The Importance of Corrosion Monitoring for the Durability of Structures

Prof. Dr. Andraž Legat
1. Introduction / Corrosion
2. Measuring techniques
3. Corrosion monitoring and durability
4. ARCHES / ER probes – description
5. ARCHES / testing fields
6. Prestressing steel
7. Conclusions
1. Introduction

Corrosion: (electrochemical) degradation of metals, different types of corrosion

General corrosion

Pitting corrosion

Crevice corrosion
Corrosion in concrete

Carbonation, Aggressive ions / Chlorides

- Corrosion process is autocatalytic
- High localized corrosion rates / Fast reduction of cross-section
Limit States:
1 – Depassivation of reinforcement
2 – Cracking of cover concrete
3 – Spalling of cover concrete
4 – Collapse of element / structure

In the diagram, the process is divided into stages:

- **Initiation**:
  - Limit State 1: Depassivation of reinforcement
  - Limit State 2: Cracking of cover concrete

- **Propagation**:
  - Limit State 3: Spalling of cover concrete
  - Limit State 4: Collapse of element / structure

The diagram also includes an increasing damage curve and a cumulative cost curve.
2. Measuring techniques

**Principle**

1. Electrochemical:
   - potential values/mapping
   - potentiodynamic polarisation ($R_p$, GP, EIS)
   - coupling current, electrochemical noise

2. Physical:
   - acoustic emission
   - impact echo
   - georadar / radiography
   - ER probes (change of thickness)

**Measuring procedure**

1. On the concrete surface (mapping, localization, poor accuracy)
2. With embedded probes (good resolution, local information)
Method description

- short time anodic current pulse applied from a counter electrode
- the applied current in the range of 5 to 400 mA
- typical pulse duration is up to 10 seconds
- the small anodic current results in change of reinforcement potential, which is recorded as a function of polarization time

Schematic set-up of the Galva Pulse

Typical potential response
Results

Ecorr (mV)
- 150-200
- 100-150
- 50-100
- 0-50
- -50-0
- -100--50
- -150--100
- -200--150
- -250--200
- -300--250
- -350--300
- -400--350
- -450--400
- -500--450

Icorr [µA/cm²]
- 0,00-0,50
- 0,50-1,00
- 1,00-1,50
- 1,50-2,00
- 2,00-2,50
- 2,50-3,00
- 3,00-3,50
- 3,50-4,00
- 4,00-4,50
- 4,50-5,00
- 5,00-5,50
- 5,50-6,00
- 6,00-6,50
- 6,50-7,00
- 7,00-7,50
- 7,50-8,00
- 8,00-8,50
- 8,50-9,00
- 9,00-9,50
- 9,50-10,00
- 10,00-10,50
- 10,50-11,00
- 11,00-11,50

Column

Height (cm)

Reinforcement

Column

Height (cm)

Reinforcement
3. Corrosion monitoring and durability

Repair alt. 1

Repair alt. 2

Repair alt. 3

EURO

Year


Year

3. Corrosion monitoring and durability

**Main goals** of corrosion monitoring (embedded probes / periodic assessment):
- detect change in chloride profiles / carbonation fronts (prediction of depassivation)
- detect change in reinforcement condition (corrosion initiation)
- evaluate corrosion rates / corrosion dynamics
- detect non-uniformities across structure (critical points)
- determine causes of corrosion
- determine type of corrosion (prestressing steel?)

**Main benefits** of corrosion monitoring (general aims):
- assess remaining life-time of a structure / prevent catastrophic events
- help to define an optimal rehabilitation procedure (technology and extent)
- evaluate the efficiency of rehabilitation procedure
- form the basis for the optimization of LCC approach
4. ER probes – description

- measuring system / specimen

![Diagram of measuring system and specimen](image-url)
Results:
- change of thickness
- $v_{corr}$
Resistance sensors - \( H_2O \)

4. ER probes – description
4. ER probes – description
4. ER probes – description
5. ER probes – testing fields

general method for the installation of the ER probes
Concrete columns with embedded ER probes

COPPER WIRE

Isolation

Reinforcement $\phi 14 \text{ mm}$

Concrete cover 2 cm

Concrete A A

CROSS SECTION A - A

Concrete columns with embedded ER probes
Installation of ER probes under CP
6. Prestressing steel /tendons / SCC
6. Prestressing steel / geotechnical anchors
6. Prestressing steel / geotechnical anchors

Measurements of:
- isolation resistance
- impedance (1 kHz)
- impedance spectra (from 0.1 Hz to 5 kHz)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>OZ 21/S2.7</td>
<td>0.712</td>
<td>2.950</td>
<td>75.6E-09</td>
<td>9.567E+05</td>
<td>4.196E-04</td>
<td>3.230E-08</td>
</tr>
<tr>
<td>OZ 21/S3.13</td>
<td>0.002</td>
<td>1.740</td>
<td>2.62E-03</td>
<td>1.944E+03</td>
<td>2.547E-03</td>
<td>4.799E-08</td>
</tr>
</tbody>
</table>
EIS – spectra (modelling)
New approach: electrical isolation

Thick corrugated plastic ducts
Tight envelope, avoids chloride ingress to the high strength steel

Avoids stray current on tendon steel

Allows measurements
- Possibility to control and monitor with non-destructive techniques
- Enhanced safety and durability
**Electrical Impedance** $Z(\omega)$

Measurements 146 days after demoulding of the big blocks

<table>
<thead>
<tr>
<th></th>
<th>resistance $R$</th>
<th>capacitance $C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>no defects</td>
<td>2.8 - 3.5 Mohm* m</td>
<td>2.32 ± 0.04 nF / m</td>
</tr>
<tr>
<td>Grout vent</td>
<td>0.57 Mohm* m</td>
<td>2.83 ± 0.03 nF / m</td>
</tr>
<tr>
<td>Hole 2 mm</td>
<td>98 kOhm* m</td>
<td>2.46 nF / m</td>
</tr>
</tbody>
</table>

Capacitance constant, Resistance very sensitive!

Laboratory measurements allowed to define the acceptance criteria for $R$ to 500 kohm* m ($\varnothing$ 59 mm)

Included in the Swiss Guideline (2001)
7. Conclusions

- Corrosion monitoring (frequent assessment) is crucial for optimal LCC based maintainance of a structure: timing, localization, cause of corrosion, type of corrosion, optimal repair technology

- ER probes in combination with other techniques were confirmed as effective tool to evaluate the effectiveness of protective measures (stainless steels, CP)

- Corrosion monitoring of prestressing steel has still several unsolved questions (initiation at normal reinforcement is not necessary): EIT, CP, EIS, AE, EN
Acknowledgement

- colleagues from COST 521 and COST 534: B. Elsener, ETH, Y. Schiegg, SGK, R. Bassler, BAM, O. Klinghoffer, FORCE

- ARCHES: I. Stipanović, IGH, R. Polder, TNO

- ZAG: V. Kuhar, A. Kranjc, N. Gartner, T. Kosec, M. Leban