Saudi Concrete Conference

# Durability of Concrete in Existing Structures

*Causes of Deterioration and*
*Assessing Damage*

Glenn Schaefer (STRUCTURAL TECHNOLOGIES
Jacques Marchand, Ph.D. (SIMCO)

# Agenda

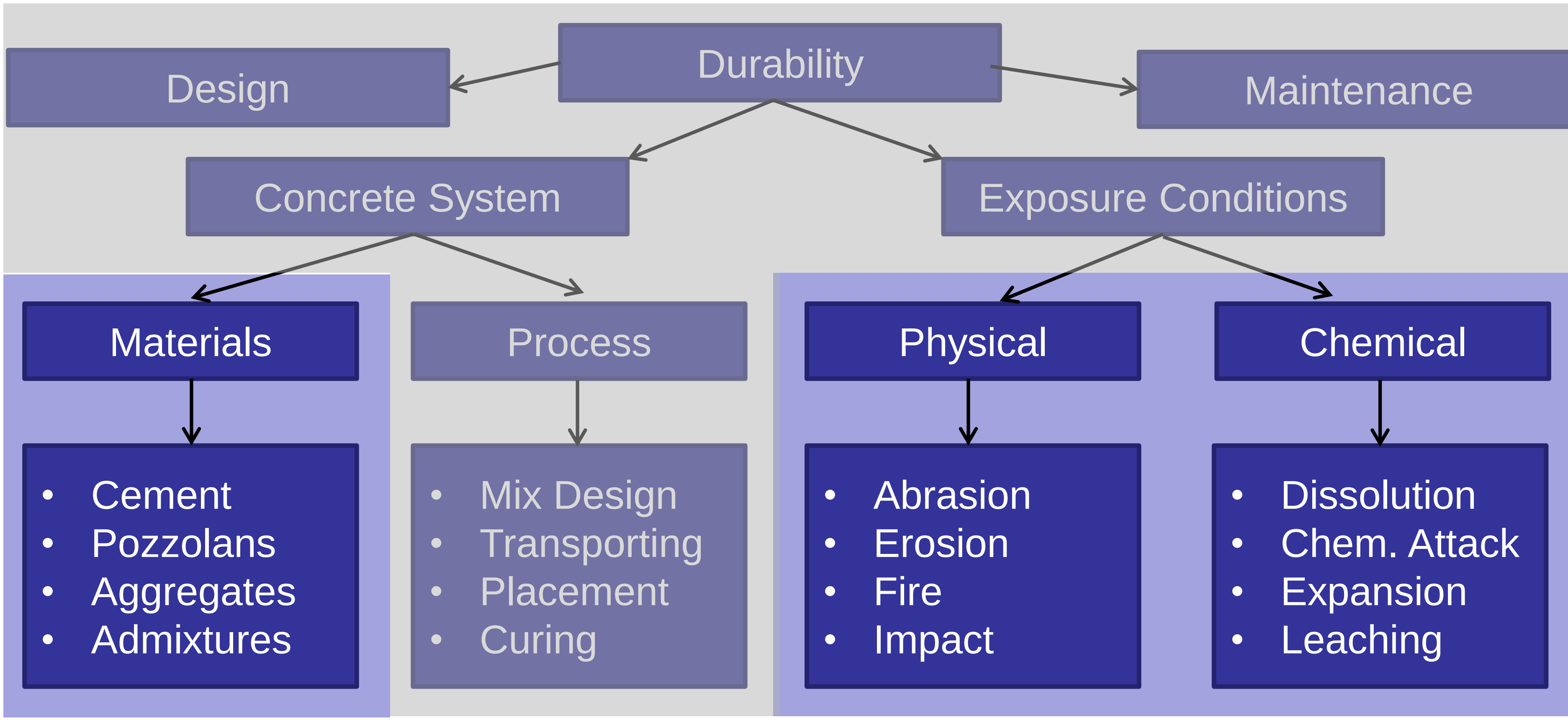
- How and why does concrete deteriorate/degrade?
- Exposure and mechanisms
- Cause / effect
- What do the issues look like?
- Evaluate and quantify
- Questions / comments

# Durability

- American Concrete Institute: “The ability of a [concrete] to resist weathering action, chemical attack, abrasion, and other conditions of service.”

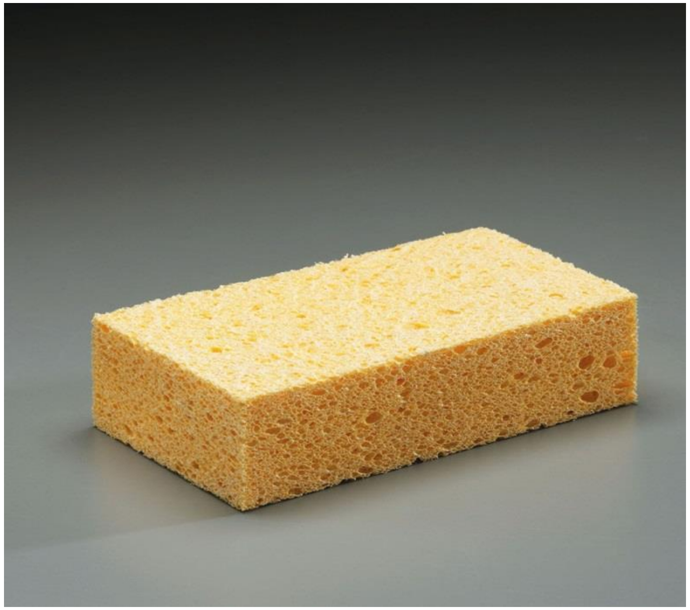
- “Ability” is influenced by materials, exposure, design, construction, and maintenance

# Durability


Durability
Design
Maintenance
Concrete System
Exposure Conditions
Materials
Process
Physical
Chemical
Cement
Pozzolans
Aggregates
Admixtures
Mix Design
Transporting
Placement
Curing
Abrasion
Erosion
Fire
Impact
Dissolution
Chem. Attack
Expansion
Leaching

# Factors Affecting Durability

- Permeability/porosity/diffusion
- Cracking
- Protective treatments



**Many of the deterioration mechanism are influenced by how easy or hard it is for ions and moisture to get into the concrete**

# Concrete Deterioration = Non-Durable

- **Defects**
  - Design, materials, construction
- **Damage**
  - Overload, fire, impact, chemical spill
- **Degradation**
  - Metal corrosion, erosion, sulfate attack, freeze/thaw

**Defects often lead to longer term degradation**

# ACI 201.2 – Guide to Durable Concrete

- Freeze/Thaw

- Aggressive Chemical Exposure
  - Acid attack
  - Sulfate attack
  - Physical salt attack
  - Seawater
  - Carbonation

- Shrinkage and Cracking

- Abrasion

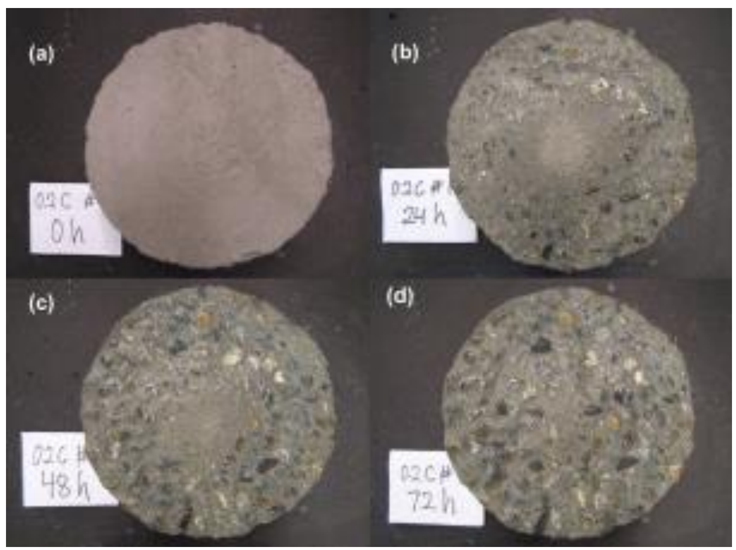
- Embedded metal corrosion

- Chemical reactions of aggregates (aggregate reactivity)

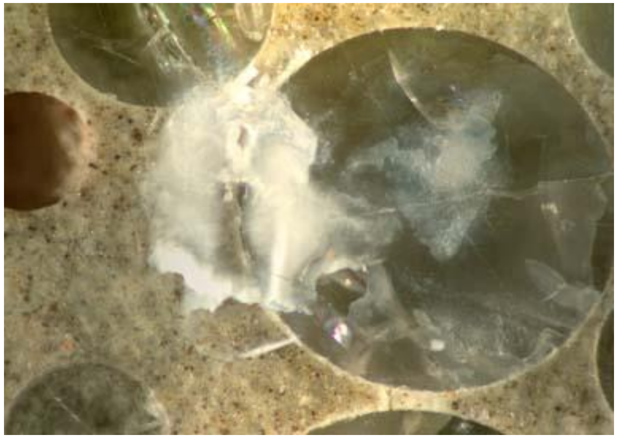
# Freeze/Thaw Degradation

# Abrasion Exposure

- Wearing away of the surface by rubbing or friction
- Mechanical stresses to the concrete surface
  - Traffic
  - Sliding materials (waste transfer station)
  - Erosion in water structures via impact of floating materials
  - Cavitation in water structures



# Alkali Aggregate Reactivity (AAR)



# Alkali Aggregate Reactivity (AAR)

- Alkali-silica reaction (ASR)
  - More common of the two
  - Siliceous minerals react with alkali forming a gel which swells

- Alkali-carbonate reaction (ACR)
  - Breakdown of dolomite and crystallization of brucite is expansive
  - ACR is relatively rare because aggregates susceptible to this generally have other issues making them more unsuitable for concrete

- <u>Assessment:</u> very visual (pattern cracking) and confirmed with petrography

- Repair: difficult – can't remove aggregates.
  Eliminate alkalis and moisture.

# Aggressive Chemical Exposure

- Concrete is rarely, if ever, attacked by solid, dry chemicals.
  - To produce a significant attack on concrete, a solution is usually required.
  - Several mechanisms – generally result is removal / destruction of the paste matrix.

- Dissolving reactions (removes the paste matrix)
  - Acid attack – dissolve cement paste and some aggregates

- Expansive reactions (disrupts the paste matrix)
  - Sulfate attack – soil/water sulfate reaction with hydration compounds to form an expansive by-product
  - Salt attack – salts dissolved in water ingress into concrete and re-crystallize (wet/dry)

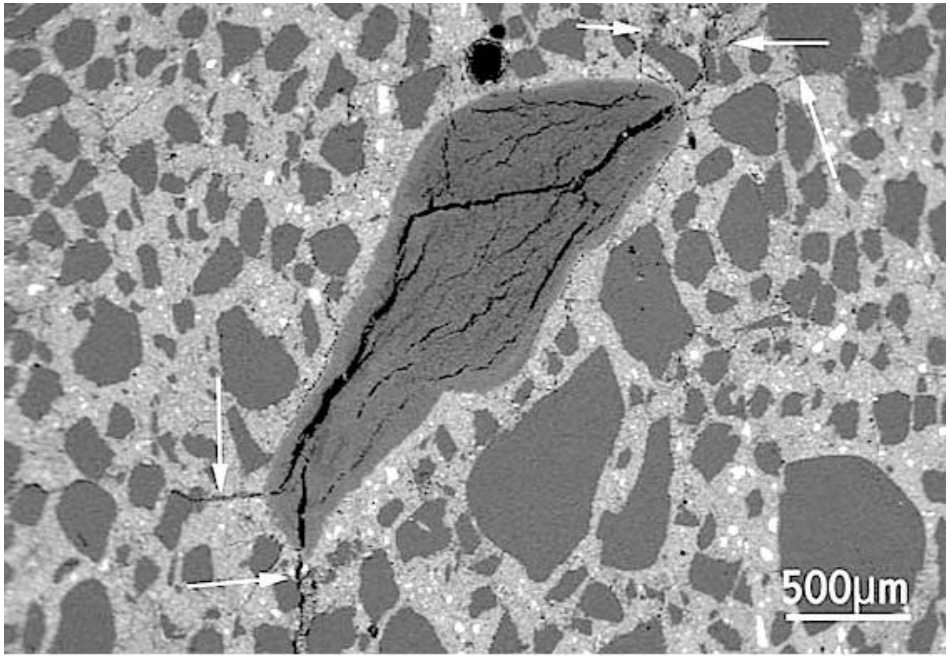
# Aggressive Chemical Exposure – Acidic

# Aggressive Chemical Exposure – Sulphur Pit

# Aggressive Chemical Exposure – Sulfate Attack

# Delayed Ettringite Formation (DEF)

- A form of <u>internal</u> sulfate attack.
- Factors such as concrete composition, curing conditions and exposure conditions influence the potential for DEF.



# Seawater Attack

- Unique because it combines a large number of durability challenges
- Most severe in tidal or splash zone (wet/dry)

- Deterioration mechanisms
  - Corrosion (chlorides, oxygen, moisture)
  - Sulfate attack

- Additional aspects
  - Alkali aggregate reactions
  - Abrasion/erosion
  - Freeze/thaw
  - Salt crystallization
  - Leaching

# Aggressive Chemical Exposure

- Assessment
  - Analysis of environment / exposure
  - Visual and/or petrographic examination
  - Chemical tests / XRF & XRD
    - Higher levels of sulfate
    - Chemical residue
  - Drill probes to assess extent and depth of damage

- Repair
  - Not just "replace in-kind"
  - Removal of suspect concrete
  - New concrete needs to be resistant to attack mechanism(s) and stable
  - Barriers of other protection can also be part of the solution

# Carbonation

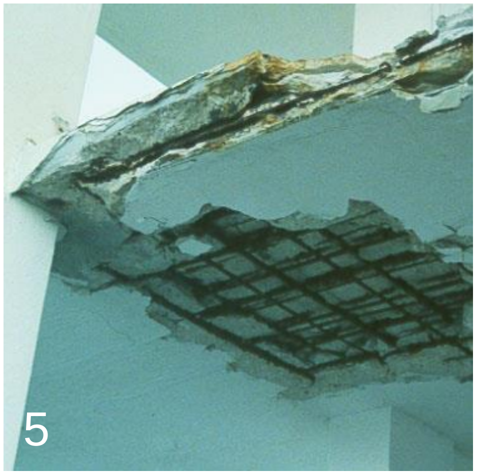
- Atmospheric Carbon Dioxide penetrates the concrete and reacts with hydration products
- Carbonated concrete has some relatively benign paste alteration
- More significantly is reduction in the pH
  - Impacts the passive layer around the steel which protects against corrosion.
- Rate of carbonation decreases with time
- Depth of carbonation can be easily determined in concrete with phenolphthalein solution test
  - Pink color indicate pH above 10

# Corrosion of Steel in Concrete

Corrosion is the #1 cause of concrete failure.

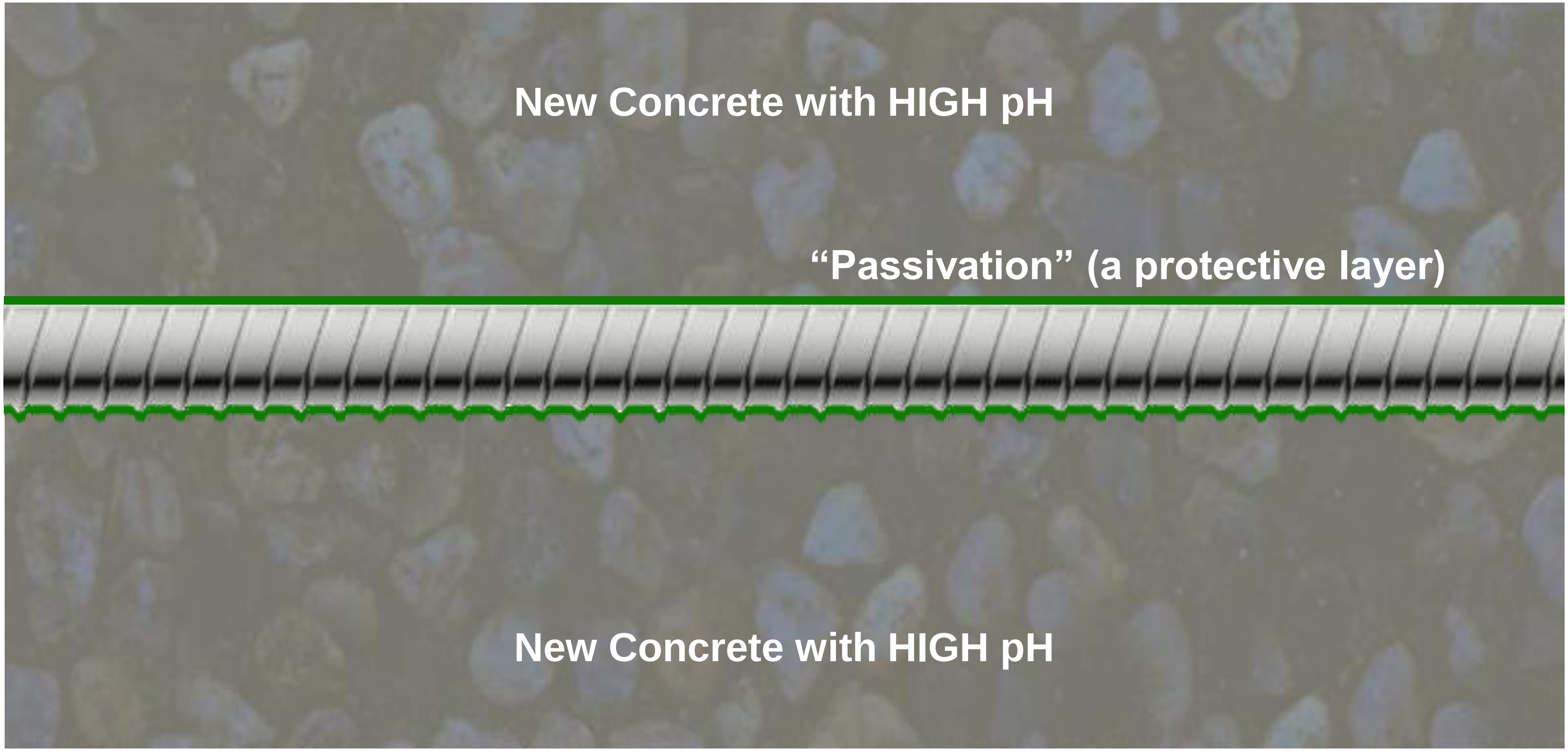



# Corrosion of Steel in Concrete





# Why "Good" Concrete Protects Against Corrosion



# Why Steel in Concrete Corrodes

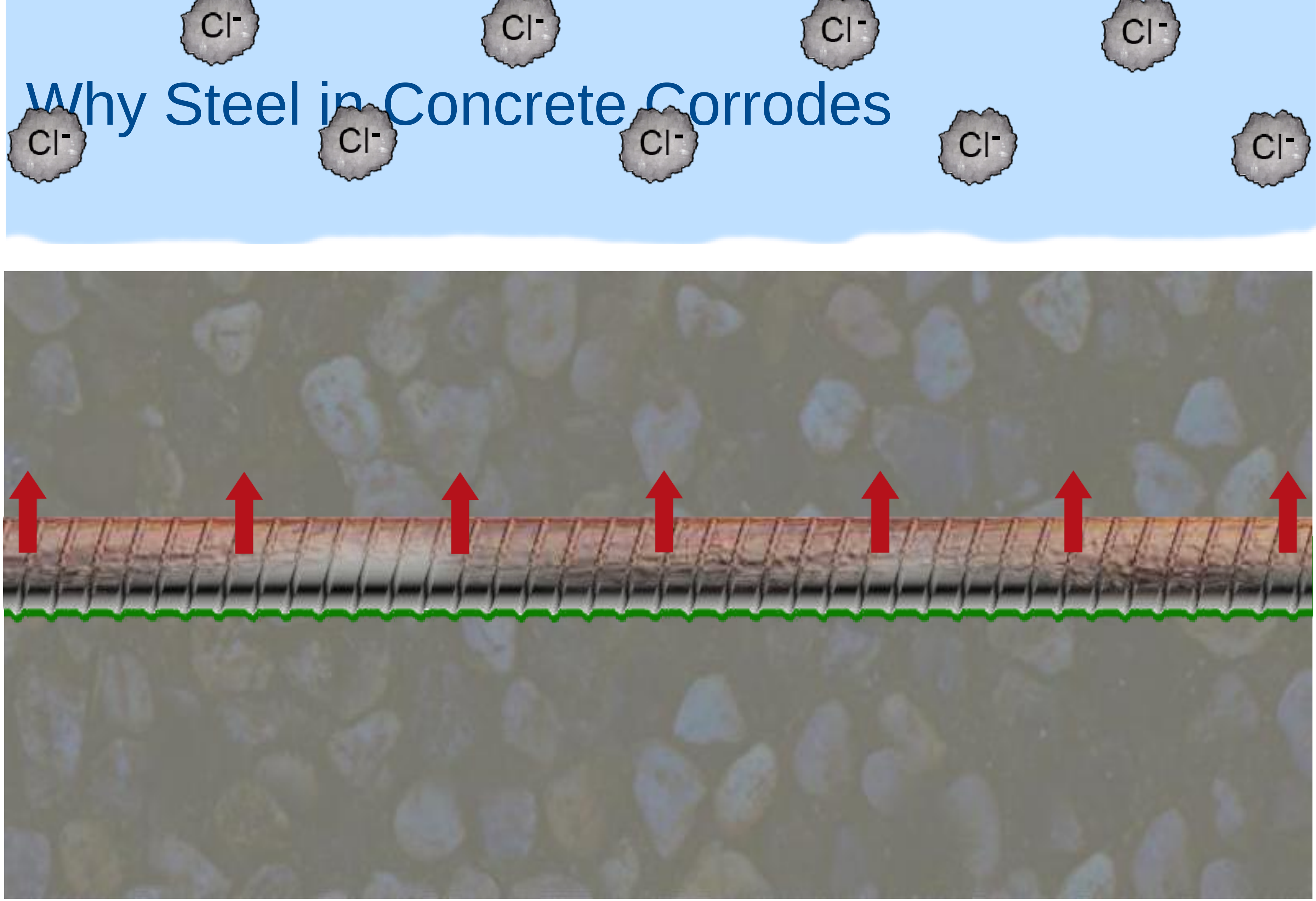
- **Passivation** = a protective layer that holds energy in, prevents steel from corroding.

- Two main disruptions to passivation:

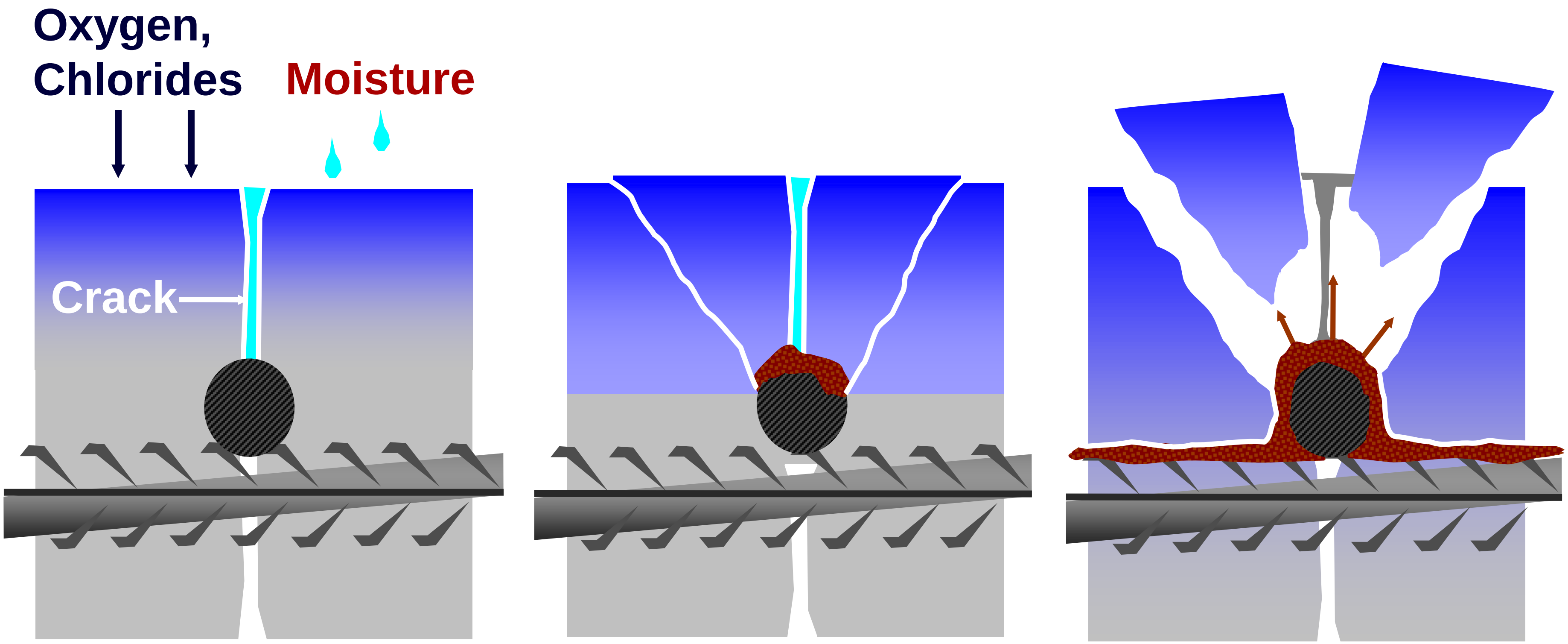
    - **Carbon Dioxide** ($CO_2$)

    - **Chlorides** (salts)

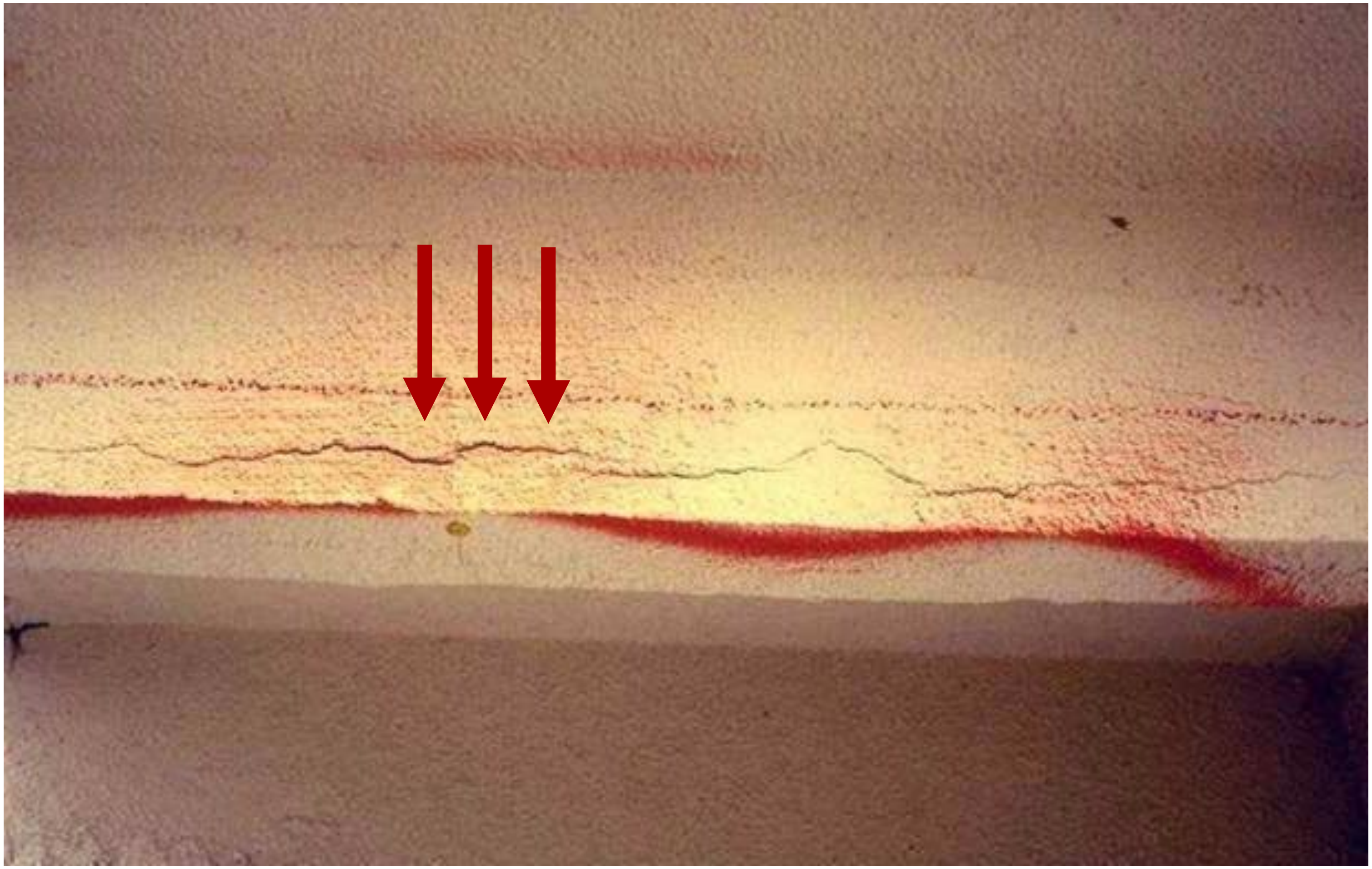
# Why Steel in Concrete Corrodes



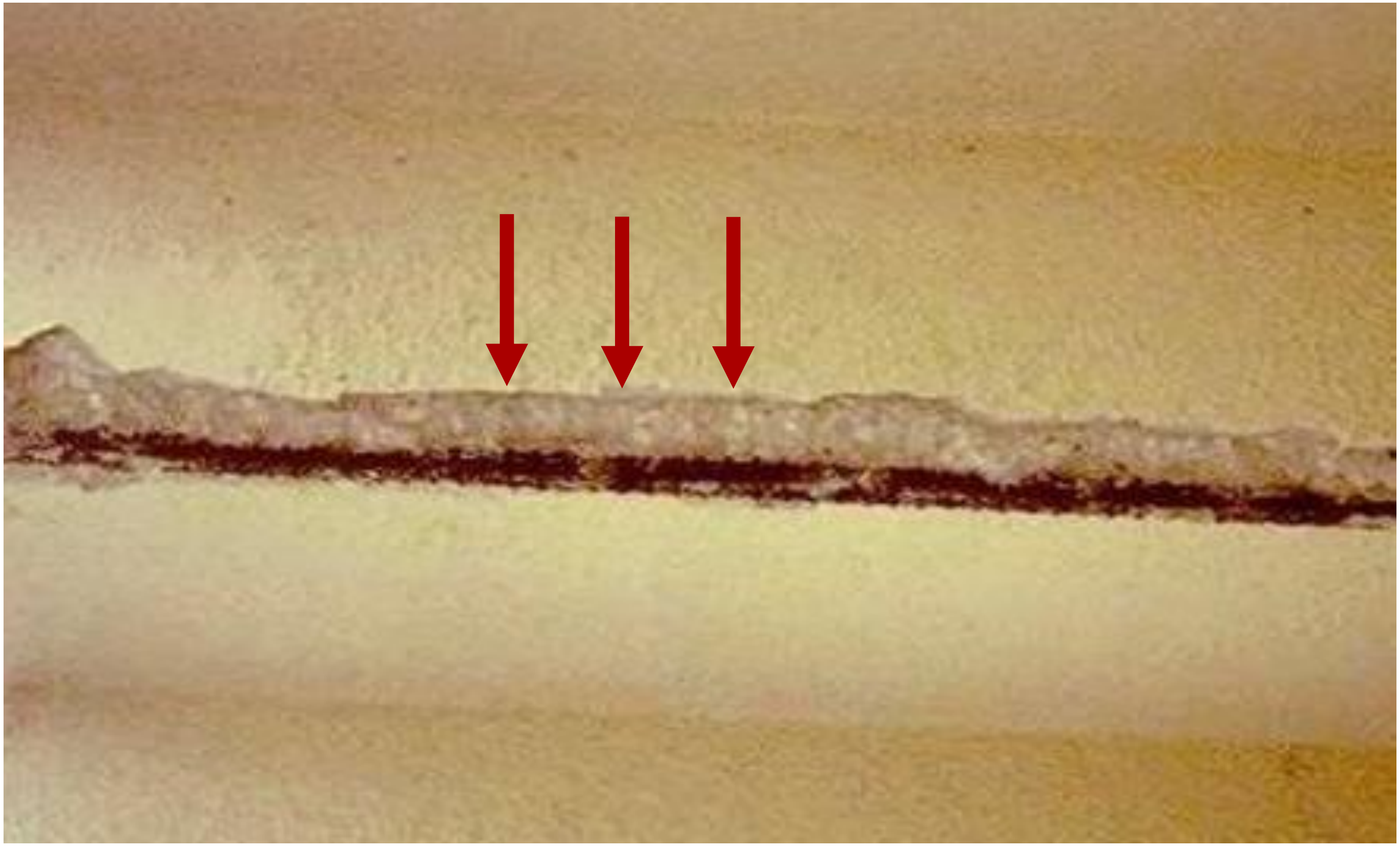
# Embedded Metal Corrosion



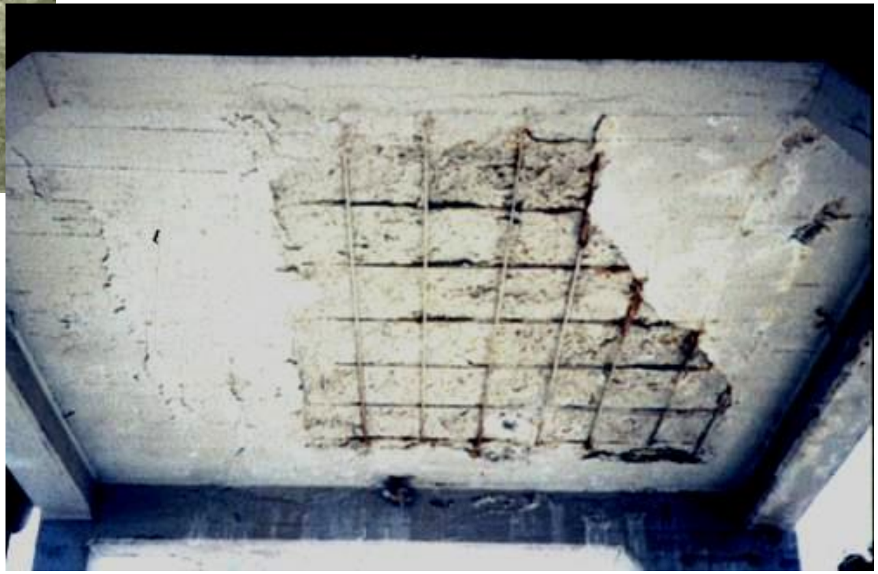
# Embedded Metal Corrosion



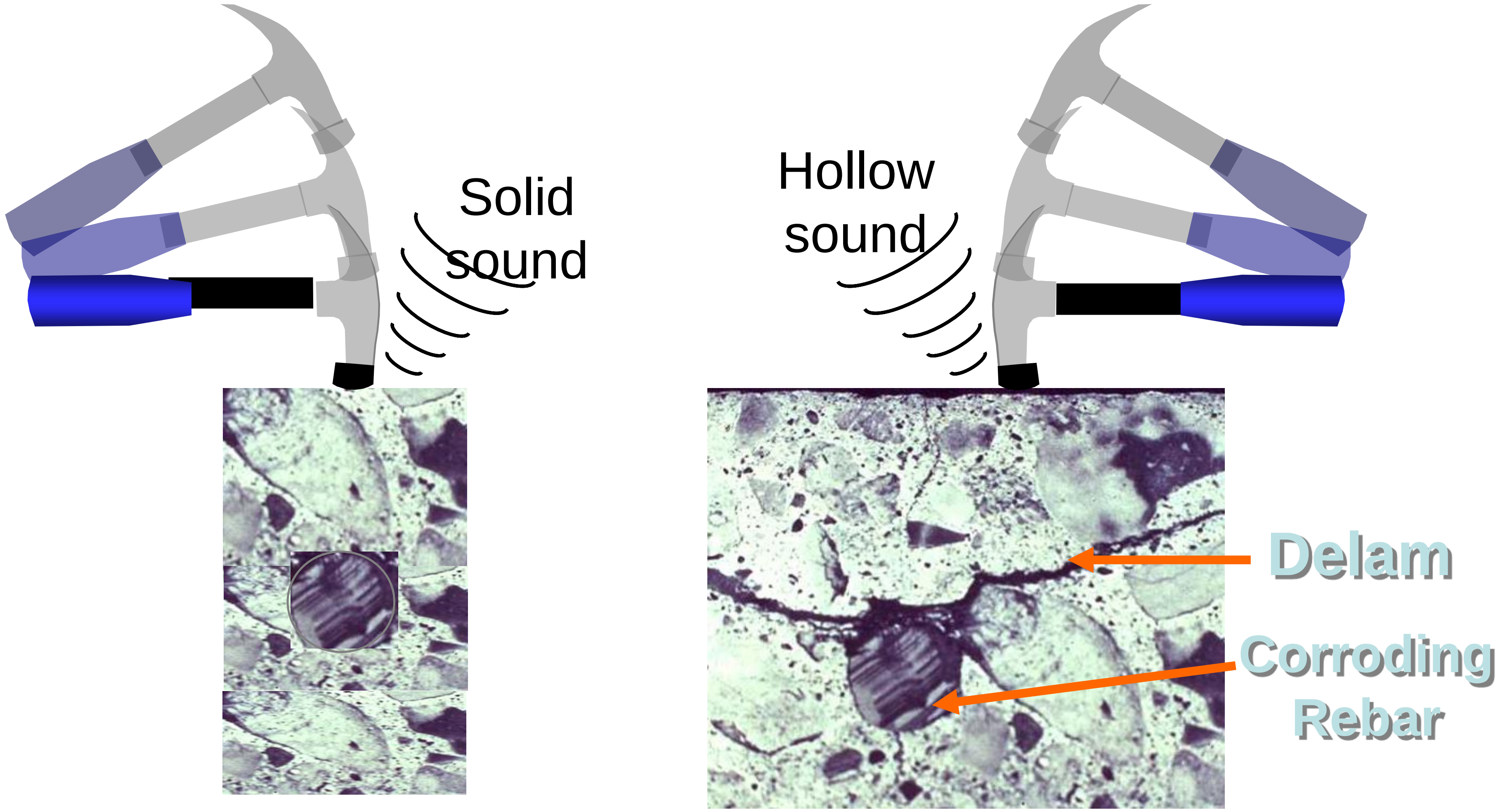
# Embedded Metal Corrosion



# Embedded Metal Corrosion



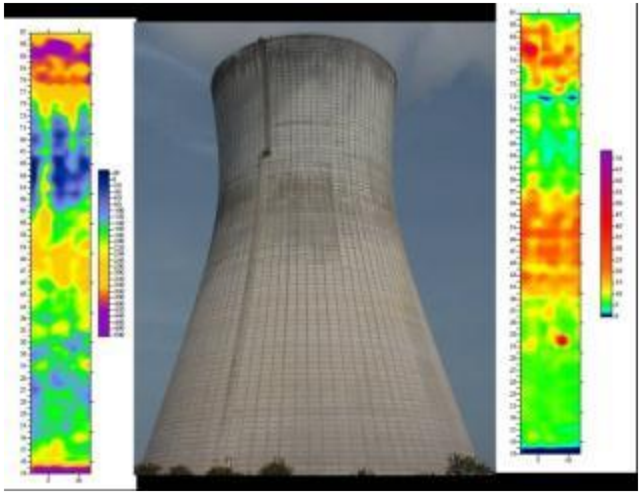
# Condition Assessment



# Corrosion Assessment

- Visual Inspections
- Chloride analysis
- Carbonation tests
- Concrete resistivity
- Corrosion potentials
- Corrosion rates

- Condition assessment
- Damage quantification
- Corrosion modeling – prognosis



# Verifying Steel Continuity

# Corrosion Assessment

- Potential Measurements
  - Portable reference cell
  - High input impedance voltmeter
  - Connection to the steel reinforcing
  - Follow ASTM C-876-09 Standard
    - Potential is > -0.2 V  90% probability there is no corrosion
    - Potential is between -0.2 and -0.35 V  uncertain
    - Potential is < -0.35 V 90% probability there is corrosion
  - Potential measurements affected by:
    - Electrical continuity
    - Oxygen availability
    - Temperature

# Condition Assessment

*Potential Mapping*

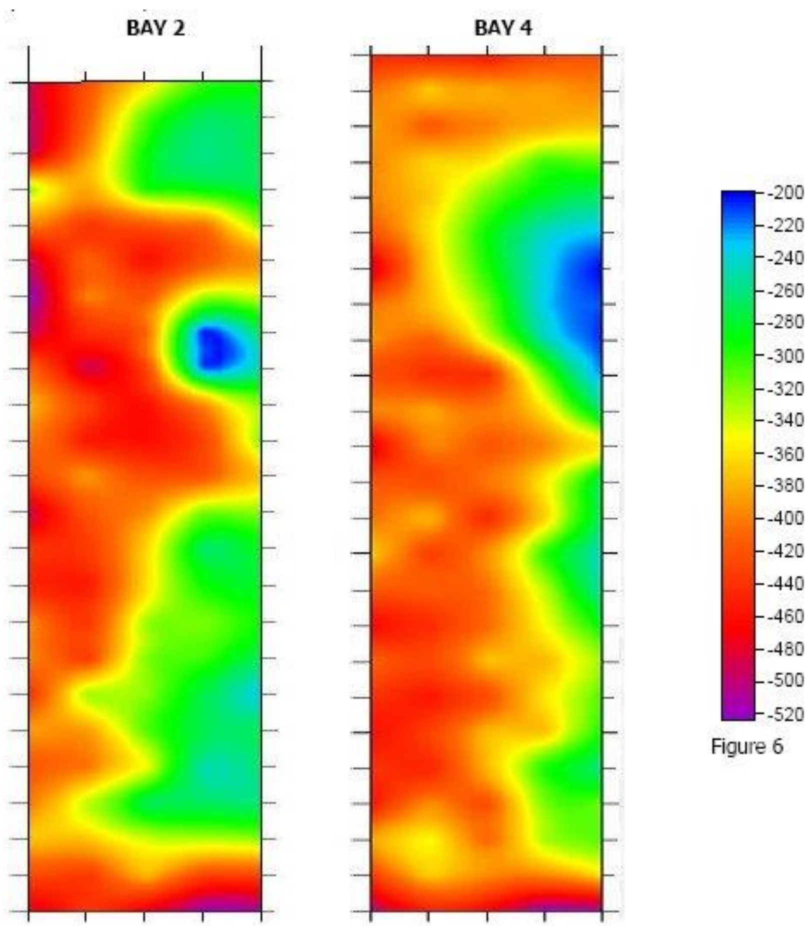
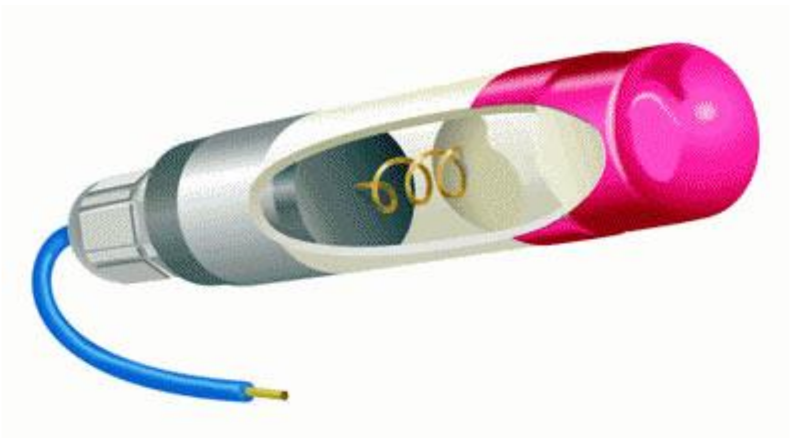
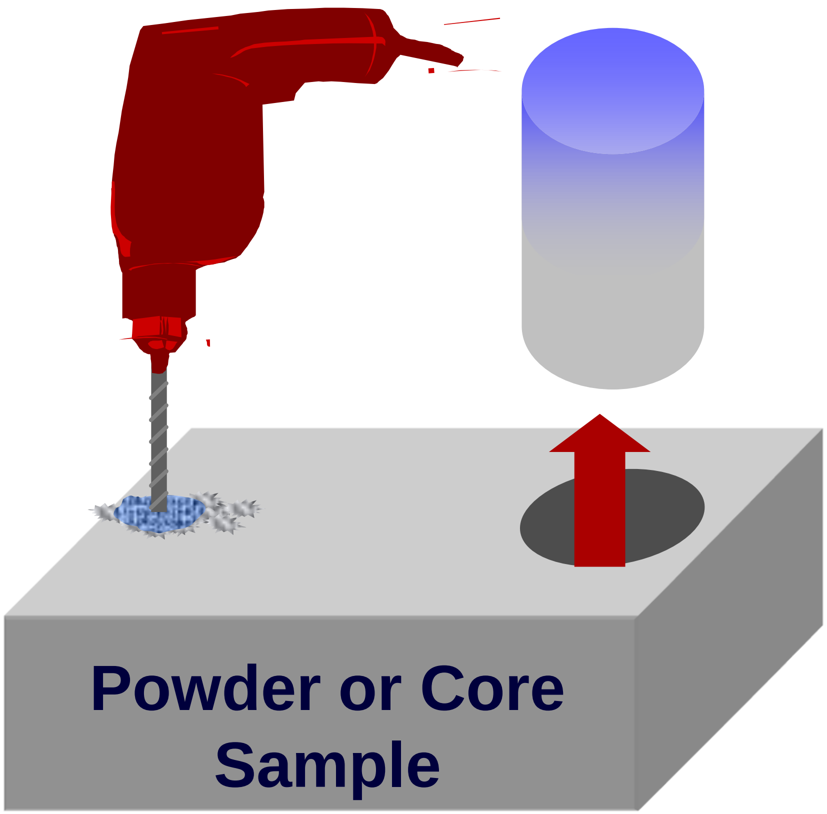



Figure 6



# Corrosion Assessment

- Depth of carbonation
- Measuring chlorides – depth and %

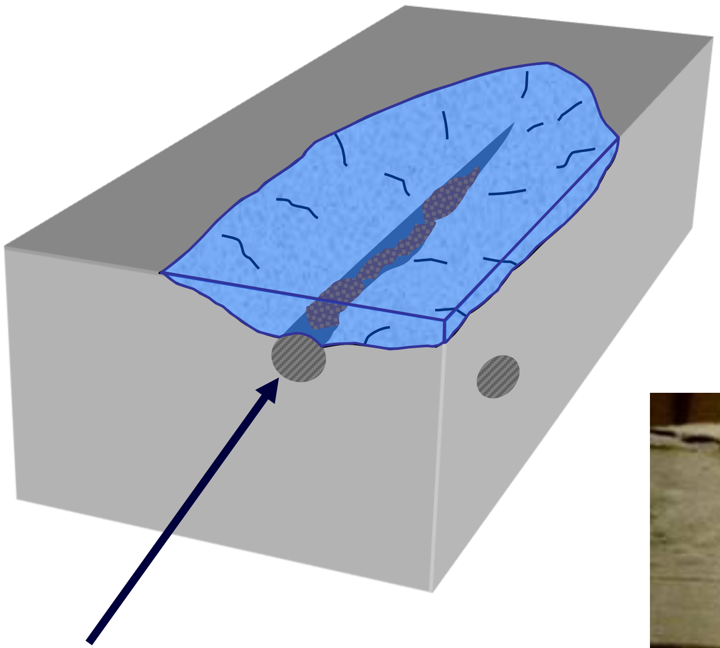




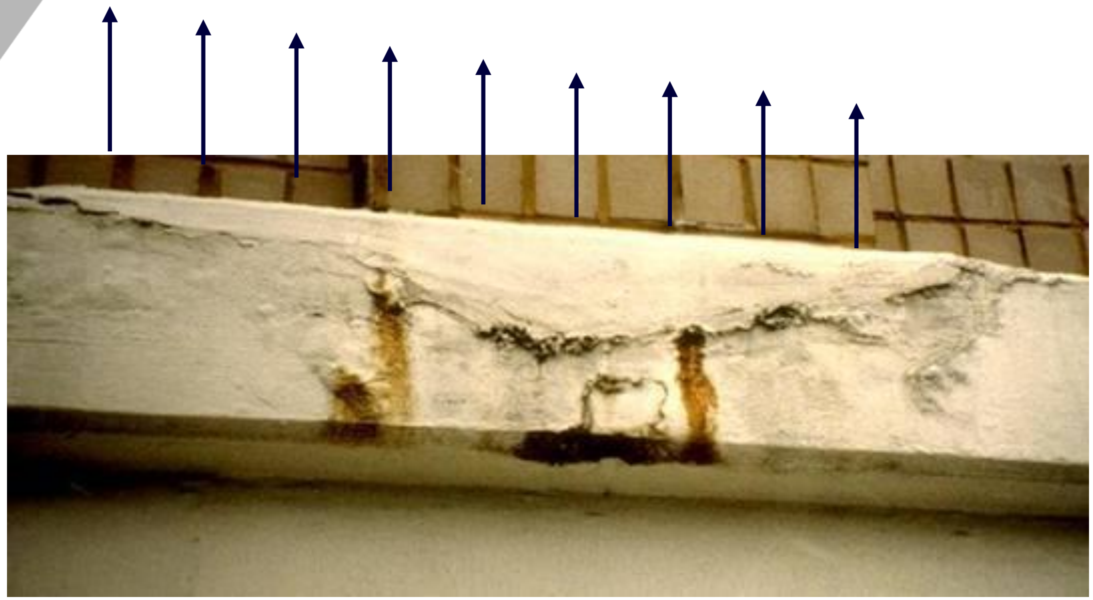
Forensic Investigation

# Surface Repair

- Improper surface preparation

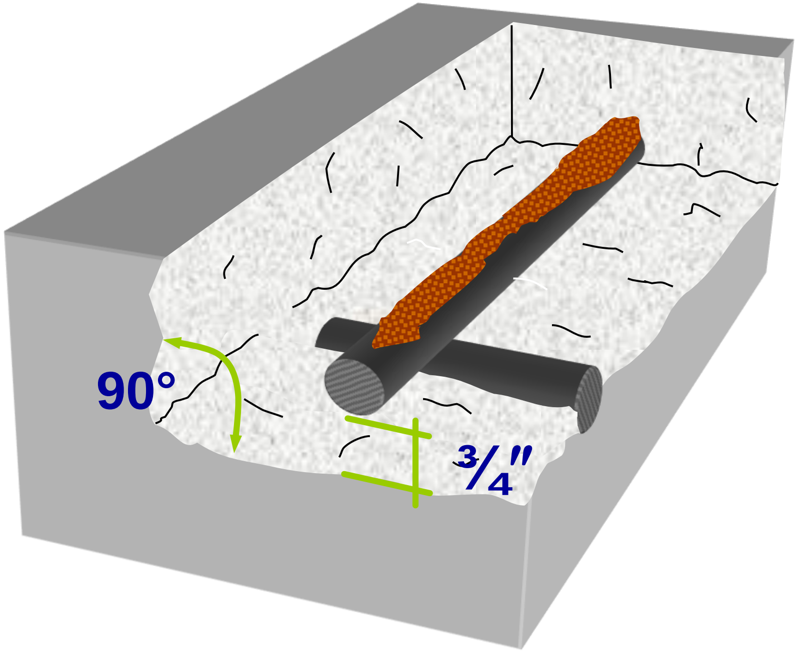


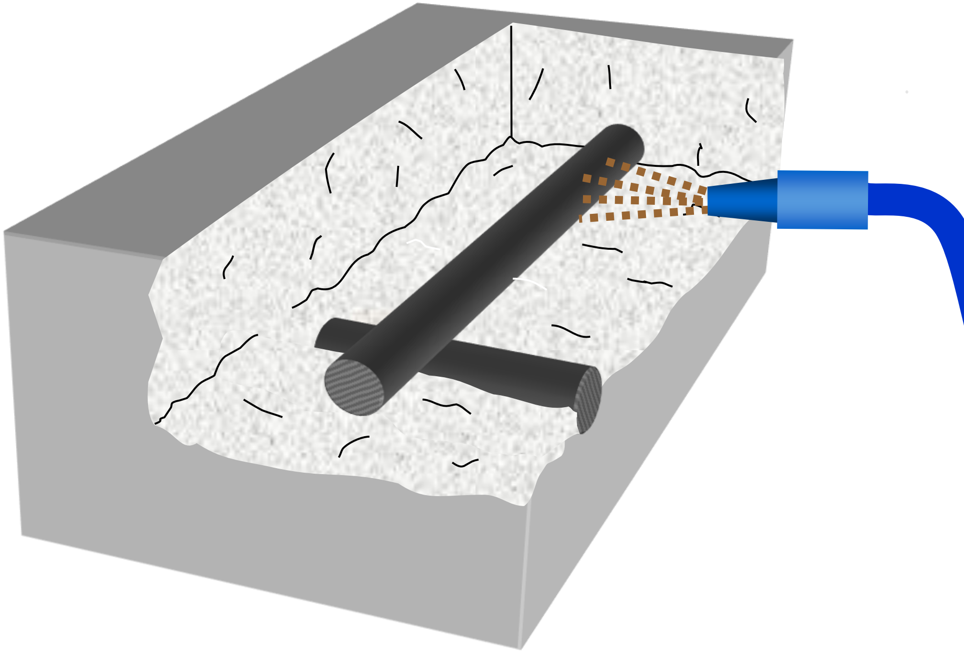
**Corrosion not removed**



# Surface Repair

- Proper surface preparation

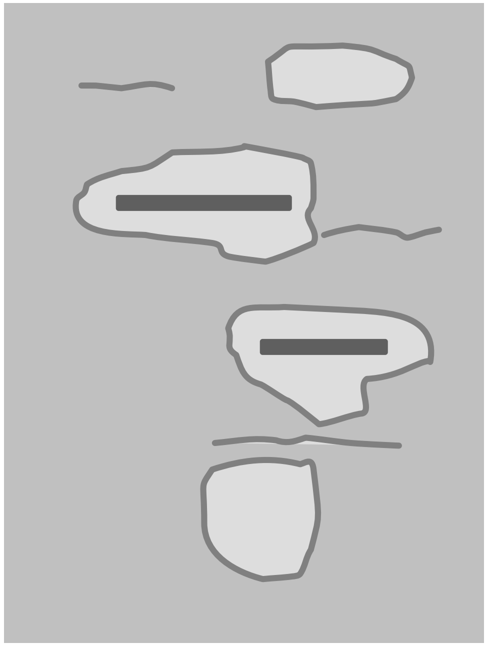


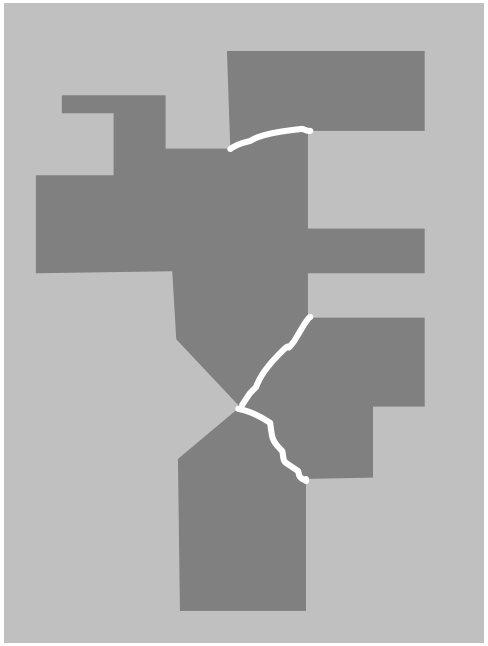
# Surface Repair

- Symmetrical repair geometry

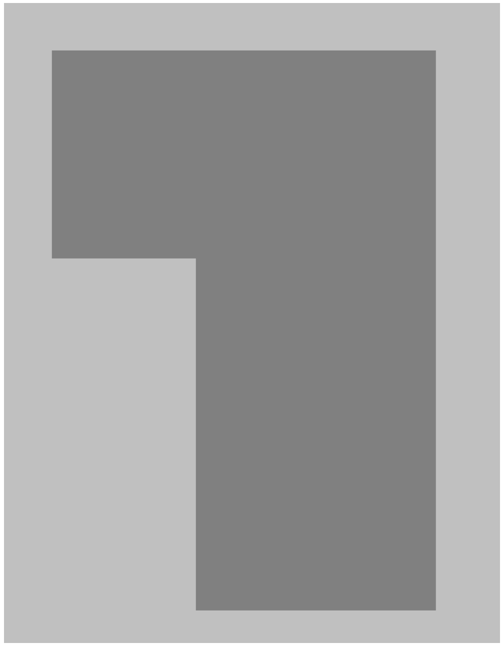
**Delaminations**



**Incorrect**



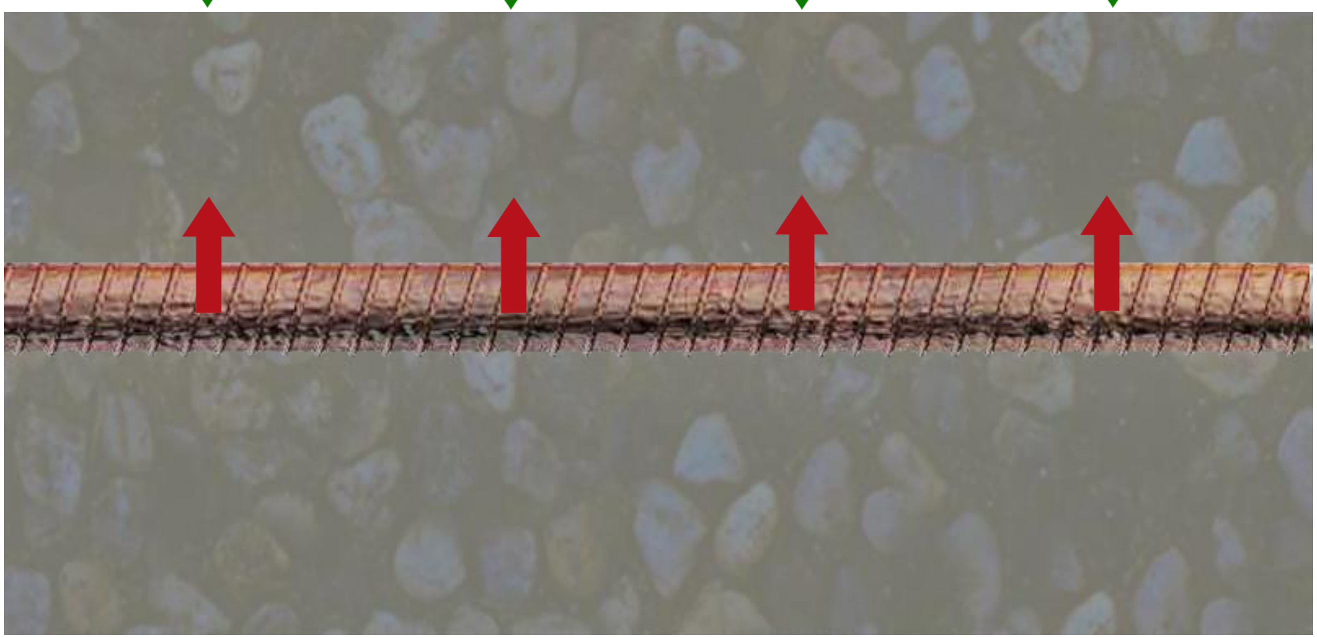
**Recommended**



# Existing Structures: Electro-Chemical Solutions

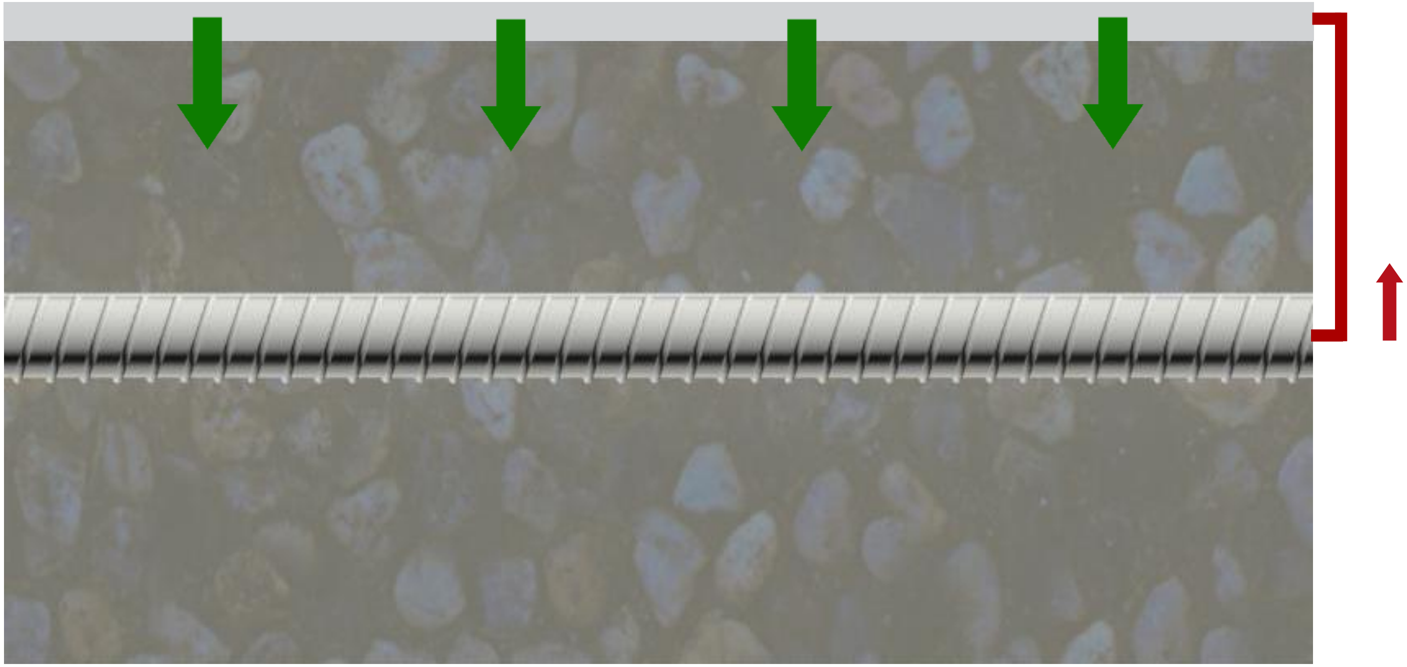
- Two types:
  - Galvanic Cathodic Protection Systems
  - Impressed Current Cathodic Protection Systems

- Protect the steel by adding energy



# Existing Structures:
# Galvanic Cathodic Protection System

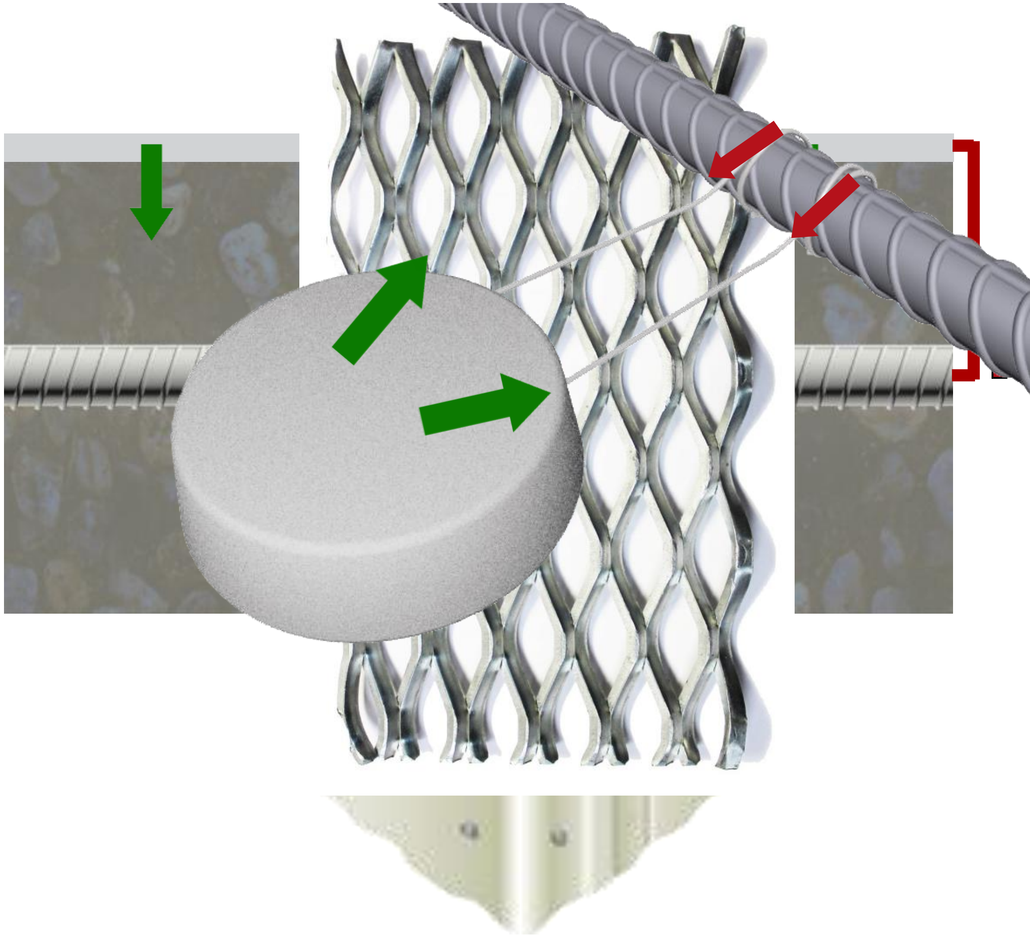
SACRIFICIAL ANODE



# Existing Structures: Galvanic Cathodic Protection System

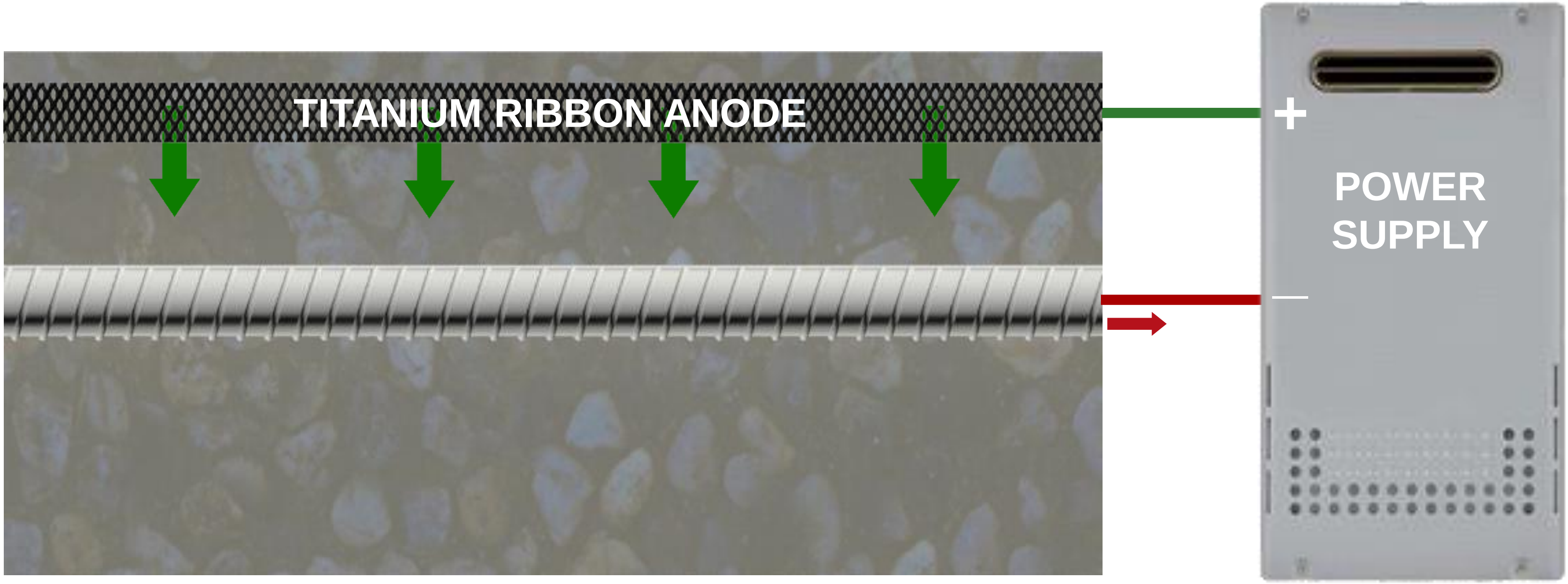
Types:

- Point anodes
- Embedded and mesh anodes
- Surface mounted anodes
- Jacketing systems



# Existing Structures: Metalizing


# Existing Structures:
# Impressed Current Cathodic Protection System



# Cracking

- Restrained volume changes
  - Plastic shrinkage
  - Drying shrinkage
  - Thermal cracking
  - Overload and impact

# Conclusions

- Concrete is durable and versatile
- There are some durability challenges that can be managed with
  - Proper materials selection
  - Good construction practices
  - Maintenance
- When durability issues arise
  - Interactions of several deterioration mechanisms
  - Ignored distress will often exponentially increase in rate
- Assessment of Cause and Effect will support the development of a solid repair / remediation approach
- Repair should not be considered a patch, rather a solution is the best path