**PRACTICE**	**CONTROL**
Specification of K_{max} on Delivered Concrete 😐	**Concrete Production**	**Standard “K” Tests on cast Specimens** ☺
	Execution: • Placing • Compaction • Finishing • Curing	**Visual Inspection** ☹

Main Milestones in P2P

Modification of Swiss Standards	**Swiss Std. (US equiv.)**
2000: Adoption of EN206-1 (Prescriptive)	SN EN 206-1 (ASTM C94)
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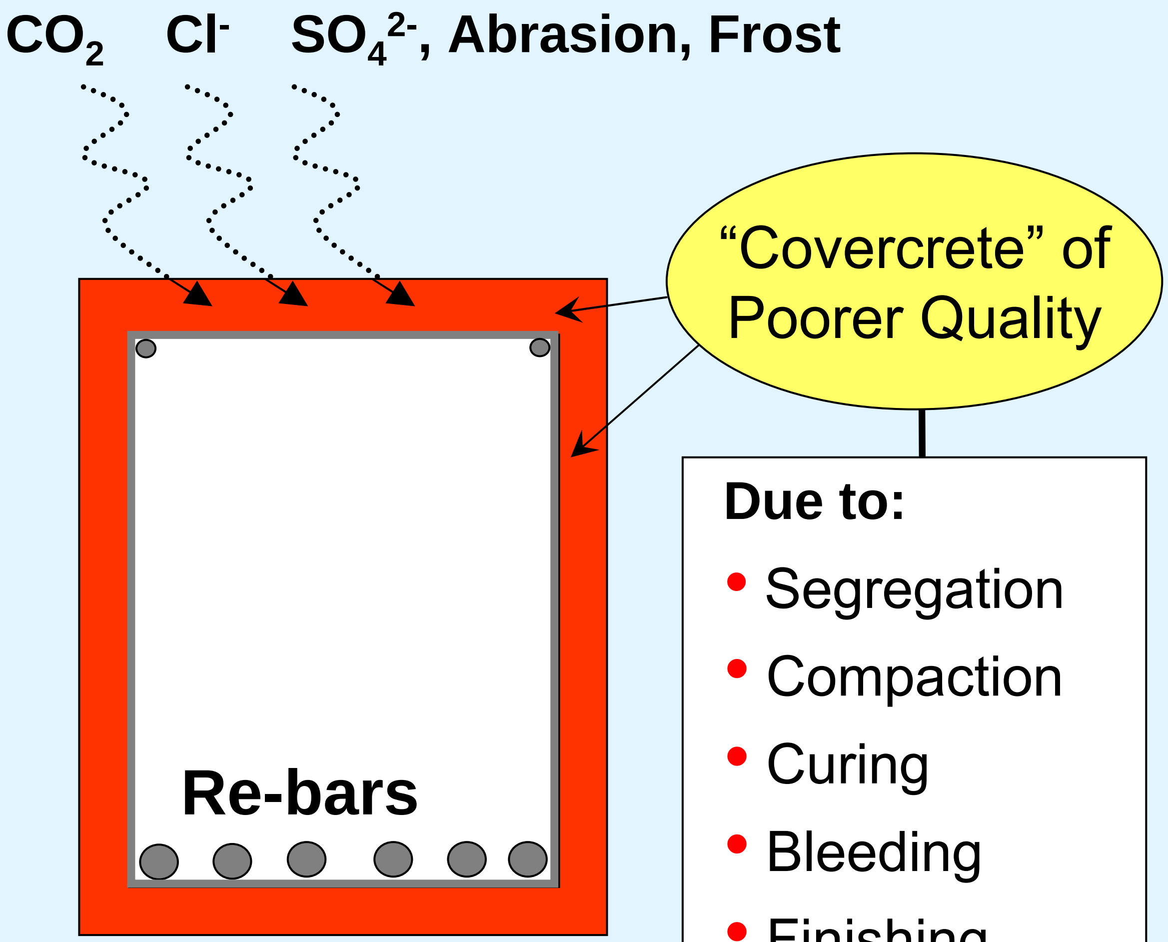
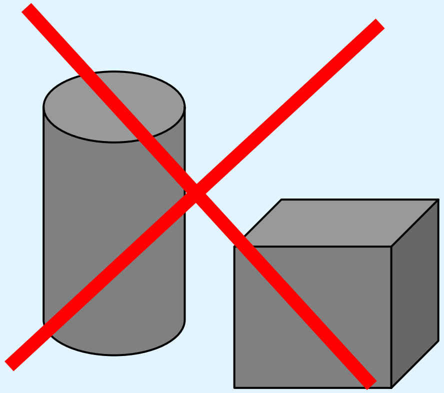
Quality of Concrete in a Real Structure



Due to:

- Segregation
- Compaction
- Curing
- Bleeding
- Finishing
- Microcracks



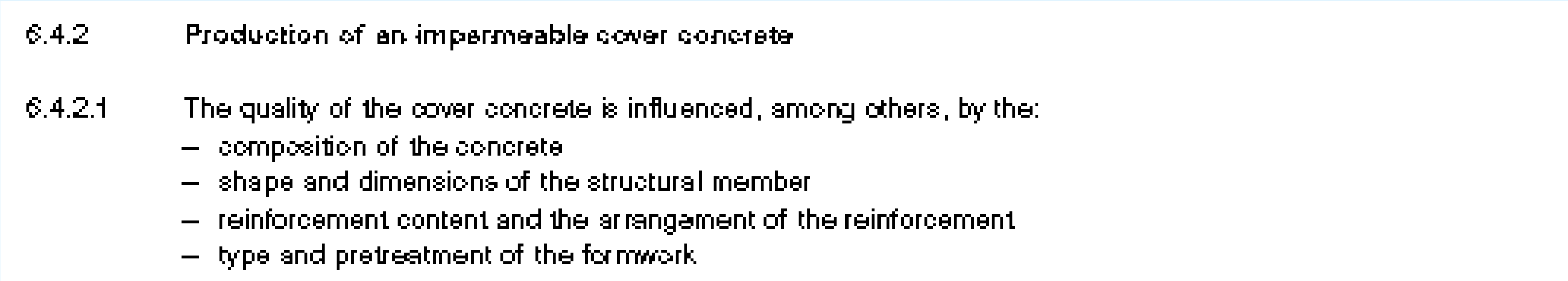
Moulded specimens, cast and cured under standard conditions, **DO NOT** represent the quality of the vital "covercrete"

Swiss Standard SN 505 262 “Concrete Construction”

2.4 **Durability**

2.4.1 General

”With regard to durability, the quality of the cover concrete is of particular importance“



6.4.2 Production of an impermeable cover concrete

6.4.2.1 The quality of the cover concrete is influenced, among others, by the:
- composition of the concrete
- shape and dimensions of the structural member
- reinforcement content and the arrangement of the reinforcement
- type and pretreatment of the formwork

”The impermeability of the cover concrete shall be checked, by means of permeability tests (e.g. air permeability measurements), on the structure or on cores taken from the structure“

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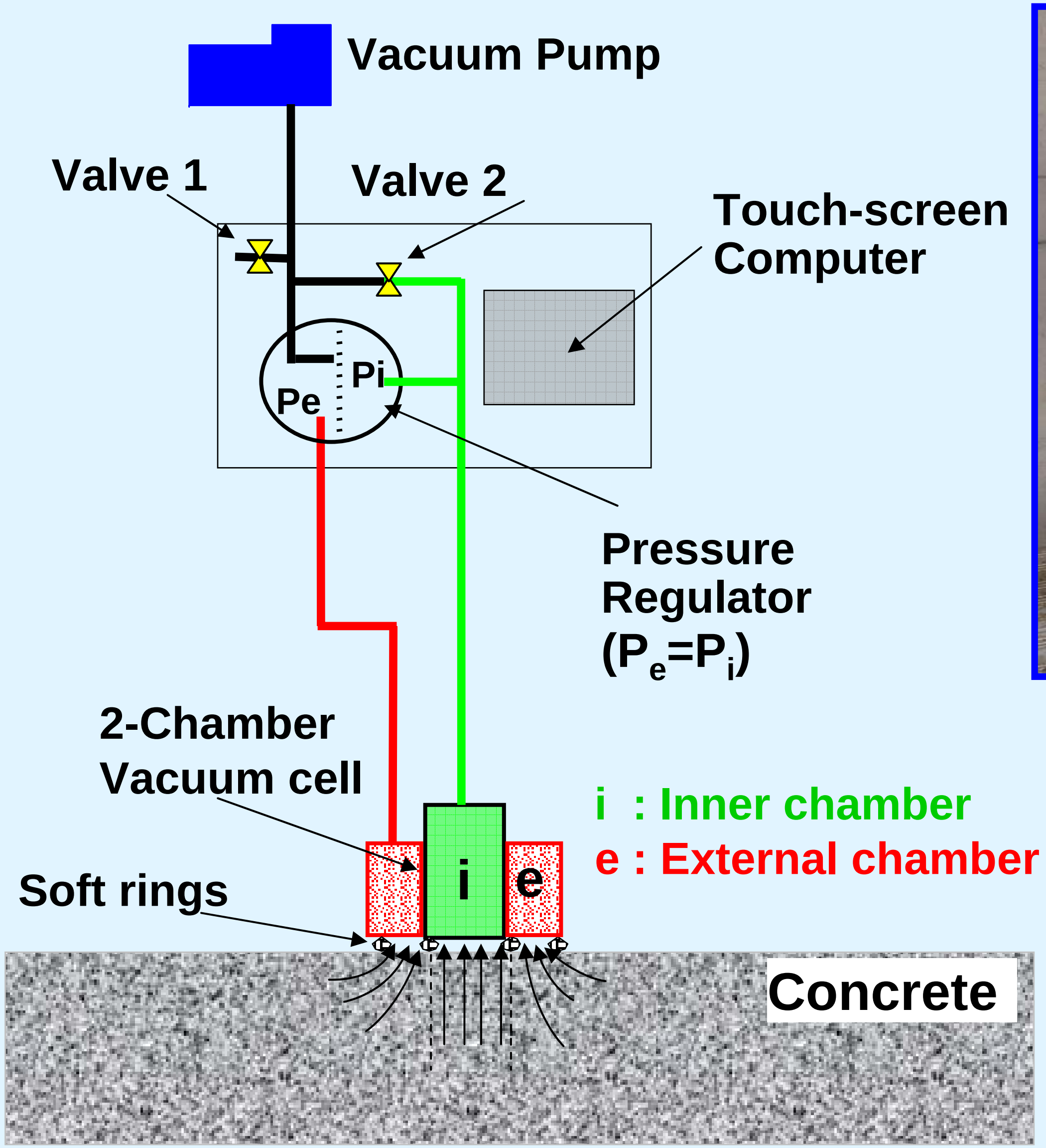
Air Permeability "in situ": SN 505 262/1-E:2003



i : Inner chamber

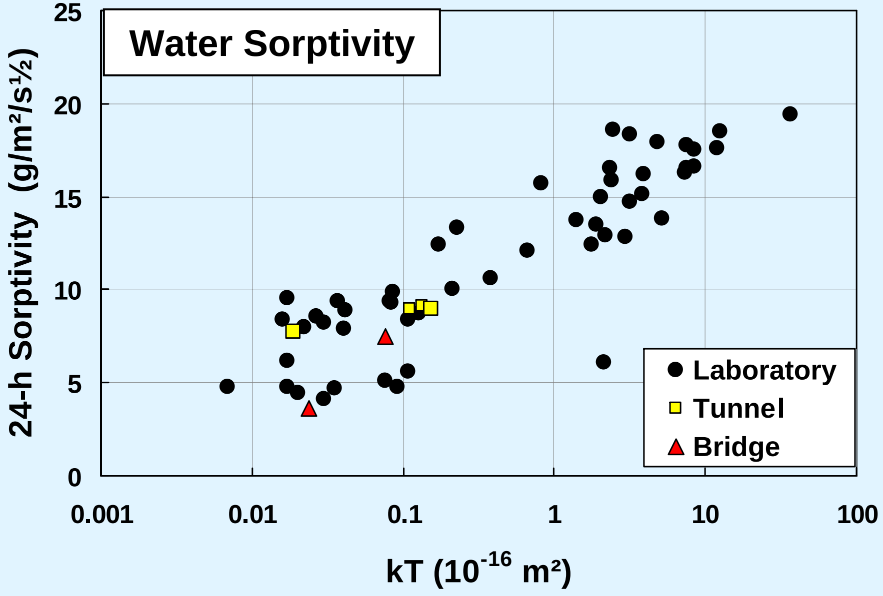
e : External chamber

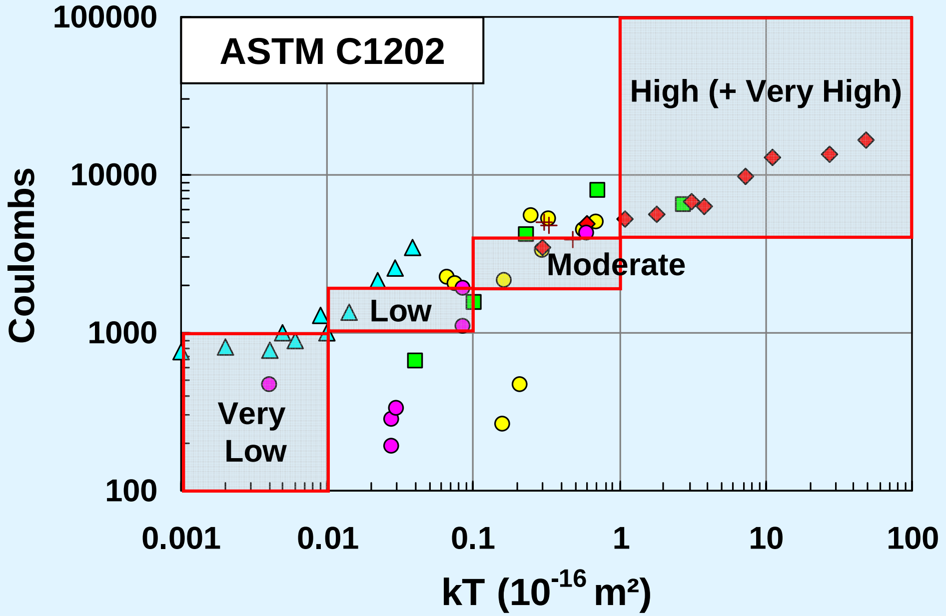
Calculation of kT

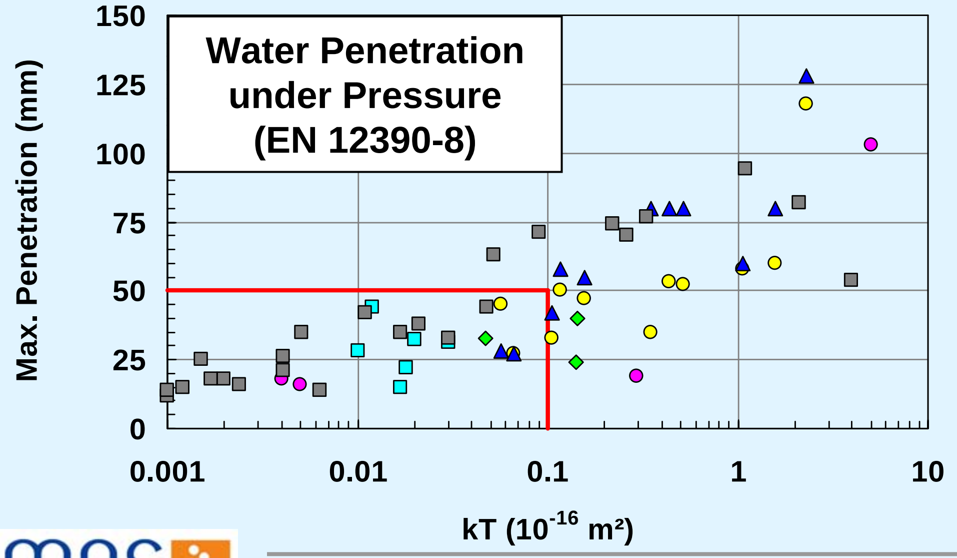
$$kT = \left(\frac{V_c}{A}\right)^2 \frac{\mu}{2\,\varepsilon\,P_a} \left(\frac{\ln \frac{P_a + \Delta P_i\,(t_f)}{P_a - \Delta P_i\,(t_f)}}{\sqrt{t_f} - \sqrt{t_o}}\right)^2$$

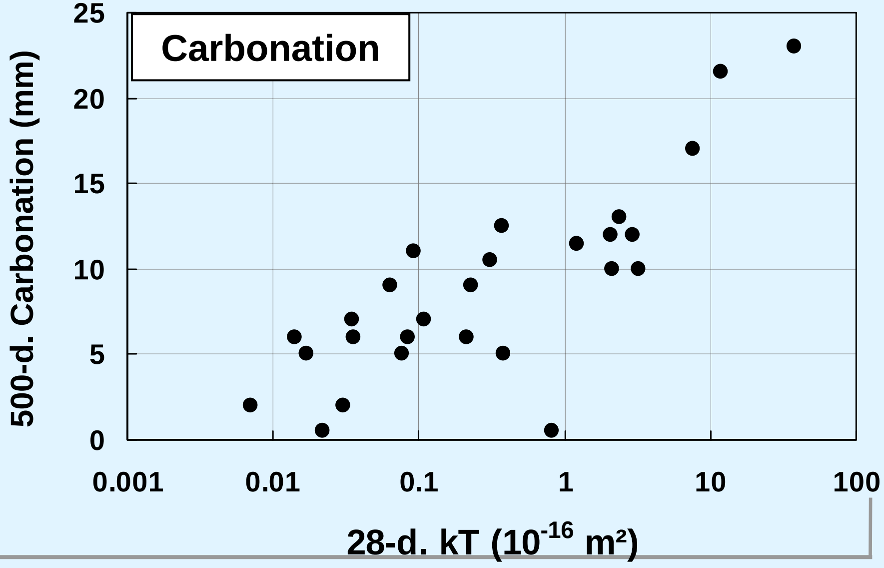
- kT: coefficient of air-permeability (m^2)
- V_c : volume of inner cell system (m^3)
- A : cross-sectional area of inner cell (m^2)
- μ : viscosity of air (= $2.0\ 10^{-5}$ $N.s/m^2$)
- ε : estimated porosity of the covercrete (= 0.15)
- P_a : atmospheric pressure (N/m^2)
- ΔP_i: pressure rise in the inner cell at end of test (N/m^2)
- t_f : time (s) at the end of the test (2 to 6 or 12 min)
- t_o : time (s) at the beginning of the test (= 60 s)

Relation of kT with other Durability Indicators









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Main Milestones in P2P

Modification of Swiss Standards	**Swiss Std. (US equiv.)**
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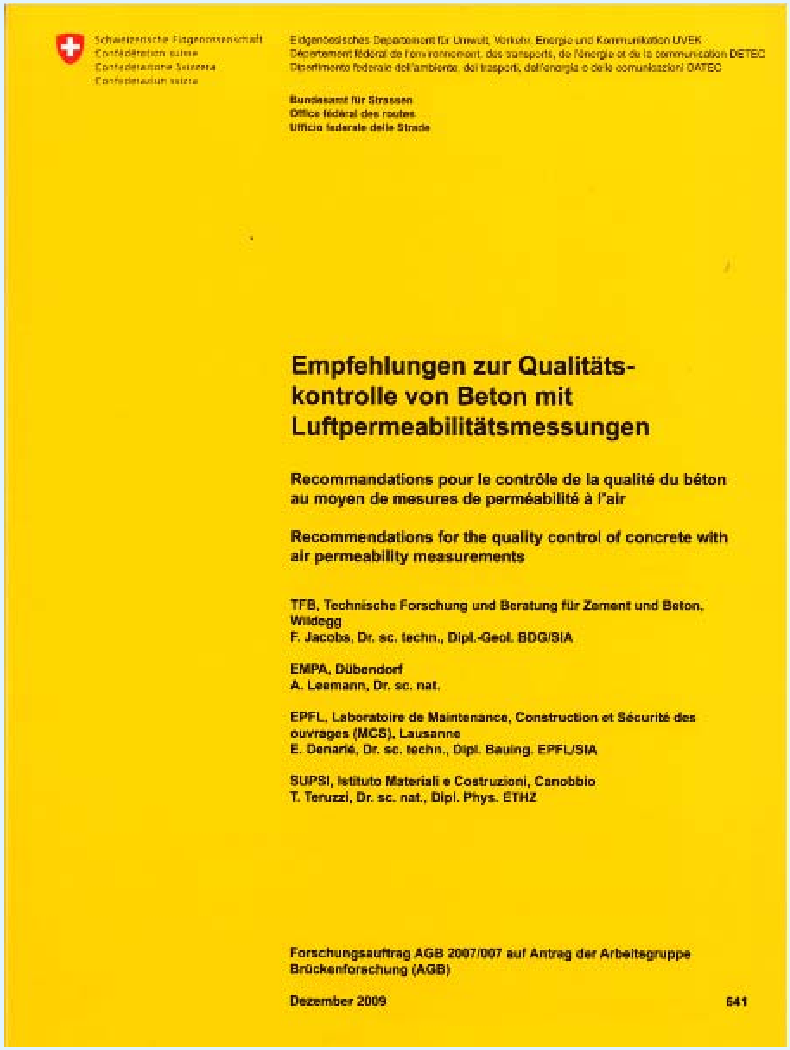
2012?: Limits for site kT_{max} → Swiss Standards	SIA 262 (ACI 318)

Recommendations for site kT quality control

Issued by the Swiss Federal Highway Administration



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK
Département fédéral de l'environnement, des transports, de l'énergie et de la communication DETEC
Dipartimento federale dell'ambiente, dei trasporti, dell'energia e delle comunicazioni DATEC

Bundesamt für Strassen
Office fédéral des routes
Ufficio federale delle Strade

Empfehlungen zur Qualitätskontrolle von Beton mit Luftpermeabilitätsmessungen

Recommandations pour le contrôle de la qualité du béton au moyen de mesures de perméabilité à l'air

Recommendations for the quality control of concrete with air permeability measurements

TFB, Technische Forschung und Beratung für Zement und Beton, Wildegg
F. Jacobs, Dr. sc. techn., Dipl.-Geol. BDG/SIA

EMPA, Dübendorf
A. Leemann, Dr. sc. nat.

EPFL, Laboratoire de Maintenance, Construction et Sécurité des ouvrages (MCS), Lausanne
E. Denarié, Dr. sc. techn., Dipl. Bauing. EPFL/SIA

SUPSI, Istituto Materiali e Costruzioni, Canobbio
T. Teruzzi, Dr. sc. nat., Dipl. Phys. ETHZ

Forschungsauftrag AGB 2007/007 auf Antrag der Arbeitsgruppe Brückenforschung (AGB)

Dezember 2009 641

- Specification of kT
- Sampling
- Suitable age, temperature and moisture conditions
- Calibration and testing
- Conformity Rules
- Reporting

2012?: Swiss Standards adopt FHWA limits

Year	**Exposure Class** →	**Carbonation (~ACI C1)**				**Chlorides (~ACI 318 C2)**			
		XC1	XC2	XC3	XC4	XD1	XD2a	XD2b	XD3
2003	Strength Class_{min}	25/ 30	25/ 30	25/ 30	30/ 37	25/ 30	25/ 30	30/ 37	30/ 37
	C_{min} (kg/m^3)	280	280	280	300	300	300	320	320
	w/c_{max}	0.65	0.65	0.60	0.50	0.50	0.50	0.45	0.45
2008	q_{wmax} (g/m^{2}h)	---	---	---	10	10	10	---	---
	$D_{Cl\ max}$ (10^{-12} m^2/s)	---	---	---	---	---	---	10	10
2012?	Site kT_{max} * (10^{-16} m^2)	---	---	---	2.0	2.0	2.0	0.5	0.5

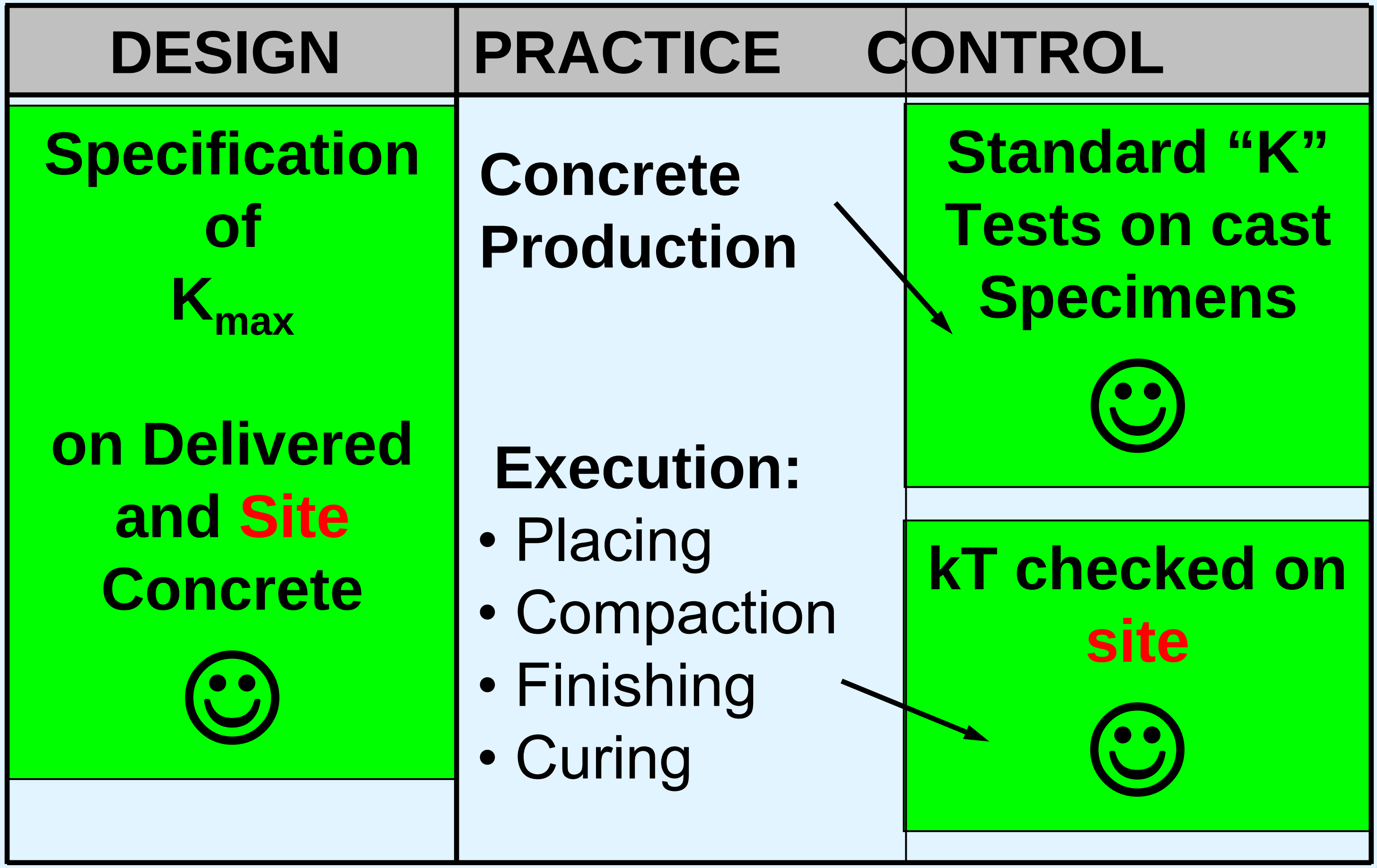
* Proposed by the Swiss Federal Highway Administration in 2009

Year 2009 (2012?)

Performance specification of site concrete

'Covercrete' Quality = K^{-1}

K = Penetrability



DESIGN	PRACTICE	CONTROL
Specification of K_{max} on Delivered and Site Concrete ☺	**Concrete Production**	**Standard "K" Tests on cast Specimens** ☺
	Execution: • Placing • Compaction • Finishing • Curing	**kT checked on site** ☺

Conclusions: Prescriptive Approach

1. The classical prescriptive approach:
   - Specifies a Durability Indicator (w/c) that:
     - is increasingly questionable (composite binders)
     - is very difficult to control in practice
   - Does not encourage innovation
   - Does not guarantee durability, as reality has confirmed
   - Is an obstacle to design sustainable concrete mixes
2. The introduction of Penetrability Tests on cast specimens instead of w/c_{max}, as Durability Indicators, is a clear step forward, but still falls short of ensuring the durability of the real structure because:
   - Establishes the last control point at the concrete plant / truck chute, ignoring what happens after sampling
   - Hence, it does not include the crucial impact of concreting practices' quality

Conclusions: Swiss Approach to Performance Specifications

1. The Swiss Standard SIA 262 approach, establishing as Durability Indicator the permeability of the cover concrete, measured on the structure , aims at controlling the final product
2. Thus, it evaluates the result of the contribution of all players in the concrete construction chain (designers, concrete producers, raw materials suppliers, contractors, inspection, etc.)

Conclusions: Swiss Approach to Performance Specifications

3. By checking the final product, a performance-oriented mindset is created in all players, ensuring a fair competition, in particular:
   - ✓ for the Contractors, who have to deliver the product to be tested (those not applying best practices will be penalized by having to order richer mixes or to apply remedial measures)
   - ✓ for the Concrete Producers, who have to efficiently design, produce and deliver a concrete capable of achieving the required performance
   - ✓ for the Raw Materials Suppliers (cement, additions, admixtures) who will have to design their products to achieve the best performance in concrete

Conclusions: Swiss Approach to Performance Specifications

4. Discourages all too common bad practices such as:
   - Accidental or deliberate transgressions of the specified w/c_{max} by RMX concrete producers
   - Uncontrolled addition of water to the ready-mixed concrete trucks after leaving the batching point
   - Incorrect placing and compaction practices
   - Poor finishing techniques of floors and pavements
   - Insufficient or total absence of moist curing

Conclusions: Swiss Approach to Performance Specifications

5. Incentives innovation by encouraging the use of:
   - SCC, that creates a more compact and uniform concrete cover than conventional vibrated concrete
   - Permeable formwork liners
   - More efficient curing compounds and/or “self-curing” concretes
   - High Performance Concretes
   - Ultra-high Performance Composites (selectively)
   - Low or no Shrinkage Concretes (ShCC)
6. Facilitates the Engineer/Inspection task, who can concentrate their efforts on checking the final product instead of all intermediate operations (+ a preventive role)

References

- Swiss Standard SN EN 206-1:2000, “Concrete - Part 1: Specification, performance, production and conformity”
- Swiss Standard SIA 262:2003, “Concrete Construction”
- Swiss Standard SIA 262/1: 2003, " Concrete Construction – Complementary Specifications“:
  - Annex A: ‘Water Conductivity’
  - Annex B: ‘Chlorides Resistance’
  - Annex E: ‘Air-Permeability on the Structure’
- 2008: Revision of Section 8.2.3.2 of National Annex of Swiss Standard SN EN 206-1:2000
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