Specification and site control of the permeability of the cover concrete: The Swiss approach

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Switzerland
Content

- Need to assess the penetrability of the covercrete on site
- Relevance of site measurement of air-permeability
- Recommendations of the Swiss FHWA
- Conclusions: foreseeable consequences of the Swiss approach for Concrete Construction
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Quality of Concrete in a Real Structure

Specimens, cast and cured under standard conditions, DO NOT represent the quality of the vital “covercrete”

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

$\text{Durability} = f(\text{penetrability, thickness})$

$\text{CO}_2$  $\text{Cl}^-$  $\text{SO}_4^{2-}$, Abrasion, Frost

“Covercrete” of Poorer Quality
"With regard to durability, the quality of the cover concrete is of particular importance."

"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."
Air Permeability “in situ”: SIA 262/1-E:2003

Valve 1
Valve 2

Vacuum Pump

Touch-screen Computer

Pressure Regulator ($P_e = P_i$)

2-Chamber Vacuum cell

Soft rings

i : Inner chamber
e : External chamber

Concrete

PermeaTORR (M-A-S 2008)

Torrent Permeability Tester (Proceq 1995)
Evolution of $P_i$ (simplified)

- $t = 0$: $P_i \approx 1000$
- Close V1
- $\Delta P = 0$
- $t_{\text{max}}$
- $\Delta P \approx 20$ mbar
- $kT = 9.2 \times 10^{-16}$ m²
- $kT = 0.070 \times 10^{-16}$ m²

Chart:
- Pressure $P_i$ (mbar)
- Time (s) – square root scale
- $t_f = 135$
- Close V2
\( P_i = P_e \Rightarrow \text{Controlled unidirectional air-flow} \)
Calculation of $kT$

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

- $kT$: coefficient of air-permeability (m$^2$)
- $V_c$: volume of inner cell system (m$^3$)
- $A$: cross-sectional area of inner cell (m$^2$)
- $\mu$: viscosity of air (= 2.0 $10^{-5}$ N.s/m$^2$)
- $\varepsilon$: estimated porosity of the covercrete (= 0.15)
- $P_a$: atmospheric pressure (N/m$^2$)
- $\Delta P_i$: 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)
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Relation of kT with other Durability Indicators

**Water Sorptivity**

- 24-h Sorptivity (g/m²/s²)
- kT (10⁻¹⁶ m²)

**ASTM C1202**

- Coulombs
- kT (10⁻¹⁶ m²)

**Water Penetration under Pressure (EN 12390-8)**

- Max. Penetration (mm)
- kT (10⁻¹⁶ m²)

**Carbonation**

- 500-d. Carbonation (mm)
- 28-d. kT (10⁻¹⁶ m²)
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Involvement of ASTRA (Swiss FHWA)

(1993)

(2009)
Recommendations for site kT quality control

Issued by the Swiss Federal Highway Administration end 2009

- Reproducibility of kT test
- Specification of kT
- Suitable age, temperature and moisture conditions
- Sampling
- Conformity Rules
- Reporting
Reproducibility on Bridge and Tunnel Elements

<table>
<thead>
<tr>
<th>Lab</th>
<th>Coeff. Air-Permeability kT ($10^{-16}$ m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Tunnel high SD N=6</td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Bridge low SD N=15</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Very Low | Low | Moderate | High | Very High
0.001    | 0.01| 0.1      | 1    | 10     | 100
<table>
<thead>
<tr>
<th>Year</th>
<th>Exposure Class</th>
<th>Carbonation</th>
<th>Chlorides</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>XC1</td>
<td>XC2</td>
</tr>
<tr>
<td>2003</td>
<td>Strength Class(_{\text{min}})</td>
<td>25/ 30</td>
<td>25/ 30</td>
</tr>
<tr>
<td></td>
<td>(C_{\text{min}}) (kg/m(^3))</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td></td>
<td>(w/c_{\text{max}})</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>2008</td>
<td>(q_{\text{Wmax}}) (g/m(^2)h)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>(D_{\text{Cl max}}) (10(^{-12}) m(^2)/s)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2013?</td>
<td>Site (kT_{s}) (10(^{-16}) m(^2))</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

\(kT_{s}\) = "statistical maximum"; limits proposed in Recommendations
Testing Recommendations

- **Age of testing:**
  Between 28 (60 for slow binders) and 90 days

- **Temperature**
  Concrete temperature should be ≥ 5°C.

- **Moisture** (one of the following conditions should be fulfilled)
  - Absolute moisture, measured by contact impedance surface tester, ≤ 5.5 %
  - Electrical resistivity, measured by Wenner method, ≥ 10-20 kΩ.cm

Guidelines given on when the above conditions are likely to be fulfilled
Sampling

- Elements made under nominally same conditions are grouped and listed chronologically
- Surface Lots defined (500 m² or 3 concreting days)
- Measurement points (6) selected at random
Conformity Criterion

- **Condition 1:**
  Not more than 1 test (out of the 6) with $k_T > k_{T_s}$

- **Condition 2:**
  If 2 tests > $k_{T_s}$, 6 new points are selected at random from the same Lot

  Not more than 1 (out of the new 6 tests) with $k_T > k_{T_s}$

If none of the above Conditions is fulfilled, the Lot is considered as non-compliant with the specified $k_{T_s}$ and consequences follow.
This gives a probabilistic meaning to $kT_s$.
New Situation

**Performance specification of site concrete**

<table>
<thead>
<tr>
<th>DESIGN</th>
<th>PRACTICE</th>
<th>CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification of $K_{\text{max}}$ on Delivered and Site Concrete</td>
<td>Concrete Production</td>
<td>Standard “K” Tests on cast Specimens</td>
</tr>
<tr>
<td>Execution: • Placing • Compaction • Finishing • Curing</td>
<td></td>
<td>$kT$ checked on site</td>
</tr>
</tbody>
</table>

'Covercrete' Quality = $K^{-1}$

$K$ = Penetrability

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Conclusions

1. Specifying the air-permeability of the covercrete, measured on site, aims at controlling the end 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.
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 covercrete
   - Permeable formwork liners
   - More efficient curing compounds and/or “self-curing” concretes
   - High Performance Concretes and Composites
   - Low or no Shrinkage Concretes (ShCC)
   - More sustainable systems, currently precluded by prescriptive standards
Conclusions

5. Allows estimating service life from measurements conducted on the structure
   - Measurement of the coefficient of air-permeability $k_T$
   - Measurement of cover depth
   - Application of models for carbonation-induced corrosion based on air-permeability $k_T$ (e.g. Parrott)
   - Application of models for chloride-induced corrosion based on air-permeability $k_T$ (e.g. EPFL) or through correlations of $D_{Cl}$ and $k_T$ (e.g. EHE-08)


SIA (2003b), Norm Swiss SIA 262: “Concrete Structures”.


