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Corrosion in Steel Reinforced Concrete Structures:

"The Science of Corrosion"

1.0 LU with HSW and SD
AIA Program ID # CORR01
Provider # J152

Katherine A. Klosowski-Blatz

Market Manager, Corrosion

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Thank you!

Corrosion in Steel Reinforced Concrete Structures
"The Science of Corrosion"

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Learning Objectives

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At the conclusion of this program, you will be able to:

- Understand the types and causes of corrosion of concrete reinforcing steel
- Understand the electrochemical corrosion process
- Anticipate conditions which promote corrosion
- Effectively specify different corrosion mitigation strategies

Why are we talking about corrosion?

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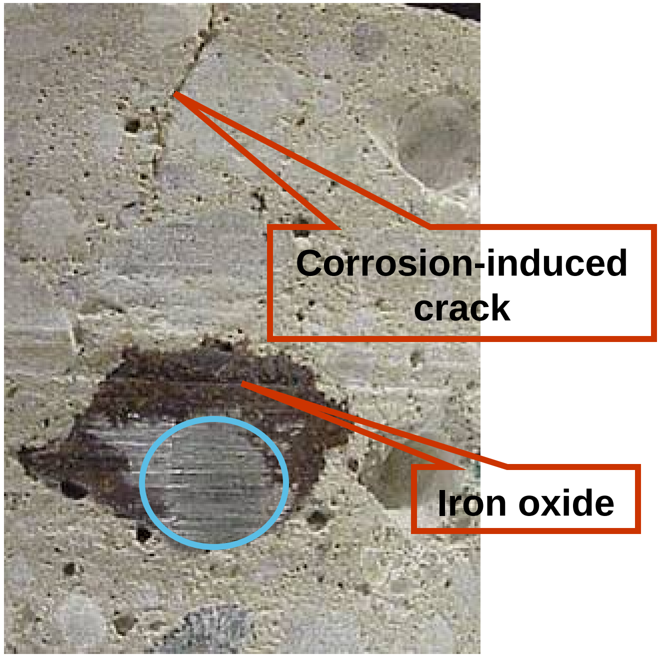
- When steel corrodes, iron is converted to iron oxide (rust)
- Iron oxide occupies 4-10x the volume of the original steel
- Internal pressure results in cracking and spalling of concrete



Corrosion results in loss of steel cross section

What Causes Corrosion?

In steel reinforced concrete, corrosion is the deterioration of steel caused by a change in its concrete surroundings (environment).

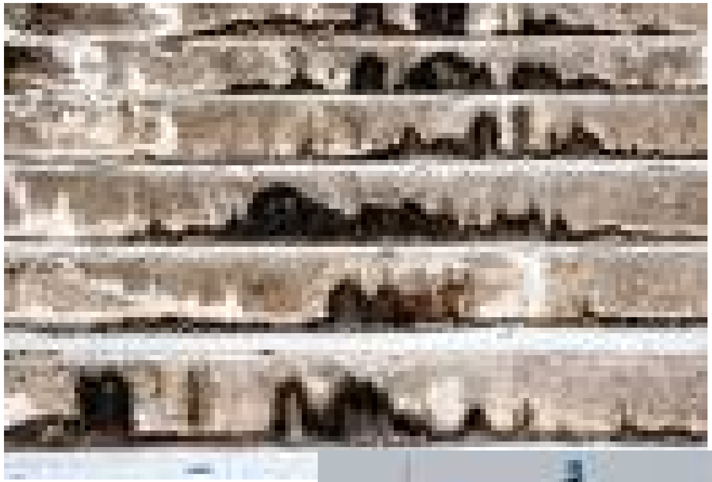
The “chemical change” can be brought on by many different factors:

- CHLORIDES
- CARBONATION
- DISSIMILAR METALS
- CHEMICAL ATTACK
- STRAY CURRENTS

Where do the chlorides come from ?

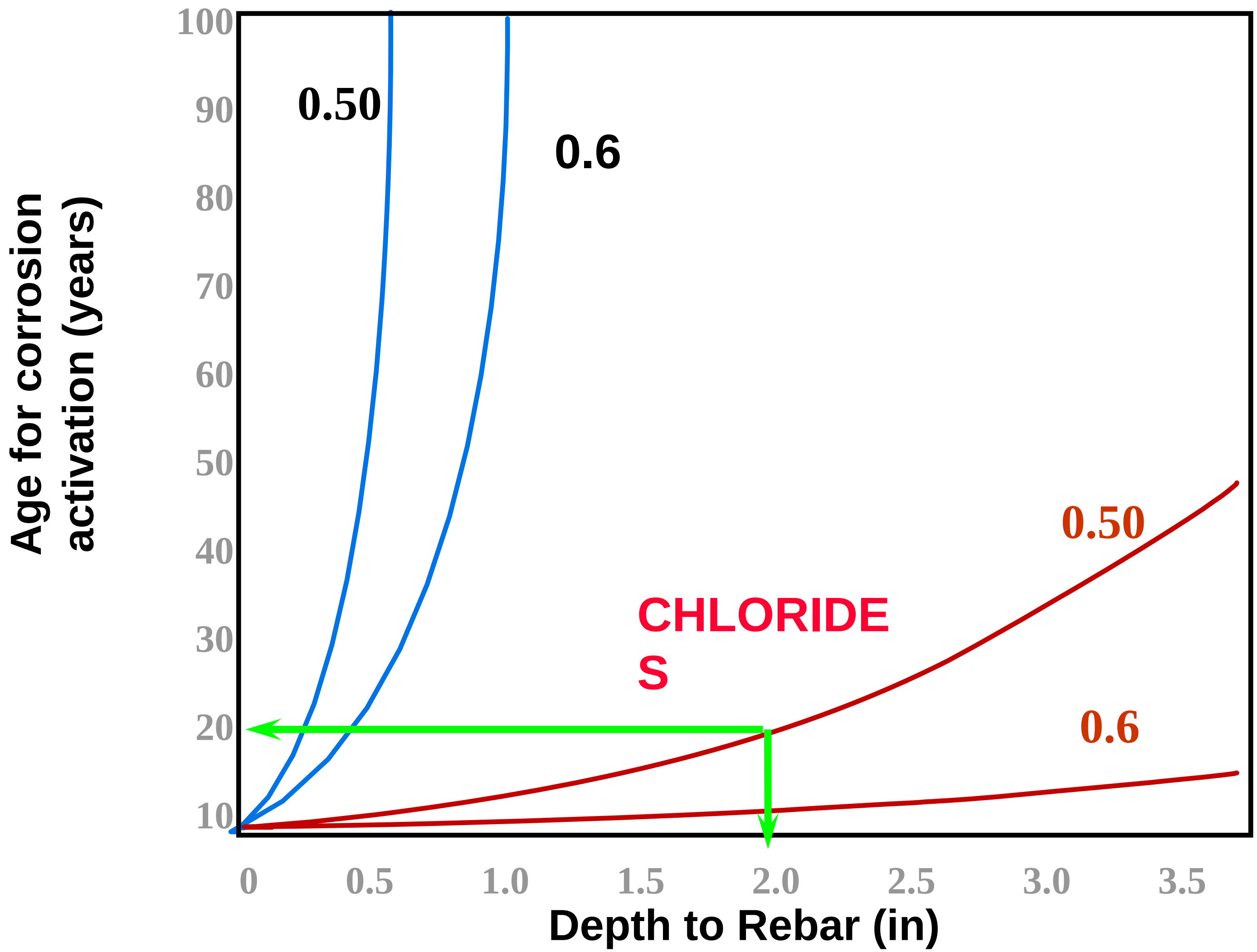
- Internal Sources
  - Mix Water
  - Aggregate
  - Admixture

- External Sources
  - De-icing salts
  - Precipitation



CAST IN CHLORIDES
“Internal Sources”

TIME TO CORROSION
Chlorides vs. Carbonation



Definitions

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- Anode – the electrode at which Net Oxidation occurs. This is where we see rust.
- Cathode – the electrode at which Net Reduction occurs.
- Electrolyte – solution containing ions (Cl^-, OH^-)
- Steel Reinforced concrete is a unique “battery” in that the electrolyte….

  IS THE CONCRETE

  …And all its components

Electrochemical Corrosion Reactions

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Reactants → **Products**

- $Fe^{+2} + 2Cl^-$ → $FeCl_2$
- $FeCl_2 + H_2O + OH^-$ → $Fe(OH)_2 + H^+ + 2Cl^-$
- $2Fe(OH)_2 + ½O^-$ → $Fe_2O_3 + 2H_2O$ **anode (rust)**
- $½O + H_2O + 2e^-$ → $2\ OH^-$ **cathode**

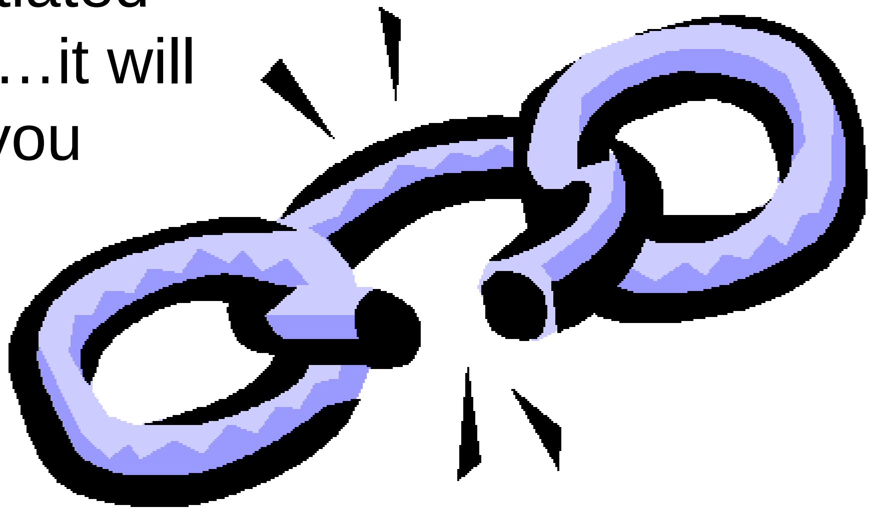
Electrolyte

Important Takeaways:

- Chlorides are not consumed in the process
- Reinforcing steel acts as both the “Anode” and “Cathode”
- [H+] produced drops pH and further deteriorates the passivation layer
- The electrolyte is the ion-rich pore solution in the concrete
- Anode-Cathode reactions occur at the same rate
- Need both oxygen and water to complete the reaction

Electrochemical Corrosion Reactions

Once corrosion has been initiated the process is like a chain……it will continue to proceed unless you break one of the links.



The question is “which link do you break ?

Corrosion Rate vs. RH

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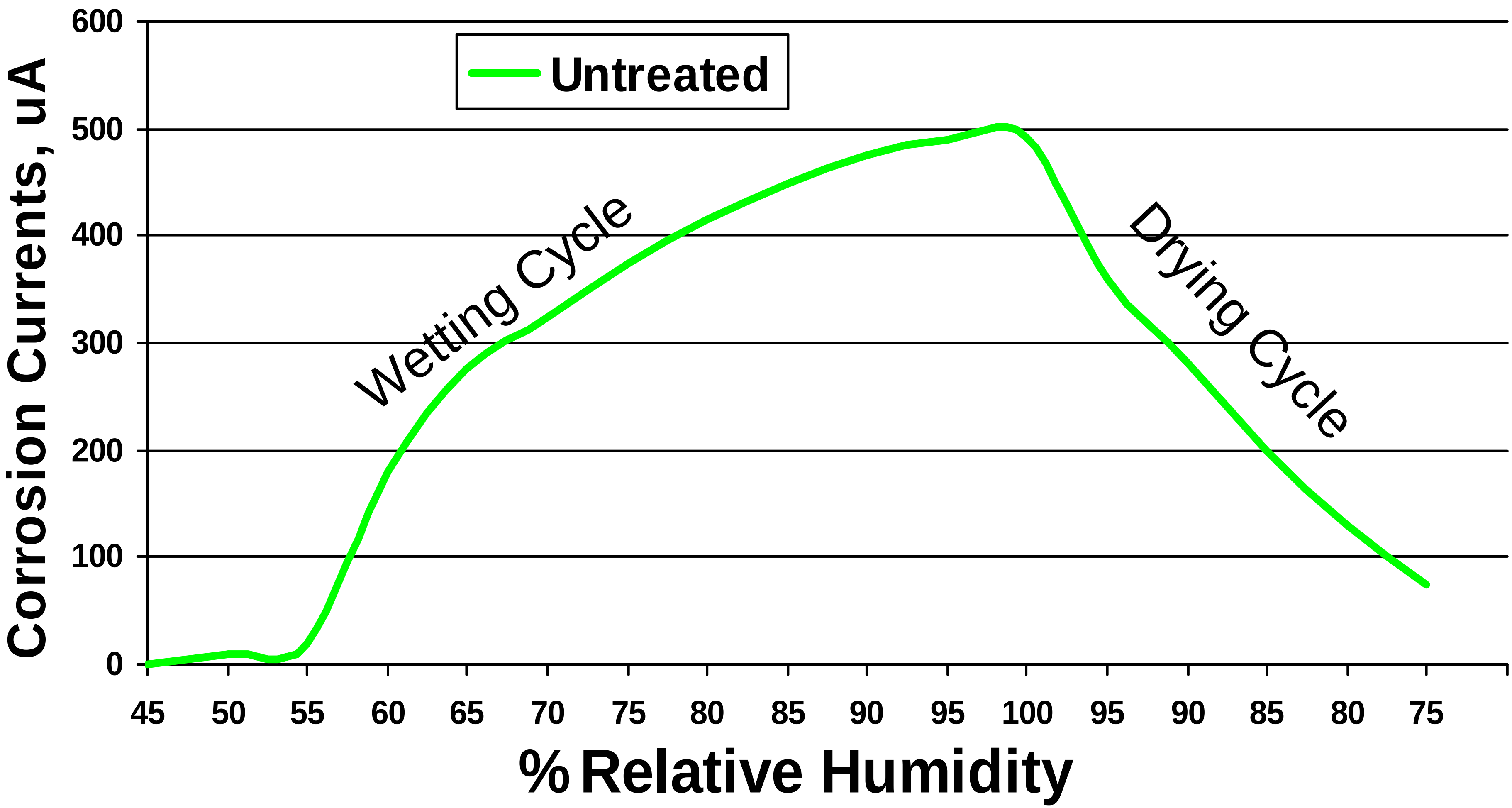

Definitions (cont'd)

- Passivating Layer – a tightly bound layer of iron oxide on the steel that naturally inhibits further corrosion (mill scale)
  - The passivating layer is stable due to the high pH (>12.5) in the concrete

The Passivation Layer

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Passivation Layer can be breached by:

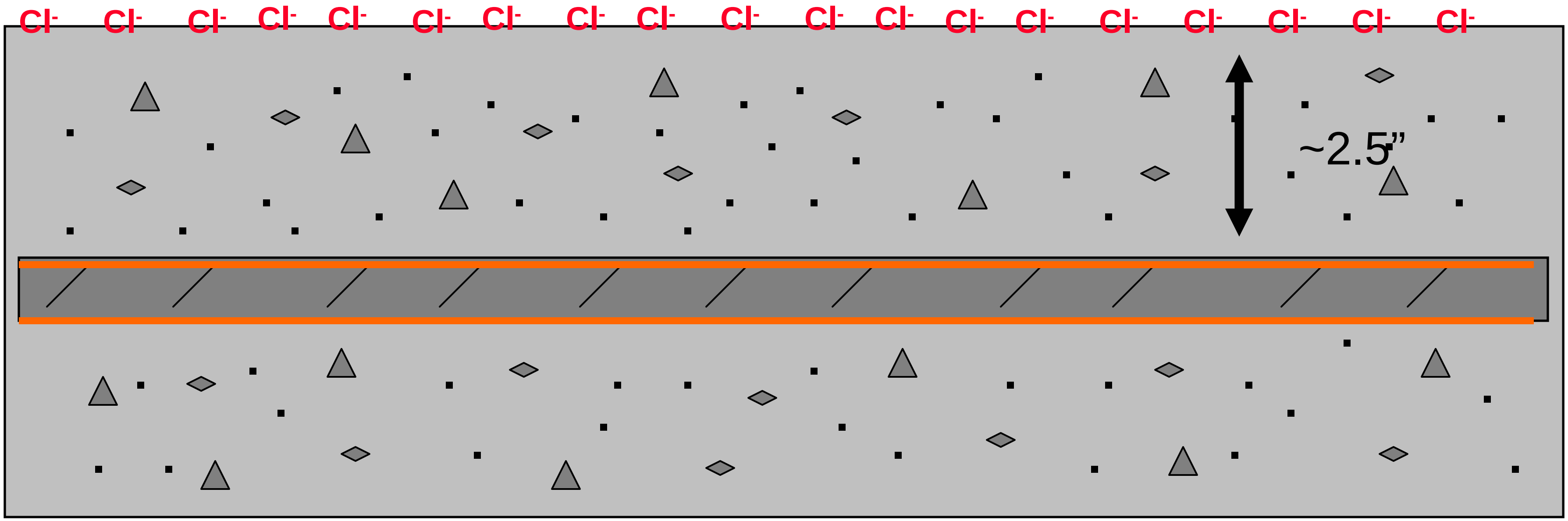
Chloride Ions -- >330 ppm (~1.2 lbs/yd^3)

or

Loss of Alkalinity -- < pH 10

How do chlorides cause corrosion ?

1. **Chlorides penetrate through the concrete substrate.**
2. **Cause an electrochemical reaction with the reinforcing steel**



How do chlorides penetrate concrete ?

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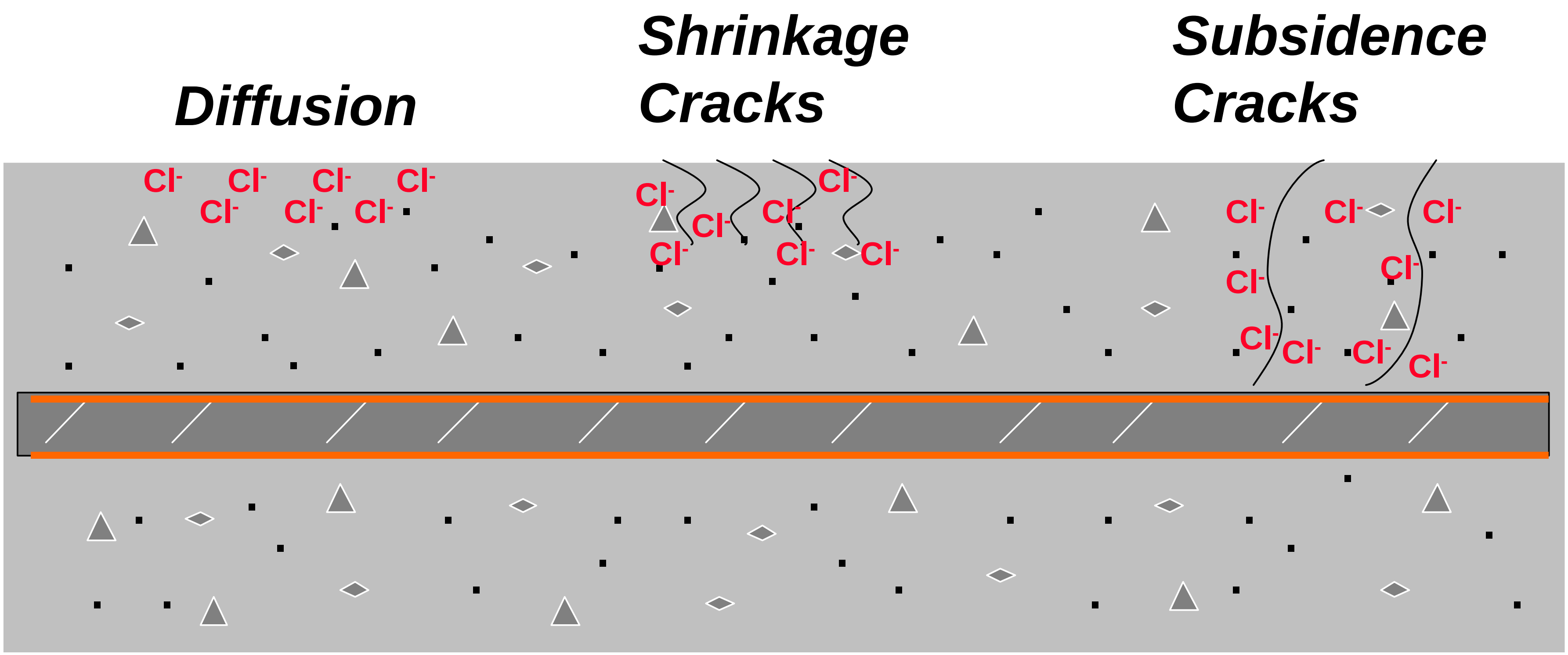

- **Straight Diffusion - ~8 years to penetrate 2.5” of concrete to a [CL-] >330 ppm**
- **Most chloride penetration occurs through shrinkage and subsidence cracks**

What happens when chlorides penetrate to the reinforcing steel and the [Cl-] > 330 ppm ?

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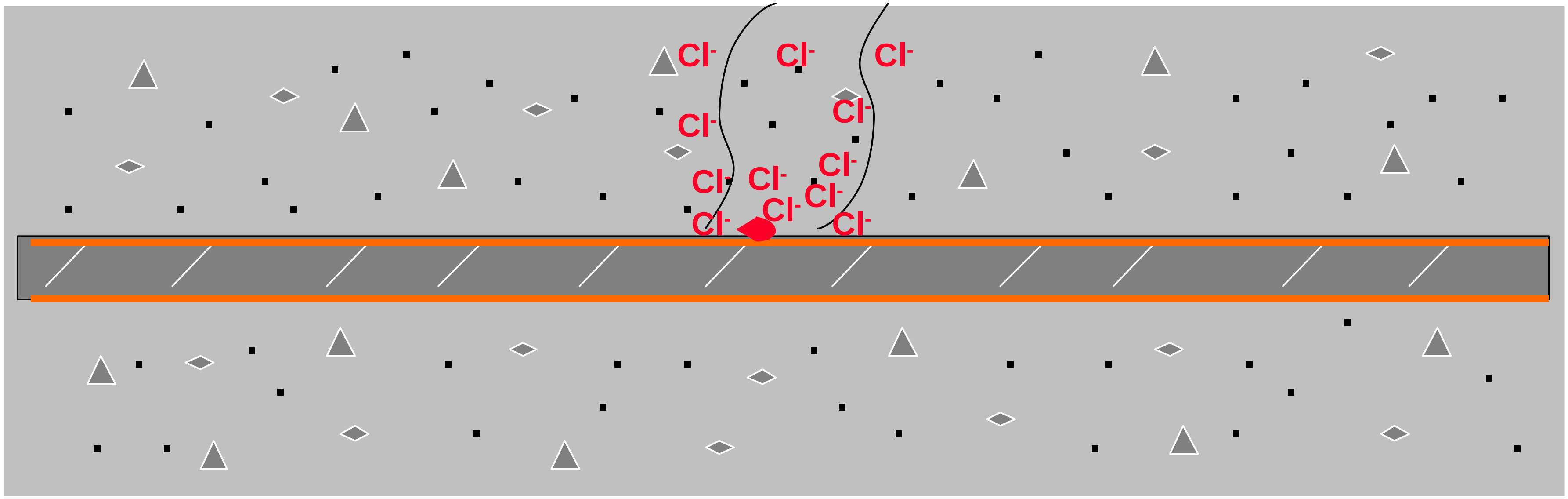
When the chlorides pass the threshold value the passivation layer is breached and exposes the reinforcing steel to the chlorides



Breakdown of the passivation layer initiates the electrochemical reaction between the steel in the rebar and the chlorides.

What Causes Corrosion?

In steel reinforced concrete, corrosion is the deterioration of steel caused by a change in its concrete surroundings (environment).

The “chemical change” can be brought on by many different factors:

- CHLORIDES
- **CARBONATION**
- **DISSIMILAR METALS**

CARBONATION

WATER + CARBON DIOXIDE

DISSIMILAR METALS

CORROSION PREVENTION OPTIONS
New Construction

- COATED REBAR
- NON-STEEL REBAR
- DESIGN WITHOUT REBAR**
- ADMIXTURES
- WATER REPELLENTS
- DECK COATINGS / MEMBRANES
- QUALITY SEALANTS
- JOINTS

CORROSION CONTROL OPTIONS
Restoration

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- REMOVAL OF CONTAMINATED CONCRETE
- REBAR COATINGS
  - Epoxy
  - Cementicous
- PATCH REPAIR MATERIAL WITH CI / W/O CI
- FRP
- GALVANIC PROTECTION
  - Zinc Rich Rebar Primers
  - Galvanic Anodes
- ELECTROCHEMICAL OPTIONS
  - ICCP – Impressed Current Cathodic Protection
  - Chloride Extraction / Re-Alkalinization
- ANTI-CARBONATION TREATMENTS
- SURFACE APPLIED CORROSION INHIBITORS

REMOVE CONTAMINATED CONCRETE

REMOVAL OF CONTAMINATED CONCRETE – ICRI GUIDELINES

REBAR COATING AND BONDING AGENT
Cementitious/Epoxy

GALVANIC PROTECTION
Zinc Rich Primer

BASIC TERMINOLOGY

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- DISSILIMAR METALS – two metal components in an electrolyte that could form an anode-cathode relationship when connected by a metallic path

- ELECTROMOTIVE SERIES - list of metals whose order indicates the relative tendency to be oxidized, or to give up electrons

Gold
↓
316 SS
↓
Steel
↓
Chromium
↓
Zinc
↓
Aluminum

GALVANIC PROTECTION
Anodes

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GALVANIC PROTECTION
Galvanic Anodes

PERIMETER REPAIRS

REPAIR MORTARS with or without C.I.

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REPAIR MATERIALS

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- SCHOOLS OF THOUGHT

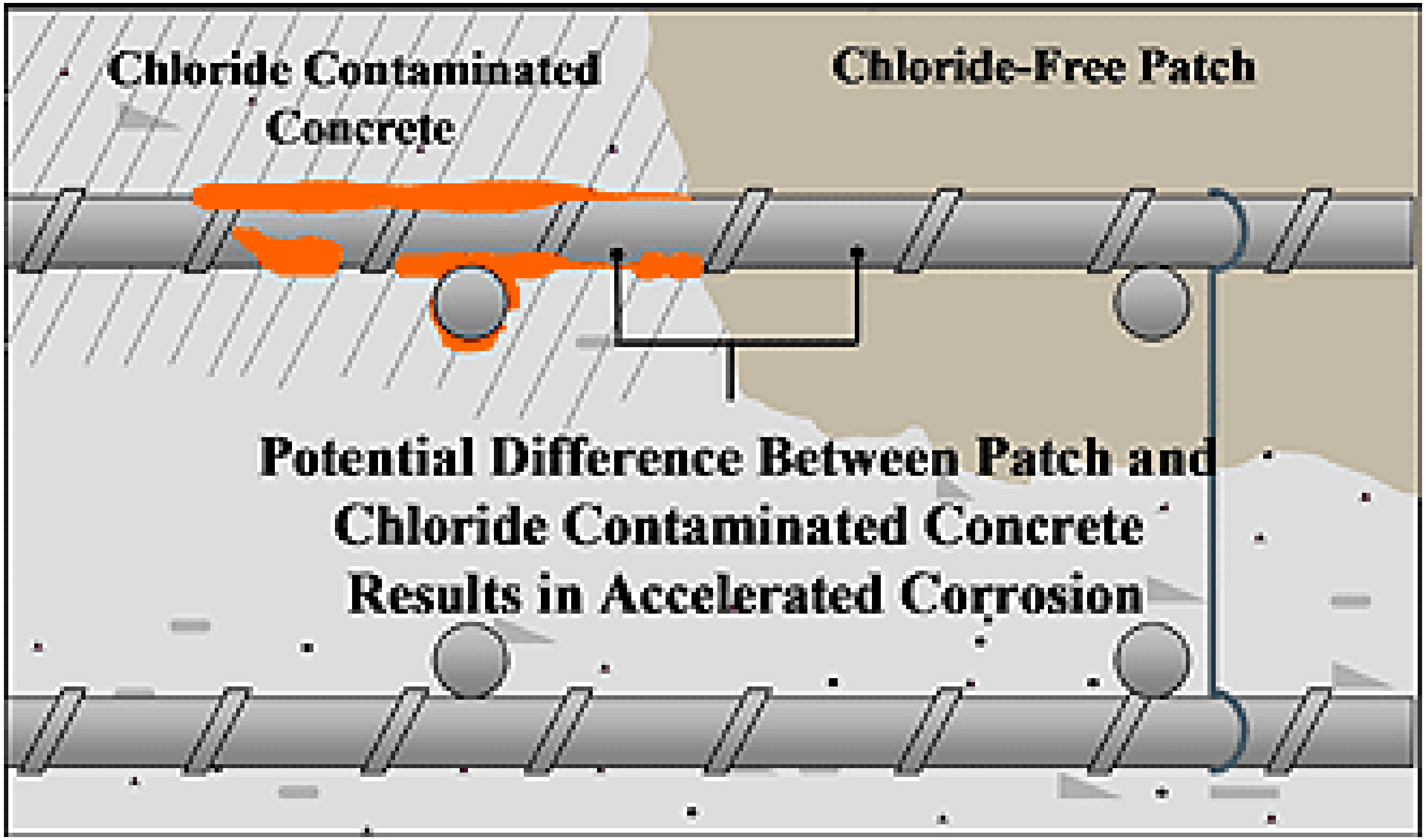
1. Match the host concrete characteristics
2. Polymer modified, high strength, high density mortars

REDUCE THE CRACKING POTENTIAL

Specify a product that has a reduced cracking potential.

Specify ASTM C 1581 as called for in DSP!

ELECTRICAL POTENTIAL DIFFERENTIAL



GALVANIC PROTECTION
Anodes Need Conductive Environment

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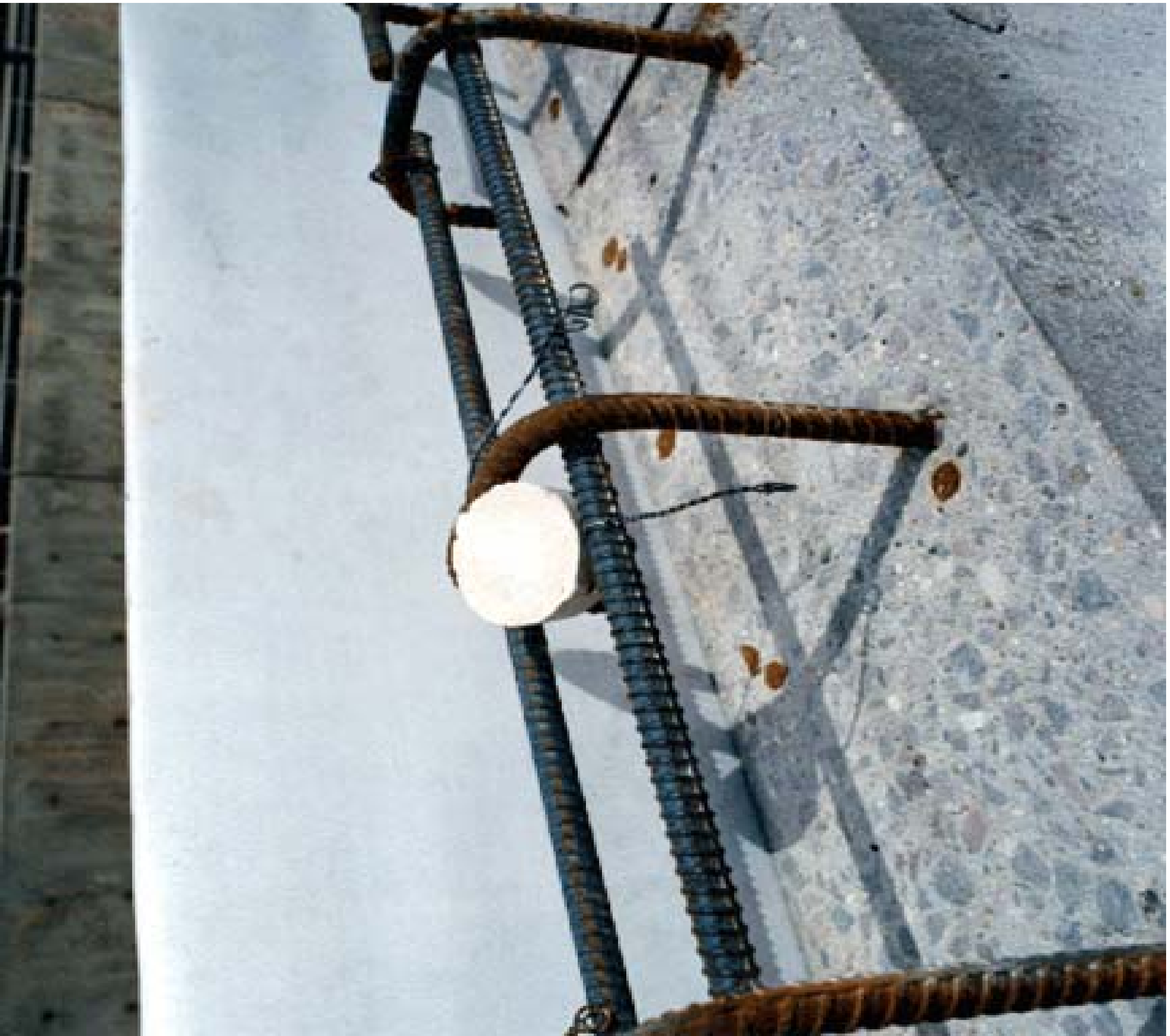

Currently:

Repair Mortar must have a resistivity of less than

15,000 Ohms-cm

Although studies are being conducted now to update this information

RAILING GROUT POCKETS

Effectiveness of Various Protection Materials on <u>Active</u> Corrosion

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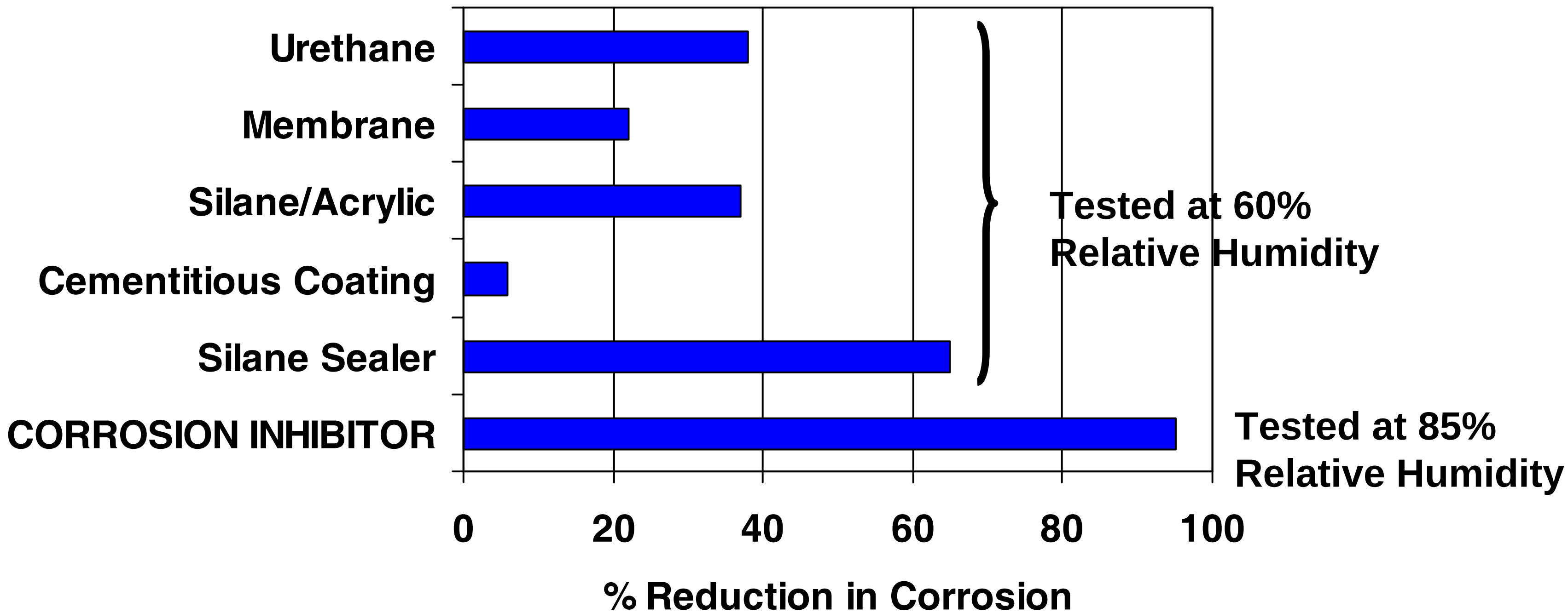

Conventional protection methods may prevent corrosion, but they are not as effective on active corrosion

Corrosion Continuing

CORROSION INHIBITOR

Field Evaluation of Organofunctional Silane Based Inhibitor

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Chemical Treatment

CASE HISTORY

Measurement of a Corrosion Inhibitor Through Online Monitoring

M. BÜCHLER, *SGK Swiss Society for Corrosion Protection, Zürich, Switzerland*
Y. SCHIEGG, *Corrosys AG, Cham, Switzerland*
S. GIESSLER, *Degussa AG, Rheinfelden, Germany*

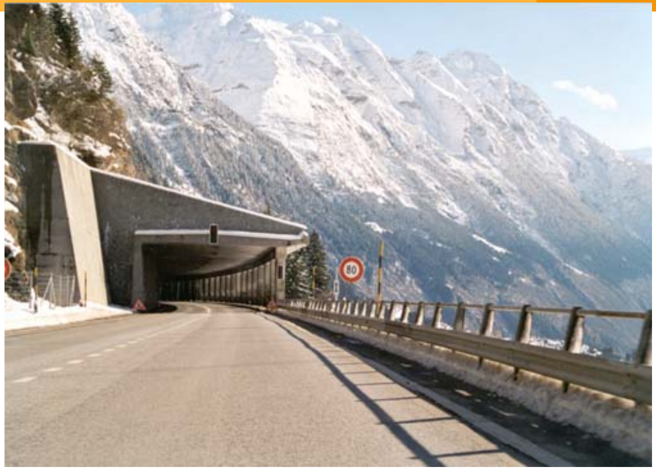
Typical repair of reinforced concrete structures showing corrosion damage involves removal of carbonated or chloride-contaminated concrete and subsequent retrofilling with new concrete. Corrosion inhibitors that can be applied by spraying onto the

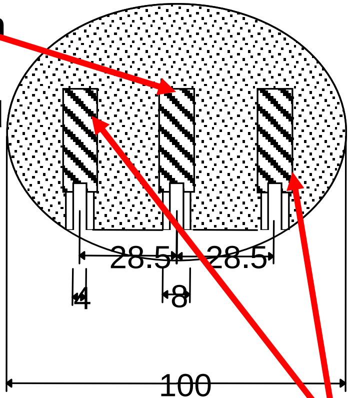
Protecting Steel in Concrete

The combination of steel and concrete provides ideal corrosion protection for steel, since the alkalinity of the concrete in combination with water and oxygen causes the formation of a thin protective oxide film on the steel surface (Figure 1[a]). This passive film decreases the corrosion rate of steel to virtually zero and increases the durability of steel-reinforced concrete structures to more than 100 years. It is well known that such natural corrosion protection of steel can be compromised by chloride ions and other substances that penetrate into the concrete and diffuse to the steel surface (Figure 1[b]). In this case, significant corrosion may occur, causing decreased load capacity in the structure. Under certain conditions, corrosion rates of up to 0.7 mm/y may occur.[1]

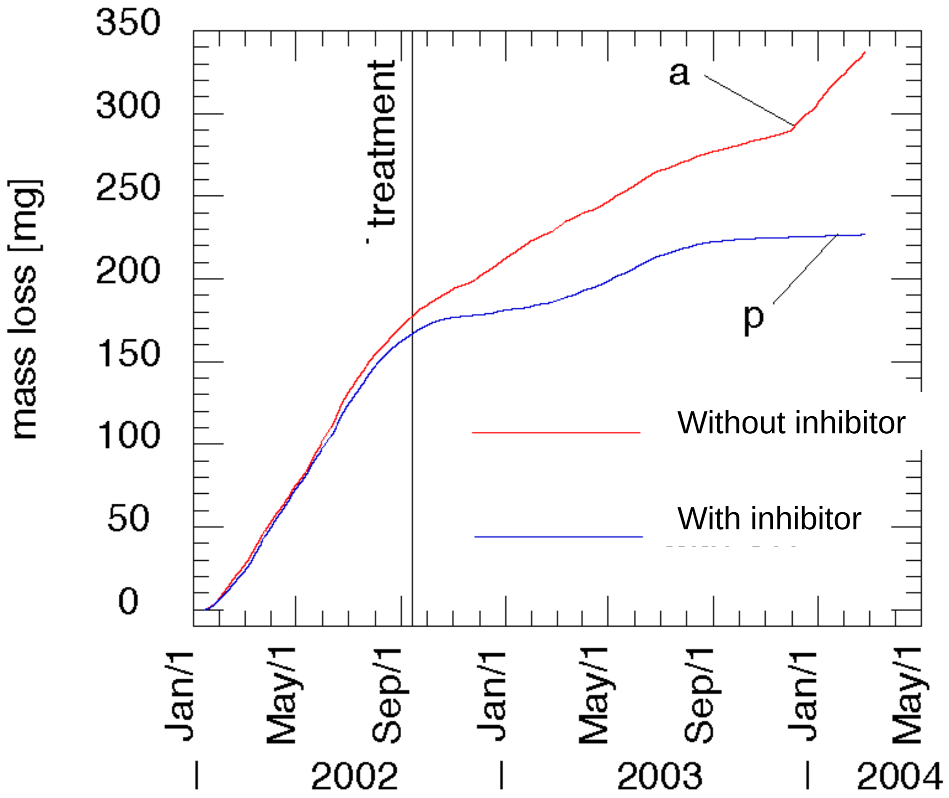
Chlorides, often originating from deicing salts, have caused significant corrosion damage on reinforced concrete structures. Also, carbonation—the reaction of carbon dioxide (CO_2) with concrete—may decrease the alkalinity of the concrete and activate corrosion.

Typically, repair for such corrosion involves the removal of the carbonated or chloride-contaminated concrete, followed





Field Evaluation of Organofunctional Silane Based Inhibitor



Field Evaluation of Organofunctional Silane Based Inhibitor

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NACE Material Journal
October 2006
Testing Performed by the Swiss Association for Corrosion Protection
Comprehensive Field Monitoring in Swiss Alps

Organofunctional silane inhibitor showed not only corrosion reduction but re-passivation of the steel

The variation of the corrosion rate due to climatic factors is significant. Even the daily temperature cycles can cause a variation in the corrosion rate by a factor of three. Also, seasonal changes influence the corrosion behavior. Hence, it is not possible to judge the corrosion behavior based on single measurements. By means of online monitoring, it is possible to obtain a reliable control of the external influencing parameters. For the owner of a structure, the use of new products or the application of existing products under severe conditions offers a risk, which can be minimized by online monitoring. The corrosion protecting effect can be observed over time. Even the application of products where the inhibition mechanism is not yet understood in detail, or where the protection time is uncertain, can be applied in combination with monitoring.

Based on the use of online monitoring, it is possible to draw some conclusions about the corrosion inhibitor used in the present investigation. It was demonstrated that the inhibitor led to a decreased corrosion rate. Possibly, even repassivation took place based on the interaction with the product.

References

1. Y. Schiegg, H. Böhni, F. Hunkeler, "Online-Monitoring of Corrosion in Reinforced Concrete Structures," in The

Reaction of Organosilane C.I. with passivation layer

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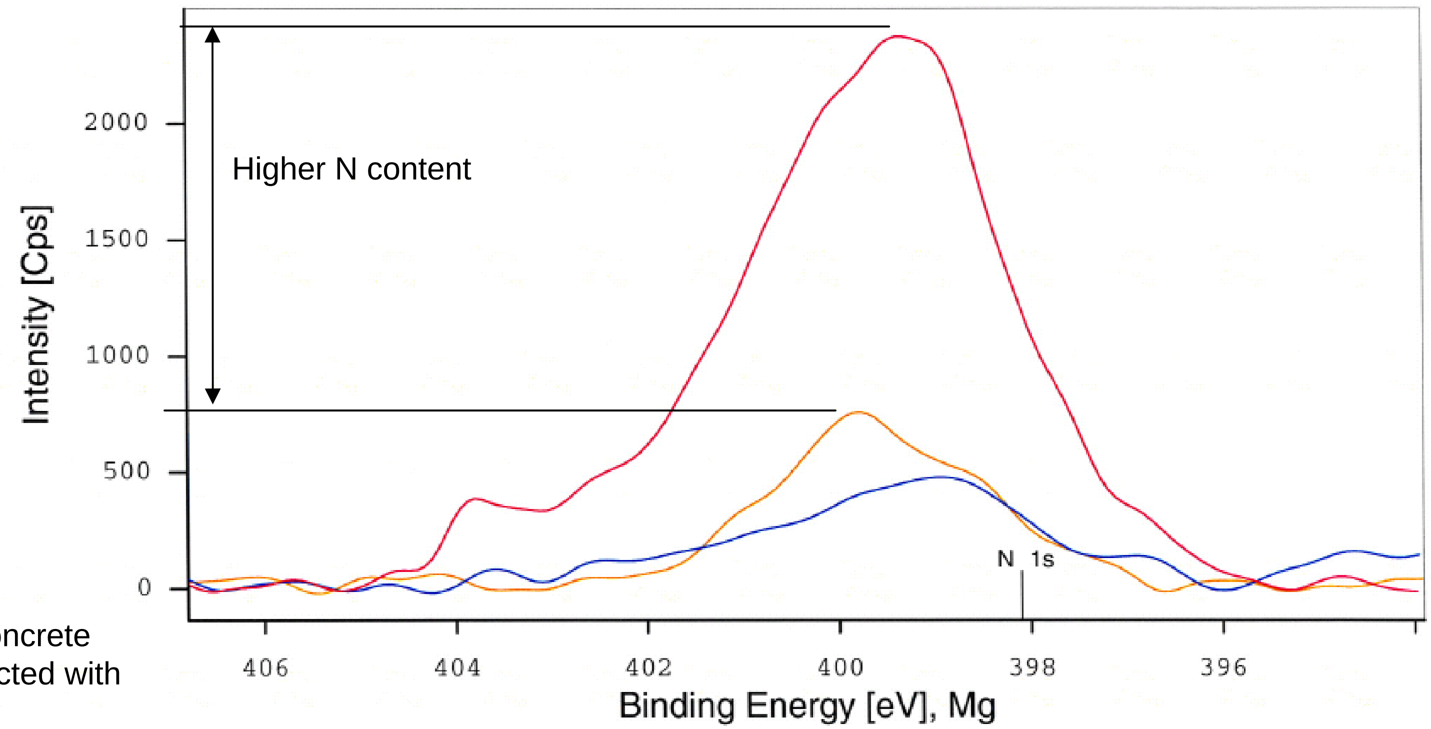
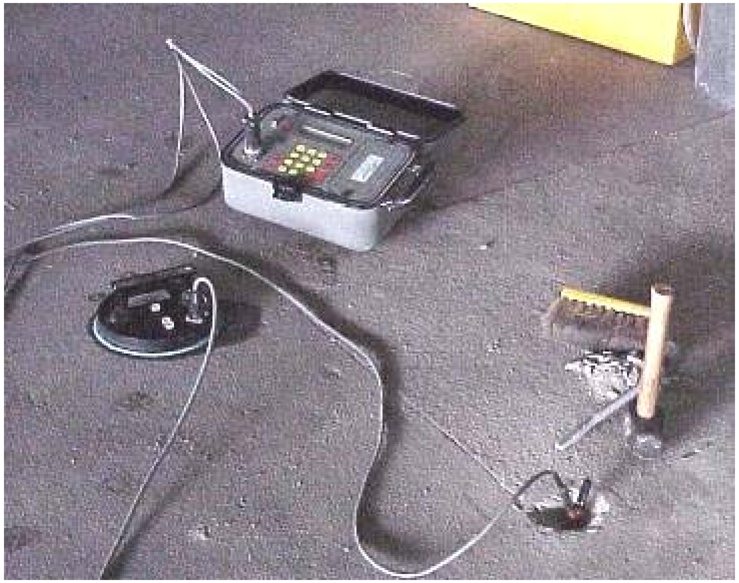
This ithe nitrogen area of the curve. The admixture contains no amines, while the surface applied MASTERSEAL CP has aminosilanes. This accounts for the higher intensity of the surface applied inhibitor.



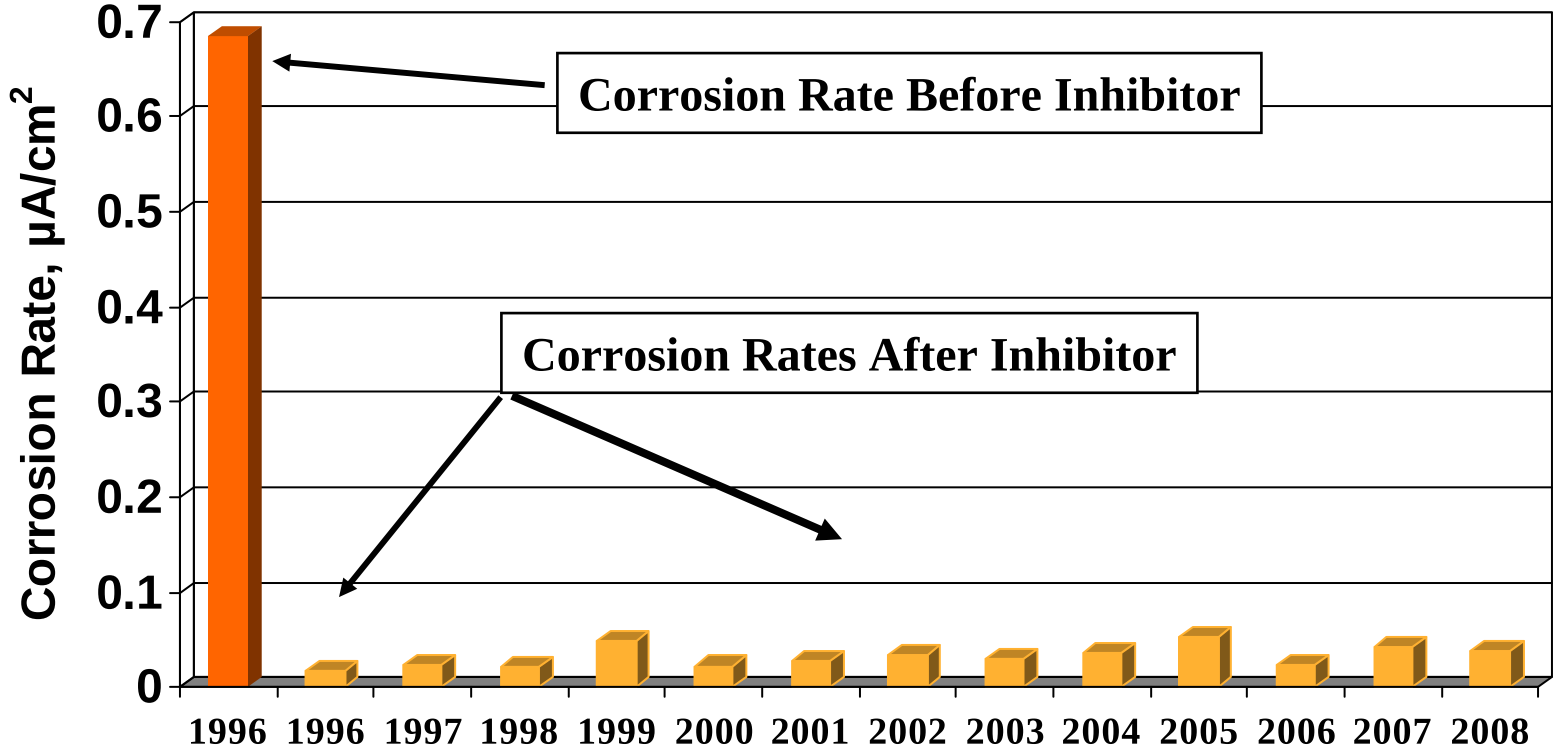
- Rebar from unprotected concrete
- Rebar from concrete protected with **Admixture**
- Rebar from concrete protected with **Amino Silane**

PARKING STRUCTURES

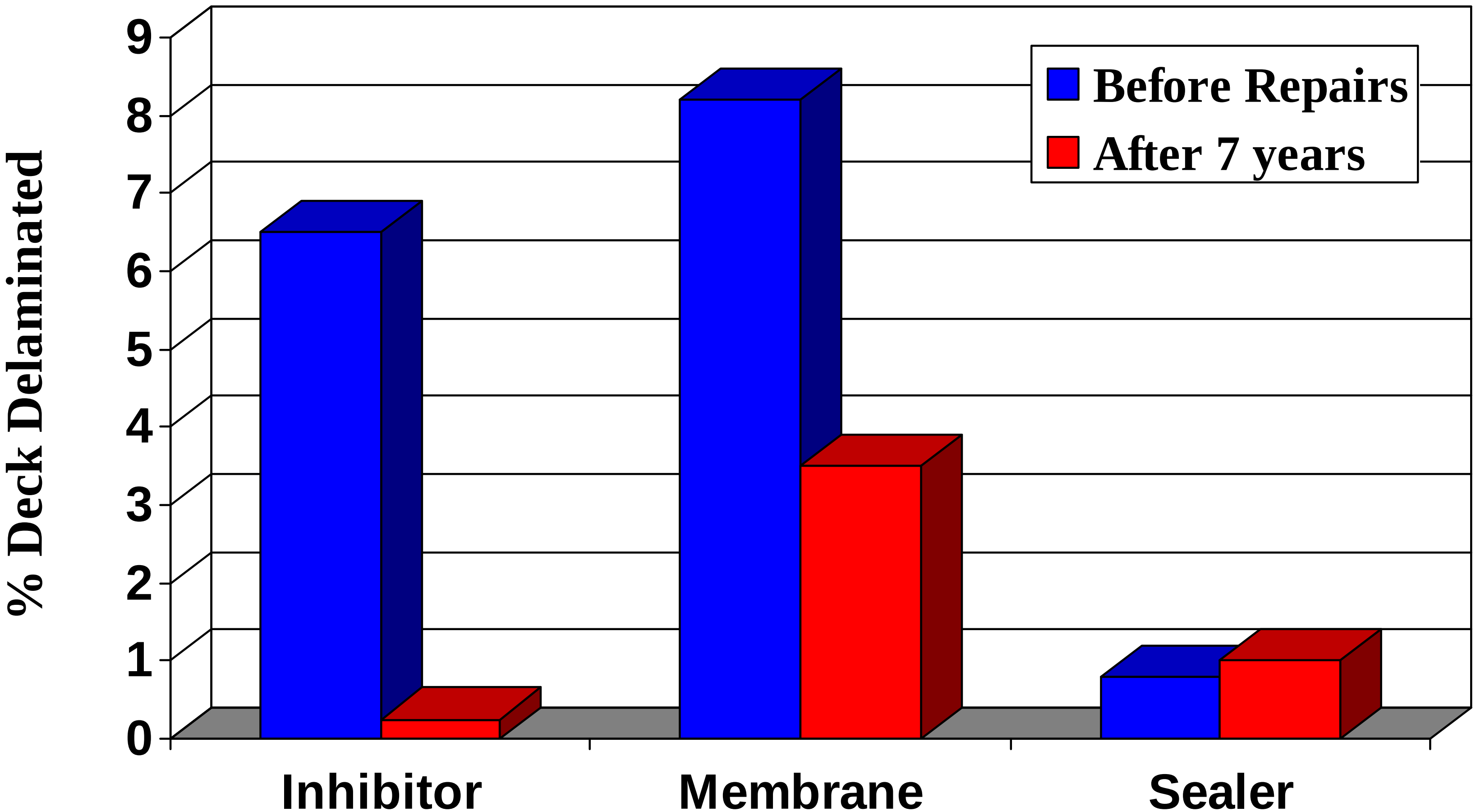
⇒ Spalls and Delaminations were repaired using standard methods
⇒ Inhibitor was applied to all the exposed concrete
⇒ Corrosion testing is performed annually to verify performance



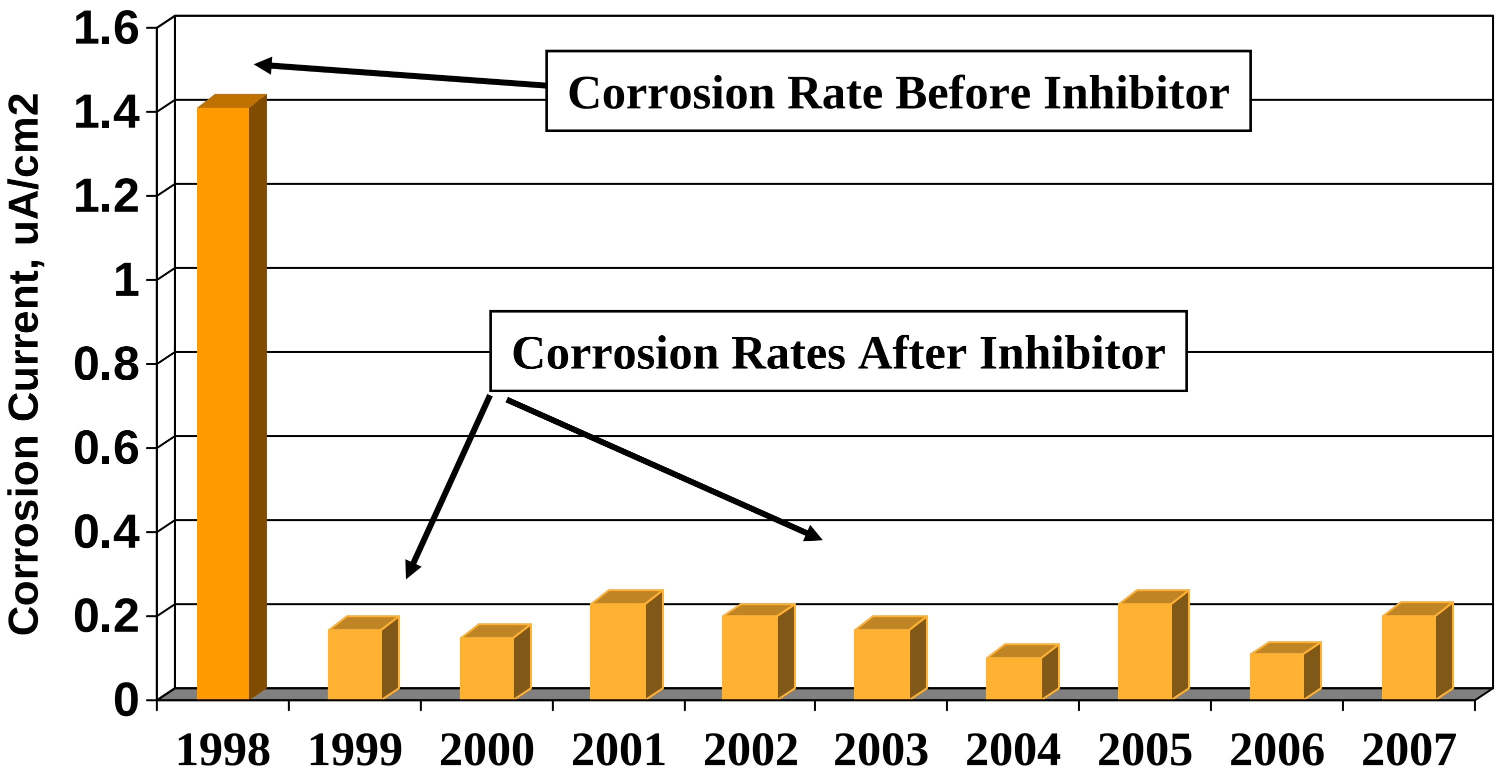
Field Performance
Car Park Exposed to Deicer Salts



Field Performance
Car Park Exposed to Deicer Salts



Performance
Balconies Near Salt Water



FHWA TESTING
“New Concrete”

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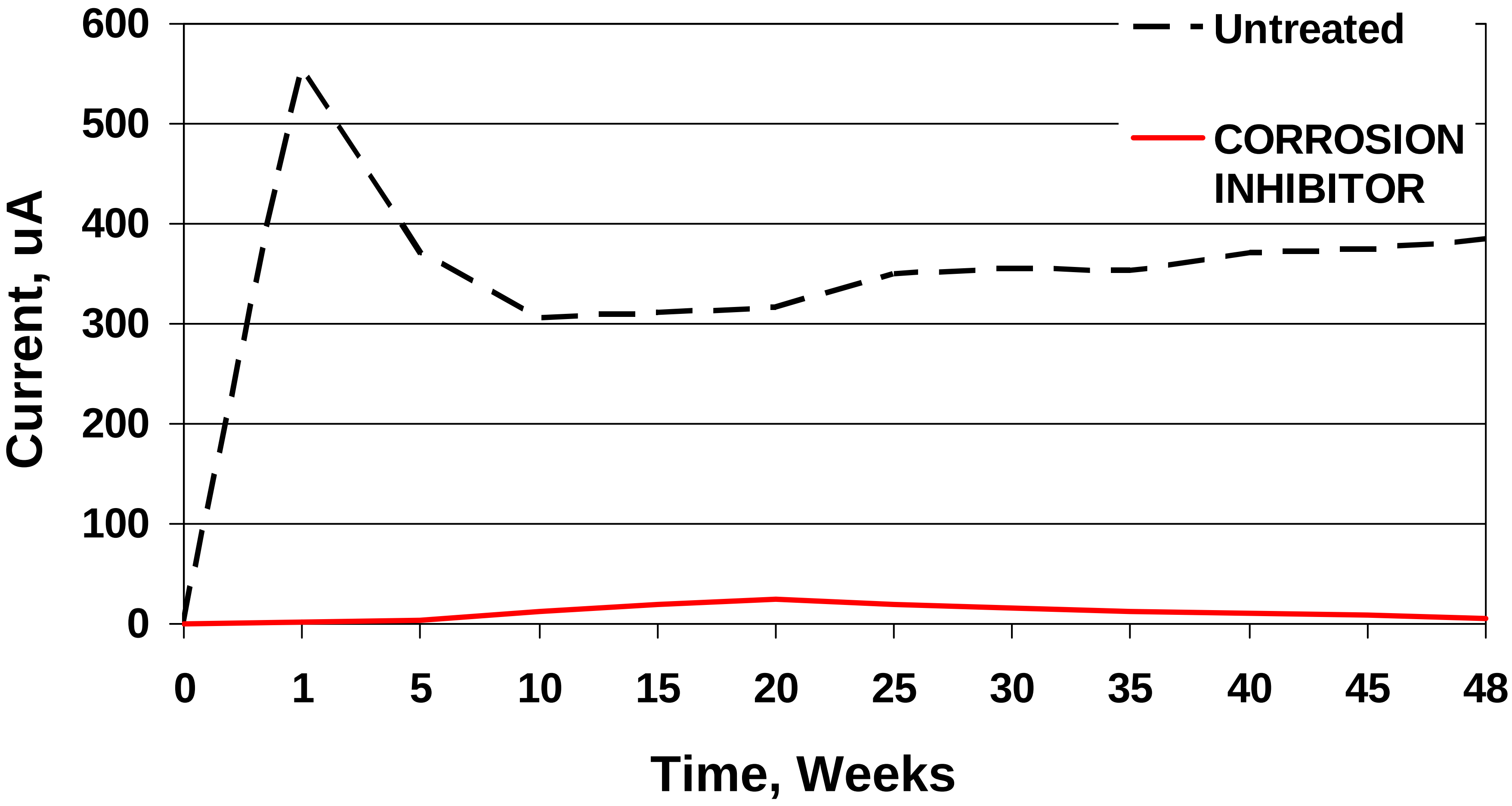
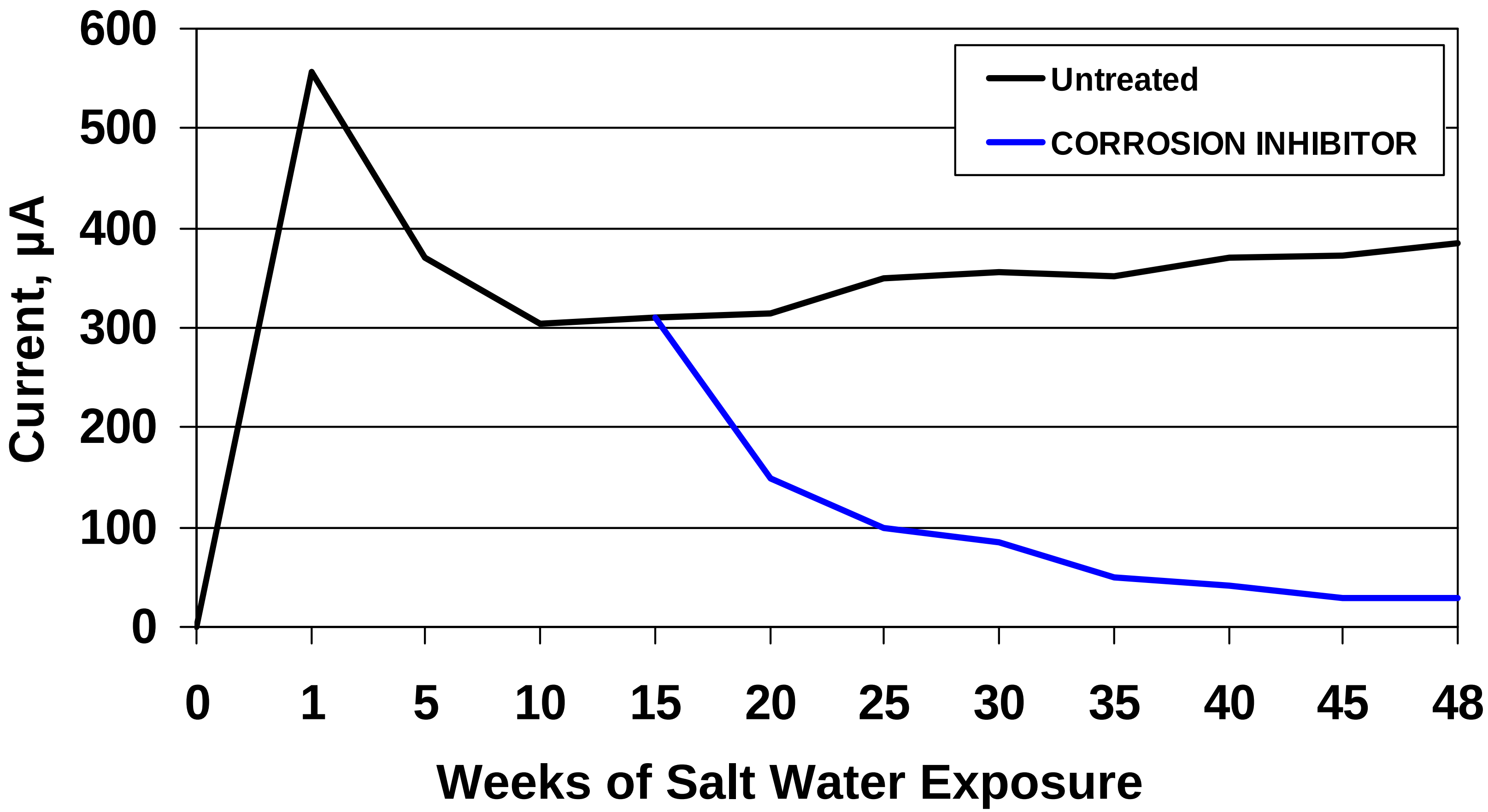


FHWA TESTING
Existing Corrosion in Concrete



Corrosion on Cracked Specimens

Corrosion on Cracked Specimens for Different Systems Using FHWA-RD-98-153 Protocol

- Black Bars -- 4053 mV
- Epoxy, 0.5% damage -- 971 mV
- Epoxy, 0.004% damage -- 325 mV
- Copper-clad -- 111 mV
- 316 SS -- 5 mV

- ORGANOFUNCTIONAL SILANE -- 58 mV

FIELD PERFORMANCE

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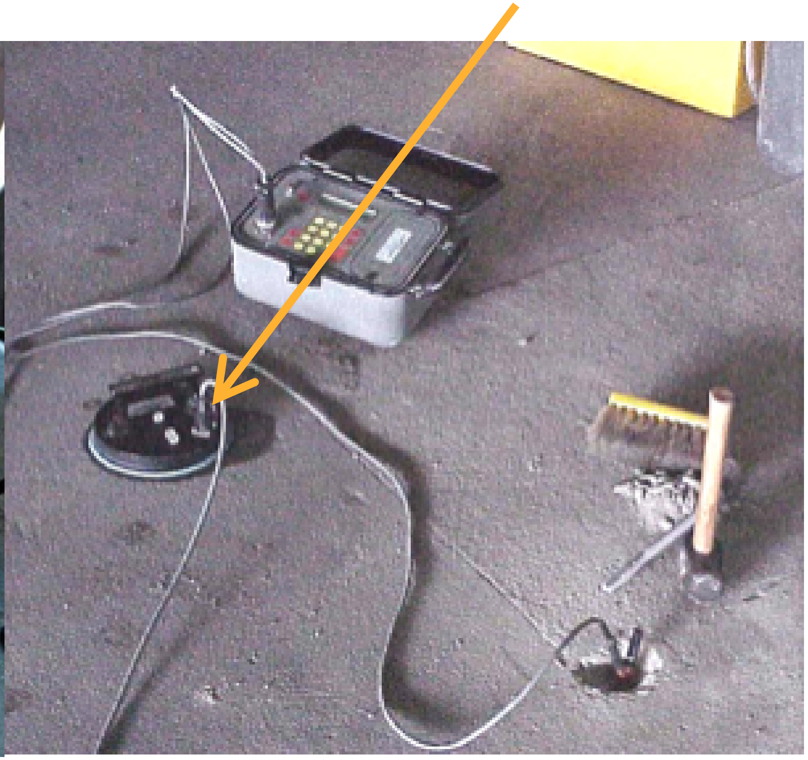
TEST IT!!!



BUT WAIT…..

- WHAT ABOUT CRACKS???

- **ONCE CORROSION IS MITIGATED**…..then you MAY be able to install a coating or crack sealer.

REVIEW

- LOTS OF OPTIONS!
- Know the root cause of your corrosion
  - STOP IT FIRST!
- Match the repair solution to the problem
- Don’t assume …..check compatibilities
  - Remember to use galvanic anodes repair material must have a resistivity of less than 15,000 ohms-cm unless otherwise tested
  - Isolate dissimilar metals so electrical potential differentials cannot be established
  - Stop active corrosion before placing non-breathable coatings

THANK YOU!

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