The Importance of Corrosion Monitoring for the Durability of Structures

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OUTLINE

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

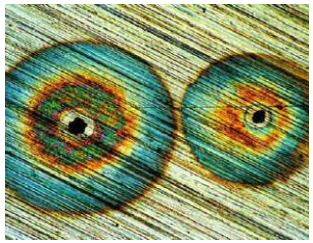
1. Introduction

Corrosion: (electrochemical) degradation of metals,

different types of corrosion

General corrosion

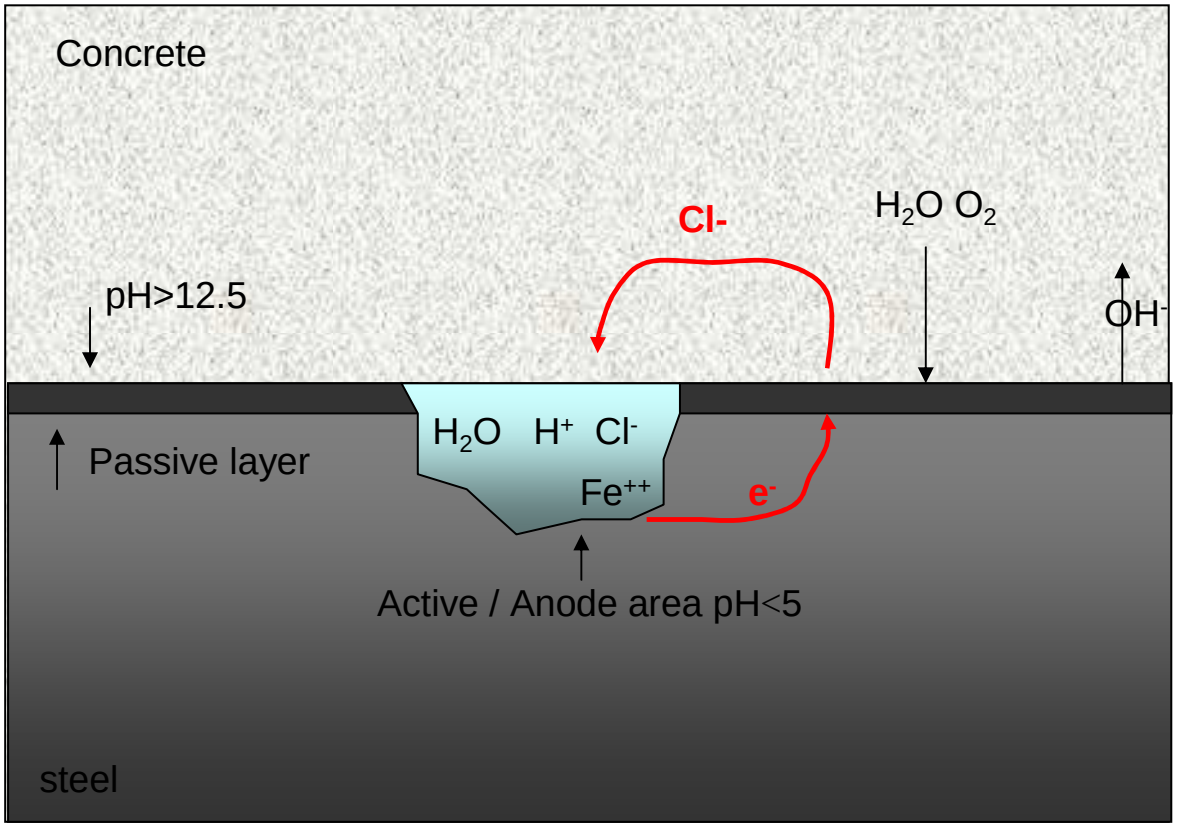
Pitting corrosion



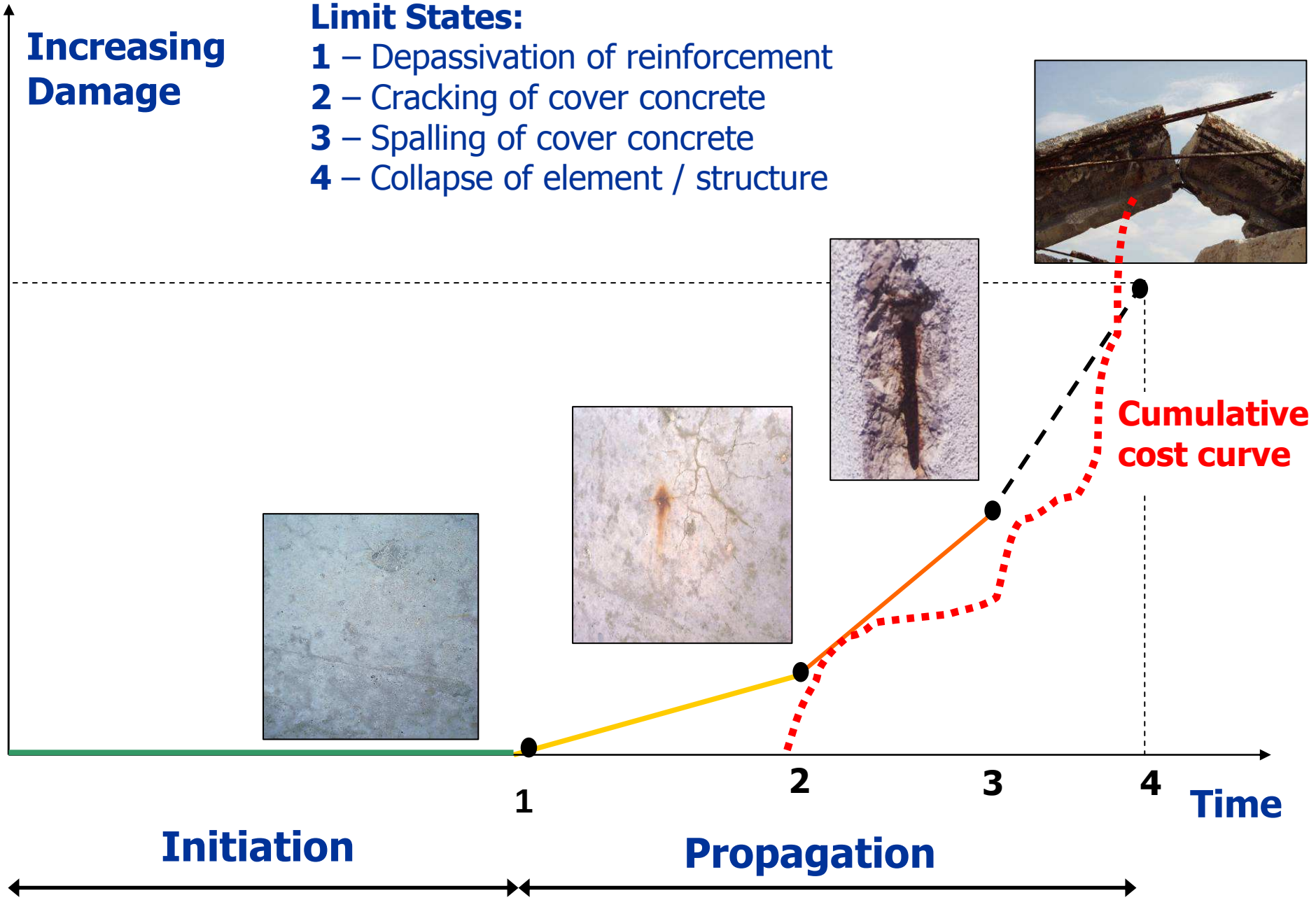
Crevice corrosion

Corrosion in concrete

Carbonation, Agressive ions / Chlorides



- **Corrosion process is autocatalytic**
- **High localized corrosion rates / Fast reduction of cross-section**


Increasing Damage
Limit States:
1 – Depassivation of reinforcement
2 – Cracking of cover concrete
3 – Spalling of cover concrete
4 – Collapse of element / structure
Cumulative cost curve
1
2
3
4
Time
Initiation
Propagation

2. Measuring techniques

Principle

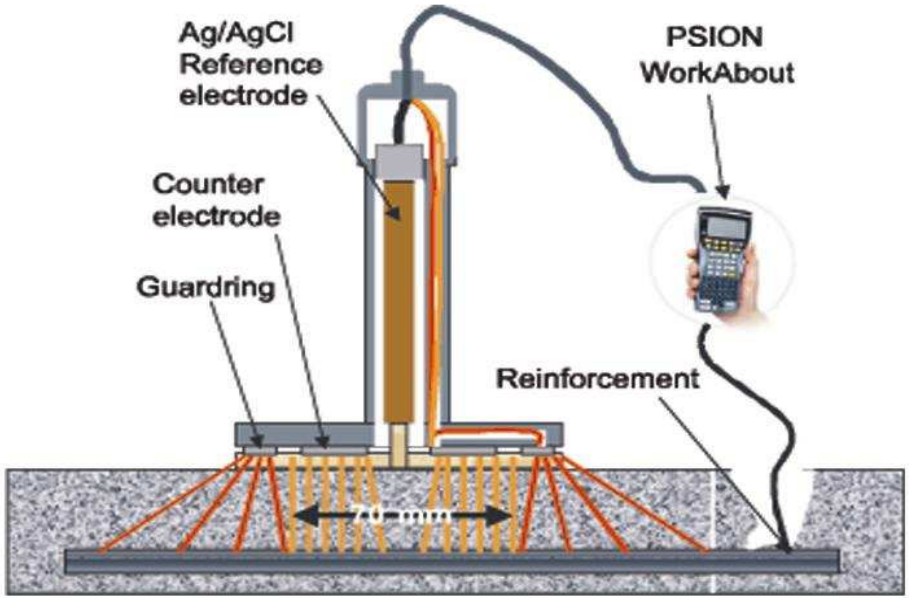
1. Electrochemical:
   - potential values/mapping
   - potentiodynamic polarisation (R_p, GP, EIS)
   - coupling current, electrochemical noise
2. Physical:
   - acoustic emission
   - impact echo
   - georadar / radiography
   - ER probes (change of thickness)

Measuring procedure

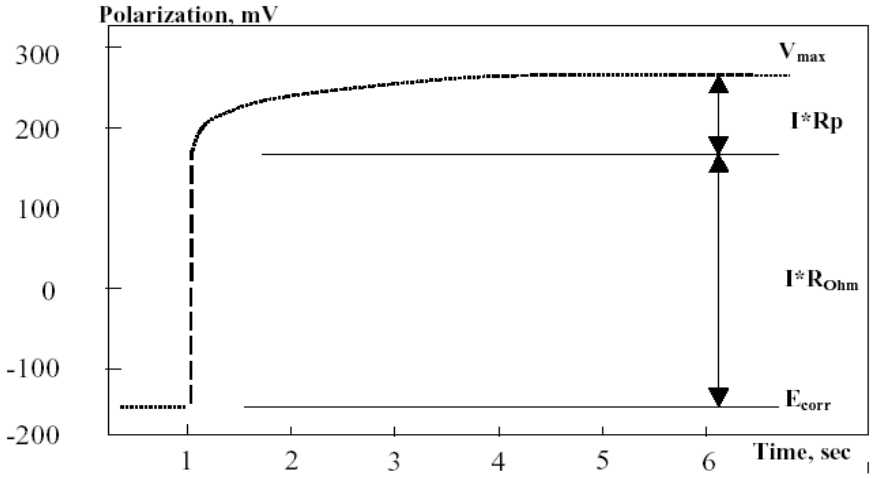
1. On the concrete surface (mapping, localization, poor acurracy)
2. With embedded probes (good resolution, local information)

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

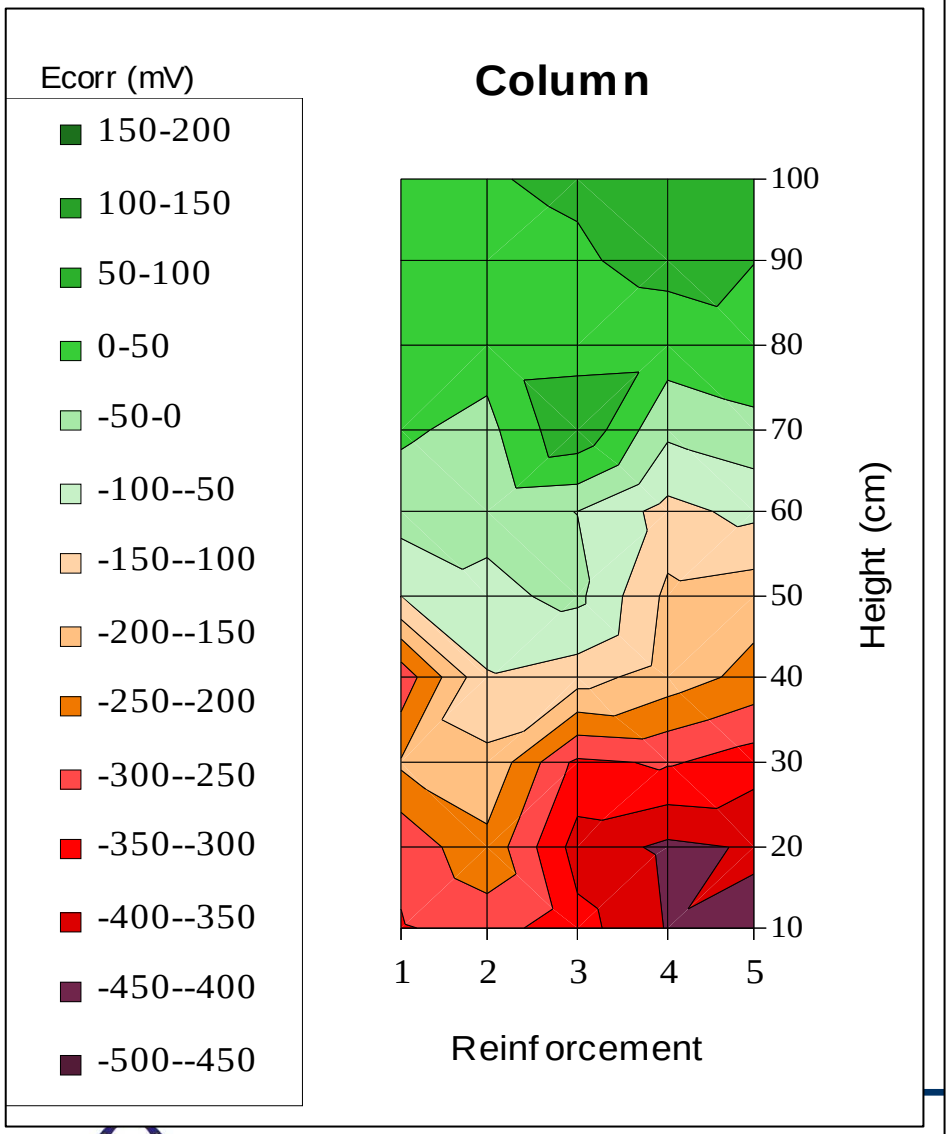


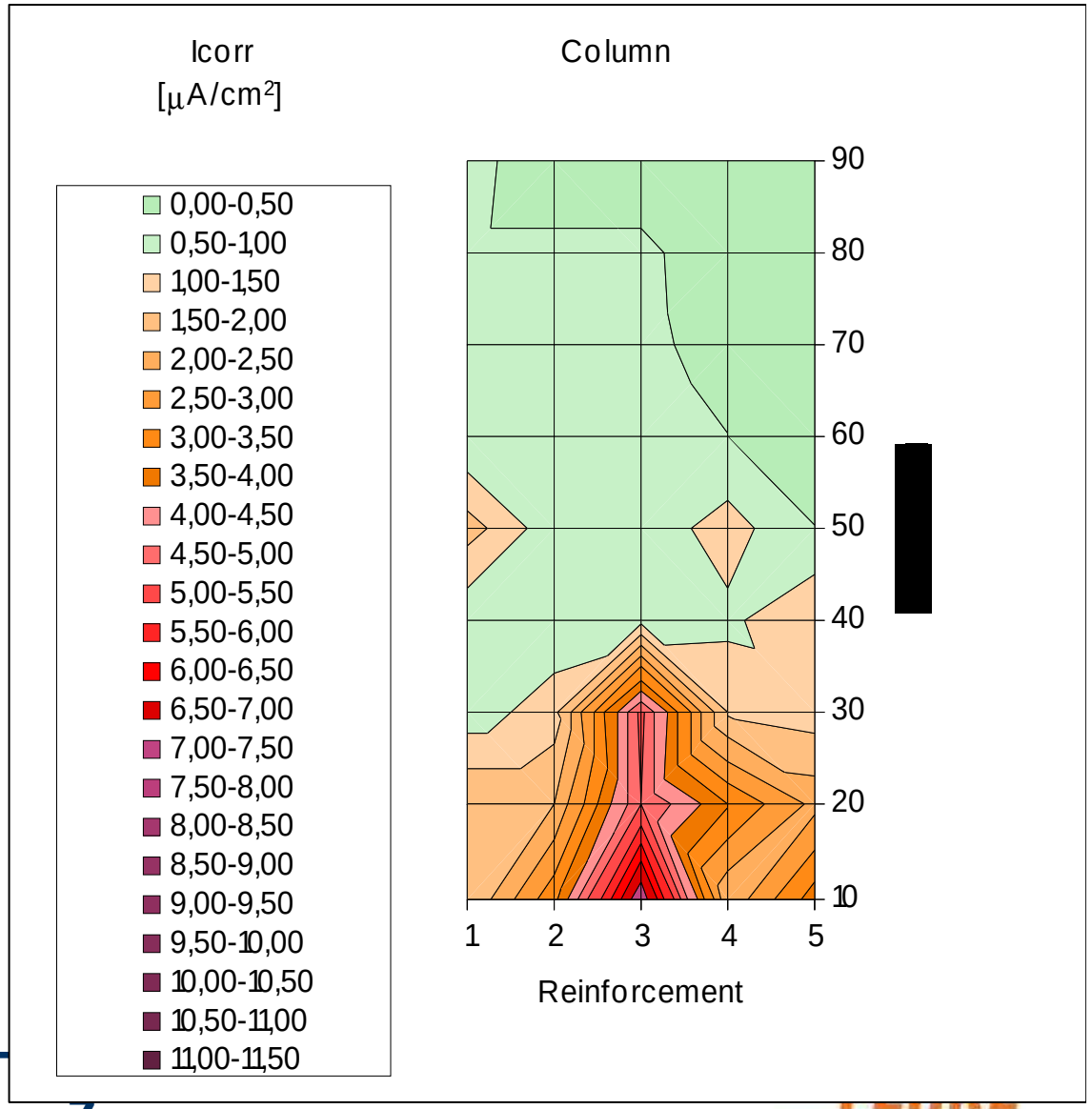
Schematic set-up of the Galva Pulse



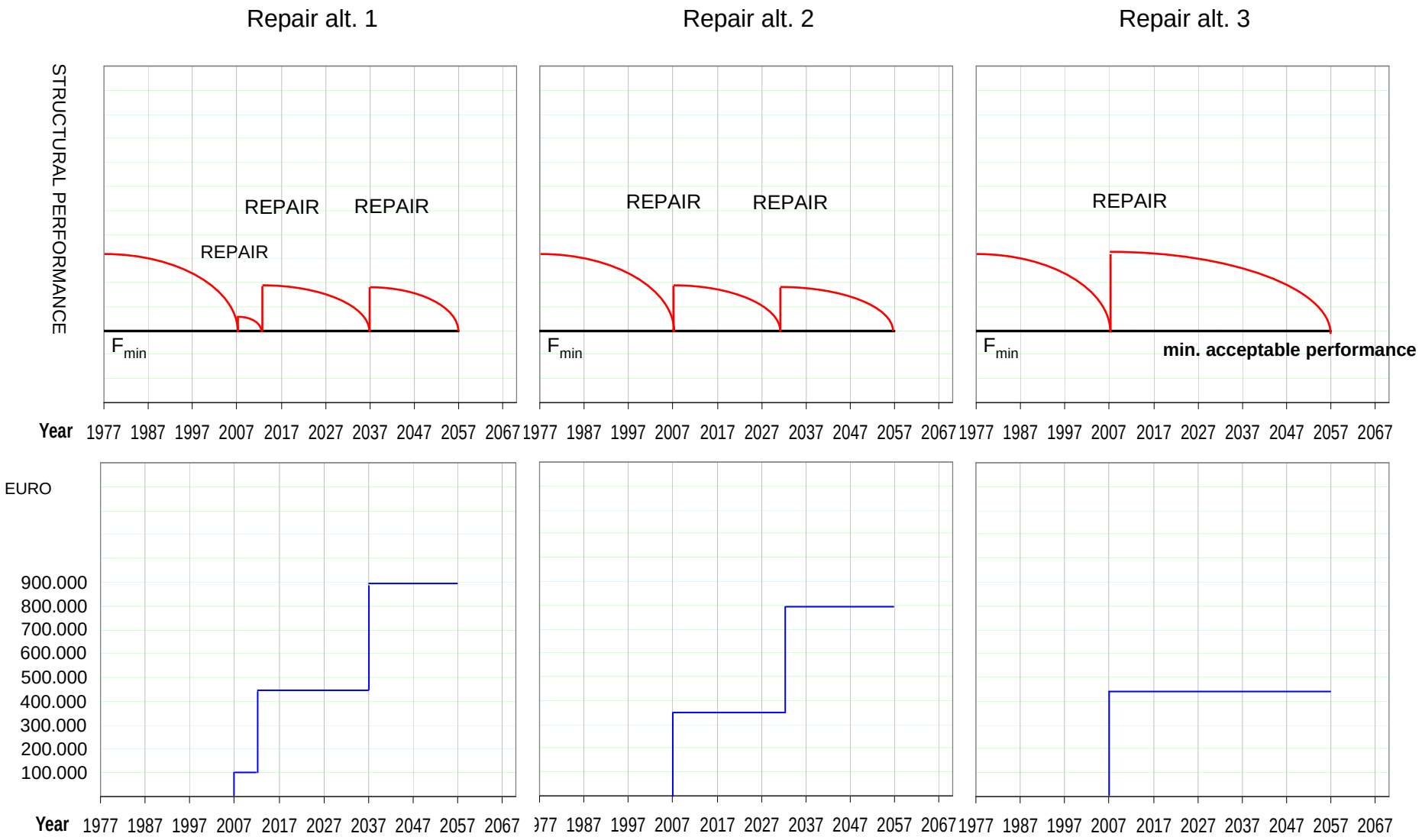
Typical potential response

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
Column
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
Height (cm)
Reinforcement


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
90
80
70
60
50
40
30
20
10
1
2
3
4
5
Reinforcement

3. Corrosion monitoring and durability



3. Corrosion monitoring and durability

Main goals of corrosion monitoring (embedded probes / periodic assessment):

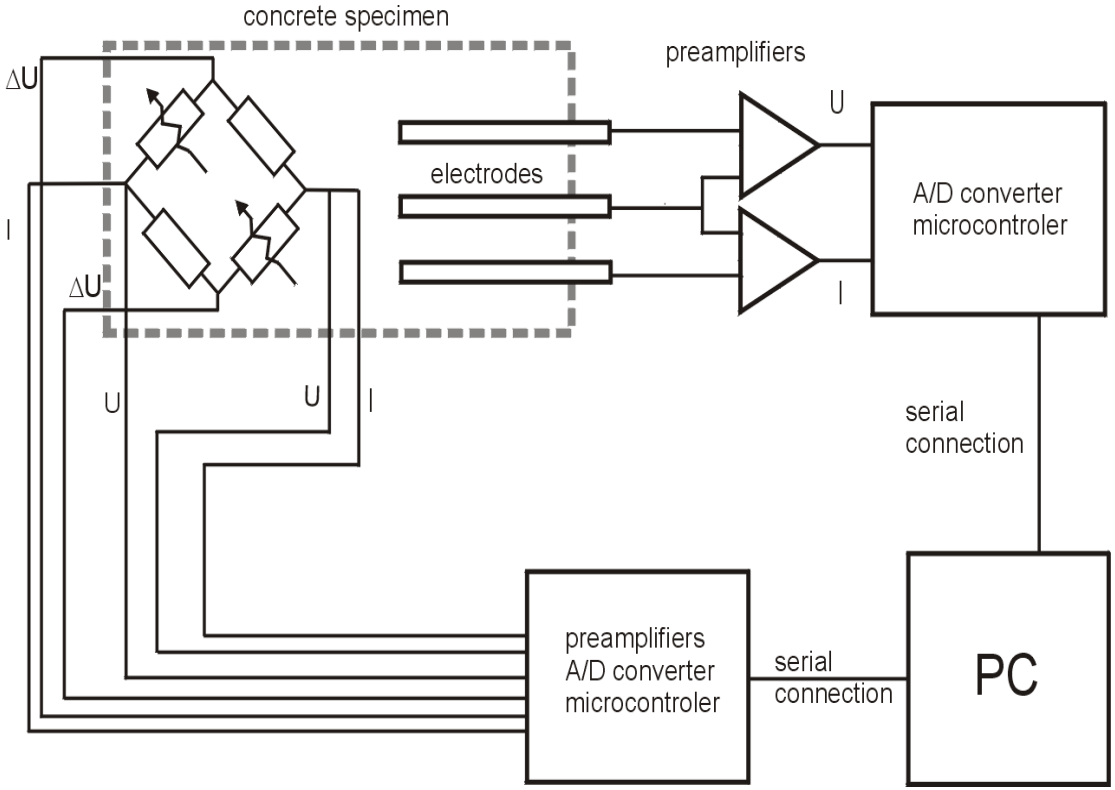
- detect change in chloride profiles / carbonation fronts (prediction of depassivation)
- detect change in reinforcement condition (corrosion initation)
- evaluate corrosion rates / corrosion dynamics
- detect non-uniformities across structure (critical points)
- determine causes of corrosion
- determine type of corrosion (prestressing steel?)

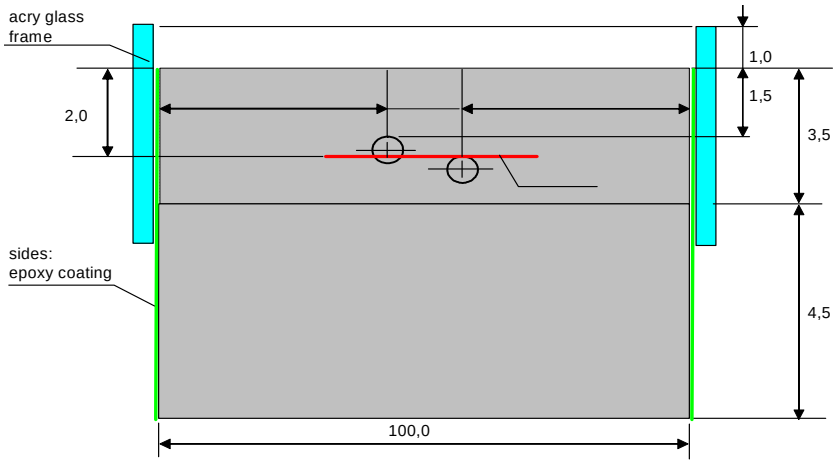
Main benefits of corrosion monitoring (general aims):

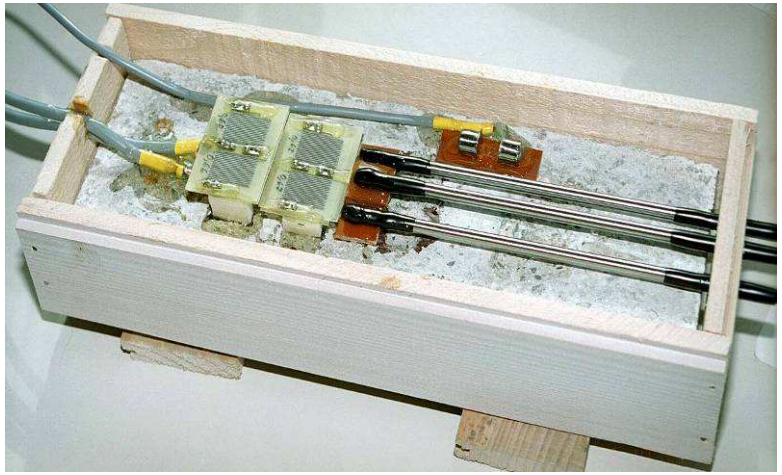
- assess remaining life-time of a structure / prevent catastrophic events
- help to define an optimal rehabilitation procedure (technology and extent)
- evaluate the efficiency of rehabilitation procedure
- form the basis for the optimization of LCC approach

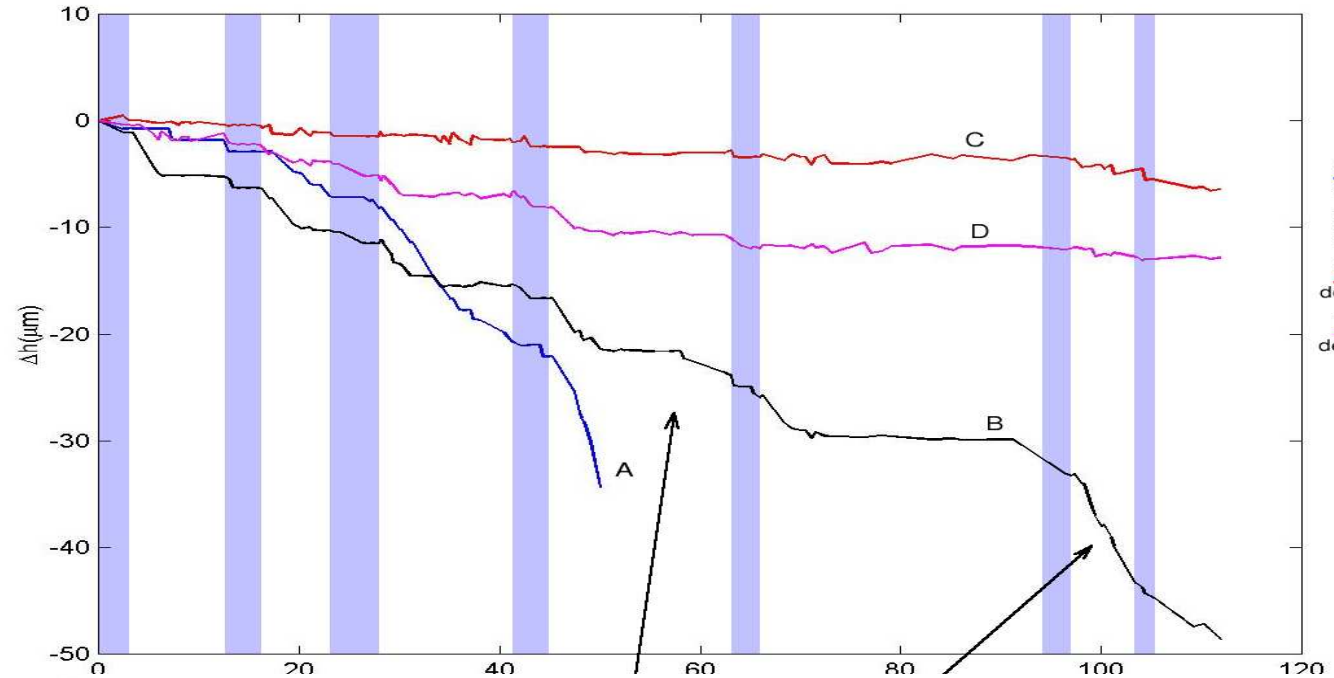
4. ER probes – description

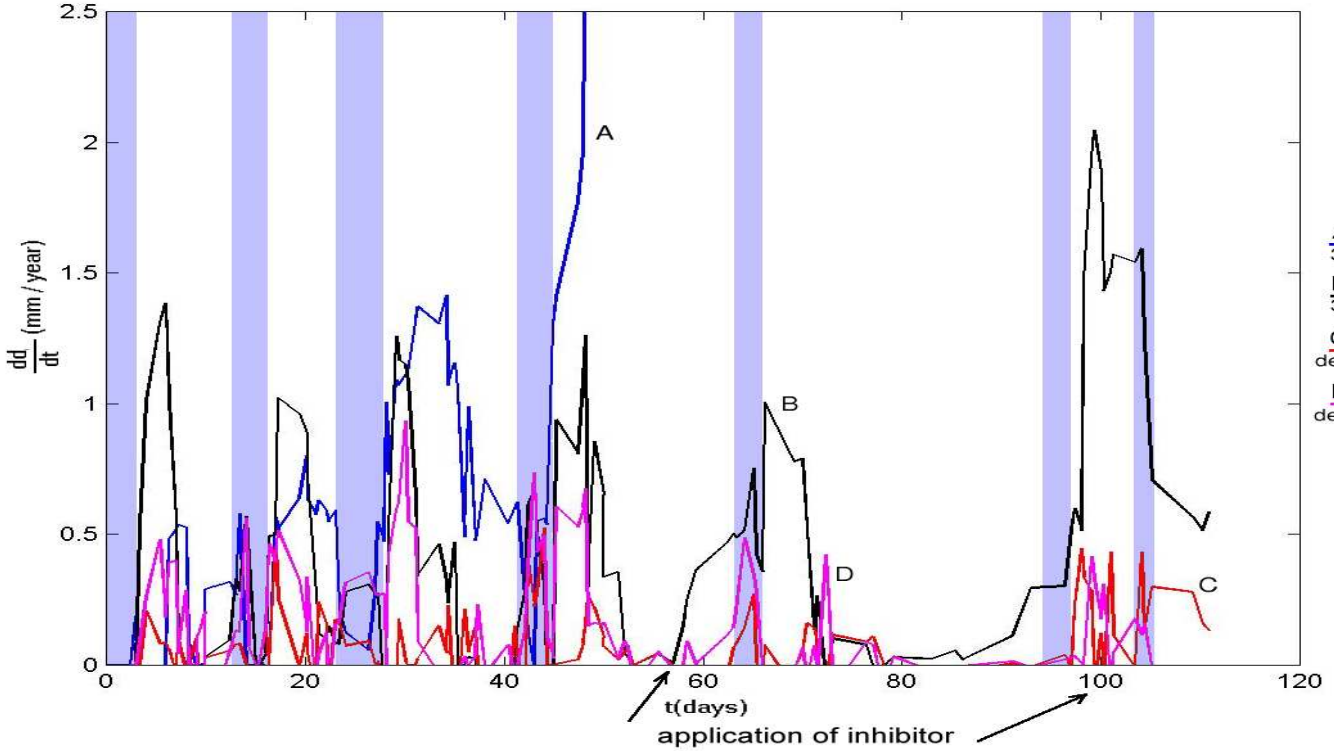
- measuring system / specimen







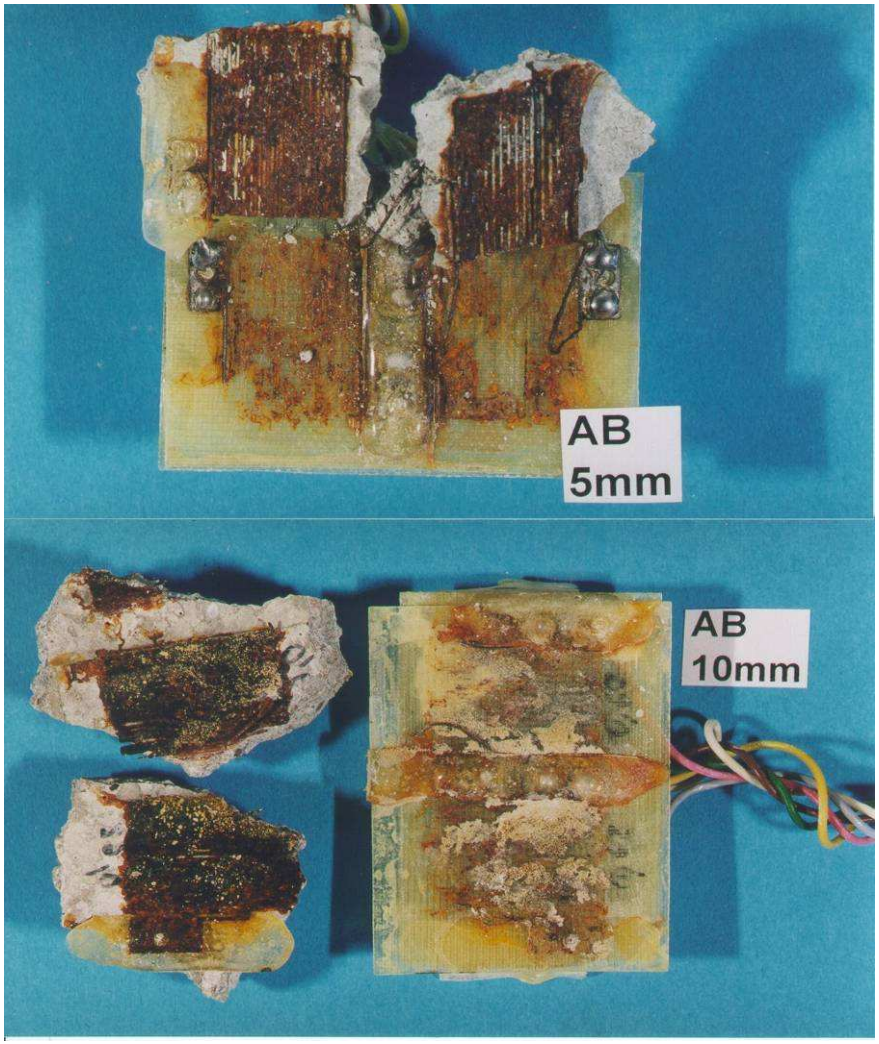




Results:

- change of thickness
- v_{corr}

4. ER probes – description



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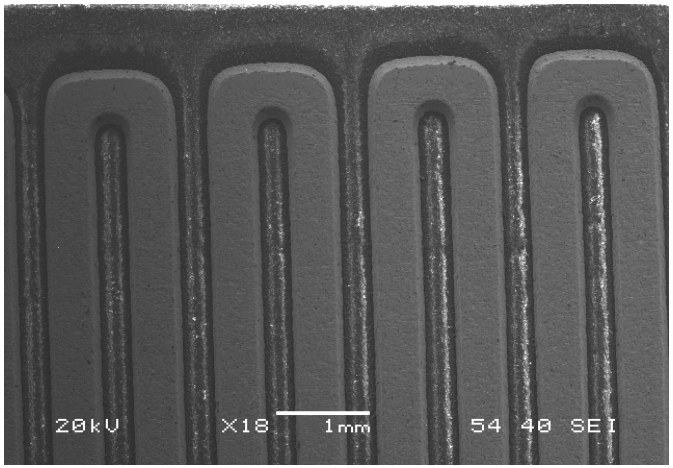
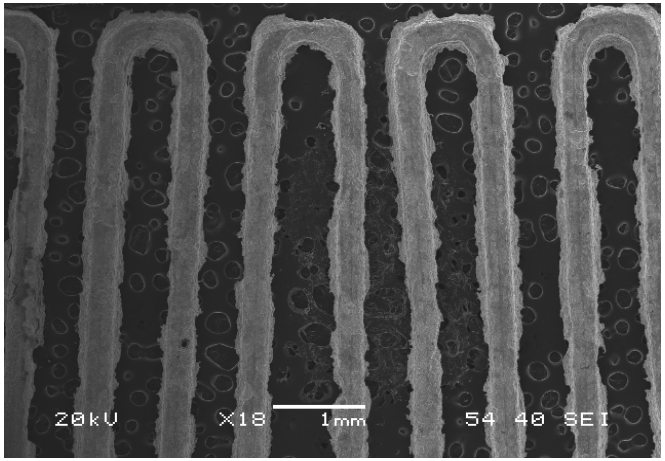
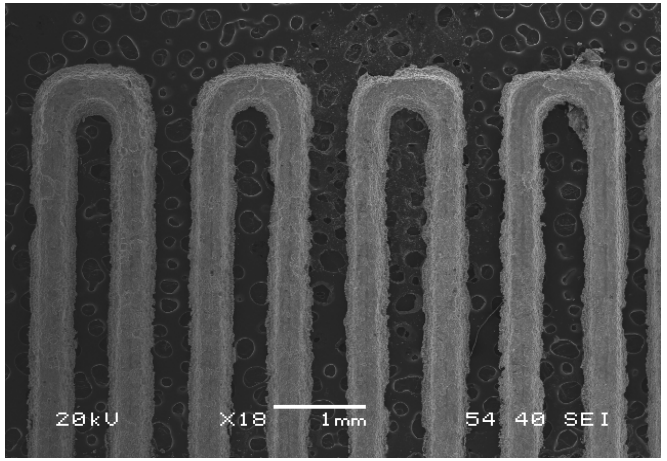
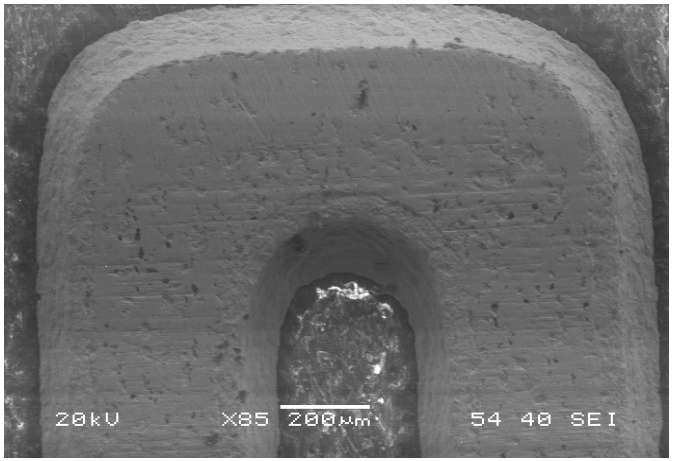
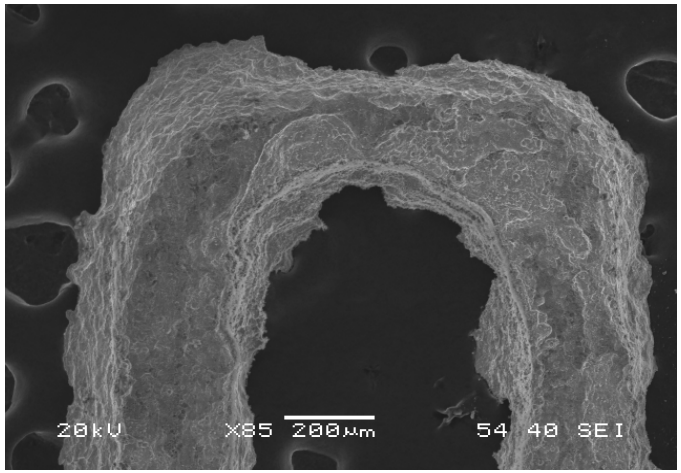
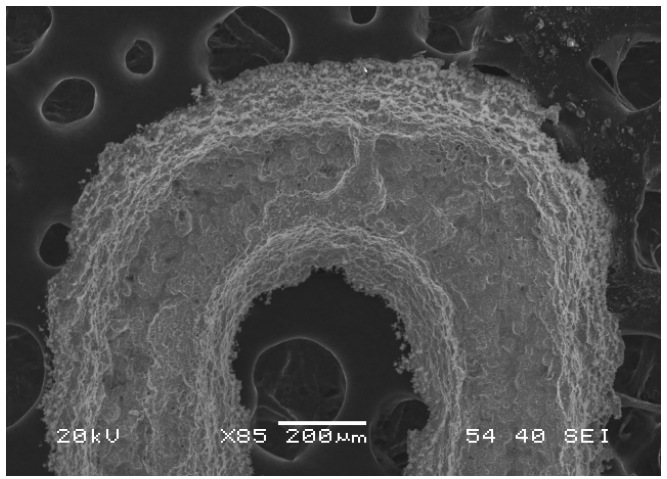




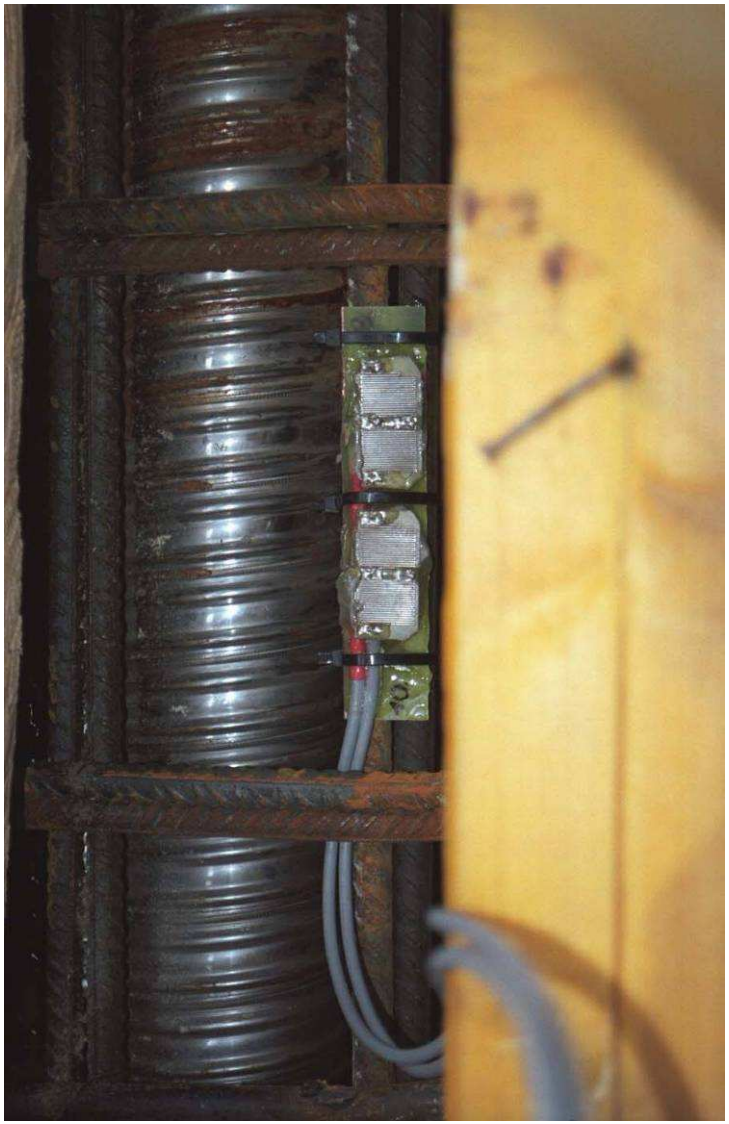


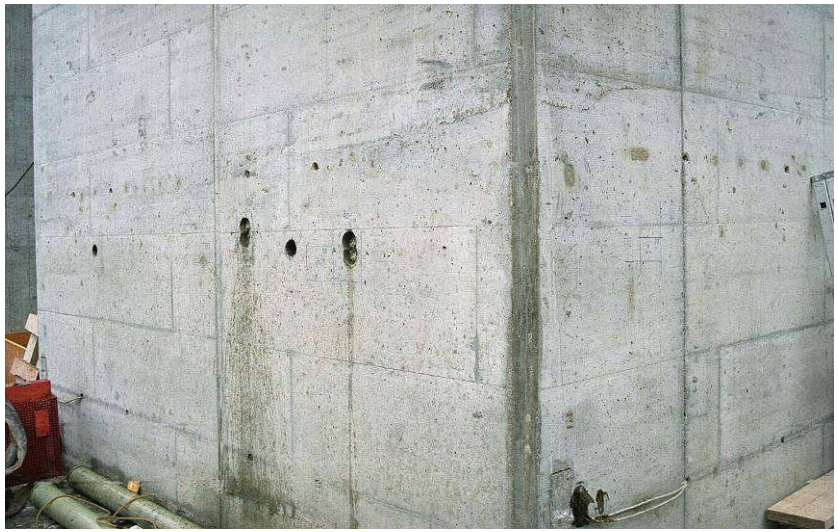






4. ER probes – description

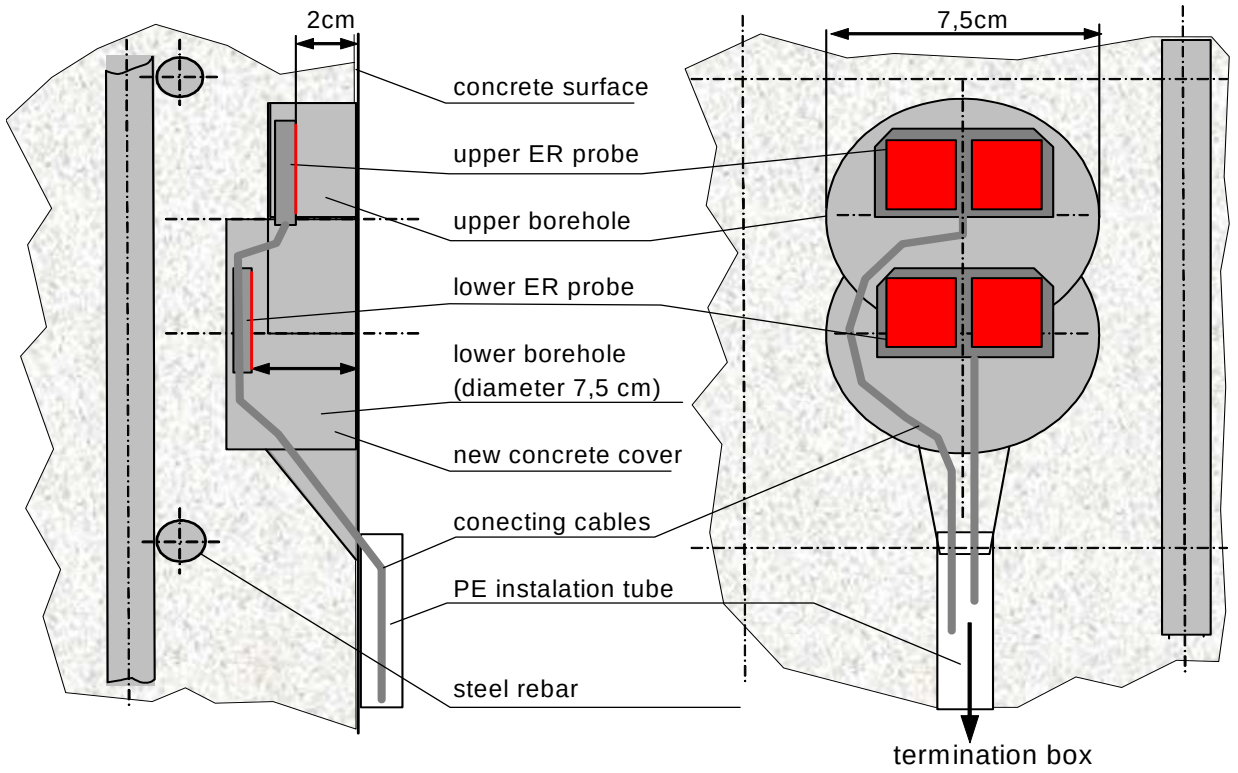




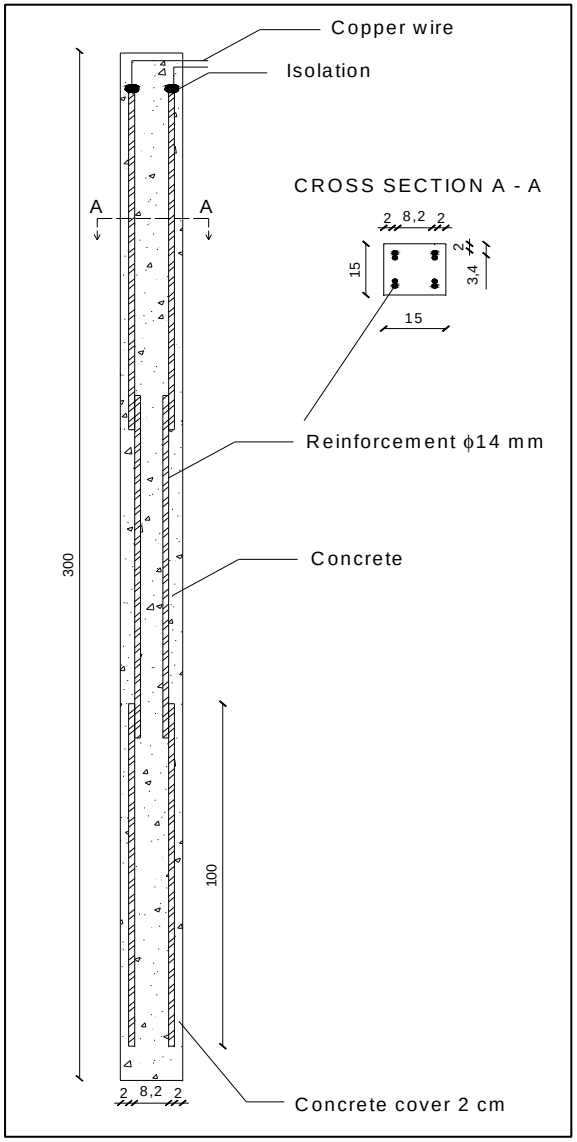
5. ER probes – testing fields

general method for the installation of the ER probes

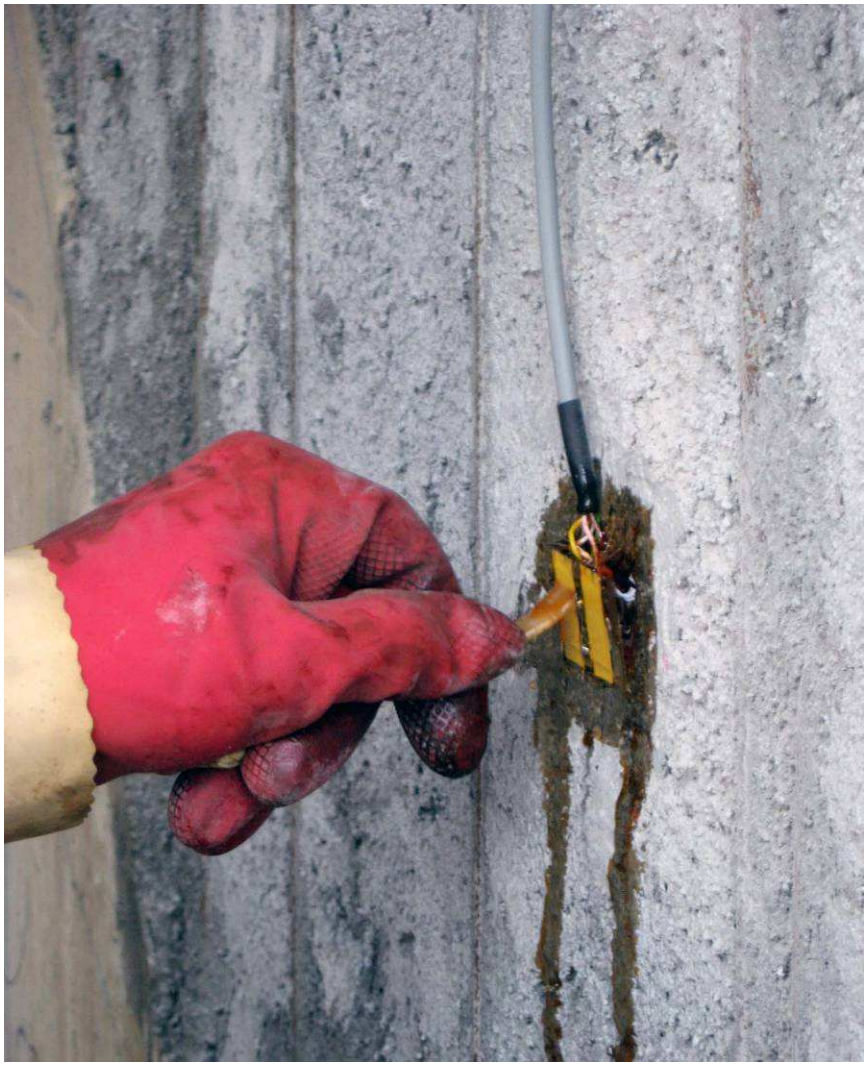
ER probes installation scheme in the old concrete

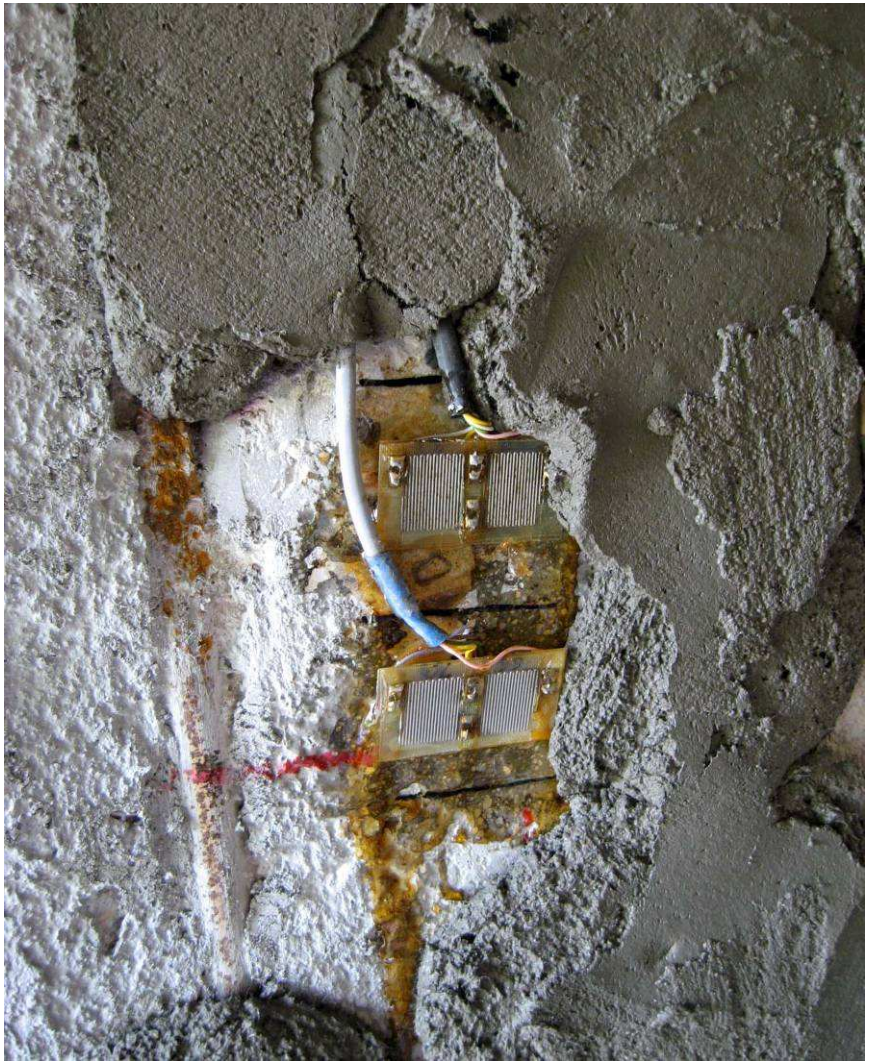


Concrete columns with embedded ER probes



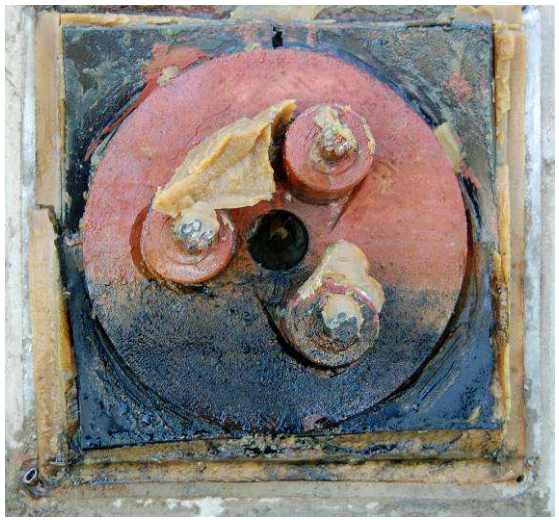
Installation of ER probes under CP

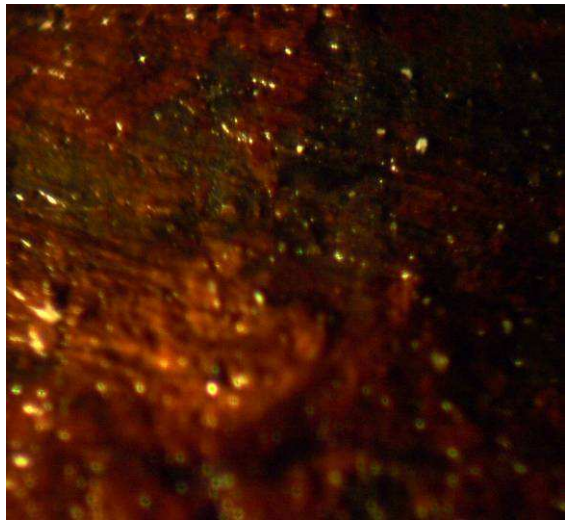


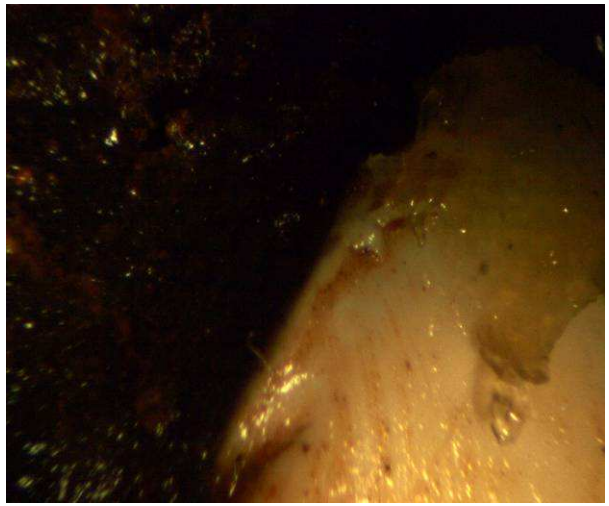


6. Prestressing steel /tendons / SCC

6. Prestressing steel /geotechnical anchors







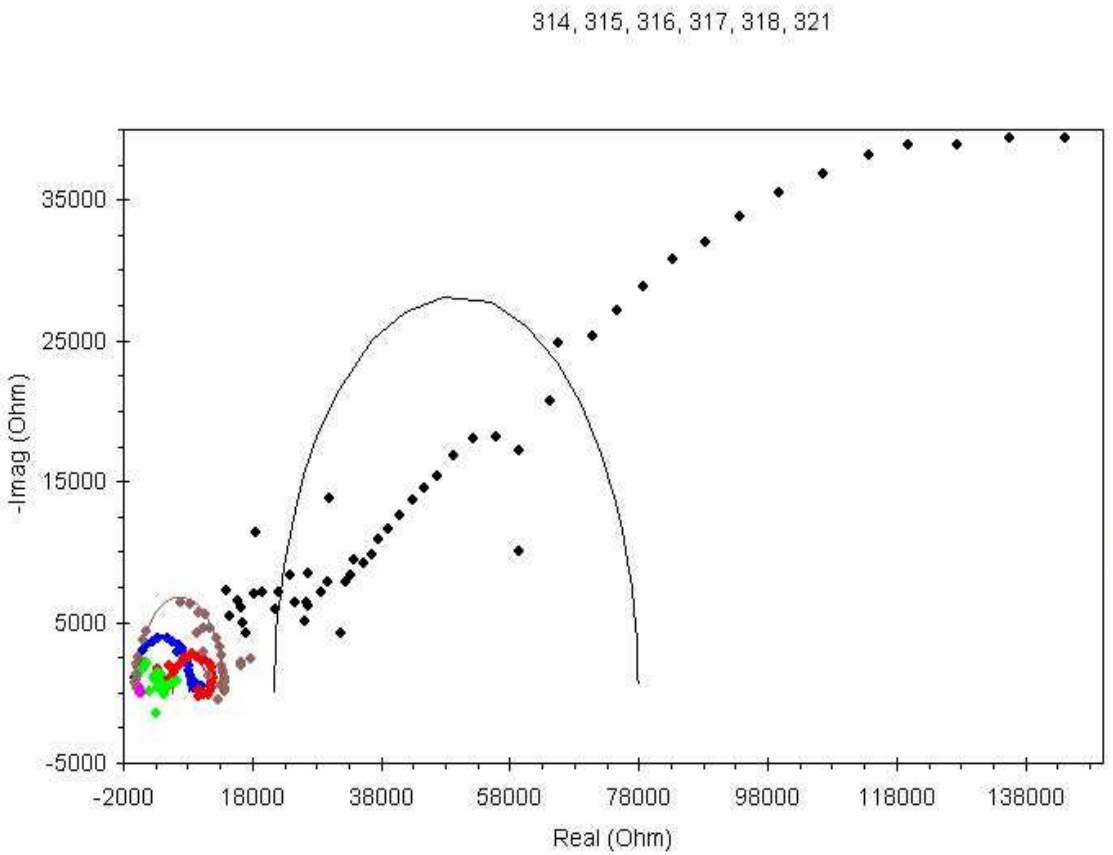
6. Prestressing steel /geotechnical anchors

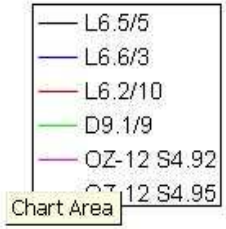
Measurements of:

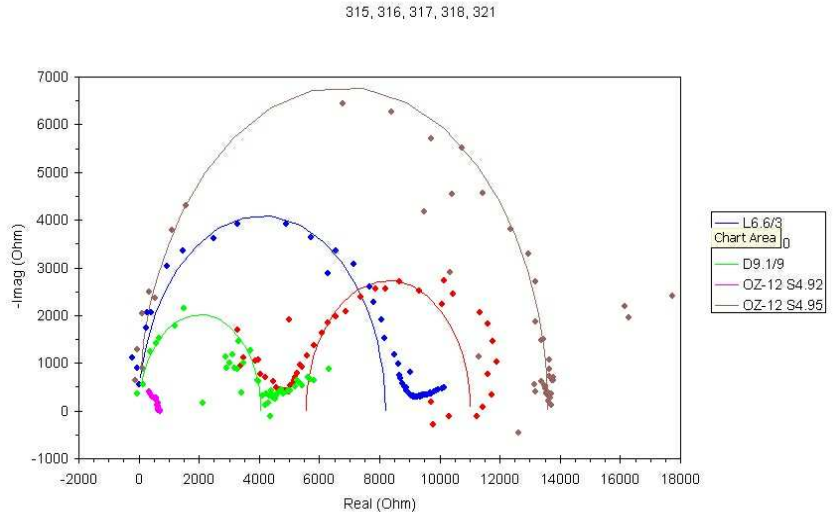
- isolation resistance
- impedance (1 kHz)
- impedance spectra (from 0.1 Hz to 5 kHz)

	Standard method EN 1573	Fluke 189 Thrue RMS Multimeter		Electrochemical impedance spectroscopy (EIS)		
Anchor	**R_I [MΩ]**	**R [MΩ]**	**C [F]**	**R_p [Ω]**	**R_u [Ω]**	**C_f [F]**
OZ 21/S2.7	0.712	2.950	75.6E-09	9.567E+05	4.196E-04	3.230E-08
OZ 21/S3.13	0.002	1.740	2.62E-03	1.944E+03	2.547E-03	4.799E-08

EIS – spectra (modelling)



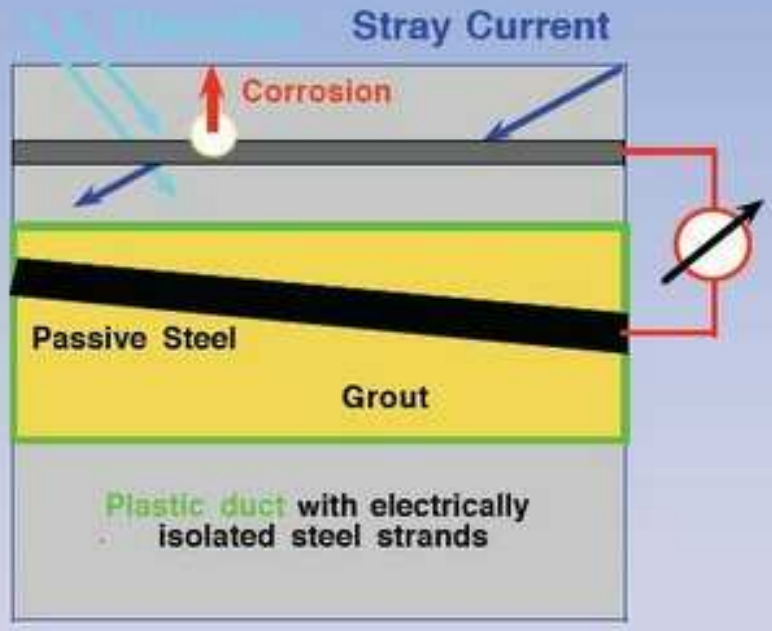




EIT : Elsener, Fuzier, Ganz, Matt

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

EIT : Elsener, Fuzier, Ganz, Matt

Electrical Impedance Z(ω)

Measurements 146 days after demoulding of the big blocks

	resistance R	capacitance C
no defects	2.8 - 3.5 Mohm*m	2.32 ± 0.04 nF / m
Grout vent	0.57 Mohm*m	2.83 ± 0.03 nF / m
Hole 2 mm	98 kOhm*m	2.46 nF / m

Capacitance constant, Resistance very sensitive !

Laboratory measurements allowed to define the acceptance criteria for R to 500 kohm*m (ø 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

Ackonwledgement

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

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