



Reinforcement Corrosion, No Perfect Solution

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What is Concrete?

- + Concrete is economical with a long life & low maintenance
- + Concrete does not rot, corrode, or decay.
- + Concrete can be molded or cast into almost any desired shape.
- + Concrete is fire-safe & able withstand high temperatures.
- + Concrete is resistant to wind, water, rodents, and insects.
- + 12 BILLION cu meters per year globally
- + ~1 cu yd / person / year in USA
- + >70 Billion cu meters placed in USA since 1930
with ~10 Billion cu meters > 20 years old

CONCRETE





Definitions

- Anode (–) the electrode at which electrons are lost and oxidation occurs. This is where we see rust.
- Cathode (+) the electrode at which electrons are gained and 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



What is the biggest ROI for concrete repair?

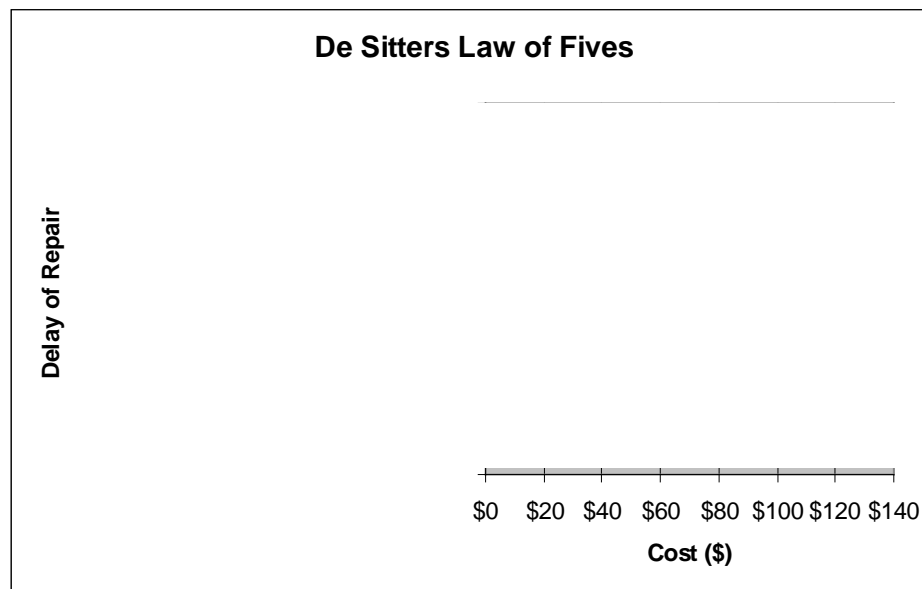
De Sitter's Law of Fives

\$1 spent Monitoring =

\$5 spent on Preventative Maintenance Before Corrosion Initiation =

\$25 spent on Repair and Maintenance after Localized Corrosion Initiation =

\$125 spent on Repair & Replacement after Generalized Corrosion



Pay Me NOW

OR

Pay Me LATER

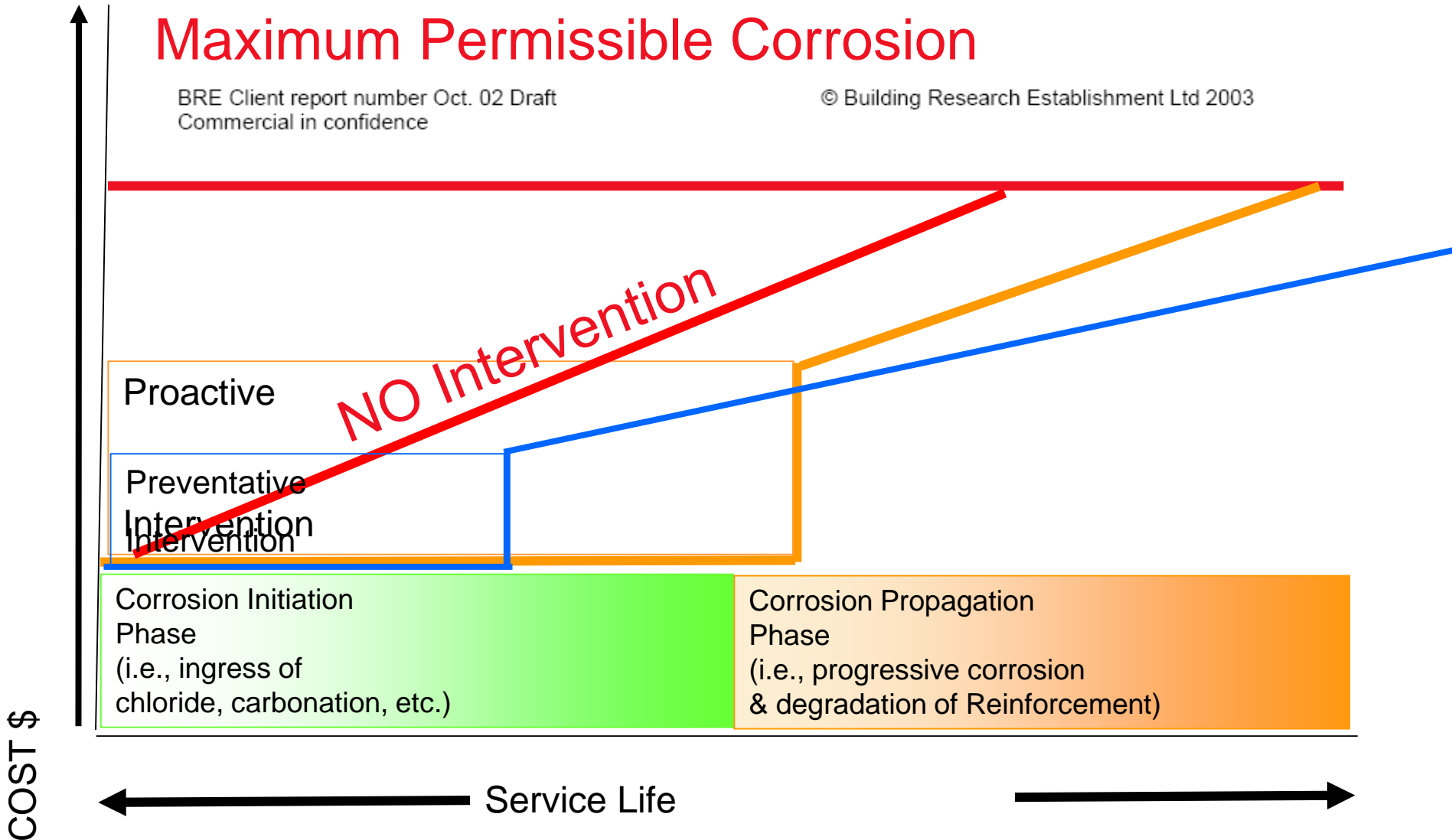


Tuutti Diagram

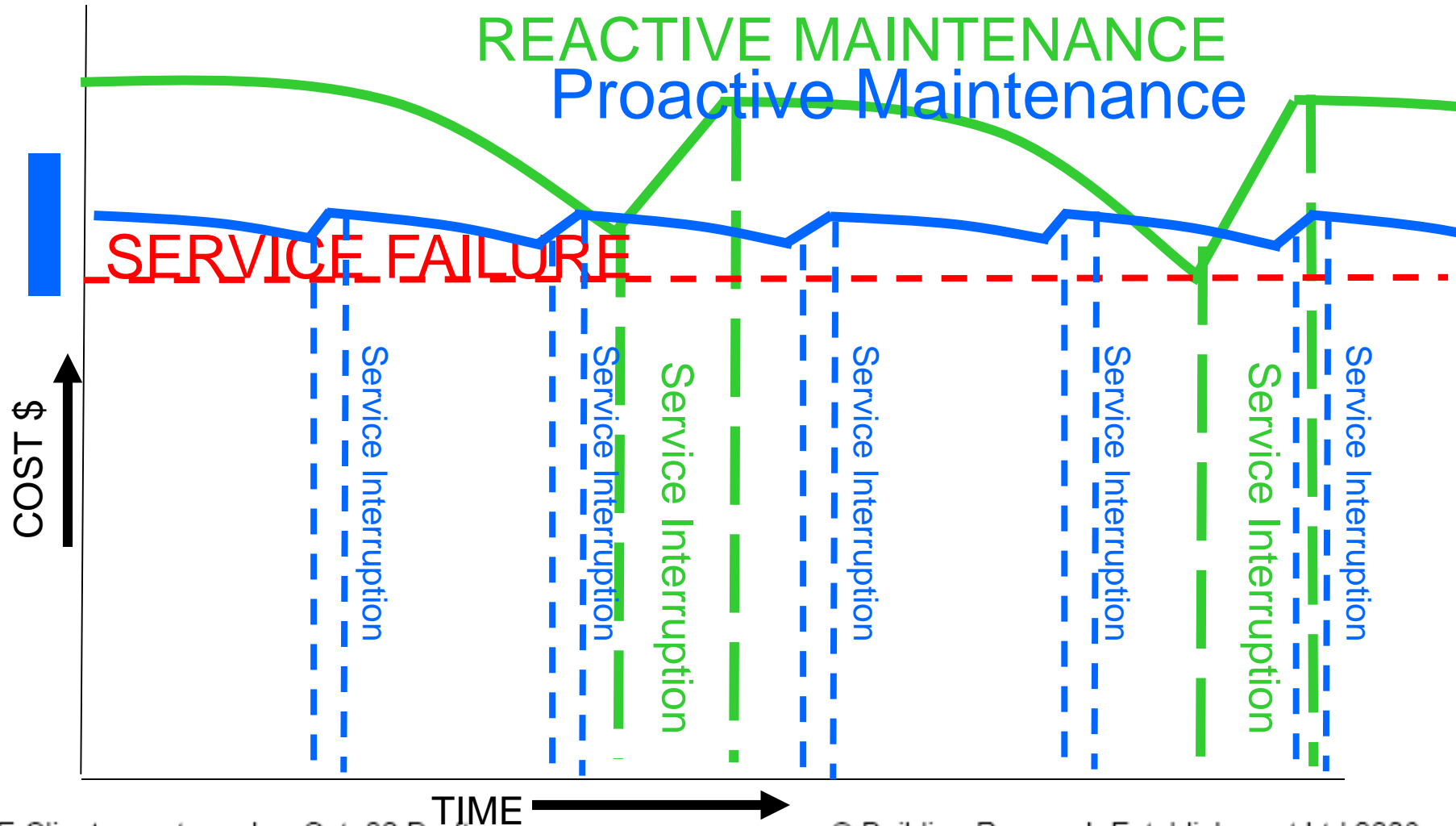
Maximum Permissible Corrosion

BRE Client report number Oct. 02 Draft
Commercial in confidence

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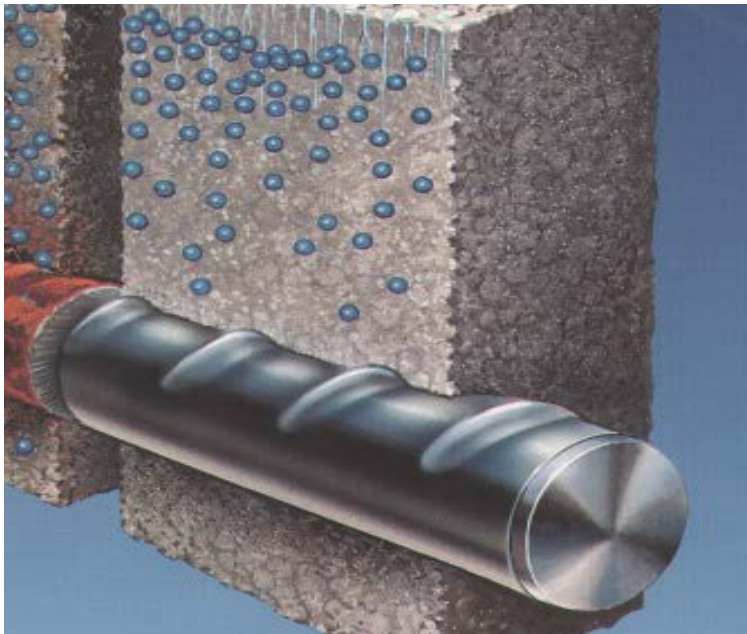


Do Unto Your Future Before Your Future Does Unto YOU!



Concrete & Reinforcement Steel

A Strong Connection

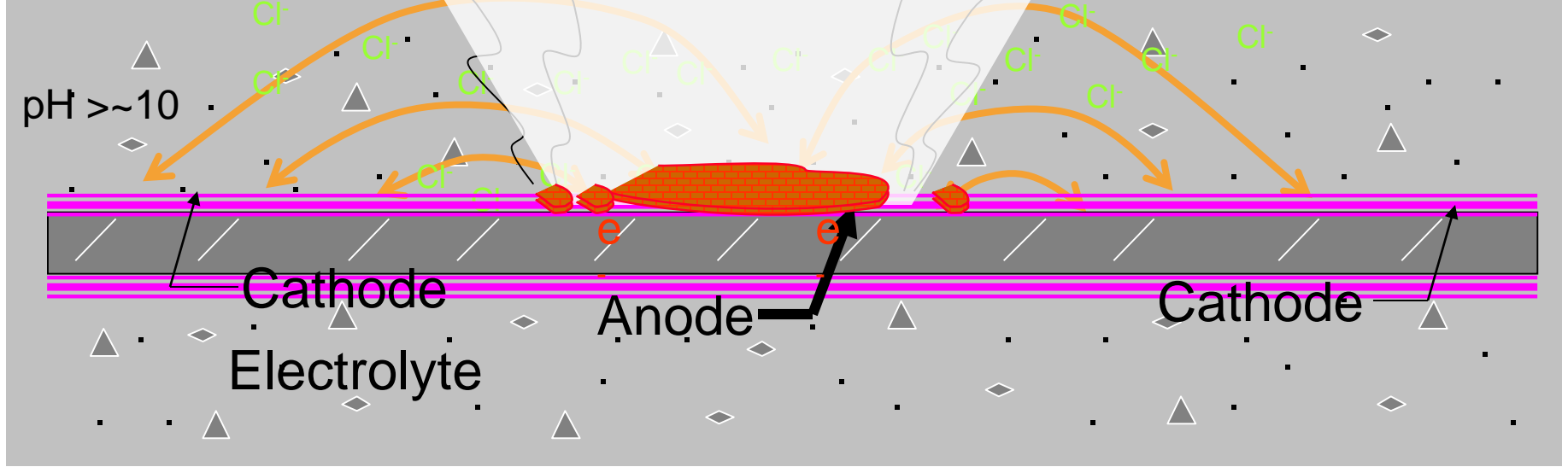


Steel strengthens concrete

- » Concrete itself cannot withstand high tensile strengths
 - Usage of steel reinforcement to provide world's most widely used building composite

Concrete protects steel

- » A dense layer of cover concrete acts as a barrier to the atmosphere
- » Alkalinity released during hydration sustains a stable oxide film on the surface
- » Additionally a lime rich layer forms on the steel surface, assisting passivation



Corrosion = Iron + Oxygen + Moisture

Either

- the pH falls due to carbonation or other chemicals
- chlorides reach the steel above the threshold concentration
- an electrical charge destroys the natural protection of the steel
- Electrons flow and ions migrate
- Rust expansion causes cracking
- Rapid deterioration
- Spalling

Corrosion of Steel in Concrete

A huge cost to society...



CaCl₂ Grout Lowe's Motor Speedway Bridge Concord, North Carolina --

May 20, 2000



Rebar detailing and installation de la Concorde overpass in Laval Canada — Sept. 30, 2006

Key Facts:

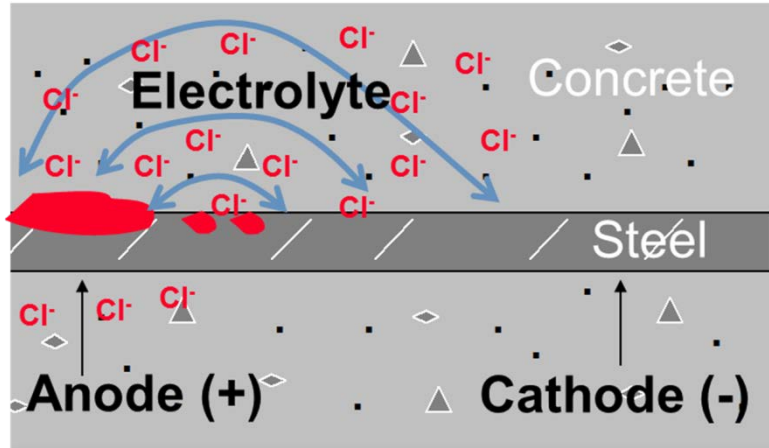
- » All steel reinforced concrete worldwide is at risk due to corrosion
- » Global cost of corrosion 1 - 5% of GNP
- » Global market size of corrosion mitigation in steel reinforced concrete = \$1 ¼ B (1 Bn€)
- » As long as we reinforce concrete with steel, it will rust.



Natural laws: Concrete cracks – steel corrodes

Corrosion of Steel in Concrete

Electrochemical Process and Materials Science

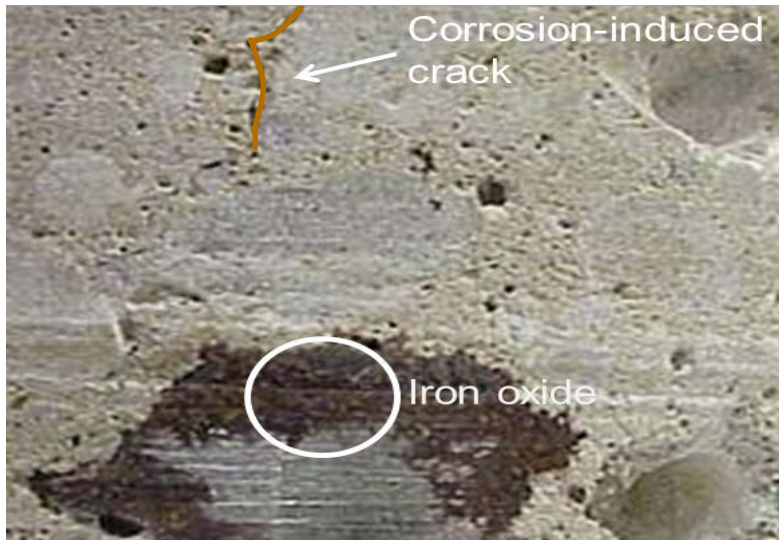


Passivation layer can be breached

- » Halide ions > ~330 ppm
- » pH value < ~10
- » In combination with Oxygen, Temperature, resistivity etc...

Steel corrosion is the problem

- » Conversion to iron oxide which occupies 4-10 times the volume
- » Internal pressure builds up, results in cracking and spalling of concrete
- » Loss of strength, weakening of the concrete faster deterioration, up to failure





Corrosion:

There is no perfect Solution. We are still Learning.

Why does Corrosion Occur?



What Can We Do?



RUST

THE SEASONAL APOCALYPSE
HAS ARRIVED

ARE YOU PREPARED?



Corrosion Management

Essential element of sustainable strategy

Sustainability

Corrosion Management of Concrete Construction

Economy



Provide return
on investments

Environment



Protects
resources

**Social
Responsibility**



Saves Lives



Anode

- Concrete Permeability
 - W/CM, Pozzolans, Chemical Additions
 - Membrane, Silane
- Corrosion Threshold
 - Inhibitor
 - Change Metal (i.e. Stainless)
- Reduce Reactive Surface
 - Coatings
- Reduce Corrosion Rate
 - Dry Out Concrete
- Force Opposite Reaction
 - Cathodic Protection

Cathode

- Reduce Area of Reactive Surface
 - Coatings
- Dry Concrete
- Reduce Oxygen
- Reduce Cathode Effectiveness
 - Inhibitors
- Cathodic Protection



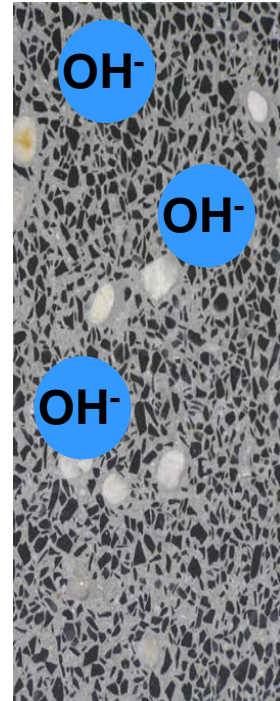
RUST

Electrical Continuity

- Disconnect Anode & Cathode
- Electrical Separation of Bars
 - Coatings

Ionic Path

- Higher Resistivity
 - Lower W/CM
 - Dry Concrete
 - SCM





Corrosion Prevention/Mitigation Strategies

“Breaking the Chain”

Mechanical/Physical

- Remove/Replace
- Barrier
- Chloride Extraction
- Alternative Materials



Electrical

- Cathodic Protection

Chemical

- Admixtures
- Surface Applied Corrosion Inhibitors





Products for Concrete Corrosion Prevention and Mitigation

include:



Concrete Quality

- » Admixtures
- » Alternative Reinforcement



Steel applied Protection

- » Coatings
- » Active Primers



Surface applied Protection

- » Coatings
- » Impregnations



Concrete Replacement

- » Repair Mortars
- » Fairing Coats



Concrete Strengthening

- » Fiber reinforced Coatings
- » Pile Encapsulation

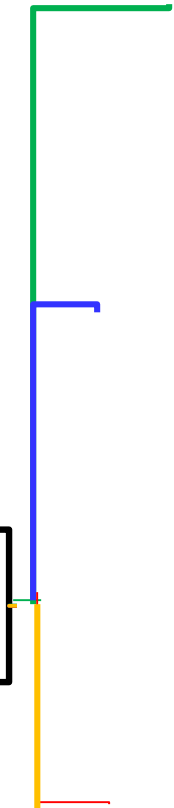


Electrochemical Protection

- » Sacrificial Anodes
- » Surface applied C. I.



**Corrosion Control
Technologies**



-



Non-Corrosive Reinforcement

- Stainless steel, FRP bar and specialty alloys
- Galvanized steel
- Epoxy coated steel
- Fiber reinforced polymer



PRO

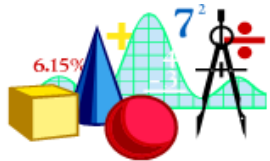
- Permanent
- Eliminates Corrosion

CON

- EXPENSIVE
- Design may be different
- Compatibility with conventional reinforcing?
- Pinholes on Epoxy Coated
- Bond on galvanized & epoxy & FRP

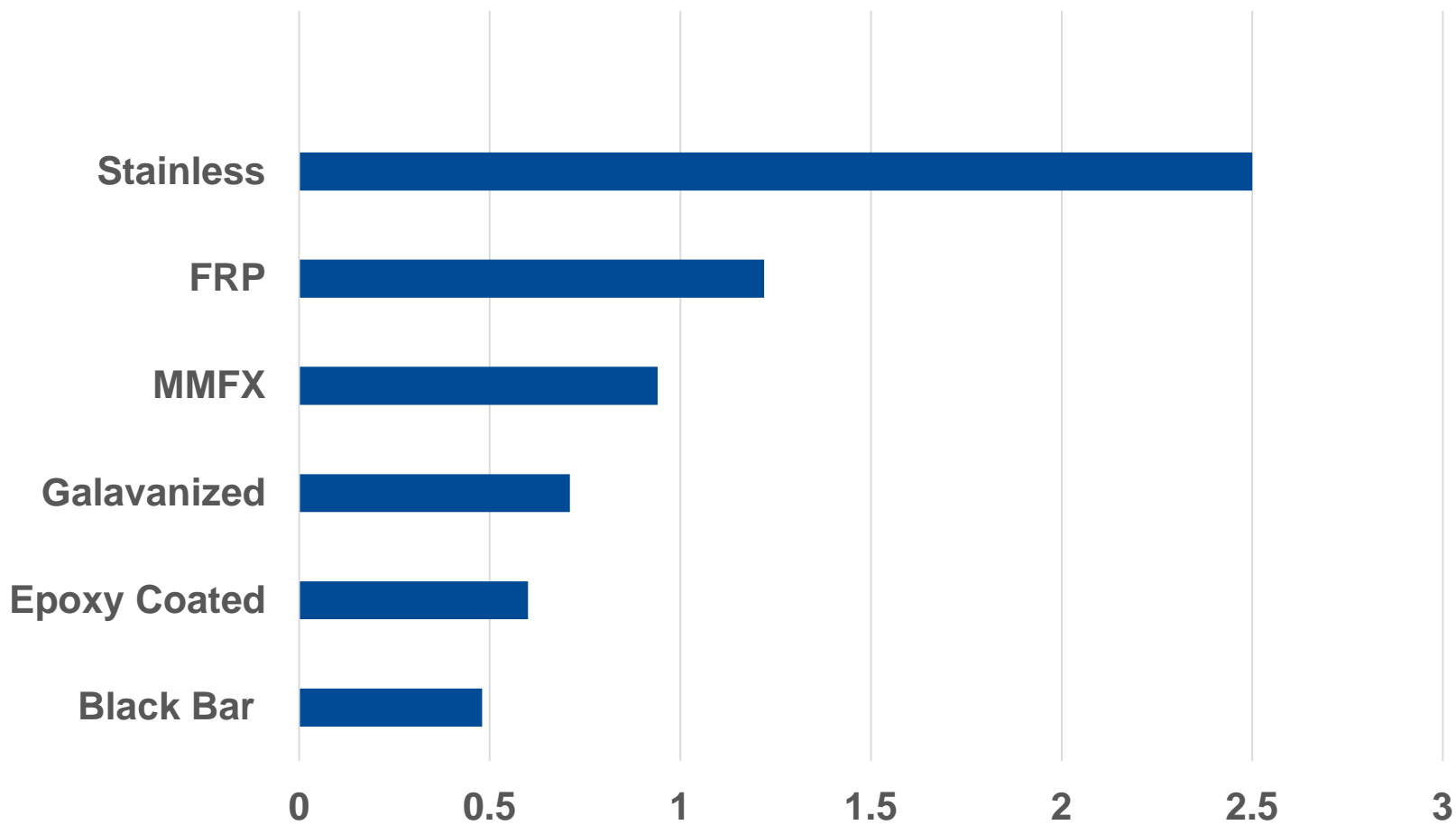


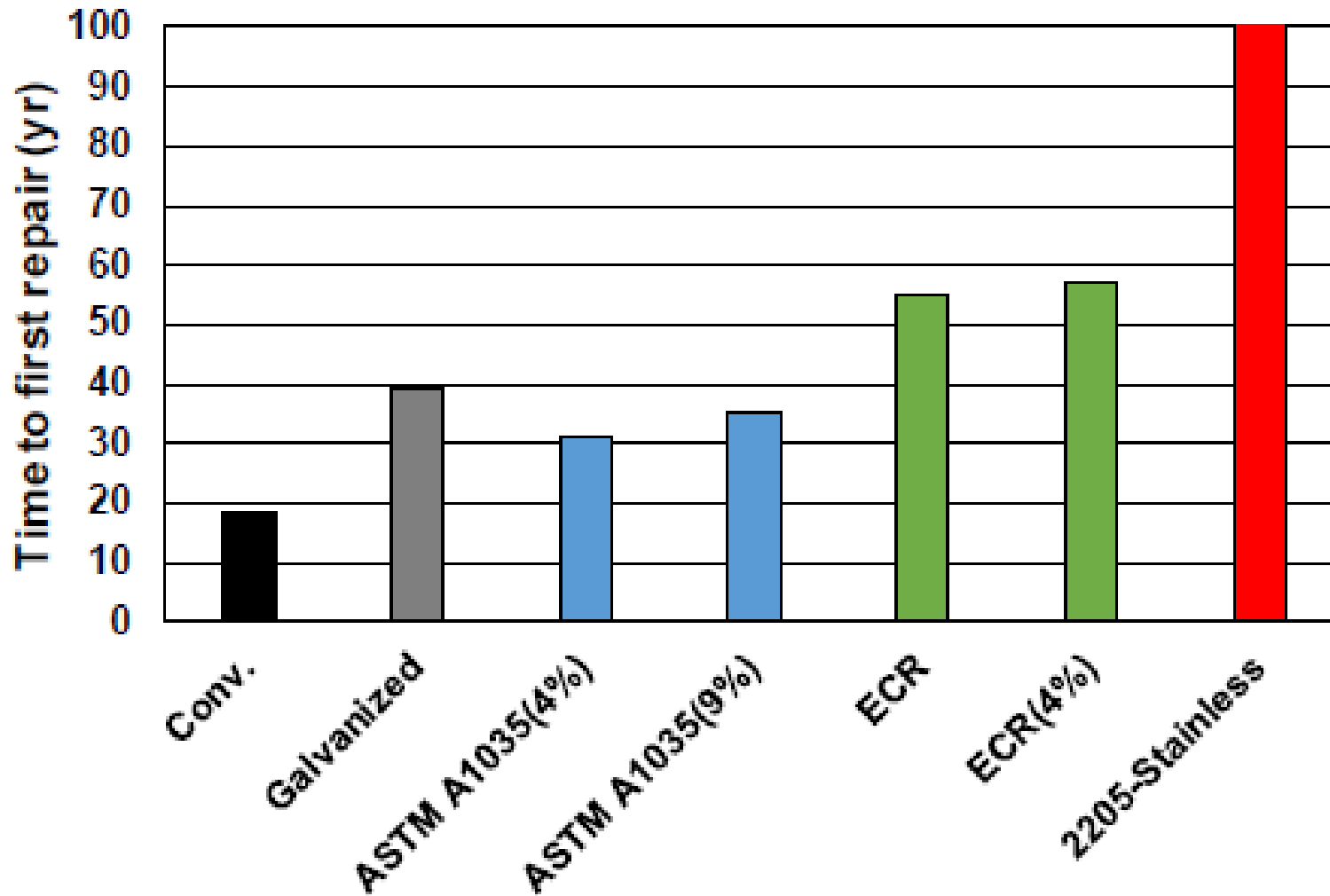
- Stainless
- Galvanized
- Epoxy Coated Bar
- FRP
- Bar
- Fabric
- Sheet



Design phase

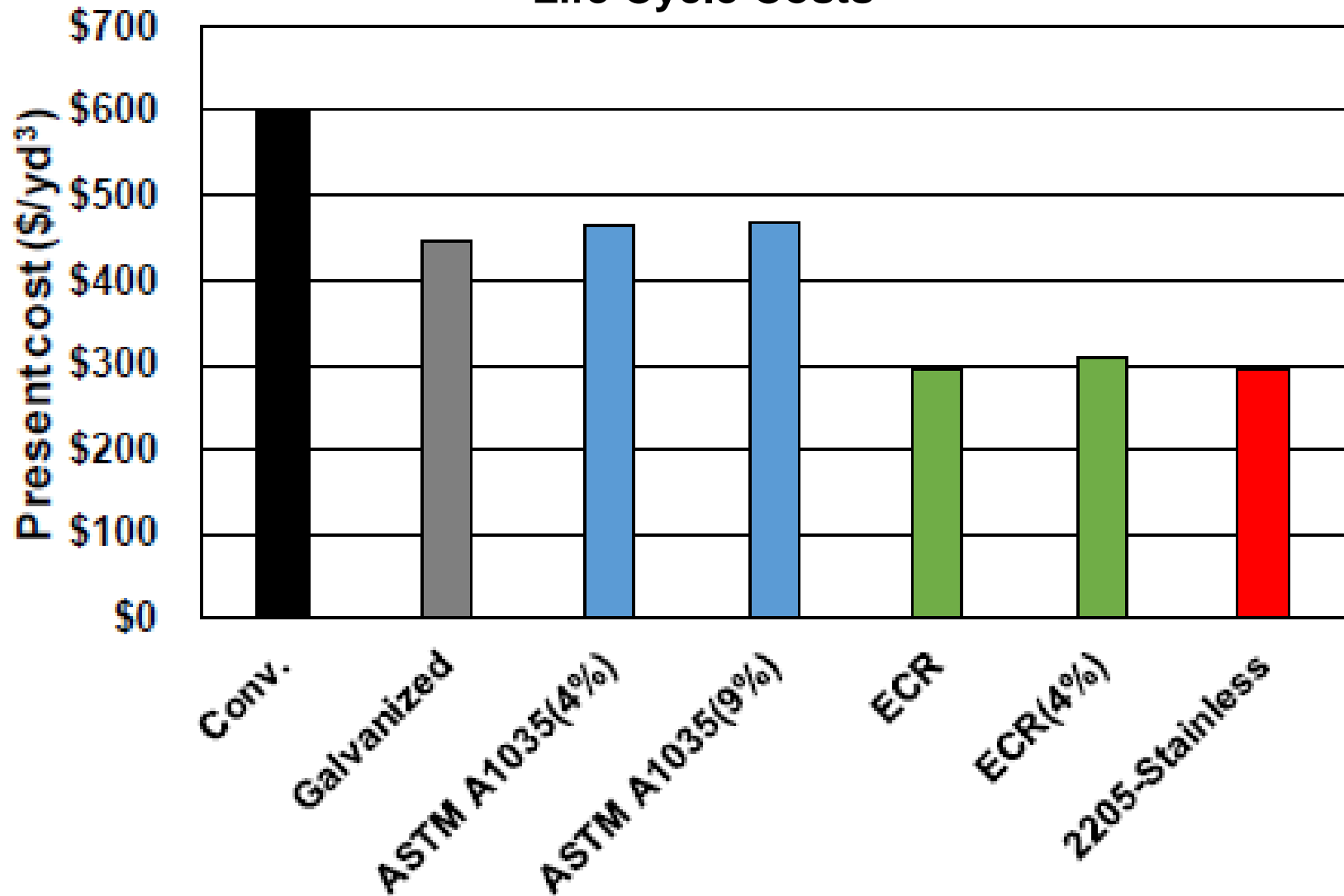
Alternative Reinforcement Relative Costs





ACI Webinar D. Darwin Corrosion Protection Systems for Reinforcing Steel
 Feb. 6, 2018

Life Cycle Costs



ACI Webinar D. Darwin Corrosion Protection Systems for Reinforcing Steel
Feb. 6, 2018



Admixtures

- E Adsorbed layer formers
- E Oxidizing inhibitors
- E Passivators
- E Conversion layer formers
- E Scavengers



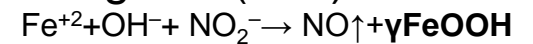
PRO

- Preventative
- Usage history
- Rebar Contact

CON

- May leach
- Dosage Verification
- Dispersion Verification
- Concentration Dependency
- Consumption during inhibition?
- Proprietary

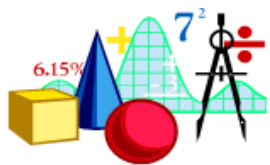
Inorganic (Nitrite)



Organic

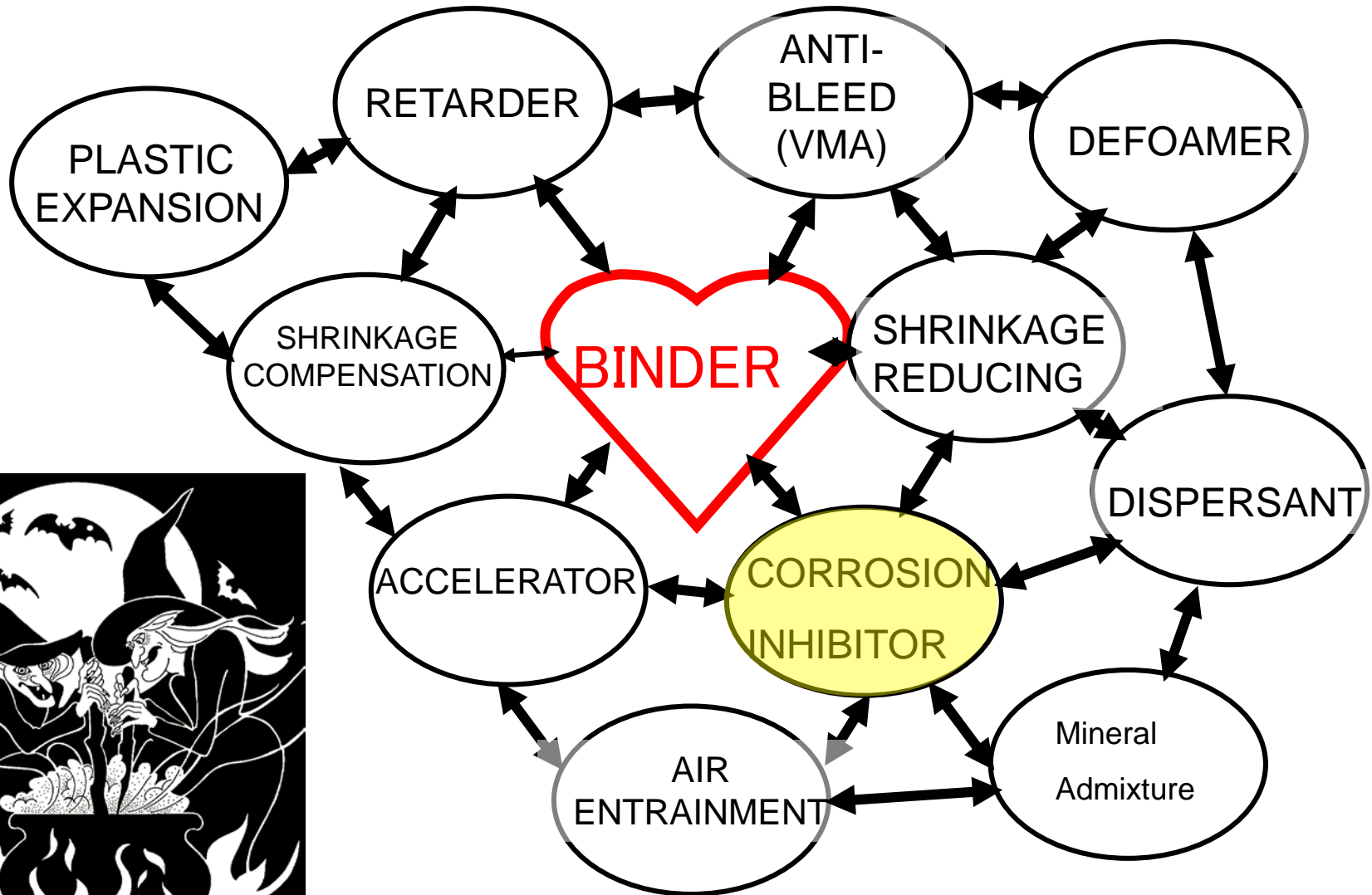
Anode and Cathode effects

Coat steel & decrease permeability



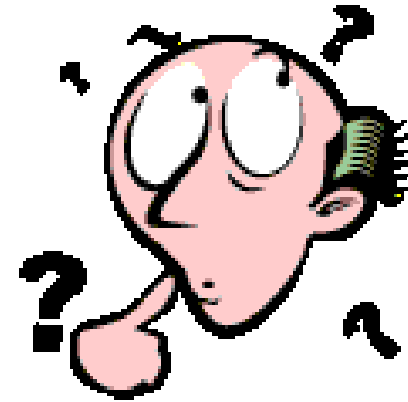
Design phase

WHAT Admixtures



WHAT Cementitious Binder Types

- OPC=Ordinary Portland Cement, Blended, & Performance-Based Hydraulic Cement
- HAC= High Alumina Cement
- AAP=Alkali Activated Pozzolan
- CSA=Calcium Sulfoaluminate Cement
- Polymer Cement = Polymer (Latex) Modifier + binder
- MagPhos=Magnesium Ammonium Phosphate
- Gypsum=Calcium Sulfate



Increased Cover

Repair mortars, Concrete
Anti-carbonation coatings

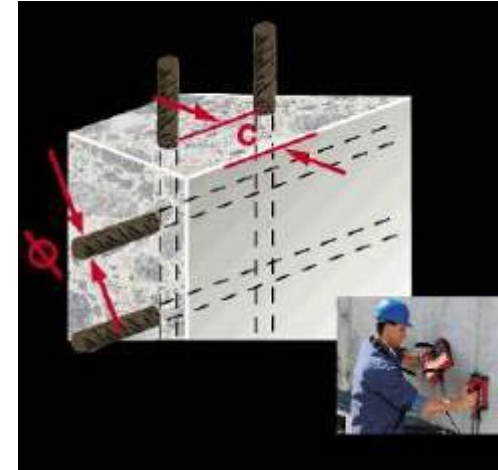
PROTECTION

PRO

- Renewable
- Inexpensive
- Possible to Enhance Appearance

CON

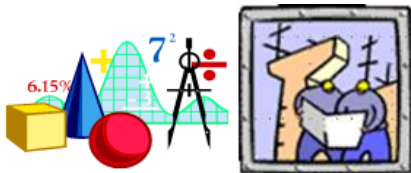
- Consumable (coatings)
- Section thickness increase (cover)
- Load increase
- Defects may magnify issues
- Detail and Inspection Intensive



[Wall Coating Products](#)

[Structural Repair](#)

[Shotcrete](#)



Design & Construction phase



PRO

- Aesthetic Appearance
- Relatively Inexpensive
- Recoatable & Repairable

CON

- May Need Dry Substrate
- Surface Preparation
- Maintenance
- Abrasion & CTE
- Snow Removal
- Impermeable Trap Moisture



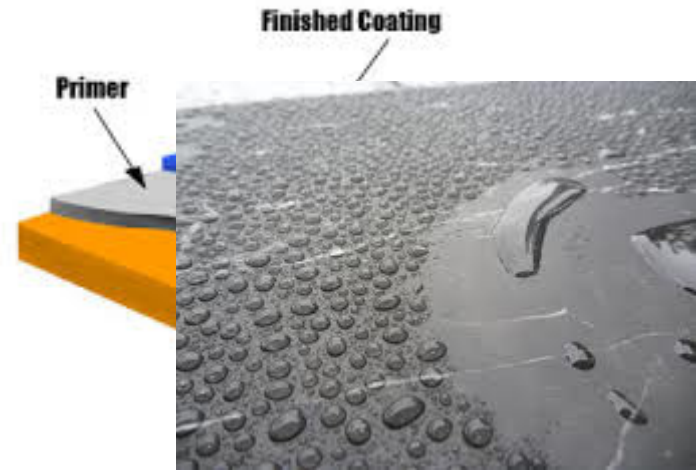
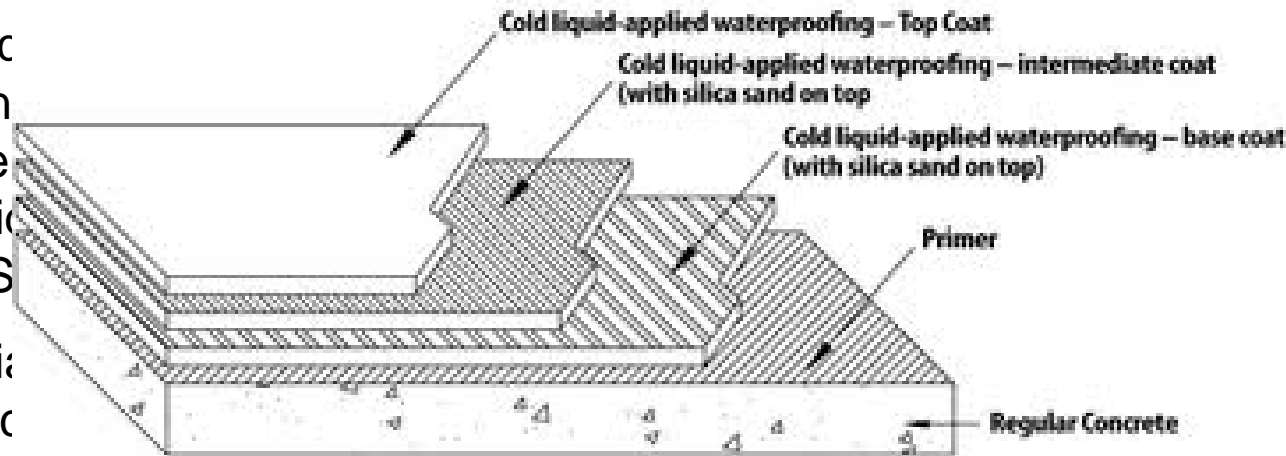
[Deck Membrane Products](#)
[Resinous Flooring](#)

- **Paint** Any pigmented liquid designed for application converted to an opaque protective film for protection, decoration, or other functional purposes (SSPC)

- **Coating** A liquid, liquefiable material that cures to a solid protective, decorative, or functional film by application as a thin layer (usually >5 mils dry) (SSPC)

- **Penetrating Sealer** A material that has the ability to penetrate and seal the surface to which it is applied to either prevent the penetration of liquid or gaseous media (after IC)

- **Membrane** A protective surface treatment with a thickness greater than 30 mils (0.75 mm) and less than 250 mils (6 mm) applied to the surface of concrete



Reinforcement Coatings

E Epoxy
E Cement/epoxy hybrid
E Cement latex
E Zinc based

PROTECTION

PRO

- Field application
- Low cost
- Mature technology
- Some claim bonding agents

CON

- Pinholes & Under-bar
- Bond to Concrete Window?
- Continuity of Coating
- Hardening Depending on Environment
- Incipient Anode



Rebar/Corrosion Protection



Repair Phase

Penetrating Sealers

- Silane
- Siloxane
- Siliconate
- Others



PRO

- Renewable
- Inexpensive
- No Appearance
- Easy to apply
- Hydrophobization

CON

- Consumable
- Maintenance
- Effectiveness Monitoring
- High Hydrostatic
- Crack Bridging
- Solvent?
- Overspray



Maintenance & Repair Phases

Water Repellents



SACI

- Amino alcohol
- Amino carboxylate
- Silicate
- Aminofunctional silanes
- Nitrites



PRO

- Renewable
- Inexpensive
- No Appearance
- Easy to apply

CON

- Inhibition, not solving
- Effectiveness monitoring
- Penetration
- Residue
- Volatility
- Many technologies
- Life cycle
- Product compatibility



Maintenance & Repair Phases

SACI

Galvanic Anodes

- “Hockey Pucks”
- Hydrogel
- Arc Spray
- Imbedded mesh
- Hybrid



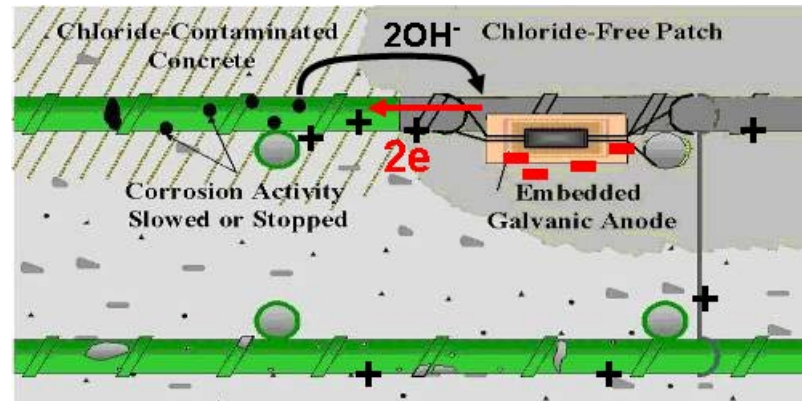
- Point source or general protection
- Follow corrosion activity (i.e. RH-Temp)
- Effectiveness monitoring
- Ring / incipient anode
- Self powered

CON

- Consumable
- Passivation?
- Excavation
- Oxidation buildup

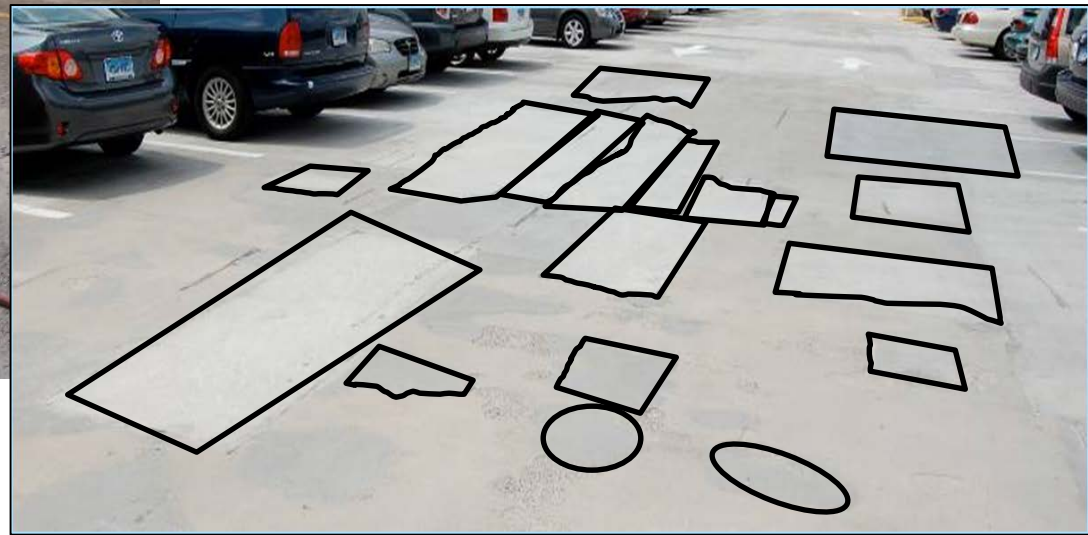
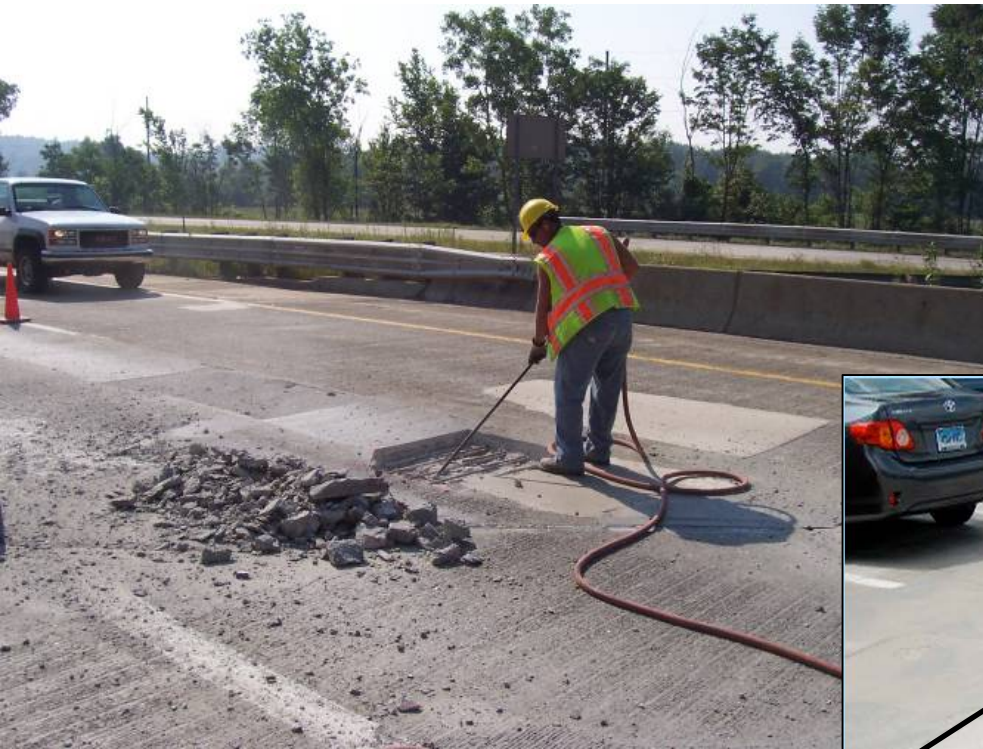


Construction & Repair Phases



Anodes

Example of NOT breaking the chain



Fixing one patch causes the surrounding concrete to act like an *incipient anode*. This is also called “Halo Effect” or “Ring Anode Effect”

Galvanic Anodes – How They Work

Host concrete, high chloride content

Repair Area, chloride-free

Cathode +

electron flow

ion flow (OH)

Electrolyte

Anode -

At the Cathode:

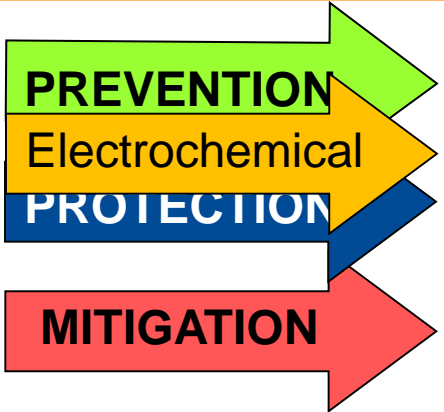
- Excess electrons are consumed in a series of reactions within the electrolyte
- No physical change in the structure of the steel takes place

- Corrosion does not occur at

At the Anode:

- Zinc dissolves into the electrolyte as positively charged ions
- physical effects of corrosion seen here
- metal loses mass and form

Impressed Current

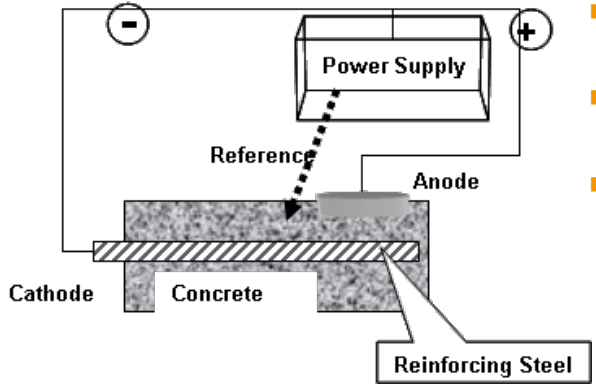


PRO

- ICCP Proven to Prevent
- Usage History
- Various Systems

CON

- Expensive
- Design and maintenance critical
- Reinforcement continuity
- Anode acidification
- May cause AAR
- H₂ Generation?
- Appearance?



Design, Construction, & Repair Phases



Good Trade Practices

- DDAS with design
- Low W/CM
- Satisfactory Material Quality
- Enough Binder for Strength
- Consistency for Consolidation
- Enough Cover
- Sufficiently Cured...

Keep the Water Out!



It's not so much about letting it go as submitting to the inevitable

Concrete Maintenance

- Verify
- Inspect
- Fix cracks
- Keep the Water Out!

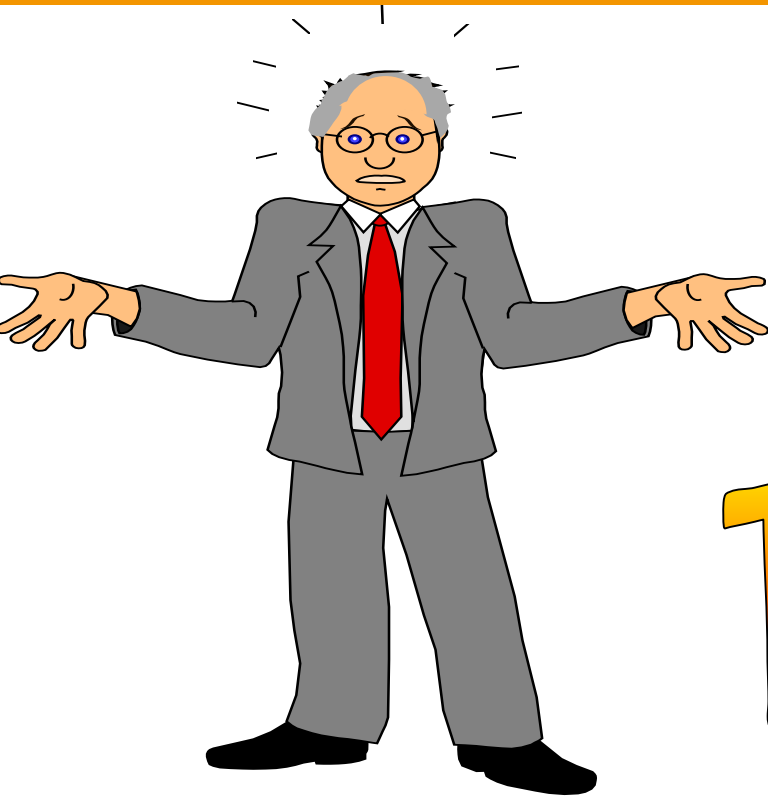
Don't Delay, Problems **GROW**

© DESPAIR.COM



MISTAKES

IT COULD BE THAT THE PURPOSE OF YOUR LIFE IS
ONLY TO SERVE AS A WARNING TO OTHERS.



Questions



THANK YOU!

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I-Wen (Evan) Huang, Corrosion Scientist

BASF Construction Chemicals, EB-N