The Swiss P2P Road: from Theorecrete to Labcrete to Realcrete

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Objective

- To present the evolution of the Swiss Standards for Durability, from purely Prescriptive (2003) to the most advanced Performance-based Standards worldwide (2013)
- To show that it is possible to escape the “Prescriptive Trap”
Content

- **Year 2003**: Prescriptive EN-based Standards

- **Year 2008**: Performance requirements on cast specimens:
  - “Labcrete”: Laboratory Durability Indicators as step forward

- **Year 2013**: Performance requirements on site concrete:
  - “Realcrete” vs “Labcrete”; Relevance of “Covercrete” for Durability

- Conclusions
Year 2003: Prescriptive Standard SN EN206-1

• In 2003 Switzerland adopted the European Standards for Concrete: EN 206-1 and Eurocode 2

• In particular, for Durability, the following were adopted:
  ➢ Exposure Classes (slightly modified in 2008)
  ➢ Prescriptive requirements in terms of \( w/c_{\text{max}} \) and \( C_{\text{min}} \), together with minimum strength classes for each Exposure Class
## Year 2003: Prescriptive Standard SN EN206-1

<table>
<thead>
<tr>
<th>Damage</th>
<th>Carbonation-induced Corrosion</th>
<th>Chloride-induced Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XC1</td>
<td>XC2</td>
</tr>
<tr>
<td>Exposure Class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/C$_{\text{max}}$</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>C$_{\text{min}}$ (kg/m$^3$)</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td>f'c$_{\text{min}}$ (MPa)</td>
<td>C25</td>
<td>C25</td>
</tr>
</tbody>
</table>
Prescriptive Standards: Shortcomings

- The w/c ratio is a poor durability indicator, because it regards constituents as commodities: same mix proportions = same performance
- The constraints to the mix proportions ($C_{\text{min}}$ and $w/c_{\text{max}}$) vary widely and are predominantly arbitrary
- Offer little room for innovation and value adding
- Limit the competitiveness of concrete as sustainable material
- Compliance almost impossible to be checked by purchaser/owner
Prescriptive Standards refer to “Theorecrete”

The author defines the prescriptive-specified concrete as “Theorecrete”, because it is based on expected (theoretical) assumptions seldom met in practice:

- theoretical performance based on the specified w/c ratio
- theoretical assumption that w/c ratio complies with prescribed limits (almost impossible to control on site)
- theoretical good construction practices (frequently not observed by contractors, e.g. the endemic “lack of curing”)
## Situation 2003

<table>
<thead>
<tr>
<th>DESIGN</th>
<th>PRACTICE</th>
<th>CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification of ( w/c_{\text{max}} ) on Delivered Concrete</td>
<td>Concrete Production</td>
<td></td>
</tr>
</tbody>
</table>
| Execution:  
  - Placing  
  - Compaction  
  - Finishing  
  - Curing | | Impossibility of checking \( w/c \) |
| Visual Inspection | |

Prescriptive specification of Theorecrete
Year 2003: Prescriptive EN-based Standards
  - “Theorecrete”: The \( w/c_{\text{max}} \) and \( \text{Cement}_{\text{min}} \) Myths

Year 2008: Performance requirements on cast specimens:
  - “Labcrete”: Laboratory Durability Indicators as step forward

Year 2013: Performance requirements on site concrete:
  - “Realcrete” vs “Labcrete”; Relevance of “Covercrete” for Durability

Conclusions
Year 2008: Theorecrete to Labcrete

In 2008, performance requirements were introduced in the Swiss Standards, coexisting with prescriptive ones.

Concrete producers must show through regular testing on cast specimens (“Labcrete“) that their concretes comply with limiting values of standard tests

Frequency = f (Volume, experience) ≥ 4 samples/year
## Swiss Standards P2P: Carbonation

### Accelerated Carbonation

<table>
<thead>
<tr>
<th>Exposure Class</th>
<th>Carbonation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strength Class</strong>&lt;sub&gt;Cube min&lt;/sub&gt;</td>
<td>XC1</td>
</tr>
<tr>
<td><strong>C&lt;sub&gt;min&lt;/sub&gt; (kg/m³)</strong></td>
<td>25</td>
</tr>
<tr>
<td><strong>K&lt;sub&gt;N max&lt;/sub&gt; (mm/√y)</strong></td>
<td>5.0</td>
</tr>
<tr>
<td><strong>K&lt;sub&gt;N max&lt;/sub&gt; (mm/√y)</strong>&lt;sub&gt;50 years&lt;/sub&gt;</td>
<td>---</td>
</tr>
<tr>
<td><strong>K&lt;sub&gt;N max&lt;/sub&gt; (mm/√y)</strong>&lt;sub&gt;100 years&lt;/sub&gt;</td>
<td>---</td>
</tr>
</tbody>
</table>

### Diagram:
- Diagram of a laboratory setup for accelerated carbonation testing.
Swiss Standards P2P: Chlorides

**Capillary Suction**

- Degree of saturation
- Curve measured
- Assumed curve for concrete on site

**Chloride Migration**

- 3% NaCl in 0.2 M KOH
- Concrete disc
- Anode
- Chloride Penetration Front
- Cathode
- 20 V DC

**Exposure Class**

<table>
<thead>
<tr>
<th>Exposure Class</th>
<th>XD1</th>
<th>XD2a</th>
<th>XD2b</th>
<th>XD3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength Class</td>
<td>Cube min</td>
<td>30</td>
<td>30</td>
<td>37</td>
</tr>
<tr>
<td>C_{min} (kg/m³)</td>
<td></td>
<td>300</td>
<td>300</td>
<td>320</td>
</tr>
<tr>
<td>w/c_{max}</td>
<td></td>
<td>0.50</td>
<td>0.50</td>
<td>0.45</td>
</tr>
<tr>
<td>q_{wmax} (g/m²h)</td>
<td></td>
<td>10</td>
<td>10</td>
<td>---</td>
</tr>
<tr>
<td>M_{Cl max} (10^{-12} m²/s)</td>
<td>---</td>
<td>---</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
**Concrete Production**

**Standard “K”**

**Tests on cast Specimens**

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**Situation 2008: from Theorecrete to Labcrete**

**Performance specification of Labcrete**

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<td>Specification of $K_{\text{max}}$ on Delivered Concrete</td>
<td>Concrete Production</td>
<td>Standard “K” Tests on cast Specimens</td>
</tr>
<tr>
<td>Execution: • Placing • Compaction • Finishing • Curing</td>
<td>Visual Inspection</td>
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$K = \text{Penetrability (Performance)}$
Content

- **Year 2003**: Prescriptive EN-based Standards
  - “Theorecrete”: The $w/c_{max}$ and $Cement_{min}$ Myths

- **Year 2008**: Performance requirements on cast specimens:
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- **Year 2013**: Performance requirements on site concrete:
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- Conclusions
“Labcrete”

Production -> Delivery

Plant or Site Sampling

Specimen Preparation

Moist Curing

≥ 28 d.

T~20°C

RH>95%

Preconditioning

Laboratory Testing
“Labcrete” vs “Realcrete”

Production  →  Sampling

Sampling  →  Delivery

Delivery  →  Placing & Compaction

Placing & Compaction  →  Curing ?

Curing ?  →  Natural Maturity

Natural Maturity  →  Specimen Preparation

Specimen Preparation  →  Moist Curing

Moist Curing  →  T~20°C

T~20°C  →  RH>95%

“Realcrete” is quite different to “Labcrete”
“Realcrete” is very different to “Labcrete”
Quality of Concrete in the Real Structure

Due to:
- CO$_2$
- Cl$^-$
- SO$_4^{2-}$, Abrasion, Frost

“Covercrete” of Poorer Quality

Due to:
- Segregation
- Compaction
- Curing
- Bleeding
- Finishing
- Microcracking

Cast specimens, made and cured under standard conditions, DO NOT represent the quality of the vital “covercrete”
Covercrete weakening due to thermal microcracks

HSC: $f'_c = 70$ MPa

Rhein Bridge Schaffhausen, Switzerland

Specimen at 20°C, >95% RH

Torrent R., ACI SP-186, Paper 17, pp. 291-308, 1999
Covercrete improvement: ShCC Floor

- Power Floating
- Chemical prestressing due to expansion restrained by steel
- Quartz hardener

[Image: Construction site with machinery and workers.]

BAUTEC
Argentina
Covercrete improvement: Use of Permeable Formwork Liners

Without liner

With liner

\[ kT \sim 1/10 \]

\[ \Delta w/c = 0.10-0.15 \]
Recognition of “Covercrete” by Standards

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."

Swiss Concrete Code SIA 262:2003
Air-Permeability Test Method: SIA 261/1 Annex E

2-Chamber Vacuum cell

Vacuum Pump

Valve 1

Valve 2

Touch-screen Computer

Pressure Regulator ($P_e = P_i$)

2-Chamber Vacuum cell

Soft rings

Concrete

$P_e$ : External chamber

$i$ : Inner chamber
Relation of $kT$ with other Durability Indicators

Water Sorptivity

24-h Sorptivity ($g/m^2/s^{1/2}$)

- Laboratory
- Tunnel
- Bridge

ASTM C1202

High (+ Very High)

Moderate

Very Low

Coulombs

Water Penetration under Pressure (EN 12390-8)

Max. Penetration (mm)

- Laboratory
- Tunnel
- Bridge

Natural Carbonation Rate

28-d. $kT$ ($10^{-16} m^2$)

Carbonation Rate (mm/y^{1/2})
Standard Method for site kT quality control
SIA 262/1:2013 (Annex E)

- Specification of kT_s for different Exposure Classes

- Grouping and Sampling (Lot = 500 m² or 3 d.)

- 6 Tests at random within Lot

- Suitable age (28 - 90 days), Temperature (≥ 10°C) and Surface moisture by impedance method (≤ 5.5%)

- Conformity Rules
**Specified Values of $kT_s$**

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<td>$kT_s$ (10^{-16} m²)</td>
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$kT_s$ = upper «characteristic» value
Compliance Rules

1. Not more than 1 out of 6 kT values above kTs

2. If just 2 out of 6 kT values are above kTs: Another series of 6 random tests are conducted within the Lot, again with not more than 1 out of 6 kT values above kTs;
Swiss Standards: Situation 2013

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<td>kT checked on site</td>
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$K = \text{Penetrability} \quad \text{(Performance)}$

Performance specification of Labcrete and Covercrete
Conclusions

1. Specifying the performance of the covercrete, measured on site, aims at controlling the end, as-built product.

2. By checking the end product, a performance-oriented mindset is created in all players, ensuring a fair competition for:
   - Contractors, who have to deliver the specified quality of the product to be tested.
   - Concrete Producers, who have to efficiently design, produce and deliver mixes capable of achieving the required performance.
   - Raw Materials Suppliers (cement, additions, admixtures) who have to design their products to achieve the best performance in concrete.
Conclusions

3. Discourages all too common bad practices such as:
   - Accidental or deliberate transgressions of the specified w/c_{\text{max}} by 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

4. Incentives innovation by encouraging the use of:
   - SCC, creating a more compact and uniform concrete
   - Permeable formwork liners
   - Efficient curing compounds, “self-curing” concretes and sealers
   - High Performance Concretes and Composites
   - Low or no Shrinkage Concretes (ShCC)
   - More sustainable systems, currently precluded by prescriptive standards
5. It is expected that, in 5 years time, the requirements of minimum cement content will be eliminated and the requirements of maximum w/c ratio will be either relaxed or eliminated altogether.

Then, a 100% performance Swiss Standard for durability will have been established