Measuring the “True” Durability Potential through Site Air-Permeability NDT

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Content

- Why measure the Permeability of the Cover Concrete “IN SITU”?
- Approach of Swiss Standard SIA 262 on “Concrete Construction” (“ACI 318” equivalent)
- Principles and History of the PermeaTORR
- Evidence as Suitable Durability Indicator
- Some Applications
- Foreseen effects on Concrete Construction quality
- Live Demo (and/or at Booth #202)
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Quality of Concrete in a Real Structure

**CO₂**  **Cl⁻**  **SO₄²⁻**, Abrasion, Frost

“Covercrete” of Poorer Quality

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

Molded specimens, made and cured under standard conditions, **DO NOT** represent the quality of the vital “covercrete”
Importance of the Concrete Cover

Service Life depends to a large extent on the Penetrability $K$ of the “Covercrete” and for steel corrosion also on the Thickness of the Cover, both as achieved in the final structure.

This achievement depends on:

- correct specifications
- delivery of potentially durable concrete
- sound concreting practices
- adequate level of inspection
- realistic control procedures
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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.
Standardization of a Non-Destructive Site Test for Air-Permeability of the “covercrete”

ANNEXE E: PERMÉABILITÉ À L’AIR DANS LES STRUCTURES

E.1 Domaine d’application

Les chiffres qui suivent spécifient une méthode permettant de déterminer dans les structures, de façon non destructive, la perméabilité à l’air d’un béton conforme à la norme SN EN 206-1. La perméabilité à l’air permet de tirer des déductions prévisionnelles sur la durabilité du béton situé au voisinage de la surface.

E.2 Références

Aucune.

E.3 Définitions

$k$ coefficient de perméabilité à l’air ou en abrégé, perméabilité à l’air [m²]

E.4 Principe

Au moyen d’une pompe à vide, on crée une dépression dans une chambre d’essai et dans une chambre de protection qui l’entoure. Les deux chambres étant ouvertes contre la surface du béton. La liaison entre la chambre d’essai et la pompe à vide est ensuite hermétiquement fermée. Pendant la durée des mesures, la dépression de la chambre de protection est gérée de manière à être toujours égale à celle de la chambre d’essai. On mesure en fonction du temps la baisse de pression induite par le flux d’air traversant le béton. On calcule ensuite la perméabilité à l’air à partir de la variation de pression en fonction du temps et d’autres valeurs caractéristiques.

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Sketch of the *PermeaTORR*
Key Test Feature: two chambers and $P_e = P_i$
kT as function of ΔPi rate

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

- \( t = 0 \) and \( P_i \approx 1000 \)
- \( t \approx 35 \) and \( P_i \approx 200 \)
- \( \Delta P_{\text{eff}} \approx 20 \text{ mbar} \)
- \( kT = 9.2 \times 10^{-16} \text{ m}^2 \)
- \( kT = 0.070 \times 10^{-16} \text{ m}^2 \)

Close V1

\( \Delta P = 0 \)

Close V2

\( kT = 9.2 \times 10^{-16} \text{ m}^2 \)

\( kT = 0.070 \times 10^{-16} \text{ m}^2 \)

Close V1

\( t = 0 \)

\( P_i \approx 1000 \)

\( t \approx 35 \)

\( P_i \approx 200 \)

\( \Delta P_{\text{eff}} \approx 20 \text{ mbar} \)

Close V2

\( t_f = 60 \)

\( \Delta P = 0 \)

\( t_f = 135 \)

\( kT_t = 10 \)

\( t_{\text{max}} = 720 \)
Swiss Federal DoT Recommendations

“Recommendations for Quality Control of Concrete with Air-Permeability Measurements”
Issued September 2010

English Translation of Chapters in our webpage:
www.m-a-s.com.ar
<table>
<thead>
<tr>
<th>Class</th>
<th>kT ((10^{-16} \text{ m}^2))</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK1</td>
<td>&lt; 0.01</td>
<td>Very Low</td>
</tr>
<tr>
<td>PK2</td>
<td>0.01 – 0.1</td>
<td>Low</td>
</tr>
<tr>
<td>PK3</td>
<td>0.1 – 1.0</td>
<td>Moderate</td>
</tr>
<tr>
<td>PK4</td>
<td>1.0 – 10</td>
<td>High</td>
</tr>
<tr>
<td>PK5</td>
<td>10 – 100</td>
<td>Very High</td>
</tr>
<tr>
<td>PK6</td>
<td>&gt; 100</td>
<td>Ultra High</td>
</tr>
</tbody>
</table>

Classes PK1 - PK4 are equivalent to ASTM C1202

Permeability Classes and Swiss DoT Limits

ASTRA (DoT) Recommended Max. Limits

Carbonation, Chlorides
Some Aspects of the Recommendations

- **Age of testing:**
  Between 28 and 90 days

- **Temperature**
  Concrete temperature ≥ 5°C (41°F)

- **Moisture**
  Absolute moisture ≤ 5.5 %

Guidelines given on when the above conditions are likely met

- **Conformity**
  ≤ 1 out of 6 test results in a Lot above Limit
Air-Permeability Test: Evolution

2nd Prototype (90)

Torrent Permeability Tester (~95)

Permea-TORR™

2008
More than 80 worldwide documents on test method and its application (list available at [www.m-a-s.com.ar](http://www.m-a-s.com.ar))

<table>
<thead>
<tr>
<th>No.</th>
<th>Code</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>09-06</td>
<td>Teruzzi, T., “Estimating the service-life of concrete structures subjected to carbonation on the basis of the air permeability of the concrete cover”, EUROINFRA 2009, Helsinki, October 14-15, 2009</td>
</tr>
</tbody>
</table>
What is new with the *PermeaTORR*?

- Is faster: 2 to 6 minutes
- Is fully automated
- Works above vapor pressure and corrects values for thin elements
- Graphical display of \((\Delta P_i - t^{\frac{1}{2}})\) with guess of the kT value
- Pressure of both chambers monitored for \(P_e \approx P_i\)
- Is compact and light (fits in single case of \(\approx 9\text{kg} / 20\text{ lb}\))
- Extended range of measurement to ultra high permeable materials
- The measurement point can be described
- Storage of up to 1000 test data → PC
- Software can be updated
PermeaTORR Repeatability at ACI Fall Convention

- Roberto 1
- Roberto 2
- Roberto 3
- Gary
- Jeff
- Dave
- Ken
- Randy
- Tony
- Victorio
- Calvin
- Larry
- Carlos
- Basheer
- Sid
- Clarissa
- Jay
- Michelle
- R. Núñez
PermeaTORR Repeatability at ACI Fall Convention

![Graph showing repeatability scores for various individuals. The x-axis represents names such as Roberto 1, Roberto 2, Roberto 3, Gary, Jeff, Dave, Ken, Randy, Tony, Victorio, Calvin, Larry, Carlos, Basheer, Sid, Clarissa, Jay, Michelle, R. Núñez. The y-axis represents scores ranging from 1 to 10. All scores are at the highest level, indicating excellent repeatability.]
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kT vs Water Sorptivity
(SIA 262/1 Annex A, similar to ASTM C1585)

Sources: 93-01, 95-03

Laboratory
Tunnel
Bridge

24-h Sorptivity (g/m²/s½)

kT (10^{-16} m²)
ASTM C1202 Coulombs vs. kT (various authors)

Source: Legend

Roberto Torrent        ACI Fall Convention, Pittsburgh   26 October 2010
Water Penetration Test (EN 12390-8)

Pressurized Water (0.5 MPa=5 at) for 72 h

d = Result of the test
Maximum Water Penetration (EN 12390-8) vs. $kT$

Graph showing the relationship between maximum water penetration (in mm) and $kT$ ($10^{-16} m^2$) for various methods:
- EN Method - CH
- DIN Method - CH
- EN Method - SP
- DIN Method - AR
- EN Method - UY
- EN Method - NL

Legend:
- Very Low
- Low
- Moderate
- High

Sources: 02-01, 03-02, 05-06, 05-07, 09-08
Site kT vs. Carbonation (Old Swiss bridges)

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>[95-03] 30 y.</td>
<td>[95-03] 60 y.</td>
<td>[08-06] 30 y.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: 95-03; 08-06
Site kT vs. Cl⁻ Content at rebar level (Old Swiss bridge)

<table>
<thead>
<tr>
<th>Chloride Content (% wt cement)</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5</td>
<td>1.0</td>
<td>0.5</td>
<td>0.01</td>
<td>0.001</td>
</tr>
</tbody>
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Source: 08-06
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Effect of w/c and curing on kT

Tests at PUC, Chile

w/c ratio

kT ($10^{-16} \text{ m}^2$)

No curing

7 d. moist

Tests at PUC, Chile

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26 October 2010
Use of Permeable Formwork Liners

More details in www.m-a-s.com.ar
Selective Use of UHPFRC

- Application only on the critical areas of exposure

UHPFRC: Ultra-High Performance Fiber-Reinforced Composite
Placement of UHPFRC
Permeability of UHPFRC (Test SIA 262/1-E)

PC: Permeability class

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<th>PK2</th>
<th>PK3</th>
<th>PK4</th>
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<tbody>
<tr>
<td>Very low</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
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</table>

Good concrete W/B=0.42

Bad concrete

25% 75%
Median

Sources 05-09, 06-11
### Improved quality in Buenos Aires Metro elements

**Permeability Rating**

<table>
<thead>
<tr>
<th>Tested Element</th>
<th>First Stage</th>
<th>Second Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N1</td>
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<tr>
<td>E6</td>
<td></td>
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<tr>
<td>E5</td>
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<td>E4</td>
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<tr>
<td>E2</td>
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<td></td>
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<tr>
<td>E1</td>
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</tbody>
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**Coeff. Air-Permeability kT (10^{-16} m²)**

<table>
<thead>
<tr>
<th>Rating</th>
<th>N2</th>
<th>N1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>E6</th>
</tr>
</thead>
<tbody>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Very High</td>
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Source 08-01

Roberto Torrent

ACI Fall Convention, Pittsburgh

26 October 2010
Shrinkage Compensating Concrete (ShCC) floor

Sound
\( kT = 0.026 \times 10^{-16} \text{ m}^2 \)

Repair
\( kT = 0.92 \times 10^{-16} \text{ m}^2 \)

Undetected cracks
\( kT = 7.1 \times 10^{-16} \text{ m}^2 \)

More details in our webpage [www.m-a-s.com.ar](http://www.m-a-s.com.ar)
Effect of coating on kT mapping of 6 y. old Wall (Japan)

Natural surface
(kT_{gm} = 5.0 \times 10^{-16} \text{ m}^2)

Coated surface
(kT_{gm} = 0.43 \times 10^{-16} \text{ m}^2)

Source: 06-10
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Classical Specifications (Prescriptive to Performance)

1. The classical prescriptive approach:
   - Specifies a Durability Indicator \( (w/c_{\text{max}}) \) that:
     - is increasingly questionable (composite binders)
     - is very difficult to control in practice
   - Does not encourage innovation
   - Does not guarantee durability, as reality confirms
   - Is an obstacle to design sustainable concrete mixes

2. The introduction of Penetrability Tests applied on cast specimens instead of \( w/c_{\text{max}} \), 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, ignoring what happens till discharge
   - Does not include concreting practices’ quality
Swiss Standard SIA 262 Performance approach

3. By checking the final product, a performance-oriented quality 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 have to design their products to achieve the best performance in concrete
Swiss Standard SIA 262 Performance approach

4. Discourages all too common bad practices such as:

- Uncertainty on compliance of specified $w/c_{\text{max}}$
- 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 Standard SIA 262 approach

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 UHPC (selectively)
   - Low or no Shrinkage Concretes (ShCC)

6. Contributes to the Sustainability and Competitiveness of concrete through a longer service life and environment-friendly and performing solutions
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