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TRIMM

Corrosion monitoring

ZAG and IGH

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TOMORROW'S ROAD INFRASTRUCTURE MONITORING & MANAGEMENT

Objectives

The main aim of the research work within this project was:

1. To select appropriate measurement techniques and parameters for direct assessment of corrosion activity,
2. To „translate“ the output of this corrosion monitoring system into values which can be implemented in the maintenance and asset management for cost-effective operation.

Presentation:

- Principle of monitoring techniques
- Summary of laboratory and in-situ investigation
- Corrosion criteria definition
- Proposed corrosion monitoring system

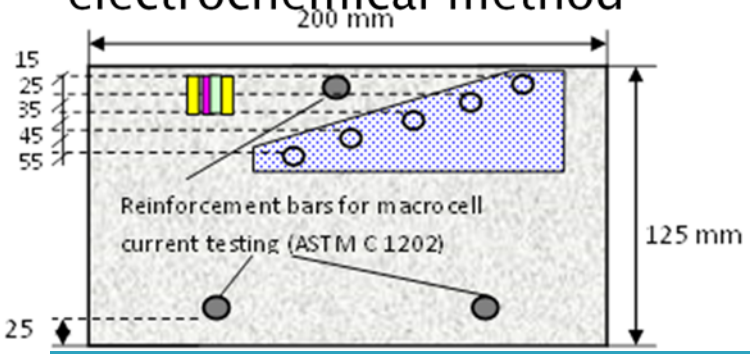
List of laboratory / in-situ investigations

Methods/techniques used during TRIMM project

	Inspection	Monitoring (continuous)
Direct assessment of corrosion activity	• Half-cell potential (potential mapping) • Galvanostatic pulse technique	• Embedded reference electrode • EIS • Macrocell current • Electrical resistance probe (ER)
Determination of influencing parameters	• Resistivity of concrete • Humidity • pH, Cl^-, T	• fiber optical sensors (pH, Cl^-) • resistivity sensors (concrete resistivity, humidity)

Principle of monitoring techniques

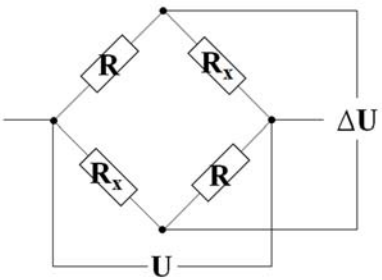
Macro-cell current measured by multi-depth sensors (IGH): electrochemical method

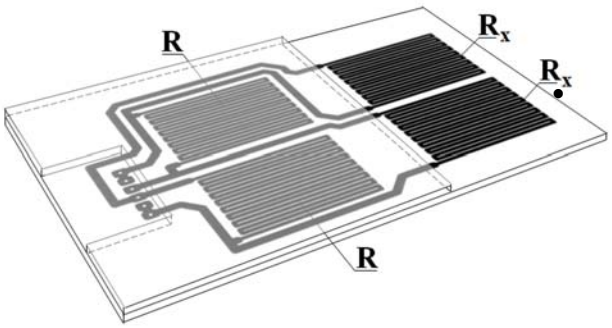


Principle:

- Macro-cell current between cathode and anodes, i_{corr}
- Steel-stainless steel potential, V_{corr}
- Electrical resistivity of concrete between neighbour anodes by AC method, $\rho_{concrete}$

Electrical resistance probes (ZAG): physical method





Principle:

- Wheatston breadge – change of resistance because of thickness reduction is measured. Measured resistance is proportional to thickness reduction and via that proportional to corrosion rate of ER sensor made from metal.

$$\Delta h = h_0 \cdot \frac{u}{1+u}$$

$$U = \frac{U_{out}}{U_{in}} \rightarrow u = \frac{\Delta U}{U}$$

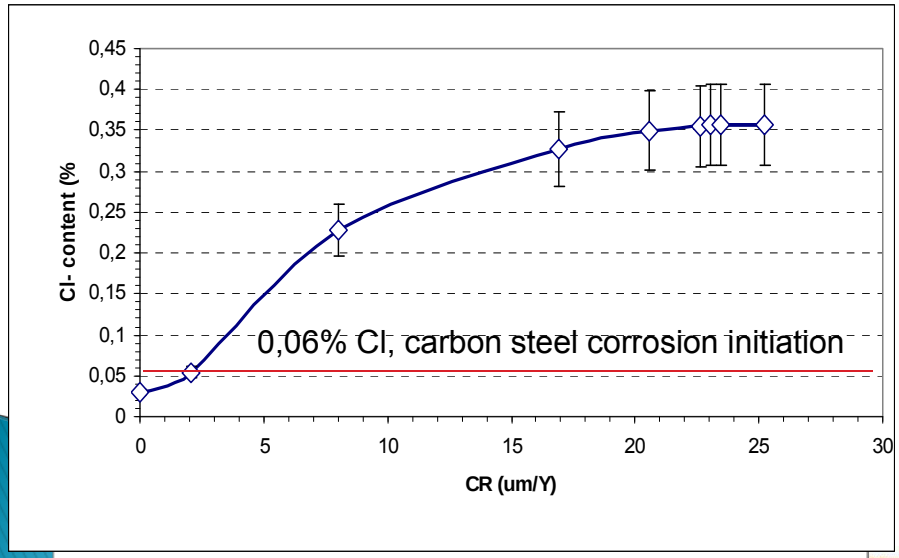
$$h = h_0 - \Delta h$$

Summary of laboratory investigations

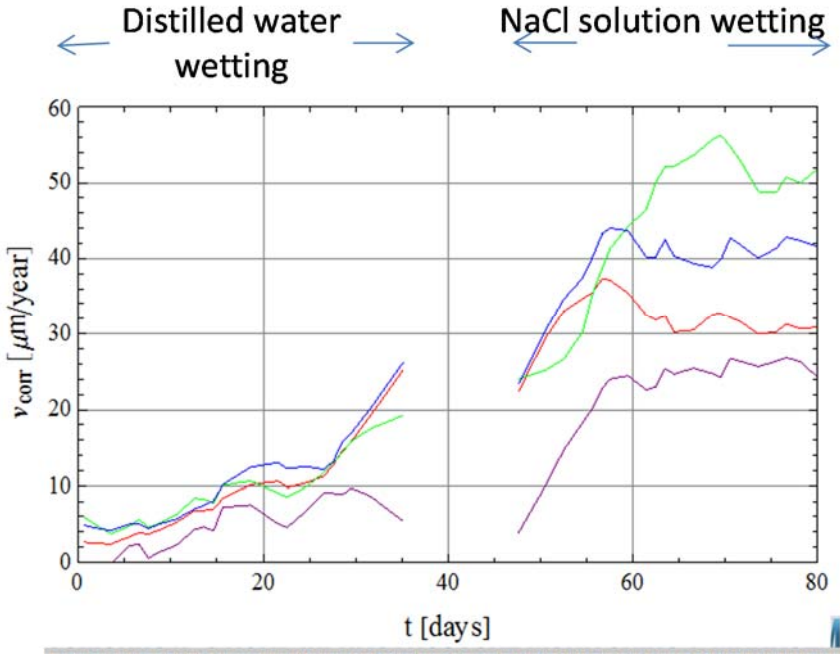
- Multi depth macro-current and electrical resistance sensors sensitive for detection of changes of corrosion processes and corrosion rate regardless to the corrosion activator

Multi depth sensors

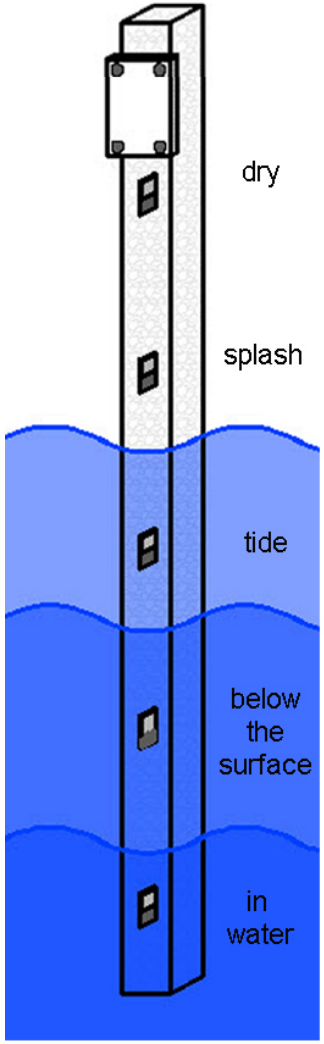
• Corrosion and chloride content increasing near reinforcement time dependent processes

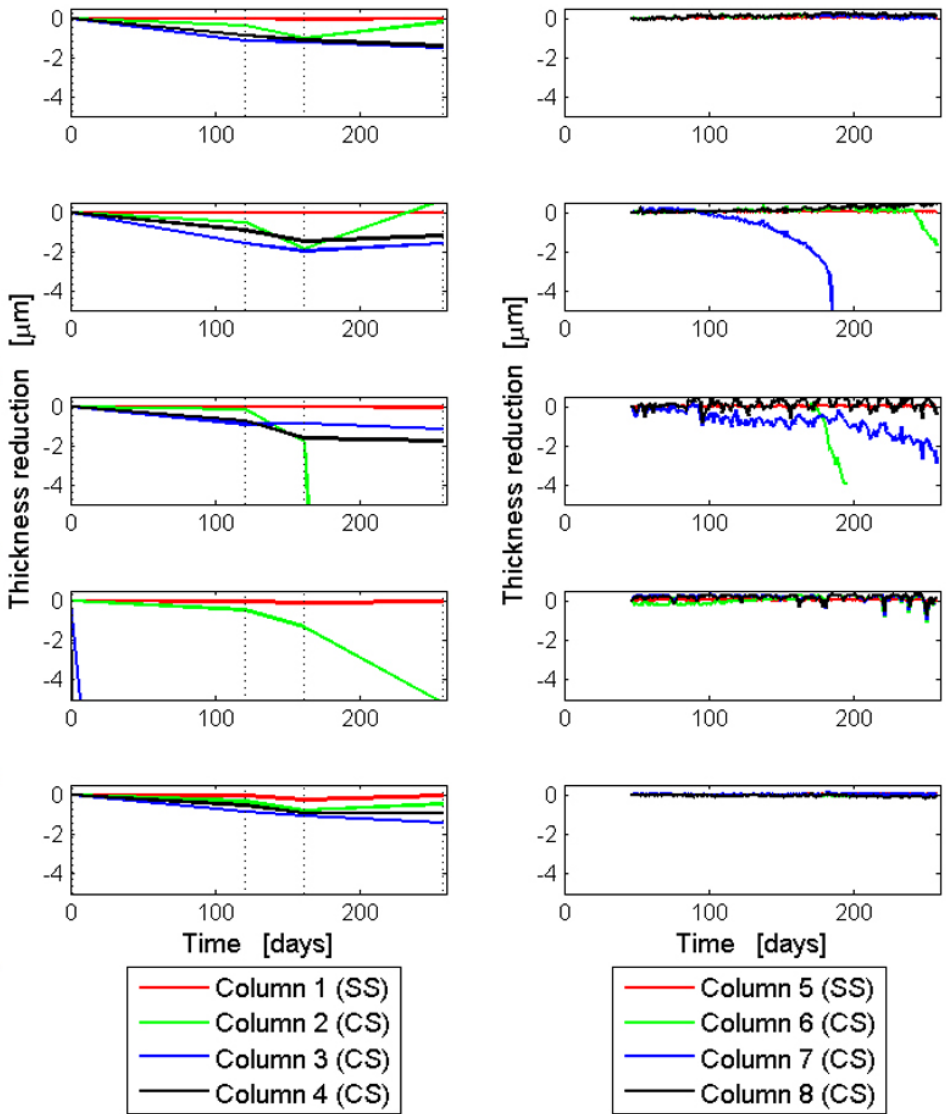


Electrical resistance sensors



Summary of in-situ investigation – ER sensors





Koper harbour test site

Since December 2013

Goals: long-term behaviour, compare different zones of exposure, compare different measuring techniques

Data avaliable on WEB page:

www.corrosion-kp.zag.si

Summary of in-situ investigation – macro-cell sensors

- IGH: Maslenica, Cetina and Krka bridge (Croatia)

Maslenica

No. of sensors: 21
Installed: 1996 - 1997 (during bridge construction)
Type of measurements: 29.01.2014. (initial measurements not available).
Type of measurement: Anode Ladder (macro cell current), concrete resistivity, Half cell potentials, temperature, chloride levels and concrete properties

Cetina

No. of sensors: 6
Installed: March 2006 - 2007
Measurements: May 17th 2007, January 19th 2014
Type of measurements: anode Ladder (macro cell current), concrete resistivity, Half cell potentials, temperature

Krka (over river)

No. of sensors: 6
Installed: July 2003 - March 2004
Measurements: May 8th 2004, September 12th 2004, February 3rd 2005, January 19th 2014
Type of measurements: Anode Ladder (macro cell current), concrete resistivity, Half cell potentials, temperature

Summary of in-situ investigation – macro-cell sensors

- IGH: Maslenica, Cetina and Krka bridge (Croatia)

Maslenica

Corrosion at the top and foot of arch – 5 cm under concrete cover layer, after 18 years

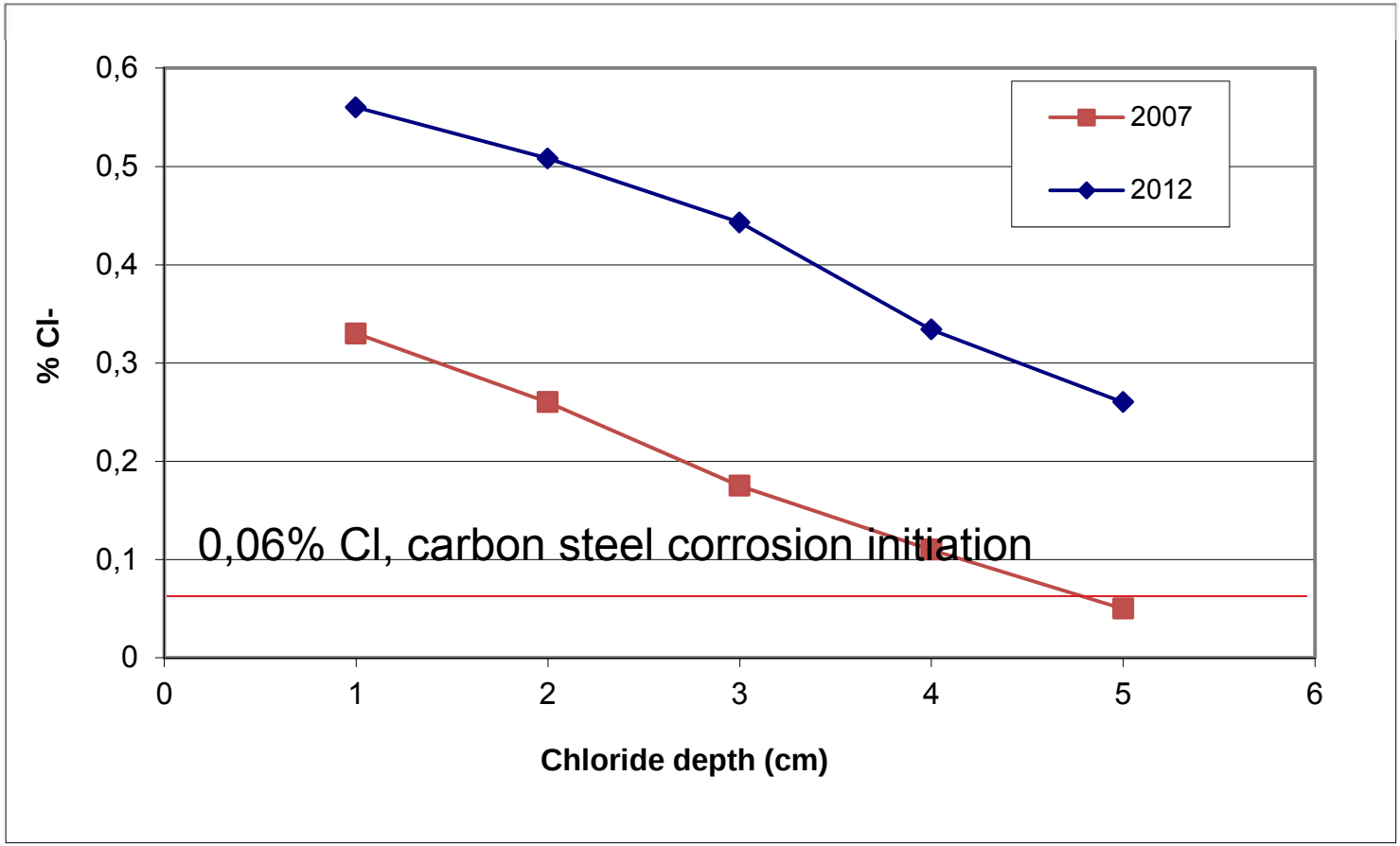
Cetina

Initiation of arch foot after 7 years

Krka (over river)

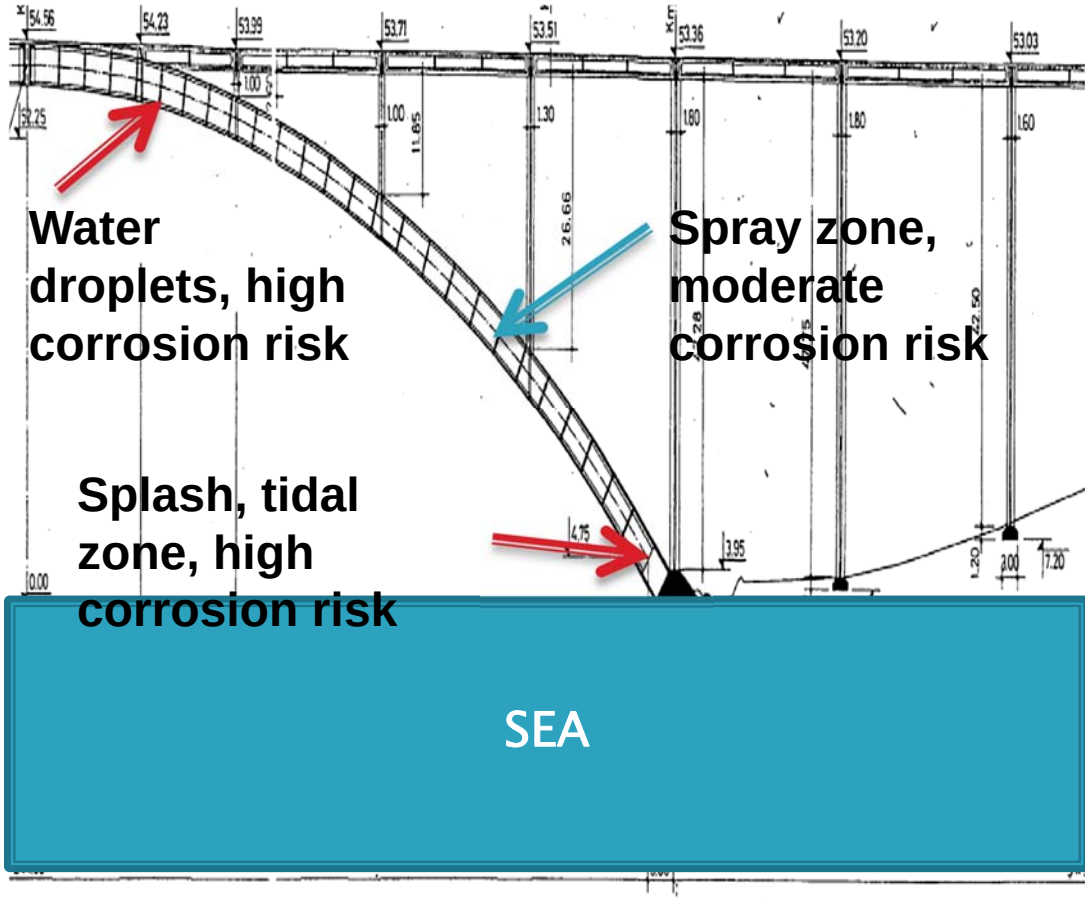
No corrosion in 10 years

Summary in-situ investigation chloride content



Chloride content (% on concrete weight) measured on Maslenica bridge

Corrosivity zones – deicing salts coastal area

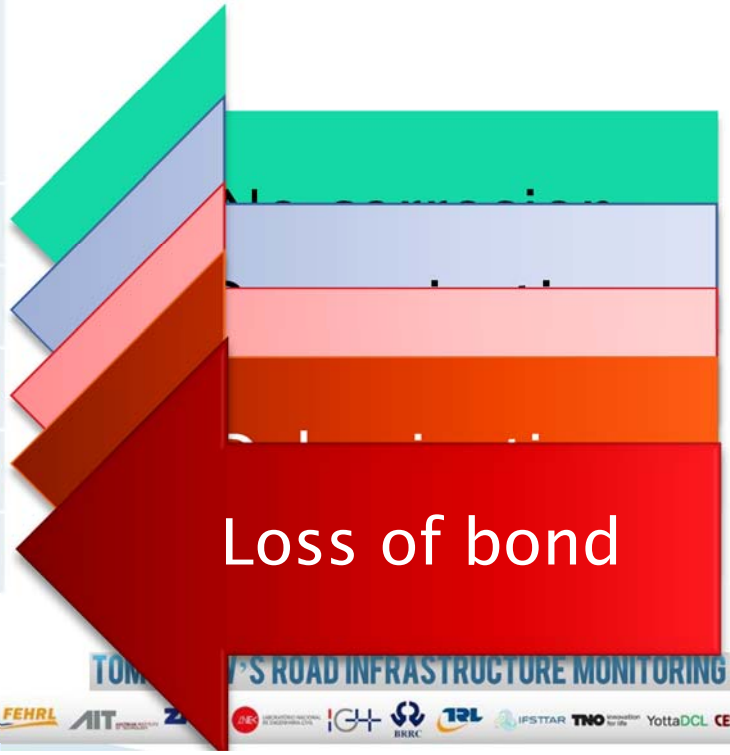


Corrosion criteria definition

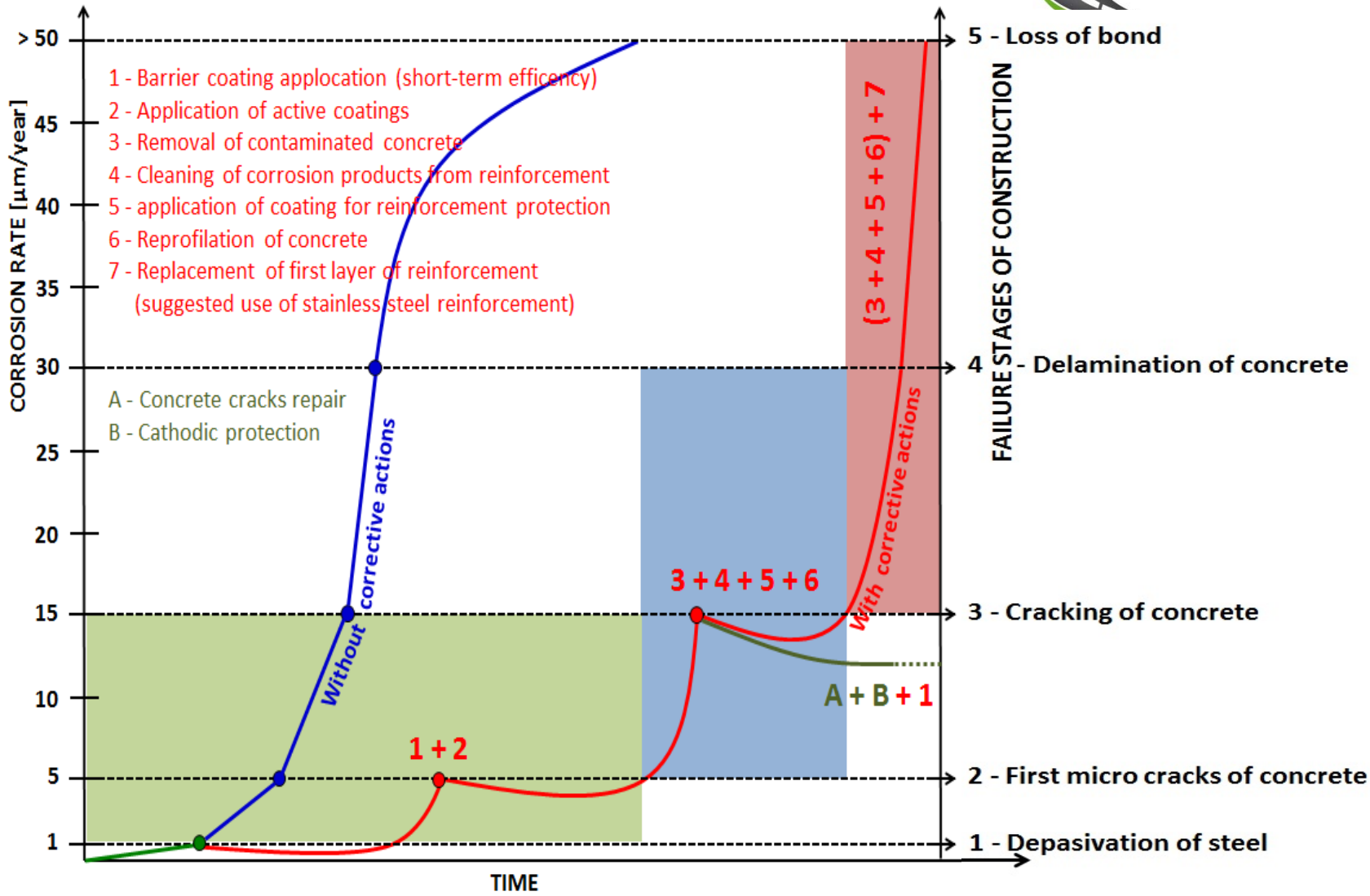
- Macro-cell currents transformation to corrosion rates (CR):
  - I_{corr} = 0,1 μA/cm^2 – CR = 1.1 μm/Y - corrosion initiation (Condition category=1)
  - I_{corr}=3 μA/cm^2 – CR = 34 um/Y - first cracks apperance (Condition category=5)

  ⇒ CR = i_{corr*}11.46

Corr. rate (μm/Y)	Condition category	
0–1	1	Very good
1–5	2	Good
5–15	3	Acceptable
15–30	4	Poor
>30	5	Very poor



Protective actions to restrain corrosion

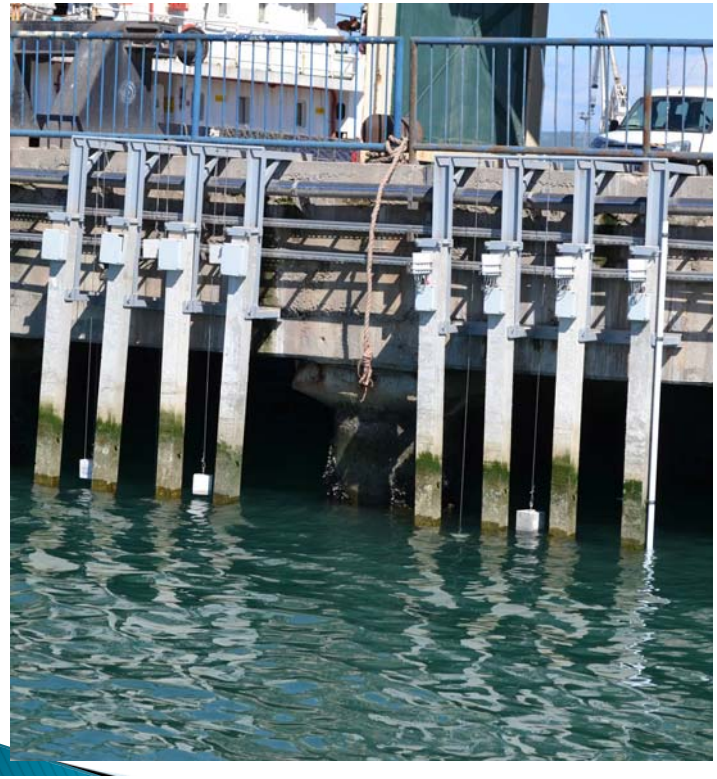


Advantages/disadvantages of proposed monitoring techniques

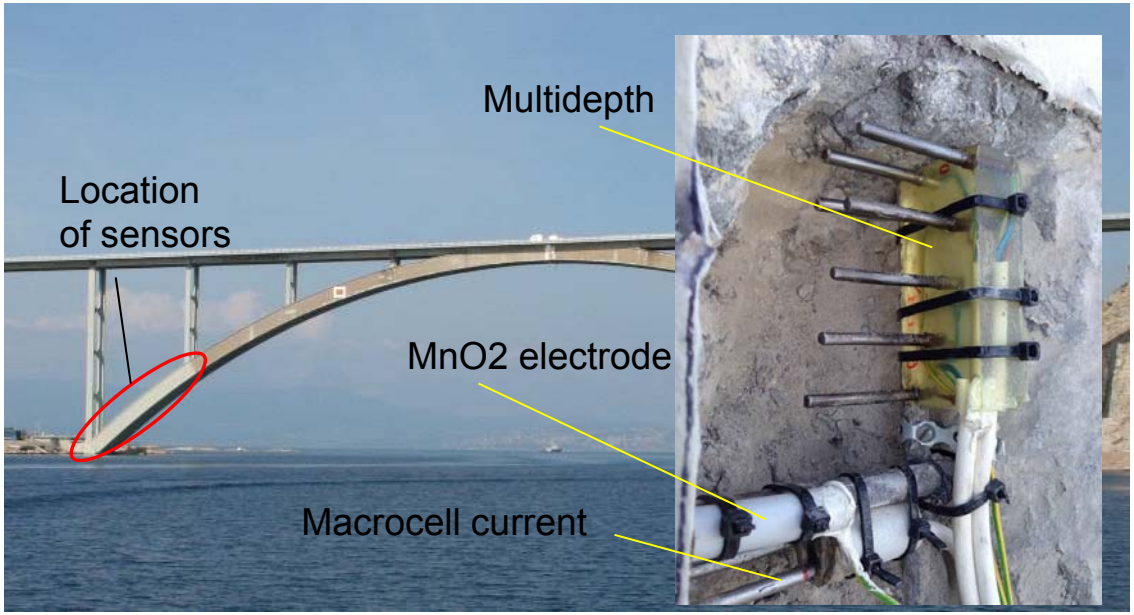
	ER PROBE		MACRO-CELL CURRENT SENSOR	
	PROS	CONS	PROS	CONS
Measuring depths	1 sensor per chosen depth	Nothing noted	Measurements at different depths	Galvanic interactions between anodes
Measuring range	Good for early stages 1-3	Not appropriate for long term monitoring during stages 4-5	High sensitivity to corrosion initiation (stage 1) Good for stages 1-4 and some time in stage 5	Breaks down at severe corrosion (stage 5)
Cost	Not costly sensors and automatic data acquisition system	Nothing noted	Not costly sensors and instruments for manual data reading	Expensive and complicated automatic data acquisition system
Results interpretation	User-friendly simple data analysis	Nothing noted	Nothing noted	Strong: needs expert to interpret the results (extensive and complicated data analysis and interpretation)

System installation on RC bridge

- December 2013 Koper harbor
- Spring 2014 Krk bridge



ER probes, EN system



Sections repaired 2013

- Multi depth sensors (December 2013),
- ER probes (July 2014)

Combined with other conventional inspection methods

Conclusion

- Good correlation between both methods during the investigation (verified in lab)
- Both techniques can be used for chloride as well as carbonation induced corrosion
- Macro-cell sensor is sensitive for detection of anodic/cathodic changes at different depth of „corroded concrete“, however, results need interpretation
- Electrical resistance (ER) sensors are sensitive method to detect initiation and monitor changes in damaged concrete in earlier stages
- Installation of sensors on critical corrosion sites of construction – necessary inter-collaboration between designer-projectant and corrosion specialist